Dual Band Ultra-Wideband Water Filled Microwave Absorber

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Abstract- This paper presents a dual band, ultra wideband water filled absorber in Microwave range. The design consists of stacked multiple layer of polymethyl methacrylate (PMMA), copper, water, and resin cap. The structure provides absorptivity of more than 90% in the frequency range of 3.62 to 4.14 GHz and 7.48 to 21.35 GHz. The size of unit cell of the absorber is of 12 x 12 x 3.80 mm^3. When the structure is filled with water the structure acts as an absorber, whereas in the absence of water the absorptivity is nearly zero. The absorber structure is polarization insensitive and have an angular stability till 45° of incidence angle for Transverse Electric (TE) and Transverse Magnetic (TM) modes. As the structure covers a wide frequency range therefore finds potential applications in various Microwave devices, RADAR and satellite applications.

Keywords- Absorber, angular stable, polarization insensitive, Ultra wideband, Water filled.

I. Introduction

Microwave absorbers play a crucial role in various applications such as radar systems, communication devices, and electromagnetic interference (EMI) shielding[1]. Their effectiveness in attenuating electromagnetic waves across a broad frequency range is essential for improving the performance and reducing interference in electronic systems. Among various types of absorbers, ultra wideband (UWB) absorbers have garnered significant attention due to their capability to absorb electromagnetic waves over a wide frequency spectrum. Traditional microwave absorbers are often single-layer materials[2] or composites[3] that are designed to absorb electromagnetic waves efficiently within a specific frequency band. However, the demand for absorbers that can operate effectively across multiple frequency bands has increased with the advancement of multi-band communication systems and radar technologies[4]. In recent years, various materials and designs are explored by researchers to develop ultra wideband absorbers with improved performance characteristics using resistors[5] or conductive inks[6]. One promising approach involves the use of water as a filler material due to its unique dielectric properties and ability to be tuned over a wide frequency range[7]. This research focuses on the design of a dual ultra wideband microwave absorber utilizing water as a filler material as sandwich material between PMMA layers with resin cap filled with water. The absorber's unit cell dimension is 0.09 x 0.09 x $0.02\lambda_g^3$. As the thickness of absorber is less then λg/10 therefore finds application as ultra thin absorber. The absorber is polarization insensitive for various polarization angles varying from 0° to 90°. Also the structure provides a wide angular stability till 45° for the incidence angle variations for Transverse electric (TE) and Transverse Magnetic (TM) modes. By leveraging the advantages of water-based absorbers and advanced electromagnetic simulation techniques, this study aims to contribute to the development of efficient absorbers capable of mitigating electromagnetic interference across a wide range of frequencies.

II. Design of Absorber

The structure consists of polymethyl methacrylate (PMMA) layers with water sandwiched in between and resin cover at the top layer filled with water in itas shown in Figure 1. The top and bottom water layer are connected through a water cylindrical channel with a radius r. The whole structure is backed with a copper layer at the bottom of PMMA layer with a thickness of 0.8 mm. The sandwiched water layer thickness is of 1.4 mm. The dielectric constant of PMMA is 2.55 and that of resin is 3 with a dielectric constant of 0.001 and 0.01 respectively. The water used is the water (Debye model).

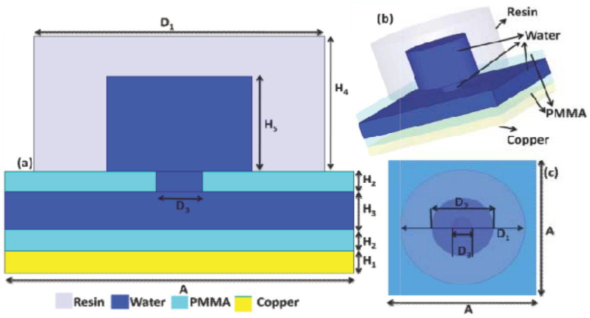

Figure 1. Design water filled Absorber unit cell (a) Side view, (b) Perspective view, (c) Top view

By perceptive optimization the impedance of structure could be closely matched to that of open space. In this manner, the incident wave's energy would be completely absorbed by the lossy water. Only a very small dielectric loss would occur in the resin cap and layer of PMMA, ensuring the creation of an ultra-broad passband. As the bottom layer is of copper with a thickness of 0.8 mm making the transmission to be equal to zero to zero($|S_{21}|^2 = 0$).

