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# Highly Efficient and Compact Dual-Band Polarization-Insensitive Metamaterial Absorber for C- and X-Band Applications

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**Abstract- A dual band absorber has been analyzed in this work. The rectangular formed shaped is analyzed using the floquent mode of analysis and also it is working at two different frequencies. The metamaterial absorber is compact sized absorbers and used for flexible electronics as it is designed using FR4 substrate. The absorbers analysis has been carried out using ANSYS HFSS and its absorption at different frequencies are recorded above 98% in all two different band of frequencies. The simulation analysis proven good agreement that absorber is good candidate for future C- and X- band applications.**

***Key words: Metamaterial absorber, terahertz, absorption bands, absorption, polarization.***

## 1. INTRODUCTION

Metamaterials have significantly transformed multiple technological fields due to their engineered electromagnetic properties. This paper explores the latest advancements in metamaterial absorbers (MMAs) and proposes a novel dual-band polarization-sensitive MMA. The unique characteristics of metamaterials have made them highly desirable for numerous applications, driving research toward the development of efficient absorbers.

Various researchers have explored MMA designs for applications such as acoustic devices, stealth technology, and advanced lens systems, contributing to breakthroughs in radar, communication systems, and electromagnetic shielding. Recent studies have highlighted remarkable properties of MMAs, including broadband absorption, polarization-independent behavior, and tunable performance. Additionally, innovations have led to the creation of high-performance absorbers, miniaturized structures, flexible and stretchable designs, wearable absorbers, active configurations, and ultrathin quad-band absorbers. These advancements continue to expand the potential of MMAs across various scientific and engineering domains.

The unique electromagnetic properties of metamaterials have brought groundbreaking advancements across multiple scientific and engineering fields. This paper explores the latest progress in metamaterial absorbers (MMAs) and introduces a novel dual-band polarization-sensitive MMA designed for enhanced absorption efficiency. Due to their ability to manipulate electromagnetic waves in ways not possible with conventional materials, metamaterials have become a widely researched topic, finding applications in diverse areas. The increasing demand for high-performance absorbers has driven extensive research into MMA design, leading to various innovative configurations. Researchers have explored different structures for applications such as acoustic devices, stealth and camouflage technology, and advanced lens systems. These developments have significantly contributed to cutting-edge solutions in radar technology, wireless communication systems, and electromagnetic shielding.

Recent studies have demonstrated that MMAs exhibit extraordinary properties, such as broadband absorption, polarization insensitivity, and tunability. These attributes make MMAs an essential component in modern electromagnetic applications, paving the way for more efficient and compact designs that can be utilized in next-generation technologies. For example, we have achieved broadband absorption [1], polarization-independent absorption [3], and tunable performance [4], [12], [13]. Furthermore, there have been advancements in the development of high-performance absorption [6], miniaturized designs [7], [8], stretchable absorbers [10], wearable absorbers [14], active configurations [15], and ultrathin quad-band absorbers [19].

The proposed MMA has the stacked substrate and remaining are reconfigurable frequency based on the requirement of the application. In the second section describe the detail structure and design of an antenna with a detailed pictures of the iteration approach have taken. The iteration and the simulation of the antenna in the stand-alone mode and conformal on the vehicle is also presented with details. The bending effects results are also discussed with details. The MMA prototype is discussed with supporting measured results along with prediction of far-field performance on thew vehicle.

## 2. PROPOSED DESIGN

A new design has been proposed for a single layer polarization-insensitive dual band metamaterial absorber at C and X-bands. The proposed structure consists of a periodic arrangement of a circular resonator embedded in a square resonator. The commercially available FR4 dielectric has been used as substrate with metallic grounded bottom and imprints on the other side. This structure resonates at 5.5 GHz and 8.9 GHz with absorptivity of 99.8 % and 99.97 %, respectively. It exhibits polarization-insensitive behavior for transverse electric and transverse magnetic polarization under oblique and normal angles of incidence.

