Suppression of Mobile Phone Radiation in Human Head Using Metamaterial

Moad Adel Suliman
Electrical and Electronics Engineering Department
University of Tripoli
Tripoli, Libya

Adel Saad. Emhemmed
Electrical and Electronics Engineering Department
University of Tripoli
Tripoli, Libya
dr.adel.elec@gmail.com

Ibrahim Asaad Aref
School of Computing and Communications
Lancaster University
Lancaster, UK
i.aref@lancaster.ac.uk

***Abstract*—This paper investigates the effect of radio frequency waves emitted by cellular phone antennas on the human head by using a 3D human head model to assess the specific absorption rate (SAR) in various human tissues. The simulation of SAR was performed using a PIFA (Planar Inverted-F Antenna) modelled in HFSS (High Frequency Structure Simulator) operating in the cellular frequency bands. To reduce the electromagnetic coupling between the mobile phone antenna and the human head, metamaterials were inserted at various locations in the vicinity of the antenna and study the effects of the metamaterial on the SAR level. The SAR in the human head was reduced by positioning the metamaterial between the PIFA antenna and the human head, with the metamaterial operating at a scale smaller than the wavelength of the antenna's operating frequency. The metamaterial structures exhibit resonance through internal capacitance and inductance, and a stop band was designed to align with the antenna's operating frequency band.**

Keywords— Absorption, SAR, Metamaterial, FSS, PIFA, Mobile Phone Radiation

I. Introduction

The widespread use of mobile phones has become a norm in today's society, with a significant portion of the global population relying on them for communication and access to information. However, along with the advantages of mobile phones, several negative effects have also been reported such as headaches, eye fatigue, sleep disruption and radiation exposure [1]. Furthermore, excessive mobile phone usage has been associated with an increased risk off mental health issues, such as anxiety, depression, and addiction. Therefore, it is vital to acknowledge and manage these potential negative impacts of mobile phone use to ensure its responsible and healthy utilization [1,3].

The measurement of electromagnetic absorption (EM) by humans is commonly expressed in terms of the Specific Absorption Rate (SAR) [2-4]. The Specific Absorption Rate (SAR) is a metric used to evaluate the amount of power absorbed by human body tissue from a mobile phone's emitted radiation [1]. This measurement is taken over a specific volume of tissue, typically corresponding to 1 gram or 10 grams, and is quantified in units of watts per kilogram (W/kg). To ensure the safety of human health, a specific limit for SAR is established to limit the maximum exposure to electromagnetic radiation[3]. This standard is set by authoritative bodies such as the International Commission on Non-Ionizing Radiation Protection (ICNIRP) and the Federal Communications Commission (FCC). The ICNIRP standard sets the safe limit of SAR at 2 W/kg for 10 grams of body tissue and is adopted by countries such as Australia, Japan, New Zealand, and Brazil. Other countries, such as Canada, South Korea, Bolivia, and Taiwan, adhere to the standard set by the FCC, which sets the limit of SAR at 1.6 W/kg for 1 gram of body tissue [1,2]

The amount of electromagnetic radiation absorbed by humans through mobile phone usage, as measured by SAR, is highly influenced by various factors such as the characteristics of the mobile phone and antenna, the mobile network carrier, the positioning of the antenna, and the emitted power from the mobile phone antenna [5]. Also, the positioning of the mobile phone or the phantom itself is considered a factor to impact the EM absorption. Additionally, the dielectric properties of human tissue can affect SAR values. An increase in conductivity and a decrease in permittivity in the human head result in a higher SAR. Tissue with higher water content, which has a greater conductivity and is more likely to absorb EM waves, also leads to higher SAR values. The conductivity and permittivity of tissue are dependent on the frequency of exposure, with these properties remaining constant at a constant frequency, but potentially changing with different exposures to different frequencies [3].

