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Ultra Thin Flexible Octagonal Metamaterials Absorber

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ABSTRACT

An ultra thin flexible octagonal metamaterial absorber on 0.13 mm fastFilm D27 material has been presented in this paper. CST microwave studio was used in designing and simulating the octagonal metamaterial absorber. The flexible octagonal metamaterial absorber was resonated at 10 GHz with highly perfect absorbance of 99.98%. However, Full Width Half Maximum (FWHM) of the absorbance was relatively small 135 MHz affected from the ultra thin substrate used. By using triangular lattice arrangement of the unit cell, the FWHM could be increased to 171 MHz. Besides that, combination of resonating frequencies technique also had increased the FWHM more than 74% increment from basic unit cell with one resonance frequency. The flexibleness of the metamaterial absorber could increase the functionality of the metamaterial absorber to be used in any application especially in reducing radar cross section for stealth application.

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1. INTRODUCTION

Metamaterial absorber is a kind of material artificially engineered to have highly absorbance characteristics. It provides properties which “may not be readily available in nature”. Metamaterial has wide benefits for wireless technologies, microwave and millimeter wave imaging applications in medicine, security, and many other areas. Operating bandwidth of an absorber is referred to as the Full Width Half Maximum (FWHM) of the absorber which maintains at least 50% of the absorbance magnitude [1]. Normally FWHM is found in between 3% to 5% for metamaterial absorber with substrate permittivity around 4 and thickness in between 0.7 mm to 1.0 mm [1-5].

Dual band metamaterial absorber with circular ring design has been proposed by O. Ayop et al. with design resonated at 9 GHz and 11 GHz [4]. The substrate used is FR4, which is rigid material with thicknesses 0.8 mm. This leads to the FWHM of 5.12% and 3.08% respectively. Dual band metamaterial absorber also has been presented by H. B. Baskey in his two technical papers [6, 7], but both results show narrow band of FWHM absorbance.

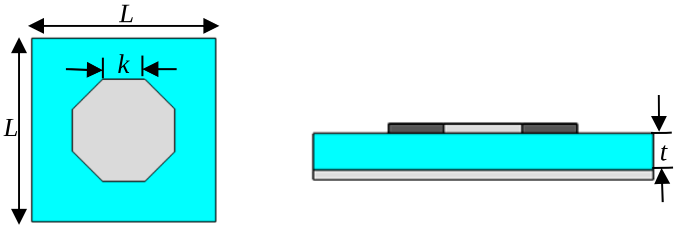
H. Lee and H. S. Lee have proposed a method to extend the metamaterial absorber bandwidth by using five different geometrical dimension of unit cell which are arranged in array [8]. H. Lee and H. S. Lee in their paper had mentioned that the results show the higher FWHM increment with vertical arrangement. Wider bandwidth also has been presented by using combination of a few adjacent resonance frequencies in journal entitled Broadband Ultrathin Low Profile Metamaterial Microwave Absorber [9] and Wideband Polarization-Insensitive Metamaterial Absorber with Perfect Dual Resonances [10].

The comparison of material characteristics used for metamaterial absorber [1-15] shows that metamaterials absorber researches at X-band frequency range are still limited on rigid substrate especially using FR4 material with thickness of 0.8 mm and above [1], [3], 4], [6], [8-10], [22-25]. Although the substrate thickness may affect the bandwidth of absorbance when using very thin material, bandwidth increment technique could be used in order to increase the FWHM of the absorber [8-10]. Recently, flexible material such as Denim Jeans, Taconic TLY-5, fastFilm D27, and Rogers RO3010 has been researched for other kind of metamaterial such as Artificial Magnetic Conductor (AMC), Frequency Selective Surface (FSS), and Electronic Band Gap (EBG) also for flexible antenna design [16-21].

Previous work on octagonal absorber concept had been reported in paper entitle, An Analysis of Dual-band Octagonal Ring Metamaterial absorber [22] was using octagonal ring design. It shows the results of very low FWHM of the absorber even maximum absorbance result was very high and almost to be perfect absorbance at the resonance frequency. The low FWHM was affected by the thickness of the material used as the absorber substrate. So that, referring to the last report, the octagonal concept is then continued to be designed on ultra thin material as the substrate. In this technical paper, single band ultra-thin flexible octagonal metamaterial absorber has been design and simulated by using CST Microwave Studio. Ultra thin material, fastFilm D27 was used as the substrate of the absorber. In order to get the best FWHM of the metamaterial absorber, two techniques were used which are triangular lattice of unit cell arrangement and combination of different resonating frequencies.