The field distributions have been studied for better understanding of the absorption mechanism. The fabricated structure has been tested and the experimental results are similar to the simulation results. This polarization-insensitive metamaterial absorber with its ease of design and nearly unity absorption can be used for radar applications. Many researches have been performed on dual band metamaterial absorber. The dual band metamaterial absorber designed at 11.15 GHz and 16.01 GHz exhibited high absorption values of 97 % and 99 % (Li et al., 2010). Lee et al. (2012) presented MMA with complementary split ring resonators and split ring resonators operating at 2.95 GHz and 3.60 GHz with absorption of 92 % and 94 %, respectively. Ni et al. (2013) used a single square ring with slits to design dual band metamaterial absorber, which was polarization-insensitive. The absorptivity of 96 % and 99% was achieved at 10 GHz and 20 GHz, respectively

Proposed Design and Simulated depicts the top layer of the proposed metamaterial absorber unit cell. The metamaterial structure was chosen for its simplicity and ease of designing. It was optimized to give negative permittivity and permeability with high absorption with less reflection leading to high absorption performance. The structure consisted of dielectric FR4 substrate of thickness 1 mm (relative permittivity) $\varepsilon_r = 4.3$, dielectric loss tangent ($\tan \delta = 0.025$) separating the metallic imprints and the metal laminated bottom ground. The top layer comprised of circular and square shaped ring resonators. The dimensions were a = 10 mm, b = 8 mm, w1 = 0.4 mm, w2 = 0.5 mm and r = 3.3 mm. The copper ($\sigma = 5.8\times107$ S/m) of thickness 0.035 mm was used for both the metal layers. Using Ansys HFSS, the designed structure has been simulated with periodic boundary conditions. For this periodic structure, floquet port excitation was used. When a wave is incident on the proposed metamaterial absorber, the transmission of the wave is obstructed by the copper grounded bottom, so the transmission coefficient $S_{21}$ becomes zero. The impedance matching achieved by proper tuning of the structure leads to zero reflection.

Therefore, the plane waves are completely absorbed by the metamaterial absorber. Initially, the metamaterial absorber with circular resonator was designed, as shown in and was simulated. This structure resonated at 8.8 GHz and had an absorptivity of 90.1 %, which is shown in depicts a square shaped metamaterial absorber that was designed separately and simulated. It showed 95 % absorptivity at 5.6 GHz.

In figure 2, the provided graph, generated from ANSYS, depicts Absorptivity vs. Frequency for different incident angles (θ) in an electromagnetic simulation of a metamaterial absorber. The multiple curves represent variations in absorptivity across different angles, demonstrating the absorber's angular performance. The presence of distinct absorption peaks at specific frequency bands suggests resonant absorption behavior, with strong absorption observed in two primary frequency ranges. This indicates that the absorber is designed for stable operation across multiple angles.

The proposed MMA in Figure.1 is the combination of circular and square resonators and the simulated absorptivity is presented in Fig. 3. It was observed that, this structure had a reflectivity of -27 dB and -37 dB with an increased absorption of 99.8 %, 99.97 % at 90 5.5 GHz and 8.9 GHz, respectively.

Figure.4 represents S-parameters (specifically return loss) of the proposed design across a frequency range. The deep notches in the curve indicate resonant frequencies where strong absorption or minimal reflection occurs, confirming efficient impedance matching at these points. The observed multiple dips suggest that the structure operates as a dual-band or multi-band absorber. Figure. 7 provided the variation of absorptivity with frequency for different phi (ϕ) angles. Multiple curves indicate the response of the metamaterial absorber at varying polarization angles, assessing its polarization sensitivity. The variation in peak intensities across different phi angles helps evaluate the absorber's performance under diverse polarization conditions.

Much of the surface current distribution was within the outer ring, thereby contributing to absorption at 5.5 GHz as shown in figure 7. The surface current distributions in show that the absorption at 8.9 GHz is due to the inner circular resonator. The electric field is incident on the metallic top layer and the magnetic field is perpendicular to the circulating current loop. The electric and magnetic fields become prominent at resonance frequencies; hence high absorption is achieved. These field responses are controlled by proper design optimization leading to nearly unity absorption at the dual band.

