Design and Simulation of Microstrip Patch Antenna operating at 28GHz Frequency using CST Microwave Studio

5th Semester Academic Project

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Outlines

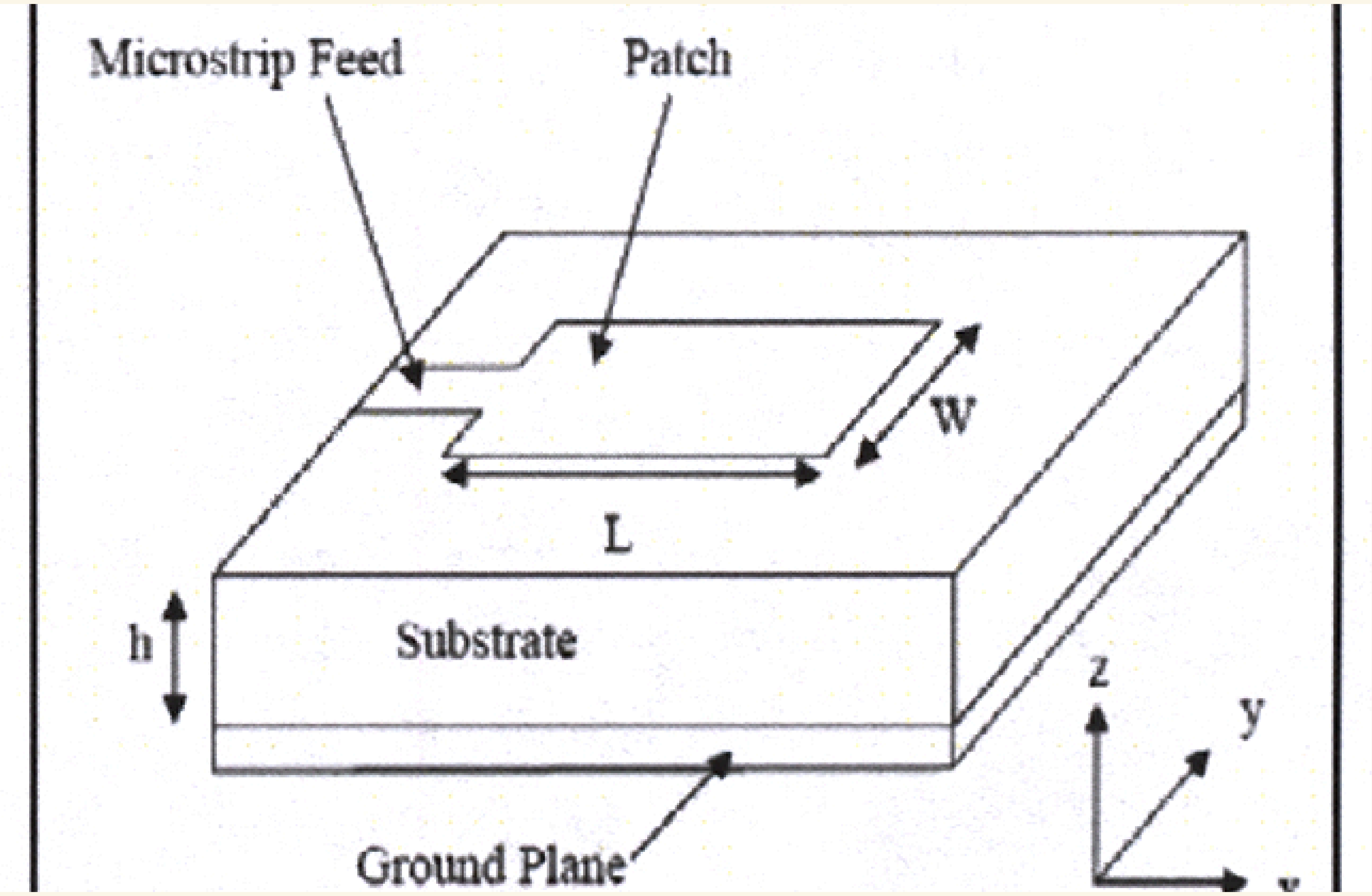
Introduction to MPA

- In general, Microstrip patch antennas are also known as *"PRINTED ANTENNAS."*
- Operates on microwave frequencies (f > 1 GHz)
- Invented by Bob Munson in 1972.
- Became popular starting in the 1970s.

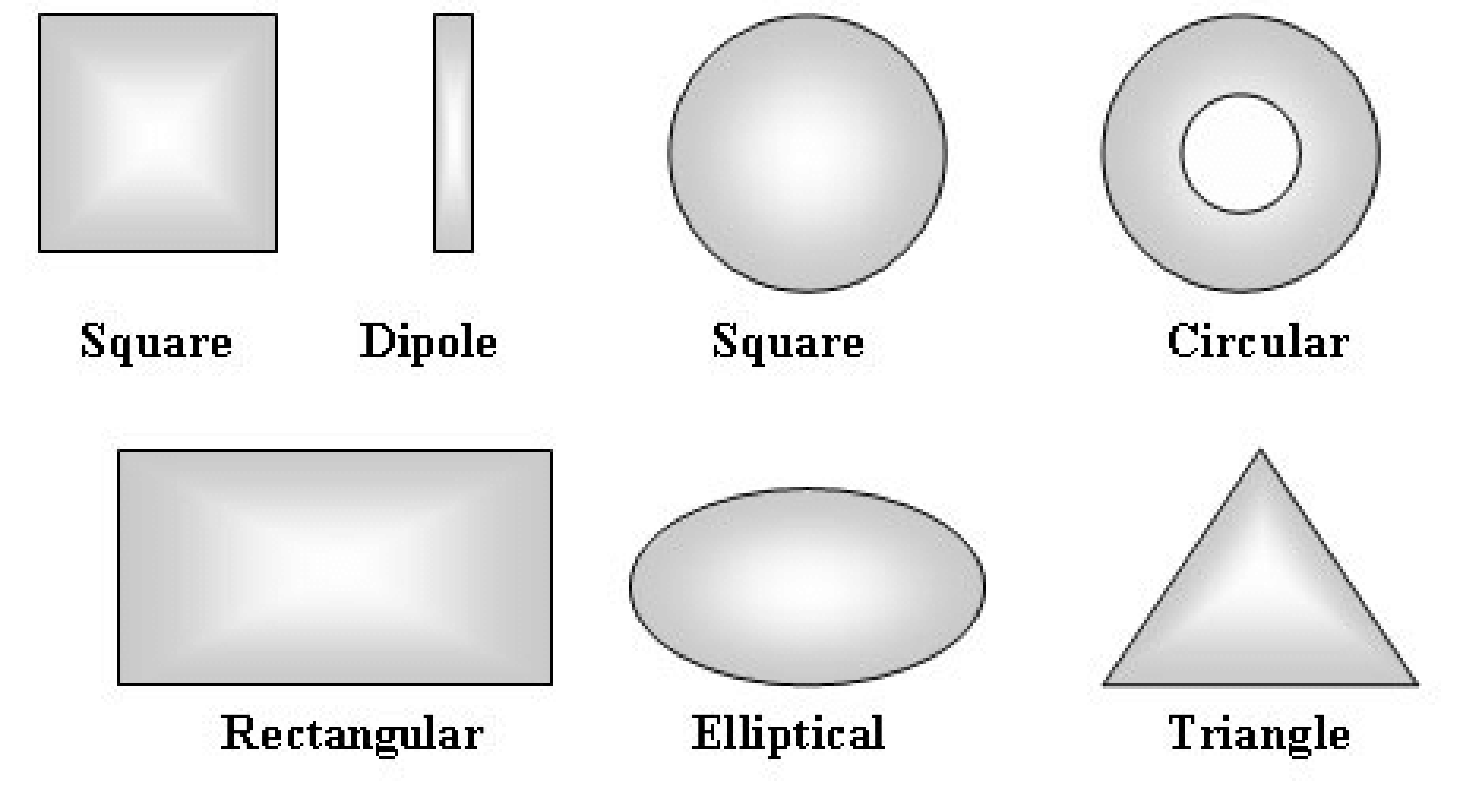
Structure of MPA

Basically, the Microstrip Patch Antenna consists of:

- Metal "Patch"
- Dielectric Substrate
- Ground Plane
- Feed Line



The patch can take different shapes, such as rectangular, circular, triangular, or U-shaped, E-shaped, etc.



Advantages of Microstrip Antennas:

- ***Easy Fabrication:*** Simple and cost-effective manufacturing.
- ***Low Cost & Compact Size***: Affordable and space-efficient design.
- ***Integration:*** Easily integrates with microwave and RF circuits.
- ***Flexible Feeding Methods:*** Supports coaxial cable, microstrip line, and others.
- ***Array Compatibility:*** Simple to design and implement in arrays for enhanced performance.
- ***Lightweight:*** Ideal for applications requiring portability (e.g., UAVs, wearables).
- ***Customizable:*** Can be tailored for specific frequencies, polarizations, and multiband operations.
- ***Planar Design***: Suitable for PCB-based applications.
- ***Low Profile:*** Perfect for embedded and compact systems like smartphones or satellites.

Disadvantages of Microstrip Antennas:

- ***Low Gain:*** Signal strength is limited, requiring additional amplification for long distances.
- ***Low Efficiency:*** Energy losses due to surface waves and dielectric losses.
- ***Narrow Bandwidth:*** Restricted frequency range without complex enhancements.
- ***Power Limitations:*** Unsuitable for high-power applications.
- ***Surface Wave Interference***: Can reduce performance and efficiency.
- ***Fragility:*** Susceptible to mechanical damage due to thin substrate layers.
- ***Temperature Sensitivity:*** Performance may degrade with temperature fluctuations.
- ***Complex Impedance Matching:*** Design can require precise matching for optimal operation.

Applications of Microstrip Patch Antenna:

1. ***Wireless Communication***
    - Mobile Phones, Wi-Fi, Bluetooth: Compact antennas for 2.4 GHz, 5 GHz bands.
2. ***Satellite Communication***
    - GPS, DBS: Lightweight antennas for satellite data links.
3. ***Radar Systems***
    - Military & Automotive: Compact radar for UAVs, collision avoidance.
4. ***Medical Applications***
    - Imaging & Wearables: Tumor detection, health monitoring devices.
5. ***IoT and Smart Devices***
    - Antennas for smart homes, cities, and industrial IoT.
6. ***Aerospace and Defense***
    - UAVs & Missile Guidance: Lightweight, efficient designs.
7. ***5G Networks***
    - Beamforming antennas for millimeter-wave communication.
8. ***Wearable Technology***
    - Embedded in smart watches, e-textiles for wireless connectivity.
9. ***Telematics***
    - V2X Communication, Fleet Tracking: Enhancing smart transportation.

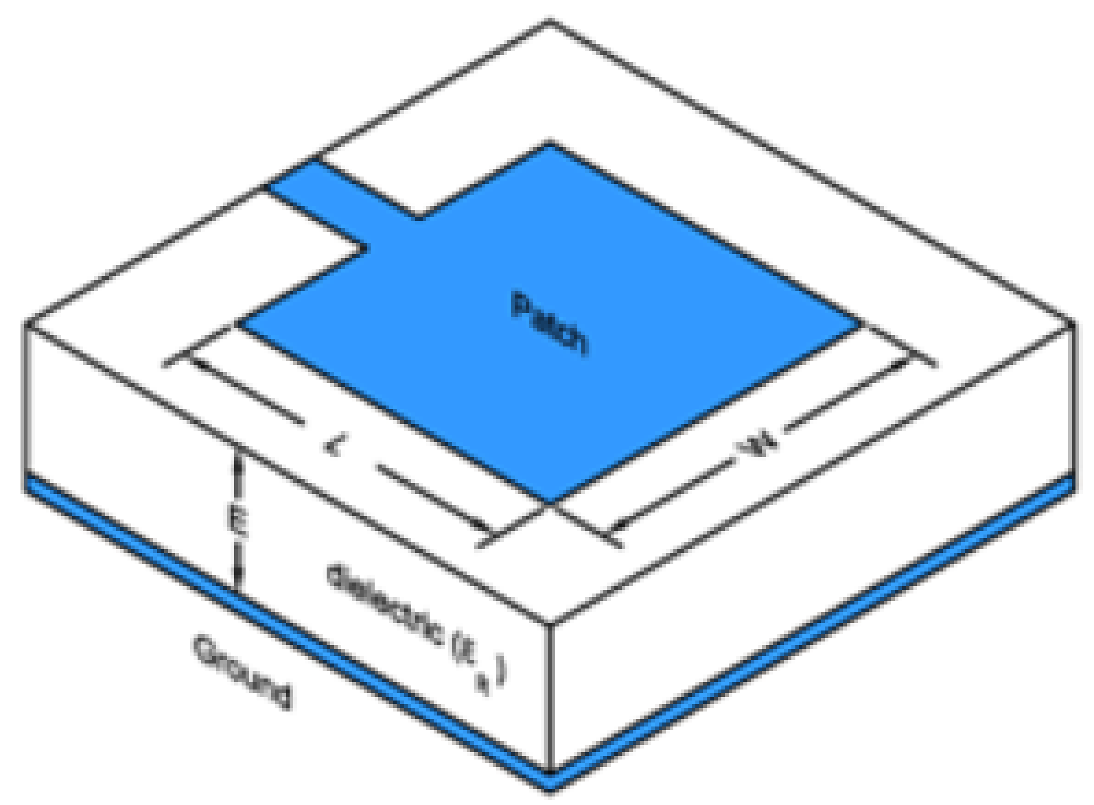
Key Highlights of Microstrip Patch Antennas

