TRANSACTIONS ON ELECTROMAGNETIC SPECTRUM

The Influence of Human Tissues on the Patch Antennas' Parameters

Claudia Constantinescu[1*], Claudia Pacurar[1], Adina Giurgiuman[1], Calin Munteanu[1], Florin Dragan[1], Sergiu Andreica[1], Marian Gliga[1]

[1]Department of Electrotechnics and Measurements, Technical University of Cluj Napoca, Cluj, Romania

*** Corresponding author's e-mail address:** claudia.constantinescu@ethm.utcluj.ro

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Abstract: In a lot of studies from literature was analyzed the influence of antennas on human body. In this article the study reflects the opposite, the influence of human tissue on antennas' parameters. In this study different types of human tissues are modelled in the vicinity of the patch antenna to analyze their influence on antennas' parameters. To model the patch antenna, the authors developed and implemented an algorithm dedicated to the determination of the antenna's geometrical dimensions in terms of dielectrics' material properties and their standard dimensions, all gathered by the authors in a very useful database. Using our algorithm, we can quickly find the antennas geometrical parameters needed for its numerical modelling and practically construction. The antenna geometry is obtained with our algorithm and next is modelled in the presence of three types of tissue: skin, muscle, and fat. The directivity, S-parameters and specific absorption rate in the tissues are determined, considering different distances between them. Analyzing our results, we can conclude that the normal functioning of the antenna is influenced by the presence of human tissues in their immediate vicinity.

Keywords: Human Tissue, SAR, S parameters, Directivity, Numerical modelling.

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1. INTRODUCTION

Microstrip antennas have received a great attention since 1970, even though the idea of such an antenna was seen in the scientific literature since 1953, the first patent for it is dated in 1955. Patch antennas are well known for their performances and their robust design. These antennas are used in various fields such as medical applications, satellites, planes, radar and GPS systems and many others. Also, microstrip antennas become widespread also on the mobile market [1-5].

During the research activities, the authors studied patch antenna functionality considering different geometrical dimensions [6-10], different patch shapes [7-9], different types of feeding [10] and different dielectrics [6-11]. Also, in recent studies, the authors widened their area of expertise and determined the influence of antennas on the human head [7,9].

This paper's purpose is the analysis through numerical modelling at high frequency of the patch antenna to determine the way in which their operation is influenced by certain types of tissue, such as skin, adipose tissue, and muscle present near them.

The geometrical dimensions of the patch antenna were determined with the help of an algorithm made by the authors to quickly design the antennas to be modelled, analysed, and future practically constructed. The user can choose the dielectric of the antenna from the database created by authors that include the dielectrics existent on the market. Based on the chosen dielectric, the user can choose the thickness from a series of specific dimensions available from the manufacturer, fact which makes the design process to be much faster and costs to be lower, considering that these dielectrics are already available and are not custom made.

The analysis through numerical modelling was made with the tridimensionality numerical modelling program for analysis at high frequency, ANSYS-HFSS (High Frequency Structure Simulator). With the help of this program, we have determined the influence of the dielectric thickness on the specific parameters of the antenna, then we've determined the influence of human tissues present in the near vicinity of the antenna considering placing the tissues at different distances from the antenna. By relating our results to similar results in the scientific literature [12], we can say that the results obtained by the authors are in accordance.

2. MATERIALS AND METHODS

The authors analysed 4 patch antennas considered to be coaxial fed. For the coaxial feeding, an inner conductor extends through the dielectric and is soldered to the patch, while an outer conductor is connected to the ground plane. Most of the studies regarding the patch antennas near tissues consider a microstrip feeding [11-13], while in our case the coaxial feeding was chosen, following the results obtained for the patch antennas with different feeding types [10], fact which ensures the novelty of this study. As a dielectric for the antennas, Rogers RO3003 (with the relative permittivity $\varepsilon_r = 3$ and dielectric loss tangent 0.0013) was used and its dimensions are: length 100 mm, width 90 mm. The height of the dielectric was varied, 4 values being considered, namely 0.25 mm, 0.5 mm, 0.75 mm and 1.52 mm, all standard dimensions from the manufacturer. These dimensions were chosen because the dielectrics with which these kinds of structures are constructed have stereotypical dimensions and the costs would decrease. For each of the dielectric dimensions considered, the dimensions of the patch are determined with the help of the software program designed by the authors. After the geometrical dimensions of the antennas are determined, the structure is numerically modelled with the help of the software program ANSYS-HFSS. The geometry of the patch antenna considered for this study is designed as it can be observed in Fig. 1.

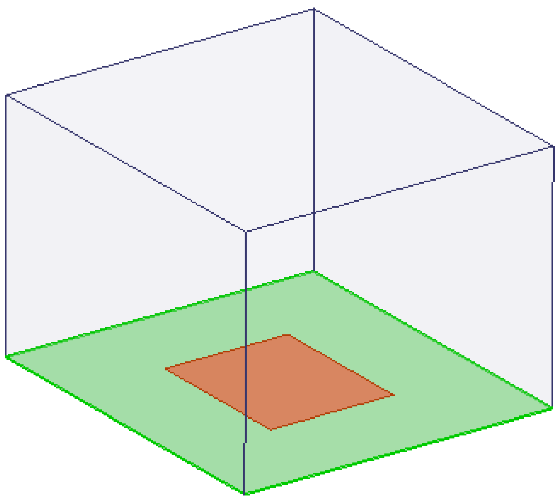


Figure 1. Patch antenna considered.

