Investigate the Effect of Dielectric Properties on Microwave Absorption of Pyramidal Microwave Absorber

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***Abstract*— This paper presents an analysis of the impact of various dielectric properties material's effects on broadband pyramidal microwave absorbers (PMA). The Computer Simulation Technology (CST) studio software simulates and analyzes the PMA over 0.7 GHz to 30 GHz frequency range. To achieve the best reflectivity performance of the PMA, different types of dielectric materials and the thickness of the base layers were analyzed and investigated. The average of four types of sample materials studied, the reflectivity level is between -50 dB and -27 dB for the desired range of frequency, 0.7 GHz to 30 GHz. The sample-4 material has a dielectric constant of 3.83, and a loss tangent of 1.52 has the best microwave absorption, absorbing microwaves above -48 dB over the frequency range of 0.7 GHz to 30 GHz. Because of its microwave absorption capability, sample-4 could be used in a microwave pyramidal absorber.**

***Index Terms*—**Dielectric material, Microwave absorber, Absorption, Reflectivity.

I. INTRODUCTION

Electronic devices have rapidly advanced in recent years and are now utilized worldwide. However, electronic devices transmit electromagnetic wave (EM) radiation, which can harm people's health and interfere with the regular operation of other electronic equipment[1]. As a result, the researchers conducted a study in microwave absorption to minimize the risk of EM radiation. Electromagnetic interference (EMI) and electromagnetic compatibility (EMC) tests in antenna measurement setup are examples of applications where microwave absorbers are theoretically applied to minimize unwanted radiation that could interfere with the operation of equipment systems [2]. Microwave absorbers must be designed with the magnitude, phase for various angles, perpendicular polarization, and absorption

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reflection loss, all considered in the parameters [3]. Pyramidal absorbers, truncated pyramidal absorbers, wedge absorbers, convoluted absorbers, hybrid absorbers, flat, hollow pyramidal absorbers, oblique, metamaterial absorbers, and other shapes can all do make as absorbers. On the other hand, pyramidal and wedge microwave absorbers are often used in the commercial and industrial markets [4], [5].

Most anechoic chamber uses microwave absorbing materials to reduce high-frequency energy reflections[1], [2]. Telecommunications, military, high-speed electronics, and automobiles are just a few applications that use this frequency range. Microwave (1 GHz-40 GHz) and low frequency (30 MHz-100 MHz) absorber items are provided [4]. Ferrite tiles are the most common low-frequency absorber material, ranging from 30 MHz to 1000 MHz[6]. Several EMC test chambers use ferrite tiles. Microwave absorbers are useful for polyurethane and polystyrene foams in 1 GHz to 40 GHz[7]. The anechoic chamber reflects and absorbs microwaves. Designing a good RF absorber for various incidence angles and parallel and perpendicular polarizations [5].

When it passes through an electromagnetic wave that travels across free space is referred to be material that will have its wavelength reflected, transmitted, or absorbed. The dielectric constant and the tangent loss parameters for material are typically applied to analyze and calculate the absorption profile. When dielectric properties are measured, the complex relative permittivity (ε_r) and complex relative permeability (μ_r) of the materials are also measured. Besides that, there are two parts to a complex dielectric permittivity: a real part and an imaginary part. Because of an external electrical field, the real component of complex permittivity, also described as the dielectric constant, is how much energy does store in a material. The imaginary part of a lossless material is zero, sometimes referred to as the "loss factor." It is the amount of energy lost when a material is measured due to an electric field outside of it. The loss tangent expresses the ratio of the complex permittivity's imaginary and real parts. The loss tangent is sometimes referred to by the term's tangent loss, dissipation factor, and loss factor. The complex relative permittivity (ε_r*) of a material can be determined by (1) [8], [9].

$$\varepsilon_r * = \varepsilon_r{}' - \mathrm{j}\varepsilon_r{}'' \qquad (1)$$

ε_r' (epsilon) represents the electromagnetic energy of storage, which is represented by the dielectric constant, ε_r'' the loss factor, also known as the dissipative factor, denotes the transformation of electromagnetic energy to heat. The performance of material when a microwave absorber can be confirmed by measuring loss tangent at an exchange of electromagnetic waves, as shown in (2),

$$\tan\delta = (\varepsilon''_r) / (\varepsilon'_r) \qquad (2)$$

The following equation as shown below (3) applied to determine the absorption qualities, the sample's electrical conductivity (σ) must be calculated,

$$\sigma = 2\pi f \varepsilon_0 \varepsilon_r{}'' \qquad (3)$$

Where $\varepsilon_0 = 8.854 \times 10^{-12}\ F/m$. Whereas an electromagnetic wave propagates across a medium, the

