Absorbency Spectrum of Dual Band Metamaterial Absorber

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Abstract
This paper study on the absorbency of dual band metamaterial absorber. The metamaterial absorber is designed based on a rectangular shaped for the patch layer and full ground plane plated as a ground layer. Both layers are used Perfect Electromagnetic Conductor (PEC) with 0.0.35 mm. Meanwhile, TLY-5 material is used as a substrate which is stacked in between the patch and ground. The thickness of the TLY-5 substrate is chosen to be 0.018λ to the respect of the lower resonant frequency. Initially, the rectangular patch is designed horizontally, then being rotated anti-clockwise from 0° to 90° to study the change of the absorbency. Thus, to study the harmonic frequency in order to developed the dual band metamaterial absorber while maintained the perfect absorbency for each band. Maximum absorbency is achieved as the rectangular patch is rotated at 45o. Dual band metamaterial absorber is developed which are resonated at 2.50 GHz with 99.92% absorbency and 4.97 GHz with 99.95% absorbency. Then, the Q-factor of the dual band metamaterial absorbed is evaluated to study the relationship between the substrate's thickness against the bandwidth at each resonant peak. These features have the potential to be utilized in reducing radar cross-section for stealth applications in satellite and radar communications transmission.

Keywords: Absorber, dual band, harmonic frequency, Q-factor

1.0 Introduction

Several types of perfect metamaterial absorber have been studied since the initial study on the absorbed [1]. The single-band [2], multi-band [3], wideband [4-6], polarization-insensitive [7-8] and flexible [9-10] are an example for variate types of the absorbed. Basically, the idea for developing the metamaterial absorbed is to minimize the reflection at the same time to eliminate the transmission. The metamaterial absorber is developed through dielectric substrate in between two metallic layers on top and bottom. The impedance matching of the patch which was on top layers was used to reduce reflection. Meanwhile, the ground plane was printed as a continuous metallic layer on the bottom of the dielectric was used to prevent transmission within the structure.

Metamaterial absorbers in the radio frequency (RF) or microwave field are materials with characteristics which do not naturally exist. The structure was typically composed of a patterned metallic layer, known as patch, which was isolated by a dielectric and a ground metallic layer. The metallic ground layer blocked the transmission while the reflection is minimized by the patch. In order to minimize the reflection, the impedance matching between surface impedance Z(ω) and free space impedance, ηo = 377 Ω is developed by adjusting the permittivity and permeability. In theory, perfectly matched metamaterial absorber is achieved whenever the space impedance match to the surface impedance. It is the basic principle for maximizing the absorbency. There is no reflection since the free space impedance contributes almost nothing to reflection. Thus, contributed to maximum absorbance, as occurred in Equation1:

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

The transmitted power of the absorbed is closed to zero due to the absences of full metallic layers at the bottom of the structure. Ideally, no transmission power should be transmitted at the back, since S21 ≈ 0. Therefore, the absorbance, A is simplified as in Equation 2:

$$A = 1 - {S_{11}}^2 \quad (2)$$

where A is absorbency, S11 is reflection coefficient and S21 is transmission coefficient.

Various characteristics of metamaterial absorber have been proposed; surface current at the front and back layers, magnetic energy, electric energy, and power loss at the resonant frequency were all proposed in 2020 (Singh et al. 2020). The surface current of the metamaterial absorber was moving top-down on the front layer. Thus, contributed to anti-parallel surface currents, indicating magnetic resonance; induced on top and bottom layers. The magnetic resonance is caused by electric energy distributions and power loss. The incident EM wave loss is dissipated within the dielectric space between neighbouring unit cells. The practical capacitors that are formed which are mainly caused the induced electric field. In other words, the dielectric loss is dominated the energy dissipation trough the structure by using magnetic resonance. This paper study a dual band metamaterial absorber. The single and simple structure of patch layer which based on rectangular shaped was designed on the 0.018λ TLY-5 substrate. Initially, the rectangular patch is designed horizontally, then being rotated anti-clockwise from 0o to 90o to study the change of the absorbency. Thus, to study the harmonic frequency in order to developed the dual band metamaterial absorber while maintained the perfect absorbency for each band.

