Polarization Insensitive Absorber with Increased Bandwidth Using Multilayer Metamaterial

Srilaxmi Gangula, MahaLakshmi Vinukonda, Neeraj Rao

***Abstract*—**A wide band polarization insensitive metamaterial absorber with bandwidth enhancement in X and C band is proposed. The structure proposed here consists of a periodic unit cell of resonator arrangements in double layer. The proposed structure shows near unity absorption at frequencies of 6.21 GHz and 10.372 GHz spreading over a bandwidth of 1 GHz and 6.21 GHz respectively in X and C bands. The proposed metamaterial absorber is designed so as to increase the bandwidth. The proposed structure is also independent for TE and TM polarization. Because of its simple implementation, near unity absorption and wide bandwidth this dual band polarization insensitive metamaterial absorber can be used for EMI/EMC applications.

***Keywords*—**Absorber, C-band, meta material, multilayer, X-band.

I. Introduction

METAMATERIALS are the artificially engineered materials to have desired properties which are not found in naturally occurring materials. Metamaterials obtain their properties from the periodic array of unit cells. The precise shape, size and geometry give these materials those properties which cannot be found in naturally occurring materials [1]-[4].

Metamaterials exhibit properties such as negative refractive index and asymmetrical transmission of electromagnetic waves. These unique electromagnetic properties of metamaterial attracted great attention [5]. Metamaterials can be represented by the complex values of magnetic permeability and electric permittivity as per effective medium theory. These properties can be regulated by changing the dimensions of electric and magnetic components [5]. In sub wavelength range, because of their attractive properties, metamaterials are being used in applications such as perfect lens [6], antenna, cloaking [7] etc.

An electromagnetic wave absorber absorbs all the incident electromagnetic waves without any reflection or transmission from its surfaces [8], [9]. The absorbers using metamaterials have an advantage over the conventional absorbers due to their ultra-thin behaviour, perfect absorption having near unity absorption values, simple manufacturing process and more effectiveness. Different types of metamaterial absorbers such as single band absorbers, multi band absorbers, polarization independent and tunable perfect metamaterial absorbers were proposed [10]. Researchers have been trying to enhance bandwidth, improve polarization insensitivity and increase absorptivity and efficiency of metamaterial absorbers.

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The metamaterial absorbers are generally composed of the metallic patch on the top in a periodic array and a metal ground plane separated by a dielectric surface. To eliminate reflection and strongly absorb the incident wave, in a metamaterial absorber, the electric and magnetic resonance makes the absorber possess the matched impedance [11]. Many metamaterial absorbers have been proposed and demonstrated in the micro wave, tera hertz, infrared and optical frequencies. Despite ultra-thin nature and high absorption values, the bandwidth of the metamaterial absorbers is seen to be narrow, as they are operated using the resonance phenomena. However, with the growing technology, to achieve bandwidth enhancement and to achieve multi bands of absorption, significant research is being made [12]. Bandwidth enhancement and polarization insensitiveness can be achieved by methods such as resistive film placement, loading lumped elements and using multi layered structures [13]-[18]. One of the important methods for enhancing the bandwidth is by using multi layered absorber structures [19], [20]. Reference [21] proposes a double layer structure based dual band metamaterial absorber.

In this paper, dual band multilayer bandwidth enhanced metamaterial absorber is proposed. The proposed structure shows near unity absorption in C and X bands. Absorption peak of 99.796% is observed at frequency of 10.372 GHz in X band with a full width at half maximum bandwidth of 3.519 GHz (10.051-13.57 GHz) which is extending into Ku band. Another absorption peak of 97.9% is also observed at a frequency of 6.21 GHz in C band with a full width at half maximum bandwidth of 1 GHz (6.0-7.0 GHz).

The proposed absorber is used in the C-band and X-band. The C-band is a portion of the electromagnetic spectrum in the micro wave range of frequencies ranging from 4-8 GHz. The C-band is used for many satellite communication transmissions, some Wi-Fi transmissions, some Wi-Fi devices, some cordless telephones as well as surveillance and weather radar systems. The frequency range of X-band is 8-12 GHz. Sub-bands of X-band are often used in modern radars, defense tracking etc.

