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DESIGNING A PATCH ANTENNA FOR 5G COMMUNICATION SYSTEM

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DESIGNING A PATCH ANTENNA FOR 5G COMMUNICATION SYSTEM

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



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ABSTRACT

DESIGNING A PATCH ANTENNA FOR 5G COMMUNICATION SYSTEM

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M.S.c., Department of Electronic and Communication Engineering

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This thesis includes the design and analyzes of rectangular, circular and hexagonal type patch antennas for the next generation (5G) mobile networks. Both the microstrip feed line and coaxial feed techniques are used to feed the patch antenna. The best feed point location for both techniques is found to achieve the highest performance. The high frequency structural simulator (HFSS 12.1) is used to simulate the antenna and find out the characteristics. The antenna performance characteristics such as VSWR, return loss, radiation pattern are obtained. Moreover, a MATLAB Graphical User Interface (GUI) is designed to calculate the antenna parameters for rectangular and circular patch antennas with different feeding methods.

Keywords: 5G Communication, feed point location, patch antenna, feeding methods

ÖZ

5G İLETİŞİM SİSTEMİ İÇİN BİR YAMA ANTEN TASARIMI

Yıldıran, Orçun

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Bu çalışma, gelecek nesil (5G) mobil ağlar için dikdörtgen, dairesel ve altıgen yama antenlerin tasarımını ve analizini içermektedir. Yama anteni beslemek için mikroşerit ve koaksiyal besleme metotları kullanılmıştır. En iyi performansı sağlamak için her iki metot için de en iyi besleme noktası bulunmuştur. Anteni simüle etmek ve karakteristiğini bulmak için High Frequency Structural Simulator (HFSS 12.0) kullanılmıştır. Anten performansının VSWR, yasıma kaybı, ışın diyagramı gibi karakteristik özellikleri elde edilmiştir. Ayrıca, değişik besleme metotları ile birlikte dikdörtgen ve dairesel yama antenlerin parametlerini hesaplamak için MATLAB Grafiksel Kullanıcı Arayüzü (GUI) tasarlanmıştır.

Anahtar Kelimeler: 5G İletişim, besleme noktası, yama anten, besleme metotları

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CHAPTER 1

INTRODUCTION

Many technologies keep developing and revolution constantly throughout their lifecycle. Among these technologies mobile communication technology is unique with its adaption and development speed. In a short time period, the mobile communication technology has reached more than six billion people and allowed them to communicate with each other. Till today, mobile communication technology has developed by numerous innovations which have end up with improved performance and lower cost [16].

Mobile communication technology started from the first quarter of the last century. Its evolution has started, which is called as generations, by the 1970s [16]. These generations differs by radio access, data rates, bandwidth, and switching schemes. From the beginning, the mobile communication technology has experienced five generations [17].

The cellular concept starts with the first generation (1G) technology. The 1G network is started for voice services those are using the frequency modulation technique for radio transmission using Frequency Division Multiple Access (FDMA). The channel bandwidth is in between 10-30 KHz and the frequency band was 824-894 MHz. The data rate, that 1G technology can provide, is around 10 kbps. Due to the demand of improved transmission quality, higher system capacity, better coverage and better spectral efficiency, the second generation (2G) technology has been presented [17].

In 1991, 2G cellular networks were released commercially on the Global System Mobile Communications (GSM) [17]. The 2G is significantly enhanced the quality of wireless communication by replacing the analog technology with digital technology [18]. There are three main advantages of 2G networks which are digitally encrypted conversations, more efficient on the spectrum, data services for

mobile such as Short Message Service (SMS). Also, 2G technologies allow the user to use the services such as text, picture and multimedia messages (MMS). Time Division Multiple Access (TDMA) and Code Division Multiple Access (CDMA) are used as digital modulation schemes. The first and second phases of 2G technologies provide a data rate up to 9.6 kbps and 300 kbps with bandwidth of 200 kHz respectively. The frequency band of 2G is 850-1900 MHz [17].

The main interest point of 3G is data communication. 3G systems compound Internet Protocol (IP) based services with high speed mobile access. Wireless web base access, multimedia services, email, and video conference are the main characteristics of it. The 3G networks supports the data rate with regard to environment. It is 2 Mbps in indoor and close range outdoor, 384 kbps in urban outdoor and 144 kbps in country side outdoor. The frequency band of 3G is 1.8-2.5 GHz [17].

The 4G system offered more advantages as mobile broadband Internet to mobile devices while covering the all services of the 3G. The differences of 4G system from 3G system are mobile broadband Internet access for smartphones, laptops and other mobile devices. The Mobile WiMAX standard and the first version Long Term Evolution (LTE) which are the applicant systems are deployed [19]. For low mobility the data rate is up to 1 Gbps and for high mobility this value decreases to 100 Mbps [17].

Wireless connections are requested by more than five billion devices for voice, data, and other applications [20]. The existing generations of cellular networks have restrictions in providing high quality and low latency applications for wireless devices [21]. Moreover, even if the demand is increasing for high data rates, there is global bandwidth shortage [20]. Therefore, 5th generation (5G) mobile communication network takes increasing attention day by day with its higher transmission rate, higher capacity, more connections and lower network latency [22]. 28 GHz and 38 GHz are the two 5G frequency bands those the antenna community pay attention to design efficient antennas to deploy [20].

CHAPTER 2

ANTENNA DESIGN AND ANALYSIS

Three different patch antennas which are rectangular, circular and C-shaped are designed and analyzed to use in 5G communication systems. HFSS 12.1 is used to design and simulate the antennas. In this chapter, the design procedure of the antennas are explained in detail and the results of the simulation such as return loss, radiation pattern and VSWR are given.

The operation frequency (resonant frequency) of the proposed antennas is 28 GHz. The substrate used for these antennas is Rogers RT/duroid 5880. It is chosen because its dielectric constant is 2.2. The fringing field around the patch increases with the low value of dielectric constant. This results in the increase of the radiated power. [12] The thickness of the selected substrate is 0.508mm. Moreover, the fringing field increases with thick substrate so for good antenna performance [12], thick substrate should be used but the proposed antennas also can be used in mobile devices so the thinnest substrate is preferred.

Both the microstrip feed line and coaxial feeding method are used to feed the antennas. The result obtained from these feeding methods are demonstrated and compared. The best feeding point location for both techniques is found to achieve the highest performance.

For each antenna the effect of the substrate dimension is investigated. The obtained results are demonstrated and compared.

2.1 Microstrip Feed Line Method

2.1.1 Rectangular Patch Antenna

The proposed rectangular patch antenna is shown in Fig. 1. In the design of this antenna, Roger RT/duroid 5880 is used. The resonant frequency of the antenna is 28 GHz. The dimensions of the antenna are calculated based on the following equations given in [1]. To find the patch width the Eqn. 1 is used.

$$W = \frac{1}{2f_r \sqrt{\mu_0 \epsilon_0}} \sqrt{\frac{2}{\epsilon_r + 1}} = \frac{V_0}{2f_r} \sqrt{\frac{2}{\epsilon_r + 1}} \quad (1)$$

where ϵ_r and f_r are dielectric constant of the substrate and resonant frequency respectively, μ_0 , ϵ_0 and V_0 are free space permeability, permittivity and velocity respectively.

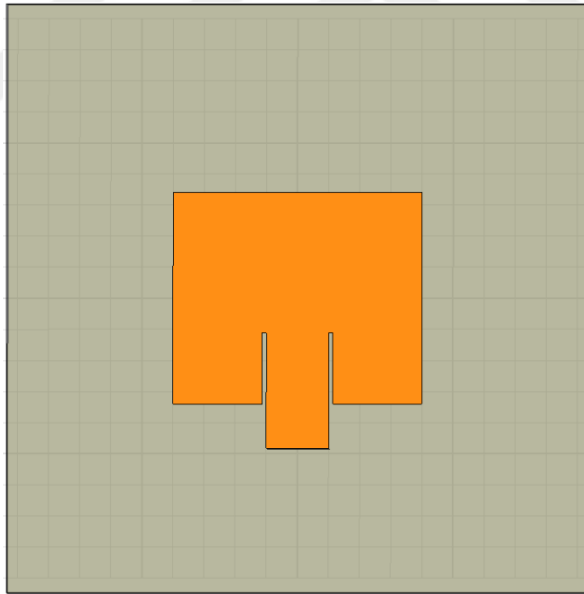
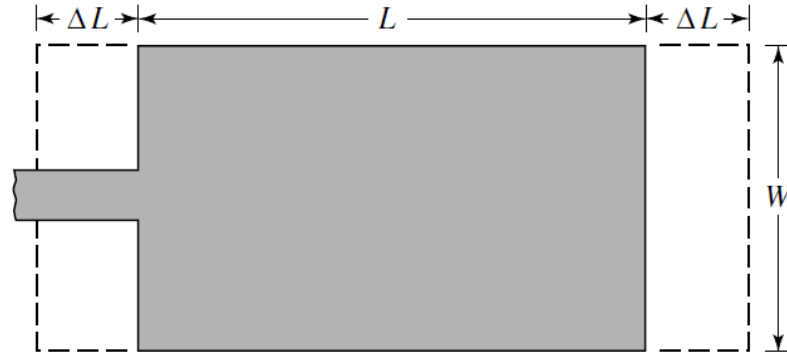


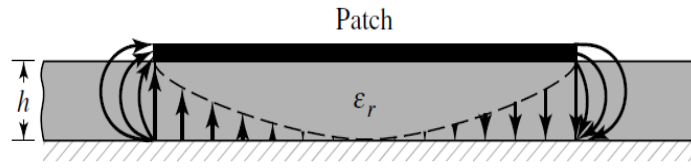
Figure 1 Proposed Rectangular Patch Antenna

Firstly, effective dielectric constant ϵ_{reff} has to be calculated from Eq. (2) to calculate the length of the patch. Then, the calculated ϵ_{reff} value is used to calculate the ΔL which is a function of ϵ_{reff} . It is a parameter which is a result of fringing effects. Due to these effects, the patch of the microstrip antenna looks greater than

its physical dimensions electrically. This situation is shown in Fig. 2 for the E-plane (xy-plane).



(a) Top View



(b) Side View

Figure 2 Physical and Effective Lengths of Rectangular Microstrip Patch [1]

The effective dielectric constant formula is given as

$$\epsilon_{\text{reff}} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2} \left[1 + 12 \frac{h}{W} \right]^{-1/2} \quad (2)$$

where h is the height of the substrate. ΔL is given as

$$\frac{\Delta L}{h} = 0.412 \frac{(\epsilon_{\text{reff}} + 0.3) + \left(\frac{W}{h} + 0.264 \right)}{(\epsilon_{\text{reff}} - 0.254) + \left(\frac{W}{h} + 0.8 \right)} \quad (3)$$

As a result of fringing effects, the length of the patch is extended by ΔL . Therefore, to calculate the effective length following formula is written as

$$L_{eff} = L + 2\Delta L \quad (4)$$

The feed line point inset distance is calculated by the formulas given in [1] is used. The inset feed consists of a physical notch that causes a junction capacitance. The resonant frequency is affected by physical notch and its junction capacitance [2].

$$R_{in} = \frac{1}{2(G_1 + G_{12})} \quad (5)$$

where R_{in} is the resonant input impedance, G_1 is conductance of a single slot and G_{12} is the mutual conductance. Firstly, G_1 and G_{12} should be calculated to find the R_{in} given in Eq. (5). These values can be calculated from below formula given in [1].

$$G_1 = \frac{I_1}{120\pi^2} \quad (6)$$

where

$$I_1 = \int_0^\pi \left[\frac{\sin\left(\frac{k_0 W}{2} \cos \theta\right)}{\cos \theta} \right]^2 \sin^3 \theta d\theta \quad (7)$$

$$= -2 + \cos(X) + X S_i(X) + \frac{\sin(X)}{X} \quad (7a)$$

$$X = k_0 W \quad (7b)$$

The G_{12} is calculated by

$$G_{12} = \frac{1}{120\pi^2} \int_0^\pi \left[\frac{\sin\left(\frac{k_0 W}{2} \cos \theta\right)}{\cos \theta} \right]^2 J_0(k_0 L \sin \theta) \sin^3 \theta d\theta \quad (8)$$

After the calculation of input resistance, the inset feed point distance y_0 is calculated by the formula below given in [1].

$$Z_0 = R_{in} \cos^2 \left(\frac{\pi}{L} y_0 \right) \quad (9)$$

The notch width (g) is the symmetrical gap between the inset feed and the microstrip feed line. It can be calculated from the below formula given in [2].

$$g = \frac{V_0}{\sqrt{2 \times \varepsilon_{reff}}} \frac{4.65 \times 10^{-12}}{f} \quad (10)$$

The microstrip feed line length (TL) is calculated by the equation given in [3].

$$TL = \frac{\lambda_0}{4\sqrt{\varepsilon_r}} \quad (11)$$

The formula given in [4], [5], [6] and [7] is used to calculate the microstrip feed line width.

$$\frac{W_f}{h} = \begin{cases} \frac{8e^A}{e^{2A} - 2h}, & \frac{W_0}{h} \leq 2 \\ \frac{2}{\pi} \left\{ B - 1 - \ln(2B - 1) + \frac{\varepsilon_r - 1}{2\varepsilon_r} \left[\ln(B - 1) + 0.39 - \frac{0.61}{\varepsilon_r} \right] \right\}, & \frac{W_0}{h} \geq 2 \end{cases} \quad (12)$$

where

$$A = \frac{Z_0}{60} \sqrt{\frac{\varepsilon_r + 1}{2}} + \frac{\varepsilon_r + 1}{\varepsilon_r - 1} \left(0.23 + \frac{0.11}{\varepsilon_r} \right) \quad (12a)$$

$$B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}} \quad (12b)$$

The dimensions of the ground plane are calculated by using the formulas given in [8], [9], [10] and [11].

$$W_g = 6h + W \quad (13a)$$

$$L_g = 6h + L \quad (13b)$$

In this thesis, notch width used as a variable to see the effect of it on the antenna performance. Moreover, the effect of the length of the microstrip feed line on the antenna performance is investigated. The obtained results are given and compared in the following pages.

The obtained results after all these calculations are done are given in the Table 1. To make the design procedure easier and calculate the dimensions of the antenna a

graphical user interface (GUI) is designed in MATLAB. This GUI will be explained in detail later. All values are in millimeter.

Table 1 Calculated Dimensions of Proposed Antenna

Patch Width (W)	4.235
Patch Length (L)	3.282
Substrate Width	7.283
Substrate Length	6.329
Inset Feed Point Distance (y_0)	1.135
Notch Width (g)	0.025
Feed Line Width	1.565
Feed Line Length	1.902

After these values are obtained, the proposed antenna is designed by using HFSS 12.1. To simulate the antenna operation and obtain the results of antenna performance, an analysis setup must be setup. The resonant frequency of the antenna is 28 GHz. Therefore, the solution frequency is set up 28 GHz. In addition to that, start and stop frequencies of the sweep setup are set up 26 GHz and 35 GHz respectively. The step size is 0.1 GHz. The designed antenna is shown in Fig. 3.

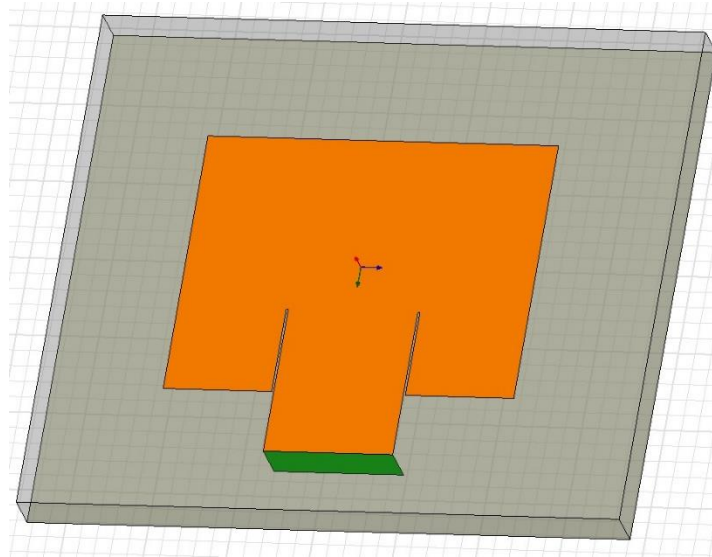


Figure 3 The Designed Rectangular Patch Antenna

The obtained results from the antenna simulation which are return loss, radiation pattern, VSWR are given in Fig. 4, 5 (a), (b) and 6 respectively.

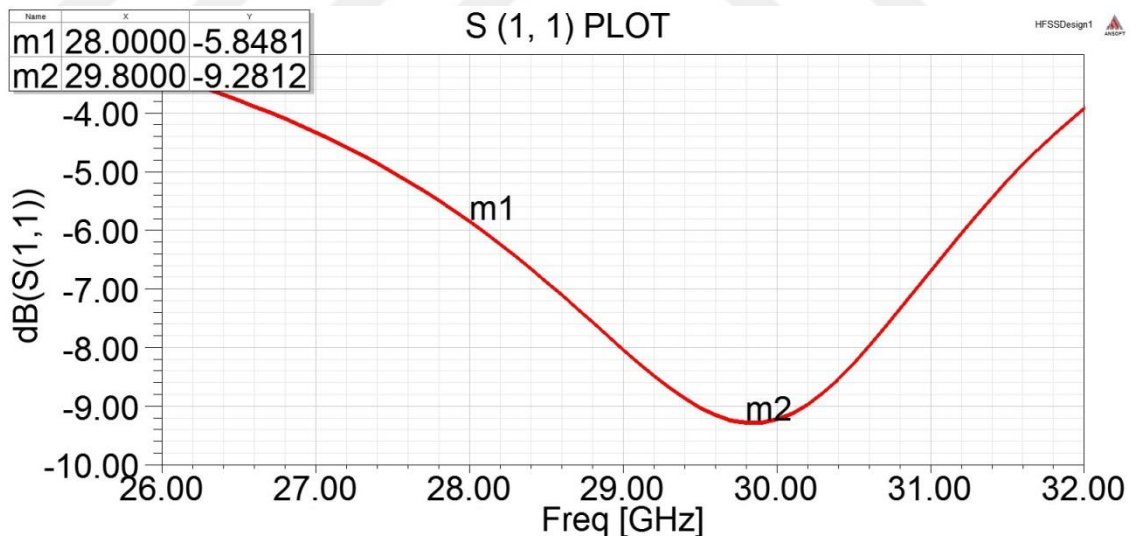
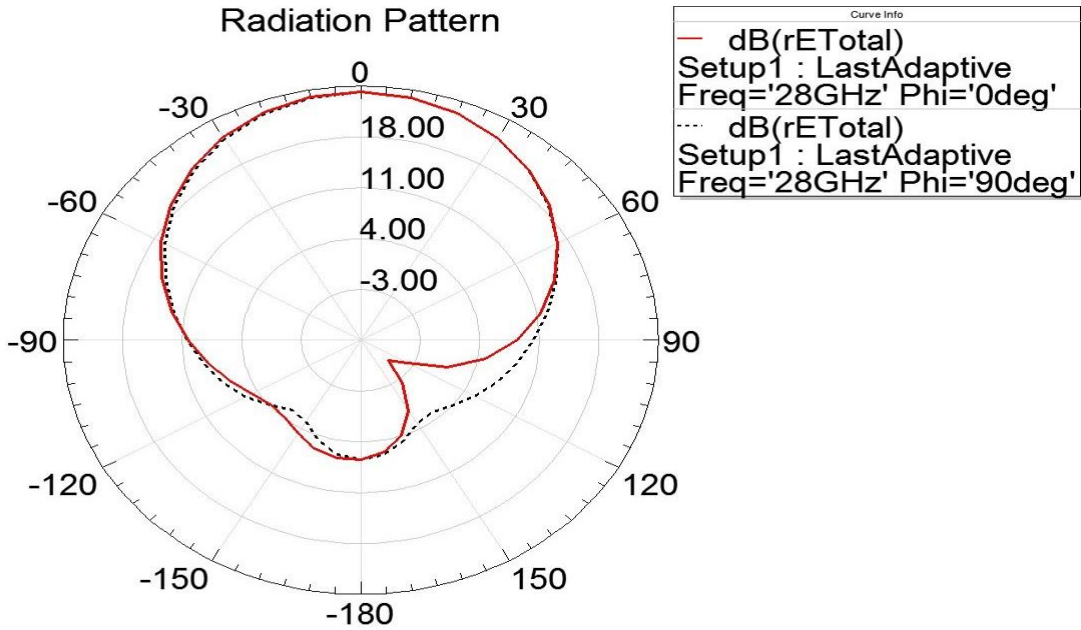


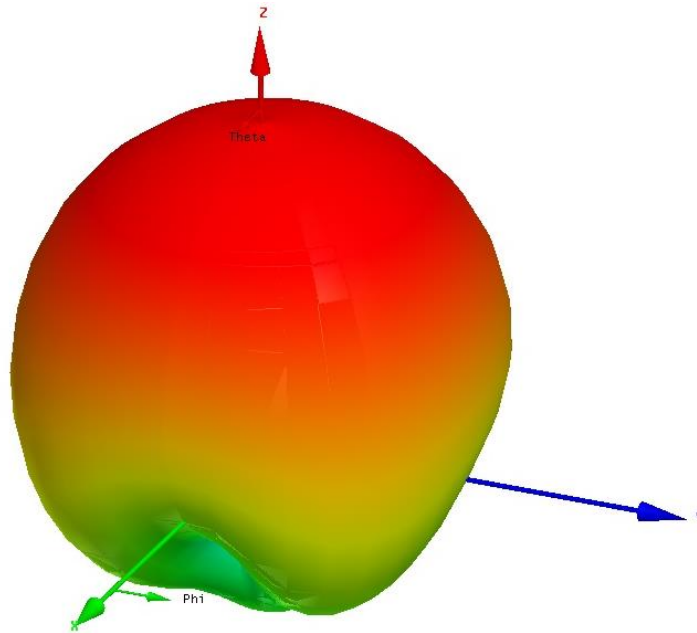
Figure 4 Return Loss Graph

In Figure 4, the return loss graph of the rectangular patch antenna is given. The y axis shows the return loss value in dB and the x axis shows the frequency in GHz. The red line represents the variation of the return loss according to frequency. In

this thesis, for a good antenna performance the return loss value should be at least -10 dB. The return loss is -9.28 dB which is the lowest value at 29.8 GHz. It increases when the frequency increases and also decreases. At 28 GHz that is the targeted resonance frequency, the return loss value is -5.8481 dB. This is an indication of the poor antenna performance.



(a) Radiation Pattern at Phi = 0° and 90°



(b) Radiation Pattern 3D Plot

Figure 5 Radiation Pattern Plots

In Figure 5 (a), there are numbers on the outside of the big circle from which straight lines are going into the center of the circle. These numbers are given in decimal degree and represent a direction. As can be seen from the graph also there are small circles inside the big circle. These are circles that represent the gain in dB. The red line represents the radiation pattern at $\phi = 0^\circ$ at 28 GHz and the short dashed black line represents the radiation pattern at $\phi = 90^\circ$ at 28 GHz. These lines represent that the intensity of the radiated power goes into one direction which is 0° in this case.

In Figure 5 (b), the antenna lies on the x-y axis and the radiating patch is looking towards to z-axis. The center of the radiating patch of the antenna is located at the origin. As expected, there is power transmitted on z-axis which corresponds to the radiation directly overhead the antenna. On x plane and y plane, the radiation is minimum.

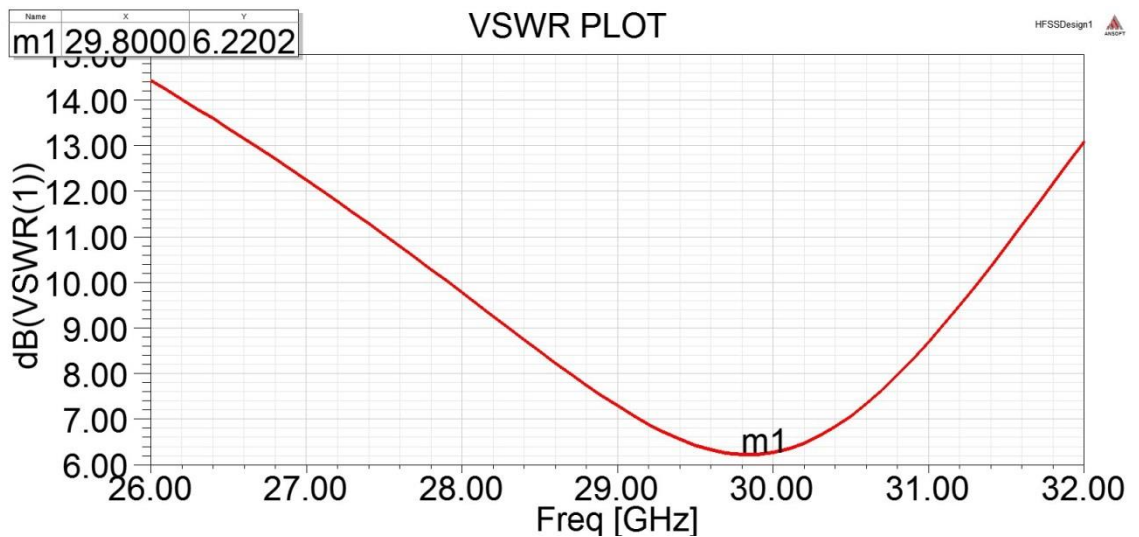


Figure 6 VSWR Graph

In Figure 6, the VSWR graph of the rectangular patch antenna is given. The y axis shows the VSWR value in dB and the x axis shows the frequency in GHz. The red line represents the variation of VSWR according to frequency. The VSWR is 6.22 dB which is the lowest value at 29.8 GHz as expected but this value is not good enough to say that the antenna has a good performance. In other words, this is an indication of the poor antenna performance. The VSWR value increases when the frequency increases and also decreases.

After these result are obtained, to see the effect of the length of the microstrip feed line, the length of it is extended till the end of the substrate. The patch antenna and the results of the simulation are given in Fig. 7, 8, 9 (a), (b) and 10 respectively.

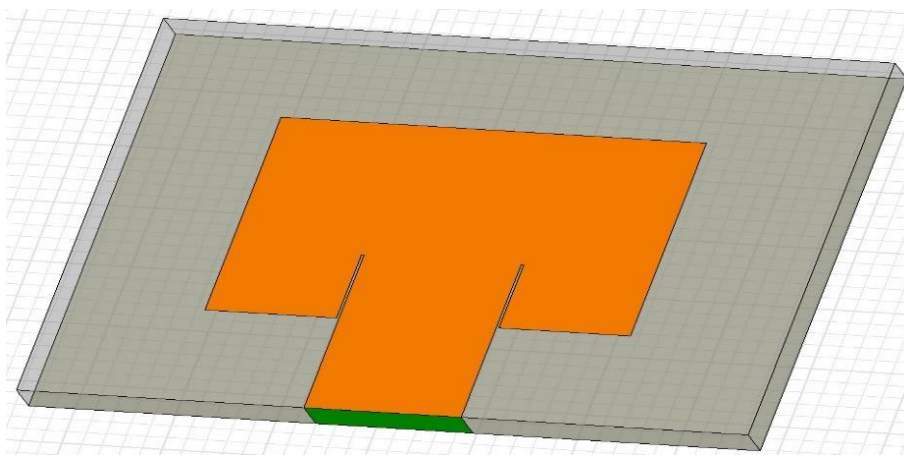


Figure 7 The Antenna that the feed line is extended

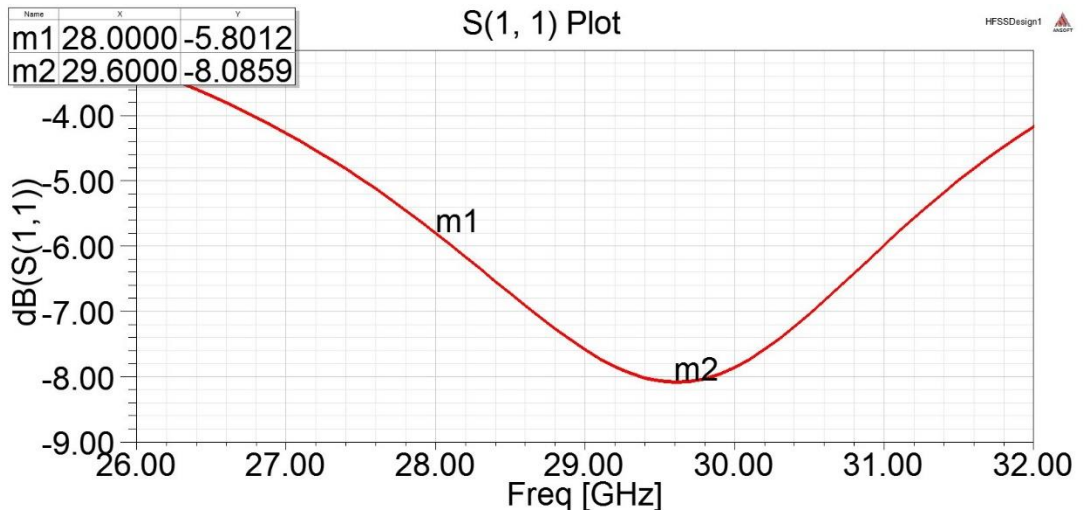
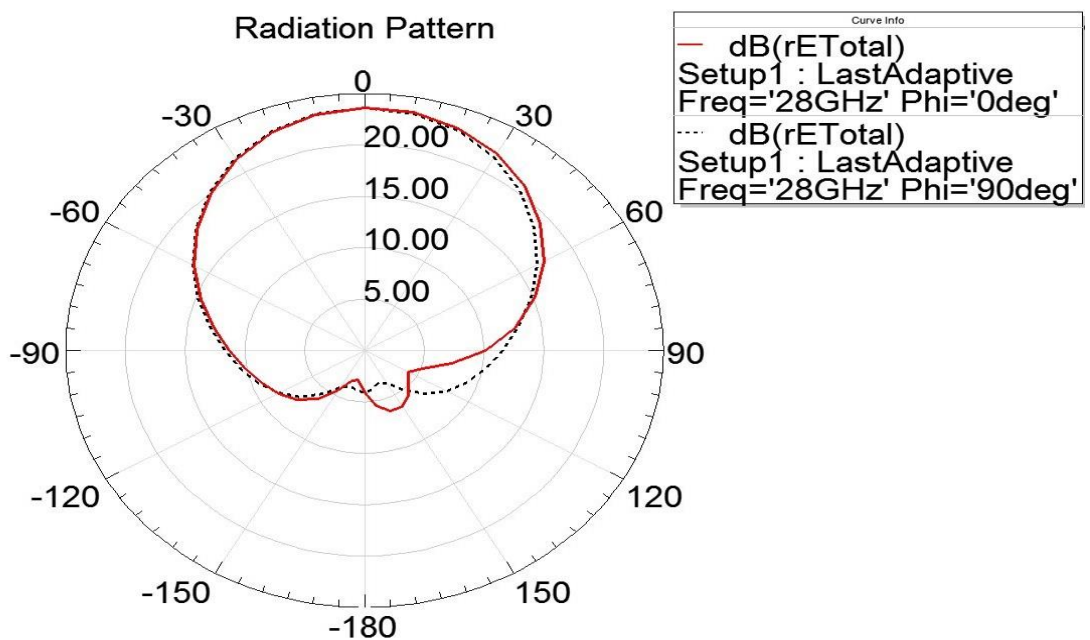
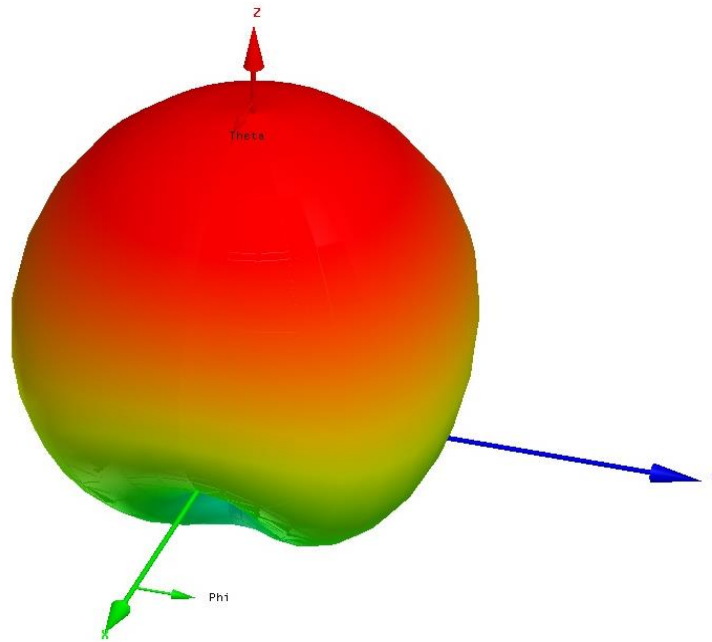


Figure 8 Return Loss Graph

In Figure 8, the return loss graph of the rectangular patch antenna is given. The y axis shows the return loss value in dB and the x axis shows the frequency in GHz. The red line represents the variation of the return loss according to frequency. The return loss is -8.08 dB which is the lowest value at 29.6 GHz. It increases when the frequency increases and also decreases. At 28 GHz that is the targeted resonance frequency, the return loss value is -5.80 dB. This is an indication of the poor antenna performance.



