A CONCEPT ON METAMATERIAL ABSORBERS FOR VARIOUS APPLICATIONS

Lakshmi Mishra, Meha Shrivastava, Rajesh Sharama

ABSTRACT

Conventional wideband absorbers used for different applications suffer from narrow bandwidth and their fabrication is also complicated because they are fragile and hard. To overcome the limitation faced by conventional absorber metamaterial absorbers are proposed. Metamaterial are artificial material whose properties are not similar as compare to nature occurring material. The metamaterial absorber proposed by different researchers are thin and easy to fabricated. In this article a review of different metamaterial absorbers for various frequencies is analysed and summarized.

Index Terms— Metamaterial, Wideband absorber, Bandwidth, Electromagnetic wave, fragile, fabrication, frequencies.

1. INTRODUCTION

Metamaterial are manmade artificial materials whose electromagnetic properties are not similar to the natural occurring materials [1]. Due to these unique electromagnetic properties' metamaterial finds applications in different field such as superlense [2], cloaking [3], antennas [4], resonators [5], sensors [6], absorbers [7], etc. Metamaterial are periodic structures which have permittivity and permeability both are negative simultaneously or zero for a particular frequency or a range of frequency [8]. Using this concept of metamaterial different metamaterial absorbers is proposed whose absorption is approaching toward unity and almost perfect absorption is achieved at different frequencies [9].

1.1 Absorption Phenomenon

The absorption phenomenon of metamaterial absorber is mathematically given by equation1 [10]

- *Lakshmi M.Tech scholar Dept. of Electronics and Communication Engineering Truba Institute of Engineering & Information Technology, Bhopal, India E-mail:lakshmimishra8989@gmail.com*
- *Meha Shrivastava Professor & Head of Dept. Electronics and Communication Engineering Truba Institute of Engineering & Information Technology,Bhopal,India Email:meha.shrivastava@trubainstitute.ac.in*
- *Rajesh Sharma Assistant Professor Dept. Electronics and Communication Engineering Truba College of Science & Technology,Bhopal,India Email: raj.oist@gmail.com*

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

Where S_{11} and S_{21} represent the reflected and transmitted power respectively. In equation 1 parameter is zero because the ground plane of metamaterial absorber is fully covered with copper due to this no wave can transmitted through the structure and absorptivity fully depend upon the parameter and now absorptivity is represented as equation 2.

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

Lower the value of means absorptivity approaching toward unity increases and more waves is absorbed by the metamaterial absorber.

1.2 Absorption Mechanism

The absorption mechanism can be explained by evaluating the effective electromagnetic parameters (ε_{eff} and μ_{eff}) by applying the formulae [11] as:

$$Z = \sqrt{\frac{(1+S_{11})^2 - S_{21}^2}{(1-S_{11})^2 - S_{21}^2}} \qquad (3)$$

$$n(\omega) = \frac{1}{kt}\cos^{-1}\left[\frac{1}{2S_{21}(1-S_{21}^2-S_{11}^2)}\right] \qquad (4)$$

Where, S_{11}= scattering parameter (reflected power)

S_{21}=scattering parameter (transmitted power)

η= refractive index

Z= impedance

d= thickness of MA

k= wave number.

In equation 3 and 4 to calculate impedance and refractive index parameter is required, but copper is placed in the ground plane therefore is zero. To calculate small square slot is remove from all four corners of the ground plan is such a manner so that there will be no distribution in the absorption curve.

Now impedance and refractive index is calculated. Using the relation given by equation 5 and 6 the effective electromagnetic parameters is evaluated [12].

$$\varepsilon_{eff} = \frac{\eta}{z} \text{ and } \mu_{eff} = \eta Z \qquad (5)$$

$$Z(\omega)=\sqrt{\frac{\mu_0\mu_{eff}}{\varepsilon_0\varepsilon_{eff}}} = \eta_0\sqrt{\frac{\mu_{eff}}{\varepsilon_{eff}}} \qquad (6)$$

$$\text{Normalized Impedance } =\frac{Z(\omega)}{\eta_0} \qquad (7)$$

2. Multi-band Metamaterial Absorbers

Initially metamaterial absorbers proposed have narrow bandwidth and they operate at particular frequencies therefore they are termed as single, double, triple, quad, penta and multi band absorbers depending upon number of absorptivity respectively.

2.1 Single Band Metamaterial Absorbers

Single band metamaterial absorber proposed by Jingping Zhong et al. in 2012 absorb nearly perfect absorption at 8.6 GHz frequency. The structure of metamaterial absorber consists of cross circular loop resonator with shorted stub. The overall dimension of unit cell structure is 5mm 5mm. The substrate used is commercially available Rogers RO4003 [13]. The proposed design and absorptive curve are shown in fig.1.

