SETUP AND RESULTS OF PYRAMIDAL MICROWAVE ABSORBERS USING RICE HUSKS

H. Nornikman, F. Malek, M. Ahmed, F. H. Wee, P. J. Soh and A. A. H. Azremi

School of Computer and Communication Engineering
Universiti Malaysia Perlis (UniMAP)
Taman Seberang Jaya Fasa 3, Kuala Perlis, Perlis, Malaysia

S. A. Ghani

School of Materials Engineering
Universiti Malaysia Perlis (UniMAP)
Kompleks Pusat Pengajian, Taman Muhibbah, Jejawi, Perlis, Malaysia

A. Hasnain

Faculty of Electrical Engineering
Universiti Teknologi MARA Pulau Pinang, Malaysia

M. N. Taib

Faculty of Electrical Engineering
Universiti Teknologi MARA Shah Alam, Selangor, Malaysia

Abstract—Agricultural wastes are considered not useful and are commonly dumped or burned after crop harvesting. Rice husks from paddy (*Oryza sativa*) are example of agricultural wastes. Rice husks have been investigated as the material for the pyramidal microwave absorbers. The setup for the fabrication and measurement of the rice husks pyramidal microwave absorbers are discussed. An 8×8 array of pyramidal microwave absorber using the rice husks-polyester-MEKP mixture has been designed and fabricated. There are four main stages in this work: the collection of the raw rice husks materials, the mould fabrication, the pyramidal microwave absorber fabrication and the experiments performed to determine the reflection loss performance of the rice husks pyramidal microwave absorbers. Experimental

results show close agreement with the simulation results (using CST Microwave Studio). Results so far have indicated that rice husks have great potential to be used as the materials for the pyramidal microwave absorbers.

1. INTRODUCTION

Crops residues are materials left in agricultural fields after the crops have been harvested. These residues include stalks and stubble (stems), leaves, and seed pods. Good management of field residues can improve the irrigation and erosion controls. The outer covers of the rice grain are referred to as rice husk or rice hull. Rice husk is a waste product of the agriculture activity in most countries in Asia and particularly in Malaysia. The environment will benefit if this rice husk can be reused. Rice husks have been used in biomass fuels to generate power and also as concrete mixture in building construction work [1–3]. Recently, rice husks have been investigated as potential materials for the pyramidal microwave absorbers [4]. The large percentage of carbon that occurs naturally in the rice husks can potentially provide good reflection loss performance for the microwave absorbers [5]. Figure 1 shows the photo of the rice husks.

Good electromagnetic absorbing materials are very important to ensure the good performance of an RF anechoic chamber. Microwave absorbers are the main components used in an anechoic chamber, to eliminate reflected signals. There are two common RF absorber types: for the microwave frequency range (1 GHz to 300 GHz) and for the lower frequency range (30 MHz to 1000 MHz). Absorber shapes affect the performance of microwave absorbers. Many shapes have been investigated for the RF absorbers: the layer type, pyramidal, wedge,
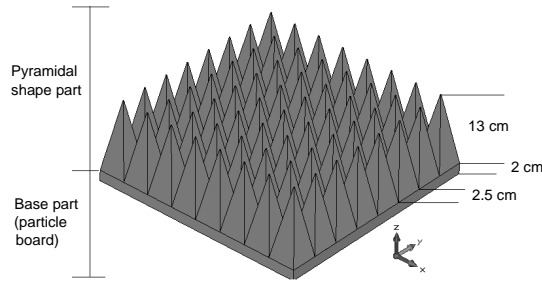

Figure 1. The photo of the rice husks.

Figure 2. Simulation design of an 8×8 array pyramidal microwave absorber using CST Microwave Studio software.

walkway, convoluted, ferrite tiles, oblique incident and metamaterial absorbers [4–30]. Pyramidal absorbers are commonly applied for the frequency range between 1 GHz and 40 GHz. For frequencies below 1 GHz, the square based pyramidal-shaped absorbers are commonly used.

A square pyramid is a polyhedron that has a regular polygon for the base and sides (the lateral faces), with isosceles triangles. The pyramidal microwave absorber designs in this work are based on the commercially available microwave absorbers of TDK$^{\text{TM}}$ and Emerson Cumming$^{\text{TM}}$ [31, 32]. Figure 2 shows the simulation design of an 8×8 array pyramidal microwave absorber using the electromagnetic simulation CST Microwave Studio software. The pyramidal shape microwave absorber has 2 main parts. The first part is the base part, consisting of a square shaped particle board, with 40 cm length $\times 40$ cm length $\times 2$ cm thickness. The second part is the pyramidal shaped section, using tetrahedron based shape with 13 cm height. The pyramidal microwave absorber set contains 64 tips per piece.

