Investigation of Gain Enhancement in Microstrip Antenna Structure in Pathological Tissue Samples

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Abstract

Pathological reports play an important role in the diagnosis and especially in the treatment of diseases. For this reason, it is important to be able to access the reports of pathological tissue samples in a short time. Today, depending on the pathologist and the number of samples, the report delivery time can take months. For this reason, microstrip antenna structures, which are frequently used in the biomedical field, are investigated to evaluate pathological tissue samples. In this study, the variation of the gain values of antenna structures depending on the simulation results is examined. FR-4 substrate material, which has a dielectric constant of 4.4, is used in the microstrip antenna structure. The diameters of four circles added to the antenna patch structure with an operating frequency of 2.45 GHz are changed parametrically. The highest gain value of the antenna structure is investigated. The gain value has been increased from 1.89 dB to about 3.5 dB.

Keywords: Pathology, Microstrip, Patch, Gain, HFSS.

Patolojik Doku Örneklerinde Mikroşerit Anten Yapısında Kazanç Artırımının İncelenmesi

Öz

Patolojik raporlar hastalıkların teşhis ve özellikle tedavisinde önemli rol oynamaktadır. Bu sebeple patolojik doku örneklerine ait raporlara kısa sürede erişim sağlayabilmek önem arz etmektedir. Günümüzde patolog ve numune sayısına bağlı olarak değişen rapor ulaşım süresi ayları bulabilmektedir. Bu sebeple, biyomedikal alanda sıklıkla kullanılan mikroşerit anten yapıları patolojik doku örneklerine ait değerlendirmeleri yapmada araştırılmaktadır. Bu çalışmada anten yapılarına ait kazanç değerlerinin simülasyon sonuçlarına bağlı olarak değişimi incelenmiştir. Mikroşerit anten yapısında 4.4 delektrik sabiti değerine sahip olan FR-4 malzemesi kullanılmıştır. 2.45 GHz çalışma frekansı olan anten yapısına eklenen dört adet dairenin çapları parametrik olarak değiştirilmiştir. Anten yapısının en yüksek kazanç değeri araştırılmıştır. Kazanç değeri 1.89 dB'den yaklaşık 3.5 dB değerine yükseltilmiştir.

Anahtar Kelimeler: Patoloji, Mikroşerit, Yama, Kazanç, HFSS.

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1. Introduction

Pathology is the science of the causes and effects of diseases, especially the branch of medicine that deals with the laboratory examination of samples of body tissue for diagnostic or forensic purposes (Kamel, 2011; Nakhleh, 2006). Pathologists prepare the pathological report results. These results can take months to prepare and reach the patient and the doctor. These periods can sometimes be long for the diagnosis to be made and the treatment to be applied to the patient.

In medical applications, antenna structures are among the growing trends (Baek, Kim, Park, Jeong, & Kim, 2018; Catherwood & Mclaughlin, 2018; Darwish & Hassanien, 2011; R. Das & Yoo, 2018; Garcia-pardo et al., 2018; Ozturk & Güneşer, 2019; Ren, Qing, Zhao, Wang, & Gao, 2018; Schwartz, n.d.; Sun, Muneer, Li, & Zhu, 2018). Especially microstrip patch antenna structures use often in biomedical solutions (Hasan, Shanto, Howlader, & Jahan, 2018; Khan, Razzaq, Iqbal, Qamar, & Zubair, 2018; Li, Guo, Zhang, & Du, 2017; Nesasudha & Fairy, 2018; Sabban, 2013; Top, 2017; Z. J. Yang & Xiao, 2018a). Small dimension, weight, cost and variations of patch structure are some advantages of them. Also ease of use and variations of dielectric substrate materials are other advantages. Low efficiency, low gain and low impedance capability are some disadvantages.

Microstrip patch antennas used in biomedical area need to carry some properties. One of these properties is 'antenna gain'. In the literature, there are studies to increase antenna gain. In addition, these studies contain several methods to do this. Some methods of it are adding shorting pins in the antenna structure, adding different slot types and making changes on ground layer (Cao et al., 2019; Chen et al., 2020; Feng, Sun, & Leung, 2016; Lesnik, Verhovski, Mizrachi, Milgrom, & Haridim, 2018; Mustacchio, Boccia, Arnieri, & Amendola, 2021; Q. Yang et al., 2011).