2. FLEXIBLE OCTAGONAL METAMATERIAL ABSORBER DESIGN

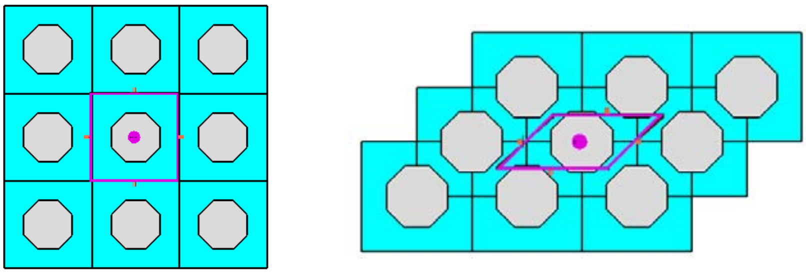
The metamaterial absorber with octagonal patch has been designed on ultra thin substrate of fastFilm-D27 with thickness $t = 0.13\, mm$. Dielectric constant of the fastFilm-D27 substrate is 2.7 with tangent loss of 0.0012. The structure of the metamaterial absorber consists of PEC octagonal patch on the substrate with full PEC grounded as shown in Figure 1 (a) and (b). Substrate size of the unit cell is $L \times L = 18\, mm \times 18\, mm$ and the length of each octagonal patch side is $k = 4.16\, mm$.



(a) (b)

Figure 1. Design of unit cell octagonal patch metamaterials absorber

CST microwave studio has been used in designing and simulating the structure of metamaterials absorber. With unit cell boundary setting, one unit cell of octagonal metamaterial absorber will be infinitely arrayed using square lattice as shown in Figure 2 (a). Besides that, the unit cell could also be finitely arrayed using triangular lattice as shown in Figure 2 (b) by introducing hypotenuse formulae. Comparison in between these two arrayed condition has been analysed in terms of the effect to the absorbance bandwidth.



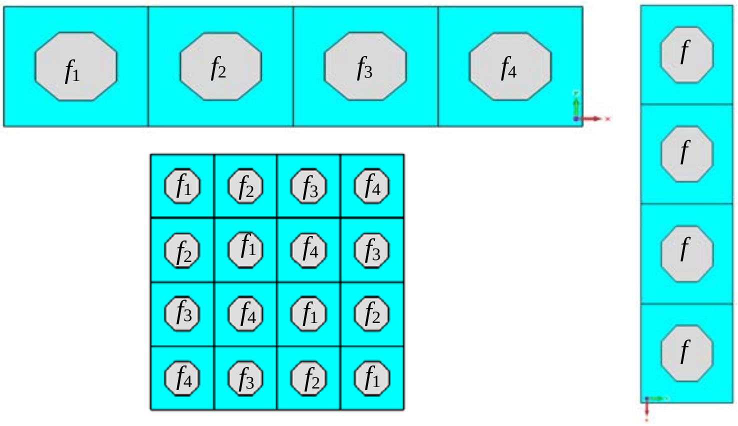
(a) (b)

Figure 2. Arrangement of unit cell array (a) normal lattice (b) triangular lattice

Further analysis also has been done with the combination of four different resonance frequencies in order to increase FWHM of the metamaterial absorber. Table 1 shows the four different patch sides, k of octagonal patch with their respective resonance frequencies. The four different resonance frequencies have been choosed by taking the frequency at the 50% absorbance of each neighbour resonance frequency. Then, the four reaonance frequency was combined with the objective to get higher absorbance bandwidth. There are three cases for the combination arrangement which are on x-axis horizontal arrangement (case 1), on y-axis vertical arrangement (case 2) and square arrangement with combination of horizontal and vertical arrangement (case 3). All the visual arrangements are shown in Figure 3.

Table 1. Four different octagonal patch sizes with respective resonance frequencies

	Patch side, k (mm)	Resonance Frequency (GHz)	Maximum Absorbance (%)
f_1	4.16	10	99.97
f_2	4.18	9.94	99.91
f_3	4.20	9.87	99.99
f_4	4.22	9.85	99.99