The effects of SAR are primarily determined by the positioning of the antenna on a mobile phone. When a mobile phone with a mounted antenna on the top is held in a tilted position, it results in increased absorption of electromagnetic radiation by the head due to the closer proximity of the antenna to the head. Moreover, SAR values can vary depending on how the mobile phone is held. Usually, mobile phones are held in either the "cheek" or "tilt" position. The "cheek" position, where the mobile phone is situated parallel to the head and close to the ear, is the most frequently used among users [4]. Therefore, this paper aims to study the impact of radio frequency waves emitted by cellular phone antennas on the human head. A 3-dimensional human head model is utilized to analyze the specific absorption rate in various human tissues. The simulation of specific absorption rates is conducted using a PIFA antenna that is modelled in HFSS and operates in cellular frequency bands. Moreover, we use metamaterials as a means to decrease the electromagnetic coupling between the mobile phone antenna and the human head [5]. The SAR in the head is diminished by positioning the metamaterial between the PIFA antenna and the human head, where the metamaterial operates at a scale smaller than the wavelength of the antenna's operating frequency. The structures exhibit resonance through internal capacitance and inductance, and a stop band is specifically engineered to align with the antenna's operating bands.

II. SPECIFIC ABSORPTION RATE

The Specific Absorption Rate (SAR) is a metric for determining the rate of energy absorption by tissue when exposed to a Radio Frequency (RF) electromagnetic field. It is quantified as the power absorbed per unit mass of the tissue and is expressed in units of watts per kilogram. SAR is calculated as the ratio of absorbed power to the mass of tissue and is expressed in units of watts per kilogram. The values are obtained by averaging the SAR over the entire body or a small sample volume, and the reported value is the highest SAR value found in the specified body part or tissue sample [4,10]. It can be calculated from the electric field within the tissue as:

$$SAR = \frac{\sigma E^2}{2\rho} \quad w/kg \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

The SAR value will be influenced by the mathematical shape of the body part that is exposed to the RF energy.

$$SAR = \frac{1}{V}\int \frac{\sigma(r)E(r)^2}{\rho(r)}dr \ldots\ldots\ldots\ldots\ldots (2)$$

Where E refers to the electric field strength (V/m), σ the conductivity (S/m) and ρ the density (kg/m^3) of human Head tissues. SAR is the standard for determining safe levels of operation for cell phones.

SAR measures exposure between 100 kHz and 10 GHz, which includes electronic equipment such as laptop computers, Wi-Fi routers, and mobile phones. The value is greatly dependent on the body parts being examined, energy levels, and proximity to the source of radiation. SAR value is determined by testing several parts of the body and determining the maximum absorption rate while exposing the area nearest to the radiating source [7,8].

A. *SAR Calculations*

Cellular or mobile phones have become a vital aspect of modern communication for people worldwide. In many countries, more than half of the population owns and uses mobile phones, and the demand for these devices continues to increase rapidly. As billions of people use mobile phones globally, a small with the widespread usage of mobile phones by billions of individuals worldwide, even a small increase in the incidence of negative health effects could have significant long-term implications for public health. Various factors such as the number of cellular phones calls each day, the duration of each call, and the amount of time individuals spend using mobile phones, all contribute to the potential health risks associated with their usage. Mobile phone usage has been linked to a number of negative health effects due to the deep penetration of electromagnetic waves in living tissues. Some of the observed effects include Parkinson's disease, cancer, alterations in gene expression, multiple sclerosis, and damage to neurological cells. The heating effects caused by the radiofrequency radiation emitted by mobile phones may be the source of this biological damage [7,8]. Additionally, the displacement of electrolytes and ions within the body caused by this radiation can interfere with the body's neurological system and weaken its defence mechanisms. The specific absorption rate (SAR) is a measure used to calculate the amount of energy absorbed by a biological object and is expressed in watts per kilogram (W/kg). It is considered an important factor in determining the potential health risks associated with mobile phone usage [6].

SAR measure reflects the amount of energy absorbed by a biological object from electromagnetic radiation, typically expressed in watts per kilogram (W/kg). The SAR value is commonly determined by averaging over the entire body or a small sample volume (such as 1g or 10g of tissue). The value reported is the highest level of SAR measured in the specific body part or tissue sample under examination [7].

The radiation emitted by mobile phones is radiofrequency energy, a type of non-ionizing electromagnetic radiation, which can be absorbed by tissues in close proximity to the device. The level of exposure to radiofrequency energy that a mobile phone user experiences is influenced by a variety of factors such as the distance between the phone and the head, as well as the angle of the handset antenna in relation to the head [6].

