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Miniature Broadband Electromagnetic Wave Absorber for X-band Signals

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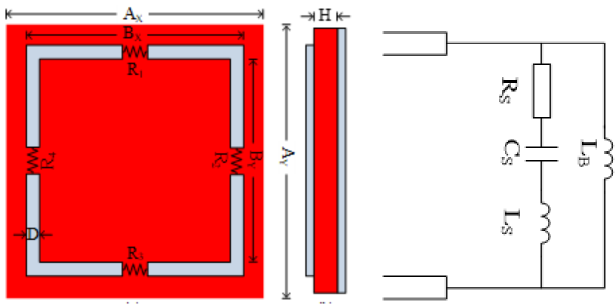
Abstract

This paper contains a unique electromagnetic (EM) radiation absorber for X-band signals. The presented EM-wave absorber exhibits a high absorptivity than conventional absorbers. The unit-cell of the EM-wave absorber is comprised of a single square loop with multiple resistive loads. The absorber is designed to resonate at a frequency of 10 GHz with a bandwidth of 4.35 GHz. The overall size of the unit-cell is 6.25 mm × 6.25 mm when constructed on a Rogers RT/Duroid 6002 laminate with a thickness of 3.04 mm. Utilizing a 3D EM solver by CST Microwave Studio that is commercially accessible, the proposed absorber was designed and analyzed. Comparing the suggested absorber to already presented EM-wave absorbers, demonstrates its benefit.

1 Introduction

Recent trends show a great progress on design and development of electromagnetic (EM) absorbers for various frequencies and applications [1]. Absorbers are widely used for radar or military applications to prevent unwanted reflections from the target body [2, 3]. Currently, the absorbers on the market are bulky, not flexible and are expensive. It is therefore of interest to develop EM absorbers based on engineered materials that are commonly known as Double Negative (DNG) materials [5], with negative permittivity as well as negative permeability [6]. The allocation of various band spectra for radar and military applications results in an increased demand for an EM absorber having compact size and broad bandwidth [7]. To meet this growing demand, researchers have proposed numerous designs of EM absorbers [8-16]. Most of these designs are proposed for broadband applications in various parts of the EM spectrum. For instance, a multiband absorber with absorption of 80-99% at K and Ku-bands is reported in [8]. This absorber is designed and constructed on three different materials FR4, RT4003, and RT3035. In case of FR4, the proposed EM absorber occupies a surface area of 100 mm^2, with ground plane covering 64 mm^2. It performed as a single negative absorber (SNG) in K-band, and as a double negative absorber (DNG) in Ku-band ranging from 19.75-21.35 GHz and 15.28-17.04 GHz. In case of Rogers RT-3035, the ground plane of the absorber has a surface area of 36 mm^2. The absorber acts as SNG in Ku-band and as DNG in K-band with peak absorption of 83%. Finally, in case of Rogers RT4003, the absorber behaves as SNG in the Ku-band and as DNG in the K-band with a peak absorption of ~93%. Although the above mentioned absorbers have simple geometrical structures, their absorption over the resonating band is relatively low.



(a) (b) (c)

Figure. 1. Proposed single loop resistive loaded EM absorber, **(a)** front view, and **(b)** side view (c) equivalent electrical circuit model of proposed EM-wave absorber.

Another interesting design is reported in [9], where a fractal absorber for dual frequencies of 0.88 GHz and 0.96 GHz is reported. The stated EM absorber has a very high absorption percentage of 99%. Still, the size of unit cell is large having narrow bandwidth. Contrary to this, [10, 11] presents the design of multilayer absorber, also known as circuit analogue (CA) absorber for broadband applications. The work presented in [10] covers C, X and Ku bands ranging from 5–8 GHz. The absorbers are designed with a simplified geometry shape along with small dimension 7 mm × 7 mm. A resistive square loop array with a unique equivalent circuit model is suggested in [11]. The reported CA absorber operates in the band of 3.5–8.5 GHz having an overall size of 32 mm × 32 mm. Both works suffer from the drawback of being multilayered structures, which results in a high profile along with increased structural complexity. In [12] all four absorber configurations were implemented on a single layer. The absorber was designed using an FR4 substrate of size of 10 mm^2. The operational range of the absorber extends between 5 GHz to 10 GHz. Reported in [13] is the design of a single layered wideband absorber. Here wwideband operation along with reduction in radar cross section (RCS) is achieved by using an array of crossed dipoles. The unit-cell of the absorber occupies an area of 13.6 mm × 13.6 mm with thickness of 4.47 mm.

