Metasurface Absorber for Reduction of Specific Absorption Rate (SAR) at 5G n78 and n258 Communication Frequencies

Mário D. A. Tavares, Maurício W. B. Da Silva and Roberto B. Di Renna

***Abstract*— In this study, the reduction of human electromagnetic exposure to millimeter waves is analyzed. Thus, the specific absorption rate (SAR) from mobile antennas used for next-generation 5G n78 and n258 communication frequencies is significantly decreased by an absorber based on periodically arranged metallic square spirals. The reduction of SAR with the optimized metasurface was investigated by CST Microwave Studio in layered human tissues by examining SAR with gram mass averaging. The proposed absorber exhibits an SAR reduction of 99.99% at 3.5 GHz and more than 80% at 26 GHz. The results are aligned with the safety compliance of the 5G user equipment.**

***Keywords*— Specific absorption rate (SAR), absorber, metasurface.**

I. INTRODUCTION

The fifth-generation (5G) communication technology for smartphones can provide many advantages, such as higher transmission rate and shorter latency compared to the former 4G system [1]. However, the antennas may emit a large amount of electromagnetic wave radiation to humans and may cause many problems and even damage organs after a long time of exposure. Many factors affect the electromagnetic (EM) interaction while using a cellular handset in close proximity to the head, hand or other parts of the body. These interactions of electromagnetic radiation can be measured [2] [3].

In this regard, the specific absorption rate (SAR) is a defined figure of merit to evaluate the power absorbed by biological tissues and, in general, its value is influenced by various parameters such as antenna positions relative to the human body, radiation patterns, radiated power and types of antennas [4]. If the power absorbed in the tissues after exposure to these radiations is considerable high, then it causes tissue heating [5]. One way to overcome this drawback is to employ absorbers designed to mitigate these forms of harmful radiations.

Many countries rule safety guidelines standards to protect human bodies from radiation exposure [6]. When considering frequencies lower than 6 GHz, the guidelines of the International Commission on Non-Ionizing Radiation Protection (ICNIRP) restrict the SAR magnitude up to 2 W/kg in a cube of mass of 10g of contiguous tissue. In contrast, the Federal Communications Commission (FCC) limits the public exposure from cellular telephones up to 1.6 W/kg in a cube of mass of 1g. For frequencies greater than 6 GHz, the limit is 4 W/kg [7] [8].

As the volume size of a smartphone is very limited, absorbers based on metasurfaces are the most suitable for SAR reduction. Metasurfaces are two-dimensional metamaterials with unique and innovative EM characteristics, resulting in properties beyond the limitations of natural materials, which have been gaining increasing interest over the last decade for SAR mitigation [9]–[13]. Their response to the EM propagation is determined by two important parameters, electric permittivity and magnetic permeability that, when combined, may provide a negative permittivity and modify the material absorption properties. They can be obtained by arranging metallic thin wires periodically [14].

The present work, unlike the works in the literature, has a simpler approach and aims to simulate the actual tissues of the human body. For instance, the absorber design (dimensions and component materials) is able to be etched into thin smartphones without the necessity of active components. For instance, [9]–[12] analyze phantoms based on a tissue simulant liquid that may affect the results found. In addition to that, complex geometries may require a long design time and are expensive to fabricate.

The structure under analysis is based on periodically arranged metallic square spirals and is proposed to reduce the SAR performance of two mobile antennas used in the 5G n78 and n258 bands, allocated for Brazilian 5G telecommunications [15]. The designed geometry can be considered an excellent candidate to protect human tissues from heating.