1. **Features and Importance**
   - Compact size, lightweight, and ease of fabrication.
   - Provide wide bandwidth suitable for modern communication systems.
   - Commonly made from copper or other perfect electric conductors (PEC).
   - Popular geometries: rectangular, circular, triangular, elliptical, and square.
   - Rectangular and circular designs are most widely used.
   - Antenna size is influenced by the dielectric constant (εr) of the substrate:
     - Higher dielectric constants result in smaller antennas.
2. **Role in Advancing Communication Technologies**
   - Transition to 5G:
     - Demands higher data rates, denser connections, and reduced latency.
     - Compact patch antennas play a crucial role in meeting these requirements.
   - Use of Innovative Designs:
     - Fractal geometries (e.g., Koch and Sierpinski) on FR4-epoxy substrates (εr = 4.4).
     - Support ultra-wideband (UWB) applications and operation over multiple frequencies.
3. **Design Examples and Applications**
   - Compact Antennas:
     - Operate at 4.3 to 9.2 GHz, offering multiple frequency bands.
     - Limitation: Gain enhancement remains a challenge.
   - CPW Feeding Techniques:
     - Enable operation at GSM, WLAN, WiMAX, and Walkie-Talkie bands.
   - Targeted Wireless Applications:
     - Specific frequencies like 1.8, 3.6, and 4.53 GHz on FR4 substrates.
   - Satellite Communication:
     - High-frequency designs at 15 GHz with bandwidth of 1.14 GHz.
     - Gain and directivity exceed 3.4 dB using RT Duroid (εr = 2.2).
     - L-slots and inverted slots improve multiband functionality (e.g., 1.48 to 2.9 GHz)
4. **Innovations in UWB Designs**
   - Bandwidth range: 2 to 9.7 GHz.
   - Substrates: FR4 with standard dimensions ensure compatibility.
   - Applications: Diverse wireless use cases.
   - Challenges: Ongoing need to address bandwidth and gain limitations.
5. **Advancements in the 5G Era**
   - Patch antennas enable:
   - Low latency.
   - High data rates.
   - Support for emerging technologies.
   - Future Research Directions:
   - Fractal geometries.
   - Advanced substrate materials.
   - Novel feeding techniques.
6. **Fabrication and Simulation**
   - Substrate Material: Roger RT5880.
   - Simulation Tool: CST MWS simulator.
   - Simulated Results Show:
   - Optimized performance across resonant frequency bands.
   - High gain and directional patterns.
   - Improved impedance bandwidth and radiation efficiency.

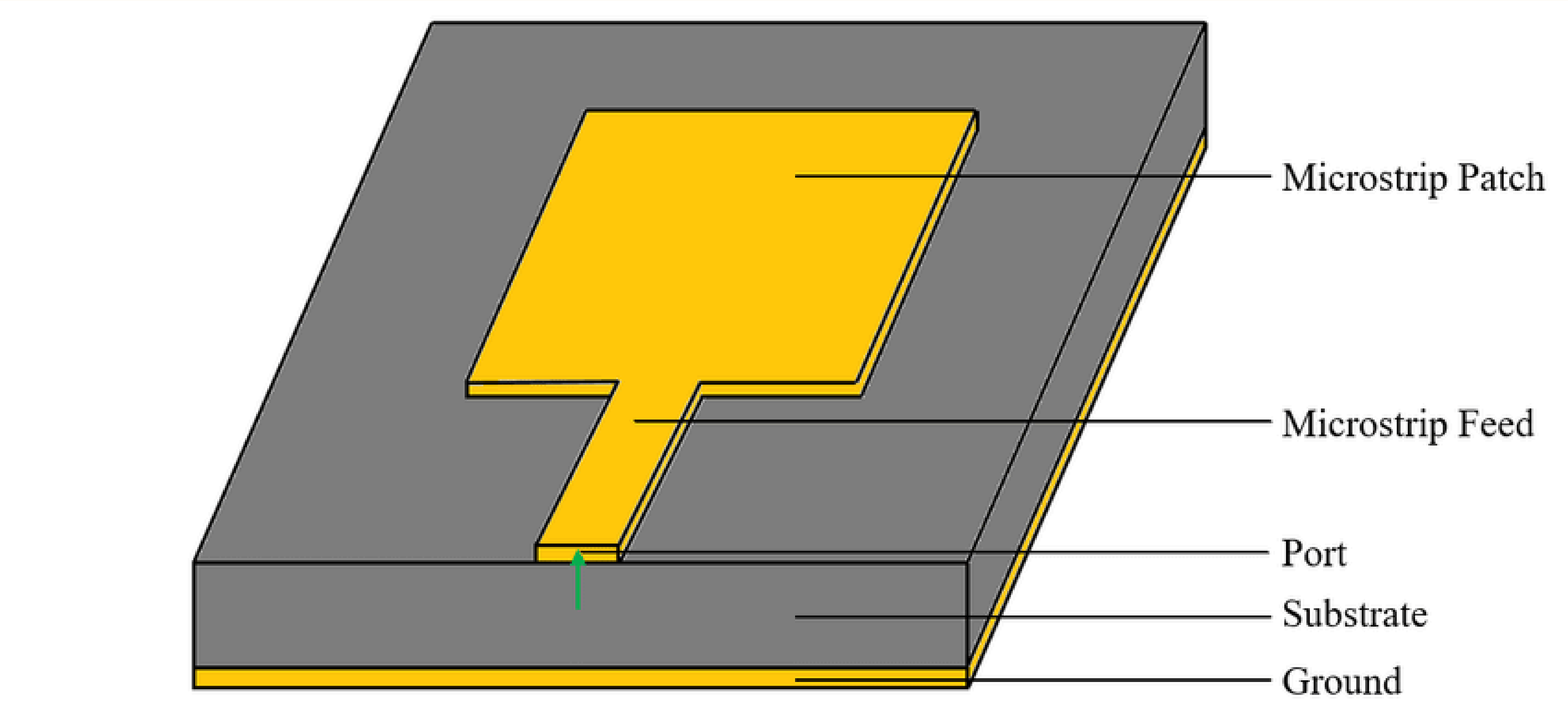
Calculation of parameters for MPA

$$Width = \frac{c}{2f_o\sqrt{\frac{\varepsilon_R+1}{2}}}; \quad \varepsilon_{eff} = \frac{\varepsilon_R+1}{2} + \frac{\varepsilon_R-1}{2}\left[\frac{1}{\sqrt{1+12\left(\frac{h}{W}\right)}}\right]$$

$$Length = \frac{c}{2f_o\sqrt{\varepsilon_{eff}}} - 0.824h\left(\frac{(\varepsilon_{eff}+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{W}{h}+0.8\right)}\right)$$



Feeding Technique used: Microstrip Line Feed



The microstrip line feed is a popular feeding method for microstrip patch antennas, where a conducting strip directly connects to the edge of the radiating patch. This feed mechanism has several key characteristics and advantages:

1. **Structure and Design**:
    - A conducting strip, narrower in width compared to the patch, is directly attached to the edge or inset of the patch.
    - Both the patch and the feed line are fabricated on the same dielectric substrate, resulting in a completely planar structure.
    - The feed line carries the signal to the patch, enabling efficient electromagnetic coupling.

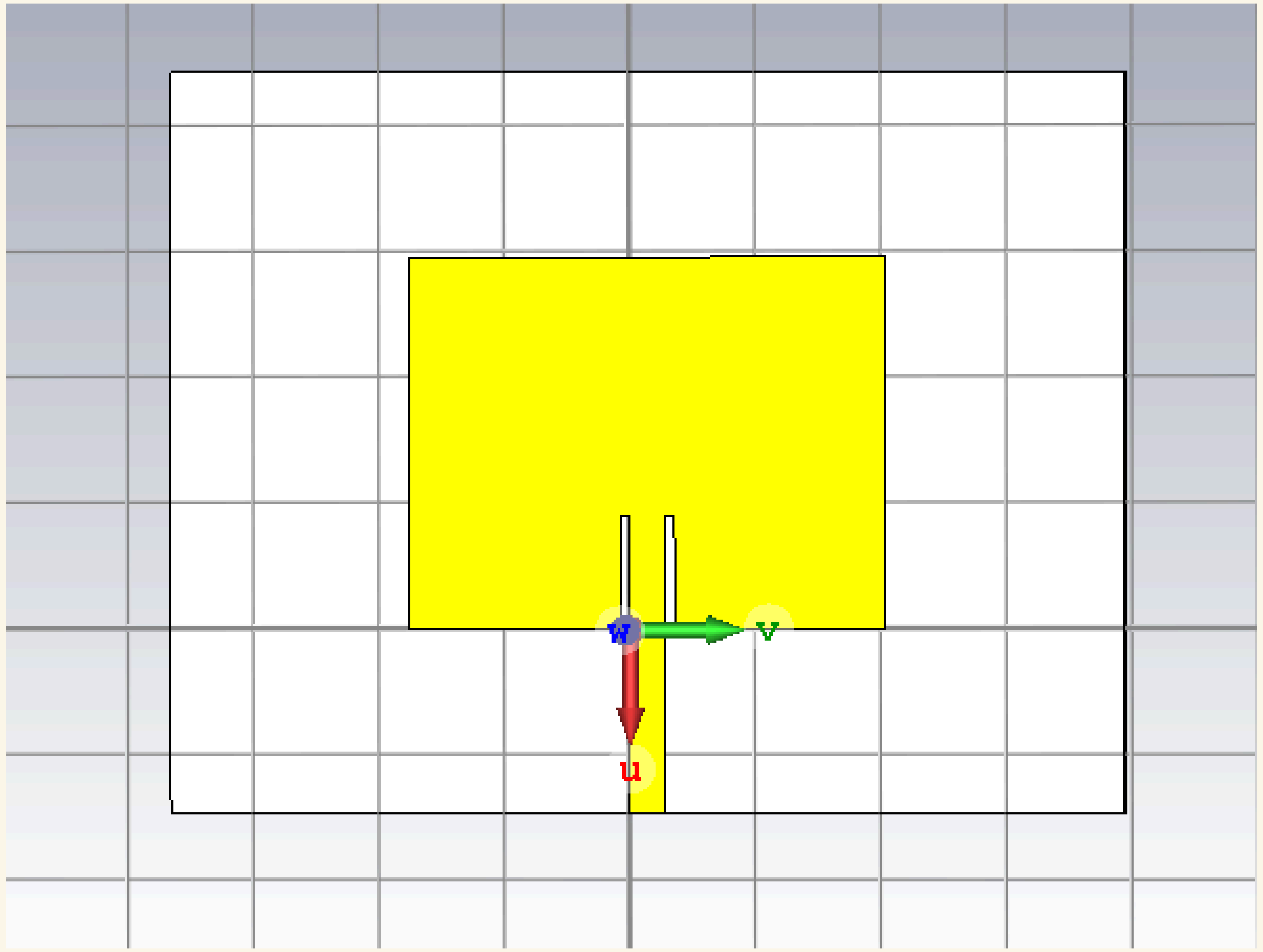
2. **Impedance Matching**
    - The width and position of the conducting feed line relative to the patch are carefully designed to match the impedance of the feed line (typically 50 ohms) to the input impedance of the patch antenna.
    - An inset cut is often introduced into the patch to fine-tune this impedance matching. By adjusting the depth of the inset, the input impedance can be modified without the need for additional matching components.

3. **Advantages**
    - *Planar Design:* Both the patch and feed line can be etched on the same substrate, simplifying manufacturing and reducing cost.
    - *Ease of Fabrication:* The planar configuration is straightforward to produce using standard PCB manufacturing techniques.
    - *Compactness:* This feed method supports the compact design of antennas, making it suitable for modern wireless applications.

