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Single Layer Wide Angle Microwave Absorber for X band Application with Bandwidth Enhancement

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Abstract: Designing wide bandwidth absorption with smaller thickness has become a challenge when designing microwave absorbers. Therefore, in this paper, a single-layer wide-angle microwave absorber for X-band application with bandwidth enhancement is presented. The microwave absorber is made up of three layers, a top layer with a double-ring resonator, a substrate layer of FR4 and a ground copper layer. In this study, the design and the analysis have been done using CST Microwave Studio on the substrate design and the parameter of the ring resonator. From the result, the designed microwave absorber is able to absorb more than 90% absorption rate from 8.344 GHz to 12.304 GHz. The microwave absorber produces dual peak absorption of 99.64% (8.831 GHz) and 99.79% (11.528 GHz) with a Full-Width Half-Maximum (FWHM) bandwidth of 60.88% ranging from 7.616 GHz to 13.704 GHz. Moreover, the microwave absorber is able to have a wide incidence angle of up to 60° for TE and TM modes. Therefore, from the result, it can be concluded that the designed microwave absorber can be applied to the X-band region.

Keywords: Single Layer Microwave Absorber, Wide Angle, X Band

1. Introduction

An absorber, from a functional standpoint, is a filter that can absorb incident electromagnetic (EM) waves in any frequency band [1]. A microwave absorber is therefore defined as an absorber that absorbs electromagnetic waves at microwave frequencies. Because microwave absorbers are widely used in stealth technology, EM interference, and other fields, there has been tremendous progress in their design. The aims of constructing a microwave absorber are for the absorber to be thin (lightweight), have a high absorption rate, and absorb over a wide bandwidth. However, creating an absorber with high absorption and a wide bandwidth has proven difficult for the researcher.

To that end, metamaterials have become frequently utilized in the construction of microwave absorbers. A metamaterial is a form of absorber based on the frequency selective surface (FSS) that

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Corresponding author: elfa@uthm.edu.my consists of periodic structural elements and is referred to by several terms such as FSS, Metamaterial, or Metasurface [2]. A metamaterial is employed because it offers benefits over natural materials such as a negative refractive index, an inverse Doppler effect, and so on [3]. Furthermore, when compared to typical radar absorbent materials (RAM), metamaterials have a thin thickness, a high absorption rate, and a flexible design [4].

Several approaches have been used in the past to construct microwave absorbers, such as employing a lumped element [5], a resonator [6], or a double structure design [7]. In [8], a microwave absorber was designed with a twofold structure to create double resonance and a 90% absorption bandwidth from 1.23 GHz to 19 GHz. In [9], a crossed-loop resonator and a lumped resistor are utilized to lower the radar cross section (RCS) at 9.5 GHz. In [10], a double circular ring with a resistor and an air gap between the dielectric layers is utilized to increase the absorber's bandwidth absorption. The absorber is capable of more than 90% absorption over a wide bandwidth ranging from 6.7 GHz to 20.58 GHz. Using a split ring resonator, [11] created a single-layer microwave absorber for the Ku and K bands. With a core frequency of 19.8 GHz, the absorber can absorb more than 98% absorptivity.

The complementary split ring resonator [12] construction was employed in this study to design a microwave absorber for X band application. The dielectric layer was built with a single layer of Flame Resistant 4 (FR4) because it is cheap cost, easy to make, and has high dimensional stability compared to typical microwave material [13]. The top structure is made up of a double-ring resonator, which has been shown to enable wide bandwidth absorption. The structure was intended for the X band, with a bandwidth of 3.96 GHz and more than 90% absorptivity. Furthermore, the microwave absorber has been examined for various broad incidence angles as well as various polarization under normal incidence angles. The simulation result indicates that the design is well-suited for the X-band application.

2. Principle and Design

In this section, the design of the single-layer microwave absorber along with the theoretical principle of an absorber is discussed.

