Electromagnetic Modeling of Radome, Thickness Optimization, Transmittance and Evaluation in Terms of Antenna Pattern (X or C Band)

GAZI UNIVERSITY FACULTY OF ENGINEERING
DEPERTMANT OF ELECTRIC-ELECTRONICS ENGINEERING

EEE 492 ELECTRICAL-ELECTRONICS ENGINEERING DESIGN II DETAILED DESIGN REPORT

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1. **Abdullah YILDIRIM (171112033)**
2. **Gökçe Yaren KARADENİZ (171110042)**

ADVISOR:
Prof. Dr. Mehmet ÇİYDEM

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SYMBOLS AND ABBREVIATIONS

Symbols Descriptions

dB Desibel

GHZ Gigahertz

Ω Ohm

mm Millimeter

cm Centimeter

Abbreviations Descriptions

MIL Military Standarts **TAI** Turkish Aerospace Industries **RF** Radio Frequency **FAA** Federal Standarts **VSWR** Voltage Standing Wave Ratio **MoM** Method of Moments **FFT** Future Fibre Technologies **FEM** Finite Element Method **MoR** Model Order Reduction **CSP** Common Spatial Patterns **IE** Internal-External

ABSTRACT

Today, antennas play an important role in the field of communication. Radomes are structures used to protect the antenna from environmental conditions. There are various types of radomes according to their usage areas. The scope of this project includes antennas placed on the nose and wing tips and their radomes on air platforms. While radomes protect antennas with environmental conditions, they also provide frequency, gain, losses, bandwidth, impedance matching, polarization and radiation diagram etc. can affect antenna parameters. Within the scope of this project, our main goal is to keep the antenna performance parameter changes caused by radome at a minimum level or to optimize it. In the first stage, an antenna working in the X or C band will be designed through the CST program and parameter measurements will be made without radome. In the next step, nose (conical, spherical) and wing tip (cylindrical) radomes will be created using different material types. These radomes will be placed on the antennas and the determined parameter tests will be carried out. Radome material selection, radome thickness, antenna-radome spacing will be optimized by reference to the lower and upper limit values determined by TAI and the results of radom-free antenna parameters. Up-to-date technology and methods will be used during these studies.

1.INTRODUCTION

1.1 Statement of Needs

Radomes protect antennas with environmental conditions. Factors such as the type of material used in the design of the radome, the wall thickness of the radome and the distance between the radome and the antenna, such as frequency, gain, losses, bandwidth, impedance matching, polarization and radiation diagram, etc. can affect antenna parameters. Depending on the design of the radome, the high changes in antenna parameters negatively affect the communication between the antenna and the receiver. In order to minimize these negative effects, the need for radome design and optimization processes arises.

1.2 Purpose

Radome type material selection, radome thickness, by simulating the antennas placed on the nose and wing tips of the air platforms and their radomes with different materials and the electromagnetic model through the CST program, by taking the lower-upper limit values determined by TAI in the X or C band and the results of the radome-free antennas as reference. It is aimed to optimize the antenna-radome range.

1.3 Literature Research

1.3.1 Definition

A radome is a protective structure that acts as an electromagnetic window and is developed to ensure that antennas and similar structures are not affected by environmental conditions and protected against damage. The name "radome" is derived from the words radar and dome. In order for us to understand that the radomes are doing their job, it is expected that they will continue to protect the antenna without being affected by environmental events such as bird strikes or lightning strikes (UZUN, 2020). They must also transmit radio frequency (RF) waves with a minimal loss under operational conditions. Generally, it is necessary to make a smart trade-off between electromagnetic and mechanical design parameters when designing a radome that serves the desired performance and purpose. The electromagnetic performance of an antenna protected with a radome structure is always affected due to interaction between the radome material's interface and the electromagnetic field. Parameters such as amplitude, phase, and polarization changes, and the near electromagnetic field of the antenna causes distortion (O. Russo, 2012). The most important measure in radome design is environmental conditions, these conditions affect the material to be used, the wall thickness and the shape of the radome.

Effects such as vibration, rain, operating temperature should be considered during the construction process of radoms. Radomes are classified by the MIL-R-7705B standard

according to the platforms in which they are used and details of their wall designs (Kozakoff, 2010). Radomes are also classified into five basic groups according to dielectric wall design types and configurations.

A-Type: It has a design that is a core structure between two dielectric structures. B-Type: Type B structures are the same as type A structures, but their wall thickness is thinner than type A.

C-Type: C type radomes have a sandwich panel structure and are also called a-sandwich multi layer wall. There are two high-density face sheets in the panel design with a lower density core materials in between. The dielectric constant of the core material is lower than the skin material’s dielectric constant.

D-Type: Very similar at C type. They consist of high-density skin and low-density core material.

E-Type: E-Types covers all remaining radome types. B-sandwich radome structures are in this class. The dielectric coefficient of the core material is greater than skin material.

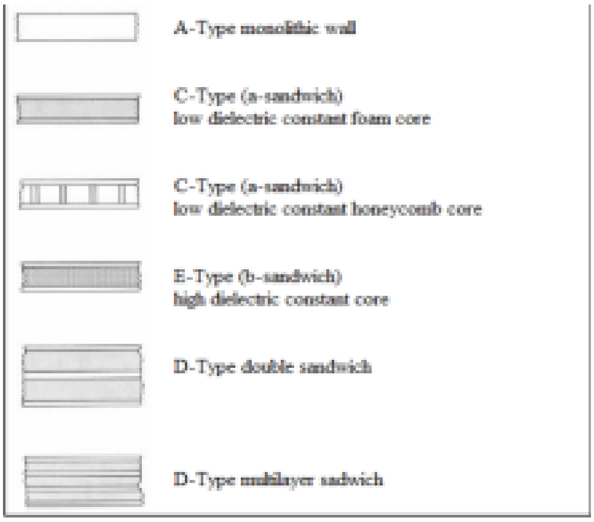


Figure 1: Radome sandwich panel configurations

1.3.2 History of Radome

At the beginning of the second world war, airplanes were slow speed. These aircraft were equipped with VHF radars using mounted dipole array antennas. There was no need for radomes because they were slow. As the speed of the aircraft increased over time, the need to protect these antennas from the physical flight environment emerged. With the use of microwave radars in the 1940s, the need for radar protection increased (Kozakoff, 2010) . Just out of speed reflective antennas are often covered with spherical dielectric radomes to provide protection from dust, wind, rain and snow (Yurchenko & Altintaş, 1999) .

Due to the high performance demand, radomes had to be designed to provide more precise transmission tolerances at larger scales and shorter wavelengths (Nair & Jha, 2014). The first radome to be used in real flight in 1941 was a thin-walled structure and its material was made of plexiglass. This radome, had a geometrically hemispherical structure.

Radomes used in the early 1943 used plywood and were approximately 0.25 inches thick. In these years, radomes made of plywood material were used on airships and boats in the US army, where moisture absorption was a major problem. In addition, since plywood is not a compatible material with curved geometries, alternative materials have been researched.

As a result of the studies carried out by the MIT Radiation Laboratory in 1944, the first a sandwich form consisting of 3 layers was developed. High-density fiberglass was preferred for the shells of the sandwich panel, while a combination of lower-density polystyrene fiber was used for the core material (UZUN, 2020) **.**

1.4 State of The Art Technology

Radome problems can be solved electrically using numerical methods such as MoM or FEM technique for small and medium sized geometries. MoR, green function, CSP methods can be used in optimization studies of radome. FFT techniques are used to calculate the Green's function (Oguzer, 2004). We know that the multiple scattering in the reflective antenna system inside the radomes is generally dependent on both the out-of-plane wave effects and the geometric structure of the radome for optimum radome design. Therefore, IE analysis of the entire system is mandatory. MoM method is insufficient for IE analysis. On the contrary, MoR based numerical solution methods can be used efficiently in radome optimization operations (Yurchenko & Altintaş, 1999).

1.5 Innovations

The innovative aspects of the project we will develop are as follows:

- It will be an effective design according to the current situation with domestic and national methods.
- With the communication problems experienced in the aviation sector, the need for industry oriented performance enhancement has arisen.
- Although there are similar studies in different sectors, it will contribute to the existing science and technology, since sufficient success has not been achieved.
- The research subject is also a scientific problem and the best solutions are sought.

2.DEFINING THE REQUIREMENTS

2.1 Engineering Requirements

a) Economical: In addition to obtaining more optimal results compared to the existing radome production, the cost should not increase much. It should be cheaper or close to current production.

b) Frequency Range: The designed antennas are expected to operate in the X and C band frequency range.

c) Achievement: Radome measurements, the s-parameter for the antenna in the C band remains below -10dB in the operating frequency range of the antenna. Our reference impedance is close to 50Ω. As little deviation of Total Efficiencies as possible. The antenna does not affect the VSWR value much. Since our antenna design is symmetrical, Farfield does not shift much in the axes. The radome is expected to pass the signals received from the antenna with the least loss.

d) Manufacturability: Our radom design should be made of easily available materials. The production process should not be interrupted.

e) Life-Time: It is expected to have a long life-time. The life-time may differ depending on enviromental conditions. The durations may differ, but our expectation is that the life-time is a least as long as the material used.

f) Maintance and Repair: Since it is made of readily available material, it is simple to cut the area neatly and put the new material in when damaged or when maintenance is required. **g) Health and Safety:** Our design will comply with MIL and CE standards. **h) Design:** The design of the radome should be sandwich-shaped, 5-layer, conical for the nose, cylindrical or rectangular for the wing tip.

	Cost	Safety	Size	Portability	Repairability	Life Time of a Product
Cost		+		+		+
Safety	+					
Size	+			-	-	
Portability	+					
Repairability		+				+
Life Time of a Product	+	+			+	

Table 1

Note:

+(directly proportional)

-(inversely proportional)

2.2 Marketing Requirements

1. The cost of the building should be low.

2. The structure should be easy to use.

3. The building should protect the antenna from all kinds of environmental conditions. **4.** The structure should be more optimized than its competitors.

5. The structure should be easy to assemble.

6. The longevity of the structure.

Marketing Requirement	Engineering Requirements	Reason
1	In addition to obtaining more optimal results compared to the existing radome production, the cost should not increase much. It should be cheaper or close to current production.	Price and performance values are important in sales. Therefore, it is necessary to keep the cost low while obtaining optimal result.
4	The designed antennas are expected to operate in the X and C band frequency range.	The design should give more optimal results in the X and C bands than their competitors. It should be more successful than its competitors.
3,4	Radome measurements, the S-parameter for the antenna in the C band remains below -10dB in the operating frequency range of the antenna. Our reference impedance is close to 50Ω. As little deviation of Total Efficiencies as possible. The antenna does not affect the VSWR value much. Since our antenna design is symmetrical, Farfield does not shift much in the axes. The radome is expected to pass the signals received from the antenna with the least loss.	It is expected that the radome measurements made will be in the desired range. Thus both optimal results are obtained.
1,6	Our radom design should be made of easily available materials. The production process should not be interrupted.	The easy supply of the materials used reduces the cost and enables quick intervention in case of failure. Thus, the usage time is extended.
3,6	Long-term lifetime in inventory. In use, the life span may differ depending on environmental conditions. These different periods are expected to be longer than the lifetime of the least used material.	The long lifetime of the materials used in the design increases the durability, thus protecting the antenna from all kinds of environmental conditions. It will also increase the durability of the structure.
1,5	Since it is made of readily available material, it is simple to cut the area neatly and put the new material in when damaged or when maintenance is required.	In case of damage to the structure, the easy availability of the repair material gives us a plus in terms of cost. After the repair, the assembly of the material is done easily.
3,6	Our design will comply with MIL and CE standards.	If MIL and CE standards are taken into account, it will increase the life span of the structure. At the same time, it will protect the antenna from all kinds of environmental conditions.
3, 4, 5,6	The design of the radome should be sandwich-shaped, 3-layer, conical for the nose, cylindrical or rectangular for the wing tip.	The geometric structure of the radome's design allows us to obtain optimized values for the test results we will perform, its lifetime, protection of the antenna from all kinds of environmental conditions and easy mounting on the aircraft.

Table 2

2.3 Constraints

2.3.1 Economic: Production will not take place in this project, it will be done in a simulation environment. Therefore, we do not have an economic limit.

2.3.2 Environmental: Materials such as fiberglass and polyurethane used for radom production are environmentally friendly materials. The resin to be used in the interior structure is harmful to the environment. However, this damage is at a tolerable level, although not too much. Since a sandwich radome is created using these products in our design, the damage to the environment is very low.

2.3.3 Sustainability: Since our product consists of recyclable materials and materials that are least likely to be consumed in the world, we think that there will be no disruption in the supply of necessary materials, as we can produce for long periods of time without material shortages.

We think that we will not have any problems in sales because our product contains products to be purchased from outside compared to competing products in its category and has a lower price than the total product price. This will ensure our sustainability in our income and expenses.

2.3.4 Manufacturability: The material structures and existing designs according to the location where the product will be used on the aircraft are such that no problems arise in mass production under today's conditions.

2.3.5 Social: The product to be revealed will be used in the military. The use of a more optimized product in the military makes the public feel more secure.

2.4 Standards:

AIA/NAS ARTC-4 - Electrical test procecures for radomes and radome materials **FAA-E-2773** - Fixed ground antenna radome

MIL-R-5082 - Radome for CTV-2 pilotless aircraft (LEARN MORE ABOUT RADOMES, 2010)

MIL-R-7705B - General design and performance requirements for radomes (RADOMES, GENERAL SPECIFICATION FOR, 1975).

The resins used in glass reinforced radome shall be in accordance with one of the following rule.

MIL-R-7575

MIL-R-25042

MIL-R-25506

MIL-R-9299

MIL-R-9300 (RADOMES, GENERAL SPECIFICATION FOR, 1975)

3.DESIGN

3.1 Conceptual

Design 3.1.1

Level 0

WING TIP RADOME NOSE RADOME

SENDING SIGNAL SENDING SIGNAL RECEIVING SIGNAL RECEIVING SIGNAL RECEIVER RECEIVER

Figure 1: Level 0 Design

Module	**Antenna**
Inputs	The antenna is powered by an external source.
Output	Sending signal
Functionally	Transmitter sends a signal, which is intercepted by a receiver.
Module	**Radome**
Inputs	Sending signal
Output	Received signal
Functionally	Radomes protect the antenna from environmental conditions.
Module	**Receiver**
Inputs	Receiving signal
Output	-
Functionally	It receives the reflected signal from the antenna.

Table 3

3.1.2 Level 1

ANTENNAS X-BAND ANTENNA

5-LAYER SANDWICH CONSTRUCTION CONICAL NOSE RADOME

RECEIVING SIGNAL RECEIVING SIGNAL

RECEIVER RECEIVER

SENDING SIGNAL SENDING SIGNAL

5-LAYER SANDWICH CONSTRUCTION CYLINDRICAL WING-TIP RADOME

RECEIVING SIGNAL

RECEIVER

C-BAND ANTENNA

5-LAYER SANDWICH CONSTRUCTION CONICAL NOSE RADOME

RECEIVER

RECEIVING SIGNAL

5-LAYER SANDWICH CONSTRUCTION CYLINDRICAL WING-TIP RADOME

Figure 2: Level 1 Design

Module	**X Band Antenna**
Input	The antenna is powered by an external source.
Output	Sending Signal
Functionally	Transmitter sends a signal, which is intercepted by a receiver. X antenna broadcasts in the 8-12 GHZ frequency range.
Module	**C Band Antenna**
Input	The antenna is powered by an external source.
Output	Sending Signal
Functionally	Transmitter sends a signal, which is intercepted by a receiver. C antenna broadcasts in the 2-6 GHZ frequency range.
Module	**Cylindrical Wing Tip Radome with 5-Layer Sandwich Structure**
Input	Sending signal
Output	Received signal
Functionally	It protects the antenna of the wing tip from environmental conditions.
Module	**Conical Nose Tip Radome with 5-Layer Sandwich Structure**
Input	Sending signal
Output	Received signal
Functionally	It protects the antenna located on the nose part from environmental conditions.
Module	**Receiving**
Input	Receiving signal
Output	-
Functionally	It receives the reflected signal from the antenna.

Table 4

3.2 Detailed Design

3.2.1 Dimensional Parameters of Final Design

a) C-Band Suspended Patch Antenna Dimensional

Parameters Start Frequency: 2 GHz

Stop Frequency: 6 GHz

Ground Plate Width: 45.6 mm

Ground Plate Length: 45.6 mm

Ground Plate Thichness: 0.035 mm

Dielectric Plate Width: 45.6 mm

Dielectric Plate Length: 45.6 mm

Dielectric Plate Tickness: 1.524 mm

Main Patch Width: 20.805 mm

Main Patch Length: 20.805 mm

Main Patch Height: 5.4 mm

Main Patch Thickness: 0.3 mm

Parasitic Patch Width: 17.67 mm

Parasitic Patch Length: 17.67 mm

Parasitic Patch Height: 4 mm

Parasitic Patch Thickness: 0.3 mm

Parasitic Patch Rotation: 45º

Feed Width: 2.917 mm

Feed Lenght: Between the tip of the dielectric material and the tip of the main patch

Feed Thickness: 0.035 mm

Probe Width: 1 mm

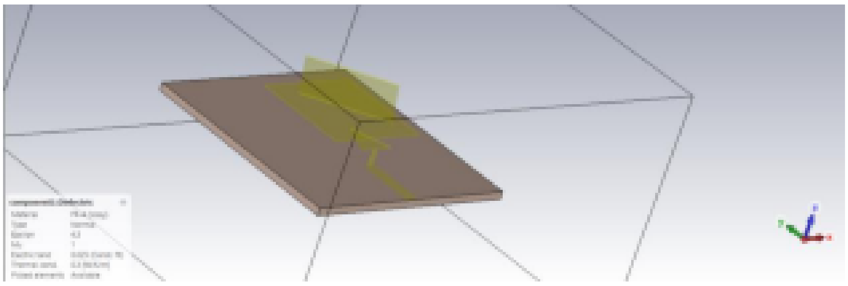
Probe Lenght: 0.3 mm

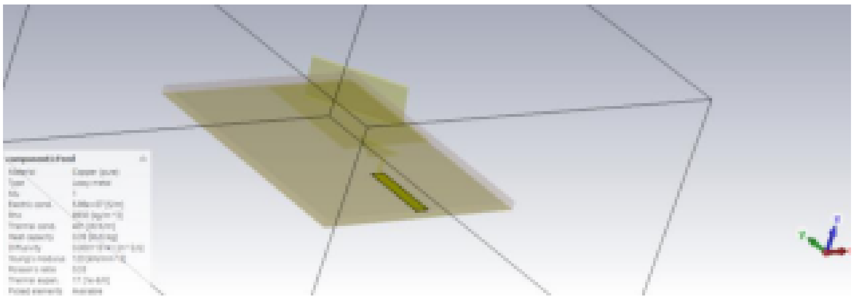
Probe Height: 3.42 mm

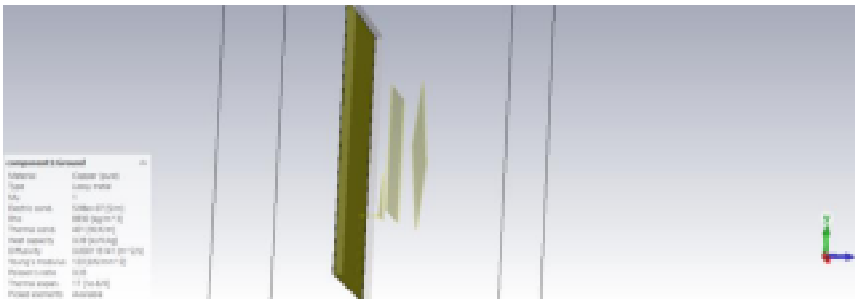
Probe Triangle Width: 7.41 mm

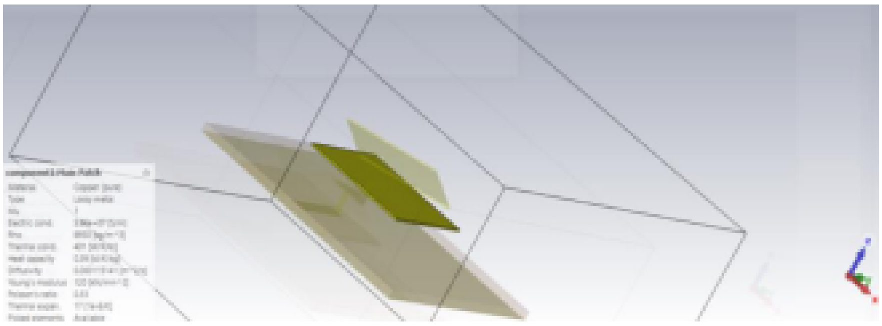
Probe Triangle Length: 7.41 mm

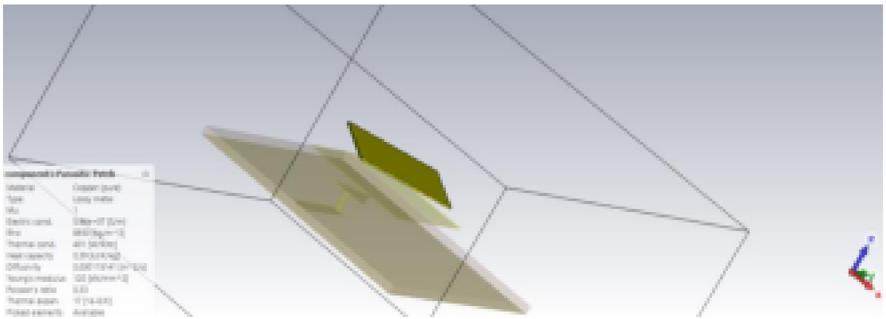
Wave Port Constant: 5.63

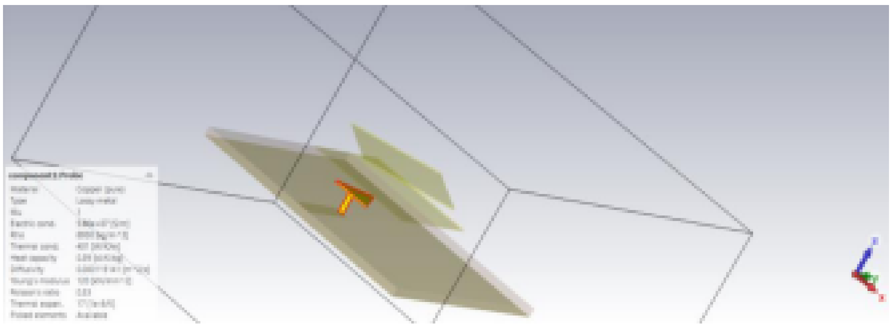












b) X-Band Suspended Patch Antenna Dimensional Parameters Start Frequency: 7 GHz (simulation start frequency)