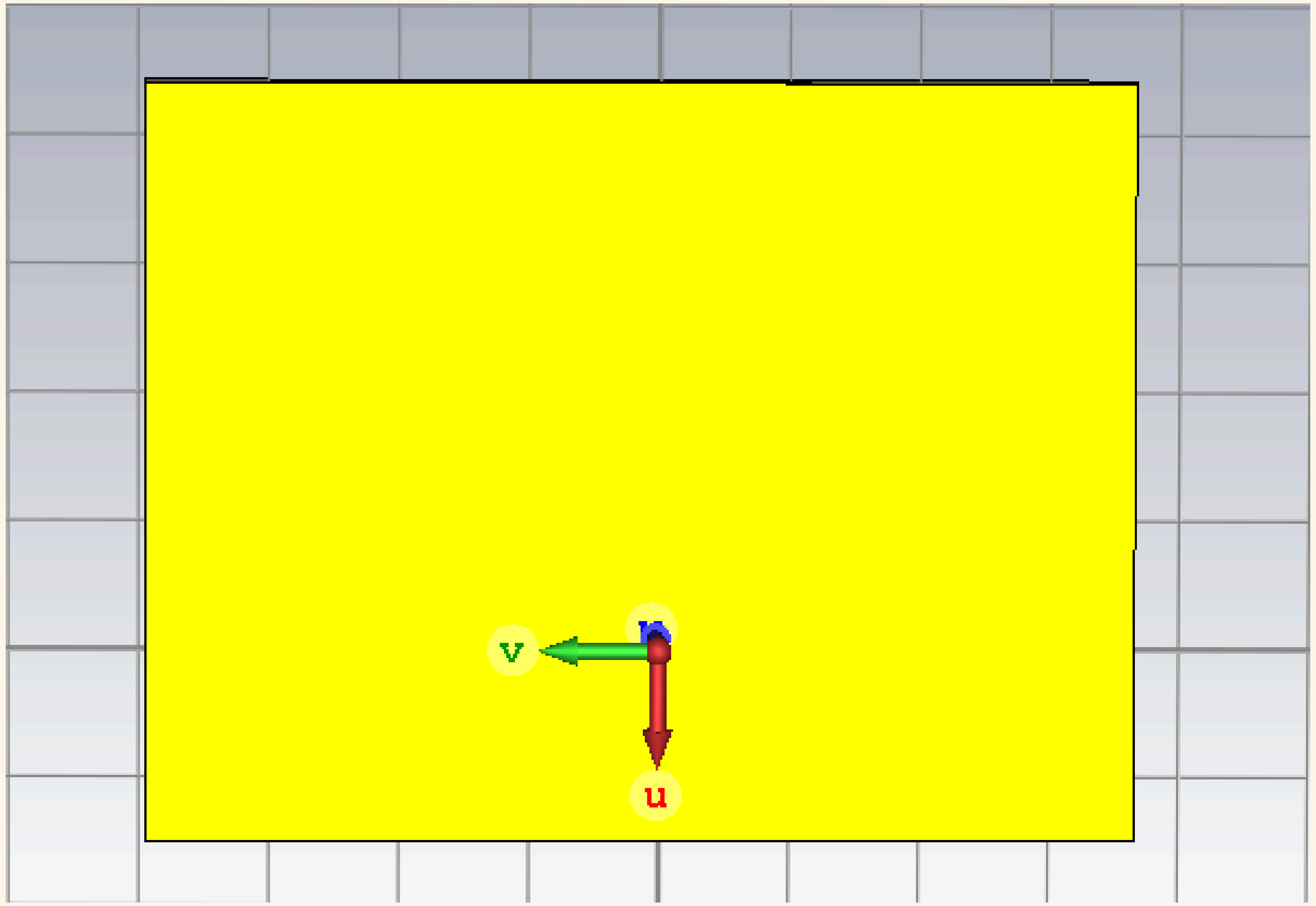
4. **Disadvantages**
    - *Radiation from the Feed Line:* Due to the direct connection, the feed line may introduce undesired radiation, slightly reducing overall antenna efficiency.
    - *Narrow Bandwidth:* Like other microstrip configurations, the bandwidth is limited unless additional techniques are employed.

The microstrip line feed is widely used in various applications, such as mobile communication, radar systems, and wireless networking, due to its simplicity, low profile, and integrability with planar circuit designs.