2.1 Theory

The microwave absorber idea principle is defined as the absorber's impedance matched to the impedance of empty space. Eq. 1 may be used to compute the free space impedance, where Z_o is the free space impedance, is the electric permittivity (ε), and is the magnetic permeability (μ).

$$Zo = \sqrt{\frac{\mu}{\varepsilon}} \qquad Eq. 1$$

From Eq. 1, the parameters of the microwave absorber may be designed by tweaking the μ and ε of the material to meet the free space impedance (Z_o), which is commonly 120 πΩ or 377Ω. The absorber's absorption is computed using Eq. 2:

$$A = 1 - S11^2 - S21^2 \quad Eq. 2$$

Where A is the absorption rate, S_{11} is the reflectance coefficient and S_{21} is the transmittance coefficient of the absorber. Since the ground is made up of copper, the transmittance coefficient of the absorber is considered to be zero and therefore, the absorption can be calculated using Eq. 3.

$$A = 1 - S11^2 \quad Eq. 3$$

2.2 Design

Figure 1 depicts the suggested microwave absorber architecture. The proposed microwave absorber is made up of three layers: the ground layer, the dielectric layer, and the top layer and Figure 2 depicts the design of the double-ring resonator. The microwave absorber is built on a 2 mm dielectric FR-4 substrate with an overall size of 7 mm X 7 mm. The top layer consists of a double circular ring resonator having an outer ring, s_{outer} = 3 mm, inner ring, s_{inner} = 1.5mm, ring radius, r = 1mm, split gap, g = 0.8 mm and the ring angle, $\theta = 45°$. Both top and bottom layer are made from copper having conductivity, $\sigma = 5.8×107$ S/m with a thickness of 0.035 mm.

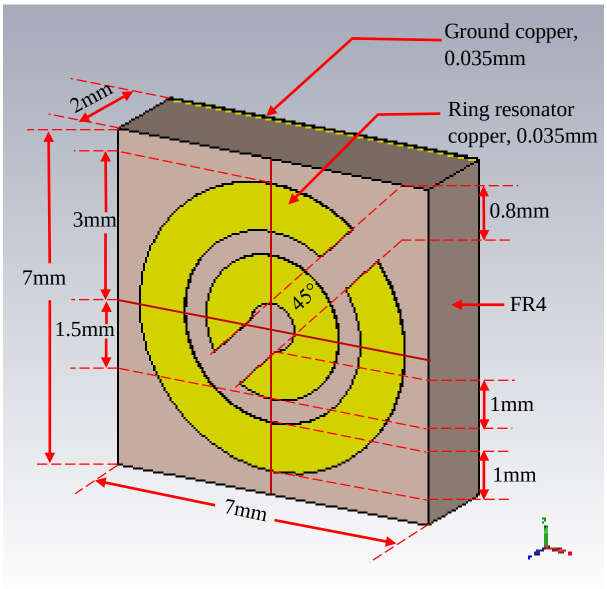


Figure 1: Schematic 3D view of the ring

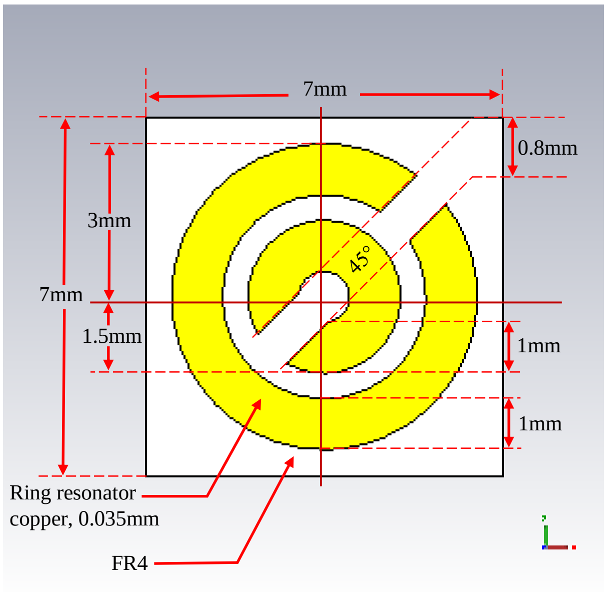


Figure 2: Dimension for the ring resonator design

Since the ring resonator is the main structure for the design, a previous study from [11] shows that a closed ring resonator is not suitable as it produced a low absorption mechanism. Therefore, a gap with an angle is proposed to maximize the absorption mechanism of the absorber as shown in Figure 3.

