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Microwave absorption study of dried banana leaves-based single-layer microwave absorber

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Research Paper

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Abstract

The ever-increasing use of electronic devices leads to a dangerous upsurge in the emission of microwave radiation; this has drawn appreciable concern in the fabrication of eco-friendly microwave absorber (MA) and it can be a prospective alternative. Present work, in the quest for possible alternatives, explores carbon-rich agricultural residues such as dry banana leaves as a microwave-absorbing material. The variation of microwave absorption efficiency with an increase in the percentage of resin has been already reported. An extensive study on the microwave absorption efficiency of dried banana leaves with sample preparation and reflectivity analysis by hardware measurement, and simulative analysis using CST microwave studio suite for different thicknesses in the frequency range of 1–20 GHz has been also explored in the present work. Single-layer MA thickness variation establishes different microwave absorption performance.

Introduction

Radiofrequency and microwave enjoy numerous applications in various fields such as point-to-point communication, wireless communication, military applications, and radar communication [1]. The intense use of electromagnetic (EM) wave in various applications gives rise to EM pollution in the environment. In our contemporary society, EM pollution causes many diseases, e.g. headaches, sleeping disorders, trepidation, etc., and has been ranked as the fourth source of pollution by the World Health Organization [2, 3]. EM pollution also deteriorates the functioning and durability of electronic equipment. Therefore, this pollution has become a serious worldwide concern and it can be reduced by either shield mechanism or absorption mechanism. Compared with EM shielding material, microwave-absorbing materials (MAM) are powerful alternatives to eliminate pollution due to their effectiveness in dissipating microwave energy without any secondary pollution. In general, MAM and microwave-absorbing structures should satisfy general requirements that are enlisted as follows: it should (i) minimize the reflection of EM waves at the air to absorber interface; (ii) have strong absorption of EM waves; (iii) have broad bandwidth and angular response; (iv) have low weight and thickness [4]. Unfortunately, meeting these competing requirements simultaneously is a challenging task. To meet these objectives and enhance the efficiency of MAM, tedious and extensive techniques have been suggested [4]. These techniques can be categorized into two main categories: material and geometry based. In the material-based technique, the microwave properties of the material complex permittivity (ε) and permeability (μ) are tailored in a manner to increase electrical and magnetic losses of the material. In the geometry approach, the MAM is constructed in a certain structure with particular geometry and dimensions that reduce the reflection and enhance confinement and absorption of the EM waves inside the structure. Different types of materials used as MAM, such as carbon, metal and metal particles, conducting polymers, polyaniline conducting polymer, tubules and filaments, and recently composite of nano-materials, have been discussed in the literature [5–11].

Nowadays, chemical-based materials and ferrite are used to fabricate microwave absorber (MA). The fabrication procedure is costly and the materials are not bio-degradable. Also, they are not environment-friendly due to their toxic emission under high temperature which can pose a health risk to direct contact personnel [12]. Due to the high cost of the ferrite materials, their transportation, and their large densities, we are forced to quest for alternative materials. The basic element that is used very often in the absorber is carbon. Being a semiconductor material, carbon allows a small amount of charge to flow through it and has favorable electrical characteristics. In order to fabricate low-cost and eco-friendly absorber, agricultural residues having high carbon content have proved to be a useful alternative material in the microwave communication field. MAM using agricultural residues, such as rice husk, rice straw, oil palm empty fruit bunch, sugar-cane bagasse, coconut coir, and coconut shell powder, has been studied and remarkable absorption performance has been reported

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[13–21]. The carbon content found in rice husk, oil palm empty fruit bunch, sugar-cane bagasse, and coconut shell charcoal is 35.77, 40.5, 17.89, and 83%, respectively [22–25].

The carbon content present in the dried banana leaves is 43.5% [26] more than the reported agricultural residues. Single-layer MA have numerous applications in military and civil industries due to expedient and cost-effective fabrication. The aim of this investigation is a first time attempt to design a single-layer flat-shaped MA using dried banana leaves and study the dielectric properties as well as microwave absorption performance. In this investigation, single-layer MA structure has been comprised of a lossy absorbing layer and a PEC (perfect electrical conductor) as a reflective layer, and the structure is usually known as Dällenbach layer [27]. A 99.9% pure copper plate of 0.21 mm thickness has been used as a PEC. In this study, we have designed the whole research work in five sections: (i) Theoretical aspects, (ii) Sample fabrication method, (iii) Measurement method, (iv) Simulation strategy, and (v) Result and analysis. Section "Theoretical aspects" introduces the basic theory on the master factor of microwave absorption. In section "Sample fabrication method", the fabrication procedure of a single-layer absorber with different thicknesses has been discussed. In section "Measurement method", particle size, the thickness of the particle board, and dielectric properties of the dried banana leaves in the form of powder as well as particle boards have been measured using an optical microscope, digital caliper, and open-ended coaxial probe (OCP) method, respectively. In section "Simulation strategy", the simulation strategy has been described. In section "Result and analysis", the absorption performance of a single-layer absorber has been analyzed in terms of experimental and simulative aspects. Also, the impact of thickness on microwave absorption efficiency has been explored in this section. Eventually, the article has been concluded with a quest for another exploration.

Theoretical aspects

MAM have to achieve general requirements which are difficult to accomplish simultaneously. While designing a MA structure, the aim is to accomplish two targets: (i) reducing reflection and (ii) increasing absorption over broadband frequency. Reducing the reflection can be met by wave impedance matching and increasing the absorption can be met by controlling the dielectric properties of the materials.

When an EM wave penetrates and propagates through the material, the experience is divided into three mechanisms which are a reflection of the incoming wave, absorption of the wave as it passes through the thickness of the material, and transmission of the wave. The absorption characteristics of the material rely on its dielectric properties such as complex permittivity, loss tangent, and conductivity [28]. The complex permittivity is a dominating factor which determines how the EM field interacts with the molecular structure of the material. When an EM field is applied across a dielectric material, translational motion of electrons or ions is induced by the internal field, thus it rotates the dipole and dipoles are aligned accordingly and the material is said to be polarized and the polarization mechanism is known dipolar polarization. Inertial, elastic, and frictional forces impede this induced motion as well as the realignment of dipoles and cause energy loss which leads to heat dissipation. Another polarization mechanism which also plays a role in absorption mechanism is conduction mechanism. In this mechanism, any mobile charge carriers (electrons, ions, etc.) move back and forth through the material under the influence of the electric field, creating an electric current. These induced currents will cause heat generation in the materials due to any electrical resistance caused by the collisions of charged species with neighboring molecules or atoms. The complex permittivity is a frequency-dependent parameter which can be expressed with the following expression [29]:

$$\varepsilon^{*}=\varepsilon' - j\varepsilon'', \tag{1}$$

where ε' is known as the dielectric constant which characterizes the material's ability to store and release EM energy, ε'' is the loss factor or dissipative factor which corresponds to the material's ability to absorb or attenuate EM energy to create thermal energy.

