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Design and Analysis of Metamaterial Absorber using Split Ring Resonator for Dual Band Terahertz Applications

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Abstract— There are numerous applications for microwave absorbers in the L, S, C, X, and Ku bands. Creating a terahertz absorber, on the other hand, has proven difficult. This paper presents a metamaterial absorber operates at terahertz frequencies. It has a square shaped outer ring and a circle shaped inner ring unit cell split ring resonator. The substrate is dielectric material and the ground is metallic. According to the simulation results, the unit cell resonates at two frequencies that is at 1.3027THz and 1.7853THz with absorptivity is greater than 90% at normal incidence .The main cause of high absorbance is due to strong electromagnetic field. The proposed structure in this paper is useful for terahertz imaging, detection of malignant tumors and stealth technology.

Keywords- Terahertz(THz), Resonant Frequency, Splitring resonator, absorber, Meta materials, permittivity, permeability.

I. INTRODUCTION

Now a days, Terahertz (THz) technology has received a lot of attention since it takes advantage of the untapped portion of the electromagnetic spectrum (EM). This portion is known as the "THz gap". It is between the band of microwave frequency and optical frequency ranges [1,2]. There are many studies about this untapped area for commercialization, even though electronics and photonics have largely commercialized either side of this THz zone. One of the THz region's characteristics is Non-ionizing radiation is the one of the region of terahetz characteristics . It has prospective uses in medical industries ,security screenings , non-destructive testing applications and many other applications [3,4]. The point to be stressed here is that most natural materials exhibit non-polar and non-conductive properties at Terahertz frequencies, which ultimately leads to less absorption.The traditional absorbers are categorised into Salisbury and Jaumann absorbers. The desired frequency of incoming radiation is only absorbed by the Salisbury absorber. On the other hand, in Jaumann absorber by increasing number of dielectric layers cause the absorption to occur at various resonance frequencies. Because it is built with several resonators and multiple dielectric layers, the later one is bulky and the former one only operates in a narrow band [5,6]. Perfect absorbers (MPAs) based on metamaterials have been offered as a solution to the aforementioned problems. MPAs are artificial devices having sub-wavelength unit cells that have been designed for specific bands of incident electromagnetic radiation. There are 3 layers make up MPAs. A dielectric layer tucked between two metallic layers which are separate. By reducing the transmission and reflection properties of the suggested device, the absorption can be increased. These two unique metallic layers were designed with two main responsibilities in mind. The surface impedance of surrounding air medium is matched with the the absorber using the patterned layer. This can be accomplished by adjusting the constituent properties, such as the unit cell's magnetic permeability and electric permittivity. Reflection is therefore reduced to a minimum. The penetration depth of electromagnetic wave which is incoming is larger than the thickness of the bottom layer which causes the continuous metallic layer entirely prevents the wave from transmitting. As a result, the device's absorption is increased by minimizing its reflectance and transmittance [7]. Due to its unique electromagnetic features, such as invisibility[8], negative refractive index[9], perfect absorbing[10] and perfect lensing[11], metamaterials have come under increased scrutiny[12-14]. Many devices are demonstrated based on metamaterial as a result of these unique features Metamaterial absorbers are one of the emerging subset of practical devices. As early perfect absorption at the resonant frequencies is achieved. Landy et al.[15] presented the metamaterial absorber in 2008 which is the first flawless metamaterial. Peak absorption of 88 percent was attained by an absorber with a conventional sandwich structure. It is made up of substrate which is of dielectric material,a split ring resonator, and a metallic cut wire. Since then, a numerous metamaterial absorbers in a variety of frequency ranges are proposed, at microwaves[16–17], terahertz[18–19], visible and infrared bands[20–21. Metamaterial absorbers offer a wide range of possible uses in solar cells, micro-bolometers, spectral imaging and photo detectors. Because of their outstanding properties of ultra-thin thickness, tunability and near unity absorption. It becomes an appealing study topic to develop the ideal absorber utilizing metamaterials (MM) at the THz frequency.