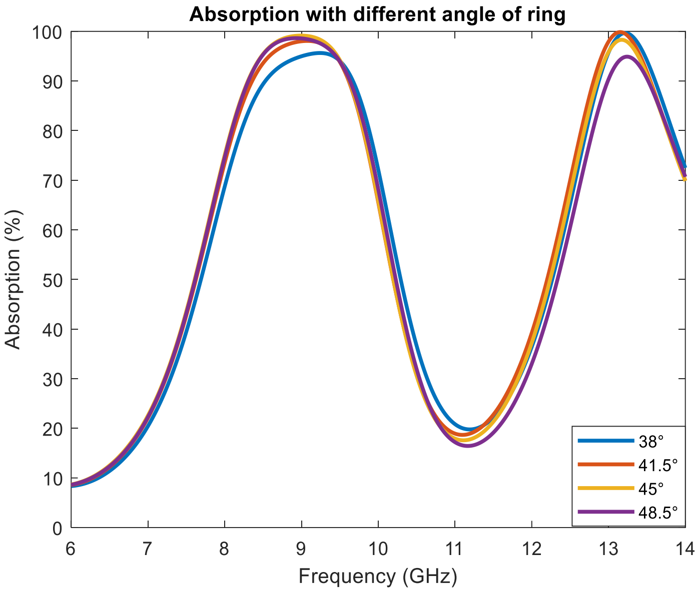


Figure 3: Performance of the designed absorber with a different angle

Moreover, the design to incorporate the double-ring resonator is due to the absorption characteristics of the absorber when designing using a single resonator. Figure 4 shows that when using a double ring resonator, the bigger ring size contributes to the absorption for the intended frequencies (8 – 12 GHz), however, it is slightly prone towards frequency above 12 GHz, while the small ring size shows that it has more ability to absorb at a higher frequency. By combining both ring sizes, only then the absorption mechanism covers the intended region.

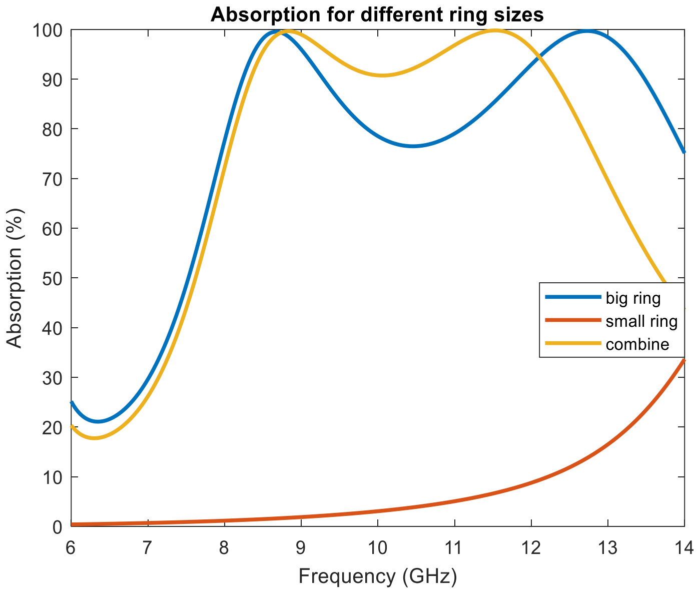


Figure 4: Performance of the designed absorber with a different angle

3. Results and Discussion

The results of modeling the ring resonator settings with CST Microwave Studio are reported in this part based on the absorber's absorption rate and bandwidth absorption. The outcome includes the microwave absorber's performance under normal incidence, varied polarizations, and incidence angles, as well as the microwave absorber's absorption method.

3.1 Performance of the microwave absorber

Figure 5 shows the result of the optimized microwave absorber under normal incidence. From the results, it can be seen that the microwave absorber can absorb more than 90% absorptivity between 8.344 GHz and 12.304 GHz. With a Full-Width Half-Maximum (FWHM) bandwidth of 60.88% (7.616 – 13.704 GHz), the absorber achieves dual peak absorption of 99.64% (8.831 GHz) and 99.79% (11.528). GHz).

