Parametric Study of a Microwave Absorber Based on Metamaterials.

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October 2024

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***Abstract* – Microwave absorbers play a crucial role in modern telecommunications and electronic systems by mitigating unwanted electromagnetic interference (EMI) and enhancing the performance of various devices. These absorbers are essential in applications ranging from radar systems and anechoic chambers to consumer electronics and medical devices. Traditional microwave absorbers, while effective, often suffer from limitations such as bulkiness and narrow bandwidth.Metamaterial-based microwave absorbers offer a promising alternative due to their unique electromagnetic properties, which are not found in natural materials. These engineered materials can achieve near-unity absorption across a wide range of frequencies, making them highly efficient. The advantages of metamaterial absorbers include their thin profile, lightweight nature, and the ability to tailor their absorption characteristics through precise structural design. This makes them ideal for applications requiring compact and efficient EMI mitigation. Additionally, metamaterial absorbers can be designed to operate over multiple frequency bands, providing versatility and enhanced performance in complex electromagnetic environments.**

Contents

I Introduction

The study begins with a theoretical exploration of absorber devices and the unique properties of metamaterials that make them suitable for electromagnetic wave absorption. Following this, the report details the implementation of a specific microwave absorber device using advanced simulation software, highlighting the practical aspects of device design and performance evaluation. Finally, the report addresses the parametric design and optimization of the device, fine-tuning structural parameters to achieve optimal absorption characteristics. Through this comprehensive approach, the report aims to provide a thorough understanding of the principles, design methodologies, and practical applications of metamaterial-based microwave absorbers.

II Theoretical Study

Metamaterials are artificially engineered materials with unique electromagnetic properties not found in nature. They are designed with specific geometrical structures that allow them to exhibit properties like negative refractive index, reverse Snell's law, and right/left-handed behavior. The first to coin the term of metamaterial absorbers was Victor Veselago [1].

An MMA typically comprises three layers:

- A periodic metallic pattern on top
- A dielectric substrate in the middle
- A bottom metallic ground plane

This layered structure enables efficient absorption of electromagnetic waves.

Impedance matching is crucial for MMAs to minimize reflection and maximize absorption. This is achieved when the impedance of the MMA is matched to the impedance of free space, ensuring that incident electromagnetic waves are absorbed rather than reflected.

Reducing the plasma frequency of metals in MMAs allows them to operate effectively at lower frequencies, expanding their applicability to various frequency ranges. This is achieved by manipulating the density of free electron carriers in the metal.

Multi-layer structures in MMAs enable broadband absorption by creating multiple resonant frequencies. By stacking different layers with varying properties, a wider range of frequencies can be absorbed effectively.

Designing MMAs for specific applications often presents challenges related to achieving the desired bandwidth and absorption ratio. Balancing these requirements while considering factors like size, complexity, and cost can be difficult, requiring careful optimization of the MMA structure and materials.

II.I Impedance Matching Free Space

An absorber can be represented as a transmission line equivalent [2]. In order to maximize the absorbance we need to optimize against a specific variable:

$$A = 1 - |\Gamma|^2 - |T|^2 \tag{1}$$

II.II Magnetic Resonance

Is what can be achieved with closed loop structures [3].

II.III Electrical Resonance

Can be achieved introducing gaps in the structure [3].

II.IV Plasma Frequency

Plasma frequency of a material is the electron cloud oscillations for a specific material.

$$\omega_p = \sqrt{\frac{Ne^2}{m\epsilon_0}} \tag{2}$$

III Simulation

The simulation has be created using the CST software in order to implement a configuration such as shown in [4].

III.I CST Implementation

First we should implement the layout in CST which consist of three layers:

- Dielectric substrate
- Air
- Metal Backplate

The dielectric substrate will also embody a metallic component made of the same material as the metal backplate; copper (5.96 $\mu 10^7$ S/m) that is.