There is another related factor to microwave absorption namely loss tangent, commonly used to indicate the efficiency of conversion of microwave energy into thermal energy within the dielectrics and is given in (2) [29]:

$$\tan\delta = \frac{\varepsilon''}{\varepsilon'}. \tag{2}$$

It is defined as the ratio of the energy dissipated to the energy stored in the dielectric material. The more energy that is dissipated into the material, the less energy will penetrate into the dielectric material. This dissipated energy is converted into heat. The main principle of absorption mechanism is heat dissipation. Absorption is a necessary parameter in determining the optimum condition when designing an MA. An optimal absorber should provide 100% absorption of the entering signal. The power loss in terms of heat generation due to the electrical component of the EM wave can be further explained by the following equation [30, 31]:

$$P = \frac{1}{2}\sigma|E|^2 + \omega\varepsilon_0\varepsilon''|E|^2, \tag{3}$$

where P represents the power density in the material (W/m^3), σ is the electrical conductivity (S/m), $\omega = 2\pi f$(Hz); f is the frequency of the incident microwaves, ε'' is the dielectric loss factor, ε_0 is the permittivity of free space, E represents the electric field strength (V/m).

Conductivity is another factor which contributes to the conductive loss and it is the main parameter in determining the loss factor. The conductivity of the material is given in (4) [32] Fig. 1:

$$\sigma = 2\pi f\varepsilon_0\varepsilon_r'', \tag{4}$$

where $\varepsilon_0 = 8.854 \times 10^{-12}$ F/m.

The components of the incident power distribution inside the material where P_i, P_r, P_a, and P_t are incident, reflected, absorbed, and transmitted power, respectively, are expresses as:

$$P_i = P_r + P_a + P_t. \tag{5}$$

Equation (6) shows the expression of return loss:

$$RL\ (dB) = 20\log\frac{P_r}{P_i}. \tag{6}$$

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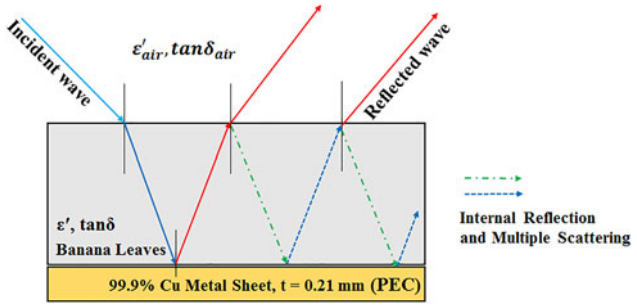


Fig. 1. Possible paths of the incident electromagnetic wave in a material.

Absorption profile $AR(\omega)$ of the material can be determined as [29]:

$$AR(\omega) = 1 - |S_{11}|^2 - |S_{21}|^2, \tag{7}$$

where S_{11} is the reflected signal and S_{21} is the transmitted signal.

In the context of the measurement setup, we measured the S_{11} parameter and the ground plane (PEC) allows minimal transmission. From both the point of view, transmission loss ($S_{21} \sim 0$) can be neglected. Therefore, (8) is the reduced form of (7) and it validates the measurement setup:

$$AR(\omega) = 1 - |S_{11}|^2. \tag{8}$$

Within the MAM, the microwave energy decays exponentially with distance x by a factor $e^{-\alpha x}$where attenuation constant (α) is given by [33]:

$$\alpha = A \times \frac{\omega}{C} \times \sqrt{\frac{\mu'\varepsilon'}{2}} \times \sqrt{\left[\sqrt{1 + (\tan\delta)^2} - 1\right]}, \tag{9}$$

where $\omega = 2\pi f$ and f is the frequency of microwave, C is the speed of light in vacuum, μ' is the relative permeability of the material ($\mu' = 1$), ε' and tan δ are the EM parameters of the material. A is the adjustment factor ($A = 8.68/100$ dB/Np) to convert α in dB/cm. The above expression indicates that the attenuation of microwave power for a dielectric absorber depends on ε' and tan δ. From (2), it can be concluded that the higher the imaginary part of the complex permittivity, the bigger the loss tangent and the better the wave absorption effect.

When an EM wave penetrates into the material and propagates through the material, the power of the wave drops to 37% of its initial value at a certain distance from the surface. The distance is known as skin depth and it is given by [34]:

$$D = \frac{C}{2\pi f \sqrt{2\varepsilon'\left[\sqrt{1 + (\varepsilon''/\varepsilon')^2} - 1\right]}}. \tag{10}$$

Sample fabrication method

Figure 2 illustrates the flow of work for developing the flat-shaped particle board. The structure of the work plan consists of five phases, i.e. collection, grinding, measurement of dielectric properties, the addition of resin and hardener agent, and simulative analysis. Shape plays a significant role in the absorption performance

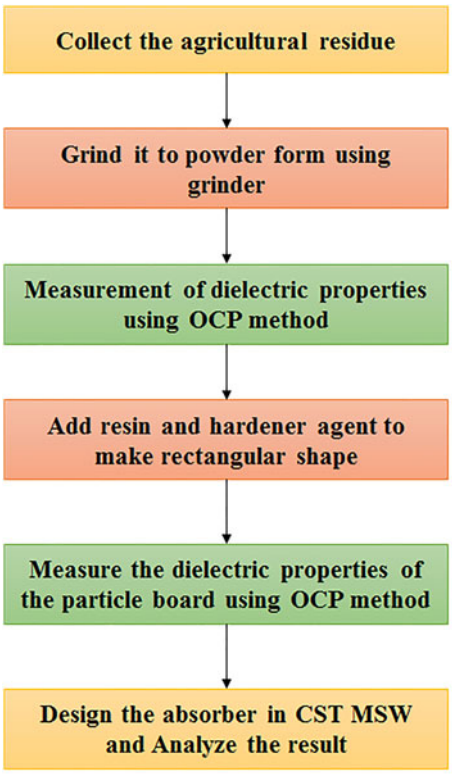


Fig. 2. Steps of developing banana leaves-based rectangular-shaped microwave absorber.

of a good MA. The frequency range considered in this investigation is 1–20 GHz. In this research work, three particle boards of various thicknesses are fabricated and the dimension of the boards is given in Table 1. Banana leaves are taken and dried for a week under the sun. They are blended using a grinder to make a fine microscopic powder. Figure 3 shows the dried banana leaves in microscopic powder form.