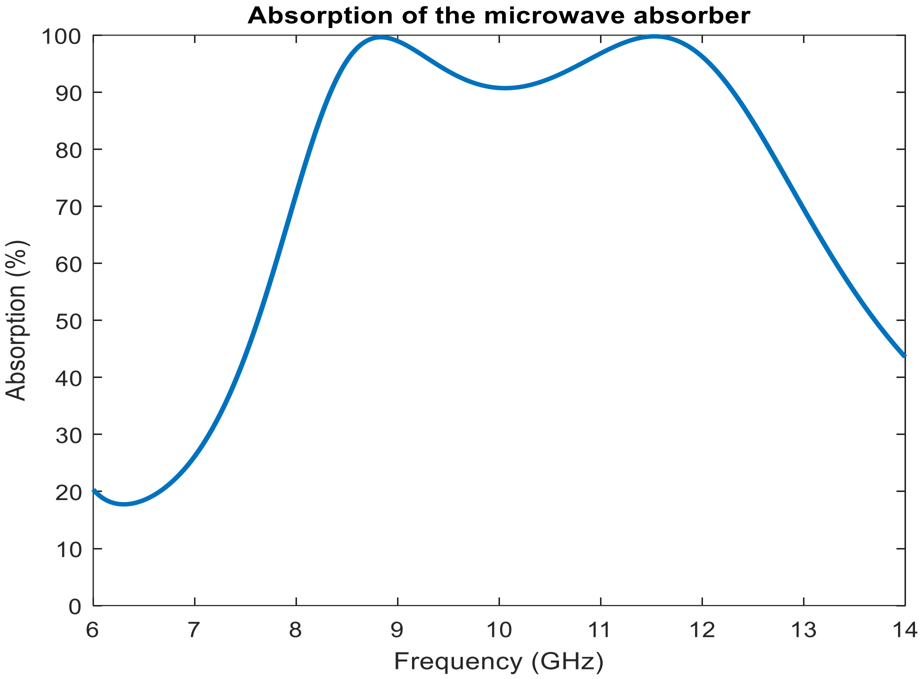


Figure 5: Performance of the designed absorber simulated using CST Microwave Studio

Then, the simulation of the microwave absorber is then evaluated to see how it performs under varied incidence (θ) and polarization (ϕ) angles. Figure 6 shows the variation of polarization angle from 0° to 90° in TE mode and Figure 7 shows the variation of polarization in TM mode. According to both results, when the angle is varied from 0° to 45°, the absorptivity decreases (90% - 20%) and begins to increase when the angle is varied beyond 45° to 90°. (20% - 90%). The corresponding result also shows that the absorption is identical for the polarized angle e.g., 0° = 90°, 15° = 75°, and so on which explains the overlapped in the absorption result. After finishing the polarization angle analysis, the simulation proceeded by varying the incidence angle from 0° to 60° in TE and TM modes. Figure 8 shows the result of different incidence angles in TE mode and Figure 9 shows the result in TM mode. Both results show that as the incidence angle increased, the absorptivity dropped. Furthermore, when the incidence angle increases, the bandwidth absorption decreases. Figure 8 shows that in TE mode, the absorber can retain 29.82% of the complete bandwidth at a 60° incidence angle and 80% absorptivity, whereas in TM mode, the absorber can maintain 85.79% of the whole bandwidth at 60° incidence angle and 80% absorptivity.

