VOL. 11, NO. 14, JULY 2016 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences
©2006-2016 Asian Research Publishing Network (ARPN). All rights reserved.

www.arpnjournals.com

SINGLE LAYER MICROWAVE ABSORBER BASED ON RICE HUSK-MWCNTs COMPOSITES

Y. S. Lee[1], F. Malek[2], E. M. Cheng[3], Wei-Wen Liu[4], K.Y. You[5], F. H. Wee[1], L. Zahid[1] and H. A. Rahim[1]
[1]School of Computer and Communication Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, Arau, Perlis, Malaysia
[2]School of Electrical Systems Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, Arau, Perlis, Malaysia
[3]School of Mechatronic Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, Arau, Perlis, Malaysia
[4]Institute of Nano Electronic Engineering, Universiti Malaysia Perlis, Kangar, Perlis, Malaysia
[5]Radio Communication Engineering Department, Faculty of Electrical Engineering, UniversitiTeknologi Malaysia, Skudai, Johor, Malaysia
E-Mail: leeyengseng@gmail.com

ABSTRACT

In this paper, rice husk (RH) and multi-walled carbon nanotubes (MWCNTs) composite have been fabricated as single layer microwave absorber. The MWCNTs with various weight ratio composites with RH have been prepared. Three different weight ratio 3 wt% MWCNTs, 5 wt% MWCNTs, and 15 wt% MWCNTs of the RH-CNTs have been designed and fabricated. Moreover, the dielectric properties of different RH-CNTs specimens have been verified by using rectangular waveguide transmission line technique. Furthermore, the microwave absorption of these RH-CNTs has been analyzed using free space measurement and CST Microwave Studio (CST-MWS). The dielectric properties and microwave absorption of different RH-CNTs were investigated in 8.2-12.4 GHz (X-band). From the measurement, the dielectric properties parameter of RH-CNTs is analyzed. The dielectric constant and loss factor of the RH-CNTs composite increases with increasing of MWCNTs weight ratio. However, the magnetic properties of RH-CNTs remain constant, u_r= 1-j0. The measurement and simulation result show that such RH-CNTs composites has excellent microwave absorption up to 33 dB in a certain frequency range.

Keywords: dielectric properties, microwave absorber, reflectivity, composites.

INTRODUCTION

The rapid growth in science and wireless technology towards gigahertz frequency applications in modern communication has increased the electromagnetic interference (EMI) (Salimbeygi *et al*., 2014). EMI is cause by uncontrolled interference of electronic devices or systems (Wang *et al*., 2009). EMI can consider as kind of environmental pollutions that emitting unwanted radiation which can cause harmful disturbance of electronic system and human body (Morari *et al*., 2011). Therefore, the efficiency of EMI shielding or microwave absorbing materials (MAMs) were enhanced to control the EMI pollution. For MAMs, it should absorb microwave energy incident on it and have minimum reflection of the microwave energy (Meena *et al*., 2010). MAMs can be used to protect electronic device and also human body from harmful effect of these microwaves energy. A good microwave absorber material must require good microwave absorption performance (> 90% absorption).

Carbon nanotubes is a high carbon dielectric material which exhibit excellent in electronic, mechanical, and material sciences (Saini et al., 2009; Liu *et al*., 2014). A composite material can defined as combining two or more materials to give a unique combination of properties. Recent years, composites based on CNTs with polymer matrix are widely used in many application due to the unique and advantageous properties offered by the new composites materials (Saini *et al.,* 2011). The dielectric properties ($\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$) of the composites is important for microwave absorber. The interaction of microwave energy with MAMs are microwave energy stored (absorption) in MAMs and conversion the energy to heat.

The electromagnetic properties of samples were investigated using Agilent Performance Network Analyzer (PNA), and measurements were carried out using transmission line method. In addition, CST-MWS software is used to analysis the microwave absorption of the samples. The microwave absorption measurement and simulation results are compared.

THEORY

There are two methods generally used in the measurement of electromagnetic properties of materials, which are free space method and transmission line method.

In free space method, the material properties characterization is much more flexible to measure under different condition. However, the material under test (MUT) required larger than the horn antennas, it is not the size of the MUT must larger than the horn antenna, instead the size of the MUT must within the 3dB beamwidth of the antenna. Therefore, we used transmission line method which is more suitable for small samples.

