# DESIGN OF A MICROSTRIP ANTENNA SYSTEM FOR HYPERTHERMIA APPLICATOR

by

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# APPROVAL PAGE

I certify that this thesis satisfies all the requirements as a thesis for the degree of Master of Science.

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This is to certify that I have read this thesis and that in my opinion it is fully adequate, in scope and quality, as a thesis for the degree of Master of Science.

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M. S. Thesis – Electrical-Electronics Engineering
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## ABSTRACT

The aim of this project is to design, simulation, fabrication and measurement of compact microstrip antennas to be used in a hyperthermia applicator antenna system for cancer treatment. The required antennas should operate at 434 MHz frequency at ISM band (a frequency band allocated for industry, science and medicine) which is suitable for deep regional hyperthermia applications in terms of penetration dept and focusing resolution considerations. The designed antennas should have a HPBW as narrow as possible and a lateral size smaller than 4cm. The designed antennas are embedded in a water bolus to have a better matching with targeted body, to cool the possible superficial heating at the skin and to shrink the antenna size. The designs and simulations were performed by means of the commercial electromagnetic software CST Microwave Studio and the fabrication was performed at RF-Microwave Lab at Fatih University. The proposed simulation and measurement results show the adequateness of the antennas for a hyperthermia applicator.

**Keywords:** Hyperthermia applicator, microstrip antenna, microstrip antenna with waterbolus, microstrip antenna technology, microstrip slot antennas, compact microstrip antennas.

# HİPERTERMİ APLİKATÖR İÇİN MİKROŞERİT ANTEN SİSTEMİ TASARLANMASI

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## ÖZ

Bu projenin amacı, kanser tedavisinde kullanılan hipertermi aplikatörü için kompakt mikroşerit antenlerin tasarlanması, benzetimi, üretimi ve test edilmesidir. Tasarlanan antenler ISM bandı 434MHz'de (endüstri, bilim ve tıp için ayrılmış bir frekans bandıdır) çalışmalıdır. Bu frekans derin bölgesel hipertermi uygulamaları için dokulara nüfuz etme derinliği ve odaklama çözünürlüğü açısından uygun bir frekanstır. Antenlerin hüzme genişliği olabildiğince dar ve anten boyutları 4cm den daha küçük olmalıdır. Hedeflenen dokularla daha iyi bir elektromanyetik eşleme olması, anten boyutlarını düşürmesi ve yüzeysel sıcaklıkları düşürmesi amacı ile antenler bir su kapsülü içerisinde gömülü olarak tasarlanmıştır. Tasarım ve simülasyonlar ticari bir elektromanyetik program olan CST Microwave Studio yazılımı ile, üretim ise Fatih Üniversitesi RF-Mikrodalga Laboratuarında yapılmıştır. Elde edilen tasarım sonuçları antenlerin hipertermi aplikatör için uygun olduğunu göstermektedir.

**Anahtar Kelimeler**: Hipertermi aplikatör, mikroşerit antenler, su içerisine gömülü mikroşerit antenler, mikroşerit anten teknolojisi, mikroşerit yarıklı antenler, kompakt mikroşerit antenler.

# DEDICATION

To my lovely son Ali, my lovely daughter Zeynep and my lovely husband Muharrem

# ACKNOWLEDGEMENT

Electromagnetic hyperthermia cancer treatment is a very popular and promising research area. In that sence a contrubition by designing single antenna elements for a possible hyperthermia applicator is very important. I am grateful to my adviser, Assist. Prof. Erdal KORKMAZ, for giving me the opportunity to study about this subject and conduct research for constitution of this thesis. I appreciate his patience, understanding and encouragement throughout my thesis study.

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**SYMBOL/ABBREVIATION**

| | |
|---|---|
| $\delta$ | Loss Tangent |
| $\varepsilon_r$ | Dielectric Constant of Substrate |
| $f_0$ | Resonant Frequency of Microstrip Antenna |
| $Z_0$ | Characteristic Impedance |
| $Y_f$ | Feeding Point in y-axis |
| $S_{11}$ | Reflection coefficient |
| $L_g$ | Length of Ground Plane |
| $Z_s$ | Transmitter impedance |
| $Z_{in}$ | Antenna impedance |
| $X_f$ | Feeding Point in x-axis |
| $V_0^+$ | Incident Voltage |
| $V_0^-$ | Reflected Voltage |
| $RL$ | Return Loss |
| $W_g$ | Width of Ground Plane |
| $L_{eff}$ | Effective Length of Patch |
| $\varepsilon_{reff}$ | Effective Dielectric Constant of Substrate |
| E-field | Electric field |
| GHz | Giga Hertz |
| h | Height of Substrate |
| HPBW | Half power beamwidth |

| | |
|---|---|
| ISM | Industrial, Scientific and Medical |
| L | Length of Patch |
| MHz | Mega Hertz |
| PEC | Perfect electric conductor |
| SAR | Specific absorption rate |
| t | The Thickness of Patch |
| TEM | Transverse ElectroMagnetic |
| UHF | Ultra High Frequency |
| VHF | Very High Frequency |
| VSWR | Voltage Standing Wave Ratio |
| W | Width of Patch |
| **Γ** | Reflection Coefficient |
| λ | Wavelength |

# CHAPTER 1

# INTRODUCTION

It is well known that cancer is a terminal disease and is caused by normal cells changing so as they grown in an uncontrolled way. These uncontrolled growing cells become into lumps and they are called tumor. If they are not healed, they spread into normal healty tissues by the way of the blood and lymph systems (Işık, 2009).

To cure cancer, many treatments have been developed. The most common types of cancer treatment are surgery, chemotherapy and radiotherapy. Cancer cells are removed or destroyed by these treatments. These treatments can be applied alone or in combination according to type of cancer. There are some advantages and disadvantages of these treatments (Işık, 2009).

Contemporarily, researchers are constantly working to find out and improve new treatment techniques. New techniques are purposed to be more exact and much less invasive than current techniques (Işık, 2009).

Electromagnetic hyperthermia is one of these new techniques. It is used in conjuction with chemotherapy and radiation therapy in general. In this treatment, the cancerous tissues are heated between 41ºC and 45ºC since it is well known that high temperatures in cancerous cells ruin the cells protein build, changes the cell construction and kills them (Işık, 2009, Korkmaz et al., - , Lee et al., 1992). In the surrounding tissues, this process must protect normal physiological temperatures (Işık, 2009).

For hyperthermia applications, an applicator is needed according to type of hyperthermia treatment (local or regional) and so several applicators have been developed (Bahl et al., 1981, Gee et al., 1984, Nikawa et al., 1986, Sherar et al., 1993, Gupta et al., 2006, Paulides et al., 2007, Trujillo et al., 2010). Applicators consist of antennas and usually superficial hyperthermia applicators use single relatively big antennas (local hyperthermia) whereas for deep located tumors a multi antenna system is used (regional hyperthermia).

In this thesis, is studied intended for multi antenna system. In a multi antenna system the constructive interference of the fields on the targeted region is intended because the electromagnetic penetration decreases rapidly through the lossy character of the tissues. Therefore, in the development of a specific applicator, the design of an effective single antenna element is the important step. And also, to develop a multi antenna applicator, directive antennas are needed.

Directive antennas operate at relatively lower frequencies (preferable ISM bands) and they have smaller lateral size and narrower beam width. However the inverse relationship about the electrical sizes of the antennas and its operating frequency constraint the design of such antennas. Also in hyperthermia applicators usually the antennas are designed as embedded in distilled water bolus to obtain a better coupling of the irradiated electromagnetic fields with the tissues, for the cooling of possible superficial heating and to reduce the size of the designed antenna with respect to the resonant frequency (Gupta et al., 2006, Paulides et al., 2007, Ganjeh and Attari, 2008, Juang et al., 2004, Neumann et al., 2004, Neumann et al., 2002, Gabriel et al., 2005, Jacobsen and Stauffer, 2002). So the design of a hyperthermia antenna significantly differs from the antenna designs in free space applications.In this study, directive antennas at 434 MHz (ISM frequency band) are designed to be used in a hyperthermia applicator. To that end a rectangular microstrip antenna which is designed by [E. Korkmaz] is chosen as a template. For applications, compact microstrip antennas are preferred. The designs are simulated by means of the commercial electromagnetic software CST Microwave Studio and fabrication is performed at RF-Microwave Lab at Fatih University.

The chapters are arranged to give general information about hyperthermia treatment, microstrip antennas, specifications of patch antenna, design of microstrip antennas and results.

# CHAPTER 2

# MICROSTRIP ANTENNAS

## 2.1 INTRODUCTION

Microstrip antenna structure includes insulating substrate located on a ground plane and conductive radiating surface (patch) located on upper surface of this material. A simple microstrip antenna structure has been described in Figure 2.1:

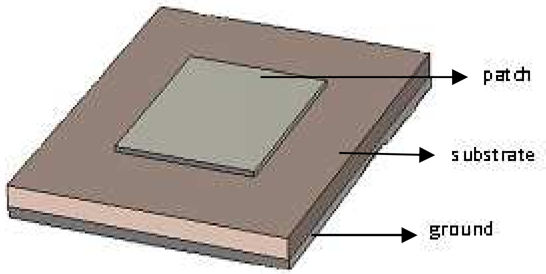


**Figure 2.1** Parts of microstrip patch antenna.

Tasks of substrates are as follows:

1. Circuit elements can be mounted in an appropriate way with microstrip antenna structure thanks to substrates.

2. They support these elements mechanically.

3. They function as a part of a transmission line,

4. Permeability and thickness of dielectric determine the electrical features of antenna (Wong, 2002). (This function of substrates shall be described in detail in "Microstrip Antenna Design" part).

Materials such as quartz, alumina, glass-reinforced polytetrafluoroethylene, air, polystyrene foam, dielectric honeycomb, fiberglass reinforced teflon and ceramic are used in selection of dielectric substrates. Electrical features of substrates are determined with dielectric constant ($\varepsilon_r$) and loss tangent ($\delta$). Because of the fact that loss tangent is small shows high antenna efficiency, materials whose tangent is small are preferred (Çakır, 2004).

Dielectric constants of substrates usually are between 2.2-12. Thickness of substrate is a very small part of wavelength (% 1.2 of wavelength). For good antenna performance, thick substrates with low dielectric constant are preferred because substrates with these features provide larger bandwidth and free boundary areas in radiating to space in terms of efficiency, however the size of antenna becomes larger. Materials with high dielectric constant, thin base are used in microwave circuit systems. Because these systems need significant border areas in order to decrease undesired radiation and connection losses. Moreover, size of the antenna would reduce. However, when these substrates are used efficiency and bandwidth reduce (James, 1990).