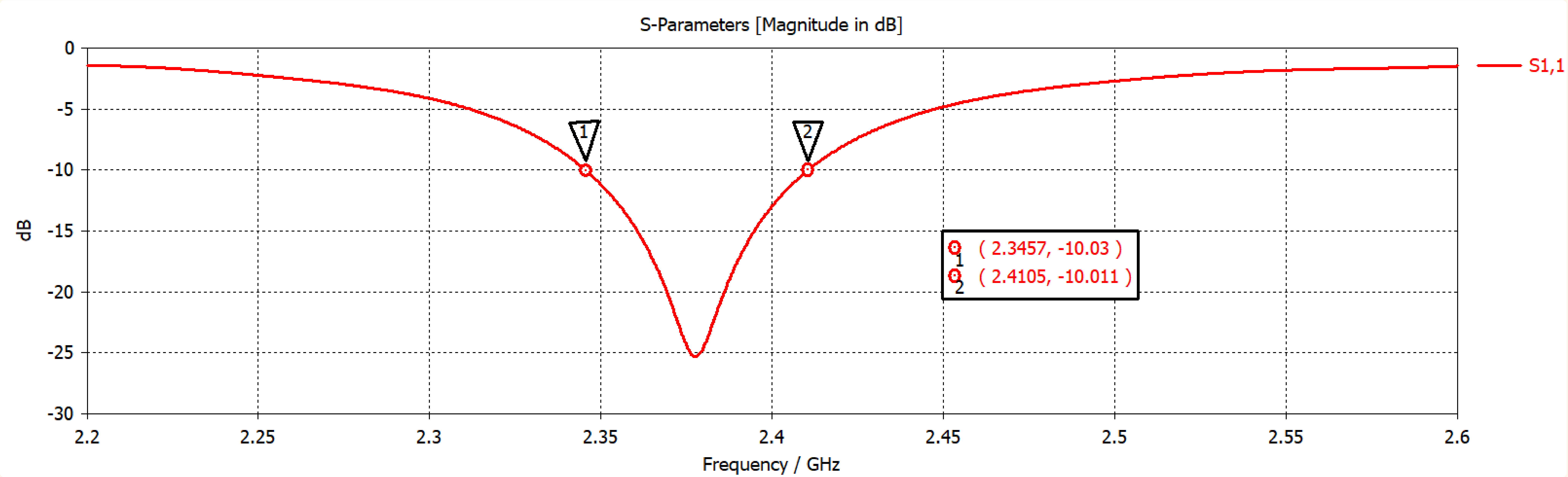
Prototype 1: 2.4 GHz MPA

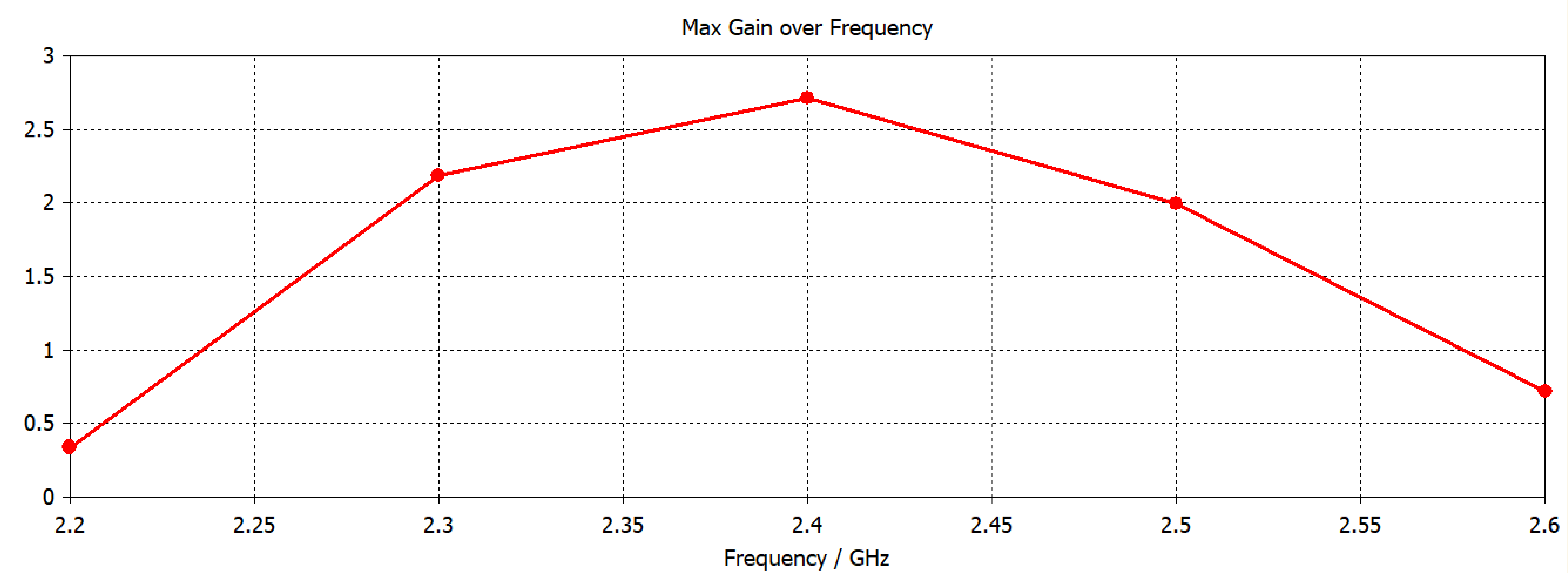


front view

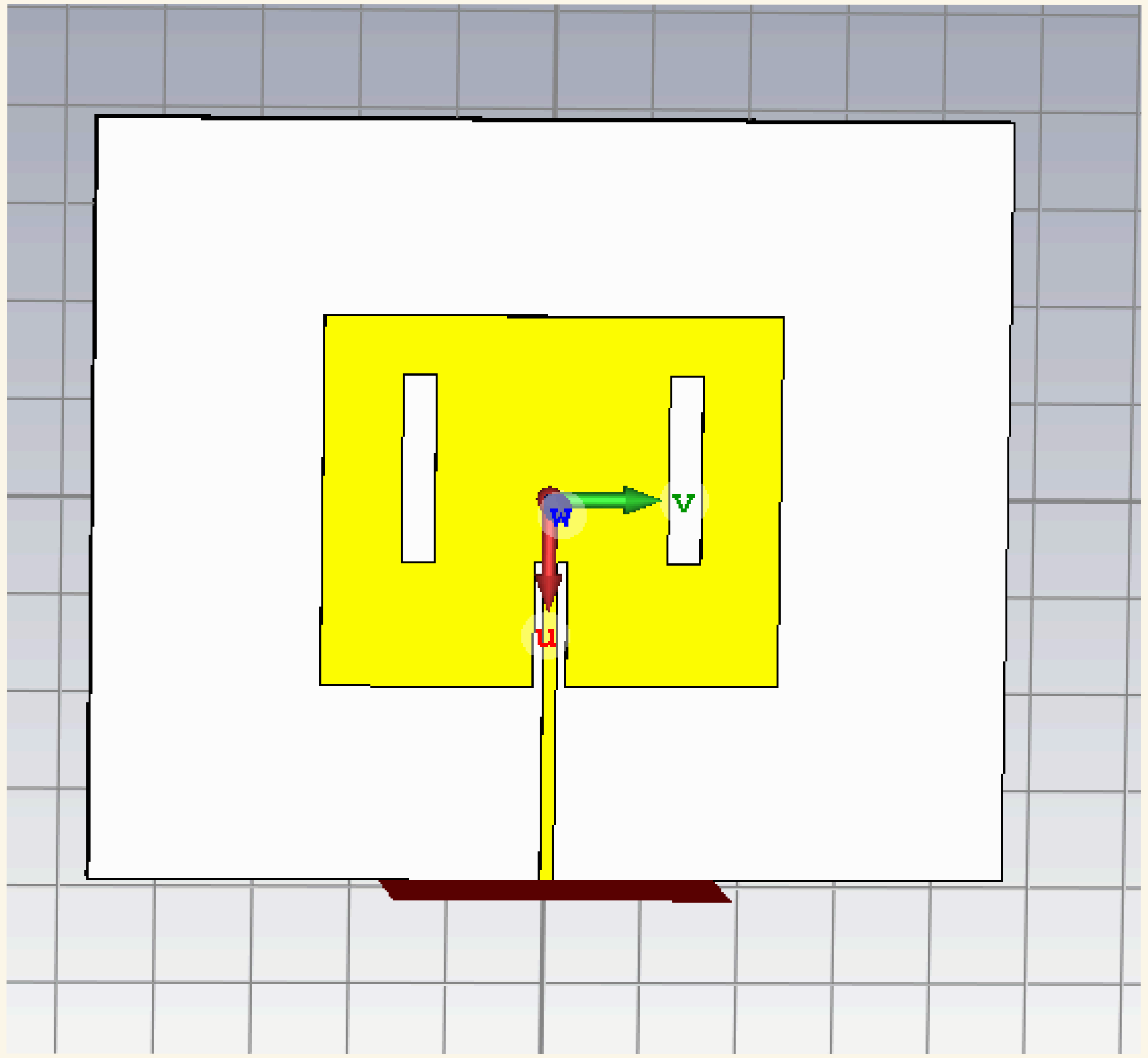


back view

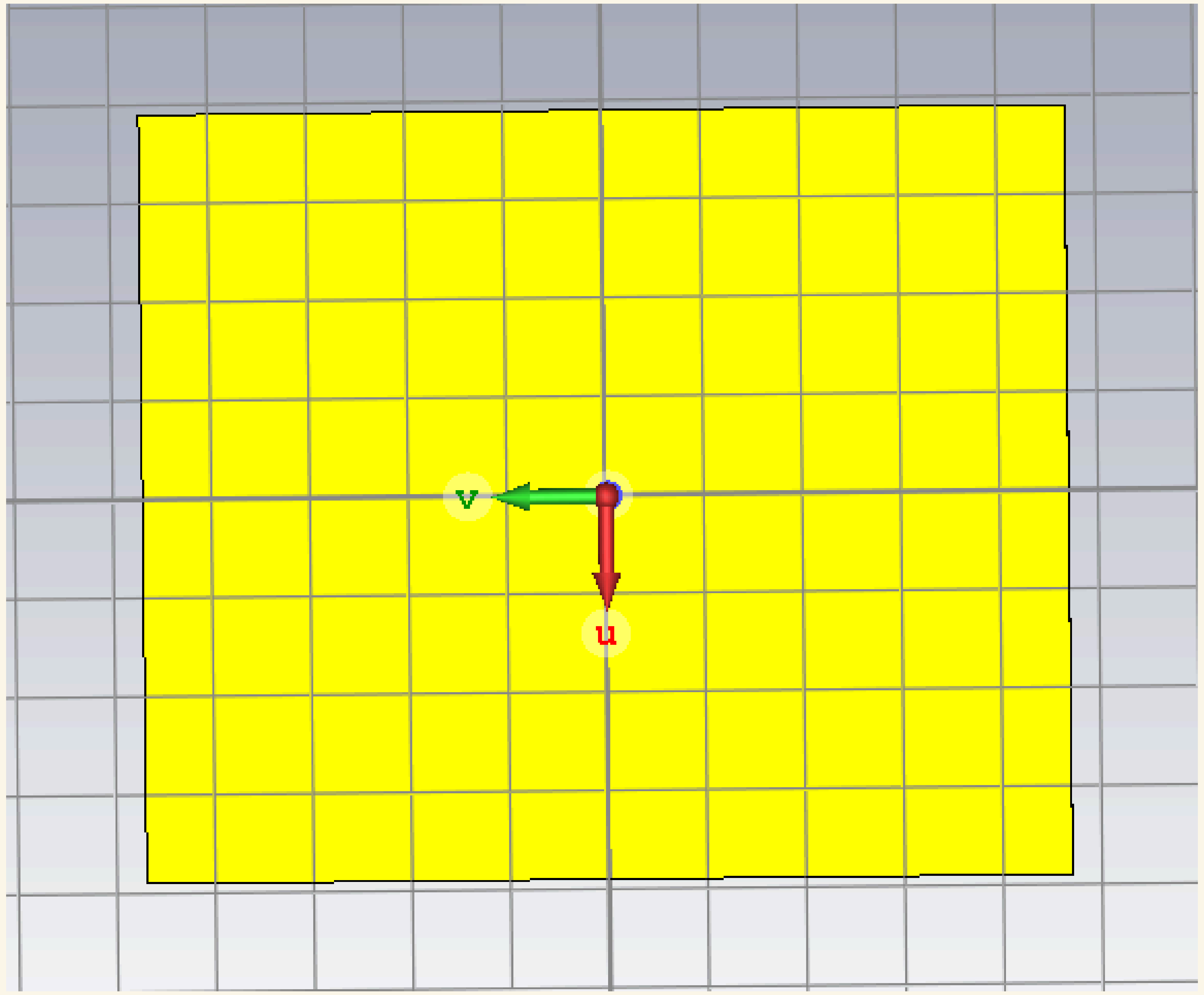

S-Parameters [Magnitude in dB]
dB
Frequency / GHz
S1,1
(2.3457, -10.03)
(2.4105, -10.011)


Max Gain over Frequency
Frequency / GHz

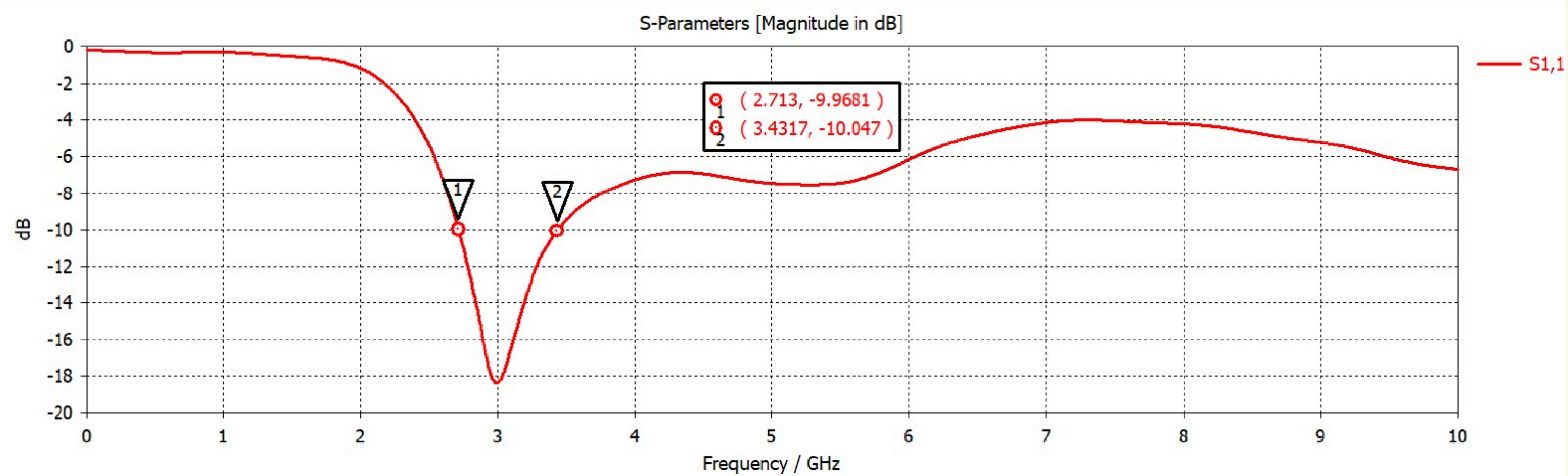
Prototype 2: 3 GHz MPA



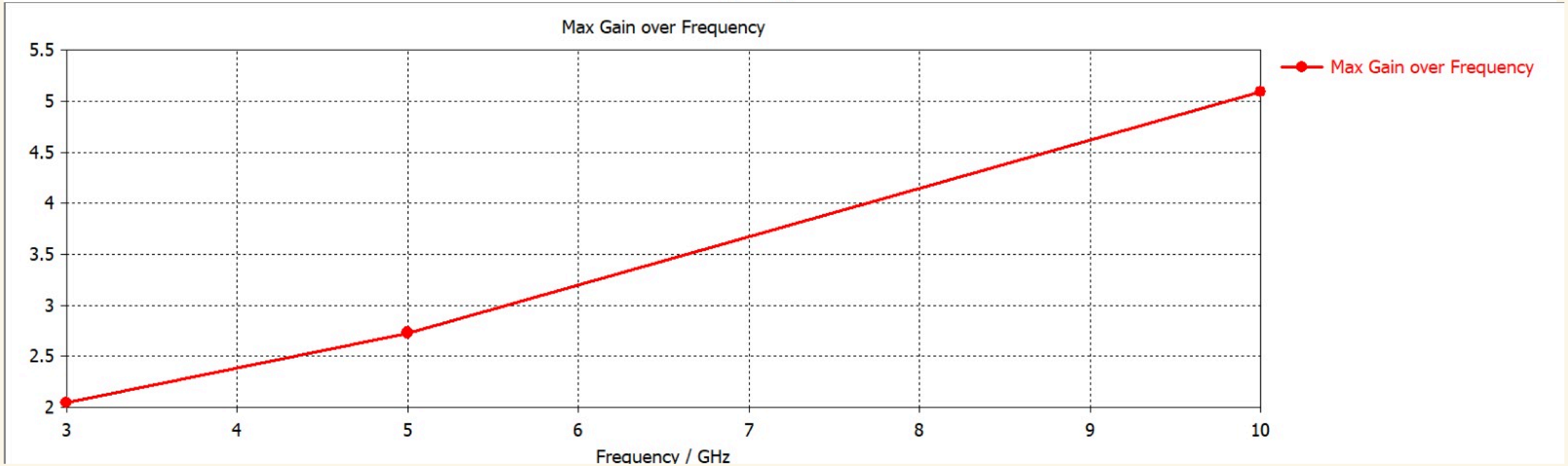
front view



back view

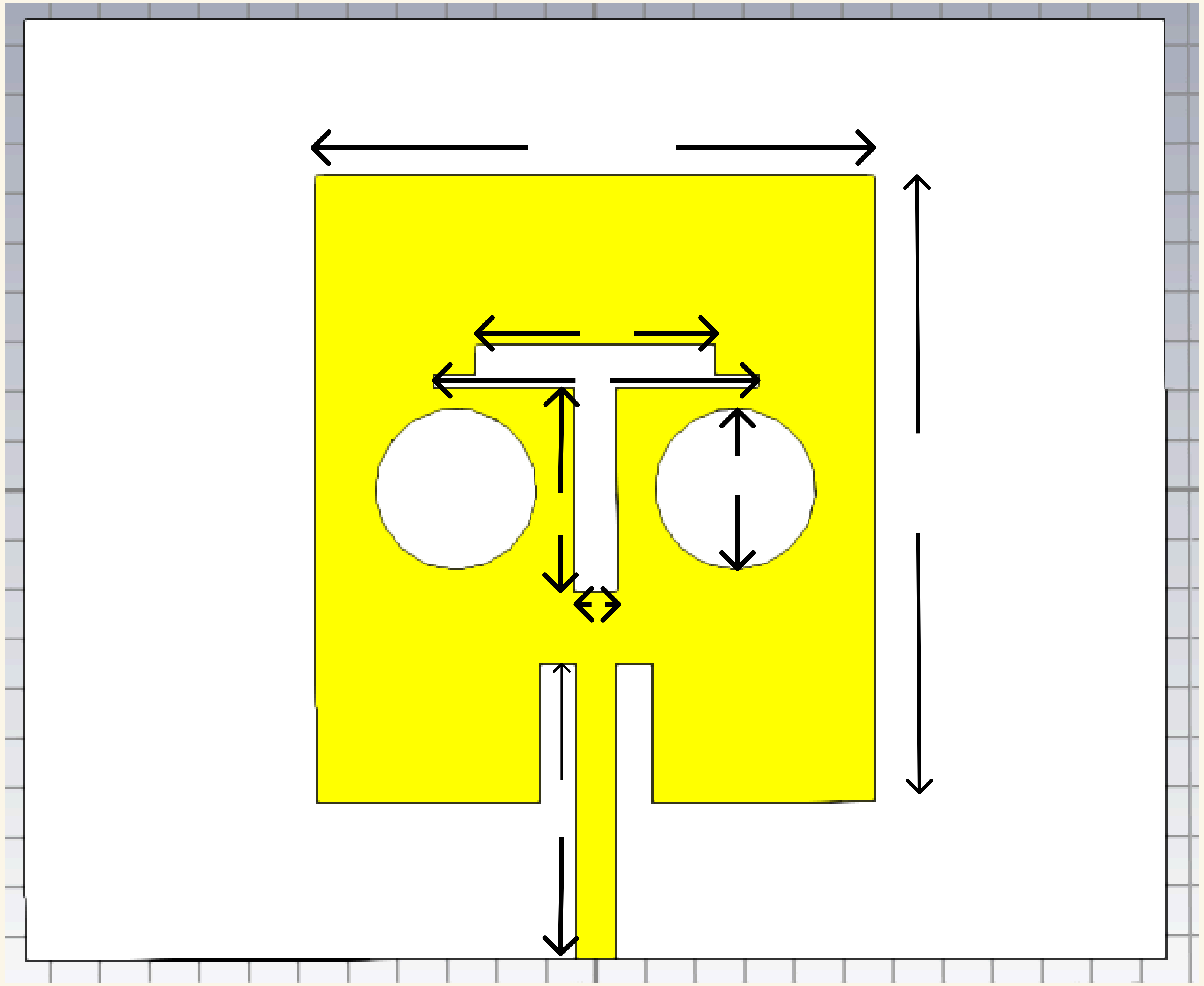


S-Parameters [Magnitude in dB]
S1,1
(2.713, -9.9681)
(3.4317, -10.047)
1
2
0
-2
-4
-6
-8
-10
-12
-14
-16
-18
-20
dB
0
1
2
3
4
5
6
7
8
9
10
Frequency / GHz