Stop Frequency: 12 GHz

Ground Plate Width: 32 mm

Ground Plate Length: 32 mm

Ground Plate Thichness: 0.035 mm

Dielectric Plate Width: 32 mm

Dielectric Plate Length: 32 mm

Dielectric Plate Tickness: 1.524 mm

Main Patch Width: 14.6 mm

Main Patch Length: 14.6 mm

Main Patch Height: 5 mm

Main Patch Thickness: 0.3 mm

Parasitic Patch Width: 12.4 mm

Parasitic Patch Length: 12.4 mm

Parasitic Patch Height: 2.4 mm

Parasitic Patch Thickness: 0.3 mm

Parasitic Patch Rotation: 45º

Feed Width: 2.917 mm

Feed Lenght: Between the tip of the dielectric material and the tip of the main patch Feed Thickness: 0.035 mm

Probe Width: 1 mm

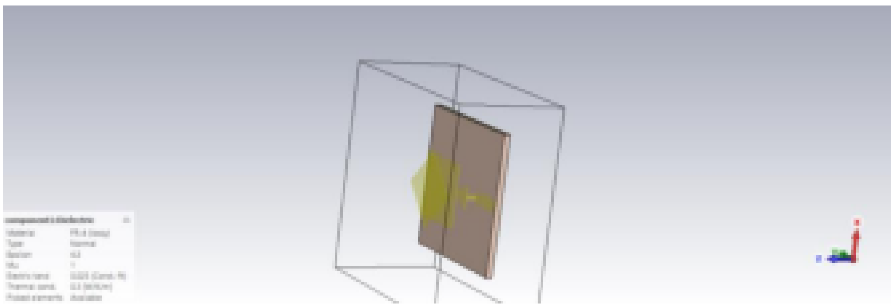
Probe Lenght: 0.3 mm

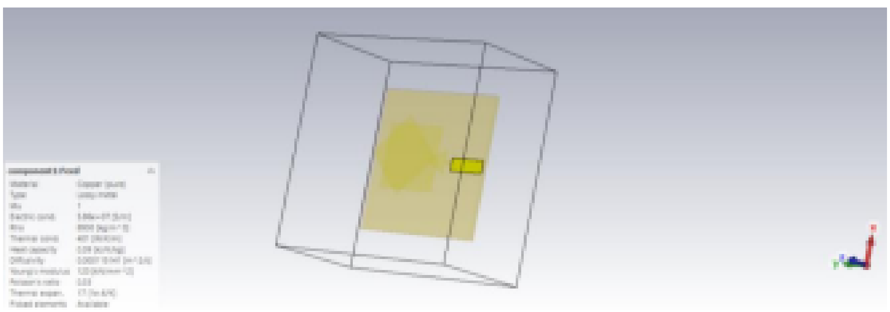
Probe Height: 2.4 mm

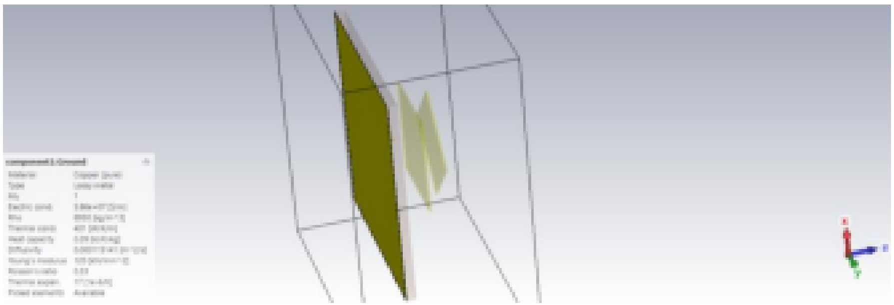
Probe Triangle Width: 5.2 mm

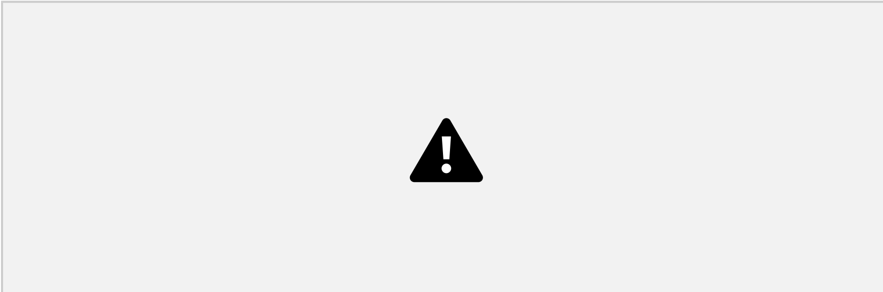
Probe Triangle Length: 5.2 mm

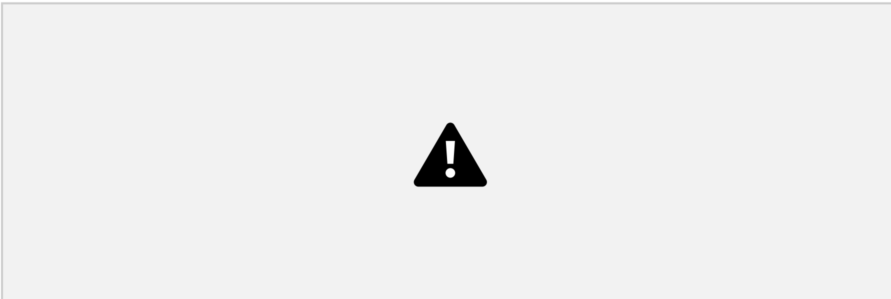
Wave Port Constant: 5.63

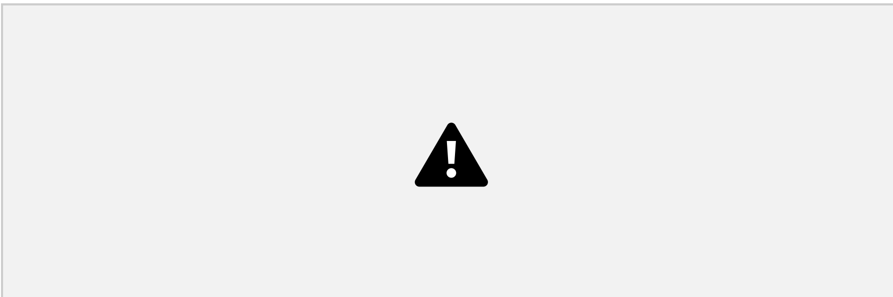










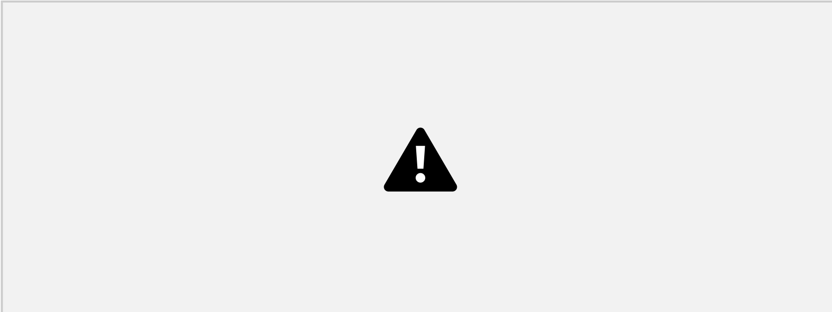


c) Conical Nose Tip Radome with 5-Layer Sandwich Structure

180 cm length

50 cm outer circle diameter

47.6 cm inner circle diameter

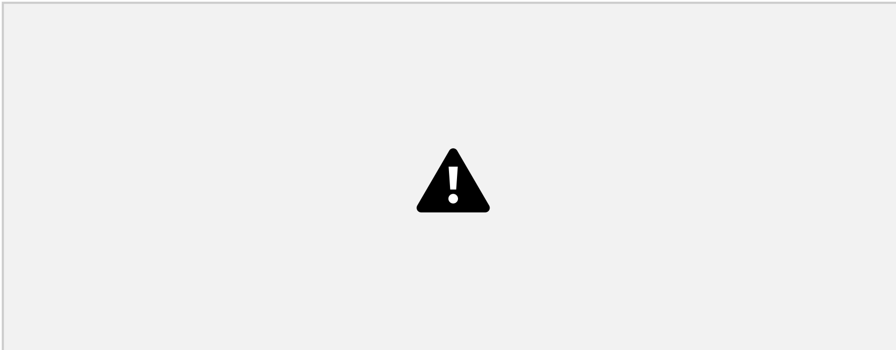


d) Cylindrical Wing Tip Radome with 5-Layer Sandwich Structure

90 cm length

50 cm outer circle diameter

47.6 cm inner circle diameter



3.2.2 Structural Features and Capabilities of the Final Design

a) C-Band Suspended Patch Antenna Dimensional Parameters

There is a dielectric material (FR-4) with a thickness of 1.524 mm on the ground layer with dimensions of 45.6x45.6x0.035 mm. Adhering to the top of this dielectric structure is a supply copper conductor 0.035 mm thick, 2.917 mm wide and long from the end of the dielectric structure to the end of the main patch structure. Starting from the point where this conductor ends, 3.42 mm upwards, 0.5mm to the sides, a 0.3mm wide copper conductor and an equilateral triangle shaped structure with 7.41mm width at the end of this structure combine to form a probe structure. There is a main patch structure of 20,805x20.805x0.3 mm, 5.4 mm above the middle of the dielectric material. We put the parasitic patch structure on top of the main patch structure for the antenna to work in a wider band range. This part is 4 mm higher than the main patch structure and measures 17.67x17.67x0.3 mm. By rotating this structure 45 degrees, we obtained a smoother structure. We limited the frequency between 2 GHz and 6 GHz in the

simulation environment. The antenna operates in this range between 4 and 6 GHz. This is an appropriate range for our study. While choosing the dimensional parameters of the antenna, the formula below was taken as a basis.

�� = �� ��

�� = �������������������ℎ

�� = ���������� ���� ������ℎ��

�� = �������������������

The reason why we chose the suspended patch antenna as the antenna is that it has a low profile and a wide bandwidth. We can expand the bandwidth more with the parasitic structure. For this reason, we used the parasitic structure.

b) X-Band Suspended Patch Antenna Dimensional Parameters

There is a 1.524 mm thick dielectric material (FR-4) on the ground layer with the dimensions of 32x32x0.035 mm. Adhering to the top of this dielectric structure is a supply copper conductor 0.035 mm thick, 2.917 mm wide and long from the end of the dielectric structure to the end of the main patch structure. Starting from the point where this conductor ends, a copper conductor 2.4 mm upwards, 0.5 mm to the sides and 0.3 mm wide, and an equilateral triangle shaped structure with a width of 5.2 mm at the end of this structure combine to form a probe structure. There is a main patch structure with dimensions of 14.6x14.6x0.3 mm, 5 mm above the middle of the dielectric material. We put the parasitic patch structure on top of the main patch structure for the antenna to work in a wider band range. This structure is 2.4 mm higher than the main patch structure and has dimensions of 12.4x12.4x0.3 mm. By turning this structure 45 degrees, we obtained a smoother structure. We restricted the frequency between 7 GHz and 12 GHz in the simulation environment. The antenna operates in this range between 8 and 10.5 GHz. This is an appropriate range for our study. This is an appropriate range for our study. While choosing the dimensional parameters of the antenna, the formula below was taken as a basis.

�� = �� ��

�� = �������������������ℎ

�� = ���������� ���� ������ℎ��

�� = �������������������

Due to the increase in the operating frequency value, the wavelength decreased, so the dimensions of the X band antenna became smaller than the dimensions of the C band

antenna.The reason why we chose the suspended patch antenna as the antenna is that it has a low profile and a wide bandwidth. We can expand the bandwidth more with the parasitic structure. For this reason, we used the parasitic structure.

c) Conical Nose Tip Radome with 5-Layer Sandwich Structure

The design of the radome is at the end of 4 mm thick dielectric material (E-Glass) from the outside to the inside, 6 mm core structure (Nomex honeycomb), after the core structure, 4 mm thick dielectric material (E-Glass), again a 6 mm thick core structure and this Just under the structure, there is a 4 mm thick dielectric material (E-glass). The reason why the 3-layer structure in the conceptual design has changed with the 5-layer structure is due to the change in TAI criteria. The core structure in the radome is in the form of honeycomb. Honeycomb shape makes the structure more durable and permeable. The reason why we chose E-Glass as the material is that the dielectric constant like FR-4 is suitable for the radome we will design and the material has a lighter structure. Generally, this structure is used in radome designs. Structurally, it is a circle with a length of 180 cm, an inner diameter of 47.6 cm, an outer diameter of 50 cm, and a diameter of 10 cm at the tip. A pointed metal conductive structure 10 cm wide is located on the end ring.

d) Cylindrical Wing Tip Radome with 5-Layer Sandwich Structure The design of the radome is 4 mm thick dielectric material (E-Glass) from the outside to the inside, 6 mm core structure (nomex) at the end, 4 mm thick dielectric material (E-Glass) again after the core structure, a 6 mm thick core structure and this structure just below it is a 4 mm thick dielectric material (E-glass). The reason why the 3-layer structure in the conceptual design has changed with the 5-layer structure is due to the change in TAI criteria. The core structure in the radome is in the form of honeycomb. Honeycomb shape makes the structure more durable and permeable. The reason why we chose E-Glass as the material is that the dielectric constant like FR-4 is suitable for the radome we will design and the material has a lighter structure. Generally, this structure is used in radome designs. Structurally, it has a cylindrical structure with a length of 90 cm and an inner diameter of 47.6 cm and an outer diameter of 50 cm.

3.2.3 Selection/Integration/Architecture of Systems and Subsystems The reason for choosing the X-Band Suspended Patch Antenna and the C-Band Suspended Patch antenna was chosen in the project because of the low profile of the antennas and their operation in a wider band range.

The reason for using a conical radome in the nose area is to reduce friction and prevent airspeed from being blocked. The reason for using radome in cylindrical shape of wing tip radome is to make air flow easier and prevent it from hindering acceleration. The reason why radomes are preferred in 5-layer and honeycomb structure should be due to the aim of increasing durability and radome permeability. There is a metal structure of approximately 10 cm in front of the radomes. This is to prevent radome damage from lightning or lightning strikes. Here it is used for grounding purpose.

The FR-4 material consists of a woven fiberglass fabric bonded with a flame resistant epoxy resin. FR-4 is resistant to water. Its insulation is very high regardless of the humidity in the environment. It has an excellent strength/weight ratio (Shamkhalichenar, Bueche, & Choi, 2020). FR-4 is a low cost and easy to use material. The dielectric coefficient of FR-4 is suitable for antenna production. For these reasons, FR-4 was used as the dielectric material in the production of the antenna.

E-Glass material is formed by hardening the melted glass by passing it through very small holes. E-glass is a light, high tensile strength, chemical resistant material. It can be gained the ability to absorb moisture with resin or special coatings. It is a long-lasting and inexpensive material that is resistant to hot and cold. It is an insulating material like FR-4 in terms of its transmission property. This means that our antenna has less effect on the signals emitted than the conductors. For these reasons, E glass was used as the dielectric material of the radome.

Nomex honeycomb was chosen as the core material. This material is made of phenolic aramid papers. It has a light structure. It is resistant to water, heat, high pressure and bending, and is resistant to moisture and dust. It adds extra durability to the structure to which it is added as a core. It is a dielectric material. For these reasons, nomex honeycomb was chosen as the core material.

The reason why copper conductor was chosen in the antenna is that it is a metal with high conductivity and it is a cheap material.

3.2.4 Performance Parameters for Final Design

·Voltage Standing Wave Ratio(VSWR)

VSWR is a function of the reflection coefficient, which describes the power reflected from the antenna. VSWR is always a real and positive number for antennas. The smaller the VSWR, the better the antenna adapts to the transmission line and the more power is supplied to the antenna. The minimum VSWR is 1.0. In other words, no power is reflected in ideal antennas, but this is not possible in practice.

�������� =�������������������

$$����������������= \frac{1 + |��|}{1 - |��|}$$

��: ��������������������� ����������������������

·Efficiency

It is the ratio of the power radiated by the antenna to the power supplied to the antenna. The expectation from an ideal antenna is that it has 100% antenna efficiency, which means it transmits all the power fed to it. In practice, however, a good antenna radiates only 50 to 60% of the power supplied to it.

�������������� ��������������������

$= \frac{��_{������}}{��_{��}} \%$

$��_{������}$: ���������� ���� ���������� ����������������

$��_{��}$: ���������� ���������������� ���� $��h��$ ��������������

·S-parameter

The measure of how much of the power sent from the source to the antenna is returned is called the return loss (Return Loss, S11) parameter. The unit is displayed in dB (decibels). The return loss parameter is one of the most important parameters of the antenna, showing the impedance matching and the maximum transfer of power. If there is no impedance match, some of the power is reflected, loss occurs and this means that all power cannot be transferred to the load. If the return loss is below -9.95 dB in a certain frequency range, it indicates that the antenna is working in this frequency range (Reineix & Jecko, 1989).

$$���� = -20 \log_{10}[��]$$

$$���� = -20 \log_{10} \left| \frac{��_{��} - ��_0}{��_{��} + ��_0} \right|$$

$��_{��}$: �������� �����������������

$��_0$: $��h$������������������������ ����������������� ���� $��h��$ ������������������������ ��������

$��$: �������������������� ����������������������

·Reference Impedance

The preference of antenna impedances of 50Ω should be due to the standards of the transmission line. Compliance with these standards facilitates measurement and calibration processes. · **Gain**

The gain is the ratio of the radiation field intensity of the test antenna to the radiation field intensity of the reference antenna (Supratha & Robinson, 2018). The indicator of how much the antenna can direct the signal coming to its input is called directivity (Johnson & Jasik, 1984).

$$��(��, ��) = \frac{��(��,��)}{��}$$

~~4π~~

�� = ��$_{��}$ * ��

��(��,��):�����������������������

��(��,��): ������������������ �����������������

���� ��ℎ�� ��������������

��$_{��}$:�������������������� ������������������

���� ��ℎ�� ����������������

��: ���������� ������ℎ ��ℎ�� �� − ��������(0º-360º)

��: ���������� ������ℎ ��ℎ�� �� − ��������(0º-360º)

·Farfield

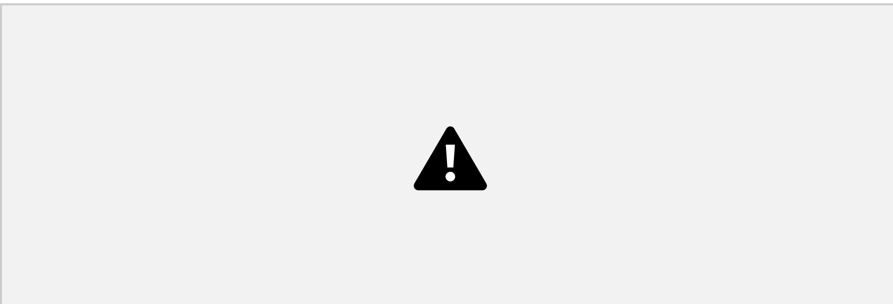
Since the designs of the antennas are square, it is expected that the farfield graph will broadcast symmetrically at 0°. It is expected that the C-band antenna will not transmit behind the antenna in the 2-6 GHz frequency range and the X-band antenna will transmit at a negligible level in the 8-12 GHz frequency range. From the far-field graphs, the directions of the antennas are followed.

