Parametric Study of a Microwave Absorber Based on Metamaterials.

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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.**

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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

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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

As 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.

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.

In order to evaluate the absorption of the microwave metamaterial absorber proposed in this study [2] the reflection and transmission power shall be calculated as well as the reflection coefficient. The bare necessary equations are shown in (1).

$$Z = Z_0\sqrt{\frac{\mu_r}{\epsilon_r}} \tag{1a}$$

$$\Gamma = \frac{Z - Z_0}{Z + Z_0} \tag{1b}$$

$$T = \frac{2Z_0}{Z + Z_0} \tag{1c}$$

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

However the Impedance across the frequency range shall be normalized and in order to be calculated the impedance of each layer shall be factored in but thankfully this is done by CST.

III Simulation

The simulation has be created using the CST software in order to implement a configuration such as shown in [2].

III.I CST Implementation

The vertical layout implemented in CST consists of a three layer structure:

- 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).

At first the FR-4 substrate is placed without the metal resonance layer and then the two other layers - all below Z=0, turning on the orthographic side view the layout is as (1).

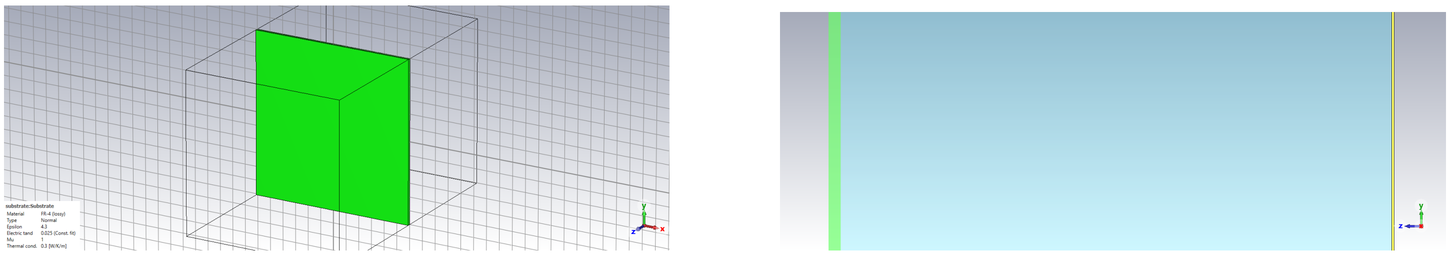


Figure 1: Basic Vertical Layout

Then the ring is added so that is of the same material and thickness as the backplate and lays on top of the dielectric substrate as shown in (2).