Radiation surface (patch) and ground plane are usually made of copper. Thicknesses of them usually change between 50-200 µm.

After general structure of microstrip antennas, their advantages can be summarized as follows:

Microstrip antennas are in small sizes and light. Their production costs are low. They provide ease of use with their planar structures. They can radiate in circular and linear polarization with small changes in feed position. Dual frequency antennas can be created easily. Solid state vehicles such as oscillators, amplifiers, variable attenuators, keys, modulators, mixers, phase changers etc. can be added to the substrate of microstrip antennas so that composite systems can be developed. Feed lines and matching circuits are already produced at the same time with the antenna.

Their disadvantages are as follows:

They have narrow band width. Their gains are low because of various losses. Isolation between feeding and radiation surface is weak. Stimulation of surface waves is possible. Poer capacity is low.

However, researches and developments have indicated that these disadvantages can be minimized by using various techniques. For instance, narrow bandwidth has been overcame. Bandwidth has been increased with developed techniques and microstrip antennas with wide bands have been created. New substrates with low loss have been made by using developed technology and methods and new materials (Paulides et al., 2007).

Microstrip antennas can be grouped in three: a) Antennas with microstrip pieces, b) Microstrip walking wave antennas, c) Slotted microstrip antennas.

Radiation surface can be square, rectangular, thin strip (dipole), circular, elliptic, triangle or in other shapes. Among these shapes the most preferable is square, rectangular, thin strip (dipole) and circular. Because, their analysis and productions are easier, radiation characteristics are more attractive.

## 2.2 THE RADIATION IN THE MICROSTRIP ANTENNAS

Generally, when an antenna is driven with a voltage source by means of the feeding line, the currents on the patch are excited, and a vertical electric field occurs between the patch and the ground plane. The electric field lines are shown on a rectangular microstrip patch antenna in Figure 2.2. The dielectric substrate is usually thin ($h \cong 0.02\lambda_0$), so the electric field lines parallel to the ground plane must be very small in the substrate. The patch resonates when its length is near $\lambda/2$ (Pozar, 1992). There are many models describing radiation occurance in microstrip antennas. Although they do not have exact solutions, current models are appropriate for practical applications. Cavity Model and Transmission Line Model are the most common known models. The most used model is transmission line model because it requires less accounting (Çakır, 2004). Below, the radiation in the microstrip antennas will be explained according to the transmission line model.

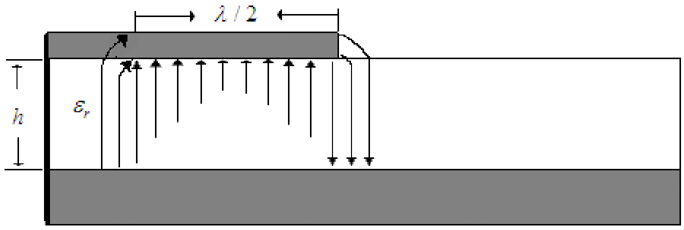


**Figure 2.2** Electric field lines on a rectangular patch antenna (side view).

According to transmission line model, the microstrip antenna is represented by two slots which are separated by a distance of length L as shown in Figure 2.3. Practically, the dimensions of the patch are finite, so the fields at the edges of patch undergo fringing. The amount of this fringing is related with the ratio between the patch dimensions and the height of the substrate. At the xy-plane (for the E-plane) fringing is a function of the ratio of the length of the patch to the height of the substrate (L/h) and the dielectric constant of the substrate. Fringing is small because L/h >> 1 for microstrip antennas, however it is taken into account because the resonant frequency of the antenna is influenced. Practically, the electric field lines are nonhomogeneous and most of them reside in the substrate and parts of some lines xist in air. If W/h >> 1 and $\varepsilon_r$>>1, the electric field lines concentrate mostly in the substrate. The microstrip line look wider electrically compared to its physical size and an effective dielectric constant $\varepsilon_{reff}$ occurs. $\varepsilon_{reff}$ is taken to account instead of $\varepsilon_r$. Then the effective length of the patch is accounted (James, 1990). (All the formulas about the calculations are given in the following parts of this Chapter, see to “2.5 Microstrip Antenna Design”).

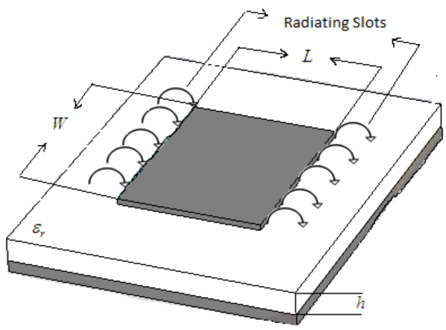


**Figure 2.3** Radiating fields on a rectangular patch antenna.

## 2.3 THE TYPES OF MICROSTRIP ANTENNAS

Microstrip antennas can be in any geometry and various sizes. However, they are grouped into three: Microstrip Patch Antennas, microstrip walking wave antennas and microstrip slot antennas. These structures can be summarized as follows:

### 2.3.1 Microstrip Patch Antennas

One side of dielectric substrate in microstrip patch antennas has been covered with ground layer, on the other side there have been available a thin conductive piece which has any geometry. Patch types often used are as in Figure 2.4:

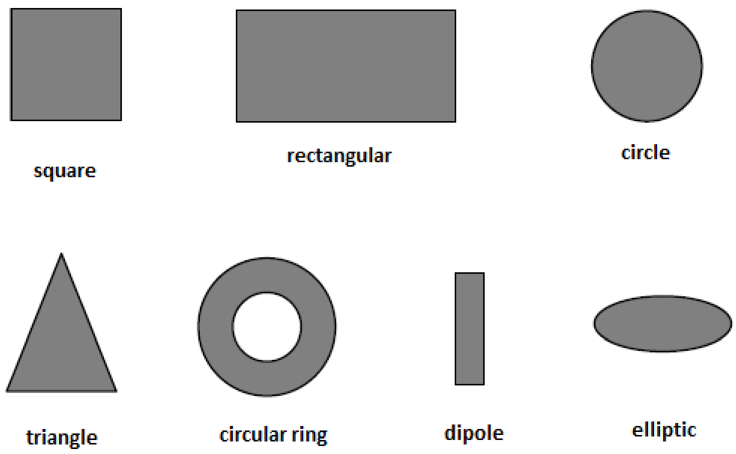


**Figure 2.4** Microstrip patch antenna shapes.

The most preferable shapes are square, rectangular, circular and thin dipole. Their productions and analysis are easier and radiation patterns are more attractive.

### 2.3.2 Microstrip Travalling Wave Antennas

These type microstrip antennas have been ended with chain-shaped conductors or open end compatible resistance on TEM line which is the longest known.  Main lobe of antenna can be provided to be positioned in any direction between horizontal and vertical position with the change in structure of antenna (Garg et al., 2001).

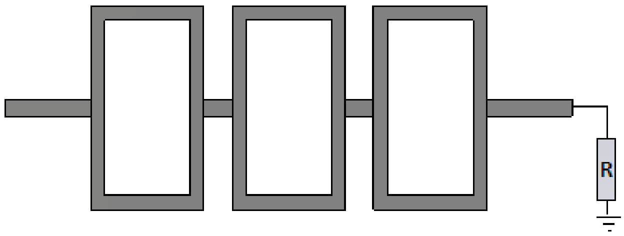


**Figure 2.5** Microstrip travalling wave antenna.

### 2.3.3 Microstrip Slot Antennas

The microstrip slot antennas occur from a slot shape on the patch surface. The slot radiates electromagnetic waves in similar way to a dipole antenna (Figure 2.6).

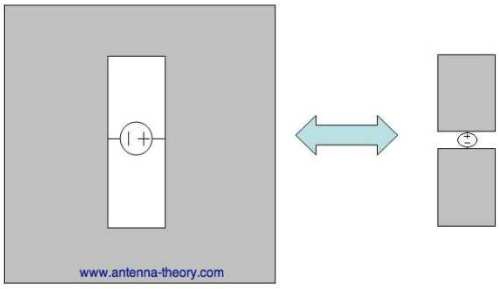


**Figure 2.6** Microstrip slot antenna.

The shape and size of the slot determine the radiation pattern, the directivity, the resonant frequency and the beamwidth of the antenna. They are often used at UHF and microwave frequencies instead of line antennas when greater control of the radiation pattern is required. Some reported slotted patch shapes are given in Figure 2.7:

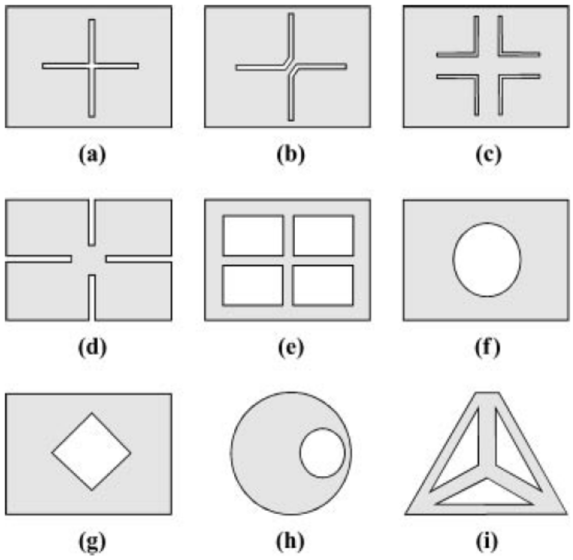


**Figure 2.7** Some reported slotted patch shapes (Wong, 2002).

## 2.4 FEEDING TECHNIQUES

Microstrip antennas are usually fed in two ways, microstrip line and coaxial line. Feeding method determines input impedance and polarization of the antenna. Position of feeding point determines the input impedance, polarization (circular or linear), antenna performance and stimulated mode. Feeding point must be adjusted well for the impedance matching between antenna and feeding line. If the input impedance of the antenna is different from 50ohm, a mediator can be located between feeding line and antenna for impedance matching.

### 2.4.1 Coaxial Feeding

Feeding line body reaches ground plane in feeding with coaxial line, axial conductor part contacts with radiation surface (Figure 2.8).

Advantage of such feeding, if position of feeding is adjusted well, impedance matching between antenna and feeding line can be provided easily and parasitic spread to disrupt the light pattern is at the lowest level.