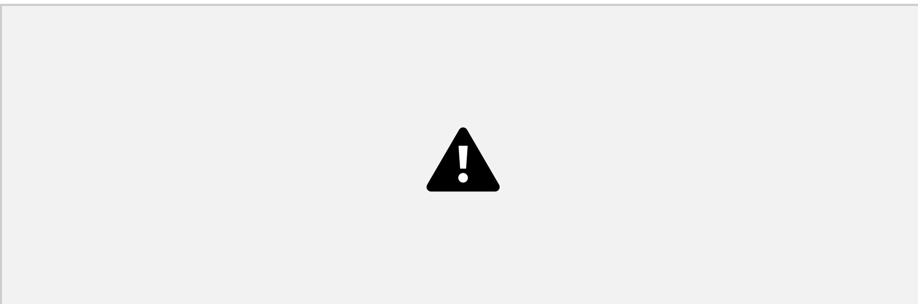
3.2.5 Cost Calculation

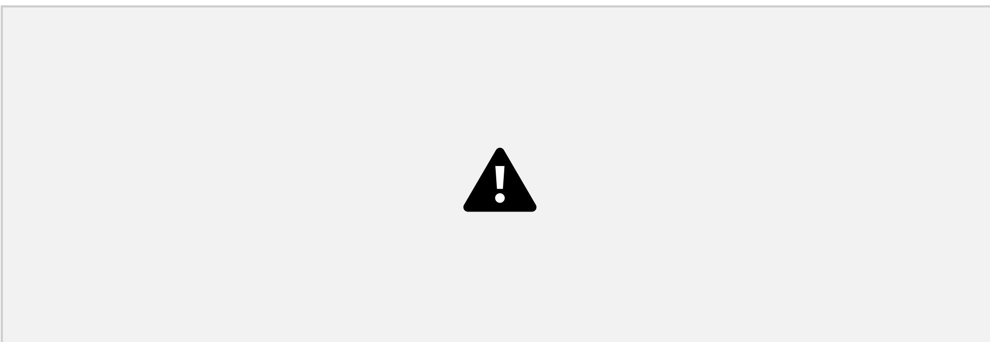
The project will be designed in a simulation program(CST). Therefore, the price analysis stage is not applicable for this project.

