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A RETROPECT SURVEY ON METAMATERIAL ABSORBER CONFIGURATION, EXECUTION AND APPLICATION

Shwetank Yadav[1], Garima Tiwari[2]

[1]ME scholar Dept. of Electronics and Communication Engineering Jabalpur Engineering College JEC, Jabalpur, India
[2]Assistant professor Dept. of Electronics & Communication Engineering Jabalpur Engineering College JEC, Jabalpur, India

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ABSTRACT:- This paper examines conceivable advantages of different metamaterial absorber prototype and their outcome. Metamaterial are synthetic arrangement that enhance electromagnetics properties evaded in nature.Evntually become Metter of concern for wide range of microwave frequency band application. Metamaterial absorber superiority over conventional absorber due to their paper thin thickness, incredible absorbility and ease to manufacturing. In this review, the basic operating principles of metamaterial absorbers and brief introduction of recent progresses in the field of MMs operating in different frequency ranges (GHz, THz and infrared/visible) are presented. Perspectives and future works for the investigation and the real application of MMs are also presented.

Keywords: Metamaterial, absorber, frequency, EM wave.

1. INTRODUCTION

Today, everyone is saying that the worlds in which we are living are full of information. That means an enormous amount of information should be exchanged with one another. High tech industrial sciences are required to fulfil the desire of human being. Technology on the limelight, essentially always evolve materials carry enhanced or contemporary and/or innovative properties appropriate for practical operation. These kinds of requirement breed comprehensive exploration in the range of metamaterials (MMs). For the first time the term "metamaterial" is used by Walser in 2001. Wasler entitle "metamaterial" as Macroscopic composites having a man-made, three dimensional, periodic cellular architecture designed to produce an optimized combination, not available in nature, of two or more responses to a specific excitation. More practical description is given by Defence Advanced Research Projects Agency, USA, as Metamaterials are a new class of ordered composites that exhibit exceptional properties not readily observed in nature. These properties arise from measuring new response functions that are (1) not observed in the constituent materials and (2) result from the inclusion of artificially fabricated, extrinsic, low-dimensional in homogeneities. The prefix "meta" comes from Greek (μετ α), meaning after or beyond. Therefore, MMs can possess novel properties which cannot be easily attainable from natural materials. According to some researchers Metamaterials (MTM) are machine made structure that manifest electromagnetic (EM) properties naturally elude. Miraculous features like reverse Doppler effects, negative refractive index,clocking,backword propagation and absorption tends to tailor electromagnetic properties and hence experiment application include super lenses, next generation handheld electronic devices, advance solar energy generation, small window material, advance antenna, clocking and absorber. Metamaterial absorbers are customized absorber that competent in absorbing EM waves. The emphatic material parameters of analogous structure can be made ultra-thin and of super absorbing capability by adapting properties derived from physical structure of various shape and size have been introduced as metamaterial absorber in different frequency ranges i.e. from microwave to visible and to infrared range. Owing to ultra-thin thickness, lighter weight and increased effectiveness metamaterial fits itself in single band, dual band, multiple band as well as broad band application. Recently bandwidth enhanced metamaterial are also reported. Metallic frequency selective surface arranged in periodic pattern printed on a very thin grounded dielectric substrate capable to regulate their compelling electromagnetic parameter like input impedance matching with free space impedance. Therefore for unity absorption the lossy dielectric substrate must absorb the incident wave completely. Nevertheless, it is not easy to combine multi-band MMA with high efficiency, since the sensitive perfect absorption conditions are easy to be broken. Therefore, the achievement is still a significant issue in the MMA researches. In spite of numerous studies, many issues remain to be explored, for example, to relax the working conditions and to increase the number of absorption peaks and the absorption bandwidth, as well as to switch the absorption properties from microwave to infrared (IR) frequencies.