(a) Radiation Pattern at $\Phi = 0^\circ$ and 90°



(b) Radiation Pattern 3D Plot

Figure 9 Radiation Pattern Plots

In Figure 9 (a), the red line represents the radiation pattern at $\phi = 0^\circ$ at 28 GHz and the short dashed black line represents the radiation pattern at $\phi = 90^\circ$ at 28 GHz. These lines represent that the intensity of the radiated power goes into one direction which is 0° in this case.

In Figure 9 (b), the antenna lies on the x-y axis and the radiating patch is looking towards to z-axis. The center of the radiating patch of the antenna is located at the origin. As expected, there is power transmitted on z-axis which corresponds to the radiation directly overhead the antenna. On x plane and y plane, the radiation is minimum.

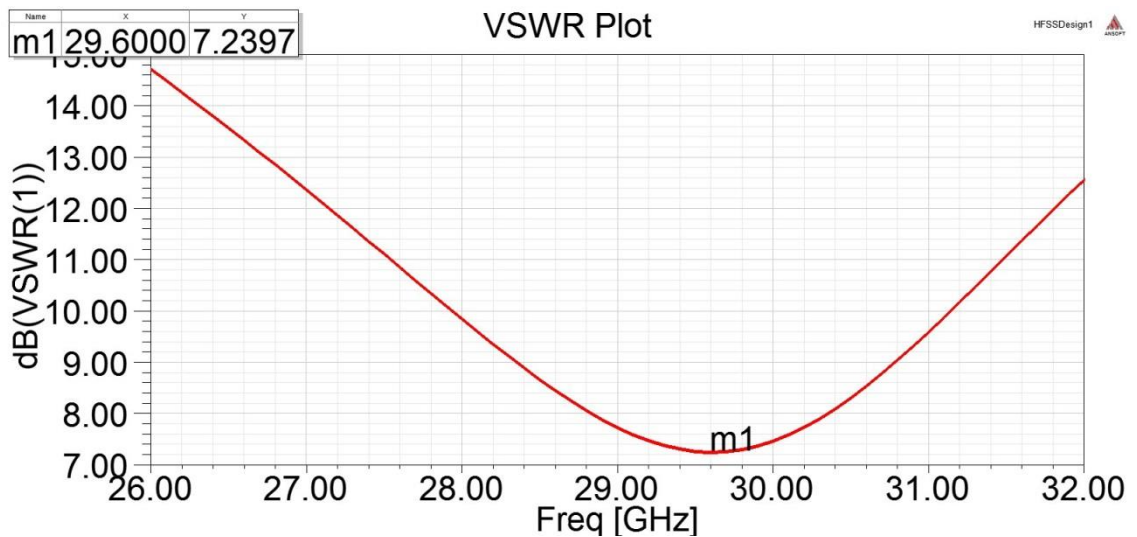


Figure 10 VSWR Graph

In Figure 10, the VSWR graph of the rectangular patch antenna is given. The y axis shows the VSWR value in dB and the x axis shows the frequency in GHz. The red line represents the variation of VSWR according to frequency. The VSWR is 7.24 dB which is the lowest value at 29.6 GHz as expected but this value is not good enough to say that the antenna has a good performance. In other words, this is an indication of the poor antenna performance. The VSWR value increases when the frequency increases and also decreases.

After the effect of feed line on the antenna performance is investigated, the effect of the notch width (g) is investigated. The gap between the antenna and microstrip feed line is increased from 0.025 mm to 0.08 mm. The obtained results are given in Fig. 11, 12 (a), (b) and 13 respectively.

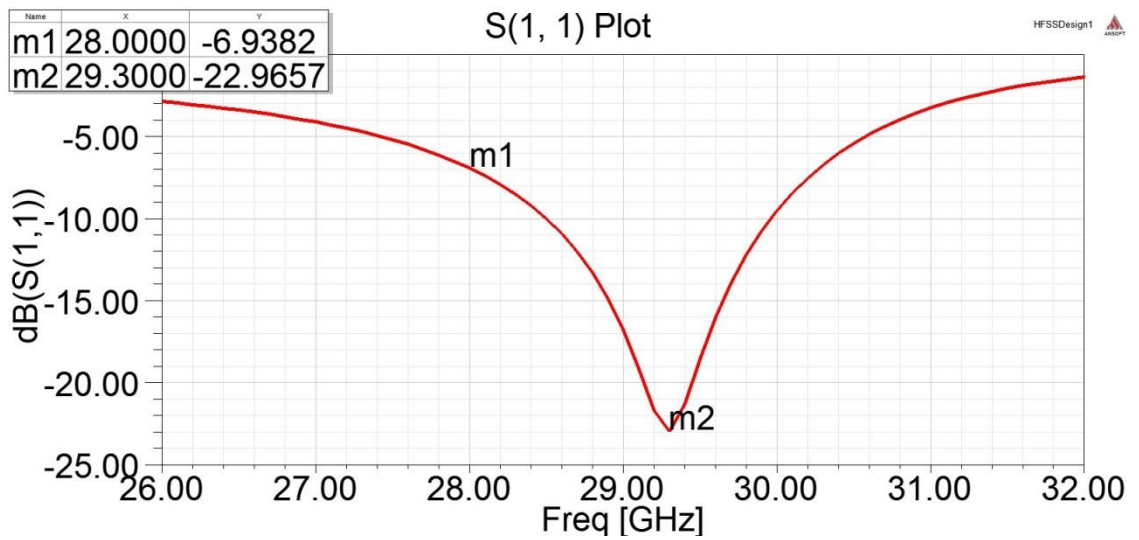
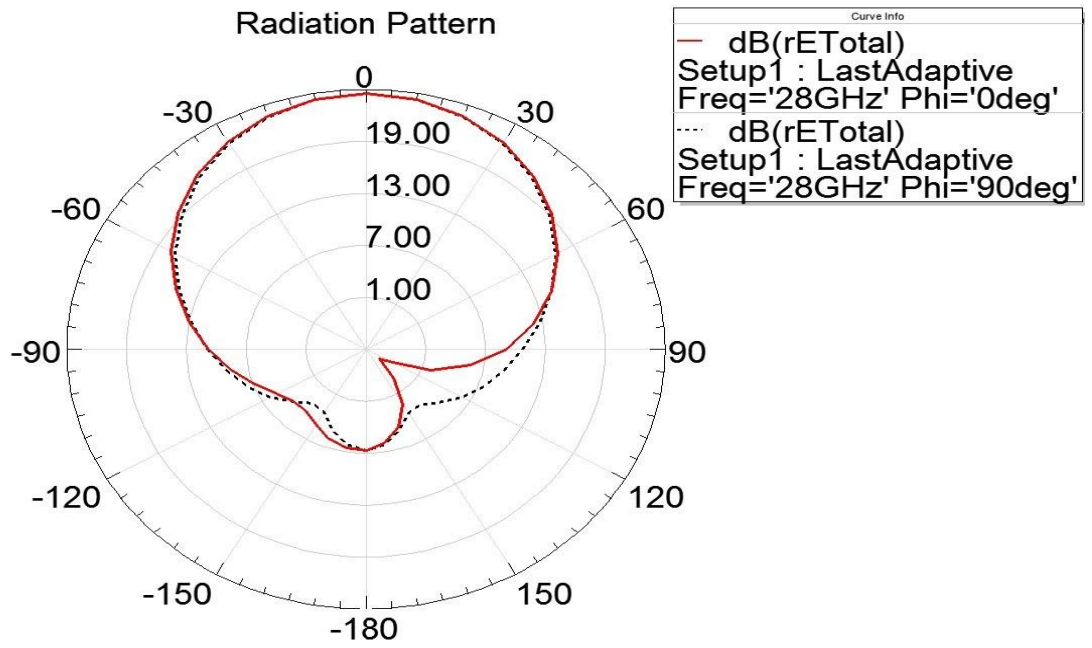
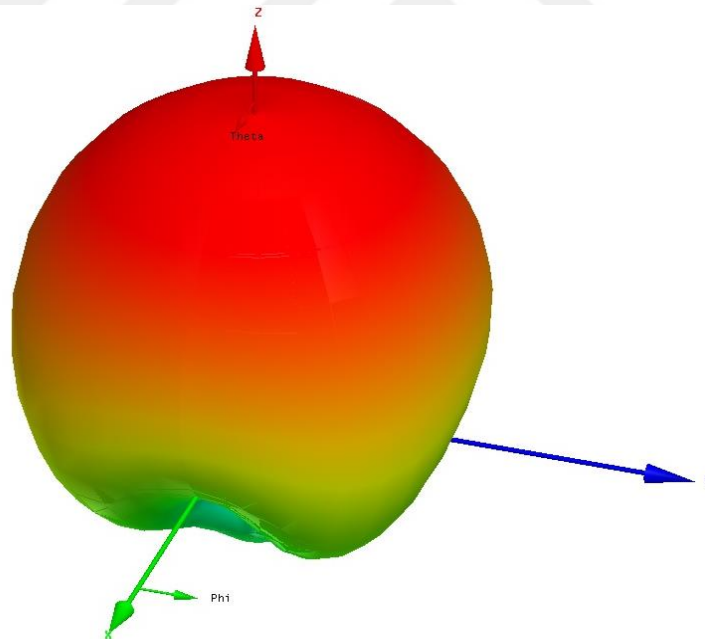


Figure 11 Return Loss Graph

In Figure 11, the return loss graph of the rectangular patch antenna is given. The y axis shows the return loss value in dB and the x axis shows the frequency in GHz. The red line represents the variation of the return loss according to frequency. The return loss is -22.97 dB which is the lowest value at 29.3 GHz. It increases when the frequency increases and also decreases. At 28 GHz that is the targeted resonance frequency, the return loss value is -6.94 dB. The antenna performance is good at 29.3 but it is poor at 28 GHz which is the targeted resonant frequency.



(a) Radiation Pattern at $\Phi = 0^\circ$ and 90°



(b) Radiation Pattern 3D Plot

Figure 12 Radiation Pattern Plots

In Figure 12 (a), the red line represents the radiation pattern at $\phi = 0^\circ$ at 28 GHz and the short dashed black line represents the radiation pattern at $\phi = 90^\circ$ at 28

GHz. These lines represent that the intensity of the radiated power goes into one direction which is 0° in this case.

In Figure 12 (b), the antenna lies on the x-y axis and the radiating patch is looking towards to z-axis. The center of the radiating patch of the antenna is located at the origin. As expected, there is power transmitted on z-axis which corresponds to the radiation directly overhead the antenna. On x plane and y plane, the radiation is minimum.

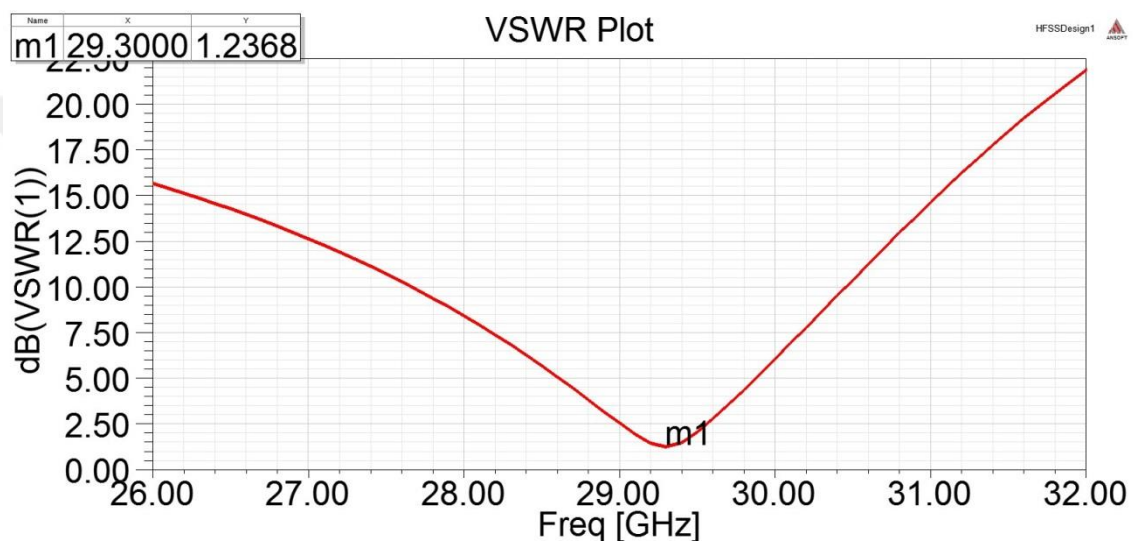


Figure 13 VSWR Graph

In Figure 13, the VSWR graph of the rectangular patch antenna is given. The y axis shows the VSWR value in dB and the x axis shows the frequency in GHz. The red line represents the variation of VSWR according to frequency. The VSWR is 1.24 dB which is the lowest value at 29.3 GHz as expected. The antenna performance is quite good at this frequency so the VSWR value is low. The VSWR value increases when the frequency increases and also decreases.

After that, to understand the effect of the notch width (g) better, the gap between the antenna and microstrip feed line is increased from 0.08 mm to 0.1 mm. The obtained results are given in Fig. 14, 15 (a), (b) and 16 respectively.

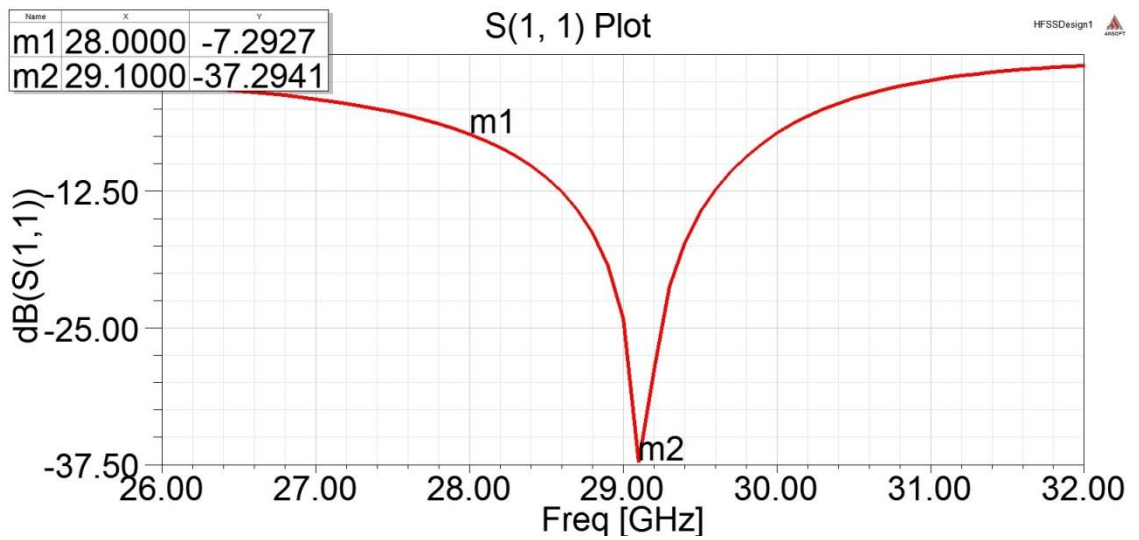
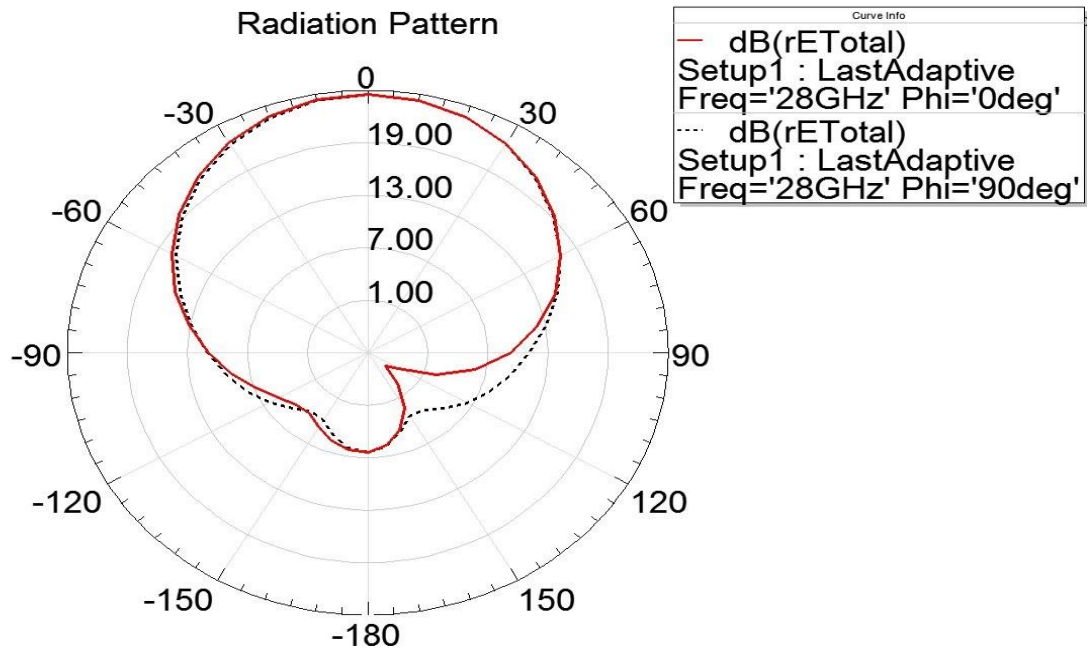
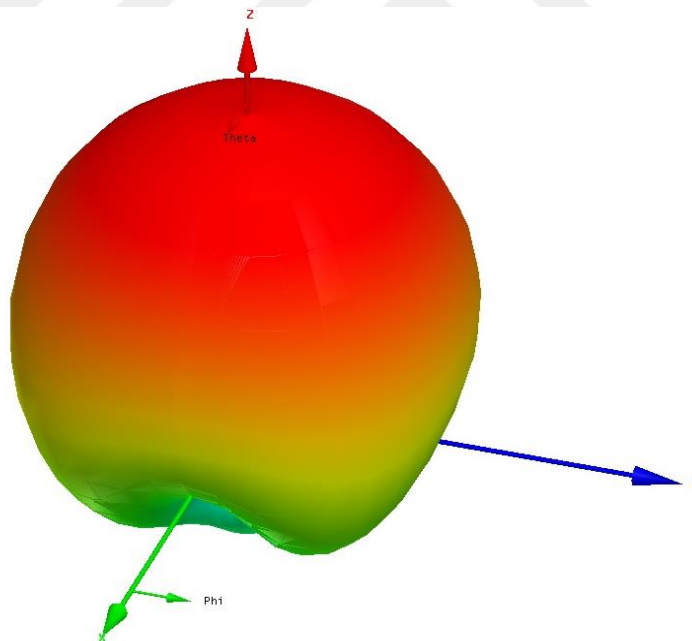


Figure 14 Return Loss Graph

In Figure 14, the return loss graph of the rectangular patch antenna is given. The y axis shows the return loss value in dB and the x axis shows the frequency in GHz. The red line represents the variation of the return loss according to frequency. The return loss is -37.29 dB which is the lowest value at 29.1 GHz. It increases when the frequency increases and also decreases. At 28 GHz that is the targeted resonance frequency, the return loss value is -7.29 dB. The antenna performance is quite good at 29.3 but it is still poor at 28 GHz which is the targeted resonant frequency.



(a) Radiation Pattern at $\Phi = 0^\circ$ and 90°



(b) Radiation Pattern 3D Plot

Figure 15 Radiation Pattern Plots

In Figure 15 (a), the red line represents the radiation pattern at $\phi = 0^\circ$ at 28 GHz and the short dashed black line represents the radiation pattern at $\phi = 90^\circ$ at 28

GHz. These lines represent that the intensity of the radiated power goes into one direction which is 0° in this case.

In Figure 15 (b), the antenna lies on the x-y axis and the radiating patch is looking towards to z-axis. The center of the radiating patch of the antenna is located at the origin. As expected, there is power transmitted on z-axis which corresponds to the radiation directly overhead the antenna. On x plane and y plane, the radiation is minimum.

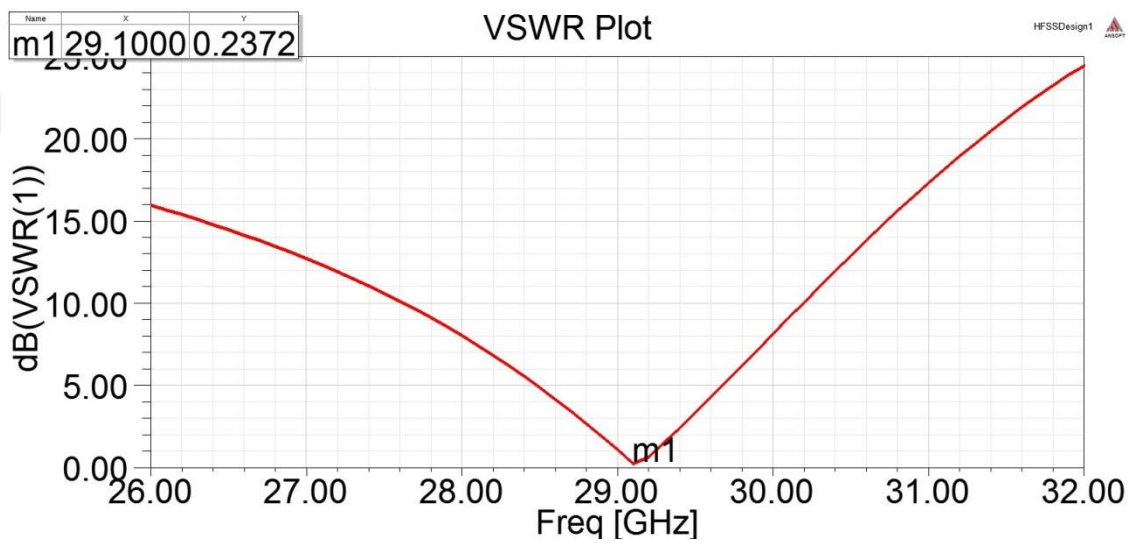


Figure 16 VSWR Graph

In Figure 16, the VSWR graph of the rectangular patch antenna is given. The y axis shows the VSWR value in dB and the x axis shows the frequency in GHz. The red line represents the variation of VSWR according to frequency. The VSWR is 0.23 dB which is a quite low value and at 29.3 GHz as expected. The antenna performance is quite good at this frequency so the VSWR value is low. The VSWR value increases when the frequency increases and also decreases.

Finally, to see the effect of a bigger gap between the antenna and microstrip feed line is increased from 0.1 mm to 0.2 mm. The obtained results are given in Fig. 17, 18 (a), (b) and 19 respectively.

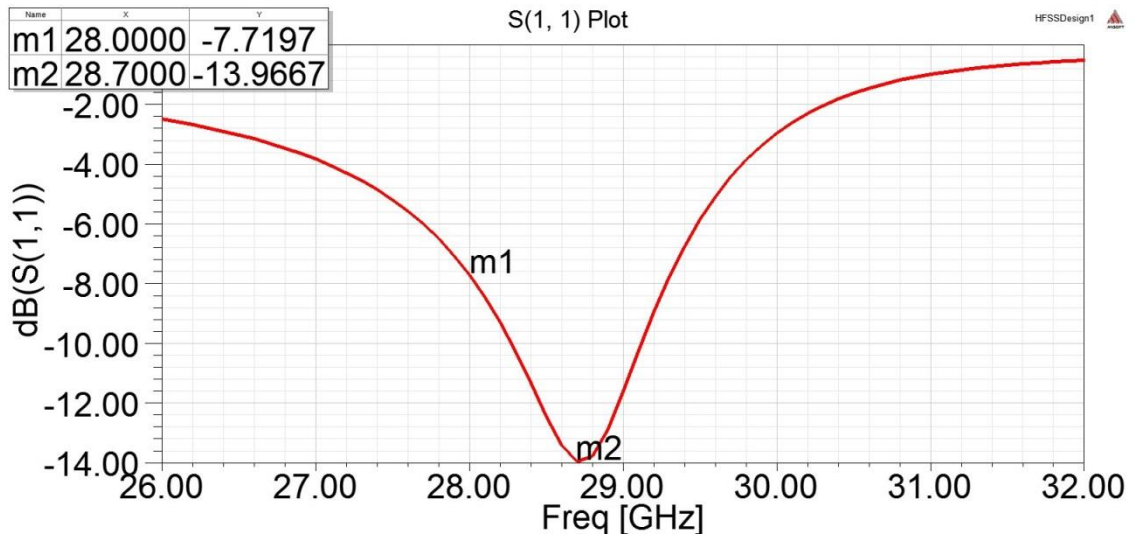
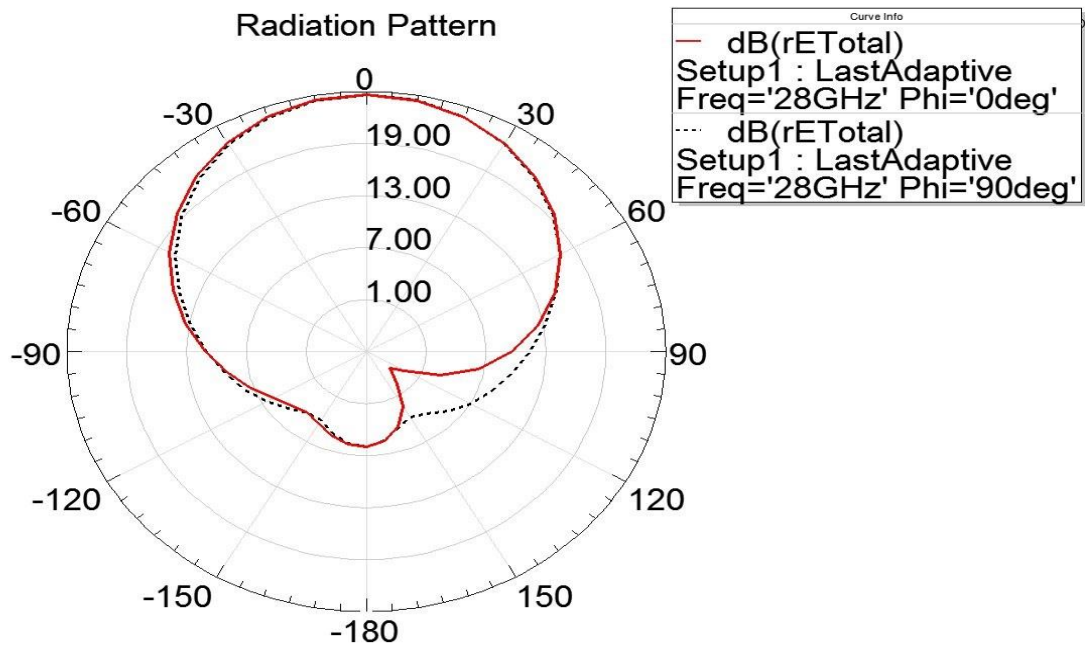
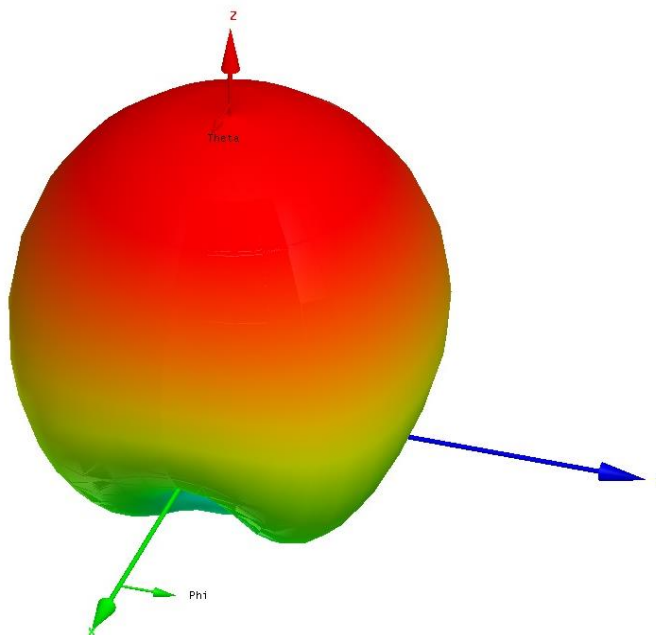


Figure 17 Return Loss Graph

In Figure 17, the return loss graph of the rectangular patch antenna is given. The y axis shows the return loss value in dB and the x axis shows the frequency in GHz. The red line represents the variation of the return loss according to frequency. The return loss is -13.97 dB which is the lowest value at 28.7 GHz. It increases when the frequency increases and also decreases. At 28 GHz that is the targeted resonance frequency, the return loss value is -7.72 dB. The antenna performance is acceptable at 28.7 GHz but it is still poor at 28 GHz which is the targeted resonant frequency.