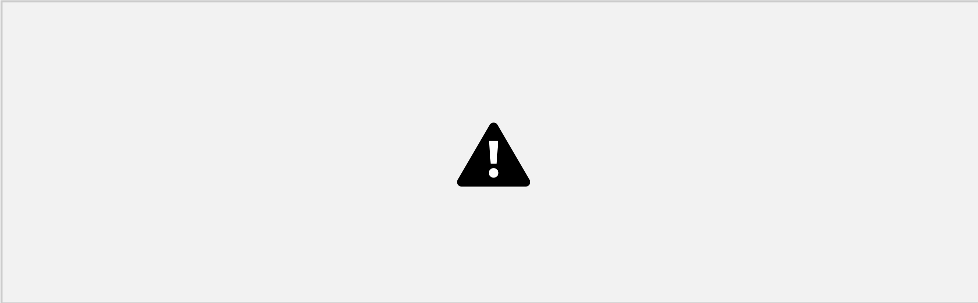
3.2.6 Simulation Results

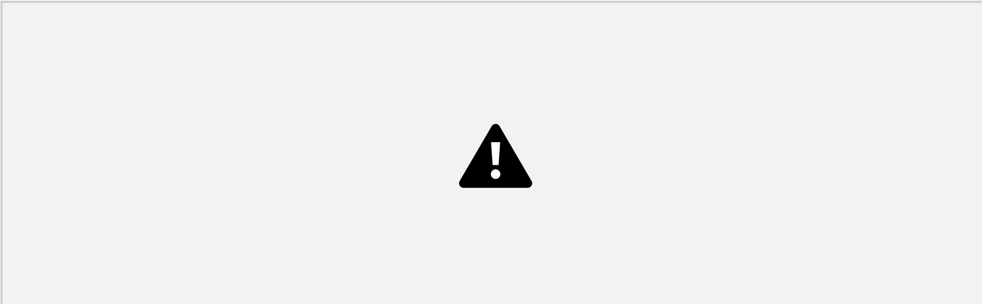
a) C-Band Suspended Patch Antenna

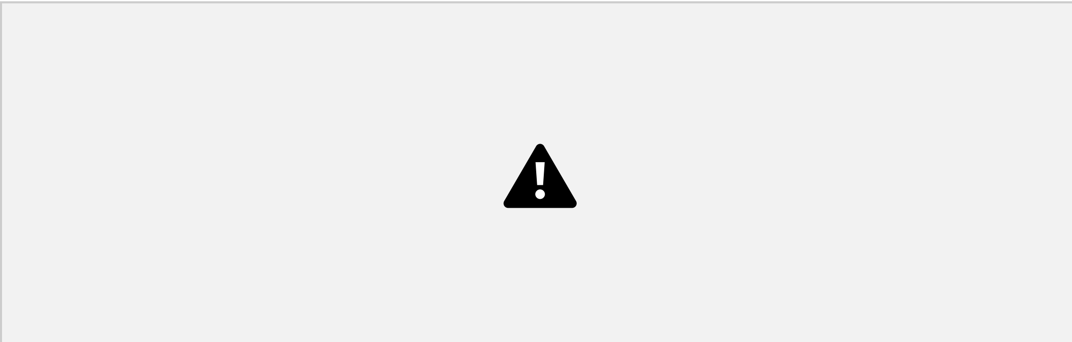


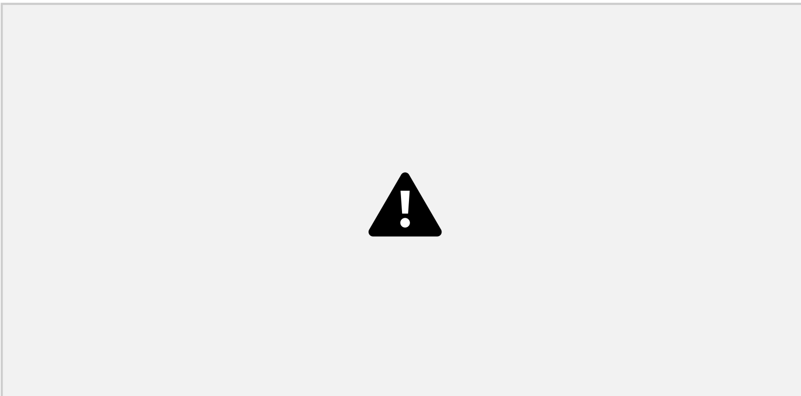


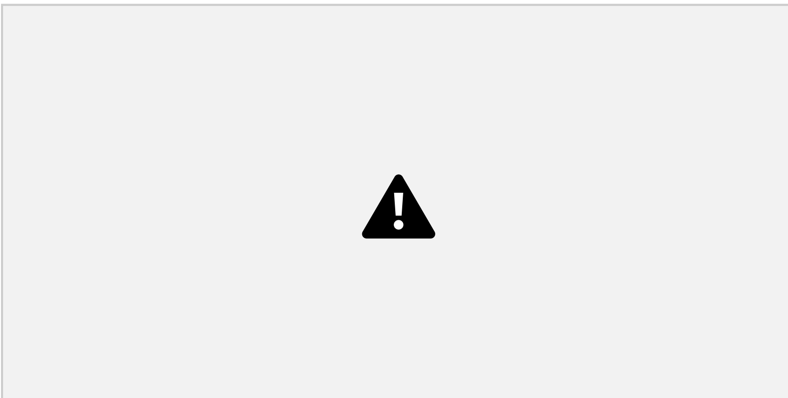


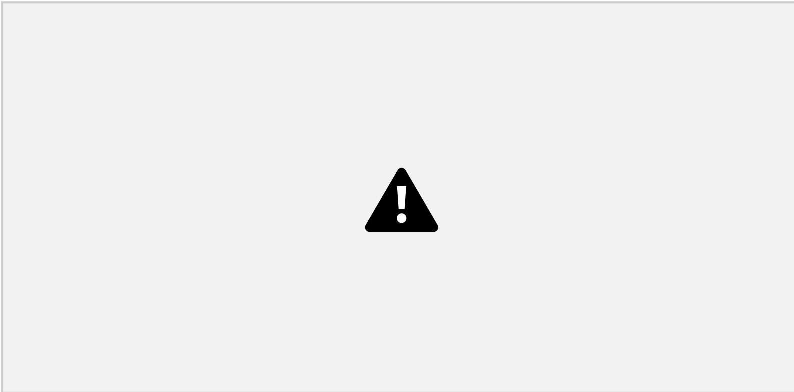


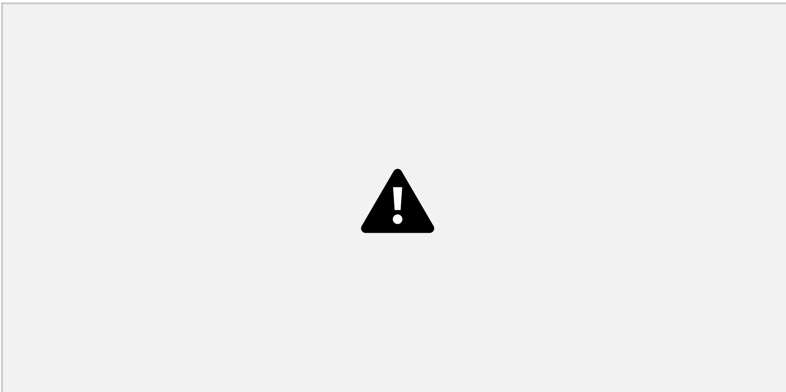


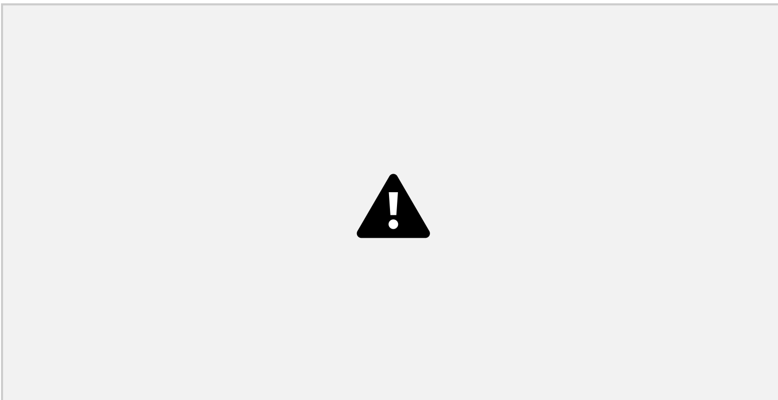


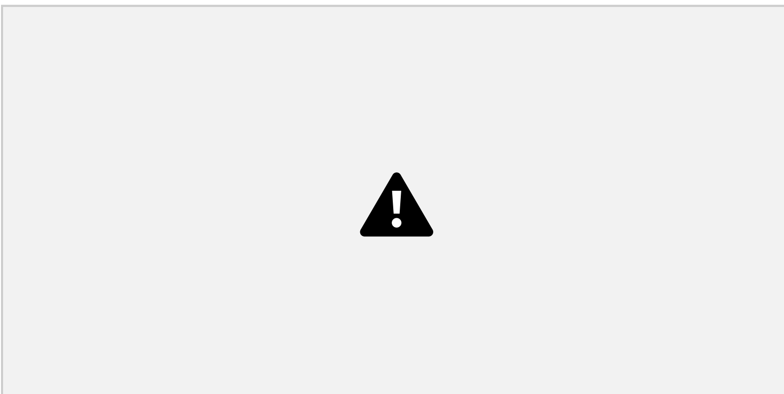


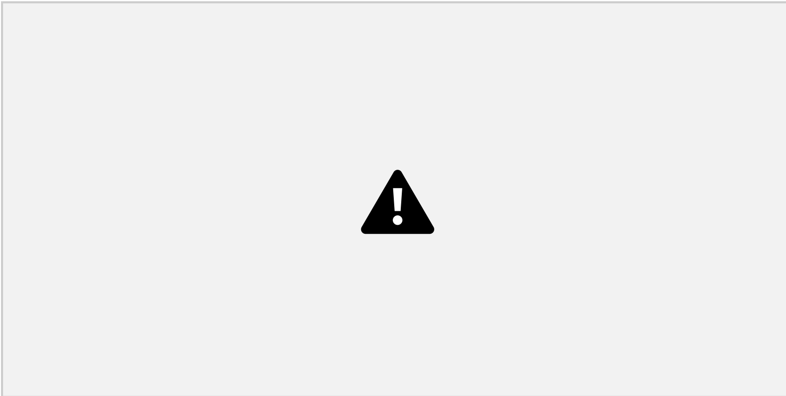


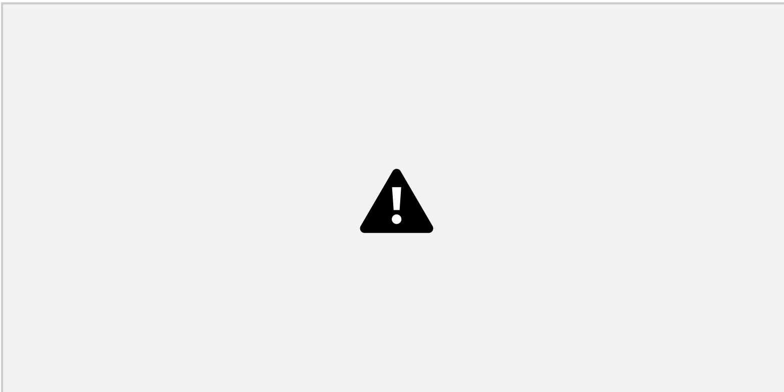


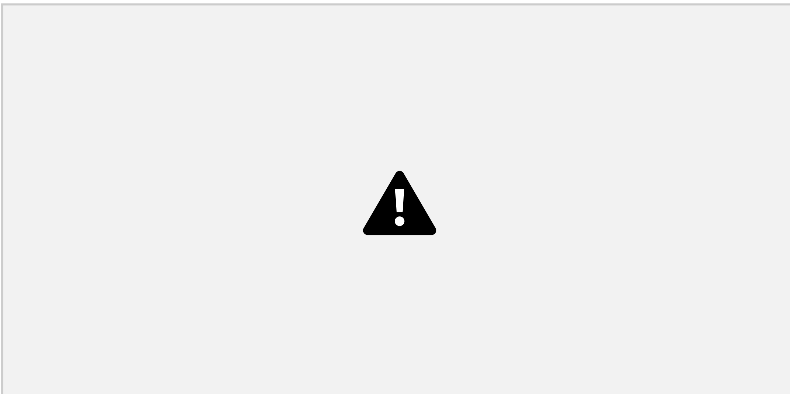


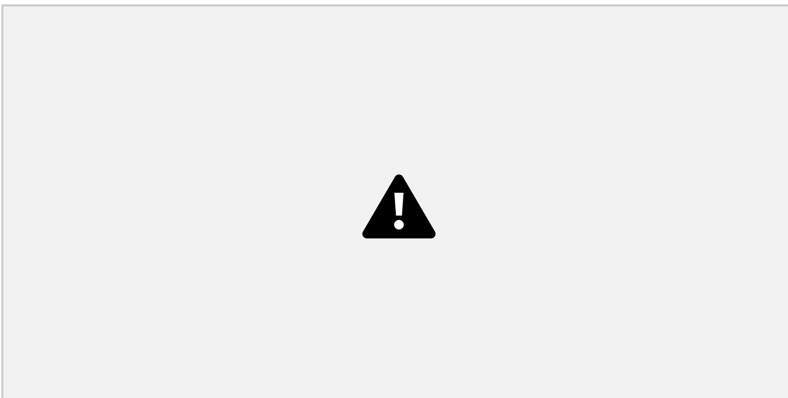




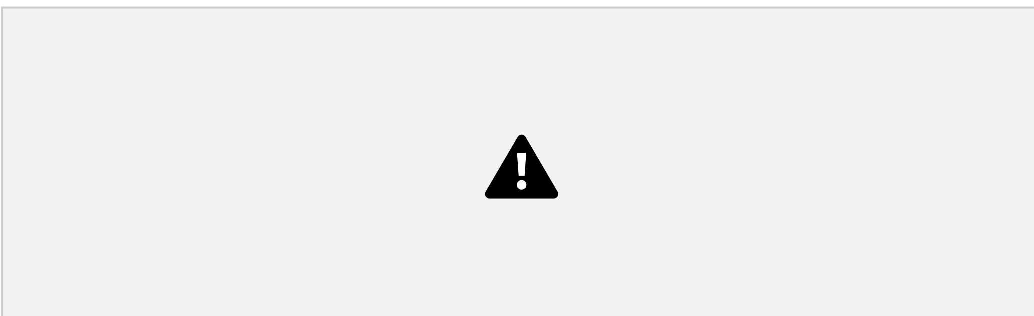


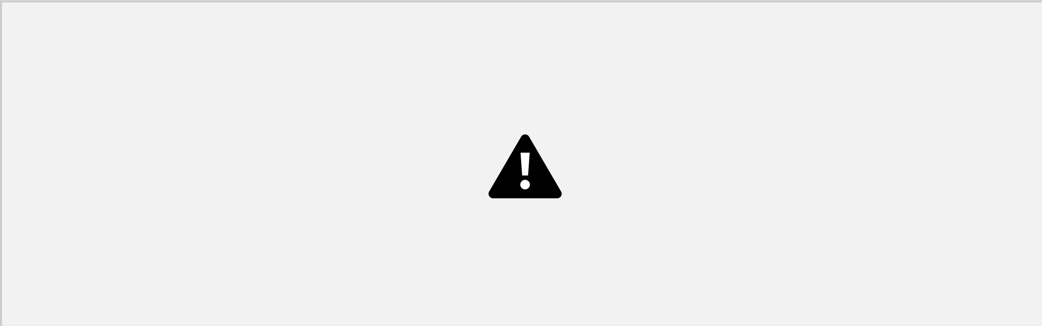


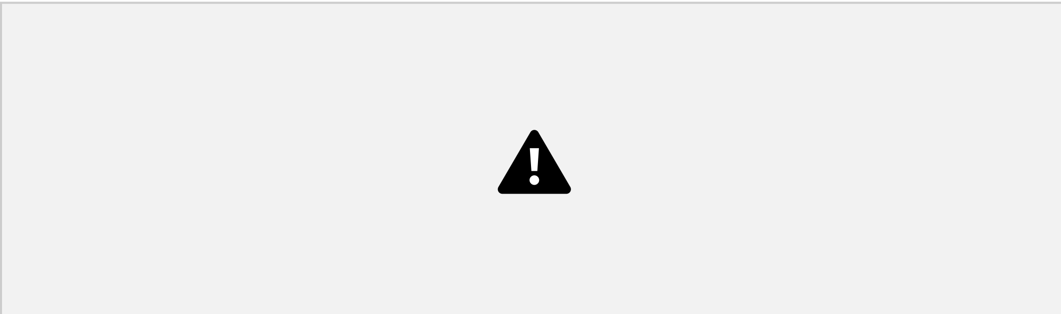


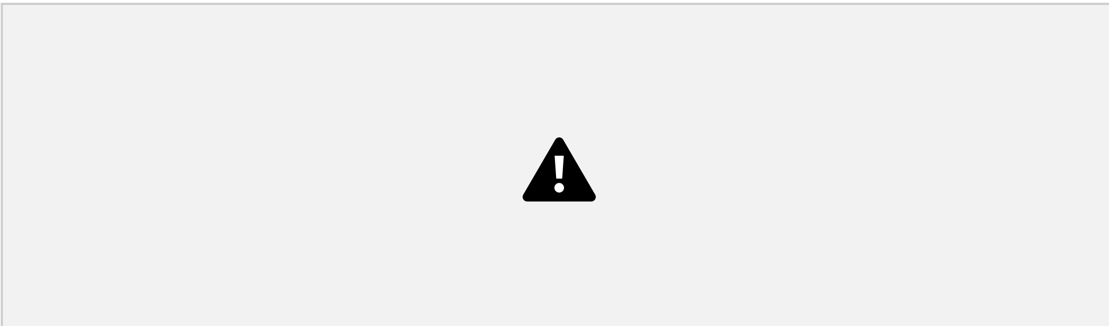


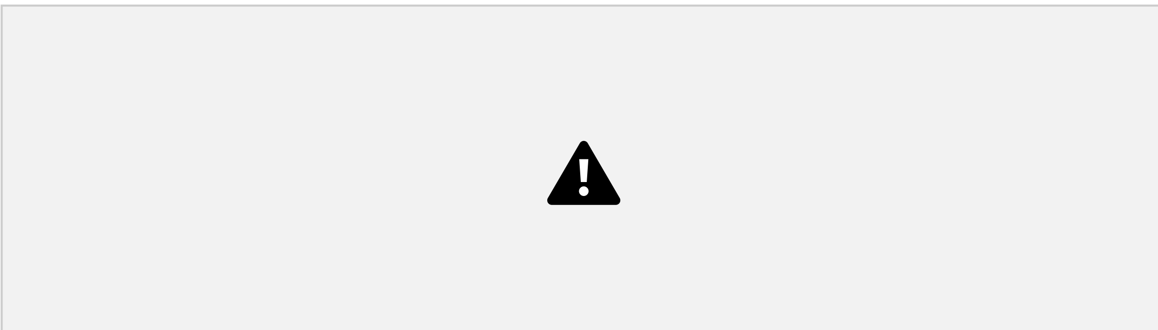
b) X-Band Suspended Patch Antenna

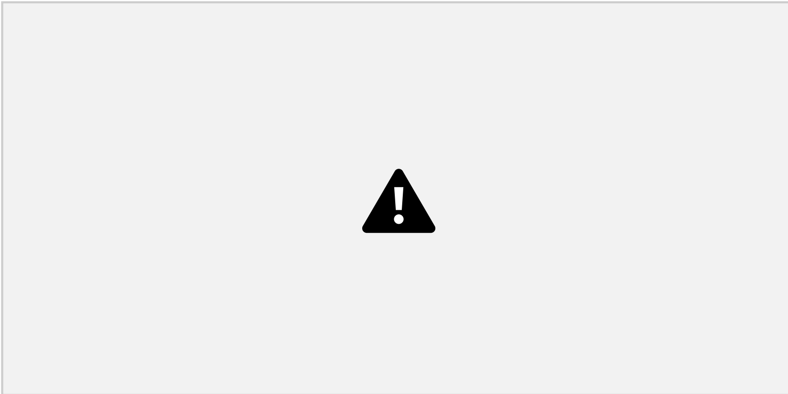


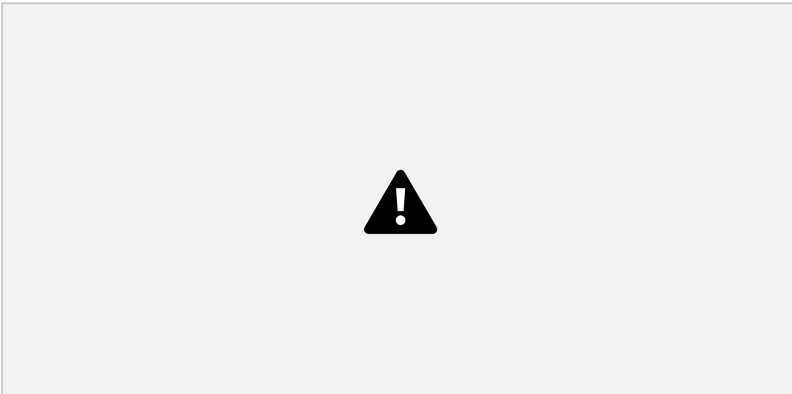












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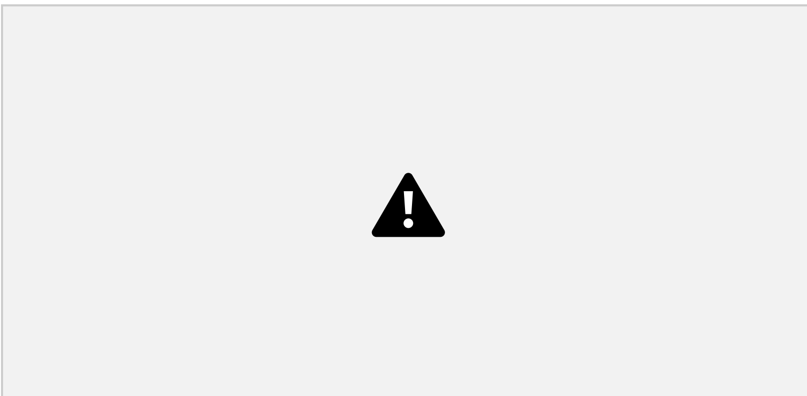

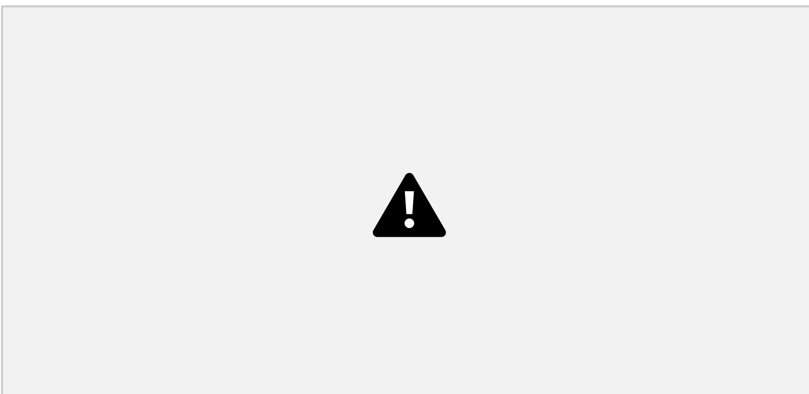

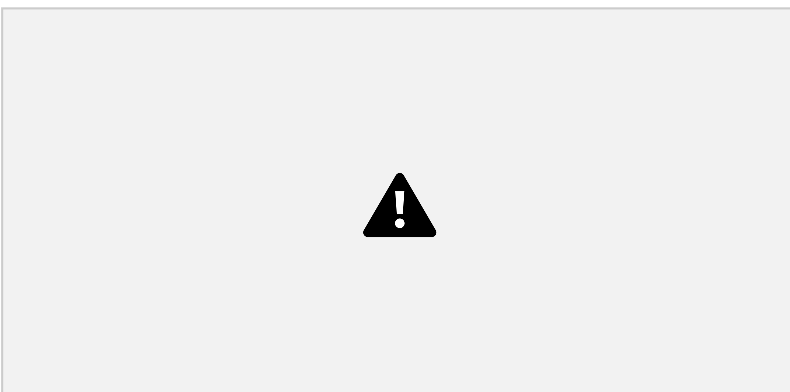

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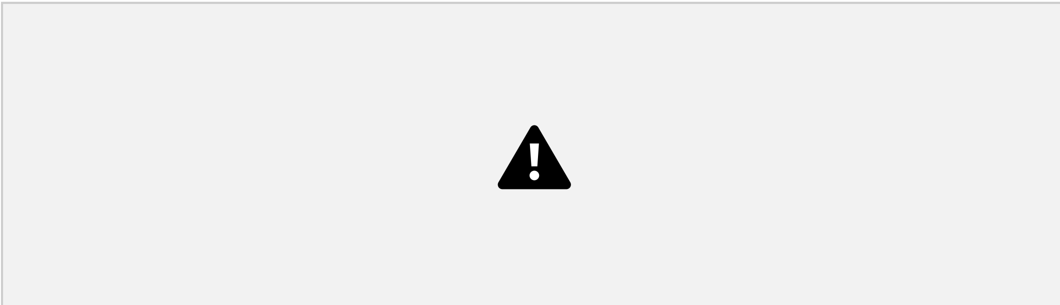
3.2.7 Technical Drawings

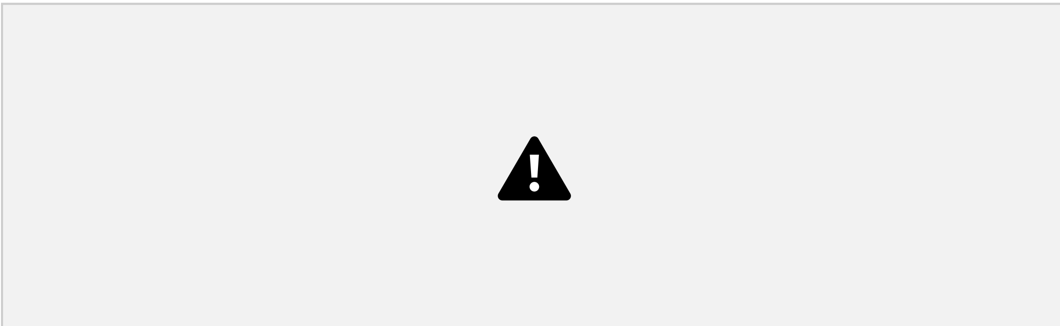
a) Radome with Antenna(Nose)

b) Radome with Antenna(Wing tip)

c) C Band Suspended Patch Antenna

d) X Band Suspended Patch Antenna





4. DESIGN VERIFICATION

4.1 Test Results

4.1.1 Testing the C-Band Suspended Patch Antenna

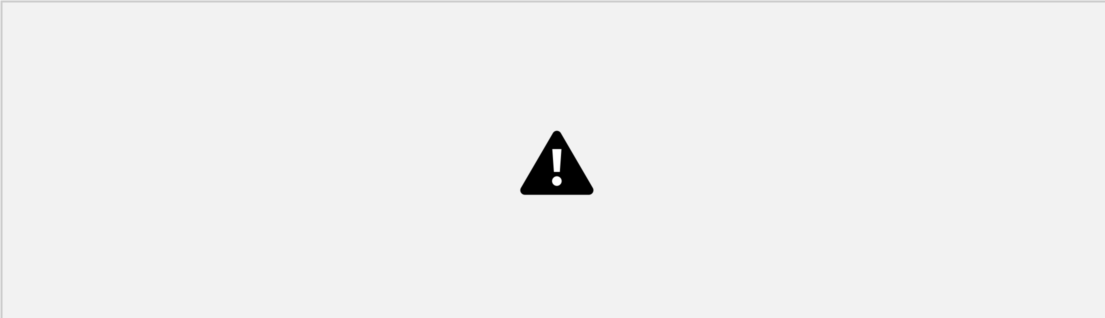


Figure 3: C-Band Suspended Patch Antenna

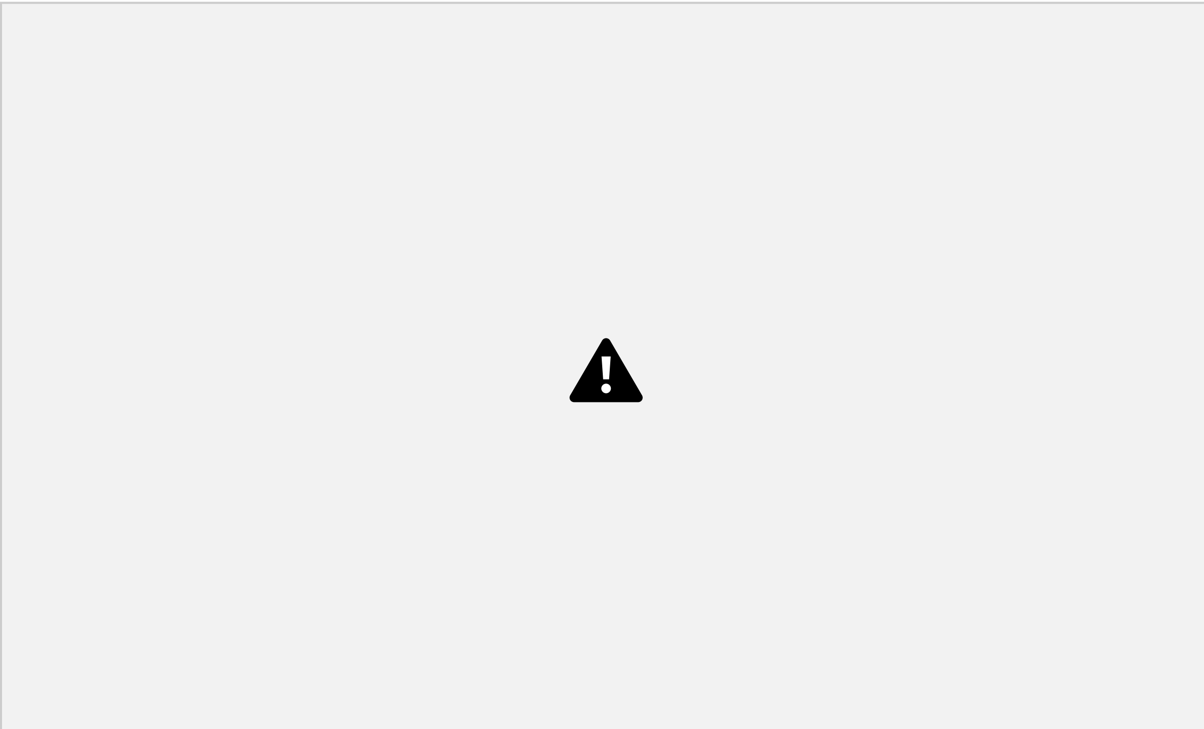


Table 5

Input impedance value of the antenna, operating frequency range in the C-band range, VSWR value, efficiency value, farfield graphics were checked. The antenna has been verified to work properly in the desired frequency range. Figure 3 shows the C-band suspended patch antenna. The simulation results are available in the 3.2.6 Simulation Results section of the report above.

4.1.2 Testing the X-Band Suspended Patch Antenna

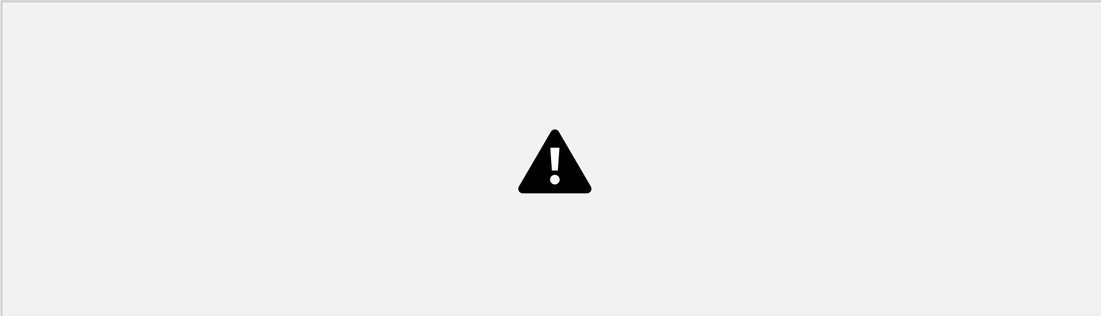


Figure 4: X-Band Suspended Patch Antenna

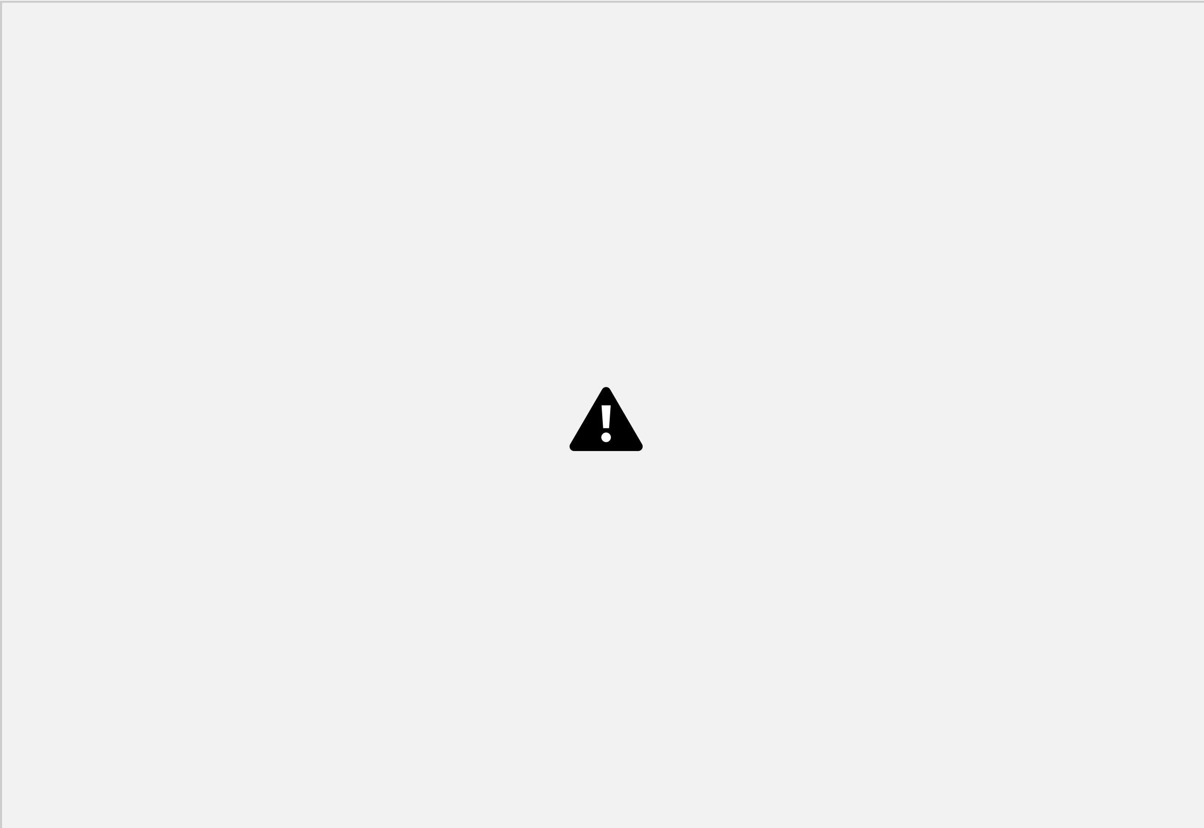


Table 6

Input impedance value of the antenna, operating frequency range in the X-band range, VSWR value, efficiency value, farfield graphics were checked. The antenna has been verified to work properly in the desired frequency range. Figure 4 shows the X-band suspended patch antenna. The simulation results are available in the 3.2.6 Simulation Results section of the report above.

