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Sujet

Frequency Reconfigurable Planar Antennas Using Multiple Pin Diodes

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To everyone who has played a part in this journey, directly or indirectly, I offer my heartfelt appreciation for your contributions and support.

Dedication

Praise be to Allah and enough and prayers be upon beloved Mustafa and his family and those who are loyal be after.
Praise be to God, who helped me to value this stage of my academic career with my grade, it is the fruit of effort and success thanks to him,
To all my generous family who supported me and who still support me,
to those who counted on them in all the great and small, and to my friends and acquaintances whom I respect and respect.
To all those who have had an impact on my life,
and to all those whom my heart loved and my pen forgot.
May this dedication serve as a testament to the immense impact of God, my family, and my friends in shaping my journey, and may it stand as a reminder of the love, support, and faith that have carried me through the challenges and triumphs of this endeavor.

SUMMARY

Abstract

in our master's degree thesis we presented a study about frequency reconfigurable planar antennas using multiple pin diodes. first we created a model design using HFss program ,the design contained 3 pin diodes in total .the antenna was analyzed based on 8 modes in total changing the states of the diodes in each mode.in the next step we created the s11 plot and noticed the reflection coefficient for each one .last step was the 3d radiation pattern and the surface current distribution of the antenna, we commented on each of the results . the conclusion was a small reduction about the theme .

ملخص

في أطروحة ماجستيرنا، قمنا بتقديم دراسة حول هوائيات مستوية قابلة لإعادة التكوين الترددية باستخدام عدة ثنائيات دبوسية. أولاً، قمنا بإنشاء نموذج تصميم باستخدام برنامج HFss، وتضمّن التصميم 3 ثنائيات دبوسية بالمجموع. تم تحليل الهوائي بناءً على 8 أوضاع مختلفة تغيير حالة الثنائيات في كل وضع. في الخطوة التالية، قمنا بإنشاء رسم S11 ولاحظنا معامل الانعكاس لكل واحد. وكانت الخطوة الأخيرة نمط الإشعاع ثلاثي الأبعاد وتوزيع التيار السطحي للهوائي، وقمنا بعرض تعليقنا على كل من النتائج. وكانت الاستنتاجات تتعلق بتقليل طفيف فيما يتعلق بالموضوع.

Résumé

Dans notre mémoire de master, nous avons présenté une étude sur les antennes planaires reconfigurables en fréquence utilisant plusieurs diodes à broche. Tout d'abord, nous avons créé un modèle de conception à l'aide du programme HFss. Le design comprenait un total de 3 diodes à broche. L'antenne a été analysée en fonction de 8 modes différents en changeant les états des diodes dans chaque mode. À l'étape suivante, nous avons créé le tracé S11 et remarqué le coefficient de réflexion pour chacun. La dernière étape était le diagramme de rayonnement 3D et la distribution du courant de surface de l'antenne. Nous avons commenté chacun des résultats. La conclusion a révélé une légère réduction sur le thème étudié.

1. General Introduction

Frequency reconfigurable planar antennas using multiple pin diodes have become increasingly popular due to their ability to operate at multiple frequency bands by selectively tuning their resonant frequency. These antennas consist of a radiating element, transmission lines, and multiple pin diodes. The number of pin diodes depends on the number of frequency bands that the antenna needs to operate in. Pin diodes are preferred over other types of diodes because they have a high switching speed, low loss, and are easy to integrate into the antenna design.

The operation of these antennas is based on the fact that its physical dimensions determine the resonant frequency of an antenna. By changing the dimensions of the antenna, its resonant frequency can be modified. In frequency reconfigurable antennas, the pin diodes are used to change the electrical lengths of the antenna. By applying a specific bias voltage to the pin diodes, they can be switched between two states: "ON" and "OFF". When the diodes are in the "ON" state, they act as a short-circuit, and the length of the transmission line is shortened, causing the resonant frequency of the antenna to increase. Conversely, when the diodes are in the "OFF" state, they act as an open-circuit, and the length of the transmission line is increased, causing the resonant frequency of the antenna to decrease.

The design of these antennas involves changing the dimensions of the radiating element and transmission lines to achieve the desired resonance frequency, radiation pattern, and polarization. The performance of the antenna is also dependent on the characteristics of the pin diodes, such as their capacitance and series inductance and resistance. Therefore, careful selection of the pin diodes is critical to the overall performance of the antenna.

Recent advancements in wireless communication systems necessitate the effective use of transceivers across diverse systems such as WLAN, WiMAX, LTE, 4G, 4.5G, 5G, and more. Antennas play a vital role in transceivers and occupy a significant portion of the system due to their essential function. When incorporating any tuning mechanism, the antenna size further increases. To meet the requirements of current transceivers, antennas must be compact and capable of switching frequencies to comply with the standards. Various methods have been employed to minimize antenna size and enable adjustability for practical applications. A frequency-reconfigurable antenna possesses the ability to alter its resonance band according to user needs. By employing different techniques to modify the surface current

distribution, highly adaptable antennas have been achieved. Specifically, the antenna described in the context converts from a single band (2.4 GHz) to dual bands (2.4 and

5.2 GHz) through the use of a lumped element positioned between the monopole and the parasitic patch. The PIN diode controls the ON and OFF states, corresponding to the two frequency bands.

Chapter 1

1.1 What are the antennas ?

Antennas are devices designed to transmit and/or receive electromagnetic waves, typically in the radio frequency (RF) or microwave frequency range. They are essential components in wireless communication systems, allowing the transmission and reception of signals between devices.

In their basic form, antennas consist of conductive elements that are designed to radiate or capture electromagnetic waves efficiently. When used as a transmitter, an antenna converts electrical signals into electromagnetic waves and radiates them into space. When used as a receiver, an antenna captures incoming electromagnetic waves from the surrounding environment and converts them into electrical signals for further processing.

Antennas come in various shapes, sizes, and configurations, depending on their intended application and operating frequency. They can be categorized into different types such as wire antennas, mainly loop antennas and dipole antennas, planar antennas and parabolic antennas. Each type of antenna has its own radiation pattern, gain, bandwidth, and impedance characteristics, making it suitable for specific communication requirements.

The performance of an antenna is characterized by several key parameters, including impedance, bandwidth, radiation pattern, gain, polarization,...

Antennas find wide applications in various fields, including wireless communication systems (such as Wi-Fi, cellular networks, and satellite communication), broadcasting, radar systems, navigation systems (such as GPS), remote sensing, and many more. They play a crucial role in enabling wireless connectivity, enabling the transmission and reception of information over long distances without the need for physical connections.

In short, antennas are devices that facilitate wireless communication by transmitting or receiving electromagnetic waves. They come in different types and configurations, each with its own unique characteristics, and are vital components in modern communication systems.

1.2 Pin diodes

A PIN diode is a type of diode that consists of three layers: P-type semiconductor material sandwiched between two N-type semiconductor layers. The name "PIN" is derived from the arrangement of these layers.

The "P" layer stands for the P-type material, which is doped with a higher concentration of positively charged carriers (holes). The two "N" layers represent the N-type material, which is doped with a higher concentration of negatively charged carriers (electrons).

The PIN diode operates based on the principle of the P-N junction and exhibits unique characteristics compared to standard diodes. It has a wide, lightly doped intrinsic region (the "I" in PIN), which provides a larger depletion region when reverse-biased. The larger depletion region allows the PIN diode to handle high voltages and handle high-power signals.

The main function of a PIN diode is its ability to act as a variable resistor when biased. When the PIN diode is forward-biased (P-region connected to the positive terminal and N-region connected to the negative terminal), it behaves like a regular diode, conducting current in the forward direction. However, when the PIN diode is reverse-biased (P-region connected to the negative terminal and N-region connected to the positive terminal), it operates in its special mode called the "PIN diode mode."

In the PIN diode mode, the intrinsic region becomes fully depleted, and the PIN diode exhibits a high resistance. This allows the PIN diode to act as a switch or attenuator for high-frequency signals. By varying the reverse-bias voltage across the PIN diode, its resistance can be controlled, enabling the modulation or control of signal power in electronic circuits.

The PIN diode's unique characteristics make it suitable for various applications, including RF and microwave systems, telecommunications, radar systems, power electronics, and optical communications. It is commonly used in RF switches, RF attenuators, microwave phase shifters, RF modulators/demodulators, and as an RF switch in frequency reconfigurable antennas, among other applications.

To summarize, a PIN diode is a three-layer semiconductor device with a wide intrinsic region that can be biased to exhibit variable resistance. It operates based on the P-N junction principle and is widely used in electronic circuits for switching, attenuating, and controlling high-frequency signals.

1.3 Definition of frequency reconfigurable planar antennas using multiple pin diodes :

Frequency reconfigurable planar antennas using multiple PIN diodes refer to a class of antennas that can dynamically change their operating frequency or characteristics by controlling the biasing of multiple PIN diodes. These antennas are designed with PIN diodes strategically placed in the antenna structure, allowing for frequency tuning, bandwidth adjustment, or beam steering without physically altering the antenna's geometry.

The PIN diodes in the antenna structure act as electronically controllable switches. By varying the biasing voltage applied to the diodes, their electrical properties can be modified, thereby altering the resonant frequency or radiation characteristics of the antenna. This configurability enables the antenna to adapt to different frequency bands, communication standards, or interference environments.

The configuration of multiple PIN diodes provides additional flexibility in tuning the antenna's performance. Each PIN diode can be individually controlled, allowing for finer adjustments and enabling multi-band operation or switching between different frequency ranges. The precise positioning of the PIN diodes and their biasing schemes play a crucial role in achieving the desired reconfigurable characteristics of the antenna.

Frequency reconfigurable planar antennas using multiple PIN diodes find applications in various wireless communication systems, including software-defined radios, cognitive radio networks, adaptive beam forming, and frequency-agile devices. They offer the advantage of adaptability to changing communication requirements, making them suitable for scenarios where dynamic frequency tuning or multi-band operation is necessary.

Overall, these antennas leverage the properties of PIN diodes to provide frequency agility and versatility, allowing for efficient and flexible wireless communication in a wide range of frequency bands and operating conditions.

Chapter 2

Introduction

In the present chapter, the simulated results of a reconfigurable microstrip antenna using three pin diodes will be presented. Firstly, the antenna structure is presented together with its dielectric properties and physical dimensions. Simulated results concerning return loss, radiation pattern, electric surface current density on the patch conductor are reported and commented. Multiple modes of operation will be shown and classified in families of double- and three-band operation.

2. Antenna Design Methodology

Figure 1 illustrates the proposed design of a monopole antenna that can change frequency bands, where the geometry of such antenna is shown. The antenna is designed on a commercially available FR-4 substrate, which has a thickness of 1.6 mm and specific electrical properties (relative permittivity, $\varepsilon_r = 4.4$, and loss tangent, tan $\delta = 0.020$).

The main radiating element of the antenna was a monopole in a hook-shaped configuration, and it was augmented with three parasitic patches connected to it via three PIN diodes. The PIN diodes were installed while maintaining a 1 mm gap between the parasitic patches. The overall dimensions of the proposed antenna were $0.21\lambda_g$, $0.35\lambda_g$, and $0.02\lambda_g$, where 'λ_g' represents the wavelength of the operating frequency.

To determine the effective length of the monopole, Equation (1) is employed as a reference.

$$L_f = \frac{C}{4f_r\sqrt{\epsilon_{eff}}} \qquad (1)$$

c is the speed of light in a vacuum,
λg is the guided wavelength,
ee f f is the effective dielectric constant,
w is the width of the substrate,
h is the thickness of the substrate

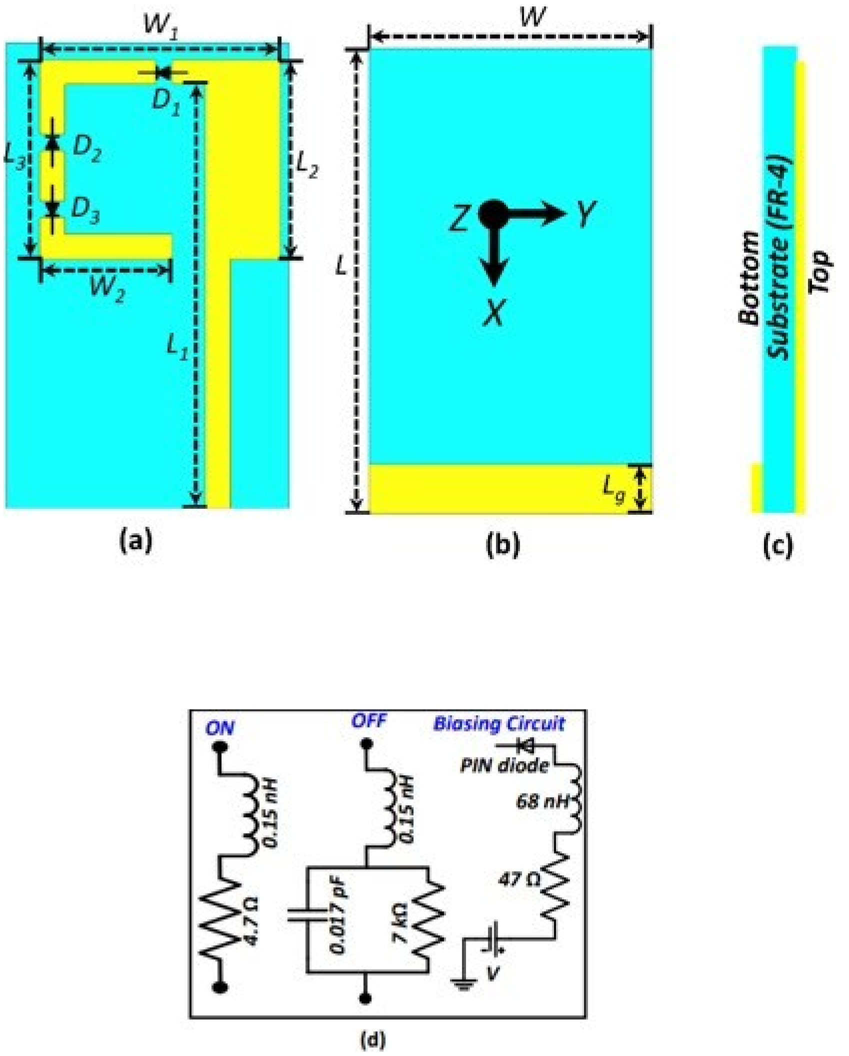

Figure 1. Geometry of the proposed antenna. (a): top view, (b) : bottom view, (c) : side view, and (d) : equivalent circuit model of the PIN diode in the ON, OFF state and the biasing circuit.

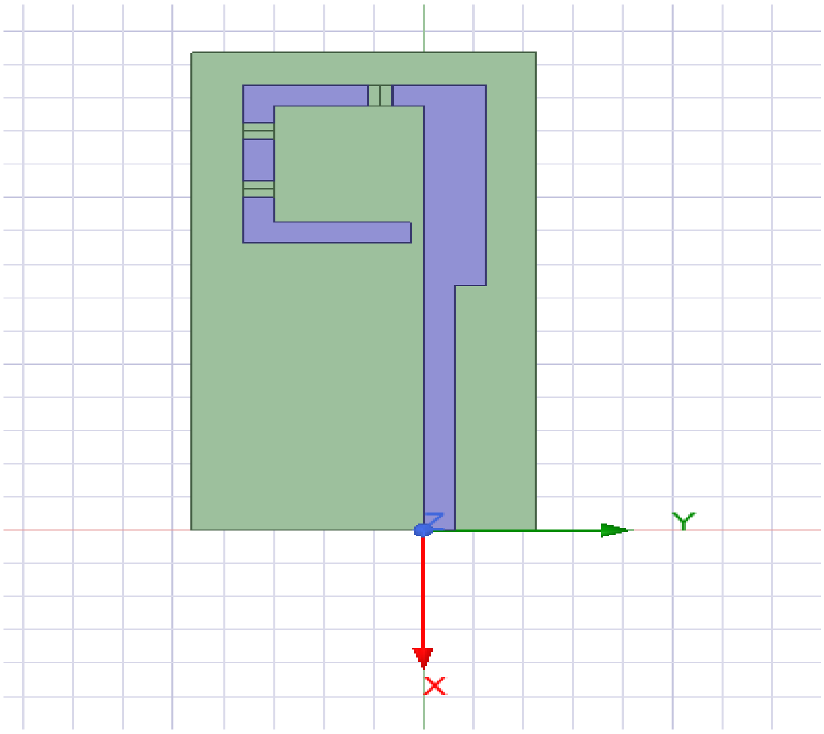

Figure 2. HFSS design used for simulating the reconfigurable planar antenna.