It has an operational bandwidth between 8.25 GHz from 3.75 GHz to 12 GHz. The absorbers in [12] and [13] have the disadvantage of been large and having increased structure complexity due to the presence of slots and truncated edges. A geometrically compact dual band absorber for X-band is presented in [14]. This absorber has a unit-cell size of 7 mm × 7 mm with thickness of 0.76 mm. It exhibits dual band resonance at 10 GHz and 12 GHz. Unfortunately, this absorber operates over a narrow bandwidth. Reported in [15] is a paired square loop shaped wideband absorber having a bandwidth range of 8–18 GHz. Although this absorber has a wide bandwidth and a geometrical structure that is simple to fabricate however its unit-cell is large. Another similar work was reported in [16] where researchers have achieved tri-band at frequencies of 2.5 GHz, 5 GHz and 8 GHz. However, the absorber is considered too large.

It is evident from previous work as elaborated above that there is a need of developing EM-wave absorbers that (i) operate over a wide bandwidth, (ii) absorb signals with little reflection, (iii) are compact in size, and (iv) relatively easy to design and fabricate. The absorber presented here is an attempt to achieve these attributes. It consists of a single square loop that is resistively loaded and designed to operate at X-band. The body of this paper is structured as follows: the proposed absorber's design is presented in section II. In section III, various absorber key parameters are covered. Section IV serves as the paper's conclusion.

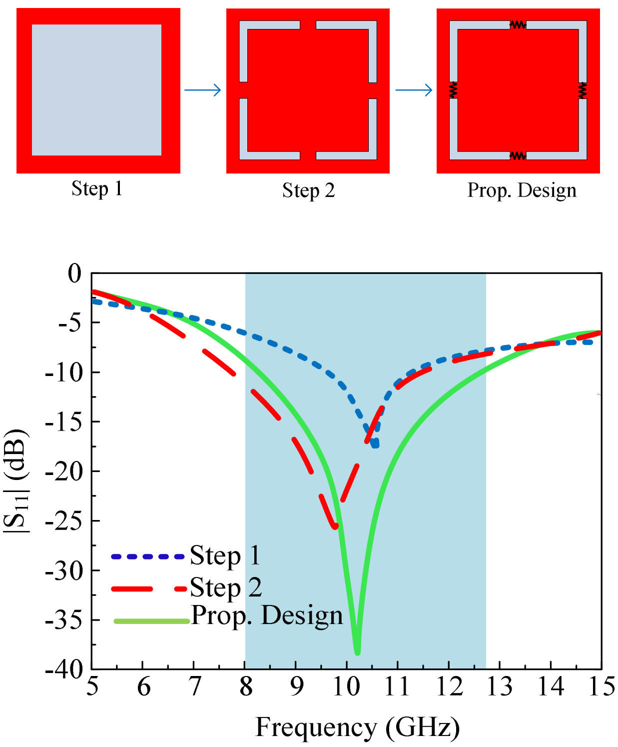


Figure. 2. Design steps of proposed absorber along with results.

2 Suggested Electromagnetic Absorber Design

Fig. 1 depicts the suggested EM-wave absorber unit-geometry. cell's It is made out of a square microstrip ring arrangement. The absorber unit-cell has resistors loaded on each side. The absorber is constructed on the upper surface of a Rogers RT/duroid 6002 substrate with a relative permittivity of 2.94 and a loss tangent of 0.0012 and a thickness of 3.04 mm [17]. The back of the substrate is a ground plane of thickness of 0.035 mm. The substrate measures 6.05 × 6.05 mm^2. The absorber unit-cell measures 5 mm^2 in size. The square ring has a 1 mm width. The resistors of 600Ω are employed. All optimized parameters of the absorber are; $A_X = A_Y = 6.05$ *mm*, $B_X = B_Y = 5$ *mm*, $D = 1$ *mm*, $H = 3.04$ *mm*, $R_1 = R_2 = R_3 = R_4 = 600\ \Omega$.