4.1.3 C-Band Antenna With Wing Radome Optimum Thickness and Diameter(Dielectric material E-glass, Core material Nomex honeycomb) Test

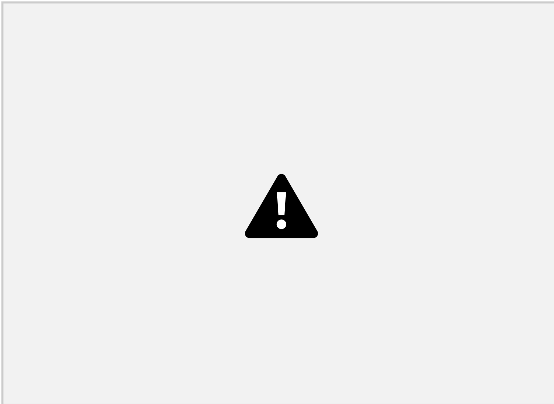
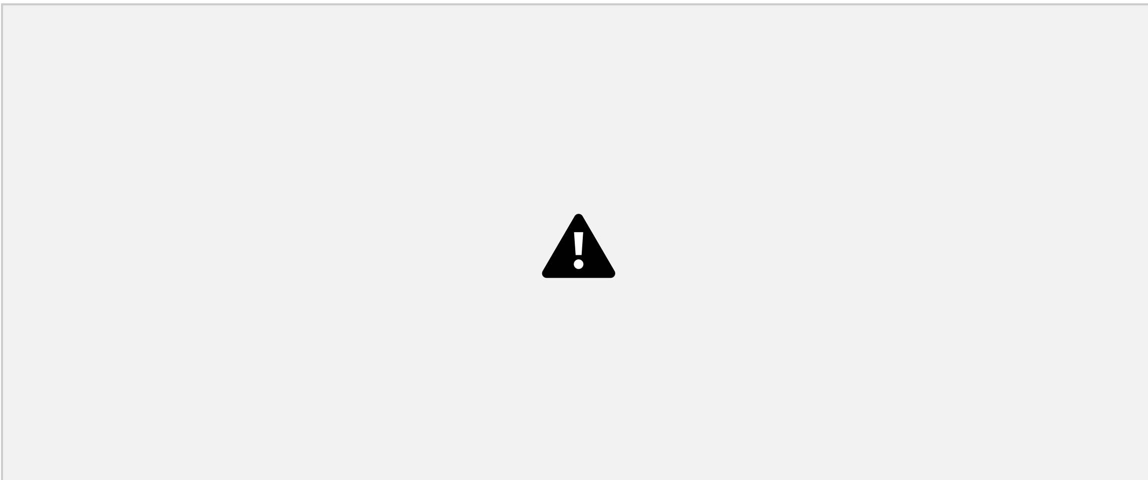


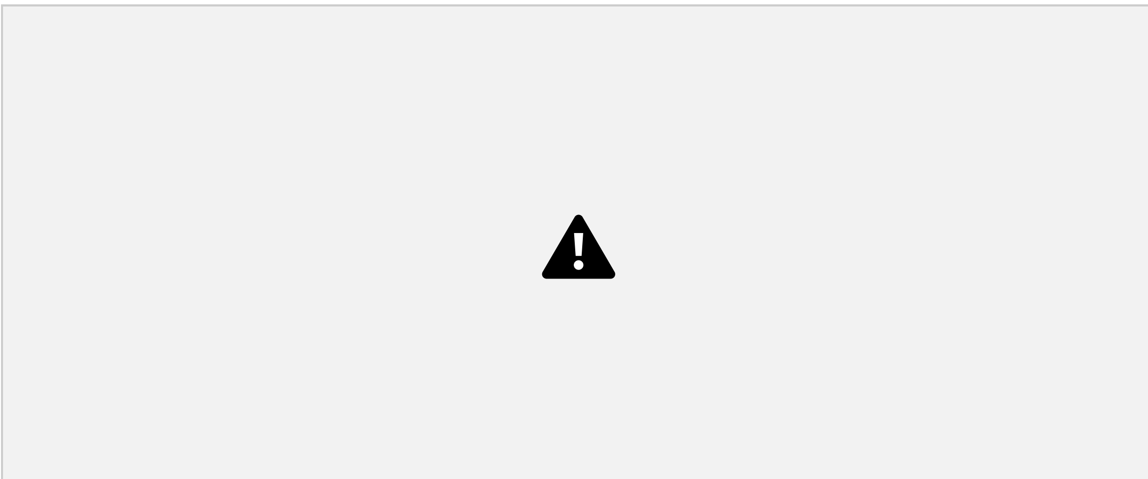
Figure 5: C-Band Suspended Patch Antenna with Wing Radome(Dielectric material E-glass, Core material Nomex honeycomb)

Parameter Resuts

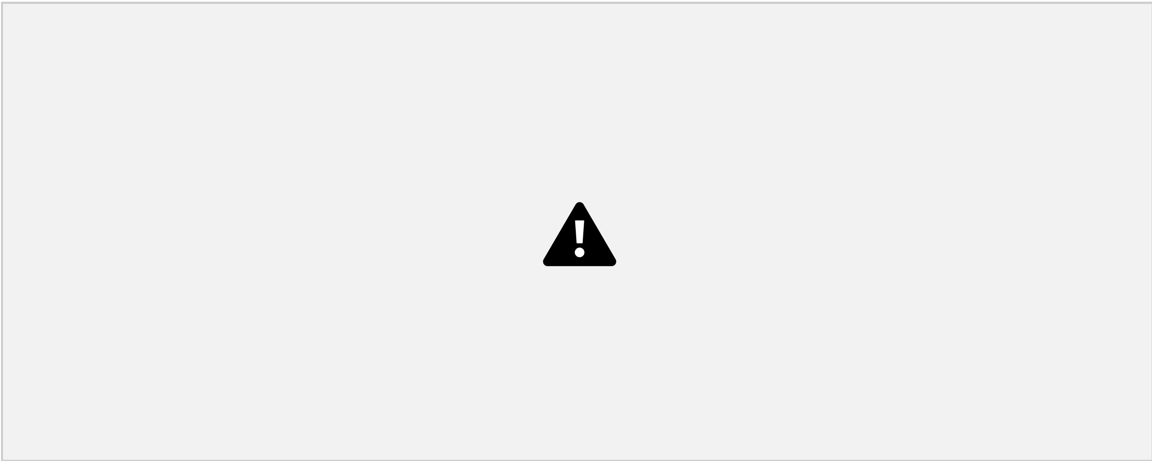
S-Parameters



Efficiency



VSWR



Farfield

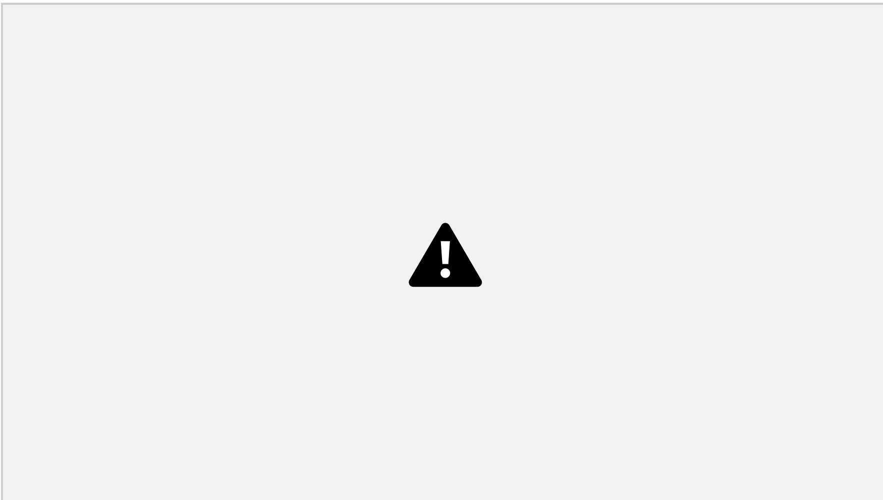


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Table 7

We selected the radome thicknesses and diameters where the S-parameter was below -10dB, which is the range in which the antenna operates, as a result of simulation in the frequency range (4-8GHz) of the radome antenna. All the thicknesses and diameters we tried provided this value. We cannot decide the best thickness and diameter by examining the S-parameter alone, so we looked at other parameters as well. The Wsvr value is the same as the S-parameter value, but we expect the Wsvr value to be below 2 or close to 2, when we examined it, we observed that all thickness and diameter values in the working range of the antenna provide the VSWR value. 24 mm thickness and 70 mm diameter here are better than other thickness and diameters. was closer to a value of 1. We reviewed the efficiency and farfield values and graphs to finalize our decision. The thickness closest to the simulation results of the radomless antenna was 24mm and the diameter was 70mm. The design of the wing radome, which is the most ideal in the test results, is in figure 5 and the parameter results are under the figure 5.

4.1.4 C-Band Suspended Patch Antenna With Wing Radome Distance Test (Dielectric

material E-glass, Core material Nomex honeycomb)

Table 8

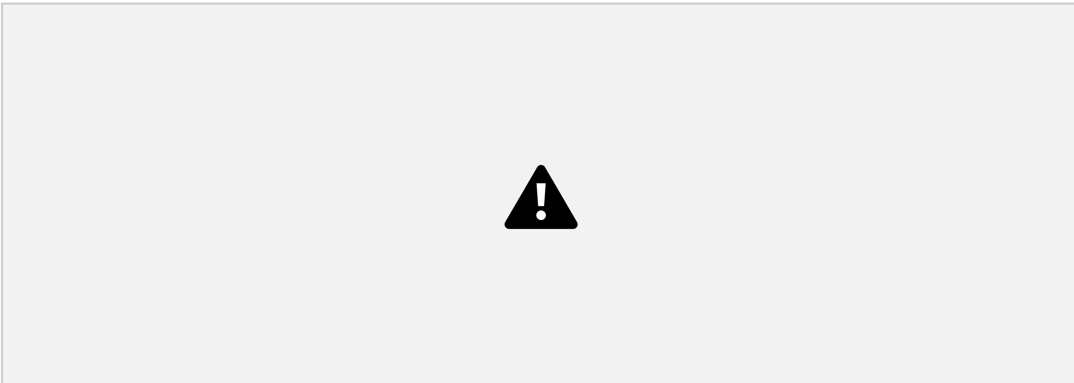
We changed the positions of the antenna in the radome according to the best thickness and diameter selected in the previous table. Here we observed that each location provides the S parameter, but we cannot decide the best position with the S-parameter alone. Therefore, we also examined the VSWR, efficiency and farfield values. We chose those values that are the same or close to the simulation values of the non-radom antenna, and as a result of the selected simulation, we saw that the antenna's radome is 54.9 mm inside from the inner surface to the center. The design of the wing radome, which is the most ideal in the test results, is in figure 5 and the parameter results are under the figure 5.

4.1.5 C-Band Antenna With Wing Radome Optimum Thickness and Diameter(Dielectric material FR-4, Core material Nomex honeycomb)

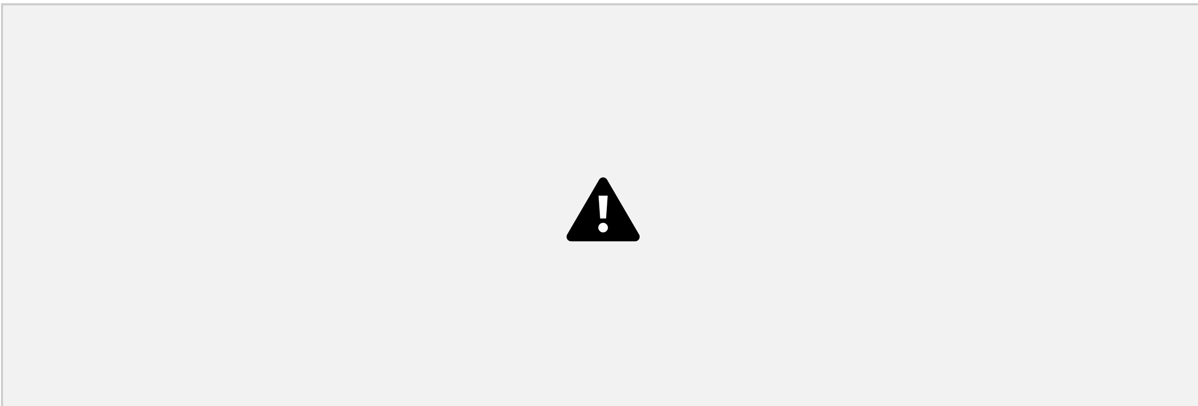
Figure 6: C-Band Antenna With Wing Radome(Dielectric material FR-4, Core material Nomex honeycomb)

Parameter Results

S-Parameters

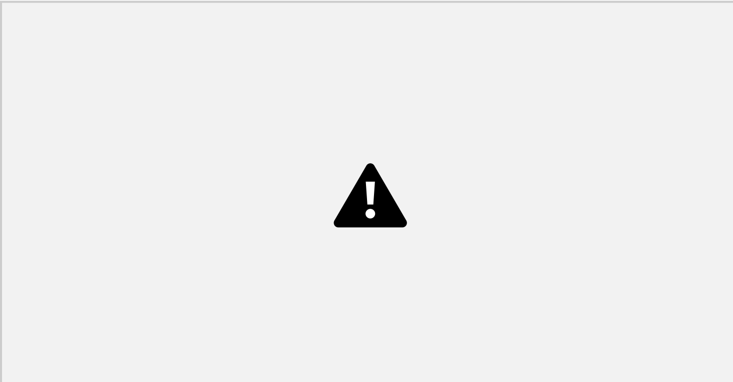


Efficiency



VSWR

Farfield



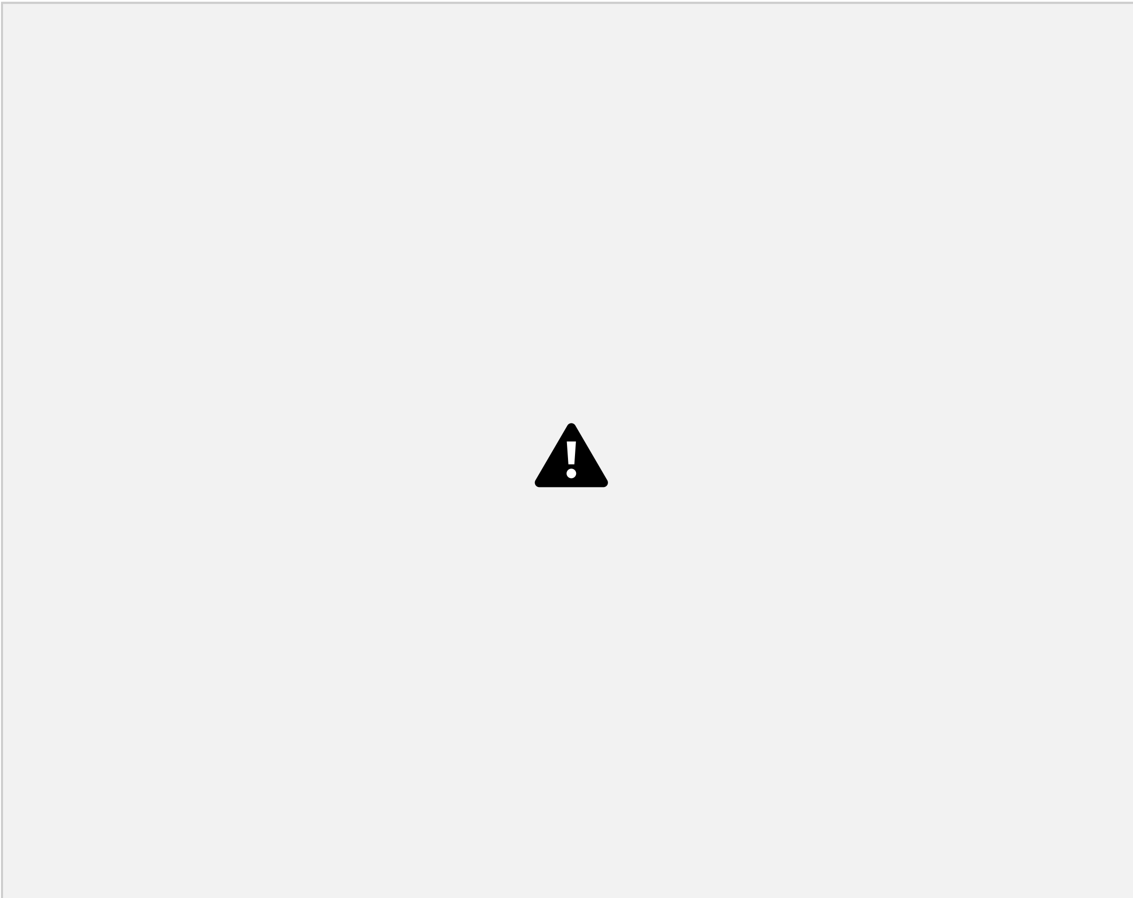


Table 9

We repeated the previous wing radome simulation tests, this time replacing the dielectric material with FR-4. We chose the radome thicknesses and diameters where the S-parameter was below -10dB, which is the range in which the antenna operates, as a result of simulation in the frequency range (4-8GHz) of the radome antenna. All the thicknesses and diameters we tried provided this value. We cannot decide the best thickness and diameter by examining the S-parameter alone, so we looked at other parameters as well. The VSWR value is the same as the S-parameter value, but we expect the VSWR value to be below 2 or close to 2, when we examined it, we observed that all thickness and diameter values in the working range of the antenna provide the Wsvr value, 14mm thickness and 70 mm diameter here than other thickness and diameters. well, it was closer to a value of 1. We reviewed the efficiency and farfield values and graphs to finalize our decision. The thickness closest to the simulation results of the radom free antenna was 14 mm and the diameter was 70 mm. The design of the wing radome, which is the most ideal in the test results, is in figure 6 and the parameter results are under the figure 6.

4.1.6 C-Band Antenna With Wing Radome Optimum Antenna-Radome (Dielectric material FR-4, Core material Nomex honeycomb) Distance

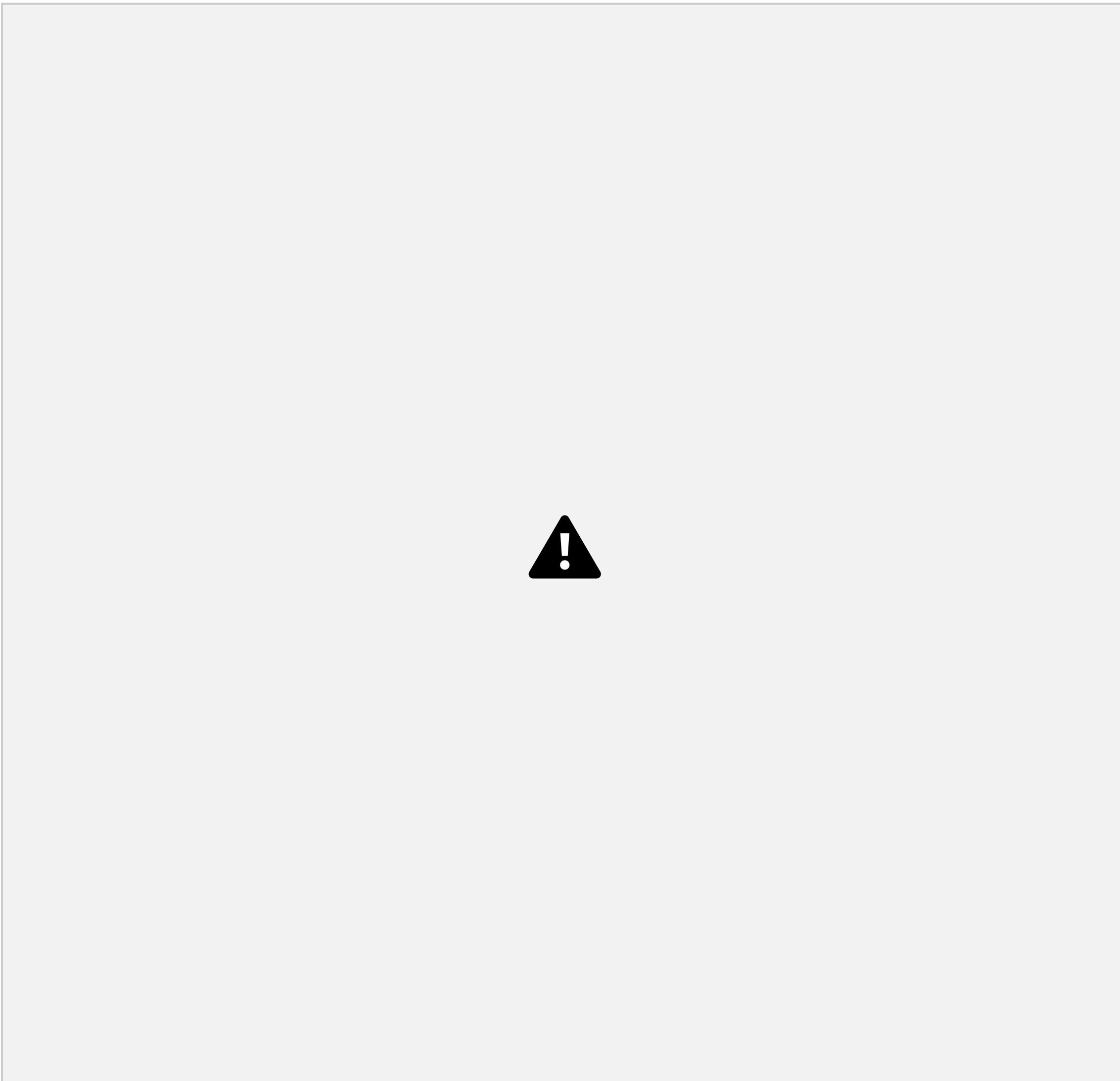


Table 10

We changed the positions of the antenna in the radome according to the best thickness and diameter selected in the previous table. Here we observed that each position provides the S parameter, but we cannot decide the best position with the S-parameter alone, so we also examined the Wsvr , efficiency and farfield values. We chose those values that are the same or close to the simulation values of the non-radom antenna, and as a result of the selected simulation, we saw that the antenna's radome was 67.1mm inside from the inner surface to the center. The design of the wing radome, which is the most ideal in the test results, is in figure 6 and the parameter results are under the figure 6.

