First Libyan International Conference on Engineering Sciences & Applications (FLICESA_LA)
13 – 15 March 2023, Tripoli – Libya

Effects of Antenna Radiation on Human Head at Frequencies of Millimeter Waves

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***Abstract*— This paper investigated the effects of millimeter radiation, especially used in the fifth generation (5G), where the specific absorption rate (SAR) of the human head was found at frequencies (28GHZ and 38GHZ), and this was achieved using the Computer Simulation Technology (CST) program by conducting simulations on a three-dimensional multi-layer model consisting of seven layers are skin, fat, muscle, skull, dura, cerebrospinal fluid (CSF), and brain. Simulation was carried out using two antennas operated at 28/38GHz, placed at a distance from the head with the use of three different emitted sources. SAR results were tabulated. Through the results, it is found that the specific absorption rate depends on several characteristics, the most important are the distance between the human head and the radiation source, the power used in the antenna, and the shape of the antenna. Also, Defective ground structure technique (DGS) used in the antennas to improve the gain was found to be increased the SAR values.**

Keywords— Millimeter Wave, Human Head, Specific Absorption Rate, Defective Ground Structure

I. INTRODUCTION

The crowdedness of current cellular bands and the demand for higher transmission speed prompt the use of the millimeter-wave (mmWave) spectrum for the next-generation mobile communication (5G) [1]. The bandwidth candidates for 5G are 24.25-27.25 GHz, 31.8-33.4 GHz, 37-43.5 GHz, 45.5-50.2 GHz, 50.4-52.6 GHz, 66-76 GHz, and 81-86 GHz [2].

Recent research on mmWave is focused mainly on the 28, 38, 40, 60 and 73GHz bands. Concern of public health hazards is growing due to fast development and implementation of mmWave wireless communications. Therefore, there is a dire need to study the absorption of electromagnetic energy in human tissues due to the exposure to mmWave radiations. [3] To protect human bodies from exposure to mmW radiation, many countries set safety guidelines standards, such as those set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the Institute of Electrical and Electronics Engineers (IEEE), as well as the Federal Communications Commission (FCC), and American National Standards Institute (ANSI) [4]. Absorption tool which is widely used to determine the health hazards in the human body due to electromagnetic field (EMF) exposure is specific absorption rate (SAR) [3].
Specific Absorption Rate (SAR) refers to the relation between human body tissue mass and the EM energy radiation received. [5]

So, in this paper, a multi-layer cubic human head model was designed that represents a part of the human head, and the value of SAR was found when this model was exposed to millimeter wave (mmW) frequencies. Two different structures and characteristics of antennas are used, by change the values of both the applied power and the distance between the antenna representing the radiation source and the model representing the human head, the effect of changing of these variables on the SAR value is observed. The obtained SAR values were compared with the safety standards stipulated in the IEEE, thus precautionary measures can be suggested to the end users of the new technology in devices with a wireless form.

This paper is organized as, brief review of the specific absorption rate is provided in Section II. Then, the design process of multilayered human head model is discussed in Section III, Simulation process and tabulated results of human head model with antennas are presented in Sections IV and V. This is followed by the conclusion in Section VI.

II. SPESIFIC ABSORPION RATE

Specific absorption rate (SAR), according to Institute of Electrical and Electronics Engineers (IEEE) standard, is defined as the power take in per unit mass of tissue, generally averaged either over the full body or over a part of the body (typically 1 g or 10 g of tissue) as in Equation (1) [5].

$$SAR = \frac{\sigma|E|^2}{2\rho} \ \text{[W/Kg]} \qquad (1)$$

Where: E is induced electric field (V/m), σ and ρ express the conductivity of biological tissue (S/m) and the density of biological tissue (Kg/m3) respectively [5].

The safety standards of FCC have an SAR exposure limit of 1.6 Watt per kilogram (W/kg) for 1g averaging mass while

ANSI/IEEE have SAR exposure limit of 2.0 Watt per kilogram (W/kg) for 10g averaging mass [2]. It is also known that the specific absorption rate is affected by several factors, the most important of which is the distance between the radiation source and the object inside which the SAR is to be measured, as well as the power used in the antenna, and the shape of the antenna's radiation pattern.