SAR is calculated by measuring the amount of radio frequency energy absorbed by a 1-gram sample of human head tissue when a mobile phone is held close to the head. The energy absorption level of each layer of tissue varies due to factors such as thickness, water content, conductivity, and permittivity. Three-dimensional SAR distribution in the head can be determined by analyzing SAR values obtained through simulations using HFSS. Fig. 1 represents the average SAR values on the HFSS realistic head with a logarithmic distribution on the surface, which shows a maximum SAR of 27.668W/kg on the tip of the ear then it starts decreasing along the head. For the purpose of examining the skull's effects, soft skull bone, cerebrospinal fluid and grey matter an anatomical head model (egg shape) is used.

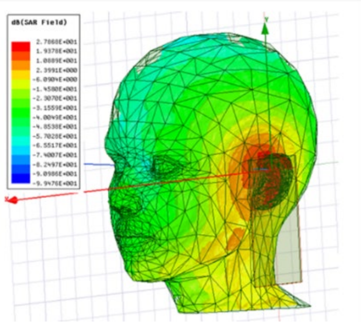


Fig. 1 Average SAR values on the HFSS realistic head that radiated from 2.1GHz PIFA Handset

For the simulation study, a realistic human head model was selected that comprised six different tissue types arranged in layers (Brain, CSF, Dura, Bone, Fat, and skin) as shown in Fig. 2 each human tissue has a Dielectric Property like relative permittivity, conductivity, loss tangent, even the thickness of each human head tissue and other properties [9].

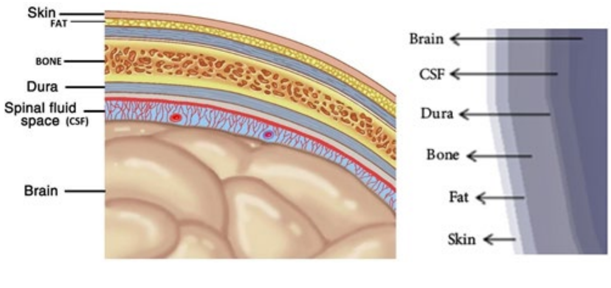


Fig. 2 Cross-section of Human head tissues with the modelled tissues

Figure 3 represents the average SAR distribution in each layer. At close range, the maximum average SAR value was 82.741W/kg, as shown by the curve in Fig. 4 Due to the unique characteristics of each human tissue, such as differences in conductivity, permeability, and other characteristics, the SAR value typically decreases with increasing distance, but at some distances, it can actually increase. The SAR value increases with conductivity and permittivity, with skin having the highest SAR for proximity to the antenna, connectivity, and power. Due to the distance in the Dura layer, the SAR value falls. Due to the CSF's high conductivity and permeability, the SAR value has increased. The brain.

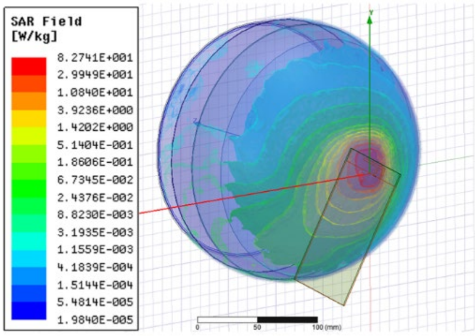


Fig. 3 Average SAR values on the anatomical head model that radiated from 2.1GHz PIFA Handset

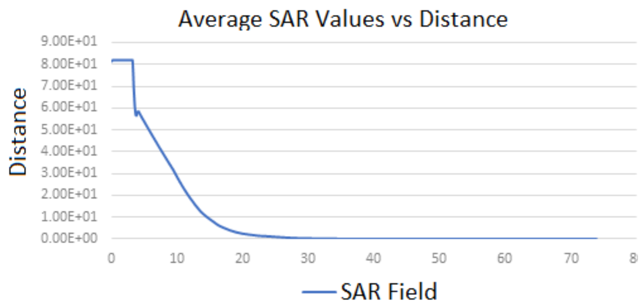


Fig. 4 Average SAR at 2.1GHz frequency Vs the distance

B. *Metamaterial FSS unit cell used in SAR reduction*

For several years, periodic structures have garnered the interest of scientists and artists alike, as they exhibit a range of intriguing properties and phenomena when interacting with electromagnetic waves. This interaction leads to the manifestation of distinctive features such as frequency stop bands, passbands, and band gaps, which may be referred to differently based on the field of application, such as filter design, gratings, or Frequency Selective Surfaces (FSS), among others. These structures collectively fall under the umbrella term "Electromagnetic Band Gap (EBG) structures." EBG structures are artificially created periodic or non-periodic objects that selectively control the propagation of electromagnetic waves within a specific frequency range, regardless of the incident angle and polarization state. These structures are made up of a periodic arrangement of metallic conductors and dielectric materials and can be broadly classified into three groups: three-dimensional volumetric structures, two-dimensional planar surfaces, and one-dimensional transmission lines.

