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Performance Evaluation of Microstrip Antenna for EM Absorption Reduction in Human Tissues at 5G Bands

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ABSTRACT

The absorption of electromagnetic waves emitted by wireless devices in human tissues is quantified by the Specific Absorption Rate (SAR) measured for 1g or 10g of body tissues. The primary objective of this research is to identify an effective shield material that can minimize the impact and potential harm of electromagnetic waves on human tissues. The study involves the design of a single radiator Microstrip antenna operating at 28 GHz and the modelling of human tissue layers. SAR calculations for 1g of body tissues are performed based on the distance between the antenna and the head model. To evaluate the influence of antenna position on the head model, SAR calculations are conducted using two different approaches. In the first approach, the head model is positioned on the patch radiator side, while in the second approach, it is placed on the ground plane side. The aim is to determine which configuration yields lower SAR values. Furthermore, SAR calculations are reanalysed by incorporating shielding materials onto the Microstrip antenna. Three different absorbed materials are used as shields, and their impact on SAR reduction and radiation parameters of the Microstrip antenna are evaluated. The objective is to identify the shield material that achieves the highest SAR reduction while minimally affecting the radiation parameters of the antenna.

Keywords: Antenna, Electromagnetic waves, Human tissue, Radiation, Specific Absorption Rate.

تقييم أداء هوائي المايكروسترب لتقليل امتصاص الموجات الكهرومغناطيسية في الأنسجة البشرية في نطاقات G5

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ملخـــــــص البحـــــــث

يتم قياس امتصاص الموجات الكهرومغناطيسية المنبعثة من الأجهزة اللاسلكية في الأنسجة البشرية بواسطة معدل الامتصاص النوعي **(SAR)** الذي يتم قياسه ل 1جرام او 10 جرام من أنسجة الجسم. الهدف الأساسي من هذا البحث هو تحديد مادة درع فعالة يمكنها تقليل التأثير والضرر المحتمل للموجات الكهرومغناطيسية على الأنسجة البشرية. تتضمن الدراسة تصميم هوائي **Microstrip** ذو مشعاع واحد يعمل بتردد 28 جيجا هرتز ونمذجة طبقات الأنسجة البشرية. يتم إجراء حسابات **SAR** لجرام واحد من أنسجة الجسم بناء على المسافة بين الهوائي ونموذج الرأس. ولتقييم تأثير موضع

الهوائي على نموذج الرأس, تجرى حسابات الامتصاص النوعي **SAR** باستخدام طريقتين مختلفتين. في النهج الأول يتم وضع نموذج الرأس على جانب **patch radiator** , بينما في النهج الثاني , يتم وضعه على جانب **ground plane**. الهدف هو تحديد النهج الذي ينتج عنه قيم **SAR** أقل. علاوة على ذلك, يتم إعادة تحليل حسابات معدل الامتصاص النوعي **(SAR)** من خلال دمج مواد الحماية في هوائي **Microstrip**. يتم استخدام ثلاث مواد ماصة مختلفة كدروع, ويتم تقييم تأثيرها على تقليل معدل الامتصاص النوعي **(SAR)** ومعلمات الإشعاع لهوائي **Microstrip**. الهدف هو تحديد مادة الدرع التي تحقق أعلى انخفاض في تقليل معدل الامتصاص النوعي **(SAR)** مع الحد الأدنى من التأثير على معلمات إشعاع الهوائي.

الكلمات الدالة: الهوائي، موجات كهرومغناطيسية، الأنسجة البشرية، الإشعاع، معدل الامتصاص النوعي.

1. Introduction

Communication plays a crucial role in the exchange of information, and the term "communication" emerged with the advent of telephones, replacing older methods such as telegrams. In modern society, communication has become a fundamental pillar [1]. The evolution of wireless communication from 1G in the late 1980s to 4G in 2010 has brought about significant technological advancements. The latest technology, 5G, promises revolutionary changes in communication, offering lightning-fast speeds and advanced capabilities [1, 2]. Antennas are essential components in electronic devices used in various applications, such as civil, military, and medical fields. The radiation pattern of an antenna represents the energy it emits [3].

