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PARAMETRIC STUDIES OF THE PYRAMIDAL MICROWAVE ABSORBER USING RICE HUSK

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Abstract—Agriculture waste has potential to be used as an alternative material for the microwave absorber used in the anechoic chamber. Compared to the current materials used, such as polystyrene and polyurethane, agricultural waste has low cost and is environmental friendly. In this paper, rice husks from paddy are used as the material in the pyramidal microwave absorber design, to operate effectively in the frequency range from 1 GHz to 20 GHz. Urea Formaldehyde (UF) and Phenol Formaldehyde (PF) are the resins investigated and are used to make the rice husk particle board. There are four main stages in designing the rice husk pyramidal microwave absorber. They are

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fabricating the rice husk particle board, deriving the dielectric constant value of the resin-rice husk mixture particle board, simulating the rice husk pyramidal microwave absorber using CST Microwave Studio software, and analyzing the performance of the rice husk pyramidal microwave absorber. Various parameters that affect the performance of the pyramidal microwave absorber are investigated, such as the dielectric constant of the material used, mixed resin percentages, source-port distance and angles between the signal source and the surface of the pyramidal microwave absorber. The excellent reflection loss results show that the rice husks can be potentially used as the material in a microwave pyramidal absorber.

1. INTRODUCTION

The rapid growth of the telecommunication industry means that more anechoic chambers are required. An anechoic chamber is an RF test facility which utilizes a lining of radar absorbing material (RAM) along its wall, ceiling and floor to create an electromagnetically quiet environment [1]. Shielded anechoic chambers are widely used to provide RF isolated test regions to simulate free-space test environment for measuring antennas. The anechoic chamber provides a controlled environment not subjected to weather and ambient conditions. The instruments or devices are needed to be tested without being affected by the wave reflections [2]. Currently, there are two types of anechoic chambers in the market: the acoustic anechoic chamber and Radio Frequency (RF) anechoic chamber.

The internal appearance of the radio frequency (RF) anechoic chamber is sometimes similar to that of an acoustic anechoic chamber. The interior surfaces of the RF anechoic chamber are covered with radiation absorbent material (RAM) instead of acoustically absorbent material. Before the design of an anechoic chamber, there are three major features of the room that must be taken into consideration. These features are the shape or orientation, the size of the room, the wall covering (absorber) and how the absorbers are assembled. There are many sizes of anechoic chambers available in the market. Anechoic chambers range from small compartments or mini portable miniature anechoic chamber for educational purpose to ones as large as aircraft hangars. The size of the anechoic chamber depends on the size of the objects to be tested and the frequency range of the signals used, although scale models can sometimes be used by testing at shorter wavelengths.

Absorbers are one of the main components in an anechoic chamber and used to eliminate reflected signals. Electromagnetic absorbing materials are very important to ensure the accuracy of RF anechoic chamber testing performances. There are many enhanced absorber technologies available in the market. The first known absorber is investigated at the Naamlooze Vennootschap Machinerieen, Netherlands in 1936 [3]. This is a quarter-wave resonant type absorber operating in the 2 GHz region. There are many shapes that can be fabricated as an absorber such as pyramidal, truncated pyramidal, wedge, convoluted, hybrid, flat, honeycomb, oblique and metamaterial absorbers [4, 5].

Microwave absorbing materials that are used in the anechoic chamber can reduce reflections of high frequency energies. The microwave absorbers in this frequency range are used in many applications such as telecommunication, military, high speed electronics and automotive. Different absorber materials are used for the microwave range (1 GHz to 40 GHz) and for the low frequency range (30 MHz to 1000 MHz), respectively [6–19]. The most common material used for the low frequency range (30 MHz to 1000 MHz) absorber is the ferrite tiles (NiZn), an electrically-thin absorber material. Ferrite tiles have also been widely used in many EMC test chambers. In the microwave frequency range (1 GHz to 40 GHz), foam materials such as polyurethane and polystyrene are widely used as the microwave absorber.

The microwave signal is reflected and absorbed in the anechoic chamber. A proper model of RF microwave absorber must be developed based on various parameters such as the absorber reflection loss, the magnitude and phase, for various angles of incidence, and for parallel and perpendicular polarizations [4, 12, 20, 21]. The reflection loss, R, can be expressed as the absorbing performance of the material and is a function of the complex permittivity, permeability of the material, and the frequency of the electromagnetic wave [22].