2.0 Methodology

The dual band metamaterial absorber is designed by using the simple structure; rectangular patch which is printed on a square dielectric with full ground plane. The dielectric substrate is stacked in between the patch and ground. Material TLY-5 with a thickness of 1.52 mm, dielectric constant of 2.2, and tangent loss of 0.0009 is used as a dielectric. The available thicker size of TLY-5 on market is selected. Thicker the dielectric, wider the bandwidth; the dielectric thickness is directly proportional to the bandwidth. Thus, led to the easier design process of dual band metamaterial absorber. Meanwhile the material used for patch and ground are Perfect Electromagnetic Conductor (PEC) with a thickness of 0.035 mm. Figure 1 shows the views of dual band metamaterial absorber: (a) front; (b) back; and (c) side.

(a) (b) (c)

Figure 1: The views of dual band metamaterial absorber: (a) front; (b) back; and (c) side.

At first, a rectangular dielectric is designed, followed by a rectangular patch which is stacked horizontally on the top layer of dielectric. Then, the rectangular patch is turned anti-clockwise from 0° to 90° with 7 steps of 15° changes. Thus, to study the harmonic frequency to developed the dual band metamaterial absorber while maintained the perfect absorbency for each band. The optimized width and length for dielectric of dual band metamaterial absorber are m=45 mm and n=48 mm, respectively in the x-y plane. The dielectric thickness of 0.018λ is in the propagation direction-z. Meanwhile, the width and length of the rectangular patch are x=18 mm and y=39 mm, respectively. Dual band metamaterial absorber is simulated using CST Microwave. It is simulated in all directions in an open free space environment. The meshing set-up set is fixed to be automatic for each simulation. The unit cell's boundary condition is set to periodic conditions in the x-plane and y-plane, with an open boundary in the z-direction. Typically, the incident electromagnetic (EM) wave is polarized, with the electric and magnetic fields parallel to the x-axis and y-axis, respectively. The simulator is evaluated the reflection and transmission magnitudes for the structure. Then, the absorbency is calculated by using Equation 1. The accuracy of the measurement is depending on the dimension values of variables. Table 1 shows the parameter for the unit cell of the slotted rectangular bar absorber.

Table 1: Technical descriptions and dimensions of the dual band metamaterial absorber

Description	**Variable**	**Dimension (mm)**
Substrate width	m	45
Substrate length	n	48
Patch width	x	18
Patch length	y	39
Slotted width	w	0.5

3.0 Result and Discussion

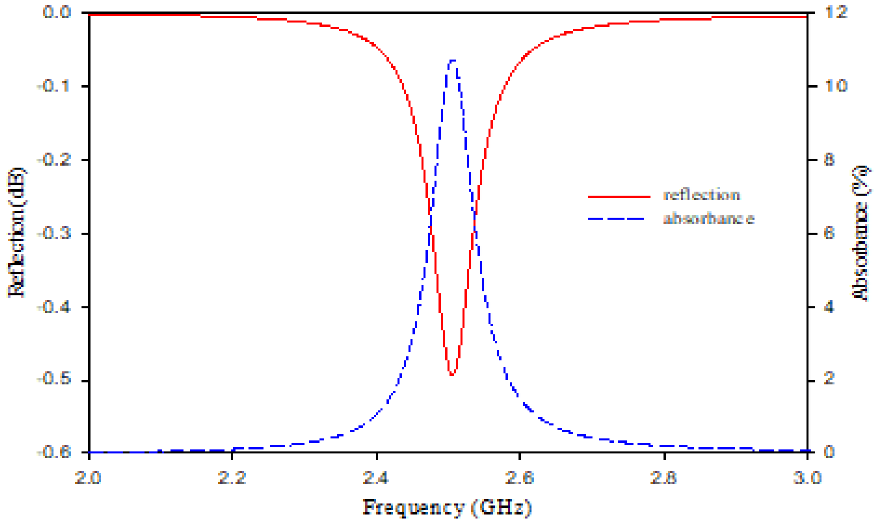
Figure 2 shows the characteristic of dual band metamaterial absorber which are reflection and absorbency and normalized impedance obtained. The structure is resonated at 2.50 GHz with an absorbency capability of 10.74%. As a result, a reflection of -4.89 dB was plotted, which is insufficient for in practically used of an absorber. The real and imaginary parts of normalized impedance are achieved approximately at one and zero, respectively. The dual band metamaterial absorber is designed horizontally, is then rotated anti-clockwise from 0° to 90° to analyze the change of the absorption spectrum. Since the thickness of the dielectric layer (1.52 mm) is much less than the length of bar patch (39 mm), the resonance modes for only the lower frequency can be calculated by using Equation 3 to Equation 5.