II. DESIGN AND CHARACTERISTICS OF THE METASURFACE ABSORBER

The unit cell design was size optimized and prioritizes not only absorptivity but also the development of a structure with dimensions small enough to fit inside a mobile phone. For the n78 5G frequency, the unit cell of the suggested metasurface absorber is designed on a glass epoxy FR-4 material substrate with a relative permittivity of 4.3, loss tangent of 0.025 and thickness of 1.6 mm. The top geometry and the bottom ground layer of the substrate are made of annealed copper with thickness of 0.035 mm and electric conductivity 5.8×10^7 S/m. The dimensions of the unit cell are depicted in Fig. 1(a). The geometry is quite simple and presents good results for the frequencies studied. As described in Fig. 1(b), the absorber

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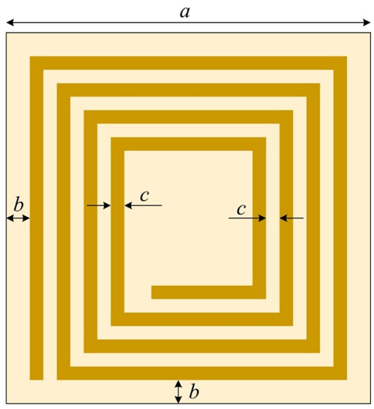
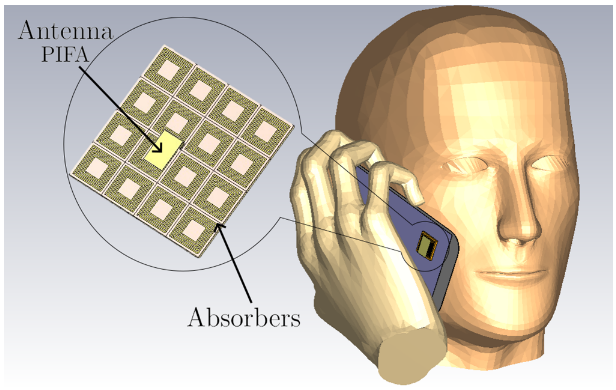


(a) Absorber unit cell: $a = 16$ mm, $b = 1$ mm, $c = 0.5$ mm.



(b) Absorber position.

Fig. 1: Unit cell and 3D schematic for SAR computing.

was placed between the antenna and the phone groundplane. This scheme shields the human body from the excess of exposure.

On the other hand, for the n258 frequency, the dimensions were rearranged. The top layer geometry is the same and the ground plane is also made of annealed copper with thickness of 0.035 mm and electric conductivity 5.8×10^7 S/m. However, the structure has an ROGERS RO4003C substrate of 0.4 mm thickness, with a relative permittivity of 3.55 and a loss tangent of 0.0027, considered more suitable for higher frequencies. Top layer material is graphite with electric conductivity 10^5 S/m and dimensions $a = 2.03$ mm, $b = 0.15$ mm and $c = 0.04$ mm.

The proposed absorbers were simulated using a frequency-domain solver with tetrahedral meshing in Computer Simulation Technology (CST) Microwave Studio Suite, 2024. The boundary conditions were set as unit cell for the x- and y-directions and the Floquet port along the positive z-direction, as the ground plane is a continuous metal. The absorptivity (A) can be defined as:

$$A(w) = 1 - R(w) - T(w) \tag{1}$$

where w is proportional to the resonant frequency and $R(w)$ and $T(w)$ are reflectance and transmittance:

$$R(w) = |S_{11}|^2_{yy} + |S_{11}|^2_{xy} \tag{2}$$

$$T(w) = |S_{21}|^2_{yy} + |S_{21}|^2_{xy} \tag{3}$$

In (2) and (3), S_{11} and S_{21} are the reflection and transmission coefficients, respectively, where the subscript yy denotes collinear polarization, and the subscript xy denotes cross-polarization.

In order to obtain perfect absorption, the reflectance and transmittance should be as small as possible. The metal ground leads the transmittance to an approximated zero of magnitude, and the reflectance is minimized by matching the structure's impedance to the free space impedance of 377 Ω.

The input impedance (Z_{in}) of the absorber is given by the following formula [13]:

$$Z_{in} = Z_0 \times \frac{\mu_r}{\epsilon_r} \tan h \left[-j\frac{2\pi f h}{c}\sqrt{\mu_r \epsilon_r} \right] \tag{4}$$

where Z_0 represents the free space impedance, h is the total thickness of the structure and μ_r is the relative permeability of the medium. As demonstrated above, the matching case (perfect absorption) occurs when $Z_{in} = Z_0$.