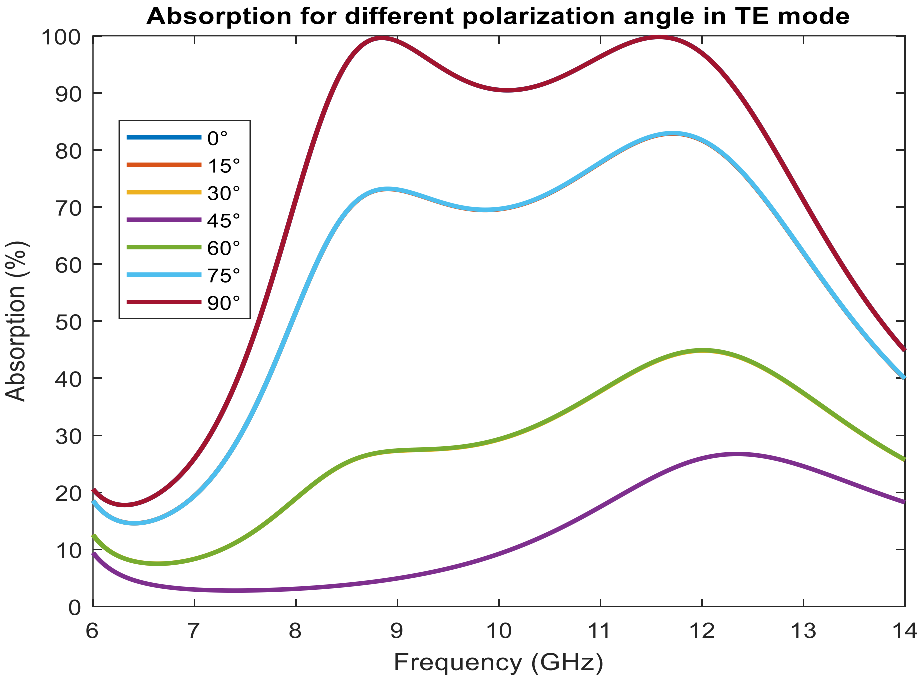


Figure 6: Performance for different polarization angle in TE mode

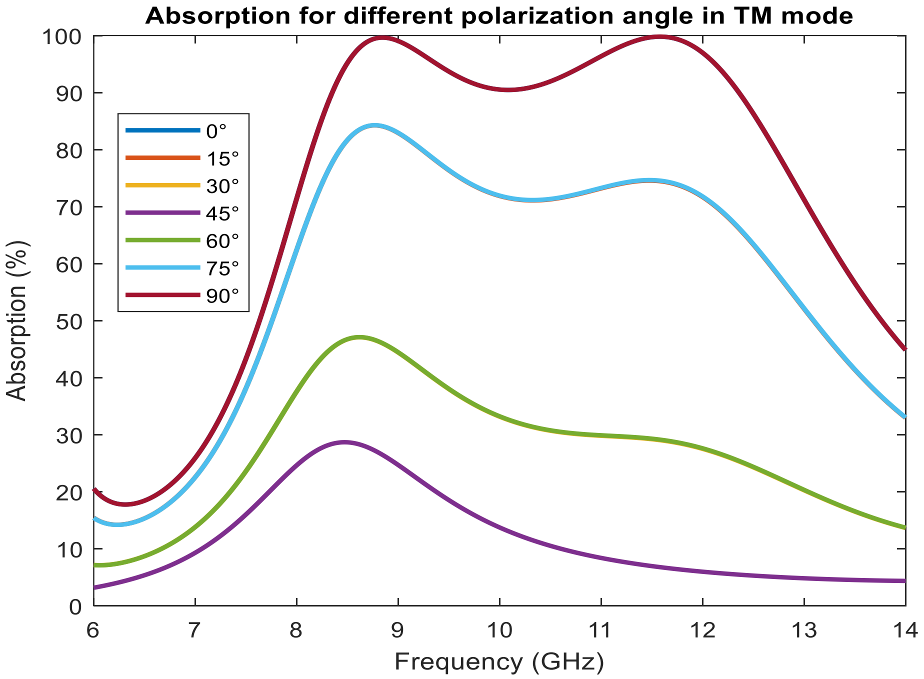


Figure 7: Performance for different polarization angle in TM mode