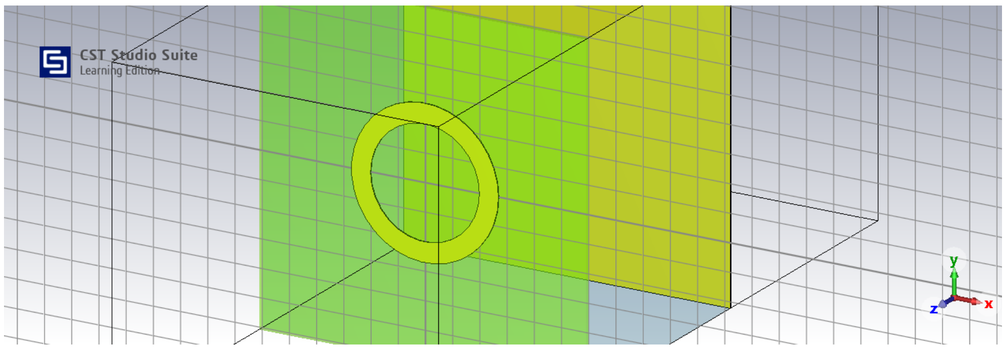


Figure 2: Ring Resonator

The assumption made is that both the arrow body and point are $\alpha = 0.5mm$ 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]);
```

Which as can be simplifies to the following equations 2.

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

where

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

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

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

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

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 3, which is why it was important to move all other layers below Z=0.

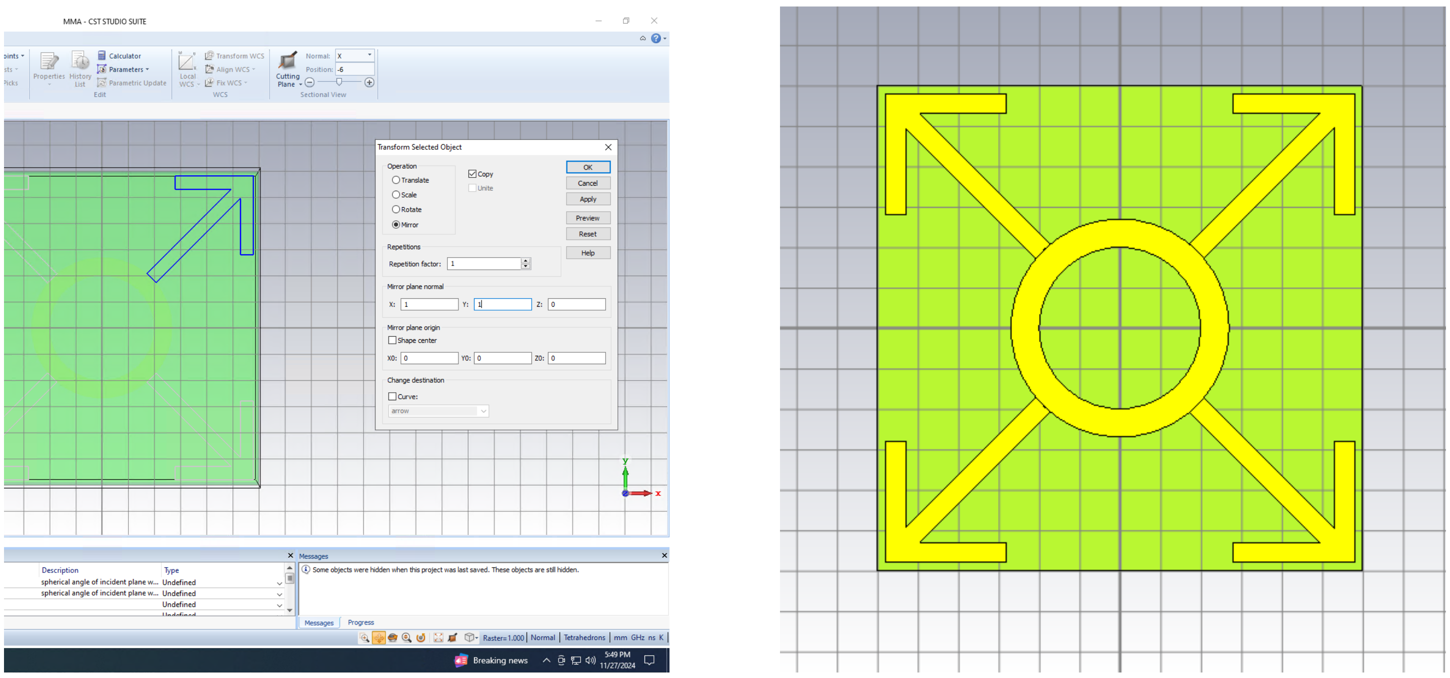


Figure 3: Mirroring Arrow and Cover