ε' (epsilon) is the absolute permittivity of the dielectric, which is a measure of the electrostatic energy stored within it and therefore dependent on the material. The dielectric constant is equivalent to the relative permittivity (ε'_r) or the absolute permittivity (ε') relative to the permittivity of free space (ε'_0) [23]. The dielectric constant of a material also affects the velocity of microwave signals when it moves through the material. A larger value of dielectric constant results in the microwave signals to travel at slower velocities [24]. A larger dielectric constant material results in a denser material. Dielectric loss tangent, $\tan\delta$ is the imaginary part of the dielectric constant, and determines the losses of the medium. Equation (1) shows the loss tangent formula, where ε_r'' is the loss factor of the dielectric constant.

$$\tan\delta = \frac{\varepsilon_r''}{\varepsilon_r'} \tag{1}$$

The signals are transmitted from the first medium to the second medium. In this case, air is the first medium while the second medium is the pyramidal microwave absorber. When the signal enters another medium at an angle, this will change the velocity of the signal which causes the signal to be deflected. The phenomenon is called refraction. The refractive index, n of a medium is a measure of how much the speed of microwave signal is reduced inside the medium. The refractive index for air is 1.00029. The refractive index of the pyramidal microwave absorber is larger than the refractive index of the air.

Agriculture waste or agriculture residue is made up from organic compounds from the living plant like rice straw, oil palm empty fruit bunch, sugar cane bagasse, coconut shell, and others. Rice husk from paddy (*Oryza sativa*) is to be investigated as the material used to make the microwave absorber. In Malaysia, for example, around 350,000 tons of rice husks are produced annually. Rice husks are unusually high in ashes. Rice husks consist of 92–95% of silica, are highly porous and lightweight, and have a very high external surface area. Rice husks' absorbent and insulating properties are useful for many industrial applications [25]. This by-product of rice cultivation has been traditionally burnt in the field or trucked out and dumped [26].

Table 1 shows the typical chemical composition of rice husks [27]. 35.77% or rice husk consists of carbon, which absorbs the microwave signal. Presently, microwave absorbers are typically manufactured by impregnating conductive carbons at the top part of the pyramidal structures. This can increase the reflection loss performance of the microwave absorber. Carbon has also the characteristic as a light absorption material.

Figure 1 shows the flow chart of the research project, starting with the collecting of the agricultural waste from its natural source. The second step is to make an agricultural waste particle board from the rice husk. The third step is to derive the dielectric constant values of the particle boards using the Free Space Measurement Technique (FSMT). The fourth step is the modeling and simulation of the pyramidal microwave absorber design using the CST Microwave Studio software. The final step is the analysis of the results using the CST Microwave Studio software.

Table 1. The elements percentages of the rice husk material.

Element	%
Silicon dioxide	22.24
Carbon	35.77
Hydrogen	5.06
Oxygen	36.59
Nitrogen	0.32
Sulphur	0.02

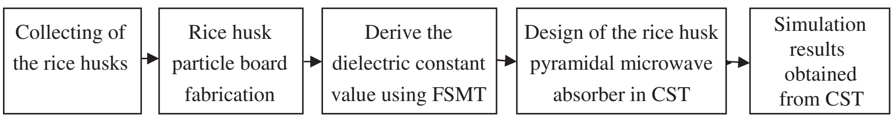


Figure 1. Flow chart of the rice husk pyramidal microwave absorber project.

2. RICE HUSK PARTICLE BOARD

After collecting the rice husk, this material is grinded using the grinder to ensure the rice husk can be easily sticked together with the resin. To fabricate the particle board, bonding agent or resin is used. Resins or bonding agents are used to glue any adjacent material layer for the bonding of the agricultural waste. Urea Formaldehyde (UF) and Phenol Formaldehyde (PF) are investigated as bonding agents to be mixed with the rice husks. Formaldehyde is a pungent, colorless gas commonly used in water solution as a preservative and disinfectant. It is also a basis for major plastics, including durable adhesives.

These resins are commonly used in adhesives, finishes and molded objects. Their attributes include high tensile strength, flexural modulus and heat distortion temperature, low water absorption, high surface hardness, elongation at break and volume resistance [28]. Figure 2 shows the process flow for the mixing of the materials for the fabrication of the rice husk particle board.

The material is shaped into a square form by transferring it into a rigid frame in the hot press machine. A hot press machine is a high pressure machine for forming a compact material at high temperature. Before the mould can be transferred into the hot press machine, transparency plastic is placed at the top of the mould. This is to avoid the cleaving of the rice husk onto the square mould. The temperature of this machine is set to 180°C for 10 minutes. After

Figure 2. The process flow for the mixing of the materials for the fabrication of the rice husk particle board.

Figure 3. The fabricated rice husk particle board.

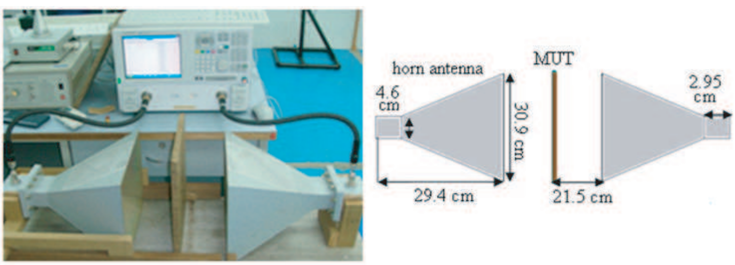
pressing, the mould (with the sample) is cooled off by transferring it to the lower section of the hot press machine. After chilled, the particle board is then taken out from the mould. To obtain a good plot form, the board is trimmed at its edges.