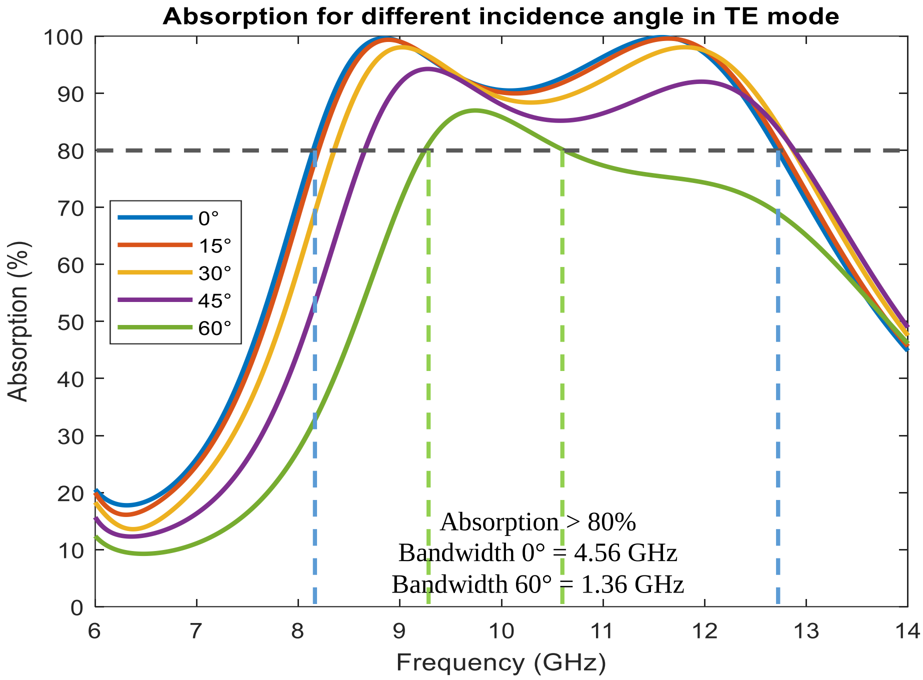


Figure 8: Performance for different incidence angle in TE mode

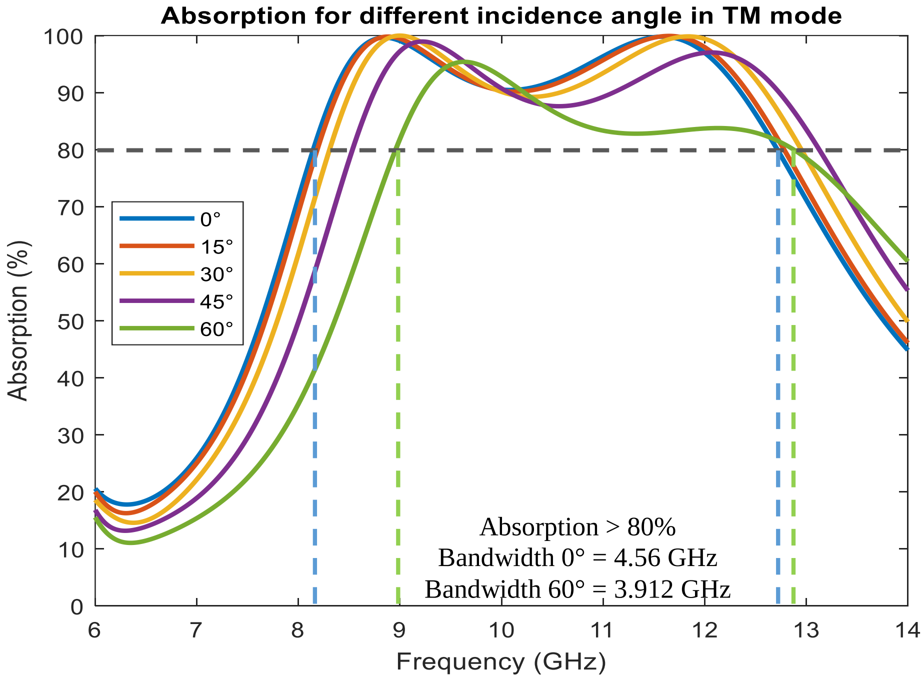
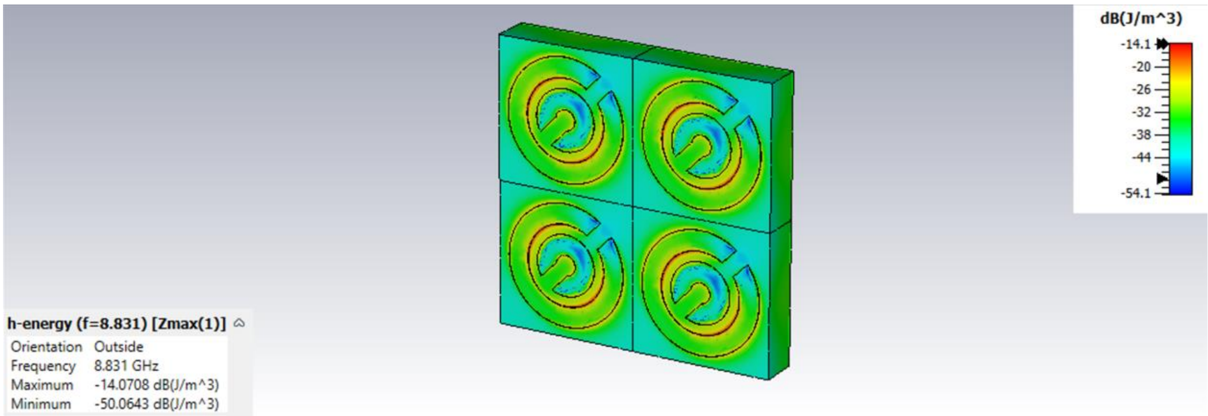