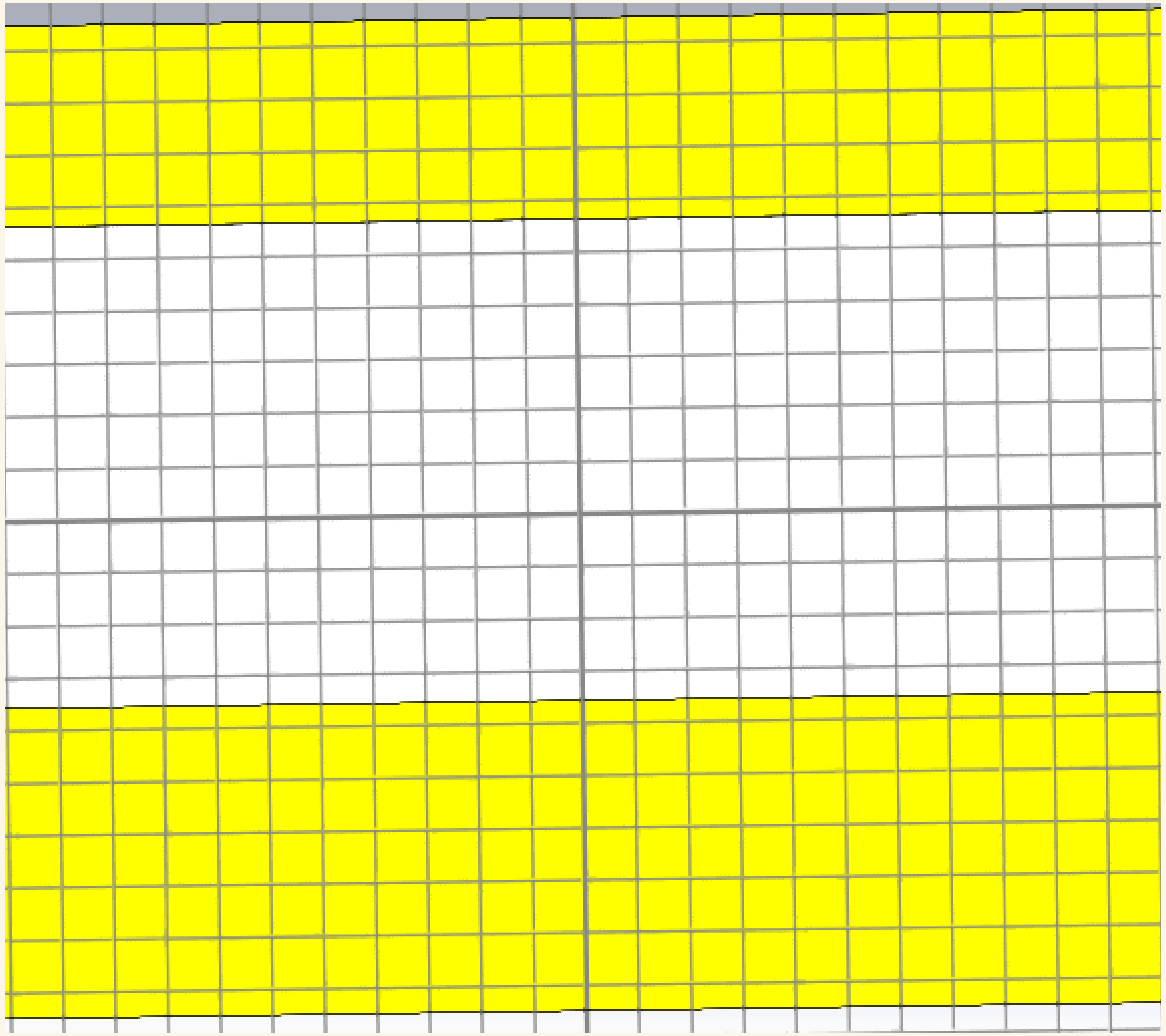


Max Gain over Frequency
Max Gain over Frequency
5.5
5
4.5
4
3.5
3
2.5
2
3
4
5
6
7
8
9
10
Frequency / GHz

PROPOSED PATCH ANTENNA DESIGN AND CONFIGURATION



front view



back view

Antenna Parameters

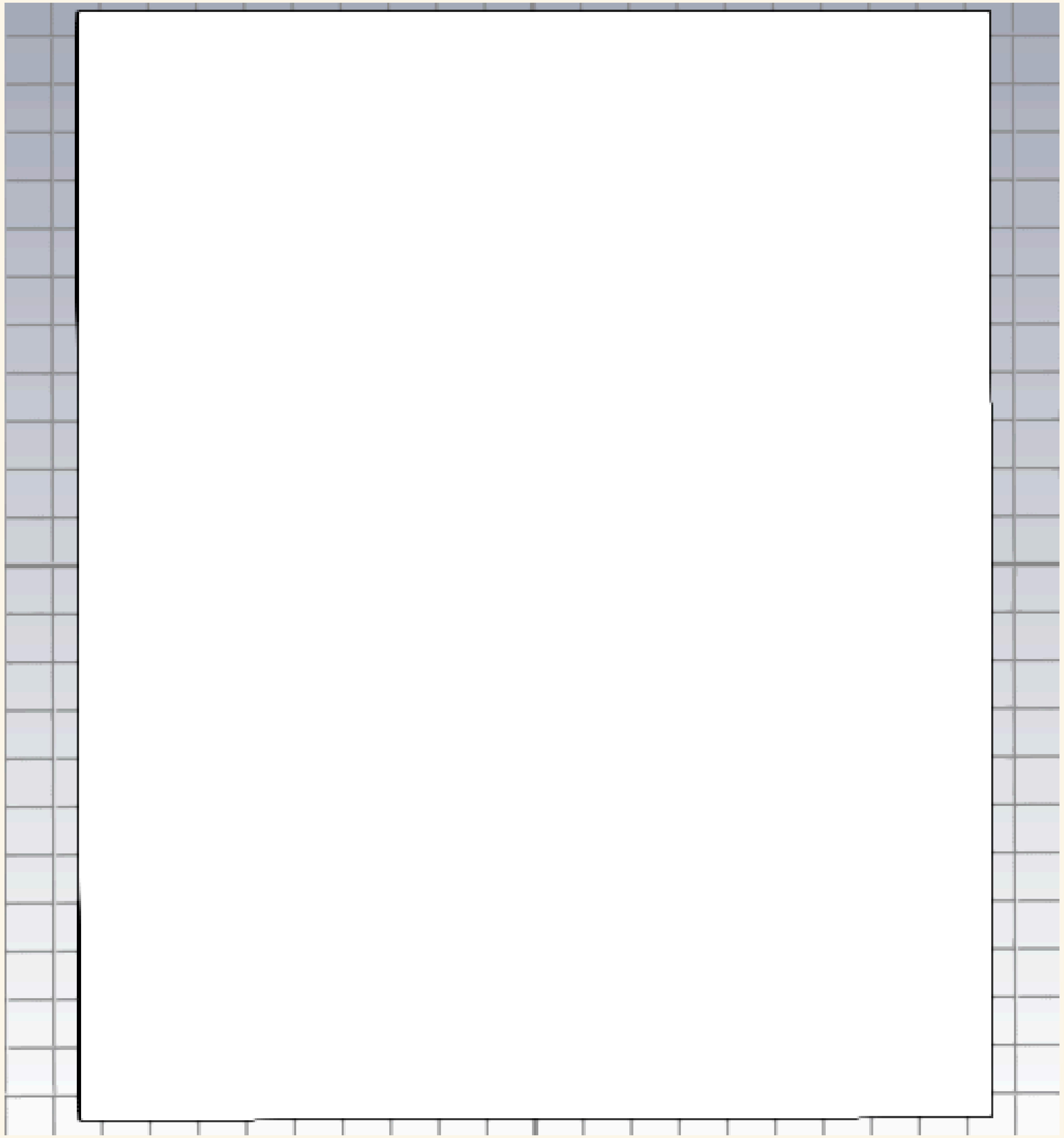
Parameter List

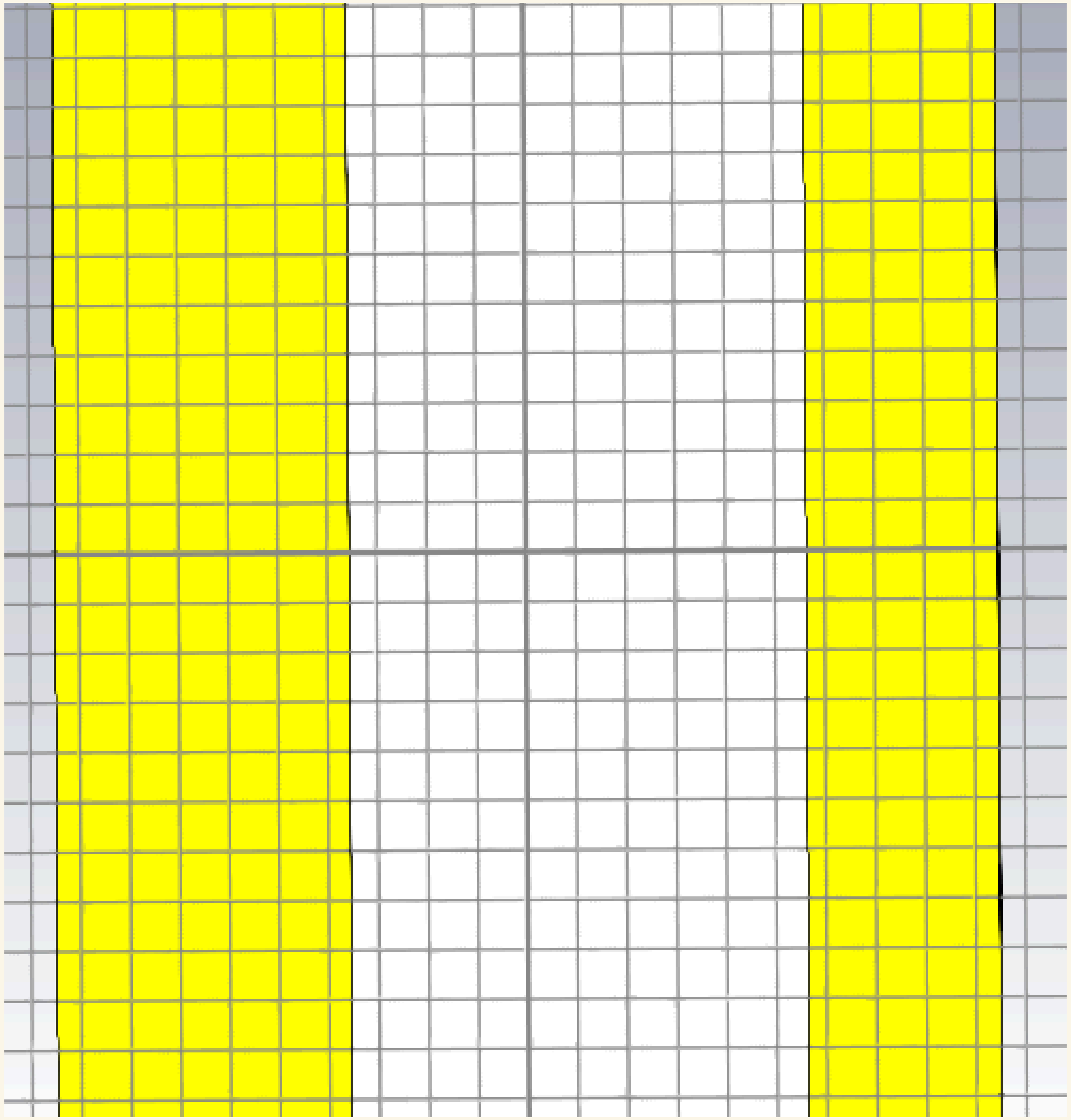
Name	Expression	Value
inner_rad	= 0	0
x_center	= 0	0
feed_pos	= 0	0
thin_height	= 0.016	0.016
subs_height	= 0.535	0.535
feed_cut_width	= 0.63	0.63
feed_width	= 0.7	0.7
u_width	= 0.75	0.75
t_width	= 0.75	0.75
rel	= 1.15	1.15
outer_rad	= 1.415	1.415
t_length	= 1.8	1.8
u_length	= 2	2
u_pos	= 2.1	2.1
feed_cut_length	= 2.44	2.44
patch_width	= 9.8	9.8
patch_length	= 11	11
length	= 16.5	16.5
width	= 20	20
y_center	= patch_width/4	2.45