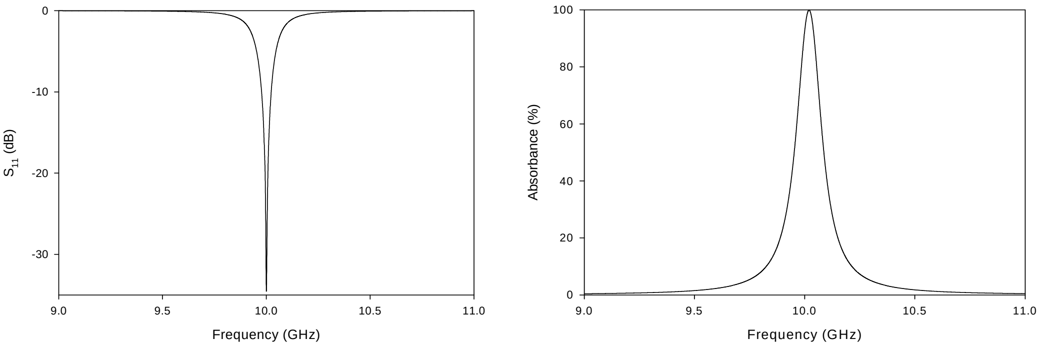


(b) (c)

Figure 3. Combination of four different resonance frequencies as one unit cell (a) case 1 (b) case 2 (c) case 3

3. RESULTS AND ANALYSIS

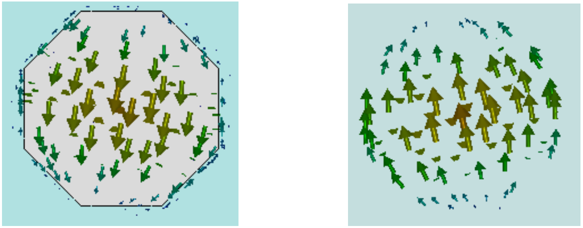
The results begin with S_{11} and absorbance of ultra-thin flexible octagonal patch metamaterial absorber with square lattice arrangement of unit cell as shown in Figure 4. S_{11} result shows -34.52 dB resulting in 99.96% of maximum absorbance. Full Width Half Maximum (FWHM) of the ultra thin flexible octagonal metamaterial absorber is 135 MHz (1.35%). This is too low compared to FWHM of the previous research of octagonal metamaterial absorber [22] around 4% using FR-4 as the substrate with 0.8 mm thickness. The lower FWHM are affected by the ultra thin and high dielectric constant of the substrate used.



(a) (b)

Figure 4. (a)S_{11}(dB) and (b)absorbance (%) of the octagonal patch metamaterials absorber

Figure 5 (a) and (b) shows the surface current at 10 GHz, where it can be seen that the high concentration of anti-parallel current flow happened in between the front and back octagonal metal layer of the ultra thin flexible octagonal metamaterial absorber. The anti-parallel current flow is contributes to the high magnetic resonance at 10 GHz. Then it had resulting to the high absorbance rate at the resonance frequency.



(a) (b)

Figure 5. Surface current flow (a) in front (b) back of the octagonal pach metamaterials absorber

Then, comparison of maximum absorbance between square and triangular lattice arrangement shows maximum absorbance of the ultra thin flexible octagonal metamaterial absorber with triangular lattice has decreased to 87.27% at absorbance frequency of 9.93 GHz as shown in Figure 6. Meanwhile, triangular lattice arrangement of the unit cell array leads to the increment of FWHM to 167 MHz at 9.97 GHz, which is higher than square lattice arrangement with slightly decrement of resonance frequency. When the optimization to resonate at 10 GHz process has been done to the unit cell with triangular lattice arrangement, the new maximum absorbance is 88.1% with FWHM of 171 MHz. The increasing of FWHM for triangular lattice arrangement may be affected by the decreasing gap between octagonal patches.

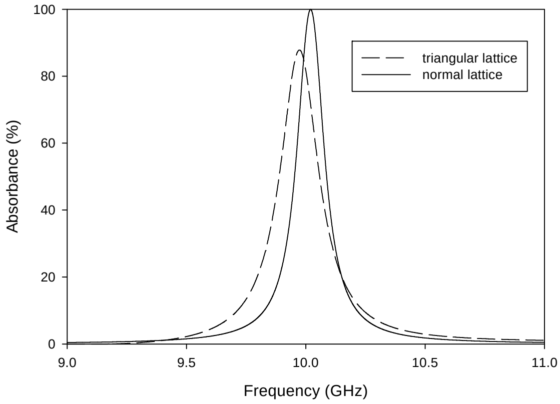


Figure 6. Comparison of absorbance in between square and triangular lattice arrangement of the unit cell

Next, the ultra thin flexible octagonal metamaterial absorber has been rearranged with combination of four different resonance frequencies. With an optimization process, the results of the 3 cases of combination technique are compared at 10 GHz as shown in Figure 7 and also as intepreted in Table 1. 2.