2. Specific Absorption Rate

Electromagnetic waves emitted by wireless devices, including mobile phones and routers, are absorbed by human tissues [4]. This absorption is quantified using the specific absorption rate (SAR), which measures the amount of radiated power from a mobile phone that is absorbed by a specific volume of body tissue, typically 1g or 10g, and is expressed in watts per kilogram (W/kg) [4].

While 5G systems offer numerous advantages such as higher bandwidth and data rates, it is crucial to evaluate their potential effects on human tissues from electromagnetic sources to ensure safety. Some reported biological effects of electromagnetic fields include cancer, blood-brain barrier issues, brain tumors, cataracts, skin diseases, and sleep disorders. Additionally, the effects of millimeter-wave (mmW) frequencies include genotoxicity, cell proliferation, gene expression, cell signaling, electrical activity, and membrane effects. To assess human safety, SAR is used as the power density (PD) unit recommended by the Federal Communication Commission (FCC) is suitable only for far-field exposures, not near-field exposures. However, certain mmW devices, such as handsets or tablets, are used in close proximity to the head, hand, or pocket, necessitating the use of SAR to evaluate human safety. SAR calculations provide insight into the absorbed power and distributed field within human tissues, offering a more comprehensive assessment [5].

SAR is determined by the rate at which energy from an electromagnetic source is absorbed per unit mass of human tissue. It is calculated using the equation $SAR = \sigma(Ei^2/\rho)$[5], where σ represents tissue conductivity, E is the electric field intensity, and ρ is the mass density of the tissue. SAR can be averaged over the entire body or a smaller sample volume, typically 1g or 10g of tissue. SAR is measured in watts per kilogram [5]. SAR limits are defined by organizations such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the IEEE C95.1–2019 standards, which set limits of 2 W/kg over 10g and 1.6 W/kg for 1g according to the FCC. These limits apply to frequencies up to 10 GHz and 6 GHz, respectively. However, SAR limits for frequencies above these thresholds, specifically for near-field exposures at mmW frequencies, have not yet been proposed [5].

Electromagnetic waves generated by natural and human-made sources have the ability to travel long distances and play a significant role in daily life. Radio frequency (RF) electromagnetic fields are utilized in communication, radio and television broadcasting, cellular networks, and indoor wireless systems. With the increasing use of technology, people are exposed to electromagnetic waves at levels far higher than those found in nature. This has led to discussions about the biological effects of electromagnetic waves [6]. The growing number of wireless device users raises concerns about potential harm from radiofrequency waves. Several studies have investigated SAR on human tissues in relation to 5G bands [7 - 9].

3. Materials

The Computer Simulation Technology (CST) Studio Suite 2019 and CST Studio Suite 2021 software were utilized for simulating this work. CST Studio Suite is an advanced 3D electromagnetic analysis software package employed for the design, analysis, and optimization of electromagnetic components and systems.

4. Methodology

The advancements in the field of communication have brought about certain drawbacks that can potentially impact human health, either directly or indirectly. Exposure to electromagnetic radiation from mobile phones can lead to various issues, including headaches, ear pain, blurred vision, memory loss, itching, burning sensations, drowsiness, and hypersensitivity. These symptoms are more commonly observed in individuals with higher levels of mobile phone radiation exposure. Moreover, as wireless devices are used in close proximity to brain tissue, electromagnetic waves, particularly at higher frequency bands, can have an impact on the brain.

To evaluate the effects of electromagnetic radiation on a specific part of the human body (in this study, the head), an experiment was conducted using a specially designed Microstrip antenna. The antenna operated at a frequency of 28 GHz. It was constructed using RT-5880 substrate, which was chosen due to its low loss factor and its common usage in antennas. The substrate had a standard dielectric constant of 2.2 and a thickness of 1.58mm. The configuration of the antenna is depicted in Figure (1).