The dimensions of the fabricated particle board are 30.3 cm width ×30.3 cm length ×1.4 cm thickness. The fabrication size of the particle board depends on the size of the horn antennas used in the measurement. Smaller horn antennas result in a smaller particle board's size requirement. The density of the particle board affects the value of the dielectric constant. A denser particle board results in a larger value of the dielectric constant. Figure 3 shows the fabricated rice husk particle board.

3. THE FREE SPACE MEASUREMENT TECHNIQUE

A free space measurement technique shown in Figure 4(a) is the technique used to derive the dielectric properties of the rice husk material. The instruments used are the Agilent E8362B PNA Network Analyzer, installed with Agilent 85071E Material Measurement software, two 2.2 GHz–3.3 GHz horn antennas, two coaxial cables, Agilent 85052D 3.5 mm calibration kit and connectors and the Material Under Test (MUT). In the initial step, the calibrations of the coaxial cable, reference board sample and the distance between the two antennas (transmitter and receiver) are performed. The reason for this calibration is to remove any undesired errors, such as noise in the coaxial cable and to ensure measurement accuracy.

The full two-port calibration has been used for both the reflection and transmission measurements. Agilent 85052D Economy Mechanical 3.5 mm calibration kit with SOLT (Short-Open-Load-Trough) standard is used in this calibration setup. For the MUT calibration setup, the reference board sample (with known dielectric constant) is placed at the center of both of the horn antennas. In this case, the copper plate is used as the reference board sample. The dielectric constant value of this reference board sample is displayed on the screen of the Agilent PNA network analyzer. After this, the reference board is then removed. The new value of $\varepsilon_r' = 1$ is obtained as the dielectric constant value of air.



(a) (b)

Figure 4. (a) The free space measurement technique, to derive the dielectric constant of the rice husk. (b) The dimensions of the horn antennas, and the distances between the horn antennas, for the free space measurement technique.

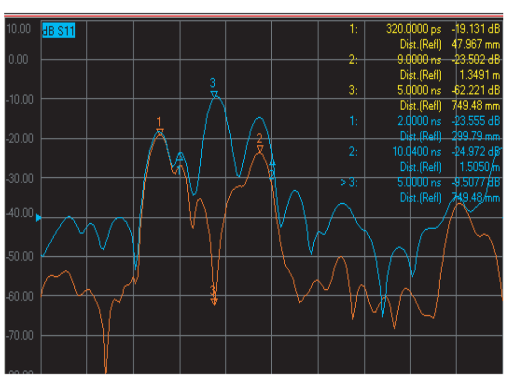


Figure 5. The time gating setting at the PNA network analyzer.

The parameters that must be considered for the free space measurement technique are the size of the horn antennas, the length of the coaxial cables and the distance between the transmitter and the receiver antennas. Figure 4(b) shows the dimensions of the horn antenna used for the free space measurement technique. The antenna dimensions that have been used for the experiment are $30.9\,\text{cm} \times 23.85\,\text{cm} \times 29.4\,\text{cm}$. The sizes of the antennas also affect the suitable distance between the transmitter and the receiver antennas. Smaller antennas sizes result in a shorter distance needed between the two antennas.

The lengths of the coaxial cables are also an important factor that need to be considered. A longer cable results in a weaker signal, due to the losses. The equipments must be located on a level ground, and in a straight line to ensure an accurate dielectric constant value. Hence, to obtain an accurate dielectric constant result, small antennas with short distance between the antennas and short coaxial cable should be used. The obtained dielectric constant value can then be used for the simulation part using the CST Microwave Studio software.

The distance used between the horn antennas and the particle board is 21.5 cm, while the distance between the two antennas is 43 cm. The actual distance between the particle board and the horn antennas is determined by applying the time gating setting at the PNA network analyzer, as shown in Figure 5. The PNA covers the frequencies ranging from 2.2 GHz to 3.3 GHz, as this is the operating frequencies of the horn antennas. There are three peaks shown at the display of the network analyzer. The first peak is the response of the transmitter horn antenna; the second peak is the time domain gating feature, while the third peak is the response of the receiver horn antenna.