2. LITERATURE SURVEY

There are two types of perfect EM wave absorbers: (i) resonant absorbers and (ii) broadband absorbers. The broadband absorbers are further divided into two categories. The first one is a geometric transition absorber, which consists of two-dimensional periodic arrays of lossy foam pyramids, cones or wedges, is widely used in anechoic rooms to reduce wall reflections. The second one is a low-density absorber. It utilizes very porous or sparse material. These classifications were done before MMs were introduced in the research field of PA. So far, the resonant absorbers can have perfect absorption in a narrow bandwidth, while only non-resonant techniques were known to be employed for broadband absorption. In the progress of research on MMs, however, the resonant absorbers can have broadband behavior. In this review, we will not discuss geometric-transition and low-density absorbers, and only focus on the resonant EM-wave absorbers, based on MMs, which can possess broadband behaviors and other useful properties for real applications.

2.1. Basic structures of MMA

The resonant EM-wave absorbers originate basically from frequency-selective surfaces (FSSs). Most of MMAs consist of three layers: (i) a layer of periodically arranged metallic patterns, (ii) a dielectric layer, and (iii) a continuous metallic layer. The first layer is periodically arranged metallic patterns, and the thickness of the dielectric layer could be much smaller than the wavelength, especially, in the GHz regime. To accomplish the total absorption, there should be no reflection and no transmission. No transmission can be accomplished by the third layer of a continuous metallic plate, which completely blocks all incident EM waves. Since the third metallic layer simply reflects all EM wave falling upon it, not much talk about it is needed.

The basic role of dielectric layer is to provide a space to the incident EM wave to stay and be absorbed. Although the absorption can also occur in the metallic region, if the absorption is due dominantly to the dielectric loss, this role is especially important. It is generally believed that, in order for the dielectric layer to provide the incident EM wave with a sufficient space, it is desirable to use high-refractive index material because it reduces the real thickness of dielectric layer. For the incident EM wave, the path should be given by nd, where n is the refractive index and d is the distance traveled. Although it is generally true, it is not necessary to have a large thickness to satisfy, for instance, the quarter-wavelength condition, which is essential for the antireflection coating and Salisbury screen. Dielectric materials usually have very small imaginary part of dielectric constant, and this small imaginary part is sometimes enough to absorb all EM waves incident upon it. The role of imaginary part in MMA is different from that of Salisbury screen.Other than providing a space for the incident EM wave to be absorbed, the dielectric layer in MMAs plays another role, and the role depends on the specific design. Sometimes it plays a role of, for instance, the Fabry–Perot cavity, one should notice that even though the role of dielectric layer it does not simply provide the enough space for the cavity resonance but it produces absorption, resulting in dual-band absorption.

No reflection implies that all of the incident EM waves onto the surface should be transmitted. The role of the first layer (patterned metallic layer) of MMA is an array of patterned metallic units, not a simple screen as a Salisbury. The patterning is necessary for the following two reasons.

First, the transmission at the first layer is led by a certain resonance at the targeted frequency regime, not by a destructive interference, as in the case of Salisbury screen. According to the Drudge model, the real and the imaginary parts of dielectric constant, ε_1 and ε_2, respectively, can be approximately represented as

$$\mathcal{E}1\ (\square) = \mathcal{E}\infty - \ \square^2 p\,\mathcal{T}^2/1+\square^2\,\mathcal{T}^2 \ \ldots\ldots (1)$$

And

$$\mathcal{E}2\ (\square) = \square\mathcal{T}\ \left[\square^2 p\,\mathcal{T}^2/1+\square^2\,\mathcal{T}^2\right]\ \ldots\ldots (2)$$

Where ω, ω_p, τ, and ε_∞ are the angular frequency of incident EM wave, the plasma frequency, the relaxation time, and a Drudge parameter, respectively. If $\omega\tau$ 1, Eq. 1 is further approximated as

$$\mathcal{E}1\ (\square) = \mathcal{E}\infty - \ \square^2 p/\square^2 \ \ldots\ldots\ldots\ldots\ldots (3)$$

