A Diamond Shaped Compact Dual-band Metamaterial Absorber for K_u and K_a Band Applications

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Abstract:

Metamaterial-based polarization insensitive absorbers have completely overcome the conventional absorbers, just because of their notable artificially engineered properties that lead towards the device compactness and thickness reduction. Here, we proposed a compact diamond shape polarization-insensitive absorber with the addition of "+" symbol slits for K_u and K_a band, 5G, satellite, 5G communication, and antennas isolation applications. The complete structure of the metamaterial absorber is 3.8 ×3.8 × 1.6 mm3, which is backed with a perfect electric conductor layer of 0.03 mm. The maximum absorption of 97 and 99.987% were observed at 24.3 and 29.5 GHz in K_u and K_a, respectively. The metamaterial absorber (MA) maintained its maximum absorption under the angular stability analysis by varying the polarization angle with a normal incident angle. However, under the TE and TM modes analysis, a minimum of 94% absorption was observed at 24.3 GHz. Thus, the results of MA proved that our suggested may be used for practical applications such as radar surface absorption, remote sensing, antennas isolation satellite, and 5G communication.

Introduction:

Metamaterial-based structures have attained a lot of interest from researcher's society owing to the deficiency of interesting features of natural materials [1-4]. These fascinating properties of metamaterials are abundantly used in many real-life applications, such as optical clocking, energy harvesting, thermal photovoltaic systems, filtering, biosensing, wavefront manipulation, perfect absorption, stealth, and antennas isolation [5-16]. The structure of MA is a combination of top conducting material, dielectric, and bottom conducting material, which looks like an array of three layers [17-19]. In addition, the absorption approach to unity when μ_{eff} and ε_{eff} are equal to make sure that the impedance of free space is perfectly matched to the MA structure. Furthermore, a conducting layer is placed under the dielectric layer to perfectly block the transmission. First time in history (2008) Landy et al. demonstrated practically a near-unity metamaterial absorber (MA) [20]. The resulting absorption of MA was narrowband just because of the resonance phenomena [21-25]. After that MA got an advantage over the conventional absorbers' usage, especially due to extraordinary properties of ultra-thickness, perfect unity absorption, and ease of fabrication [26-33].

However, the narrow bandwidth and larger size of the structure were the main issues. A lot of researchers put their effort to overcome the above problems by employing different approaches, techniques, and geometry structures. In [34] a V-shaped MA on FR-4 substrate was proposed for Ku band application with 98% absorption at 15 GHz resonating frequency. Some authors also used multilayer structures to make absorption broadband and multiband [35-47]. In a few approaches, authors used lumped resisters to enhance the bandwidth, but this approach results in a bulky device [48-55]. A hexagonal shape multiband absorber was reported with a maximum 99% and minimum 81% absorption at 4.5 and 12.4 GHz frequency, respectively

[56]. Agarwal et al. proposed a polarization-insensitive metamaterial absorber based on a closed loop structure which provided maximum absorption at 6 GHz and minimum at 10 .5 GHz, respectively [57]. Another actively tunable absorber with Jerusalem-shaped reported with above 95% absorption at 4.5 and 6.5 GHz, respectively [58]. Zeng et al. reported a dual-band metamaterial absorber for Ku and Ka band application with 98% and 85% absorption, respectively [59]. Furthermore, in [60] a dual band T shaped metamaterial absorber was proposed for Ku and Ka band with 99 and 88% absorption. Hoque et al. proposed a dual band absorber for X and Ku band application with maximum 99% absorption at 13. 75 and 15.25 GHz [61]. Although, most above-discussed design of metamaterial absorbers are dual-band, they have deficiencies in terms of size and operating band. From literature, it has been noted that mostly metamaterial absorbers design are for X, S, Ku and lower microwave band applications. However, mostly multiband absorber didn't cover both Ku and Ka band, as this difference is visible in comparison Table 1.

Therefore, we proposed a diamond shape with plus symbol radiating dual band absorber for Ku and Ka band applications. The proposed design of MA provided 100% and 94% absorption at 24 and 29 GHz frequency, which is polarization insensitive for extensive oblique angle range. The overall size of the design is 3.8 x 3.8 mm^2, with a substrate thickness of 1.6 mm. Thus, compactness in size and high absorption in Ku and Ka bands can make our design an appealing candidate for remote sensing, stealth materials, radar surfaces, MIMO antennas isolation, 5G, and satellite communication.