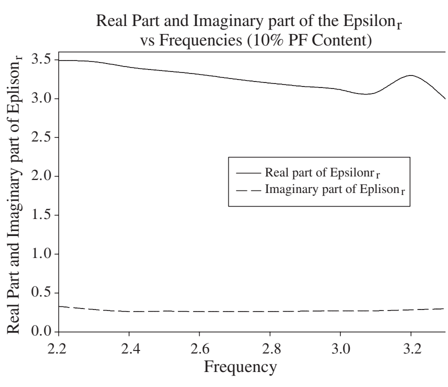


Figure 6. The real and imaginary parts of ε_r for the Phenol Formaldehyde (PF)-rice husk particle board (with 10% PF content) using the free space measurement technique.

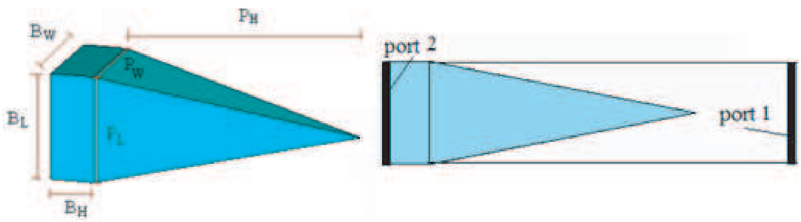
For a good performance, a result of better than 40 dB should be obtained for the differences between the non metal plate (MUT) and the metal plate (copper plate). The result obtained for this difference between two plates is approximately 52.7 dB, which is a good result. The real and imaginary parts of ε_r for the Phenol Formaldehyde (PF)-rice husk particle board (with 10% PF content) are obtained using the free space measurement technique, and are plotted in Figure 6.

4. PARAMETRIC STUDIES

The pyramidal microwave absorbers are designed using the Computer Simulation Technology Microwave Studio software. The design and shape of the pyramidal microwave absorber are based on the Eccosorb *VHP-8-NRL* Pyramidal Microwave Absorber [29] and the *TDK ICT-030* Pyramidal Microwave Absorber [30]. The Eccosorb *VHP-8-NRL* absorber is designed by using the urethane foam as its base material, with carbon loading. The *TDK ICT-030* absorber uses the polystyrene as its base with carbon loading.

Figure 7(a) shows the simulation design of the pyramidal microwave absorber using the CST Microwave Studio software. Figure 7(b) shows the boundary condition of the pyramidal microwave absorber, with port 1 as the transmitter port and port 2 as the receiver port. The value of the dielectric constant for this design is taken from the previous free space measurement technique, that is $\varepsilon_r' = 2.9$. In this simulation design, the waveguide port or the starting signal point is located as normal incident (0°) with a distance of 30 cm from the origin of the pyramidal microwave absorber. Table 2 shows the dimensions of pyramidal microwave absorber. The pyramidal shape has two main parts. The first part is the base part with 5 cm length $\times$5 cm length $\times$2 cm thickness. The second part is the pyramid part with 13 cm height. Six parameters of the pyramid must be considered before the pyramidal microwave absorber can be simulated. These parameters are the pyramid width (P_W), the pyramid length (P_L), the pyramid height (P_H), the base width (B_W), the base length (B_L), and the base height (B_H).

There are various factors that can affect the performance of the pyramidal microwave absorber. These parameters are the dielectric constant of the material used, the mixture of the resin percentage, the source port distance and the angles between the signal source and the surface of the pyramidal microwave absorber. The parametric study uses the parametric sweep function in the CST Microwave Studio software.



(a) (b)

Figure 7. (a) Simulation design of the pyramidal microwave absorber using CST Microwave Studio software. (b) The boundary condition of the pyramidal microwave absorber with port 1 as the transmitter port and port 2 as the receiver port.

Table 2. Dimensions of the pyramidal microwave absorber.

Part	**Symbol**	**Dimension (cm)**
Pyramid Width	P_W	5
Pyramid Length	P_L	5
Pyramid Height	P_H	12
Base Width	B_W	5
Base Length	B_L	5
Base Height	B_H	2

Table 3. Parametric study for different resin percentages of the pyramidal microwave absorber.

Resin	**The different resin percentages in the rice husk-resin mixture**
Urea Formaldehyde (UF)	10%
	20%
	30%
Phenol Formaldehyde (PF)	10%
	20%
	30%

4.1. Different Resin Percentages

The first investigation is to compare the different resin percentages in the rice husk-resin mixture, as shown in Table 3. Two resins are used in this measurement: the Urea Formaldehyde (UF) and the Phenol Formaldehyde (PF). The percentages considered in this parametric study are 10%, 20% and 30% of the resin respectively. The three different resin percentages are used to observe the dielectric constants of the rice husk-resin mixtures.

4.2. The Distance between the Signal Souce and the Surface of the Pyramidal Material

The distance between the signal source (the starting transmit point or starting port) and the surface of pyramidal microwave absorber is an important parameter that can affect the performance of the microwave absorber. This is shown in Figure 8. In this investigation, three values of distances are considered: 30 cm, 60 cm and 90 cm, respectively. The 10% PF content is used for the PF-rice husk pyramidal microwave absorber.

