Parametric Study of a Microwave Absorber Based on Metamaterials.

Department of Electrical & Computer Engineering

University of Western Macedonia

Markos Delaportas *

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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

*E-mail: ece01316@uowm.gr

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.

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).

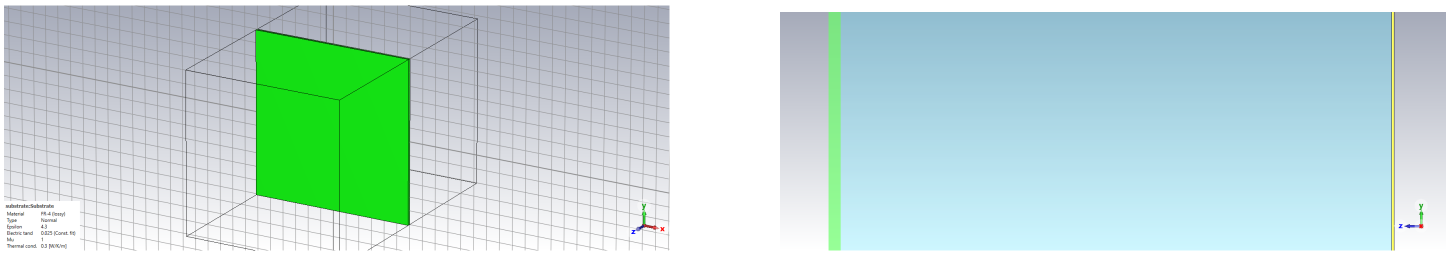

Figure 1: Basic Vertical Layout

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)