The important properties for microwave absorbers are permittivity or dielectric constant and loss tangent. The permittivity of a material has both real and imaginary mathematical representation. The real part of permittivity determines the amount of electrostatic energy stored per unit volume in a material for a given applied field. The imaginary part of the permittivity or sometimes called energy loss is represented in mathematical notation as ε_r'' [33]. Loss tangent refers to the dissipation of power or energy from the incident waves [34].

2. COLLECTION OF THE RICE HUSKS

These raw paddies, shown in Figure 3(a) are obtained from the Padiberas Nasional Berhad (BERNAS) paddy factory at Kuala Perlis,

(a)   (b)

Figure 3. (a) The paddy materials. (b) The grinded and sieved rice husks.

Malaysia. Rice husks are the waste materials resulting from the separation of the rice from the paddy seeds. Firstly, the rice seeds of the rice plant are milled using a rice huller to remove the rice husks. The outcome is 78% brown rice and 22% rice husk [35]. The rice husks are then separated and collected.

The rice husks are then grinded to ensure sure they can be easily mixed with the resins and hardener agents. Next, the rice husks are sieved to ensure that the grinded rice husks particles have regular and similar sizes. The end product of the collected rice husks are shown in Figure 3(b).

3. MICROWAVE ABSORBER FABRICATION

The pyramidal microwave absorber fabrication is performed in two parts. The first part is the base part (squared-shape particle board) fabrication and the second part is the pyramidal shape microwave absorber fabrication.

3.1. Base Part Fabrication

The grinded rice husks are mixed with polyester (as resins) and methyl ethyl ketone peroxide (MEKP) (as hardener agents). The dimensions of the base part particle board are 20 cm length $\times$ 20 cm width. Figure 4 shows the mixing process to make the rice husks pyramidal microwave absorbers. The resin composition is 10% of the total rice husks amount used for making this rice husks base part particle board.

Figure 5 shows the available hot press machine, for the fabrication of the rice husks pyramidal microwave absorbers. The hot press machine is a high pressure, low strain rate material process, operating
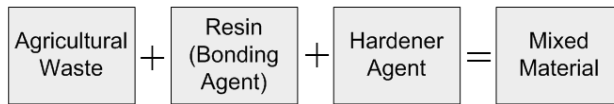
Figure 4. The mixing process to make the rice husks pyramidal microwave absorbers.

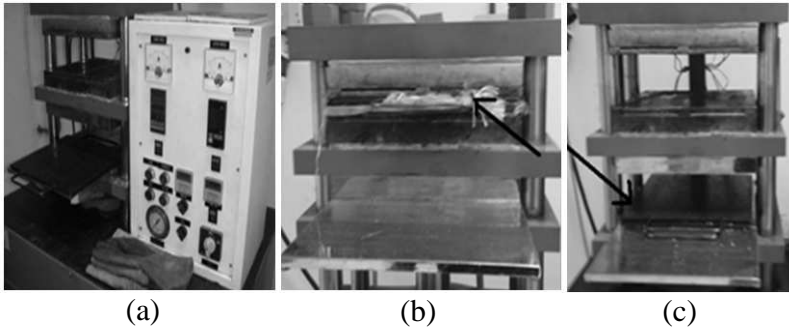

(a)   (b)   (c)

Figure 5. (a) The hot press machine. (b) The upper part of the hot press machine. (c) The lower part of the hot press machine.

at high temperature, for forming compact materials. The rice husks are shaped into a square form. Transparency plastics are placed at the top of the mould, to avoid the agricultural waste cleaving onto the square mould. The rice husks are then transferred into a rigid frame over the hot press machine. The temperature of this machine is set to 180° C for 10 minutes. After pressing, the mould and the rice husks are cooled off by transferring them to the lower section of the hot press machine. After chilled, the rice husks particle board is taken out from the mould. To obtain a beautiful plot form, the board is trimmed at its edges.

3.2. Pyramidal Shape Part Fabrication

The pyramidal microwave absorber moulds consists of two semi-pyramid mould shapes, two semis cubic mould with inner pyramid shape area, hand press, eight fasteners and Allen keys. Figure 6 shows the mould of the pyramidal microwave absorber, made from steel.