Antenna Preparation

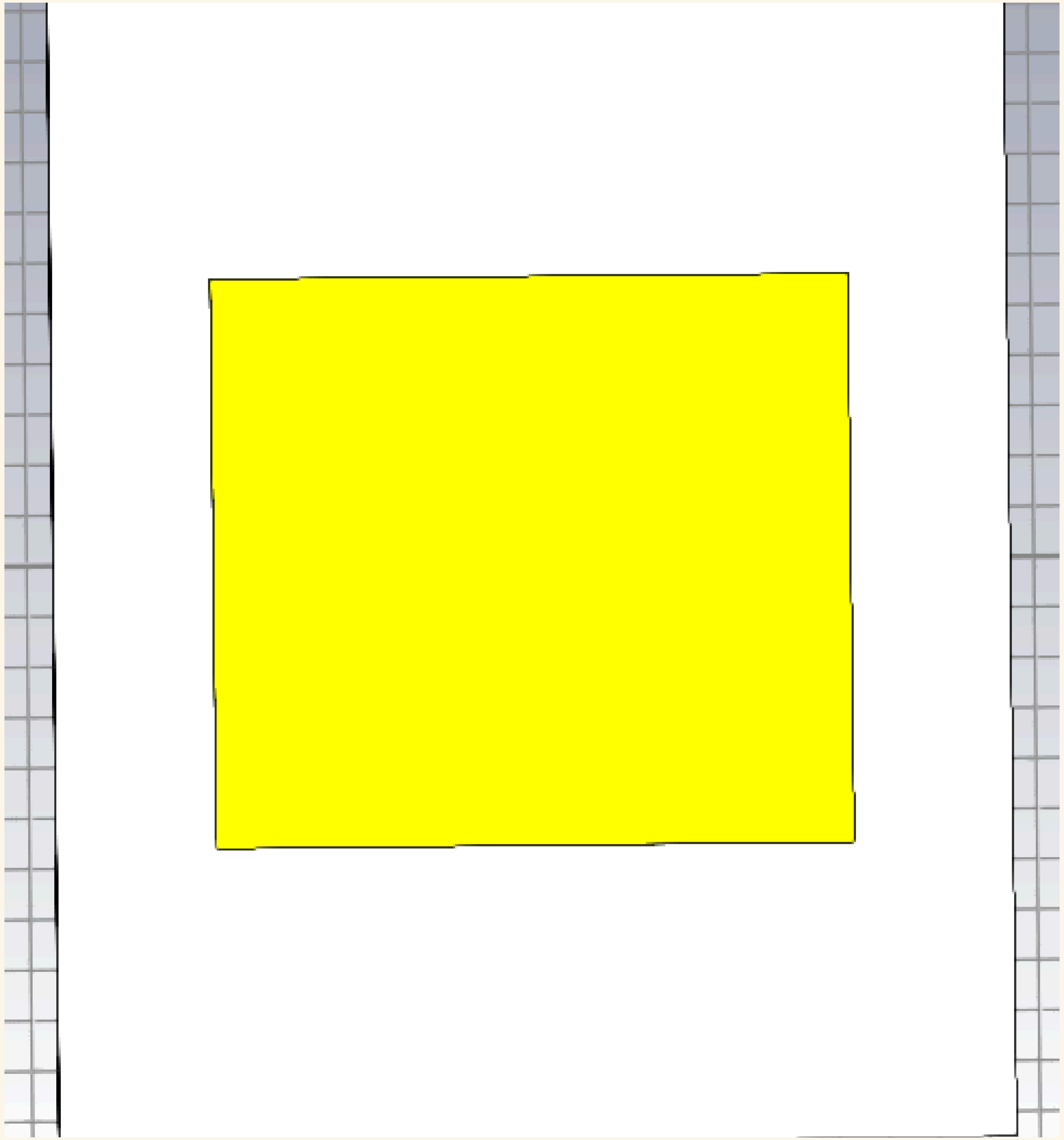
Step 1

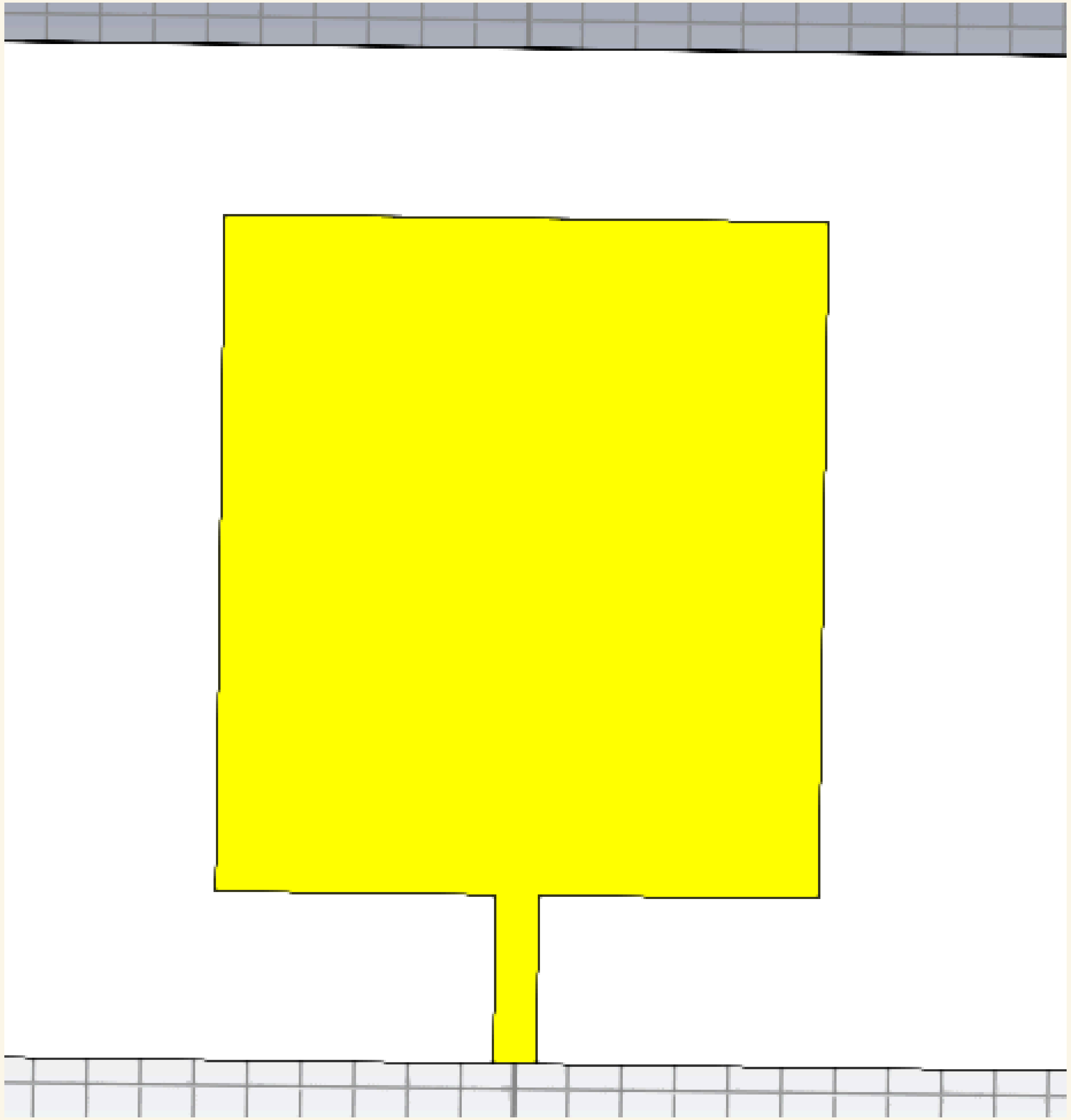
Step 2





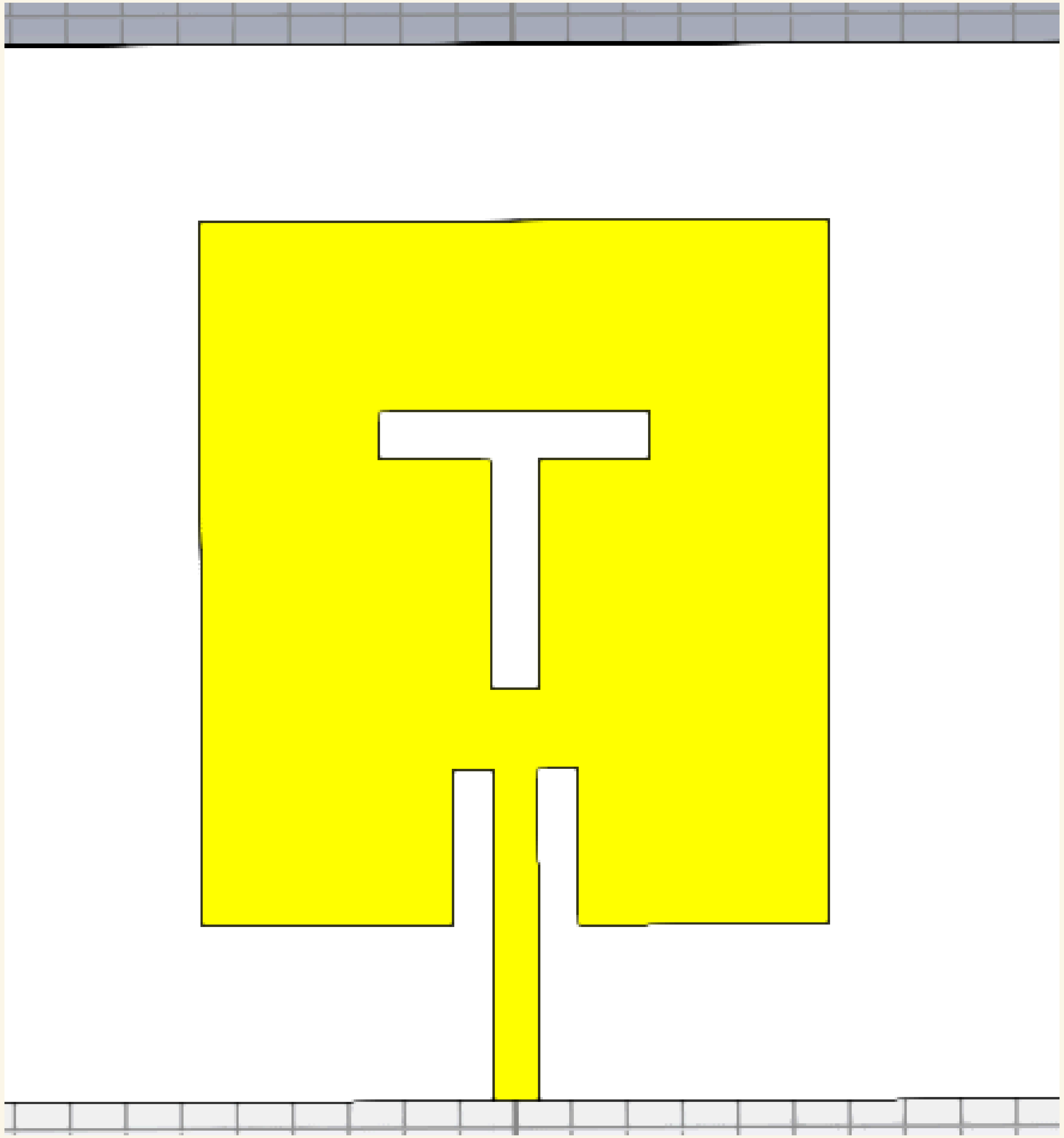
Step 3

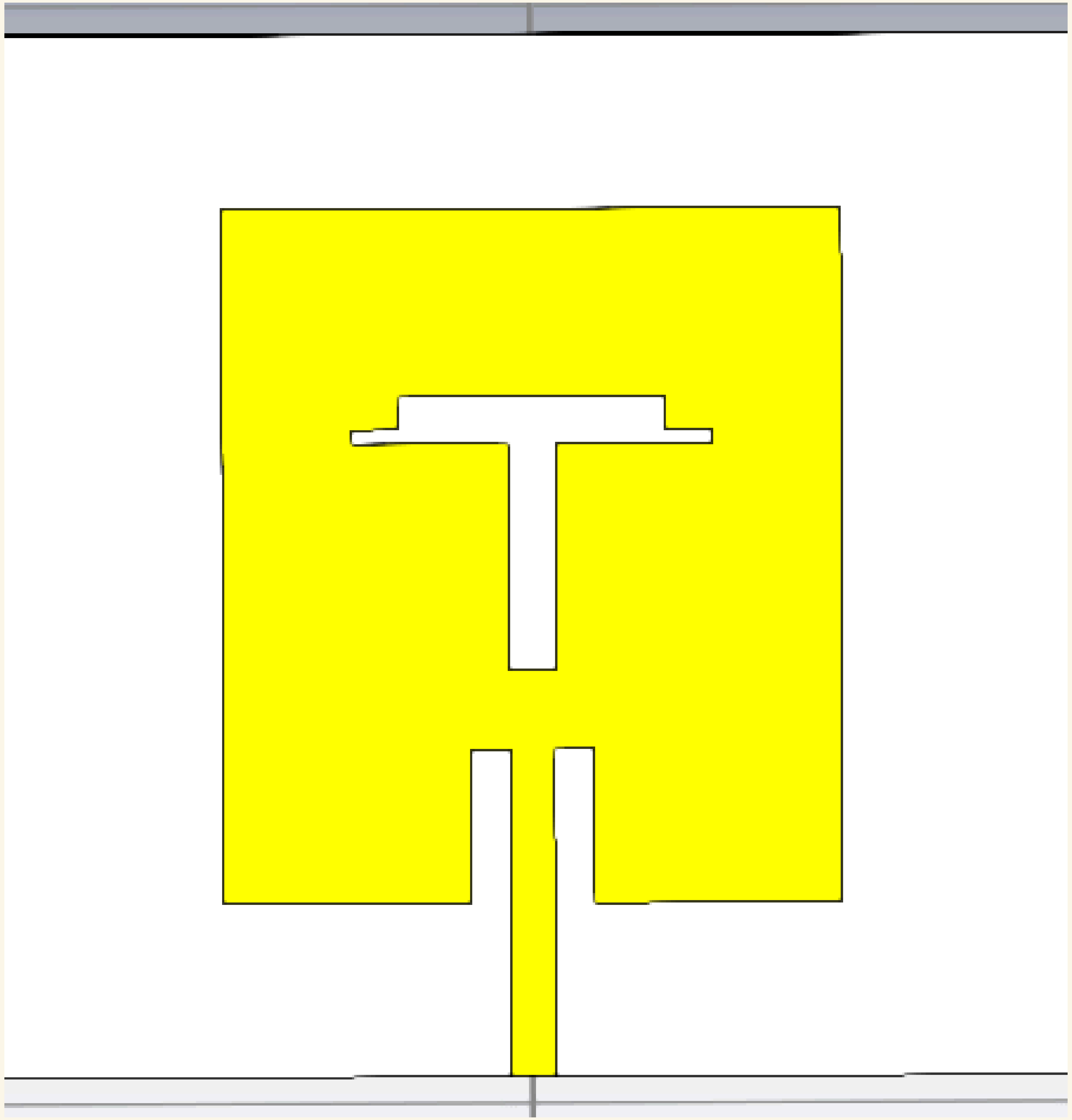




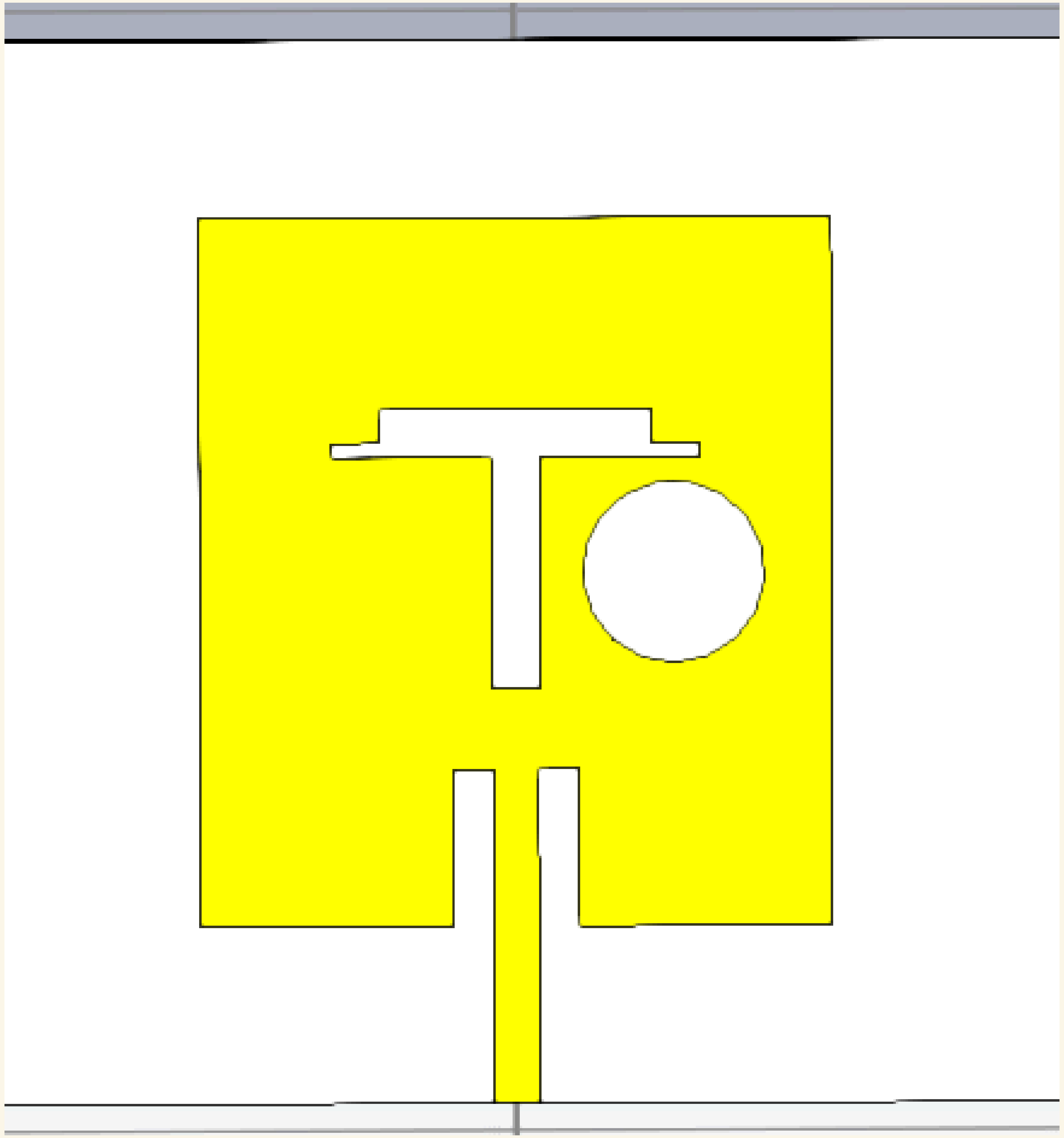
Step 4

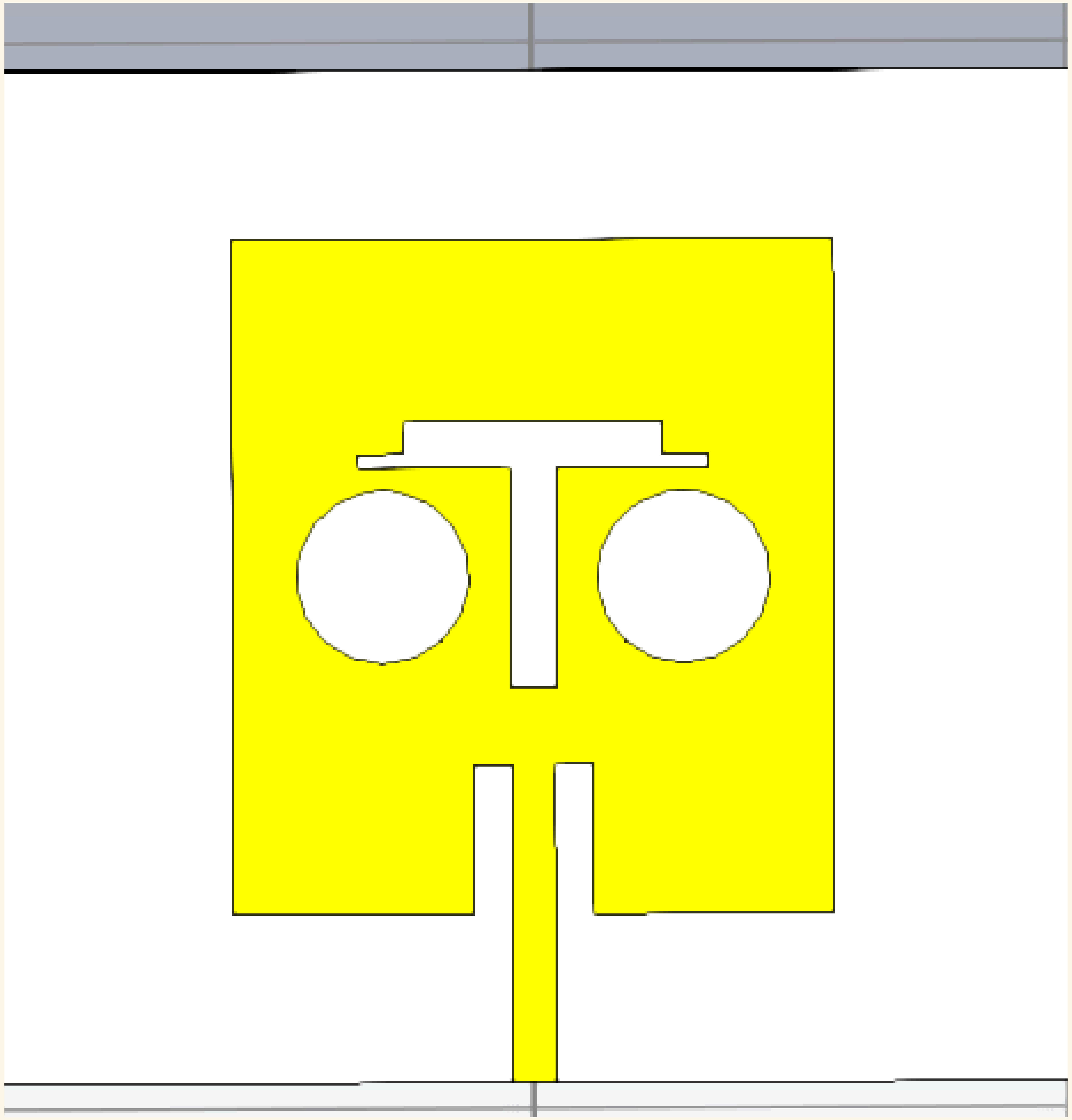
Step 5



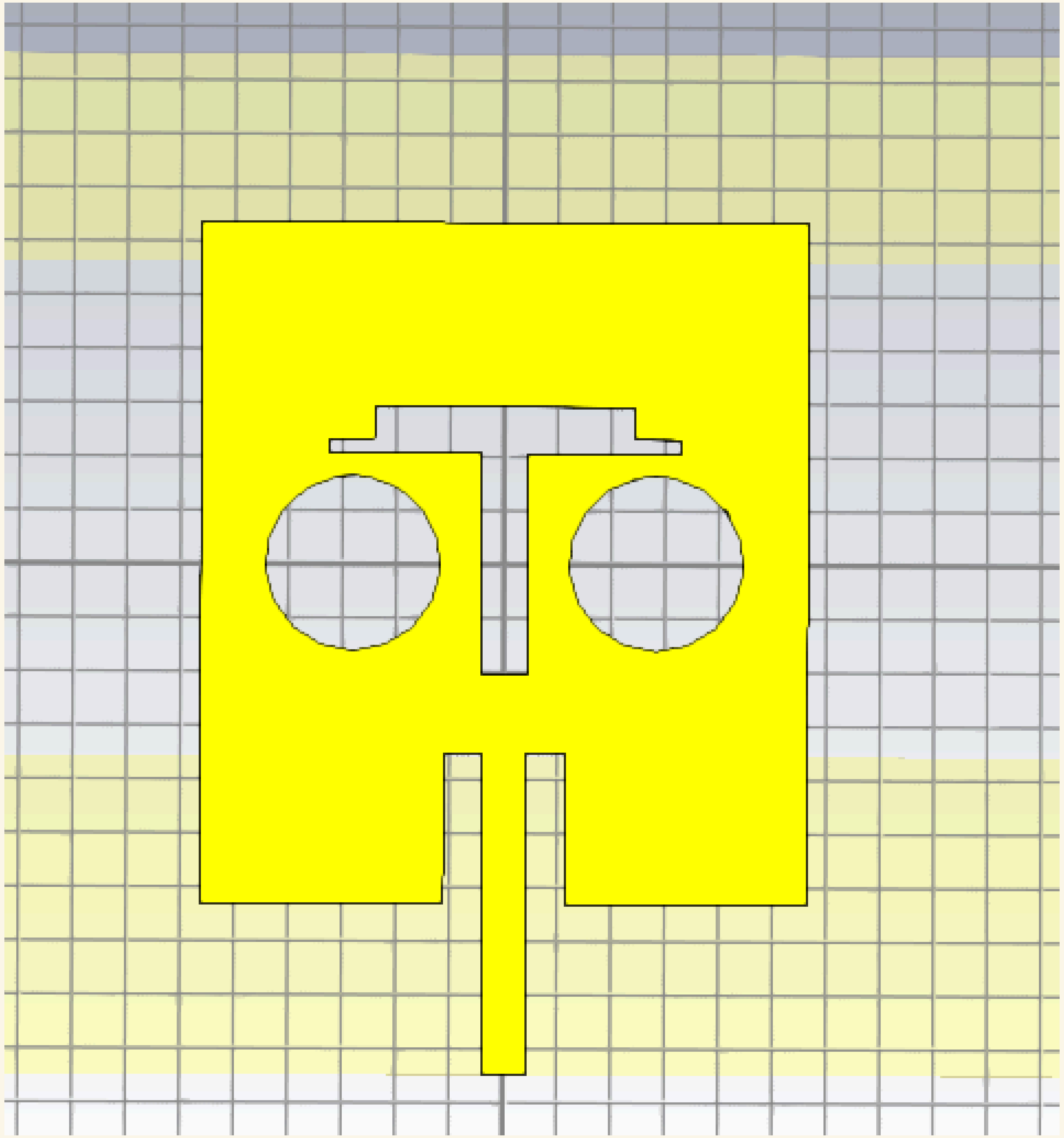


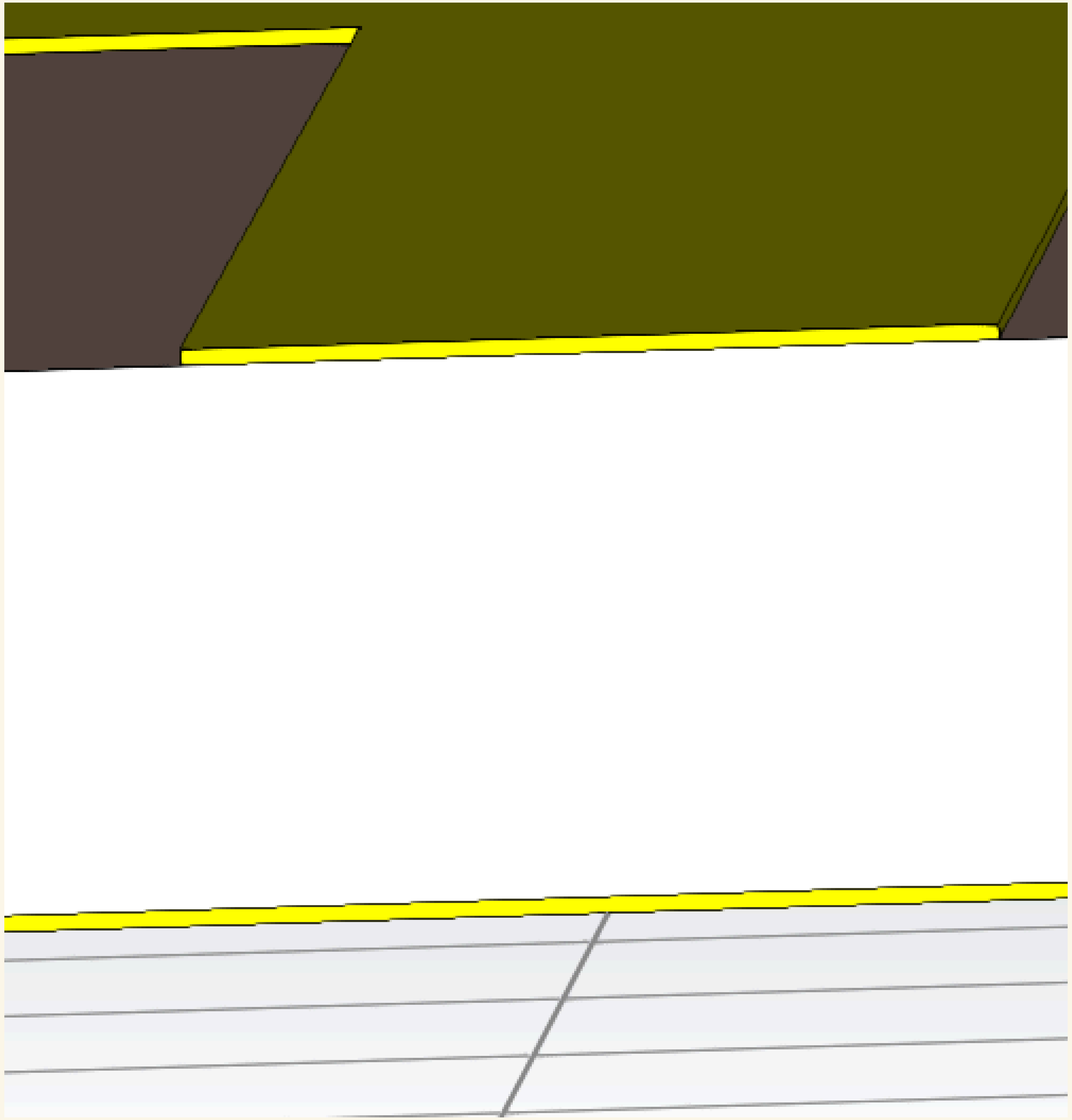
Step 6





Overview





Features

1. **Geometry:**
   - The patch shape is rectangular with two circular cutouts symmetrically positioned on the patch.
   - A **T**-shaped slot is centrally placed within the rectangular patch.
2. **Feed Structure:**
   - A microstrip feed line extends vertically from the bottom of the antenna and connects to the main patch.
3. **Symmetry:**
   - The design is symmetric along the vertical axis, ensuring uniform current distribution and potentially consistent radiation performance.
4. **Purpose of Cutouts and Slots**:
   - The circular cutouts and "T" slot serves to alter the current paths, enabling multi-band or wideband operation by introducing additional resonances.
   - They are also intended to reduce the overall size of the patch while maintaining effective radiation characteristics.
5. **Substrate:**
   - Rogers RT5880 as the substrate, this antenna benefits from its low dielectric constant ($\varepsilon r \approx 2.2$) and low loss tangent ($\tan\delta \approx 0.0009$), making it ideal for high-frequency applications like 5G, satellite communications, and IoT. The choice of substrate enhances the antenna's efficiency and reduces signal losses, supporting better bandwidth and gain performance.
6. **Partial Ground Plane:**
   - The ground plane consists of two yellow rectangular sections at the top and bottom, leaving the central portion uncovered. This configuration is characteristic of partial ground plane designs
   - Partial ground planes are often used to enhance impedance matching and improve bandwidth by allowing better coupling between the radiating patch and the ground plane.
   - As the antenna uses Rogers RT5880, the ground plane is composed of copper, a conductive material, ensuring low losses and high efficiency.

S-Parameters [Magnitude in dB]
0
-10
-20
-30
-40
-50
-60
-70
20
25
28.16
30
35
40
45
50
Frequency / GHz
S1,1
1
2
(26.861, -10.083)
(32.103, -10.06)
S1,1 : -66.65874

Reference Impedance [Real Part]
80
79
78
77
76
75
74
73
72
71
70
Impedance / Ohm
ZRef 1(1)
ZRef 1(1) : 71.791612
20
25
28.16
30
35
40
45
50
Frequency / GHz


1D Results\Efficiencies [Magnitude]
Rad. Efficiency [1]
Tot. Efficiency [1]
(26.926, 0.88476)
(32, 0.74954)
(27.097, 0.8241)
(31.889, 0.69222)
Rad. Efficiency [1] : 0.89865419
Tot. Efficiency [1] : 0.89522657
0.95
0.9
0.85
0.8
0.75
0.7
0.65
0.6
0.55
0.5
0.45
20
25
28.16
30
35
40
45
50
Frequency / GHz


Voltage Standing Wave Ratio (VSWR)
VSWR1 : 1.0009296
(26.788, 1.983)
(32.269, 1.9378)
VSWR1
5
4.5
4
3.5
3
2.5
2
1.5
1
20
25
28.16
30
35
40
45
50
Frequency / GHz


Max Gain over Frequency
Max Gain over Frequency : 4.9805784
(26.549, 5.2672)
(32.027, 4.2401)
1
2
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
20
25
28.16
30
35
40
45
50
Frequency / GHz
Max Gain over Frequency