The equivalent electrical circuit model of the resistive loaded square ring unit-cell is shown in Fig. 1 (c). The equivalent model is a modified version of the one presented in [18]. This model includes an additional inductive component represented by L_B. Electrical elements L_S and C_S are the respective equivalent inductance and capacitance of the square ring, where R_S is the equivalent resistance of absorber. The value of R_S includes the lumped resistors. The design step for proposed absorber is given in figure. 2. It can be observed that, the absorber is designed after following three steps. In initial step, the rectangular patch is loaded over substrate material, which offers a narrow band at 11 GHz. Afterward, the square slot is etched for initial design to improve bandwidth and return loss. The slots are also etched from the middle of each boundary. The absorber at second stage, operate at 8 – 11 GHz with return loss of -25 dB. In final stage the resisters are loaded to improve bandwidth and return loss. The resultant absorber offers 8 – 12.75 GHz as shown in Figure. 2.

Figure. 3 express the parametric analysis of the two key parameters of the proposed absorber. The height of the substrate material is key parameter by varying the thickness of the substrate, the operational frequency as well the reflection coefficient changes significantly. In the case of a substrate thickness of 1.52 mm, the operational range for $S_{11} \leq -10$dB shifts towards lower frequencies, while for a thickness of 4.56 mm, the operational range shifts toward the higher frequency end. Figure. 3(a) shows the optimum reflection coefficient is obtained with a thickness of 3.04 mm.

The other key parameter is the magnitude of the resistive load. Figure. 3(b) shows how the reflection coefficient varies for distinct resistor values. It can be noticed that when the value of resistor is reduced from the optimized value of 600 Ω to 400 Ω, the reflection coefficient reduces. This also has a negative impact on the absorber's operational bandwidth. Likewise, when the value of the resistor is varied from 600 Ω to 800 Ω, the reflection coefficient of the absorber reduces, and its operational bandwidth is also reduced.

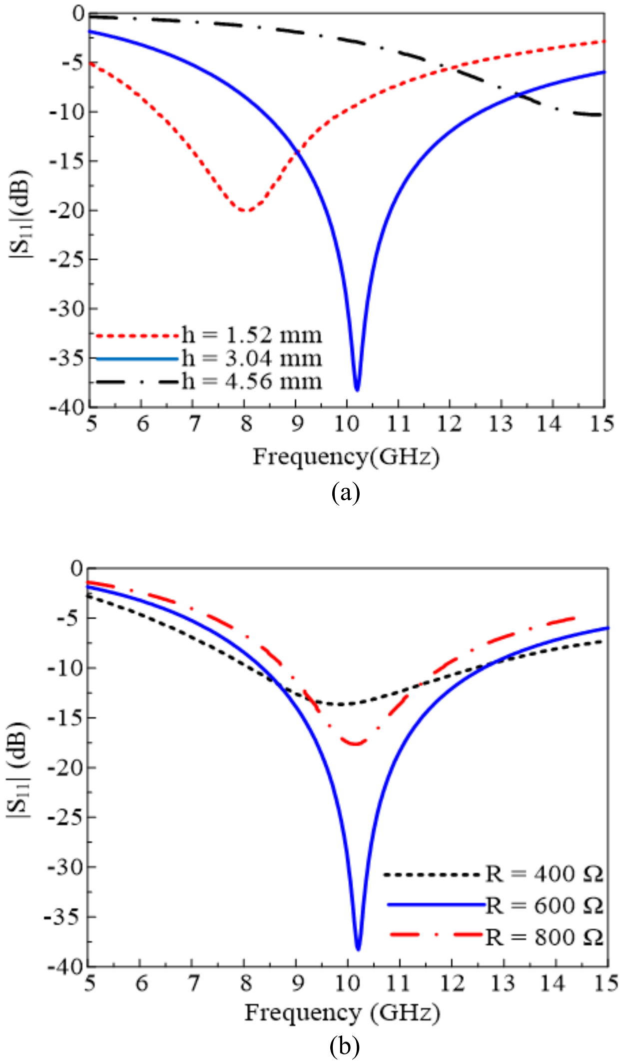


Figure. 3. Parametric analysis of the key parameters of the EM-wave absorber, **(a)** reflection coefficient as a function of substrate thickness, and **(b)** reflection coefficient as a function of resistor values.

3 Results and Discussions

3.1 Reflection and Transmission Coefficient

Figure 4(a) illustrates the reflection and transmission coefficient of said EM-wave absorber. Based on the results, the absorber runs at 4.4 GHz from 8.2-12.6 GHz for |S11| -10 dB, which corresponds to a 44% fractional bandwidth. Almost the entire X-band (8–12 GHz), which is used for radar and military purposes, is covered by the proposed absorber. Figure. 4 also illustrates the suggested absorber's transmission coefficient. Very low value of the transmission coefficient indicates the absorber isolation is excellent. This means multiple unit-cells can be arranged in close proximity to realize a much larger EM-absorbing surface where the performance of individual absorbers is unaffected.

