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# Ultra-Thin, Broad-Bandwidth FSS-Based Metamaterial Absorber with High Absorption Efficiency

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## Abstract

In this paper, we present a frequency selective surface (FSS)-based metamaterial absorber characterized by minimal thickness and broad bandwidth. The structures, with a total thickness of just 2 mm, were fabricated on an F4B substrate. Each repeating unit measured 20 mm × 20 mm. This absorber demonstrated an impressive absorption bandwidth of 5 GHz, covering the frequency range from 9.1 GHz to 14.5 GHz when an electromagnetic wave was incident perpendicularly. Notably, the absorptions of the material remained consistently above 90%, with the peak absorption reaching 100%. Extensive simulations were conducted to optimize the structural design, ensuring maximum efficiency. To elucidate the absorption mechanism, electromagnetic parameters such as ε_eff (effective permittivity) and μ_eff (effective permeability) were plotted. Additionally, current distribution images of both the top and bottom layers were analyzed to provide further insights into the absorption behavior and validate the theoretical models. The optimization process involved fine-tuning various parameters to achieve the desired absorption characteristics across a wide frequency range. These simulations helped in understanding the interaction between the electromagnetic waves and the absorber's structure, leading to the observed high absorption rates. Finally, the structure's effectiveness in absorbing vertically incident electromagnetic waves was verified through experimental testing. The experimental results corroborated the simulation findings, demonstrating the absorber's robustness and reliability in practical applications. This verification process included detailed measurements and analysis, ensuring the absorber's performance met the anticipated standards. Overall, the combination of minimal thickness, large bandwidth, and high absorption efficiency makes this FSS-based metamaterial absorber a significant advancement in the field. Its potential applications span various domains, including electromagnetic interference (EMI) shielding, stealth technology, and other areas requiring efficient absorption of electromagnetic waves. The successful experimental validation further emphasizes the practical utility of this innovative design.

## Keywords

*FSS, Metamaterial, perfect absorber, GHz, EMI*

## 1. INTRODUCTION

Metamaterials (MTMs) are artificially structured materials with unique electromagnetic properties, consisting of periodic metallic and dielectric components [1-4]. These structures do not naturally occur and possess electromagnetic properties that are typically not found in nature. Consequently, metamaterials have a wide range of applications, including radar stealth, metamaterial antennas, energy harvesting, and sensors. Compared to traditional absorbers, such as bulky, fragile, and complex-to-manufacture multilayer absorbers, metamaterials offer advantages like thinness, light weight, and low cost. The impedance can be adjusted by altering the geometric dimensions of the periodically arranged metallic patterns [5-11].

Frequency selective surface (FSS) absorbers are a type of periodic structure with a series of periodic metallic structures on the top surface, spaced at certain intervals in the direction of the bottom surface and separated by a dielectric. At resonant frequencies, due to the impedance matching between the material and air, the reflection wave is reduced. Additionally, the transmitted wave is absorbed due to the dielectric loss of the medium. However, this structure has the drawback of a narrow absorption bandwidth [9-17]. To achieve broader absorption bands, dual-band and multi-band MTM absorbers have been developed. Researchers have also attempted to use multilayer structures to achieve greater bandwidth, with each layer having a periodic metallic structure corresponding to an absorption band, thereby extending the bandwidth [15,18-23]. Although this structure can increase the bandwidth, the thickness of the absorber is significantly increased due to the use of multilayers. Some studies have aimed to design single-layer absorbers, with metal resonant-type metamaterial absorbers consisting of multiple resonant units [7,9,12,24]. By adjusting the size and structure of different resonant units, different resonant peaks can be controlled. To achieve broadband absorption, different resonant units can be designed to achieve the superposition of adjacent resonant peaks at different adjacent frequency points. Many FSS absorbing metamaterials have evolved from the Salisbury screen by adding resistive sheets to the periodic metallic structures of the absorber. While this structure offers the advantage of a large absorption bandwidth, it often has a relatively large thickness and involves complex manufacturing processes[25,26].

In this paper, we propose a frequency selective surface-based absorbing material that offers the benefits of large bandwidth and thin thickness. The metamaterial properties of the structure are illustrated by plotting the real and imaginary parts of the electromagnetic parameters (ε_eff and μ_eff) and current distribution diagrams. Finally, a sample was prepared for experimental verification.

## 2.DESIGN AND METHODS

For microwave metamaterial absorbers based on frequency selective surfaces (FSS), the absorption bandwidth generated by a single resonant frequency band is very small. To achieve a large bandwidth, it is necessary to obtain as many resonant frequency bands as possible and connect these bands together to form a wide absorption band. [18] designed an FSS-based metamaterial with a large absorption bandwidth by summarizing part of the design rules for folded structures. However, to achieve a large bandwidth, the unit shape became quite complex, significantly increasing the adjustment workload. To achieve a wide absorption bandwidth while simplifying the unit structure, this paper further explores design principles, ultimately creating a metamaterial absorber with a simple structure and large bandwidth.