III. DESIGN OF THE MULTILAYERED HUMAN HEAD MODEL

The model or the phantom can be defined as a simulated biological body or as a physical model simulating the characteristics of the biological tissues. The aim of such a phantom is to explore the interaction between the human tissue and the electromagnetic fields. For this purpose, phantoms have been used extensively in medical research on the effects of electromagnetic radiation on health. [6]

In this paper is interesting for evaluating the maximum SAR of 1 g for seven tissues representing the human head. To facilitate the calculation of SAR, human heads can be approximated using three-dimensional multi-layer model, these layers are skin, fat, muscle, skull, dura, cerebrospinal fluid (CSF), and brain. as shown in Figure 1. The length and the width of the model, i.e. w, is set to 20 mm. As long as w is large compared to the size of the thermal hot spot caused by the illuminating EMFs, the computational results are marginally affected if a model with a larger dimension is used. The separation distance between antennas and the head model is denoted by *h*.

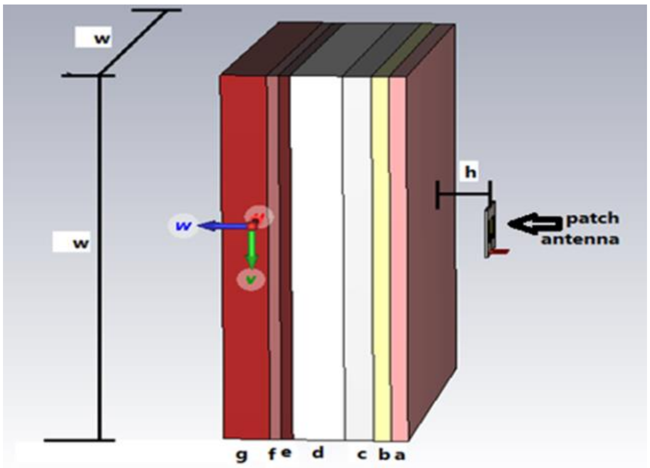


Figure 1: The multilayer human head model

Table I, presents the thickness of the tissue layers and the density of each layer in the adult head model. All of these tissue density values are very stable and will not change with temperature, frequency or age.

TABLE I. THICKNESS AND DENSIY OF HUMAN HEAD TISSUES. [1]

	Issue	Thickness(mm)	Density (kg/m^3)
a	Skin	1.5	1100
b	Fat	1.5	916
c	Muscle	2.5	1041
d	Skull	4.5	1990
e	Dura	1.0	1130
f	Cerebrospinal fluid	1.0	1007
g	Brain	4.0	1041

The human body's field is a combination of biological electromagnetic fields. The relative permittivity (ε_r), and the conductivity, σ are two key parameters for modeling electrical properties including, the attenuation of EM waves and current conduction. The permittivity and conductivity of the seven layers is given as similar to the real human brain to resemble the same. It is worth mentioning that, the body is so weakly magnetic such that, generally, the relative permeability (μ_r) is assumed to be 1 [7][8].
The electrical properties of different tissues used in the model at 28 and 38 GHz are shown in Table II.

TABLE II. DIELECTRIC PROPERTIES OF HUMAN HEAD TISSUES AT 28/38 GHZ.[9]

	Issue	Relative Permittivity (εr)		Conductivity σ (S/m)		Loss tangent	
a		28 GHZ	38 GHZ	28 GHZ	38 GHZ	28 GHZ	38 GHZ
b	Skin	18.714	14.692	26.187	31.962	0.89836	1.0291
c	Fat	3.6985	3.4444	1.6979	2.1358	0.29471	0.29331
d	Muscle	24.44	19.056	33.609	41.823	0.88284	1.0382
e	Skull	7.5132	6.366	8.8763	10.586	0.75845	0.78663
f	Dura	19.50	15.769	24.736	30.647	30.647	0.81435
g	Cerebrospi-nal fluid	28.191	21.563	43.798	53.321	53.321	0.99742
a	Brain	21.002	16.357	30.214	36.884	0.92360	1.0667

IV. SIMULATION OF HUMAN HEAD MODEL

In this paper, a human head model is simulated to evaluate the maximum specific absorption rate (SAR) inside the human head at millimeter frequencies. This study used a power of 24 dBm, 18 dBm, and 15 dBm emitted from a microstrip antenna with frequencies of 28 GHZ and 38 GHZ located at a distance of 0, 2, and 5 mm of the human tissue mock model with a size of (20 x 20 x 160 mm). The head model was simulated and analyzed with two different antennas.