Figure 9: Performance for different incidence angles in TM mode

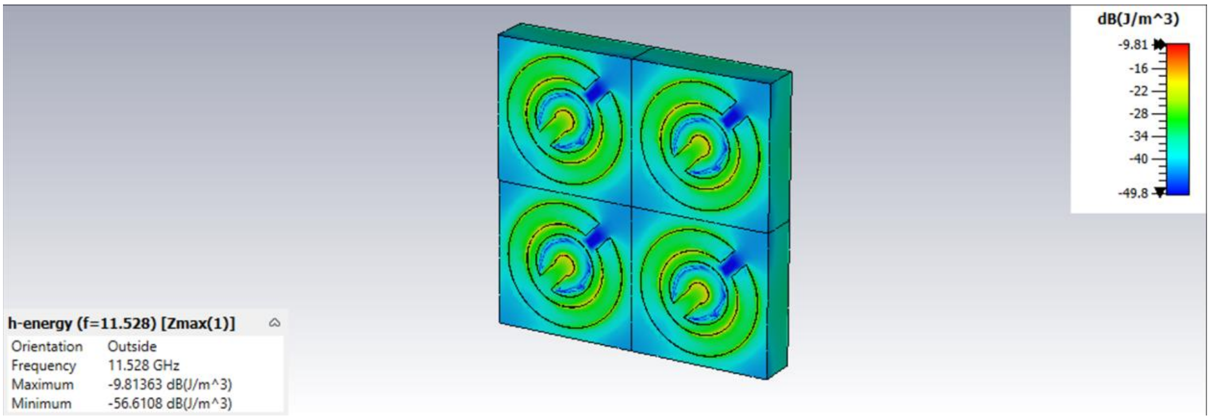
3.2 Absorption mechanism

The absorption mechanism of the absorber is analyzed after assessing the performance of the microwave absorber under normal incidence and varying polarization and incidence angle. This allows us to better understand the performance absorption in a magnetic field and surface current distribution. The simulation was tested on two peak absorption frequencies, 8.831 GHz and 11.528 GHz, as illustrated in Figures 8 and 9, respectively. Figure 10 shows that the outer ring is the largest contributor to the absorption at 8.831 GHz. Figure 11 shows that the inner ring is the dominant contributor to the magnetic field around it for absorption at 11.528 GHz.



h-energy (f=8.831) [Zmax(1)]
Orientation Outside
Frequency 8.831 GHz
Maximum -14.0708 dB(J/m^3)
Minimum -50.0643 dB(J/m^3)

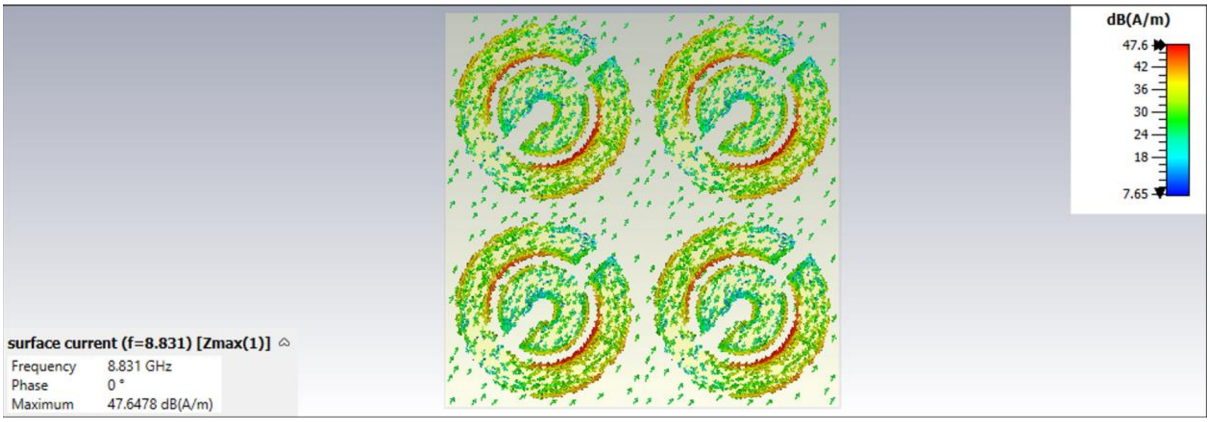
Figure 10: Magnetic field at 8.831 GHz



h-energy (f=11.528) [Zmax(1)]
Orientation Outside
Frequency 11.528 GHz
Maximum -9.81363 dB(J/m^3)
Minimum -56.6108 dB(J/m^3)