The following is a series of cuts in the resonance layer (boolean subtractions) in order to add the resistors between the copper faces near the arrows 4.

And have the same width for both near the arrows and for near the ring 5.

Then the resistors are added connecting to the center points of the faces created by the previous subtractions 6 (it is important to state that performance may be reduced in this implementation as better absorbance may be observed if the connection height is: $d = 0.035mm$).

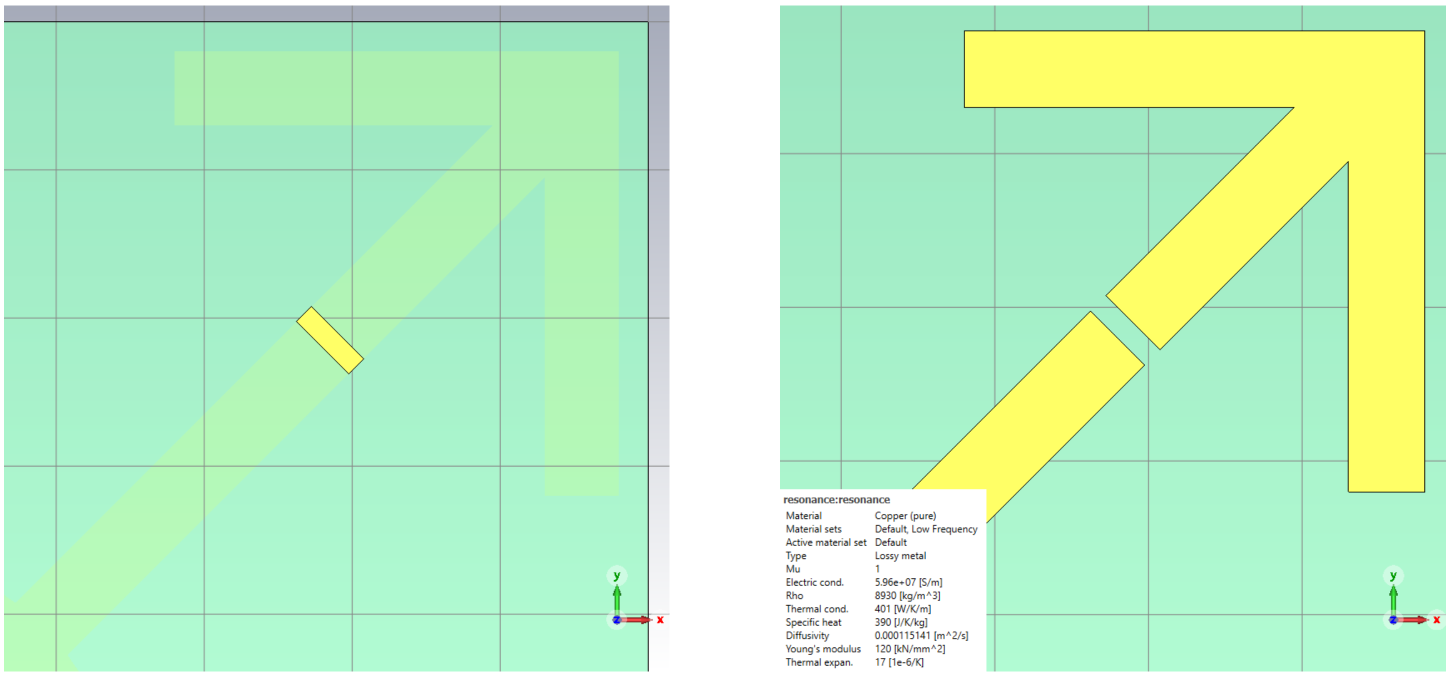


Figure 4: Cuts Near the Arrows

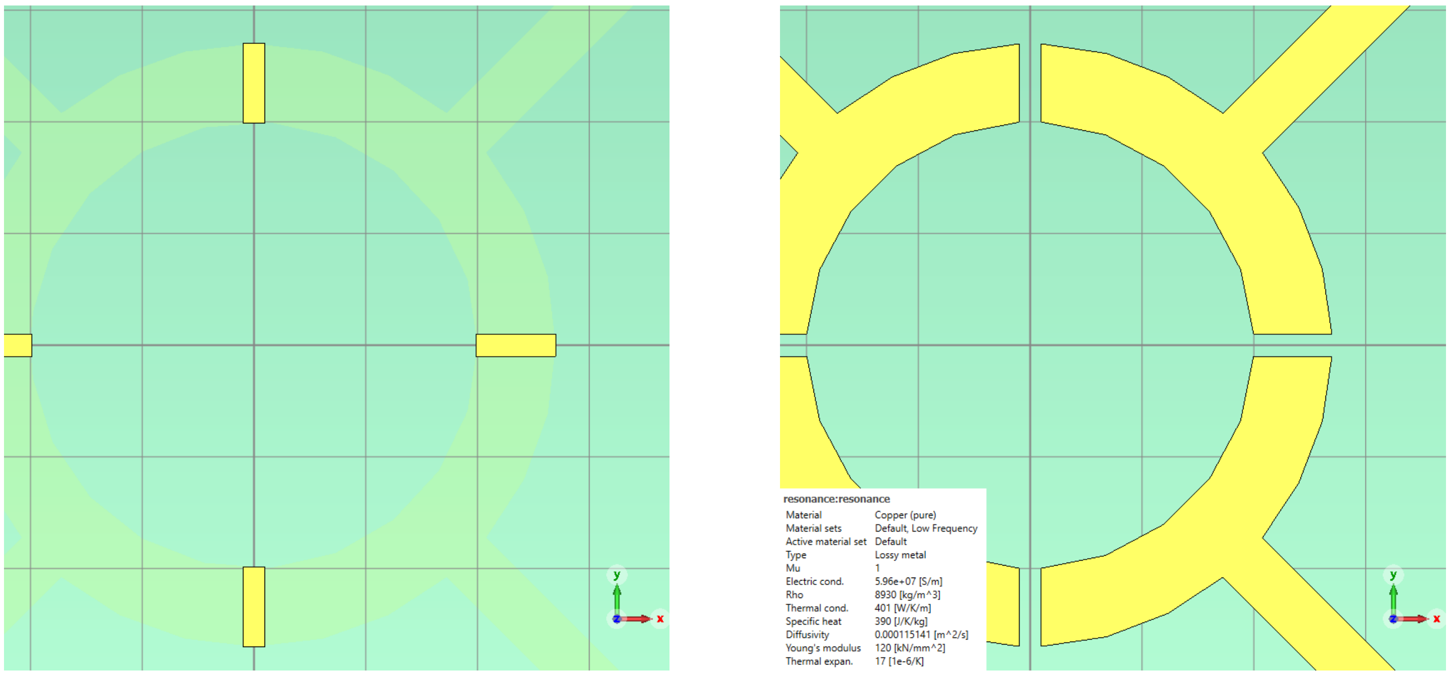


Figure 5: Cuts Near the Ring

Now to perform a simulation using the frequency solver in CST, the boundaries will be periodic along the XY plate free space conditions will be added along the Z axis. The Mesh that ends up being calculated is as 7.