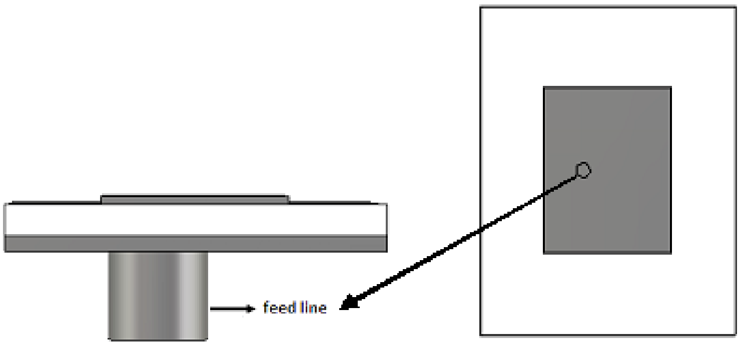


**Figure 2.8** Coaxial feeding side view (left) and top view (right).

If axial conductor in microstrip antennas, fed with coaxial line, is on the edge of radiation surface and feeding position does not disrupt simetry, microstrip antenna is called as in the center-fed. If microstrip antenna disrupts simetry, it is called as in off the center fed. If axial conductor is in the inner part of radiation surface it is called as various fed.

### 2.4.2 Microstrip Line Feeding

Although the parasitic spread is too much, microstrip line feeding is preferable because of the production ease. Such feeding provides convenience in combining the antenna with an array or an integrated circuit. A microstrip line fed rectangular patch antenna is indicated in Figure 2.9.

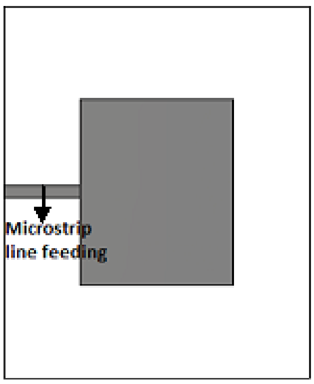


**Figure 2.9** Microstrip line feeding (top view).

Microstrip line fed antenna is called as in center fed if it is symmetric, and called as in off center fed if it is not symmetric. Although a slight shift is observed in operating frequency of antenna with shifting the feed point, radiation pattern is not affected from this change.

## 2.5 MICROSTRIP ANTENNA DESIGN

We can divide microstrip antenna structure in four parts as indicated in Figure 2.10:

1. Thin insulating substrate,

2. Ground plane covered by chemical methods to the upper part of substrate,

3. Radiation surface added to the upper surface of substrate with chemical methods,

4. Feed line.

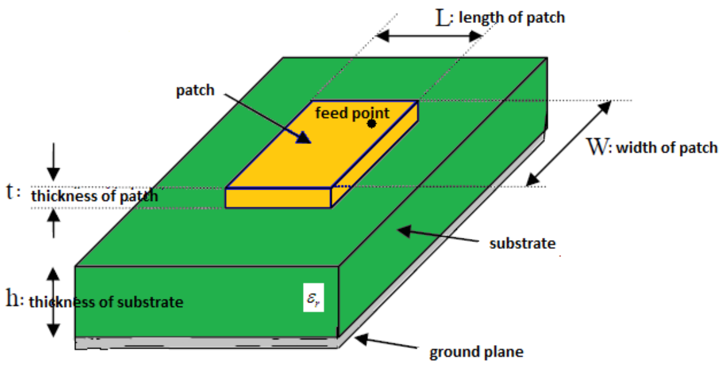


**Figure 2.10** Parts and dimensions of microstrip patch antenna.

### 2.5.1 Calculations

In this part, microstrip antenna design will be on explaining the calculations by using the simple rectangular probe-fed (coaxial-fed) patch. The calculations of the parameters: h, t, $W$, $L$, $W_g$, $L_g$, ($X_f$, $Y_f$) and $\varepsilon_r$ which are showed on the Figure 2.10 are described below.

Frequency of operation ($f_0$) which is called resonant frequency too must be selected according to the working range of the application. Dielectric constant of the substrate ($\varepsilon_r$) and height of the substrate (h) are determined according to desired aim. The relationship between these parameters and performance, bandwidth, size of the antenna is described in Table 2.1 below:

**Table 2.1** Relationship between "h, $\varepsilon_r$" and "performance, bandwidth, size" of the antenna.

| **Parameter** | **The Size of Parameter** | **Antenna Performance** | **Antenna Bandwidth** | **Antenna Size** |
|---|---|---|---|---|
| h | big | good | large | large |
| $\varepsilon_r$ | low | | | |
| h | small | reduces | narrow | small |
| $\varepsilon_r$ | high | | | |

The transmission line model will be used to design and the calculations are as follows:

**Calculation of the patch width:** After the frequency of operation and the substrate dielectric constant are defined, the width of patch (Figure 2.10) is calculated by the following equation:

$$W = \frac{c}{2 f_0 \sqrt{\frac{\varepsilon_r + 1}{2}}} \text{ m} \tag{2.1}$$

In this equation, c is the velocity of light and its value is $3.10^8$ m/s. The unit of $f_0$ is Hz and the unit of $W$ is meter.

**Calculation of effective dielectric constant ($\varepsilon_{reff}$):** The effective dielectric constant due to the air dielectric boundary is given in Equation (2.2):

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-\frac{1}{2}} \tag{2.2}$$

**Calculation of the effective length (Leff):** Equation (2.3) gives the effective length as:

$$L_{eff} = \frac{c}{2 f_0 \sqrt{\varepsilon_{reff}}} \text{ m} \tag{2.3}$$

**Calculation of the length extension ($\Delta L$):** Equation (2.4) gives the length extension as:

$$\Delta L = 0.412h \frac{\left(\varepsilon_{reff} + 0.3\right)\left(\frac{W}{h} + 0.264\right)}{\left(\varepsilon_{reff} - 0.258\right)\left(\frac{W}{h} + 0.8\right)} \text{ m} \tag{2.4}$$

**Calculation of actual length of patch (L):** The actual length is calculated with the follows equation:

$$L = L_{eff} - 2\Delta L \text{ m} \tag{2.5}$$

**Calculation of the ground plane dimensions ($W_g, L_g$):** The transmission line model is applicable to infinite ground planes only. However, practically, there are not infinite ground planes. It has been shown that similar results for finite and infinite ground plane can be obtained if the dimensions of the ground plane are greater than the patch dimensions by approximately six times the substrate thickness all around the periphery. Hence, for the rectangular patch antenna, the ground plane dimensions are calculated as follows:

$$L_g = 6h + L \text{m} \tag{2.5.a}$$

$$W_g = 6h + W \text{m} \tag{2.5.b}$$

**Determination of feed point location ( $X_f$ , $Y_f$ ) for coaxial feeding:** As shown in Figure 2.10, if the center of the patch is taken as the origin point, the feed point location is given by the coordinates ( $X_f$ , $Y_f$ ) from the origin point. The feed point must be located where the input impedance is 50 ohms for the resonant frequency. Hence, a trial and error method is used to locate the feed point. For different locations of the feed point, the return loss is compared and the feed point is selected where the return loss is most negative

.

# CHAPTER 3

# SPECIFICATIONS OF PATCH ANTENNA

Before proceeding to the antenna design, the important specifications of patch antenna will be explained in this chapter.

## 3.1 CHARACTERISTIC IMPEDANCE ( $Z_0$ )

An antenna behaves as input port of two port-network at feeding point. In this point, the antenna has an impedance between the points where the feeding voltage source is placed. This impedance is entitled as "input impedance of the antenna". The input impedance is important due to the power transfer between the antenna and the source. At usually, the resistance of the source and the transmission line characteristic impedance are chosen as 50ohm. The calculations are made according to this choise. If the impedance matching can be obtained between the antenna and the feeding line, the maximum power transfer can be obtained also and the antenna operates efficiently (Sevgi, 2005).

## 3.2 REFLECTION COEFFICIENT $(\Gamma)$

If the impedance matching can not be obtained between the antenna and the feeding line, the reflected waves occur in the transmission line. Reflection coefficient "$\Gamma$" is derived by normalizing the amplitude of the reflected wave,"$V_0^-$", to the amplitude of the incident wave, "$V_0^+$". This ratio is as given as in the equation below (Ghafar, 2005):

$$\Gamma = \frac{V_0^-}{V_0^+} = \frac{Z_L - Z_0}{Z_L + Z_0} \quad (Z_L\text{: Load impedance, } Z_0\text{: Characteristic impedance}) \tag{3.1}$$

## 3.3 RETURN LOSS ( $RL$ )

When the impedance matching can not obtained between the antenna and the feeding line, the amount of power can not transferred to the antenna and a loss occurs. It is entitled as “Return Loss”. It is explained also as a logarithmic ratio measured in dB that compares the power reflected by the antenna to the power that comes from feeding line into the antenna. It is related with reflection coefficient as shown in Equation (3.2):

$$RL = -20\log|\Gamma| \text{ dB} \tag{3.2}$$

Return loss is a significant parameter to explain the antennas efficiency and performance. If it is greater than – 10 dB, it means that the antenna does not operate efficient and there is a mismatch between the feeding line and the antenna.

## 3.4 VOLTAGE STANDING WAVE RATIO (VSWR)

VSWR is a parameter which is related with the antenna input power. It is an indicator of the impedance matching or non-matching between the antenna and feeding line. The relationship between the VSWR and reflection coefficient is like that:

$$SWR = \frac{V_{max}}{V_{min}} = \frac{1+|\Gamma|}{1-|\Gamma|} \tag{3.3}$$

When the VSWR is 1 to 1 (1:1) the matching is perfect and all the energy is transferred to the antenna prior to be radiated. In addition, for an antenna to be reasonably functional, a minimum VSWR≤1.5 is required.