To fabricate a particle board, different types of resin and hardener can be used. Urea formaldehyde, phenol formaldehyde, and polyurethane were used in some studies [13, 21]. But these resins are not eco-friendly and are human health hazards. In this work, polyester resin, methyl ethyl ketone peroxide, and cobalt have been used as a binding agent, hardening agent, and an accelerator for the fabrication of the particle board. These compounds are also USDA approved for food container production [35]. Hence, they are not malign agents for either human health or the environment. Resin with a hardening agent binds the material, and the layers of the two constituents impart strength to it and protect it from abrasion. Figure 4 shows the particle board fabricated by banana leaves powder.

Measurement method

Particle size measurement

Figure 5 shows the microscopic view of the banana powder particles with 20× optical zoom. The size of the particles is not uniform as it is crushed using a grinder. The size of the particles is in the micrometer range, i.e. from 100 to 500 μm. The size of the grain plays an important role in microwave absorption performance. Small size grain means a higher surface area, more surface

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Table 1. Sample preparation for microwave property measurement and mould sample dimensions

Samples	Percentage of resin and hardener agent (wt. %)	Mould dimensions	Sample thickness (measured) (mm)	Sample thickness with PEC (mm)
A_1	33.3	5 cm × 3 cm × 8.16 mm	8.16	8.37
A_2	33.3	5 cm × 3 cm × 15.98 mm	15.98	16.19
A_3	33.3	5 cm × 3 cm × 32.02 mm	32.23	32.23



Fig. 3. Dried banana leaves in powder form.

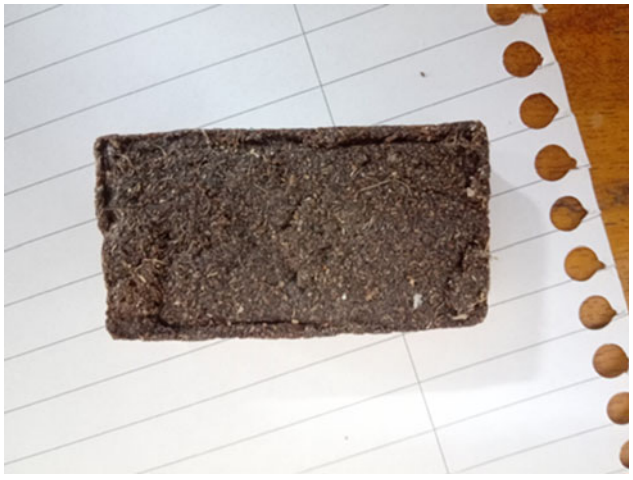


Fig. 4. Banana leaves particle board.

atoms, multiple reflections, and thus larger dielectric constant or/and dielectric loss. These lead to the interfacial polarization and multiple scatter which is useful to enhance the microwave absorption performance [36].

Thickness measurement

The thickness of the sample has an important role in microwave absorption performance. The microwave absorption performance is analyzed by varying the thickness of the rectangular sample. Hence, it becomes very much necessary to measure the sample's thickness. In this study, the digital caliper is used to measure the thickness of the samples. Figure 6 shows the thickness measurement setup using a digital caliper and the measured value is given in Table 1.

Hardware measurement

Different measurement methods such as OCP method, transmission line technique, free space measurement technique, and resonant cavity technique can be used to determine dielectric properties [37]. In this investigation, the OCP method has been used to measure the dielectric properties of the banana leave powder and the particle board. The sample is placed in close contact with the probe or the probe is pressed against a material under test or immersed into the liquid sample. Therefore, the dielectric properties are calculated from the phase and amplitude of the reflected signal using software embedded in the vector network analyzer (VNA). Before measurement, the dielectric probe is first calibrated with the help of air, a metallic shorting block, and water [38].

In this investigation, R&S ZNB-20 VNA and DAK (Dielectric Assessment Kit) are used to measure the dielectric properties of the banana leaves powder as shown in Fig. 7. The measurement set up is shown in Fig. 8.

Simulation strategy

The single-layer absorber has been designed in CST Microwave Studio (CST MWS) 2019 3D EM simulation software for high-frequency components. The dimension taken for the simulation is given in Table 1. The material is dispersive and that is why the absorber has been designed and simulated in CST MWS using the 1000 value of dielectric constant and loss tangent at 1000 frequency point in the range from 1 to 20 GHz obtained from the measurement. The CST simulations are carried out under plane wave incidence along with open-add space boundary conditions.

Result and analyses

Dielectric properties of dried banana leaves powder and particle board

At the foremost, the frequency-dependent EM parameters of the dried banana leaves have been measured using DAK-3.5 probe, P/N: SM DAK 040 CA as shown in Fig. 9. The average value of the dielectric properties has been computed using the equation given below:

$$Avg.\,value = \frac{\sum^{(} f_{1.000} + \cdots + f_{20.000})}{N}, \tag{11}$$

where N is the floating point of frequency.

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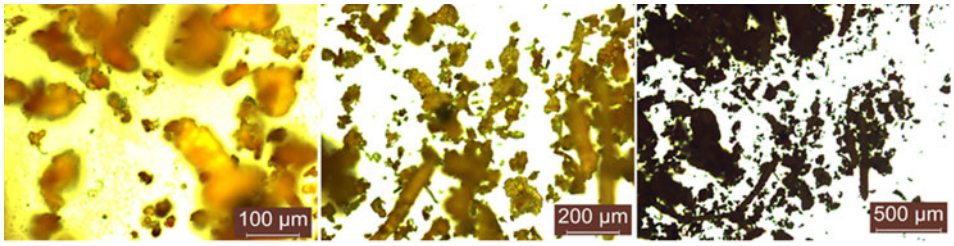


Fig. 5. Microscopic view of banana leaves powder.