2.1 Parameters of the design

Table 1. Physical dimensions of the created HFSS design.

Parameter	**Value**
Wstrip	1.25mm
L	28mm
L2	12mm
Wsx	1.25mm
Wt	1.25mm
yD1	1.25mm
Gap	1 mm
W1	14.5mm
X1	1mm
X2	2.5mm
X3	2.5mm
W2	8 mm
Wv	1.25mm
Capacitance_Pack	0.1pF
Inductance	0.15nH
STATE	ON or OFF
Resistan ce_Forward	4.7ohm
Resistance_Reverse	7kOhm
Capacitane_Reverse	0.15pF

Capacitance_Reverse	0.017pF
X_Sub	L-Wsx+W_Edge
Y_Sub	W1/2+Wstrip+Wt+2*W_Edge
H	1.6mm
W_Edge	2mm
Lg	2mm

3. Insertion of the coordinates of the design

Ansys HFSS (High-Frequency Structure Simulator) is a commercial electromagnetic simulation software package used for designing and analyzing antennas, microwave circuits, and other electromagnetic systems to insert parameters in HFSS, follow these steps:

1. Open the HFSS project in which you want to add parameters.

2. Click on the “Design Properties” tab in the “Project Manager” pane.

3. in the “Design Properties” pane, click on the “Parameters” tab.

4. Click on the “Add” button to add a new parameter.

5. Enter a name for the parameter, its value, and its units.

6. Click “OK” to save the parameter.

7. To use the parameter in a simulation setup, go to the “Analysis Setup” tab in the “Project Manager” pane.

8. In the “Analysis Setup” pane, select the field for which you want to use the parameter.

9. In the “Properties” tab, select the parameter value field and click on the “…” button.

10. Select the parameter you want to use and click “OK”.

11. The parameter value will be used in the simulation setup.

12. You can edit or delete parameters at any time by going back to the “Design Properties” pane

3.1 Coordinates of the design

Table 2. Coordinates of the design. All the conducting parts of the patch lay in the XOY plane; Z = 0.

Coordinates	X	Y
1	0	0
2	0	Wstrip
3	-(L-(L2+Wsx))	Wstrip
4	-(L-(L2+Wsx))	Wstrip+Wt
5	-(L-(L2+Wsx))-L2	Wstrip+Wt
6	-(L-(L2+Wsx))-L2	-yD1
7	-(L-(L2+Wsx))-L2+Wstrip	-yD1
8	-(L-(L2+Wsx))-L2+Wstrip	0
9	0	0
10	-(L-(L2+Wsx))-L2	-yD1-gap
11	-(L-(L2+Wsx))-L2	-W1/2
12	-(L-(L2+Wsx))-L2+Wstrip+X1	-W1/2
13	-(L-(L2+Wsx))-L2+Wstrip	-W1/2 +Wstrip
14	-(L-(L2+Wsx))-L2+Wstrip	-yD1-gap
15	-(L-(L2+Wsx))-L2	-yD1-gap
16	-(L-(L2+Wsx))-L2+Wstrip+X1+gap	-W1/2
17	-(L-(L2+Wsx))-L2+Wstrip+X1+gap+X2	-W1/2
18	-(L-(L2+Wsx))-L2+Wstrip+X1+gap+X2	-W1/2+Wstrip
19	-(L-(L2+Wsx))-L2+Wstrip+X1+gap	-W1/2+Wstrip
20	-(L-(L2+Wsx))-L2+Wstrip+X1+gap+gap+X2	-W1/2
21	-(L-(L2+Wsx))-L2+Wstrip+X1+gap+X2+X3+Wstrip	-W1/2
22	-(L-(L2+Wsx))-L2+Wstrip+X1+gap+X2+X3+Wstrip	-W1/2+W2-Wv
23	-(L-(L2+Wsx))-L2+Wstrip+X1+gap+X2+X3	-W1/2+W2-Wv
24	-(L-(L2+Wsx))-L2+Wstrip+X1+gap+gap+X2	-W1/2+Wstrip

4. Frequency Configurability

By manipulating the states of the PIN diodes located between the parasitic patches, the proposed antenna achieves frequency configurability. There are a total of eight operating modes available for this antenna design. Table 1 provides an overview of the PIN diodes' states corresponding to each mode.

For the operational modes, the antenna exhibits two or three distinct frequency bands. In Mode 1, when the PIN diodes (D1, D2, and D3) are in the ON state, the antenna functions accordingly. As depicted in Figure 1, the suggested antenna system operates in Mode 1 at frequencies of 2.12 GHz, 3.3 GHz, and 6.31 GHz.

In Mode 2 (D1 = ON, D2 = ON, and D3 = OFF), the same antenna operates at 2.53 GHz (3G advanced/LTE band) and 3.33 GHz (5G sub-6 GHz band). Mode 3 (D1 = ON, D2 = OFF, and D3 = OFF) enables the antenna to cover the frequency ranges of 2.65 GHz (Wi-Fi/WLAN/ISM/Bluetooth band) and 5.03 GHz (5G sub-6 GHz band).

In Mode 4 (D1 = OFF, D2 = OFF, and D3 = OFF), the antenna operates at 2.92 GHz (Airport Surveillance Radar band) and 5.93 GHz (WLAN band).

By manipulating the states of the PIN diodes located between the parasitic patches, the proposed antenna achieves frequency configurability. There are a total of eight operating modes available for this antenna design. Table 1 provides an overview of the PIN diodes' states corresponding to each mode.

Table 3. State of the PIN diodes for various operating modes, initial configuration before classification.

Mode number	D1	D2	D3	Resonance frequency band in GHz
1	1	1	1	2.12, 3.43, and 6.31
2	1	1	0	2.53 and 4.33
3	1	0	0	2.65 and 5.03
4	0	0	0	2.92 and 5.93
5	1	0	1	2.63 and 4.72
6	0	0	1	2.92 and 5.78
7	0	1	0	2.90 and 5.80
8	0	1	1	2.90 and 6.30

As it is noticed from Table 3, eight different modes have been obtained which correspond to the eight possible states of the three PIN diodes. The eight modes are then classified and reduced into six sets, in which mode number 4, 6 and 7 are put in the same set since they have identical lower frequency of 2.90 GHz and similar upper frequency of 5.70 GHz. and the first set contains 3 resonant frequencies; 2.12, 3.43, and 6.31 GHz. The 5 other modes remain in their first initial set. For each resonance frequency, the characteristics of the antenna are presented. In particular, the 3D radiation polar and the electric current distribution on the conductors.

Table 4. State of the PIN diodes for various operating modes after combining similar modes.

Mode number	D1	D2	D3	Resonance frequency band in GHz
1	1	1	1	2.12, 3.43, and 6.31
2	1	1	0	2.53 and 4.33
3	1	0	0	2.65 and 5.03
4	0	0	0	2.92 and 5.93
5	1	0	1	2.63 and 4.72
6	0	1	1	2.90 and 6.30

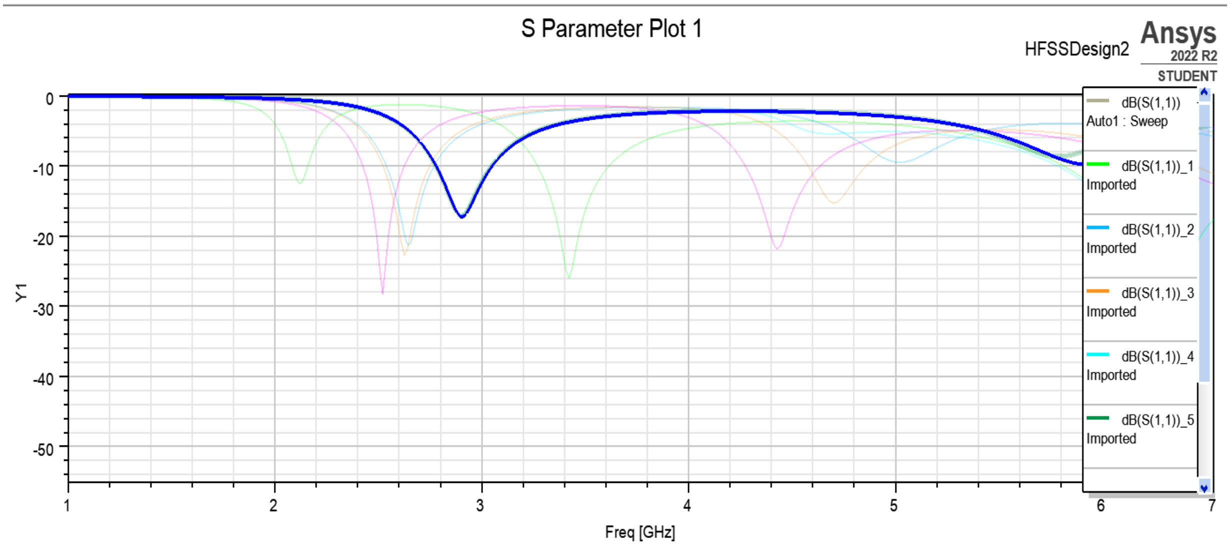

Figure 3 Reflection coefficient of the antenna for different operating modes.

4.1 Frequency bands

In this section, we present the simulated results of the reconfigurable antenna for each mode of operation of the six identified modes above in Table 4.

- Mode 1 : consists of three sub-bands : 2.12, 3.43, and 6.31 GHz

at a frequency of 2.12 GHz, the S11 parameter magnitude is approximately -12.50 dB. At a frequency of 3.43 GHz, the S11 parameter magnitude is approximately -25.98 dB.For the third frequency at 6.31 GHZ the magnitude is -56.98 dB. The same pattern continues for each frequency point, with the S11 parameter magnitude gradually decreasing as the frequency increases negative sign indicates that the magnitude of the S11 parameter is less than 0 dB, which means that there is some reflection occurring at the antenna. A lower magnitude indicates a better match between the antenna and its source, resulting in lower reflection and better performance.

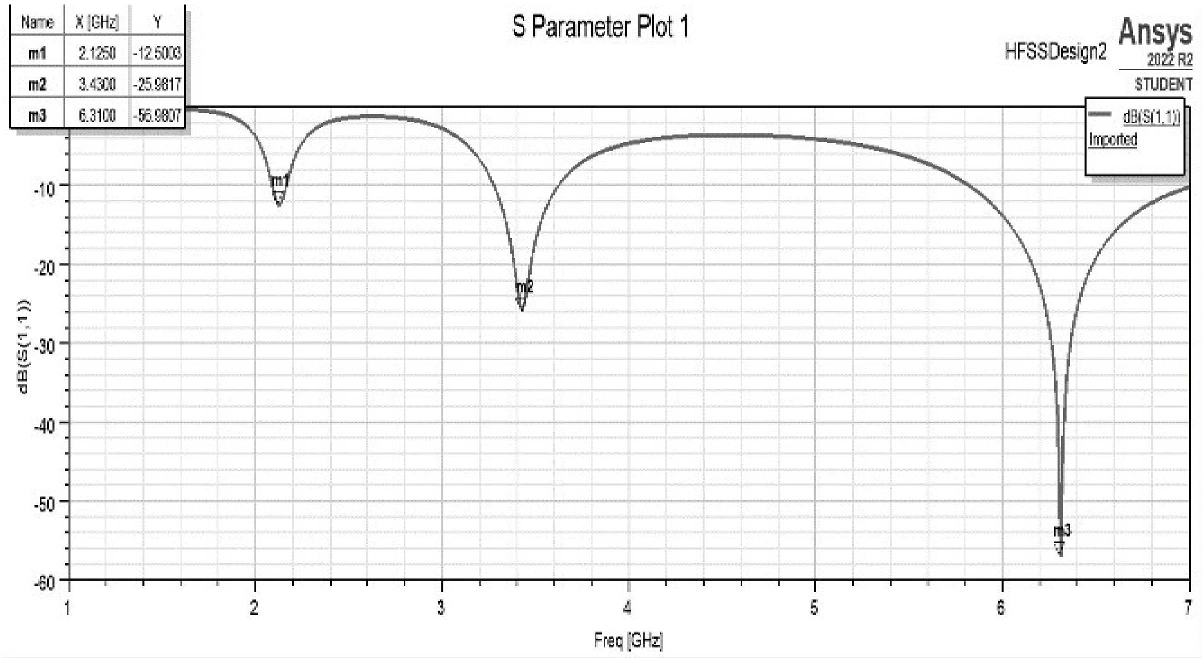

Figure 4 Mode (1) =>111.

- **mode 2** with a state of (110), we only have only two resonant

frequencies at a frequency of 2.53 GHz, the S11 parameter magnitude is approximately -28.25 dB. At a frequency of 4.43 GHz, the S11 parameter magnitude is approximately -21.80 dB. The same pattern continues for each frequency point, with the S11 parameter magnitude gradually decreasing as the frequency increases negative sign indicates that the magnitude of the S11 parameter is less than 0 dB, which means that there is some

reflection occurring at the antenna. A lower magnitude indicates a better match between the antenna and its source, resulting in lower reflection and better performance.

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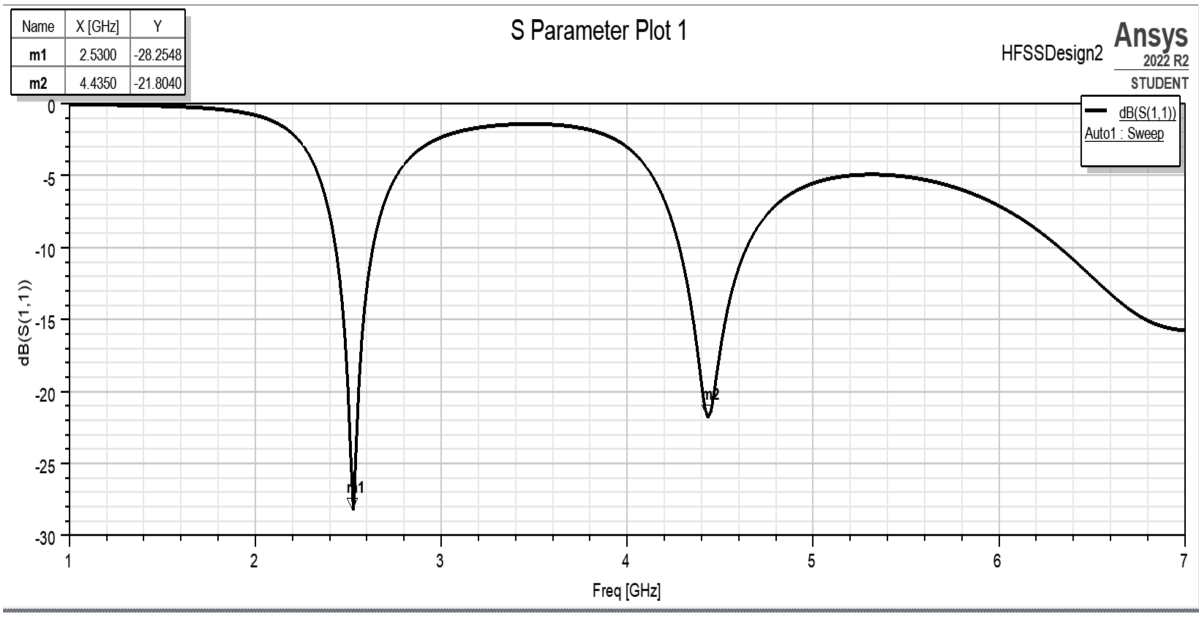

Figure 5. Mode (2) =>110.

Mode 3: the table consists of two columns: "Frequency [GHz]" represents the frequency in gigahertz (GHz) at which the simulation is performed, and "dB(S (1, 1)) " represents the magnitude of the S11 parameter in decibels (dB) at that frequency.
At a frequency of 2.6500 GHz, the S11 parameter magnitude is approximately -21.2702 dB.
At a frequency of 5.0350 GHz, the S11 parameter magnitude is approximately -9.4887 dB.