The length and the width of the patches corresponding to the other dielectric thicknesses considered are determined considering the dielectric constant, the dielectric thickness and the functioning frequency, based on the formulas below which represent the base of the design process. The length of the patch is calculated with the formula (1) where v_0 is the space velocity.

$$W = \frac{1}{2f_r\sqrt{\mu_0\varepsilon_0}}\sqrt{\frac{2}{\varepsilon_r + 1}} = \frac{v_0}{2f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{1}$$

The length of the antenna is calculated with formula (4). For the result is first necessary to calculate the effective dielectric constant (2) and the extension of length ΔL which represents the suplimentary length at the end of the patch.

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \tag{2}$$

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{reff} + 0.3)(\frac{W}{h} + 0.264)}{(\varepsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)} \tag{3}$$

$$L = \frac{1}{2f_r\sqrt{\varepsilon_{reff}}\sqrt{\mu_0\varepsilon_0}} - 2\Delta L \tag{4}$$

All these formulas were included in a software program with the help of Visual Studio Community Edition which, based on these values, will give the user the dimensions of the patch. The interface of the software program can be seen in Fig. 2.

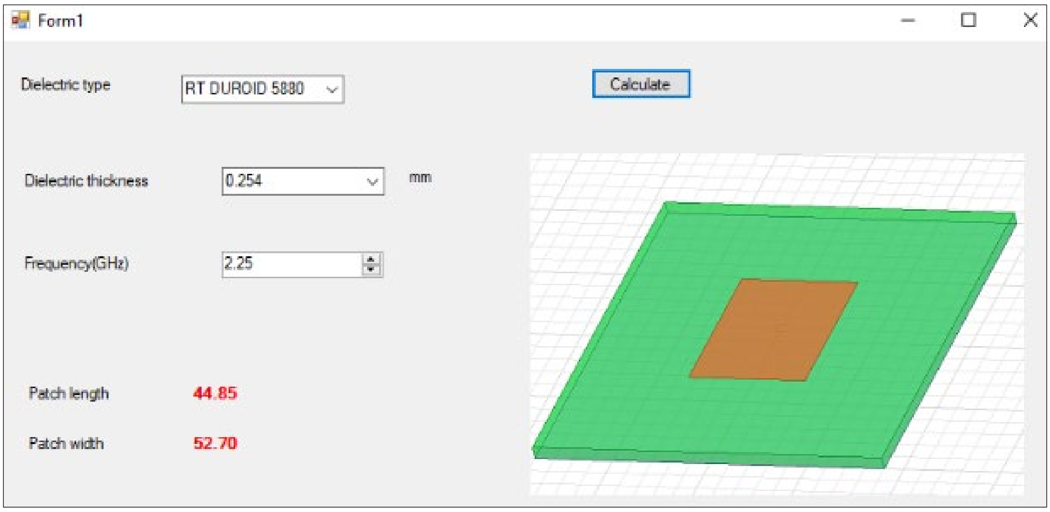


Figure 2. Patch antenna design software interface.

The list of available thicknesses is generated only after a specific dielectric is chosen. The database linked to this interface was also created by the authors after carefully analysing the dielectric market.

The user can select the dielectric used from a list of different materials. After the material is chosen, the dielectric thickness can be also chosen from a list which contains the specific dimensions for each individual materials taken from the dielectric datasheet.

The frequency for which the antenna is designed to function is also inserted in the algorithm as input data. After clicking the calculate button, the program calculates and gives us the patch length and width [10].

After the four antennas were designed, the specific parameters for their structures were determined and compared. All the antennas are fed via a coaxial cable. [1,2,14]

The next step is to determine the influence of the tissues on the antenna functionality. For this, three types of human tissue were modelled with the numerical modelling program used. The first one is skin. From previous study it can be observed that the properties of the skin are easily influence by hydration, but in this study, it is considered to have a relative permittivity, ε_r =41.19 and the conductivity, σ =0.88 S/m. The second layer of tissue is the adipose one, with the relative permittivity ε_r =11.59 and conductivity, σ=0.092 S/m. The last one is the muscle tissue with a relative permittivity, ε_r =55.52 and conductivity, σ =0.902 S/m. Their thicknesses, as in the real life, differs. So, for the first part of the study, the skin has 2 mm, the adipose substrate 10 mm and the muscle 28 mm, while in a different study the thickness of the adipose tissue will be varied. The length and the width of the modelled tissues is the same as the ones for the antenna placed near them [12,16-19]. The model designed in the 3D numerical modelling program is presented in Fig. 3.