In addition, Frequency Selective Surfaces (FSS) have a wide range of applications, including reflectors to reflect specific frequency bands, satellite and telecommunications, scientific and medical research, industrial applications, reduction of radar cross-section of antennas, microwave band-pass and band-stop filters, and various wireless communication applications. Using frequency selective surface (FSS) as shielding in front of the human head, provides a solution to reduce the value of the Specific Absorption Rate (SAR) and obtain better performance.

III. DESIGN OF A SQUARE LOOP FSS UNIT CELL

Figure 5 illustrates the geometry of the proposed FSS unit cell. The metamaterial comprises a board of FR4 Glass Epoxy with a permittivity of 4.4 and a loss tangent of 0.013. The top surface of the substrate features a metallic square loop with dimensions listed in Table 1, with the bottom conductor etched out, resonating at 2.1 GHz. The simulation of the FSS unit cell was performed using unit cell boundary conditions, including the use of a Floquet port at the top and bottom of the radiation boundary and linking adjacent boundaries to a Floquet port through the use of Master and Slave boundaries in HFSS.

TABLE I. THE PARAMETERS OF THE PROPOSED SQUARE LOOP FSS UNIT CELL

Parameters	Calculated value	Optimized value
a	22mm	20.58507077mm
p	24mm	23.9420066265908mm
w	0.5mm	0.5mm
h_1	1.6mm	1.7mm

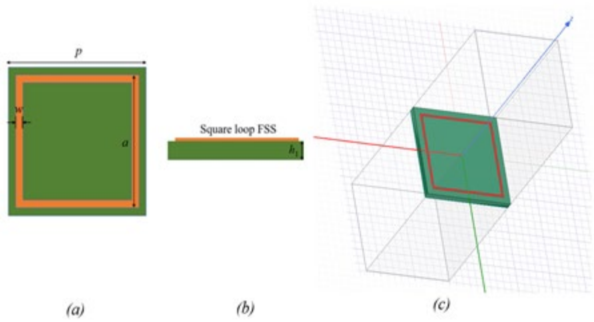


Fig. 5 Geometry of the square loop FSS unit cell: (a) top view, (b) side view, (c) 3D view

The FSS square loop equivalent circuit model is represented by a series RLC circuit, as illustrated in Figure 6. The dimensions of the FSS unit cell play a role in determining the values of L and C, which subsequently determine the resonant frequency of the FSS. The presence of inductance (L) is a result of current flow within the square loop, and is dependent on the periodicity and width of the loop.

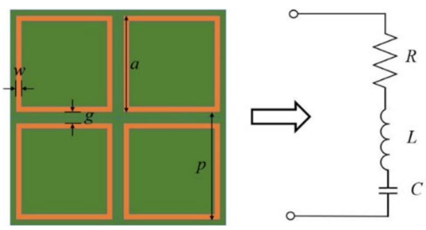


Fig. 6 Geometry of the square loop FSS: (a) array, (b) equivalent circuit.

The capacitance (C) of the Frequency Selective Surface (FSS) square loop is dependent on the dielectric spacing between the conductive components of the FSS, and is influenced by the periodicity and distance between the square loops. The inductive reactance (X_L) and capacitive susceptance (X_C) are given as [10].

$$\frac{X_L}{Z_o} = \frac{\omega L}{Z_o} = \frac{a}{p}.F(p, 2w, \lambda) \quad (1)$$

$$X_c.Z_o = \omega C.Z_o = 4\frac{a}{p}.F(p, g, \lambda) \quad (2)$$

$$F(p, w, \lambda) = \frac{p}{\lambda}\cos\theta\left[\ln\left(\csc\left(\frac{\pi.w}{2p}\right)\right) + G(p, w, \lambda)\right] \quad (3)$$

The correction term G(p, w, λ) is a function of angle of incidence (θ), wavelength (λ) at the resonant frequency, and the characteristic impedance in free space (Z_o). The FSS structure is positioned between free space and a FR4 dielectric substrate with loss properties, and the effective permittivity (ε_{eff}) is estimated as the average of the permittivity values for free space and the dielectric substrate.