### 3.5 RADIATION PATTERN

Radiation pattern is to be shown of the propagated power by the antenna at the spherical coordinates as a function of angle. Practically, one is interested for the vertical and horizontal patterns. The most basic antenna is the isotropic antenna. As many antennas are used, the array antennas can be constituted and the desired radiation characteristics can be obtained. These antennas are directional antennas. A radiation pattern of a generic directional antenna is showed below in Figure 3.1. The pattern consists of a main lobe and several minor lobes. Some definitions about the radiation patterns are explained below:

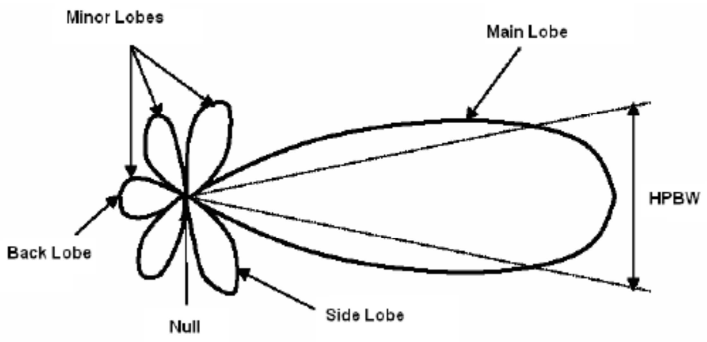


**Figure 3.1** Radiation pattern of a directional antenna.

1. Main Lobe:

This is the radiation lobe which occurs on the direction of maximum radiation.

2. Minor Lobe:

All the lobes which occur besides of the main lobe are called the minor lobes. These lobes represent the radiation in undesired directions.

3. Back Lobe:

This is the minor lobe diametrically opposite the main lobe.

4. Side Lobes:

These are the minor lobes adjacent to the main lobe and are separated by various nulls. Side lobes are generally the largest among the minor lobes. A good antenna design should minimize the minor lobes.

5. HPBW:

The half power beamwidth is a measurement of the directivity for having directivity antennas. It can be defined as the angular width where the power of main lobe falls by half.

### 3.6 DIRECTIVITY AND GAIN

The directivity and the gain are two important parameters which are defined according to an isotropic antenna. The isotropic antenna radiates at the same amount into all directions and is used as reference antenna. The directivity means to propagate the same power into a direction.

The gain of an antenna is a measure of the ability of an antenna to concentrate power into a narrow angular region of space.

### 3.7 BANDWIDTH

The bandwidth is the range of frequencies on either side of the resonant frequency where the antenna characteristics like input impedance, radiation pattern, beamwidth, polarization, side lobe level or gain, are close to those values which have been obtained at the center frequency.

There are several definitions of bandwidth exist: impedance bandwith, directivity bandwidth, polarization bandwidth and efficiency bandwidth. Usually only the impedance bandwidth is specified.

- Impedance bandwidth/return loss bandwidth: This is the frequency range wherein the antenna has a usable bandwidth compared to a certain impedance, usually 50 ohm.
- Directivity/gain bandwidth: This is the frequency range wherein the antenna meets a certain directivity/gain requirement.
- Efficiency bandwidth: This is the frequency range wherein the antenna has reasonable (application dependent) radiation /total efficiency.
- Polarization bandwidth: this is the frequency range wherein the antenna maintains its polarizations.

- Axial ratio bandwidth: this bandwidth is related to the polarization bandwidth and this number expresses the quality of the circular polarization of an antenna.

### 3.8 POLARIZATION

Polarization is the figure that the Electric field (E-field) wave traces out while propagating. There are two types polarization of the plane waves: Linear and Circular polarization:

- Linear polarization: The E- field only propagates in one direction (in x-axis) as shown as in Figure 3.2. If the x-axis was parallel to the ground, this field could also be described as "horizontally polarized". If the field was oriented along the y-axis, this wave would be said to be "vertically polarized”.

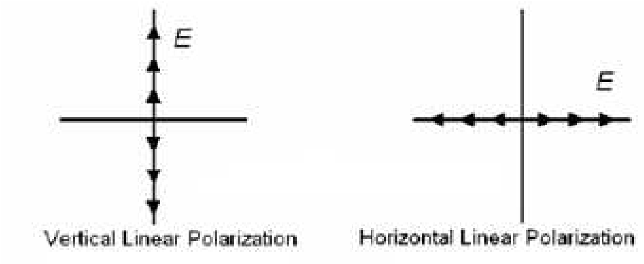


**Figure 3.2** Linear Polarization (vertical and horizontal).

- Circular polarization: The E-field rotates in a circular path. To have a circularly polarization: The E-field must have two orthogonal (perpendicular) components, these components must have equal magnitude and must be 90 degrees out of phase. The field is rotating in the counter-clockwise direction and is said to be “Right Hand Circularly Polarized”. If the fields were rotating in the clockwise direction, the field would be “Left Hand Circularly Polarized”. These polarization types are shown below:

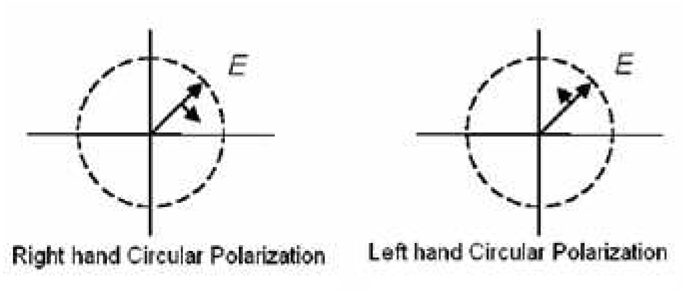


**Figure 3.3** Circular polarization (right hand and left hand).

# CHAPTER 4

# DESIGN OF THE MICROSTRIP ANTENNAS

## 4.1 INTRODUCTION

In this study, many antennas including slots were designed and simulated by means of CST Microwave Studio Program. As first a rectangular patch antenna and a spiral patch antenna designed by [E. Korkmaz] is chosen as a template. The goal is to investigate the possibilities for an improved design to increase the overall requirements to be used in a hyperthermia applicator. The disadvantage of the patch antenna is its wider HPBW and the spiral antenna is not a robust design since it does not have a solid substrate (suspenped in water), can be deformed easily which will alter the antenna characteristics. Because of these results we designed it in new configurations as we constituted slots/splits on the patchs.

Such these configurations are entitled as “compact microstrip antennas”. Since the microstrip antennas have narrow bandwidth and their performances are not very good, in present-day, compact microstrip antennas are used. In this way, it is possible to enhance the bandwidth, gain or obtain dual-frequency operated antennas, antennas having dual-polarized radiation and meet the miniaturization requirements in the applications. On this subject, many significant studies have been published in the open literature since 1997 and many techniques have been developed in this area (Wong, 2002).

As a slot shape is constituted at the patch’s nonradiating edges and size of this shape is changed the surface currents on the patch surface are increased and the current path is changed. As a result of this, when a suitable model is designed the performance of the antenna can be better and the efficiency can increase.

You will find many novel configurations in this thesis. We studied many configurations of antenna, however i did not give place some designs which did not have significant results.

## 4.2 RECTANGULAR PATCH ANTENNA

The rectangular patch antenna, is given in Figure 4.1., consists of a ground plane with a patch length of 33.126mm and width of 14mm and the height from ground plane to patch is 3.5mm, the patch and ground plane thicknesses are 0.3mm, and it has feeding point 5.521mm from the patch's longitudinal direction. The antenna is fed by a SMA connector and the inner pin of the connector has a diameter of 1.25mm and it is embedded in a 5cm high water bolus. The material properties of the deionized water at 434MHz and room temperature are $\varepsilon_r$ = 78.4 and the electrical conductivity σ = 5.55μS/m (Except the place of feeding point, the dimensions of the ground plane and patch, all the features which are explained above are same for the following antennas below).

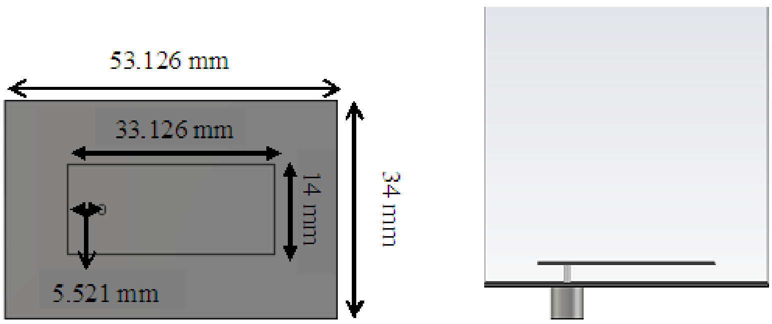


**Figure 4.1** Rectangular patch antenna (top and side view).

The simulation results are like below:

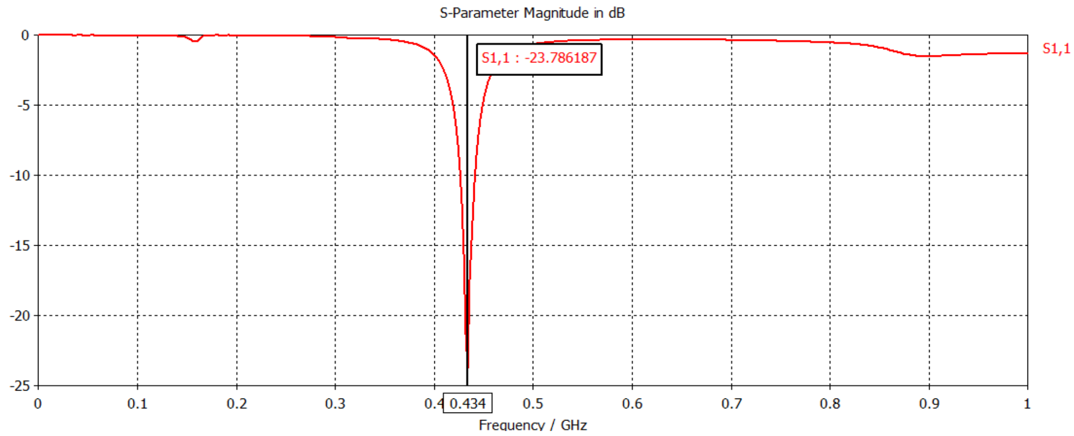


**Figure 4.2** $RL$ - $S_{11}$ parameter of rectangular patch antenna.

The return loss is approximately -24 dB. The resonant frequency is 434MHz. The -10dB bandwidth is approximately 14.2MHz.

