Design of a microstrip implant antenna for biotelemetry applications

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In this study, a unique microstrip implant antenna design that can be used for biotelemetry applications is proposed. Antenna size is designed as 30 mm *28 mm*1.59 mm. In its design, FR4 base material with dielectric constant of 4.3, loss tangent of 0.025 and height of 1.52 mm was used. The analysis of the implant antenna was performed in the CST Microwave Studio program. After the desired values were obtained, the tissue model was created and the implant antenna was placed in the skin tissue. The return loss and SAR value of the designed microstrip implant antenna were measured at 2.45 GHz in the ISM band. As a result of the measurements, the return loss in and out of the tissue was observed as -18 dB and -33 dB, and the SAR value as 153 W/kg, respectively. Then, the antenna was realized with the printed circuit technology, a phantom fluid was created showing the properties of the skin tissue, and the antenna was placed in this fluid. Finally, the simulation and experimental results of the designed antenna were evaluated and compared with the studies in the literature. It has been observed that the measurement results in the skin tissue are quite compatible with the simulation results.

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1. Introduction

Telemetry is the control and monitoring of an area of a system that cannot be reached remotely. Telemetry used for humans and animals is called biotelemetry. The foundations of biotelemetry systems were revealed in 1958 by NASA, the American National Aeronautics and Space Administration. The researches carried out to transmit the physiological parameters of the astronauts sent to space to the health workers on earth formed the main body of biotelemetry systems [1]. In the same year, Ake Senning's placement of a pacemaker inside the human body for the first time took place in our daily life as the civilian use of implantable biomedical devices [2].

The main task of biotelemetry systems is to monitor the vital parameters of the human body remotely and to assist doctors in the diagnosis and treatment of diseases. In today's biotelemetry applications, it is possible to measure many values such as EKG, EMG, EEG, blood pressure, blood flow and body temperature remotely. This diversity in the application areas ensures the differentiation of the biomedical devices to be used in biotelemetry systems and changes the designs of the devices day by day. Especially in recent years, when the pre-diagnosis of diseases has gained importance, there is a need to develop/produce innovative elements (such as antenna, microprocessor /microcontroller, sensor) that will meet the requirements of biotelemetry applications.

The antenna element, which is one of the important components of these systems, plays a critical role in downsizing the system while ensuring the transmission of data. In this context, the development of biocompatible and miniature antenna designs that will meet the application requirements is an important parameter to be overcome in terms of the success of the medical system [3].

Antenna designs used in medical applications are generally examined in three groups as edible, wearable and implantable antennas. Swallowable antennas are used in the transfer of some parameters (eg, temperature) that vary within the body and in the diagnosis of colon cancer [4]. Wearable antennas, on the other hand, can be placed on the body surface and used to measure values such as heart rhythm, the amount of oxygen in the blood and the level of sugar in the blood [5]. Implant antennas are placed in a fixed position in the body and used in microwave imaging, heart rhythm disorders, cancer diagnosis and treatment [6].

2. Literature review

Gozel, et al. studied biomedical antennas placed on the body [7]. An antenna design was made and this antenna was simulated. An H-shaped microstrip antenna was designed in the 868 MHz UHF band to be used in the study. FR4 was used as the infrastructure material in the designed antenna. The texture created for simulation consists of three different layers.

These layers consist of muscle, fat and skin. The antenna is at the boundary between the skin and the fat layer in this tissue sample. According to the simulation result, the SAR value was calculated as 396.8 W/kg in the CST simulation program. In the study, it was seen that an average value was found by comparing with other studies. In addition, it has been observed that the operating frequency of the antennas designed in the tissue can be adjusted, and many parameters such as the conductivity and dielectric of the tissue depend on the location of the antenna in the tissue.