II. Design of the Metamaterial Absorber Unit Cell

The design of the proposed broadband metamaterial absorber unit cell is shown in Fig. 1. The unit cell is designed to achieve high absorption and wide bandwidth. To achieve high absorption, the structure is optimized to provide negative refractive index (i.e., negative permittivity and permeability). This design consists of top, middle and bottom layers as shown in Fig. 3. The structure has two dielectric layers, having a thickness of 1.6 mm. The dielectric layers are composed of FR-4 material. The dielectric constant of FR-4 substrate is 4.3 and the loss tangent is 0.025. The top, middle and bottom (ground) layers are made of copper that has a conductivity of 5.8 X 10^7 S/m. The top and middle layers consist of resonators and the bottom layer at the back of the unit cell is ground plane. These layers are made of copper that has a conductivity of 5.8 X 10^7 S/m. The thickness of resonators as well as ground plane is 0.035 mm.

Fig. 2 shows the front view of the unit cell of the top layer of the proposed structure. The top surface consists of two square shaped rings with splits at the four arms. It also contains a split ring of width r, 1 mm. FR-4 substrate is used as dielectric with 1.6 mm thickness, t and is placed right below it. The next layer below it is the middle layer which is designed as shown in Fig. 2. FR-4 dielectric is present below the middle layer. The middle layer is made of copper of thickness 0.035 mm and two square shaped slots with four arms are made in it.

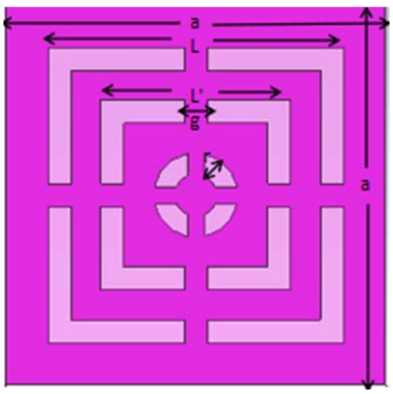

Fig. 1 Middle layer of the design

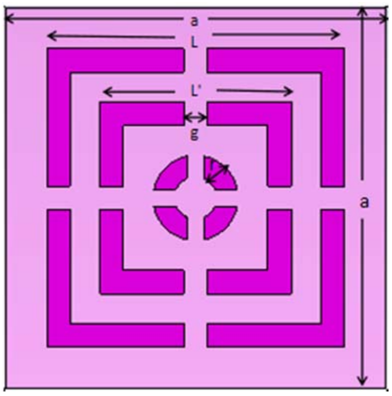

Fig. 2 Top layer of the design

The dimensions of the unit cell as shown in Fig. 1 are a = 18 mm, L = 14 mm, L1 = 9 mm, w = 1.1 mm, g = 1.1 mm and r = 1 mm. These dimensions are optimized for best results. For numerical analysis, CST Microwave Studio based on Finite Integration Technique (FIT) is used. The boundaries in CST along X and Y axes is unit cell and along Z axis is Open. Periodic boundaries are chosen.

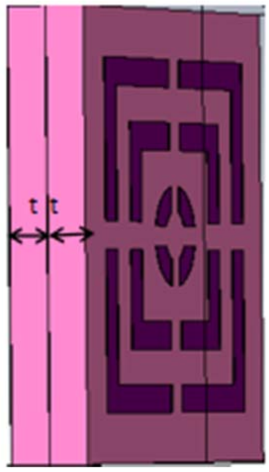

Fig. 3 Side view of structure

III. Simulation Results

The absorption (A) can be calculated by using

$$A = 1 - T - R \tag{1}$$

where R = The reflectance and is given by

$$R = |S_{11}|^2 = \left\{\frac{r_0[1-\exp(i2nk_0d)]}{1-r_0^2\exp(in2k_0d)}\right\}^2 \tag{2}$$

T = The transmittance and is given by

$$T = |S_{21}|^2 = \left\{\frac{(1-r_0)^2[1-\exp(i2nk_0d)]}{1-r_0^2\exp(in2k_0d)}\right\}^2 \tag{3}$$

where $|S_{11}|$ = Reflected power. $|S_{12}|$ = Transmitted Power. d = Length of the slab. n = Refractive index. Z = Impedance. K_0 = Wave number of incident wave in free space. r_0 = (Z-1)/(Z+1).

When the reflected power and the transmitted power are minimized, the absorption can be maximized. As the ground plane is made of copper, there is no transmitted power, |S21| = 0. Hence, the formula for absorption can be modified as

$$A = 1 - |S_{11}|^2 \tag{4}$$

Absorption is near unity when the reflected power is almost zero (i.e., |S11| = 0). When effective permittivity and effective permeability become equal to each other, the Reflected Power (|s11|) becomes equal to zero. Then the impedance of absorber becomes equal to free space impedance at resonance condition. As a result the reflected power is minimized. Therefore, maximum absorption can be achieved.