In this paper, gain enhancement study of a microstrip antenna operating in the 2.45 GHz radiation region has been carried out. The process of it actualizes by changing the patch area of the antenna structure (S. Das & Mitra, 2018; Feng et al., 2016). The antenna with increased gain has been tested on pathological tissue samples with normal and tumorous skin tissue. To increase the antenna gain, microstrip patch dimensions are modified. To simulate the antenna and system design, ANSYS HFSS is used.

Section 2 explains material and method of the study. Results and Discussion is in Section 3. Finally, Conclusions and Recommendations are in Section 4.

2. Material and Method

2.1. Antenna Structure

Antenna operating frequency is selected 2.45 GHz because of ISM (Industrial, Scientific and Medical) bands. As substrate material is used FR-4 that has 4.4 dielectric constant value. Antenna dimensions are obtained from Equations 2.1 and 2.2 (B. J. Kwaha, O. N. Inyang, 2011). For finding the resonance frequency, lots of simulations are implemented. After simulations, substrate dimension is found $38.3x38.3x1.575$ mm³. Proposed antenna patch structure is obtained by combining a concentric circle with a diameter of 28.84 mm and 4 concentric circles with a diameter of 16 mm at the same distance from the center. Figure 1 shows the antenna structure.

$$a = \frac{F}{\{1+\frac{2h}{\pi\varepsilon_r F}[\ln(\frac{\pi F}{2h})+1.7726]\}^{\frac{1}{2}}} \qquad (2.1)$$

$$F = \frac{8.971x10^9}{f_r\sqrt{\varepsilon_r}} \qquad (2.2)$$

Where, a is radius of the circular patch, f_r is resonance frequency, ε_r is dielectric constant of substrate and h is height of substrate.

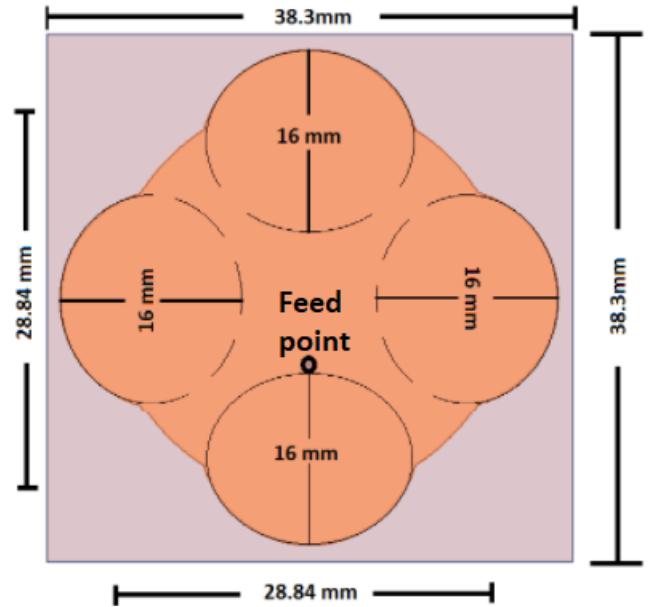Return loss of the proposed antenna is showed in Figure 2.

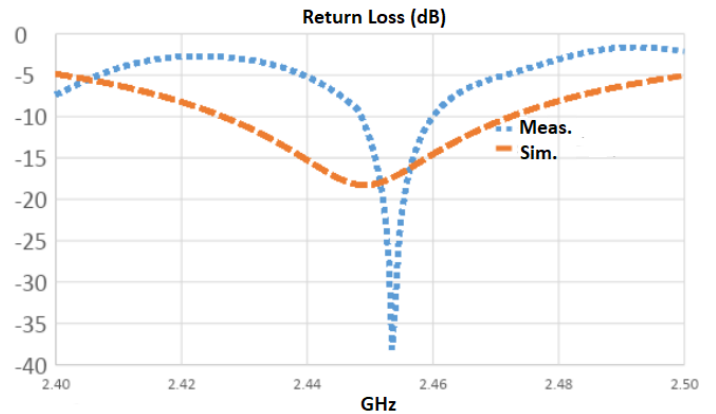*Figure 1. Proposed antenna structure and its dimensions*