Yeap, et al. studied an implantable dual-band antenna. The resonant frequencies of the designed antenna are 402 MHz and 2.45 GHz. RO3210 is used as the material in the antenna [8]. The dimensions of the antennas used in intra-tissue applications are designed very small. The dimensions of the antenna used in this study are 22 mm*16 mm*1.27 mm. According to the simulation results, the SAR value was calculated as 0.352 and 0.054 uW/kg at the frequencies of 402 MHz and 2.45 GHz, respectively. These values were found to be below the limits set by IEEE C95.1-1999. Measurements were then made by placing the antenna first on human skin and then on shredded pork. As a result of the measurements, it has been observed that the antenna has good radiation properties and is a usable antenna with a low SAR value.

A new implant antenna design was made for biomedical applications by Kumar [9]. With such a study, it is aimed to examine some events in the human body wirelessly. The designed antenna is a patch antenna whose dielectric material is Teflon. Its dimensions are 16 mm*16 mm*1 mm. The frequency of the proposed antenna is designed as 2.4-2.48 GHz. Human tissue is considered as a single layer. The properties of muscle tissue were used as simulation. Simulations were made on CST. Then, the phantom model of the tissue was created and the measurements were performed. As a result of the measurements, the return loss of the antenna was observed as 37 dB. It has been observed that the size of this antenna designed in the ISM band is small and it is suitable to be used for such applications as a result of the measurements made.

The importance of biomedical telemetry, which is used to control the condition of patients with radio signals without restricting their movements and behaviors, is increasing [10]. In this study, implantable microstrip antenna design for biomedical range finder is presented. The introduced antenna covers the 402-405 MHz MICS band and the 2.45 GHz ISM band. In order for the antenna to be implantable, the antenna must be small in size. The dimensions of the introduced antenna are 10.5 mm*11.5 mm*1.27 mm. The antenna is designed with Rogers 3010 base material. The analysis of the implant antenna was made using the CST Microwave Studio program. In addition, measurements were made by creating a single-layer skin tissue phantom model. In addition, three different sizes of antenna designs are presented in this study to show flexibility. As a result of the measurements, it offers 42.1% bandwidth in the MICS band and 5.8% in the ISM band.

Antenna gains are -39 dB and -22.9 dB, respectively. Its SAR values are 369 W/kg and 396.4 W/kg, respectively. In the light of these measurements, it was observed that the results were satisfactory compared to other studies.

Two implant antennas are presented for neuro-motor prosthesis at 434 MHz by See et al. [11]. This antenna is a dipole implant antenna. In the simulation of the antenna, a three-dimensional tissue model consisting of skin, fat and muscle tissue was used. The antenna thickness is 0.8 mm and is positioned 20 mm away from the tissue. The simulations of the designed antenna were used using HyperLynx 3D electromagnetic software program. The directivity of the antenna was 3.8 dBi and the bandwidth was 4.6%. In the measurements made, it was observed that there was a loss of 14 dB at 8 cm. For future studies, better signal transfer is suggested by increasing the bandwidth.

An implant antenna was designed for a pacemaker implanted in the human body by Huang [12]. This antenna operates at 403 MHz in the MICS band. The antenna is a spirally designed microstrip antenna. Rogers was used as the base material. It is placed in the muscle tissue as tissue. The measurements were first made in the HFSS simulation program, then the phantom equivalent fluid of the muscle tissue was created and the measurements were completed. According to the measurement results, the S11 of the antenna in the tissue is 403 MHz, while the S11 of the antenna is 489 MHz when the antenna is in space. The measured SAR value was observed as 2.749 W/kg. As a result of the observations, it was seen that the simulation and the measurements were close to each other.

Kiourti and Nikita investigated the design and electromagnetic effects of implant antennas in tissue [13]. For this purpose, PIFA antenna designs were made at four different frequencies (402 MHz, 433 MHz, 868 MHz, 915 MHz). In this study, measurements were made according to the skin tissue properties on the antenna head. Measurements were made by creating an equivalent phantom model of skin tissue. As a result of the measurements, the SAR values were measured as 324.74 W/kg, 309.74 W/kg, 296.94 W/kg, and 294.86 W/kg in 1 g tissue at the frequencies of 402 MHz, 433 MHz, 868 MHz, and 915 MHz, respectively. The gains of the antennas were observed as -36.9 dB, -35.99 dB, -35.14 dB, -32.94 dB, respectively.