$$\varepsilon_{eff} = \frac{(\varepsilon_r+1)}{2} \quad (4)$$

Thus, the effective capacitance of the FSS is represented by Cε_eff, and the resonant frequency of the equivalent circuit is given in [11].

$$f_c = \frac{1}{2\pi\sqrt{LC\varepsilon_{eff}}} \quad (5)$$

The resonant frequency (f_c= 1.96 GHz) was calculated using equations (4) and (5) to be 1.96 GHz, which was found to be slightly lower than the resonant frequency obtained from simulation results. This comparison indicates a close agreement between the calculated and simulated resonant frequencies.

A. Square loop FSS unit cell absorber

The utilization of FSS (Frequency Selective Surface) as an electromagnetic wave absorber was found to be effective in the desired frequency range. Related to metamaterial absorbers, metamaterial absorbers can be regulated by varying the thickness of the substrate's geometric parameters to achieve the appropriate absorption intensity and operating frequencies.

The absorption is defined as $A = 1-|S_{11}|^2-|S_{21}|^2$. Since the proposed absorber is backed by a metallic sheet, then $S_{21} = 0$, the absorption (A) can be simplified as

$$A = 1-|S_{11}|^2 \quad (6)$$

Figure 7 illustrates that the center frequency is at f_r = 2.1GHz with a maximum absorptivity of 99.10%.

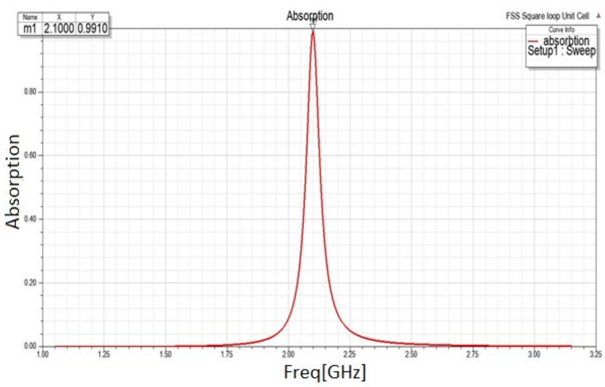


Fig. 7 The absorption of the FSS unit cell as a function of frequency

Figure 8 represents the proposed FSS, which is an array of 5x5 cells, which is designed to be as an absorber with 98.15% of the EM waves than are emitted from the antenna which is side by side between the antenna and the realistic head model.

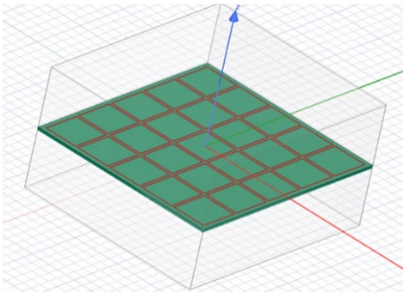


Fig. 8 Geometry of the square loop FSS array with 5x5 elements

IV. SAR REDACTION

The use of metamaterials as shown in Figure 9 is one method of reducing radiation directed towards the user from handsets. As was discussed Metamaterials exhibit electro-magnetic responses not readily available in naturally occurring materials and structures. by designing a square Metamaterial as absorption for reducing the SAR value by placing it between the head and the handsets antenna.

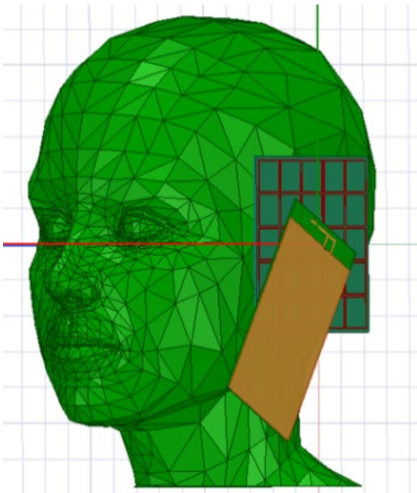
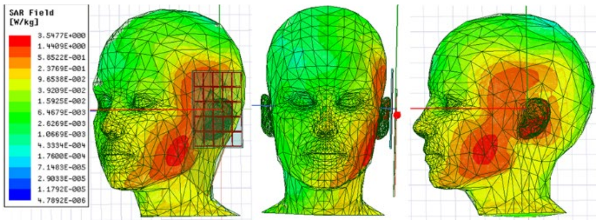


