Optically Transparent Triple and Dual Band Terahertz Metamaterial Absorber Based on Indium Tin Oxide and PET Substrate

Mahendran K (srimahendrancs@gmail.com)
Saveetha Engineering College
Sudarsan H
K. Ramakrishnan College of Engineering,
Rathika S
Prince Shri Venkateshwara padmavathy Engineering College

Research Article

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Optically Transparent Triple and Dual Band Terahertz Metamaterial Absorber Based on Indium Tin Oxide and PET Substrate

[1]K. Mahendran, [2]H. Sudarsan, [3]S. Rathika
[1]Assistant Professor, Saveetha Engineering College, srimahendrancs@gmail.com
[2]Assistant Professor, K. Ramakrishnan College of Engineering, sudarsanrg@gmail.com
[3]Associate Professor, Prince Shri Venkateshwara padmavathy Engineering College, s.rathika.mba@psvpec.in

Abstract: A simple optically transparent polarization and angular insensitive triple and dual band Terahertz (THz) Metamaterial Absorber (MMA) is designed and analysed in this paper. The MMA consists of three layers, dielectric layer is placed in-between the ground plane and top metallic patch. Without using stacked layers, doping and multiple resonators the absorber is designed here. The metal and substrate used here is Indium Tin Oxide (ITO) and Polyethylene Terephthalate (PET). The ITO with PET combination produces the optical transparency. The important thing in this work is the same design produces the triple and dual band operation while changing the top patch radius value. The absorber produces the triple band operation when the radius of the top circle is 65 and it produces the dual band when the radius of the top circle is 55. It covers the frequency ranges from 0.3 THz to 1.4 THz. The designed structure is analysed by electric field, magnetic field distribution and surface current distributions. This structure is polarization and angle independent up to 90 degrees. From the parametric analysis, we found this absorber will work in both triple and dual band operation. So, this bifunctional working absorber will find more applications in optically transparent devices, sensing and imaging.

Key Words: Optically Transparent, Terahertz, Metamaterial Absorber, Indium Tin Oxide, Polyethylene Terephthalate

1. Introduction

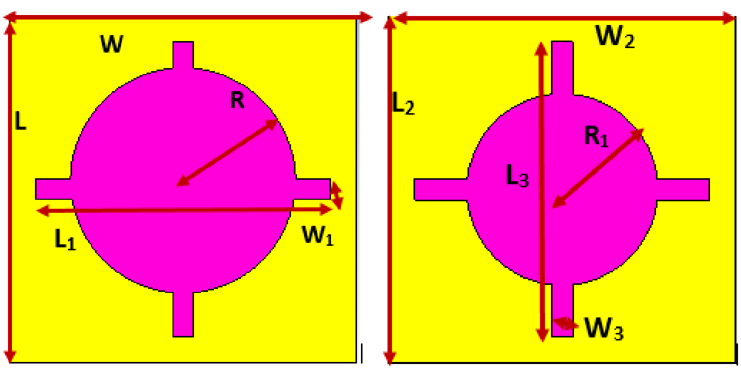
Terahertz (THz) technology has significant uses in a variety of industries, including biological imaging, sensing, non-destructive evaluation of materials, communication, and high-speed, multiband, and broadband applications [1]. The metamaterial (MM) structure has been utilised extensively in the construction of THz devices, including filters, antennas, waveguides, modulators, switches, and absorbers, as a subwavelength artificial electromagnetic material [2]. Most THz MMA researches adopt one of the two following technical pathways to achieve broadband absorption: (1) grouping the resonant units of various sizes in a coplanar structure, or (2) layering the resonant unit surface and the dielectric layer to create a multilayer structure. Although many great accomplishments have been done using these techniques, layered or overlaying resonant structure designs have several drawbacks: First off, big system size and time-consuming piece of technology are problems with combining different structures. Second, the broadband or multiband absorber is often sensitive to the polarisation angle of the incident wave because of the asymmetrical nature of the resonance structure. Thirdly, it is costly and challenging to manufacture the stacked structures. Although few studies have been recorded thus far, it is very desirable to achieve triple band absorption with reduced structures [3-5].