Figure 2. Return Loss of the antenna structure

2.2. Gain Enhancement

In microstrip patch antenna applications, there are several methods to increase antenna gain. Antenna gain depends on directivity and efficiency of the antenna structure (Equation 2.3) (Balanis, 2013). Where, G is gain, η is the efficiency and D is directivity of antenna structure.

$$G = \eta D \qquad (2.3)$$

Patch dimension is modified to increase the proposed antenna gain. In the literature, there are many studies about this subject. If explained in detail, the gain of any antenna structure depends on its effective radiating area, A_{eff}. Gain value can be expressed with an identical reference antenna in Equations 2.4 and 2.5 (Guha, Chattopadhya, & Siddiqu, 2010).

$$\Delta G[dB] = 10 \log \left[\frac{\left(\frac{A_{eff}}{\lambda_0{}^2} \right)_{air}}{\left(\frac{A_{eff}}{\lambda_0{}^2} \right)_{ref}} \right] \quad (2.4)$$

$$A_{eff} = (L + 2\Delta L)(W + 2\Delta W) \quad (2.5)$$

Where λ_0 is the operating wavelength of the signal, L and W are the length and width of the patch, respectively.

So, patch dimensions of the antenna are important parameters on antenna gain values. In this study, by changing patch dimensions, it is aimed to increase the gain of antenna structure. Figure 3 shows the phsysical changes on antenna patch. By adding 4 same circles as showed in the Figure 3, the parametric analysis is done in HFSS. The circle radius is from 1.5 mm to 9.5 mm by changing 0.5 mm step.
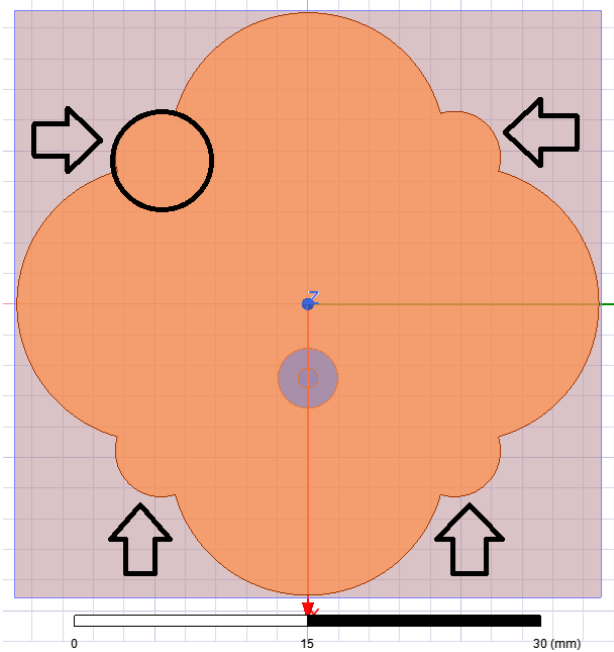

Figure 3. Changes on the patch of the antenna structure

2.3. Modeled System

Pathological tissue samples are modeled as showed in Figure 4. Normal and tumorous skin tissues are introduced in HFSS program. Any body part has different electrical properties like any material. So, normal and tumorous skin tissue have different dielectric constant values. These values are obtained in (Gabriel, 1996). Normal and tumorous skin tissue has the dielectric constant of 38 and 50, respectively. Thus, the modeled system is shown in Figure 4. For simulations, two identical antenna structures are used in the system.
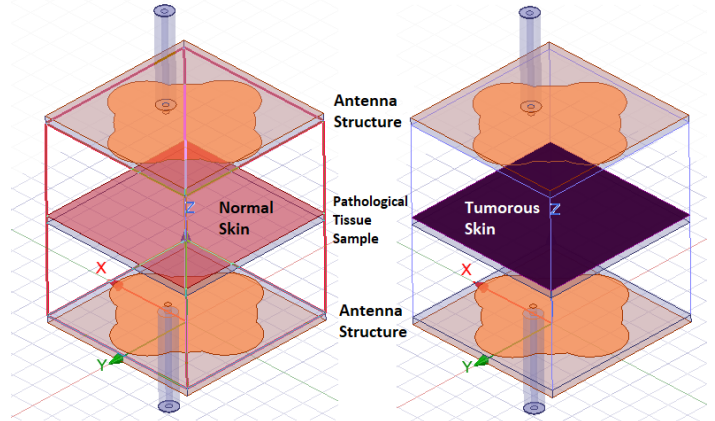

Figure 4. Modeled system

Also, between two antenna structures, there are pathological tissue samples. In the centre there is a glass slide that fixed skin tissue samples. These samples are spread on the glass to cover the entire slide. Height of samples is 5 µm. Normally patological tissues' heights changes from 2 µm to 5 µm.