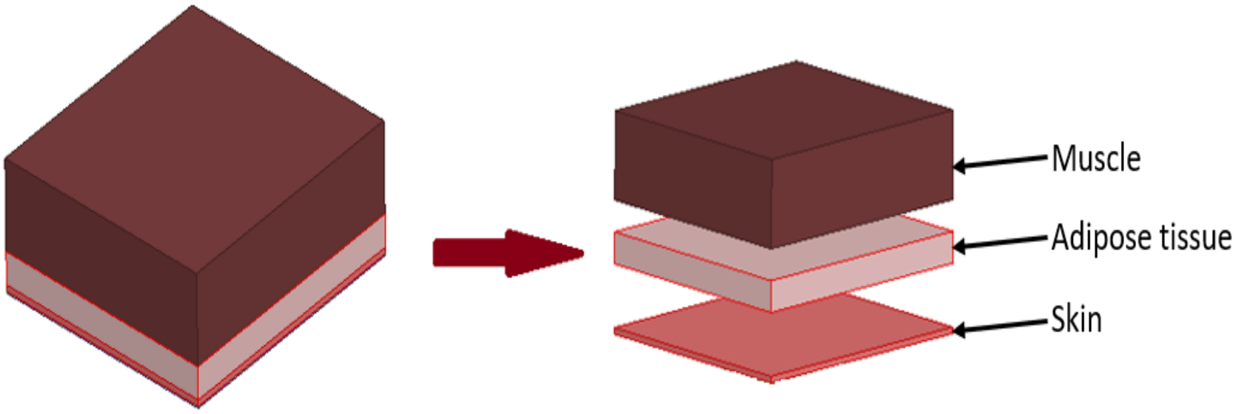


Figure 3. General views of the interface.

3. MATERIALS AND METHODS

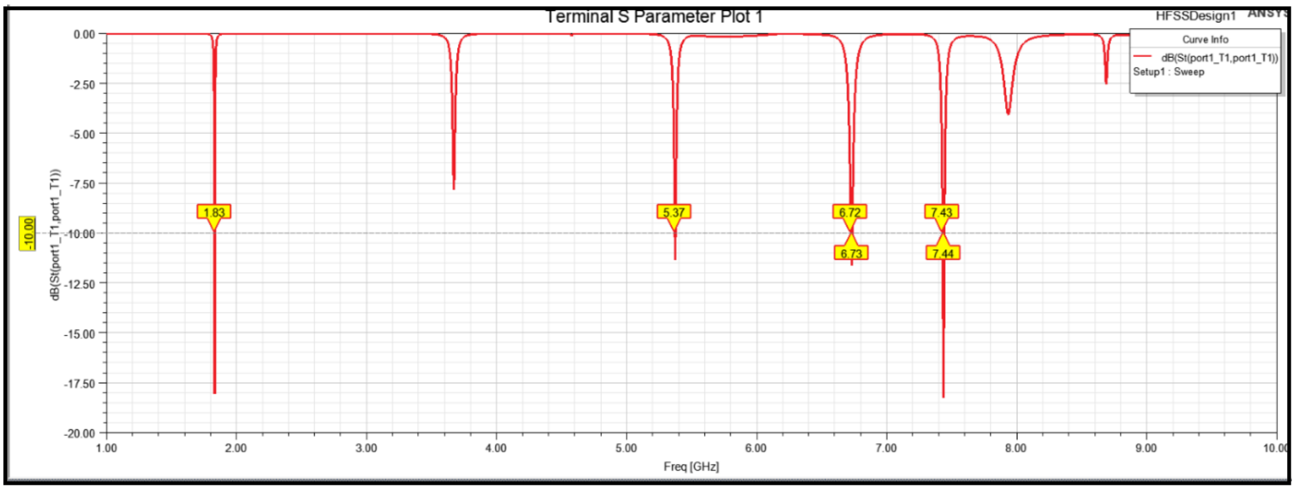
The first step of the study is determining the influence of the dielectric thickness on the antenna parameters, followed by the evaluation of the influence of the tissues present in the proximity of the antenna has on the antenna functionality

3.1. Influence of the Dielectric Thickness of the Antenna Parameters

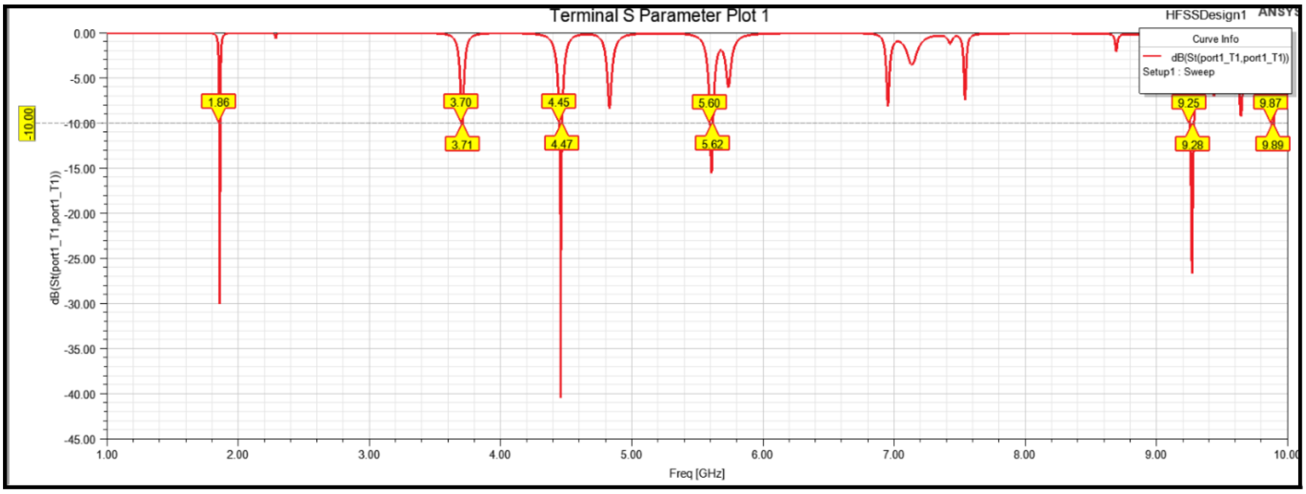
Considering the four different structures designed for different dielectric thicknesses, the specific parameters for each structure are determined, compared, and analysed and some conclusions are drawn. The analysed parameters are S parameters, directivity, and specific absorption rate (SAR).