The development of excellent performance design for exploiting electric wave and its applications is restricted by electromagnetic disturbances and interferences. Terahertz absorbers are frequently employed to minimise or eliminate undesired electromagnetic energy or scattering in order to enhance performance or lessen electromagnetic pollution, which significantly enhances the system performance as a whole [6]. Following years of intensive research, microwave absorbers have significantly improved in terms of excellent absorptivity, wide bandwidth, and thin material thickness, and are now used in electronic measuring devices and mobile communication [7]. The low emission intensity of the majority of conventional electromagnetic absorbing materials is a drawback that prevents various real-world uses. Metamaterials have attracted a lot of interest and development in recent decades as a great substitute. By logically structuring the unit cell microstructure of metamaterials within the context of specific base materials, one can arbitrary tune the properties and functionalities of metamaterials. Metamaterials have been researched as major innovations in getting better illumination communication for general relativity and apps in diffraction-unlimited imaging, invisible cloaking, sub-wavelength cavities, polarisation manipulation, and electric and magnetic absorbers varying from the microwave range to visible frequencies due to their special properties, such as deleterious permittivity, hurtful permeability, and negative refraction. For instance, it has been shown that metamaterials microwave absorbers (MMAs) offer various benefits, including perfect absorptivity, small thickness, and light weight. It is still difficult to create MMAs with ultra-wide bandwidth, but it is also crucial and urgent to create optically transparent MMAs given the demands of practical applications [8-12].

The microwave metamaterial absorber that seems to be highly absorptive in the specific range of frequencies was first proposed by Landy et al. [13] At microwave and terahertz frequencies, the resistive indium tin oxide (ITO) placed on a dielectric sheet has been used to create an absorber [14]. ITO is a semiconductor with a plasma frequency that, for typical doping levels, corresponds to below 250 THz and is opaque at optical frequencies. ITO is a fantastic prospective photonic material for infra - red frequencies and can function as a barrier metal at microwave frequencies, together with Al-doped ZnO and TiN. Using the various surface resistivity's of ITO sheets, optically clear absorption with fractional bandwidths of 71 percentages, 83 percentages, and 124 percentages is accomplished [15-16]. Numerous different applications, including solar cells, touch screens, optoelectronic devices, security barriers, and radio antenna, can benefit from the usage of optical transparency [17]. At lower frequencies between 2.2 and 5.8 GHz, Yanghui et al. [18] showed an optically clear absorber in operation. However, this structure is polarisation sensitive, has low absorption (only over 80%), and in particular frequency range below 5 GHz, the absorption is similarly low.

In this work we designed a polarization and angular insensitive triple and dual band Terahertz (THz) Metamaterial Absorber. The MMA consists of three layers. The metal and substrate used here is Indium Tin Oxide (ITO) and Polyethylene Terephthalate(PET). The ITO with PET combination produces the optical transparency. The important thing in this work is the same design produces the triple and dual band operation while changing the top patch radius value. The absorber produces the triple band operation when the radius of the top circle is 65 and it produces the dual band when the radius of the top circle is 55. It covers the frequency ranges from 0.3 THz to 1.4 THz. The designed structure is analysed by electric field, magnetic field distribution and surface current distributions. This structure is polarization and angle independent up to 90 degrees. The absorption rate of the triple band absorber is 90%, 98% and 99.9% at the frequencies of 0.479 THz, 1.04 THz and 1.15 THz respectively. The absorption rate of the double band absorber is 95% and 98% at the frequencies of 0.5 THz and 1.1 THz respectively. This work is compared with previous works which is shown in table 2.

2. Structure and Design



(a) (b)

Figure 1. (a) Unit cell design of triple band MMA, (b) Unit cell design of dual band MMA

Figure 1 displays a top view of the bi-functional MMA. The triple band MMA is shown in figure 1(a) and dual band MMA is shown in figure 1 (b). This absorption device is made up of an optically transparent (opaque) indium tin oxide (ITO) ground plane and a straightforward planar construction as a unit cell that are separated by a 50 µm PET dielectric substrate layer. The conductivity of the ITO metal is $\rho = 7.2 \times 10^{-4}\ \Omega\cdot cm$ [19]. The top metal patch measures 0.185 mm in thickness. Table 1 displays the planned variables and their dimensions. A practical implementation of metallic films for applications requiring optical transparency and stretch ability is polyethylene terephthalate (PET) layer coated with indium tin oxide (ITO). They are a viable contender for usage in transparent MMAs due to their simplicity of accessibility and range of sheet resistance values [20].