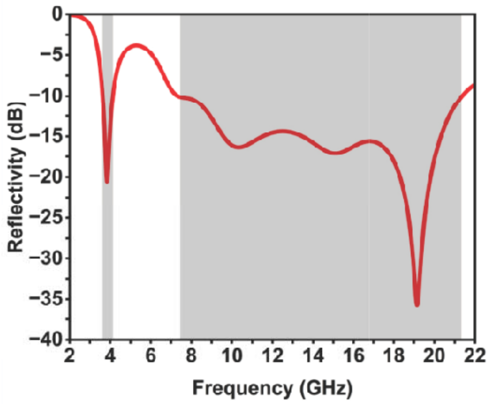

Figure 2. Reflectivity curve of the designed Water filled absorber.

The Absorptivity is calculated as eq(1)[3]

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

To attain maximum absorption the transmittivity and reflectivity parameters should be minimum. The Absorber is designed using CST microwave studio available commercially in Frequency domain solver. The optimized dimensions of the designed structure are A=12 mm, D_1= 10 mm, D_2= 5 mm, D_3= 1.6 mm, H_1=0.8 mm, H_2= 0.8 mm, H_3= 1.4 mm, H_4= 3.5 mm, H_5= 5 mm. The Reflectivity and the Absorptivity curves obtained are depicted in Figure 2 and Figure 3 respectively. As inferred from the Figure 3 that the Absorber have a ultra-wide absorption band width from 3.62 to 4.14 GHz and 7.48 to 21.35 GHz in which the achieved absorptivity is greater than 90%. The periodicity is of 0.09λ_g and the thickness is of 0.02 λ_g, where λ_g is the guide wavelength.

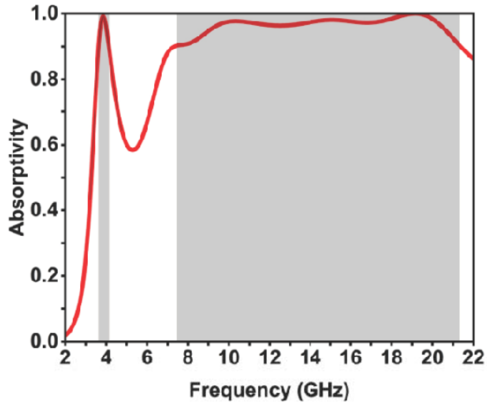

Figure 3. Absorptivity curve for Designed water filled absorber

III. Polarization insensitive and angular stability analysis

The absorptivity of the design absorber is studied for the variation of polarization angle (ϕ) from 0° to 90°. The polarization angle is the angle between Electric field and the magnetic fields which is rotated with the direction of incident wave is kept unchanged. The angle of polarization is varied from 0° to 90° with the step size of 15°. The obtained absorptivity curve is having the similar response for the entire polarization angle as the structure is symmetric. Thus the designed absorber is polarization insensitive for the variation of various polarization angles. The absorptivity curve for variations of incidence angle is analyzed in Figure for TE and TM modes. The Electric field's direction is kept constant while the angle between the magnetic field and the direction of propagation is kept varying at various incident angles for TE mode. And for TM mode the direction of magnetic field is kept constant whiles the angle between the electric field and the direction of propagation is kept varying at various incident angles. As the obtained responses have the similar response for the incident angle variation from 0° to 45°, therefore the designed absorber is wide angular stable till 45° for both TE and TM modes.

Figure. 7 represents the permittivity of water filled as water (Debye model) under room temperature with its real and imaginary part from 2 to 22 GHz. It is depicted that the permittivity is dispersive with respect to frequency, which is responsible for broad impedance matching.

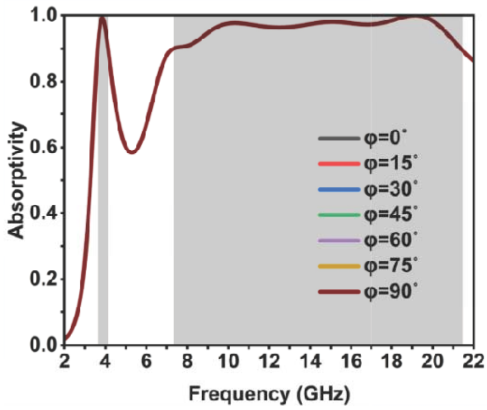

Figure 4. Absorptivity curve of designed water filled absorber for polarization angle variation from 0° to 90° with a step size of 15°.

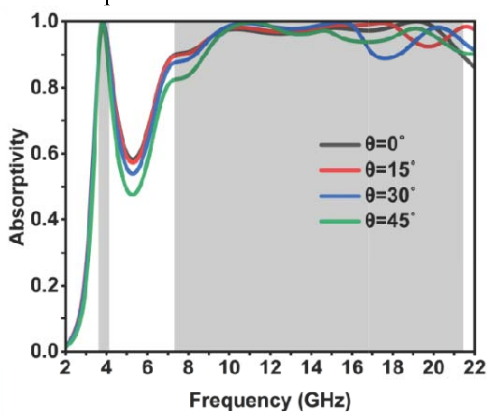

Figure 5. Absorptivity curve of designed water filled absorber for incident angle variation from 0° to 45° with a step size of 15° for TE mode.