4.1.7 X-Band Antenna With Nose Radome Optimum Thickness (Dielectric material E glass, Core material Nomex honeycomb)

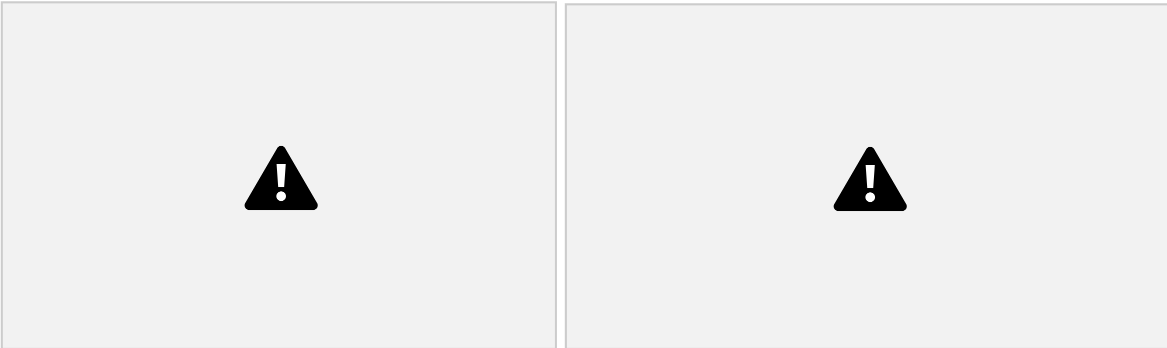
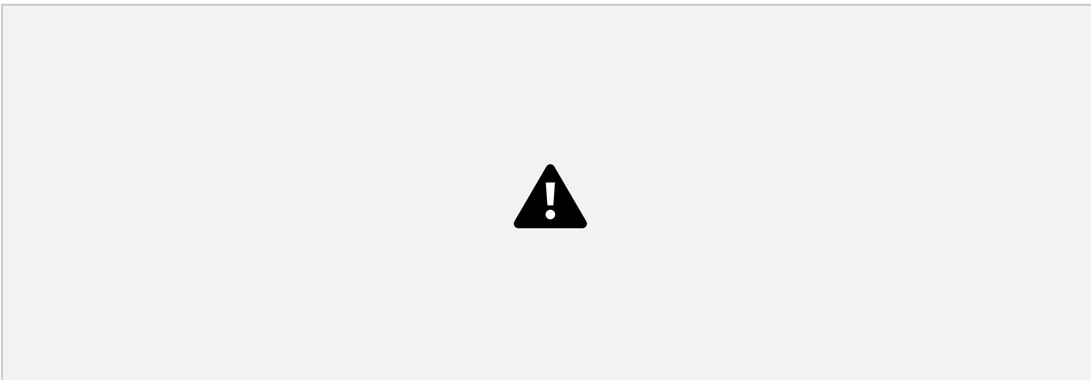


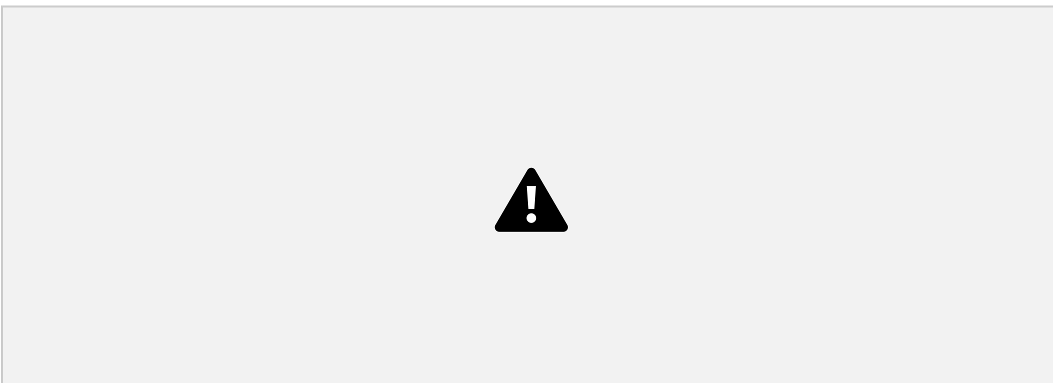
Figure 7: X-Band Antenna With Nose Radome(Dielectric material E-glass, Core material Nomex honeycomb)

Parameter Results

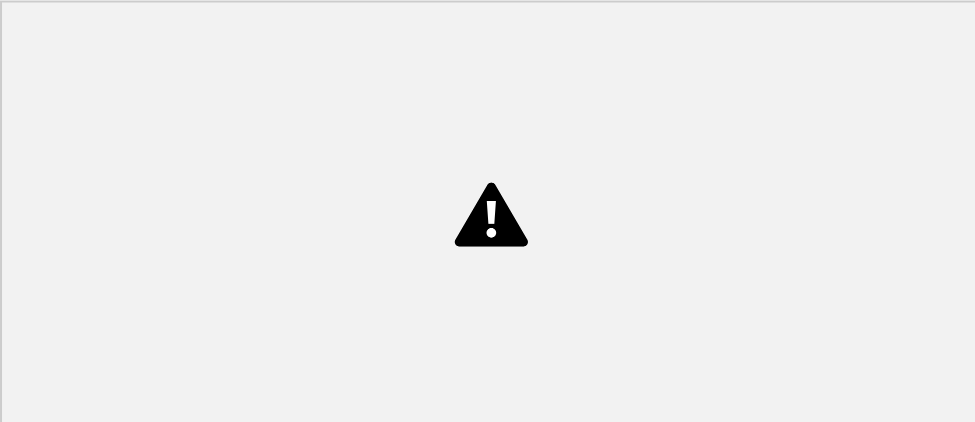
S-Parameters



Efficiency



VSWR


Farfield

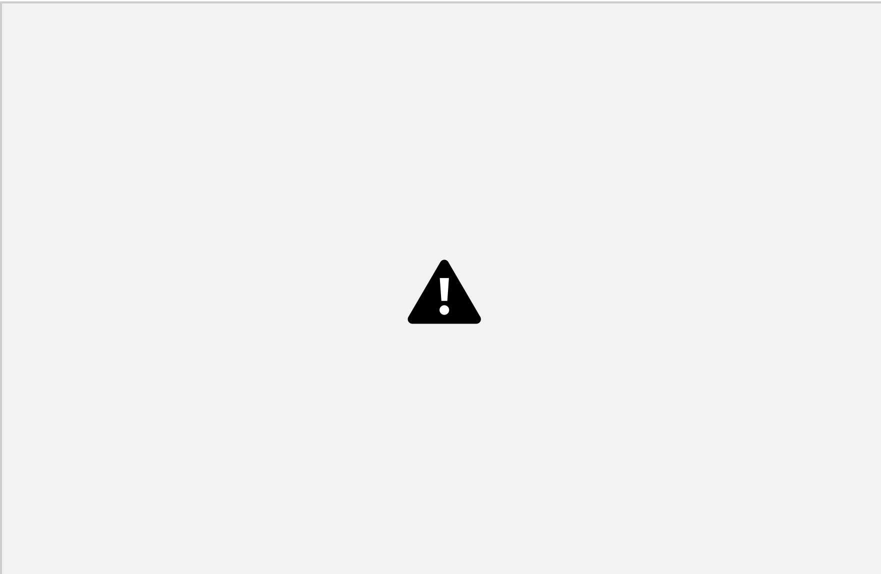

39

Table 11

We chose the radome thicknesses where the S-parameter was below -10dB, which is the range in which the antenna works best, as a result of simulation in the frequency range (8-12GHz) of the radome antenna, and all the thicknesses we tried provided this value. We cannot decide the best thickness by examining the S-parameter alone, so we looked at other parameters as well. The VSWR value is the same as the S-parameter value, but we expect the VSWR value to be below 2 or close to 2, when we examined it, we observed that all of our thicknesses provided the VSWR value in the working range of the antenna. 24mm thickness here was better than the other thicknesses and closer to 1. We examined the efficiency and farfield values and graphs to finalize our decision. The thickness closest to the simulation results of the radomless antenna of these values was 24 mm. Therefore, 24 mm was chosen as the radome thickness. The design of the nose radome, which is the most ideal in the test results, is in figure 7 and the parameter results are under the figure 7.

4.1.8 X-Band Antenna With Nose Radome Optimum Antenna-Nose Radome Distance(Dielectric material E-glass, Core material Nomex honeycomb)

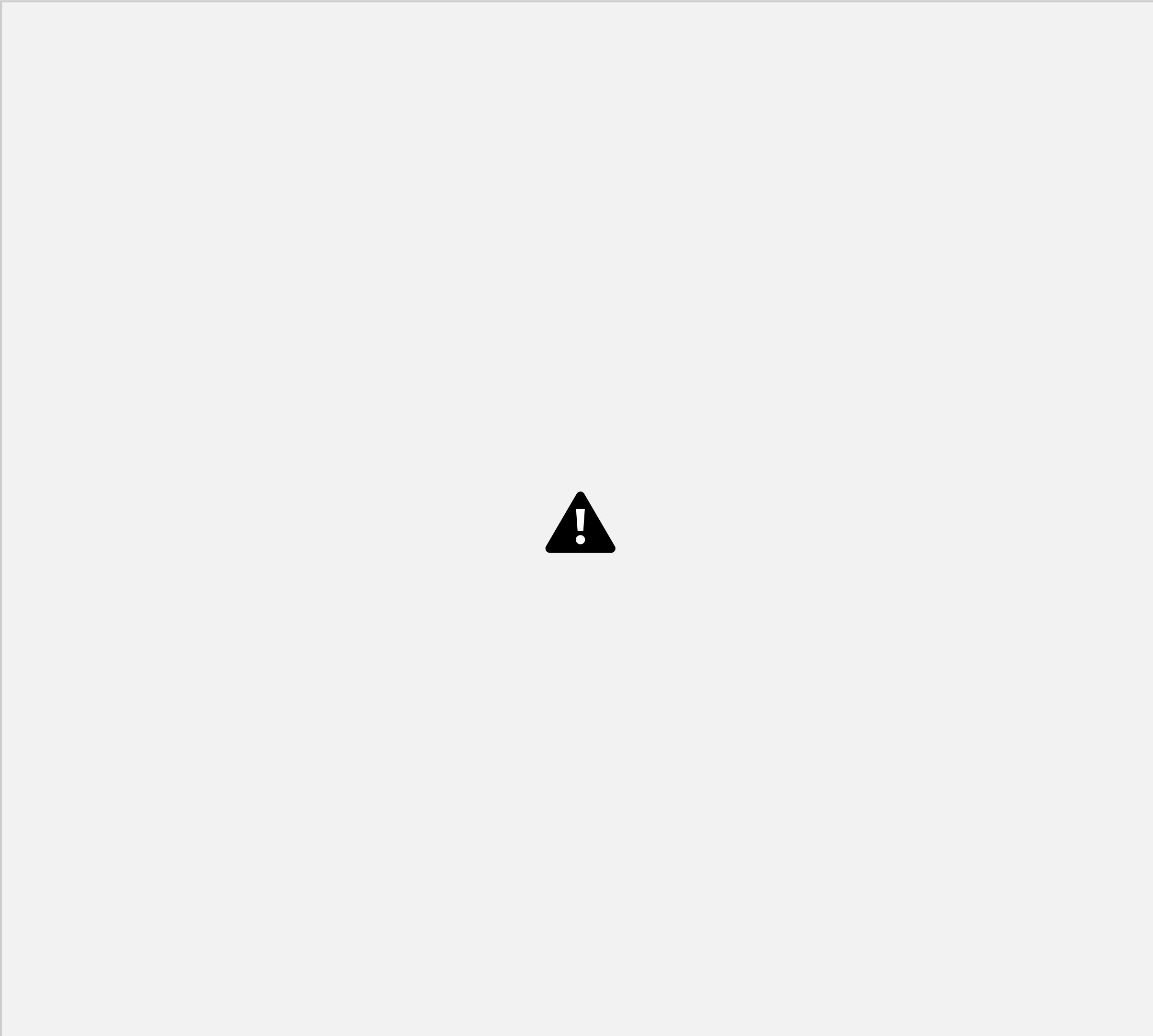


Table 12

We changed the positions of the antenna in the radome according to the best thickness selected in the previous table. Here we observed that each position provides the S-parameter, but we do not decide the best position with the S-parameter alone, so we also examined the VSWR, efficiency and farfield values. We chose the one that is the same or close to the simulation values of the non-radome antenna and we saw that the selected simulation result is the upper part of the inner diameter of the radome (55 mm y-axis in the simulation). The design of the nose radome, which is the most ideal in the test results, is in figure 7 and the parameter results are under the figure 7.

4.1.9 X-Band Antenna With Nose Radome Optimum Antenna Angle(Dielectric material E-glass, Core material Nomex honeycomb)

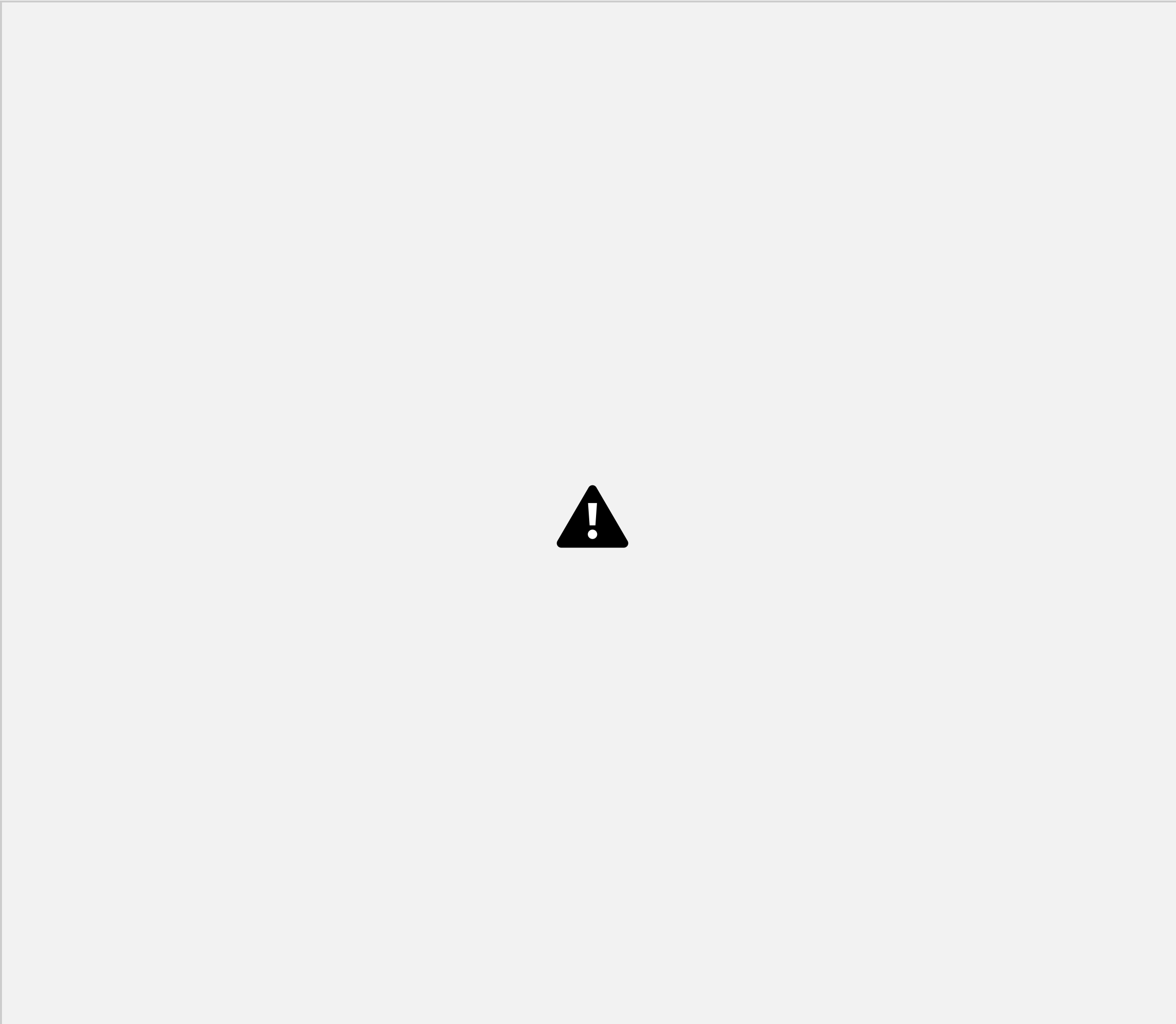
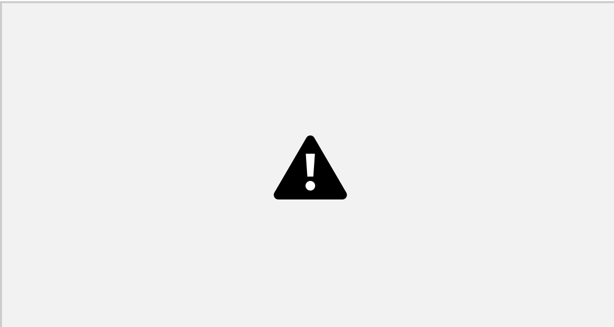


Table 13

We changed the orientation of the antenna by taking the thickness and antenna position selected in the tables above and giving an angle. Because our antenna is symmetrical, orientation 20 degrees upwards and 20 degrees downwards is the same inside the radome. Orienting 20 degrees to the right is the same as orienting 20 degrees to the left. We observed this in the simulation environment, but there were very few differences. We directed the antenna to the right, left, up and down directions at 20 degrees inside the radome. We examined the antenna parameters in these directions. Since all orientations provide the S-parameter values, we examined other antenna parameters to choose the best order. The closest values to our antenna provided 20 degrees left direction. As a result of this test, we observed that the best orientation degree was 20 degrees to the left and compared our degree with 30 degrees. We observed that the 30 degree orientation is more optimized than the 20 degree orientation. The design of the nose radome, which is the most ideal in the test results, is in figure 7 and the parameter results are under the figure 7.