4.3. The Different Signal Source Angle

Three different angles between the signal source (the starting port) and the surface of the pyramidal microwave absorber are investigated in this parametric study. The angles selected are 0°, 30° and 45° respectively. The 0° is the normal incident while the 30° and 45° are the oblique incidents. The distance between the signal source and the pyramidal microwave absorber is set to 30 cm. The 10% Phenol Formaldehyde (PF) content is used for the PF-rice husk pyramidal microwave absorber. Figure 9 shows the different angles that are used in this parametric study.

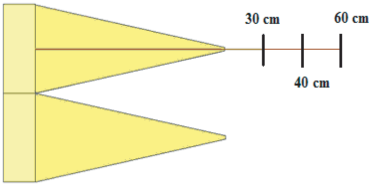


Figure 8. The different distances between the signal source and the pyramidal microwave absorber.

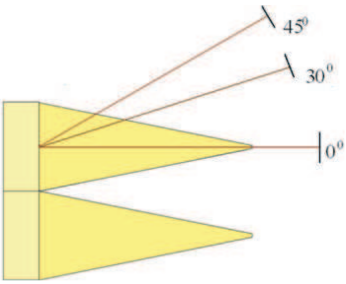


Figure 9. The different angles between the signal source and the surface of the pyramidal microwave absorber.

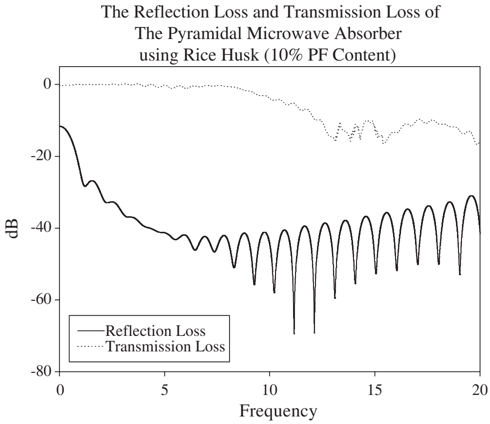


Figure 10. The reflection loss and transmission loss results for the PF-rice husk pyramidal microwave absorber (10% PF content).

5. RESULTS AND DISCUSSIONS

5.1. The Pyramidal Microwave Absorber

The requirement for a good performance for a microwave absorber is to have reflection loss results better (below) than −10 dB. A desirable performance is to achieve an average reflection loss of better (below) than −30 dB. The 10% Phenol Formaldehyde (PF) mixture, with the dielectric constant value of $\epsilon_r = 2.9$ is used in this experiment. Figure 10 and Table 4 show the reflection loss results of the pyramidal microwave absorber in the range between 0.01 GHz to 20 GHz. The results indicate better (below) than −30 dB values for the range of 1.87 GHz to 20 GHz.

Table 4. The reflection loss performance of the pyramidal microwave absorber (10% PF content) for 0.01 GHz to 20 GHz range.

Frequency (GHz)	**dB**
Average reflection loss (0.01 to 1)	−16.0
Average reflection loss (1 to 5)	−35.3
Average reflection loss (5 to 10)	−45.9
Average reflection loss (10 to 15)	−44.5
Average reflection loss (15 to 20)	−38.3
Average reflection loss (0.01 to 20)	−40.0
Best point for reflection loss (0.01–20)	−70.2
Average transmission loss (0.01–20)	−5.82

For all the frequency range (0.01 GHz to 20 GHz), the average reflection loss result of the pyramidal microwave absorber is −40.0 dB. The best average reflection result occurs at the frequency range in between 10 to 15 GHz, with a value of −44.5 dB. The worst average reflection loss result is −16.0 dB, which occurs in between the 0.01 GHz and 1 GHz frequency range. The best point for the reflection loss occurs at 9.14 GHz, with a value of −70.2 dB. The average transmission loss result of the pyramidal microwave absorber is −5.82 dB, for the 0.01 GHz to 20 GHz frequency range.

5.2. Different Resin Percentages

Table 5 shows the results of the dielectric constants for the different percentages of resin in the rice husk-resin particle board. The experiment is performed using the Free Space Measurement Method. Different resin percentages can affect the value of the dielectric constants of the material. The dielectric constant result, obtained by measurement from 2.2 GHz until 3.3 GHz, uses the formula, as shown in Equation (2).

$$\varepsilon_r' \mathrm{Avg} = \frac{\Sigma(f_{2.2} + \ldots + f_{3.3})}{500} \tag{2}$$

From Table 5, the largest value of dielectric constant, $\varepsilon_r' = 3.68$ is achieved using 30% PF content. The lowest value of dielectric constant, $\varepsilon_r' = 2.89$, is achieved using 10% PF content. It can be seen that the dielectric constant increases when the resin percentage content increases.