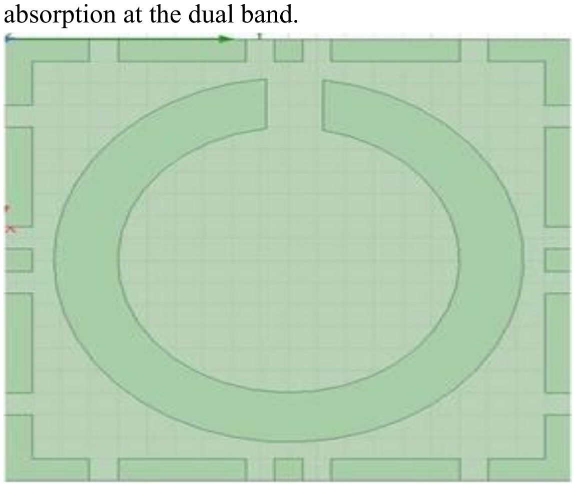

Figure 1: Proposed design

The proposed metamaterial absorber structure was fabricated on FR4 dielectric substrate of thickness 1 mm through printed circuit board technology. The size of the fabricated structure was 300 mm × 360 mm, and it is presented. The measurement set up diagram is shown in the figure 1. The vector network analyzer, with the help of broadband horn antennas, was used to measure the power reflected from the fabricated structure. At first, a copper sheet with the same dimension as that of the fabricated structure was placed. The reflected power was measured and it was used as a reference. Then, the copper sheet was replaced by the fabricated structure and the power reflected from the structure was measured.

The actual reflection from the fabricated MMA was the difference between the reflection measured from the structure and the reference measurement. The experimental result showed peaks at 5.44 GHz and 9.04 GHz with 98.88 % and 99.9 % absorptivity, respectively. A small deviation in the measured absorption may be due to the fabrication imperfections. The experimentally measured and simulated reflection and its absorptivity are compared in The TE polarization-insensitive behavior of the fabricated structure was verified for the normal angles of incidence by rotating the structure in steps of 5° and placing the antennas in static position., it is observed that the proposed structure is polarization- insensitive for 20°, 45° and 60° under normal angles of incidence and there is a slight variation in absorptivity peaks compared to the simulated response.

## 3. RESULTS AND ANALYSIS

The absorptivity and the unit cell size of the proposed structure was compared with metamaterial absorbers whose frequency band was closer to the frequency band of the proposed MMA, and are listed in Table 1. The unit cell size of the proposed structure was the same as that of the triple band MMA designed by Bhattacharyya et al. (2014). However, the absorptivity obtained by the proposed MMA at 5.5 GHz was higher than that of the latter structure. The proposed MMA had a comparable unit cell size and absorption of the structure designed by Zhai et al. (2013) near 8.9 GHz, but it has the advantage of achieving dual bands leading to added practical use.