The radiation patterns are given below:

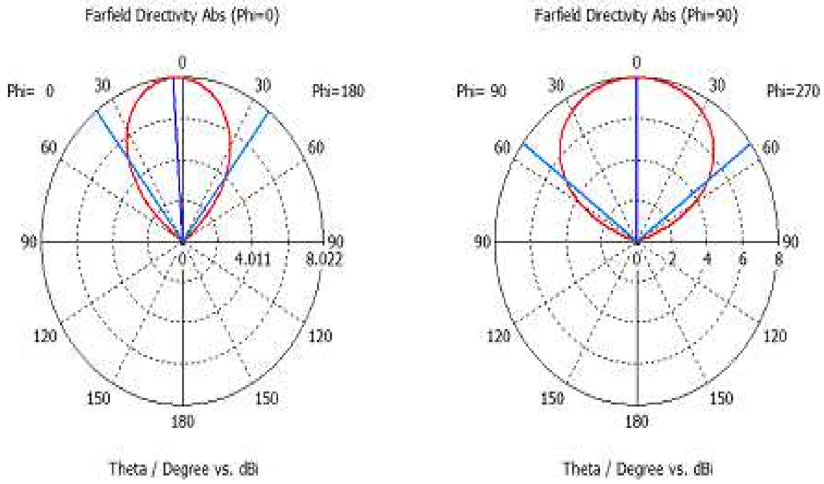


**Figure 4.3** Polar radiation patterns of rectangular patch antenna at $\phi$ =0° and $\phi$ =90°.

The HPBW is 75.1º at $\phi$ =0º and 106.7º at $\phi$ =90º. The main lobe magnitude is 8dB.

### 4.2.1 Rectangular Patch Antenna with Slot_1

The first designed slot antenna is like in the Figure 4.4:

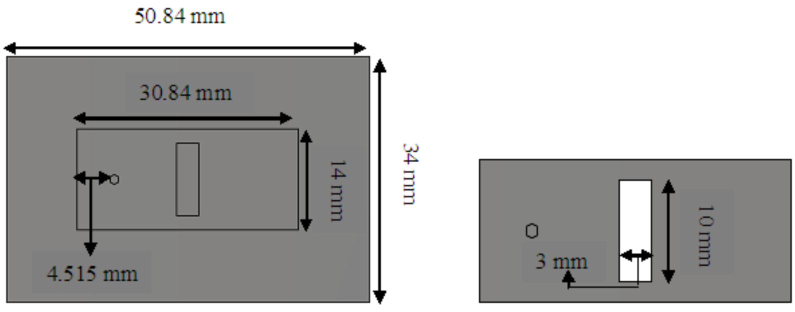


**Figure 4.4** Dimensions of rectangular patch antenna with slot_1.

As can be seen from the figure, the dimensions of the antenna were decreased by means of the constituting of the slot. When this slot shape has been constituted on the original rectangular patch antenna, it was seen from the results that the resonant frequency decreased. Therefore, to increase the resonant frequency the dimensions were decreased.

The results of the rectangular patch antenna with slot_1 are given in the following figures:

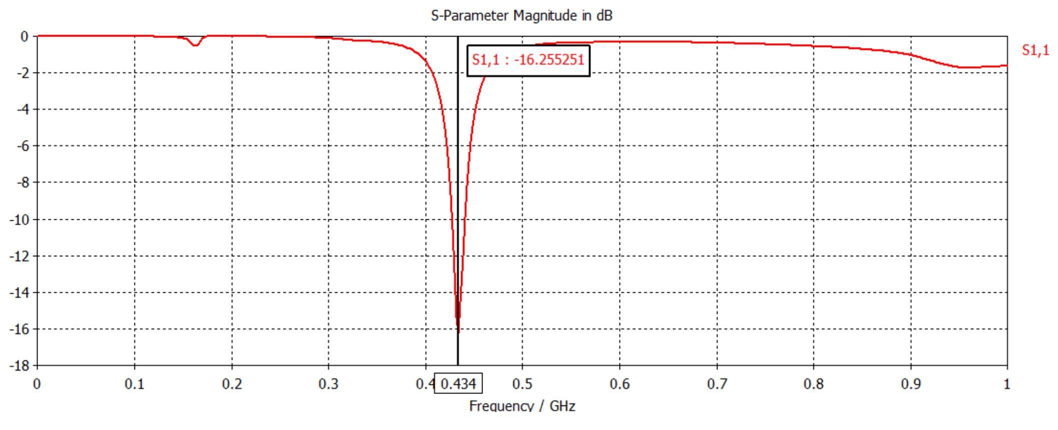


**Figure 4.5** *RL* - $S_{11}$ parameter of rectangular patch antenna with slot_1.

According to the results, $S_{11}$ parameter of rectangular patch antenna with slot_1 is approximately -16.25dB. The resonant frequency is 434MHz. The -10dB bandwidth is approximately 12.43MHz.

The radiation patterns of rectangular patch antenna with slot_1 are like below:

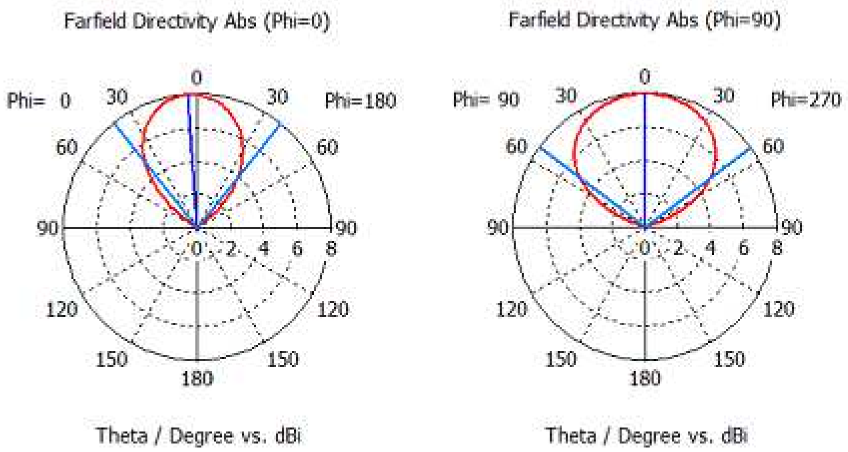


**Figure 4.6** Polar radiation patterns of rectangular patch antenna with slot_1 at $\phi$ =0° and $\phi$ =90°.

The main lobe magnitude is 8dB. The HPBW is 76.7º at $\phi$=0°, 106.2º at $\phi$=90°.

### 4.2.2 Rectangular Patch Antenna with Slot_2

The second design is like below:

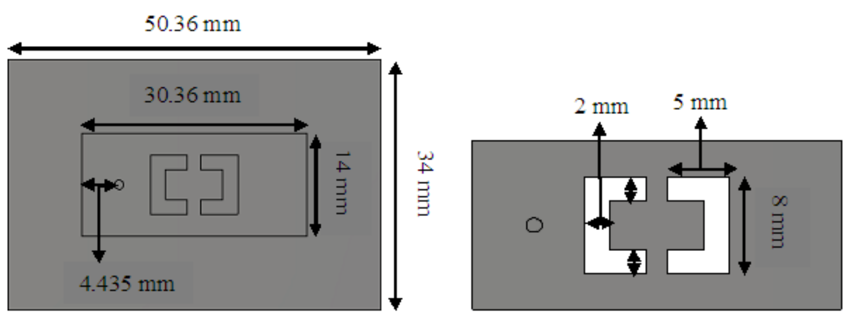


**Figure 4.7** Dimensions of rectangular patch antenna with slot_2 (The slots are similar and the slots' widths are similar everywhere).

The results of the rectangular patch antenna with slot_2 are given below:

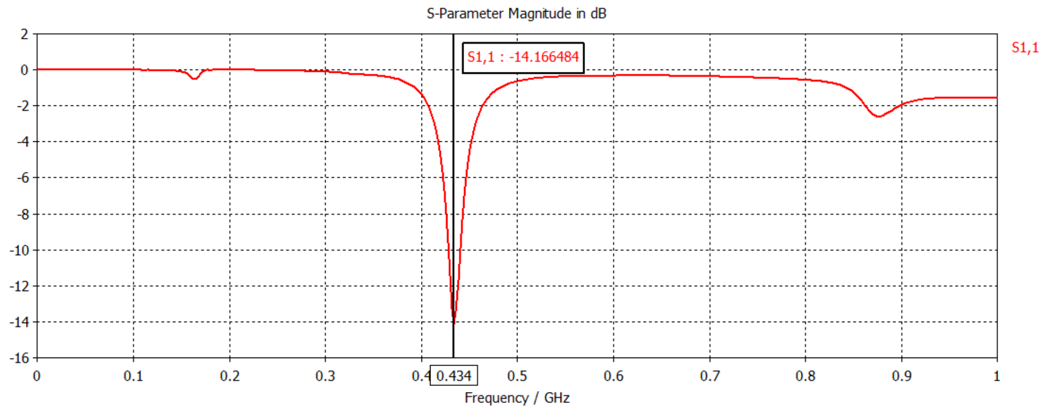


**Figure 4.8** $RL - S_{11}$ parameter of rectangular patch antenna with slot_2.

The return loss is -14dB at the resonant frequency: 434MHz. The -10dB bandwidth is approximately 11.36MHz. The radiation patterns in polar form are given in Figure 4.9.

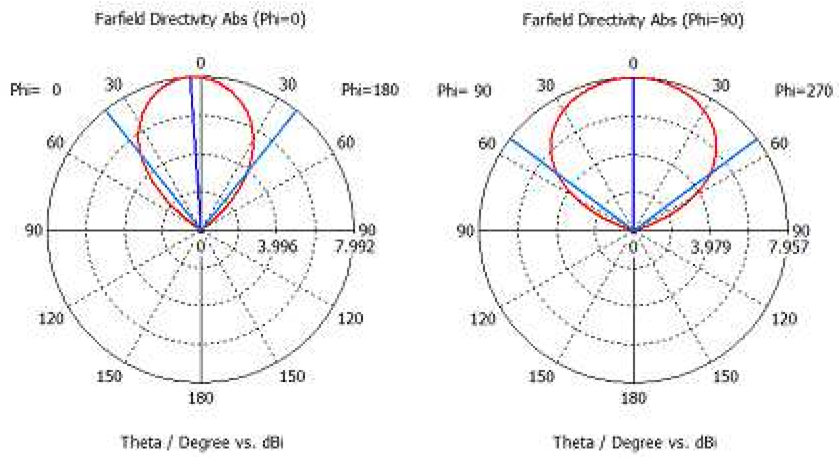


**Figure 4.9** Polar radiation patterns of rectangular patch antenna with slot_2 at $\phi$ =0° and $\phi$ =90°.

The main lobe magnitude is approximately 8dB. The HPBW is 77° at $\phi$=0°, 105.7° at $\phi$=90°.