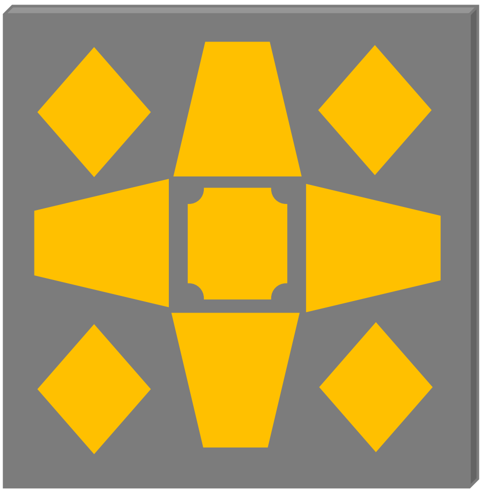

Fig. 1 Unit cell

The cross-sectional view of the metamaterial structure is shown in Figure 1. This absorber consists of three layers. The first layer is a periodic unit made of copper with a conductivity of σ=5.8×10^7 S/m and a thickness of 0.035mm. The second layer is a dielectric layer made of FR4, with a dielectric constant of 4, a loss tangent of

0.002, and a thickness of 2.5 mm. The third layer is a copper layer with a thickness of 0.035mm. Figure 1 shows the detailed dimensions of the periodic unit.

The simulation setup is shown in Figure 2. The front, back, left, and right surfaces of the cube are set as periodic boundary conditions to simulate an infinite plane. Electromagnetic waves are emitted from port 1, and port 2 is used to calculate S21. Air is present between the ports and the metamaterial absorber. The metal is simulated using perfect electric conductor conditions. In this setup, the absorber is considered a homogeneous medium. To obtain more accurate normalized impedance values and minimize the influence of the air layer on the calculation results, port 1 is placed as close as possible to the top surface of the absorber (set at a distance of 0.5 mm in this study). Note that the distance shown in the figure is greater than 0.5 mm for illustrative purposes. Similarly, port 2 is placed as close as possible to the bottom surface of the absorber (also set at a distance of 0.5 mm, with the figure showing a greater distance for clarity).

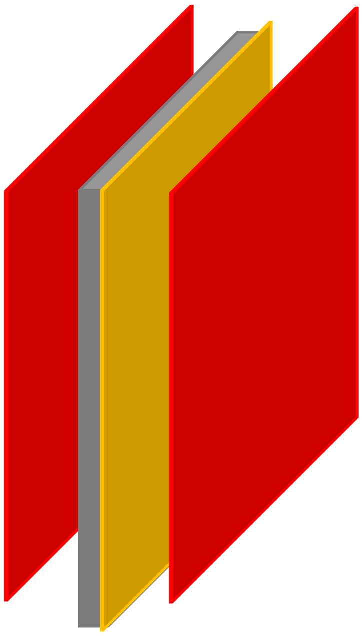

Fig. 2 Left red port 1, right red port 2

When the electromagnetic wave is incident perpendicularly, the simulation results are shown in Figure 3. The structure of the absorbing metamaterial generates three absorption bands, with absorption rates over 90% in the frequency ranges of 9.1 -14.5 GHz, around an overall bandwidth of 5.4GHz. The figure indicates absorption peaks within these bands. The absorption rates for the frequencies exceed 99.98%. The shape of the double-bent structure is relatively simple, requiring fewer adjustments while achieving a large bandwidth.

The absorption coefficient A(ω) is calculated as follows[1,3,26-29]:

$$A(\omega)=1-|S_{11}|^2-|S_{21}|^2$$

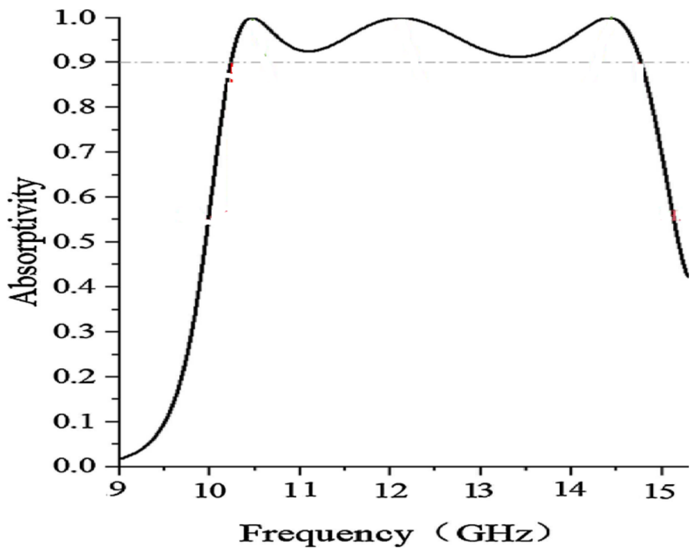


Fig. 3 absorbance rate

## 3. CONCLUSION

This study introduces a frequency selective surface (FSS)-based metamaterial absorber with minimal thickness and broad bandwidth. The absorber, composed of periodic metallic and dielectric structures, showcased an impressive absorption bandwidth, effectively covering the frequency range of 9 GHz to 15 GHz, with absorption rates consistently above 90% and peaking at 100%. Extensive simulations optimized the design, illustrated by electromagnetic parameters (ε_eff and μ_eff) and current distribution diagrams, and confirmed through experimental verification.

By connecting multiple resonant frequency bands, the study achieved a wide bandwidth while maintaining a simplified single-layer structure. The simulation setup demonstrated three significant absorption bands, with five peaks mostly exceeding 99.98%. The double-bent structure's simplicity allowed for easy adjustments and large bandwidth. Overall, this FSS-based metamaterial absorber represents a significant advancement in microwave absorption technology, offering a thin, lightweight, and cost-effective solution for applications like EMI shielding and stealth technology.

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