The proposed structure has been simulated using CST. The simulated results are shown in Fig. 4. From the simulated results, it can be seen that the structure is resonated at two frequencies which are 6.21 GHz and 10.372 GHz having absorption of 99.796% and 97.9% respectively. These absorption frequencies provide a bandwidth of 1 GHz and 3.519 GHz respectively.

The absorptivity of the top surface and the bottom surface of the designed structure is shown in Figs. 6 and 7 respectively. It is observed that the absorptivity and bandwidth of the proposed double layered structure is more than the individual absorptivity and bandwidth of the top layer and middle layer of the proposed structure separately.

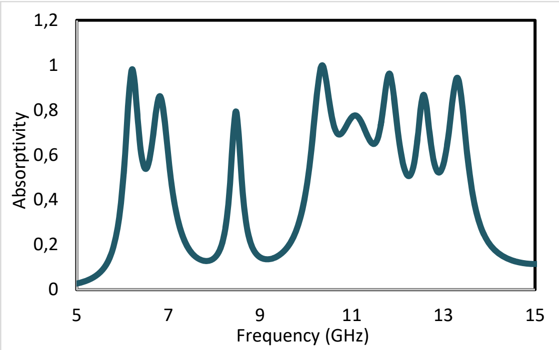

Fig. 4 Absorptivity plot

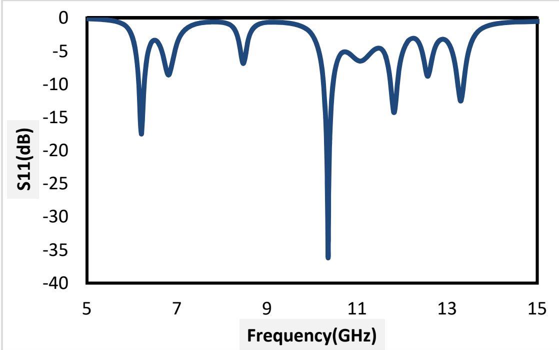

Fig. 5 Reflection coefficient

The magnetic field and the surface current distributions at the two resonant frequencies (6.21 GHz and 10.372 GHz) of the top layer and the middle layer of the proposed structures are shown in Figs. 9 (a), (b), 10 (a), (b) and 11 (a), (b), 12 (a), (b) respectively. Also various parameters such as design size, centre frequencies, absorptivity and HFBW of different designs are compared and tabulated in Table I.

