EE492
Senior Design Project Midterm Report

Design of an implantable antenna for microwave hyperthermia

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1. Introduction

The recent technological advancements are revolutionizing the way healthcare is being delivered and they are also a key factor driving the advances of surgical treatment. Joint replacement surgery (hip and knee replacement) is considered the most effective intervention for severe osteoarthritis and hip fractures, reducing pain and disability and restoring some patients to near normal function. [1] As a consequence, hip replacement surgery shows increasing trends in most OECD countries. On average, the rate of hip replacement increased by 30% between 2000 and 2015.[1] Revision burden can be seen as a rough measure of the success of hip replacement surgeries. In the USA the revision burden was 10.2% for hips between 2012 and 2015 [2], but revision surgery of the hip is expensive owing to the increased cost of pre-operative investigations, surgical implants and instrumentation. [3]

The six most common indications for revision after primary hip replacement (listed in order of frequency) are aseptic loosening, pain, adverse soft tissue reaction to particulate debris, dislocation, infection and peri-prosthetic fracture.[4] Especially performing the revision surgery for infection is riskier considering the instrumentation. Staphylococcus aureus and Staphylococcus epidermidis are the leading etiologic agents of orthopedic implant infection.[5] Traditional antibiotic therapy will never be successful against these pathogens after the biofilm is formed. [6] This property of bacteria is called antimicrobial resistance (AMR) and it is a major concern worldwide. The other modes of treatment will be needed to prevent biofilm formation in the first place.

A hip implant can be equipped with sensors and microelectronics forming a wireless communication link between the implant and an on-body sensor to collect continuous data or provide real-time feedback.[7] In this project it is aimed to design an antenna taking action against infection before and during the biofilm formation through microwave hyperthermia with the help of the feedback from the antenna which monitors its environment.

2. Objectives

The objective of this project is to take action against infection through microwave hyperthermia. In this context, the electrical characteristics of the tissue surrounding the implant will be determined immediately after the operation. (when the infection is present) In addition to that, numerical and physical modelling of the propagation environment will be performed. After all of the optimizations are completed, the optimum working frequency for the microwave hyperthermia will be determined and the antenna design will be completed.

The second objective of this project is to develop the phantom and to build the measurement setup on which the measurements will be performed next semester.

3. Approach and Methodology

a. *Optimizations for microwave hyperthermia*

Because the human body absorbs electromagnetic waves it is often difficult to connect an implanted device to the outside world. The effect of hyperthermia depends on the depth of the implant, surrounding tissues and near field losses. It should be noted that the surrounding tissue properties and depth of the implant vary from patient to patient, but only in one patient as the patient ages. Therefore, an antenna which can adapt to the changing environment and target energy to the required region should be designed for microwave hyperthermia. The antenna parameters will be optimized considering both the thermal and electromagnetic distribution.

b. *Phantom development and building of measurement setup*

1- *Digital 3D design of the phantom model*

A 3D model will be developed to mimic the environment in which the hip implant will be located in real life. The model should include the hip implant, a portion of the femur, pelvis, body fluid, hip muscle, fat and skin.

2- *The integration of 3D phantom model with liquid/gel phantoms*

The printed 3D model should be filled up with liquid/gel in accordance with the approximate dielectric constant and conductivity values of the corresponding parts described above.

3- *Development of measurement setup*

A test kit will be developed for measuring the input response and the transmission response of the designed antenna. The test kit will consist of a mini vector network analyzer (VNA), a rotary stage and absorber material. The test kit will be used in system level tests too.

4. Work Completed

In the first part of the project (EE 491), great progress had been made. You can review my previous reports to see what I did. At the beginning of the semester a meeting was held with my supervisor and we talked about what we are going to do this semester.

It was important to test that we did the thermal analysis correctly. The coaxial-slot antenna of Koichi Ito is designed and tested accordingly. The further explanation can be found on the final report of first part of the project.

The first task of this semester was to design a prototype antenna to test heating at different frequencies. One can see the prototype antenna and measurement setup on Figure 1. It is a circular slot antenna. To operate this antenna at the different frequencies (0.5 GHz to 2.5 GHz) one should definitely change the size of the slot in other words change the diameter of the inner circle and the width of the slot. One can also the change of the slots of antennas operating at 2 GHz and 2.5GHz on Figure 2 and Table 1.

This first task was very critical, because doing this we can find the optimum operating frequency value of the antenna which results in perfect SAR distribution. This process is also called heating optimization. It is clear that the heating occurs because of near field losses and it is frequency dependent. We have the possibility to test different frequencies unlike the Koichi's circular slot antenna, because for our purposes only the specific small neighborhood of the antenna is important, not the depth or area of the heated region.

To determine the antenna's working frequency is also important because I should also get a transmitter which works at this frequency value. So, it is an initial step for prototyping.

This was a simple setup as one can also see on Figure 1, but things did not go the way we wanted. We concluded that testing different frequencies is difficult in this setup. The limitation was that I could not change the antenna size as much as I wanted. To overcome this obstacle, it was decided to use a miniaturized antenna. The setup can be seen on Figure3. This design is initially made by my supervisor Prof. Sema Dumanlı Oktar. It is a complex design and was a little bit hard to understand. But after spending some time on the model I got it.