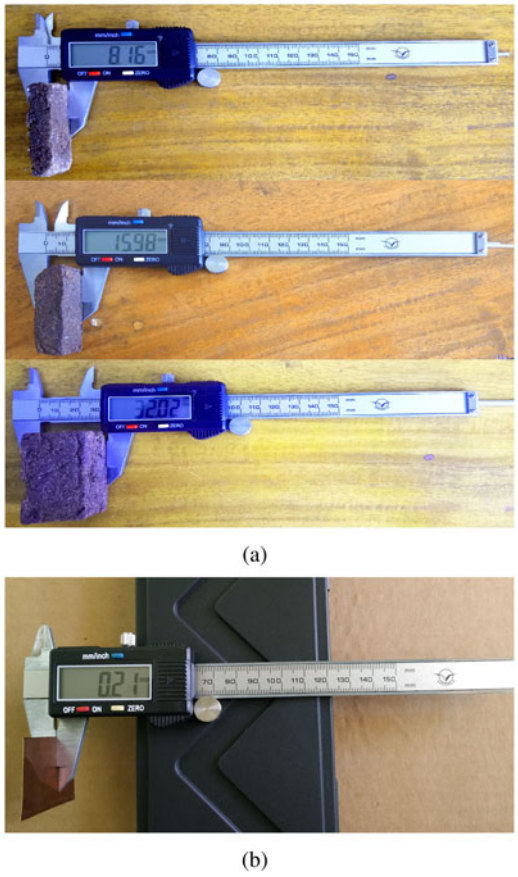


Fig. 6. Thickness measurement using a digital caliper: (a) samples and (b) PEC.



Fig. 7. Dielectric parameter measurement of dried banana leaves to powder using a dielectric probe technique.

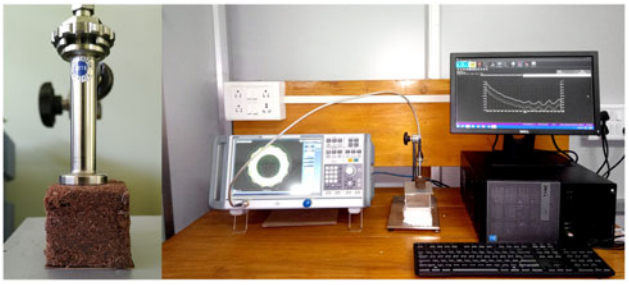


Fig. 8. Measurement setup.

In our investigation, N has been considered as 1000 to obtain the dielectric behavior precisely in the entire frequency range from 1 to 20 GHz. The average dielectric constant, loss factor, loss tangent, and conductivity are 1.47, 0.078, 0.041, and 0.053 S/m, respectively, in the entire frequency range.

The measurement of dielectric properties of samples A_1, A_2, and A_3 is also performed as given in Fig. 10. The result shows the better dielectric properties of a single-layer MA structure in comparison with dried banana leaves powder. An increase in density leads to a high dielectric constant [17] which causes the decrease of wave velocity [13]. Resin with a hardener agent and accelerator binds the material and the layers of two constituents by reducing the air gap between consecutive particles. Therefore, the dipolar polarization and density are increased and the effect points toward the increase in the dielectric constant of the single-layer MA structure. The result also shows that the dielectric properties vary with change in the thickness of the absorber as given in Table 2. The loss factor and loss tangent are little fluctuating in nature as observed in earlier studies [39]. This is probably due to the free electron (conduction current) and dipolar polarization within the compact design. However, the decrease in static permittivity (ε') with an increase in frequency for each sample indicates the natural phenomenon because of orientation polarization. An increase in the thickness increases the dielectric constant which is not the same for sample A_3. It may be because of an increase in the flow of conduction current due to larger surface area. The result shows that sample A_2 exhibits the better dielectric characteristics among three

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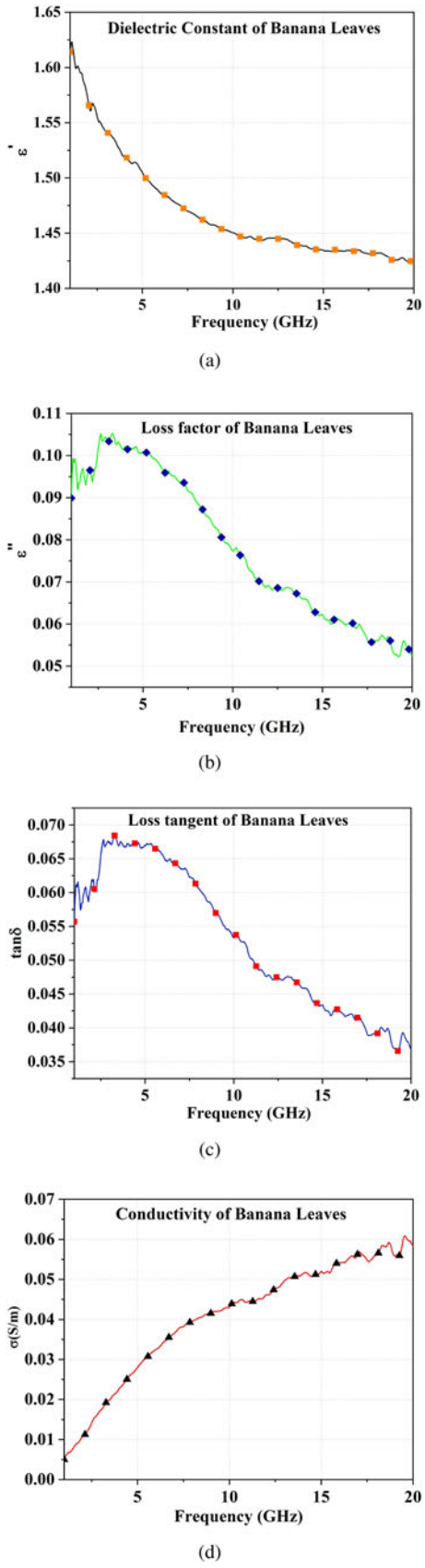


Fig. 9. Dielectric properties of dried banana leaves, (a) dielectric constant, (b) loss factor, (c) loss tangent, and (d) conductivity.