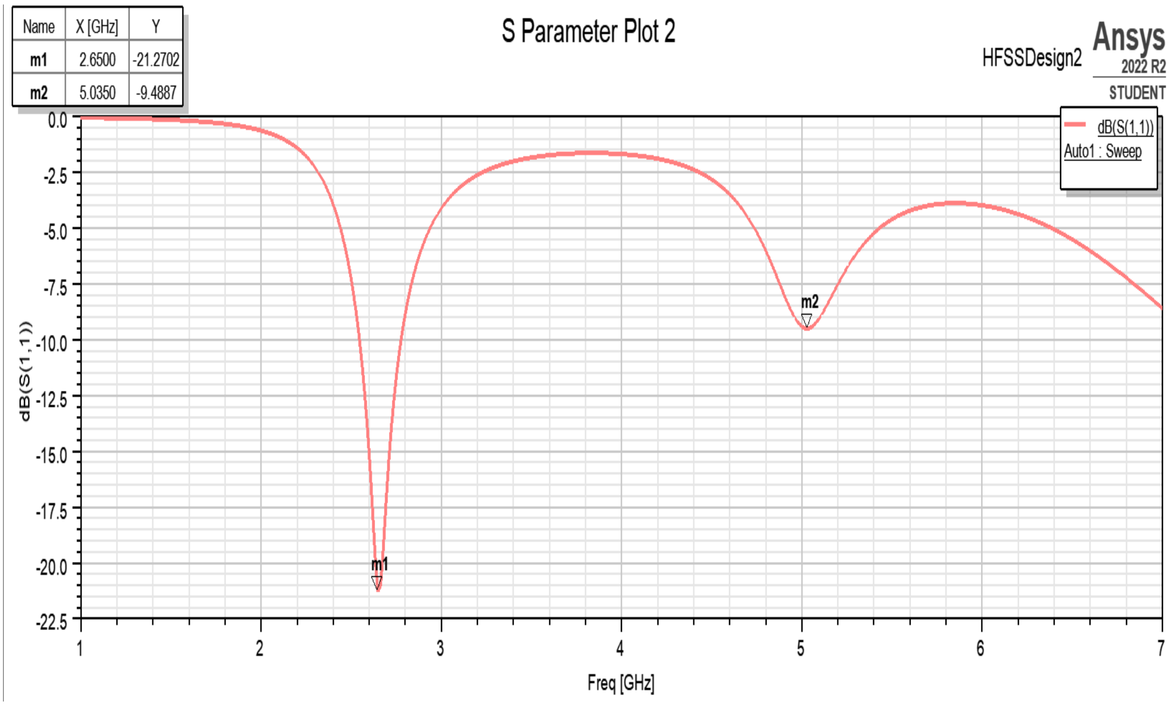

Figure 6. Mode (3) =>100.

- **Mode 4 :**At a frequency of 2.9200 GHz in mode [0;0;0] , the S11

parameter magnitude is approximately-17.2064dB.At a frequency of 5.9350 GHz, the S11 parameter magnitude is approximately -9.7863 dB.

In this case, two peaks are marked as seen in figure 7, as m1 and m2 both with negative values .the slope of the plot on either side of the minimum indicates the rate of change of the reflection coefficient with frequency, which can provide insight into the impedance characteristics of the antenna.

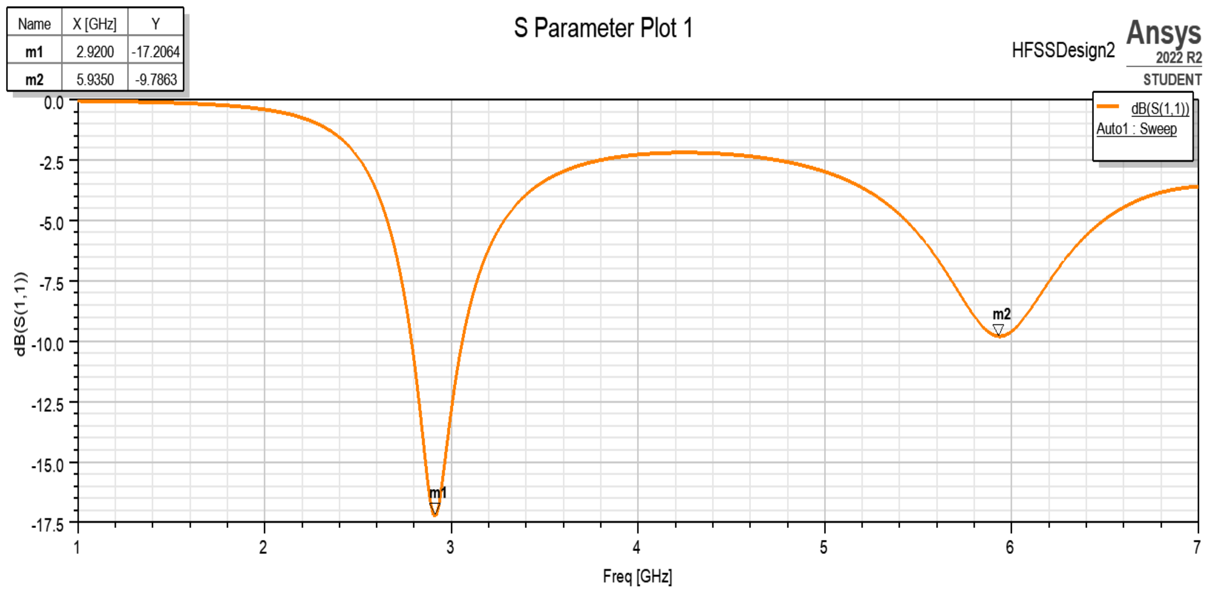

Figure 7: Mode (4) =>000.

- **Mode 5** : which corresponds to mode [1, 0, 1] presented in

figure 8 .the two resonant frequencies here are m1 at a frequency of 2.6350 GHz, the S11 parameter magnitude is approximately -22.6506 dB. Which means the antenna is most efficient here as well as m2 at a frequency of 4.7200 GHz; the S11 parameter magnitude is approximately -15.2071 dB.

The presence of any ripples or irregularities in the plot can indicate issues with the antenna design or fabrication, such as unwanted resonances or parasitic elements.

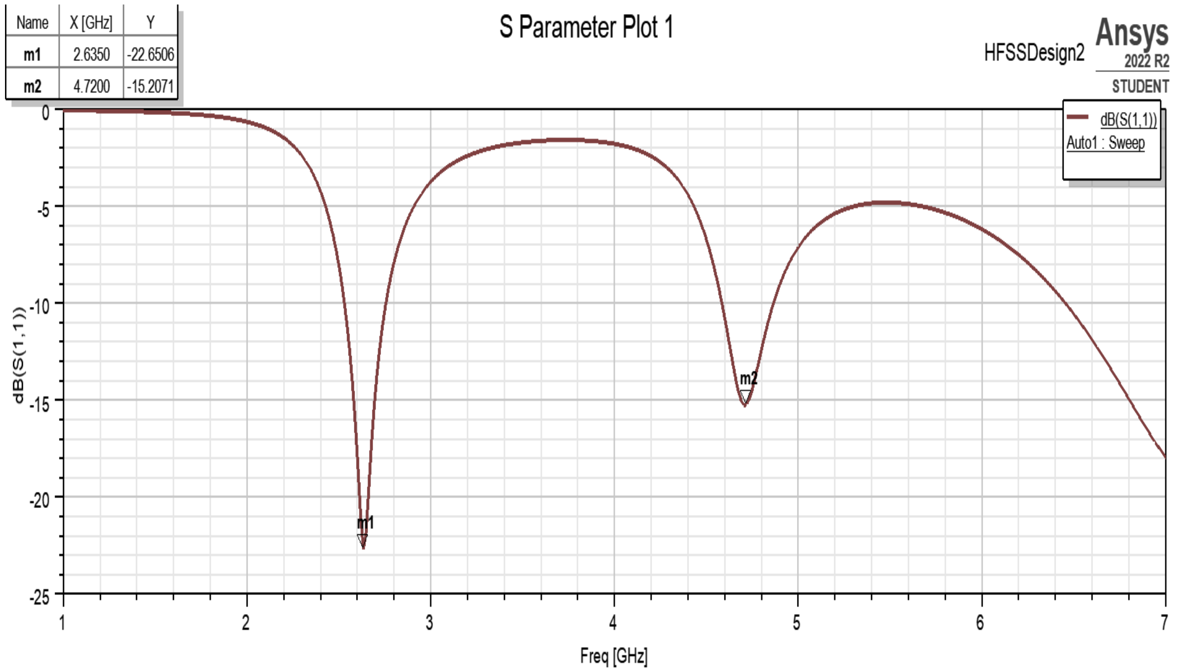

Figure 8: Mode (5) =>101.

- **Mode 6:** or mode [0, 0, 1], the bandwidth in this s11 plot which

can be seen with values under -10 db. At a frequency of 2.9200 GHz, the S11 parameter magnitude is approximately -17.0754 dB.
At a frequency of 5.7850 GHz, the S11 parameter magnitude is approximately -10.3058 dB.

As noticed here the performance of this antenna at this specific mode presents lower values of magnitude, which means the antennas efficiency is high.

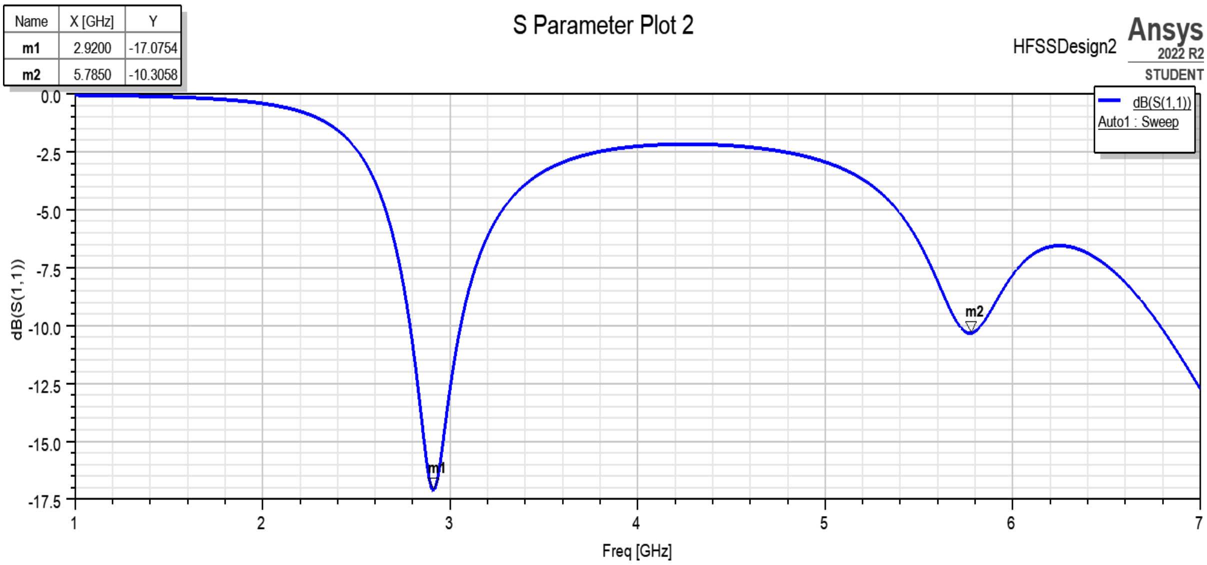

Figure 9: Mode (6) =>001.

- **Mode 7 :** The table consists of two columns: " frequency

[GHz]" represents the frequency in gigahertz (GHz) at which the simulation is performed, and "dB(S(1,1)) []" represents the magnitude of the S11 parameter in decibels (dB) at that frequency.

in mode 7 the plot shows two distinct minimums which are at a frequency of 2.9250 GHz, the S11 parameter magnitude is approximately -17.1270 dB and a frequency of 5.8000 GHz, the S11 parameter magnitude is approximately -8.6260 dB. indicating that the antenna has two resonant frequencies

the shape of the plot, including the location and depth of the minimum ,can be used to design a matching network to improve the performance of the antenna

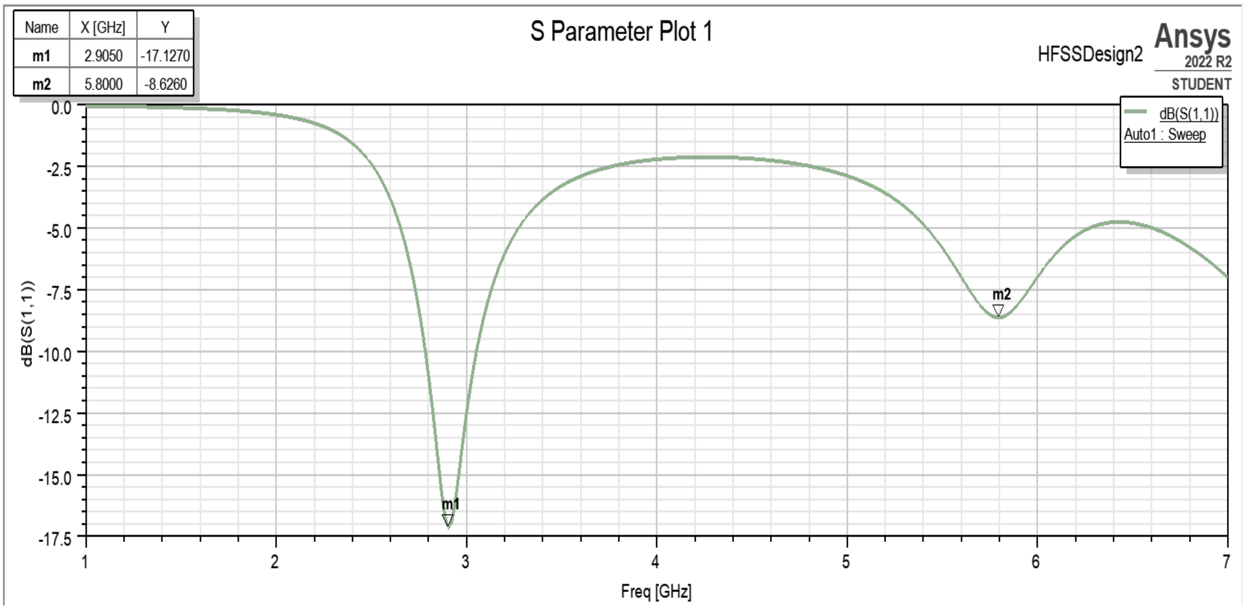

Figure 10 : Mode (7) =>010.

- **Mode 8** with a state of[0,1,1] the two minimums are located at a frequency of 2.9050 GHz, and a magnitude that is approximately -16.9677 dB.

and the second one at a frequency of 6.3100 GHz, the S11 parameter magnitude is approximately -32.7157 dB.which suggests the antenna can operate officiently at both frequencies .

the bandwidth of the antenna can be determined from the plot which is the range of frequencies over which the reflection coefficient is below a certain threshhold .

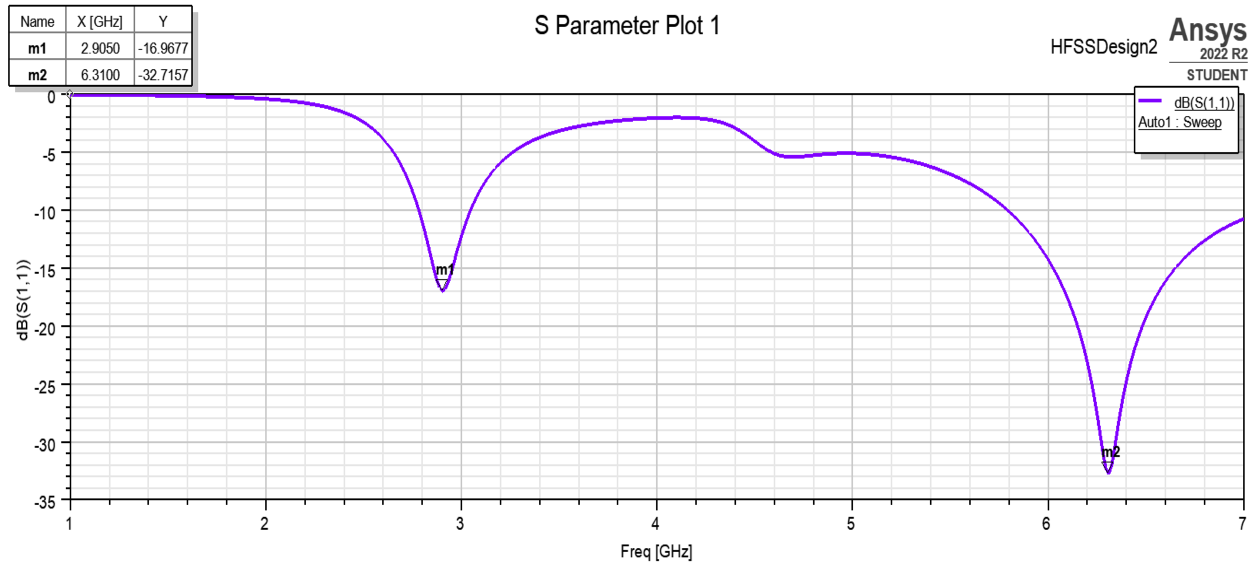

Figure 11: Mode (8) =>011.