V. SIMULATION OF HUMAN HEAD MODEL WITH ANTENNAS

Microstrip antennas are mostly considered suitable for modern day gadgets due to their low cost, low profile, simple fabrication and easy replication for large arrays. Microstrip antennas work well at higher frequencies as well, keeping the overall size much smaller.[3] In this paper**,** the CST program was used to simulate the human head model when exposed to millimeter waves, and the specifications of the computer used (Core i7-7th Gen, RAM 8GB, SSD 500GB). The two selected microstrip patches antennas are described in references [10,11] will be used in the simulation in this paper.

A. Configuration and Characteristic of Antenna 1

As described in Ref. [10], the proposed single patch antenna is designed to operate at 28GHz for the local multipoint distribution service band. An antenna is designed with a rectangular patch and the inset feed technique as a transmission line. The substrate of Taconic TLY-5 type has a thickness of 0.12 mm, a dielectric constant (ε_r) is 2.2 and loss tangent (*tan δ*) is 0. 0009. The characteristics of Antenna 1 is shown in Figure 2. It can be seen that, the antenna resonant at 28GHz with return loss of -28dB as shown in Figure 3. It also has gain of 8.4 dBi at 0° main lobe direction and half power beam width (HPBW=59°), as Figure 4 displays.

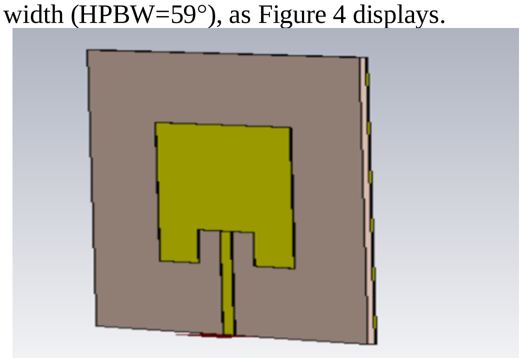


Figure 2. 3D view of rectangular Microstrip antenna 1

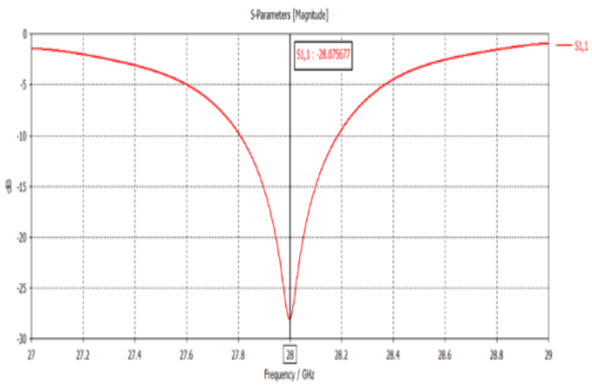


Figure 3. Resonance and return loss of antenna 1

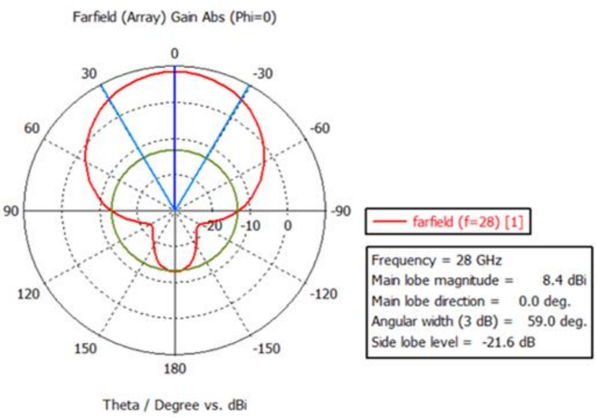


Figure 4. Gain pattern of antenna 1.