$$k_{mn} = \frac{\omega_{mn}\sqrt{\varepsilon}}{c} = \frac{\pi}{l}\sqrt{m^2 + n^2} \qquad (3)$$

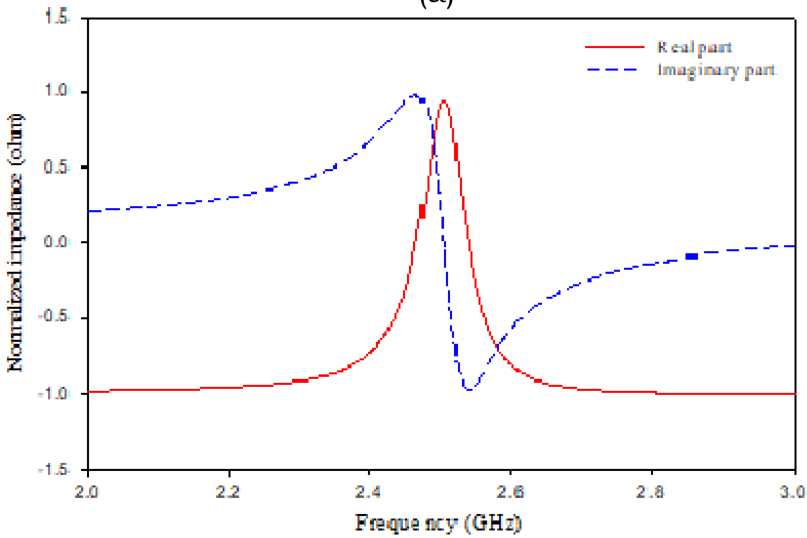
$$\omega_{mn} = 2\pi f_{mn} \qquad (4)$$

$$f_{mn} = \frac{c\sqrt{m^2 + n^2}}{2l\sqrt{\varepsilon}} \qquad (5)$$

where kmn was resonance modes, n and m are integers (0, 1, 2...) and l was the length of bar patch.



(a)



(b)

Figure 2: Dual band metamaterial absorber: (a) reflection and absorption and (b) normalized impedance

The first resonance is occurred at 2.59 GHz indicate that the absorption is induced by the fundamental magnetic resonance (m = 1, n = 0). The second resonance is occurred at 5.18 GHz, which correspond to the second harmonic magnetic resonance (m = 2, n = 0). Two calculated resonance frequencies are almost near to the simulated ones. Figure 3 shows the absorption spectra according to the anti-clockwise rotation of the dual band metamaterial absorber. Single-band is occurred at both 0° and 90° with almost 10% of absorption. At the same time, a dual band absorber is determined as the rectangular bar is rotated from 15° up to 75°. The absorption for dual resonating frequencies is around 30% at both 15° and 75° of the rotation. Meanwhile, 80% of absorption is achieved at the rotation of 30° and 60°. Dual band metamaterial absorber is achieved as the rectangular patch is rotated at 45° at both bands: 2.50 GHz and 4.97 GHz, with the absorption of 99.92% and 99.95%, respectively.