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reflectivity and transmissivity are determined by how well the impedance matching is performed. To study the absorption profile in terms of impedance matching, we need to calculate the reflectivity (R) as well as transmissivity (T), which can be calculated from the transmission line theory equation (4) as shown below,

$$R =- 20\log|(Z_R - Z_0)/(Z_R + Z_0)|dB \tag{4}$$

Z_R is the interface's input impedance between the thin layer and the air, and Z_0 is the intrinsic impedance of free space $\sqrt{\frac{\mu_0}{\varepsilon_0}}$ = 377 ohms. As a result, according to (5), free space is the incident medium for microwaves, and a material with an impedance of 377 ohms will not absorb electromagnetic energy.

$$T =- 20\log|2Z_R/(Z_R + Z_0)|dB \tag{5}$$

Equation (6) is used to determine the absorption profile of a material, as shown in [10],

$$AR(\omega) = 1 - |S_{11}|^2 - |S_{21}|^2 \tag{6}$$

The reflected and transmitted signals are indicated by S_{11} and S_{21}, respectively.

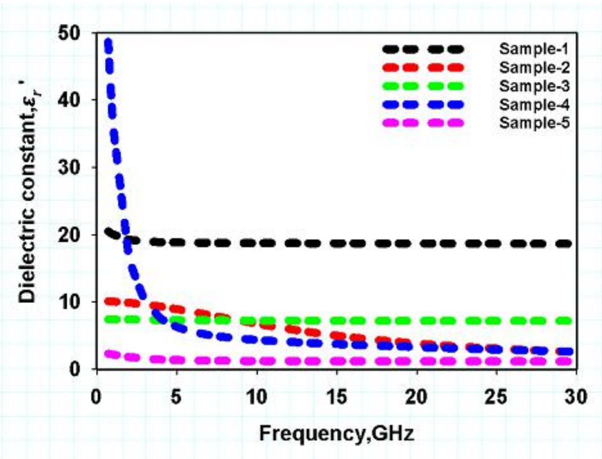
II. Design and Simulation

The software Computer Simulation Technology (CST) studio was used in this project study to design and simulate a pyramidal microwave absorber (PMA). The CST software can define dielectric properties and affect PMA reflectivity over 0.7 GHz to 30 GHz. A commercial microwave absorber was used to design the PMA. To determine the S-parameter(S_{11}) graph, the PMA was simulated with a Transient Solver in CST. The microwave absorber's design and structure are based on the different dielectric properties of sample materials shown in Table Ⅰ. Overall, a material's dielectric constant, denoted by the term ε_r', its ability to store electrical energy relates to the quantity of polarisation available. Apart from that, the dielectric loss factor, indicated by the term ε_r'', represents the dissipated electric energy in the material. The increasing frequency of losses due to dielectric breakdown is mainly produced by dipolar polarisation with interfacial polarisation while operating in the microwave range [3], [11]. The average measurement of the sample material's dielectric properties over 0.7 GHz to 30 GHz is shown in Table Ⅰ. Fig.1 (a) shows the average dielectric constant values, and Fig. 1 (b) represents the average loss factor of different materials, which are sample-1, sample-2, sample-3, sample-4, and sample-5, respectively, as shown in the figures. As illustrated in Fig.1(c), the average loss tangent value for sample-2 and sample-4 has better 0.83 and 1.52, respectively. The dielectric properties are defined at a frequency range of 0.7 GHz to 30 GHz. Improved storage capacity and dissipation ability of the material are attributed to the increase in dielectric properties. The dielectric constant is expressed as the ratio of the loss factor to the dielectric constant; thus, it is possible to define the loss tangent, tan δ [9].