B. Simulation of Human Head Model with Antenna 1

To evaluate the maximum specific absorption rate inside the human head, the distances (h), and output powers values were changed.

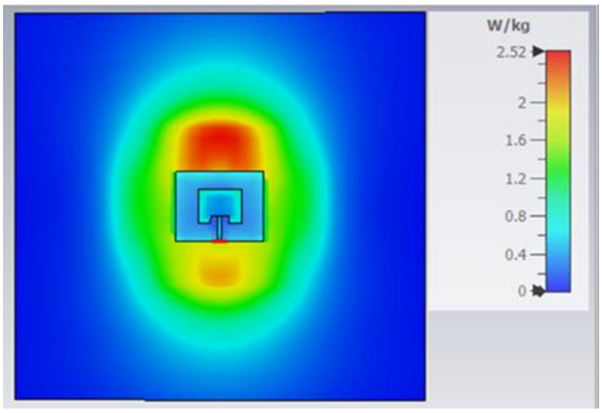
In this paper, the distances are fixed to, 0, 2 and 5mm away from the head and the 24, 18 and 15dBm power will be emitted from antenna at 28 and 38 GHz.

The simulation is carried out for each case and SAR values and EM concentration zones are displayed. The simulation time was recorded, it takes a long-time simulation (days) for each distance.

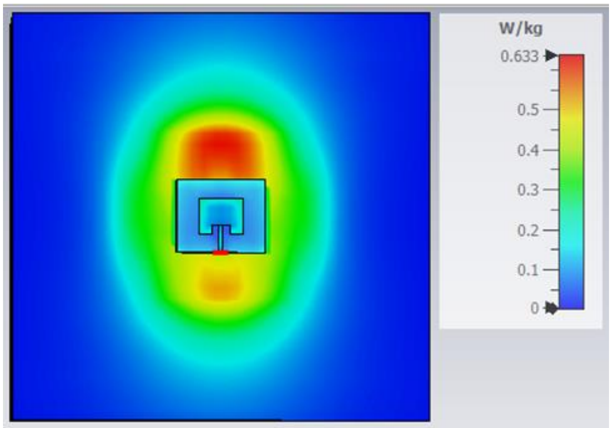
When a power of 24 dBm with different distances (0,2, 5 mm), the maximum SAR value obtained, when the antenna was adjacent to the head tissue without leaving any distance (*h=0mm*) was 2.52 W/Kg, as shown in Figure 5.a, It is higher than the FCC's safety standards (1.6 W/kg) for an average mass of 1 gram.

When 18 dBm and 15dBm power were used with *h* distance (0 mm), the maximum SAR values obtained are below FCC safety standards (1.6 W/kg), as shown in Figure 5.b,c .and the antenna can be used with these indicated powers without any affected radiation on human head.

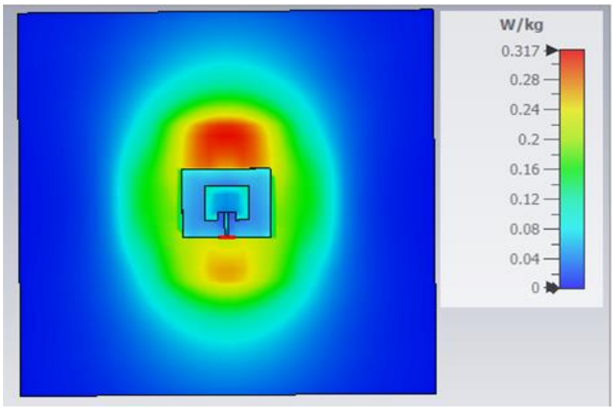
Figure 5. a,b,c, shows all the simulated cases, when there is no any distance (*h = 0 mm*) between the antenna and the head, whereas, Table III, lists all the simulated cases.



a. SAR value and EM concentration zones (24dBm and 0mm)



b. SAR value and EM concentration zones (18dBm and 0mm)



c. SAR value and EM concentration zones (15 dBm and 0mm)