A differentially fed dual band implant antenna design is presented by Duan [14]. This is the first implant antenna design in the literature as a form of feeding. This antenna operates at two resonant frequencies, 433.9 MHz and 542.4 MHz. The measurement was made by placing the antenna on each layer of the three-layer tissue model. The study was first simulated in the HFSS program, and then the measurement was made in the phantom liquid. As a result of the measurements, it has been observed that there is not much difference between the single-layer tissue and the multi-layered tissue of the antenna. In addition, based on the measurements made in different tissues, the measurements made in skin and muscle tissue are slightly lower in adipose tissue close to each other.

The reason for this is that the conductivity and permeability of the fat tissue are high and the dielectric is low. In the measurements made, the SAR values were observed as 0.930 mW/kg and 0.936 mW/kg in the y-z plane, 0.895 mW/kg and 0.933 mW/kg in the x-z plane at 423 MHz and 532 MHz, respectively, in 10 g tissue.

3. Material and methods

3.1. Design and Implementation of Implant Antenna

Two stages were used in implant antenna design. First, a texture model was created in the CST simulation program in the computer environment and the simulation was carried out. Secondly, the measurements were made by creating the equivalent fluid of the tissues. The purpose of this is that it cannot be measured directly on the human body. There are many studies in the literature that make measurements using phantom models [9, 15, 16]. At the same time, these measurements can be made on animals [8,15].

Since one of the most important parameters to be considered in implant antenna design will be applied in in-vivo applications of the antenna, it should be implemented in small sizes. It is very difficult to obtain the desired S11 performance at the desired frequency of the antenna designed in small dimensions. Considering these reasons, an antenna design with a size of 30 mm*28 mm was realized. A patch antenna design with dielectric material of FR4 is used. In its design, FR4 base material with dielectric constant of 4.3, loss tangent of 0.025 and height of 1.52 mm was used. This study is carried out in the 2.45 GHz ISM band.

It is quite difficult to tune the resonant frequency of a small antenna. Many methods can be used to adjust the center frequency. In this design, as shown in Fig. 1, center frequency adjustment is made by placing a conductor connected to the ground on the right and left sides of the beginning of the feed line on the front of the antenna.

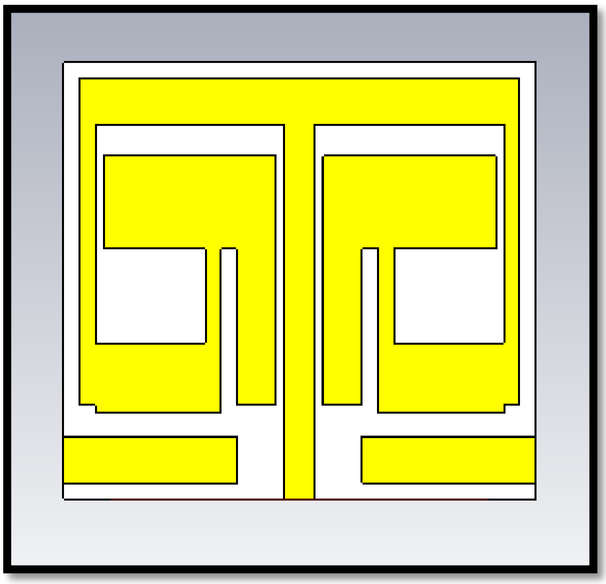

Fig. 1. Simulation image of microstrip antenna (color online)

The measurement parameters of the designed microstrip antenna are shown in Fig. 2.