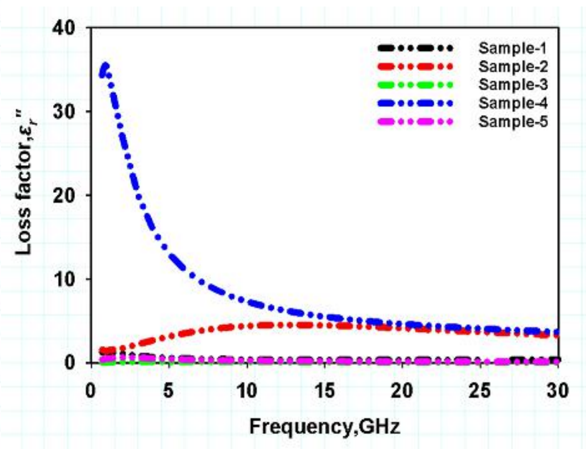
In this work, five different types of materials are conducted to determine the absorption of dielectric properties based on the materials' absorption properties. The material used is sample-1, sample-2, sample-3, sample-4, and sample-5. These were all different dielectric properties values. These materials exhibit high permeability (magnetic loss qualities) as well as high permittivity (electrical conductivity) (dielectric loss properties). In addition to having a unique combination of features, these materials effectively eliminate high-frequency EMI. However, these materials are being used in this study to analyze the absorption of microwave absorbers.

TABLE I. AVERAGE DIELECTRIC PROPERTIES OVER 0.7 GHz TO 30 GHz.

Type of material	Average dielectric constant	Average Loss Factor	Average Loss Tangent
Sample-1	18.72	0.33	0.02
Sample-2	5.29	4.50	0.83
Sample-3	7.2	0.08	0.01
Sample-4	3.83	5.74	1.52
Sample-5	1.19	0.19	0.16



(a)



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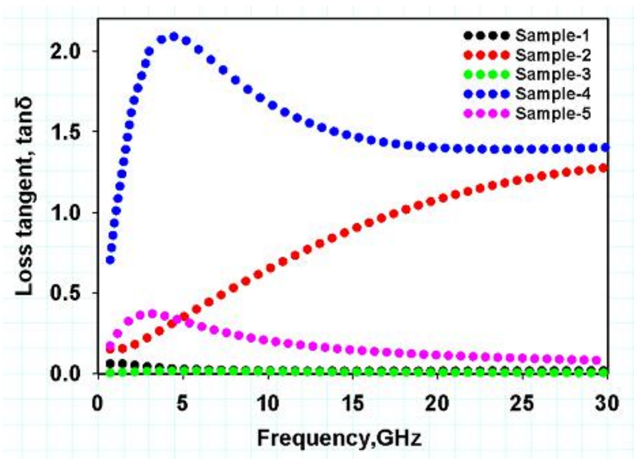

(c)

Fig. 1. Dielectric properties of different types of materials.

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A. PMA Design

For this project, a pyramidal absorber was chosen since it is a great microwave absorber recognized for use in situations where energy is incident at a normal angle. Regarding specular treatment, pyramidal absorbers are often used on the rear walls, sidewalls, floors, and ceilings of the chamber to minimize reflections [12], [13]. In addition, a pyramidal microwave absorber has a numerically optimized design and is highly fire retardant [13]. The dimension for the absorber's base part is 10 cm (width) × 10 cm (length)× t cm (thickness). Meanwhile, the dimensions of the pyramidal base part are 5cm (width) ×5 cm (length) × 10.8cm (height). Fig. 2 shows the dimension of PMA in CST software with the metal back plated (PEC) placed at the flat microwave absorber's bottom.

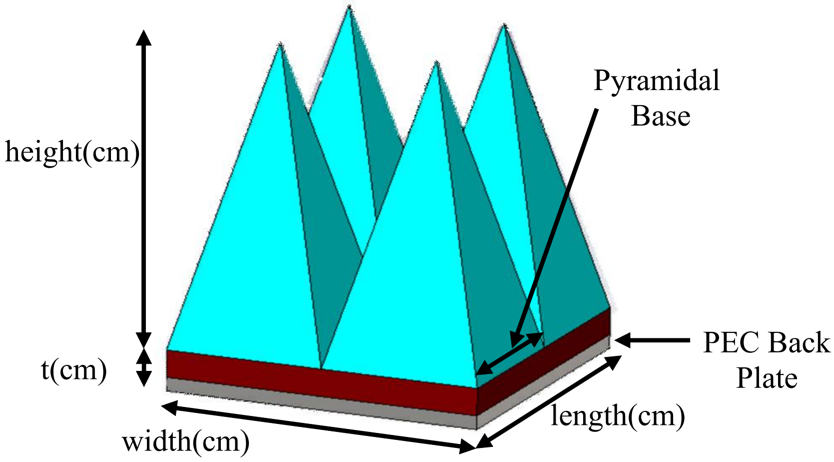

Fig. 2. PMA in CST Microwave Studio simulation software.