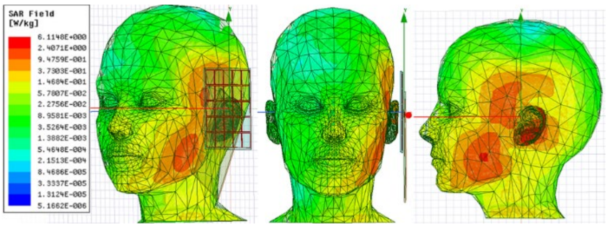
Fig. 9 placing of the metamaterial between the realistic model of Human Head and handsets antenna in the HFSS to reduce SAR value

The value of the SAR is lowered in accordance with the distance at which the metamaterial is placed, starting at 4 mm away from the handset and down to a smaller distance for improved absorption.

As shown in Figure 10, the average SAR values that were absorbed in the head were shown with the using of Metamaterial. It was found that all the concentration was in the ear and palate area. The average SAR value was about 3.5477W/kg, then dropped to 1.4409W/kg, and it gradually decreases towards the top of the head. When the distance of the instep to the antenna was reduced, the absorption decreased in the palate but increased in the ear region, from 3.5477 to 6.1148 W/kg, as shown in Figure 10(b).



(a)

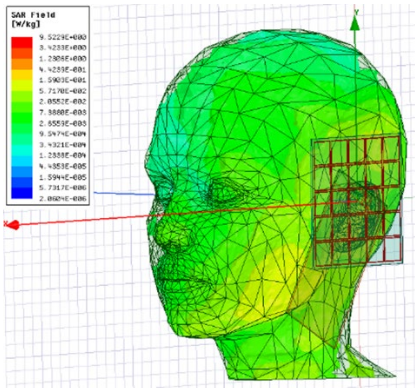


(b)

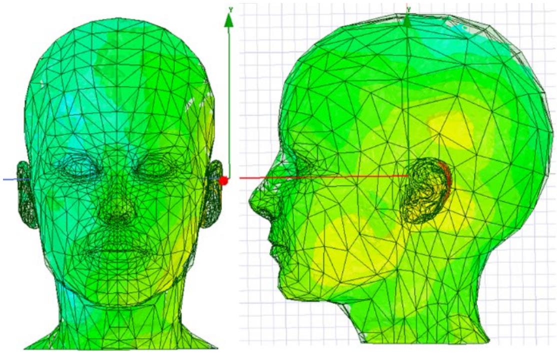
Fig. 10 The average SAR values reduced at 2.1GHz in 1 g is obtained, (a) for Metamaterial with 4 mm distance from the handset, (b) for Metamaterial with 2 mm distance from the handset.

From Figure 10(a), the maximum SAR value was reduced from 16.253 W/kg to 3.5477 W/kg by using the designed metamaterial, which provided the solution. However, 3.5477 W/kg is still a higher value than in the standards, and in order to reach the values set in the standards, the distance where the metamaterial is placed must be reduced. To satisfy the standards, the distance has to be reduced to produce average SAR values of less than 1.6W/kg. In this design, the distance from the handset was 0.1 mm.

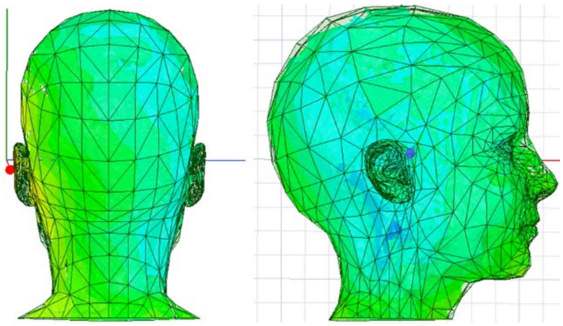
As indicated in Figure 11, the specific absorption rate in the head was minimized; the highest was at the tip of the ear, which progressively decreased on the borders of the tip of the ear, not the entire ear, as shown in Figure 11, and the interesting part was that the specific absorption rate in the head was 0.1 W/kg. It's a long way off from 1.6W/kg (the standard).