3.2 Absorptivity

The absorptivity of the proposed unit-cell is determined by its reflection and transmission coefficient values given by the following expression [19]:

$$A = 1 - |S_{11}|^2 - |S_{12}|^2 \quad (1)$$

Eqn. (1) indicates that a low value of the reflection and transmission coefficient will result in a high absorptivity level. Figure. 4(b) depicts the absorptivity of the suggested absorber. The figure clearly illustrates that over the desired band, the absorber exhibits an absorptivity of greater than 92% with a peak value of 99.98% at 10 GHz.

Table I shows compares the presented EM-wave absorber and state-of-the-art absorbers reported in literature. It shows that the peak absorption of 99.9% is near prefect with the proposed unit-cell. This is achieved with a much smaller unit-cell size than other absorbers cited in the table.

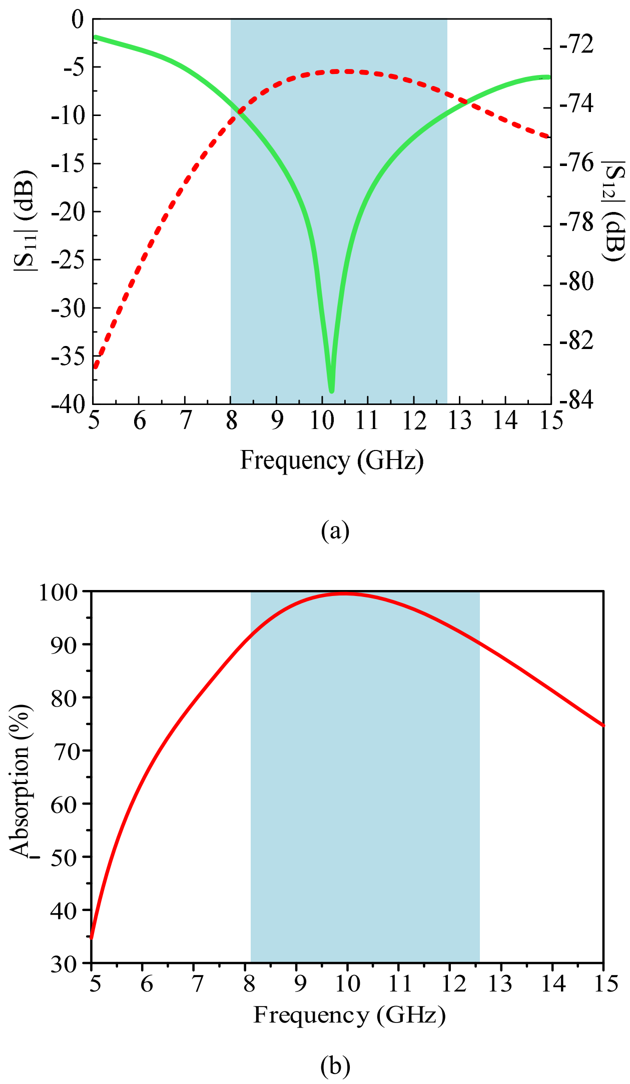


Figure. 4. (a) Reflection and transmission coefficient (b) absorbability percentage performance of the proposed EM-wave absorber.

TABLE I. COMPARISON OF THE SUGGESTED ABSORBER WITH REPORTED ABSORBERS IN LITRATURE

Ref	Unit Cell Size (mm^2)	Thickness (mm)	Freq. range (GHz)	Absorption (%)
[10]	31.5 × 31.5	3.2	0.87 - 0.89 0.925 - 0.99	99
[12]	32 × 32	7	3 - 8	-
[14]	13.6 × 13.6	4.47	3.75 - 12	98
[15]	7 × 7	0.762	10 - 12	-
[16]	32 × 32	3.175	8 - 18	97.6
[17]	18.5 × 25	14	2 - 9	97
Proposed Work	**6.25 × 6.25**	**3.04**	**8 - 12.76**	**99.9**

4 Conclusion

The suggested miniature EM-wave absorber is shown to have peak absorbability of 99.9% at X-band from 8.2–12.6 GHz. The absorber consists of a single loop resonator loaded that is resistively loaded. The absorber is simple microstrip structure that is easy to design and fabricate. On a typical dielectric substrate with a comparatively thin thickness, the suggested EM absorber displays a broad bandwidth. The very high isolation exhibited by the proposed absorber makes it suitable for realizing tightly knit large absorption surfaces. The features of the absorber make it suitable for radar and military applications in the X-band.