IV. Effect of various parameters

The parameters of D_1 is varied from 8 mm to 12 mm is varied and their effects on values of absorptivity is represented in Figure. 8. It is observed that the good response with larger bandwidth is observed for the value of D_1= 10 mm. The value of D_2 is varied from 4 mm to 8 mm and its effect on absorptivity is depicted in Fig 9. It is observed that for D_2= 5 mm the obtained bandwidth of operation is largest amongst them.

The real part and imaginary part of effective permittivity (Eps) and effective permeability(Mu) effective parameters are calculated from following equations(2-5) [8] and are represented in figure. 10.

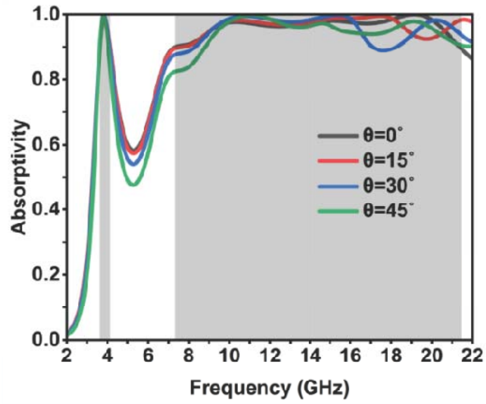

Figure 6. Absorptivity curve of designed water filled absorber for incident angle variation from 0° to 45° with a step size of 15° for TM mode.

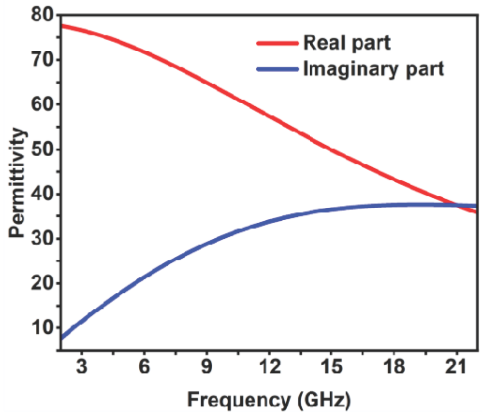

Figure 7. Permittivity of filled water real and imaginary part based on Debye formula.

$$\chi_e = \frac{2j}{k_0}\left[\frac{1-S_{11}}{1+S_{11}}\right] \quad (2)$$

$$\chi_m = \frac{2j}{k_0}\left[\frac{1+S_{11}}{1-S_{11}}\right] \quad (3)$$

$$eps = 1 + \frac{\chi_e}{d} \quad (4)$$

$$mu = 1 + \frac{\chi_m}{d} \quad (5)$$

Where χ_e and χ_m are electric and magnetic susceptibility, d is incident wave's distance travelled and k_0 is free space's wave number. eps is effective permittivity and mu is effective permeability. The real part of Eps and Mu are of opposite sign to each other, which represents zero transmission also intersects at the x axis. Imaginary part of Eps and Mu has defined values which represent the losses which is responsible for absorption.