(a) Radiation Pattern at $\Phi = 0^\circ$ and 90°



(b) Radiation Pattern 3D Plot

Figure 18 Radiation Pattern Plots

In Figure 18 (a), the red line represents the radiation pattern at $\phi = 0^\circ$ at 28 GHz and the short dashed black line represents the radiation pattern at $\phi = 90^\circ$ at 28

GHz. These lines represent that the intensity of the radiated power goes into one direction which is 0° in this case.

In Figure 18 (b), the antenna lies on the x-y axis and the radiating patch is looking towards to z-axis. The center of the radiating patch of the antenna is located at the origin. As expected, there is power transmitted on z-axis which corresponds to the radiation directly overhead the antenna. On x plane and y plane, the radiation is minimum.

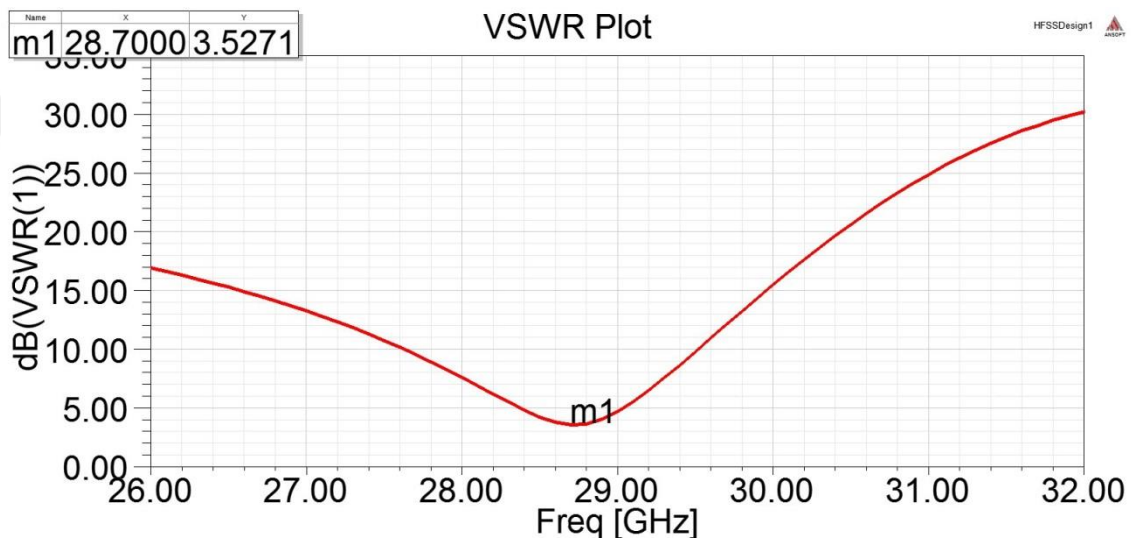


Figure 19 VSWR Graph

In Figure 19, the VSWR graph of the rectangular patch antenna is given. The y axis shows the VSWR value in dB and the x axis shows the frequency in GHz. The red line represents the variation of VSWR according to frequency. The VSWR is 3.52 dB which is a low value and at 28.7 GHz as expected. The VSWR value increases when the frequency increases and also decreases.

It is seen that, when the gap between the microstrip feed line and the antenna is too small or too big, the antenna performance decreases. The best results are obtained when this gap is set to 0.1 mm. Now, the effect of the microstrip feed line width will be investigated.

The feed line width of the antenna which is investigated till now has 1.565 mm width. To see the effect of the feed line width, the width of the feed line is decreased firstly. It is decreased to 1.45 mm. The graphs of the obtained results are given in Fig. 20, 21 (a), (b) and 22 respectively.

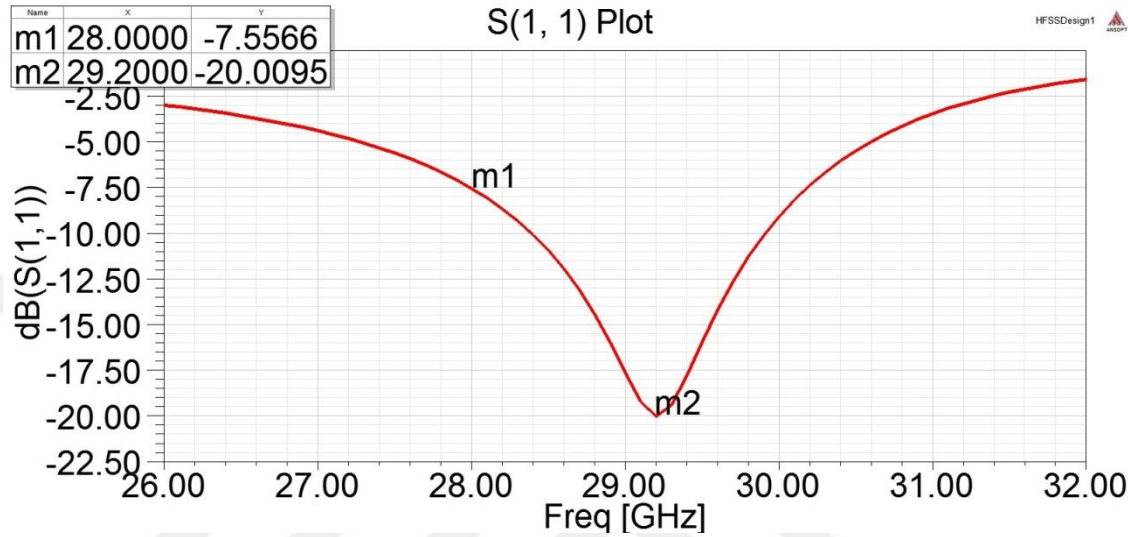
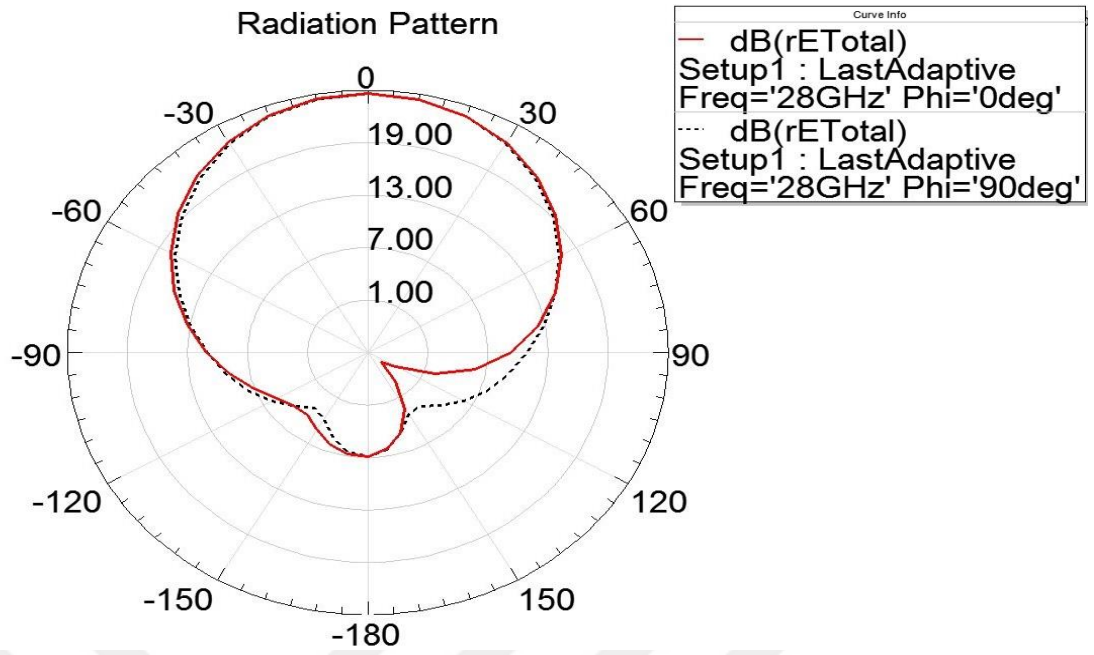
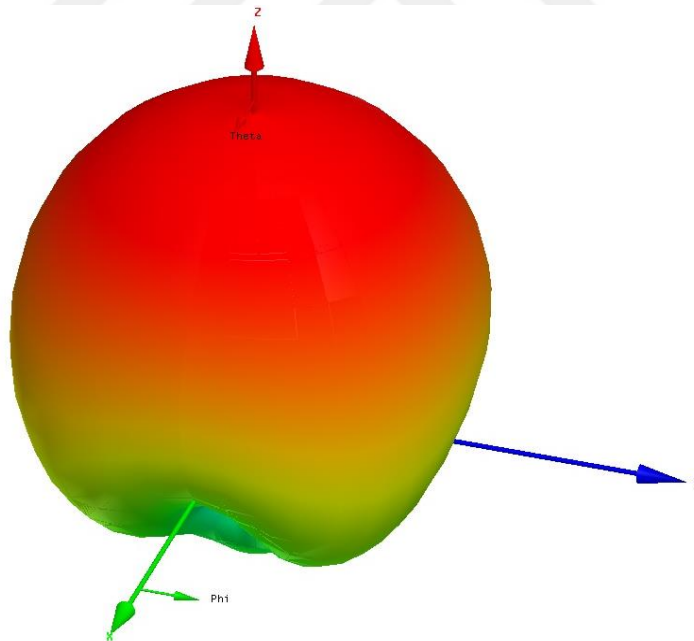


Figure 20 Return Loss Graph

In Figure 20, the return loss graph of the rectangular patch antenna is given. The y axis shows the return loss value in dB and the x axis shows the frequency in GHz. The red line represents the variation of the return loss according to frequency. The return loss is -20 dB which is the lowest value at 29.2 GHz. It increases when the frequency increases and also decreases. At 28 GHz that is the targeted resonance frequency, the return loss value is -7.55 dB. The antenna performance is good at 29.2 but it is still poor at 28 GHz which is the targeted resonant frequency.



(a) Radiation Pattern at $\Phi = 0^\circ$ and 90°



(b) Radiation Pattern 3D Plot

Figure 21 Radiation Pattern Plots

In Figure 21 (a), the red line represents the radiation pattern at $\phi = 0^\circ$ at 28 GHz and the short dashed black line represents the radiation pattern at $\phi = 90^\circ$ at 28 GHz. These lines represent that the intensity of the radiated power goes into one direction which is 0° in this case.

In Figure 21 (b), the antenna lies on the x-y axis and the radiating patch is looking towards to z-axis. The center of the radiating patch of the antenna is located at the origin. As expected, there is power transmitted on z-axis which corresponds to the radiation directly overhead the antenna. On x plane and y plane, the radiation is minimum.

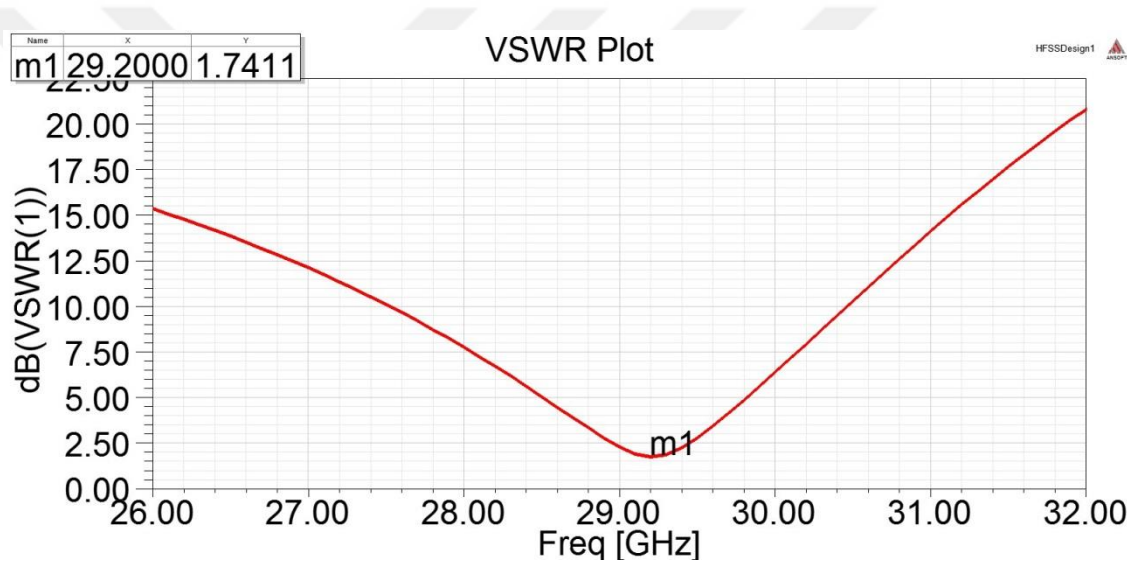


Figure 22 VSWR Graph

In Figure 22, the VSWR graph of the rectangular patch antenna is given. The y axis shows the VSWR value in dB and the x axis shows the frequency in GHz. The red line represents the variation of VSWR according to frequency. The VSWR is 1.74 dB which is a quite low value and at 29.2 GHz as expected. The antenna performance is good at this frequency so the VSWR value is low. The VSWR value increases when the frequency increases and also decreases.

A trial and error method is used to find the best result at 28 GHz. The dimensions those are found to obtain optimum performance are given in Table 2. All of the

values are given in millimeter. The results obtained from the simulation of the antenna are given in Fig. 23, 24 (a), (b) and 25 respectively.

Table 2 Dimensions of Proposed Rectangular Patch Antenna

Patch Width (W)	4
Patch Length (L)	3.4
Substrate Width	9.356
Substrate Length	9.47
Inset Feed Point Distance (y_0)	1.14
Notch Width (g)	0.07
Feed Line Width	1

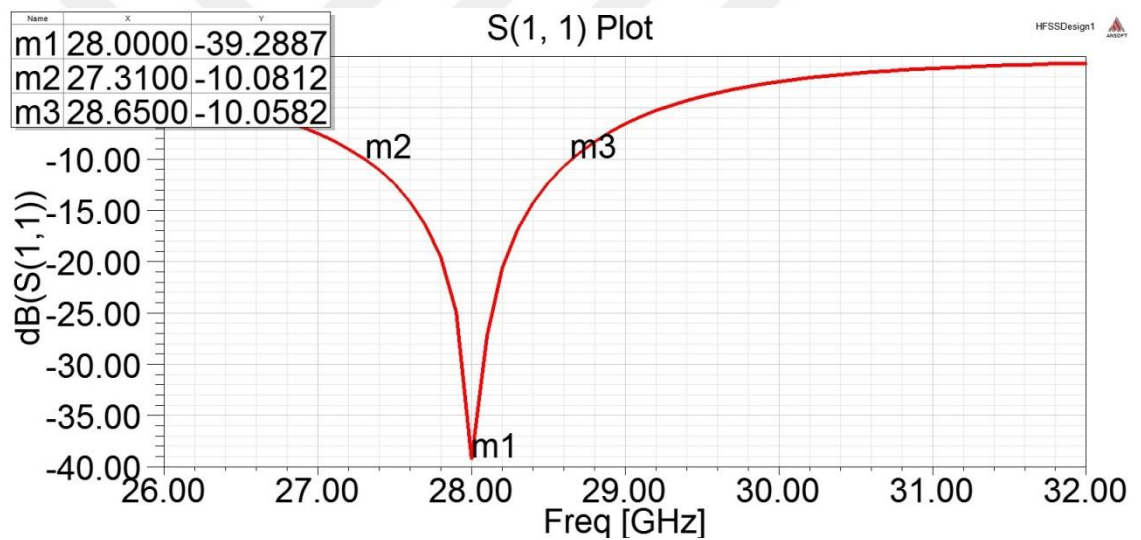
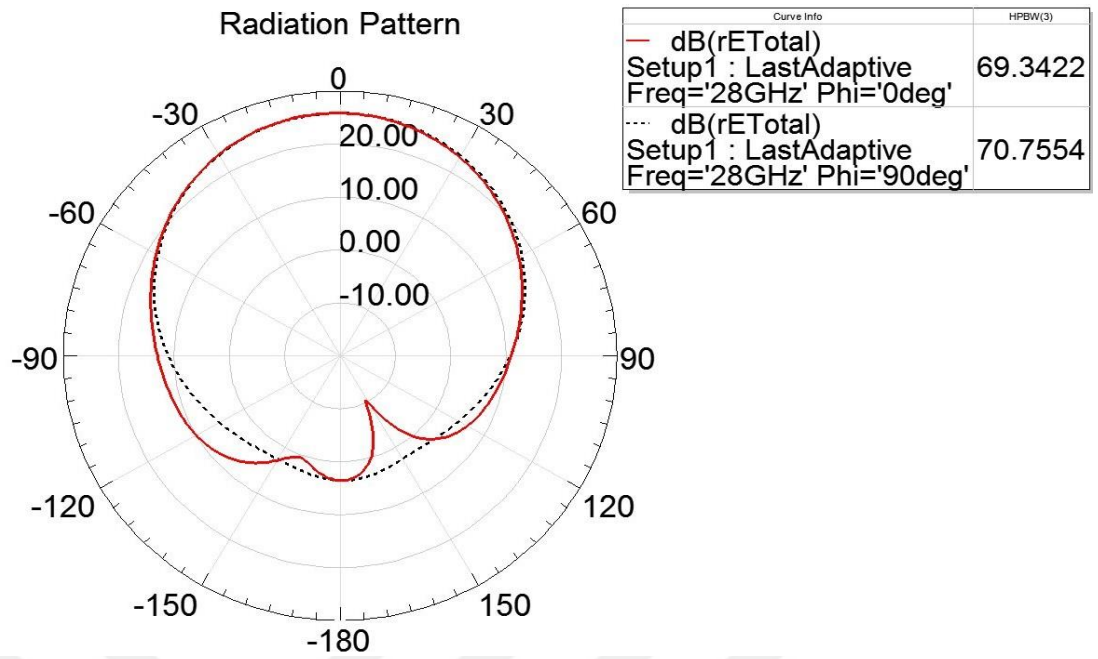
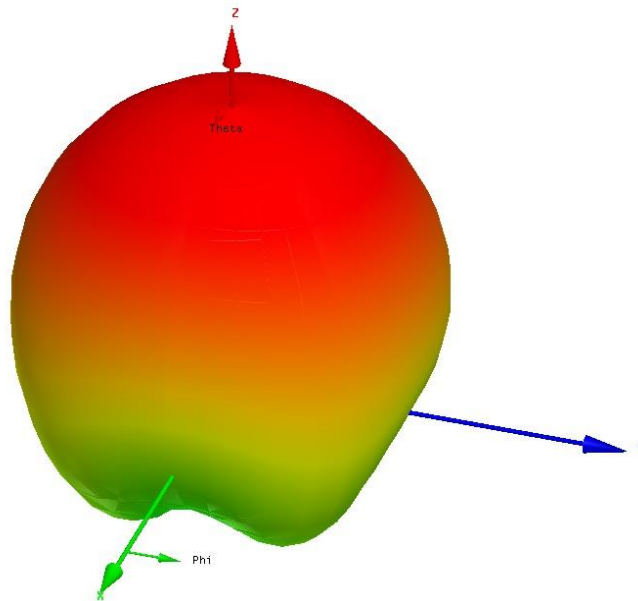


Figure 23 Return Loss Graph

In Figure 23, the return loss graph of the rectangular patch antenna is given. The y axis shows the return loss value in dB and the x axis shows the frequency in GHz. The red line represents the variation of the return loss according to frequency. The return loss is -39.29 dB which is the lowest value at 28 GHz that is the targeted resonance frequency. It increases when the frequency increases and also decreases. The antenna performance is quite good at 28 GHz. The antenna covers the band from 27.3 GHz to 28.65 GHz with overall bandwidth of 1.35 GHz.



(a) Radiation Pattern at $\Phi = 0^\circ$ and 90°



(b) Radiation Pattern 3D Plot

Figure 24 Radiation Pattern Plots

In Figure 24 (a), the red line represents the radiation pattern at $\phi = 0^\circ$ at 28 GHz and the blue line represents the radiation pattern at $\phi = 90^\circ$ at 28 GHz. These lines

represent that the intensity of the radiated power goes into one direction which is 0° in this case. Also, the half power beamwidth (HPBW) value is given in the legend table of the graph. The HPBW value is 69.3422 when ϕ is equal to 0° and 70.7554 when ϕ is equal to 90° .

In Figure 24 (b), the antenna lies on the x-y axis and the radiating patch is looking towards to z-axis. The center of the radiating patch of the antenna is located at the origin. As expected, there is power transmitted on z-axis which corresponds to the radiation directly overhead the antenna. On x plane and y plane, the radiation is minimum.

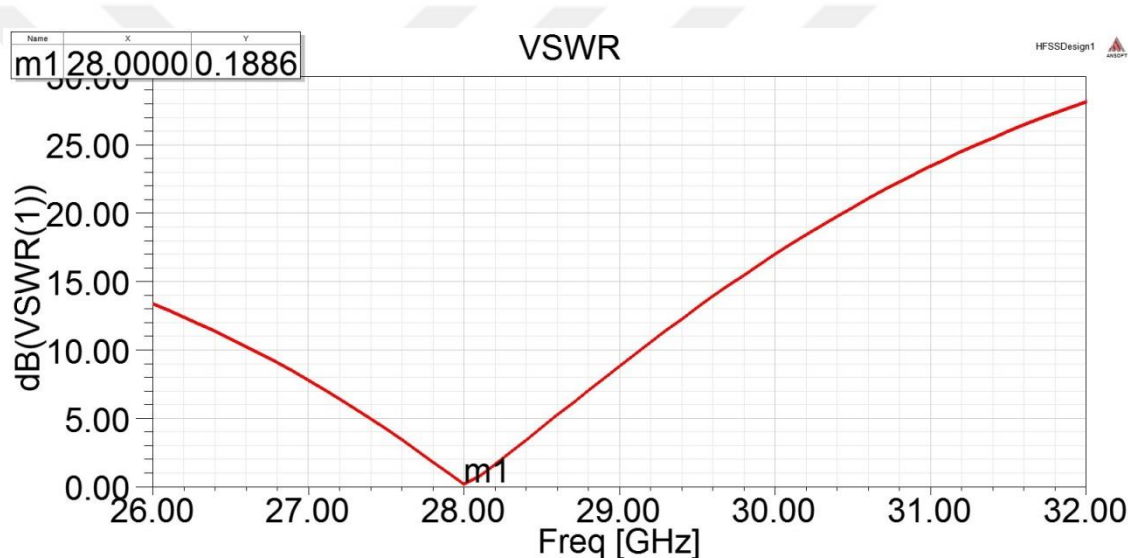


Figure 25 VSWR Graph

In Figure 25, the VSWR graph of the rectangular patch antenna is given. The y axis shows the VSWR value in dB and the x axis shows the frequency in GHz. The red line represents the variation of VSWR according to frequency. The VSWR is 0.18 dB which is a quite low value and at 29.2 GHz as expected. The antenna performance is quite good at this frequency so the VSWR value is low. The VSWR value increases when the frequency increases and also decreases.

2.1.2 Circular Patch Antenna

The proposed circular patch antenna is shown in Fig. 26. In the design of this antenna, Roger RT/duroid 5880 is used. The resonant frequency of the antenna is 28 GHz. The dimensions of the antenna are calculated based on the following equations given in both [1] and [14]. To find the patch width the Eq. 14 is used.

$$a = \frac{F}{\left\{1 + \frac{2h}{\pi\epsilon_r F} \left[\ln\left(\frac{\pi F}{2h}\right) + 1.7726 \right] \right\}^{1/2}} \quad (14)$$

where a is the diameter of the circular patch antenna, h is the substrate thickness and ϵ_r is the dielectric constant of the substrate. The F given in Eqn. 14 is calculated by below formula.

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\epsilon_r}} \quad (15)$$

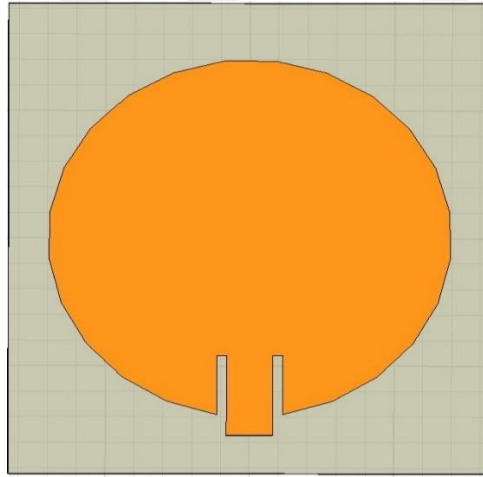


Figure 26 Proposed Circular Patch Antenna

Firstly, the dimension of the circular patch antenna is calculated by using Eqns. 14 and 15. At the beginning the antenna is designed without the feed line point inset distance. To calculate the microstrip feed line length and width Eqns. 11 and 12 are used. The dimension of the ground plane is calculated by Eqn 13(a) and 13(b). The

length of the substrate is increased to 6.84 mm due to the length of the microstrip feed line. The obtained results are given in Table 3. All values are in millimeter.

Table 3 Dimensions of Designed Circular Patch Antenna

Patch Radius (a)	1.89058 mm
Substrate Width	4.93858 mm
Substrate Length	4.93858 mm
Feed Line Width	1.56524 mm
Feed Line Length	1.90158 mm

A graphical user interface (GUI) is designed in MATLAB to make the design procedure easier and calculate the dimensions of the antenna. This GUI will be explained in detail later. After the antenna is simulated in HFSS with the calculated dimensions given in Table 3, obtained results are given in Fig. 27, 28 (a), (b) and 29 respectively.

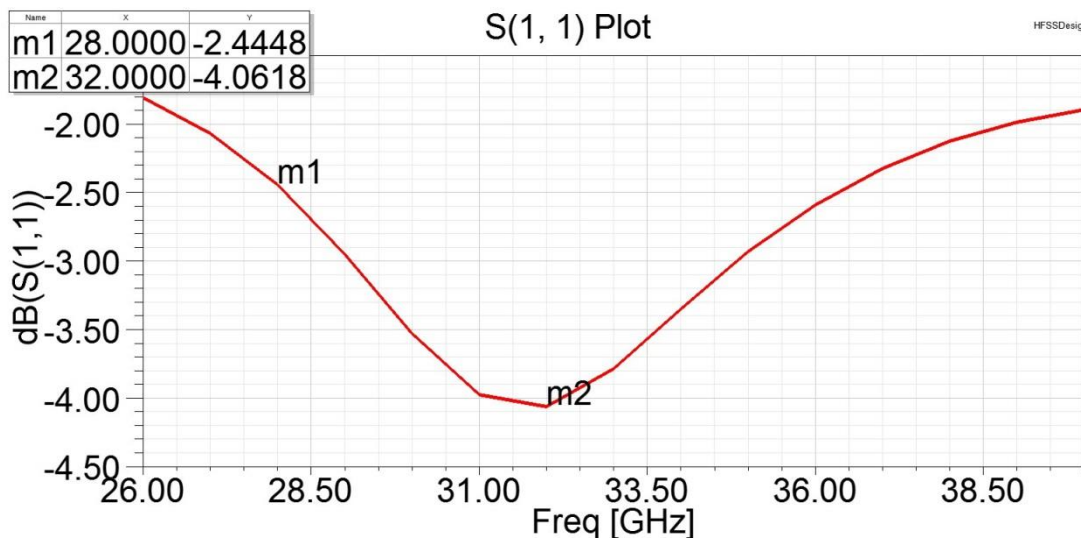
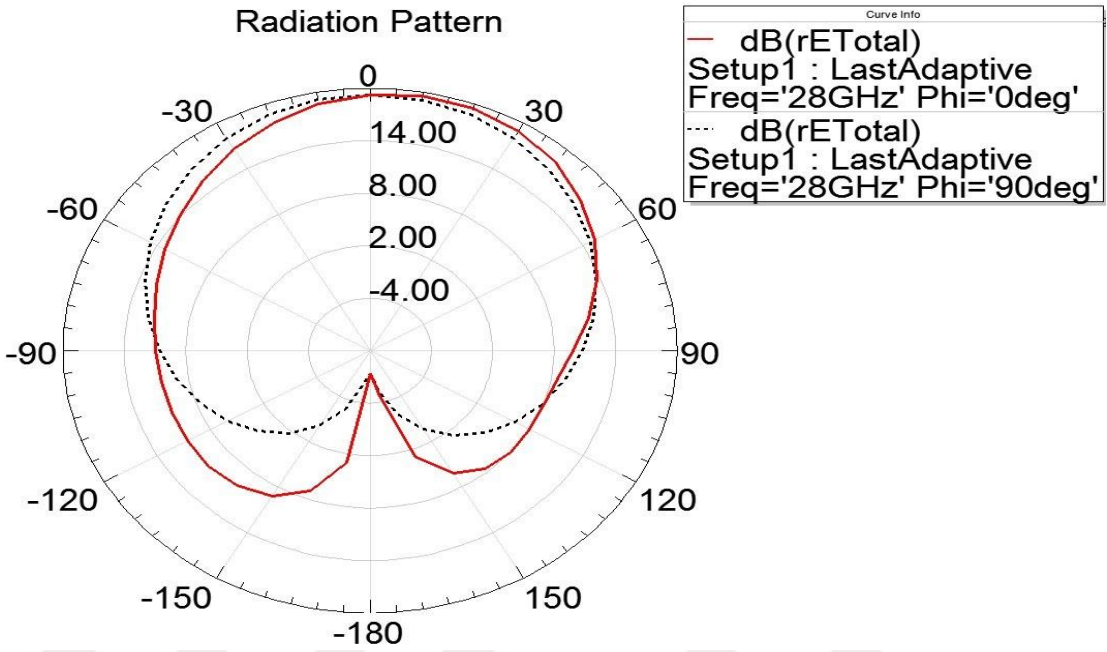


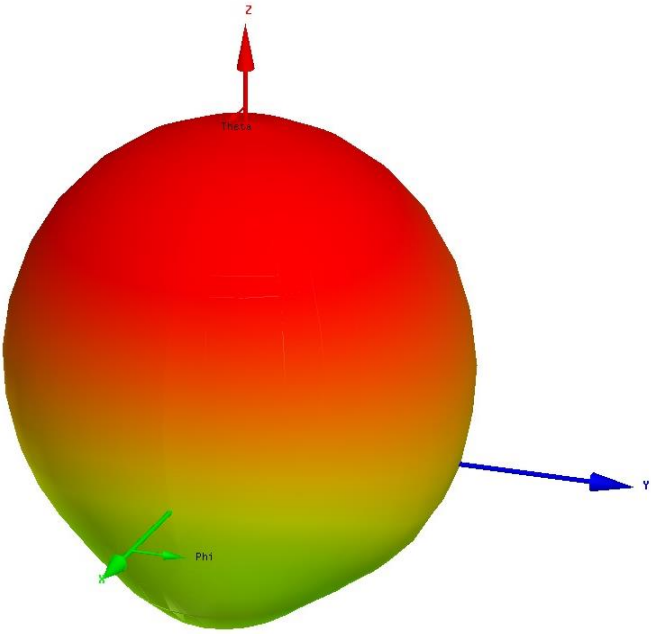
Figure 27 Return Loss Graph

In Figure 27, the return loss graph of the rectangular patch antenna is given. The y axis shows the return loss value in dB and the x axis shows the frequency in GHz. The red line represents the variation of the return loss according to frequency. The

return loss is -4.06 dB which is the lowest value at 32 GHz. It increases when the frequency increases and also decreases. At 28 GHz that is the targeted resonance frequency, the return loss value is -2.44 dB. This is an indication of the poor antenna performance.