5. The 3D radiation pattern

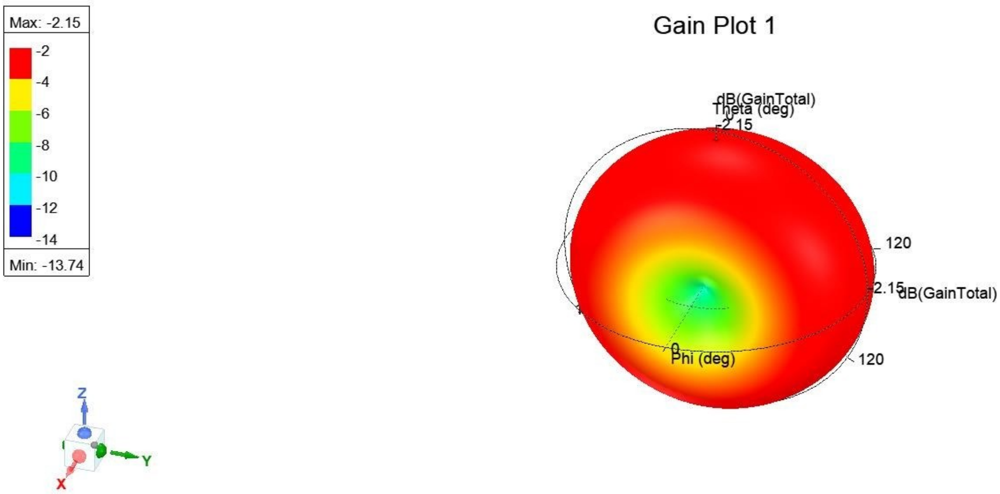

Figure 12: Mode (1) =>111 at frequency 2.12 GHz.

Figure 13: Mode (1) =>111 at frequency 3.43GHZ.

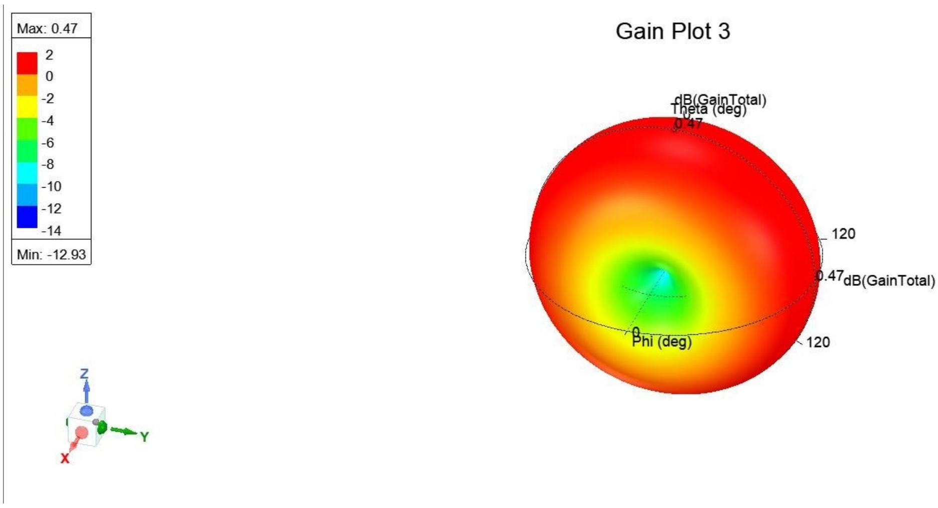

Figure 14.:Mode (2) =>110 at frequency 2.53GHZ.

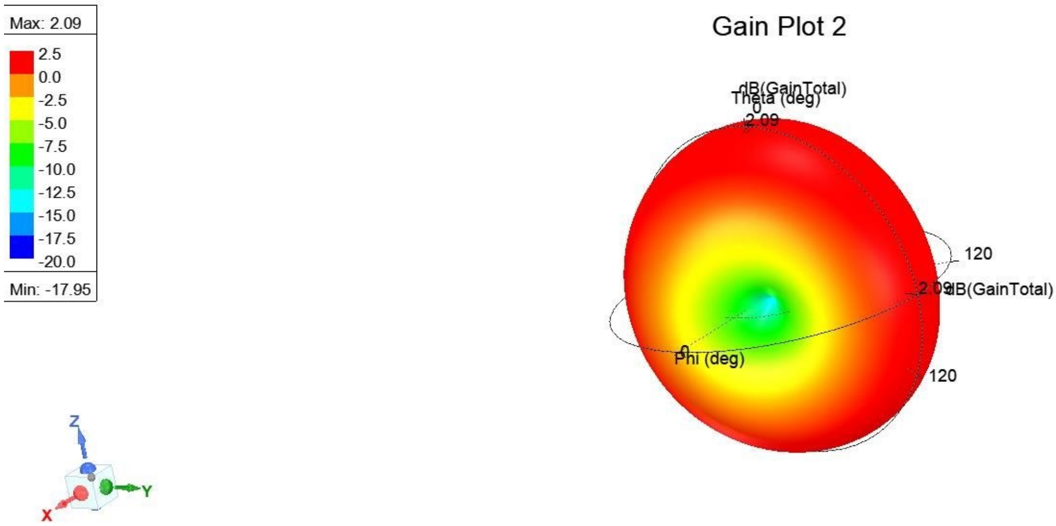

Figure 15: Mode (3) =>100 at frequency 5.03GHZ.

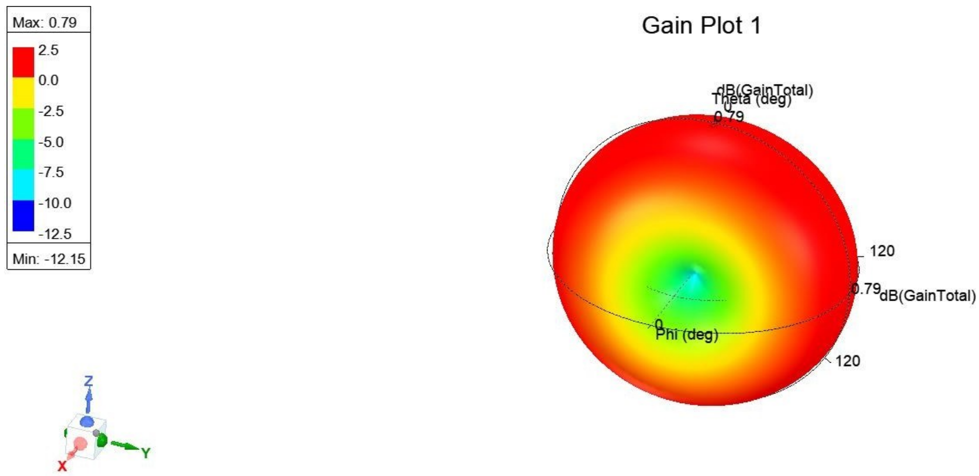

Figure 16: Mode (4) =>000 at frequency 2.92GHZ.

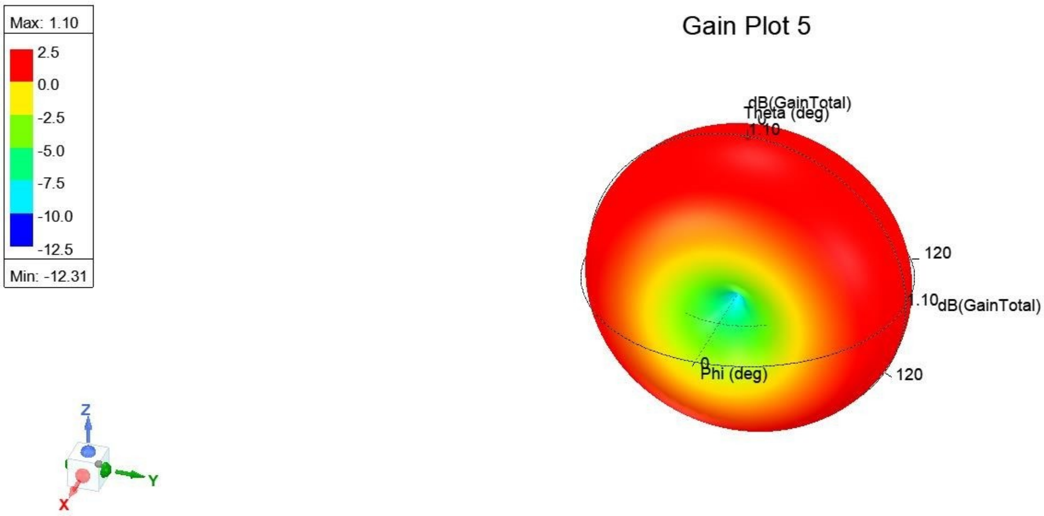

Figure 17: Mode (5) =>101 at frequency 2.63GHZ.

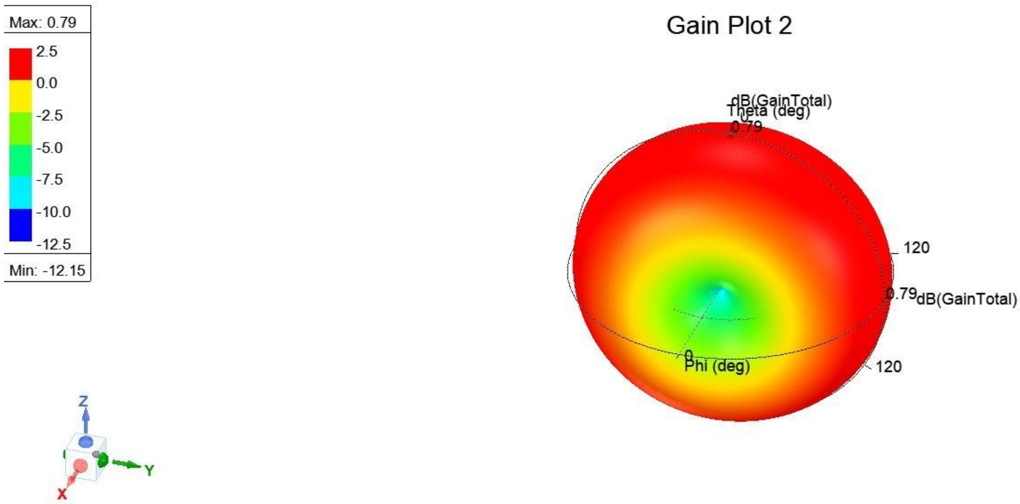

Figure 18: Mode (6) =>001 at frequency 2.92GHZ.

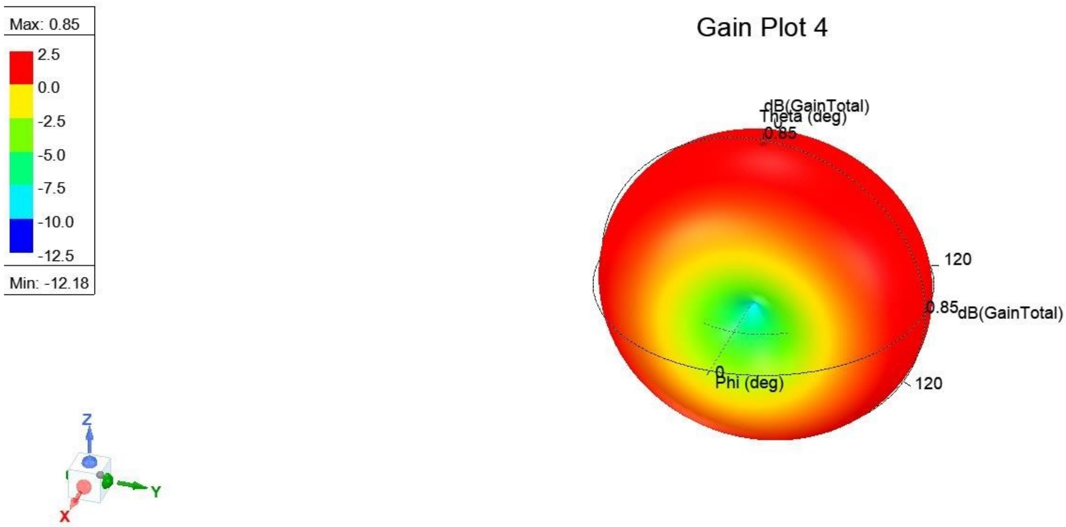

Figure 19 : Mode (7) =>011 at frequency 2.90GHZ.

In the previous modes with different frequencies 111 at frequency 2.12GHZ and 3.43GHZ ,110 at frequency 2.53GHZ ,100 at frequency 5.03GHZ, 000 at frequency 2.92GHZ, 101 at frequency 2.63GHZ 001 at frequency 2.92GHZ, 011 at frequency 2.90GHZ.

The radiation pattern achieved is a toroidal-shaped radiation pattern. The main lobe narrow and focused In this case, along the z-axis, which would correspond to the radiation directly above the antenna, there is very little transmitted power. In the x-y plane (perpendicular to the z-axis), the radiation is maximum. It present two main lobes with theta equals zero or pi with nulls (zero radiation) in XOY horizontal plane. Green region, which represent lower values, is stranded for theta between 30° and 30° for phi between 30° and 30°. there is no deformation in the center because the value of the Gain is not very low it’s stranded between -2.5dB and -7.5dB.

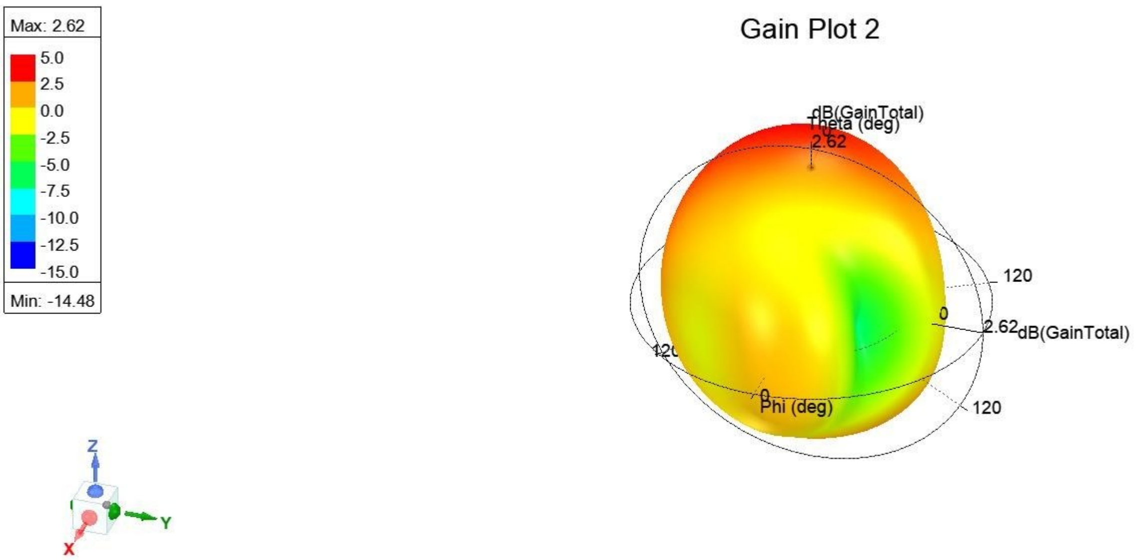

Figure 20: Mode (1) =>111 at frequency 6.31GHZ.