ITO is utilised in touchscreen technology, flat screen and liquid crystal displays, nanoscale solar cells, scientific slides and real projects, solar panels, aviation windshields, Electromagnetic interference shielding, electricity windows, and the glass panels of supermarket freezers, in addition to touchscreen devices. The chemical stability and endurance of ITO coatings are additional key benefits. Optoelectronic applications employ PET [21–22].

Table 1 Parameters and values of designed MMA

Absorbers	R (µm)	L, L2 (µm)	W, W2 (µm)	L1 (µm)	W1 (µm)	L3 (µm)	W3 (µm)	T (µm)
Dual Band	55	200	200	-	-	170	12	0.185
Triple Band	65	200	200	170	12	-	-	0.185

For simulation, the finite element methodology (FEM)-based CST Microwave Studio software is utilised, which is available for purchase. The electric or magnetic wave is impacted along the z-axis, and the master-slave set - up is configured in the x and y axes to mimic the unit structure's true periodic recurrence. In the x and y directions, the unit cell criterion is applied, and in the z-direction, the open space boundary condition is applied. In order to satisfy the master-slave boundary condition, the floquet port is chosen as the port excitation. Equation (1) can be used to determine that the absorber's absorption depends on the incident wave frequency.

$$AB(\omega)=1-TR(\omega)-RE(\omega) \qquad \text{-----(1)}$$

The absorption rate, reflectance, and transmittance of the THz energy are denoted by the letters AB(ω), RE(ω), and TR(ω), respectively. while S11 and S21 are the S parameters that can be determined by simulation in a straightforward manner. Additionally, reflection and transmission values are derived from S11 and S21 values, such as $RE = |S11|^2$, $TR = |S21|^2$. Maximum absorbance is accomplished by minimizing, both the RE(ω) and TR (ω). Since the wave cannot flow through the metallic backing sheet typically employed in MMA, the transmittance is zero. On the other hand, by creating the unit cell of the MMA so that way that its impedance is best matched with that of the empty space, zero reflectance is achieved.

3. Results and Discussions

3.1 Absorption Rate, Return Loss (S11)

Triple and dual band MMA is designed and simulated here and the simulation results are shown in figure 2 (a) and (b). The absorption rate of the triple band absorber (figure 2(a)) is 90%, 98% and 99.9% at the frequencies of 0.479 THz, 1.04 THz and 1.15 THz respectively. The absorption rate of the double band absorber (figure 2(b)) is 95% and 98% at the frequencies of 0.5 THz and 1.1 THz respectively. The average absorption rate is above 90%. So the triple and dual band absorber produces the better absorption rate.