Figure 5. SAR values using antenna 1with 24, 18 and 15dBm

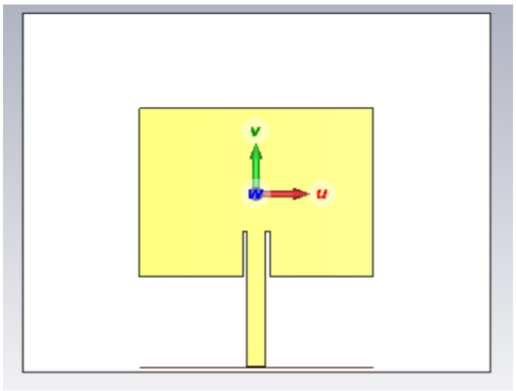
TABLE III. SIMULAION OF SAR VALUES USING ANTENNA 1

Power (dBm)	Distance (mm)	SAR (W/kg)
24	0	2.52
	2	0.842
	5	0.403
18	0	0.633
	2	0.211
	5	0.101
15	0	0.317
	2	0.106
	5	0.0508

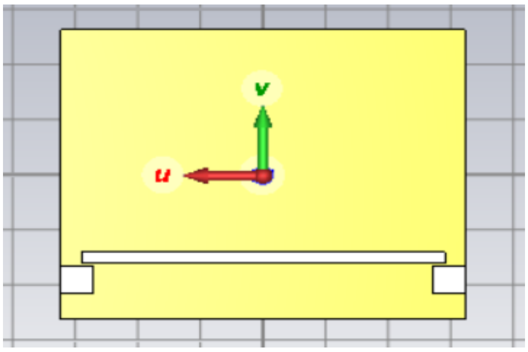
C. Configuration and Characteristic of Antenna 2

As described in Ref. [11], the proposed single patch antenna is designed to resonate at 38 GHz. The antenna has a relatively compact size, with Rogers RT5880 as substrate material and dielectric constant (εr) is 2.2 and loss tangent is 0.0009, with a height of 0.208 mm. This type of antennas can find applications in 5G within the mm-Wave band, where it is necessary to maintain high rates of Gbps, in this antenna the Defected Ground Structure (DGS) was used, the purpose of (DGS) is to get a wider bandwidth with maintaining acceptable values of efficiency and return loss.

The configuration of Antenna 2 is shown in Figure 6, whereas Figure 7, shows a characteristics of the antenna.
It obviously that, the antenna resonant at 38GHz with return loss of -30dB as shown in Figure 7. It also has gain of 6.99 dBi at 5° main lobe direction as Figure 8 displays.