4.1.10 X-Band Antenna With Nose Radome Optimum Thickness(Dielectric material FR 4, Core material Nomex honeycomb)



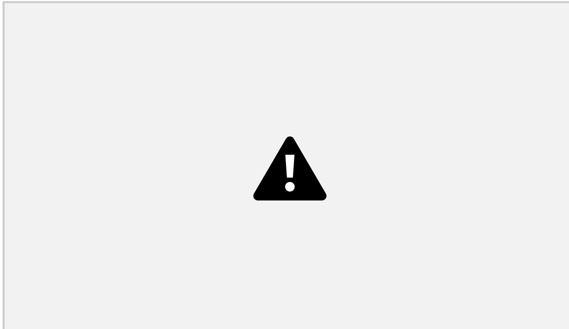
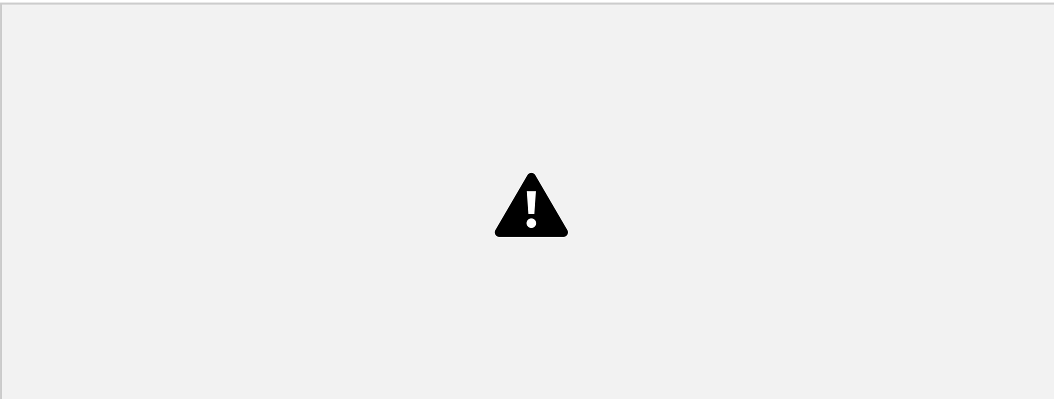


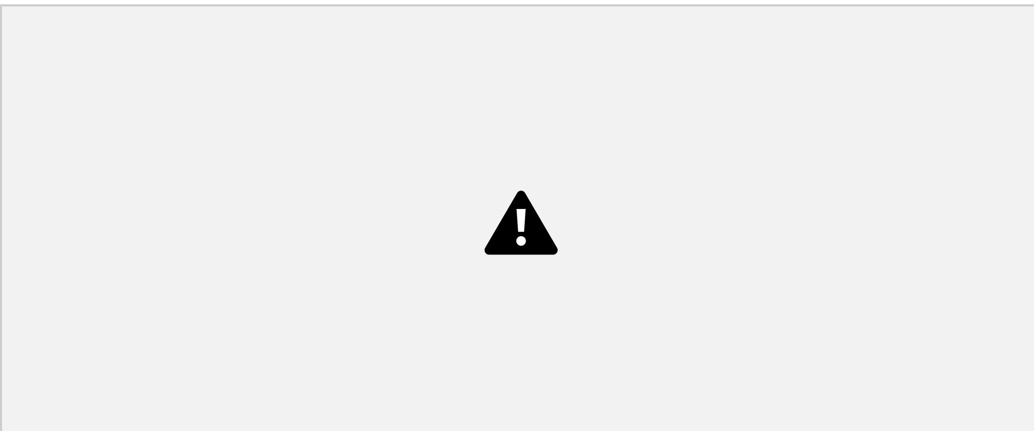
Figure 8: X-Band Suspended Antenna With Nose Radome

Parameter Results

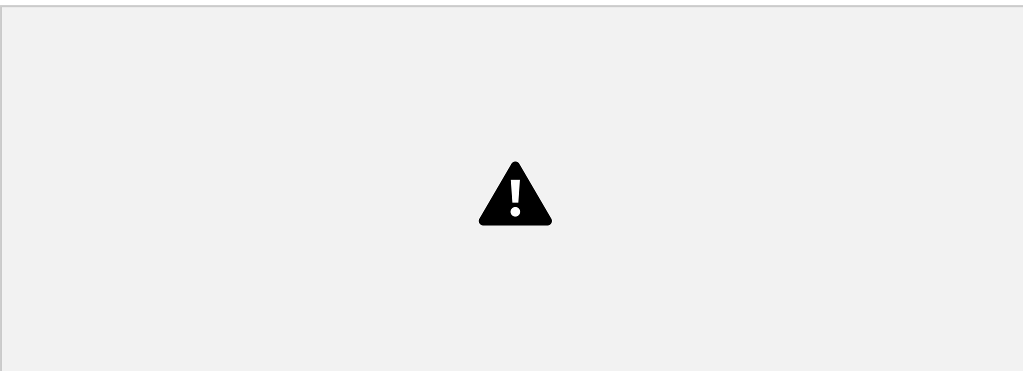
S-Parameters



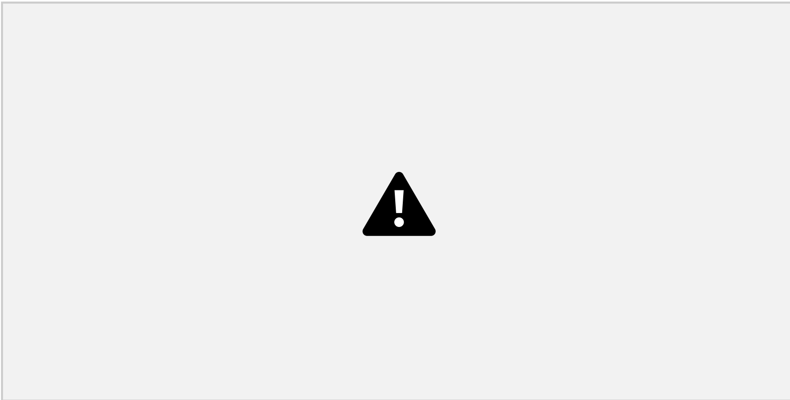
Efficiency



VSWR



Farfield



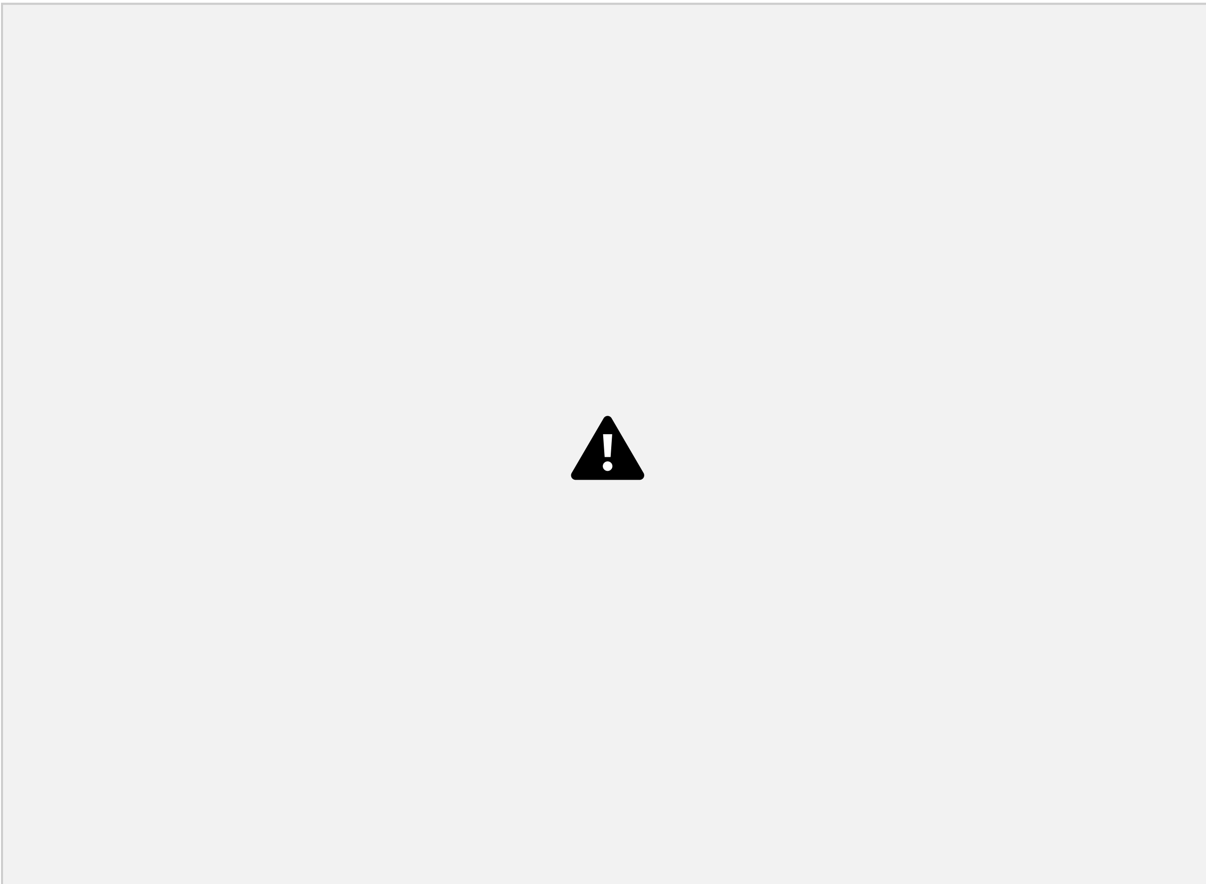


Table 14

We repeated the test by replacing the dielectric material of the nasal radome with FR-4. In this test, we used the optimum degree we found in the last stage of the previous simulation, which is the 30 degree left orientation of the antenna. We chose the radome thicknesses where the S parameter was below -10dB, which is the range in which the antenna works best, as a result of simulation in the frequency range (8-12GHz) of the radome antenna, all thicknesses we tried provided this value, we cannot decide the best thickness by examining the S-parameter alone. So we looked at other parameters as well. The Wsvr value is the same as the S-parameter value, but we expect the Wsvr value to be below 2 or close to 2, when we examined it, we observed that all of our thicknesses provided the VSWR value in the working range of the antenna. We examined the efficiency and farfield values and graphs to finalize our decision. The thickness closest to the simulation results of the radomless antenna of these values was 24mm. Therefore, 24mm was chosen as the thickness. The design of the nose radome, which is the most ideal in the test results, is in figure 8 and the parameter results are under the figure 8.

4.1.11 X-Band Antenna With Nose Radome Optimum Antenna-Radome Distance (Dielectric material FR-4, Core material Nomex honeycomb)

Table 15

We changed the positions of the antenna in the radome according to the best thickness selected in the previous table. Here we observed that each position provides the S-parameter, but we do

not decide the best position with the S-parameter alone, so we also examined the VSWR, efficiency and farfield values. We chose the one that is the same or close to the simulation values of the non-radom antenna and we saw that the selected simulation result is the upper part of the inner diameter of the radome (55 mm y-axis in the simulation). The design of the nose radome, which is the most ideal in the test results, is in figure 8 and the parameter results are under the figure 8.

4.2 Verification

4.2.1 Requirements Verification

The antenna parameters obtained in the tests of the antennas we designed as a success criterion, without radomes, were taken as reference. As a result of the tests, successful results were obtained in the wing and nose radome. In order to increase our success criteria, if the simulation conditions were met, array antennas could be used. Since we do not have enough simulation environment, it can be examined by using the array factor in the CST program for the best values. If array antenna could be used instead of single element antenna in this project, results closer to real results would be obtained. In the simulations we made using single antenna, it affects the beam of the metal antenna at the tip of the nose radome, since the beam of Array antennas is narrower, it would not affect the metal beam at the end. Since we work with a single element, we have provided our success criteria by proportioning the actual dimensions of our radome designs with the dimensions of our antenna.

4.2.2 Constraint Verification

Frequency range is within the desired range of values. The radome parameter measurements in our achievement criteria have been successfully tested. There are no problems in the production and repair stages of the designs, as materials that are easy to obtain are used. Economic constraints in our project are not a measure of success for us. The designs comply with the standards. The designs meet the established design criteria without any problems.

4.2.3 Standarts

Our designs comply with MIL-R-9300, MIL-R-7505B standards. MIL-R-9300 is a standard used for lamination epoxy resin materials, one of the materials used in the manufacture of glass fabric plastic laminates. Our project provides this standard during the production phase. MIL R-7705B covers the general design and performance requirements of radomes used in flight vehicles and fixed ground. Our project has met these requirements.

5. SUMMARY AND CONCLUSION

Today, antennas play an important role in the field of communication. Radomes are structures used to protect the antenna from environmental conditions. There are various types of radomes according to their usage areas. The scope of this project includes antennas placed on the nose and wing tips and their radomes on air platforms. While radomes protect antennas from environmental conditions, they also provide frequency, gain, losses, bandwidth, impedance matching, polarization and radiation diagram etc. can affect antenna parameters. In this project, it is aimed to keep the antenna performance parameter changes caused by radome at a minimum level or to optimize it. In the first stage, X-Band suspended patch antenna and C-Band suspended patch antenna designs were made using the CST program, and radomless parameter measurements of these antennas were made. In the next step, nose (conical, spherical) and wing tip (cylindrical) radomes were created using different material types. In order to carry out the simulation, we reduced the design of the radome according to the antenna dimensions. These radomes were placed on the antennas and determined parameter tests were carried out. Firstly,

parameter tests were performed by using E-glass in the dielectric layer of the wing radome and NOMEX material in the core layer, by changing the radome wall thickness, the radome diameter and the distance between the antenna and the radome. According to the test results, the optimum antenna and radome distance and radome wall thickness were determined. Afterwards, the processes were repeated using FR-4 in the dielectric layer of the wing radome and NOMEX in the core layer. Parameter tests were performed by changing the radome wall thickness, the distance between the antenna and the radome and the antenna angle, using E glass in the dielectric layer and NOMEX material in the core layer in the nose radome, which is another radome region we studied. According to the test results, the optimum antenna and radome distance, radome wall thickness and antenna angles were determined. Parameter tests were repeated using FR-4 material in the dielectric layer of the nose radome and NOMEX material in the core layer by determining the best selected antenna angle, radome wall thickness and the distance between the antenna and the radome. Summarize the results of our simulation studies, we obtained the most optimal results in the wing radome with dielectric material E glass and core layer material NOMEX with a radome wall thickness of 24 mm, a diameter of 70 mm, and a distance of 54.9 from the antenna to the radome. In the wing radome dielectric material is FR-4 and the core layer material is NOMEX, we achieved the most optimal results in the design with a radome wall thickness of 14mm, a diameter of 70mm, and a distance of 67.1 mm between the antenna and the radome. In the design with dielectric material E-glass in the nose radome and NOMEX core layer material, the radome wall thickness is 24 mm, the position of the antenna is tangential to the inner wall of the radome, the antenna angle is 30, and we achieved the most optimal results. We achieved the most optimal results in the design with FR-4 dielectric material in the nose radome and NOMEX core layer material, the radome wall thickness of 24 mm, the position of the antenna antenna at the tangent to the inner wall of the radome, the antenna angle of 30.

As a suggestion, if the simulation environment studies are improved, the use of array antennas has improved the results in our results as can be seen. The design seen in Figure 9 cannot be simulated with the equipment we have. Therefore, simulations were made with a single antenna in the project. It is shown that the most optimal design of the array antenna is used without simulating it using the array factor function on the CST. Firstly, this study was conducted for X-Band Suspended Antenna (Array) With Nose Radome (Dielectric material E-glass, Core material Nomex honeycomb). Farfield results for 8GHz are available in Figure 10 and Figure 11. Farfield results for 10 GHz are available in Figure 12 and Figure 13. Farfield results for 11 GHz are available in Figure 14 and Figure 15. The same studies were repeated for X-Band Suspended Antenna (Array) With Nose Radome (Dielectric material FR-4, Core material Nomex honeycomb). Farfield results for 8GHz are available in Figure 16 and Figure 17. Farfield results for 10 GHz are available in Figure 18 and Figure 19. Farfield results for 11 GHz are available in Figure 20 and Figure 21. However, these results do not give as realistic results as the simulation of an array antenna radome. Here, 24mm between 8-10 GHz, 22mm between 10-11GHz, 20mm between 11-12 GHz, array factor antenna gaps are left. The reason for this is that as the frequency increases, the wavelength decreases and the antenna size decreases. In addition, the number of simulations can be increased by increasing the trial intervals and material types in order to obtain more optimum values.

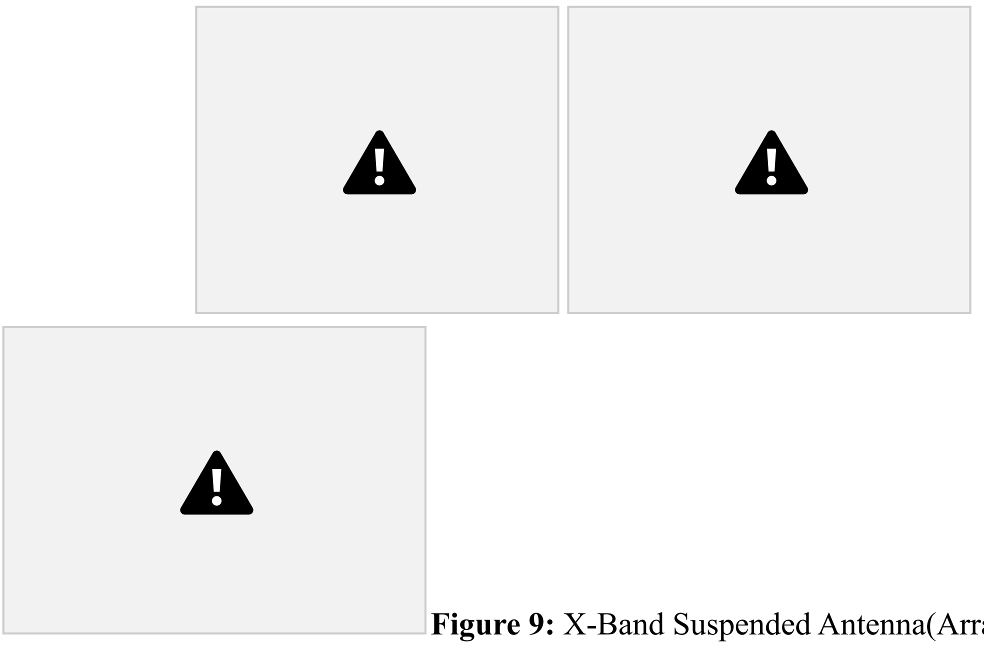


Figure 9: X-Band Suspended Antenna(Array) With Nose Radome

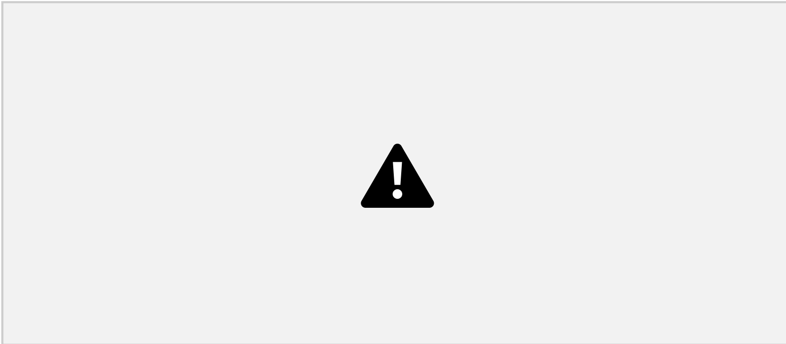


Figure 10: 3D Farfield Result of X-Band Suspended Antenna (Array) With Nose Radome (Dielectric material E-glass, Core material Nomex honeycomb)

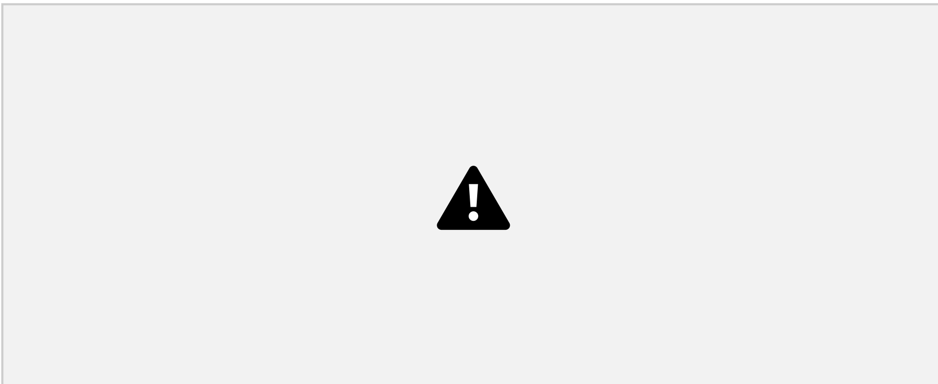


Figure 11: Cartesian Farfield Result of X-Band Suspended Antenna (Array) With Nose Radome (Dielectric material E-glass, Core material Nomex honeycomb) for 8GHz

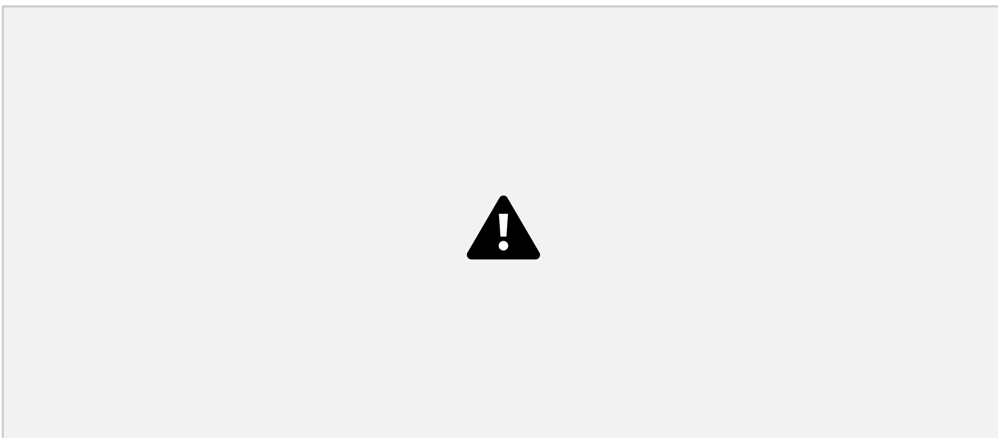


Figure 12: 3D Farfield Result of X-Band Suspended Antenna (Array) With Nose Radome