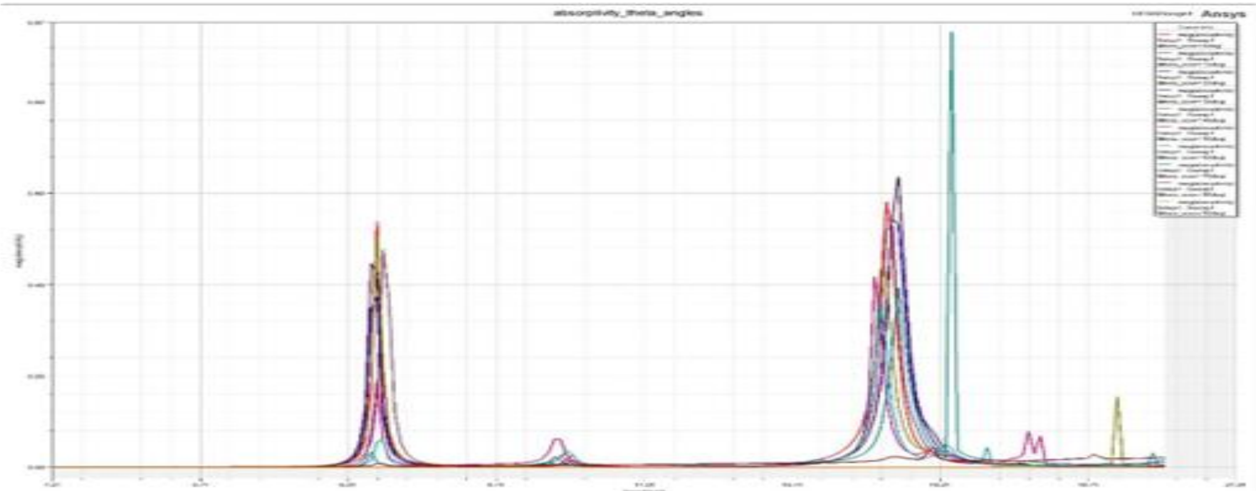


Figure 2: Absorbity vs frequency theta angles

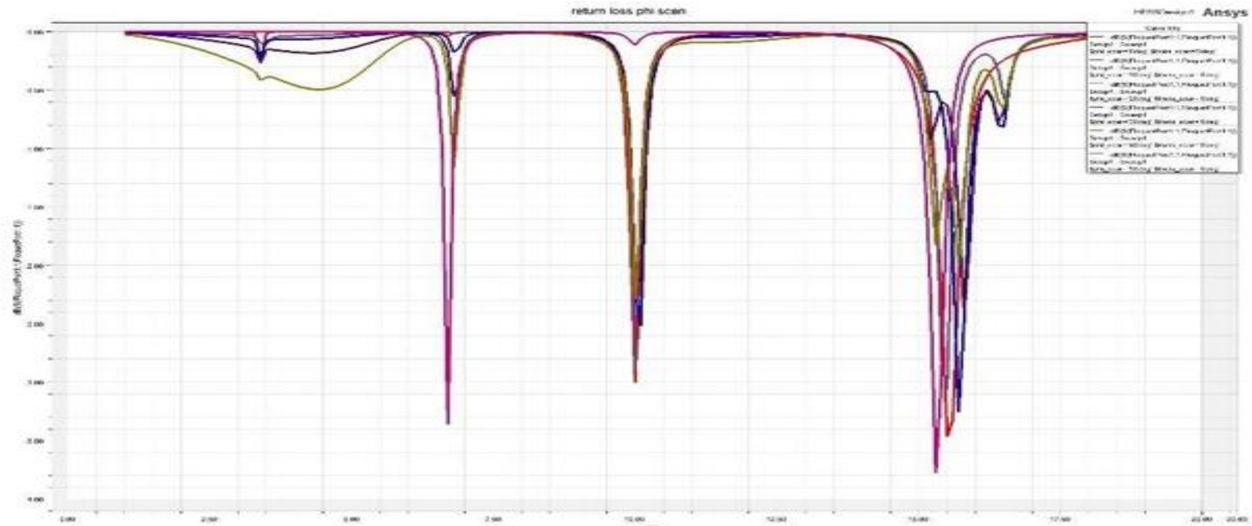


Figure:3: Absornbity vs frequency phi angles

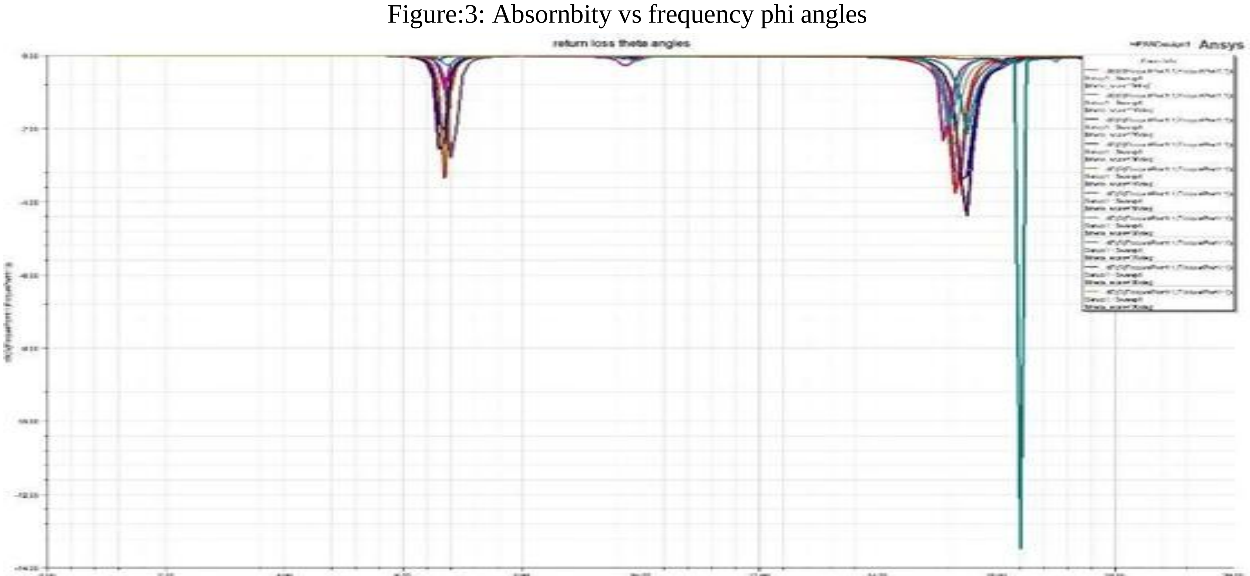


Figure:4 S parameters of proposed design

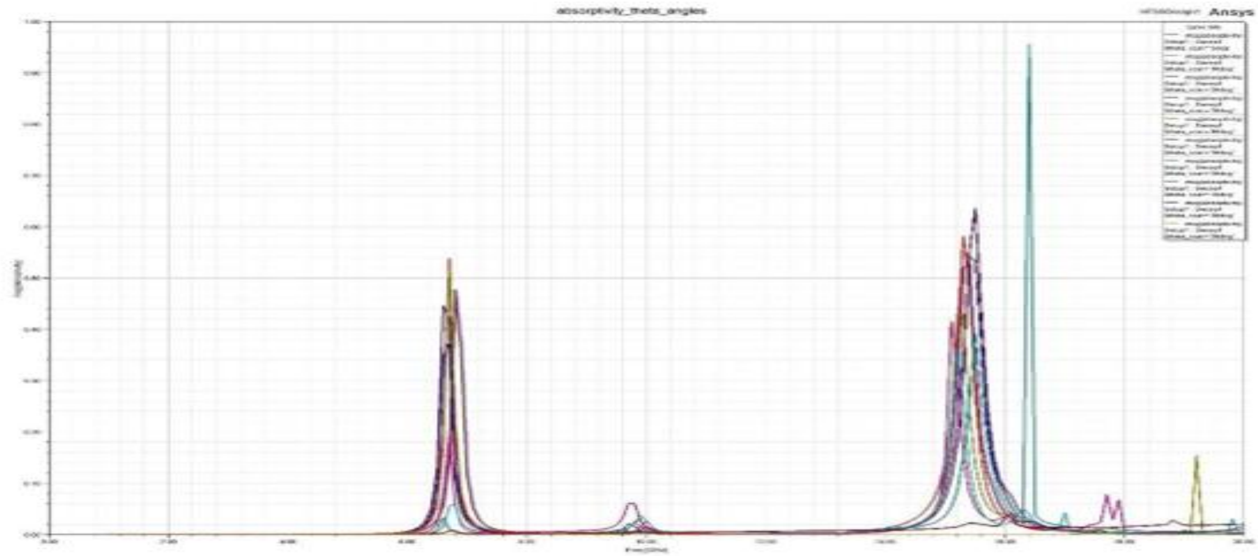


Figure:5 Parametric S parameters

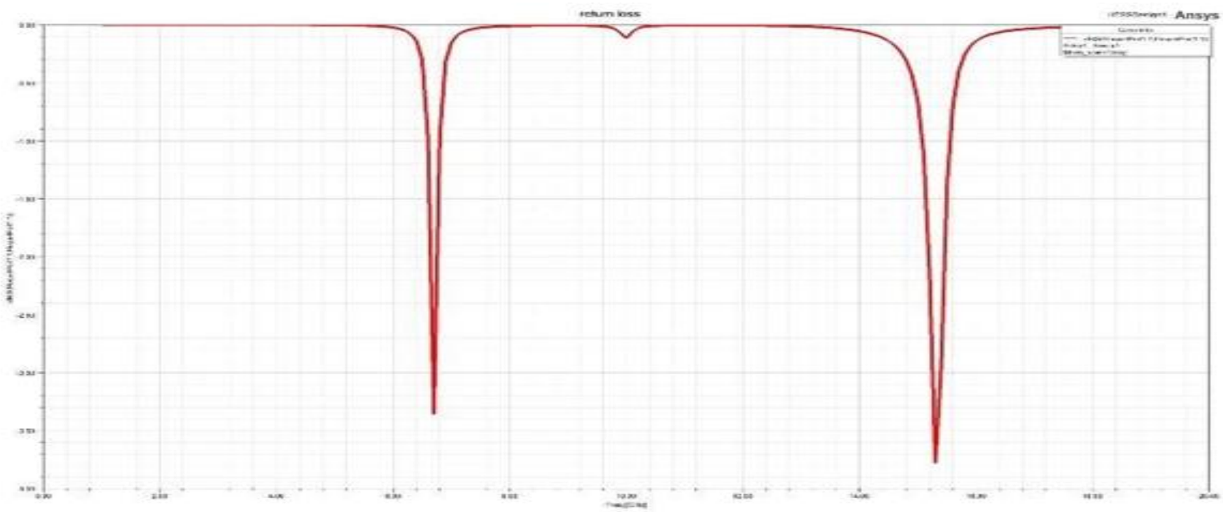


Figure:6 Parametric variations of proposed design

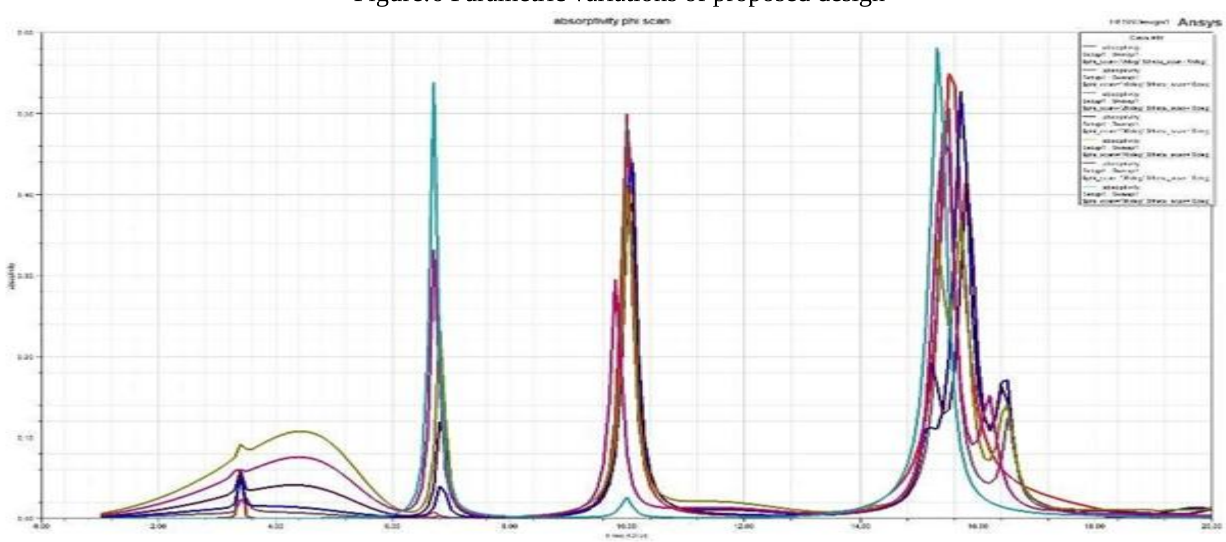


Figure 7: theta angles of absorbity and frequency

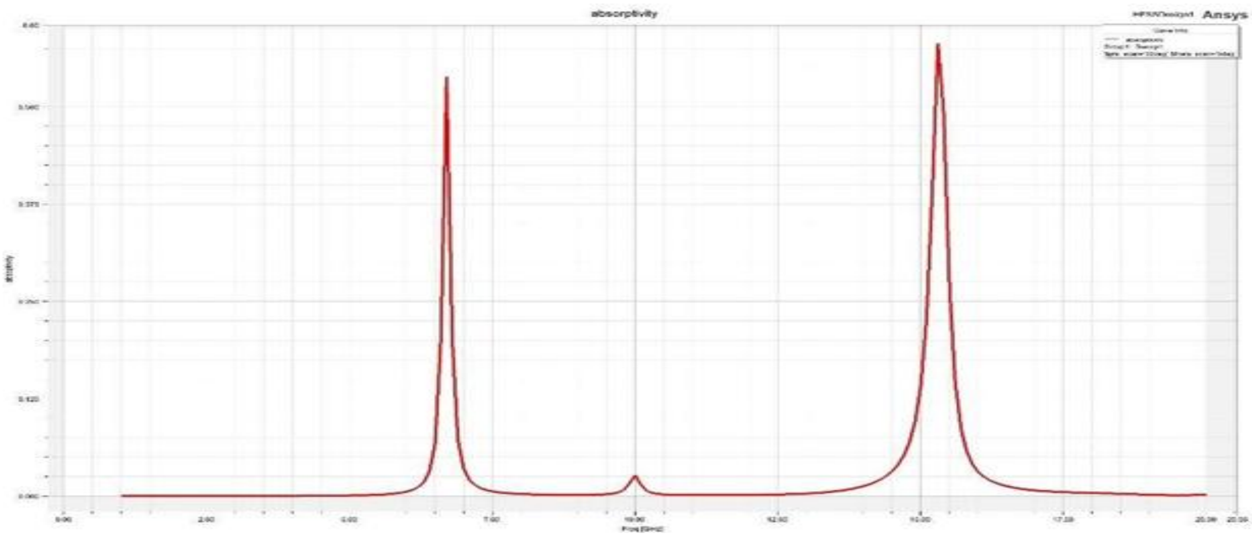