Combination of the four different resonance frequencies on x –axis (case 1) leads to the increasing of FWHM to 221 MHz which is 63.7% higher than basic one unit cell with one resonance frequency. Maximum absorbance of the horizontal combination is 94.58%, which is almost perfect absorbance. Figure 8 shows the power loss densities of the horizontal combination at two different resonance frequencies, 10 GHz and 9.94 GHz. The power loss densities are concentrated on two or three neighboring patch of the unit cell at different resonance frequency. At 10 GHz, it shows the power loss was high at f_1, meanwhile at 9.94 GHz, the power loss was high both at f_1 and f_2 because of the neghbouring resonance frequencies.

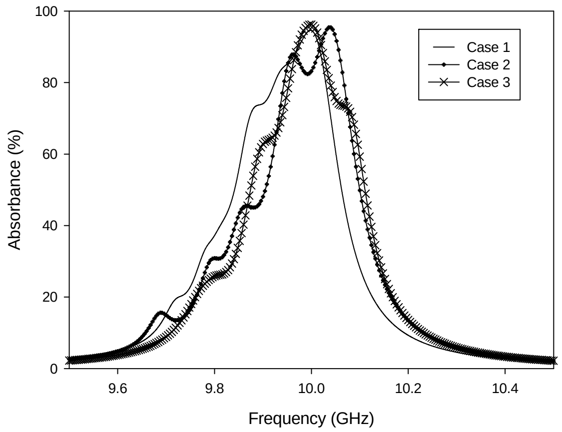
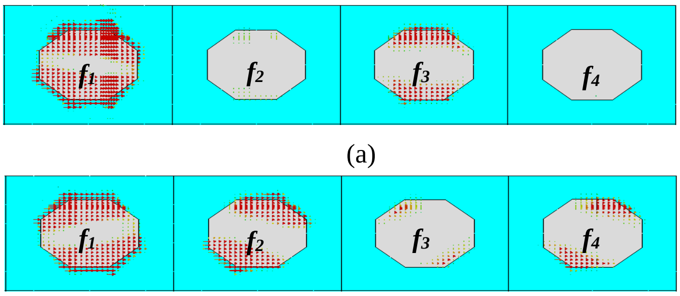


Figure 7. Absorbance comparisons between 3 cases of combination technique of four different resonance frequencies

Table 2. Comparisons between 3 cases of combination technique

Case	FWHM (MHz)	Maximum Absorbance (%)
1	221	94.58
2	196	95.44
3	236	96.20



(a)

(b)

Figure 8. Power loss densities of the horizontal combination (a) at 10 GHz (b) at 9.94 GHz

Next, the combination of four different resonance frequencies on y-axis (vertical) shows the FWHM of 196 MHz, slightly lower than horizontal combination. Result of the maximum absorbance for this case was divided into two peaks which are 87.82% at 9.96 GHz and 95.44% at 10.04 GHz. Square combination of four different resonance frequencies, which is combination of horizontal and vertical arrangement, producing to the highest FWHM, 236 MHz in between 9.874 GHz until 10.11 GHz. The highest FWHM of the ultra thin flexible octagonal metamaterial absorber shows 74.8% increment from FWHM of basic unit cell with one resonance frequency. In the meantime, the maximum absorbance is 96.2% occurred at 10 GHz, which is relatively high absorbance.

4. CONCLUSION

Provide Ultra thin Flexible octagonal metamaterial absorber has been successfully designed and analyzed at 10 GHz. The use of ultra thin fastFilm-D27 was very useful in terms of flexibleness of the metamaterial absorber. Triangular lattice arrangement of unit cell has been proved to increase the full width half maximum (FWHM) of the metamaterial absorber. For the proposed design, ultra thin flexible metamaterial with combination of four different resonance frequencies had increased the FWHM to more than 74%. The fabricated design will be measured later for the verification of the simulation results. Then, the proposed design also could be use for further research work to increase the FWHM of ultra thin flexible metamaterial absorber to 100%. Meanwhile, the flexibleness of the proposed substrate could be investigate further with other flexible materials or design to increase the functionality of the metamaterial absorber which can be applied in any absorber application especially in reducing radar cross section for military and stealth application.

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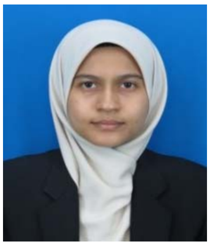

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