The tools needed for this pyramidal microwave absorber fabrication are the hand press machine, transparent plastics, WD40, digital weighing machine and absorber mould. Firstly, 150 grams of
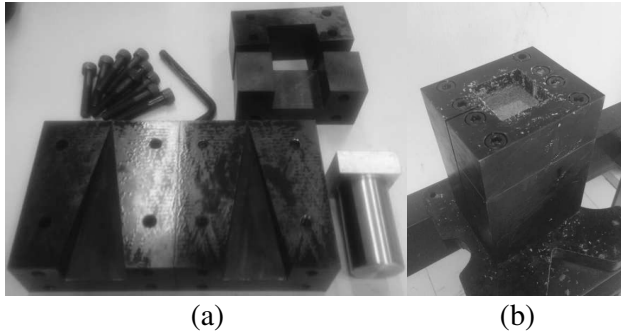
(a)   (b)

Figure 6. (a) The pyramidal shaped mould with the associated components. (b) The rice husks placed in the mould.

rice husks and 15 grams of Polyester resins are weighed using the digital weighing machine. Then, 2 ml of MEKP hardener and the rice husks — Polyester mixture are mixed together and stirred in a cup. The inner part of the absorber is sprayed with WD40. WD40 or 'Water Displacement — 40th Attempt' is a formula to prevent corrosion, by displacing the standing water that causes it.

Before transferring the mixed material into the absorber mould, the transparent plastic is placed onto the absorber mould, to facilitate the opening of the absorber after being impressed. The absorber mould is pressed for two minutes by using the hand press machine to ensure compactness of the rice husks in the mould and to prevent cracking up of the rice husks after reopening of the mould. After the two minutes, more rice husks-resin-hardener mixtures are added into the absorber mould and then pressed. This process is repeated until the mixtures are fully compacted. Figure 7 shows the hand press machine, available at the Materials Engineering Laboratory, Universiti Malaysia Perlis. Figure 8 shows the fabricated pyramidal microwave absorber using rice husks.

4. REFLECTION LOSS MEASUREMENTS

The Radar Cross Section (RCS) method is used to determine the reflection loss performance of the fabricated rice husks pyramidal microwave absorbers. 21 frequencies are measured from 7 GHz to 13 GHz with increments of 0.25 GHz.

The equipments used in this RCS measurement are a pair of horn antennas (for transmit and receive), coaxial cable, signal generator, spectrum analyzer, reference metal, plywood board and the rice
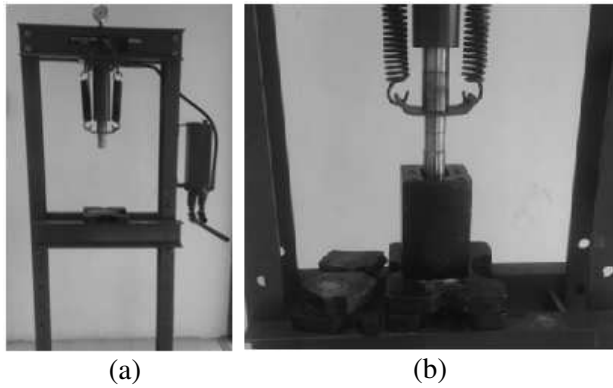
Figure 7. (a) The hand press machine. (b) The pyramidal shaped mould located on the hand press machine.
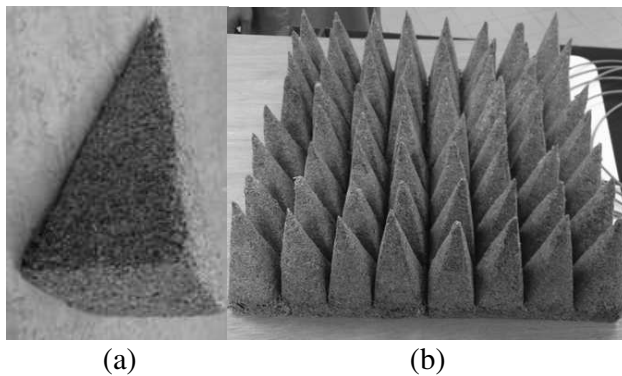

Figure 8. The fabricated rice husks pyramidal microwave absorbers. (a) Single unit. (b) An 8×8 array rice husks pyramidal microwave absorbers.

husk pyramidal microwave absorbers. The reference metal is placed in between the rice husks pyramidal microwave absorbers and the plywood board. The optimum distance between the horn antennas and plywood board is determined from the experiment.

In the first step, the signal analyzer is connected to the transmit horn antenna for transmitting the input microwave signal, and the receiver horn antenna collects the microwave signal. The experimental setup is shown in Figure 9. 64 pieces of pyramidal microwave absorbers, with a total area of $40\,\text{cm}^2$ are located above the reference metal board. 10 different points are taken for this reflection loss measurement to