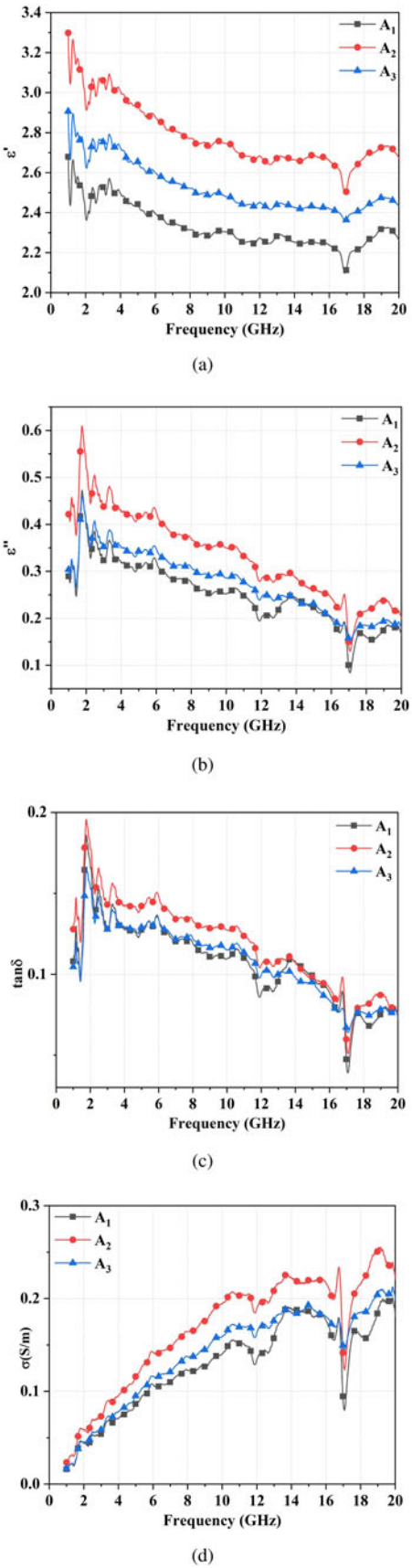


Fig. 10. Dielectric properties of a single-layer absorber for 8, 16, and 32 mm thickness, respectively, (a) dielectric constant, (b) loss factor, (c) loss tangent, and (d) conductivity.

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Table 2. Comparative study of average dielectric properties and skin depth of the single-layer absorber using dried banana leaves

Samples	ε'	ε''	Tan δ	σ (S/m)	D (mm)
A_1	2.33	0.25	0.107	0.13	0.042
A_2	2.78	0.33	0.119	0.17	0.034
A_3	2.52	0.28	0.108	0.14	0.040

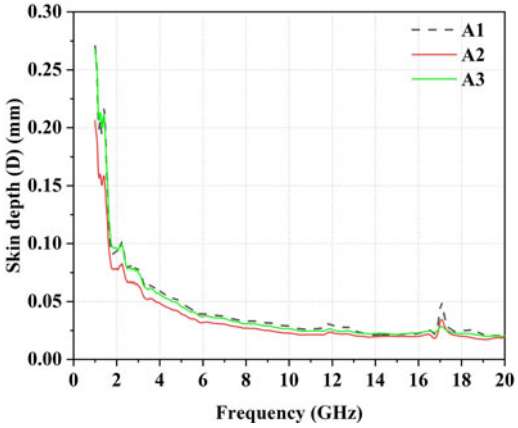


Fig. 11. Skin depth of a single-layer absorber for 8, 16, and 32 mm thickness.

samples and it points toward the better absorption of microwave power comparatively than others.

The skin depth is calculated using (10) and is plotted in Fig. 11. The skin depth analysis depicts that the microwave loses 37% of its initial power at 1 GHz frequency for every sample and it occurs at 0.86, 0.37, and 0.49 mm distance from the surface of the samples 1, 2, and 3, respectively. It is very much evident from this investigation that the skin depth varies with frequency, loss factor, and dielectric constant of the material.

Microwave absorption performance and absorption mechanism

When the EM waves transverse through the medium, the amplitude of the wave experiences an exponential decay with respect to the distance (x) by a factor $e^{-\alpha x}(E = E_m \times e^{-\alpha x})$, where α is the attenuation constant of the material and is a function of loss tangent and is expressed in (9). The effect of the various parameters for the absorption (A) of EM wave incident is given by [40]:

$$A = \frac{1}{2}\sigma|E|^2 + \frac{1}{2}\omega\varepsilon_0\varepsilon_r|E|^2 + \frac{1}{2}\omega\mu_0\mu_r|H|^2, \tag{12}$$

where E and H are the electric and magnetic field strength of the incident wave, respectively, σ is the conductivity of the material, ε_0 and μ_0 are the permittivity and permeability of the free space, respectively, ε_r and μ_r are the relative permittivity and permeability of the material.

As the paper concerns with a dielectric material, the above expression can be rewritten as:

$$A = \frac{1}{2}\sigma|E|^2 + \frac{1}{2}\omega\varepsilon_0\varepsilon_r|E|^2. \tag{13}$$