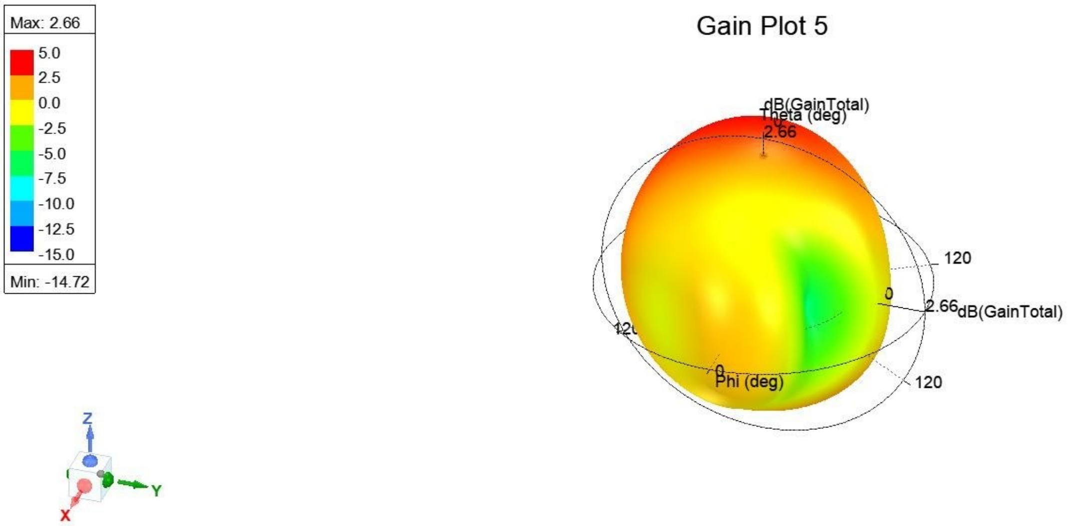

Figure 21: Mode (7) =>011 at frequency 6.30GHZ.

- **Mode 1 :** In mode 011 with a frequency of 6.30 GHz and the

mode 111 at frequency 6.31GHZ the radiation pattern presented is asymmetrical. The main lobe is not centered with a vertical bump with weak radiation; the transmitted power is lower than the side lobe, along the z-axis. In the x-y plane (perpendicular to the z-axis), the radiation is not spread evenly where we can see that the upper side lobe's radiation is higher than the lower lob. It present two main lobes with theta equals zero or pi with nulls (zero radiation) in XOY horizontal plane. Green region, which represent lower values, is stranded for theta between 30° and 170° for phi between 35° and 55°. As we can see, there is a deformation in the center because of the lower value of the Gain, it is stranded between -5dB and -7dB.

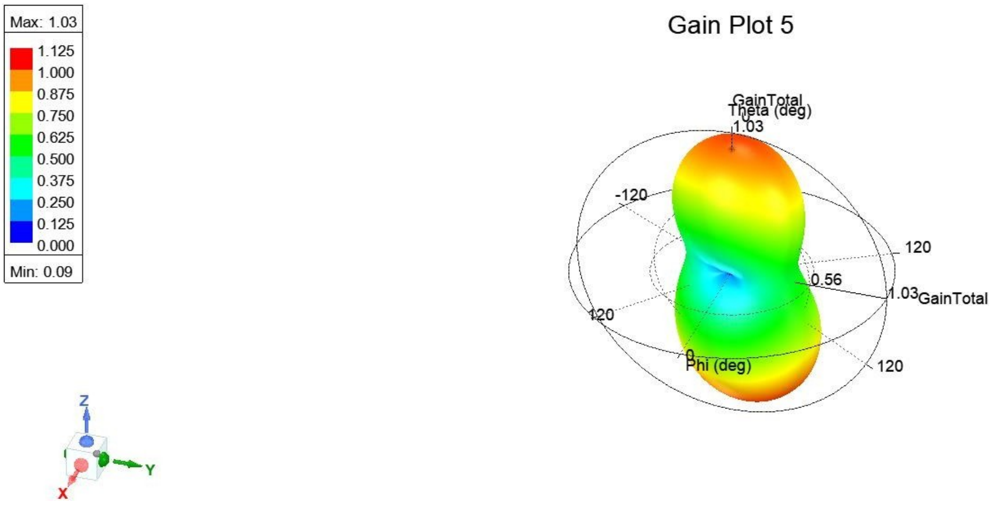

Figure 22: Mode (2) =>110 at frequency 4.33GHZ.

- **Mode 2:** which corresponds to the state (1, 1,0) and the

frequency of 4.33 GHz, resulting in circular polarized with an omnidirectional radiation pattern. The main lobe is narrow and focused with minimal transmitted power we observes a complete reorientation in the azimuthal plane, and a null of radiation according to the main axis of the antenna (x-axis). The highest gain is 1.4 dB. (Along the Z-axis of the Cube Sat). The lowest gains are 0.6 to -0.3 dB (along the X- and Y-axes)

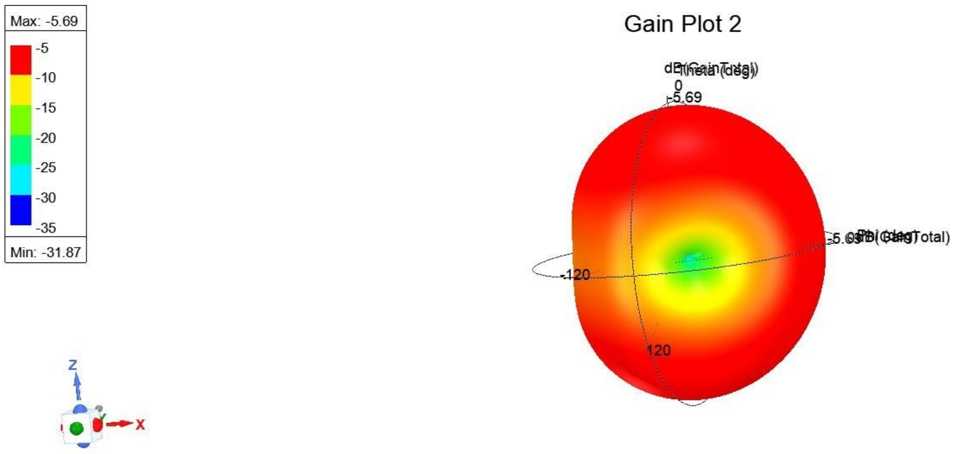

Figure 23 :. Mode (3) =>100 at frequency 2.65GHZ.

- **Mode 3:** In mode 100 with a frequency of 2,65GHz the

radiation pattern achieved is almost toroidal radiation pattern. The main lobe narrow with average radiation, along the z-axis, whereas the side lob is at maximum radiation. It present two main lobes with theta equals zero or pi with nulls (zero radiation) in XOY horizontal plane. Green region, which represent lower values, is stranded for theta between 10° and 10° for phi between 10° and 10°. There is no deformation in the center because the value of the Gain is high, it is stranded between -15dB and -25dB.

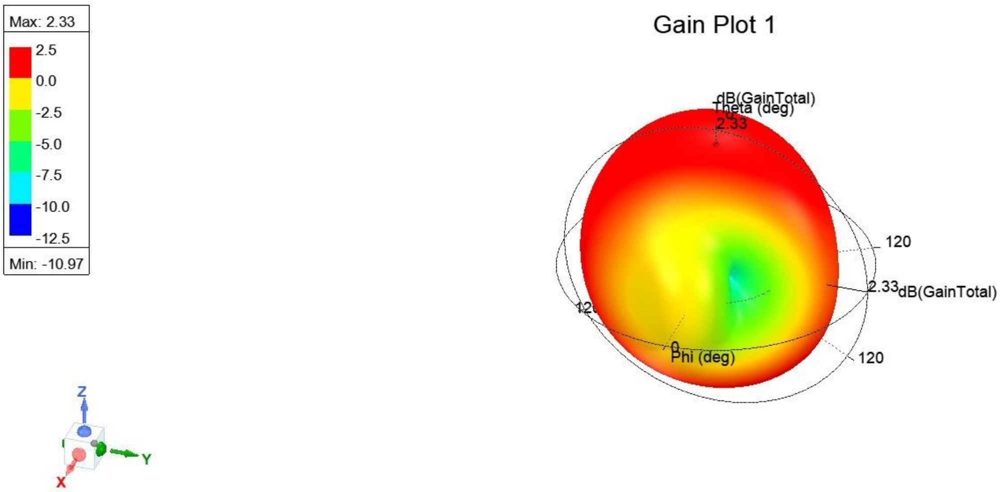

Figure 24: Mode (4) =>000 at frequency 5.93GHZ.

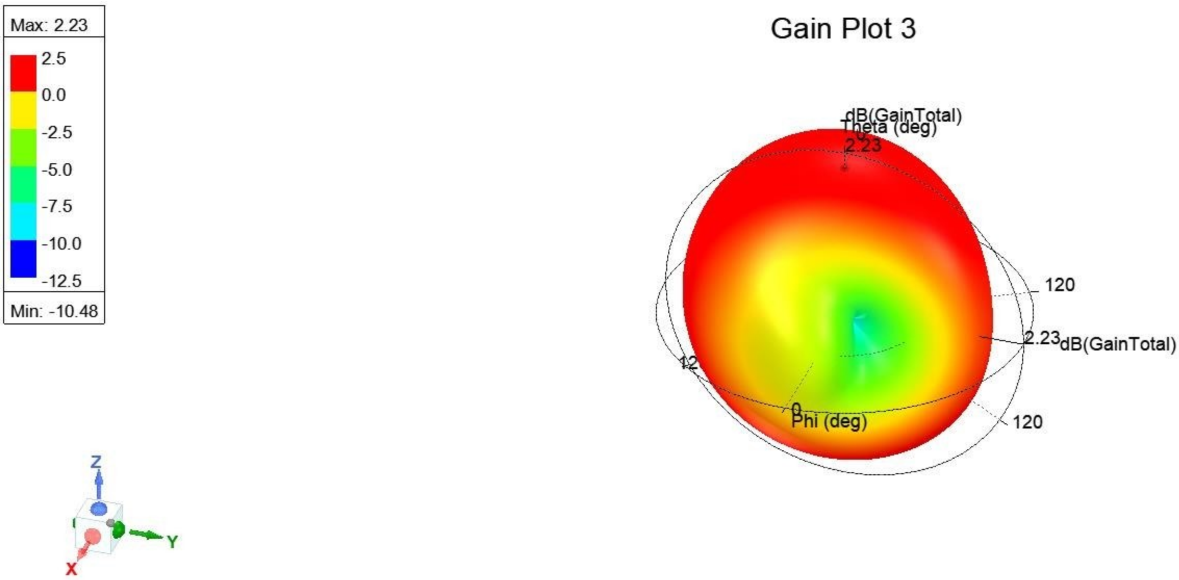

Figure 25:. Mode (6) =>001 at frequency 5.78GHZ.

- **Mode 6 :** 001 with a frequency of 5,93GHz and mode 001 at

frequency 5.78GHZ The radiation pattern achieved is an asymmetrical. The main lobe is not centered with a small bump; the transmitted power is lower than the side lobe, along the z-axis. In the x-y plane (perpendicular to the z-axis), the radiation is maximum. It present two main lobes with theta equals zero or pi with nulls (zero radiation) in XOY horizontal plane. Green region, which represent lower values, is stranded for theta between 30° and 150° for phi between 25° and 55°. As we can see, there is a deformation in the center because of the lower value of the Gain, it is stranded between -2.5dB and -7.5dB.

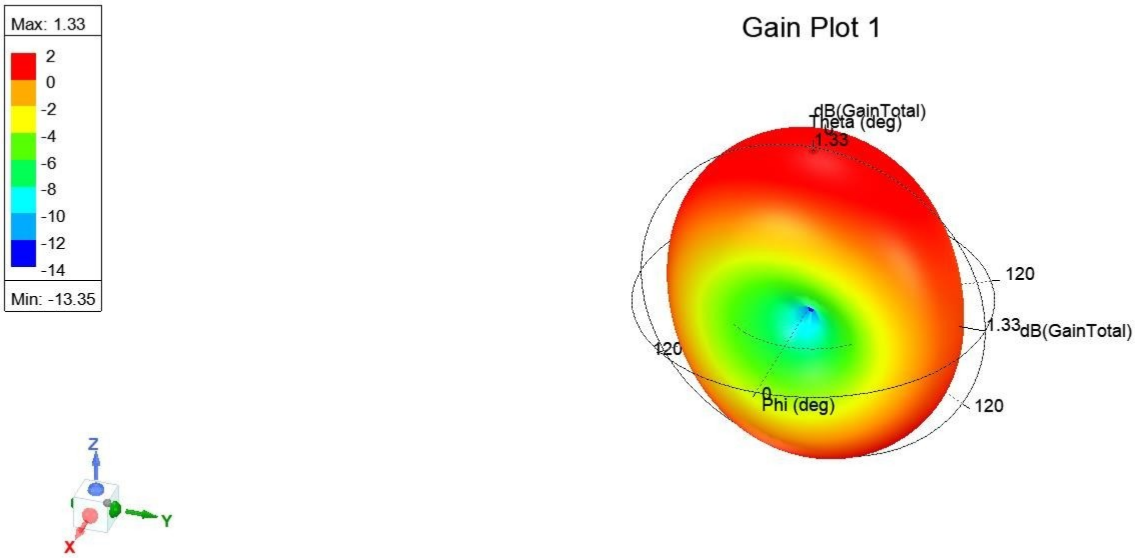

Figure 26: Mode (5) =>101 at frequency 4.72GHZ.

- **Mode 5:** In mode 101 with a frequency of 4.72 GHz the

Radiation pattern achieved is an oval radiation pattern. The main lobe is narrow and focused In this case, along the z-axis, which would correspond to the radiation directly above the antenna; there is very little transmitted power whereas it gets higher as we get further from the center. Which presents that the side lob is at maximum radiation. We have two main lobes with theta equals zero or pi with nulls (zero radiation) in XOY horizontal plane. Green region, which represent lower values, is stranded for theta between 60° and 60° for phi between 65° and 70°. There is no deformation in the shape of the Gain, it is stranded between -4dB and -8dB.

6. The surface current distribution of the antenna

The pictures below are showing the surface current distribution of the antenna for different operating modes,

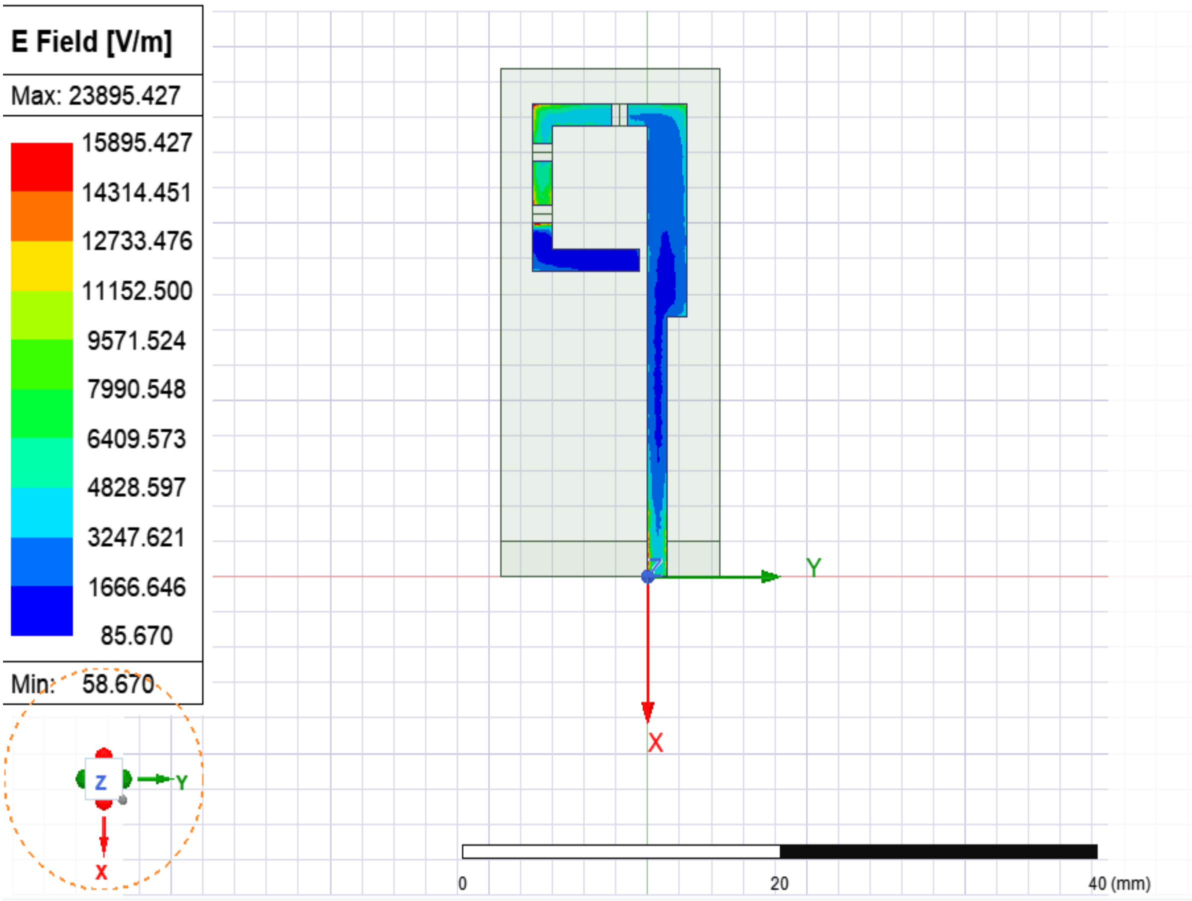

Figure 27: Mode (1) =>111 at frequency 2.12GHZ.