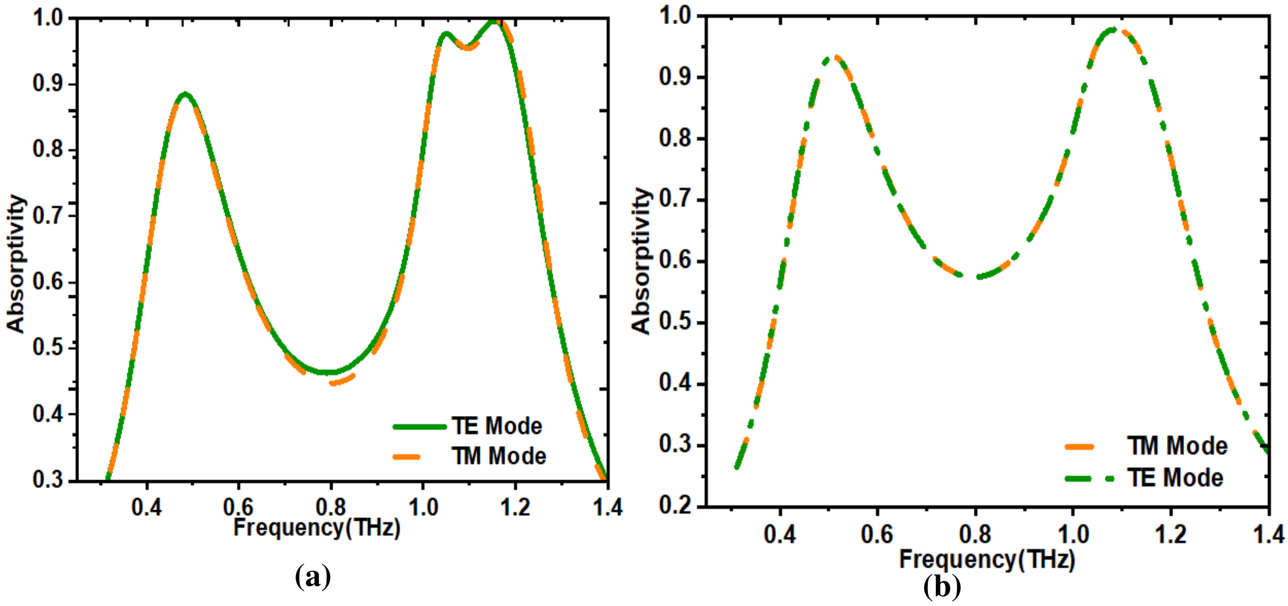


Figure 2. (a) Absorption rate of triple band MMA (b) Absorption rate of dual band MMA

And the absorption rate is calculated for both transverse electric (TE) and transverse magnetic(TM) modes. For both the modes the absorption is same which gives the polarization independent behaviour.

Return loss characteristics are shown in figure 3. For all the frequencies the return loss is below -10 decibel. So it produces the better output absorption.

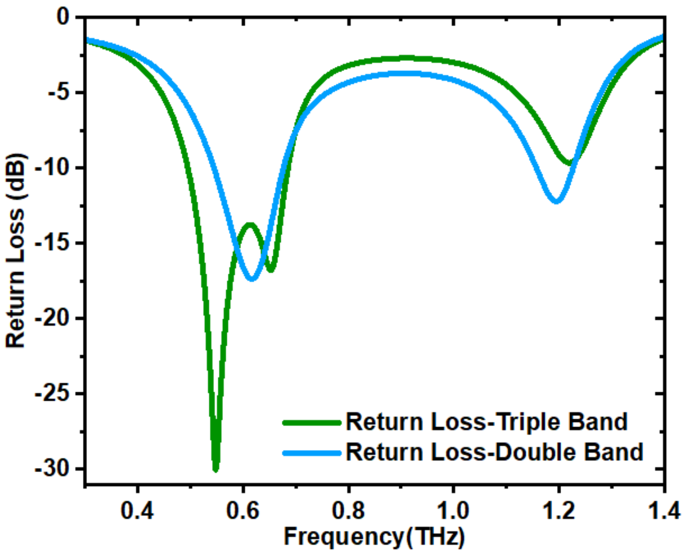
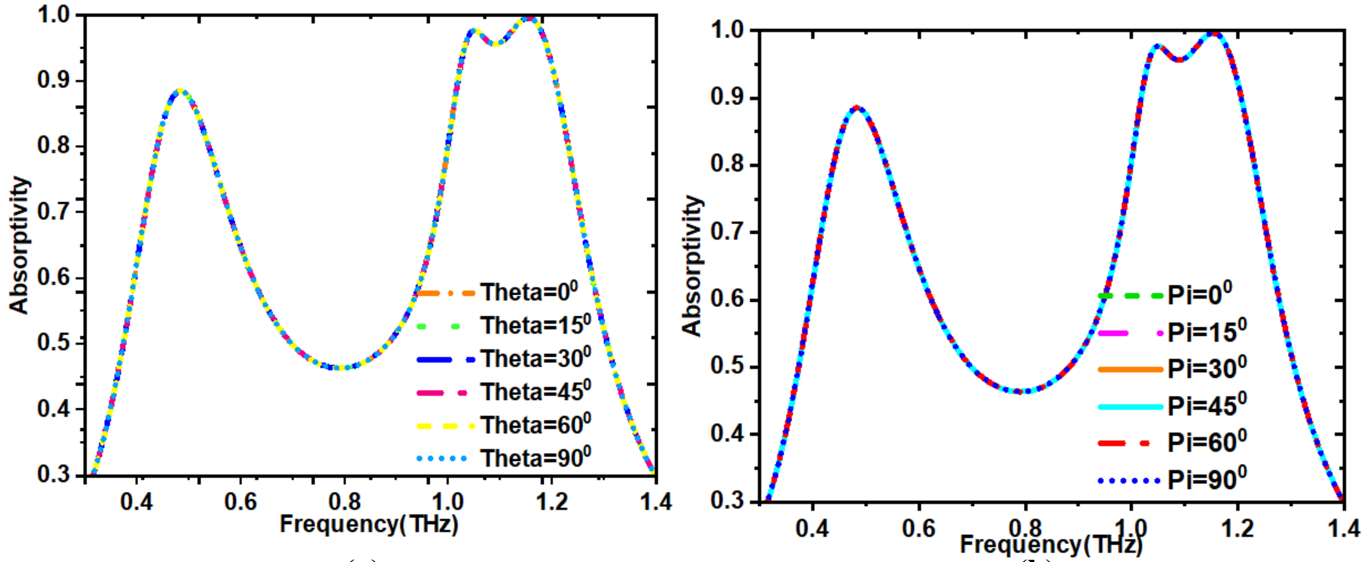