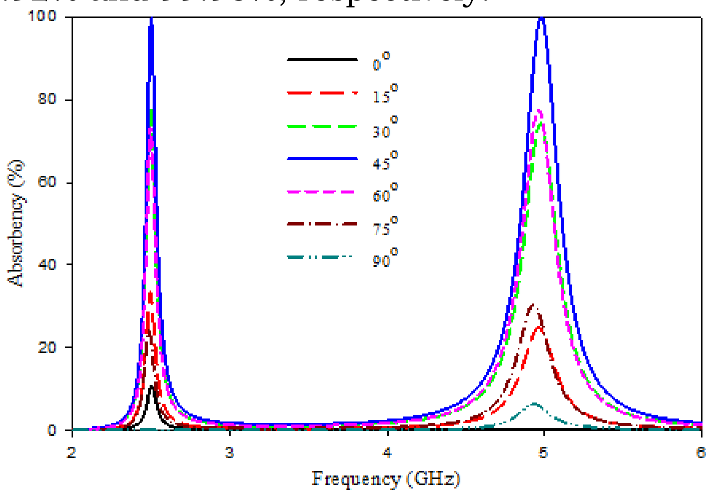
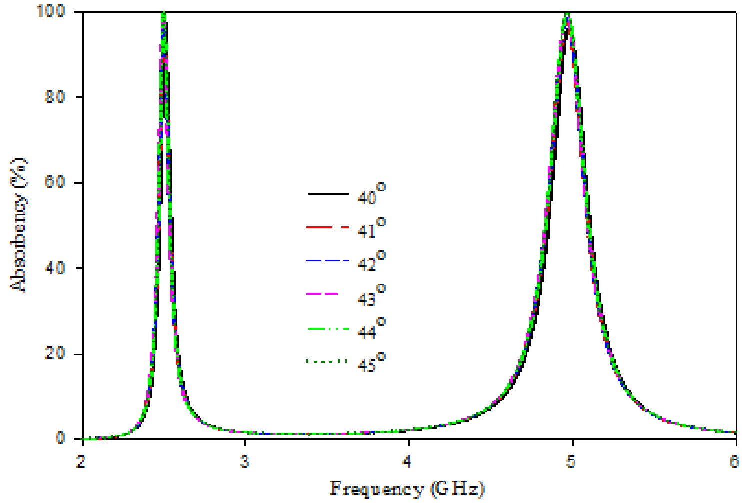
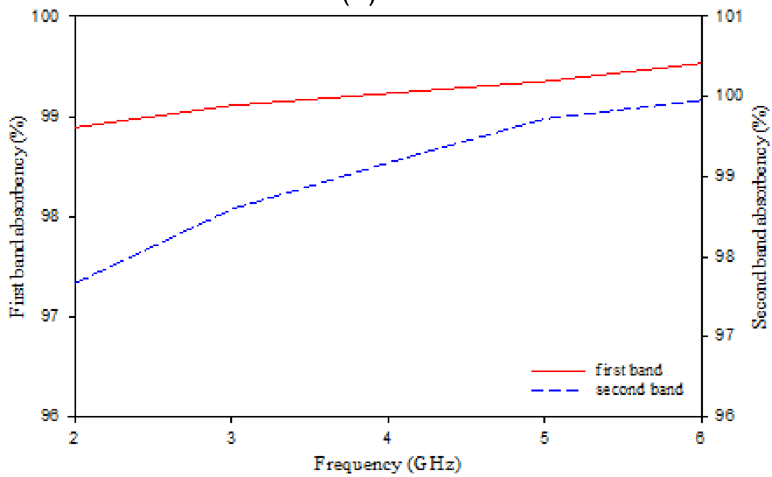


Figure 3: The absorption spectra of dual band metamaterial absorber at different rotation angle

To further analyze the in-depth variation of the spectra at the rotation of 45°, the detailed absorption spectra at rotation angles between 40° to 45° are also simulated, as shown in Figure 4. When the rotation angle of the rectangular patch is varied from 40° to 45°, the absorbance capability of both bands is increased. Noted that the absorption is relatively high at the rotation of 45°; the absorption of the first band is 99.50% at 2.50 GHz, and the second resonance band is 99.95% at 4.97 GHz.



(a)



(b)

Figure 4: Simulated absorption spectra: (a) for rotation angles from 40° to 45° and (b) at 45° for first band and second band

In order to enhance the absorption of all the resonance bands, the thickness of the dielectric substrate was controlled because the dielectric loss was the dominant loss process for the absorption mechanism. The thickness of the dielectric substrate was adjusted based on the available thickness in the market; 0.09 mm, 0.25 mm, 0.76 mm, and 1.52 mm at a fixed rotation angle of the rectangular patch of 45°. Figure 5 presents the absorption spectra by the thickness of the dielectric substrate. For the first resonance band, the frequency was shifted from 2.50 GHz for 1.52 mm to 2.56 GHz for 0.09 mm thickness. At the same time, it was slightly shifted to the upper side for the high-frequency absorption, which is from 4.98 GHz to 5.38 GHz with 99.95% and 94.35% absorbency, respectively. The absorbency was improved as the thickness of the dielectric was increased for both resonance bands. It is also noted that the thicker dielectric contributed to the enhancement of bandwidth for each resonance band.