With these definitions in mind, the absorptivity $A(w)$ for co-polarization and cross-polarization of the fields under the normal and oblique incidence of the EM wave on the absorber under study can be measured.

III. SAR CALCULATION

The specific absorption rate (SAR) is the measure of the energy absorbed by a mass of biological tissue placed in a volume with the mass density ρ. It is defined as [16]:

$$\text{SAR}_i = \frac{P_i}{\rho_i} = \sigma_i \frac{|E|^2}{2\rho_i} \, [W/kg] \tag{5}$$

where P is the power loss density, ρ the density of human tissue, E the electric field strength, σ the electrical conductivity, and the subscript i the i-th tissue.

One can verify that SAR is proportional to the square of the internal electric field strength. In the CST Microwave Studio Suite, it is important to define a power loss density monitor at the resonant frequency that basically records the losses inside the calculation domain in the form of electric and magnetic losses. These losses are used to compute the SAR distribution in the tissues model [6].

There are two methods to perform SAR calculations: point SAR and averaging SAR. The first one is the value without mass averaging and is defined as the maximum SAR of all the grid cells; in the second one, averaging SAR, a cube with defined mass is used for each cell and the power loss density is integrated on this cube.

To study the performance of the proposed absorber, we considered a PIFA (3.5 GHz) and a patch antenna (26 GHz). Both designs are from the commercially available Antenna Magus to CST Design Environment software and were placed inside a template in which a volume of biological tissues was simulated for SAR averaged calculation, as depicted in Fig. 2. Then, the absorber was placed between the antenna and the

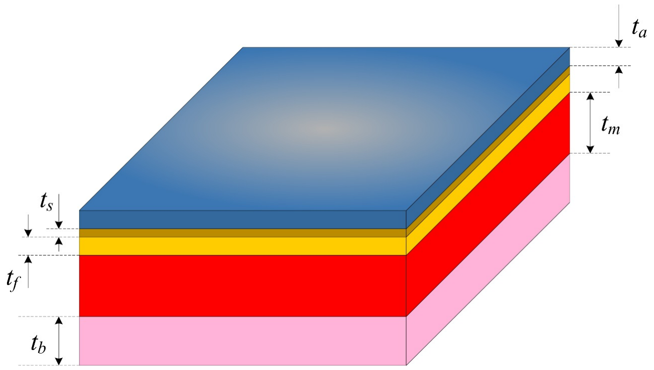


Fig. 2: 3D schematic for SAR computing. The slab thickness is as follows: $t_a = 3mm$ (air); $t_s = 1mm$ (skin); $t_f = 3mm$ (fat); $t_m = 23mm$ (muscle); and $t_b = 15mm$ (bone).

TABLE I: Properties of the layers.

layer	$\sigma\,[S/m]$	ϵ_r	$\rho\,[kg/m^3]$	$k\,[W/m \cdot K]$
skin	2.0249	37.005	1100	0.4
fat	0.15553	5.1739	910	0.23
muscle	2.5575	51.444	1041	0.46
bone	0.61457	10.793	1850	0.64

tissue slabs in order to evaluate the SAR reduction in the head, as shown in Fig. 1(b).

The volume of 16 cm^2 shown in Fig.2 is made of five layers: air, skin, fat, muscle and bone. The air layer simulates the distance between the cellphone and the human portion of biological tissue. Table I shows the properties of each surface [17], where σ is the electrical conductivity, ϵ_r the relative permittivity, ρ the material density, and k the thermal conductivity. Air is considered to have a unitary relative permittivity. The legend of Fig. 2 depicts the thickness of the slabs.

It is worth highlighting that the use of tissue simulant liquid does not grant the specification of each biological tissue. In contrast, this work focuses on the characterization of the simulated layers.