Table 5. The dielectric properties results for the different percentages of resin and rice husk particle board.

Resin	Resin Percentage	Dielectric Constant, ε_r'	Loss Factor, ε_r''	Loss Tangent, $\tan\delta$
Urea Formaldehyde (UF)	10%	3.24	0.274	0.085
	20%	3.27	0.268	0.082
	30%	3.58	0.439	0.123
Phenol Formaldehyde (PF)	10%	2.89	0.222	0.077
	20%	3.41	0.329	0.096
	30%	3.68	0.273	0.074

Table 6. The reflection loss and transmission loss for the pyramidal microwave absorber, using different percentages of Urea Formaldehyde (UF).

Frequency (GHz)	dB		
	Urea Formaldehyde = 10%	Urea Formaldehyde = 20%	Urea Formaldehyde = 30%
Average reflection loss (0.01 to 1)	−15.5	−15.3	−15.0
Average reflection loss (1 to 5)	−35.6	−35.9	−36.0
Average reflection loss (5 to 10)	−47.6	−48.7	−49.2
Average reflection loss (10 to 15)	−43.6	−43.7	−43.4
Average reflection loss (15 to 20)	−38.2	−38.0	−37.5
Average reflection loss (0.01 to 20)	−40.2	−40.5	−40.5
Best point of reflection loss (0.01–20)	−63.1	−63.7	−69.2
Average transmission loss (0.01–20)	−8.03	−8.00	−7.38

Table 6 and Figure 11 show the reflection loss and transmission loss results for the pyramidal microwave absorber using the Urea Formaldehyde-rice husk mixture. The best point reflection loss result occurs with 30% UF content, resulting in −69.2 dB at the frequency

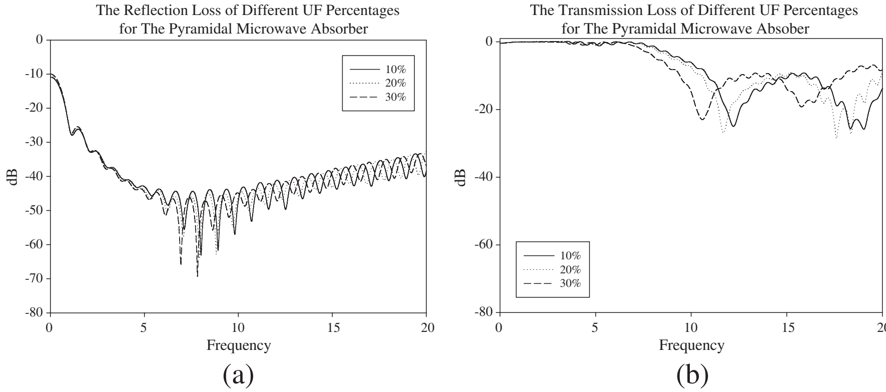


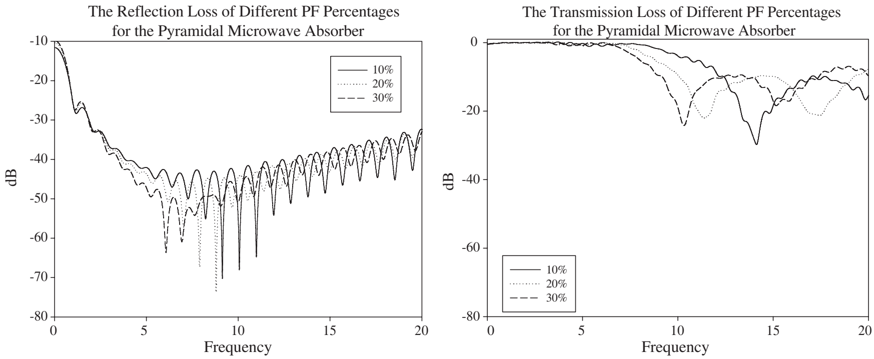
Figure 11. Results of the different UF percentages for the pyramidal microwave absorber. (a) Reflection loss. (b) Transmission loss.

Table 7. The reflection loss and transmission loss for the pyramidal microwave absorber using different percentages of Phenol Formaldehyde (PF).