ensure the accuracy of the measurements. The signal generator is switched on with an input signal of 0 dB at a chosen frequency point. The horn antennas are then moved until the best value of reflection loss result (dB) is achieved. The distance between the horn antennas and the plywood board is then determined. The optimum distance found between the horn antennas and plywood board is 12.3 cm. Figures 10, 11 and Table 1 show the different point locations chosen for these reflection loss measurement experiments.
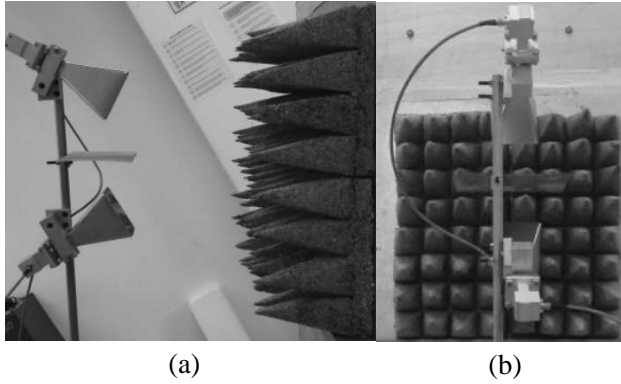

(a)   (b)

Figure 9. Reflection loss measurement setup. The reference metal is placed in between the rice husks pyramidal microwave absorbers and the plywood board. (The reference metal and plywood board are not shown in the photos).
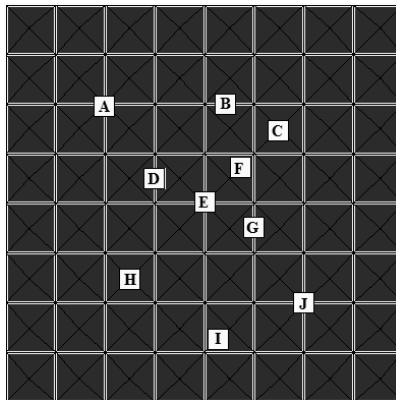

Figure 10. Ten different location points on the pyramidal microwave absorbers (Top view).
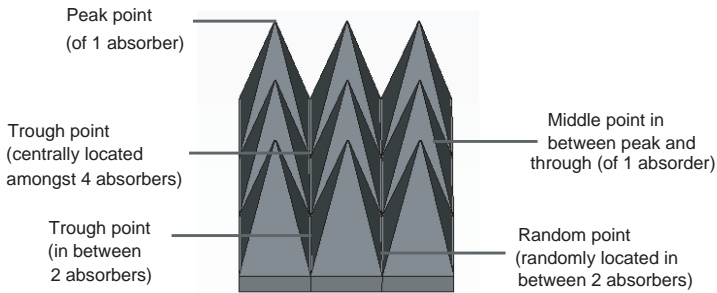
Figure 11. The different location points on the pyramidal microwave absorber (perspective view).

Table 1. Locations of the 10 points for the RCS measurements.

Points Names	Location Points
A, E, J	Trough Point (Centrally located amongst 4 absorbers)
B	Random Point (Randomly located in between 2 Absorbers)
C, H	Peak Point (of 1 absorber)
D, G	Trough Point (In between 2 absorbers)
F, I	Middle point in between peak and trough (of 1 absorber)

5. RESULTS AND DISCUSSIONS

The reflection loss results are obtained from experiments using the Radar Cross Section measurement method. The reflection loss value in increments of 0.25 GHz for the frequencies from 7.0 GHz and 13.0 GHz are obtained. The real and imaginary parts of ε_r for the Polyester — rice husk particle board (with 10% polyester content) are obtained using the free space measurement technique, and are plotted in Figure 12.

Figure 13 shows the reflection loss performance at the different points for the simulation of the pyramidal microwave absorbers (using CST Microwave Studio). From this graph, the reflection loss results obtained are in the range of -28 dB to -58 dB. Therefore the reflection loss performances of the pyramidal microwave absorbers vary with frequencies. Figure 14 shows the reflection loss performance at the different points for the fabricated pyramidal microwave absorbers. From this graph, the reflection loss results obtained are in the range from -22 dB to -53 dB.

For the simulations, the result obtained at point A is similar with the results obtained at point E and point J. These three points are
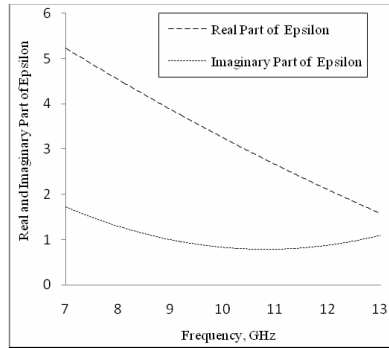
Figure 12. The real and imaginary parts of ε_r for the Polyester — rice husk particle board (with 10% Polyester content) using the free space measurement technique.
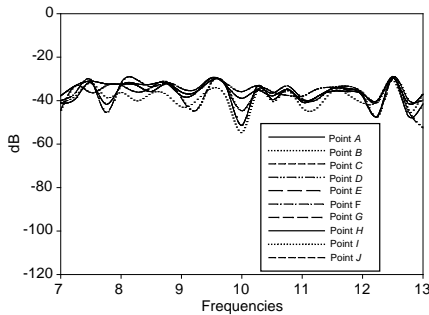