Table 1. Comparison of design metamaterial absorber with reported absorbers design

References	Pub. Year	Size (mm^2)	Peak Resonance	Absorption (%)	Operating Band
[56]	2019	8 × 8	15, 27	98, 80	Ku and K
[57]	2016	13.8 × 13.8	4.3, 5.9	99.5, 99.1	C
[58]	2017	8.5 × 8.5	16, 30	98, 99	Ku and K
[59]	2018	19 × 19	13, 15	99.5, 99.1	X and Ku
This work	---------	3.8 × 3.8	24.3, 29.5	97.2, 99.98	Ku and Ka

Design of Proposed MA

The final design of the proposed metamaterial absorber is a mixture of diamond shapes with the addition of the mathematical "+" symbol. The insertion of the plus symbol into the diamond structure increased the mutual coupling phenomena. The overall dimensions of the proposed MA absorber are 3.8 × 3.8 × 1.6 mm^3, as shown in Figure 1. A layer of perfect conductor with 0.04 mm thickness was placed beneath the dielectric substrate to block the transmission, whereas the dielectric constant ε_r of the FR4 is 4.3 with a thickness of 1.6 mm. The absorption of the proposed absorber can be calculated by using the $A(w) = 1 - |S_{11}|^2 - |S_{21}|^2$. However, S_{21} represents the transmission that is 0 due to the placement of PEC under the dielectric substrate. Therefore, MA absorption can be easily calculated by using the $A(w) = 1 - |S_{11}|^2$.

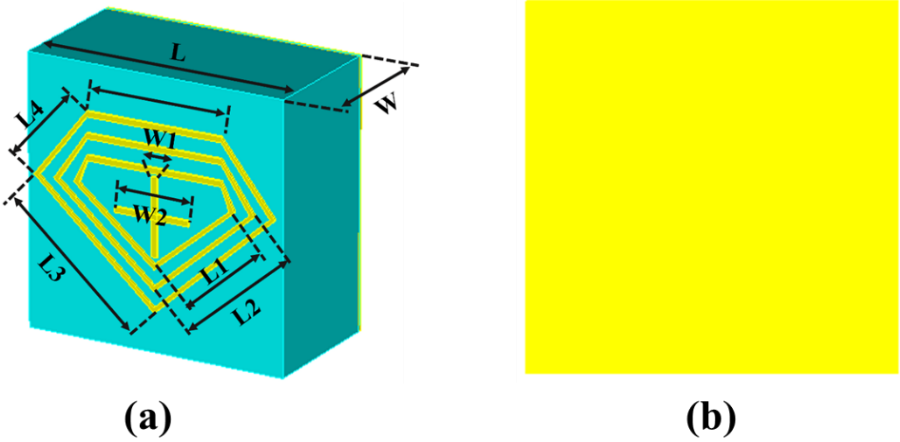

Figure 1: Proposed dual band antenna design. (a) Side view. (b) Back view. The parameters dimension are following: L = 3.8, L1 = 1.6, L2 = 1.98, L3 =2.4, L4 = 0.35, W = 2, W1 = 2, W2 = 1.1 and PEC layer with thickness of 0.03 mm.

Results and Discussion:

Furthermore, all the simulations of the MA are performed in CST Microwave Studio, 2019. Initially, on rational standards design a single diamond shape on a dielectric substrate backed with a PEC layer. The absorption of a single diamond shape was not good, whereas the motivation was to design a dual-band high absorption MA for K_u, and K_a. Therefore, by employing the mutual coupling phenomena, two more diamond shapes with the symbol of Plus were added to the existing design. The optimized design of MA provided dual-band absorption for K_u, and K_a, as given in Figure 2. The MA provided a maximum of 99.98% and a minimum of 94% absorption at 24.3 and 29.5 GHz resonance frequencies, respectively. These frequencies band lie in the spectrum range of K_u and K_a band.

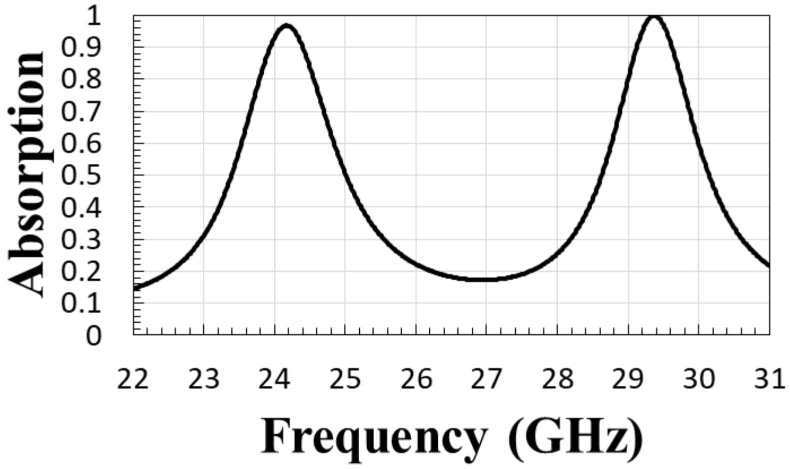

Figure 2: Simulated absorption of the proposed dual-band for the Ku and Ka band.