(a) Radiation Pattern at Phi = 0° and 90°



(b) Radiation Pattern 3D Plot

Figure 28 Radiation Pattern Plots

In Figure 28 (a), the red line represents the radiation pattern at $\phi = 0^\circ$ at 28 GHz and the short dashed black line represents the radiation pattern at $\phi = 90^\circ$ at 28 GHz. These lines represent that the intensity of the radiated power goes into one direction which is 0° in this case.

In Figure 28 (b), the antenna lies on the x-y axis and the radiating patch is looking towards to z-axis. The center of the radiating patch of the antenna is located at the origin. As expected, there is power transmitted on z-axis which corresponds to the radiation directly overhead the antenna. On x plane and y plane, the radiation is minimum.

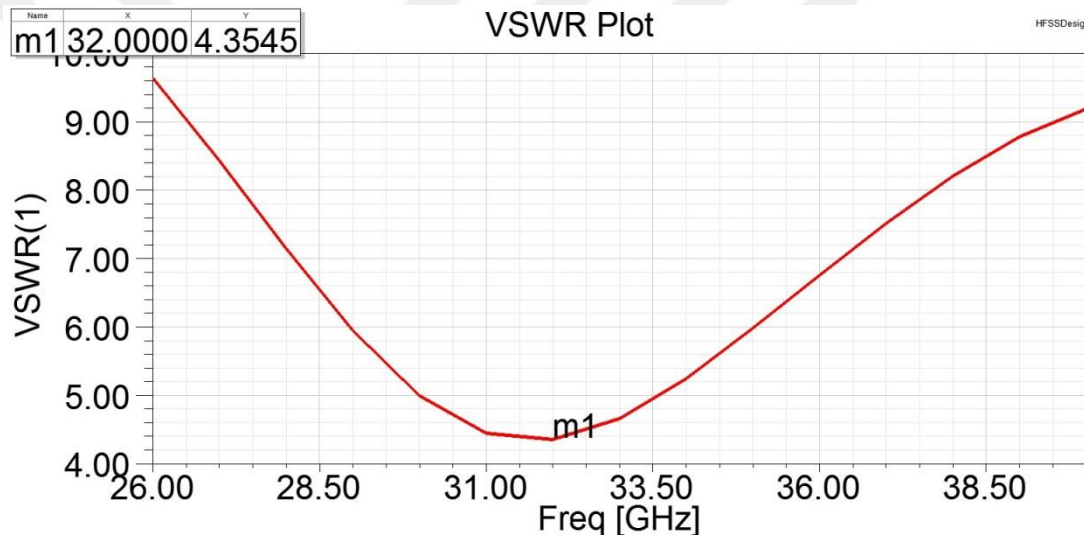


Figure 29 VSWR Graph

In Figure 29, the VSWR graph of the rectangular patch antenna is given. The y axis shows the VSWR value in dB and the x axis shows the frequency in GHz. The red line represents the variation of VSWR according to frequency. The VSWR is 4.35 dB which is the lowest value at 32 GHz as expected but this value is not good enough to say that the antenna has a good performance. In other words, this is an indication of the poor antenna performance. The VSWR value increases when the frequency increases and also decreases.

Both the substrate (ground plane) dimension and the microstrip feed line width values are changed on the design to see the effects of these values on the antenna

performance and the new result are obtained. Firstly, the length of the substrate is decreased to 6.5 mm. The obtained results are given in Fig. 30, 31 (a), (b) and 32 respectively.

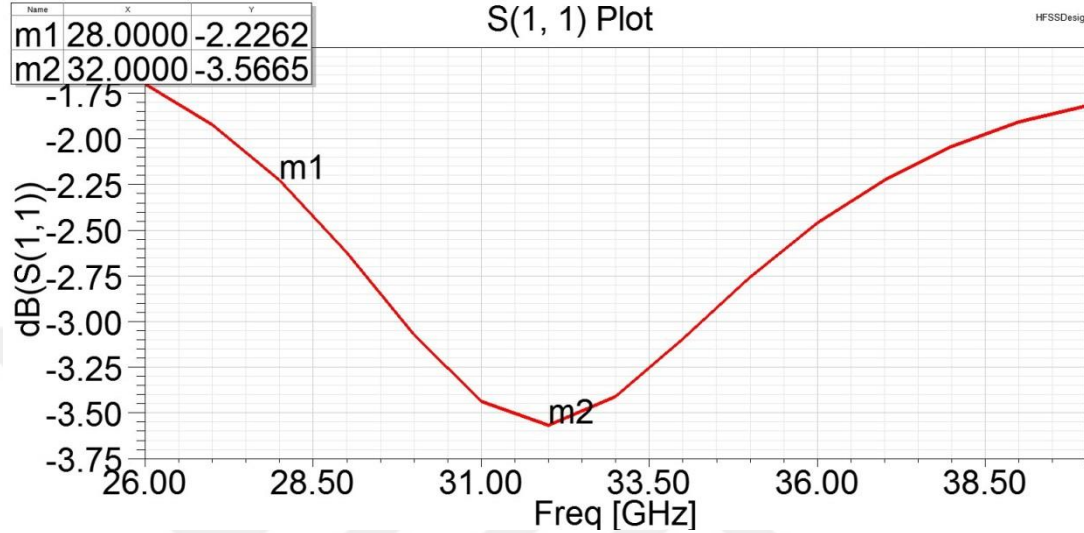
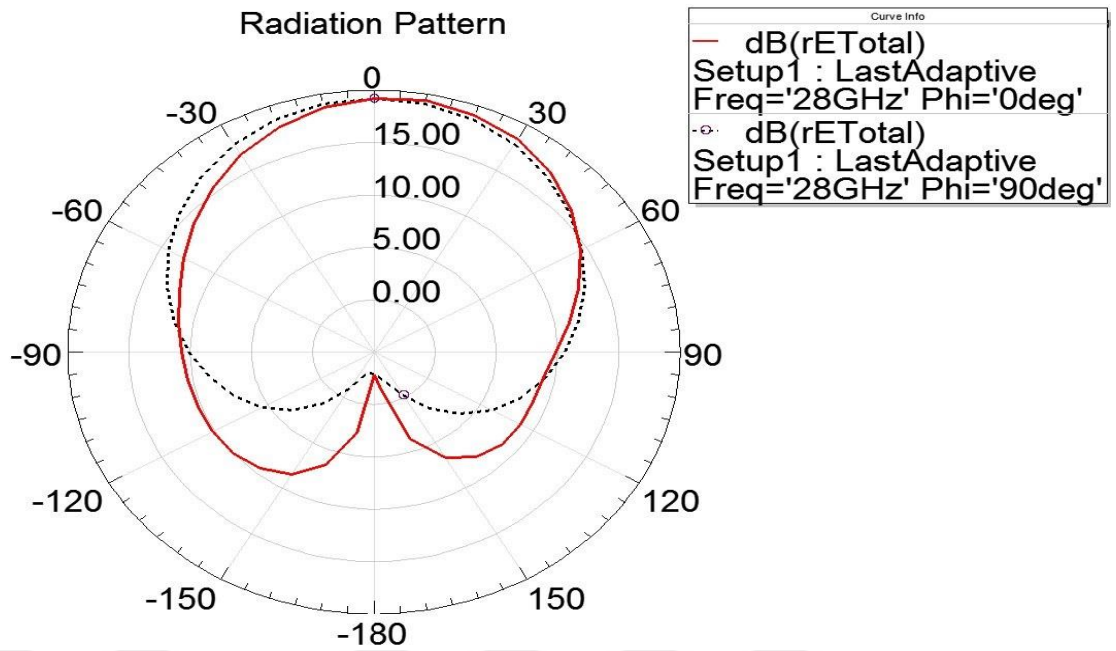
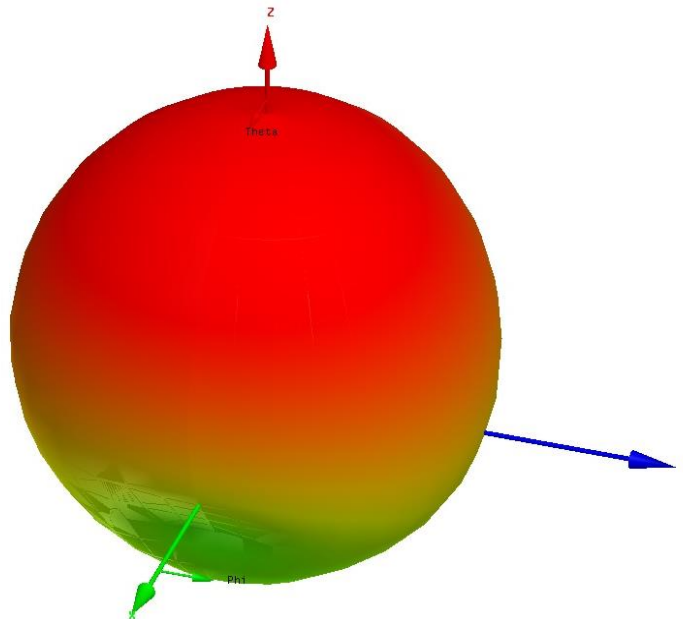


Figure 30 Return Loss Graph

In Figure 30, the return loss graph of the rectangular patch antenna is given. The y axis shows the return loss value in dB and the x axis shows the frequency in GHz. The red line represents the variation of the return loss according to frequency. The return loss is -3.56 dB which is the lowest value at 32 GHz. It increases when the frequency increases and also decreases. At 28 GHz that is the targeted resonance frequency, the return loss value is -2.22 dB. This is an indication of the poor antenna performance.



(a) Radiation Pattern at $\Phi = 0^\circ$ and 90°



(b) Radiation Pattern 3D Plot

Figure 31 Radiation Pattern Plots

In Figure 31 (a), the red line represents the radiation pattern at $\phi = 0^\circ$ at 28 GHz and the short dashed black line represents the radiation pattern at $\phi = 90^\circ$ at 28

GHz. These lines represent that the intensity of the radiated power goes into one direction which is 0° in this case.

In Figure 31 (b), the antenna lies on the x-y axis and the radiating patch is looking towards to z-axis. The center of the radiating patch of the antenna is located at the origin. As expected, there is power transmitted on z-axis which corresponds to the radiation directly overhead the antenna. On x plane and y plane, the radiation is minimum.

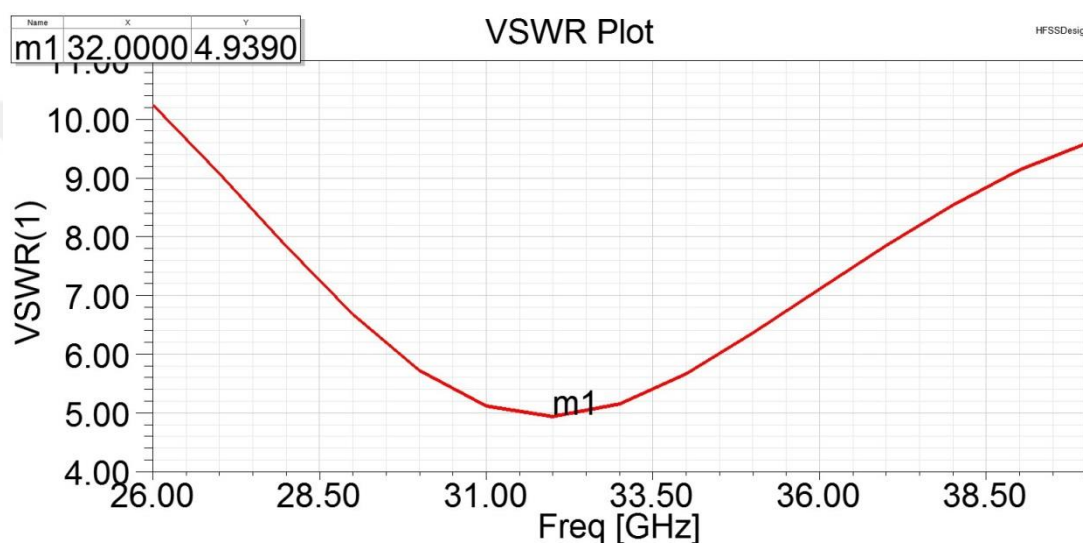


Figure 32 VSWR Graph

In Figure 32, the VSWR graph of the rectangular patch antenna is given. The y axis shows the VSWR value in dB and the x axis shows the frequency in GHz. The red line represents the variation of VSWR according to frequency. The VSWR is 4.93 dB which is the lowest value at 32 GHz as expected but this value is not good enough to say that the antenna has a good performance. In other words, this is an indication of the poor antenna performance. The VSWR value increases when the frequency increases and also decreases.

After that, the microstrip feed line width is decreased to 1.3 mm firstly and then 1.1 mm respectively. The return loss and VSWR graphs for both feed line are given in Fig 33, 34, 35, 36 respectively.

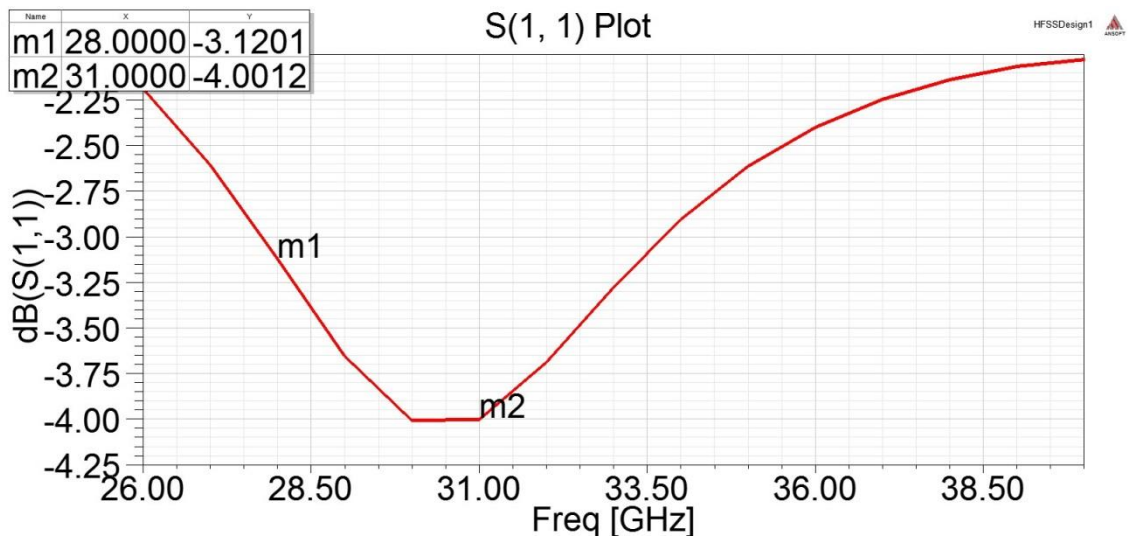


Figure 33 Return Loss Graph when feed line width is 1.3 mm

In Figure 33, the return loss graph of the rectangular patch antenna with 1.3 mm feed line width is given. The y axis shows the return loss value in dB and the x axis shows the frequency in GHz. The red line represents the variation of the return loss according to frequency. The return loss is -4 dB which is the lowest value at 31 GHz. It increases when the frequency increases and also decreases. At 28 GHz that is the targeted resonance frequency, the return loss value is -3.12 dB. This is an indication of the poor antenna performance.

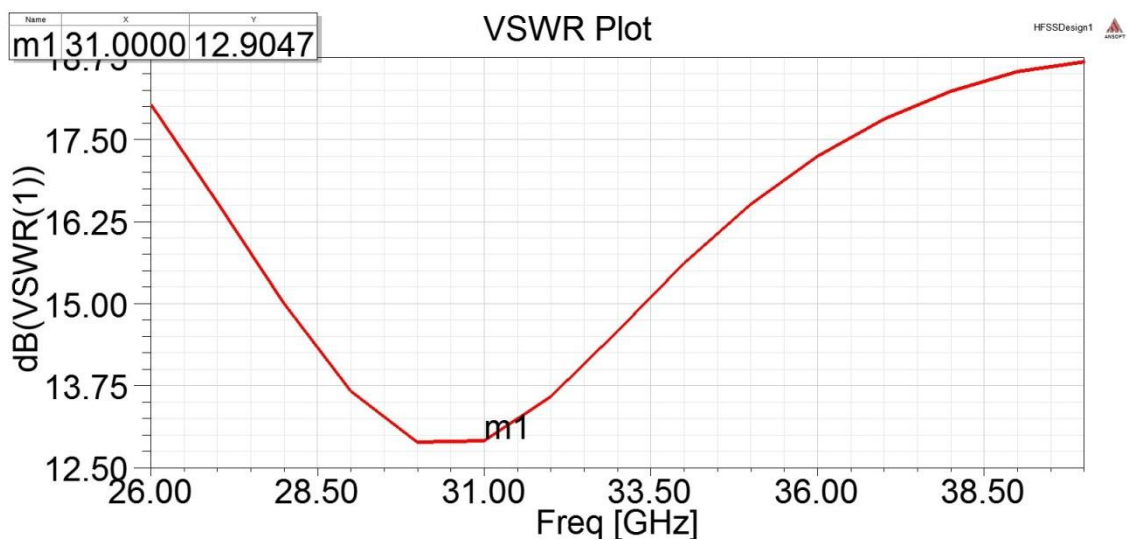


Figure 34 VSWR Graph when feed line width is 1.3 mm

In Figure 34, the VSWR graph of the rectangular patch antenna is given. The y axis shows the VSWR value in dB and the x axis shows the frequency in GHz. The red line represents the variation of VSWR according to frequency. The VSWR is 12.9 dB which is the lowest value at 31 GHz as expected but this value is not good enough to say that the antenna has a good performance. In other words, this is an indication of the poor antenna performance. The VSWR value increases when the frequency increases and also decreases.

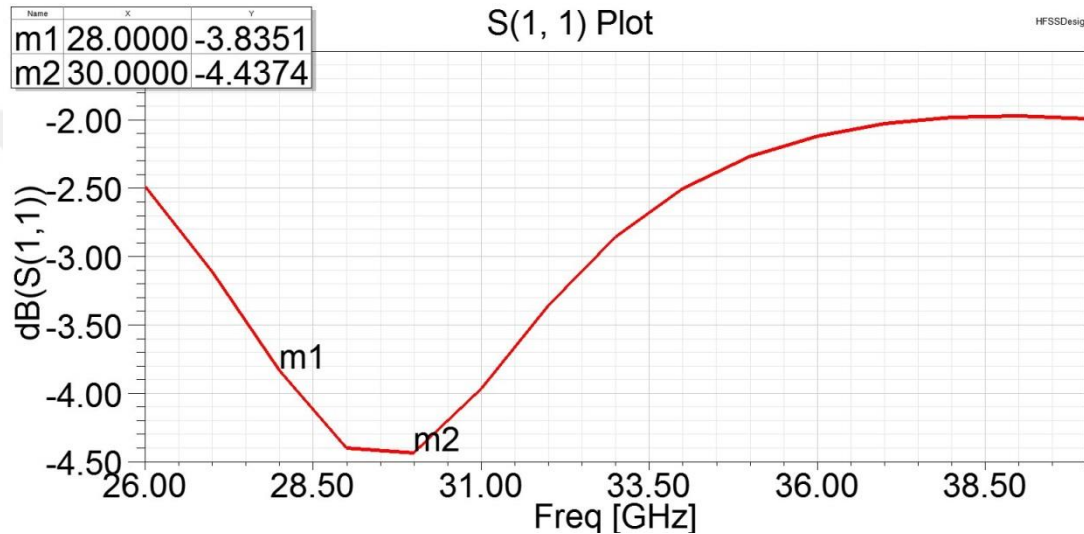


Figure 35 Return Loss Graph when feed line width is 1.1 mm

In Figure 35, the return loss graph of the rectangular patch antenna with 1.1 mm feed line width is given. The y axis shows the return loss value in dB and the x axis shows the frequency in GHz. The red line represents the variation of the return loss according to frequency. The return loss is -4.44 dB which is the lowest value at 30 GHz. It increases when the frequency increases and also decreases. At 28 GHz that is the targeted resonance frequency, the return loss value is -3.84 dB. This is an indication of the poor antenna performance.

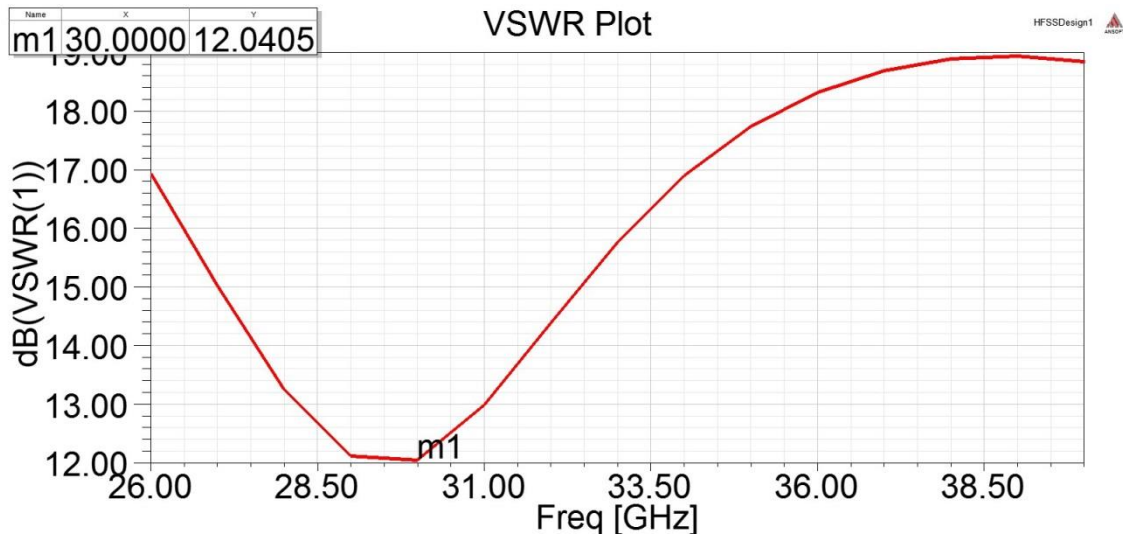


Figure 36 VSWR Graph when feed line width is 1.1 mm

In Figure 36, the VSWR graph of the rectangular patch antenna is given. The y axis shows the VSWR value in dB and the x axis shows the frequency in GHz. The red line represents the variation of VSWR according to frequency. The VSWR is 12 dB which is the lowest value at 30 GHz as expected but this value is not good enough to say that the antenna has a good performance. In other words, this is an indication of the poor antenna performance. The VSWR value increases when the frequency increases and also decreases.

A trial and error method is used to find the dimensions of the antenna for the optimum antenna performance at 28 GHz. The dimensions those are found to obtain optimum performance are given in Table 4 and the antenna is given in Fig. 26. The results obtained from the simulation of the antenna are given in Fig. 37, 38 (a), (b) and 39 respectively.

Table 4 Dimensions of the Circular Patch Antenna

Patch Radius (a)	3.5 mm
Substrate Width	8.356 mm
Substrate Length	9.216 mm
Inset Feed Point Distance (y_0)	1.2 mm
Notch Width (g)	0.34 mm
Feed Line Width	0.8 mm
Feed Line Length	2 mm

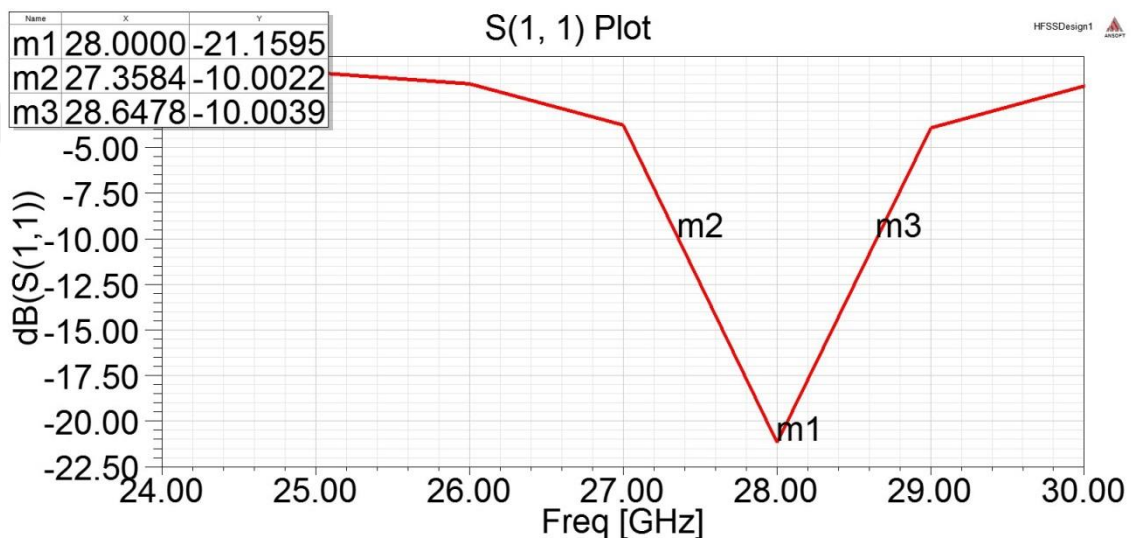
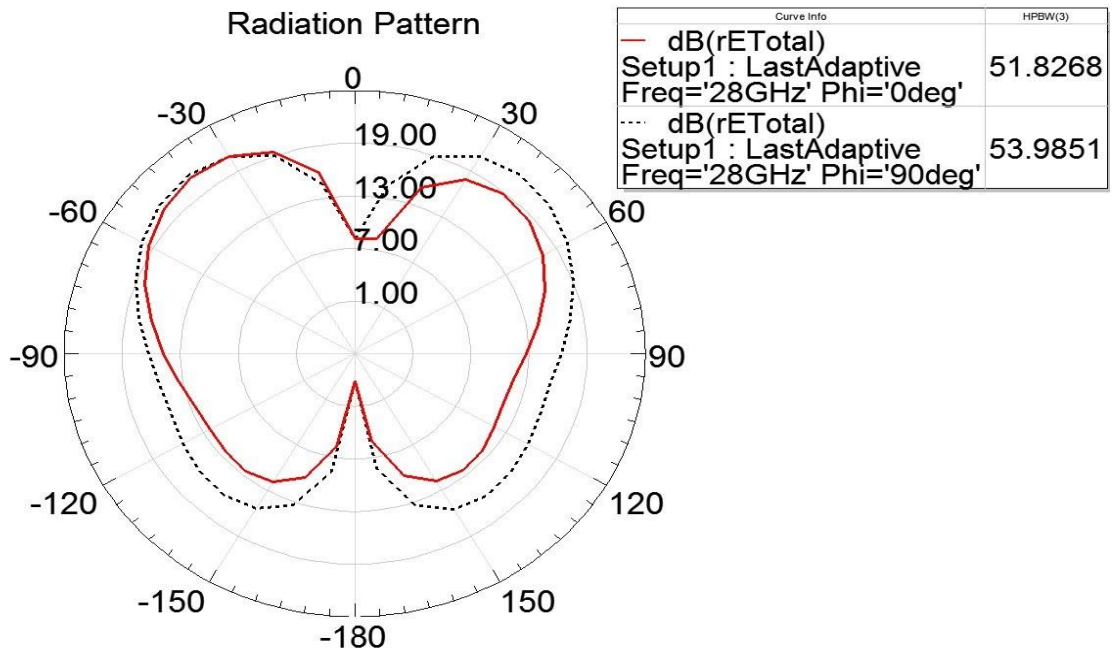
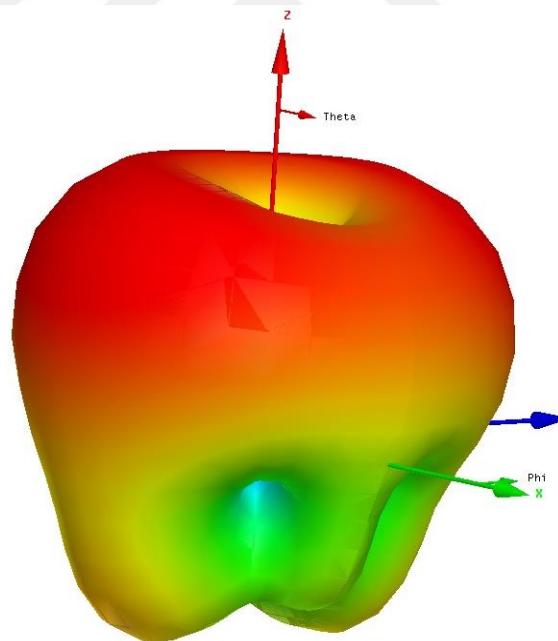


Figure 37 Return Loss Graph

In Figure 37, the return loss graph of the rectangular patch antenna is given. The y axis shows the return loss value in dB and the x axis shows the frequency in GHz. The red line represents the variation of the return loss according to frequency. The return loss is -21.16 dB which is the lowest value at 28 GHz that is the targeted resonance frequency. It increases when the frequency increases and also decreases. The antenna performance is quite good at 28 GHz. The antenna covers the band from 27.35 GHz to 28.65 GHz with overall bandwidth of 1.3 GHz.



(a) Radiation Pattern at $\Phi = 0^\circ$ and 90°



(b) Radiation Pattern 3D Plot

Figure 38 Radiation Pattern Plots

In Figure 38 (a), the red line represents the radiation pattern at $\phi = 0^\circ$ at 28 GHz and the short dashed black line represents the radiation pattern at $\phi = 90^\circ$ at 28 GHz. These lines represent that the intensity of the radiated power goes into one

direction which is 0° in this case. Also, the half power beamwidth (HPBW) value is given in the legend table of the graph. The HPBW value is 51.8268 when phi is equal to 0° and 53.9851 when phi is equal to 90° .

In Figure 38 (b), the antenna lies on the x-y axis and the radiating patch is looking towards to z-axis. The center of the radiating patch of the antenna is located at the origin. As expected, there is power transmitted on z-axis which corresponds to the radiation directly overhead the antenna. On x plane and y plane, the radiation is minimum.