Figure 13. The reflection loss performance at the different points for the simulation (using CST Microwave Studio) of the pyramidal microwave absorbers.
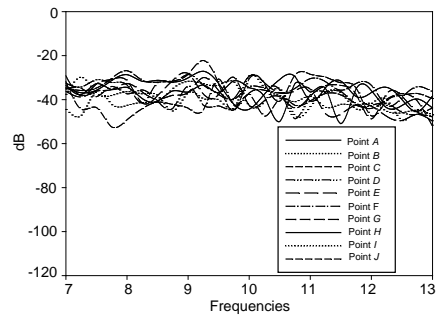
Figure 14. The reflection loss performance at the different points for the fabricated pyramidal microwave absorbers.

located at the trough point (centrally located amongst 4 absorbers), near to the base of the microwave absorber. For the fabrication, all three points (A, E, J) for the fabricated microwave absorbers have slightly different reflection loss results from each other. For the fabricated microwave absorbers, there are different sizes of rice husks particles and different sizes of empty spaces in between the particles. In addition, the percentages of rice husk particles — resin — hardener agent are not exactly similar at the different points for the fabricated absorber. Moreover, the CST Microwave Studio software, used for the simulation operates up to four decimal points, while two decimal points

Table 2. Average reflection losses of simulation (using CST Microwave Studio) and fabricated rice husks pyramidal microwave absorbers at different points.

Points	Average Reflection Loss Results (dB)		Results difference between simulation and fabricated
	Simulation	Fabricated	
A	−35.908	−37.898	1.990
B	−38.956	−40.426	1.470
C	−36.655	−33.863	2.792
D	−35.603	−37.419	1.816
E	−35.908	−39.095	3.187
F	−37.012	−37.007	0.005
G	−35.603	−37.336	1.733
H	−36.655	−35.070	1.585
I	−37.012	−39.785	2.773
J	−35.908	−41.969	6.061

are shown at the display of the spectrum analyzer.

Table 2 shows the measurement results of the reflection losses of the fabricated pyramidal microwave absorbers at different location points. The reflection loss results obtained are in the range from −23.0 dB to −53.0 dB for the frequencies from 7.0 GHz to 13.0 GHz. For the fabricated rice husks pyramidal microwave absorbers, the best average reflection loss result is achieved at Point J with −41.969 dB, while point C shows the worst reflection loss result with −33.863 dB. For the simulation (using CST Microwave Studio), the best average reflection loss result is achieved at Point B with −38.956 dB, while the worst average reflection loss is obtained at Point D and G, with −35.603 dB.

The largest variation in the result between the simulation and fabricated is obtained at point J, with 6.061 dB. The smallest variation in the result between the simulation and fabricated is obtained at point F, with 0.005 dB. The rice husks are grinded using normal (non-industrial) grinder and hence the fabricated rice husks microwave absorbers are not as fine as desired. The humidity of the rice husks microwave absorbers, the humidity of the air, the reflections from the surroundings and human error during measurements can affect the performance of the rice husks microwave absorbers. In addition, the range between the microwave absorbers and the antennas and the angle between the transmitter and receiver antennas should be kept constant

for each measurement.

Figures 15 to 19 show the comparison of the reflection loss performance results between the simulated and fabricated rice husks pyramidal microwave absorbers. For the fabricated rice husks microwave absorbers, the worst reflection loss (averaged from all frequency range) for one single point is at point C with $-22.23\,\mathrm{dB}$ and at $9.25\,\mathrm{GHz}$. For the simulation (using CST Microwave Studio), the worst point is obtained at point F with reflection loss result of $-28.88\,\mathrm{dB}$ at a frequency of $12.25\,\mathrm{GHz}$. From the all graphs, it can be seen that the results between the simulation (using CST Microwave Studio) and the fabricated rice husks pyramidal microwave absorber show reasonable agreement. Based on the reflection loss results, it can be concluded that rice husks have good potential as the material used for the pyramidal microwave absorbers.