The Drudge parameter ε_∞ can be obtained as follows. ε_1 in the region satisfying the condition $\omega\tau$ 1 can be fitted as a function of ω^{-2} or λ^2. The plot ε_1-vs.-ω^{-2} or ε_1-vs.-λ^2 is a straight line and ε_∞ is the intercept at $\omega^{-2} = 0$ or $\lambda^2 = 0$. ε_∞ is usually different from unity because it is not $\varepsilon_1(\infty)$, which is the real part of dielectric constant measured at $\omega = \infty$ and is unity. ε_∞ reflects the contributions from the polarization of core electrons. Most of metals have the plasma frequency corresponding to the energy greater than 5 eV. Therefore, ε_1 is negative with very large absolute value in visible and IR regimes. If one wants to fabricate MMs operating in the GHz, THz, IR, and even visible regimes, it is necessary to lower the "effective" plasma frequency to the targeted frequency regime because the desired properties revealed in the targeted frequency regime can be usually attained by accompanied plasma oscillations. Since the plasma frequency is given by

⍰p $= \sqrt{\frac{4\pi n e^2}{m^*}}$ (in CGS units) …….. (4)

Where e is the electronic charge, n is the charge density, and m^* is the effective mass, one need to make a "diluted" metallic units. Here, the term "diluted" implies that the "effective" charge density in MMs should be properly diluted to facilitate the plasmatic resonance in the targeted frequency regime. It is the reason that an array of the patterned unit cells is necessary for MMs. By partially removing the metallic layer, the "effective" charge density can be properly adjusted to facilitate the plasmatic resonance in the targeted frequency regime.

Second, the first layer plays not a passive, but an active role. The thin glossy screen of the Salisbury screen simply reflects the incident EM wave back to the space, where the incident wave comes, and transmits the reflected wave from a continuous metallic surface. Eventually, these two EM waves interfere destructively, resulting in no reflection. In the case of Salisbury screen, the first layer plays a passive role; however, the first layer of MMA plays a more active role. There should be, of course, no reflection on the first layer. No reflection would be, however, achieved in MMAs not by destructive interference, but by requiring that the impedance of the first layer (periodically arranged metallic patterns) should match to that of free space or atmosphere. The incident waves do not have any way to notice the difference between the atmosphere and the first layer because of impedance matching. To incident waves, the perfect impedance matching implies that the two media, atmosphere and the first layer, are optically identical. Ordinary natural materials are impossible to possess the impedance perfectly matching with that of environment. Only MMs, whose geometric parameters of metallic patterns are carefully adjusted, can possess such properties. Such impedance matching can only be achieved via certain resonances or plasmatic couplings, as argued in the previous paragraph. Therefore, MMs should be treated as a *homogeneous* material even though it is macroscopically inhomogeneous. As a consequence, the so-called effective-medium approximation (EMA) is necessary.

One more point should be addressed now. The role of the imaginary part of the dielectric function is sometimes misunderstood. It is generally believed that the large magnitude of the imaginary part implies a strong absorption. This belief is approximately true, but one should be very cautious. There are two different ways to represent the optical constants of media; the complex dielectric function ($\tilde{\varepsilon} \equiv \varepsilon_1 + i\varepsilon_2$) and the complex refractive index ($\tilde{n} \equiv n + i\kappa$, where n is the ordinary refractive index and κ is the extinction coefficient). The absorption, more exactly the attenuation, of the incident EM wave is directly determined not by the imaginary part of the dielectric function but by the extinction coefficient as $e^{-\kappa\, r/\delta}$, where δ is the skin depth. The relationship between the complex dielectric function and the complex refractive index,

$\tilde{\varepsilon} = \tilde{n}^2 = (n + i\kappa)^2$, holds.