a. Top view



b. Bottom view

Figure 6. Configuration of Antenna 2

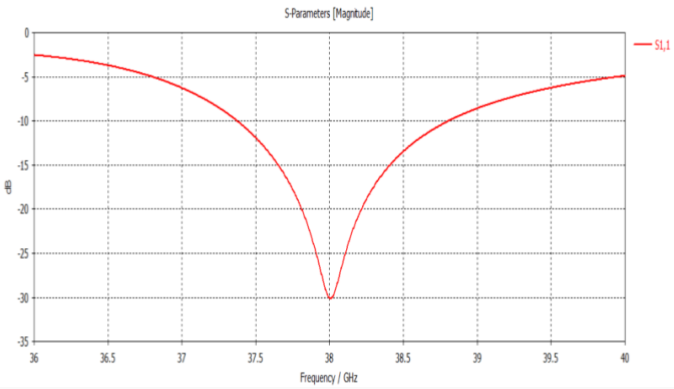


Figure 7. Resonance frequency and return loss of Antenna 2

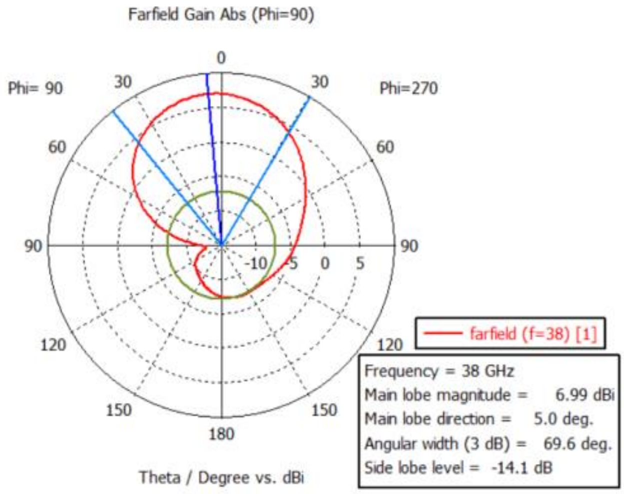


Figure 8. Gain pattern of Antenna 2

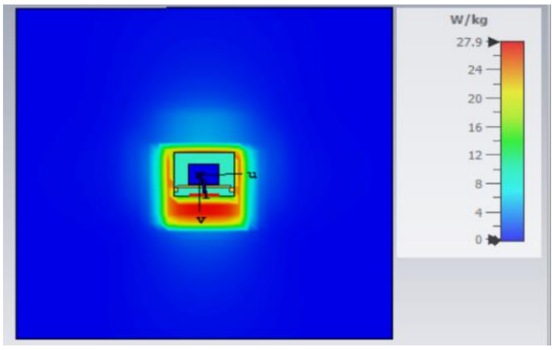
D. Simulation of Human Head with Antenna 2

To evaluate the maximum specific absorption rate inside the human head with antenna 2, by the same procedure carried out using the antenna 1with the same distances, and output powers.

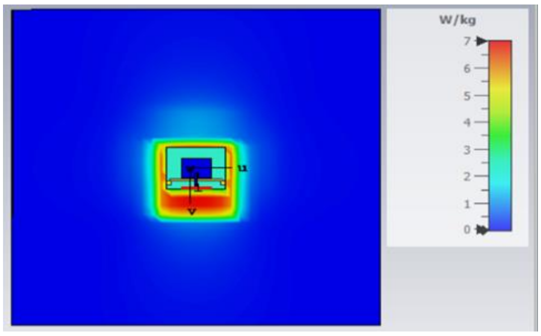
By fixing the distance to 0 mm, SAR values and EM concentration zones are displayed in Figure 9. a,b,c. Also all the simulated cases with SAR values are listed in Table IV.
When the power of 24 dBm is applied with different distances (0,2,5 mm), the maximum SAR value obtained.
At distance (0mm) SAR was 27.9 W/Kg, as illustrated in Figure 9. a. It is very high and not safe according to the FCC's safety standards.

When a power of 18 dBm is used with distances (0 mm), the maximum SAR value obtained was 7 W/Kg, as shown in Figure 9. b.
Using a power of 15 dBm with distances (0 mm), the maximum SAR value obtained 3.51 W/Kg, as shown in Figure 9.c. It is higher than the FCC's safety standards.
It can be concluded that, this antenna does not obey the FCC's safety standards for the radiated power and separation distances. This may due to the available slotted lines in ground plane (Defective ground structure) allows to apart of radiation to pass towards the head. For this reason, another simulation was carried out for Antenna 2 without using defective ground plane technique.

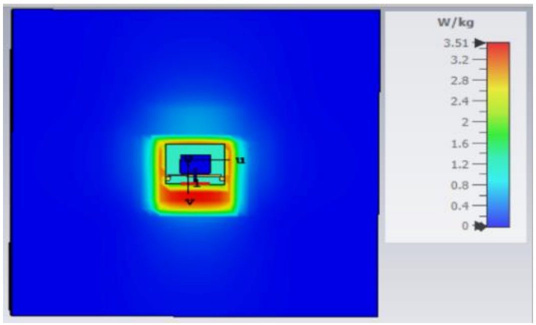
A simulation was performed using 24dBm power with 0mm distance between the antenna and a head. The obtained results are compared with previous result. These Comparison are tabulated in Table V.
It can be seen that, SAR value with DGS 27.9 W/Kg decreases more to 5.98 W/Kg, which means that DGS technique was used to improve the gain but it is increase the SAR.



a. SAR value and EM concentration zones (24dBm and 0mm)



b. SAR value and EM concentration zones (18dBm and 0mm)



c. SAR value and EM concentration zones (15 dBm and 0mm)

Figure 9. SAR values using antenna 2 with 24, 18 and15dBm

TABLE IV. SIMULATION OF SAR VALUES USING ANTENNA 2

Power (dBm)	Distance (mm)	SAR(W/kg)
24	0	27.9
	2	4.73
	5	3.32
18	0	7.0
	2	1.19
	5	0.835
15	0	3.51
	2	0.595
	5	0.418

TABLE V. SIMULATION OF SAR VALUES USING ANTENNA 2 WITH DGS

VI. CONCLUSION

Specific absorption rate (SAR) values are affected by several factors, the most important factors are, the distance between the radiation source and the object at which the SAR is to be measured. The greater the distance, the lower the specific absorption rate, and vice versa.