(a)



(b) (c)



(d) (e)

Fig. 11 average SAR values with a distance of 0.1mm placing of the metamaterial between the realistic model of the human head and the handset antenna in order to obtain less than 1.6W/kg average SAR in the HFSS, (a)3D view with the average SAR values, (b)front

A. Comparison of SAR values without and with FSS to achieve the reduction factor.

The metamaterial design demonstrated satisfactory levels of absorption reduction, leading to the introduction of a square loop-shaped metamaterial structure for reducing SAR as shown in Figure 12.

- Calculate Reduction factor

Table II show reduction factor of peak average SAR values as a result of using the metamaterial. The percentage reduction factor can be defined as follow:

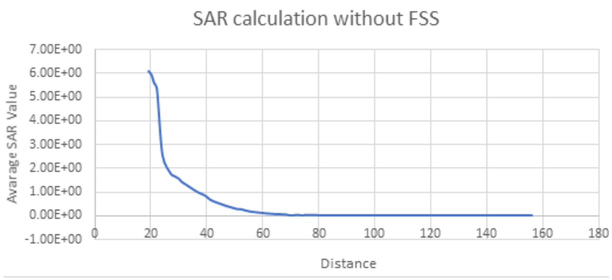
$$reduation\ factor = \frac{Psarw/o - Psar\_w}{Psarw/o} \times 100 \ (6)$$

Where:

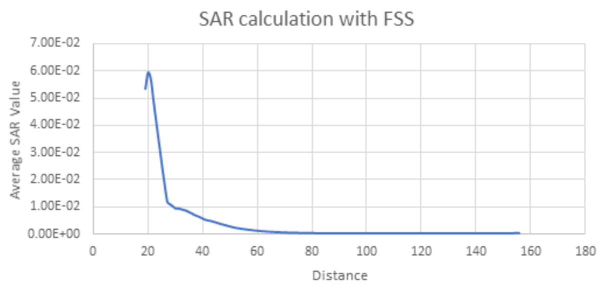
- $P_{SAR\_w\_met}$: peak SAR with metamaterial
- P_{SAR_w/o_met} : peak SAR without metamaterial

TABLE II. REDUCTION FACTOR OF LOCAL PEAK SAR VALUES

Average SAR value (w/kg)		**Reduction %**
Without metamaterial	**With metamaterial**	
6.11	0.06	99



(a)



(b)

Fig. 12 average SAR at 2.1GHz frequency Vs the distance at the realistic head model (a) without FSS Absorber shield, (b) with FSS Absorber shield

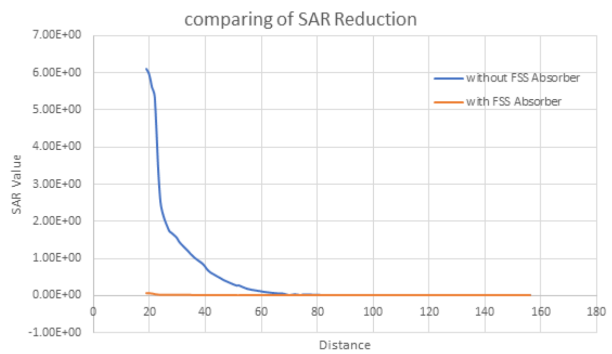


Fig. 13 Comparing SAR reduction

V. Conclusion

The influence of RF waves emitted from the handset antenna on the human head was tested by changing the head-to-antenna distance as well as the antenna angle. A 3-D Ansoft HFSS realistic human head model has been utilized in order to find SAR distribution. The use of this model allowed us to investigate SAR against different head tissues and distributions, also has been computed by using simulated SAR values. However, the SAR problem was discussed, also presenting the factors affecting it and how to calculate its value. A survey has been conducted about many effective methods for reducing SAR. The RF-Shields are the most effective method, especially using a metamaterial substrate. The RF-Shields are the most effective method, especially when using the EBG substrate. However, when using one of these methods to reduce SAR value, other important factors affecting antenna operation must be considered, such as impedance matching, providing high efficiency, decreasing antenna size, increasing compactness and robustness of the antenna, and integration with existing RF circuit components.

The obtained results show an inversely proportional relationship between SAR and the distance and the confined angle between the model and the excitation source. Therefore, when the distance between the source and the head model is incremented from 0 mm to 10 mm that will cause the SAR to decrease by the angle and the distance increases. The SAR rates that are calculated in Phantom have been reduced but with a slight effect on the antenna radiation efficiency.

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