B. Simulation Setup

In this simulation design, a waveguide port, also known as the initial signal point, is situated in a normal incidence (0˚) position because the normal incident (0˚) signal point is 15 cm from the PMA's origin. Using the CST studio software, a PMA in boundary conditions with waveguide port (red) is presented in Fig. 3. The incident angle, often known as the S-parameter(S_{11}), is transmitted from port 1. The PMA material properties are defined in CST, and the absorber is measured using the dielectric properties analyzed. The thickness of a 2×2 array base of PMA investigates over 0.7 GHz to 30 GHz. The S-parameter results in dB are also used to calculate the combined absorber's reflectivity.

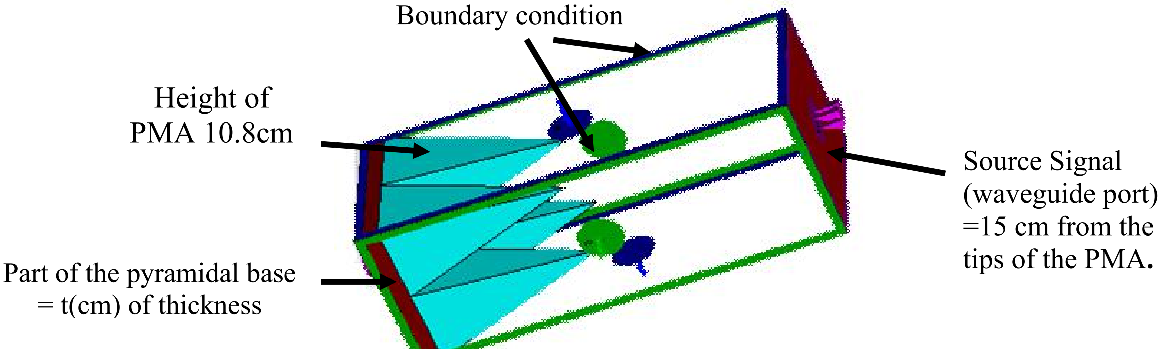

Fig. 3. Setup of Pyramidal Microwave Absorber in boundary conditions with waveguide port (red).

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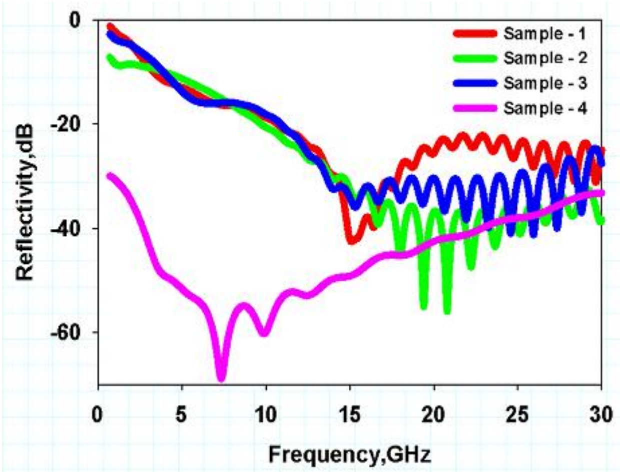
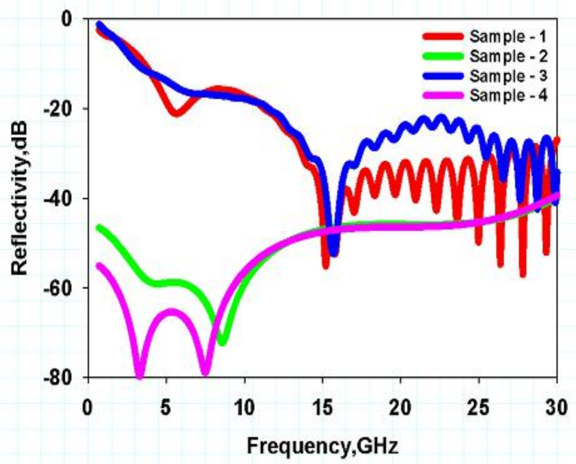
III. Result and Discussion