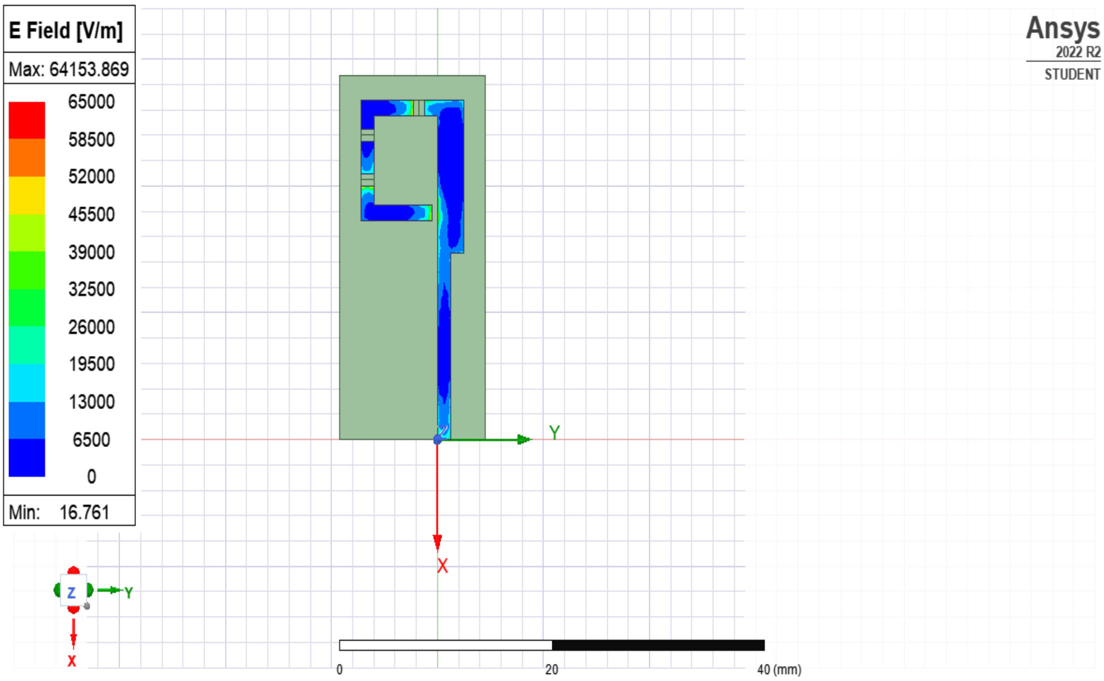

Figure 28: Mode (1) =>111 at frequency 3.43GHZ.

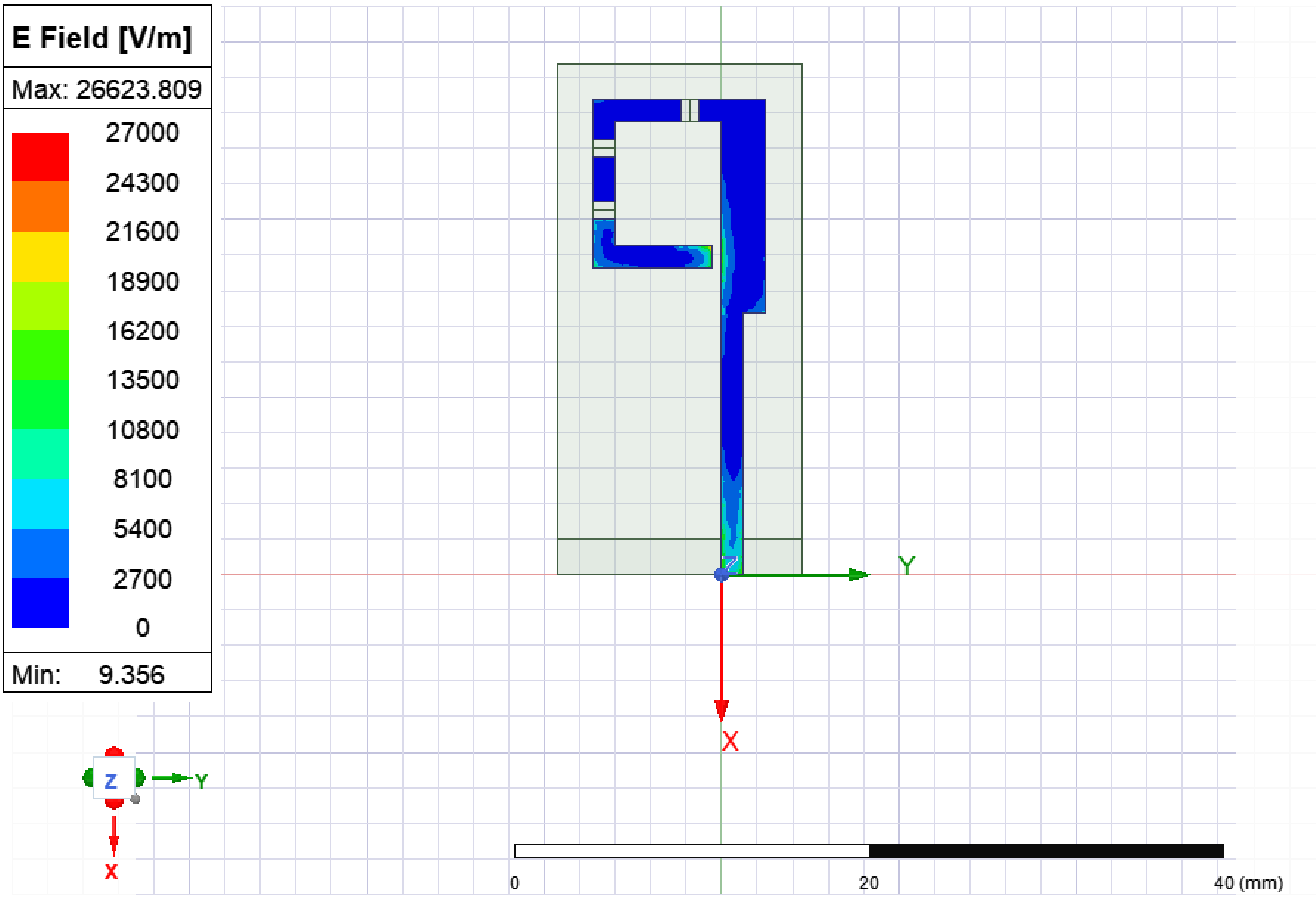

Figure 29: Mode (1) =>111 at frequency 6.31GHZ.

Mode 1: In this state (ON, ON, ON) which is mode one we have three resonant frequencies the first one is 2.12GHz the distribution on the conductive patch is mostly seen in parts two and three near pin diodes one, two and three the colors green orange and light blue are presented whereas for the remaining parts only dark blue or low values can be seen

For the second resonant frequency of 3.43GHZ first we have the input in part one presenting average values but getting near pin diode one and two the values get lower .part three which is between pin diodes two and three shows green and light yellow colors for average values ,in contrast to part four with low values as well the frequency 6.31GHz which is the highest resonant frequency showed lower values in most of the patch such as parts two and three with dark blue ,only the input of the design presents different values

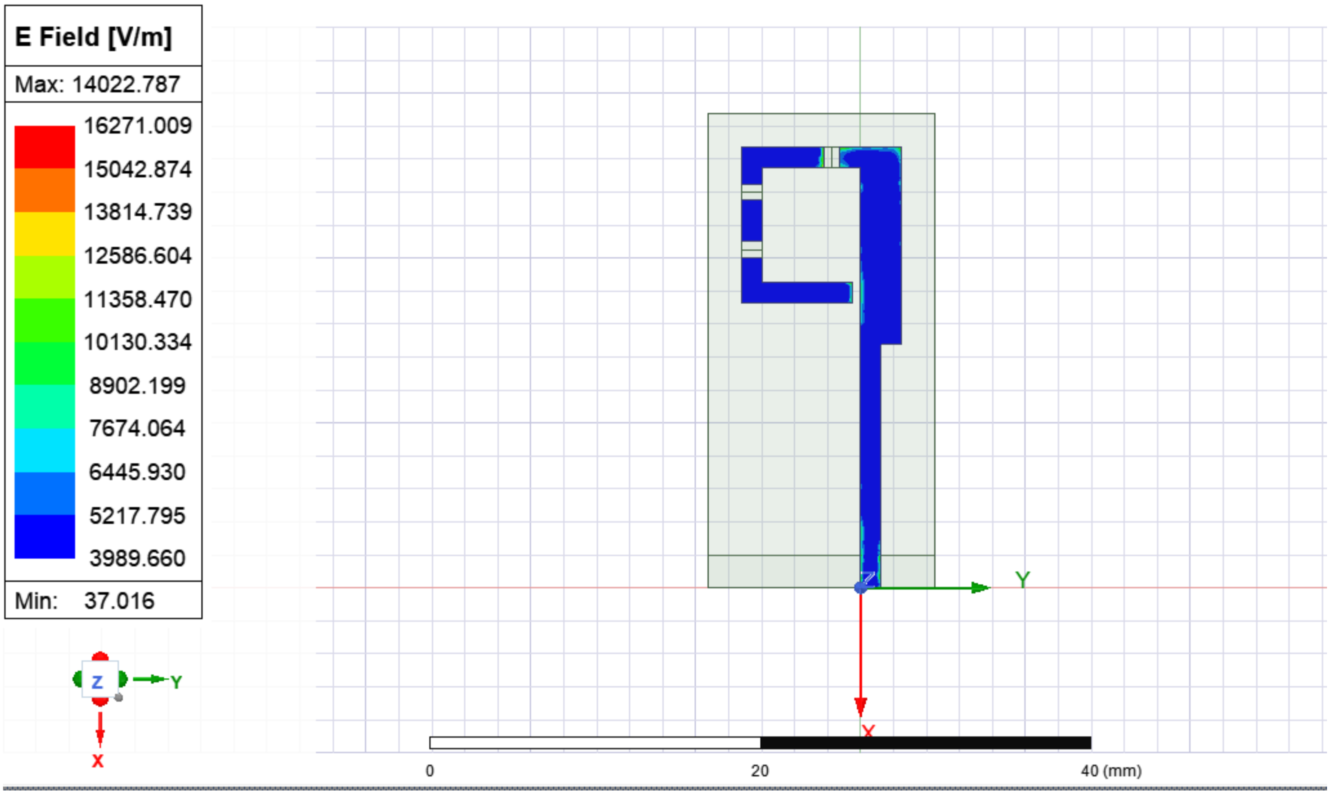

Figure 30: Mode (2) =>110 at frequency 2.53GHZ.

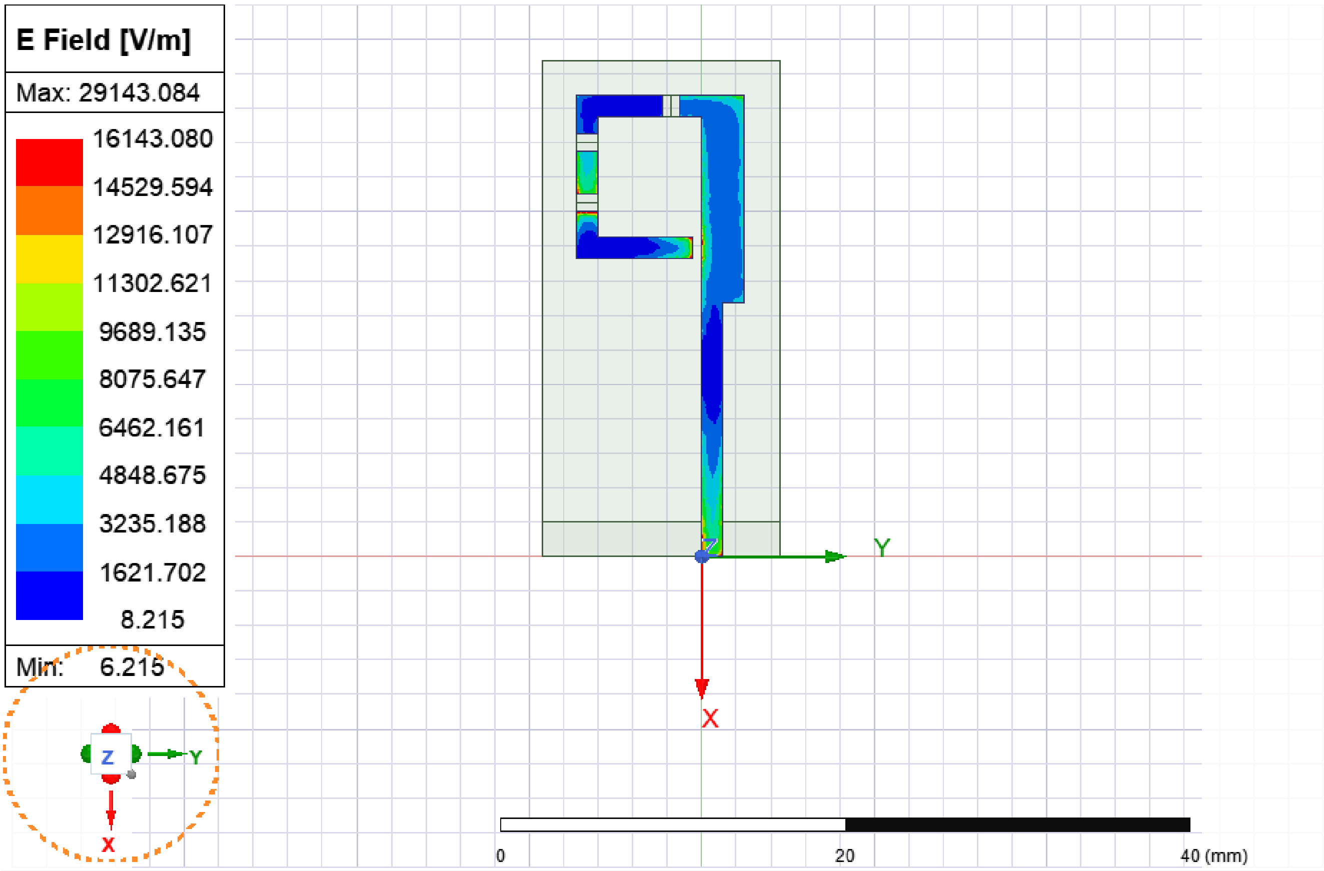

Figure 31: Mode (2) =>110 at frequency 4.33GHZ.

- **Mode 2** : For the state ON, ON, OFF we can see that the antenna

is mainly covered by dark blue except for small places such as the first part in input, the corner, the beginning and the end of the first pin diode those are covered with light blue, which means the frequency, is not as low as previous parts a resonant frequency of 4.33GHZ ,the pin diodes two and three are surrounded by average values shown in green, orange and light blue, which can also be seen at the input in the first part . Part two presents low values entirely therefore no high values can be seen using this resonant frequency.