Figure 8: Absorbity vs frequency

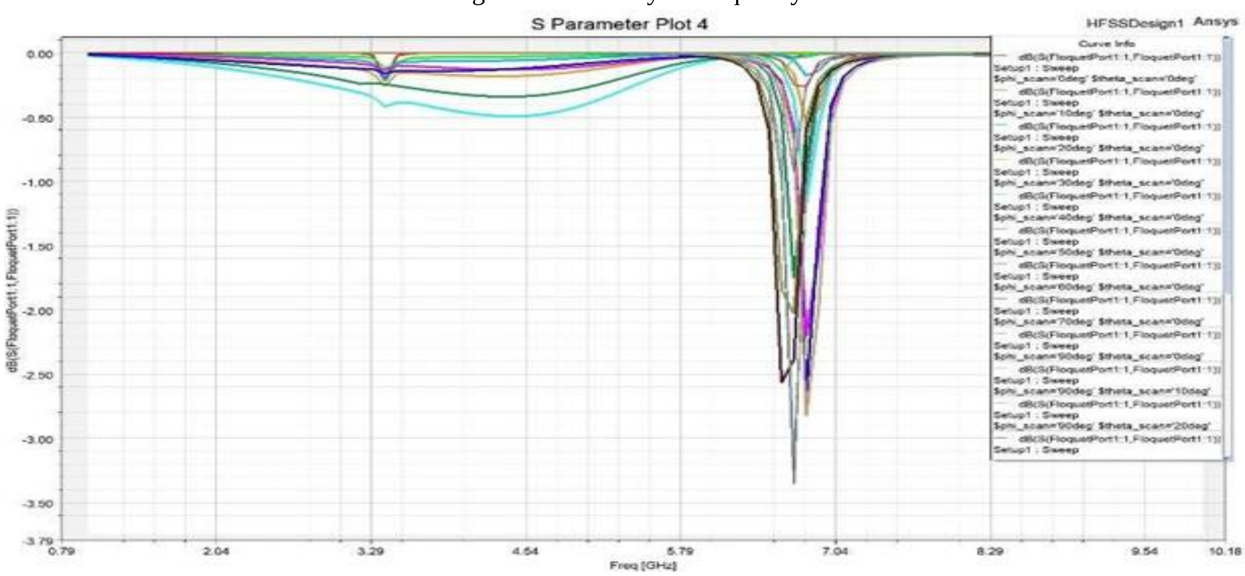


Figure 9: S parameters of proposed design

The proposed absorber has achieved good correlation with the cited research works shown in the following table 1.

| [Ref] | Absorber configuration | Frequency Band of operation [GHz] | Size of the unit cell (in mm) | Absorbed bands | % Absorption |
|---|---|---|---|---|---|
| [2] | Metamaterial resonators | 11.5 | 12 x 4.2 x 0.2 | 1 | > 88% |
| [4] | Metamaterial resonators | 11.76-14.43 | 72 x 72 x 3 | 1 | > 90% |
| [7] | Hybrid dielectric layer absorber | 1.35-3.5 | 20 x 20 x 1.6 | 1 | > 90% |