In a transmission line method, the MUT are placed in samples holder between two waveguide adaptors. This method is widely used in the measurement electromagnetic properties of small samples. The electromagnetic properties of material are characterized based on the basis of the reflection from the MAMs and transmission through the MAMs.

ARPN Journal of Engineering and Applied Sciences
©2006-2016 Asian Research Publishing Network (ARPN). All rights reserved.

General, researchers use a perfect electric conductor (PEC) such as a metal back plate to measure reflection loss of the microwave absorber(Oyharçabal *et al.*, 2013).Figure-1 shows the illustration of the MAMs with metal backed plate.

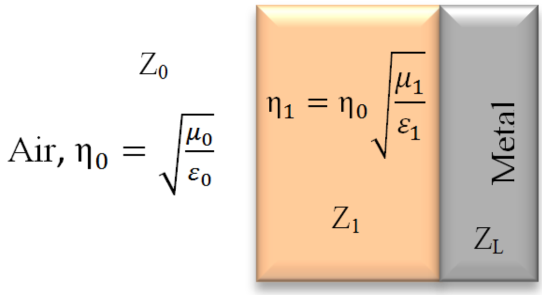


Figure-1. Illustration of single layer MAMs.

MAMs are functional materials that absorb microwave energy with minimum reflection and maximum attenuation/absorption of the microwave energy. The reflection of microwave energy occurs when incident energy reflected from the surface of MAMs and metal backing of the MAMs. The input impedance (Z_{in}) of MAMs is close to air (377 *ohm*) impedance, the reflection at the interface can be minimized. When an electromagnetic wave is incident normally to a single layer microwave absorber backed with a metal back plate, the impedance is given by(Kong *et al.*, 2014);

$$Z_{in} = Z_0 tanh(j\frac{2\pi}{c}\sqrt{\mu_r \varepsilon_r} fd) \quad (1)$$

where, Z_0 is the free space impedance given by, $Z_0 = \sqrt{\mu_0/\varepsilon_0} = 377\ ohm$; c, f *,and* d are the propagation velocity of the wave in free space, frequency of the incident wave, and thickness of the MAMs, respectively. The material properties namely the relative complex permittivity, $\varepsilon_r = \varepsilon_r' - j\varepsilon_r''$ and relative complex permeability, $\mu_r = \mu_r' - j\mu_r''$; d is the thickness of MAMs; c and f are the velocity of light in vacuum and the frequency of microwaves in free space, respectively. For dielectric MAMs, the permeability, $\mu_r \approx 1 - j0$.

In case of a metal backed single layered absorber, the normalized input impedance with respect to impedance offree space and the reflection loss with respect to the normal incident plane wave are given by(Sarkar *et al.*, 2014)

$$R_L(dB) = -20log_{10}\left[\frac{Zin-1}{Zin+1}\right] \quad (2)$$

There have two reflection phenomenon occurs when the microwave energy interact with MAM. The first reflection is at the air-absorber interface while another reflection is the energy propagated through the materials and bounce back from the metal backing of the MAMs. Reflection at the interface of air-absorber can be minimized by making input impedance of MAMs close to that of free space impedance matching.

In the present study, the samples were optimized using CST Microwave Studio for the best performance in microwave absorption over 8.2- 12.4 GHz frequency. The result can be explained base on the impedance matching as equation (1). The microwave absorption of the MAMs was calculated using equation (1-3).R_{linear} is the conversion of R_L decibel (dB) to linear form.

$$Microwave\ absorption,\ \% = [1- R_{linear}]x\ 100\ \% \quad (3)$$

EXPERIMENTAL

The multi-walled carbon nanotubes (MWCNTs) used in this experiment was purchased from USAINS SdnBhdSdnBhd with purity 99 wt% purity. MWCNTs is a nanomaterial which is very hard to be compacted due to its very large surface area. Hence, MWCNTs in this experiment was composites with polymer (polyester resins). In this experiment, the PE resins and Methyl ethyl ketone peroxide (MEKP) harden agent weight ratio were remain constants. The different weight ratio of MWCNTs filler is the main parameter in this study. The RH-CNTs composites are prepared using mechanical mixing and MEKP was used as curing agent for RH-CNTs samples. The samples were prepared in different MWCNTs weight ratio (3wt%, 5wt%, and 15 wt%) with dimension 22.860 mm x 10.160 mm x 5 mm. The preparation process of the under test sample was mixed the MWCNTs with PE resins and stir for 1 hour.