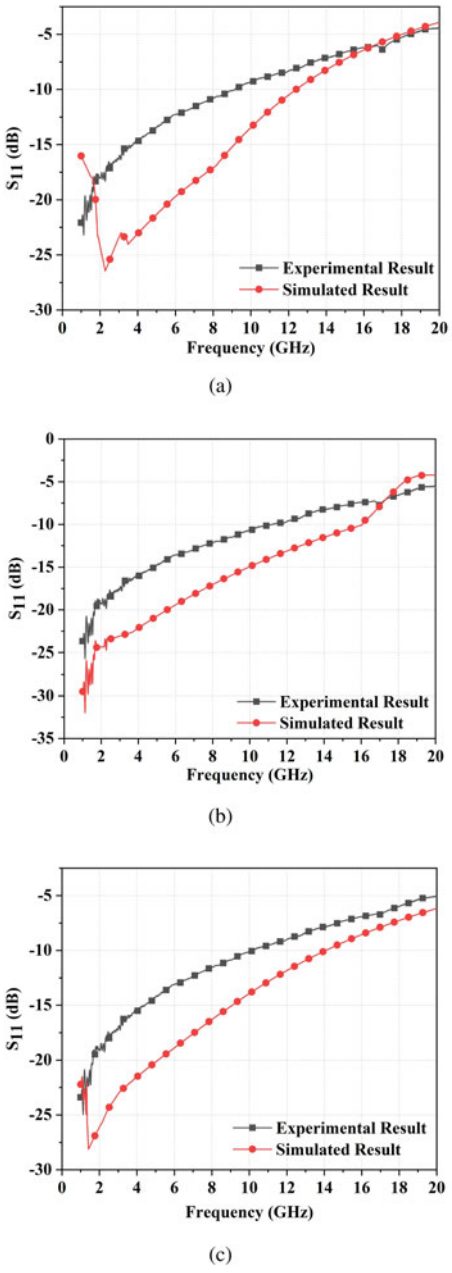


Fig. 12. Comparative analyses of return loss profile of a single-layer MA for the samples with various thicknesses: (a) A_1, (b) A_2, and (c) A_3.

Therefore, the absorption of EM wave incident on the absorbing surface is dependent on the attenuation constant of the material which is a function of loss tangent as well as the imaginary part of permittivity. Therefore, it can be inferred that the bigger the imaginary part of complex permittivity, the better the wave absorption effect [41].

The maximum return loss point cannot depict the entire performance of an absorber as it barely interprets at a particular frequency or in the limited frequency range. Hence to obtain the overall scenario of the absorption performance of an absorber, one needs to calculate the average return loss profile. The average reflectivity is computed using (11), where $N = 1000$. The requirement for acceptable performance of an MA is to have return loss

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Table 3. Maximum absorption rate of the single-layer absorber for 8, 16, and 32 mm thickness at the resonant frequency

	Experimental result			Simulated result		
Samples	S_{11} (dB)	Absorption rate (%)	RL<−10 dB at freq. (GHz)	S_{11} (dB)	Absorption rate (%)	RL<−10 dB at freq. (GHz)
A_1	−23.187	99.52	1.133	−26.444	99.77	2.254
A_2	−25.663	99.73	1.133	−31.991	99.94	1.133
A_3	−24.974	99.68	1.133	−28.131	99.85	1.418

Table 4. Average absorption rate in terms of the return loss of the single-layer absorber for 8, 16, and 32 mm thickness over 1–20 GHz frequency range

	Experimental result		Simulated result		
Samples	S_{11} (dB)	Absorption rate (%)	S_{11} (dB)	Absorption rate (%)	%Error
A_1	−10.0008	90.002	−13.39	95.42	25.31
A_2	−11.283	92.558	−14.83	96.71	23.90
A_3	−10.77	91.625	−14.39	96.36	25.16

Table 5. Comparison of proposed outcomes with significant existing outcomes

Absorber material	Dimensions	Shape	RL min. (dB)	RL<−10 dB BW (GHz)	Remarks	Ref.
Coconut fiber coir + charcoal powder	22.860 mm × 10.16 mm	Rectangular mould	−29.2444	8.2–12.4	For 15 wt. % charcoal Only experimental analysis	[34]
Coconut shell	200 mm × 200 mm	Single layer	−22	9.7	Thickness: 7.5 mm, both experimental and simulation analysis-based work	[18]
Rice husk	As per TDK ICT-030	Pyramidal	−85.947	7.98	For 20% phenol formaldehyde Only simulative-based work	[13]
Rice husk	H_{w1} = 15 cm, H_{w2} = 10 cm, H_b = 2 cm, W_b = 15 cm, L_b = 10 cm.	Wedge	−77.468	9.13	Only simulative-based work	[19]
Rice husk + CNT	200 mm × 200 mm	Single layer	−18.5	14.4	Thickness: 10 mm. RH + CNT MA with thickness 2 mm has a large BW compared to RH with thickness 10 mm. Experimental analysis	[44]
Rice husk	15.799 mm × 7.899 mm	Single layer	−28.4	13.81	Thickness: 20 mm. 80 wt.% RH. Simulation and experimental-based work	[45]
Rice husk	W = 15 cm, L = 15 cm,	Pyramidal	−46.55	7.6	Only experimental-based work	[46]
Sugarcane bagasse			−38.33	8.2		
Banana leaves			−43.13	6.6		
Rice husk	$W \times L \times H$ = 15 × 15 × 15(cm^3)	Pyramidal	−38.223	0.01≤RL≤20	Simulative-based work	[39]
Banana leaves			−82.302			
Banana leaves	$W \times L \times H$ = 15 × 15 × 13(cm^3)	Pyramidal	−49	12	Using RCS measurement technique	[47]
Banana leaves + charcoal			−76	16	Simulated analysis only	
Banana stem fiber	Thickness = 0.14 mm		−5.04	10.3	Experimental work	[29]
Banana leaves	5 cm × 3 cm × 15.98 mm	Single layer	−25.663	1.133	Experimental and simulative analyses-based work	This work

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better than −10 dB (90%) [18, 22]. The microwave absorption performance in terms of reflectivity is analyzed by reflectivity (S_{11}) measurement and simulative analysis.

The experimental analyses are the validation of simulative analyses of three different samples. The OCP method is used to extract the S_{11} parameter of the samples shown in Fig. 8 and (8) is used to compute the microwave absorption. Both the results show that the maximum reflectivity occurs at very low frequency for every sample as shown in Fig. 12 and Table 3. Skin depth analysis also indicates the same, i.e. the power of the wave drops to 37% of its initial power for each sample at 1 GHz frequency. As the single-layer MA structure is homogeneous in nature, the absorption mechanism is influenced by the dipolar polarizability of the absorbing layer of the absorber. At very low frequency, the dipoles of the absorber are free to rotate and dissipate the energy in terms of heat which indicates the imaginary part of the complex permittivity. As the frequency increases, the material's net polarization drops as each polarization mechanism ceases to contribute, and hence the decrease in the imaginary part of complex permittivity as well as dielectric constant. The outcome is the decrease in absorption performance with the increase in frequency as observed in Fig. 12. The maximum return loss profile and average return loss profile of samples A_1, A_2, and A_3 have been illustrated in Tables 3 and 4. From the dielectric properties measurement, the result shows $A_2\ (\varepsilon'') > A_3\ (\varepsilon'') > A_1\ (\varepsilon'')$ and the same trend has been observed in the absorption performance of the samples.