In this study, we offer a straight forward structured metamaterial absorber split ring resonator made of three layers: a grounded metallic film, an outside square and inner circular split ring, and a dielectric substrate. The simulation findings shows the unit cell resonates at two frequencies at 1.3027THz and 1.7853THz with absorptivity greater than 90% at normal incidence The design of proposed absorber offers structures with more flexibility and operating at terahertz frequencies.

II. DESIGN EQUATIONS

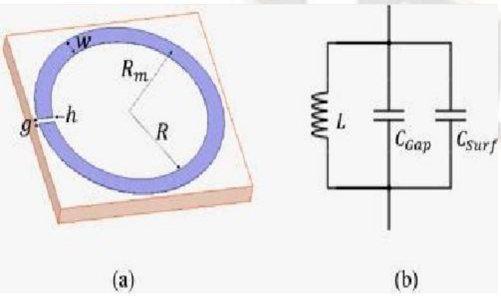

Figure 1: Structure and Equivalent circuit of a single split ring resonator

Split-ring resonators (SRRs) consist of concentric rings which are metallic in a square or circle form are etched onto the substrate. At one end or both ends, they have gaps or splits. The splits are the structural in homogeneities, resonance wavelengths that are substantially longer than the rings diameter which help to support SRR. The splits or gaps in the rings creates a capacitance with a high value, where the relationship between the capacitance and the resonant frequency is inverse. This significant capacitance enables the resonator to demonstrate resonance at frequencies that are far higher than its dimension. The split ring resonator's diameter is greater than the resonant wavelength consequently, quality rises. Based on it, we may conclude that the SRR's shape, resonant frequency, and associated attributes are interrelated. At resonance, current loops are produced when the rings are subjected to a uniform, time-varying magnetic field. The split ring resonator acts as an L-C resonator because of the capacitance from the splits, which completes the closed-loop for current circulation. The resonance phenomenon's huge capacitance and current circulation lower the resonator's electric size. Split ring resonators employ inter element spacing and various diameters for higher frequencies and smaller sizes. There are several split rings are there . Nested split rings, rod split rings, spiral split rings, distorted split rings, and single split rings are the various types of SRRs.

$$f_r = \frac{1}{2\pi\sqrt{LC_{total}}} \qquad (1)$$

$$L = \mu_0\left(R + \frac{W}{2}\right)\left(ln\frac{8\left(R + \frac{W}{2}\right)}{h + w} - 0.5\right) \qquad (2)$$

$$C_{gap} = \varepsilon_0\left[\frac{wh}{g} + \frac{2\pi h}{\ln\left(\frac{2.4h}{w}\right)}\right] \qquad (3)$$

$$C_{total} = Cgap + C_{surface} \qquad (4)$$

R stands for the ring's inner diameter, g for the split gap, and h for the ring's height relative to the substrate. From the design equations, it is clear that we may make oscillators, mixers, or filters out of SRRs that perform flawlessly at the given resonant frequency by varying the radius, breadth, length, and height of single split- ring structures.

III. PROPOSED UNIT CELL STRUCTURE

We go into great depth about the proposed absorber's geometrical structure in this section. The proposed THz absorber's geometrical structure is shown in 2D and 3D views, respectively, in Figure 1. The proposed unit cell is a three-layered structure. It is made up of two split rings an inner ring shaped as circle and an outer ring shaped as square along with a metallic continuous film, which is sandwiched between the rings and protected by a dielectric substrate. The circular ring radii are u_1=24μm, u_2=21μm, while the gap of the split ring $w=w_1=w_2$ is set to be 4μm. The length of the square split ring is v= 42μm and 39μm ,the dimension of the cell is $x=y$=70μm. The commercial FDTD solver CST

Microwave Studio2012 was used to simulate the given absorber. An open (addition of space) boundary condition has been established along the Z-axis and along the lateral axes, unit cell boundary conditions are established. Further,to achieve the operating frequency range, bottom layer thickness is maintained high than the penetration depth of the EM waves. Hence,the transmission of the EM waves is prohibited by the bottom layer.