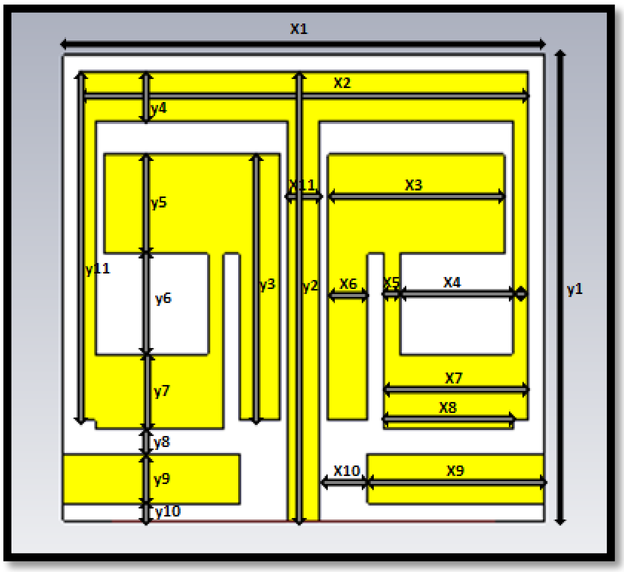

Fig. 2. Length parameters of the microstrip antenna (color online)

The length parameters of the antenna are given in Table 1 below. In the simulation of the patch antenna, the thickness of the dielectric material is 1.52 mm and the thickness of the conductor is 0.035 mm.

Table 1. Length parameters of the designed microstrip antenna

Length Values (mm)	**Length Parameters**	**Length Values (mm)**	**Length Parameters**
28	Y1	30	X1
27	Y2	28	X2
16	Y3	11	X3
3	Y4	7	X4
6	Y5	1	X5
6	Y6	2.5	X6
4.5	Y7	9	X7
1.5	Y8	8	X8
3	Y9	11	X9
1	Y10	2.5	X10
21	Y11	2	X11

After simulating the microstrip antenna, the antenna is realized with print-circuit technology. The image of the microstrip antenna performed is given in Fig. 3.

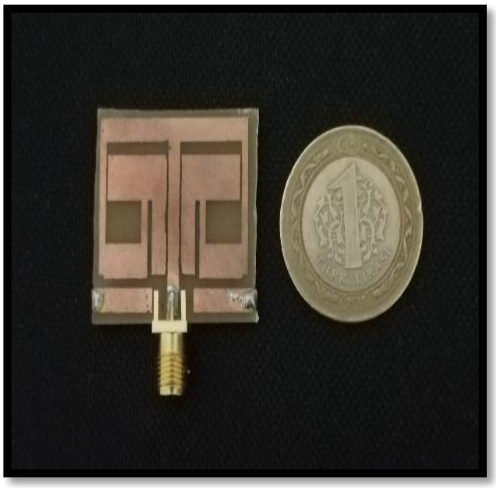

Fig. 3. Realized view of the designed antenna

3.2. Creation of a tissue model

In this study, a three-layer tissue model was used. As it was mentioned in the previous section, since it is not possible to use the human body directly in making the measurements, a design was made in this way in order to obtain the closest results during the simulation phase. When the studies conducted in the past years are evaluated, it has been observed that the majority of the studies have three-layer designs [7, 17, 18, 19]. This design was designed and measured using the CST Microwave Studio program.

The three-dimensional tissue model is shown in Fig. 4. The designed implant antenna is placed inside the skin tissue.

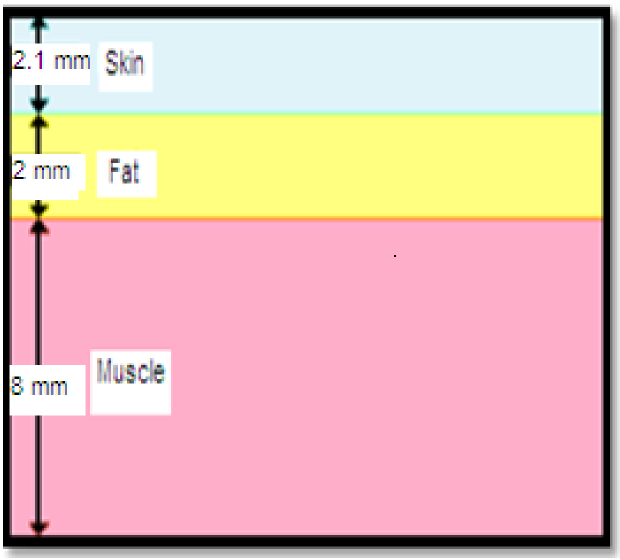

Fig. 4. Three-layer tissue model (color online)