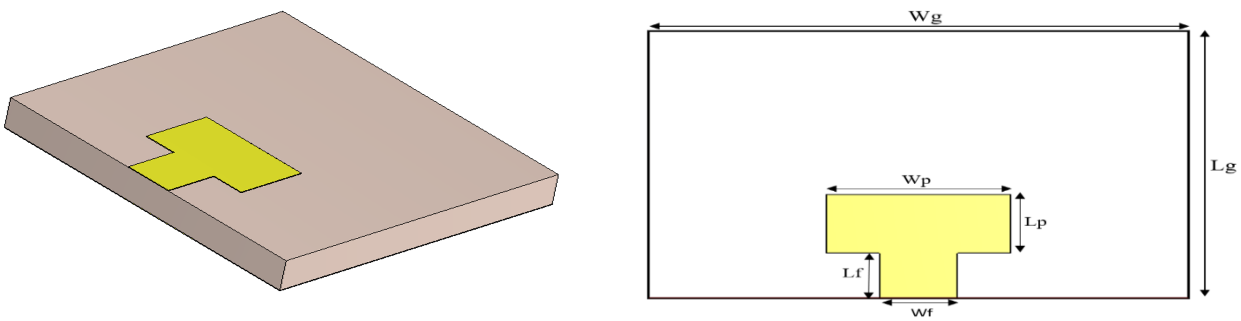


Figure (1): Designed Microstrip Antenna 3D view & Antenna dimensions

The design of single rectangular patch antenna is done by the calculation of the dimensions of the patch.

The width of the patch (Wp) is calculated by

$$W = \frac{1}{2f_r\sqrt{\mu_0\epsilon_0}}\sqrt{\frac{2}{\epsilon_r+1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\epsilon_r+1}} \qquad \textbf{(2) [10]}$$

$$W = \frac{3 \times 10^8}{2 \times 28 \times 10^9} \sqrt{\frac{2}{2.2 + 1}}$$

$$= 4.3 \text{ mm}$$

The length of the patch (Lp) is calculated by

$$L = \frac{1}{2f_r\sqrt{\epsilon_{reff}}\sqrt{\mu_0\epsilon_0}} - 2\Delta L = L_{eff} - 2\Delta L \qquad \textbf{(3)}$$

Calculation of the effective dielectric constant by

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{w}\right]^{-1/2} \qquad \textbf{(4)}$$

$$\epsilon_{reff} = \frac{2.2 + 1}{2} + \frac{2.2 - 1}{2}\left[1 + 12\frac{1.58}{4.3}\right]^{-1/2}$$

$$\epsilon_{reff} = 1.85$$

The normalized extension of the length is calculated by

$$\frac{\Delta L}{h} = 0.412\frac{(\epsilon_{reff} + 0.3)(\frac{w}{h} + 0.264)}{(\epsilon_{reff} - 0.258)(\frac{w}{h} + 0.8)} \qquad \textbf{(5)}$$

$$\Delta L = 0.412\frac{(1.85 + 0.3)(2.32 + 0.264)}{(1.85 - 0.258)(2.32 + 0.8)} \times h$$

$$\Delta L = 0.73$$

The length of the patch is

$$L = 6.81 - (2 \times 0.73)$$

$$L = 5.35 \text{ mm}$$

It should be noted that after the simulation, the length of the patch (Lp) was optimized to obtain the suitable specifications of the antenna

$$L = 2.506 \text{ mm}$$

The dimensions of the antenna ground and substrate (Lg and Wg) is calculated by

$$Wg = Wp + 6h \qquad \textbf{(6)}$$

$$Wg = 4.3 + (6 \times 1.58)$$

$$Wg = 13.78 \text{ mm}$$

$$Lg = Lp + 6h \qquad \textbf{(7) [10]}$$

$$Lg = 2.506 + (6 \times 1.58)$$

$$Lg = 11.98 \text{ mm}$$

The dimensions of the antenna feed line (width and length) are obtained by calculation program (Microstrip Line Calculator: em: talk 2006-2011) based on the antenna characteristic impedance $Z_0 = 50\ \Omega$, and electrical length $\text{Elec. Length} = 90 \text{ deg}$. The substrate parameters (ε_r and h) and the antenna frequency.