After the stirring process, the composites of the RH-MWCNTs was poured into the rectangular standard steel mold flange and cured in room temperature 25 °C for 24 hours. Different rectangular sample of RH-CNTs was fabricated. Figure-2 shows the fabricated rectangular samples of RH-MWCNTs. In this study, three samples were prepared for each type of RH-MWCNTs for more accuracy measurement and results. Each type of RH-MWCNTs dielectric properties was determined according average of the three similar type of samples.

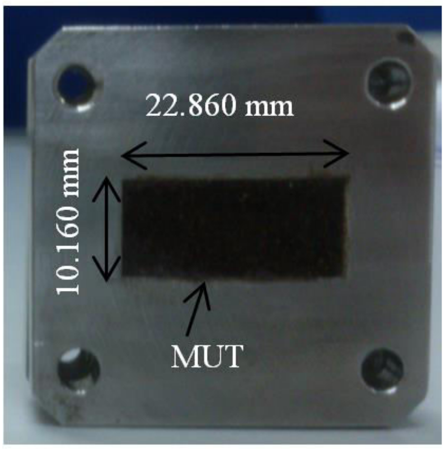


Figure-2. RH-CNTs rectangular samples fit inside the sample holder.

ARPN Journal of Engineering and Applied Sciences
©2006-2016 Asian Research Publishing Network (ARPN). All rights reserved.

DIELECTRIC MEASUREMENT

The rectangular waveguide transmission line method was used to measure the material properties of the RH-MWCNTs. The two coaxial cables were connected between Agilent network analyzer E8362B and the rectangular waveguide adaptors (WR-90). The samples were fabricated and placed into the sample holder as shown in Figure-3. The sample holder is special manufacture with size a = 22.860 mm, b = 10.160 mm, and d (thickness) = 5 mm. An incident energy from port 1 propagate through the target sample and the receive energy detected at port 2. The sample holder is well connected between two rectangular waveguide adaptors with screws as shown in Figure-3. Figure-4 shows the Thru-Reflect-Load (TRL) calibration for transmission line of rectangular waveguide.

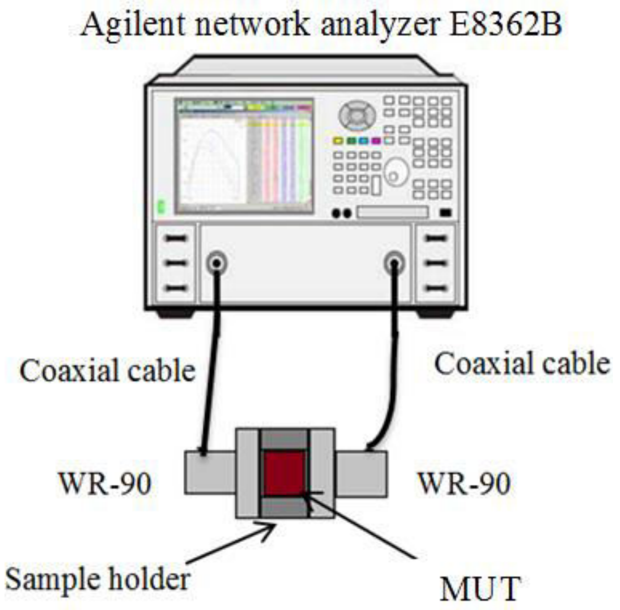


Figure-3. Dielectric properties measurement setup.