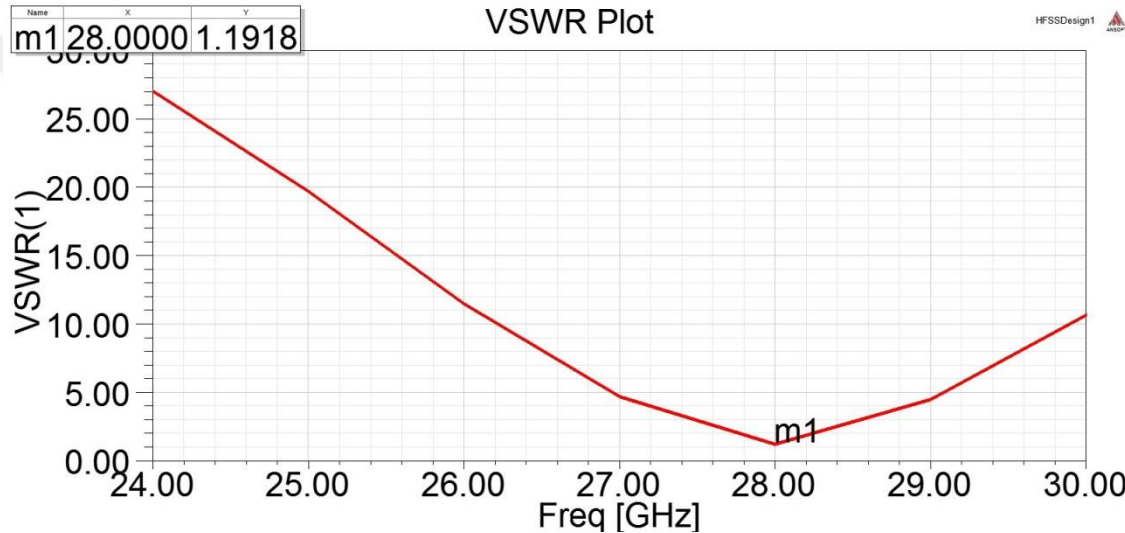


Figure 39 VSWR Graph

In Figure 39, the VSWR graph of the rectangular patch antenna is given. The y axis shows the VSWR value in dB and the x axis shows the frequency in GHz. The red line represents the variation of VSWR according to frequency. The VSWR is 1.19 dB which is a quite low value and at 28 GHz as expected. The antenna performance is quite good at this frequency so the VSWR value is low. The VSWR value increases when the frequency increases and also decreases.

2.1.3 Ç-Shaped Patch Antenna

The proposed Ç-shaped patch antenna which operates at 28 GHz is shown in Fig. 40. The difference of the antenna from conventional patch antennas is the shape of the radiating patches.

As can be seen from the Fig. 40, it consists of a Ç-shaped and a hexagonal radiating patches which are inner and outer ones respectively. To find the optimum performance of the antenna, substrate dimension, radiating patches dimension to investigate also the coupling effect, and dimension of the microstrip feed line is changed by a trial and error method. To find a dimensions for the proposed antenna as a start point, Eqns. 4 to 13 are used. The calculated results are given in Table 5. All values are in millimeter. To make the design procedure easier and calculate the dimensions of the antenna a graphical user interface (GUI) is designed in MATLAB. This GUI will be explained in detail later.

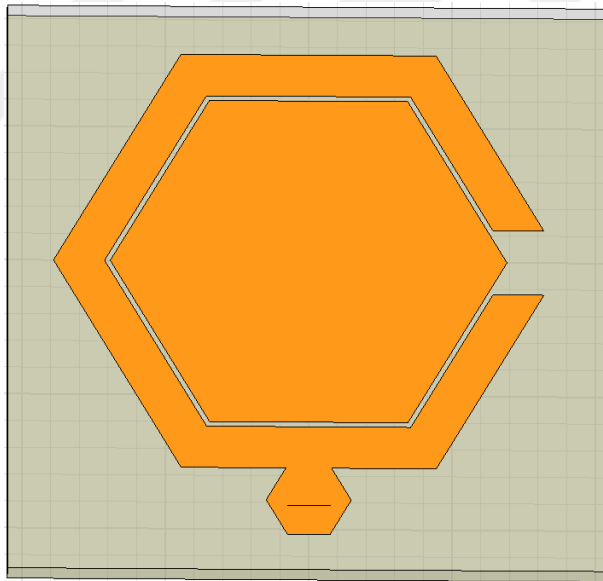


Figure 40 Proposed Ç-Shaped Antenna

Table 5 Calculated Dimensions

Patch Width (W)	4.24
Patch Length (L)	3.93
Substrate Width ($W_s = W_g$)	11.528
Substrate Length ($L_s = L_g$)	9.834

For the proposed antenna to find the best feeding position for the microstrip feed line method, a trial and error method is used. Due to the regular hexagon shape of the logo of Çankaya University, calculated length and width values are used one by one and looked for the best result.

Firstly, 4.24 mm and 11.528 mm are taken as the size of the radiating patch (outer patch) and the size of the ground plane respectively. The antenna is fed from the bottom of the tail of 'C' which is considered as the microstrip feed line of the antenna. In this case, the return loss value is obtained as -3.32 dB at 28 GHz.

Secondly, 3.93 mm and 9.83 mm are taken as the size of the radiating patch (outer patch) and the size of the ground plane respectively. The antenna is fed from the bottom of the tail of 'C' again. In this case, the return loss is -0.75 dB at 28 GHz.

Then to get a better return loss value, the dimension of the patch and the ground plane are changed. The best result is obtained when 4.5 mm, 9.5 mm and 9.7 mm are taken as the size of the patch, the ground width and the ground length respectively. In this situation, the return loss of the antenna is obtained as -16.33 dB. Some of the obtained results are presented in Table 6.

Table 6 Result of Feeding from Bottom of the Microstrip Feed Line

Patch Size (mm)	Ground Width (mm)	Ground Length (mm)	Return Loss (dB) at 28 GHz
4.5	9.5	9.8	-8.08
4.5	9.5	9.9	-11.97
4.55	9.5	9.9	-5.04
4.55	9.5	9.8	-5.8
4.45	9.5	9.8	-10.4

Now, the effect of the feeding point location will be investigated. Till now, the antenna is fed from the bottom of the microstrip feed line. When the feed point location moved to the center of the microstrip feed line, better results are obtained.

When 4.24 mm and 11.528 mm are taken as the patch dimension and the ground plane dimension respectively, the return loss is -4.67 dB at 28 GHz.

The return loss is observed as -4.67 dB for 4.24 mm patch size and 11.528 mm ground plane at 28 GHz. In addition, for 3.39 mm patch size and 9.83 mm ground plane, the return loss is found as -2.01 dB. After that, the antenna is fed from the points shown with green in Fig. 41 and 42.

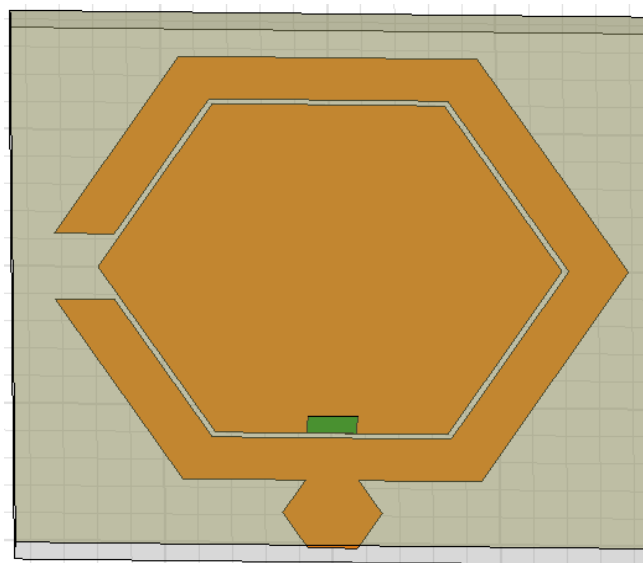


Figure 41 Feed from the Bottom of the Inner Hexagonal Patch

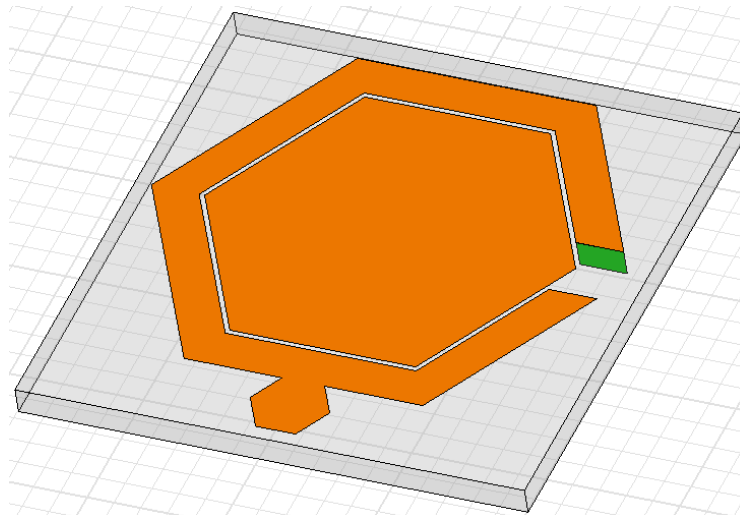


Figure 42 Feed from the Top End Point of Ç-Shaped Patch

After the simulation is done, the obtained return loss values are -3.14 dB and -3.05 dB at 28 GHz respectively. These return loss values are too high to get a good performance from the antenna.

The best results are obtained when the patch size, the ground plane width and length are 4.45 mm, 9.5 mm and 9.7 mm respectively. The return loss graph, radiation pattern and VSWR graph are given in Figs. 43, 44 (a), (b) and 45 respectively.

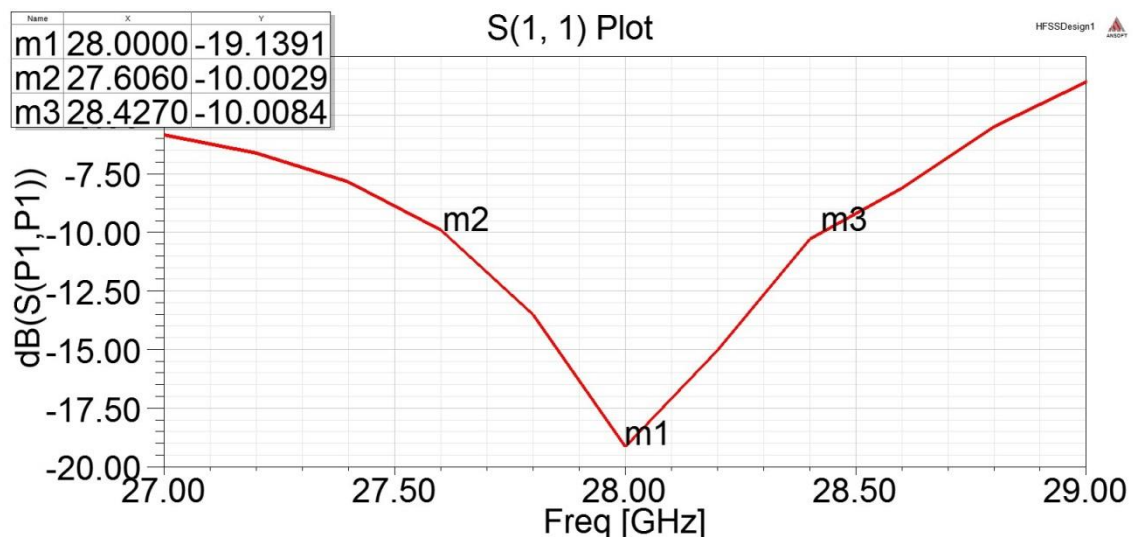
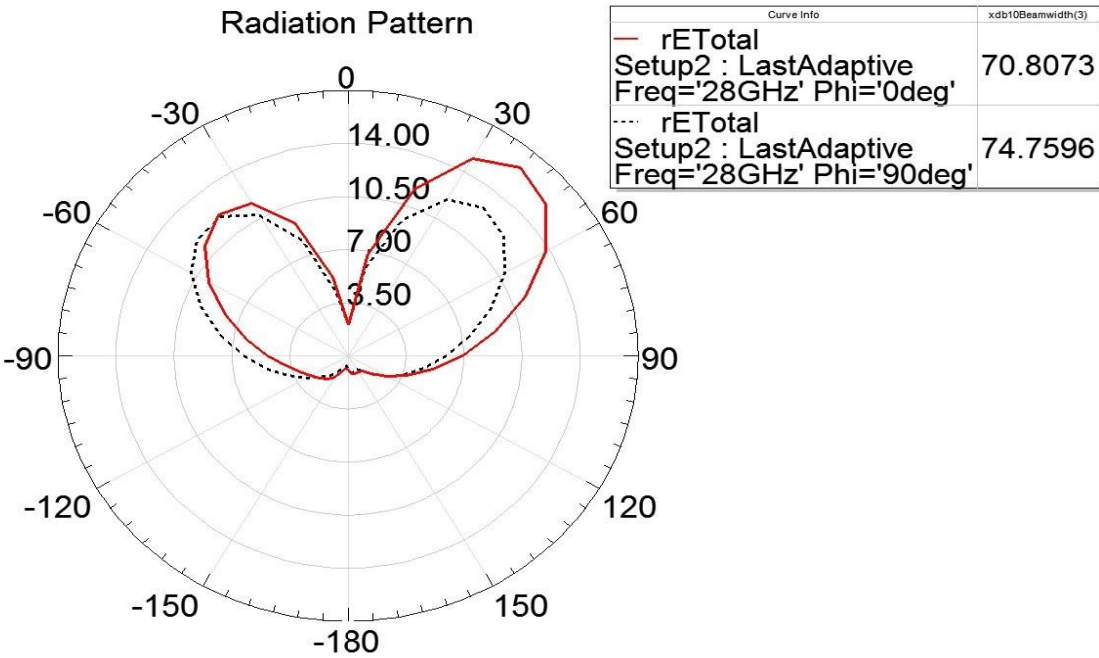
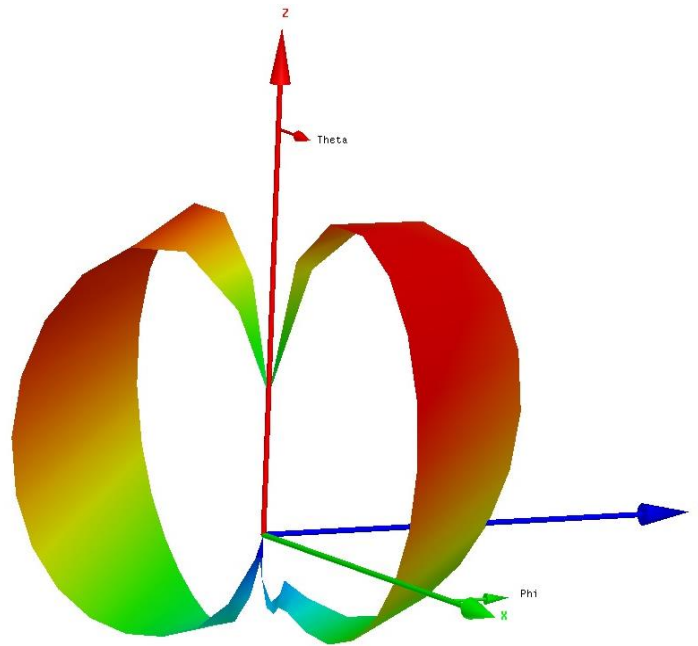


Figure 43 Return Loss Graph

In Figure 43, the return loss graph of the rectangular patch antenna is given. The y axis shows the return loss value in dB and the x axis shows the frequency in GHz. The red line represents the variation of the return loss according to frequency. The return loss is -19.14 dB which is the lowest value at 28 GHz that is the targeted resonance frequency. It increases when the frequency increases and also decreases. The antenna performance is good at 28 GHz. The antenna covers the band from 27.6 GHz to 28.43 GHz with overall bandwidth of 830 MHz.



(a) Radiation Pattern at $\Phi = 0^\circ$ and 90°



(b) Radiation Pattern 3D Plot

Figure 44 Radiation Pattern Plots

In Figure 44 (a), the red line represents the radiation pattern at $\phi = 0^\circ$ at 28 GHz and the short dashed black line represents the radiation pattern at $\phi = 90^\circ$ at 28 GHz. These lines represent that the intensity of the radiated power goes into one direction which is 0° in this case. Also, the half power beamwidth (HPBW) value is given in the legend table of the graph. The HPBW value is 70.8073 when ϕ is equal to 0° and 74.7596 when ϕ is equal to 90° .

In Figure 44 (b), the antenna lies on the x-y axis and the radiating patch is looking towards to z-axis. The center of the radiating patch of the antenna is located at the origin. As expected, there is power transmitted on z-axis which corresponds to the radiation directly overhead the antenna. On x plane and y plane, the radiation is minimum.

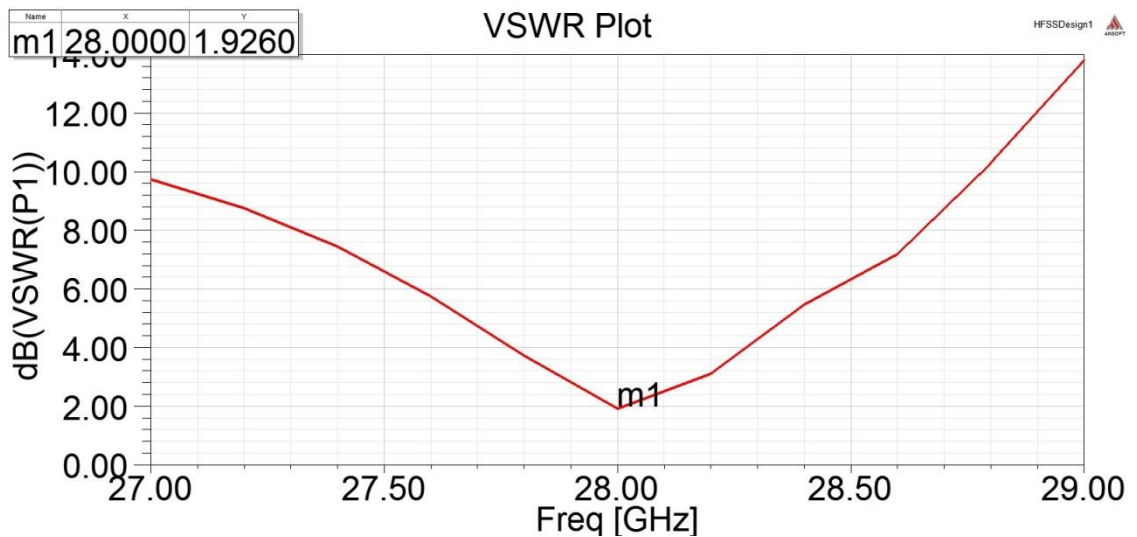


Figure 45 VSWR Graph

In Figure 45, the VSWR graph of the rectangular patch antenna is given. The y axis shows the VSWR value in dB and the x axis shows the frequency in GHz. The red line represents the variation of VSWR according to frequency. The VSWR is 1.92 dB which is a low value and at 28 GHz as expected. The antenna performance is good at this frequency so the VSWR value is low. The VSWR value increases when the frequency increases and also decreases.

2.2 Coaxial (Probe) Feed Method

2.2.1 Rectangular Patch Antenna

The rectangular patch antenna that is fed by coaxial feed method is shown in Fig. 46. The dimensions of the antenna are calculated by Eqns. (1), (2), (3), (4) and (13).

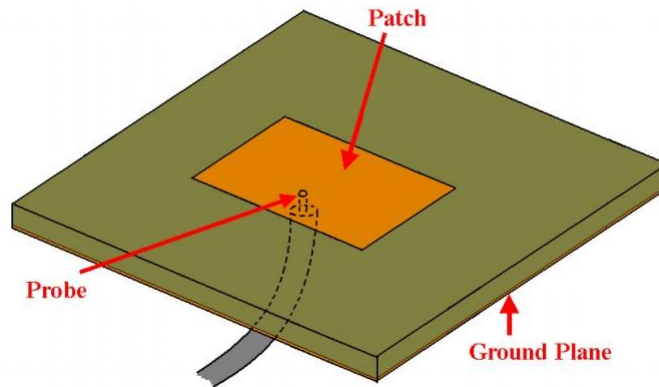


Figure 46 Rectangular Patch Antenna fed by Coaxial Feed Method [15]

The formulas given in [11], [12] and [13] are used to find the feed point location.

$$X_f = \frac{L}{\sqrt{\epsilon_{eff}}} \quad (16a)$$

$$Y_f = \frac{W}{2} \quad (16b)$$

Where X_f and Y_f are the input feed point at x-axis and y-axis respectively. After the calculation $X_f = 2.21$ mm and $Y_f = 2.12$ mm.

After the necessary calculations are done to find the feeding point location, it is seen that the x value of the location is $|x| = 0.57$ mm and $y = 0$ mm from the center point of the antenna. Then, the antenna simulation is done firstly taken the x value as 0.57 mm and the obtained results are given in Fig. 47, 48 (a), (b) and 49 respectively.

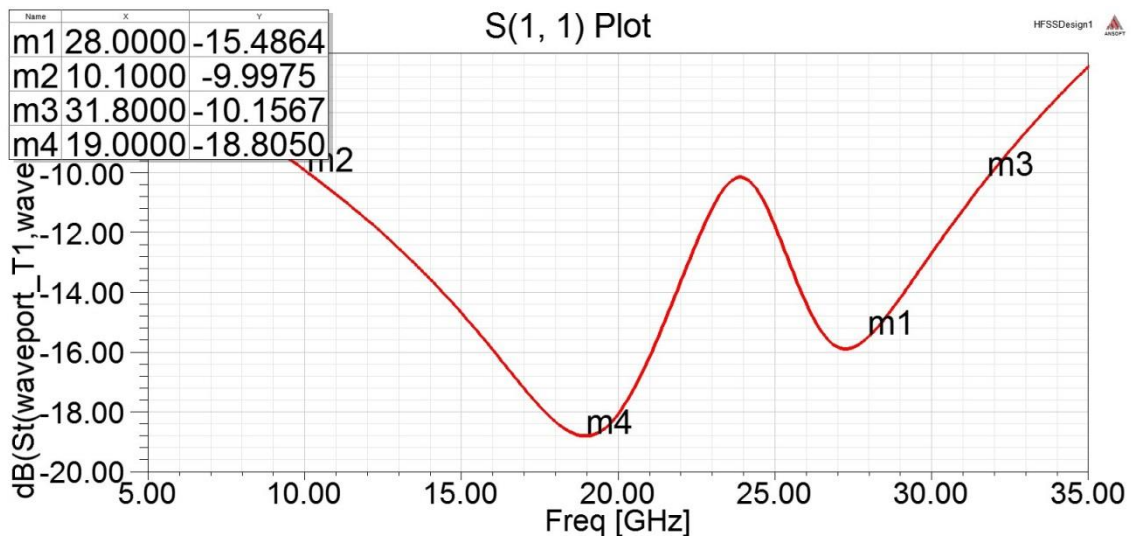
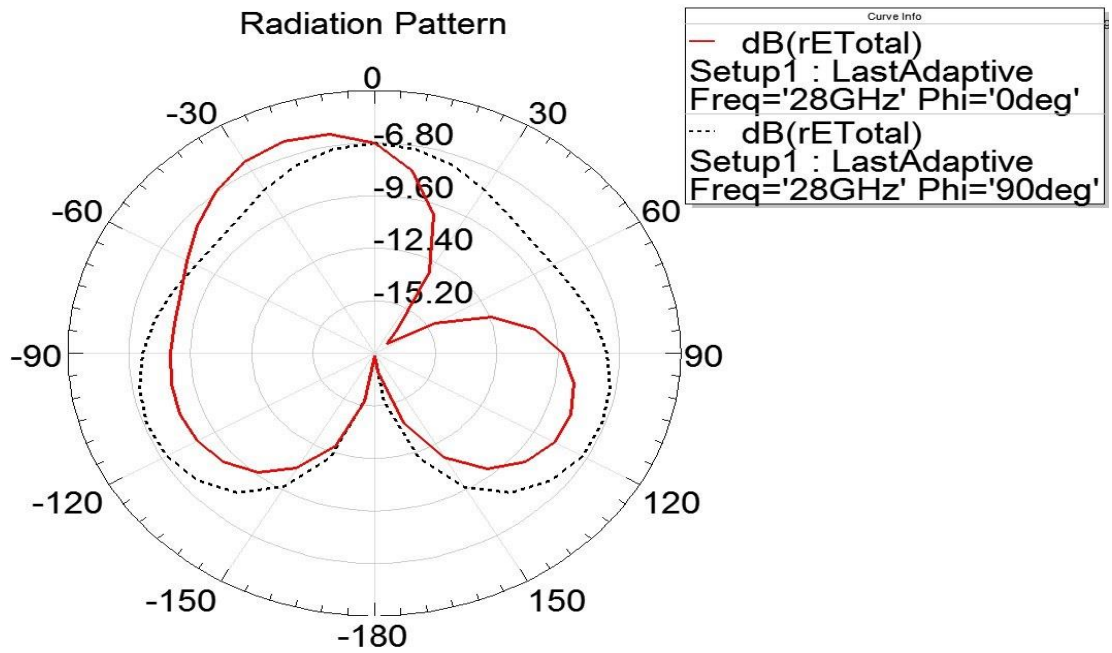
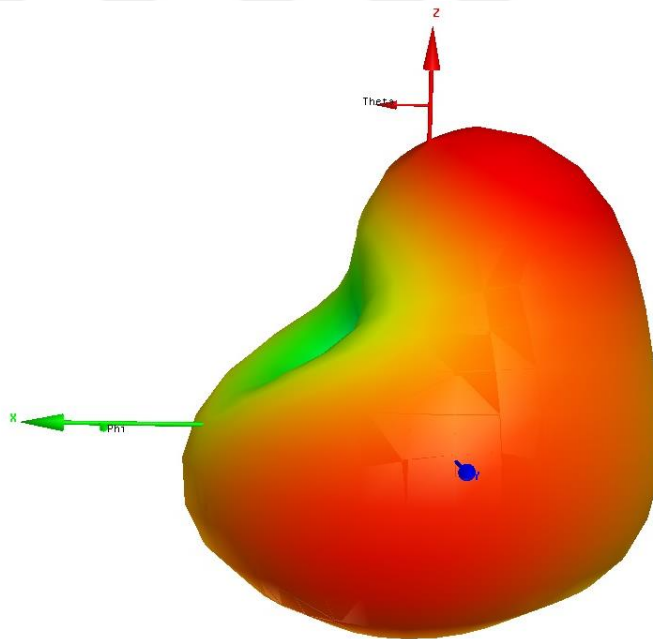


Figure 47 Return Loss Graph

In Figure 47, the return loss graph of the rectangular patch antenna is given. The y axis shows the return loss value in dB and the x axis shows the frequency in GHz. The red line represents the variation of the return loss according to frequency. The return loss is -18.81 dB which is the lowest value at 19 GHz. As can be seen from the graph there is another peak at 27.3 GHz. The return loss value at 28 GHz is -15.49 dB. The antenna performance is good at both 19 GHz and 28 GHz but it decreases at around 24 GHz. The antenna covers the band from 10.1 GHz to 31.8 GHz with overall bandwidth of 21.7 GHz.



(a) Radiation Pattern at $\Phi = 0^\circ$ and 90°



(b) Radiation Pattern 3D Plot

Figure 48 Radiation Pattern Plots

In Figure 48 (a), the red line represents the radiation pattern at $\Phi = 0^\circ$ at 28 GHz and the short dashed black line represents the radiation pattern at $\Phi = 90^\circ$ at 28

GHz. These lines represent that the intensity of the radiated power goes into one direction which is 0° in this case.

In Figure 48 (b), the antenna lies on the x-y axis and the radiating patch is looking towards to z-axis. The center of the radiating patch of the antenna is located at the origin. As expected, there is power transmitted on z-axis which corresponds to the radiation directly overhead the antenna. On x plane and y plane, the radiation is minimum.

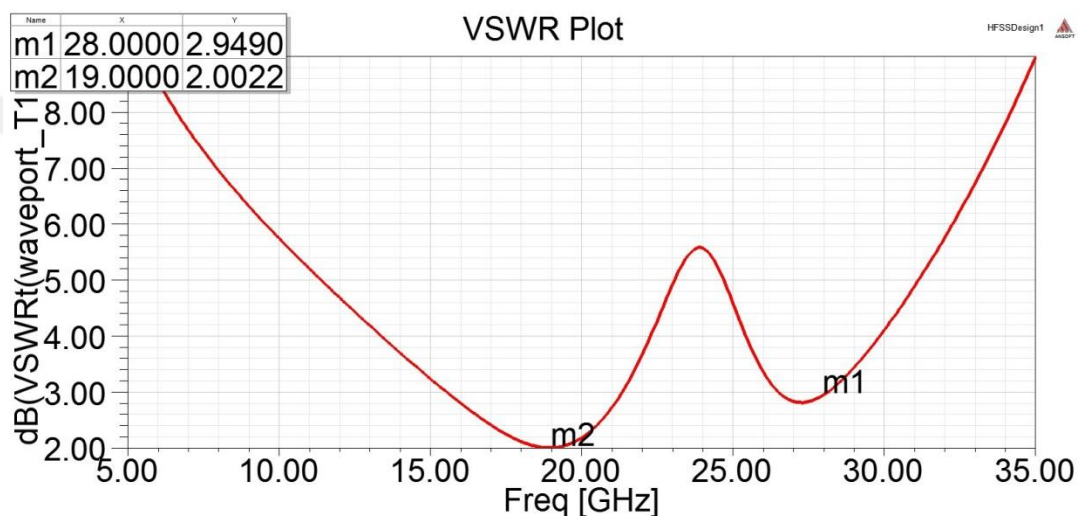


Figure 49 VSWR Graph

In Figure 49, the VSWR graph of the rectangular patch antenna is given. The y axis shows the VSWR value in dB and the x axis shows the frequency in GHz. The red line represents the variation of VSWR according to frequency. The VSWR has two peaks at 19 GHz and 27.3 GHz as expected. The VSWR is 2 dB at 19 dB which is the lowest value. The VSWR is 2.95 dB at 28 GHz. The antenna performance is good at this frequency so the VSWR value is low. The VSWR value increases when the frequency increases and also decreases.

In the Eqn. 16, the reference point of the feed location is not indicated so the minus value of the x is taken and the antenna is simulated again. The result are given in Fig. 50, 51 (a), (b) and 52 respectively.

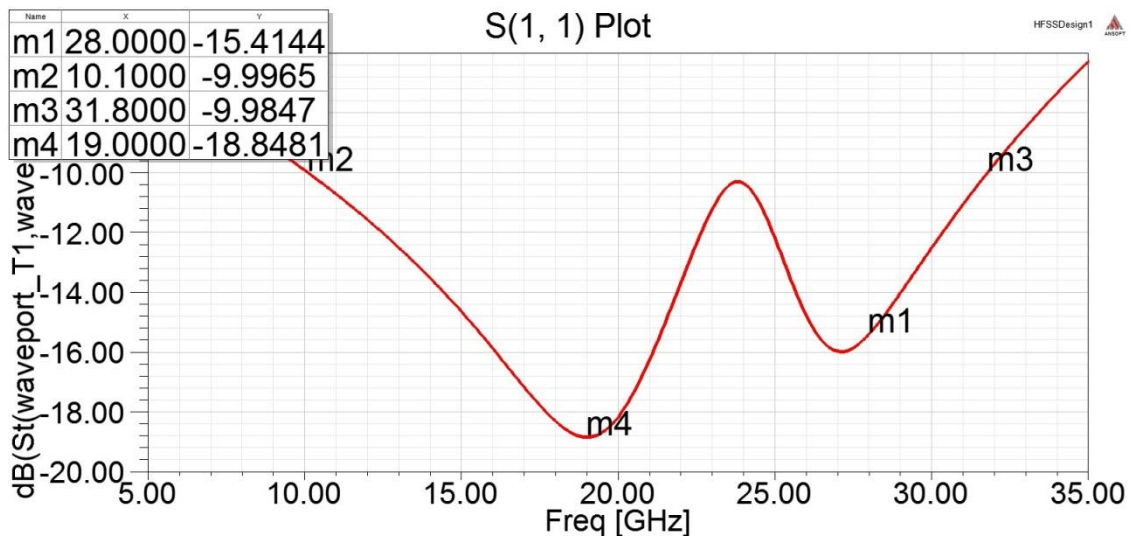


Figure 50 Return Loss Graph

In Figure 50, the return loss graph of the rectangular patch antenna is given. The y axis shows the return loss value in dB and the x axis shows the frequency in GHz. The red line represents the variation of the return loss according to frequency. The return loss is -18.85 dB which is the lowest value at 19 GHz. As can be seen from the graph there is another peak at 27.3 GHz. The return loss value at 28 GHz is -15.41 dB. The antenna performance is good at both 19 GHz and 28 GHz but it decreases at around 24 GHz. The antenna covers the band from 10.1 GHz to 31.8 GHz with overall bandwidth of 21.7 GHz.