3.3. Creation of tissue phantom fluid

In this study, phantom fluid was created according to the 2.45 GHz ISM band. The materials used and their size are given in Table 2 below.

Table 2. Phantom Description on MICS and ISM band of skin tissue

MATERIAL USED	MICS BAND	ISM BAND
DEIONIZED WATER	%41.49	%47.00
SUGAR (SUCROSE)	%56.18	%53.00
SALT (NaCl)	%2.33	-
AGAROZ	1 g is added to the 100 ml mixture.	

There are different definitions in the literature for studies conducted in the ISM band. This is because the materials used for the ISM tape are very difficult to find and expensive. E.g; A solution made with 58.2% deionized water, 5.1% DGBE and 36.7% Triton was used by adding 1 g of agarose to a 100 ml mixture, and the phantom liquid recipe was given in some studies [10, 20].

While the measurements of the antenna in the tissue are made in three layers in the simulation, the measurement will be made by creating only the skin tissue in the phantom liquid. Because some studies in the literature have proven that only one tissue is sufficient for measurements [10,14]. Since it is difficult and expensive to use the three-layer model in a phantom fluid, the single-layer model was applied in this study.

3.4. Antenna placement

One of the reasons for using the three-dimensional tissue model in the study is that muscle, fat and skin tissue are found in almost every part of the body. Placing the antenna in the skin tissue is considered in terms of good antenna efficiency and easy surgical operation. The deeper the antenna is placed in the tissue, the lower the efficiency will be. In addition, the rate of absorption by the tissues will increase even more. Fig. 5 shows the position of the implant antenna in the tissue in the simulation.

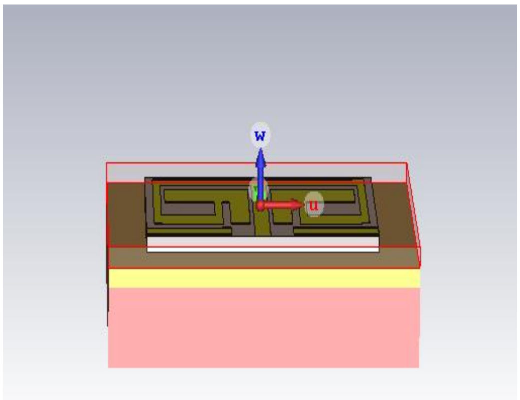

Fig. 5. Position of the implant antenna placed in the skin tissue (color online)

3.5. Experimental setup and measurement

In order to realize the simulated measurements, phantom fluid was prepared as shown in Table 2. This prepared liquid was placed in a container as shown in Fig. 6 and positioned in the antenna. Measurements were made using a Rohde & Schwarz (FSH6) brand spectrum analyzer.

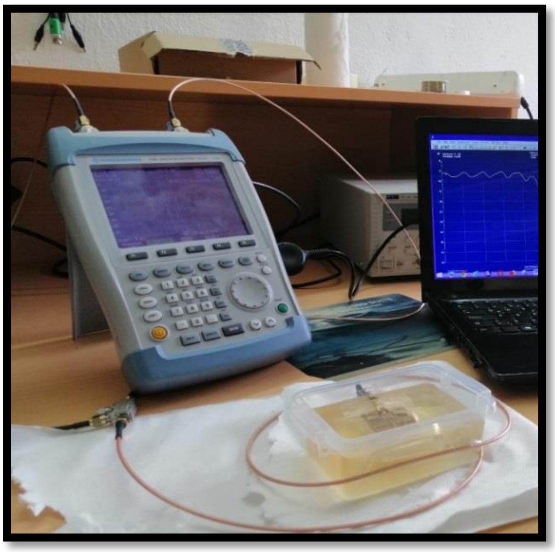

Fig. 6. Phantom fluid and measuring setup (color online)