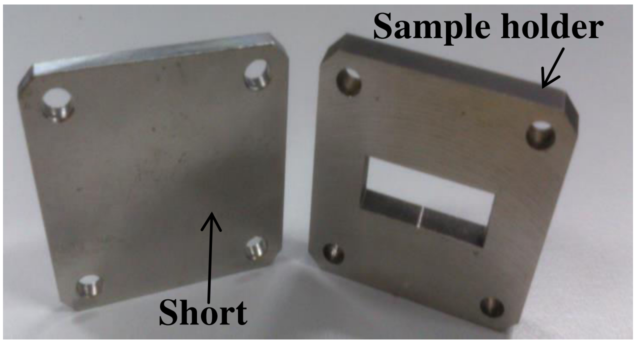


Figure-4. TRL calibration Line and short for rectangular waveguide.

The calibration of the measurement is mean to eliminate the testing error induced by the gap between sample and flange. The real and imaginary parts of the dielectric constant of RH-MWCNTs can be directly computed by using the rectangular waveguide transmission line test system with Agilent software 85071E. The transmission line is enclosure with conductor material. Therefore, the microwave energy only propagated inside the rectangular waveguide transmission line.

REFLECTIVITY MEASUREMENT

For the reflectivity measurement of MUT, the scattering parameters (S-parameter)have been measured using a pair of horn antennas connect to Agilent network analyzer E8362B with a pair of coaxial cables. The network analyzer transmits incident energy from port 1 to the MUT and the reflected power was detected at Port 2, as known as S_{21}. The free space transmission coefficients S_{21} of a sample were measured for a normal incident plane wave(Abdalla 2013). A metal back plate acts as a short circuit and allocated at bottom of the MUT. The MUT was fabricated with 300 mm (length) x 300 mm (width) x 8 mm (thickness) flat square shape.

SIMULATION PART

In simulation, the MUT was designed with 300mm (length) x 300 mm (width) x t (thickness) flat square shape with different thickness. The metal back plated (iron) are placed bottom of the MUT**.**The distance between the port 1 source and the MUT are 30 cm(Iqbal *et al.*, 2013). The simulation setup is shown in Figure-5. The incident signal are propagate from port 1 to MUT and the reflected signal from the MUT and metal back plate are receive in port 1 as known as scattering parameter (S_{11}). The MUT material properties must be defined in CST-MWS using the measured dielectric properties results.

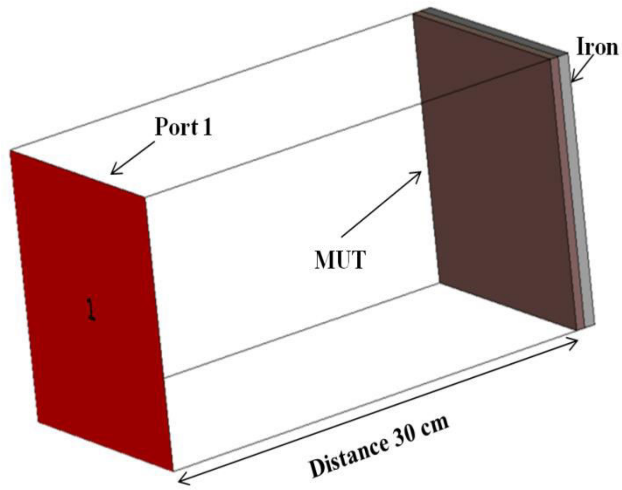


Figure-5. Single layer flat absorber design in CST-MWS.

The reflectivity in decibel, R_{dB} of the MUT was calculated using Equation 1 (Dai et al., 2010):

$$R_{dB} = 20\log\frac{R_{MUT}}{R_{ref}} \quad (4)$$

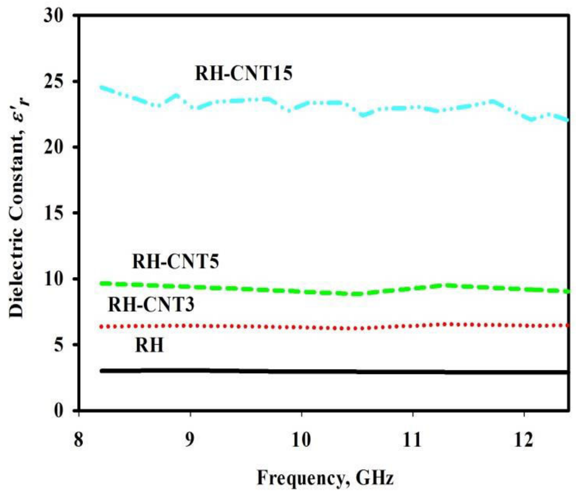
$$\mathrm{R_{linear}} = 10^{\frac{R_{dB}}{20}} \quad (5)$$

©2006-2016 Asian Research Publishing Network (ARPN). All rights reserved.