Therefore, two following relationships.

$$\varepsilon_1 = \mathrm{Re}[\tilde{\varepsilon}] = \mathrm{Re}[(n + i\kappa)^2] = n^2 - \kappa^2 \qquad (5)$$

And

$$\varepsilon_2 = \mathrm{Im}[\tilde{\varepsilon}] = \mathrm{Im}[(n + i\kappa)^2] = 2n\kappa \qquad (6)$$

Can be easily derived. According to Equations (1) and (2), $-\varepsilon_1$ 1 and ε_2 1 if ω ω_p. It implies that n 1, κ 1, and, more importantly, n κ even in the optical range of frequency. The large magnitude of the extinction coefficient in the optical range of frequency indicates that the incident EM waves are strongly attenuated. The strong attenuation does not necessarily mean a strong absorption. Rather, it implies that the larger the extinction coefficient, the smaller the skin depth. As a consequence, the incident EM wave cannot penetrate deeply inside the metal. If there is any absorption of the incident EM wave, it occurs on the very thin surface of metals. Therefore, in metals, there is insignificant absorption and no transmission if the thickness of the metallic layer is very much larger than the skin depth, and, as a result, most of the incident EM waves in the Drude region are reflected. Since most metals have their plasma frequency far above the visible range, most of the visible lights are nearly reflected. This is the reason for glossiness of the smooth surface of metals, especially, novel metals. On the contrary to the conventional belief, the large magnitude of the imaginary part of the dielectric function does not result in a strong absorption, but a strong reflection. This is another reason that the role of the patterned metallic layer is so important. If the dominant mechanism of absorption is dielectric, the large magnitude of the imaginary part is important for the perfect absorption even though the imaginary part is, in general, much smaller than the real part. Sometimes, the dominant mechanism of absorption can be Ohmic. In this case, the large magnitude of the imaginary part does not play a decisive role for the perfect absorption, but plays a very important role for reducing the so-called Q-factor. The reduced Q-factor leads to an increase of the bandwidth of absorption peak, which is very important for the broadband response of MMAs.

2.2. Effective-medium approximation

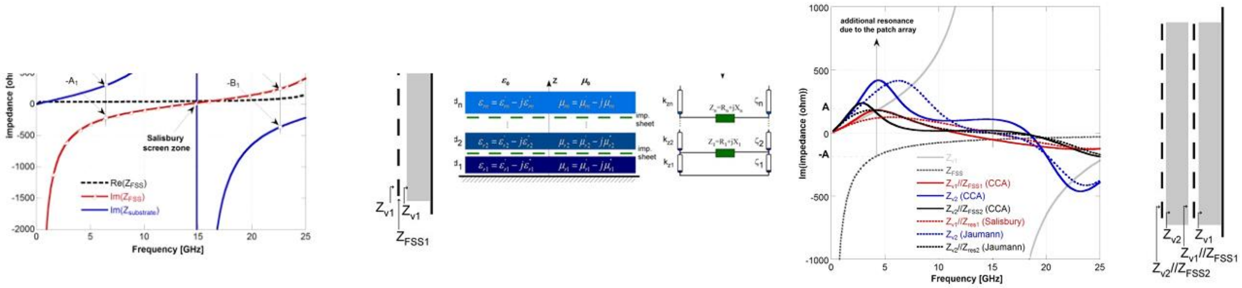
The EMA, or often called as "effective-medium theory", is especially necessary for the first layer (MM layer) of MMA. As afore mentioned, the first layer, composed of intentionally-designed metallic patterns with a periodic arrangement, should be treated as homogeneous. Usually, MMs are intentionally fabricated as composite structures. It means that the first layer cannot achieve a perfect impedance matching with the space above the first layer, where the incident EM waves are entering, unless it behaves as homogeneous.

Quantum mechanics comes into play in the microscopic level. All the material properties are determined, in principle, by the details of wave functions of particles in quantum regime. Quantum-mechanical effects, however, are not easily detectable in macroscopic-level measurements. Furthermore, when lights are interacting with materials, the size of constituent atoms and molecules is usually very smaller than the wavelength of light. Therefore, it is not possible for light to see the details of electronic structures of materials, which determine the material properties observed in the macroscopic level. It implies that the material can be treated as homogeneous. It is the basic principle of EMA. This basic principle can be extended to the macroscopic level unless the inhomogeneity of composite materials plays a significant role. It is, therefore, believed that the long-wavelength limit is crucial for the application of EMA.