Figure 15 shows the reflection losses at the trough point (centrally located amongst 4 absorbers) for the simulation (using CST Microwave Studio) and the fabricated rice husks pyramidal microwave absorbers. The best performance is obtained at point J (fabricated microwave absorbers), with a result of $-52.450\,\mathrm{dB}$, at $7.75\,\mathrm{GHz}$. Figure 16 shows the reflection losses plot for the random point B (randomly located in between 2 absorbers), for the simulation (using CST Microwave Studio) and the fabricated rice husks pyramidal microwave absorbers. From this figure, the best result for the simulation is obtained at $10\,\mathrm{GHz}$,
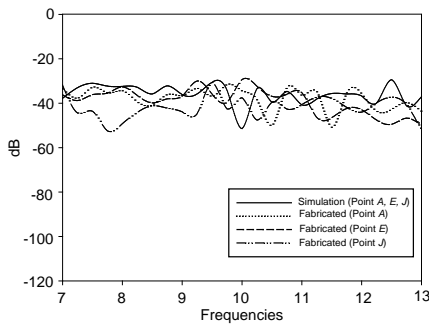

Figure 15. The reflection losses at the trough point (centrally located amongst 4 absorbers) for the simulation (using CST Microwave Studio) and the fabricated rice husks pyramidal microwave absorbers.
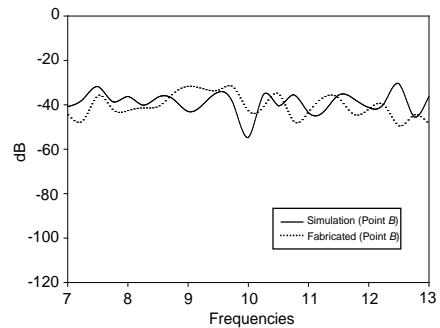
Figure 16. The reflection losses at the random point (randomly located in between 2 absorbers) for the simulation (using CST Microwave Studio) and the fabricated rice husks pyramidal microwave absorbers.
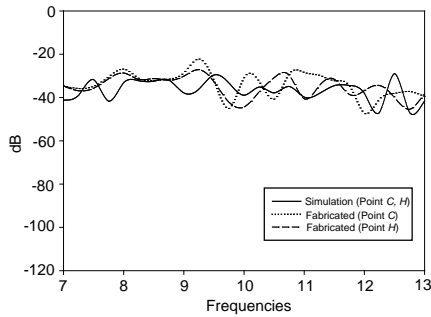
Figure 17. The reflection losses at the peak point (for 1 absorber) for the simulation (using CST Microwave Studio) and the fabricated rice husks pyramidal microwave absorbers.
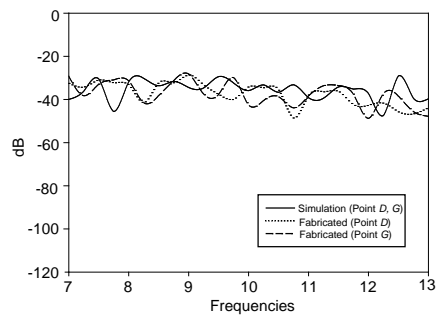
Figure 18. The reflection losses at the trough point (in between 2 absorbers) for the simulation (using CST Microwave Studio) and the fabricated rice-husks pyramidal microwave absorbers.

Figure 19. The reflection losses for the middle point in between the peak and trough (for 1 absorber) for the simulation and fabricated rice husks pyramidal microwave absorbers.

with -54.720 dB. Meanwhile, the reflection loss result obtained at 10 GHz for the fabricated rice husks microwave absorbers is -42.87 dB. Figure 17 shows the reflection losses results at the peak point (for 1 absorber) for the simulation (using CST Microwave Studio) and for the fabricated rice husks pyramidal microwave absorbers. The best reflection loss result is obtained at Point C (Simulation) with -47.41 dB at 12 GHz.

Figure 18 shows the reflection losses at the trough point (in between 2 absorbers) for the simulation (using CST Microwave Studio)

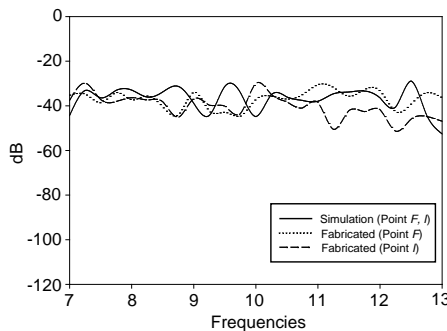and the fabricated rice-husks pyramidal microwave absorbers. The reflection loss performance at point D (fabricated) is -41.530 dB while at point G (fabricated) is -41.520 dB, at 8.25 GHz. Figure 19 shows the reflection losses at the middle point in between the peak and trough (for 1 absorber) for the simulation and fabricated rice husks pyramidal microwave absorbers, The point I (fabricated) shows the best reflection loss result of -45.360 dB at 12.25 GHz. Generally, it can be observed
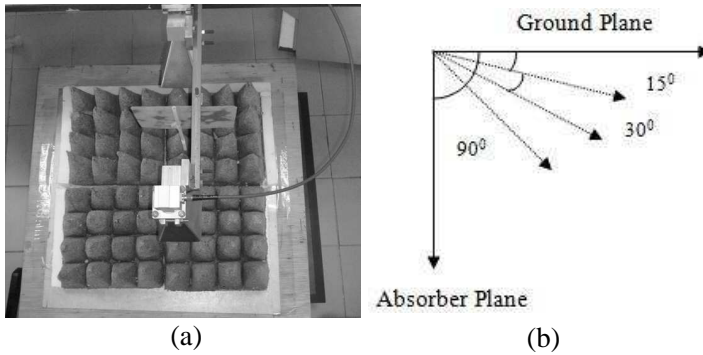