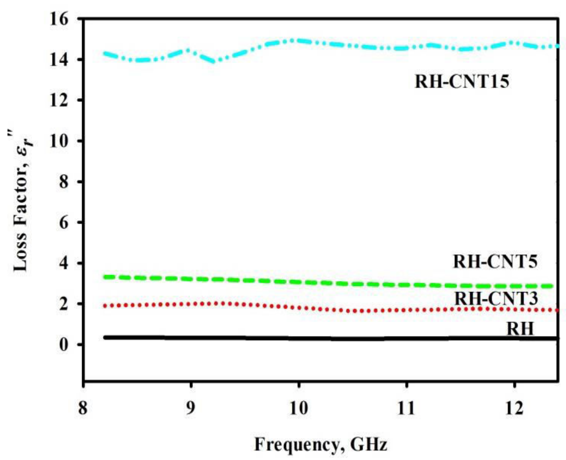
R_{MUT} is referring to reflectivity of the MUT with the metal back plate. Metal back plate (iron) as a reference for the reflectivity, usually are nearly reflected the entire signal ($RL_{ref} \approx 0\ dB$). Percentage of Microwave absorption are calculated using Equation (3) (Wang and Zhao 2013).

RESULTS AND DISCUSSIONS

Figure-6 (a) and (b) represents the dielectric constant and loss factor of RH-MWCNTs different MWCNTs filler 0 wt% (RH), 3 wt% (RH-CNT3), 5 wt% (RH-CNT5), and 15 wt% (RH-CNT15) respectively. The dielectric properties of RH-CNTs samples were measured using rectangular waveguide method in X-band. For the dielectric properties, it is obviously shows that the increasing wt. % MWCNTs loading affect the real and imaginary part of dielectric properties. The dielectric properties increase with increasing of wt. % MWCNTs content in X-band. This can be attributed to the fact that increasing the wt% of CNTs increases the electrical conductivity and dipolar polarization.



(a



(b)

Figure-6. (a) Real part and (b) Imaginary part of dielectric properties with RH-CNTs samples.

The dielectric constant and loss factor values of RH shows a constant values approximate to 3and 0.3 respectively over the X-band. The ε'_r values for RH-CNTs 15% lie from 24.5 at 8.2 GHz to 21.9 at 12.4 GHz. Meanwhile, as shown in Figure-6 (b), For RH, 3, 5, and 15 wt% of RH-CNT, the values of loss factor, ε''_r are in the range 0.3-0.35, 1.65-2.0, 2.83-3.31, and 13.9-14.9 respectively. Table-1 lists the average dielectric constant and loss factor of RH-CNT samples. The $\varepsilon'_r$of RH composite with 15 wt.%is increases from 2.98 to 22.82. Meanwhile, the loss factor increases from 0.30 to 15.45.

Table-1. Average values of dielectric constant and loss tangent of RH-MWCNTs samples in frequency range 8.2 GHz – 12.4 GHz.

Sample	Average values	
	Dielectric constant	Loss factor
RH	2.98	0.30
RH-CNT3	6.44	0.49
RH-CNT5	9.33	3.05
RH-CNT15	22.82	15.45

Figure-7 shows the reflectivity simulated result of RH-CNTs samples with thickness 8 mm. From Figure-7, RH, RH-CNT5, and RH-CNT15 it is obviously show that, these samples are not suitable to be used to absorb microwave radiation in X-band with thickness 8 mm. RH, RH-CNT5, and RH-CNT15 samples with thickness 8 mm are absorbed less than 90% (>-10 dB) of microwave energy in X-band. However, the reflectivity results shows only RH-CNT3 sample has the ability to absorb 90 % microwave absorption at certain frequency. The minimum reflectivity of RH-CNT3 with – 34 dB takes place at the frequency of 9.9 GHz. The RH-CNT3 sample also has greater than 90% microwave absorption (<-10 dB) from 9.34 to 10.55 GHz.