farfield (f=27) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Gain
Frequency 27 GHz
Rad. effic. 0.8868
Tot. effic. 0.8164
Gain 3.410
3.41
3.2
2.98
2.77
2.56
2.34
2.13
1.92
1.7
1.49
1.28
1.07
0.852
0.639
0.426
0.213
0
Y
x
y

3.21
3.01
2.81
2.61
2.41
2.21
2.01
1.81
1.61
1.41
1.2
1
0.803
0.602
0.402
0.201
0
z
y
x
Phi
farfield (f=28) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Gain
Frequency 28 GHz
Rad. effic. 0.8969
Tot. effic. 0.8958
Gain 3.212


farfield (f=29) [1]
Type Farfield
Approximation enabled (kR >> 1)
Component Abs
Output Gain
Frequency 29 GHz
Rad. effic. 0.9078
Tot. effic. 0.8925
Gain 2.831
2.83
2.65
2.48
2.3
2.12
1.95
1.77
1.59
1.42
1.24
1.06
0.885
0.708
0.531
0.354
0.177
0
Y
Phi
Theta
Z

Applications of proposed antenna operating at 28 GHz

1. 5G Communication Systems

- The frequency range overlaps with 5G mm Wave bands (e.g., 28 GHz), making it ideal for 5G base stations or user equipment.
- Suitable for small-cell deployment to support high-speed, low-latency communication.

2. Satellite Communication

- The band falls within *Ka-band* satellite frequencies used for earth observation, communication satellites, and high-throughput satellites.

3. Radar Systems

- Can be applied in short-range radar systems, such as for autonomous vehicles or drone navigation, due to its gain and compact size.

4. Wireless Backhaul

- Supports high-capacity wireless backhaul links between small-cell base stations in urban networks.


Millimeter Waves
5G
Small Cell Concept
Collision Determination ECU
Image Sensor
Smart Driving
Radar
Pre-Crash Seatbelt
Pre-Crash Brakes
Pre-Crash Brake Assist
Virtual Reality

5. Point-to-Point Communication

- Suitable for high-speed data transfer in dedicated point-to-point links in industrial or urban setups.

6. IoT and Smart Devices

- Can be used in Internet of Things (IoT) applications requiring high data rates and operating in mmWave frequencies.

7. Medical Imaging and Sensing

- Applicable in *mm*Wave medical imaging, such as breast cancer detection or other diagnostic techniques.

8. High-Frequency Testing and Measurement

- Suitable for use in testing operating in the 26.5–32 GHz band for characterization of high-frequency systems.

9. Military and Defense

- Can be utilized in secure military communication systems or battlefield radar operating in Ka-band.

10. **Frequency Band Adjustment:** Change the dimensions of the patch, ground plane, or slots to shift the operating frequency range

- *Wi-Fi 6E and Future Wi-Fi Standards:* Adjust to operate in the 6 GHz or 60 GHz bands for high-speed wireless communication
- *Automotive Radar:* Design for operation at 77 GHz or 24 GHz, commonly used in adaptive cruise control and collision avoidance systems

11. **Material Modification:** Change the substrate material to one with different dielectric properties or flexibility (e.g., flexible polymers or fabric-based substrates)

- *Wearable Antennas:* Flexible substrates allow integration into clothing or body-worn devices for health monitoring or military applications
- *Conformal Antennas:* Applicable for curved surfaces like aircraft, missiles, or vehicle body-mounted antennas