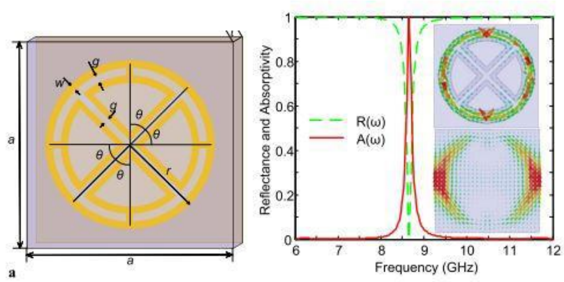

Fig. 1 Proposed Metamaterial Absorber design and absorptivity curve.

Pramod K. Singh et al. in 2011 proposed a single band metamaterial absorber at 77 GHz frequency. The structure consists of c shape split ring resonator; single c shaped resonator consists of split ring provide single band absorption. The substrate used is a flexible polymide substarte [14]. The proposed design and absorptive curve is shown in fig.2.

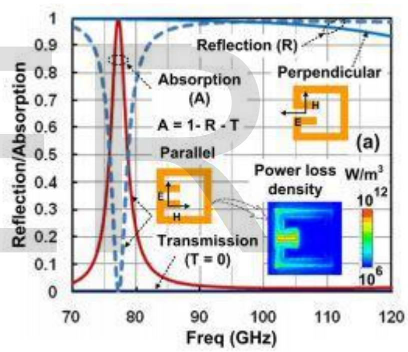

Fig. 2 Proposed Metamaterial Absorber design and absorptivity curve.

2.2 Double Band Metamaterial Absorbers

Hu Tao et al. in 2010 present dual band metamaterial absorber whose characterization and fabrication is done at two peaks are obtained at 0.85 and 1.4 THz. The structure consists of a metallic ground plane and dual band electric field coupled resonator. The overall dimension of the structure is 33.3 × 23.3 [15]. The proposed design and absorptive curve are shown in fig.3.

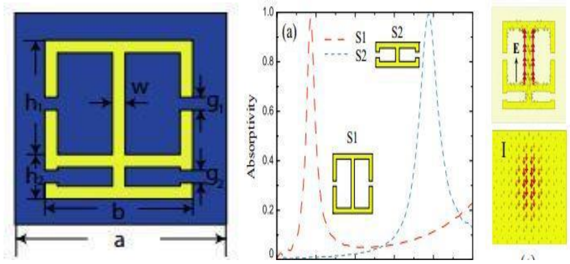

Fig. 3 Proposed Metamaterial Absorber design and absorptivity curve.

Zhaoxian Su et al. in 2015 present an ultra-thin metamaterial absorber at terahertz range. The structure is based on grapheme. Multilayer structure is designed on Au film to obtained dual band absorption [16]. The proposed design and absorptive curve are shown in fig.4.

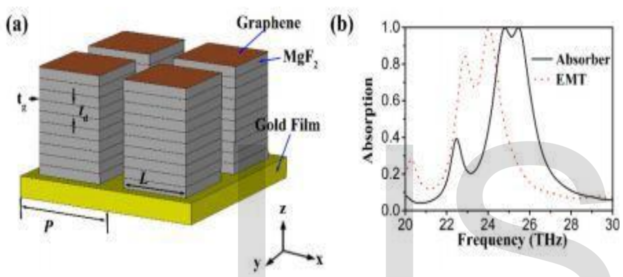

Fig. 4 Proposed Metamaterial Absorber design and absorptivity curve.

M.-H. Li et al. in 2010 present dual band metamaterial absorber in microwave range. Simulation and measurement results confirm that the perfect absorption is achieved at 11.15 and 16.01 GHz. The structure consists of single split ring resonator having overall dimension of a single unit cell is 25 × 25 mm [17]. The proposed design and absorptive curve are shown in fig.5.

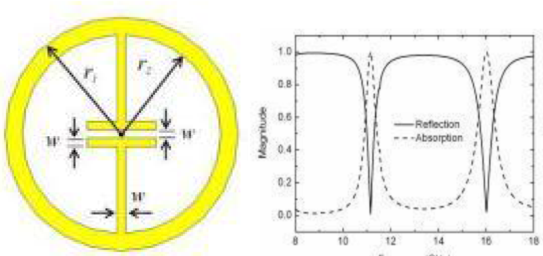

Fig. 5 Proposed Metamaterial Absorber design and absorptivity curve.

H.-M. Lee et al. in 2012 present a new type of a double negative metamaterial absorber based with resonant-magnetic structures, with a periodic array composed of a split-ring resonator and two open complementary split-ring resonators. The overall dimension of the structure if 7.2 6 mm, having perfect absorption at 2.95 and 3.60 GHz [18]. The proposed design and absorptive curve are shown in fig.6.