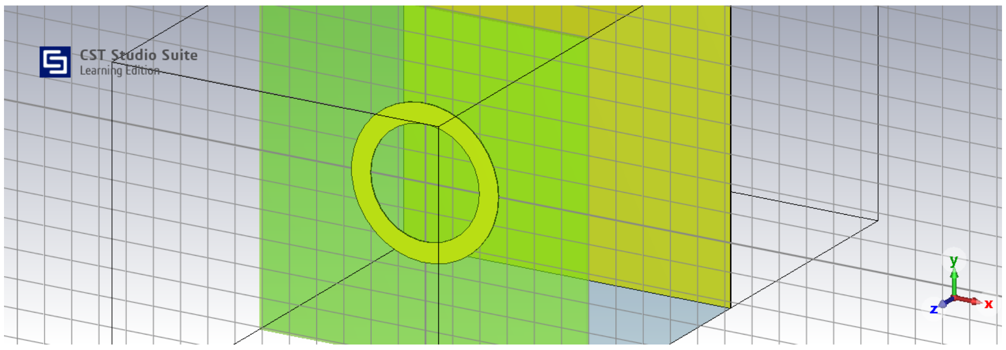

Figure 2: Ring Resonator

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]);
```

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

where

$$\sigma_1 = \sqrt{\frac{729}{200} - \frac{7\sqrt{59}}{80}} \tag{1}$$

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

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

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

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.

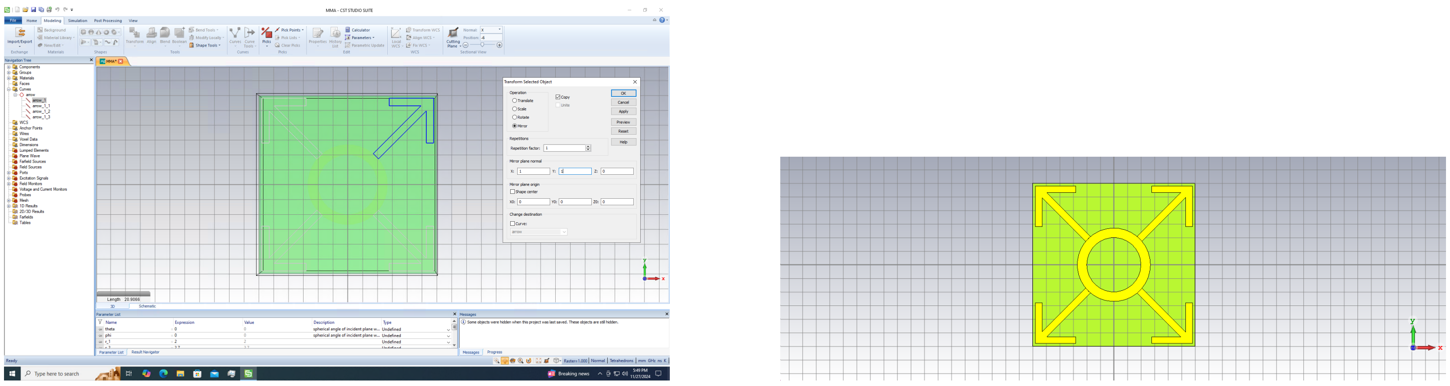

Figure 3: Mirroring Arrow and Cover

Now to perform a simulation using the frequency solver in CST, the boundaries will be periodic along the XY plate absorbing conditions will be added along the Z axis.

Now the Mesh that ends up including the arrows is as such:

Taking a look in the Electrical Field for $Z_{max}(1)$ after the simulation it behaves as such (5)

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)

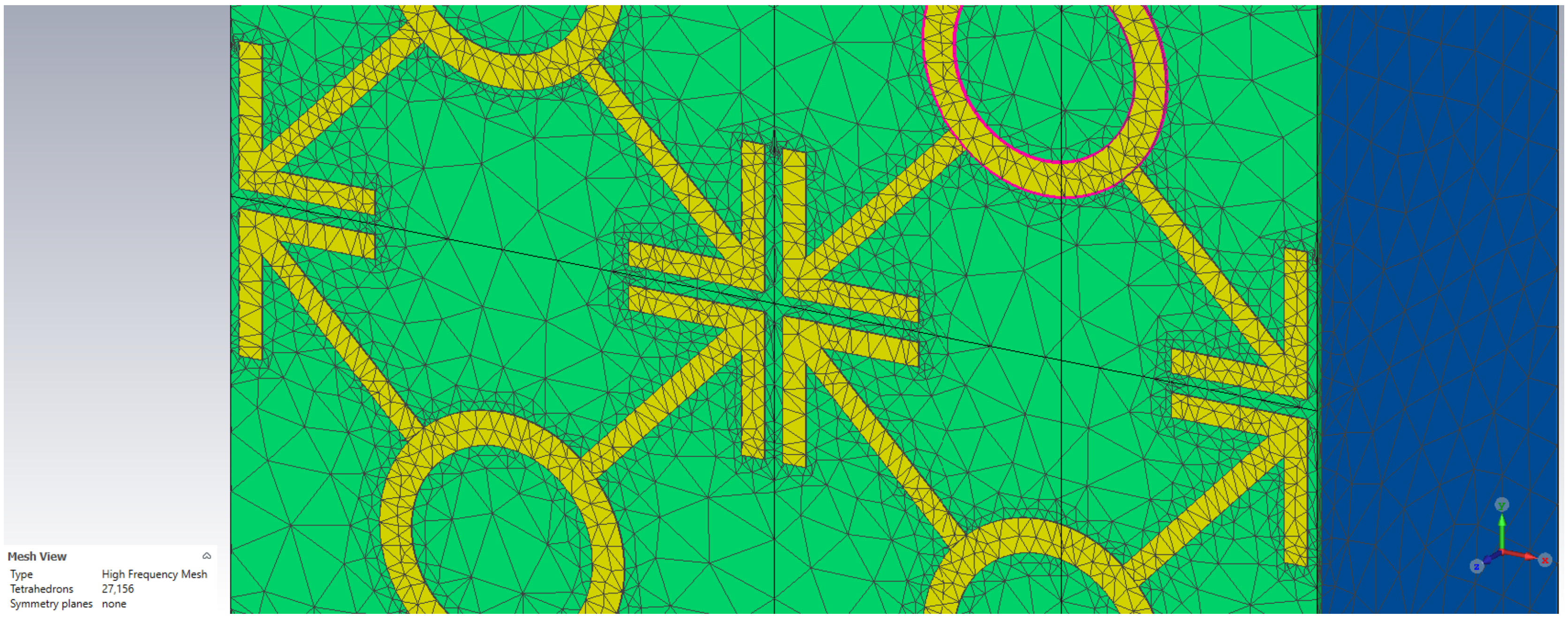

Figure 4: Ring Mesh for reference

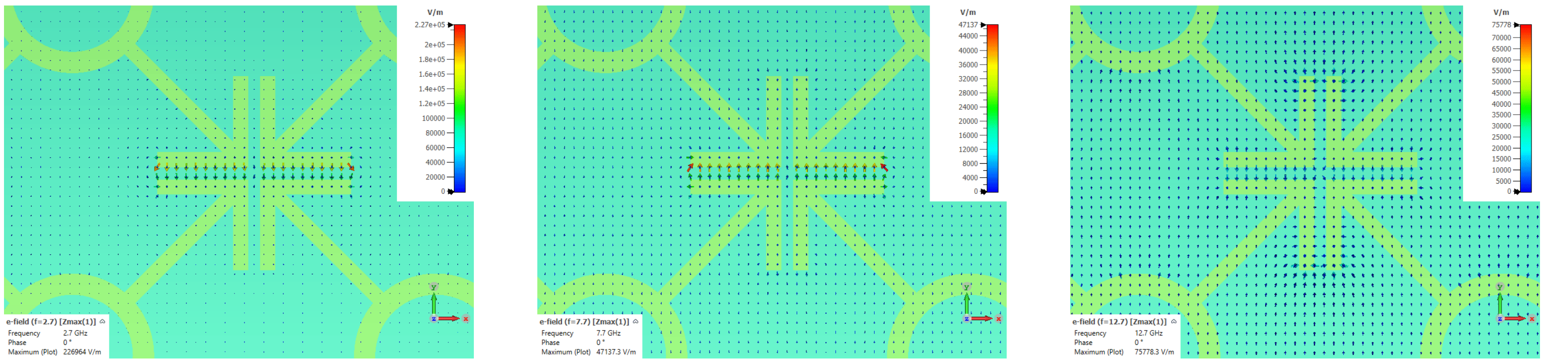

Figure 5: Electrical Field for [2.7, 7.7, 12.7] GHz $Z_{max}(1)$

IV Optimization

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).