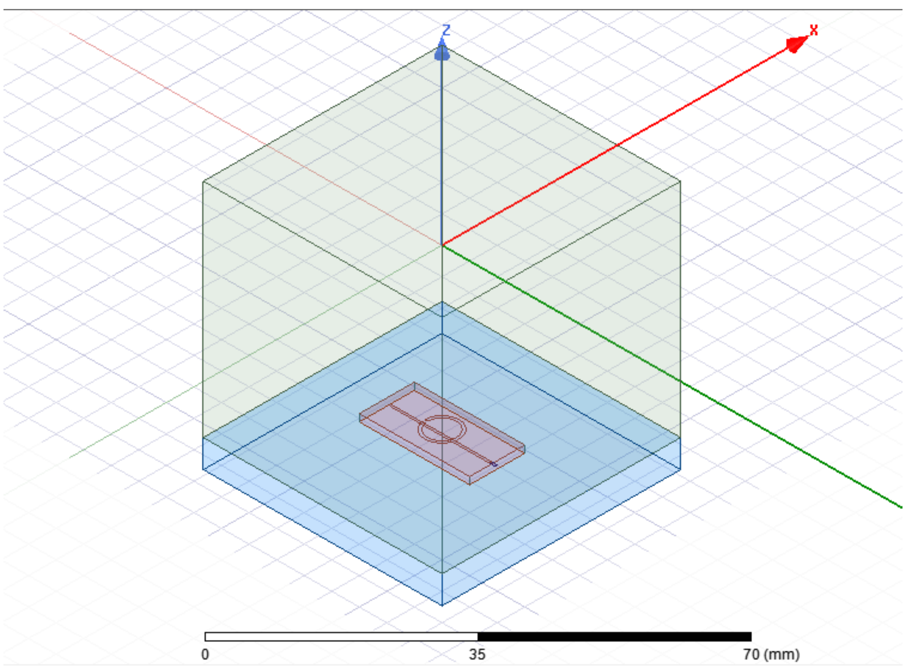

Figure 1: Measurement setup

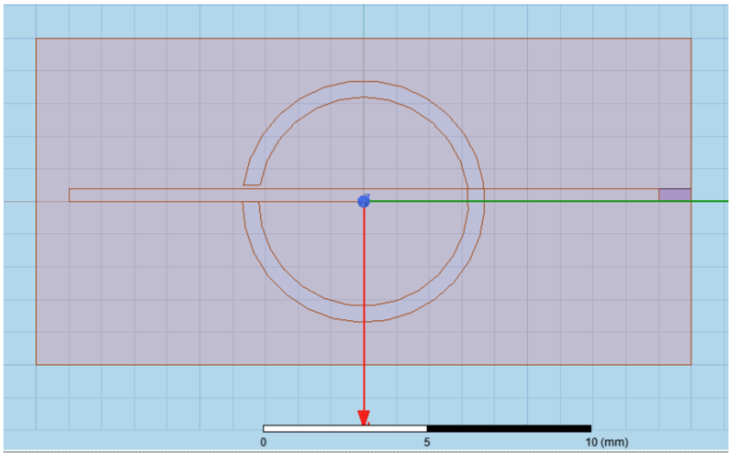

Figure 2.a : Operating at 2.0 GHz

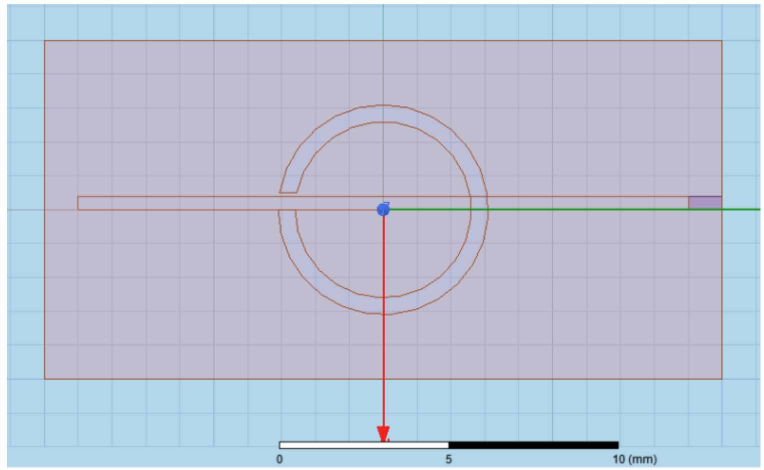

Figure 2.b : Operating at 2.5 GHz

Operating Frequency	feedLength	Innerslot length	Slotwidth
1.5 GHz	63 mm	4.3 mm	0.5 mm
2.0 GHz	63 mm	3.2 mm	0.5 mm
2.5 GHz	63 mm	2.6 mm	0.5 mm