According to the circuit model, it is widely known that the resonator's inductance and capacitance (L and C) are connected to its resonance frequency (f) as per equation 1.

The double splits inner circular ring and outer square are used in our simulation were composed of lossy gold. It has a conductivity (σ) of 4.56 $*10^7$ S/m and a thickness of 0.4μm The lossy polyimide used as dielectric material had a dielectric constant(ε) of 3(1+i0.06)[29] and was 26 μm thick. The formula for the absorptivity A(ω) is

$$A(\omega)=[1-R(\omega)-T(\omega)] \qquad (5)$$

where R(ω) -denotes the reflectivity .
T(ω) -denotes the transmissivity.

Because there is a continuous metallic sheet at the bottom, the transmissivity becomes zero and the absorptivity may be stated as

$$A(\omega)=1- R(\omega) \qquad (6)$$

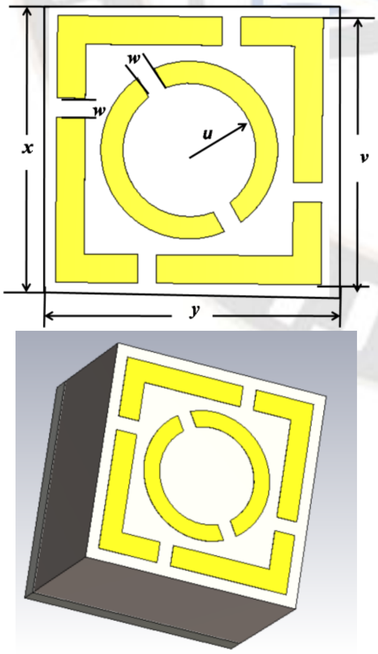

Figure 2: Schematic representation of Proposed metamaterial absorber unit cell using CST

Parameter	value(in μm)
x	*70*
y	*70*
u	*21*
v	*42*
w	*3*

TABLE 1: Proposed Unit cell absorber Dimensions

IV. SIMULATION RESULTS AND DISCUSSIONS

The developed unit cell dual band resonances are observed at terahertz frequency that is at 1.3027THz and 1.7853THz ,which is shown in figure 3.The resonance at 1.7853THz is due to inner circle split ring structure and resonance at 1.3027 THz is due to outer square split ring.

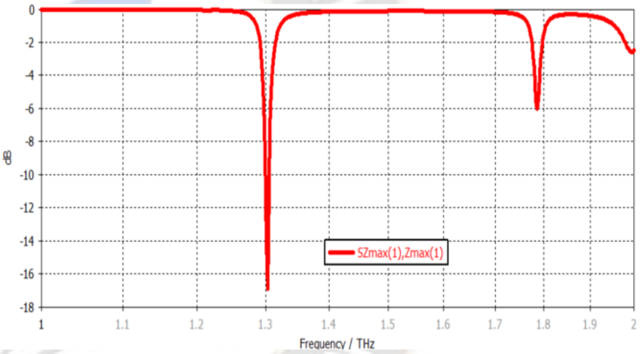

Figure 3: Return loss of the proposed unit cell

From figure 4 it is observed that the absorption of a structure is 97.4% and 74.73%