The first analysed parameters are the S parameters for the four structures with different dielectric thicknesses. The results are presented in Fig. 4 in a frequency range between 1 – 10 GHz.

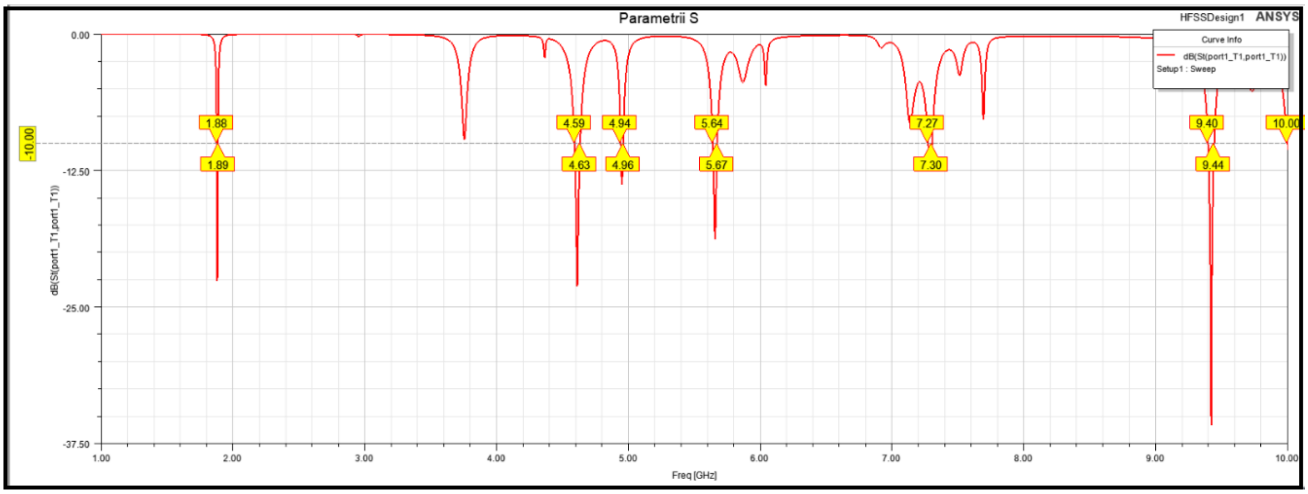
It can be observed that the allure of the graph remains the same for the four structures and also the number of resonant frequencies is approximately the same. The structures with 0.5 mm and 0.75 mm dielectrics have more resonant frequencies, thus are functioning in more frequency ranges.