Width of the antenna feed line $\quad Wf = 2 \text{ mm}$

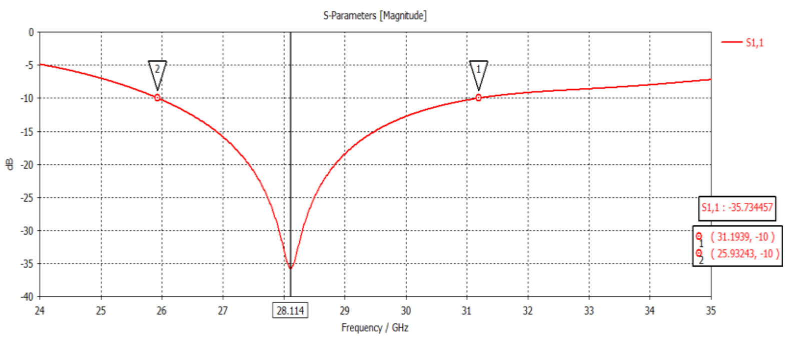
Length of the antenna feed line $\quad Lf = 1.996 \text{ mm}$

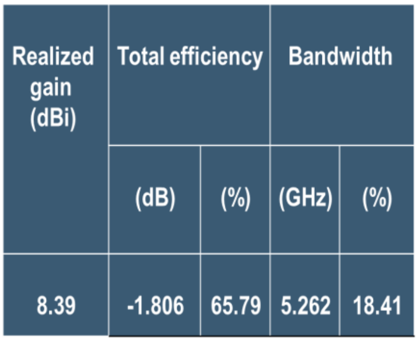
The final optimized design specifications of the simulated antenna at 28 GHz are tabulated in Table 1.

Table (1) Design Specifications

Parameter		**Value (mm)**
Patch	Wp	4.302
	Lp	2.506
ground	Wg	13.78
	Lg	11.98
Feedline	Wf	2
	Lf	1.996
Thickness of substrate	H	1.58
Thickness of copper	T	0.035

By simulating the designed antenna, the variation of return loss versus frequency clarified in figure (2). It can be noted that the resonant frequency of antenna is located at 28.114 GHz with return loss 35.734457 dB





Realized gain (dBi)	Total efficiency		Bandwidth	
	(dB)	(%)	(GHz)	(%)
8.39	-1.806	65.79	5.262	18.41

Figure (2) Variation of return loss with frequency at 28 GHz

3D radiation pattern of realized gain of Microstrip antenna at 28 GHz are illustrated in figure (3), this radiation pattern of antenna waves is designed with Computer Simulation Technology (CST). The maximum realized Gain of 8.39dBi at ϕ= 90°, the radiation efficiency of 70.4% (-1.524 dB), and the total efficiency of 65.97% (-1.806dB).

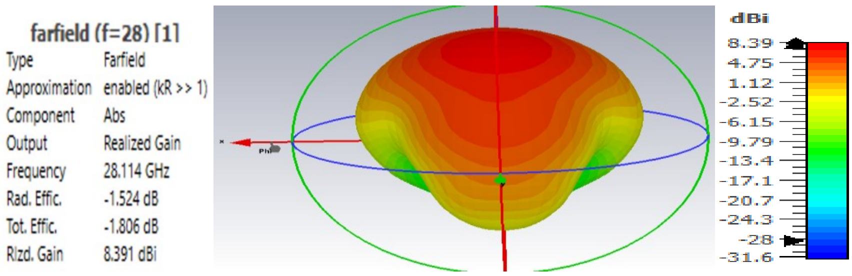


Figure (3): 3D radiation pattern of realized gain of Microstrip antenna at 28 GHz

5. Simulation & Results

The human head layers model is illustrated in figure (4).