12. **Polarization Control:** Introduce circular polarization by modifying the patch shape (e.g., truncating corners adding a perturbation) or using dual-feed designs

- *Satellite Communication:* Circularly polarized antennas reduce the effects of signal orientation mismatch between ground stations and satellites
- *GNSS (Global Navigation Satellite Systems):* Suitable for navigation systems like GPS or GLONASS, which use circularly polarized signals

13. **Modification:** Add a parasitic layer, employ an array configuration, or integrate a reflector to enhance the gain

- *Long-Range Wireless Communication:* Higher gain makes the antenna suitable for long-distance point-to-point links or satellite ground stations.
- *Remote Sensing:* High-gain antennas are valuable for applications like weather monitoring, earth observation etc

Conclusion and Future Scope

The proposed microstrip patch antenna, designed using the Rogers RT5880 substrate, demonstrates excellent performance characteristics suitable for 5G applications. With a wide bandwidth ranging from 26.5 GHz to 32 GHz and an operating frequency centered at 28 GHz, the antenna provides the necessary frequency range for high-speed communication. The achieved S11 parameter of -66 dB indicates superior impedance matching, while the impedance of 72 ohms, which is slightly mismatched with the standard 50/100-ohm impedance commonly used in the industry. To ensure optimal power transfer and minimize signal reflection, a separate matching circuit will be required to match the line impedance to the standard 50/100 ohms. Additionally, the antenna exhibits an efficiency of 80–90%, reflecting low power losses and high radiation performance. The maximum far-field gain of 4.5–5.5 dB ensures adequate signal strength for communication over short to medium ranges. These attributes make the antenna an excellent candidate for 5G millimeter-wave communications, IoT, and other advanced wireless technologies.

1. **Further Miniaturization**: Explore novel fractal geometries or metamaterials to reduce the antenna size further while maintaining its performance metrics
2. **Polarization Diversity**: Modify the design to support dual or circular polarization, enhancing its capability for diverse communication scenarios
3. **Array Integration**: Extend the design into an antenna array for increased gain and beam steering to support high-capacity and directional 5G communication systems
4. **Substrate Optimization**: Investigate alternative substrates with even lower loss tangents to improve efficiency further and reduce thermal effects at high frequencies
5. **Fabrication and Testing**: Fabricate and experimentally validate the simulated performance of the antenna, analyzing real-world challenges such as fabrication tolerances and environmental effects
6. **Environmental Adaptability**: Design the antenna to maintain performance under varying environmental conditions, such as temperature fluctuations and humidity

These advancements will enhance the applicability of the antenna for future communication systems, ensuring optimal performance for emerging 5G and millimeter-wave technologies.

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Thank You