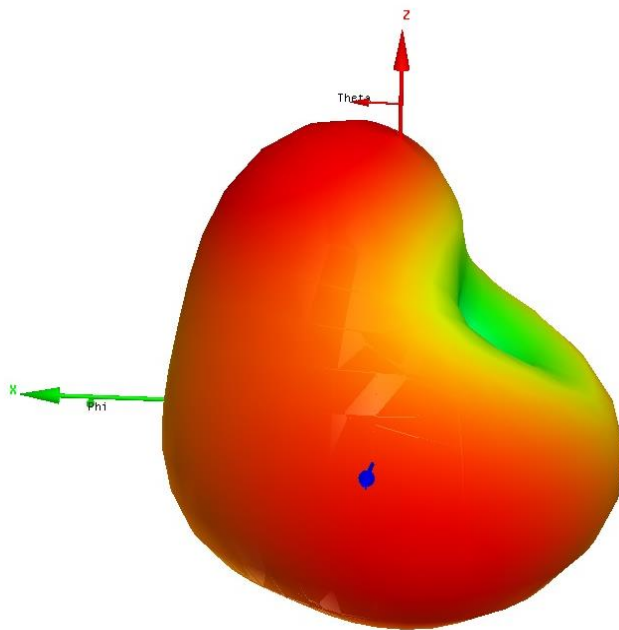
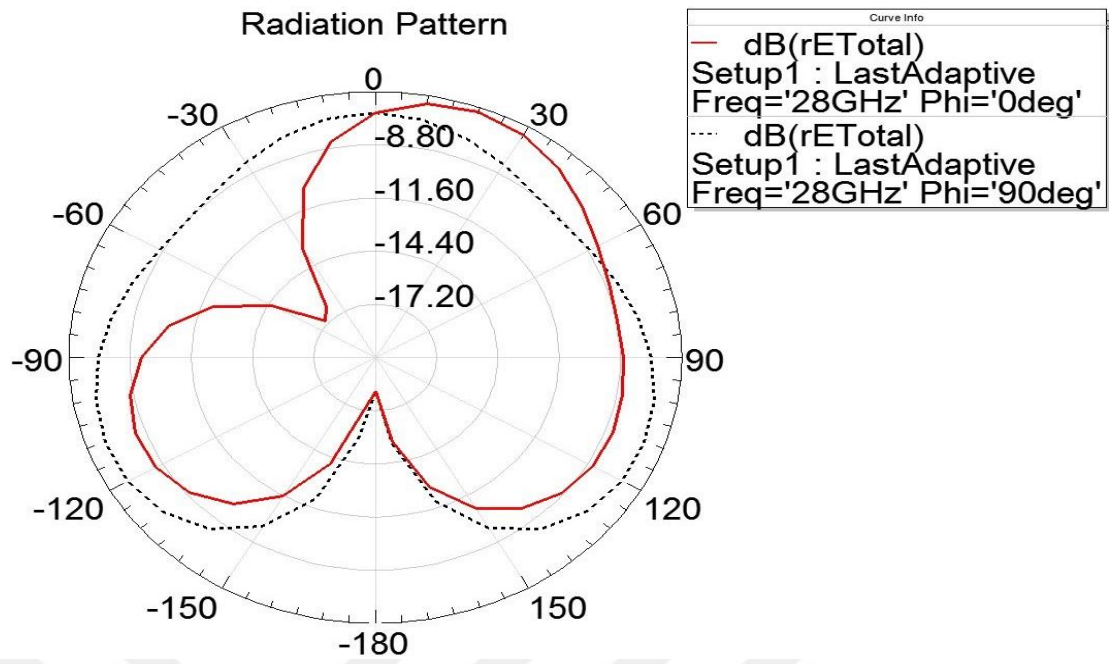


Figure 51 Radiation Pattern Plots

In Figure 51 (a), the red line represents the radiation pattern at $\phi = 0^\circ$ at 28 GHz and the short dashed black line represents the radiation pattern at $\phi = 90^\circ$ at 28

GHz. These lines represent that the intensity of the radiated power goes into one direction which is 0° in this case.

In Figure 51 (b), the antenna lies on the x-y axis and the radiating patch is looking towards to z-axis. The center of the radiating patch of the antenna is located at the origin. As expected, there is power transmitted on z-axis which corresponds to the radiation directly overhead the antenna. On x plane and y plane, the radiation is minimum.

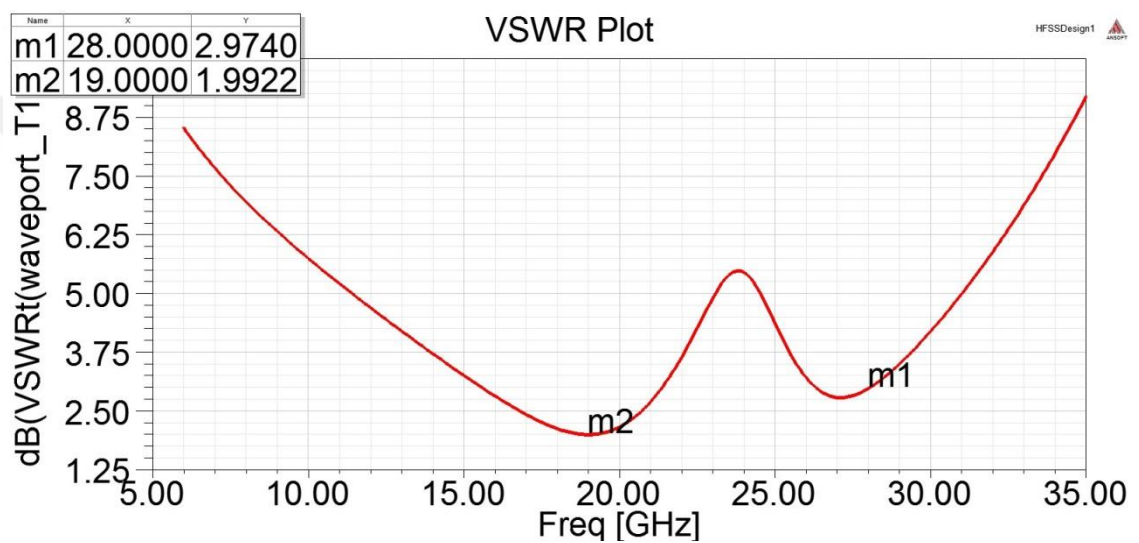


Figure 52 VSWR Graph

In Figure 52, the VSWR graph of the rectangular patch antenna is given. The y axis shows the VSWR value in dB and the x axis shows the frequency in GHz. The red line represents the variation of VSWR according to frequency. The VSWR has two peaks at 19 GHz and 27.3 GHz as expected. The VSWR is 1.99 dB at 19 dB which is the lowest value. The VSWR is 2.97 dB at 28 GHz. The antenna performance is good at this frequency so the VSWR value is low. The VSWR value increases when the frequency increases and also decreases.

The designed antenna by using Eqns. (1), (2), (3), (4), (13) and (16) gives the best performance at around 19 GHz. It also radiates at 28 GHz which is the targeted frequency. The return loss value at 28 GHz is -15.42 dB. To increase the antenna performance at 28 GHz, the dimensions of the antenna and feeding point location

are changed. The dimensions which the best results are obtained, are given in Table 7. All the values are in millimeter. The obtained results are given in Figs. 53, 54 (a), (b) and 55 respectively.

Table 7 Dimensions of the Rectangular Patch Antenna

Patch Width (W)	2.3
Patch Length (L)	2
Feed Position in x	-0.1
Feed Position in y	0
Substrate Width ($W_s = W_g$)	5.5
Substrate Length ($L_s = L_g$)	4.5

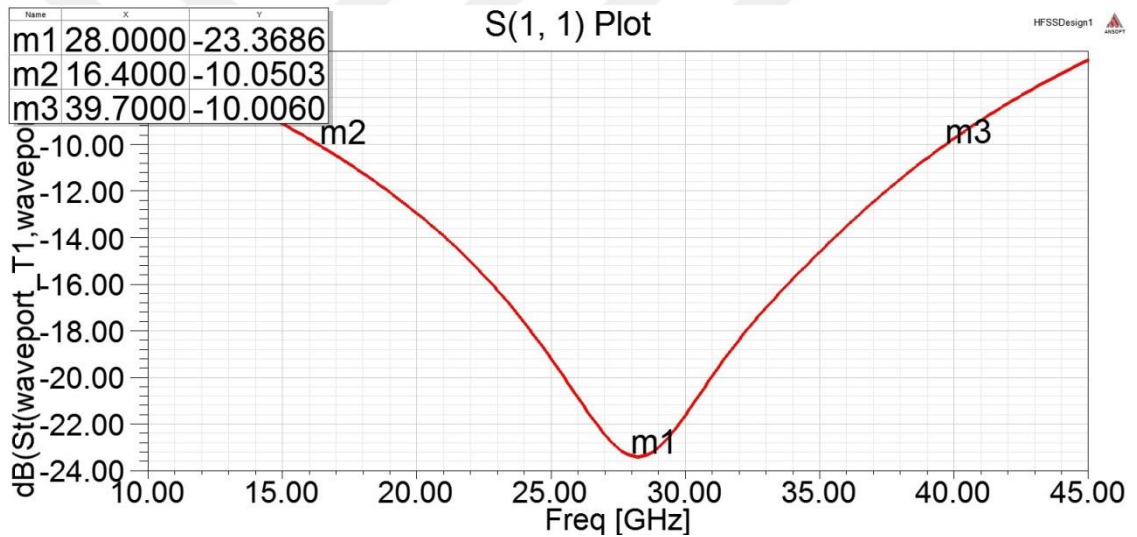
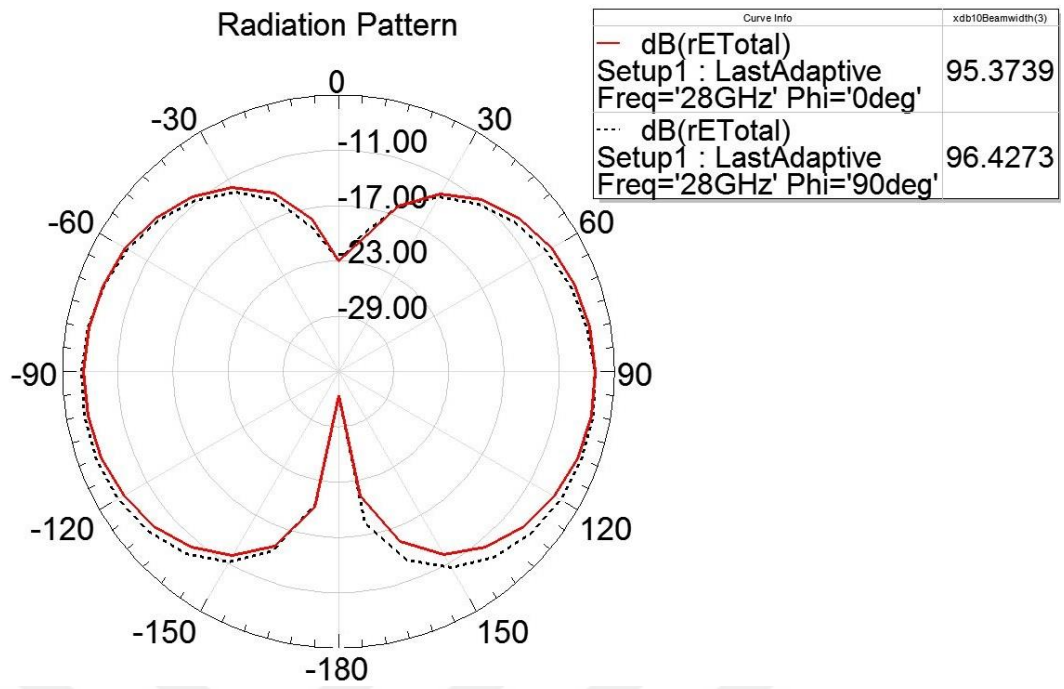
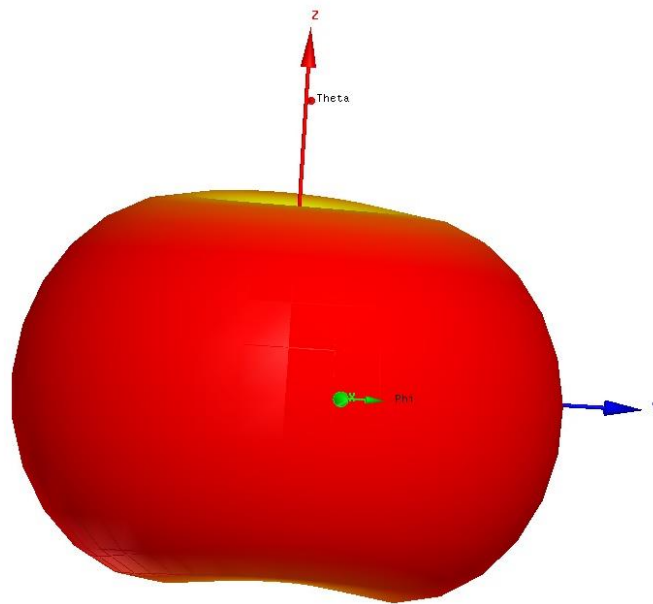


Figure 53 Return Loss Graph

In Figure 53, the return loss graph of the rectangular patch antenna is given. The y axis shows the return loss value in dB and the x axis shows the frequency in GHz. The red line represents the variation of the return loss according to frequency. The return loss is -23.37 dB which is the lowest value at 28 GHz that is the targeted resonance frequency. It increases when the frequency increases and also decreases. The antenna performance is good at 28 GHz. The antenna covers the band from 16.4 GHz to 39.7 GHz with overall bandwidth of 23.3 GHz.



(a) Radiation Pattern at $\Phi = 0^\circ$ and 90°



(b) Radiation Pattern 3D Plot

Figure 54 Radiation Pattern Plots

In Figure 54 (a), the red line represents the radiation pattern at $\phi = 0^\circ$ at 28 GHz and the short dashed black line represents the radiation pattern at $\phi = 90^\circ$ at 28 GHz. These lines represent that the intensity of the radiated power goes into -90° and 90° in this case. Also, the half power beamwidth (HPBW) value is given in the legend table of the graph. The HPBW value is 95.3739 when ϕ is equal to 0° and 96.4273 when ϕ is equal to 90° .

In Figure 54 (b), the antenna lies on the x-y axis and the radiating patch is looking towards to z-axis. The center of the radiating patch of the antenna is located at the origin. As expected, there is power transmitted on z-axis which corresponds to the radiation directly overhead the antenna. On x plane and y plane, the power is radiated.

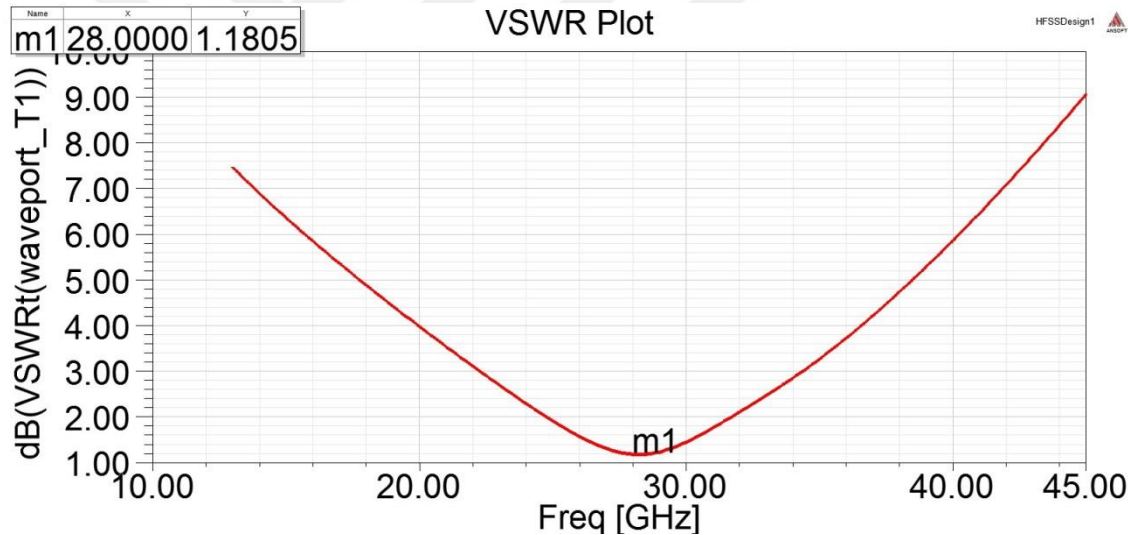


Figure 55 VSWR Graph

In Figure 55, the VSWR graph of the rectangular patch antenna is given. The y axis shows the VSWR value in dB and the x axis shows the frequency in GHz. The red line represents the variation of VSWR according to frequency. The VSWR is 1.18 dB which is a low value and at 28 GHz as expected. The antenna performance is good at this frequency so the VSWR value is low. The VSWR value increases when the frequency increases and also decreases.

2.2.2 Circular Patch Antenna

The dimension of the antenna is calculated by using Eqns. 14 and 15 in the previous sections. The position of the coaxial feed is calculated by Eqn. 16 but for the circular patch the width and the length of the patch so the width and length is taken as 3.7812 mm for the calculation. The obtained results for the position are 0.616 mm in x and 0.945 mm in y. All the possibilities of the position of the feed [(x, y), (-x, y), (x, -y), (-x, -y)] point are simulated. After the antenna simulation is done in HFSS, it is seen that there is no big difference between the feed positions. All the results are given in Table 8. The antenna is a dual band antenna so the resonant frequency is given for two different frequency values.

Table 8 Result of Coaxial Feed Circular Patch

Feed Point Position (x, y)	Resonant Frequency	Return Loss (dB)	VSWR (dB)	Bandwidth
(0.616, 0.945)	19 GHz	-21.38	1.49	8.39 GHz
	37 GHz	-15.75	2.86	9.4 GHz
(-0.616, 0.945)	19 GHz	-21.39	1.48	8.35 GHz
	37 GHz	-15.81	2.84	9.22 GHz
(0.616, -0.945)	19 GHz	-21.36	1.49	8.35 GHz
	37 GHz	-15.78	2.85	9.22 GHz
(-0.616, -0.945)	19 GHz	-21.33	1.49	8.35 GHz
	37 GHz	-15.75	2.86	9.17 GHz

As can be seen from the results given in Table 8, there is no big difference between the all possible positions of the feed point. The best results in return loss and VSWR are obtained when the feed point position is at -0.616 mm in x and 0.945 mm in y. The results are given in Figs. 56, 57 (a), (b) and 58 respectively.

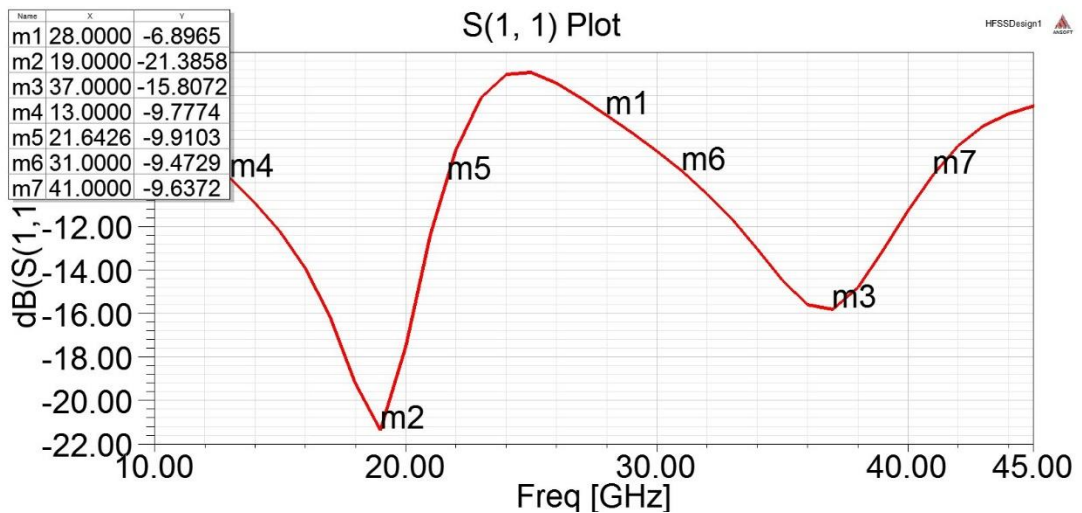
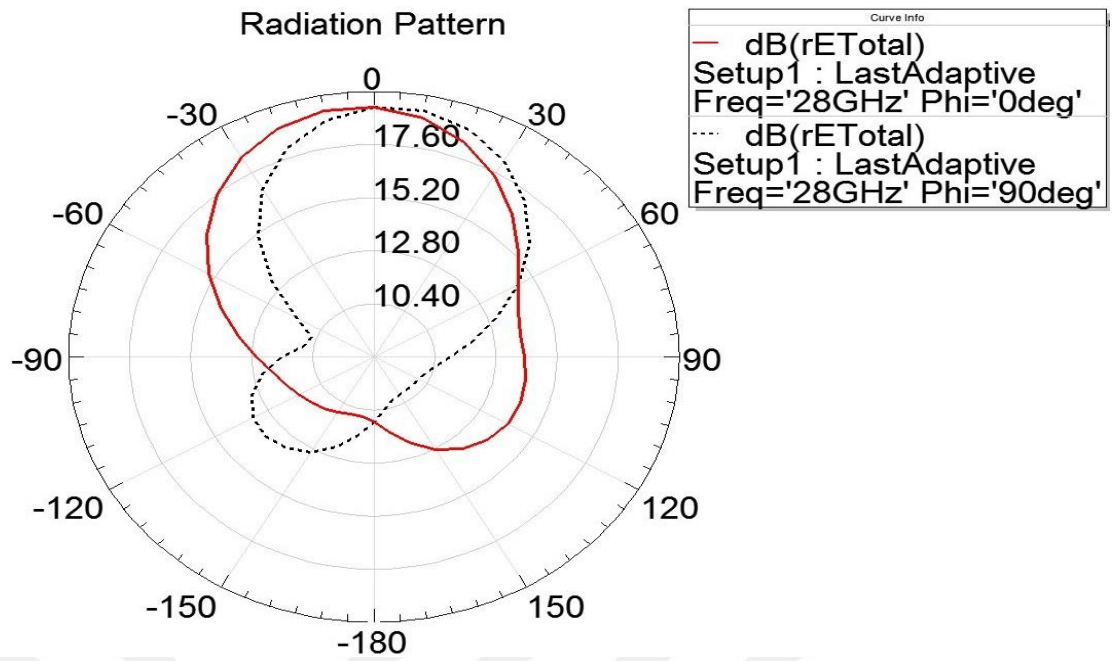
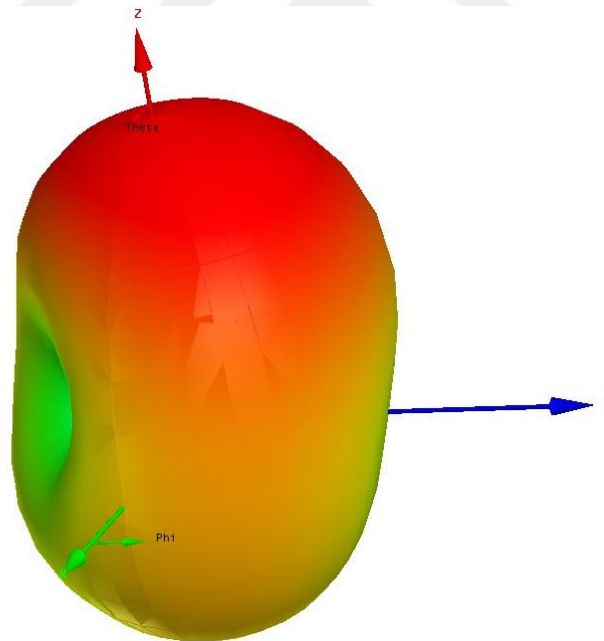


Figure 56 Return Loss Graph

In Figure 56, the return loss graph of the rectangular patch antenna is given. The y axis shows the return loss value in dB and the x axis shows the frequency in GHz. The red line represents the variation of the return loss according to frequency. The return loss is -21.39 dB which is the lowest value at 19 GHz. There is another peak which is at 37 GHz. The return loss at this frequency is -15.81 dB. The return loss value at 28 GHz that is the targeted resonance frequency is -6.89 dB. The antenna performance is good at 19 GHz and the antenna covers the band from 13 GHz to 21.6 GHz with overall bandwidth of 8.6 GHz. At 37 GHz, the antenna performance is low when it is compared with 19 GHz but its performance is good. The antenna covers the band from 31 GHz to 41 GHz with overall bandwidth of 10 GHz. The antenna has a poor performance in between 21.64 GHz to 31 GHz.



(a) Radiation Pattern at $\Phi = 0^\circ$ and 90°



(b) Radiation Pattern 3D Plot

Figure 57 Radiation Pattern Plots

In Figure 57 (a), the red line represents the radiation pattern at $\phi = 0^\circ$ at 28 GHz and the short dashed black line represents the radiation pattern at $\phi = 90^\circ$ at 28

GHz. These lines represent that the intensity of the radiated power goes into one direction which is 0° in this case.

In Figure 57 (b), the antenna lies on the x-y axis and the radiating patch is looking towards to z-axis. The center of the radiating patch of the antenna is located at the origin. As expected, there is power transmitted on z-axis which corresponds to the radiation directly overhead the antenna. On x plane and y plane, the radiation is minimum.

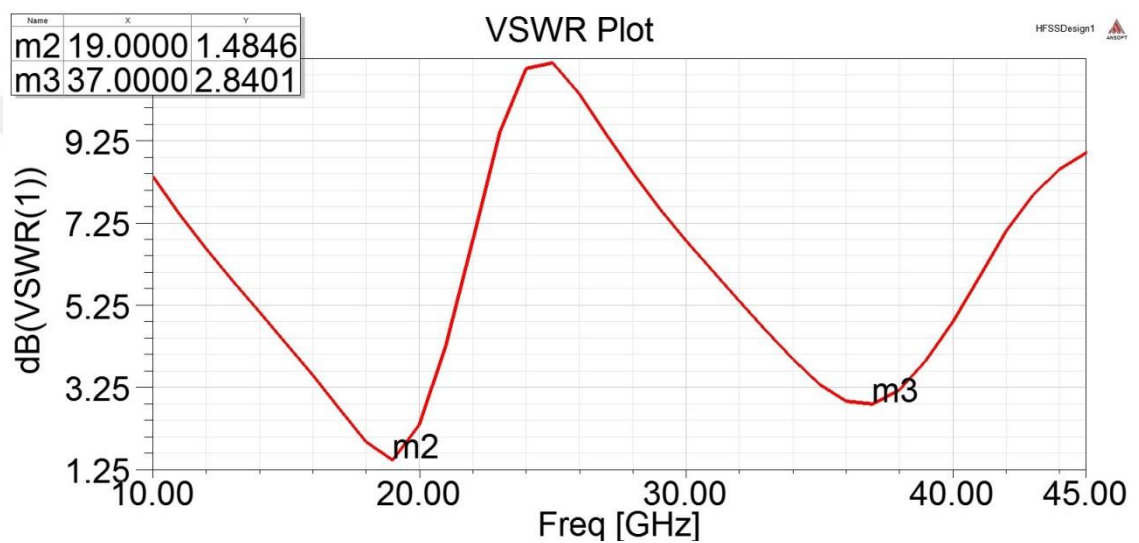


Figure 58 VSWR Graph

In Figure 58, the VSWR graph of the rectangular patch antenna is given. The y axis shows the VSWR value in dB and the x axis shows the frequency in GHz. The red line represents the variation of VSWR according to frequency. The VSWR has two peaks at 19 GHz and 37 GHz as expected. The VSWR is 1.48 dB at 19 dB which is the lowest value. The VSWR is 2.84 dB at 37 GHz. The antenna performance is good at these frequencies so the VSWR value is low. The VSWR value increases when the frequency increases and also decreases.

After that, to obtain the minimum return loss value which results in the best antenna performance, the dimensions of the radiating patch, ground plane and the feeding point location are changed by using a trial and error method. The dimensions which

the best results are obtained, are given in Table 7. The results are given in Figs. 59, 60 (a), (b) and 61 respectively.