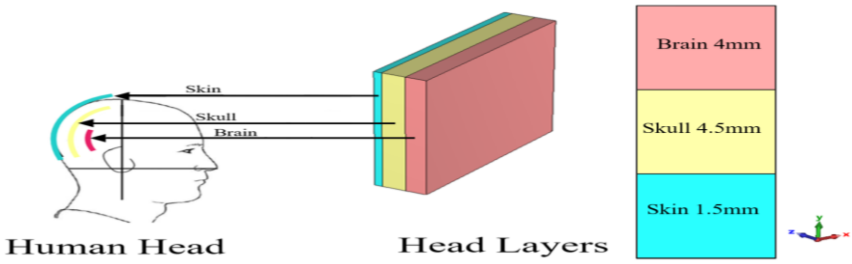


Figure (4) Thickness of human head layers

The human head layers were modelled based on properties in paper [11] are listed in table 2.

Table (2) Human head model properties at 28GHz

Tissue	ϵ_r	σ (s/m)	ρ (kg/m^3)	Thickness (mm)
Skin	18.71	26.19	1100	1.5
Skull	7.51	8.88	1990	4.5
Brain	18.59	21.86	1041	4

In this research, the designed microstrip antenna with the human head layers model is called Antenna Human Head Model (AHHM).

AHHM will be simulated in two approaches, the first when the human head layers are above the patch of the antenna and the second is when the human head layers are under the ground plane of antenna. In two approaches, the SAR calculations are done based on the distance between the antenna and the human head layers model which are 0mm, 10mm and 20 mm respectively.

a. AHHM with human head layers model above the patch of microstrip antenna at 28 GHz, is shown in Figure (5)

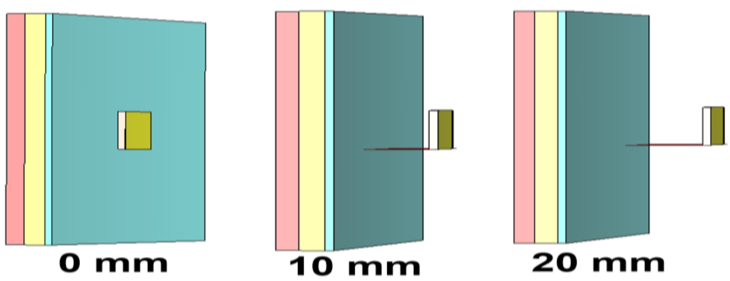


Figure (5) AHHM model with human head layers model above the patch of microstrip antenna at 28 GHz (a) 0mm (b) 10mm (c) 20mm

b. AHHM with human head layers model under the ground plane of microstrip antenna at 28 GHz, is shown in Figure (6).

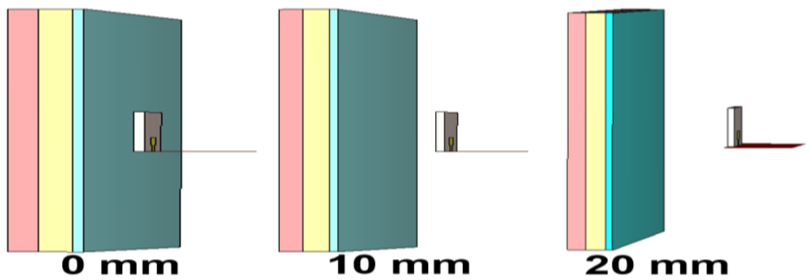


Figure (6) AHHM model with human head layers model under the ground plane of the patch of microstrip antenna at 28 GHz (a) 0mm (b) 10mm (c) 20mm

SAR results when AHHM with human head layers model above the patch & under the ground plane of microstrip antenna at 28GHz, shown in Figure (7) & Figure (8) respectively.