In the figure for the Electrical field absorbance the surfaces can be observed for $Z_{max}1$ as in (8).

As well as for the $Z_{max}2$ the Electrical field can be observed as in (9).

Taking a look in the S_{11} of Z_{max} after the simulation as such (III.I). The Absorptivity (against the frequency) is an essential metric and CST calculates it as shown in (III.I). For the evaluation of the absorber Absorptivity can be calculated using the formula: $A = 1 - |S_{11}|^2 - |T|^2$, where T is the transmission coefficient and can be calculated using the formula: $T = \frac{2Z_0}{Z+Z_0}$. However the Z mentioned needs to be the normalized impedance of the absorber so this is where the calculation will start.

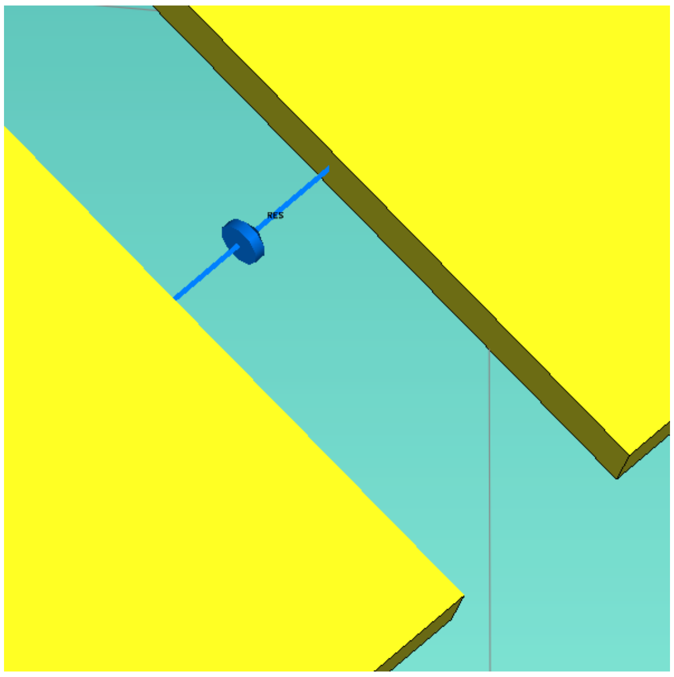


Figure 6: Resistor Placement