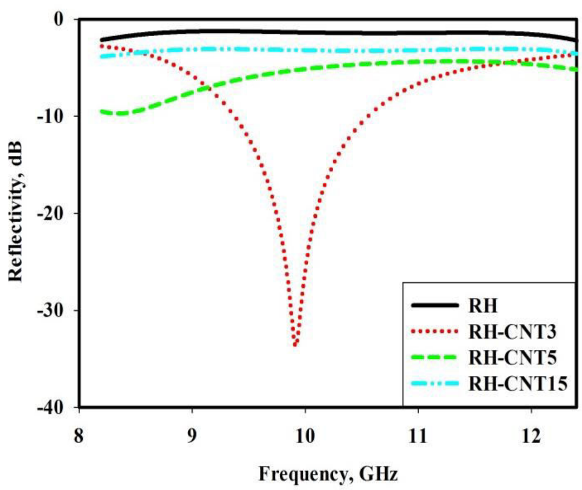


Figure-7. Simulated results of the reflectivity of RH-CNTs samples with thickness 0.8 mm.

ARPN Journal of Engineering and Applied Sciences
©2006-2016 Asian Research Publishing Network (ARPN). All rights reserved.

Based on Figure-8, it is found that the minimum reflectivity peak are shift from higher frequency to lower frequency when increasing the thickness of the samples. For RH-CNT3 samples with thickness 7 mm, the minimum reflectivity of -25.73 dB takes place at the frequency of 11.3 GHz. Similarly, RH-CNT3 samples with thickness 8 mm have the below -10 dB values between 9.38 - 10.55 GHz with the bandwidth of 1.17 GHz. The minimum reflectivity of -33.7dB takes place at the frequency of 9.91GHz.

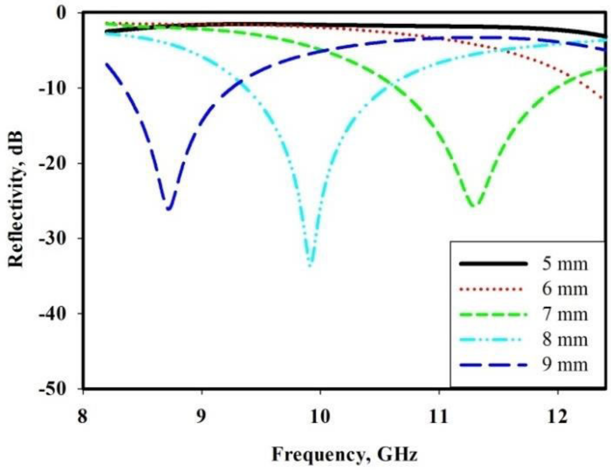


Figure-8. Simulated results of the reflectivity of RH-CNT3 samples with different layer thicknesses.

Figure-9 shows that the comparison of measured and simulated results of RH-CNT3 sample. In Figure-9, the reflectivity of RH-CNT3 with thickness 8 mm and 9 mm were measured using the free space method in normal incident. RH-CNT3 can be selected as the potential microwave absorber due to the ability microwave absorption in X-band. The center frequencies and minimum reflectivity of experimental results were slightly different from the simulation. It may be caused by measurements error or some experimental scatters in fabrication procedure of sample. The results of minimum reflectivity peak are slight move to lower frequency. However, the results of measurement and simulation are still acceptable.

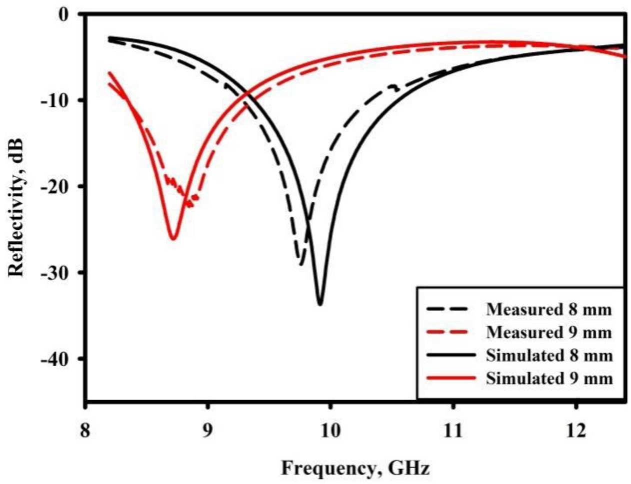


Figure-9. Measured and simulated result of the reflectivity of RH-CNT3 with thickness 8 mm and 9 mm.