At first I'll place the substrate without the resonance layer:

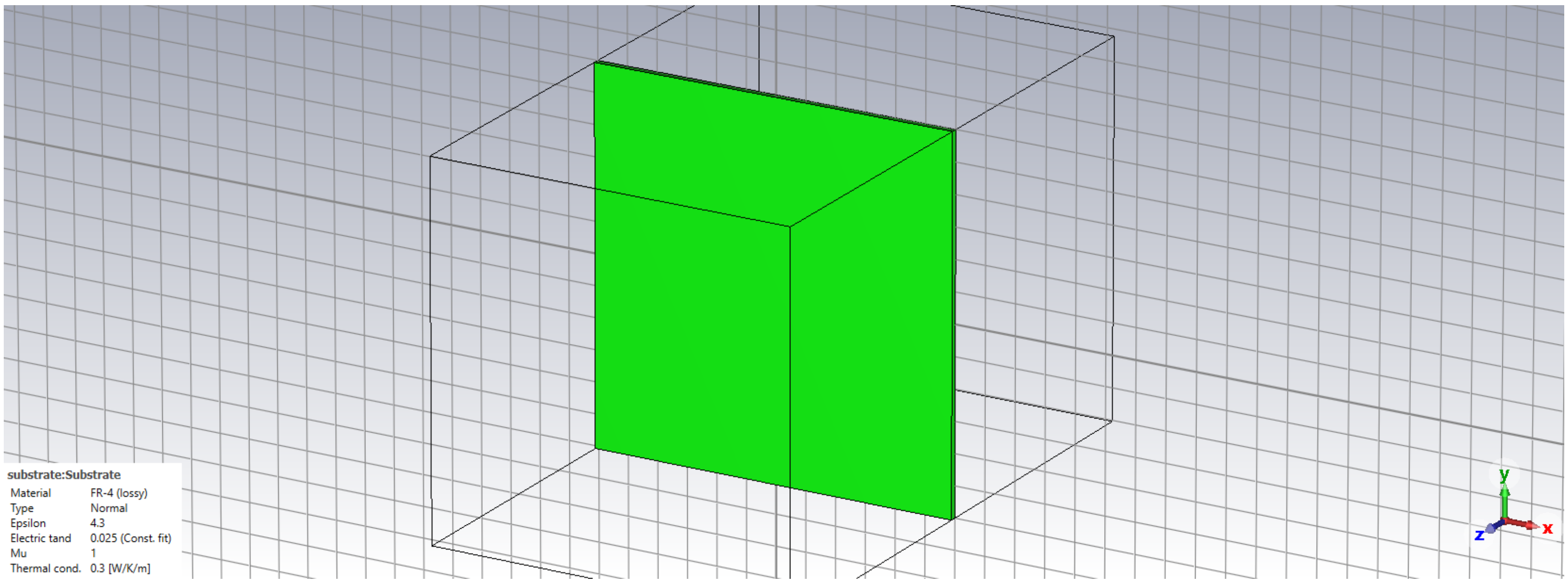

Figure 1: FR4 Dielectric Substrate

Later I'll place the metal resonance layer as well but there are a number of possible candidates I think of trying to simulate whereas the vertical layout is pretty much fixed.

I'll place the two other layers below Z=0, turn on the orthographic side view to remove shadows and voila: I think it really gives a sense of scale as the air layer truly shadows the other two.

Now its time to add the ring that is of the same material and thickness as the backplate and lies on top of the dielectric substrate.

Then I will move the substrate, air and backplate layers all below Z=0 just ti make is easier with designing the arrows. For this I make the assumption that both the arrow body and point are a=0.5mm of width. In order to accurately place all the curve points that define the arrow some basic calculations shall be made. The two points of the arrow base lie exactly on the arc of the ring and are equidistant from curve y=x so the in order to find their cartesian coordinates the following system shall be solved.

```
        syms x1 x2

        eq1 = 2*(x1 - x2)^2 == .5^2;
```

```
    eq2 = sqrt(x2^2 + x1^2) == 2.7;

    sol = solve([eq1, eq2], [x1 x2]);
    disp([sol.x1 sol.x2]);
```

$$\begin{pmatrix} \sigma_3 - \frac{2916\,\sigma_1}{1433} & -\sigma_1 \\ \sigma_4 - \frac{2916\,\sigma_2}{1433} & -\sigma_2 \\ \frac{2916\,\sigma_1}{1433} - \sigma_3 & \sigma_1 \\ \frac{2916\,\sigma_2}{1433} - \sigma_4 & \sigma_2 \end{pmatrix}$$

where

$$\sigma_1 = \sqrt{\frac{729}{200} - \frac{7\sqrt{59}}{80}} \tag{3}$$

$$\sigma_2 = \sqrt{\frac{7\sqrt{59}}{80} + \frac{729}{200}}$$

$$\sigma_3 = \frac{400\left(\frac{729}{200} - \frac{7\sqrt{59}}{80}\right)^{3/2}}{1433}$$

$$\sigma_4 = \frac{400\left(\frac{7\sqrt{59}}{80} + \frac{729}{200}\right)^{3/2}}{1433}$$