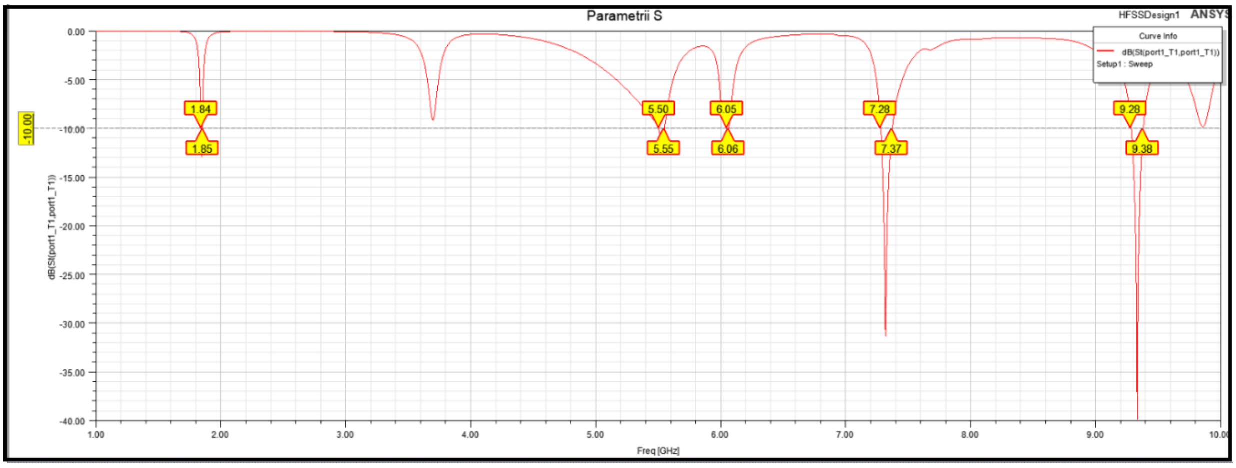
a) 0.25 mm



b) 0.5 mm



c) 0.75 mm



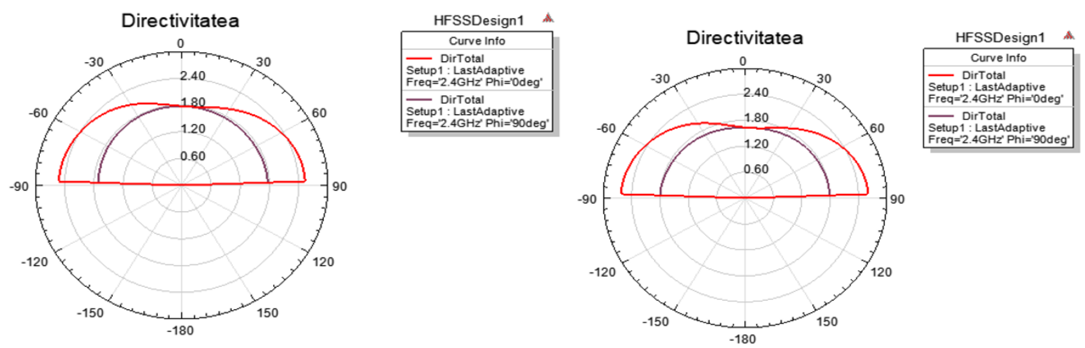
d) 1.52 mm

Figure 4. S parameters for the 4 analyzed structures.

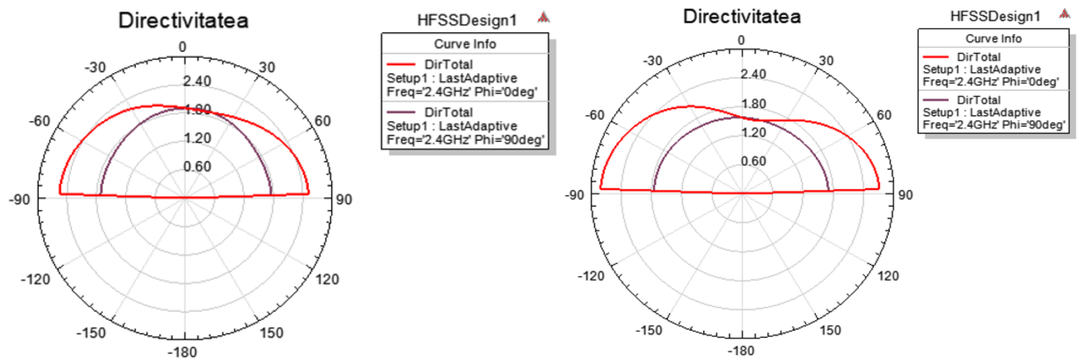
The directivity is also determined for the 4 different structures in the workspace constructed for the model and can be observed in Fig. 5.

In the case of the coaxial cable feeding the antenna emits above the patch, thus only this part of the directivity is represented. The graphs show that the thickness of the dielectric does not significantly affect the directivity of the antenna in the H and E plane.

SAR was only represented on the surface of the patch because this is where the values are the highest. Analysing the SAR representations, it can be observed that all the values from the patch are below the imposed limits by the standards in force. Also, the highest values are present near the coaxial feeding and on the patch extremities.

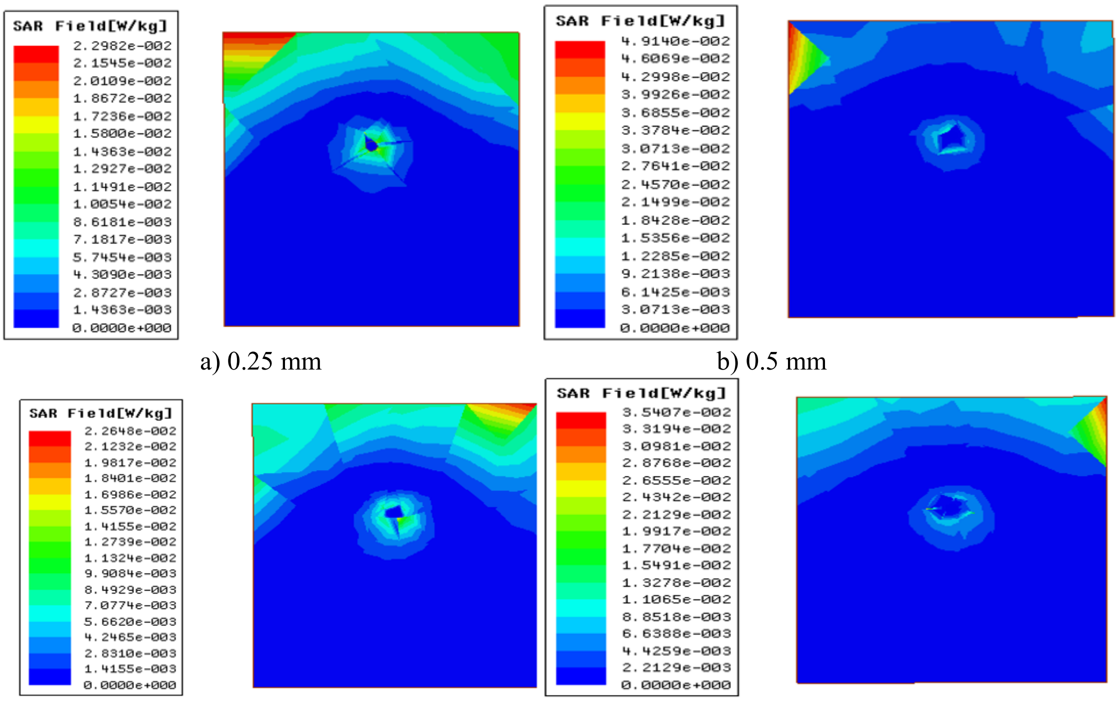


a) 0.25 mm b) 0.5 mm



c) 0.75 mm d) 1.52 mm

Figure 5. Directivity for the 4analyzed structures.



a) 0.25 mm b) 0.5 mm

c) 0.75 mm d) 1.52 mm

Figure 6. SAR for the analyzed structures.