Very recently, a generalized effective-medium theory for metamaterials was proposed. They predicted that near the resonance, the refractive index effectively becomes infinitely large. This means that the wavelength be-comes nearly zero, contradictory to the long-wavelength approximation.In that sense, the model was derived from the zero-scattering condition within the dipole approximation, but does not invoke any additional long-wavelength approximations. As a result, it captures the effects of spatial dispersion and predicts a finite effective refractive index and anti-resonances in the electric permittivity and the magnetic permeability, in agreement with numerical finite-element calculations.

2.3 Filippo costa, Agostino monorchio, Mialiana manara "Theory, Design and Perspective of electromagnetic wave absorbers":

Metamaterials properties are more physical rather to be chemically blending this basic theory allowed author to discuss physical design and perspective of electromagnetic wave absorber. Classical Salisbury and jaumann configurations were compared with FSS based absorber the later technique provide unity absorption with ultra-narrow band, narrow band, wide band and ultra-wideband behavior even by removing bulkiness of prototype absorber.



(1.1) (1.2) (1.3)

Fig. 1 –(1.1) Impedance behavior of a single layer FSS absorber.(1.2) Layout of a general absorbing structure and its transmission line equivalent circuit and Salisbury screen, Jaumann screen, Dallenbach layer and Circuit analogue absorbers (CCA) and different FSS-based absorbers are particular cases of the represented stratified structure.(1.3) Input impedance at

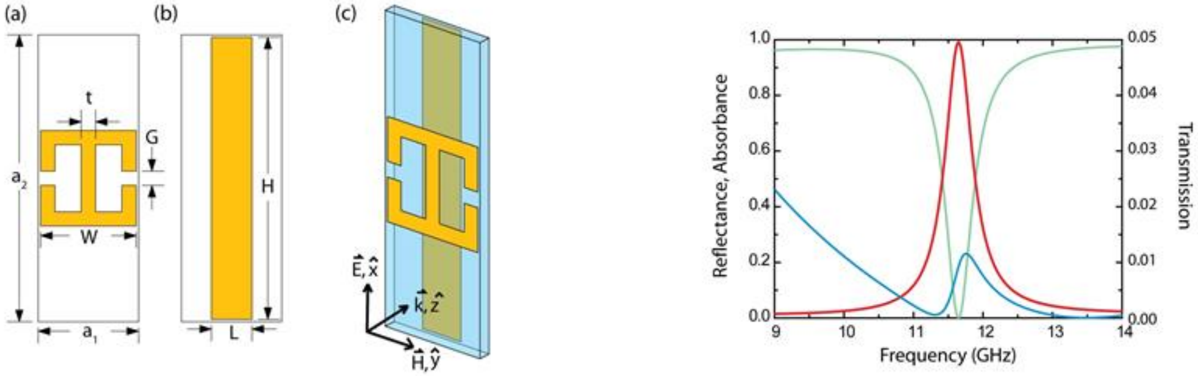
various level of the stack up both for Jaumann screen and for capacitive circuit absorber (CCA). The capacitive impedance of the FSS enable to tenaciousely expand the absorption bandwidth at low-frequencies.

2.4. Y.Radi, V.S.Asadchy, S.A.Tretyakov "Total absorption of electromagnetic waves in ultimately thin layers".

A single-layer array of electrically small lossy particles is considered that completely absorb electromagnetic waves at normal incidence. Essential conditions for electromagnetic properties of bi-anisotropic particles have been diagnose in the most common case of uniaxial reciprocal and non-reciprocal particles. We consider the design possibilities offered by the particles of all four fundamental classes of bi-anisotropic inclusions: reciprocal chiral and omega particles and nonreciprocal Telligent and moving particles. We also analyze the reflection/transmission properties of asymmetric arrangement with contrasting properties when adorn from the opposite sides of the sheet. It reveal that it is happen to realize single-layer grids which manifest the total absorption property when illuminated from one corner but are entirely transparent when illuminated from the opposite corner (decisive thin isolator). Additional considerable properties are co-polarized or twist polarized reflection from the corner opposite to the absorbing one. At last, we discuss considerable approximation to practical existence of particles with the properties needed for single-layer perfect absorbers and other introduced devices.