Table I: Parameters used on the model

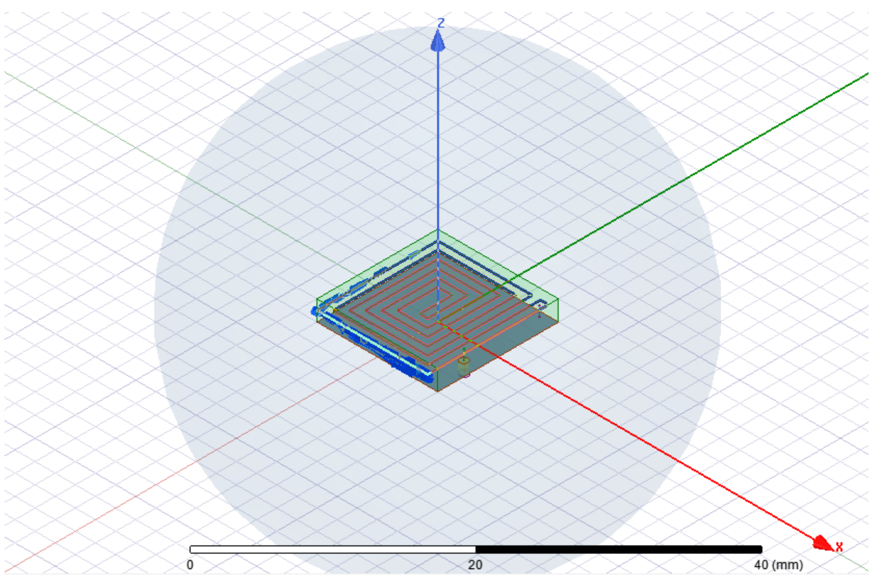

Figure 3: Measurement setup

The antenna is inside a spherical medium which is human bone cortical. The antenna consists of a labyrinth like slot, a ground plane, implant substrate and feeding mechanism. An optimization process has done like before. Only by changing the slot width of the labyrinth like slot the antenna is matched at different frequencies. You can see the related S-parameters plot below.