### 4.2.3 Rectangular Patch Antenna with Slot_3

The third design is depicted below:

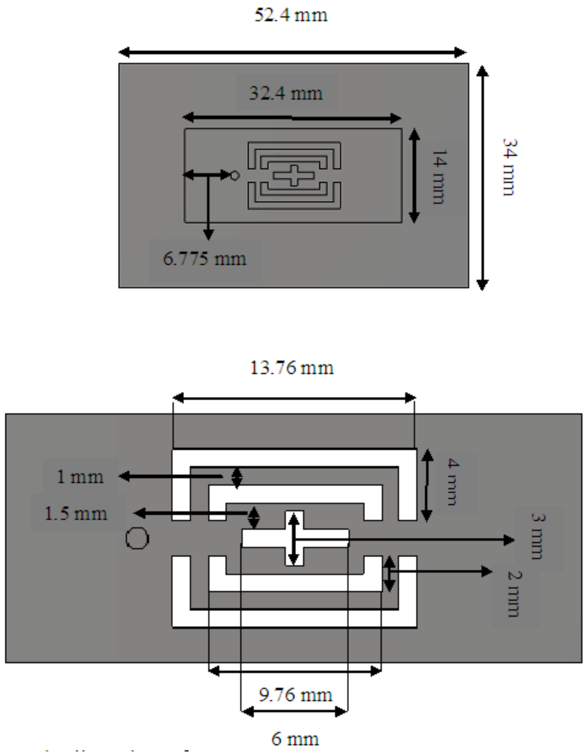


**Figure 4.10** Dimensions of rectangular patch antenna with slot_3 (The slot shape is symmetric and the slots' widths are 1mm everywhere).

The simulation results are like below:

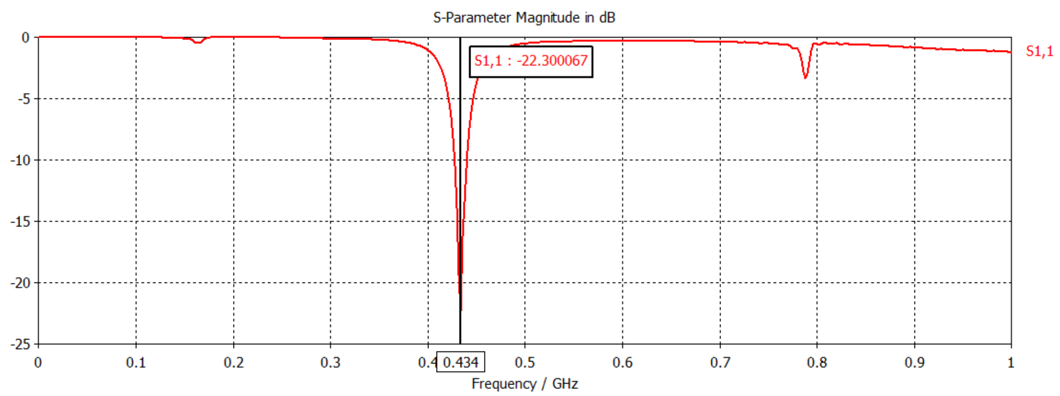


**Figure 4.11** $RL-S_{11}$ parameter of rectangular patch antenna with slot_3.

The return loss parameter is -22.3dB at resonant frequency: 434MHz. The -10dB bandwidth is approximately 11.84MHz. The radiation patterns in polar form are given in Figure 4.12.

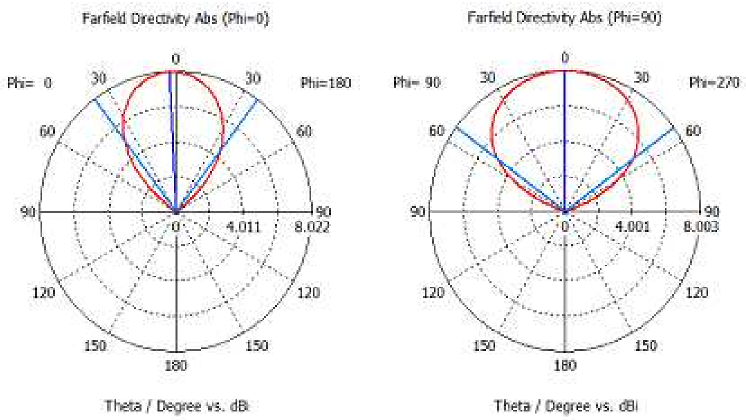


**Figure 4.12** Polar radiation patterns of rectangular patch antenna with slot_3 at $\phi$ =0° and $\phi$ =90°.

The main lobe magnitude is 8dB. The HPBW is 73.7° at $\phi$=0°, 106.3° at $\phi$=90°.

### 4.2.4 Rectangular Patch Antenna with Slot_4

The fourth design is like in the following figure:

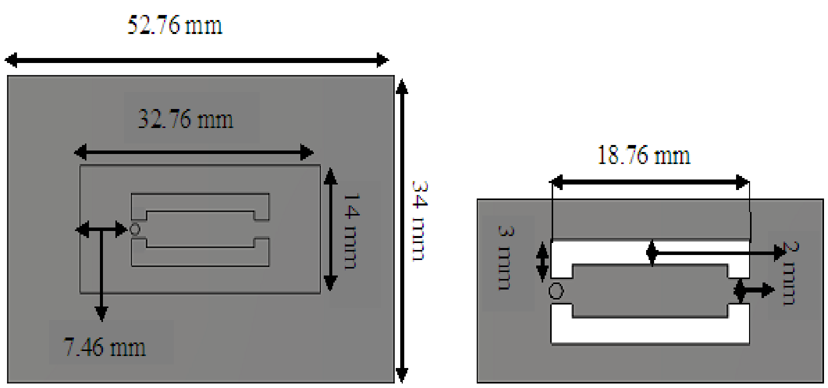


**Figure 4.13** Dimensions of rectangular patch antenna with slot_4 (The slot shape is symmetric and the slots' widths are 2mm everywhere).

The simulation results are below:

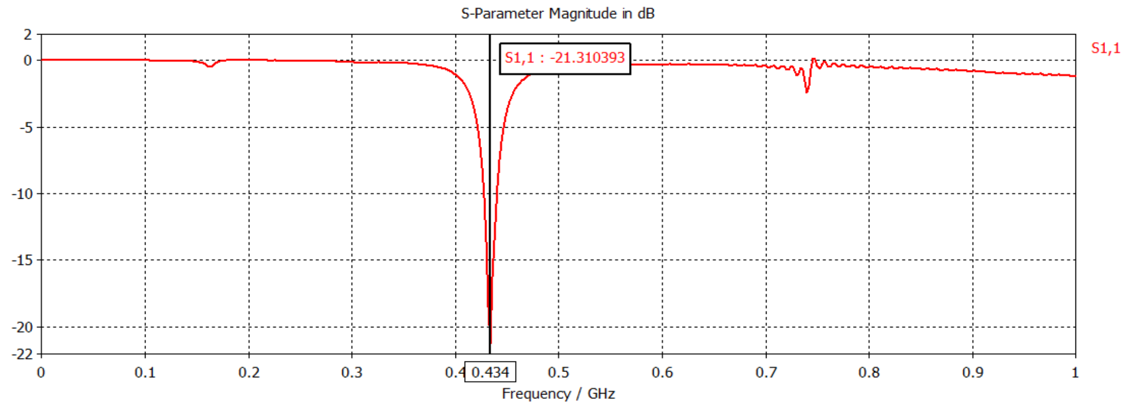


**Figure 4.14** $RL - S_{11}$ parameter of rectangular patch antenna with slot_4.

The return loss parameter is -21.3dB at resonant frequency: 434MHz. The -10dB bandwidth is approximately 11.82MHz. The radiation patterns in polar form are given in Figure 4.15.

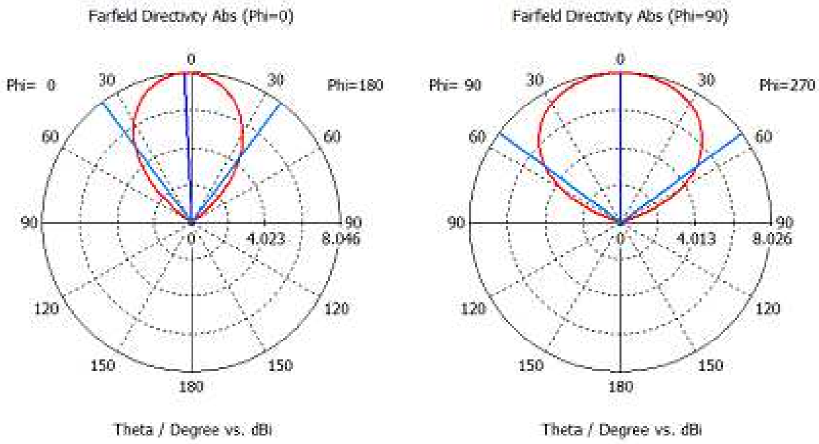


**Figure 4.15** Polar radiation patterns of rectangular patch antenna with slot_4 at $\phi$ =0° and $\phi$ =90°.

The main lobe magnitude is 8dB. The HPBW is 73.5º at $\phi$ =0°, 106.4º at $\phi$ =90°.

**4.2.5 Rectangular Patch Antenna with Slot_5**

The fifth design is like below:

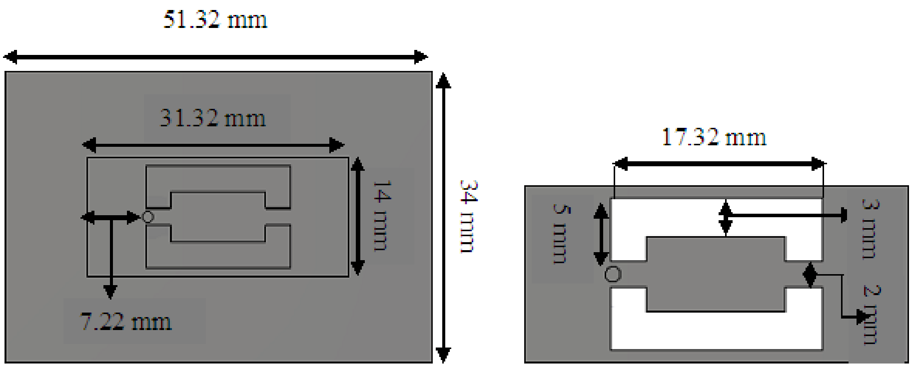


**Figure 4.16** Dimensions of rectangular patch antenna with slot_5 (The slot shape is symmetric and the slots' widths are 3mm everywhere).