Table 9 Dimension of the Circular Patch Antenna for Best Results

Patch Radius (a)	2.5 mm
Substrate Width	7.856 mm
Substrate Length	7.856 mm
Feed Position in x	0.1 mm
Feed Position in y	-1.5 mm

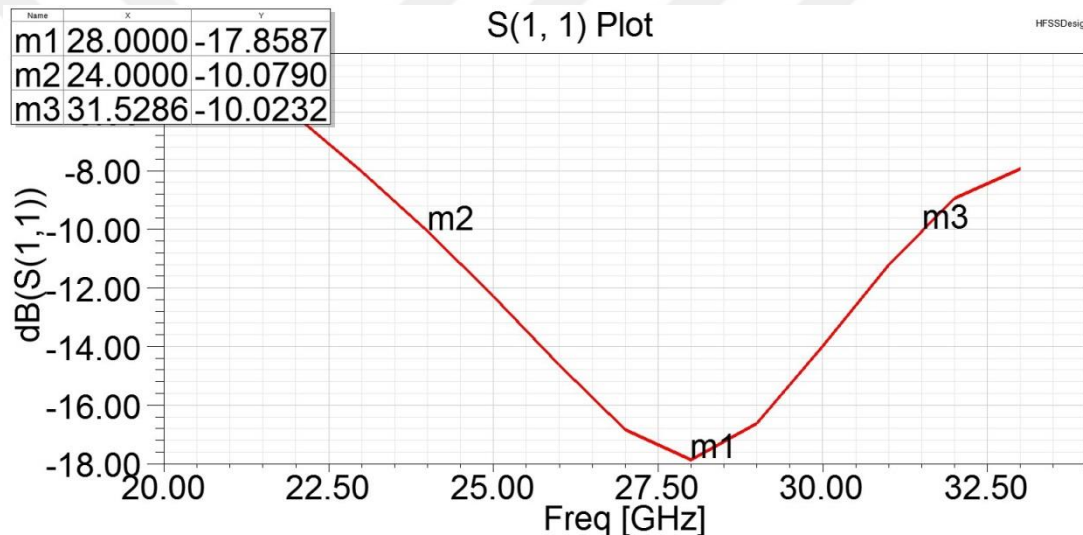
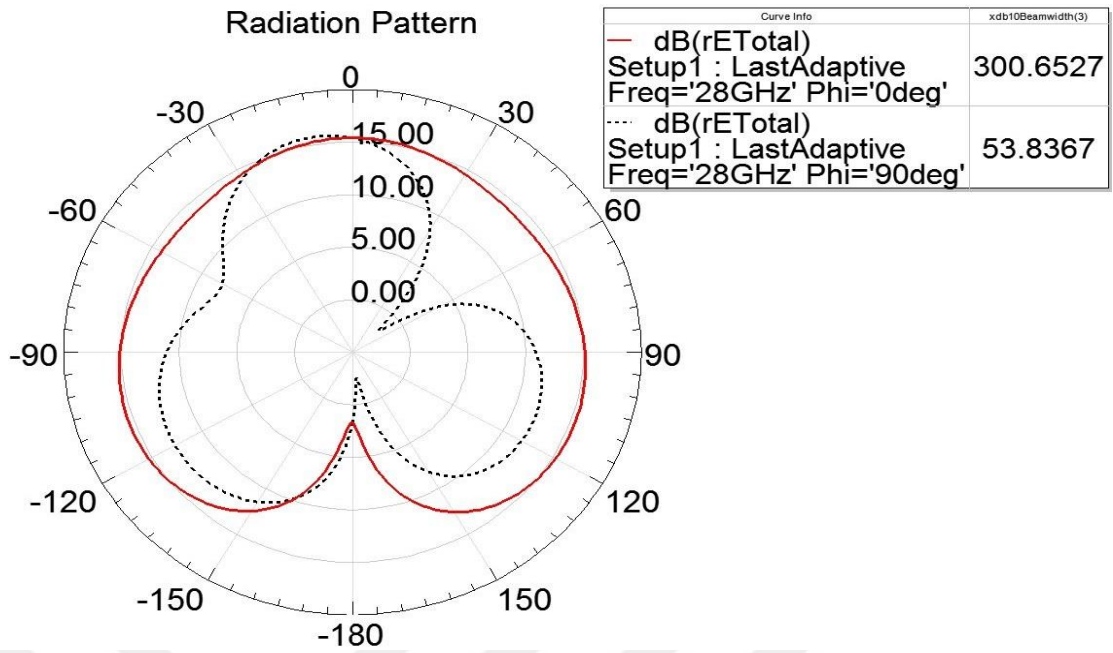
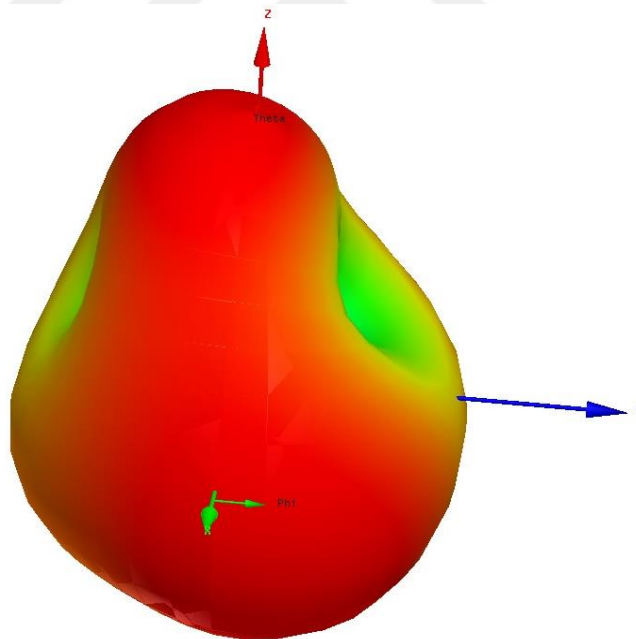


Figure 59 Return Loss Graph

In Figure 59, the return loss graph of the rectangular patch antenna is given. The y axis shows the return loss value in dB and the x axis shows the frequency in GHz. The red line represents the variation of the return loss according to frequency. The return loss is -17.86 dB which is the lowest value at 28 GHz that is the targeted resonance frequency. It increases when the frequency increases and also decreases. The antenna performance is good at 28 GHz. The antenna covers the band from 24 GHz to 31.5 GHz with overall bandwidth of 7.5 GHz.



(a) Radiation Pattern at Phi = 0° and 90°



(b) Radiation Pattern 3D Plot

Figure 60 Radiation Pattern Plots

In Figure 60 (a), the red line represents the radiation pattern at $\phi = 0^\circ$ at 28 GHz and the short dashed black line represents the radiation pattern at $\phi = 90^\circ$ at 28 GHz. These lines represent that the intensity of the radiated power goes into one

direction which is 0° in this case. Also, the half power beamwidth (HPBW) value is given in the legend table of the graph. The HPBW value is 300.6527 when phi is equal to 0° and 53.8367 when phi is equal to 90° .

In Figure 60 (b), the antenna lies on the x-y axis and the radiating patch is looking towards to z-axis. The center of the radiating patch of the antenna is located at the origin. As expected, there is power transmitted on z-axis which corresponds to the radiation directly overhead the antenna. There is also power transmitted on x plane. On y plane, the radiation is minimum.

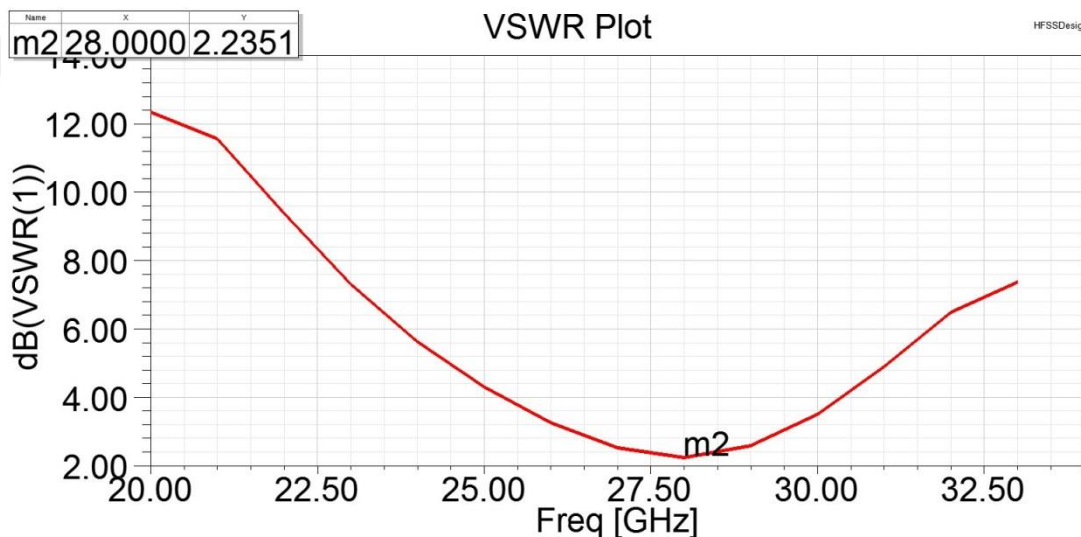


Figure 61 VSWR Graph

In Figure 61, the VSWR graph of the rectangular patch antenna is given. The y axis shows the VSWR value in dB and the x axis shows the frequency in GHz. The red line represents the variation of VSWR according to frequency. The VSWR is 1.18 dB which is a low value and at 28 GHz as expected. The antenna performance is good at this frequency so the VSWR value is low. The VSWR value increases when the frequency increases and also decreases.

2.2.3 Ç-Shaped Patch Antenna

The coaxial feed method is also used extensively. It is easy to manufacture and match. Also it has low spurious radiation but it has narrow bandwidth but it is not

easy to model specially for thick substrates [1]. For the proposed antenna to find the best feeding position for the coaxial feeding method, a trial and error method is used.

Firstly, the antenna is tried to feed from inner hexagon. The center of it is taken as a feeding position. Then x and y values are changed one by one and tried to find the best position. The results for the inner hexagon are given in Table 10 with its x and y values.

Table 10 Results for Coaxial Feed from Inner Hexagon

x (mm)	y (mm)	Return Loss (dB)
0	0	-1.6
-1	0	-2.59
-1.5	0	-3.88
1	0	-2.31
1.5	0	-3.07
0	-1	-2.53
0	-1.5	-3.86
0	1	-2.62
0	1.5	-3.58

Secondly, points on the outer hexagon are investigated and the best result is obtained on the tail of the ‘C’. At this position where $x = 3.1$ mm and $y = 0$ mm the return loss value is -17.79 dB.

After the best feeding point is found, the size of the inner hexagon is reduced from 2.38 mm to 2.28 mm. As a result of this the resonant frequency decreased to 27 GHz and the return loss is -18.45 dB. To shift the resonant frequency to 28 GHz the length of the substrate is decreased to 7.4 mm. The antenna covers the band from 27.45 GHz to 28.84 GHz with overall bandwidth of 1.39 GHz. The final design of

the antenna, the return loss graph, the radiation pattern plots and the VSWR graph are given in Fig. 63, 64 (a), (b) and 65 respectively.

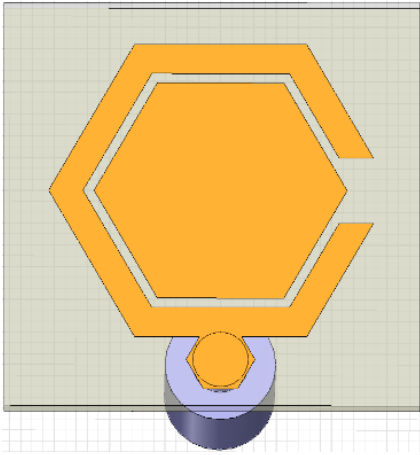
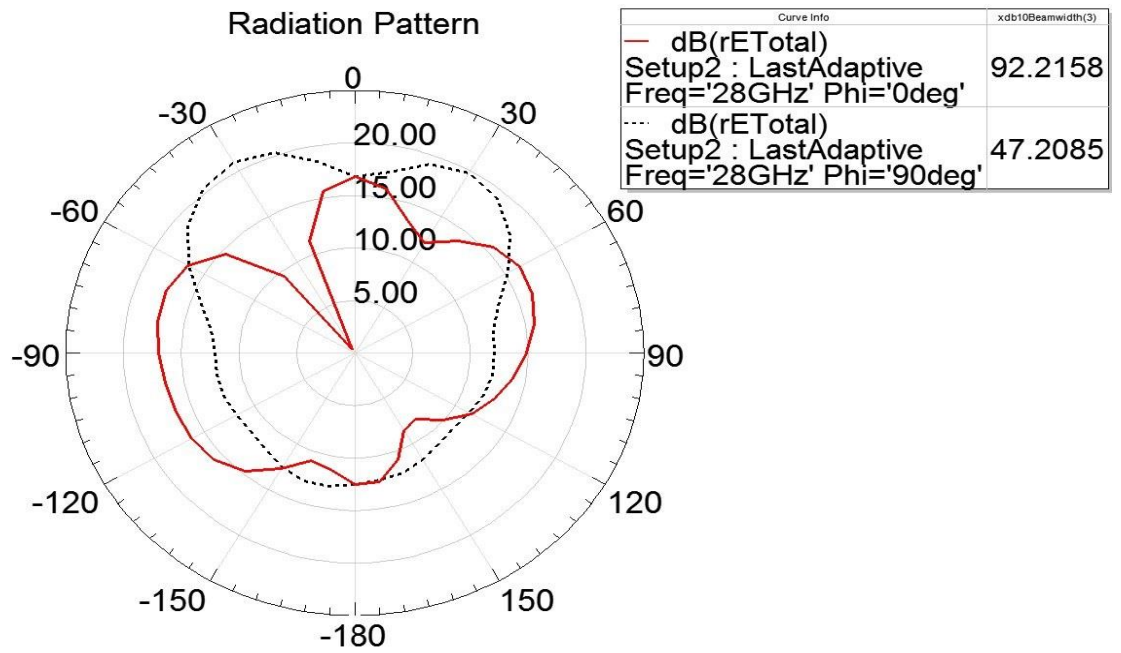


Figure 62 The Proposed Antenna with Coaxial Feed

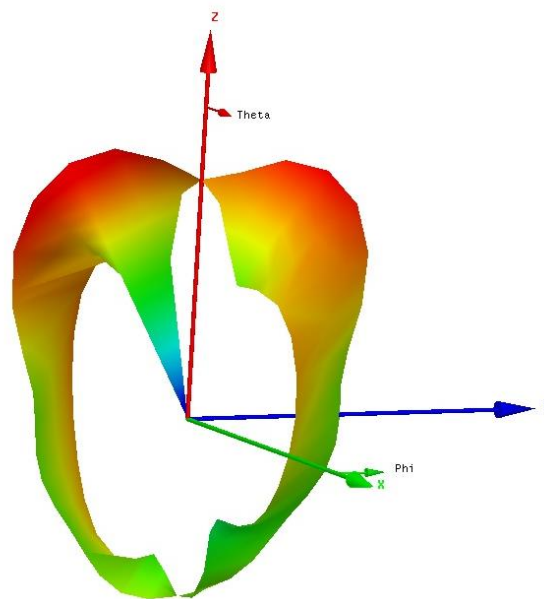


Figure 63 Return Loss Graph of Coaxial Feed

In Figure 63, the return loss graph of the rectangular patch antenna is given. The y axis shows the return loss value in dB and the x axis shows the frequency in GHz. The red line represents the variation of the return loss according to frequency. The return loss is -19.02 dB which is the lowest value at 28 GHz that is the targeted resonance frequency. It increases when the frequency increases and also decreases. The antenna performance is good at 28 GHz. The antenna covers the band from 27.5 GHz to 28.9 GHz with overall bandwidth of 2.4 GHz.



(a) Radiation Pattern 3D Plot of Coaxial Feed when Phi = 0° and 90°



(b) 3D Plot of the Radiation Pattern of the Antenna

Figure 64 Radiation Pattern Plots

In Figure 64 (a), the red line represents the radiation pattern at $\phi = 0^\circ$ at 28 GHz and the short dashed black line represents the radiation pattern at $\phi = 90^\circ$ at 28 GHz. These lines represent that the intensity of the radiated power goes into one

direction which is 0° in this case. Also, the half power beamwidth (HPBW) value is given in the legend table of the graph. The HPBW value is 92.2158 when phi is equal to 0° and 47.2085 when phi is equal to 90° .

In Figure 64 (b), the antenna lies on the x-y axis and the radiating patch is looking towards to z-axis. The center of the radiating patch of the antenna is located at the origin. As expected, there is power transmitted on z-axis which corresponds to the radiation directly overhead the antenna. On x plane and y plane, the radiation is minimum.

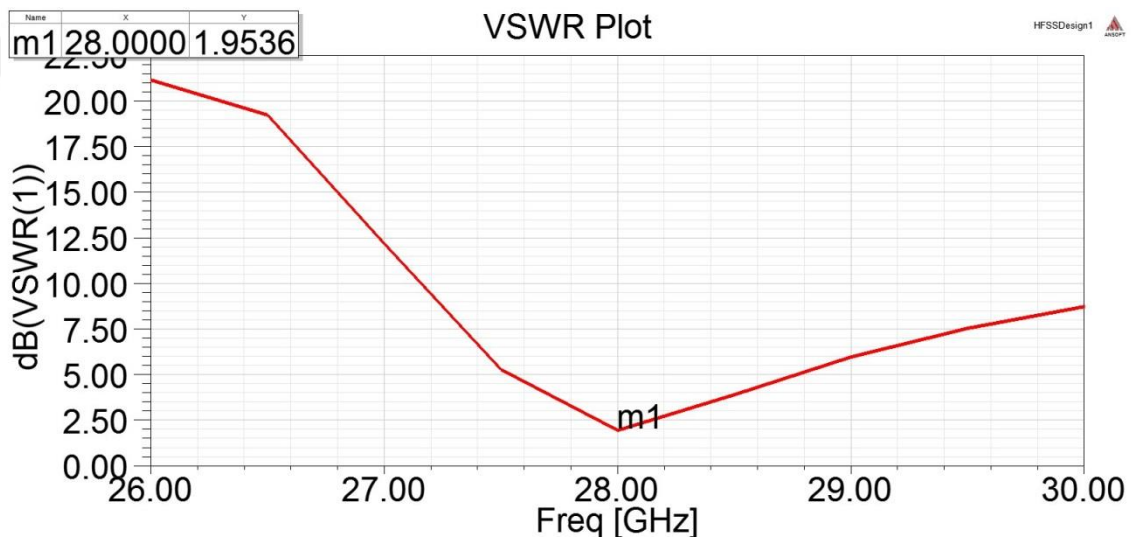


Figure 65 VSWR Graph

In Figure 65, the VSWR graph of the rectangular patch antenna is given. The y axis shows the VSWR value in dB and the x axis shows the frequency in GHz. The red line represents the variation of VSWR according to frequency. The VSWR is 1.95 dB which is a low value and at 28 GHz as expected. The antenna performance is good at this frequency so the VSWR value is low. The VSWR value increases when the frequency increases and also decreases.

Finally, the inner hexagon is removed totally and the resulting return loss is -23.4 dB at 28 GHz. It has a better return loss but its shape is different from the proposed antenna.

CHAPTER 3

MATLAB Graphical User Interface

In this thesis, the given equations in the previous sections are used to design a MATLAB GUI to calculate the parameters for the rectangular and circular patch antennas easily. The designed interface is given in Fig. 66.

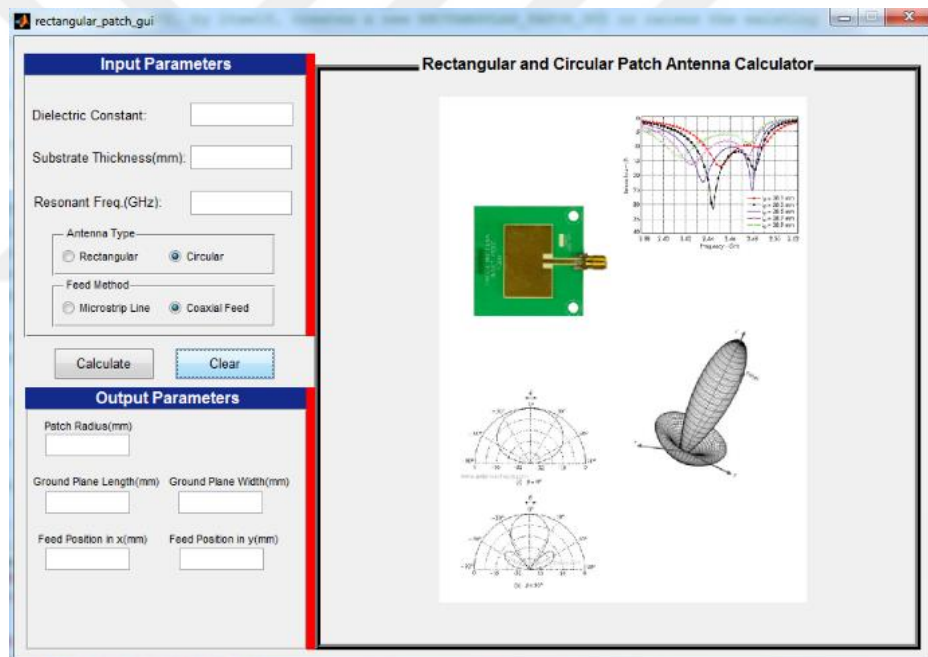


Figure 66 The Designed MATLAB Interface

Firstly, the dielectric constant and thickness of chosen substrate and the targeted resonant frequency must be written to the related boxes to calculate the antenna parameters. After that, the antenna type and the feeding method must be chosen.

The calculated values are given in the “Output Parameters” section. Also, the values are shown on related parts of the antenna figure. The results of rectangular and

circular patch antennas fed with microstrip feed line method are given in Fig. 67 and 68 respectively. Moreover, the results of coaxial feed method for the antennas are given in Fig. 69 and 70 respectively. The code is given in Appendix A.

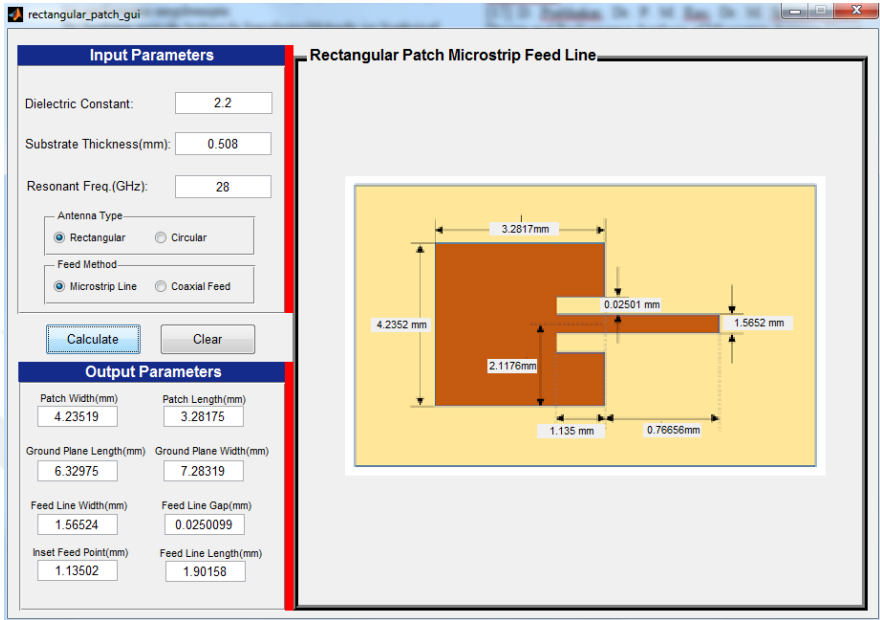


Figure 67 Rectangular Patch Antenna fed with Microstrip Feed Line Method

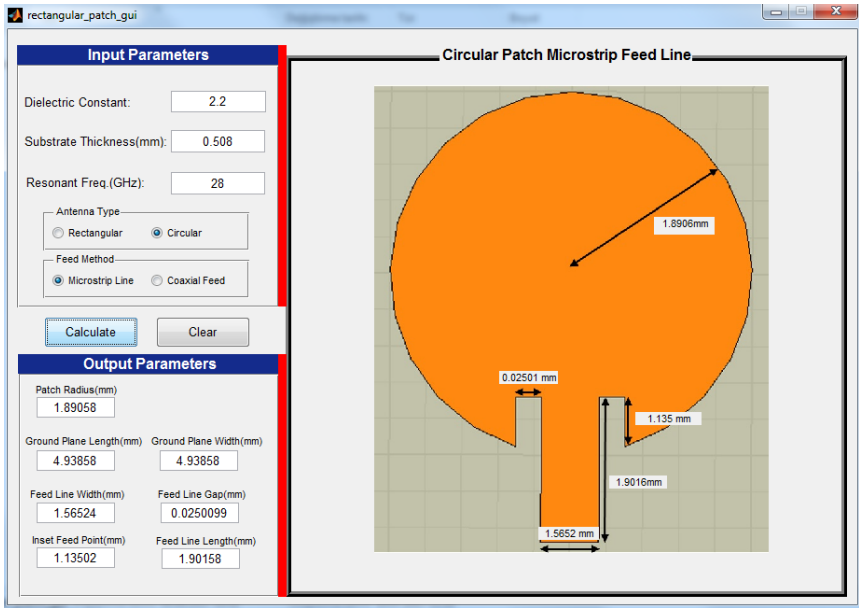


Figure 68 Circular Patch Antenna fed with Microstrip Feed Line Method

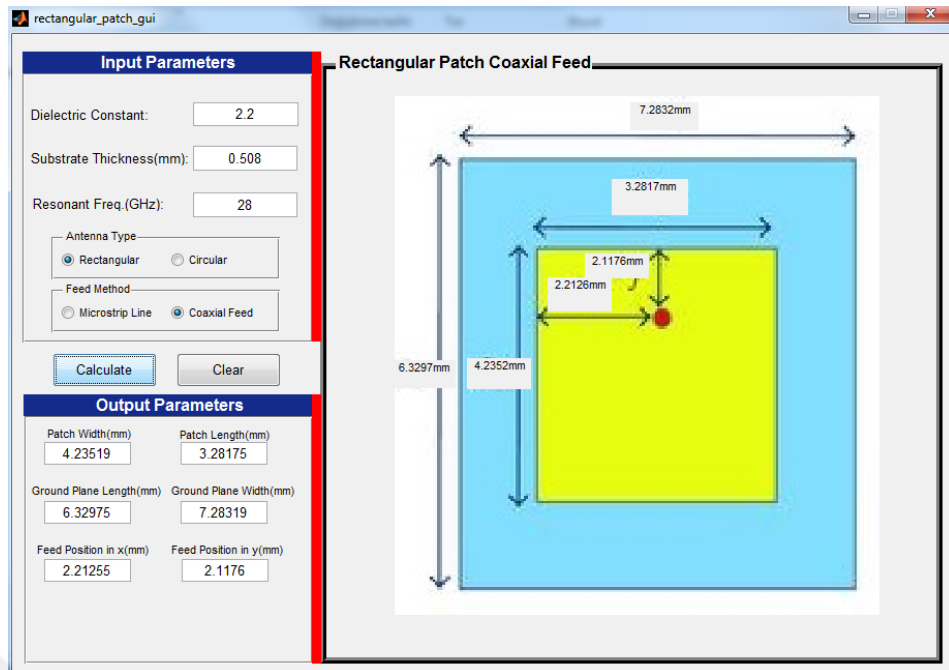


Figure 69 Rectangular Patch Antenna fed with Coaxial Feed Method

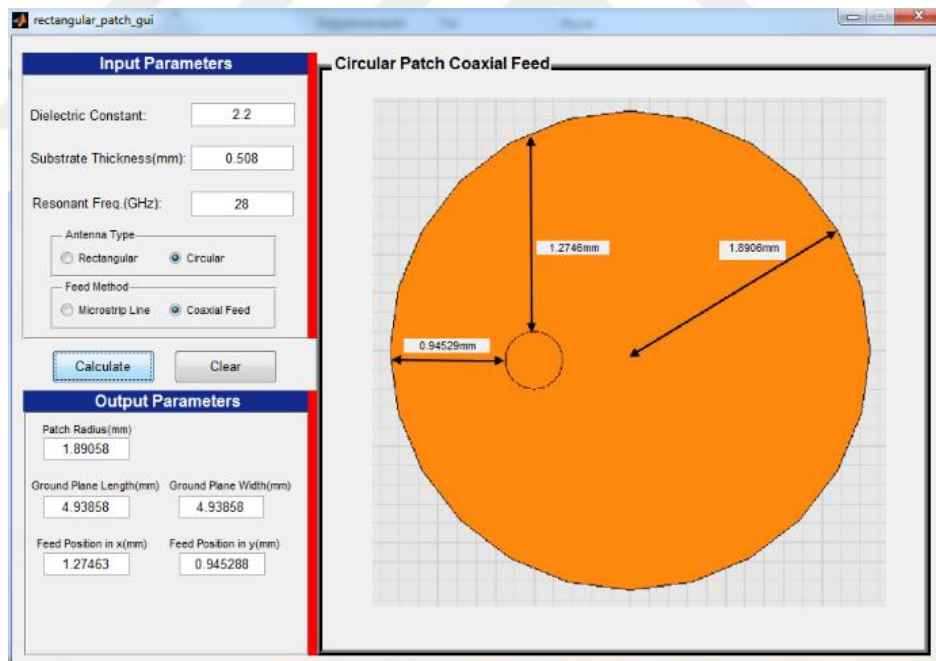


Figure 70 Circular Patch Antenna fed with Coaxial Feed Method

CHAPTER 4

CONCLUSION

In this thesis, three different types of patch antenna are designed to be used for next generation (5G) mobile networks. All of the antennas are designed to resonate at 28 GHz and simulated by HFSS 12.1. The dimensions of radiating patch, substrate, ground plane, feeding method and feeding point position are investigated in terms of the effects on the antenna performance.

When the antennas fed with microstrip feed line method are compared, it is seen that the best result is obtained from rectangular patch antenna. The return loss and VSWR values of rectangular patch are the best in all antennas fed with microstrip feed line method. The bandwidth value of rectangular patch antenna is 1.3 GHz where the circular patch antenna's is 1.29 GHz and the Ç-shaped patch antenna's is 800 MHz. When the radiation patterns are compared, it is seen that the rectangular patch antenna has a better result than others.

When the antennas fed with coaxial feed method are compared, it is seen that the best result is obtained from rectangular patch antenna. The return loss value and VSWR values are the best in all antennas fed with microstrip feed line method. The bandwidth value of rectangular patch antenna is 23.7 GHz where the circular patch antenna's is 7.5 GHz and the Ç-shaped patch antenna's is 1.4 GHz. When the radiation patterns are compared, it is seen that the rectangular patch antenna has a better result than others.

In the future, the designed antennas in the scope of this thesis can be printed and the return loss and VSWR values can be measured by using a network analyzer. The obtained results can be compared with the theoretical values in this study. Moreover, the designed antennas can be used to design an antenna array for 5G communication systems especially. In addition to that, the Ç-shaped patch antenna

is designed and analyzed by using rectangular patch antenna formulas in this thesis. It can be designed and analyzed by using circular patch antenna formulas and the obtained results can be compared.

Finally, the feeding methods are compared. The microstrip feed line method has better results in return loss. Their return loss values are lower than the coaxial feed method. The microstrip feed line method has narrower bandwidth than the coaxial feed method.



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- O. Yıldırım and H. D. Başdemir, “Rectangular and Circular Patch Antenna Design for 5G Networks and Investigation of Microstrip Feed Line and Coaxial Feed Methods”, Electrical and Electronic Engineering Conference (EEMKON, 2017), Istanbul.
- O. Yıldırım and H. D. Başdemir, “Wideband Hexagonal Type Antenna Design for 5G Networks”, International Conference on Electrical and Electronics Engineering (ELECO, 2017), Bursa

HOBBIES

Basketball, Fitness, Reading, Movies.