Frequency (GHz)	**dB**		
	Phenol Formaldehyde = 10%	**Phenol Formaldehyde = 20%**	**Phenol Formaldehyde = 30%**
Average reflection loss (0.01 to 1)	−16.0	−15.2	−14.9
Average reflection loss (1 to 5)	−35.3	−35.8	−36.9
Average reflection loss (5 to 10)	−45.9	−48.6	−51.1
Average reflection loss (10 to 15)	−44.5	−43.5	−43.2
Average reflection loss (15 to 20)	−38.3	−37.8	−37.6
Average reflection loss (0.01 to 20)	−40.0	−40.4	−41.1
Best point of reflection loss (0.01–20)	−70.2	−72.9	−63.5
Average transmission loss (0.01-20)	−6.85	−7.75	−7.27

point of 7.82 GHz. The second best point reflection loss result occurs with 20% UF content, resulting in −63.7 dB at 7.92 GHz frequency point. The worst point reflection loss result occurs with 10% UF content, resulting in −63.1 dB at 8.02 GHz frequency point. The best average reflection loss (0.01–20 GHz) result is −40.5 dB, with 30% UF content. The worst average reflection loss (0.01–20 GHz) result is −40.2 dB with 10% UF content. It can be concluded that the reflection loss, S_{11} increases when the percentage of resin content increases. This is because the resin increases the density of the mixture. Without resin, the rice husks cannot bond very well, resulting in hollow spaces occurring in between the rice husks. From Table 6, the best frequency range for this UF resin is in between 5 GHz to 10 GHz, while the worst frequency range is in between 0.01 GHz to 1 GHz. The best average transmission loss is −7.38 dB, using 30% UF content, for the 0.01 GHz to 20 GHz frequency range.

Table 7 and Figure 12 show the reflection loss and transmission loss results of the pyramidal microwave absorber using Phenol Formaldehyde (PF)-rice husk mixture. It can be seen that the best point reflection loss result is −72.9 dB, at the frequency point of 8.8 GHz, using 20% PF content. The second best point reflection loss result is −70.2 dB, at the frequency point of 9.14 GHz, using 10% PF content. The worst point reflection loss result is −63.5 dB, at the frequency point of 6.06 GHz, using 30% PF content. The best average reflection loss (0.01–20 GHz) result is at −41.1 dB, using 30% PF content. The worst average reflection loss (0.01–20 GHz) result is at −40.0 dB, using 10% PF content. The best average transmission loss is −6.85 dB, using 10% PF content, for the 0.01 GHz to 20 GHz frequency range.



(a) (b)

Figure 12. Results of the different PF percentages for the pyramidal microwave absorber. (a) Reflection loss. (b) Transmission loss.

5.3. Different Signal Source Distances

The different distances between the port and the absorber are investigated, and the reflection loss (S_{11}) results are observed. The Phenol Formaldehyde-rice husk pyramidal microwave absorber, with 10% Phenol Formaldehyde (PF) content is used for this experiment. The reflection loss and transmission loss results, for three different distances (30 cm, 45 cm, and 60 cm) are shown in Table 8 and Figure 13. The results show that the signal source or port with 30 cm distance

Table 8. The results of the pyramidal microwave absorber (10% PF content) with different port distances.

Frequency (GHz)	**dB**		
	30 cm	**45 cm**	**60 cm**
Average reflection loss (0.01 to 1)	−16.0	−16.0	−24.0
Average reflection loss (1 to 5)	−35.3	−34.7	−35.4
Average reflection loss (5 to 10)	−45.9	−43.7	−41.9
Average reflection loss (10 to 15)	−44.5	−43.6	−41.4
Average reflection loss (15 to 20)	−38.3	−38.4	−37.3
Average reflection loss (0.01 to 20)	−40.0	−39.1	−38.4
Best point of reflection loss (0.01–20)	−70.2	−70.8	−58.6
Average transmission loss (0.01–20)	−6.85	−6.85	−6.87

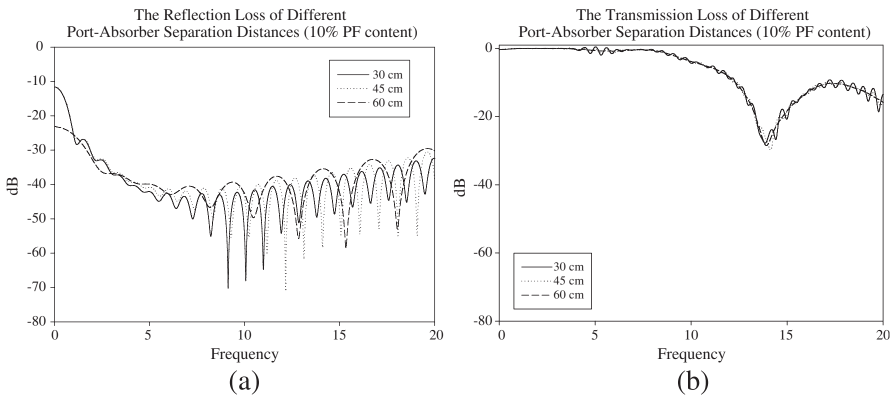


Figure 13. The results for the pyramidal microwave absorber (10% PF content) with different port-absorber separation distances. (a) Reflection loss. (b) Transmission loss.

from the microwave absorber has the best average reflection loss or S_{11}. The best average reflection loss result obtained is -40.0 dB for the 0.01 GHz to 20 GHz frequency range, with 30 cm port-absorber separation distance. The worst average reflection loss result is -38.4 dB, for the frequency range 0.01 GHz to 20 GHz, with 60 cm port-absorber separation distance. The best average transmission loss is -6.85 dB, with 30 cm port-absorber separation distance, for the 0.01 GHz to 20 GHz frequency range. It can be concluded that better reflection loss results can be obtained with a smaller port-absorber separation distance. A large port-absorber separation distance, results in weaker signals arriving at the pyramidal microwave absorber.