3. Results and Discussion

The maximum gain of the antenna structure in Figure 1 is obtained as 1.89 dB from HFSS (Figure 5).
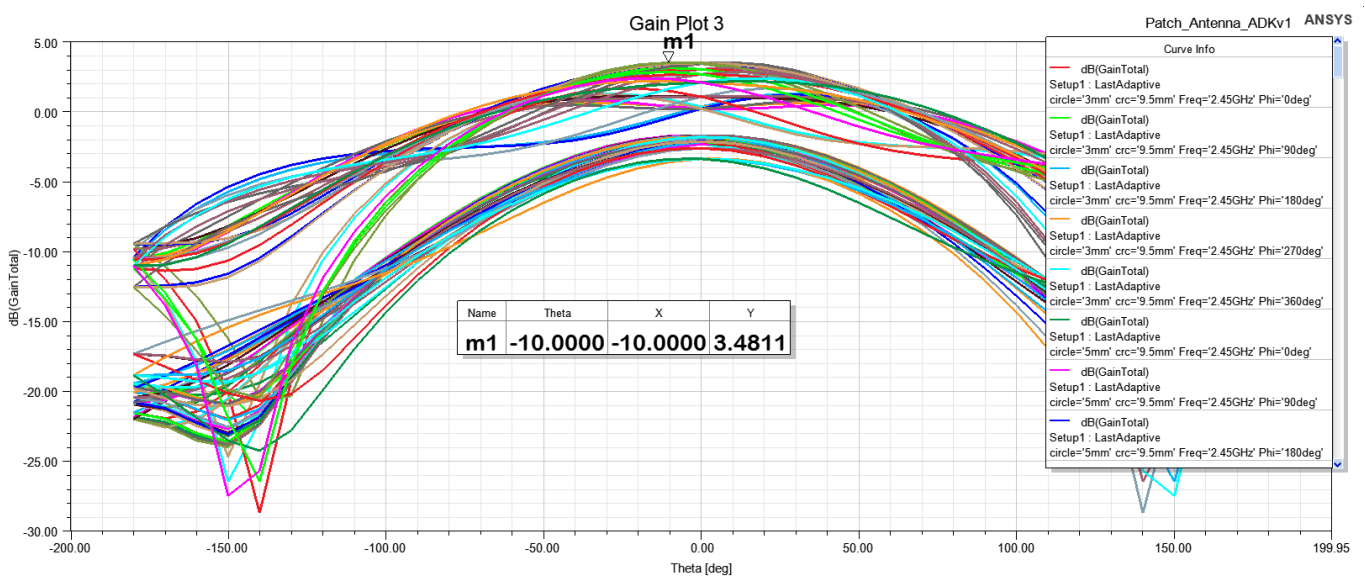

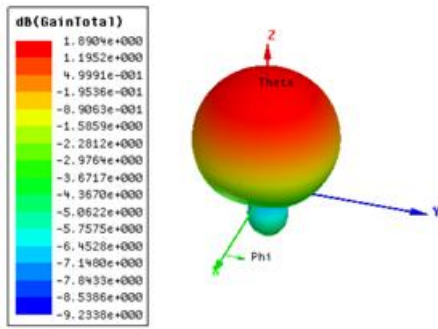*Figure 6. Gain values in dB after parametric analyzes*

Figure 5. The gain of the antenna in Figure 1

Table 1. The comparition of gain values with reference antennas

References	Dimensions (mm³)	Gain (dBi)
(Z. J. Yang & Xiao, 2018b)	80	-20.80
(Li et al., 2017)	120.69	-22.70
(Nikolayev et al., 2019)	695	-15
(Marnat, Ouda, Arsalan, Salama, & Shamim, 2012)	-	-16
(Liu, Guo, & Xiao, 2012)	-	-29
(Schmidt et al., 2014)	-	-19.90
Proposed normal antenna	2310.3	1.89
Proposed gain antenna	2310.3	3.48