The second factor, the power used in the antenna, the higher the power, the higher the specific absorption rate, and vice versa. The third parameter, shape of the antenna and its radiation pattern.

In this paper, the simulation was carried out for two antennas operated at 28GHz and 38GH, SAR values were obtained. In Antenna 1 all SAR were below FCC safety standards (1.6 W/kg) with an average mass of 1 gram. Except when the power of 24dBm were used and there is no distance (0 mm), the result was higher than the safety and this antenna is not suitable for human use in this case only.

In Antenna 2 when we used the power of 24 dBm and the different distances (0,2,5), and also when we used the power of 18dBm and 15dBm with the distance of 0mm, the SAR were higher than the safety standards of the FCC. The antenna is not suitable for human to use in these cases.

When the antenna 2 used, one of its characteristics was that it was Defected Ground Structure (DGS), and this made the SAR significantly increase, because it is known that the Ground layer works to reflect radiation in order to protect the human body from radiation.

Power (dBm)	Distance (mm)	SAR(W/kg)	
24	0	With DGS	27.9
		Without DGS	5.98

REFERENCES

[1] He, Wang, et al. "RF compliance study of temperature elevation in human head model around 28 GHz for 5G user equipment application: Simulation analysis." *IEEE Access* 6 (2017): 830-838.

[2] Awada, Basel, et al. "Simulation of the Effect of 5G Cell Phone Radiation on Human Brain." *2018 IEEE International Multidisciplinary Conference on Engineering Technology (IMCET)*. IEEE, 2018.

[3] Hamed, Tooba, and Moazam Maqsood. "SAR calculation & temperature response of human body exposure to electromagnetic radiations at 28, 40 and 60 GHz mmWave frequencies." *Progress In Electromagnetics Research M* 73 (2018): 47-59.

[4] Morelli, Maria Sole, et al. "Numerical analysis of electromagnetic field exposure from 5G mobile communications at 28 GHZ in adults and children users for real-world exposure scenarios." *International Journal of Environmental Research and Public Health* 18.3 (2021): 1073.

[5] Ali, Israa H., Huda I. Hamd, and Ali I. Abdalla. "Design and comparison of two types of antennas for SAR calculation in wireless applications." *2018 Advances in Science and Engineering Technology International Conferences (ASET)*. IEEE, 2018.

[6] Augustine, Robin. *Electromagnetic modelling of human tissues and its application on the interaction between antenna and human body in the BAN context*. Diss. Paris Est, 2009.

[7] Sabbah, Ayman Ibrahim. "Evaluation of SAR and temperature elevation in a multi layered human head model exposed to RF radiation." *Jordan University of Science and Technology* (2010).

[8] Sindhuja, NM Mary, et al. *Design Of Metamaterial Based Microstrip Patch Antenna For Brain Tumor Detection*. No. 5406. EasyChair, 2021.

[9] Carrara, N. "Dielectric properties of body tissues in the frequency range 10 Hz-100 GHz." *Italian National Research Council, Institute for Applied Physics*. 2015.

[10] Darsono, M., and A. R. Wijaya. "Design and simulation of a rectangular patch microstrip antenna for the frequency of 28 GHz in 5G technology." *Journal of Physics: Conference Series*. Vol. 1469. No. 1. IOP Publishing, 2020.

[11] Binshitwan, Anas Abu Bakr, et al. "38GHz Rectangular Microstrip Antenna with DGS for 5G Applications." *2021 International Congress of Advanced Technology and Engineering (ICOTEN)*. IEEE, 2021.