4. Results

In the study, the S11 and SAR (Specific Absorption Rate) values of the implant microstrip antenna were investigated in simulation. In the realization of the measurements, only the S11 results of the implant antenna were evaluated. As the limit value for SAR, the IEEE C95.1 standard has set 1.6 W/Kg per 1 g of tissue [7]. The SAR value of the implant antenna studies conducted in the past years and the SAR value of the current study are given in Table 3.

Table 3. Comparison of the SAR value in the current study with some studies in the literature

Some studies in the literature	**$SAR_{1\ gr}$ (W/kg)**
Gozel et al [7]	396.8
Kiorti et al [13]	324.7
Chein et al [21]	797
Ha et al [22]	130.5
Current study	153

The SAR value in the current study, the image of the tissue measured for 1 W input with the CST simulation program, and the SAR value are presented in Fig. 7.

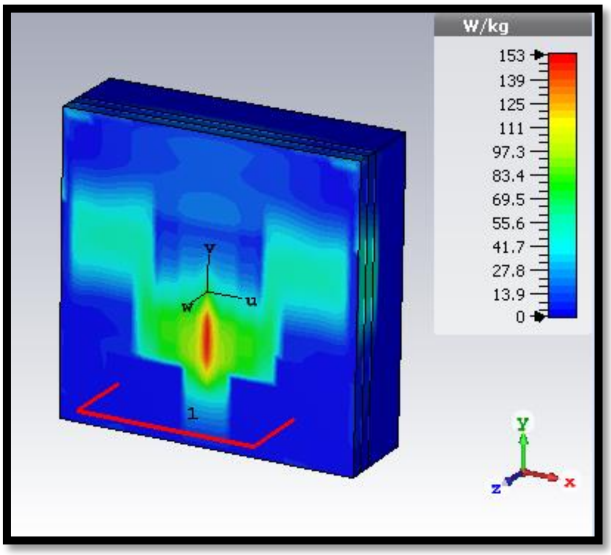

Fig. 7. SAR distribution and outcome scale in tissue (color online)

As seen in Fig. 7, the maximum SAR value of the designed antenna was measured as 153 W/kg. According to the comparison made in Table 3, it is seen that it is a very good value. The S11 results of the designed implant antenna were measured in two different ways, inside and outside the tissue of the antenna.

The graph S11 of the antenna outside the tissue is given in Fig. 8. As seen in the figure, as a result of the simulation, the center frequency is 2.45 GHz and the return loss is -33 dB. The actual measurement result of the antenna was measured as -23 dB at 2.49 GHz.

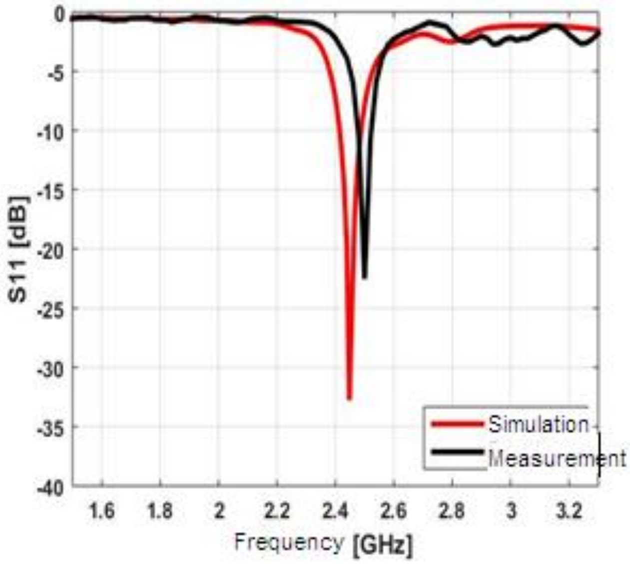

Fig. 8. Non-tissue S11 measurement results (color online)

In-vivo measurements are given in Fig. 9 as S11 graph. As seen in the graph, the center frequency was 1.56 GHz and the return loss was -18 dB as a result of the simulation. The measurement result after the antenna was placed in the phantom liquid was measured as -41 dB at 2.16 GHz.