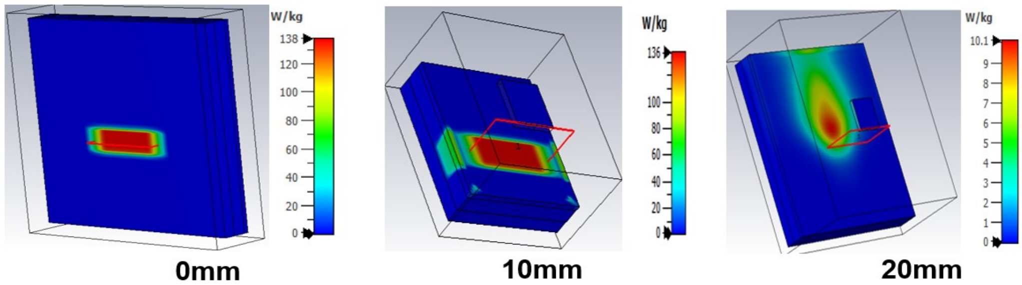


Figure (7) SAR results when human head layers are above the patch of microstrip antenna at 28GHz (a) 0mm (b)10mm (c) 20mm

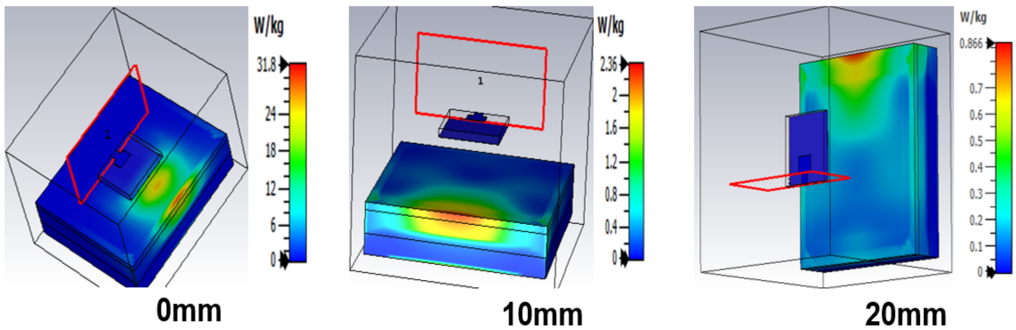


Figure (8) SAR results when human head layers are under the ground plane of microstrip antenna at 28GHz (a) 0mm (b) 10mm (c) 20mm

The SAR results of AHHM according to the position of the human head layers with respect of antenna are tabulated in Table (3).

Table (3) SAR results of AHHM for 1g of body tissues at 28 GHz

Thickness (mm)	**Human head layers under the ground plane of the antenna**		**Human head layers above the patch of the antenna**	
		SAR		**SAR**

	Realized gain (dBi)	value (w/kg)	time (hr)	Realized gain (dBi)	value (w/kg)	time (hr)
0 mm	6.7	31.8	17	-33.8	138	17
10 mm	9.12	2.36	15	-44.2	136	10
20 mm	8.18	0.866	8	-17.3	10.1	18

5.1 Adding absorbent material & simulation

Based on the findings from the previous SAR simulation, it was observed that when the layers of the human head were positioned beneath the ground plane of the antenna, the SAR value was lower. Consequently, in this specific scenario, only the absorbed material would be added.

To reduce the Specific Absorption Rate (SAR), an absorbed material is introduced as a shield on the ground plane side. Three types of shielded materials are chosen, namely Germanium, Teflon, and Plastic. The properties of these selected materials are obtained from a previously referenced paper [12]. Each of these materials possesses specific properties, which are detailed in Table (4).