| [8] | Square loop loaded lumped resistor MMA | 0.86-0.96 | 20 x 19.2 x 1.6 | 1 | > 90% |
| [10] | Stretchable Metamaterial Absorber | 11-11.4 | 8 x 8 x 3 | 1 | > 90% |
| [11] | Ultra-thin Metamaterial Absorber | 3.25, 9.45, 10.9 | 11 x 11 x 1.03 | 3 | > 90% |
| [14] | Wearable MMA | 9, 9.85 | 30 x 30 x 1 | 2 | > 90% |
| [15] | Active MMA | 4.3, 5.9 | 13.8 x 13.8 x 1 | 2 | > 90% |
| [16] | Ultra-Wideband MMA | 0.8-2.7 | 20 x 20 x 1.6 | 1 | > 90% |
| Proposed | Metamaterial absorber | 5.5 & 8.9 | 30x 36 x 1.6 | 2 | > 98% |

Table 1. comparison of different absorbers structures with proposed

## 4. CONCLUSION

A new design for polarization-insensitive dual band metamaterial absorber has been proposed. The proposed structure had two different shaped ring resonators etched on FR4 dielectric substrate operating at C and X-bands. The inner circular and outer square resonators provide absorption of 99.97 % at 8.9 GHz (X-band) and 99.8 % at 5.5 GHz (C-band), respectively. The electric field and surface current density were plotted at two distinct frequencies, and their absorption mechanisms were also examined. The proposed structure exhibited polarization-insensitive behavior for transverse electric and transverse magnetic modes at particular angles for normal and oblique incidence. The designed metamaterial absorber structure was fabricated and tested. The experimental results matched the simulated results. Further, the measured results prove the polarization insensitivity of the proposed structure. Hence, this polarization-insensitive dual band metamaterial absorber with near-unity absorption may be well suitable for radar applications.

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