2.5. N.I. Landy,S. Sajuyigbe,J.J. Mock,D.R. Smith, & W.J. Padilla "Perfect metamaterial absorber":

MM absorber has been firstly proposed by Landy et al., which had advantage of small size and thin thickness compared with the conventional absorbers. The most popular and satisfactory metamaterial resonator were been tailored to form electromagnetic absorber still having potential for enhancement. This paper presents, narrow band perfect metamaterial absorber characterized to be used in bolometer such that single unit of the absorber are fabricated by placing two distinct metallic elements. Absorption results were found using standard equations. The simulated results shows maximum absorption at the frequency 11.5 GHz while experimental results shows 96% of unity. This roots the ability to design metamaterial element which can individually absorbs the electric and magnetic component of electromagnetic wave.

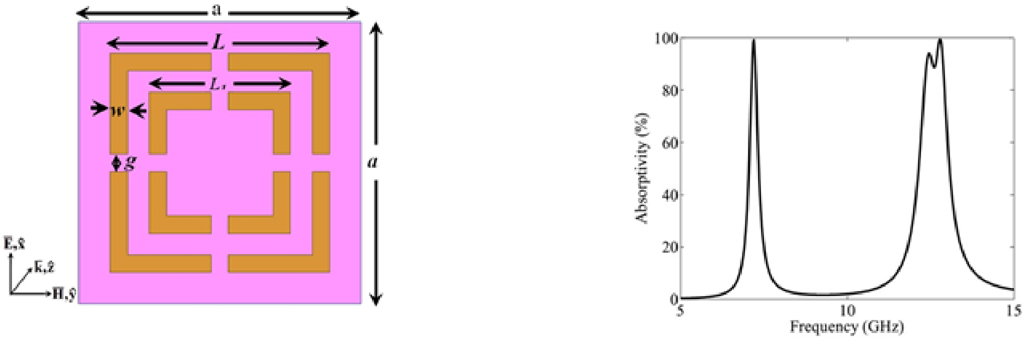


(2.1) (2.2)

FIG. 2-(2.1) Electric resonator (a) and a cut wire (b). Dimension notations are listed in (a) and (b). The unit cell structure is shown in (c) with axes mark the direction of propagation of a TEM wave. (2.2)-Simulated perfect metamaterial absorber. Reflectance (green curve) and absorbance (red curve) are mark from zero to 100% (left axis). The transmission is mark on the right axis.

2.6. Devkinandan Chaurasiya, Saptarshi Ghosh, Somak Bhattacharyya and Kumar Vaibhav Srivastava "Dual-band Polarization-Insensitive Metamaterial Absorber with Bandwidth-Enhancement at Ku-band for EMI/EMC Application".

This study shows, a dual-band MM absorber with bandwidth-enhancement at Ku-band is introduced in microwave frequency region. The unit cell composition comprises of two split ring resonators in the top surface of a metal-backed dielectric substrate. Simulation graph shows that the structure has dual-band absorption response with one band present in C band and another in Ku-band with an enhanced bandwidth having full width at half maxima (FWHM) bandwidth of 1 GHz. The structure is symmetric in design and gives polarization independent response under normal incidence. It also shows high absorption (above 80%) for oblique incidence up to 45 degree under TE polarization. The structure introduced has been fabricated and absorption is analyzed in anechoic chamber, which shows good congruency with the simulated results. The designed absorber is ultra-thin and act to be promisingly acquainted for distinct EMI/EMC applications.