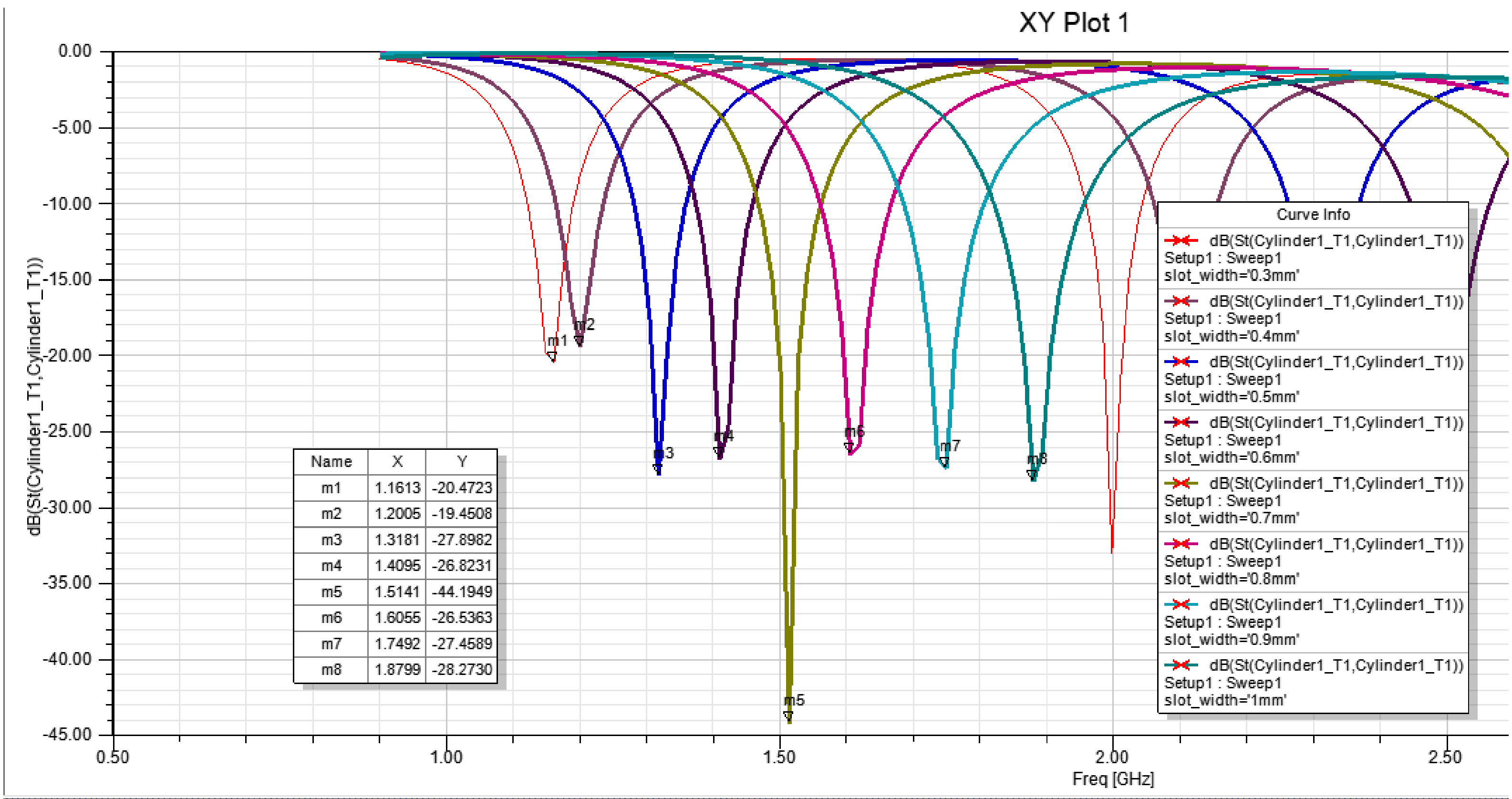

Figure 4: S parameters plot

One can see here the antenna has perfectly matched to operate at different frequencies. After deciding the slot widths of the labyrinth like antennas and their corresponding frequencies (see Table **II**). Specific simulations at specific frequencies were performed and electric fields were calculated accordingly. The SAR plots were drawn and interpreted with my advisor. You can see the SAR plots seen from different angles below. (**Figure 5 to Figure 12**)

Working frequency	**Slot width**
1.16 GHz	0.3 mm
1.20 GHz	0.4 mm
1.31 GHz	0.5 mm
1.41 GHz	0.6 mm
1.51 GHz	0.7 mm
1.60 GHz	0.8 mm
1.75 GHz	0.9 mm
1.88 GHz	1.0 mm