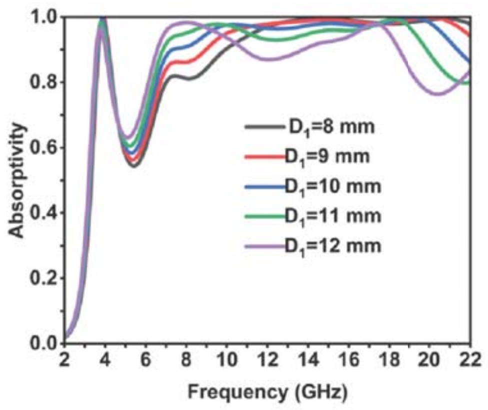

Figure 8. Effect of various values of D_1 on absorptivity

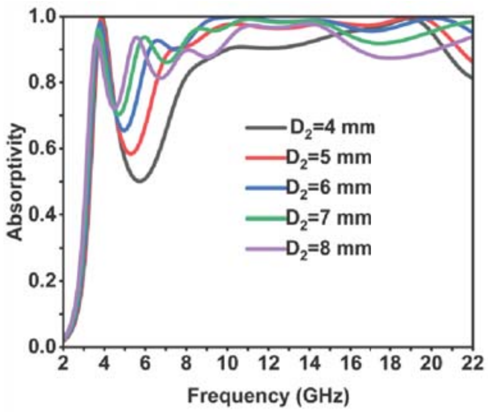

Figure 9. Effect of various values of D_2 on absorptivity

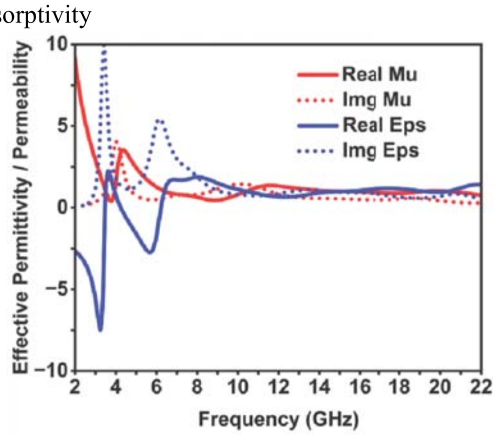

Figure 10. Real and Imaginary part of Effective permittivity (Eps) and Effective permeability (Mu)

V. Conclusion

This paper presents an ultra-wide band with dual bands microwave absorber generated due to high lossy effects of water filled between the PMMA layers and resin cap. The Absorber has the absorptivity greater than 90% 3.62 to 4.14 GHz and 7.48 to 21.35 GHz. The proposed absorber is an ultra thin absorber with a thickness of 0.02 λ_g. The designed absorber have polarization insensitive and angular stable behaviors for both TE and TM modes. The effect of various parameters on absorptivity is studied. Also the constituent parameter effective permittivity and permeability is derived from the equation and absorptivity is observed. As the designed absorber has an ultra high frequency band therefore finds application in various purpose in S, C, X, Ku and K bands.

References

[1]. R. K. Mishra, R. D. Gupta, and S. Datar, “Metamaterial Microwave Absorber (MMA) for Electromagnetic Interference (EMI) Shielding in X-Band,” *Plasmonics*, vol. 16, no. 6, pp. 2061–2071, 2021, doi: 10.1007/s11468-021-01465-y.

[2] M. Amano and Y. Kotsuka, "Detailed Investigations on Flat Single-Layer Selective Magnetic Absorber Based on the Equivalent Transformation Method of Material Constants," in *IEEE Transactions on Electromagnetic Compatibility*, vol. 57, no. 6, pp. 1398-1407, Dec. 2015, doi: 10.1109/TEMC.2015.2475282.

[3] R. Panwar, S. Puthucheri, V. Agarwala and D. Singh, "Fractal Frequency-Selective Surface Embedded Thin Broadband Microwave Absorber Coatings Using Heterogeneous Composites," in *IEEE Transactions on Microwave Theory and Techniques*, vol. 63, no. 8, pp. 2438-2448, Aug. 2015, doi: 10.1109/TMTT.2015.2446989.

[4] S. Jain and R. Sharma, "Designing of Polarization Insensitive Microwave Absorber for WLAN Application," *2023 IEEE Wireless Antenna and Microwave Symposium (WAMS)*, Ahmedabad, India, 2023, pp. 1-4, doi: 10.1109/WAMS57261.2023.10242798.

[5] V. Kondigari and S. R. Thummaluru, "Bandwidth Enhancement of Metamaterial Absorber using Resistive Loading for X- and Ku-Band Applications," *2024 IEEE Wireless Antenna and Microwave Symposium (WAMS)*, Visakhapatnam, India, 2024, pp. 1-5, doi: 10.1109/WAMS59642.2024.10527832.

[6] M. Yoo, H. K. Kim, S. Kim, M. Tentzeris and S. Lim, "Silver Nanoparticle-Based Inkjet-Printed Metamaterial Absorber on Flexible Paper," in *IEEE Antennas and Wireless Propagation Letters*, vol. 14, pp. 1718-1721, 2015, doi: 10.1109/LAWP.2015.2420712.

[7] H. Xue, H. Cong, Z. Fu, Z. Zhu, L. Liu and Z. Li, "Function switchable broadband saline water-based metamaterial absorber," *2023 International Conference on Microwave and Millimeter Wave Technology (ICMMT)*, Qingdao, China, 2023, pp. 1-3, doi: 10.1109/ICMMT58241.2023.10277159.

[8] Kalraiya, Sachin & Chaudhary, Raghvendra & Gangwar, Ravi. (2021). “Polarization Independent Triple Band Ultrathin Conformal Metamaterial Absorber for C- and X-Frequency Bands,” AEU - International Journal of Electronics and Communications. 135. 153752. 10.1016/j.aeue.2021.153752.