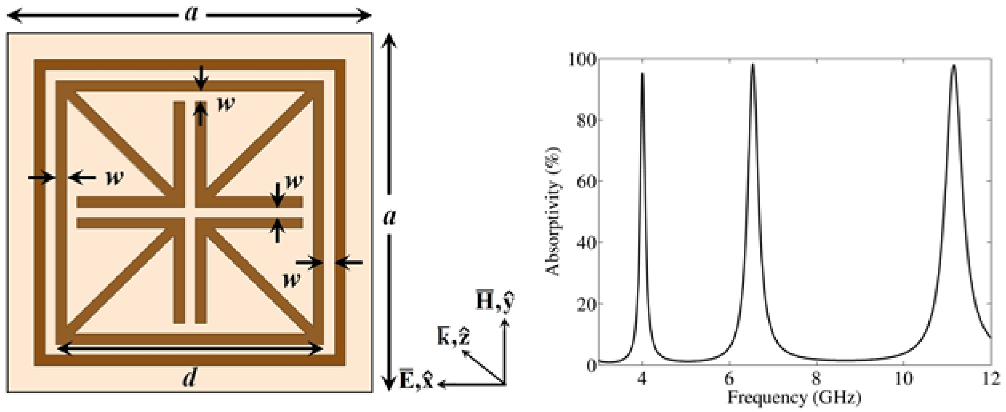


(3.1) (3.2)

Fig.3.- (3.1). Front view of unit cell geometry of the proposed structure.(3.2). Simulated absorptivity of proposed structure.

2.7. Saptarshi Ghosh, Somak Bhattacharyya, Yadunath Kaiprath, Devkinandan Chaurasiya, and Kumar Vaibhav Srivastava "Triple-Band Polarization-Independent Metamaterial Absorber using Destructive Interference".

This paper presents a dual-band metamaterial absorber with bandwidth-enhancement at Ku-band in microwave frequency range. The unit cell composition having two split ring resonators in the top surface of a metal-backed dielectric substrate. The structure has dual-band absorption response with 1st band lying in C band and 2nd in Ku-band with an enhanced bandwidth having full width at half maxima (FWHM) bandwidth of 1 GHz is shown after simulation. Symmetry in design and polarization insensitive behavior under normal incidence is shown by the absorber. It also shows high absorption (above 80%) for oblique incidence up to 45o under TE polarization. The proposed structure has been fabricated and absorption is measured in anechoic chamber, which shows good compatibility with the simulated response. The designed structure is ultra-thin and appears to be potentially instructive for various EMI/EMC applications.

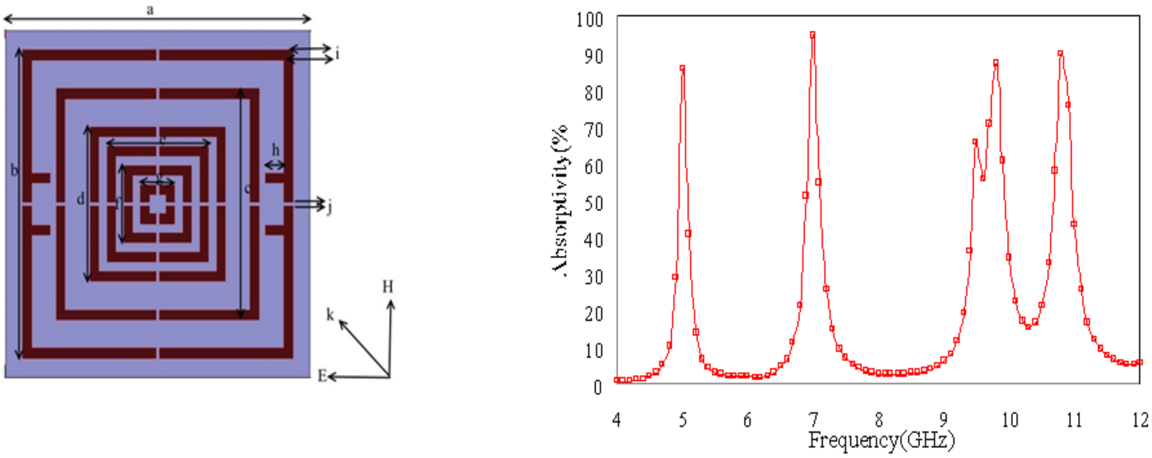


(4.1) (4.2)

Fig.4. (4.1) Front view of the proposed unit cell structure with geometrical dimensions: a =13.6, d =10, w =0.4 (unit: mm). (4.2) Simulated absorptivity of the proposed triple-band structure.