IV. RESULTS AND DISCUSSIONS

To investigate the high-performance absorption mechanism of the proposed structure, the absorptivity for 3.5 GHz and 26 GHz for incident angles until 60° is depicted in Fig. 3 and Fig. 4, respectively (left column). The figures also depict the reflection characteristic curves (S11) for normal incidence (right column). Moreover, Fig. 5 and Fig. 6 illustrate the absorptivity for different polarization angles under normal incidence.

It can be noted that the first spiral pattern provides several frequency peaks of absorption. The second one represents a wide band absorber as a result of the change in constituent materials. For n78 frequency, the proposed metasurface absorber has absorptivity over 95% for TE polarization when the incident angle is varied until 50°. For n258 frequency, the absorptivity is over 90% until the same angle variation.

Regarding polarization angles, Fig. 5 and Fig.6 exhibit that the proposed structure is polarization insensitive, with angles

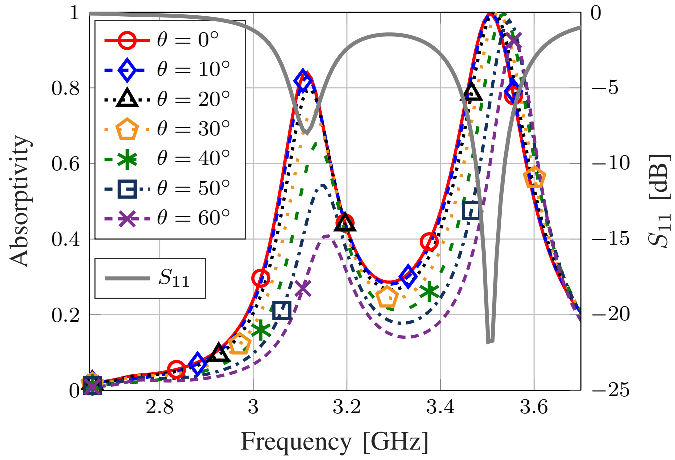


Fig. 3: 3.5 GHz Absorptivity for different incident angles θ and reflection characteristic curve (S_{11}).

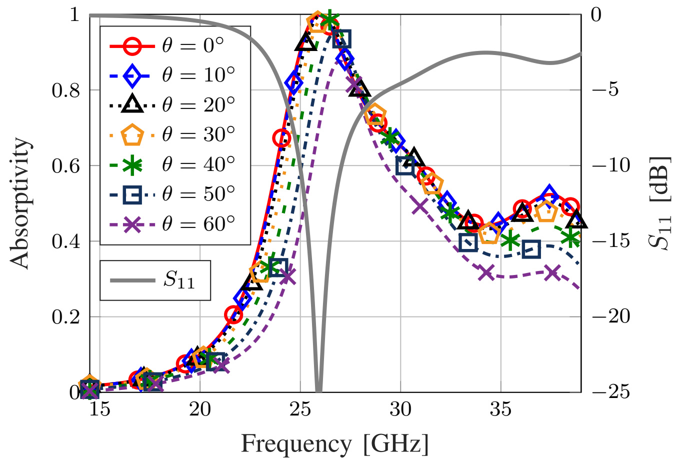


Fig. 4: 26 GHz Absorptivity for different incident angles θ and reflection characteristic curve (S_{11}).

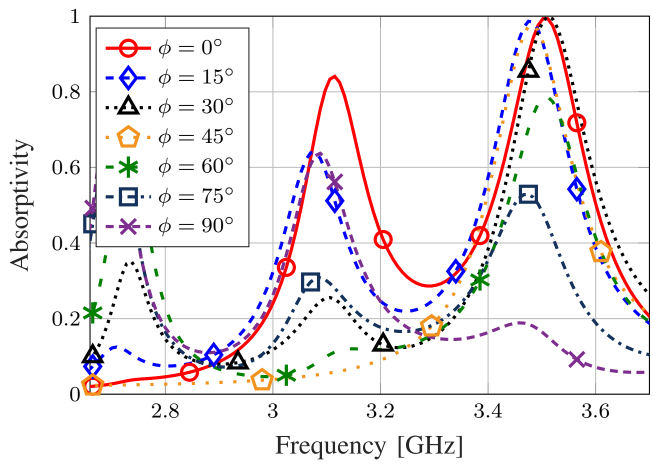


Fig. 5: 3.5 GHz Absorptivity for ϕ polarization variations.

ranging from 0° to 75° for n78 and from 0° to 60° for n258 frequency.