The simulative analyses of return loss profile differ slightly from experimental validation. The average error has been also given in Table 4 and it is approximately 25%, quite significant and also observed in earlier studies [42]. The factor could have affected the simulation results is the anisotropic nature of ε_r in different directions, which is quite often found in practice [43]. Other factors are roughness and conductivity of the absorbing surface, and environmental variation could have affected the experimental result. However, in the end, the investigation creates an illustration by doing an extensive comparative study on microwave absorption efficiency of a single-layer MA structure for different thicknesses. Comparison of microwave absorption performance between existing MA and proposed banana leaves-based MA is given in Table 5. From this thorough empirical analysis, it is very much explicit that the single-layer absorber has exhibited the utmost efficiency to reduce the microwave inference at 16 mm thickness.

Conclusion

An attempt has been made to investigate the effect of variation in thickness on the dielectric properties and the performance of microwave absorption of the single-layer absorber. The results of exhaustive experiments establish the aim of this investigation with satisfactory performance. The appreciable performance indicates that the dried banana leaves can be used as a single-layer MA. It is also important to mark that the proposed single-layer absorber may not be precisely comparable to its conventional equivalents, especially for application in electronic and communication sector. In such cases, this investigation shall be of immense help to the investigators in the advancement of the absorbers for conventional application. Eventually, there is a further scope of analyzing the efficiency of microwave absorption of the single-layer absorber at different thicknesses for varying percentages of resin.

References

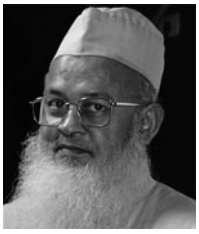
1. **Qin F and Brosseau C** (2012) A review and analysis of microwave absorption in polymer composites filled with carbonaceous particles. *Journal of Applied Physics* **111**, 1–24.
2. **Seyhan N** (2010) Electromagnetic pollution and our health/electromagnetic pollution and our health. *Noro-Psychiatry Archive* **47**, 158–161.
3. **Ionut N** (2014) Electromagnetic pollution in urban areas. *International Conference and Exposition on Electrical And Power Engineering.*
4. **Al-Zoubi OH and Naseem H** (2017) Enhancing the performance of the microwave absorbing materials by using dielectric resonator arrays. *Modelling and Simulation in Engineering* **2017**, 1–8.
5. **Melvin GJH, Ni QQ, Suzuki Y and Natsuki T** (2014) Microwave absorbing properties of silver nanoparticle/carbon nanotube hybrid nanocomposites. *Journal of Materials Science* **49**, 5199–5207.
6. **Grandidier J, Weitekamp RA, Deceglie MG, Callahan DM, Battaglia C, Bukowsky CR, Ballif C, Grubbs RH and Atwater HA** (2013) Solar cell efficiency enhancement via light trapping in printable resonant dielectric nano-sphere arrays. *Physica Status Solidi (A)* **210**, 255–260.
7. **Munir A** (2015) Microwave radar absorbing properties of multi-walled carbon nanotubes polymer composites: a review. *Advances in Polymer Technology* **36**, 362–370.
8. **Che BD, Nguyen BQ, Nguyen LTT, Nguyen HT, Nguyen VQ, Van Le T and Nguyen NH** (2015) The impact of different multi-walled carbon nanotubes on the X-band microwave absorption of their epoxy nanocomposites. *Chemistry Central Journal* **9**, 1–13.
9. **Savi P, Miscuglio M, Giorcelli M and Tagliaferro A** (2014) Analysis of microwave absorbing properties of epoxy MWCNT composites. *Progress in Electromagnetics Research Letters* **44**, 63–69.
10. **Olmedo L, Hourquebie P and Jousse F** (1993) Microwave absorbing materials based on conducting polymers. *Advanced Materials* **5**, 373–377.
11. **McNally T and Pötschke P** (2011) *Polymer-Carbon Nanotube Composites: Preparation, Properties and Applications*. Cambridge, England: Woodhead Publishing.
12. **Smythe B, Casserly S and Arakaki D** (2011) Organic based microwave frequency absorbers using corn-stover. *USA Antennas and Propagation Society, International Symposium Proceedings.*
13. **Nornikman H, Soh PJ, Azremi AAH, Wee FH and Malek F** (2009) Investigation of agricultural waste as an alternative material for microwave absorbers. *PIERS Online* **5**, 506–510.
14. **Wee FH, Soh PJ, Suhaizal AHM, Nornikman H and Ezanuddin AAM** (2009) Free space measurement technique on dielectric properties of agricultural residues at microwave frequencies. *2009 SBMO/IEEE MTT-S International Microwave and Optoelectronics Conference (IMOC).*
15. **Sian MS, Azizah S and Imran MI** (2011) Microwave absorbing material using rubber wood sawdust. *ISWTA 2011–2011 IEEE Symposium on Wireless Technology and Applications.*
16. **Iqbal MN, Malek F, Lee YS, Zahid L, Yusof NFM and Abdullah FS** (2013) Anechoic characteristics of a metal-backed anechoic agro-waste for EMC applications. *IEEE International RF and Microwave Conference (RFM2013)*, Malaysia.
17. **Mezan MS, Malek MFA, Jusoh MS, Abdullah FS and Affendi NAM** (2014) Reflection loss performance and performance assessment of pyramidal microwave absorber using agriculture waste. *Progress in Electromagnetics Research Symposium.*
18. **Salleh MKM, Yahya M, Awang Z, Muhamad WNW, Mozi AM and Yaacob N** (2011) Single-layer coconut shell-based microwave absorber. *IEEE TENCON*, Indonesia.
19. **Nornikman H, Malek F, Seng LY, Ramli MH, Syafiq NAM, Mazlan MH, Abd Aziz MZ, Ahmad BH and Salleh A** (2015) Green technology design of modified wedge microwave absorber using rice husk. *ARPN Journal of Engineering and Applied Science* **10**, 7380–7385.
20. **Jabal SNA, Seok YB and Hoon WF** (2016) The potential of coconut shell powder (CSP) and coconut shell activated carbon (CSAC) composites As electromagnetic interference (EMI) absorbing material. *Malaysian Journal of Analytical Sciences* **20**, 444–451.
21. **Liyana Z, Malek F, Nornikman H, Mohd Affendi NA, Mohamed L, Saudin N and Ali AA** (2012) Investigation of sugar cane bagasse as