(a)   (b)

Figure 20. Angle variations for the received antenna for the reflection loss measurements: (a) The received antenna is setup at 90° with respect to the absorber plane. (b) The angle variations setup for the received antenna.
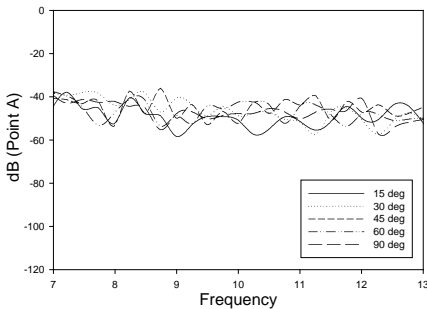

Figure 21. The reflection losses for various reflection angles (at the received antenna) at the trough point A (centrally located amongst 4 absorbers) for the fabricated rice husks pyramidal microwave absorbers.

Figure 22. The reflection losses for various reflection angles (at the received antenna) at point B for the fabricated rice husks pyramidal microwave absorbers.

that the results obtained from the fabricated microwave absorbers are better than the results obtained from the simulation, for the frequencies ranging from 10.75 GHz to 12.50 GHz.

From the observations so far, it can be concluded that the reflection loss results for different locations (with the same location type) show very close agreements. The reflection loss difference between the best result (obtained at point B) and the worst result (obtained at point G) is 3.353 dB. The parameter that gives the largest changes is the shape of the pyramidal microwave absorber. Figure 20 shows the angle variation setup to observe the behavior of the reflection loss by varying the angles of the received antenna, at 15°, 30°, 45°, 60° and 90° respectively. The transmit antenna is maintained at a constant angle of 60°.

Figure 21 shows the reflection losses for various reflection angles (at the received antenna) at the trough point A (centrally located amongst 4 absorbers) for the fabricated rice husks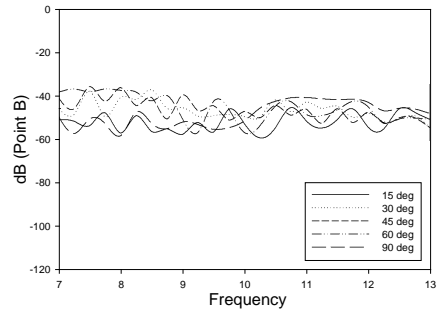 pyramidal microwave absorbers. The plot shows that there are small variations in the reflection loss results for different reflection angles (at the receive antenna). Figure 22 shows the reflection losses for various reflection angles (at the received antenna) at point B for the fabricated rice husks pyramidal microwave absorbers. Similarly, this plot shows that there are small variations in the reflection loss results for different reflection angles (at the receive antenna). Figure 23 shows the reflection losses for various reflection angles (at the received antenna) at the peak point

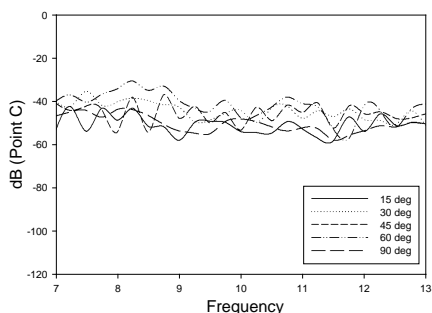**Figure 23.** The reflection losses for various reflection angles (at the received antenna) at the peak point C (for 1 absorber) for the fabricated rice husks pyramidal microwave absorbers.
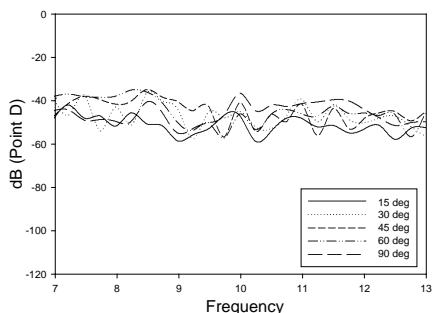

Figure 24. The reflection losses for various reflection angles (at the received antenna) at the trough point D (in between 2 absorbers) for the fabricated rice husks pyramidal microwave absorbers.

Figure 25. The reflection losses for various reflection angles (at the received antenna) at the middle point in between the peak and trough (for 1 absorber) for the fabricated rice husks pyramidal microwave absorbers.