Which results in two points/quadrant so picking out the two points of the 1st quadrant and inserting them to CST the arrow body is parallel again

Then the arrow is mirrored against the X, the Y and the XY planes in order to reach all four sides of the cell, then the face is covered with copper and a height of d=0.035mm is also attributed, which is why it was important to move all other layers below Z=0.

Now I'll try and perform a simulation using the frequency solver in CST just to get an idea how the component behaves, the boundaries will be periodic along the XY plate and I will add absorbing conditions along the Z axis.

For reference the mesh with only the ring element on the surface ends up such as:

III.II Alternative Modeling Methods

In order to simulate the absorber there are also a few other ways to go about it:

- Transmission Line equivalent
- Electrical circuit equivalent
- Mathematical modeling & code (MATLAB)

So at first I start by designing a basic layout in CST..

IV Optimization

Figure 2: Vertical Layout Orthographic View

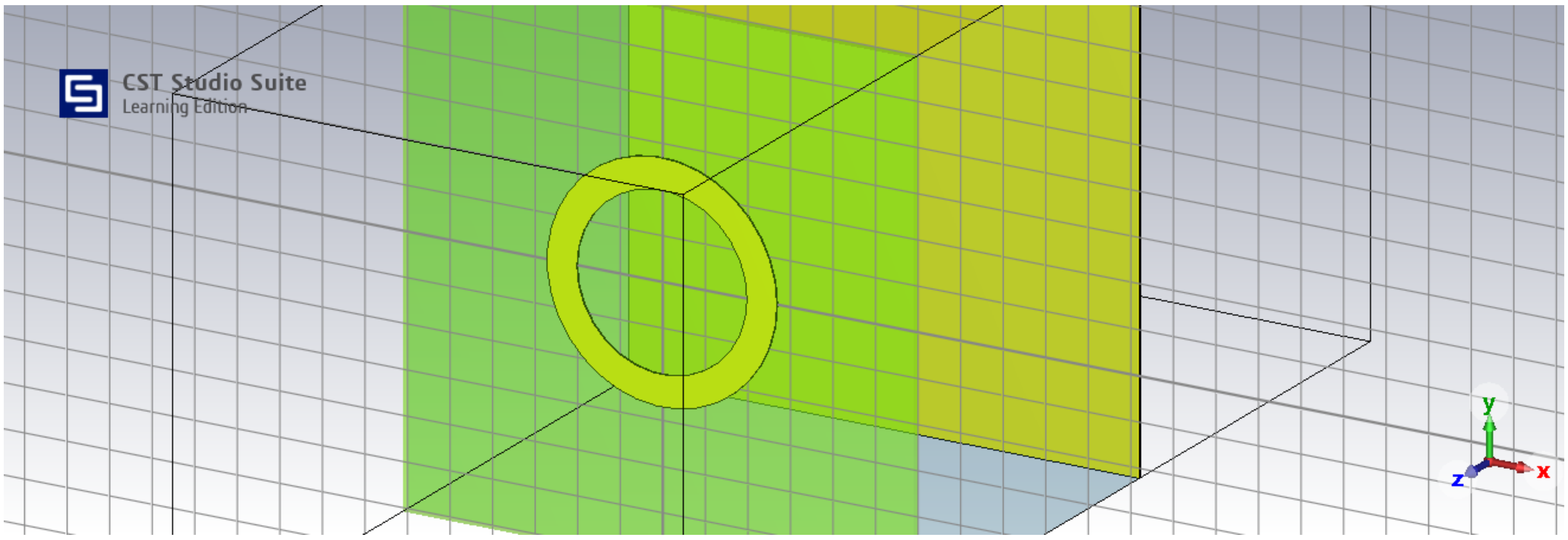