Table (4) Properties of absorbed materials used

Materials	Conductivity (S/m)	Relative permittivity	Mass density (kg/m3)
Germanium	2.17	16.2	5350
Teflon	0	2.1	2250
Plastic	0	2.25	930

SAR result when AHHM under the ground plane with 1 mm thickness of Germanium, Plastic and Teflon shields for 1g at 28 GHz, are shown in Figure (9), Figure (10), and Figure (11) respectively.

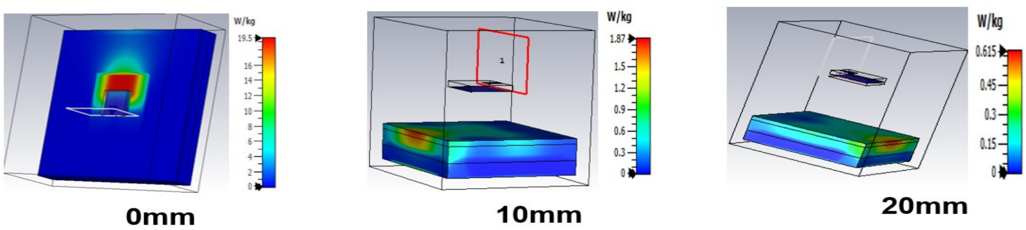


Figure (9) SAR values with 1 mm thickness of Germanium shield for 1g at 28 GHz (a)0mm (b)10mm (c)20mm

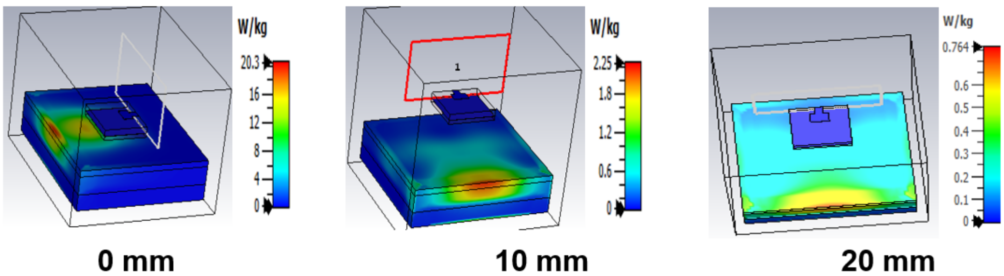


Figure (10) SAR values with 1 mm thickness of Teflon shield for 1g at 28 GHz (a)0mm (b)10mm (c)20mm

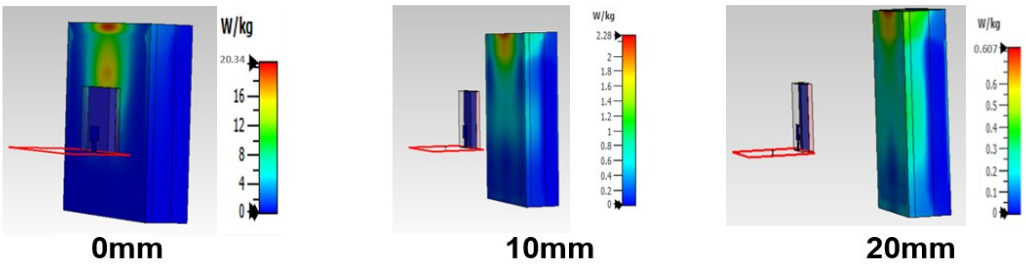


Figure (11) SAR values with 1 mm thickness of Plastic shield for 1g at 28 GHz (a)0mm (b)10mm (c)20mm

The chart shown in figure (12), generated using Microsoft Excel program provides a clear visual representation of the SAR reduction percentage based on the distance and the type of shield material. It helps to illustrate the variations in the ratios between different distances and shield materials:

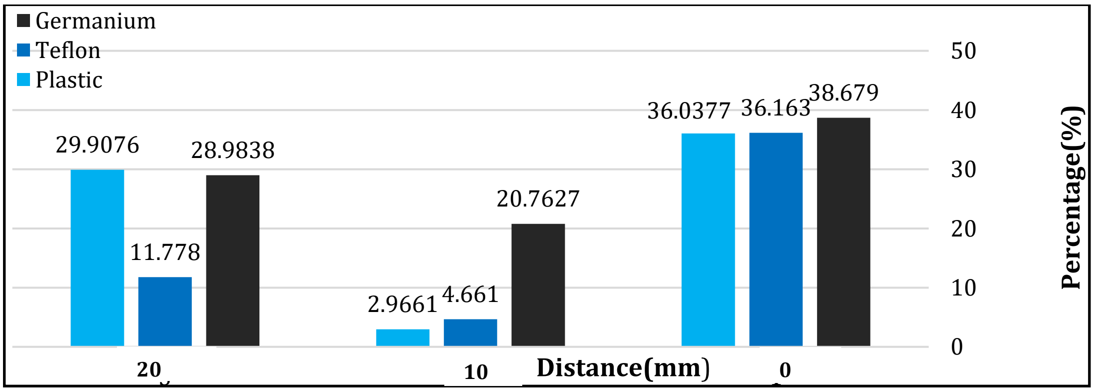


Figure (12) comparison of materials SAR reduction percentage

5.1.1 Discussion & Analysis

The chart presents the SAR reduction percentages achieved with different shield materials: Germanium, Teflon, and Plastic. The black column represents the SAR reduction percentages with Germanium as a shield, the blue column represents the SAR reduction percentages with Teflon as a shield, and the light blue column represents the SAR reduction percentages with Plastic as a shield.

For distances of 0mm and 10mm, the SAR reduction percentage was higher with Germanium as a shield compared to Teflon and plastic materials. Similarly, for 0mm and 10mm distances, the SAR reduction percentage was greater with Teflon as a shield compared to plastic material. However, at a distance of 20mm, the SAR reduction percentages differed for the three materials.

Considering the 0mm and 10mm distances, it can be concluded that Germanium is the most effective material for isolating radiation and reducing absorption, followed by Teflon and then plastic.

These findings align closely with a previous paper [12], and the decreased SAR values further support the results obtained in this study.

6. Conclusions

In this study, a Microstrip patch antenna was simulated for 5G communications operating at 28 GHz. The antenna was designed on a Rogers RT/duroid 5880 (Lossy) substrate with a dielectric constant of 2.2 and a thickness of 1.58mm. Additionally, human head layers were modeled, and the 1g SAR values absorbed by these layers were calculated. The simulations were conducted using Computer Simulation Technology (CST) Studio Suite 2019 and CST Studio Suite 2021.

Based on the simulated results, several conclusions can be drawn. Firstly, the designed single-element antenna exhibited good performance at 28 GHz, with a realized gain of 8.39 dBi, an impedance bandwidth of 18.418%, and a radiation efficiency of 70.4%.

The 1g SAR values varied depending on the position of the human head relative to the antenna. SAR values were higher when the human head was positioned on the patch side of the antenna compared to when it was placed on the ground plane side. Moreover, when the human head model was positioned on the ground plane side, the antenna demonstrated good radiation parameters, and the SAR values decreased as the distance between the antenna and the human head increased. The SAR values exhibited a reduction of 92.58% and 97.28% when the distance increased from 0 mm to 10 mm and from 0 mm to 20 mm, respectively.

By introducing shield materials individually, such as Germanium, Teflon, and Plastic, from the ground plane side of the antenna, the 1g SAR values were further reduced. The simulation results revealed that Germanium exhibited the best reduction in SAR values compared to Teflon and Plastic, with a reduction percentage exceeding 20%.

Consequently, the simulated antenna offered a compact size (13.78 mm×11.98 mm) with a simple design, ease of fabrication, and integration with other circuits. The antenna could be effectively shielded with Germanium material to reduce SAR values in 1g of body tissues, while experiencing minimal changes in antenna parameters and maintaining good performance at 28 GHz. These findings align closely with a previous paper and support the importance of reduced SAR values.

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