Subsequently, SAR distributions due to the radiating source

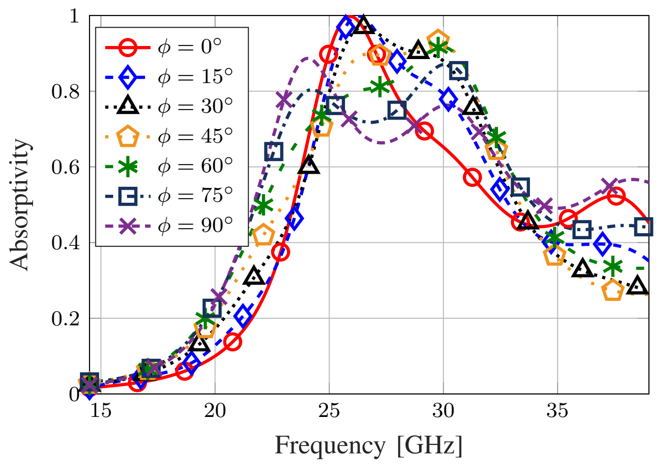
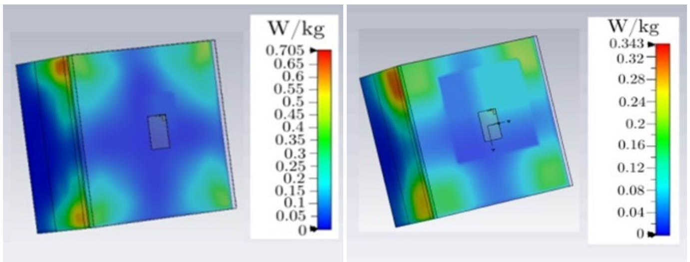
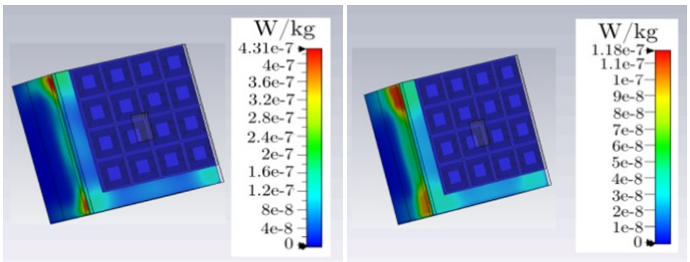


Fig. 6: 26 GHz Absorptivity for ϕ polarization variations.



(a) 1g averaged SAR. (b) 10g averaged SAR.

Fig. 7: SAR distribution for 3.5 GHz without absorber.



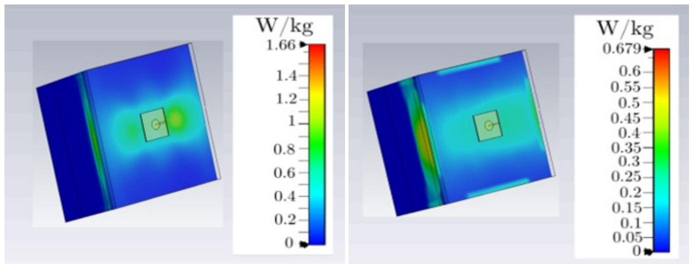
(a) 1g averaged SAR. (b) 10g averaged SAR.