APPENDICES:

APPENDIX A - MATLAB Code

```
function varargout = rectangular_patch_gui(varargin)
% RECTANGULAR_PATCH_GUI MATLAB code for rectangular_patch_gui.fig
%   RECTANGULAR_PATCH_GUI, by itself, creates a new
RECTANGULAR_PATCH_GUI or raises the existing
%   singleton*.
%
%   H = RECTANGULAR_PATCH_GUI returns the handle to a new
RECTANGULAR_PATCH_GUI or the handle to
%   the existing singleton*.
%
%
RECTANGULAR_PATCH_GUI('CALLBACK',hObject,eventData,handles,...)
calls the local
%   function named CALLBACK in RECTANGULAR_PATCH_GUI.M with the
given input arguments.
%
%   RECTANGULAR_PATCH_GUI('Property','Value',...) creates a new
RECTANGULAR_PATCH_GUI or raises the
%   existing singleton*. Starting from the left, property value pairs are
%   applied to the GUI before rectangular_patch_gui_OpeningFcn gets called. An
%   unrecognized property name or invalid value makes property application
%   stop. All inputs are passed to rectangular_patch_gui_OpeningFcn via
varargin.
%
%   *See GUI Options on GUIDE's Tools menu. Choose "GUI allows only one
%   instance to run (singleton)".
%
% See also: GUIDE, GUIDATA, GUIHANDLES

% Edit the above text to modify the response to help rectangular_patch_gui

% Last Modified by GUIDE v2.5 07-Jun-2017 14:07:40
```

```

% Begin initialization code - DO NOT EDIT
gui_Singleton = 1;
gui_State = struct('gui_Name',    mfilename, ...
                  'gui_Singleton', gui_Singleton, ...
                  'gui_OpeningFcn', @rectangular_patch_gui_OpeningFcn, ...
                  'gui_OutputFcn', @rectangular_patch_gui_OutputFcn, ...
                  'gui_LayoutFcn', [] , ...
                  'gui_Callback', []);
if nargin && ischar(varargin{1})
    gui_State.gui_Callback = str2func(varargin{1});
end

if narginout
    [varargout{1:nargout}] = gui_mainfcn(gui_State, varargin{:});
else
    gui_mainfcn(gui_State, varargin{:});
end
% End initialization code - DO NOT EDIT
% --- Executes just before rectangular_patch_gui is made visible.

function rectangular_patch_gui_OpeningFcn(hObject, eventdata, handles, varargin)
% This function has no output args, see OutputFcn.
% hObject    handle to figure
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% varargin   command line arguments to rectangular_patch_gui (see VARARGIN)
% Choose default command line output for rectangular_patch_gui
handles.output = hObject;

% Start program at the center of the screen
movegui(gcf,'center');

    set(handles.uipanel11_results_coax,'Visible','on');
    set(handles.uipanel_coax,'Visible','on');
    set(handles.uipanel_coax,'Title','Rectangular and Circular Patch Antenna
Calculator');
    set(handles.uipanel_coax,'TitlePosition','centertop');
    imshow('Untitled.png','Parent',handles.axes7_coax);

%microstrip feed line static text boxes on the figure
set(handles.text_mll,'Visible','off');
set(handles.text_mlw,'Visible','off');
set(handles.text_mlg,'Visible','off');

```

```

set(handles.text_fll,'Visible','off');
set(handles.text_mlww,'Visible','off');
set(handles.text_d,'Visible','off');
set(handles.text_mlp,'Visible','off');
%Coaxial feed static text boxes on the figure
set(handles.text_wg_coax,'Visible','off');
set(handles.text_wp_coax,'Visible','off');
set(handles.text_lg_coax,'Visible','off');
set(handles.text_lp_coax,'Visible','off');
set(handles.text_xf_coax,'Visible','off');
set(handles.text_yf_coax,'Visible','off');

%circular patch static text boxes on the figure
set(handles.text_radius,'Visible','off');
set(handles.edit_radius,'Visible','off');
set(handles.text_coax_pos,'Visible','off');
set(handles.text_coax_pos1,'Visible','off');
set(handles.text_radius1,'Visible','off');
set(handles.text_gap_cir,'Visible','off');
set(handles.text_inset_cir,'Visible','off');
set(handles.text_pl_cir,'Visible','off');
set(handles.text_mlww_cir,'Visible','off');

% Update handles structure
guidata(hObject, handles);

% UIWAIT makes rectangular_patch_gui wait for user response (see UIRESUME)
% uiwait(handles.figure1);
% --- Outputs from this function are returned to the command line.

function varargout = rectangular_patch_gui_OutputFcn(hObject, eventdata,
handles)
% varargout cell array for returning output args (see VARARGOUT);
% hObject handle to figure
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)
% Get default command line output from handles structure
varargout{1} = handles.output;

% --- Executes on button press in Calculate.
function Calculate_Callback(hObject, eventdata, handles)
% hObject handle to Calculate (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB

```



```

% handles  structure with handles and user data (see GUIDATA)

%taking values as input
er = str2double(get(handles.Dielectric,'String'));
h = str2double(get(handles.Substrate,'String'));
fr = str2double(get(handles.Resonant_f,'String'));

%warning box
if get(handles.radiobutton_ML,'Value') == 0
    if get(handles.radiobutton_CF,'Value') == 0
        warndlg('Please Select a Feeding Method','!! Warning !!')
    end
end
end

if get(handles.radiobutton_rec,'Value') == 0
    if get(handles.radiobutton_cir,'Value') == 0
        warndlg('Please Select an Antenna Type','!! Warning !!')
    end
end
end

%resonant frequency
f = fr*1e9;

%Width
W = ((3e11/(2*f))*(sqrt(2/(er+1))));

%effective dielectric constant
ereff = ((er+1)/2)+((er-1)/2)*(1+((12*h)/W))^-0.5;

%extension in L
delta_L = (0.412*h)*((ereff+0.3)*((W/h)+0.264))/((ereff-0.258)*((W/h)+0.8));

%Effective Length
L_eff = (3e8/(2*f*sqrt(ereff)))*1000;

%Actual Length
L = L_eff-(2*delta_L);

%Input Impedance
lam = (3e8/f)*1000;
k0 = (2*pi)/lam;
x = k0*W;
i1 = -2+cos(x)+(x*sinint(x))+(sin(x)/x);

```

```

g1 = i1/(120*pi*pi); %conductance
a =
@(th)(((sin((x./2).*cos(th))./cos(th)).^2).*(besselj(0,(k0.*L.*sin(th)))).*(sin(th)).^3)
;
a1 = integral(a,0,pi);
g12 = a1/(120*pi*pi); %siemens
r_in = 1/(2*(g1+g12)); %ohm

%matched impedance
z = 50;

%inset feed position
inset = (L/pi)*(acos(sqrt(z/r_in))); %mm

%ground plane and substrate length and width
Lg_min = 6*h+L;
Wg_min = 6*h+W;

%Feed Line Width
B = (377*pi)/(2*z*sqrt(er));
m1 = 2*B-1;
m = log(m1);
n1 = B-1;
n = log(n1);
Width = (2*h/pi)*(B-1-m+(((er-1)/(2*er))^(n+(0.39-(0.61/er)))));

%Feed Line Length
mfl = (3e11/f)*(1/(4*sqrt(ereff)));
mfl_1 = mfl - inset;

%Feed Line Gap
g = (3e11/sqrt(2*ereff))*((4.65e-12)/fr);

%Feed Line Position
flp = W/2;

%position of coaxial feed point for rectangular patch
Xf = L/(sqrt(er));
Yf = W/2;

%Circular Patch Radius Calculation
h1 = h/10;
F = 8.791e9/(f*sqrt(er));

```

```

a = 10*(F/sqrt((1 + ((2*h1)/(pi*er*F))*(log((pi*F)/(2*h1)) + 1.7726)))));
%position of coaxial feed point for circular patch
Xfc = a/(sqrt(er));
Yfc = a/2;

%Circular Patch Ground Dimension
Lg_cir = 6*h + a;

if get(handles.radiobutton_rec,'Value') == 1
    if get(handles.radiobutton_ML,'Value') == 1

        set(handles.uipanel_coax,'Title','Rectangular Patch Microstrip Feed Line');
        set(handles.uipanel_coax,'TitlePosition','lefttop');
        set(handles.text17,'String','Feed Line Width(mm)');
        set(handles.text18,'String','Feed Line Gap(mm)');

        %microstrip feed line static text boxes on the figure
        set(handles.text_mll,'Visible','on');
        set(handles.text_mlw,'Visible','on');
        set(handles.text_mlg,'Visible','on');
        set(handles.text_fll,'Visible','on');
        set(handles.text_mlww,'Visible','on');
        set(handles.text_d,'Visible','on');
        set(handles.text_mlp,'Visible','on');
        set(handles.text_mfl,'Visible','on');
        set(handles.edit_mfl,'Visible','on');
        set(handles.text16,'Visible','on');
        set(handles.edit_ifp,'Visible','on');
        set(handles.edit_pl,'Visible','on');
        set(handles.text15,'Visible','on');
        set(handles.PW_text,'Visible','on');
        set(handles.edit_radius,'Visible','off');
        set(handles.edit_pw,'Visible','on');
        set(handles.text_coax_pos,'Visible','off');
        set(handles.text_coax_pos1,'Visible','off');

        %Coaxial feed static text boxes on the figure
        set(handles.text_wg_coax,'Visible','off');
        set(handles.text_wp_coax,'Visible','off');
        set(handles.text_lg_coax,'Visible','off');
        set(handles.text_lp_coax,'Visible','off');
        set(handles.text_xf_coax,'Visible','off');
        set(handles.text_yf_coax,'Visible','off');

```

```

set(handles.text_radius,'Visible','off');
set(handles.text_radius1,'Visible','off');
set(handles.text_mlw_cir,'Visible','off');
set(handles.text_gap_cir,'Visible','off');
set(handles.text_inset_cir,'Visible','off');
set(handles.text_pl_cir,'Visible','off');

```

```

%microstrip feed line value assign for panel

```

```

set(handles.edit_pw, 'String', W);
set(handles.edit_pl, 'String', L);
set(handles.edit_ifp, 'String', inset);
set(handles.edit_flw, 'String', Width);
set(handles.edit_flg, 'String', g);
set(handles.edit_gpl, 'String', Lg_min);
set(handles.edit_gpw, 'String', Wg_min);
set(handles.edit_mfl, 'String', mfl);
imshow('ml.png', 'Parent', handles.axes7_coax);

```

```

%microstrip feed line value assign for static text boxes on the figure

```

```

set(handles.text_mll,'String', [num2str(L), 'mm']);
set(handles.text_mlp,'String', [num2str(fl_p), 'mm']);
set(handles.text_mlw,'String', [num2str(W),' mm']);
set(handles.text_mlg,'String', [num2str(g),' mm']);
set(handles.text_fll,'String', [num2str(mfl_1), 'mm']);
set(handles.text_mlww,'String', [num2str(Width),' mm']);
set(handles.text_d,'String', [num2str(inset),' mm']);

```

```

elseif get(handles.radiobutton_CF,'Value') == 1

```

```

set(handles.text_coax_pos,'Visible','off');
set(handles.text_coax_pos1,'Visible','off');
set(handles.edit_ifp,'Visible','off');
set(handles.edit_mfl,'Visible','off');
set(handles.text16,'Visible','off');
set(handles.text_mfl,'Visible','off');
set(handles.text_radius,'Visible','off');
set(handles.edit_pl,'Visible','on');
set(handles.text15,'Visible','on');
set(handles.PW_text,'Visible','on');
set(handles.edit_radius,'Visible','off');
set(handles.edit_pw,'Visible','on');
set(handles.text17,'String','Feed Position in x(mm)');
set(handles.text18,'String','Feed Position in y(mm)');

```

```

set(handles.uipanel_coax,'Title','Rectangular Patch Coaxial Feed');
set(handles.uipanel_coax,'TitlePosition','lefttop');
set(handles.edit_pw,'String',W);
set(handles.edit_pl,'String',L);
set(handles.edit_gpl,'String',Lg_min);
set(handles.edit_gpw,'String',Wg_min);
set(handles.edit_flw,'String',Xf);
set(handles.edit_flg,'String',Yf);
imshow('coax.jpg','Parent',handles.axes7_coax);

```

```

%Coaxial feed static text value assign for panel

```

```

set(handles.text_wg_coax,'Visible','on');
set(handles.text_wp_coax,'Visible','on');
set(handles.text_lg_coax,'Visible','on');
set(handles.text_lp_coax,'Visible','on');
set(handles.text_xf_coax,'Visible','on');
set(handles.text_yf_coax,'Visible','on');

```

```

%microstrip feed line static text boxes on the figure

```

```

set(handles.text_mll,'Visible','off');
set(handles.text_mlw,'Visible','off');
set(handles.text_mlg,'Visible','off');
set(handles.text_fll,'Visible','off');
set(handles.text_mlww,'Visible','off');
set(handles.text_d,'Visible','off');
set(handles.text_mlp,'Visible','off');
set(handles.text_radius1,'Visible','off');
set(handles.text_mlw_cir,'Visible','off');
set(handles.text_gap_cir,'Visible','off');
set(handles.text_pl_cir,'Visible','off');
set(handles.text_inset_cir,'Visible','off');

```

```

%coaxial feed value assign for static text boxes on the figure

```

```

set(handles.text_wg_coax,'String',[num2str(Wg_min),'mm']);
set(handles.text_wp_coax,'String',[num2str(L),'mm']);
set(handles.text_lg_coax,'String',[num2str(Lg_min),'mm']);
set(handles.text_lp_coax,'String',[num2str(W),'mm']);
set(handles.text_xf_coax,'String',[num2str(Xf),'mm']);
set(handles.text_yf_coax,'String',[num2str(Yf),'mm']);

```

```

end

```

```

elseif get(handles.radiobutton_cir,'Value') == 1
    if get(handles.radiobutton_ML,'Value') == 1

```

```

set(handles.uipanel_coax,'Title','Circular Patch Microstrip Feed Line');
set(handles.uipanel_coax,'TitlePosition','centertop');
set(handles.text17,'String','Feed Line Width(mm)');
set(handles.text18,'String','Feed Line Gap(mm)');
set(handles.text_coax_pos,'Visible','off');
set(handles.text_coax_pos1,'Visible','off');
set(handles.PW_text,'Visible','off');
set(handles.edit_pw,'Visible','off');
set(handles.text15,'Visible','off');
set(handles.edit_pl,'Visible','off');
set(handles.text_wg_coax,'Visible','off');
set(handles.text_wp_coax,'Visible','off');
set(handles.text_lg_coax,'Visible','off');
set(handles.text_lp_coax,'Visible','off');
set(handles.text_xf_coax,'Visible','off');
set(handles.text_yf_coax,'Visible','off');
set(handles.text_mll,'Visible','off');
set(handles.text_mlw,'Visible','off');
set(handles.text_mlg,'Visible','off');
set(handles.text_fll,'Visible','off');
set(handles.text_mlww,'Visible','off');
set(handles.text_d,'Visible','off');
set(handles.text_mlp,'Visible','off');
set(handles.text_radius,'Visible','on');
set(handles.edit_radius,'Visible','on');
set(handles.text_mfl,'Visible','on');
set(handles.edit_mfl,'Visible','on');
set(handles.text16,'Visible','on');
set(handles.edit_ifp,'Visible','on');
imshow('circular.jpg','Parent',handles.axes7_coax);
set(handles.text_radius1,'Visible','on');
set(handles.text_mlw_cir,'Visible','on');
set(handles.text_pl_cir,'Visible','on');
set(handles.text_gap_cir,'Visible','on');
set(handles.text_inset_cir,'Visible','on');

```

%circular patch with microstrip feed line value assign for panel

```

set(handles.edit_radius,'String',a);
set(handles.edit_ifp,'String',inset);
set(handles.edit_flw,'String',Width);
set(handles.edit_flg,'String',g);
set(handles.edit_gpl,'String',Lg_cir);
set(handles.edit_gpw,'String',Lg_cir);

```

```
set(handles.edit_mfl, 'String', mfl);
```

%circular patch with microstrip feed line value assign for static text boxes on the figure

```
set(handles.text_radius1, 'String', [num2str(a), 'mm']);  
set(handles.text_mlw_cir, 'String', [num2str(Width), 'mm']);  
set(handles.text_pl_cir, 'String', [num2str(mfl), 'mm']);  
set(handles.text_inset_cir, 'String', [num2str(inset), 'mm']);  
set(handles.text_gap_cir, 'String', [num2str(g), 'mm']);
```

```
elseif get(handles radiobutton_CF, 'Value') == 1
```

```
set(handles.uipanel_coax, 'Title', 'Circular Patch Coaxial Feed');  
set(handles.uipanel_coax, 'TitlePosition', 'lefttop');
```

%circular patch with coaxial feed value assign for panel

```
set(handles.PW_text, 'Visible', 'off');  
set(handles.edit_pw, 'Visible', 'off');  
set(handles.text15, 'Visible', 'off');  
set(handles.edit_pl, 'Visible', 'off');  
set(handles.text_mlw_cir, 'Visible', 'off');  
set(handles.text_pl_cir, 'Visible', 'off');  
set(handles.text_gap_cir, 'Visible', 'off');  
set(handles.text_inset_cir, 'Visible', 'off');  
set(handles.edit_ifp, 'Visible', 'off');  
set(handles.edit_mfl, 'Visible', 'off');  
set(handles.text16, 'Visible', 'off');  
set(handles.text_mfl, 'Visible', 'off');  
set(handles.text_mll, 'Visible', 'off');  
set(handles.text_mlw, 'Visible', 'off');  
set(handles.text_mlg, 'Visible', 'off');  
set(handles.text_fll, 'Visible', 'off');  
set(handles.text_mlww, 'Visible', 'off');  
set(handles.text_d, 'Visible', 'off');  
set(handles.text_mlp, 'Visible', 'off');  
set(handles.text_radius, 'Visible', 'on');  
set(handles.text_coax_pos, 'Visible', 'on');  
set(handles.text_coax_pos1, 'Visible', 'on');  
set(handles.edit_radius, 'Visible', 'on');  
set(handles.text_radius1, 'Visible', 'on');  
set(handles.text17, 'String', 'Feed Position in x(mm)');  
set(handles.text18, 'String', 'Feed Position in y(mm)');  
set(handles.text_wg_coax, 'Visible', 'off');
```

```

set(handles.text_wp_coax,'Visible','off');
set(handles.text_lg_coax,'Visible','off');
set(handles.text_lp_coax,'Visible','off');
set(handles.text_xf_coax,'Visible','off');
set(handles.text_yf_coax,'Visible','off');
imshow('circular_coax.jpg', 'Parent', handles.axes7_coax);

```

```

%circular patch with microstrip feed line value assign for panel

```

```

set(handles.edit_radius, 'String', a);
set(handles.edit_gpl, 'String', Lg_cir);
set(handles.edit_gpw, 'String', Lg_cir);
set(handles.edit_flw, 'String', Xfc);
set(handles.edit_flg, 'String', Yfc);

```

```

%circular patch with coaxial feed value assign for static text boxes on the
figure

```

```

set(handles.text_radius1,'String', [num2str(a), 'mm']);
set(handles.text_coax_pos,'String', [num2str(Xfc), 'mm']);
set(handles.text_coax_pos1,'String', [num2str(Yfc), 'mm']);

```

```

end

```

```

end

```

```

handles.output = hObject;

```

```

% --- Executes on button press in Clear.

```

```

function Clear_Callback(hObject, eventdata, handles)

```

```

% hObject handle to Clear (see GCBO)

```

```

% eventdata reserved - to be defined in a future version of MATLAB

```

```

% handles structure with handles and user data (see GUIDATA)

```

```

set(handles.Dielectric, 'String', '')
set(handles.Substrate, 'String', '')
set(handles.Resonant_f, 'String', '')
set(handles.edit_pw, 'String', '')
set(handles.edit_pl, 'String', '')
set(handles.edit_ifp, 'String', '')
set(handles.edit_flw, 'String', '')
set(handles.edit_flg, 'String', '')
set(handles.edit_gpl, 'String', '')
set(handles.edit_gpw, 'String', '')
set(handles.edit_mfl, 'String', '')
set(handles.edit_radius, 'String', '');

```

```

%Rectangular patch microstrip feed line static text boxes on the figure

```



```

set(handles.text_mll,'Visible','off');
set(handles.text_mlw,'Visible','off');
set(handles.text_mlg,'Visible','off');
set(handles.text_fll,'Visible','off');
set(handles.text_mlww,'Visible','off');
set(handles.text_d,'Visible','off');
set(handles.text_mlp,'Visible','off');

```

%Rectangular patch coaxial feed static text boxes on the figure

```

set(handles.text_wg_coax,'Visible','off');
set(handles.text_wp_coax,'Visible','off');
set(handles.text_lg_coax,'Visible','off');
set(handles.text_lp_coax,'Visible','off');
set(handles.text_xf_coax,'Visible','off');
set(handles.text_yf_coax,'Visible','off');

```

%Circular patch microstrip feed line static text boxes on the figure

```

set(handles.text_gap_cir,'Visible','off');
set(handles.text_mlw_cir,'Visible','off');
set(handles.text_pl_cir,'Visible','off');
set(handles.text_inset_cir,'Visible','off');
set(handles.text_radius1,'Visible','off');

```

%Circular patch coaxial feed static text boxes on the figure

```

set(handles.text_coax_pos,'Visible','off');
set(handles.text_coax_pos1,'Visible','off');
set(handles.uipanel11_results_coax,'Visible','on');
set(handles.uipanel_coax,'Visible','on');
set(handles.uipanel_coax,'Title','Rectangular and Circular Patch Antenna
Calculator');
set(handles.uipanel_coax,'TitlePosition','centertop');
imshow('Untitled.png', 'Parent', handles.axes7_coax);

```

```
handles.output = hObject;
```

```
function Wp_Callback(hObject, eventdata, handles)
```

```

% hObject handle to Wp (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of Wp as text
% str2double(get(hObject,'String')) returns contents of Wp as a double
% --- Executes during object creation, after setting all properties

```

```
function Wp_CreateFcn(hObject, eventdata, handles)
```

```

% hObject   handle to Wp (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function Lp_Callback(hObject, eventdata, handles)
% hObject   handle to Lp (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of Lp as text
% str2double(get(hObject,'String')) returns contents of Lp as a double
% --- Executes during object creation, after setting all properties.

```

```

function Lp_CreateFcn(hObject, eventdata, handles)
% hObject   handle to Lp (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function Inset_feed_Callback(hObject, eventdata, handles)
% hObject   handle to Inset_feed (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of Inset_feed as text
% str2double(get(hObject,'String')) returns contents of Inset_feed as a double
% --- Executes during object creation, after setting all properties.

```

```

function Inset_feed_CreateFcn(hObject, eventdata, handles)
% hObject   handle to Inset_feed (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.

```

```

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function Wfl_Callback(hObject, eventdata, handles)
% hObject    handle to Wfl (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of Wfl as text
% str2double(get(hObject,'String')) returns contents of Wfl as a double
% --- Executes during object creation, after setting all properties.

```

```

function Wfl_CreateFcn(hObject, eventdata, handles)
% hObject    handle to Wfl (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function FL_bosluk_Callback(hObject, eventdata, handles)
% hObject    handle to FL_bosluk (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of FL_bosluk as text
% str2double(get(hObject,'String')) returns contents of FL_bosluk as a double
% --- Executes during object creation, after setting all properties.

```

```

function FL_bosluk_CreateFcn(hObject, eventdata, handles)
% hObject    handle to FL_bosluk (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function Lg_Callback(hObject, eventdata, handles)

```

```

% hObject   handle to Lg (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of Lg as text
% str2double(get(hObject,'String')) returns contents of Lg as a double
% --- Executes during object creation, after setting all properties.

```

```

function Lg_CreateFcn(hObject, eventdata, handles)

```

```

% hObject   handle to Lg (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
    get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function Wg_Callback(hObject, eventdata, handles)

```

```

% hObject   handle to Wg (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of Wg as text
% str2double(get(hObject,'String')) returns contents of Wg as a double
% --- Executes during object creation, after setting all properties.

```

```

function Wg_CreateFcn(hObject, eventdata, handles)

```

```

% hObject   handle to Wg (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
    get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function Dielectric_Callback(hObject, eventdata, handles)

```

```

% hObject   handle to Dielectric (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of Dielectric as text
% str2double(get(hObject,'String')) returns contents of Dielectric as a double

```

```
% --- Executes during object creation, after setting all properties.
```

```
function Dielectric_CreateFcn(hObject, eventdata, handles)
% hObject    handle to Dielectric (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function Substrate_Callback(hObject, eventdata, handles)
% hObject    handle to Substrate (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of Substrate as text
% str2double(get(hObject,'String')) returns contents of Substrate as a double
% --- Executes during object creation, after setting all properties.
```

```
function Substrate_CreateFcn(hObject, eventdata, handles)
% hObject    handle to Substrate (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function Resonant_f_Callback(hObject, eventdata, handles)
% hObject    handle to Resonant_f (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of Resonant_f as text
% str2double(get(hObject,'String')) returns contents of Resonant_f as a double
% --- Executes during object creation, after setting all properties.
```

```
function Resonant_f_CreateFcn(hObject, eventdata, handles)
% hObject    handle to Resonant_f (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
```

```
% handles empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
```

```
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function Impedance_Callback(hObject, eventdata, handles)
% hObject handle to Impedance (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of Impedance as text
% str2double(get(hObject,'String')) returns contents of Impedance as a double
% --- Executes during object creation, after setting all properties.
```

```
function Impedance_CreateFcn(hObject, eventdata, handles)
% hObject handle to Impedance (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end
```

```
function edit_pw_Callback(hObject, eventdata, handles)
% hObject handle to edit_pw (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of edit_pw as text
% str2double(get(hObject,'String')) returns contents of edit_pw as a double
% --- Executes during object creation, after setting all properties.
```

```
function edit_pw_CreateFcn(hObject, eventdata, handles)
% hObject handle to edit_pw (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
```



```

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function edit_pl_Callback(hObject, eventdata, handles)
% hObject    handle to edit_pl (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of edit_pl as text
% str2double(get(hObject,'String')) returns contents of edit_pl as a double
% --- Executes during object creation, after setting all properties.

```

```

function edit_pl_CreateFcn(hObject, eventdata, handles)
% hObject    handle to edit_pl (see GCBO)
% eventdata  reserved - to be defined in a future version of MATLAB
% handles    empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.

```

```

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

% function edit15_Callback(hObject, eventdata, handles)
% % hObject    handle to edit15 (see GCBO)
% % eventdata  reserved - to be defined in a future version of MATLAB
% % handles    structure with handles and user data (see GUIDATA)
% % Hints: get(hObject,'String') returns contents of edit15 as text
% % str2double(get(hObject,'String')) returns contents of edit15 as a double
% % --- Executes during object creation, after setting all properties.

```

```

% function edit15_CreateFcn(hObject, eventdata, handles)
% % hObject    handle to edit15 (see GCBO)
% % eventdata  reserved - to be defined in a future version of MATLAB
% % handles    empty - handles not created until after all CreateFcns called
% % Hint: edit controls usually have a white background on Windows.
% %    See ISPC and COMPUTER.
% if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
%     set(hObject,'BackgroundColor','white');
% end

```

```

function edit16_Callback(hObject, eventdata, handles)
% hObject    handle to edit16 (see GCBO)

```

```

% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of edit16 as text
%       str2double(get(hObject,'String')) returns contents of edit16 as a double
% --- Executes during object creation, after setting all properties.

```

```

function edit16_CreateFcn(hObject, eventdata, handles)

```

```

% hObject handle to edit16 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function edit_gpl_Callback(hObject, eventdata, handles)

```

```

% hObject handle to edit_gpl (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of edit_gpl as text
%       str2double(get(hObject,'String')) returns contents of edit_gpl as a double
% --- Executes during object creation, after setting all properties.

```

```

function edit_gpl_CreateFcn(hObject, eventdata, handles)

```

```

% hObject handle to edit_gpl (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function edit_gpw_Callback(hObject, eventdata, handles)

```

```

% hObject handle to edit_gpw (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of edit_gpw as text
%       str2double(get(hObject,'String')) returns contents of edit_gpw as a double
% --- Executes during object creation, after setting all properties.

```



```

function edit_gpw_CreateFcn(hObject, eventdata, handles)
% hObject   handle to edit_gpw (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
%    See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function edit19_Callback(hObject, eventdata, handles)
% hObject   handle to edit19 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of edit19 as text
%    str2double(get(hObject,'String')) returns contents of edit19 as a double
% --- Executes during object creation, after setting all properties.

```

```

function edit19_CreateFcn(hObject, eventdata, handles)
% hObject   handle to edit19 (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
%    See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function edit21_Callback(hObject, eventdata, handles)
% hObject   handle to edit_pl (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of edit_pl as text
%    str2double(get(hObject,'String')) returns contents of edit_pl as a double
% --- Executes during object creation, after setting all properties.

```

```

function edit21_CreateFcn(hObject, eventdata, handles)
% hObject   handle to edit_pl (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles   empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.

```

```

% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function edit23_Callback(hObject, eventdata, handles)
% hObject handle to edit_gpl (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of edit_gpl as text
% str2double(get(hObject,'String')) returns contents of edit_gpl as a double
% --- Executes during object creation, after setting all properties.

```

```

function edit23_CreateFcn(hObject, eventdata, handles)
% hObject handle to edit_gpl (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function edit24_Callback(hObject, eventdata, handles)
% hObject handle to edit_pw (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of edit_pw as text
% str2double(get(hObject,'String')) returns contents of edit_pw as a double
% --- Executes during object creation, after setting all properties.

```

```

function edit24_CreateFcn(hObject, eventdata, handles)
% hObject handle to edit_pw (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.
if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function edit_flw_Callback(hObject, eventdata, handles)
% hObject handle to edit_flw (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of edit_flw as text
% str2double(get(hObject,'String')) returns contents of edit_flw as a double
% --- Executes during object creation, after setting all properties.

```

```

function edit_flw_CreateFcn(hObject, eventdata, handles)
% hObject handle to edit_flw (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.

```

```

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function edit_flg_Callback(hObject, eventdata, handles)
% hObject handle to edit_flg (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of edit_flg as text
% str2double(get(hObject,'String')) returns contents of edit_flg as a double
% --- Executes during object creation, after setting all properties.

```

```

function edit_flg_CreateFcn(hObject, eventdata, handles)
% hObject handle to edit_flg (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles empty - handles not created until after all CreateFcns called
% Hint: edit controls usually have a white background on Windows.
% See ISPC and COMPUTER.

```

```

if ispc && isequal(get(hObject,'BackgroundColor'),
get(0,'defaultUicontrolBackgroundColor'))
    set(hObject,'BackgroundColor','white');
end

```

```

function edit_ifp_Callback(hObject, eventdata, handles)
% hObject handle to edit_ifp (see GCBO)
% eventdata reserved - to be defined in a future version of MATLAB
% handles structure with handles and user data (see GUIDATA)
% Hints: get(hObject,'String') returns contents of edit_ifp as text

```

```
% str2double(get(hObject,'String')) returns contents of edit_ifp as a double  
% --- Executes during object creation, after setting all properties.
```

```
function edit_ifp_CreateFcn(hObject, eventdata, handles)  
% hObject handle to edit_ifp (see GCBO)  
% eventdata reserved - to be defined in a future version of MATLAB  
% handles empty - handles not created until after all CreateFcns called  
% Hint: edit controls usually have a white background on Windows.  
% See ISPC and COMPUTER.  
if ispc && isequal(get(hObject,'BackgroundColor'),  
get(0,'defaultUicontrolBackgroundColor'))  
    set(hObject,'BackgroundColor','white');  
end
```