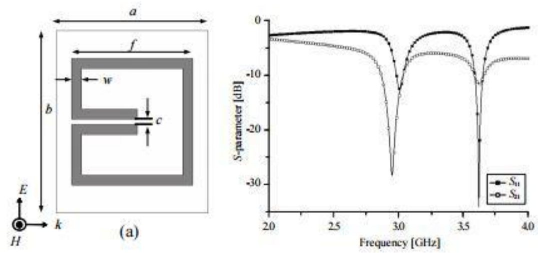

Fig. 6 Proposed Metamaterial Absorber design and absorptivity curve.

2.3 Multi Band Metamaterial Absorbers:

Somak Bhattacharyya et al. in 2013 present square shaped closed ring resonators which have triple band over wide angle of incidence. The proposed structure is polarization-independent. The overall dimension of the unit cell is 18×18 mm. The three absorption peaks exist at 2.55, 7.44 and at 9.96 GHz [19]. The proposed design and absorptive curve are shown in fig.7.

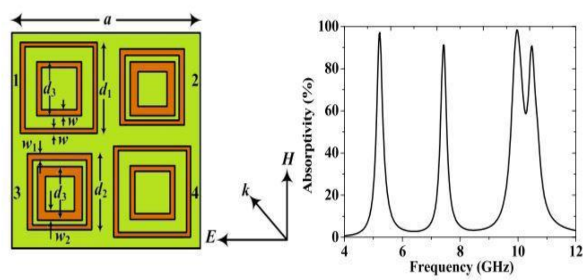

Fig. 7 Proposed Metamaterial Absorber design and absorptivity curve.

Somak Bhattacharyya et al. in 2014 present electric field-driven LC resonators which is polarization-independent over wide angle of incidence. The unit cell parameter is optimizing such that triple band is obtained at 4.74, 5.55 and at 7.98 GHz. The overall dimension of the unit cell is 252×252 mm [20]. The proposed design and absorptive curve are shown in fig.8.

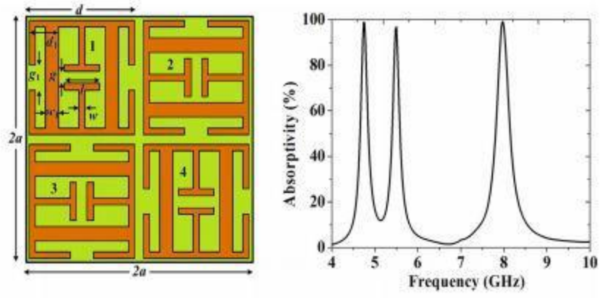

Fig. 8 Proposed Metamaterial Absorber design and absorptivity curve.

M. Agarwal et al. in 2016 propose a closed ring resonator-based quad-band metamaterial absorber. The four different absorption peaks occur at 4.34, 6.68, 8.58 and 10.64 GHz. The overall dimension of the structure is 20 × 20 mm [21]. The proposed design and absorptive curve are shown in fig.9.

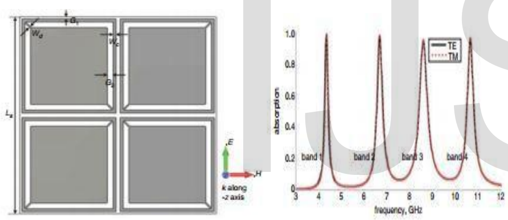

Fig. 9 Proposed Metamaterial Absorber design and absorptivity curve.

Ben-Xin Wang in 2017 present a quad-band metamaterial absorber operated at terahertz region. The structure is a three-layer sandwich structure. The overall dimension of the structure is 70 ×70 mm. The structure consists of four obvious resonance absorption peaks at the frequencies of 1.31, 1.91, 3.40, and 4.00 THz [22]. The proposed design and absorptive curve are shown in fig.10.

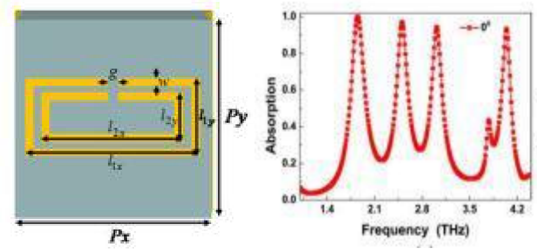

Fig. 10 Proposed Metamaterial Absorber design and absorptivity curve.

Deepak Sood et al. in 2017 present a compact ultrathin band metamaterial absorber having five-band. The structure is fabricated and measurements is done to show five band. The proposed absorber exhibits five distinct absorption peaks at frequencies of 5.28, 7.36, 9.52, 12.64, and 16.32 GHz. The overall dimension of the structure is 10 × 10 mm [23]. The proposed design and absorptive curve are shown in fig.11.