Figure 3. Return Loss Curves of Terahertz MMA

3.2 Polarization (ϕ) and Incident Angle (θ) Stability

Polarization angle and oblique incident angle values are changed from zero degree to ninety degrees and the output curves are shown in figure 4. while changing the angle values from 0 degree to 90-degree absorption rate and resonant values did not vary so from that we analysed this structure is polarization and angle independent in nature.

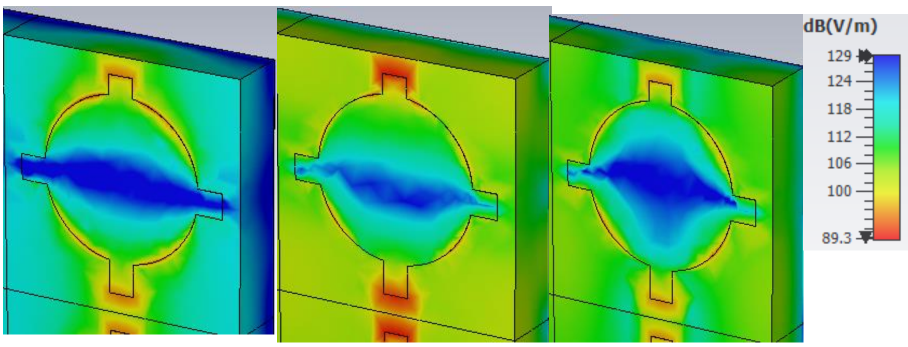


(a) (b)

Figure 4. (a) Simulated absorption curves for different polarization angle (ϕ) (b) different incident angle (θ)

3.3 Electric Field Distribution

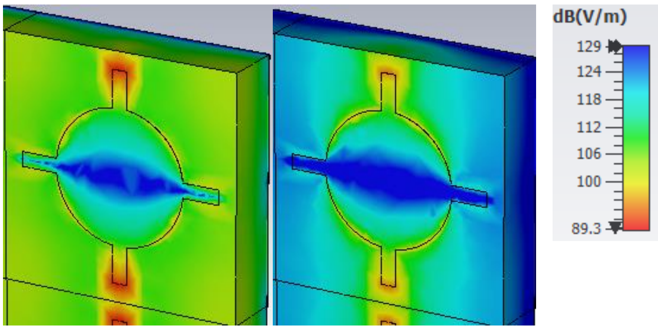
The internal characteristics and mechanisms of the structure is analysed by electric field and magnetic field distributions. Figure 5 shows the electric field distribution of a triple band metamaterial absorber. Figure 5(a) shows the electric field distribution at 0.479 THz, here electric field is maximum at inside the patch structure and surface of the dielectric. At 1.04 THz the electric field is maximum at surface of the dielectric and inside, edges of the patch structure. When the frequency value is 1.15 THz the electric field distribution is maximum at whole patch structure and surface of the dielectric. The intensity of the colour scale (last diagram) is displayed in figure 5.