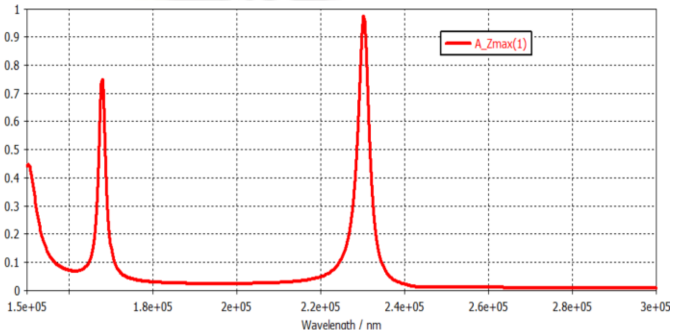

Figure 4: Absorbitivity of the proposed unitcell

Next, we examined the surface impedance of a unit cell structure. The effective surface impedance Z is frequency dispersion for the metamaterial may be characterized as

$$Z = \sqrt{\frac{\mu}{\varepsilon}} \tag{7}$$

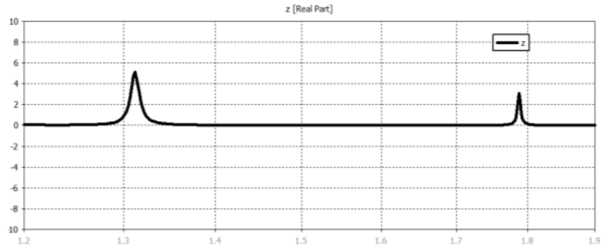

Figure 5: Surface impedance of a proposed unitcell

Here, the electric permittivity of the intended absorber is ε, and μ is the magnetic permeability of the intended absorber. Z' and Z are the surface impedance components real and imaginary respectively. Additionally, the surface impedance's normalised form in terms of the S_{11} and S_{21} transmission coefficients is as follows which is equation 8.

$$Z = \sqrt{\frac{(1+S11)^2 - S21^2}{(1-S11)^2 - S21^2}} \tag{8}$$

It should be noted that the transmission of the absorber will eventually becomes zero because of the continuous metal plate at the bottom,. As a result, the surface impedance linked to the absorber's reflection coefficients as in equation 9.

$$Z = \sqrt{\frac{(1+S11)}{(1-S11)}} \tag{9}$$

Equation 9 may be used to determine the absorber's surface impedance. According to this research, from figure 4 it is observed that the actual component of Z at 0.796 THz and 0.749 THz, is very near to unity. This demonstrates very clearly how the surrounding air medium's surface impedances and the top layer of the absorber are identical. As a result, the reflection becomes minimal.

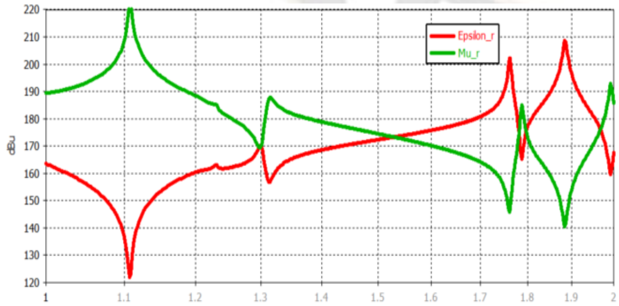

Figure 6: Effective permeability of a proposed unit cell

The effective material properties, such as the effective permittivity (ε_{eff}) and effective permeability (μ_{eff}) are computed for a unit cell for the better understanding. The ε_{eff} and μ_{eff} are depicted in Figure 6. It is observed from figure 6 at resonance frequencies, the real component of effective permittivity is equal to the real part of effective permeability (ε_{eff}=μ_{eff}).

V. CONCLUSION

Finally, utilizing a split ring resonator, we created metamaterial absorber that can capture two frequencies of incoming radiation that is at 1.3027THz and 1.7853THz and it achieves a absorptions of 97.4% and 74.73% respectively. By examining the surface impedance, effective permittivity, and permeability, the absorption mechanism is demonstrated. The concept behind the suggested design is transferable to other split ring constructions in addition to circular and square split ring absorbers. Additionally, an absorber in the terahertz range can be easily generated by altering the absorber structure's size. As a result, it offers us a versatile and practical method to select the type of structure and the metamaterial absorber operating frequency range . We believe that the developed THz metasurface absorber would make a good option for communication, radar, and stealth technology based on the aforementioned results.

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