Fig. 8: SAR distribution for 3.5 GHz with absorber.

antennas were investigated using the finite-difference time domain (FDTD) solver in CST. For a power loss density of 3.5 GHz, Fig. 7(a) and Fig. 7(b) illustrate the averaged SAR calculations considering a cube of mass of 1g and 10g in each cell analyzed, respectively, without the presence of the proposed absorber and according to ICNIRP Guidelines.

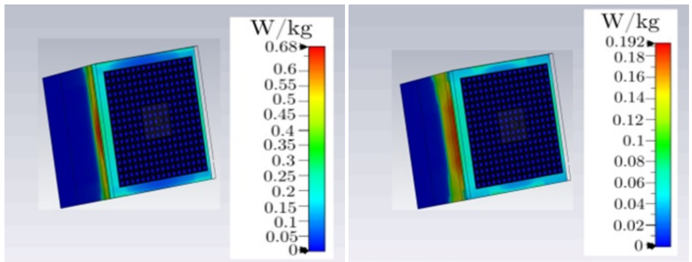
Thereafter, the proposed metasurface absorber was placed between the antenna and the cellphone groundplanes, with the aim of reducing the SAR distribution. Fig. 8(a) and Fig. 8(b) show that, in the presence of the 4x4 absorbers, the value of SAR decreases from 0.705 W/kg to 4.31×10^{-7} W/kg for the average mass of 1g and decreases from 0.343 W/kg to 1.18×10^{-7} W/kg for average mass of 10g, which indicates a reduction of SAR by 99.99% for both cases.

Furthermore, for a power loss density of 26 GHz, Fig. 9(a)



(a) 1g averaged SAR. (b) 10g averaged SAR.

Fig. 9: SAR distribution for 26 GHz without absorber.



(a) 1g averaged SAR. (b) 10g averaged SAR.

Fig. 10: SAR distribution for 26 GHz with absorber.

and Fig. 9(b), and Fig. 10(a) and Fig. 10(b), represent the evaluation of the SAR reduction of the 17x17 absorbers. As the previous case, one can observe that the absorber is able to mitigate the exposure over 60% for both averaged mass cases. Despite having less percentage reduction, the energy distribution is only over the surface of the tissues, therefore the inner organs will not suffer heating.

For the sake of completeness, table II illustrates a comparison between the present work and other ones found in the literature to date. The previous researches for SAR reduction, when evaluate single-layer absorbers, have complex geometries that could lead to expensive designs. When analyzing simple and easy to synthesize structures, they do not inform the bandwidth. So, the present work shows that the proposed geometry is able to resonate at different frequencies, by simply changing its dimensions, and has an easy design. Additionally, for the n258 5G frequency, a wide band characteristic for the absorber was found, which is very useful for cellular applications.

V. Conclusions

In this paper, the SAR of two mobile antennas is reduced by a miniaturized high-performance absorber based on periodically arranged metallic square spirals. The proposed metasurface (positioned behind the 5G antenna and facing the smartphone screen) achieves a maximum absorption of 99% and a SAR reduction of more than 99.99% in the desired 5G n78 band. The same geometry, with suitable higher frequency materials, presented an absorption of 99% and a SAR reduction of 60% in the 5G n258 band. The first case has several resonance peaks. The second one has a wideband

TABLE II: A comparison between proposed metamaterial design and previous studies.

References	Resonance Frequency (GHz)	Single layer	Simplicity	Unit cell size (mm)	Approx. bandwidth
[9]	0.9 and 1.8	yes	no	7.16×5.8	not informed
[10]	0.9 and 1.8	yes	yes	13×13.68	1 GHz
[11]	3.580	no	no	10×10	not informed
[12]	3.6	yes	no	18×18	80 MHz
[13]	23.2 – 33.4	no	no	1×1	10.2 GHz
this work	3.5 and 26	yes	yes	16×16 and 2.03×2.03	100 MHz and 3.3 GHz

behavior. Both have great potential to produce low SAR for devices commercialized for 5G communications.

VI. Aknowledgements

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