5.4. Different Signal Source Angles

The different angles between the port (signal source) and the microwave absorber are investigated. The reflection loss results for the different port-absorber angles (0°, 30°, 45° and 60°) are shown in Figure 14 and Table 9. The 10% Phenol Formaldehyde (PF) content is used in the PF-rice husk pyramidal microwave absorber. The normal incident (0° angles) shows better reflection loss (S_{11}) results compared to the oblique incidents (non-zero angles). The normal incident angle between the port and the absorber achieves average reflection loss of -40.0 dB, for the 0.01 GHz to 20 GHz frequency range. The normal incident angle also results in the best reflection loss point result of -70.2 dB.

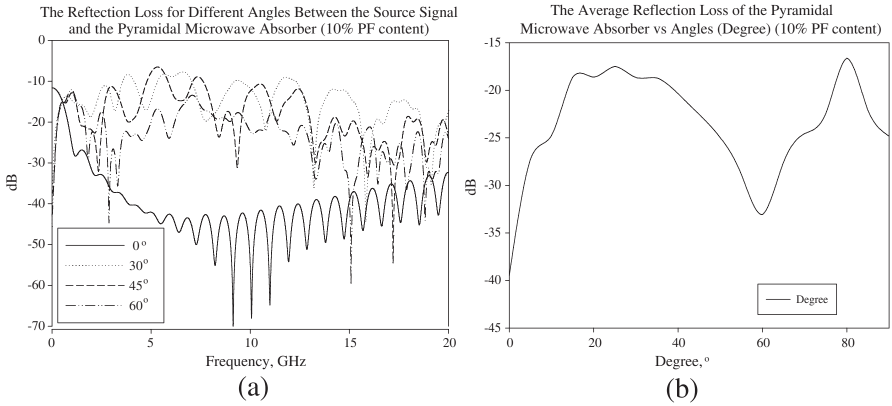


Figure 14. (a) The reflection loss results for the pyramidal microwave absorber (10% PF content) with different starting signal source (port) angles. (b) Average reflection loss of the pyramidal microwave absorber at different degrees.

Table 9. The results of the pyramidal microwave absorber (10% PF content) with different signal source angles.

Frequency (GHz)	dB			
	0°	30°	45°	60°
Average reflection loss (0.01 to 1)	−16.0	−18.2	−19.3	−19.4
Average reflection loss (1 to 5)	−35.3	−13.9	−17.3	−22.9
Average reflection loss (5 to 10)	−45.9	−12.0	−14.4	−18.1
Average reflection loss (10 to 15)	−44.5	−14.6	−17.6	−24.2
Average reflection loss (15 to 20)	−38.3	−20.6	−24.9	−29.2
Average reflection loss (0.01 to 20)	−40.0	−15.5	−18.7	−23.4
Best point of reflection loss (0.01–20)	−70.2	−45.6	−53.8	−59.8

The Snell's Law indicates that the velocity of the signal from the normal incident is faster than the velocity of the signals from oblique incidents. Hence, the incident angles affect the total signal absorption for the pyramidal microwave absorber. Faster signal velocities increase the absorption rate for the pyramidal microwave absorber. Figure 14(b) shows the results for the average reflection loss for various angles (degree). The best result is obtained at 0° followed by 60°. In this figure, the reflection loss (dB) result at each frequency from 0.01 to 20 GHz (in steps of 0.02 GHz) are summed and then averaged to obtain the average reflection loss result (dB) for each angle.

6. CONCLUSION

The rice husks have been mixed with different percentages of resins to make a rice husk-resin particle board. Urea Formaldehyde (UF) and Phenol Formaldehyde (PF) are investigated as the resins used in the rice husk-resin particle board. The free space measurement technique has been used to derive the dielectric constant of the resin-rice husk particle board. Simulations have been performed using the CST Microwave Studio software, where the dielectric constant value of the rice husk-resin mixture has been taken from the free space measurement technique. Various parameters that affect the performance of the pyramidal microwave absorber have been investigated. These are the dielectric constant of the mixed resin-rice husk particle board, the mixed resin percentages, the source-port distance and the angles between the signal source and the surface of the pyramidal microwave absorber. The results so far indicate that the rice husks can have a great potential to be used as the material in a microwave pyramidal absorber.

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