Table I: Slot widths and corresponding working frequencies

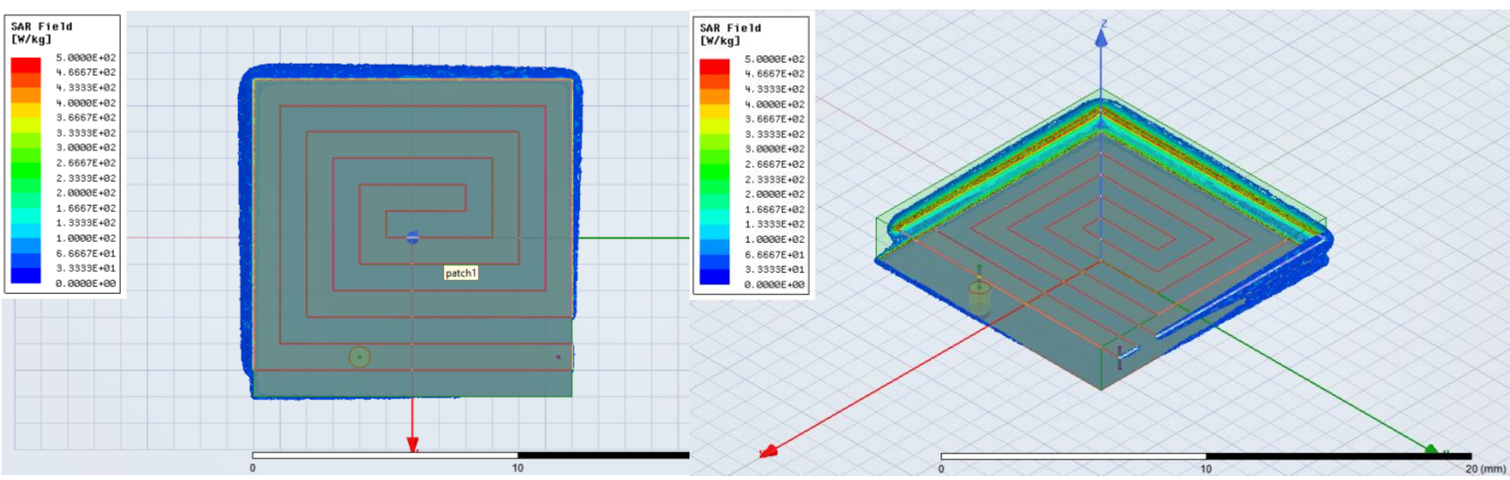

Figure 5: SAR distributions at 1.88 GHz seen from different angles

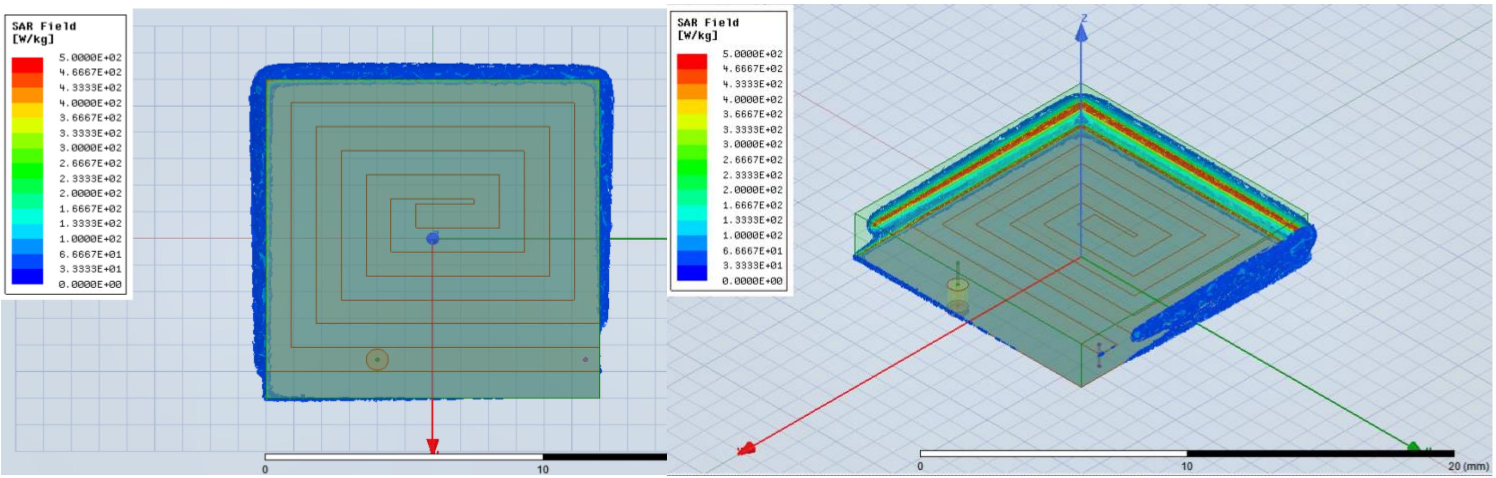

Figure 6: SAR distributions at 1.75 GHz seen from different angles

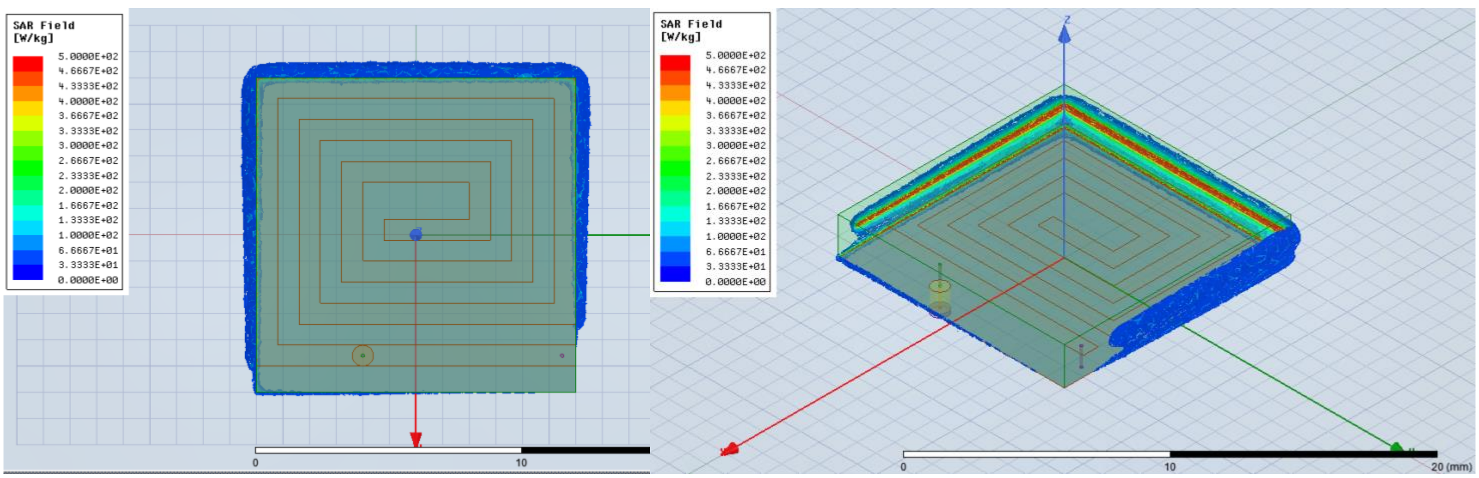

Figure 7: SAR distributions at 1.60 GHz seen from different angles

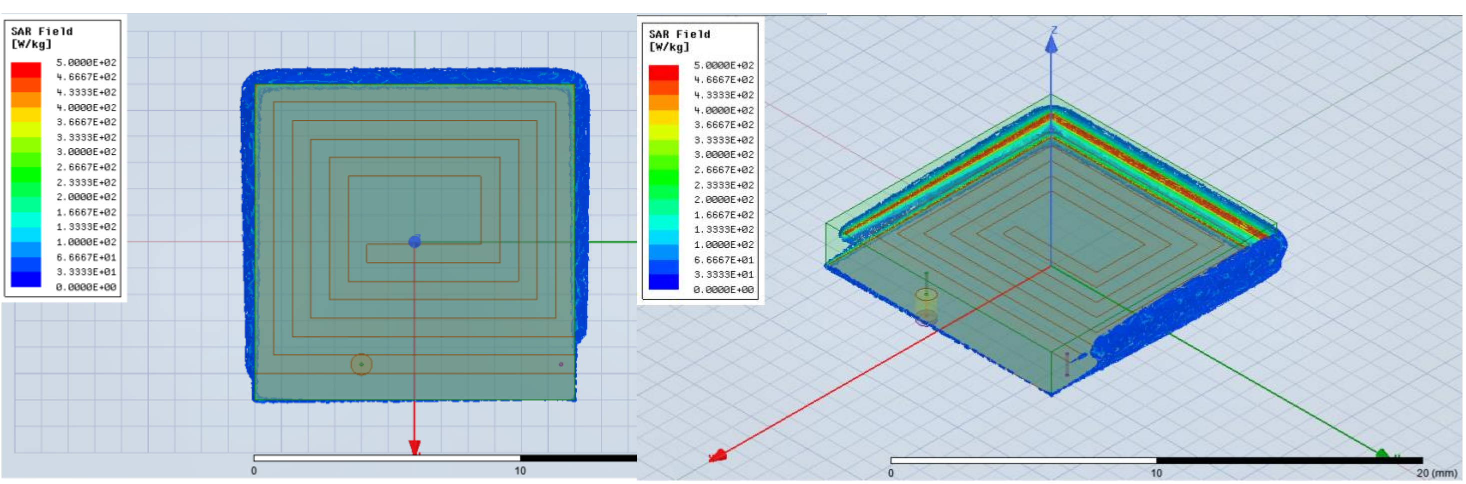

Figure 8: SAR distributions at 1.51 GHz seen from different angles

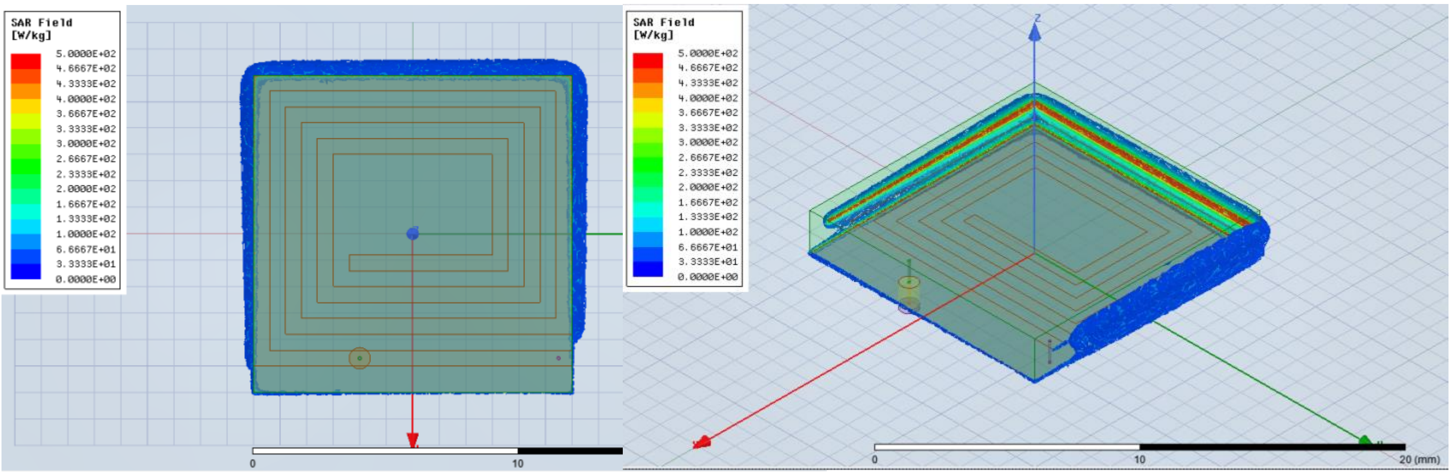

Figure 9: SAR distributions at 1.41 GHz seen from different angles

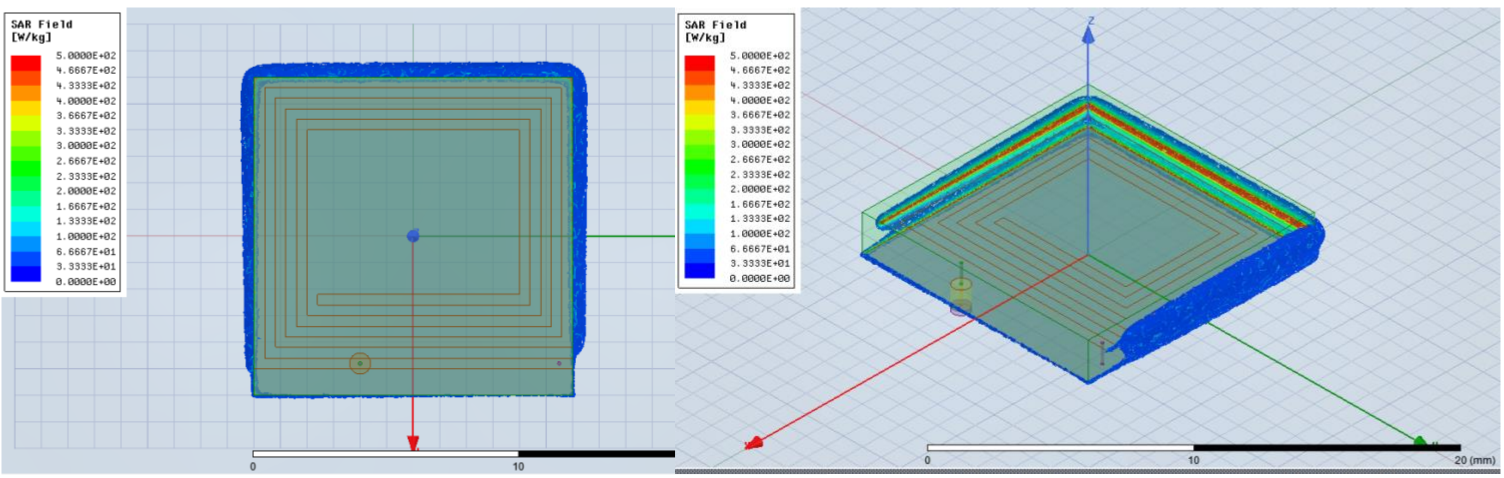

Figure 10: SAR distributions at 1.31 GHz seen from different angles

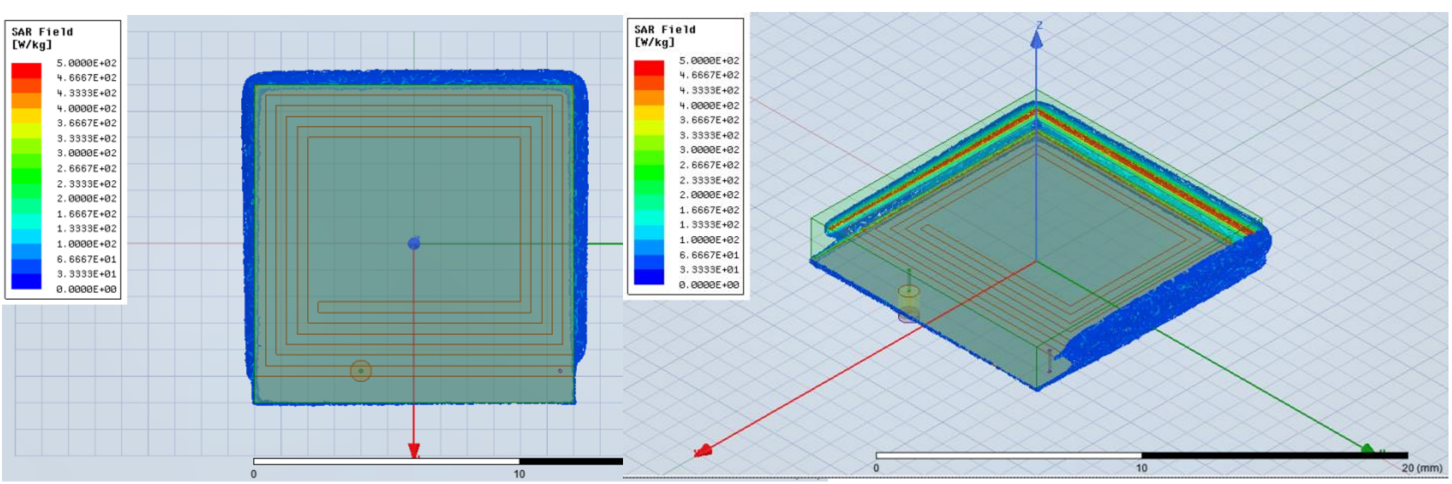

Figure 11: SAR distributions at 1.20 GHz seen from different angles

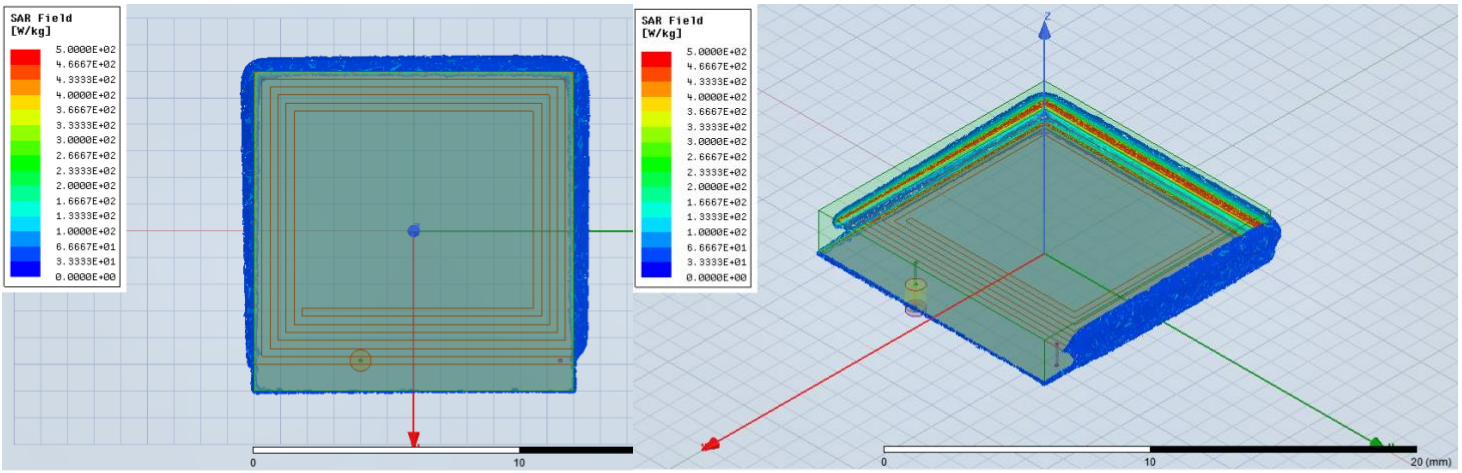

Figure 12: SAR distributions at 1.16 GHz seen from different angles

According to these results, one can obtain a better SAR distribution at lower frequencies.

5. Work to Be Completed

Literature review		EE 491
Power-density-based optimization	Single Layer	
	Cylindrical Layer	
	Detailed Layer	
Temperature-based optimization	Single Layer	
	Cylindrical Layer	