3.2. Influence of the Tissue Presence on the Antenna Parameters

The study about the influence of the tissue presence on the antenna parameters was conducted on all four antennas mentioned before, but the results only for one of the antennas will be presented in this part of the paper, namely the one with 1,52 mm dielectric thickness. The tissues will be placed at 0 mm, 5 mm and 10 mm from the antenna and the results will be compared. The tissues considered have the dimensions presented above so the skin has 2 mm thickness, the adipose substrate has 10 mm thickness, while the muscle has 28 mm thickness. A representation of all the tissues and the antenna modelled can be seen in Fig. 7.

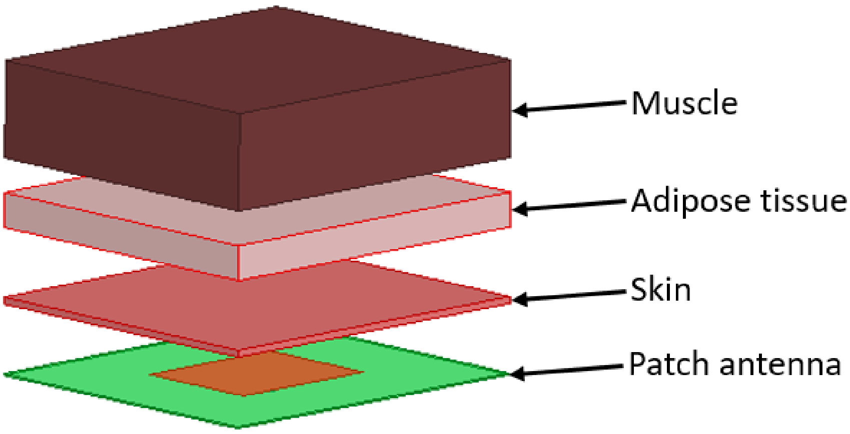
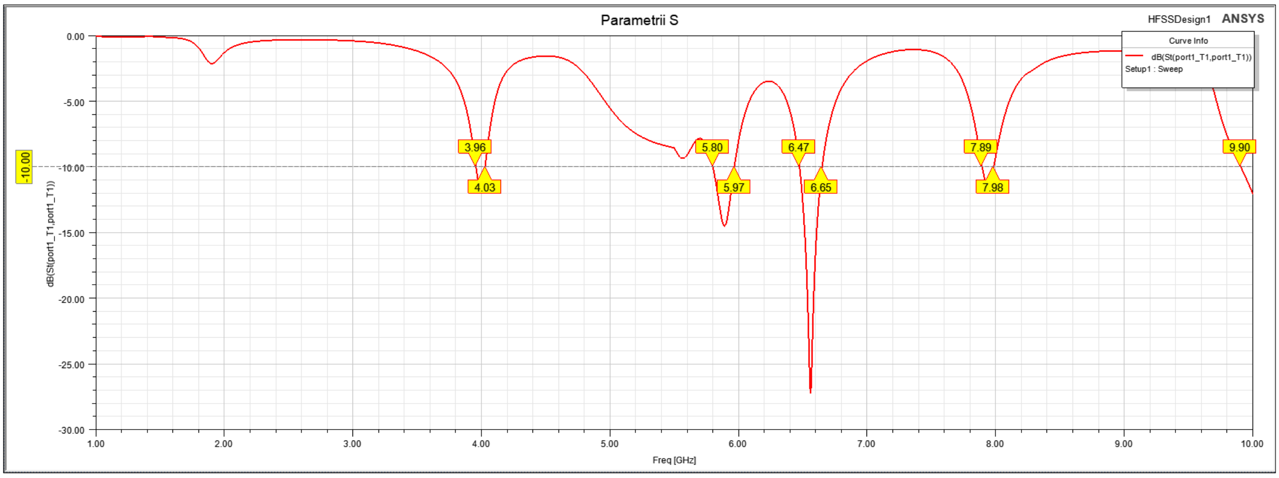
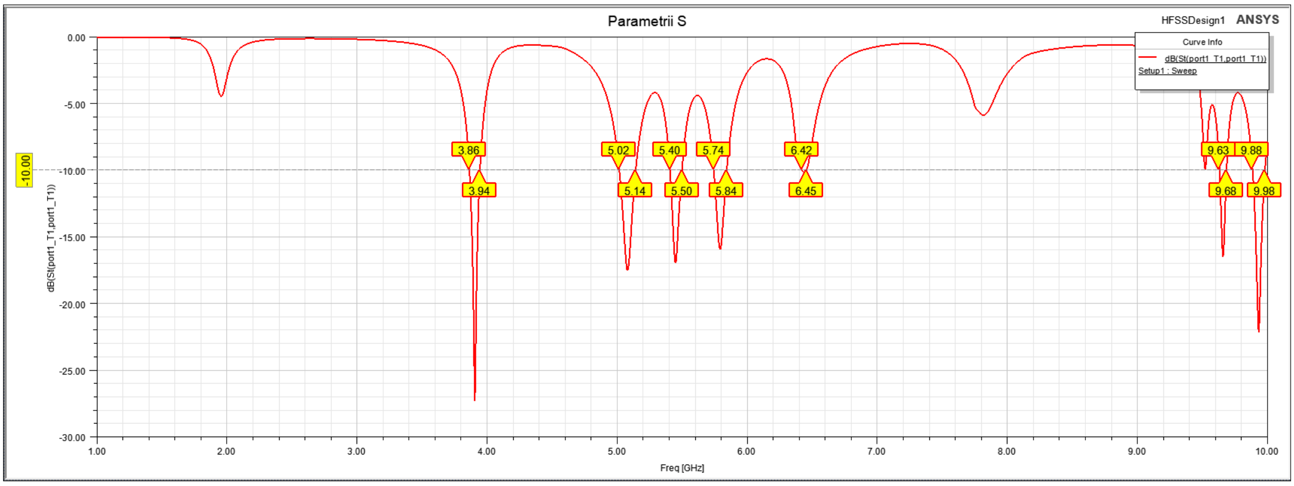