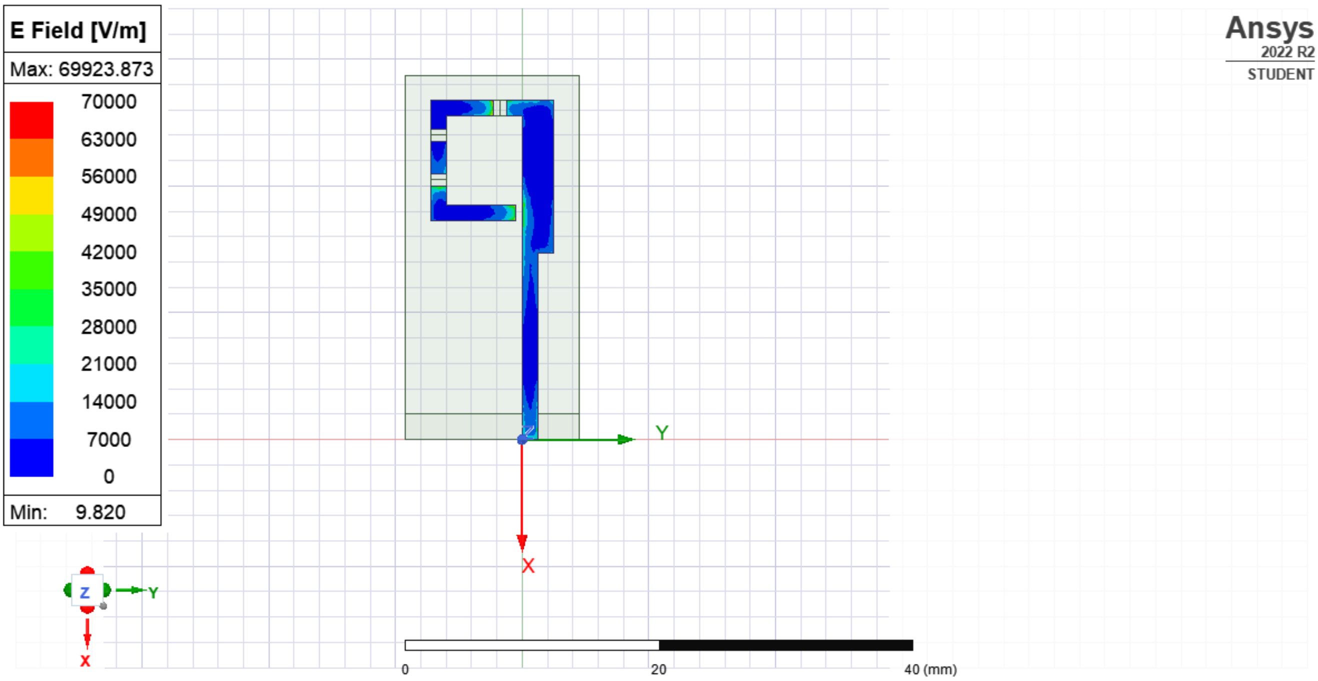

Figure 32: Mode (3) =>100 at frequency 2.65GHZ.

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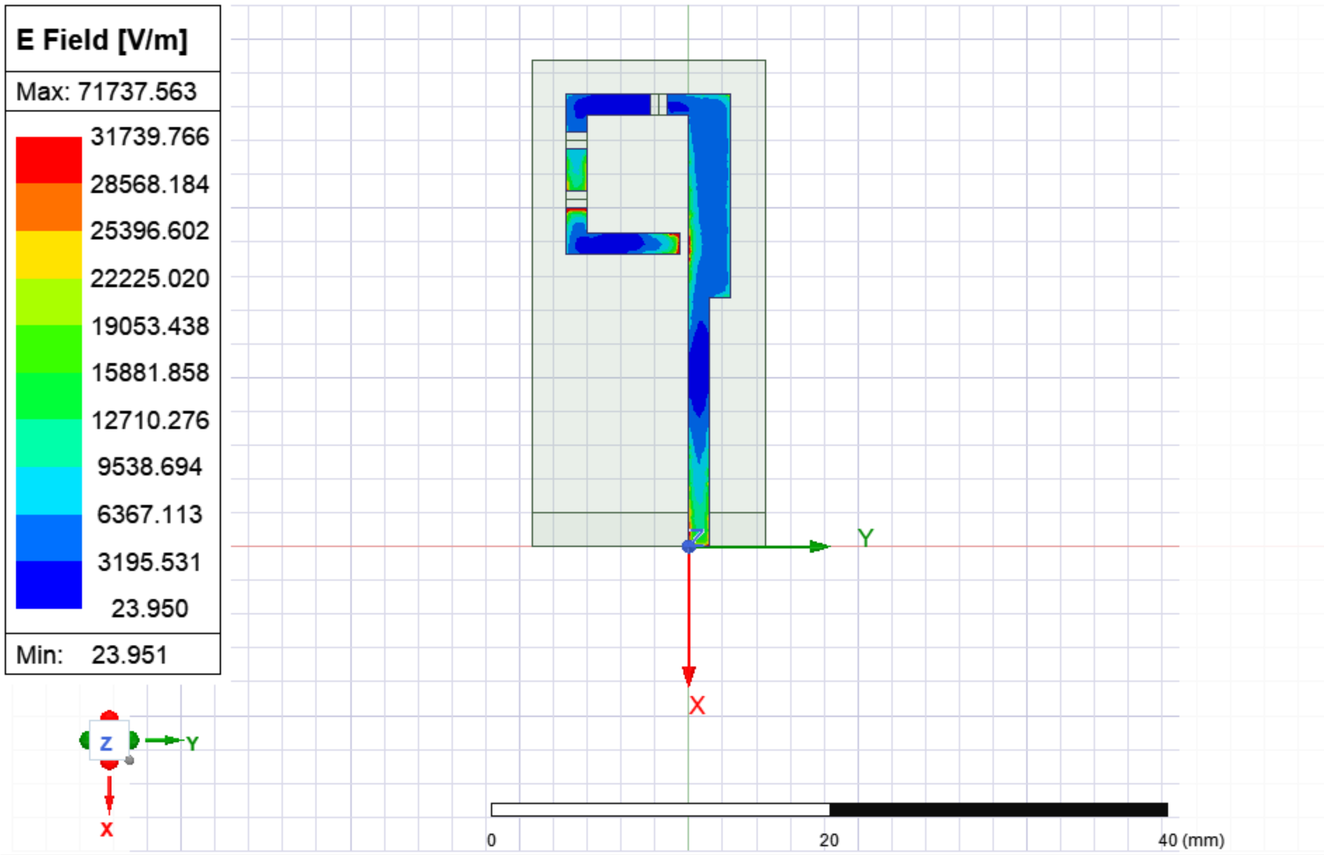

Figure 33: Mode (3) =>100 at frequency 5.03GHZ.

- **Mode 3:**ON,OFF,OFF,(100) the field is representing a resonant

frequency of 2.65GHZ ,the pin diodes one, two and three are surrounded by average values shown in green ,which can also be seen at the input in the first part .no high values can be seen using this resonant frequency the values presented vary in the four parts, part one presents higher values at the input but moving close to the pin diode the values are at a minimum in part two as well in contrast to part three and four where the values are average.

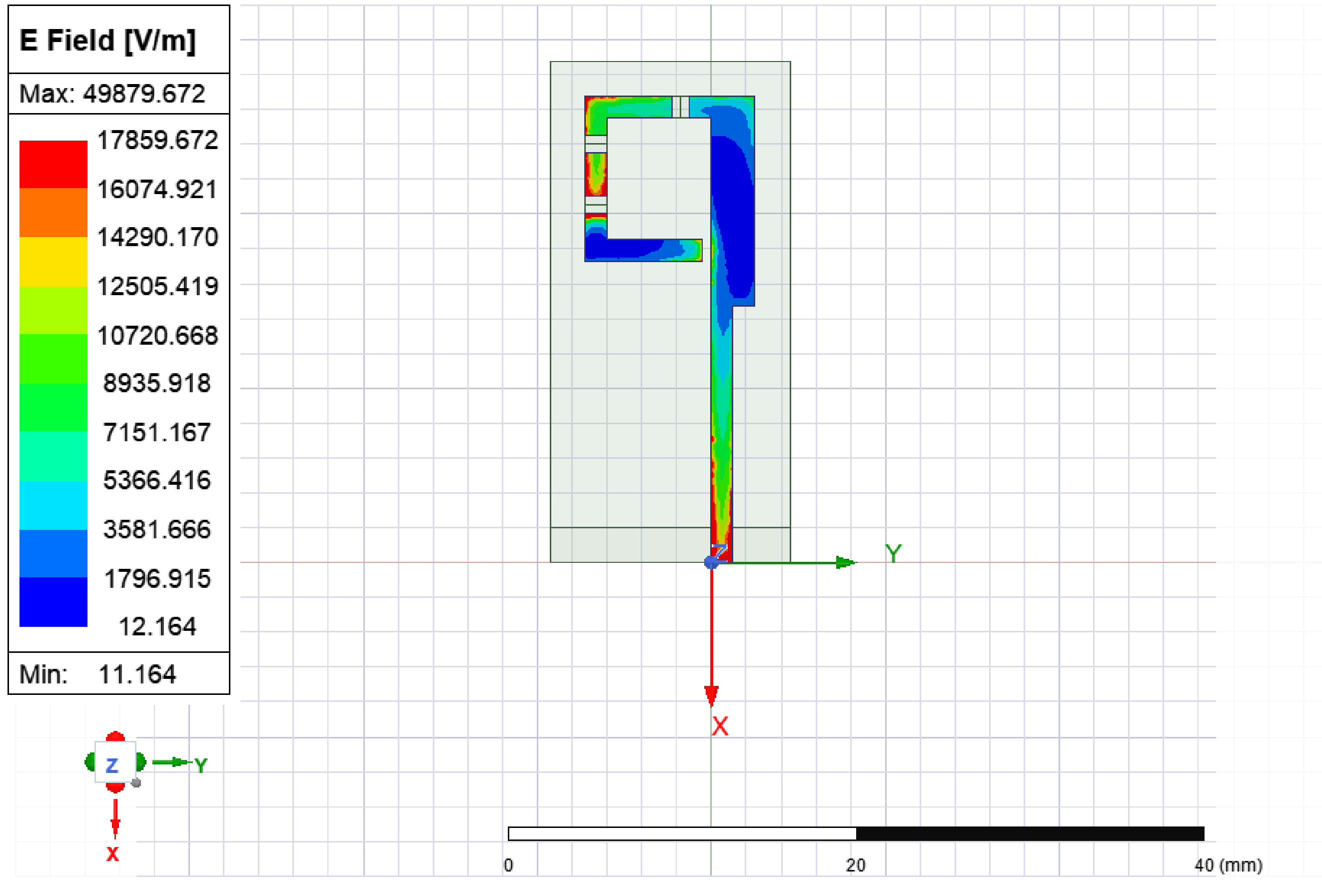

Figure 34: Mode (4) =>000 at frequency 2.92GHZ.

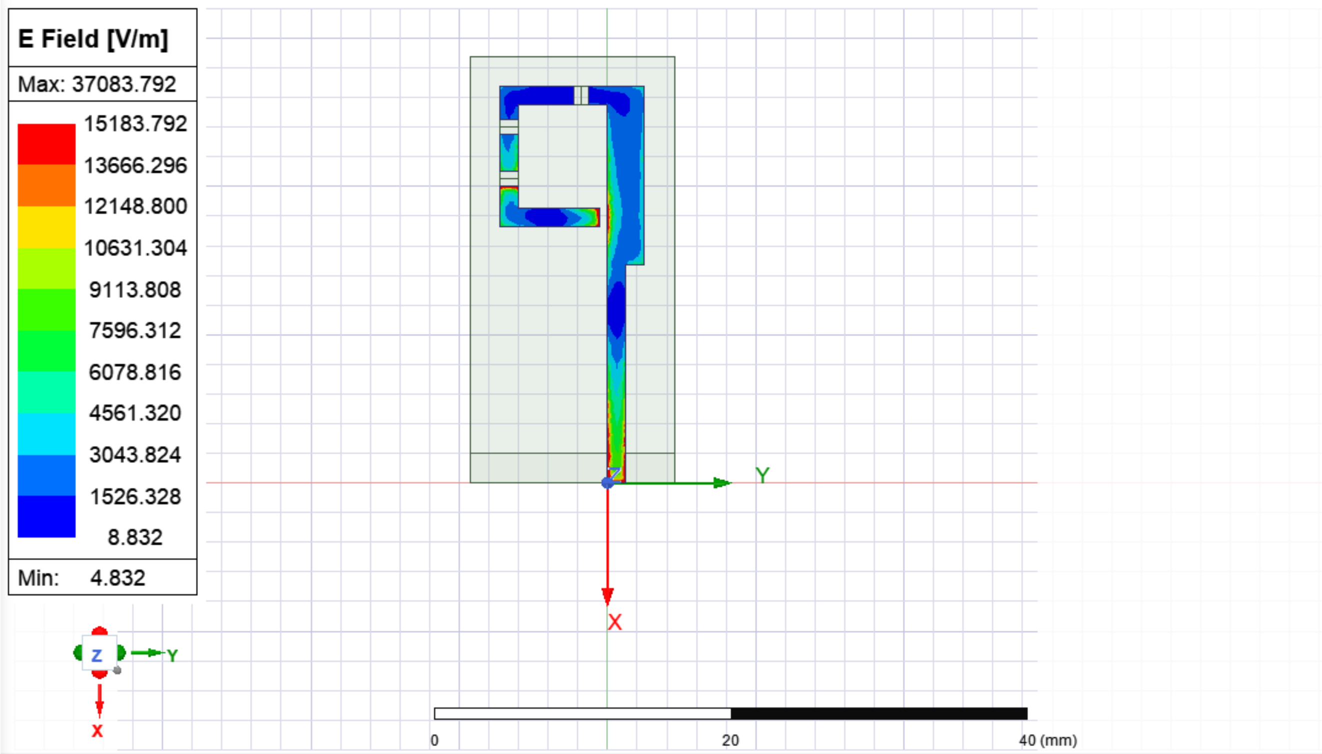

Figure 35: *Mode (4) =>000 at frequency 5.93GHZ.*

- **Mode 4:** represents the state OFF, OFF, OFF the resonant

frequency presents the highest values at the input and in the corners of part two and three some average frequencies can also be seen in these parts whereas for part four and the end of part one near the pin diodes lower frequencies are presented with a dark blue color. frequency of 5.93GHZ , the values are mainly low since most of the design is showing a dark blue color which is a result of a high frequency ,the input presents some higher values shown in part one and part four but only at the ending .