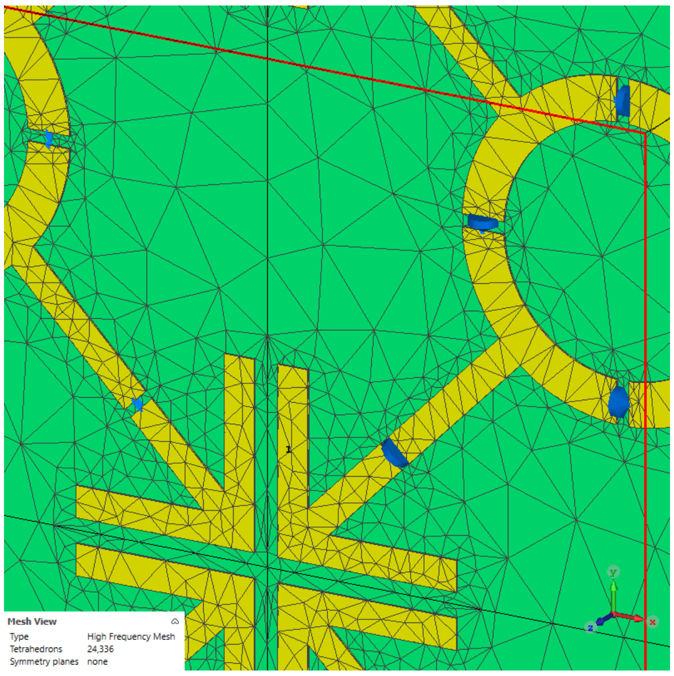
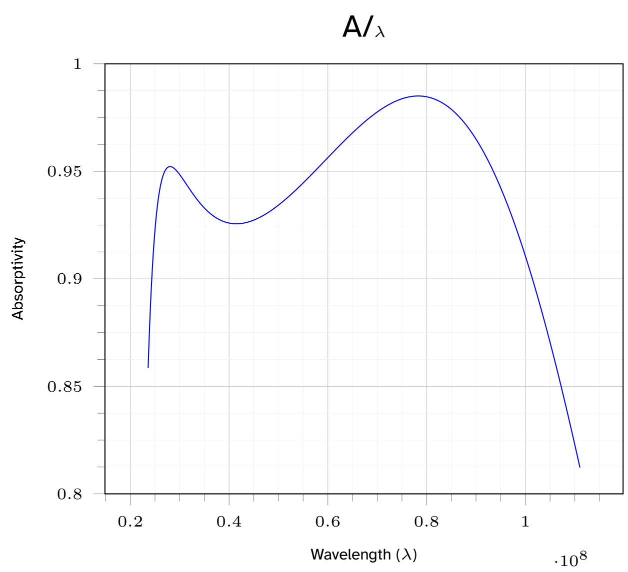


Figure 7: Ring Mesh for reference



The $\epsilon$and $\mu$are being extracted from the S_{11} and S_{12} parameters. and their imaginary parts are shown respectively 10.

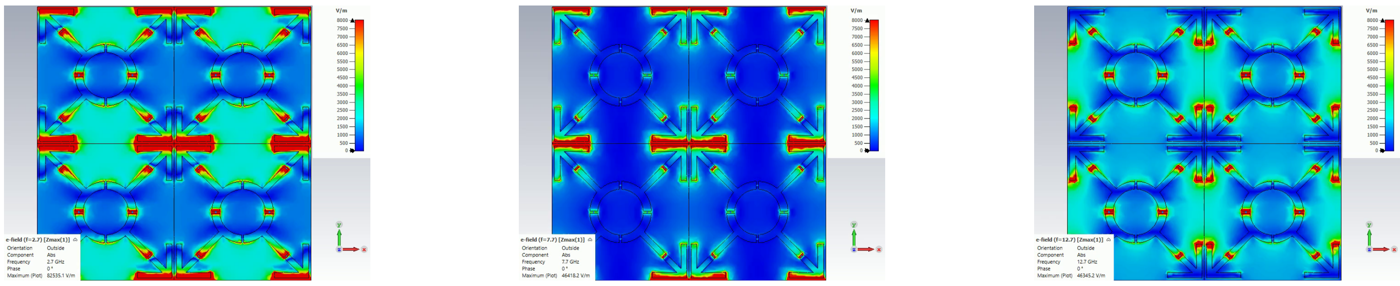


Figure 8: Electrical Field for [2.7, 7.7, 12.7] GHz $Z_{max}(1)$

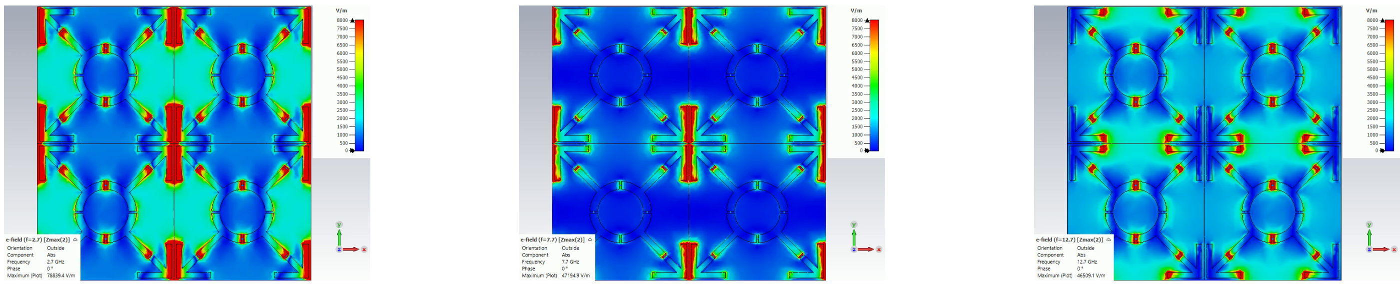


Figure 9: Electrical Field for [2.7, 7.7, 12.7] GHz $Z_{max}(2)$

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)

After having completed the simulation it is easy to extract the impedance of the absorber in order to try and implement the transmission line equivalent.

IV Optimization

For this step the IdeM package as well as matlab in order to tweak the parameters that describe dimensions...

V Discussion