Figure 7. The patch antenna and the tissues numerically modeled.

The results for the three considered positions of the antenna in the vicinity of the tissues is presented in Fig. 8. Analysing Fig. 8 in comparison to Fig. 4, it can be stated that the presence of the tissues is highly influencing the antennas' S parameters. Also, the resonant frequencies are different when the distance between the antenna and the tissues are modified in the considered frequency range between 1 and 10 GHz. When the antenna is 10 mm from the tissues the number of resonant frequencies is the highest, while the antenna doesn't function when placed at 0 mm from the tissue in the frequency range considered. The directivity is also influenced by the presence of the tissue in the vicinity of the antenna. Comparing the representations with the ones for the antenna alone where the emissions were concentrated in one main lobe, it can be stated that there are 2 main lobes when the tissues are situated above the antenna and have the same dimensions as the antenna, just as to bypass the tissues. The most prominent and narrow of the lobes are in the case of the tissue stuck to the antenna (Fig. 9(a)).

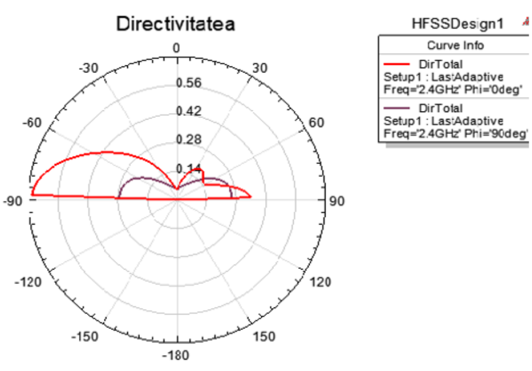


a) 5 mm

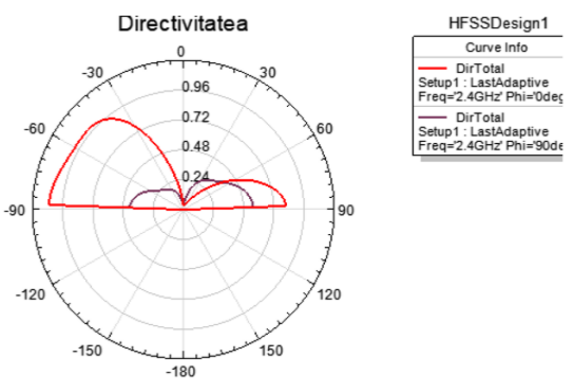


b) 10 mm

Figure 8. S parameters considered for the antenna in the proximity of the tissues at (a) 5 mm and (b) 10 mm from the antenna.



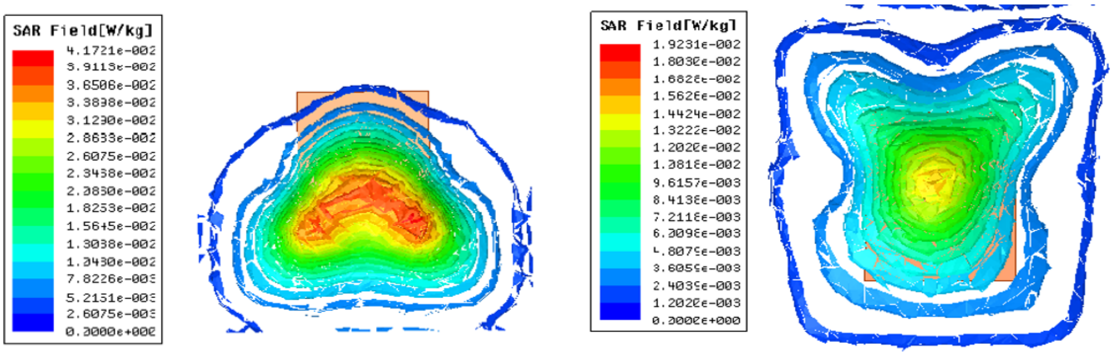
a) 5 mm



b) 10 mm

Figure 9. Directivity considered for the antenna in the proximity of the tissues at (a) 5 mm and (b) 10 mm from the antenna.