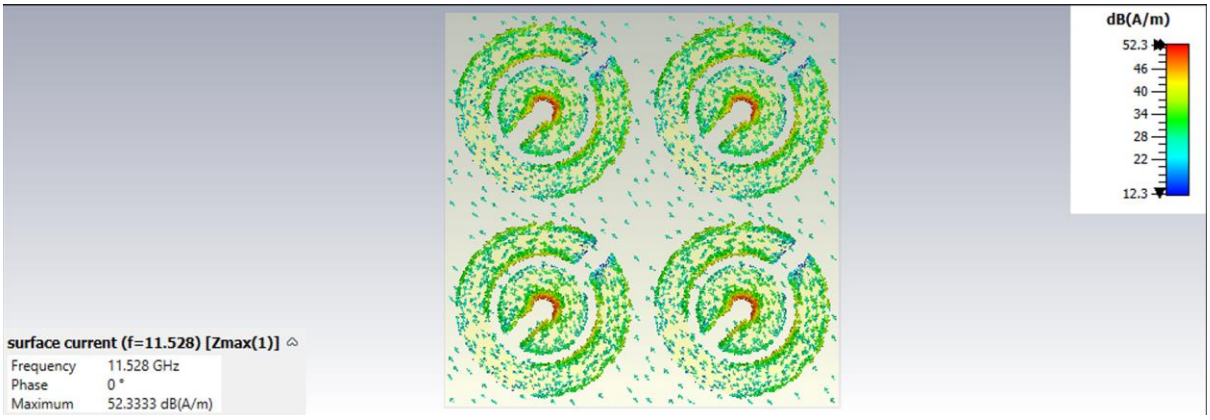
Figure 11: Magnetic field at 11.528 GHz

After assessing the magnetic field, the surface current distribution is examined for the two absorption peaks, 8.831 GHz and 11.528 GHz, as shown in the figure below. Figure 12 indicates that the surface current is mostly distributed on the outer ring of the ring resonator for the 8.831 GHz absorption, whereas Figure 13 shows that the surface current is primarily distributed on the inner ring of the ring resonator for the 11.528 GHz absorption. As a consequence of the magnetic field and surface current results, high absorption is obtained due to the strong resonance between the surface current and the magnetic field on the ring resonator.



surface current (f=8.831) [Zmax(1)]
Frequency 8.831 GHz
Phase 0 °
Maximum 47.6478 dB(A/m)

Figure 12: Surface current on 8.831 GHz



surface current (f=11.528) [Zmax(1)]

Frequency 11.528 GHz

Phase 0 °

Maximum 52.3333 dB(A/m)

Figure 13: Surface current on 11.528 GHz

4. Conclusion

A single layer wide angle microwave absorber for X band application was constructed utilizing a double-ring resonator and simulated using CST Microwave Studio. According to the modeling findings, the microwave absorber can absorb more than 90% absorptivity from 8.344 GHz to 12.304 GHz, with a dual peak absorption of 99.64% (8.831 GHz) and 99.79% (11.528 GHz). The absorber's Full-Width Half-Maximum (FWHM) is 60.88% (7.616 – 13.704 GHz), which satisfied the project because it covers the whole X band area. The absorber's capabilities under varied incidence and polarization angles have also been tested, and the results suggest that the absorber can absorb a wide incidence angle of up to 60°. Table 1 shows a comparison of the suggested structure to existing studies. It is apparent that the suggested structure's FWHM bandwidth has been greatly expanded compared to [9], [11], and [15]. Although the absorber in [14] has a wider FWHM bandwidth than the designed absorber, the cell size and thickness of the substrate are larger, and the incidence angle is lower. As a result, it can be inferred that the proposed absorber is well-suited for use in the X-band area.

Table 1: Comparison with previous research

Absorber	Cell size (mm)	Substrate thickness (mm)	Maximum absorption (%)	FWHM (%)	Incidence angle
[9]	7.6	3.2	>80	48.78	60°
[14]	9.0	3.2	99.9	81.85	45°
[15]	7.2	1.0	96	11.9	45°
This work	**7.0**	**2.0**	**99.79**	**60.88**	**60°**

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