(a) (b) (c)

Figure 5. (a) Electric field distribution at (a) 0.479 THz, (b) 1.04 THz, (c) 1.15 THz

Figure 6 shows the electric field distribution of a dual band metamaterial absorber. Figure 6(a) shows the electric field distribution at 0.5 THz, here electric field is maximum at inside the patch structure and surface of the dielectric. At 1.1 THz the electric field is maximum at surface of the dielectric and inside, edges of the patch structure which is shown in figure 6(b). The intensity of the colour scale (last diagram) is displayed in figure 6.

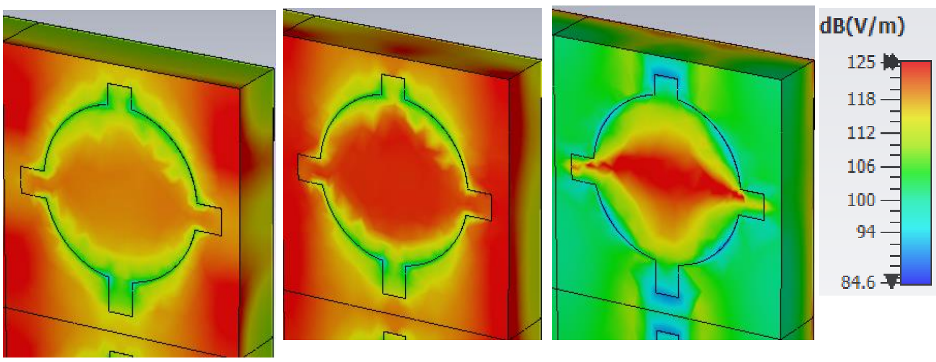


(a) (b)

Figure 6. (a) Electric field distribution at (a) 0.5 THz, (b) 1.1 THz

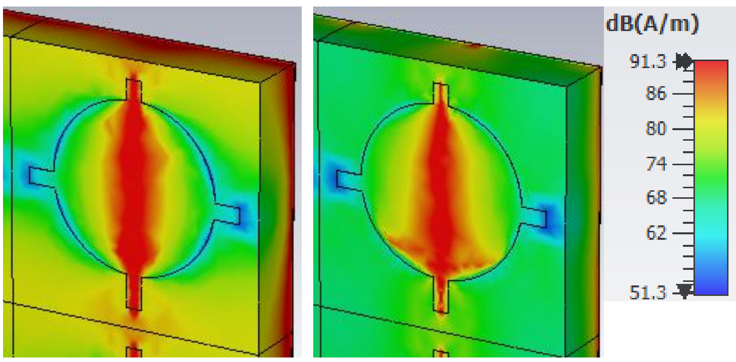
3.4 Magnetic Field Distribution

The internal characteristics and mechanisms of the structure is analysed by electric field and magnetic field distributions mostly. Figure 7(a) shows the magnetic field distribution at 0.479 THz, here magnetic field is maximum at whole patch structure and surface of the dielectric. At 1.04 THz the magnetic field is maximum at surface of the dielectric and whole patch structure, edges of the patch structure which is shown in figure 7(b). When the frequency value is 1.15 THz the magnetic field distribution is maximum at inside of the patch structure and surface of the dielectric which is shown in figure 7(c). The intensity of the colour scale (last diagram) is displayed in figure 5.



(a) (b) (c)

Figure 7. (a) Magnetic field distribution at (a) 0.479 THz, (b) 1.04 THz, (c) 1.15 THz



(a) (b)

Figure 8. (a) Magnetic field distribution at (a) 0.5 THz, (b) 1.1 THz.