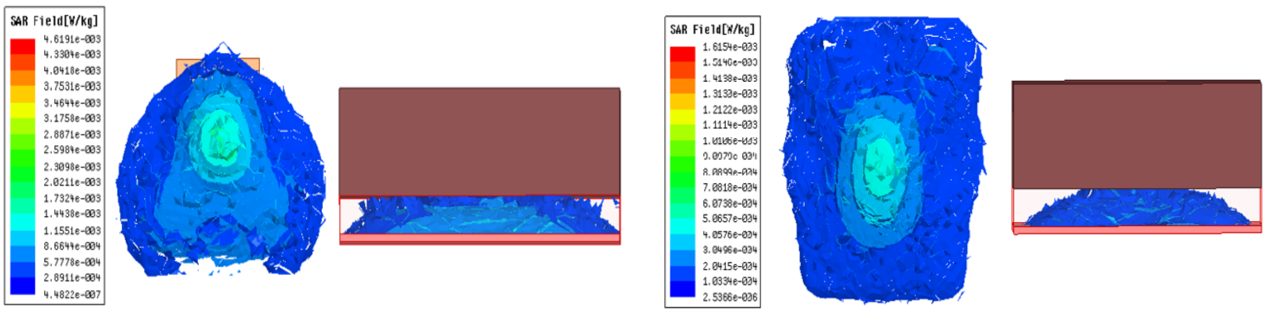
Every one of the tissues are considered for the representation of the SAR for the three distances considered. Thus, in Fig. 10 the SAR values for skin are represented when the antenna is at a distance of 5 mm and 10 mm from the tissues. It can be observed that the values are the highest when the antenna is at 10 mm, while the smallest values are when the antenna is at 5 mm from the skin. The highest values are present in the middle of the tissues due to the fact that there is the emitting patch. This is the most affected tissue because in smaller regions the values of SAR exceed the limits imposed by the standards in force. This study is very important because the distance at which the antenna must be placed so that it does not affect the subject can be determined.



a) 5 mm b) 10 mm

Figure 10. SAR values on the skin tissue considered for the antenna in the proximity of the tissues at (a) 5 mm and (b) 10 mm from the antenna.

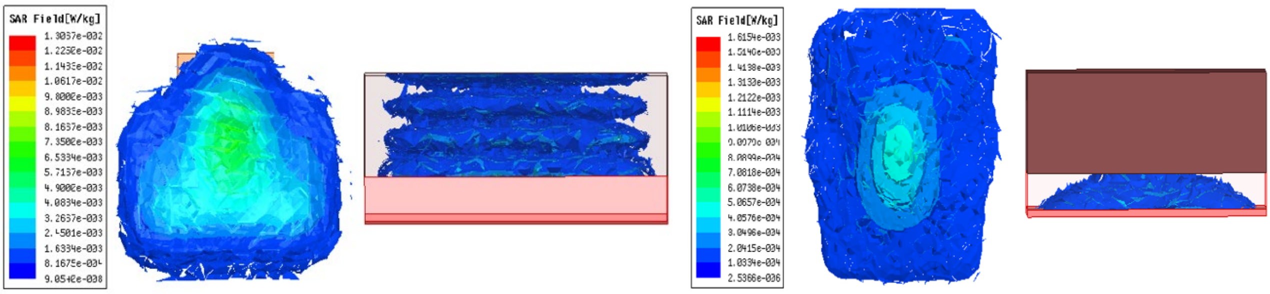
The adipose tissue is the next considered. Here the values of SAR have lower values, the limits are not exceeded. The difference is so noticeable that we can say that using an emitting antenna next to some tissues can lead to the determination of the type of tissue and also its thickness. Also, like in the other case, the values do not decrease with the in-crease of the distance between the antenna and tissues, the directivity of the antenna influences the values. The representations for the adipose tissue are presented in Fig. 11.



a) 5 mm b) 10 mm

Figure 11. SAR values on the adipose tissue considered for the antenna in the proximity of the tissues at (a) 0 mm, (b) 5 mm and (c) 10 mm from the antenna.

Even though the muscle tissue is the farthest from the antenna, the values of the SAR are higher than the ones obtained in the adipose tissue. The conclusions remain the same as the ones from the representation in the other tissue types (Fig. 12).



(a) 5 mm (b) 10 mm

Figure 12. SAR values on the muscle tissue considered for the antenna in the proximity of the tissues at (a) 0 mm, (b) 5 mm and (c) 10 mm from the antenna.

3.3. Influence of the Adipose Tissue Thickness on the Antenna Parameters

The study continues with the modification of the adipose tissue thickness to determine its influence on the antenna parameters. This could lead to the determination of the thickness of one’s adipose tissue only by placing an emitting antenna near him/her, without intrusive surgery. Considering only one structure, namely the one with 1.52 mm substrate at 5 mm from the tissues and while maintaining all the other parameters constant, the adipose tissue thickness is modified to 15 mm and 20 mm and compared with the results obtained for the 10 mm adipose tissue. Analysing the S parameters, there are a few differences between the representations for different adipose tissue thicknesses in the frequency range considered. It can be concluded that the number of resonant frequencies is the same, but the frequency ranges in which the antenna functions slightly differ. Considering the thickness of the adipose tissue modification, it can be observed that a small modification leads to a totally different directivity of the antenna.

4. CONCLUSIONS

The most important assumption, that the distance and the thickness of the tissues in the proximity of the antenna influences the antenna parameters, was confirmed. The resonances are sensible to the positioning of the tissue near the antenna and also the directivity of the antenna changes. It can be stated that if an antenna is constructed for this purpose, it could determine the thickness of different tissues or even the existence of abnormal tissues in the human body analyzing the variation of the directivity diagrams and S parameters from the modelled structures.

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