References

[1] Nguyen, T.T., Lim, S. Design of Metamaterial Absorber using Eight-Resistive-Arm Cell for Simultaneous Broadband and Wide-Incidence-Angle Absorption. Sci Rep 8, 6633 (2018).

[2] Li, M., Xiao, S. Q., Bai, Y. Y. & Wang, B. Z. An Ultrathin and Broadband Radar Absorber Using Resistive FSS. IEEE Antennas Wirel. Propag. Lett. 11, 748–751 (2012).

[3] Chen, J. et al. High-impedance surface-based broadband absorbers with interference theory. IEEE Trans. Antennas Propag. 63, 4367–4374 (2015).

[4] Landy, N. I., Sajuyigbe, S., Mock, J. J., Smith, D. R. & Padilla, W. J. Perfect Metamaterial Absorber. Phys. Rev. Lett. 100, 207402 (2008).

[5] Li, S. J. et al. Analysis and Design of Three-Layer Perfect Metamaterial-Inspired Absorber Based on Double Split-SerrationRingsStructure. IEEE Trans. Antennas Propag. 63, 5155–5160 (2015).

[6] Ghosh, S., Bhattacharyya, S., Kaiprath, Y. & Vaibhav Srivastava, K. Bandwidth-enhanced polarization-insensitive microwave metamaterial absorber and its equivalent circuit model. J. Appl. Phys. 115, 104503 (2014).

[7] Xu, H. et al. Broad bandwidth of thin composite radar absorbing structures embedded with frequency selective surfaces. Compos. Part A Appl. Sci. Manuf. 80, 111–117 (2016).

[8] S. Hannan, et al. "Design of a novel double negative metamaterial absorber atom for Ku and K band applications." *Electronics* 8.8 (2019): 853.

[9] F. Venneri, S. Costanzo, and A. Borgia, "A dual-band compact metamaterial absorber with fractal geometry." *Electronics,* 8(8), pp. 879, 2019.

[10] S. Ghosh, S. Bhattacharyya, and K. V. Srivastava, "Design, characterisation and fabrication of a broadband polarisation-insensitive multi-layer circuit analogue absorber." *IET Microwaves, Antennas & Propagation*, 10(8), pp. 850-855, 2016.

[11] Y. Han, et al. "A fast and efficient design method for circuit analog absorbers consisting of resistive square-loop arrays." *IEEE Transactions on Electromagnetic Compatibility* 58.3 (2016): 747-757.

[12] A. K. Rashid, Z. Shen, and R. Mittra, "On the optimum design of a single-layer thin wideband radar absorber." *International Symposium on Antennas and Propagation (APSURSI)*. IEEE, 2011.

[13] D. Kundu, A. Mohan, and A. Chakrabarty, "Single-layer wideband microwave absorber using array of crossed dipoles." *IEEE Antennas and Wireless Propagation Letters,* 15, 1589-1592, 2016.

[14] M. R. Tripathy, and D. Ronnow, "Dual band Frequency Selective Surface for X-band applications." *Progress in Electromagnetic Research Symposium (PIERS)*. IEEE, 2016.

[15] J. Yang, and Z. Shen, "A thin and broadband absorber using double-square loops." *IEEE Antennas and Wireless Propagation Letters,* 6, pp. 388-391, 2007.

[16] Y. Shang, Z. Shen, and S. Xiao, "On the design of single-layer circuit analog absorber using double-square-loop array." *IEEE Transactions on Antennas and Propagation,* 61(12), pp. 6022-6029, 2013.

[17] M. Hussain, and N. Nadeem, "A Co-Planer Waveguide Feed Dual Band Antenna with Frequency Reconfigurability for WLAN and WiMax Systems." *2019 International Conference on Electrical, Communication, and Computer Engineering (ICECCE)*. IEEE, 2019.

[18] N. Hussain, S. I. Naqvi, W. A. Awan, and T. T. Le, "A metasurface-based wideband bidirectional same-sense circularly polarized antenna." *International Journal of RF and Microwave Computer-Aided Engineering,* 30(8), e22262, 2020.

[19] S. A. Naqvi, and M. A. Baqir, "Ultra-wideband symmetric G-shape metamaterial-based microwave absorber." *Journal of Electromagnetic Waves and Applications,* 32(16), pp. 2078-2085, 2018.