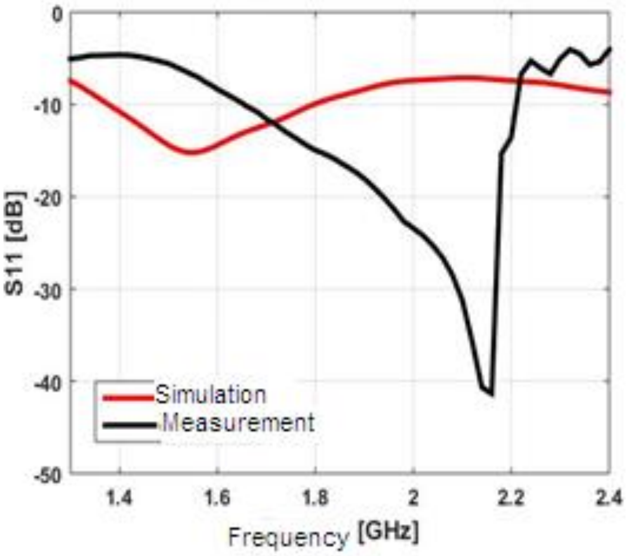

Fig. 9. In-vivo S11 measurement results (color online)

The graphs in Fig. 8 and Fig. 9 above were created by entering the data taken from CST Microwave Studio and spectrum analyzer into the MATLAB program.

5. Conclusion

In this study, a microstrip antenna design that can be used in the field of biotelemetry has been made. The designs were modeled in the CST Microwave Studio program, which is based on the finite integral technique in space, which is a 3D electromagnetic simulation software, and the analyzes of the designs were made.

The designed antenna is a microstrip patch antenna operating at 2.45 GHz center frequency in the ISM band. FR4 is used as dielectric material in the antenna. The designed antenna size is 30 mm*28 mm*1.59 mm. As a result of the simulation, the center frequency of the antenna is 2.45 GHz and the return loss is -33 dB. As a result of the actual measurement, the center frequency was measured as 2.49 GHz and the return loss was measured as -27 dB. In the in-vivo measurements, the return loss was measured as -18 dB as a result of the simulation, and the return loss of the antenna placed in the phantom liquid was measured as -41 dB. In the measurements made, there was little difference in the extra-tissue measurements, while there was a slight difference in the in-vivo measurements. This difference is likely to be due to the inability to fully adjust the temperature value and the dielectric constant while preparing the phantom liquid. In addition, as a result of the measurement simulation, the SAR value in the tissue was calculated as 153 W/kg. It has been observed that the measurement results in the skin tissue are quite compatible with the simulation results.

One of the important parameters of this study is the way the tissue is formed, its size and the in-vivo location of the antenna. The larger the tissue created, the better for the measurements to be healthy. However, it has been understood from other studies in the literature that there is no significant difference in the measurement results.

The growth of tissue volume significantly increases the simulation process. In addition, the chemicals, which are the components of the phantom fluid created for the realization of the measurements, are quite expensive. Therefore, less phantom fluid may have to be created. The position of the antenna in the tissue may vary depending on the purpose of the study. Based on the studies in the literature, it can be said that while the skin and muscle tissue show almost the same properties in the three-layered tissue, the conductivity and permeability of the adipose tissue are high and the dielectric is low. These will be important research topics of the future. In future studies; By fabricating the antenna, phantom and living tissue measurements can be repeated and medical implant device production can be performed for these measurements.

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