A. *Effect of samples in PMA*

The reflectivity of the PMA with a fixed height of h = 10.8 cm and material of sample-5 with several types of material base layers in CST studio software was used to conduct the initial investigation under normal incidence, and the results are shown in Fig. 4 as a comparison. The simulation results indicate those materials with a high level of performance loss tangent values will have low reflectivity, which is following Fresnel's wave theory, according to the findings [9], [14]–[19]. As illustrated in Fig. 4 (a), (b), (c), and (d), the reflectivity of sample-1, sample-2, and sample-3 of pyramidal microwave absorbers with base layer thicknesses of 0.1 cm, 0.3 cm, 0.6 cm, and 1 cm is observed to be less than −20 dB (with 99 % of absorption) with frequencies in the range of 11.65 GHz to 30 GHz.



(a)



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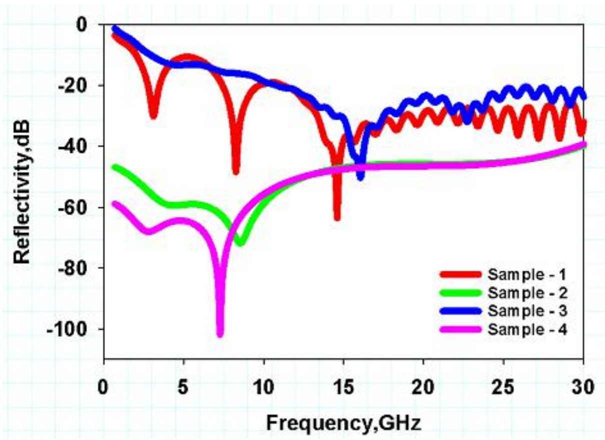

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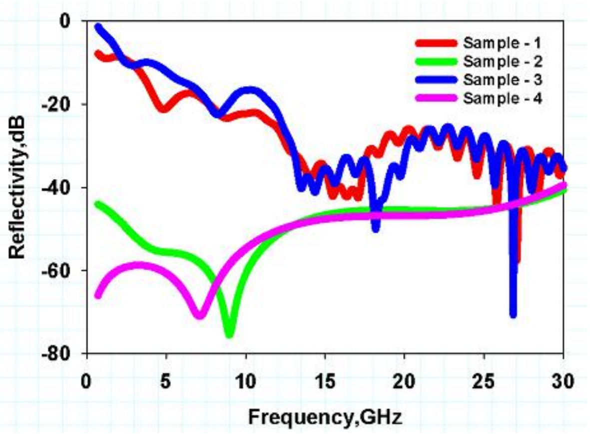

(d)

Fig. 4. Reflectivity comparison of different base layer thicknesses on a PMA with (a) t=0.1cm, (b) t=0.3cm, (c) t=0.6cm and (d) t=1cm.

Furthermore, when operating from 0.7 GHz to 9 GHz at base layer thicknesses of 0.3 cm, 0.6 cm, and 1 cm, the reflectivity of various types of base layers, including sample-2 and sample-4, was improved by between – 40 and –70 dB. It is observed that using a 1 cm thick base layer sample-2 for a PMA with a reflectivity range of −50 dB to −70 dB between the frequencies of 5 GHz and 9 GHz. It is possible to achieve 99.99 % absorption from 5 GHz to 9 GHz. Adding a particular material between the PMA and the base layer and the backing of a metal plate (PEC) can improve the reflectivity of a pyramidal microwave absorber at lower frequencies (from 6.5 GHz to 7.9 GHz). The lowest reflectivity (R) of up to 90 dB at 7.3 GHz, a 0.6 cm thick base layer, on the other hand, performs best with sample-4. Apart from reflectivity, combined optimization of the sample-5 material for the PMA and the thickness of the base layer is predicted to improve impedance matching [15]. The value has a higher loss tangent, better absorption (lower reflectivity), and thinner thickness than material samples, as seen in Fig.4. Table Ⅱ shows average simulated reflectivity over 0.7 GHz to 30 GHz for a 10.8 cm height PMA with a different type of base layer.