	Detailed Layer	
Report & Presentation		
Working frequency optimization on two different models		02.10.2019 – 20.11.2019
Last simulations		20.11.2019 – 30.11.2019
Prototyping	Antenna element	01.12.2019 – 12.12.2019
Measurements	System level measurements	12.12.2019 – 19.12.2019
	Heating measurements	
Report & Presentation		20.12.2019 – 31.12.2019

The antenna parameters will be optimized using outputs of each layer structure as feedbacks step by step from the simplest one (single layer) to the most complicated one (detailed layer) considering both power density-based optimization and temperature-based optimization and hence, they will be considered as a whole.

6. Realistic Constraints

a. Social, Environmental and Economic Impact

Although from an economical point of view, the project does not aim for any profit or further labor, if the project will turn out to be a real success, then it will yield a great economic and social benefits for users and device manufacturers. Moreover, using the designed antenna will save the patients and physicians a lot of time, because the implant antenna has its own feedback mechanism. Implicitly it will reduce the cost associated with the healthcare and it will improve the healthcare provided. It is a fact that implanted wireless devices are going to find wider application in tomorrow's world. Whether my project will be completed successfully is not going to change this fact.

b. Cost Analysis

The project requires a workstation on which the simulations to be implemented. I will be using the workstation of BOUNTENNA during my project. To create the measurement setup a vector network analyzer (VNA), a rotary stage and absorbers will be used. In addition to these costs, a 3D printer and chemicals will be used to create the phantom which should imitate the biological tissue. These materials should also be included in the costs. Moreover, I will be investing a specified amount of time for this project throughout the year. My plan is to work at least for three days each week for a faster progress.

c. Standards

In this project, the engineering ethics and code of conduct will be considered. Besides, the IEEE, IET, ETSI and EU standards will be followed in addition to Turkish standards.

7. References

[1] OECD (2017), "Hip and knee replacement", in Health at a Glance 2017: OECD Indicators, OECD Publishing, Paris.