In addition, the angular stability of the designed MA absorber under the normal incident wave was evaluated over the range of polarization angle (φ = 0 to 60^o). The output results of absorption remain the same with minor fluctuation over the given range of angles, as given in Figure 3. The minimum 92% absorption is noted for Ku band at 24.3 GHz frequency. Thus, the output results concluded that our proposed design is a polarization incentive. Furthermore, Transverse Electrics (TE) and Transverse Electromagnetics (TM) analyses are performed for oblique incident angle. In both cases, the oblique angle varied from 0 to 60^o with a step width of 20^o, as shown in Figure 4. The results showed that the proposed absorber could provide more than 90% observation under the variation of oblique incident angles. These absorption results for both modes concluded the robustness of the proposed absorber.

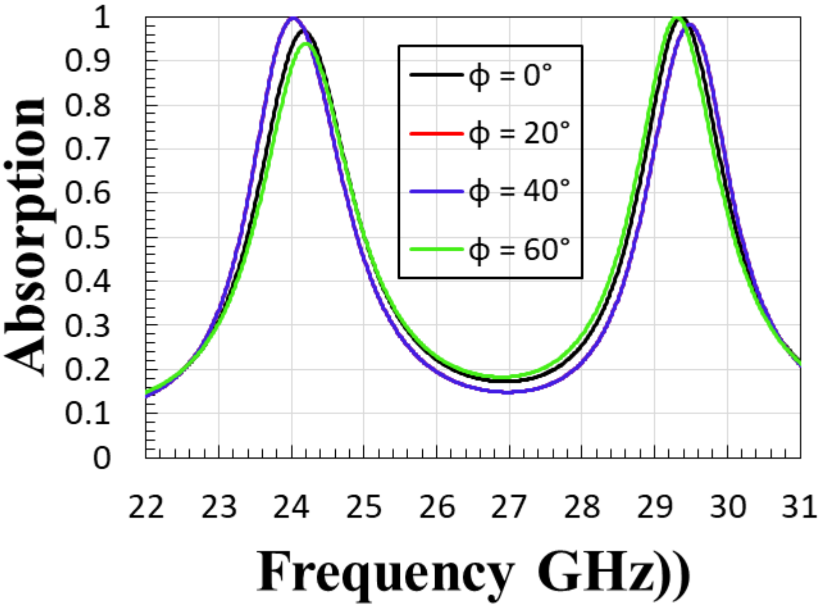

Figure 3: Absorber simulated absorption under variation of polarization angle.

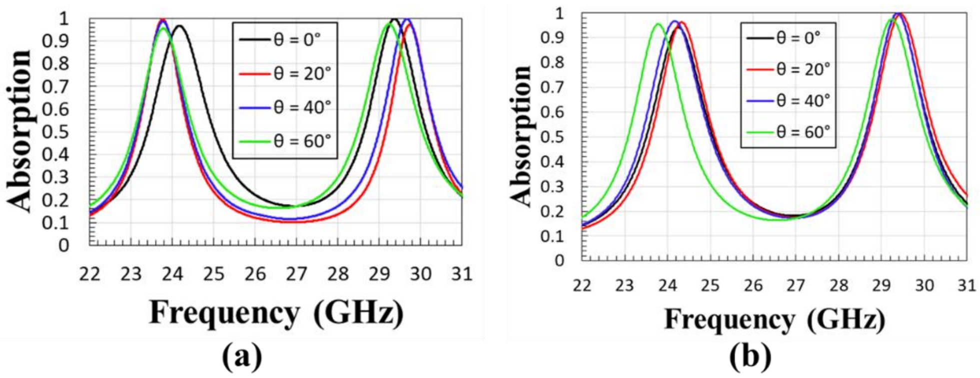

Figure 4: Absorption of the MA under the variation of oblique angle. (a) TM mode. (b) TE mode.

Conclusion:

We demonstrated a diamond shape compact dual-band absorber for K_u and K_a band 5G communication applications. The proposed absorber provided 97 and 99.98 % absorption at resonance frequencies of 24.3 and 29.5 GHz, respectively. However, high absorption in K_u and K_a with compact size as compared to the literature absorbers design make our MA an appealing candidate for radar surface absorption, satellite communication, remote sensing for defense, and isolation between the MIMO antennas. The absorption results of MA under the evaluation of polarization sensitivity and rotation of incident angle are significant. Our prosed MA is polarization in sensitivity when normal incident wave $\theta = 0^o$. The minimum absorption is 94% observed in TM modes analysis under the variation of the oblique angle. Thus, the simulated result of MA absorber concluded that our proposed MA may be a good candidate for MIMO antennas isolation, radar surface absorption, remote sensing, and 5G communication.

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