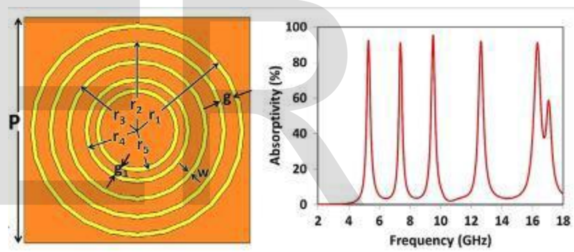

Fig. 11 Proposed Metamaterial Absorber design and absorptivity curve.

Somak Bhattacharyya et al. in 2015 proposes an ultrathin penta-band polarization-insensitive metamaterial absorber which consists of an array of a closed ring embedded in a tetra-arrow resonator. Structure exhibits five distinct absorption peaks at 3.4, 8.34, 9.46, 14.44, and 16.62 GHz. The overall dimension of the structure is 14 × 14 mm [24]. The proposed design and absorptive curve are shown in fig.12.

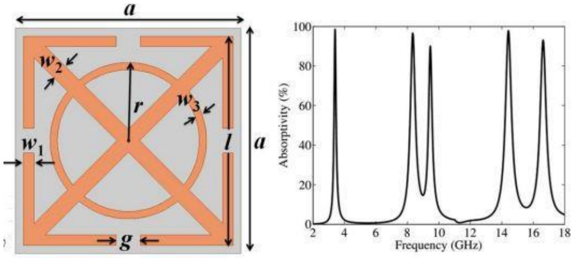

Fig. 12 Proposed Metamaterial Absorber design and absorptivity curve.

Prakash Ranjan et al. in 2018 proposed a six band ultra-thin polarization-insensitive pixelated metamaterial absorber using a novel binary wind driven optimization algorithm. six discrete bands of absorptions at 7.6, 10.1, 13.3, 14.7, 15.8 and 16.7 GHz with more than 90% absorptivity under normal incidence of the wave [25]. The proposed design and absorptive curve are shown in fig.13.

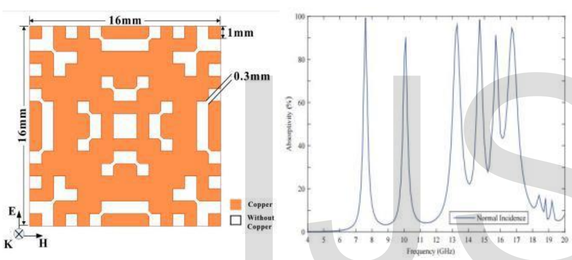

Fig. 13 Proposed Metamaterial Absorber design and absorptivity curve.

3. Wideband Metamaterial Absorbers

Chetan Barde et al. present a set square shape wideband metamaterial absorber for x band applications. The overall dimension of the absorber is 10×10mm. The substrate used is FR4 having thickness of 1.6mm. The set square absorber absorbs incident wave from 8.36 to 10.87 GHz with bandwidth of 2.51 GHz [26]. The proposed design and absorptive curve are shown in fig.14.

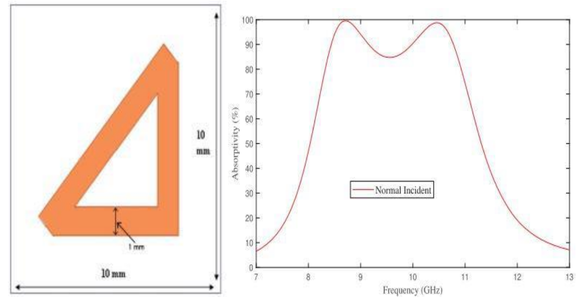

Fig. 14 Proposed Metamaterial Absorber design and absorptivity curve.

4. DESIGN CONSIDERATION

Some essential parameters should be considered for designing multi band and wideband metamaterial absorber

4.1 Resonant Frequency

The resonant frequency is the frequency in which MA is operating. In case of multi band there will be more than one operating frequency but in case of wideband there will be range of frequencies in which absorber is operating. The desired resonant frequencies depend upon the structure design and length and width of the substrate.

4.2 Dimension of substrate

The substrate is the middle layer of the design and it is one of the important parameters in terms of material and thickness. The commercially available substrate is FR4 and Rogers. The thickness can be vary depending upon the resonant frequency.

4.3 Patch Design

Patch design is one of the important parameters in metamaterial absorber, different reported absorbers have different novel designs. Depending on the designs the absorb operate at different frequencies.

Conclusion

This article presents a mechanism, phenomenon and different methods to achieve absorption by using metamaterial. Firstly, single band, double band and multi band metamaterial absorber is discussed followed by wideband metamaterial is discussed in details for different frequencies and for different applications. The basic parameters required for developing metamaterial absorber is also discussed in section 4. There are some problems like bandwidth enhancement, complexity of structure, reduction of gain etc. which need to be solved to make the design work efficiently. Hence, there is a need of further research in problem areas.

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