The simulation results are below:

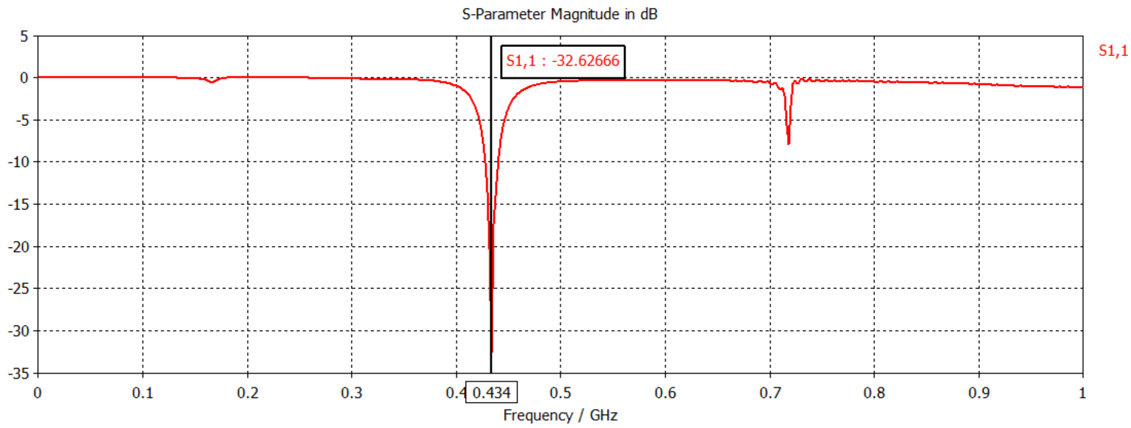


**Figure 4.17** $RL - S_{11}$ parameter of rectangular patch antenna with slot_5

The return loss parameter is -32.6dB at resonant frequency: 434MHz. The -10dB bandwidth is approximately 11.51MHz. The radiation patterns in polar form are given in Figure 4.18.

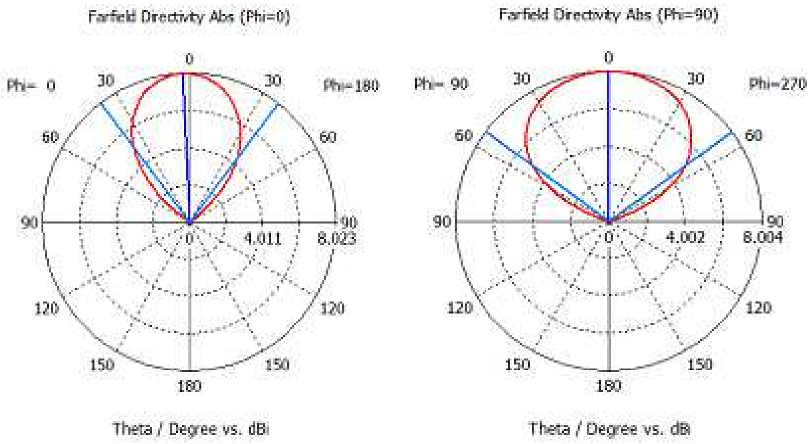


**Figure 4.18** Polar radiation patterns of rectangular patch antenna with slot_5 at $\phi$ =0° and $\phi$ =90°

The main lobe magnitude is 8dB. The HPBW is 74.1° at $\phi$=0°, 106.3° at $\phi$=90°.

### 4.3 THE RECTANGULAR PATCH ANTENNA WITH SLITS

After the slot antennas we designed slit antenna. As we constituted slits on the edge of the patch, we wanted to change the current path. We tried many different slits on the patch. After the optimizations, the two best antennas of them are given below.

The first configuration is like in Figure 4.19. There are 8 slits on the bottom and top edge both of them. The widths of slits are 1mm and the lengths of them are 2mm. The spaces' widths and lengths are respectively 1 mm and 2mm too. The feeding point is placed to 5.06mm away from the patch's longitudinal direction.

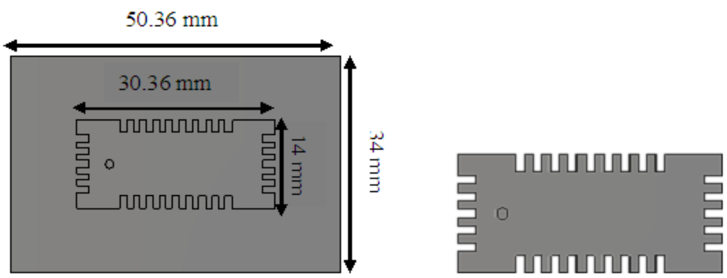


**Figure 4.19** Dimensions of rectangular patch antenna with 8x4 slits.

The simulation results are like below:

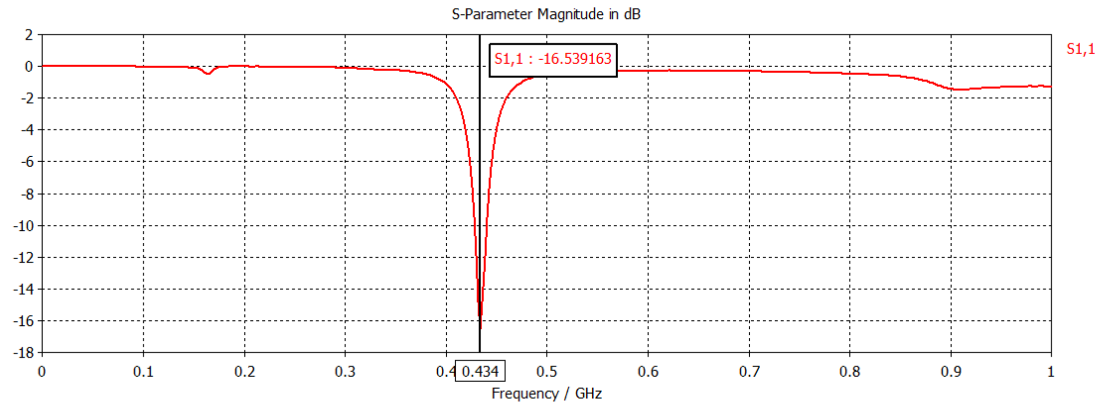


**Figure 4.20** $RL - S_{11}$ parameter of rectangular patch antenna with 8x4 slits

The return loss parameter is -16.5dB at resonant frequency: 434MHz. The -10dB bandwidth is approximately 11.2MHz. The radiation patterns in polar form are given in Figure 4.21.

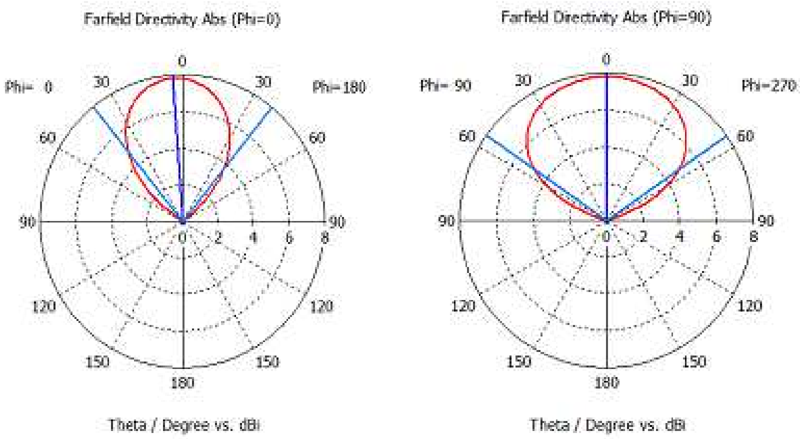


**Figure 4.21** Polar radiation patterns of rectangular patch antenna with 8x4 slits at $\phi$ =0° and $\phi$ =90°.

The main lobe magnitude is 7.8dB. The HPBW is 77.4º at $\phi$ =0°, 109.6º at $\phi$ =90°.

As a second design for slit antenna, the lengths of the slits were increased from 2mm to 3mm, the number of the slits on the top and bottom edge of the patch was increased from 8 to 9 too, the slits on the right and left sides became 3. The feeding point is placed to 5.74mm away from the patch’s longitudinal direction.

This new configuration is like below:

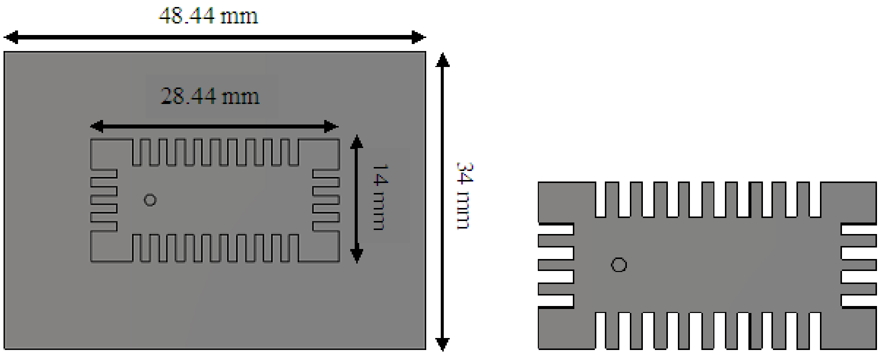


**Figure 4.22** Dimensions of rectangular patch antenna with 9x3 slits.

The simulation results became better than the previous design and the dimensions of the antenna became smaller as seen in Figure 4.22. The simulation results are like below:

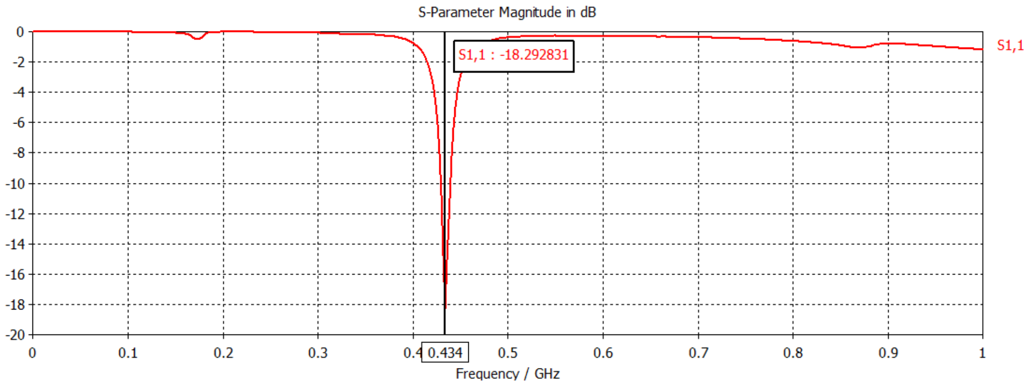


**Figure 4.23** $RL-S_{11}$ parameter of rectangular patch antenna with 9x3 slits.

The return loss parameter is -18.2dB at resonant frequency: 434MHz. The -10dB bandwidth is approximately 9.32MHz. The radiation patterns in polar form are given in Figure 4.24.