[2] Third AJRR Annual Report on Hip and Knee Arthroplasty Data. (2016). [ebook] Rosemont, Illinois: American Joint Replacement Registry, pp.13-21. Available at: http://www.ajrr.net/images/annual_reports/AJRR_2016_Annual_Report_final.pdf [Accessed 21 Feb. 2019].
[3] Vanhegan, I. S., Malik, A. K., Jayakumar, P., Islam, S., Haddad, F. S. 2012. "A financial analysis of revision hip arthroplasty: the economic burden in relation to the national tariff", J Bone Joint Surg Br, 94(5), 619-623.
[4] The NJR Editorial Board, Ed., "National Joint Registry 13th Annual Report 2016," rep., 2016.
[5] L. Montanaro, P. Speziale, D. Campoccia, S. Ravaioli, I. Cangini, G. Pietrocola, S. Giannini, and C. R. Arciola, "Scenery of Staphylococcus implant infections in orthopedics," Nov-2011. [Online]. Available: https://www.futuremedicine.com/doi/pdf/10.2217/fmb.11.117. [Accessed: 20-Feb-2019].
[6] G. D. Ehrlich, F. Z. Hu, Q. Lin, J. W. Costerton, and J. C. Post, "Intelligent implants to battle biofilms | Request PDF," 03-Nov-2004. [Online]. Available: https://www.researchgate.net/publication/292688877_Intelligent_implants_to_battle_biofilms. [Accessed: 20-Feb-2019].
[7] S. Dumanli, "A cornered shallow cavity backed slot antenna suitable for smart hip implants," *2016 10th European Conference on Antennas and Propagation (EuCAP)*, 2016.