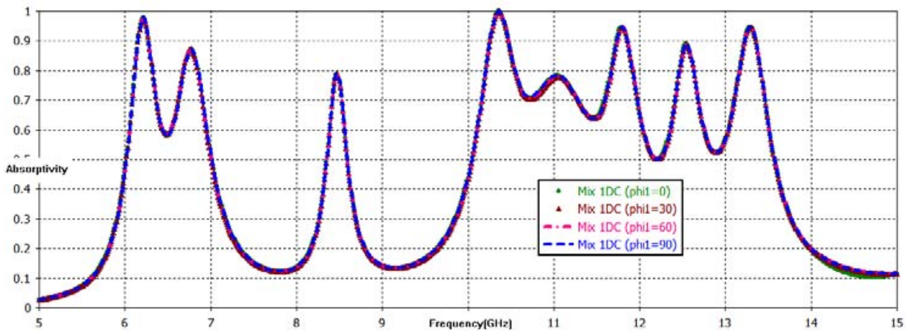

Fig. 6 Absorptivity for various angles of incidence

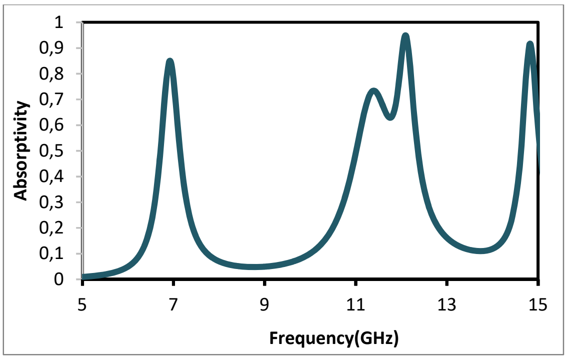

Fig. 7 Absorptivity of top layer

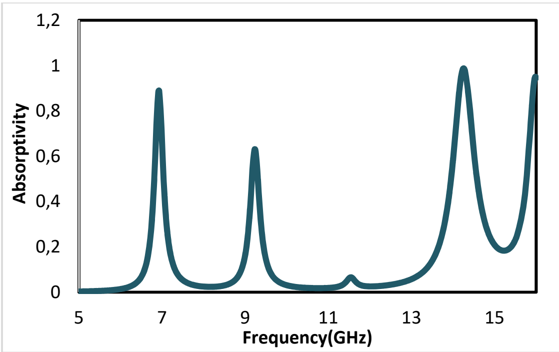

Fig. 8 Absorptivity of middle layer

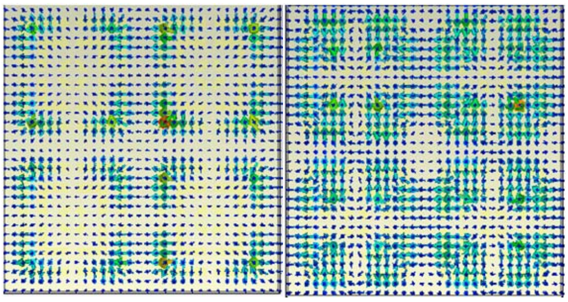

Fig. 9 (a) H-field of top layer (6.21 GHz)   Fig. 9 (b) H-field of top layer (10.37 GHz)

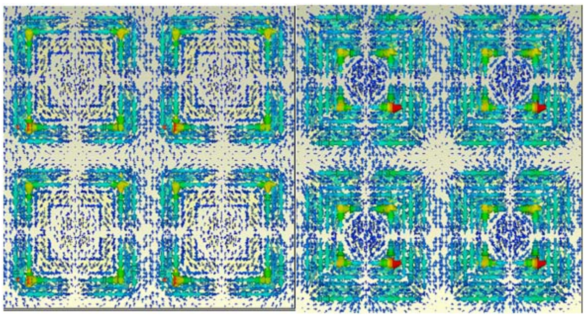

Fig. 10 (a) surface current of top layer (6.21 GHz)   Fig. 10 (b) surface current of top layer (10.37 GHz)

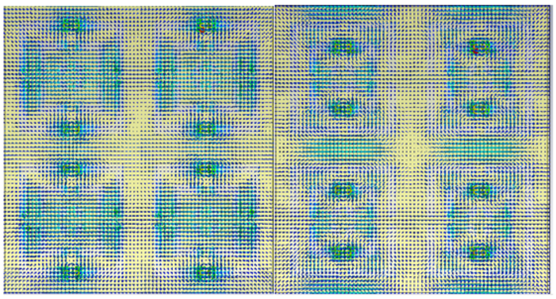

Fig. 11 (a) H-field of middle layer (6.21 GHz)   Fig. 11 (b) H-field of middle layer (10.37 GHz)

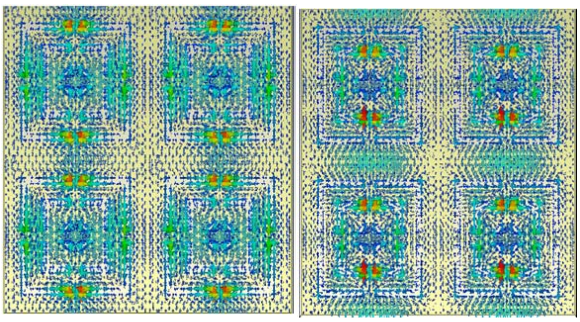

Fig. 12 (a) surface current of middle layer (6.21 GHz)   Fig. 12 (b) surface current of middle layer(10.37 GHz)

IV. Conclusion

The proposed structure shows almost perfect absorption at frequencies of 6.21 GHz and 10.372 GHz spreading over a bandwidth of 1 GHz and 6.21 GHz respectively. The H-field and surface current distributions are depicted for both top layer and middle layer to illustrate the absorption mechanism. The absorptivity and bandwidth of the proposed structure are compared with different designs and it is observed that optimum bandwidth and absorptivity is obtained for the proposed structure. The absorptivity remains same for various angles of incidence. Hence it is polarization insensitive. This absorber can be used for EMI and EMC applications in X and C bands, where maximum bandwidth is observed.

TABLE I
COMPARISON OF PROPOSED STRUCTURE WITH OTHER DESIGNS

Reference number	Number of bands	Design size	Centre frequencies (GHz)	Absorptivity (%)	HFBW (GHz)
20	3	14X14	2.9, 4.2	Around 90	0.27, 0.24
11	1	5.8X5.8	10	93	0.94
21	2	Hexagon of diagonal 14.2 mm	9.75, 10.36	About 98	1
proposed	2	18X18	6.21,10.372	About 99	1,6.21

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