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.

References

[1] V. G. Veselago and E. E. Narimanov, "The left hand of brightness: Past, present and future of negative index materials," *Nature Materials*, vol. 5, no. 10, pp. 759–762, Oct. 1, 2006, ISSN: 1476-1122, 1476-4660. DOI: 10.1038/nmat1746. [Online]. Available: https://www.nature.com/articles/nmat1746 (visited on 11/05/2024).

[2] Y. Zhang, W. Yang, X. Li, and G. Liu, "Design and analysis of a broadband microwave metamaterial absorber," *IEEE Photonics Journal*, vol. 15, no. 3, pp. 1–10, Jun. 2023, ISSN: 1943-0655, 1943-0647. DOI: 10.1109/JPHOT.2023.3277449. [Online]. Available: https://ieeexplore.ieee.org/document/10129034/ (visited on 11/05/2024).

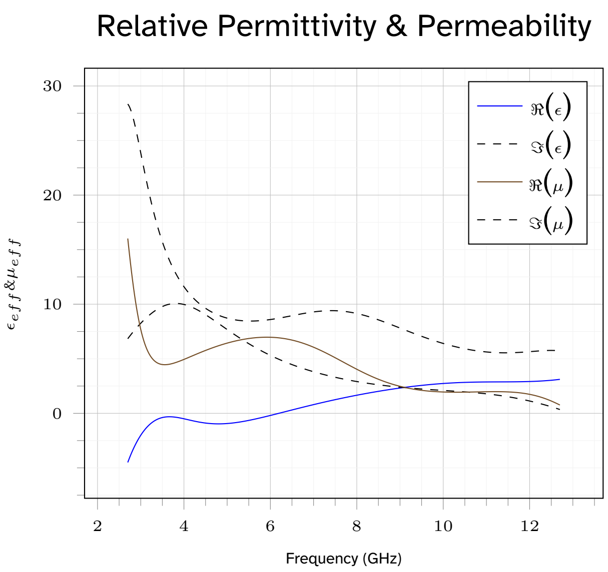


Figure 10: Effective $\epsilon\&\mu$