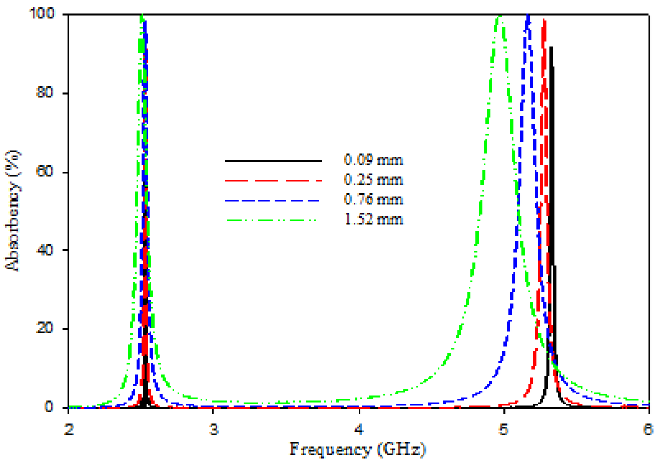
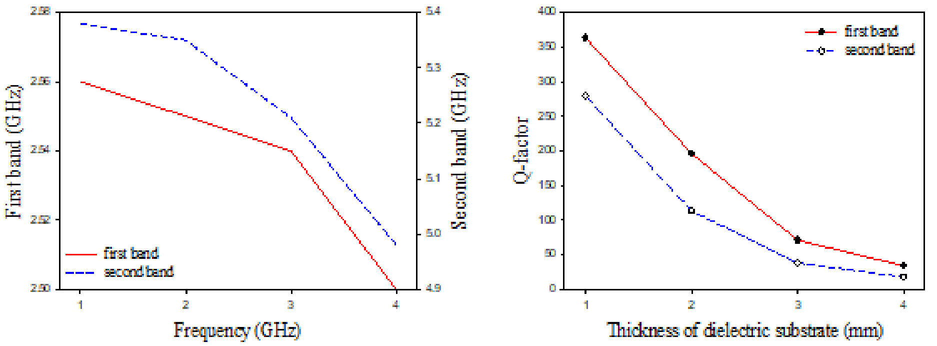


Figure 5: Dual band metamaterial absorber based on simulated absorption spectra according to the dielectric thickness

Figure 6 shows the resonance frequencies for each band and Q-factor according to dielectric thickness. Both the first and the second bands were shifted to higher frequencies. These results were consistent with the resonance frequency to be inversely proportional to the thickness of the dielectric substrate. For the first and the second bands, the calculated Q-factor was decreased with the dielectric thickness, which means that the bandwidth was wider. From these results, although the thickness of the dielectric substrate was slightly thick, it was realized the broad dual bands by the dielectric thickness.



(a) (b)

Figure 6: Dual band metamaterial absorber: (a) resonance frequencies for each band and (b) Q-factor according to the dielectric thickness

4.0 Conclusion

A dual band absorber was successfully designed. The single and simple structure of patch layer which based on rectangular shaped was designed on the 0.018λ TLY-5 substrate. Initially, the rectangular patch is designed horizontally, then being rotated anti-clockwise from 0° to 90° to study the change of the absorbency. Maximum absorbency is achieved as the rectangular patch is rotated at 45°. Dual band absorbed is developed which are resonated at 2.50 GHz with 99.92% absorbency and 4.97 GHz with 99.95% absorbency. The Q-Factor is decreased for thicker substrate which contributed to broad bandwidth of the absorbed. These features have the potential to be utilized in reducing radar cross-section for stealth applications in satellite and radar communications transmission.

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Author Contributions

N. Aziziuddin: Original idea of study and conceptualization, Methodology, Testing, Data curation and analysis, Software, Validation,; **S. A. M. Ali:** Writing, reviewing and editing, Proof reading.

Conflicts of Interest

The manuscript has not been published elsewhere and is Not under consideration by other journals. All authors have approved the review, agree with its submission, and declare no conflict of interest in the manuscript.

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