Figure 8 shows the magnetic field distribution of a dual band metamaterial absorber. Figure 8(a) shows the magnetic field distribution at 0.5 THz, here magnetic field is maximum at inside the patch structure and surface of the dielectric. At 1.1 THz the magnetic field is maximum at surface of the dielectric and inside, edges of the patch structure which is shown in figure 6(b). The intensity of the colour scale (last diagram) is displayed in figure 8.

4. Parametric Study

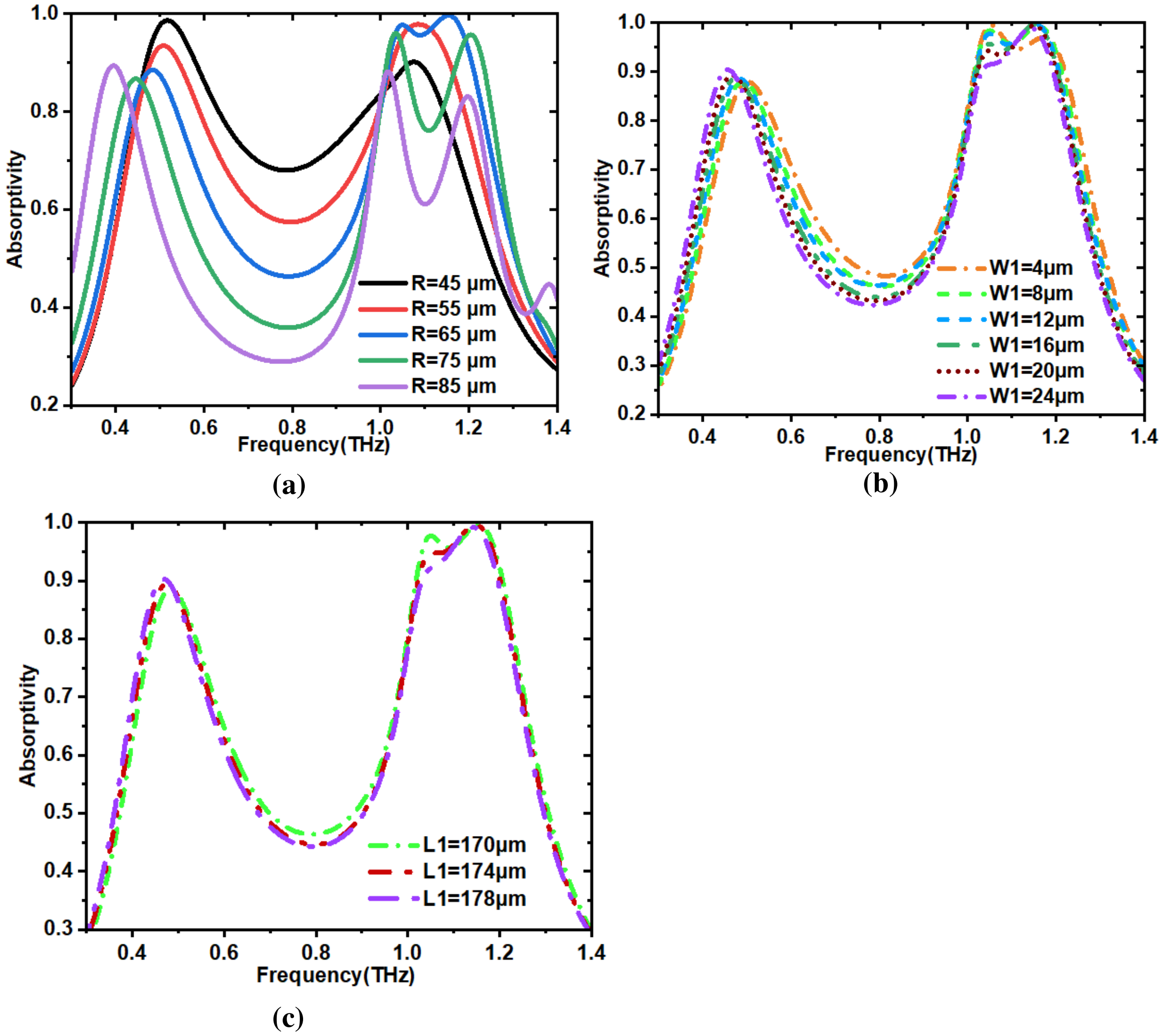


Figure 9. Parametric study graphs for varying (a) Radius value, (b) W_1 value, (c) L_1 value