C (for 1 absorber) for the fabricated rice husks pyramidal microwave absorbers. This time, the plot shows that from 7 to 11 GHz, the reflection angle of $60°$ has the worst reflection loss results compared to other investigated angles. This is because at the peak point of one absorber, more EM waves are reflected at various angles, compared to the same angle as the transmit antenna's angle. Figure 24 shows the reflection losses for various reflection angles (at the received antenna) at the trough point D (in between 2 absorbers) for the 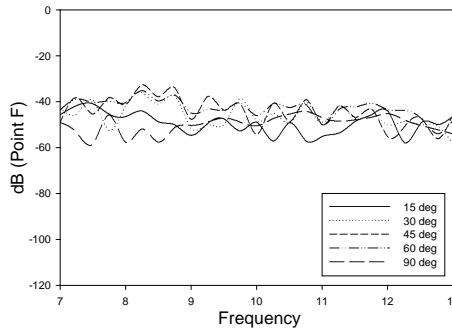fabricated rice husks pyramidal microwave absorbers. It can be seen that there are small variations in the reflection loss results for different reflection angles (at the receive antenna). Figure 25 shows the reflection losses for various reflection angles (at the received antenna) at the middle point in between the peak and trough (for 1 absorber) for the fabricated rice husks pyramidal microwave absorbers. Similarly, it can be concluded that there are small variations in the reflection loss results for different reflection angles (at the receive antenna).

6. COMPARISON BETWEEN THE RICE HUSKS MICROWAVE ABSORBERS AND THE CONVENTIONAL MICROWAVE ABSORBERS

For the fabrication of a single pyramidal microwave absorber, as shown in Figure 8(a), 150 grams of rice husks, 15 grams of polyester and 0.3 grams of MEKP are used. Therefore, the weight ratio of the rice husks: Polyester: MEKP is 100: 10: 0.2, for a single pyramidal microwave absorber with dimensions of 250 mm × 250 mm × 130 mm.

The rice husks are available for free, while the cost for the polyester is USD 0.0103/gram, and the cost for the MEKP is USD 0.0035/gram. Therefore, the cost for making a single rice husks pyramidal microwave absorber is USD 0.0423, and the cost for making an array of 8×8 rice husks pyramidal microwave absorbers is USD 2.71.

TDK[TM] absorbers are generally made from polyethylene and carbon [36]. The weights for the TDK[TM] absorbers (ICT-30 and ICT-45 materials) are 350–600 grams, with dimensions of 150 mm $\times$ 150 mm $\times$ 120 mm [25]. Hence, the rice husks microwave absorbers are more cost-effective and lightweight compared to the currently commercially available microwave absorbers.

In Malaysia, 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, highly porous and lightweight, with a very high external surface area. Rice husks have been traditionally burnt in the field or trucked out and dumped [4]. Therefore the use of rice husks as the materials for the microwave absorbers utilizes the available by-products of paddy that are abundant in nature. The advantages of using rice husks are the availability, sustainability, environmental friendly, comparable performance compared to the conventional microwave absorbers and significant reduction in fabrication costs. The drawbacks are the rice husks are only available in tropical climate countries, and also depend on the yield of the paddy. The paddy yields could be reduced or interrupted due to extreme flooding or other environmental disasters, which could result in the reduction of rice husks. In addition, there is a slight variation in the SiO_2 and carbon composition in the rice husks for different paddy seeds, which might produce slight variations in the performances of the rice husks microwave absorbers.

7. CONCLUSION AND FUTURE WORK

The reflection loss results obtained for the rice husks pyramidal microwave absorbers are significantly better then -10 dB (i.e., the threshold dB for the characteristics of microwave absorbers). The reflection loss results obtained from the fabricated rice husks pyramidal microwave absorbers also show reasonable agreement with the reflection loss results obtained using simulation (performed with CST Microwave Studio). The experimental results obtained in this work therefore validate the simulation results performed by Nornikman et al. [4]. The different point locations at the pyramidal microwave (peaks and troughs) do not results in large variations for the reflection loss performances. Therefore, rice husks have great potential to be

used as the materials for pyramidal microwave absorbers.

Further work will be performed to investigate the performance of the rice husks microwave absorbers due to humidity, temperature and other environmental parameters. This is important to ensure the viability and robustness of the rice husks pyramidal microwave absorbers and to meet various international standards prior to commercialization. Regulatory and standards testing will be performed on the rice husks microwave absorbers by placing the item in temperature and humidity chambers. In addition, package drop tests and vibration tests will be performed to ensure robustness. In the future, the rice husks microwave absorbers will be fabricated using industrial grade machines such as industrial grade mixer, grinder and press machine.

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