2.8 Kunal Srivastava, Ashwani Kumar, A.K.Verma and Qingfeng Zhang "Quad-Band Polarization Independent Ultra-Thin Microwave Absorber Using Metamaterial."

The paper introduced a design of Quad-Band polarization independent microwave absorber using metamaterial. The absorber is employ for C-band as well as for X-band application. The absorptivity equivalent for frequencies 5.0GHz and 7GHz in C-band are 85% and 95% and for frequencies 9.8GHz and 10.8GHz in X-band are 88% and 90%. This category of absorber could be used in advanced communication systems for airborne and surveillance radar signal absorption application.



(5.1) (5.2)

Fig.5.-(5.1) Layout with dimensions of unit cell. (5.2) Absorptivity with frequency.

2.9. DESIGN CONSIDERATION

The 3 absolute parameters for the design of a quad band MTM absorber are,

Resonant Frequency (fr):

The resonant frequency preferred for this composition will be in GHz. The aim of this assortment is to craft our design work with maximum efficiency, so as to give enhanced results.

Dielectric constant of the substrate (εr):

The dielectric material preferred for the design is FR-4(NEMA grade designation for glass-reinforced epoxy laminate material) which has a dielectric constant of 4. A substrate with an acute dielectric constant is to be preferred subsequently it reduces the dimensions of the absorber. The abbreviation in dimensions of the absorber is done to obtain enhanced results.

Height of dielectric substrate (h):

It is important that the design of absorber should not be heavy hence height should be compressed.

3. Perspectives

With simple design and geometrical scalability, the suggested MM absorbers might operate at higher or lower frequency with perfect absorption and be modified to reveal other capabilities relevant to the practical applications. They include flexible printed circuit and camera unit in cellular phone, interface and data driver in PDP television, interface in large LCD panel, and GPS unit and signal input in car navigation. They also comprise infrastructures relevant to EM wave, such as radar mast of a ship, building wall in front of a broadcasting station, and ceiling and wall of intelligent-transportation-system toll gate.

Especially for MMs operating in the GHz and the lower-frequency ranges, another important challenging aspect should be overcome: the size of the unit cell. The operating frequency, or equivalently wavelength, is critically determined by the lattice parameter. Since the lattice parameter increases for MMAs operating in the low-frequency range and, as a result, the same is true for the total size of sample, deep-subwavelength (lattice parameter $\lambda/10$) MMAs should be investigated for immediate and versatile applications.

4. SUMMARY

From the paper analyzed so far, Conceivable advantages of different metamaterial absorber prototype and their outcome it is observed that a flexible band MTM absorber gives better absorption peaks within a particular range of frequency. By introducing assured alternate in the design, they can be appoint to work for quad band of frequencies, hence, the design can be used in large number of applications. As we move further in the design accumulation to more complex components and devices, contemporary appearing marvel and more intricate functionalities might be synthesized at each level, paving the way to a new age for MMAs. We feel assurance that the MM innovation in the field of absorption has just begin, and will introduce exciting new developments in the dominion of practical applications in the coming years by brush the entry obstacle and take over the prototype applications using abide materials/structures, and by exploiting new ones.

5. CONCLUSION

The study speaks for the inspection of techniques, analysis and composition for the making of MTM absorbers. The characteristics limitations of prototype MTM absorber can be enhanced by using any method, which is mentioned above. The analysis of work is done on various techniques to design MTM absorbers and to get the various characteristics for the same, even though meaningful solutions are still needed. Enhancement of bandwidth, structure complexity, gain reduction etc. is some of the complication which needs to be solved to make the design work properly. Hence, further research is needed to resolve this dilemma.

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