Table 2 Comparison of this work with previous works

Ref.	Range (THz)	No. of bands	Materials used	No. of dielectric layers	Polarization stability	Angular Stability	No. of Sub-Resonators
[23]	0.4-2	3	Au, Polyimide, Silicon Nitride	Multiple	insensitive analysis up to 60^0	No analysis	6
[24]	2.5-15	1/2/3	Copper, SiO2, Graphene	Multiple	No analysis	No	4
[25]	0.5-1	3	Aluminium, PET	Single	insensitive	No	3
[26]	0.3-0.9	3	Au, Silicon	Single	Insensitive up to 45^0	insensitive	2
[27]	0.2-1	3	Al, PET	Single	Insensitive up to 90^0	Insensitive upto 90^0	3
[28]	0.9-3.6	2/3	Au, Polyimide	Multiple	No analysis	No analysis	3
[29]	0.4-1.4	1/2	Au, Si, Polyimide	Multiple	No analysis	No analysis	6
[30]	0.2-1.4	broad	ITO, PET	Single	Insensitive up to 90^0	Insensitive up to 40^0	1
[31]	3-9	3	Cu, FR4	Single	Insensitive up to 90^0	Insensitive up to 90^0	6
[32]	0-3	3	Au, Polyimide	Single	Polarization insensitive up to 60^0	No analysis	1
This Work	0.3-1.4	3	ITO, PET	Single	Insensitive up to 90^0	Insensitive up to 90^0	1

Studying parameters helps to choose the best values and getting the best absorption rate from that. So that we are changing the patch radius (R) value from 45 μm to 85 μm and other values we keep it as constant which is shown in figure 9 (a). That time 55 μm based absorber provides the dual band operation and 65 μm based absorber provides the triple band operation with better absorption rate compare to other values. And the figure 9 (b) shows the variation of W_1 values while all other values are kept as constant. Changing the values from 4 μm to 24 μm that time, 12 μm based absorber provides the good absorption rate compare to others. Figure 9(c) shows the absorption curves while varying L_1 values and kept other values are constant. The maximum value of L_1 is 190 μm. So we are changing the values from 170 μm to 178 μm that time we got high absorption rate when the value is 170 μm. So from the parametric analysis we chose best absorption rate value and found this absorber will work in both triple and dual band operation.

5. Conclusion

An optically transparent polarization and angular insensitive triple and dual band Terahertz (THz) Metamaterial Absorber (MMA) is designed and analysed. The MMA consists of three layers, without using stacked layers, doping and multiple resonators the absorber is designed here. The metal and substrate used here is Indium Tin Oxide (ITO) and Polyethylene Terephthalate(PET). The ITO with PET combination produces the optical transparency. The important thing in this work is the same design produces the triple and dual band operation while changing the top patch radius value. It covers the frequency ranges from 0.3 THz to 1.4 THz and it gives the five absorption bands totally, within this range at the frequencies of 0.479 THz, 1.04 THz, 1.15 THz, 0.5 THz and 1.1 THz. The designed structure is analysed by electric field, magnetic field distribution and surface current distributions. This structure is polarization and angle independent up to 90 degrees. From the parametric analysis, we found this absorber will work in both triple and dual band operation. So this bifunctional working absorber will find more applications in optically transparent devices, sensing and imaging.

6. Declaration

Ethics approval

Not applicable
This research not performed with any Human or Animal and not affected environment directly or indirectly.

Consent to participate

All authors are included in the manuscript are participated, and there is no other participation.

Consent for publication

Hereby, we confirm that, the article titled as "Compact size Easily Extendable Self Isolated Multi-port Multi-band Antenna for Future 5G High band and sub-THz band Applications" has not been published previously and it is not under consideration elsewhere.

Availability of data and materials

There is no data available for this research.

Competing interests

There is no conflict of interest and no completing interest in this work.

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Authors' contributions

All three authors are equally contributed on this work in terms of idea, simulation task and manuscript preparation.

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