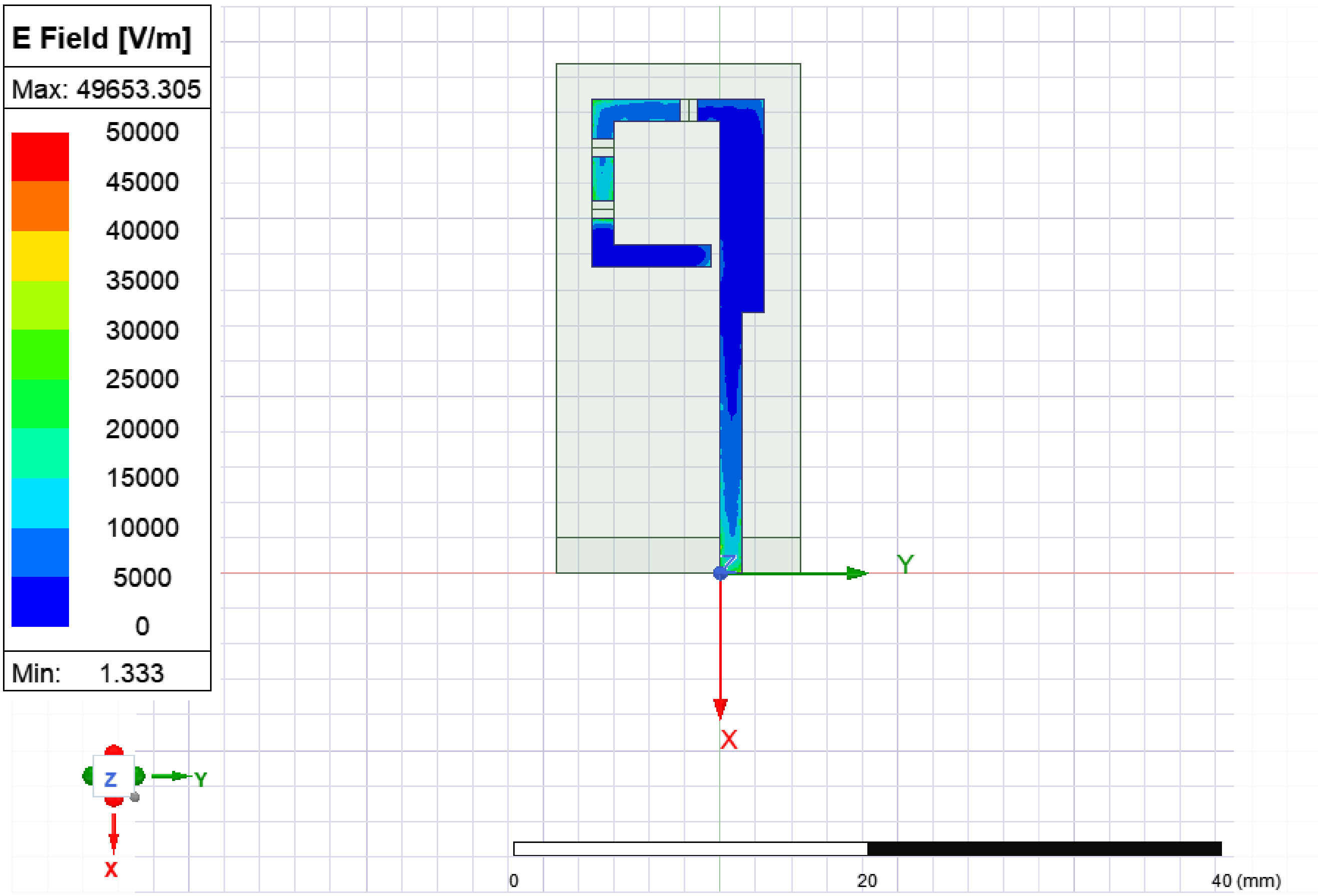

Figure 36: Mode (5) =>101 at frequency 2.63GHZ.

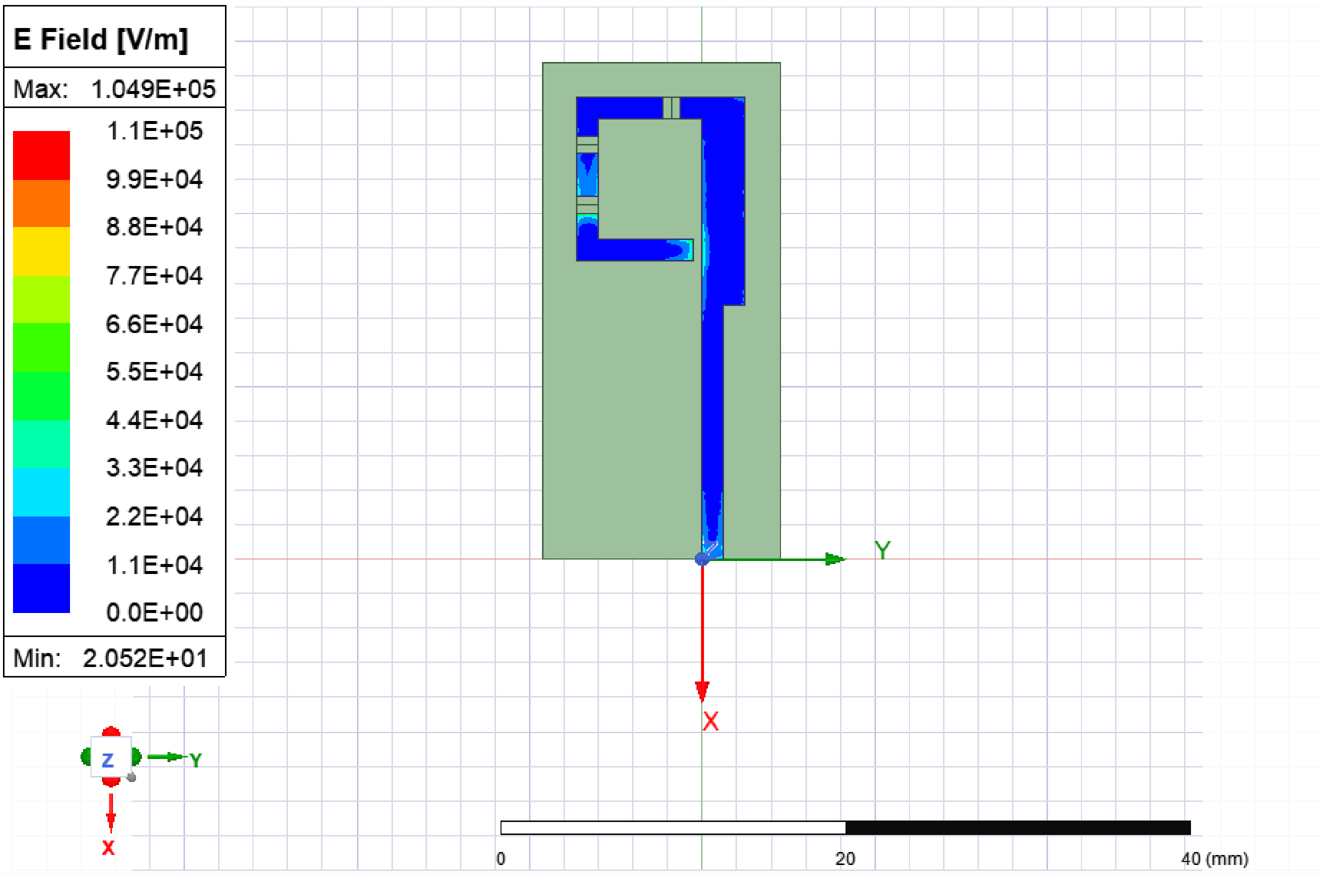

Figure 37: Mode (5) =>101 at frequency 4.72GHZ.

- **Mode 5 :** state (ON, OFF, ON) the two frequencies which are

2.63 and 4.72 GHz present low values especially at parts one, two and four. A slight difference can be seen in part three near the pin diode but they are still low as presented with light blue and green colors

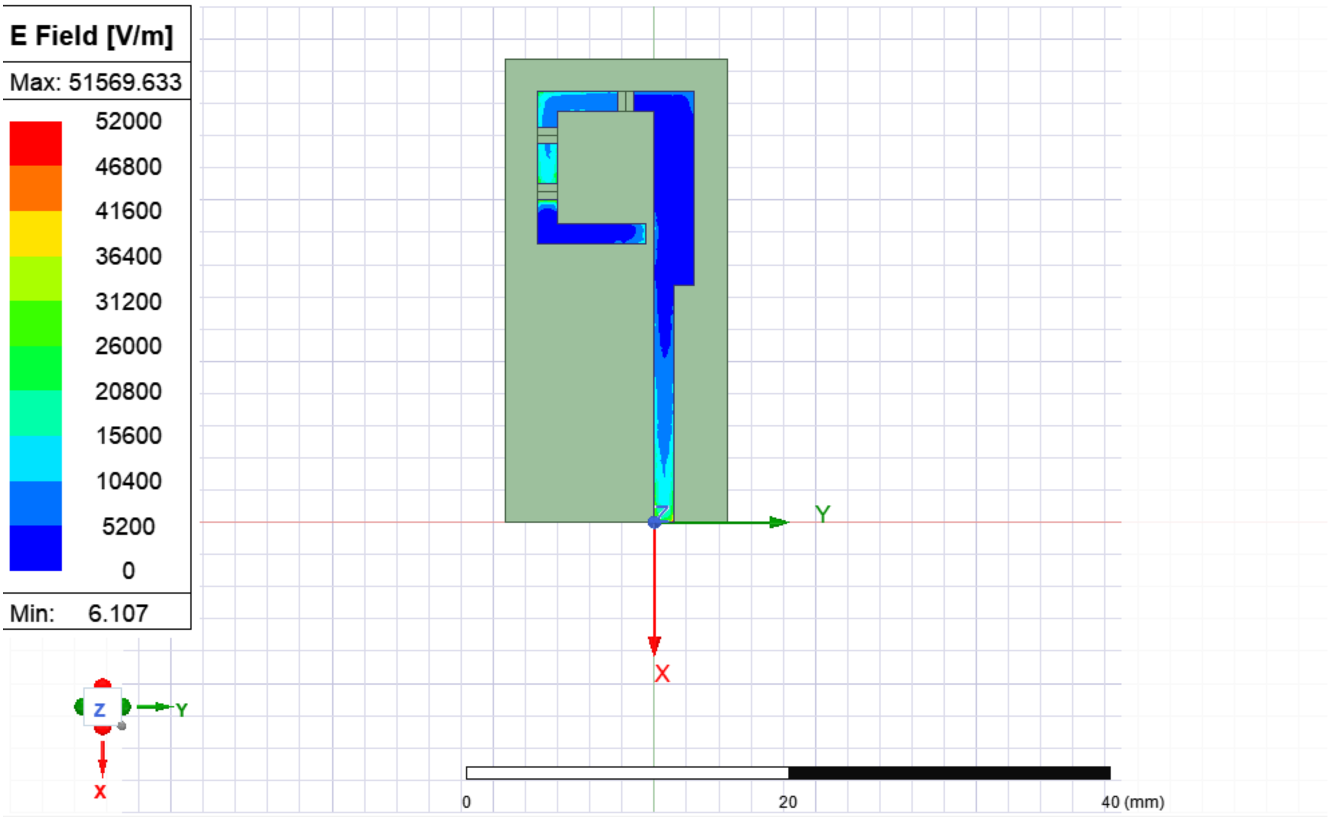

Figure 38: Mode (6) =>011 at frequency 2.92GHZ.

- **Mode 6:** In this mode, the state is OFF, ON, ON with a frequency

of 2.90 GHZ. in this field we noticed that the state changes the distribution of the frequencies, that is why a minimum frequency is spread all over the conductive patch especially in parts four, two and near the first pin diode. The green color and light blue could only be seen on a few spots of the patch such as part three and near the input.

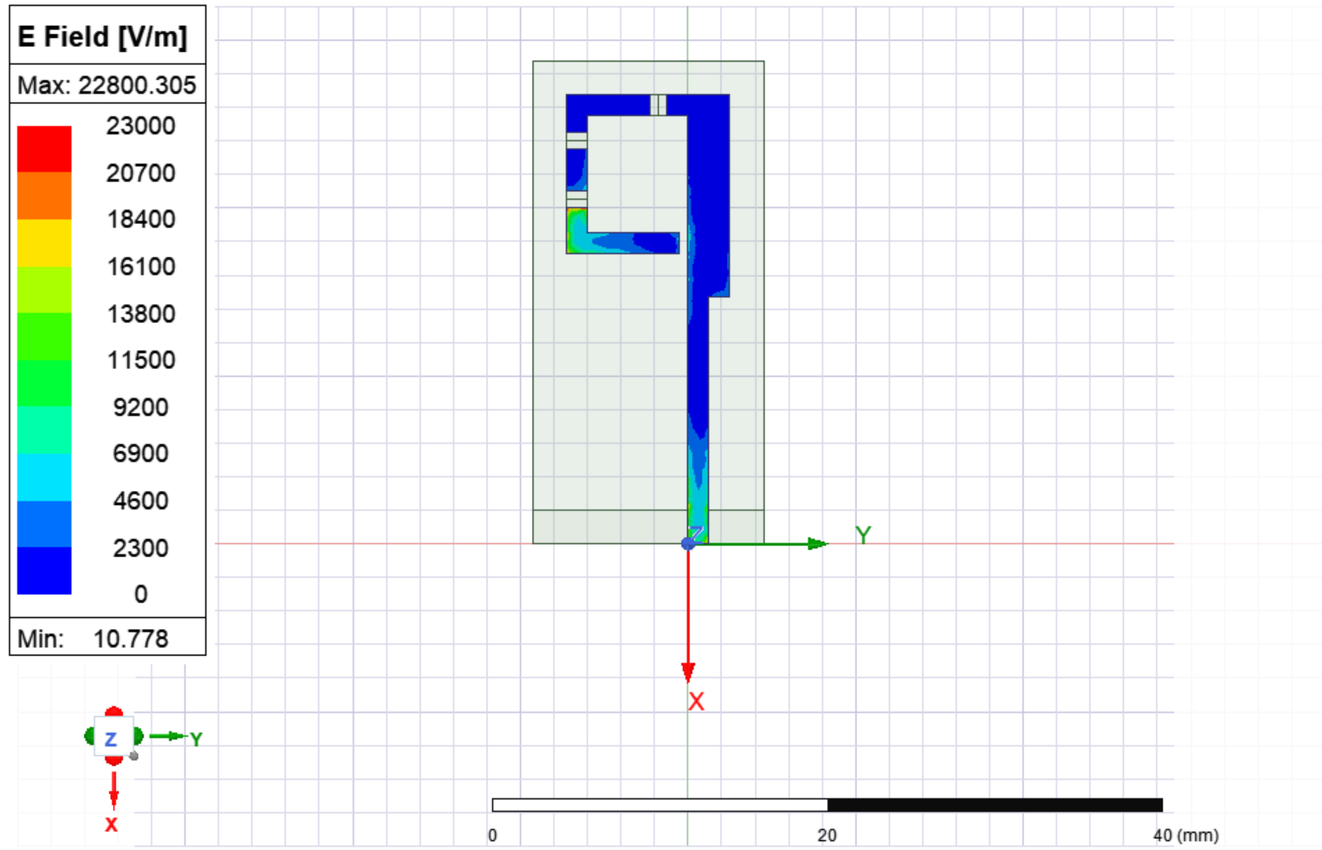

Figure 39:Mode (6) => (011) at frequency 6.90GHZ.

- **Mode 6:** In this mode, the state is OFF, ON, ON with a frequency

of 2.90 GHZ. in this field we noticed that the state changes the distribution of the frequencies, that is why a minimum frequency is spread all over the conductive patch especially in parts four, two and near the first pin diode. The green color and light blue could only be seen on a few spots of the patch such as part three and near the input.for the frequency of 6.90 GHz in the same state only minor changes could be seen on the conductive patch ,the dark blue is covering parts one, two and three completely where as for the input and near pin diode 3 the frequency is in average ranges.

7. Conclusion

Frequency-reconfigurable planar antennas using multiple PIN diodes offer significant advantages in terms of their versatility and adaptability. These antennas can dynamically change their operating frequency or characteristics by controlling the biasing of PIN diodes, enabling them to cover a wide range of frequencies or switch between multiple frequency bands.

One of the key benefits of frequency reconfigurable antennas is their ability to operate across different frequency bands without the need for physically changing the antenna structure. This flexibility is especially valuable in applications where multi-band or frequency-agile communication is required, such as software-defined radios, cognitive radio systems, and wireless communication devices.

By employing multiple PIN diodes strategically positioned in the antenna structure, the resonant frequency and radiation properties can be adjusted. The PIN diodes act as switches that modify the antenna's electrical length, impedance, or radiation pattern, allowing for frequency tuning or beam steering. This reconfigurability enables the antenna to adapt to varying operating conditions, interference environments, or communication standards.

The performance of frequency-reconfigurable planar antennas using multiple PIN diodes is typically evaluated in terms of parameters such as return loss, radiation pattern, gain, and efficiency. Through proper design and optimization, these antennas can achieve desirable performance characteristics across the reconfigurable frequency range.

However, there are also challenges associated with frequency-reconfigurable antennas. The insertion loss introduced by the PIN diodes can degrade the overall antenna performance, including reduced radiation efficiency and increased mismatch losses. Additionally, the complexity of the control circuitry required to bias and control the PIN diodes adds to the overall system complexity and cost.

Despite these challenges, frequency reconfigurable planar antennas using multiple PIN diodes have demonstrated promising results and have been widely investigated in research and development. Ongoing advancements in antenna design, material selection, and control circuitry are addressing the challenges and improving the performance of these antennas.

To summarize, frequency-reconfigurable planar antennas using multiple PIN diodes offer a versatile solution for adapting to different frequency requirements and operating conditions. Their ability to dynamically adjust the resonant frequency and radiation properties makes them well suited for a wide range of applications in wireless communication systems. Continued research and development in this field will further enhance the performance and capabilities of these antennas, opening up new possibilities for advanced wireless communication technologies.

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