https://doi.org/10.1017/S1759078720000707 Published online by Cambridge University Press

alternative material for pyramidal microwave absorber design. *IEEE Symposium on Wireless Technology and Applications (ISWTA)*.
22. **Nornikman H, Malek MFBA, Soh PJ, Abdullah Al-Hadi A, Wee FH and Hasnain A** (2010) Parametric study of pyramidal microwave absorber using rice husk. *Progress In Electromagnetics Research* **104**, 145–166.
23. **Mohd BWD** (2008) Overview of the Malaysian oil palm industry 2007, Malaysian Agriculture Research and Development Institute (MARDI). econ.mpob.gov.my/economy/overview07.htm.
24. **Kadam KL** (2000) Environmental life cycle implication of using bagasse-derived ethanol as a gasoline oxygenate in Mumbai (Bombay), National Renewable Energy Laboratory.
25. **Sai S, Ahmed J and Krishnaiah K** (1999) Production of activated carbon from coconut shell char in a fluidized bed reactor. *Industrial & Engineering Chemistry Research* **38**, 1169–1171.
26. **Zulkifli NA, Wee FH, Mahrom N, Yew BS, Lee YS, Ibrahim SZ and Am Phan AL** (2017) Analysis of dielectric properties on agricultural waste for microwave communication application. *MATEC Web of Conferences*.
27. **Dallenbach W and Kleinsteuber W** (1938) Reflection and absorption of decimeter-waves by plane dielectric layers. *Hochfreq. U Elektroak* **51**, 152–156.
28. **Vinoy KJ and Jha RM** (1996) *Radar Absorbing Materials from Theory to Design and Characterization*. Boston: Kluwer Academic Publishers.
29. **Nath G** (2018) Agricultural waste based radar absorbing material. *International Journal of Advanced Technology Engineering Research* **1**, 21–25.
30. **Tsubaki S, Azuma JI, Fujii S, Singh R, Thallada B and Wada Y** (2018) Microwave-driven biorefinery for utilization of food and agricultural waste biomass. In Bhaskar T, Pandey A, Venkata Mohan S, Lee D-J and Khanal SK (eds), *Waste Biorefinery*. Amsterdam: Elsevier, pp. 393–408.
31. **Rosa R, Veronesi P and Leonelli C** (2013) A review on combustion synthesis intensification by means of microwave energy. *Chemical Engineering and Processing: Process Intensification* **71**, 2–18.
32. **Green M and Chen X** (2019) Recent progress of nanomaterials for microwave absorption. *Journal of Materiomics* **5**, 503–541.
33. **Rubrice K, Castel X, Himdi M and Parneix P** (2016) Dielectric characteristics and microwave absorption of graphene composite materials. *Materials* **9**, 1–10.
34. **Yah NFN, Rahim HA, Lee YS, Wee FH and Zainal HH** (2018) Electromagnetic wave absorption properties of novel green composites coconut fiber coir and charcoal powder over X-band frequency for electromagnetic wave absorbing applications. *Advanced Electromagnetics* **7**, 13–18.
35. U.S. Composites, Isophthalic Polyester Resin datasheet. http://www.uscomposites.com/specs/spec404.html.
36. **Idris FM, Hashim M, Abbas Z, Ismail I, Nazlan R and Ibrahim IR** (2016) Recent developments of smart electromagnetic absorbers based polymer-composites at gigahertz frequencies. *Journal of Magnetism and Magnetic Materials* **405**, 197–208.
37. **Rohde Schwarz** (2012) Measurement of dielectric material properties, 1–36, Changi Business Park Central 2, Singapore.
38. **Pattanayak SS, Bachhar T and Sahoo S** (2018) Dielectric relaxation phenomena of aniline and substituted anilines with acetonitrile under 9.36 GHz electric field. *3rd International Conference for Convergence in Technology (I2CT)*, Pune.
39. **Farhany ZS, Malek F, Nornikman H, Affendi NM, Mohamed L, Saudin N and Ali AA** (2012) Potential of dried banana leaves for pyramidal microwave absorber design. *IEEE Symposium on Wireless Technology and Applications (ISWTA)*.
40. **Tirkey MM and Gupta N** (2019) Electromagnetic absorber design challenges. *IEEE Electromagnetic Compatibility Magazine* **405**, 59–65.
41. **Huo J, Wang L and Yu H** (2009) Polymeric nanocomposites for electromagnetic wave absorption. *Journal of Materials Science* **44**, 3917–3927.
42. **Wee FH, Soh PJ, Suhaizal AHM, Nornikman H and Ezanuddin AAM** (2009) Free space measurement technique on dielectric properties of agricultural residues at microwave frequencies. *IEEE MTT-S International Microwave and Optoelectronics Conference (IMOC)*.
43. **Srivastava GP, Singh PP and Nath J** (1992) Microwave absorber composed of rubber, carbon and ferrites. *AMPC Asia-Pacific Microwave Conference*.
44. **Seng LY, Malek F, Wee FH, Cheng EM, Liu WW, Liyana Z, Rahim HA and Ezanuddin AAM** (2015) Improved rice husk ash microwave absorber with CNTs. *International Workshop on Electromagnetics: Applications and Student Innovation Competition (IWEM)*.
45. **Lee YS, Malek F, Cheng EM, Liu WW, Wee FH, Iqbal MN, Zahid L, Abdullah F, Abdullah AZ, Noorpi NS, Mokhtar NM and Jusoh MA** (2015) Composites based on rice husk ash/polyester for use as microwave absorber. *Theory and Applications of Applied Electromagnetics* **344**, 41–48.
46. **Mezan MSA, Malek MFAB, Jusoh MSA, Abdullah FSB and Affendi NAMB** (2014) Reflection loss performance and performance assessment of pyramidal microwave absorber using agriculture waste. *Progress in Electromagnetics Research Symposium*.
47. **Kaur R, Aul GD and Chawla V** (2015) Improved reflection loss performance of dried banana leaves pyramidal microwave absorbers by coal for application in anechoic chambers. *Progress in Electromagnetics Research M* **43**, 157–164.



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