When analyzes are applied to mention above, the expression of the gain in dB is shown in Figure 6. According to theta angle, while phi angle is changing from 0 degree to 360 degree by 90 degree, gain plot in dB is shown. Maximum gain value is about 3.5 dB in theta = -10º and phi = -90º, when the radii of the circles are 7 mm. The comparition of gain values with the proposed gain antenna and reference antenna structures is in Table 1. Reference antennas are selected to be able to compare as microstrip antennas.

Table 2. The variation of S-parameters with respect to their arithmetic mean

S-parameters	S_{11}	S_{21}	S_{12}	S_{22}
Skin value of proposed antenna	0.92	32.29	32.20	0.92
Skin value of gain antenna	0.70	33.05	32.97	0.70
Tumorous value of Proposed antenna	0.93	32.41	32.40	0.93
Tumorous value of gained antenna	0.72	34.02	34.00	0.72
Percentage change for gain antenna in skin tissue	75.70	102.33	102.14	75.40
Percentage change for gain antenna in tumorous tissue	77.31	104.90	104.93	77.12

Also, Table 2 explains the variation of S-parameters with respect to their arithmetic mean. That is obtained by taking absolute values for every S-parameter value, S_{11}, S_{21}, S_{12} and S_{22}. Especially in the antenna applications, these values are important because of giving the radiation information of antenna structure (Caspers, 2011).

When Table 2 is examined, it is reached a different value for each S-parameter. These values matter the success of the gain antenna. While the differences for S_{11} and S_{22} values are 0.01 for a normal antenna, this difference is 0.02 for a gain antenna. For S_{21} and S_{12}, these values are 0.12 and 0.20 for normal antenna, and 0.97 and 1.03 for gain antenna, respectively. When the values of the gain antenna are compared with the values of the normal antenna, it is seen that the differences of the gain antenna are higher.

When the values obtained from the normal antenna are compared for the values obtained from the gain antenna, the percentage of differences for each tissue is shown in the Table 2. As handling the skin tissue, the percentage of difference is about 25% for S_{11} and S_{22}. It is about 2.5% for S_{21} and S_{12}. As handling the tumorous skin tissue, the percentage of difference is about 23% for S_{11} and S_{22}. It is about 5% for S_{21} and S_{12}.

4. Conclusions and Recommendation

Access to pathological results reports can take months. It is important to access these reports, which are important for the patient and the doctor, in a short time. because it directs the diagnosis and treatment of the patient and the disease. For this purpose, antenna structures that are frequently used in the literature are investigated. One of them is microstrip antenna structures due to its various advantages.

Microstrip patch antennas have low gain. Studies are being done to increase the gain of antenna structure in this area. Some of these studies can be listed as adding a short-circuit pin, modifying the ground layer and opening different slots on the patch.

In this study, it is aimed to increase the gain by changing the pre-designed microstrip patch antenna dimensions. Parametric analysis was carried out with the 4 equal circle structure added to the patch part. As a result of the analysis, the antenna gain increased from 1.89 dB to 3.48 dB with circles with a radius of 7 mm. With this gain antenna, simulations of pathological normal and tumorous skin tissue were made. To do this, a system is modelled that mentioned above. The absolute values of the obtained S-parameters were taken and their arithmetic averages were checked. When the data of the obtained S-parameters are examined, it is shown that the gain antenna reaches a higher difference for each S-parameter value.

For example, for skin tissue, S_{11} arithmetic mean value is 0.92 of proposed antenna and 0.70 of gain antenna. If the difference is examined as a percentage, it is seen that there is a difference of approximately 25%. Or S_{12} arithmetic value is 32.20 of proposed antenna and 32.97 of gain antenna. There is a difference of 2.3% for skin tissue. When the differences and percentages are examined, it is possible to say that the use of the gain antenna structure in pathological tissue samples will be beneficial.

Designing microstrip antennas with different gain values with a modeled system will increase the quality and quantity of the study.

5. Acknowledge

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