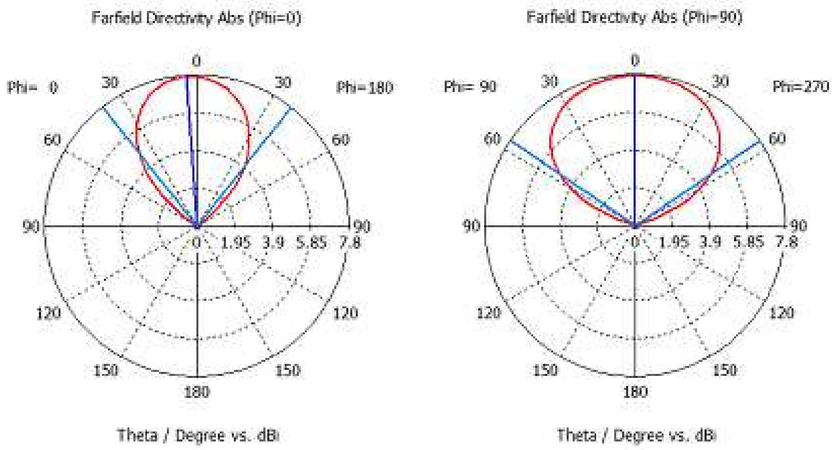


**Figure 4.24** Polar radiation patterns of rectangular patch antenna with 9x3 slits at $\phi$ =0° and $\phi$ =90

The main lobe magnitude is 7.8dB. The HPBW is 76.7º at $\phi$ =0°, 111.7º at $\phi$ =90°.

### 4.4 THE LOOP ANTENNA

After the rectangular patch antennas, we designed a loop antenna like in Figure 4.25.

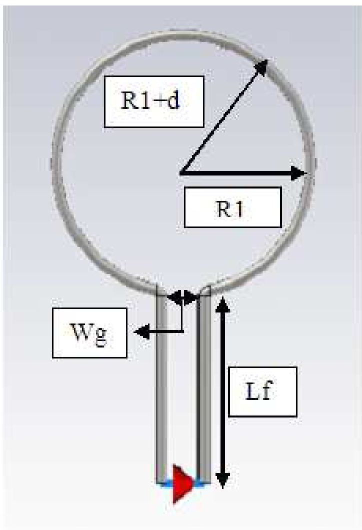


**Figure 4.25** Loop antenna (R1= 13.45mm, d=1.25mm, Wg=3.4mm, Lf=20.5mm).

The antenna was embedded in a 5cm high water bolus. This antenna was simulated in CST Microwave Studio Program. The simulation results are like below:

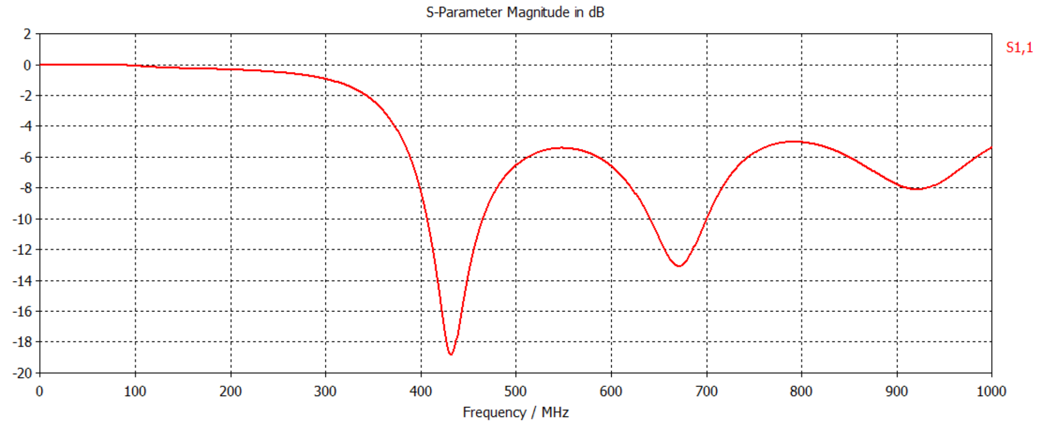


**Figure 4.26** $RL - S_{11}$ parameter of loop antenna.

The return loss parameter is -20.5dB at resonant frequency: 434MHz. The -10dB bandwidth is approximately 61.14MHz. As seen from the Figure 4.27, the antenna operates at multiple frequencies. However, the required frequency for our application is 434MHz.

The radiation patterns in polar form are given in Figure 4.27.

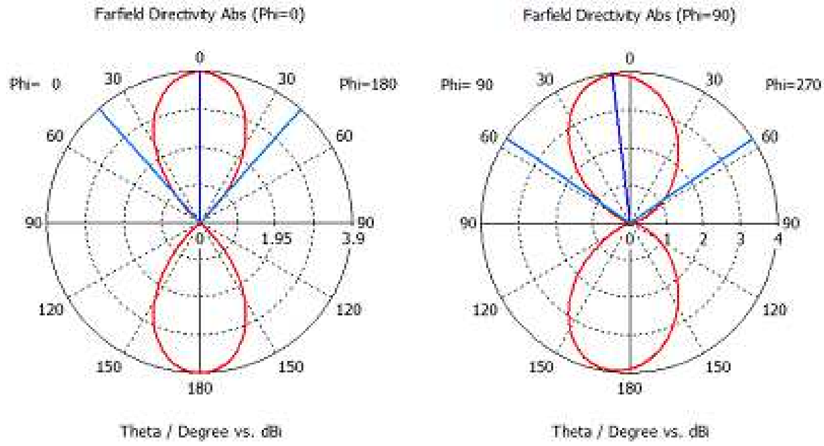


**Figure 4.27** Polar radiation patterns of loop antenna at $\phi$ =0° and $\phi$ =90°.

The main lobe magnitude is 3.9dB. The HPBW is 82.4° at $\phi$ =0°, 111.4° at $\phi$ =90°.

The loop antenna was produced from a copper wire having a 1.25mm diameter as shown in the Figure. It is placed in a 5cm high rectangular box filled with deionized water. A vector network analyser (VNA) of Anritsu Vectorstar MS4642A is used to measure of the loop antenna return loss value. The measurement setup is depicted in Figure 4.28. Also the simulated and measured values were plotted in MATLAB program. They are given below in Figure 4.29. A good agreement has been obtained between the measurement and simulation results.  The designed antenna operates at 434MHz too. However its bandwidth is narrower according to the simulation result. It may be because the antenna is not like a right loop shape. It was studied obtaining a right loop shape. However we do not have a mould at the same dimensions as the antenna, so we can not obtain the antenna exactly at the original dimensions.

**Figure 4.28** Measurement setup for return loss measurements.

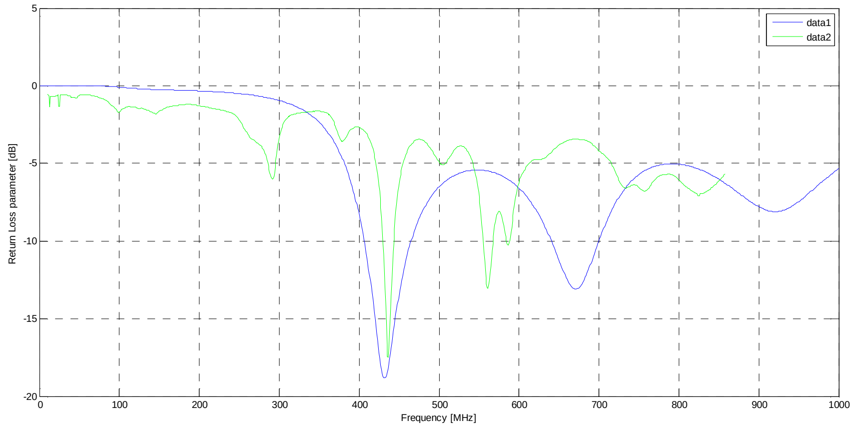


**Figure 4.29** Comparison of simulation and measurement return loss values (data 1: simulation result, data2: measurement result).

# CHAPTER 5

# CONCLUSION

In this thesis, many compact antennas including slots/slits and a loop antenna which operate at ISM band were designed, simulated and the loop antenna was fabricated and measured for hyperthermia applicator, in the RF Microwave Lab. Fatih University.

The aim of this study is to investigate of the characteristics of the microstrip antennas having slots/slits on their patch surfaces and to obtain a suitable antenna model to be used for hyperthermia applicator.

Actually this study was planned as three parts: 1. Simulation, 2. Product, 3. Test. As first a rectangular patch antenna designed by [E. Korkmaz] is chosen as a template. Many slots/slits shapes were constituted on the patch surface and approximately twenty new configurations were obtained. All the designs were simulated and their simulation results were investigated. However the time was not enough, just one antenna was fabricated and tested and some of them are not placed here because their simulation results are not very well.

Man was worked on the bandwidth, the dimension and the HPBW (Half Power Beamwidth) of these antennas. The aim is to increase the bandwidth, to decrease the dimension and to narrow the HPBW and to obtain the most useful and suitable model for hyperthermia applicator.

We could decrease the HPBW in some models as 1-2º. The dimension decreased in all designs as 1-5mm. In rectangular patch antenna models, we could not increase the bandwidth. When the slots/slits are constituted on the patch, the antenna characteristic becomes more specific and so the bandwidth narrows. So, because the bandwidth of the loop antenna is bigger than others, it was fabricated and tested.

The simulation results and measurement results of the loop antenna are good in terms of the resonant frequency and return loss. Its bandwidth is approximately 58MHz in simulation results and 13.5MHz in measurement results. This difference may be based on the shape of the loop antenna. Because we do not have a mould at the same size with loop antenna, we made it as manual. So, it could not be like the size of the original design.

According to the literature researches, more advanced techniques are needed to increase the bandwidth, also to enhance the antenna gain, to increase the performance and the efficiency of the antenna. Because the time was not enough, these techniques were not tried.

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