TABLE Ⅱ. AVERAGE SIMULATED REFLECTIVITY OVER 0.7 GHz TO 30 GHz FOR A 10.8 CM HEIGHT PMA WITH A DIFFERENT TYPE OF BASE LAYER.

Type of Material	**Base layer thickness, t (cm)**			
	t =0.1 cm	**t =0.3 cm**	**t =0.6 cm**	**t =1cm**
Sample-1	−27.62	−28.50	−32.25	-33.88
Sample-2	−28.28	−48.58	−48.50	-48.33
Sample-3	−29.40	−29.26	−27.22	-40.25
Sample-4	−50.63	−48.77	−48.69	-48.65

The comparison of simulated findings of material sample-4 with different base layer thicknesses is shown in Fig. 5. For example, in Fig. 5, the reflectivity of sample-4 was determined using the free space method in a normal incident with thicknesses of 0.1 cm, 0.3 cm, 0.6 cm, and 1 cm, respectively. Sample-4 material thickness, t = 1 cm, produces the best reflectivity at lower frequencies. This was also determined that the PMA with sample-4 base layer has better absorption (low reflectivity) at low frequency throughout a wide frequency range. As analyzed, the PMA of sample-4 material also can apply it as a tunable microwave absorber, which indicates that the operating frequency range can be shifted by changing the thickness of the bottom layer [9], [20]. As the thickness of the PMA base layer is improved, the wavelength of the incident wave that matches the base layer is improved steadily. As a result, the matching frequency will shift from high to low frequency. Because of the increases in the base thickness, the most insufficient reflectivity peak findings show a slight shift to a lower frequency. The outcomes of the simulation, on the other hand, are still acceptable. Given the ability of sample-4 to absorb microwaves at low frequencies, it can be considered a microwave absorber for further investigation.

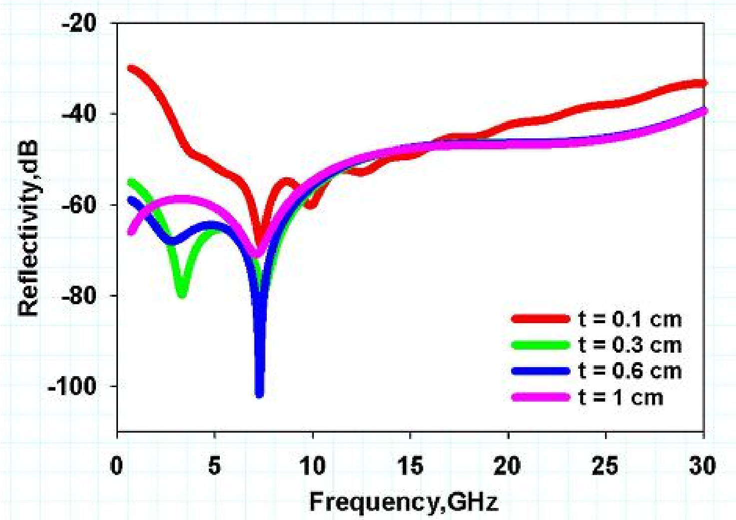

Fig.5. Reflectivity comparison between sample-4 with different thicknesses of base layers on the pyramidal microwave.

IV. Conclusion

In the conclusions, PMA with different dielectric properties and base layer thicknesses may perform at varying levels of microwave absorption. The loss tangent of samples plays a vital role in microwave absorption, and the pyramidal microwave absorber base layer reaches a specific value due to loss tangent values [20]. If the thickness of the sample is varied throughout a range of frequencies, it is possible to change the frequency range of microwave absorption. The study demonstrates that a high loss tangent value has a severe effect on the ability of a microwave absorption system to work well at low frequencies. The thickness and dielectric properties of absorber materials were used to determine absorber materials' dielectric microwave absorption characteristics. Throughout this investigation, it was observed that using sample-4 material with thicknesses of 0.1 cm, 0.3 cm, 0.6 cm, and 1 cm for the pyramidal microwave absorber produced the most effective results.

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