Figure 3: Ring Resonator

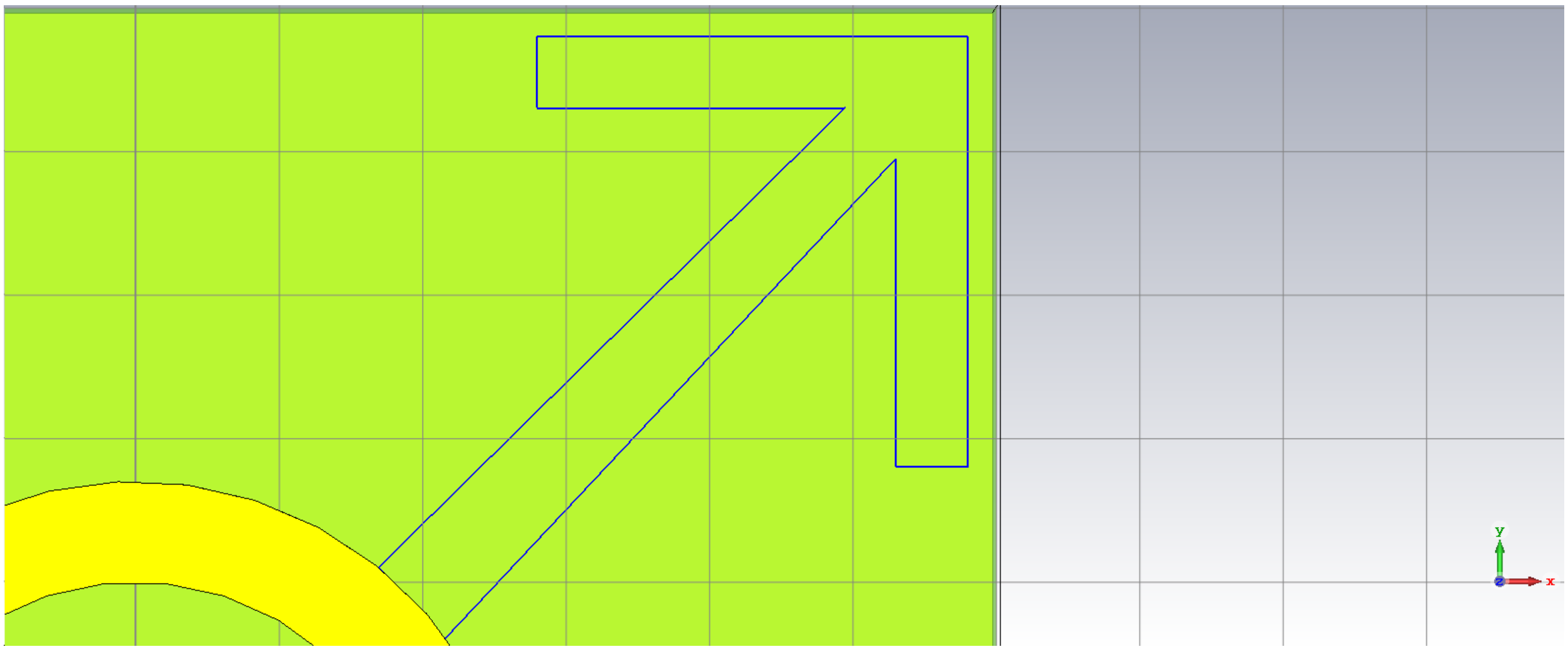

Figure 4: Initial Arrow Base

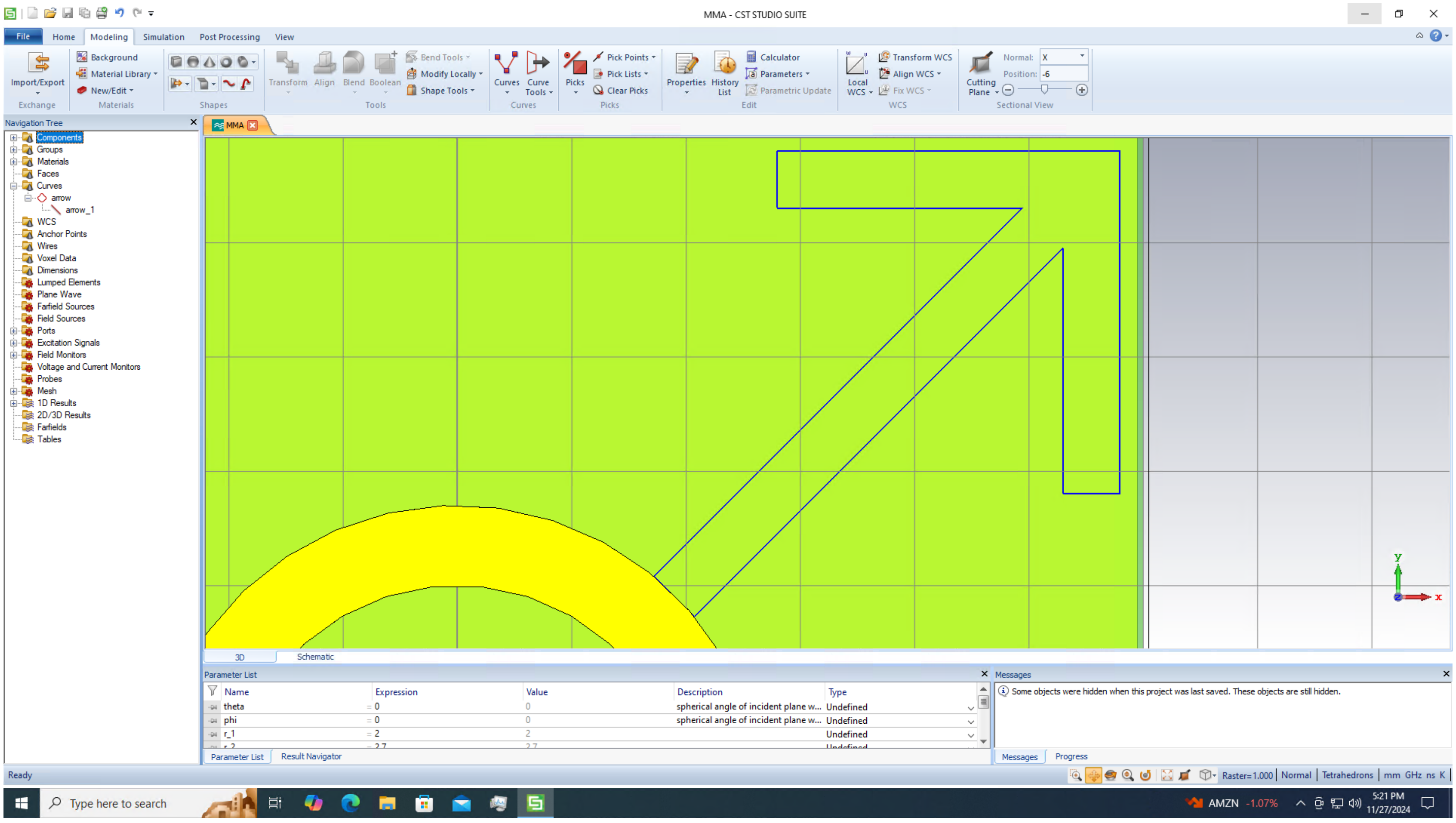

Figure 5: Correct Arrow Base

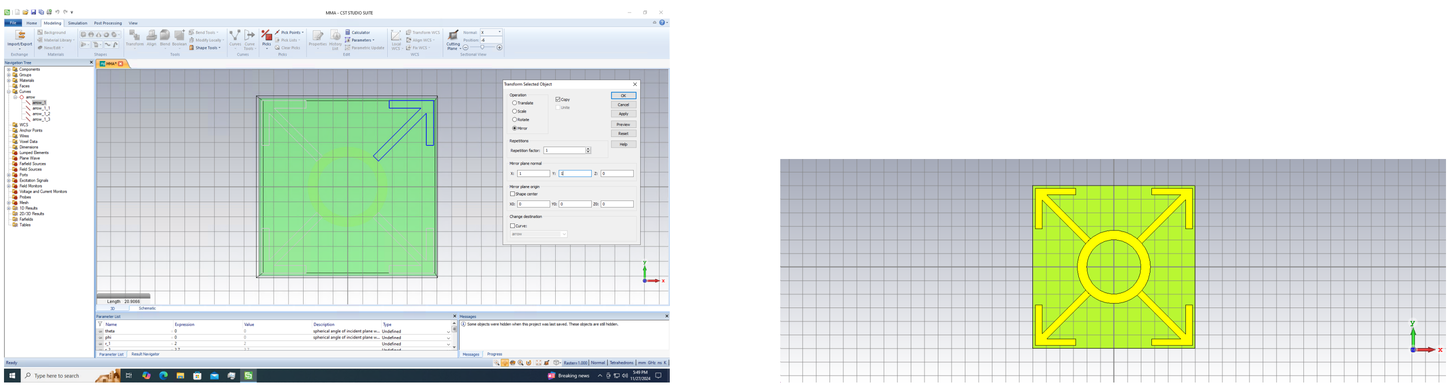

Figure 6: Mirroring Arrow and Cover

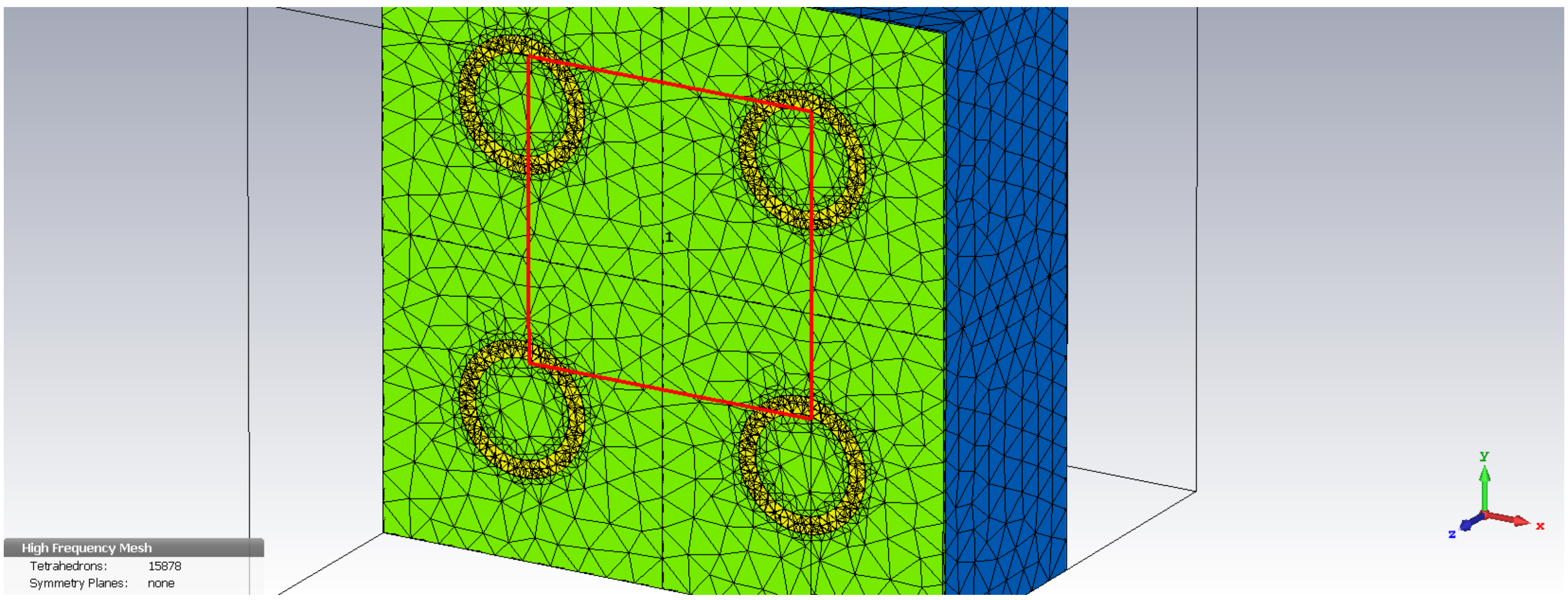

Figure 7: Ring Mesh for reference

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