(Dielectric material E-glass, Core material Nomex honeycomb) for 10 GHz

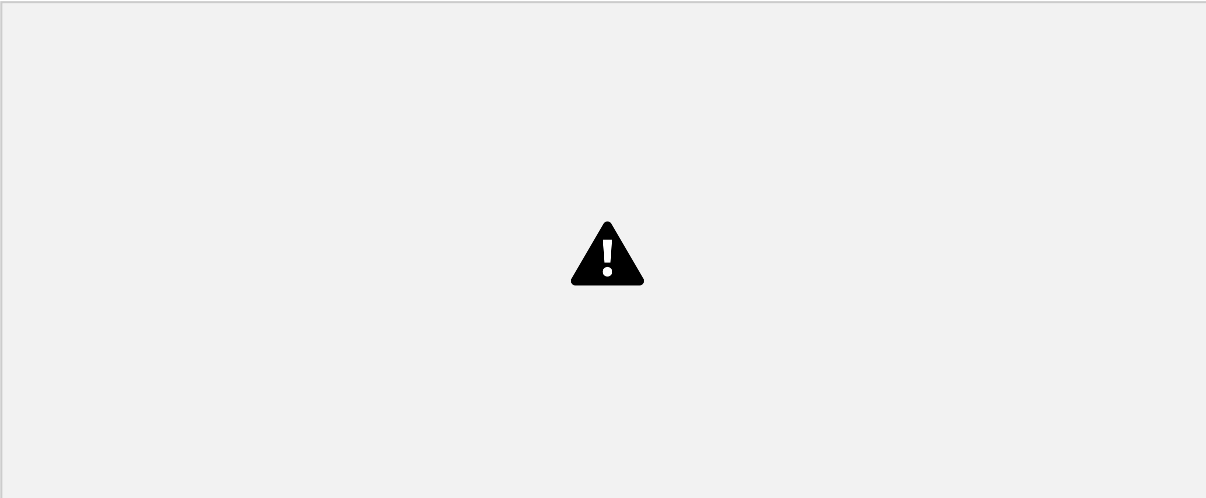


Figure 13: Cartesian Farfield Result of X-Band Suspended Antenna (Array) With Nose Radome (Dielectric material E-glass, Core material Nomex honeycomb) for 10GHz

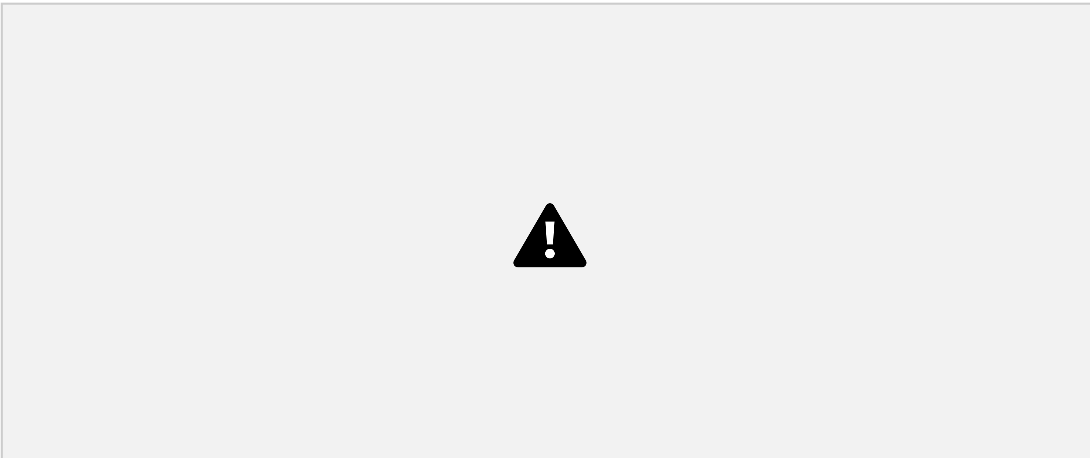


Figure 14: 3D Farfield Result of X-Band Suspended Antenna (Array) With Nose Radome (Dielectric material E-glass, Core material Nomex honeycomb) for 11 GHz

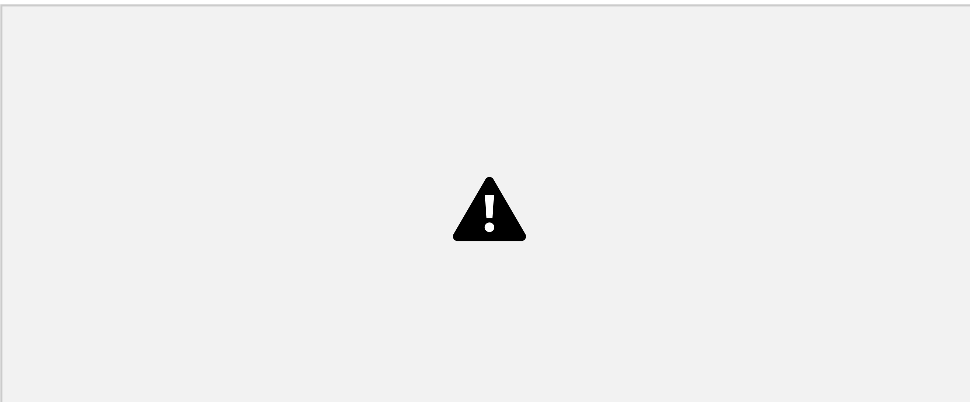


Figure 15: 3D Farfield Result of Cartesian Farfield Result of X-Band Suspended Antenna (Array) With Nose Radome (Dielectric material E-glass, Core material Nomex honeycomb) for 11GHz

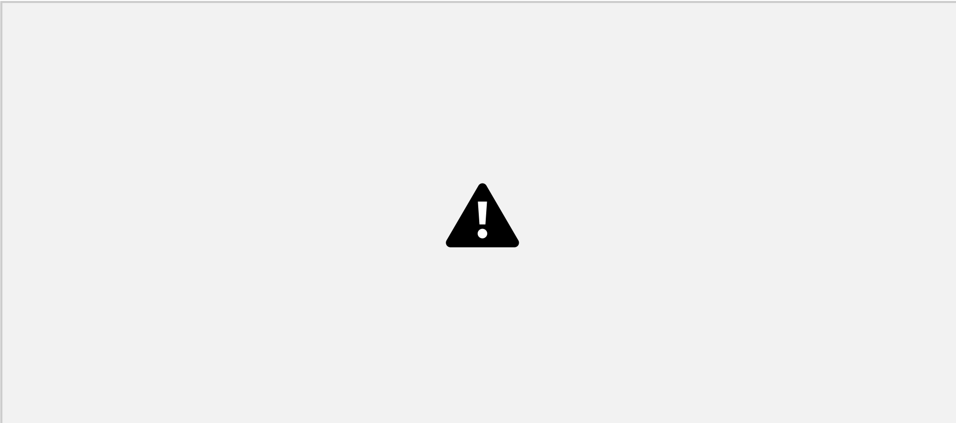


Figure 16: 3D Farfield Result of X-Band Suspended Antenna(Array) With Nose Radome (Dielectric material FR-4, Core material Nomex honeycomb) for 8 GHz

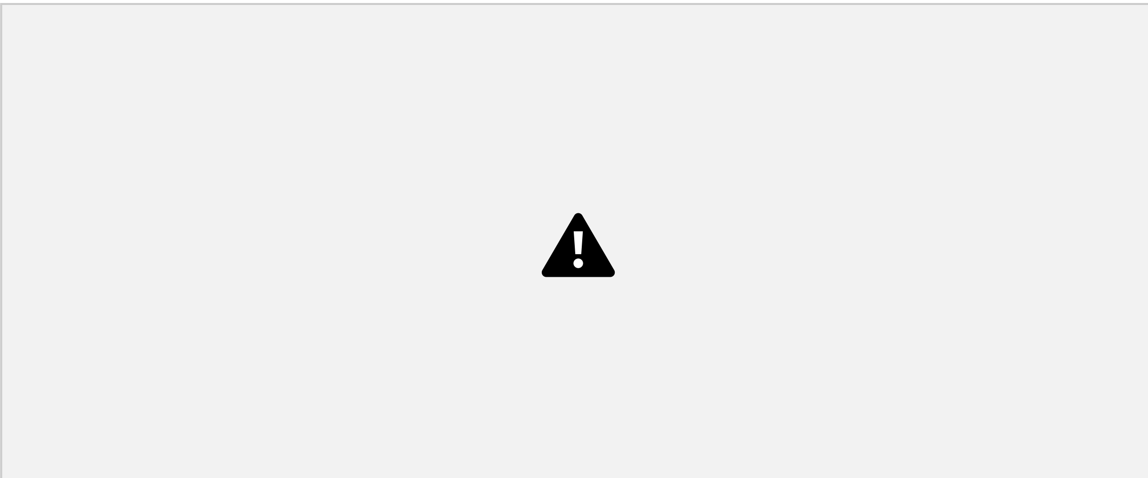


Figure 17: Cartesian Farfield Result of X-Band Suspended Antenna (Array) With Nose Radome (Dielectric material FR-4, Core material Nomex honeycomb) for 8GHz

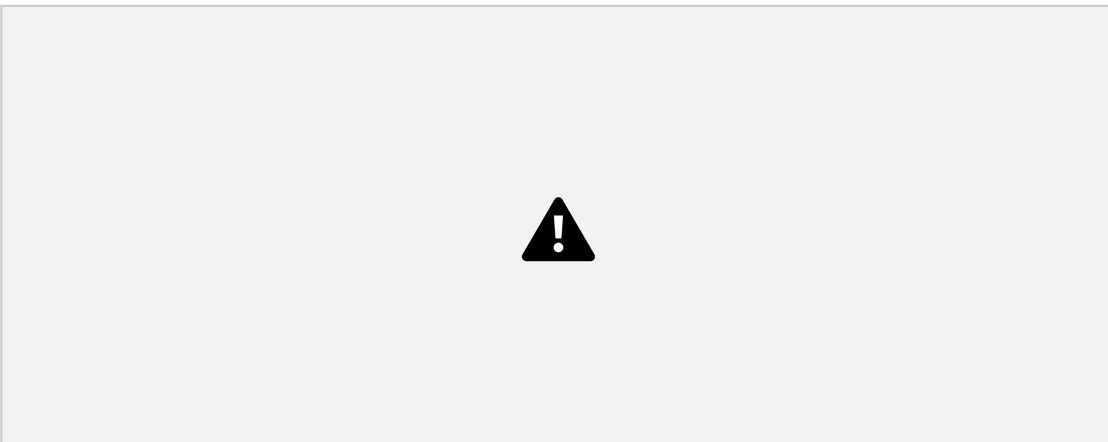


Figure 18: 3D Farfield Result of X-Band Suspended Antenna(Array) With Nose Radome (Dielectric material FR-4, Core material Nomex honeycomb) for 10 GHz

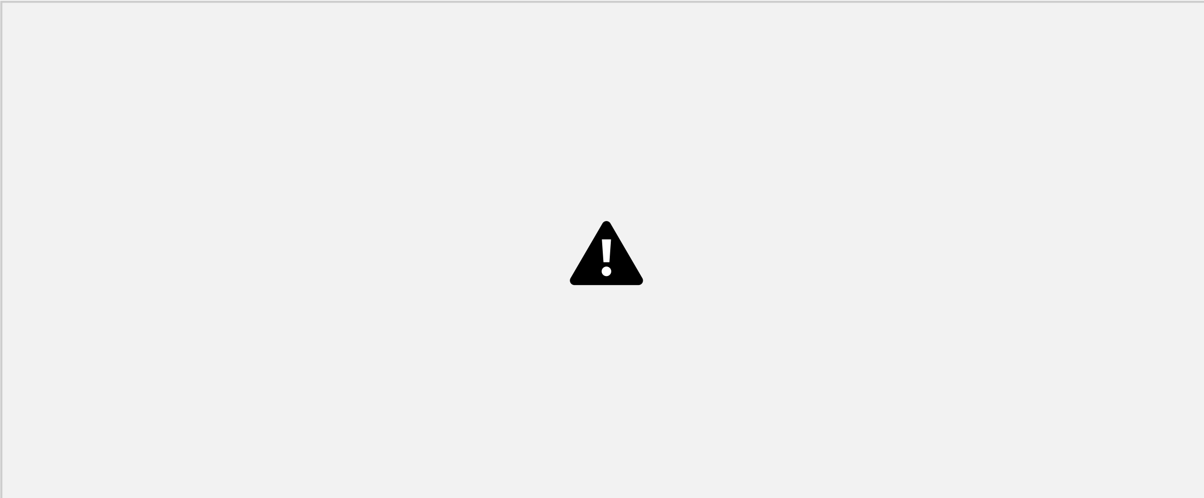


Figure 19: Cartesian Farfield Result of X-Band Suspended Antenna(Array) With Nose Radome (Dielectric material FR-4, Core material Nomex honeycomb) for 10 GHz

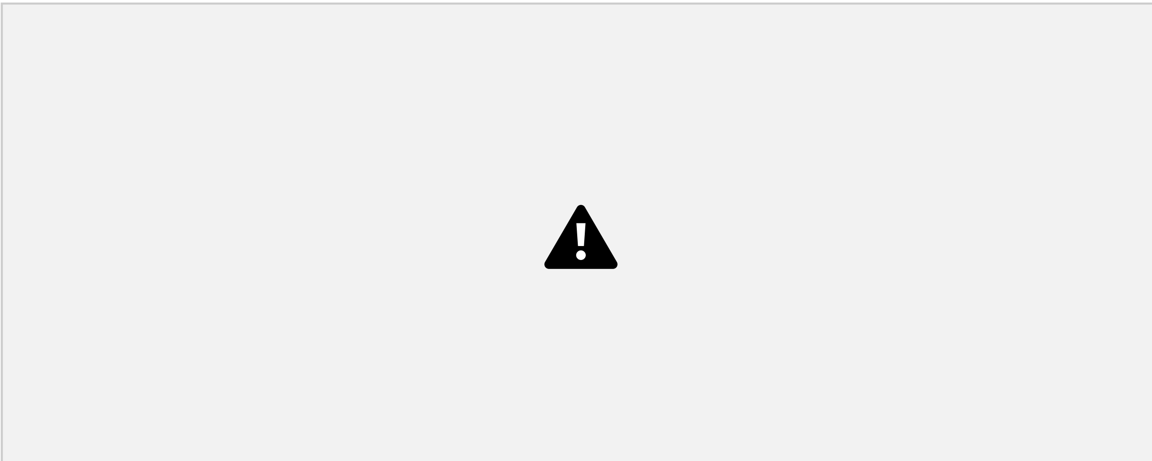


Figure 20: 3D Farfield Result of X-Band Suspended Antenna(Array) With Nose Radome (Dielectric material FR-4, Core material Nomex honeycomb) for 11 GHz

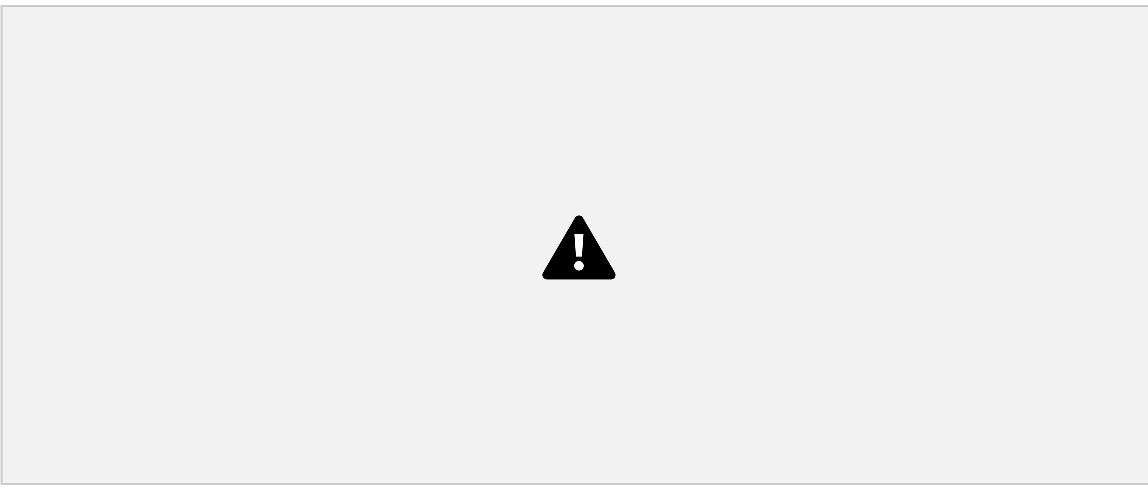


Figure 21: Cartesian Farfield Result of X-Band Suspended Antenna(Array) With Nose Radome (Dielectric material FR-4, Core material Nomex honeycomb) for 11GHz

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ATTACHMENTS

ATTACHMENT A: Project Management Plan

Tolga ÇİFTÇİ

LİFT UP PROJECT MANAGER
Merve ÖZDEMİR

ADVISOR
Prof.Dr.Mehmet ÇİYDEM

TEAM MEMBER
Gökçe Yaren KARADENİZ

TEAM LEADER
Abdullah YILDIRIM

INDUSTRY CONSULTANT

ANTENNA DESIGN(X-BAND) ANTENNA DESIGN(C-BAND) RADOME DESIGN(WING TIP) RADOME

DESIGN(NOSE)

Simulation Analysis (X-Band Antenna s parameters without radomes, X-Band Antenna s parameters with radomes)

Simulation Analysis (X-Band Antenna s parameters without radomes, X-Band Antenna s parameters with radomes)

Results of radome thickness optimization ,transmittance and optimum radome–antenna distance.

Results of radome thickness optimization ,transmittance and optimum radome–antenna distance.

Prof. Dr. Mehmet ÇİYDEM: He completed his undergraduate education in Electrical and Electronics Engineering (1989-1993). Afterwards, he continued his master's (1993-1995) and doctorate (1999-2004) studies at the Middle East Technical University. He received the title of Associate Professor in 2015. He worked in various defense industry companies, consultancy and various educational institutions in the sector. He is actively working as a lecturer in Gazi University Electrical and Electronics Engineering. He has also published many awards and academic articles. He continues his studies in the fields of antennas and wave propagation, RF/microwave engineering, electromagnetic, radar systems, communication systems (fixed, wireless), avionics.

Tolga ÇİFTÇİ: He completed his undergraduate education at Bilkent University, Department of Electrical and Electronics Engineering (2005-2012). He completed his master's degree in Engineering Management at the Middle East Technical University (2015-2019). He is actively working as a design engineer at TAI. He is the industry consultant of our graduation project, which we carried out within the scope of the graduation project with TAI.

Merve AYAS ÖZDEMİR: She completed her undergraduate education at Ankara University, Department of Chemical Engineering (2013-2018). She completed his master's degree in Gazi University Chemical Engineering (2019-2021). She is the Lift Up responsible of the project we carried out within the scope of the graduation project with TAI.

Gökçe Yaren KARADENİZ: She is a 4th year student of Electrical and Electronics Engineering at Gazi University. She has completed her internships in various defense industry companies. She worked as a summer researcher at Koç University. She is actively working as a candidate engineer at ELSIS Electronic Systems Industries Co. Inch. She is a student of the Lift Up project. She is responsible for C-Band antenna design and nose radome design.

Abdullah YILDIRIM: He is a 4th year student of Electrical and Electronics Engineering at Gazi University. He completed his internships in various defense industry companies. He is actively working as a candidate engineer at TUBITAK SAGE. He is a student of the Lift Up project. He is the team leader of the project. He is responsible for X-Band antenna design and wing tip radome design.

ATTACHMENT B: Team Members Contributions

Table 16

ATTACHMENT C: Gantt Chart

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