Table-2 lists the simulation and measurement of maximum absorption results of RH-CNT3 sample. For RH-CNT3 sample with thickness 8 mm, the measured maximum absorption was 99.8% at 9.7 5 GHz, while the maximum absorption of the simulation result was 99.9at 9.91 GHz. The differences in the results between the measurement and the simulation were 0.10%, 4.64 dB, and 0.16 GHz for the maximum absorption, the minimum reflectivity, dB and maximum frequency, respectively. The measured maximum absorption was 99.4 % while the maximum absorption of simulation result was 99.7 %. The maximum absorbing frequencies were 8.85 and 8.72 GHz for the measurement and simulation, respectively. The maximum absorption difference was only 0.3 % between the results of the measurement and the simulation.

Table-2. Measurement and simulation comparison results of the microwave absorption performance of RH-CNT3 with 8 mm and 9 mm thickness.

RH-CNT3 with 8 mm thickness			
Method	**Maximum absorption, %**	**Minimum Reflectivity, dB**	**Frequency, GHz**
Measurement	99.8	-29.06	9.75
Simulation	99.9	-33.7	9.91
difference	(0.1)	(4.64)	(0.16)
RH-CNT3 with 9 mm thickness			
Measurement	99.4	-22.34	8.85
Simulation	99.7	-26.10	8.72
difference	(0.3)	(3.76)	(0.13)

©2006-2016 Asian Research Publishing Network (ARPN). All rights reserved.

CONCLUSIONS

Rice husk and MWCNTs composites have been successful fabricated and their absorption performance was evaluated. The dielectric properties of RH-CNT samples depend on the wt% MWCNTs, where it increases with the increase in wt% of MWCNTs. The results had been analyzed using CST-MWS software and validated with free space measurement. Both microwave absorption and reflectivity of simulated and measured results have been compared. The microwave absorption frequency range can be shifted by changing the thickness of RH-CNT3 sample. The results show indicated that, high dielectric properties does not gurantee good microwave absorption in X-band. For dielectric absorber, the microwave absorption of the MAMs is depending on the thickness and dielectric properties. The materials properties performance of RH-CNT3 composites has the potential to be used as microwave absorber in X-band application.

REFERENCES

Abdalla, M. A. 2013. Experimental verification of a triple band thin radar absorber metamaterial for oblique incidence applications. Progress in Electromagnetics Research Letters, 39, pp.63-72.

Dai, Y., M. Sun, C. Liu, *et al.* 2010. Electromagnetic wave absorbing characteristics of carbon black cement-based composites. Cement and Concrete Composites, 32(7), pp.508-513.

Iqbal, M. N., M. F. B. A. Malek, Y. S. Lee, *et al.* 2013. A Simple Technique for Improving the Anechoic Performance of a Pyramidal Absorber. Progress in Electromagnetics Research M, 32, pp.129-143.

Kong, L., X. Yin, X. Yuan, *et al.* 2014. Electromagnetic wave absorption properties of graphene modified with carbon nanotube/poly (dimethyl siloxane) composites. Carbon, 73, pp.185-193.

Liu, Y., D. Song, C. Wu, *et al.* 2014. EMI shielding performance of nanocomposites with MWCNTs, nanosized Fe 3 O 4 and Fe. Composites Part B: Engineering, 63, pp.34-40.

Meena, R., S. Bhattachrya and R. Chatterjee. 2010. Development of “tuned microwave absorbers” using U-type hexaferrite. Materials & design, 31(7), pp.3220-3226.

Morari, C., I. Balan, J. Pintea, *et al.* 2011. Electrical conductivity and electromagnetic shielding effectiveness of silicone rubber filled with ferrite and graphite powders. Progress In Electromagnetics Research M, 21.

Oyharçabal, M., T. Olinga, M.-P. Foulc, *et al.* 2013. Influence of the morphology of polyaniline on the microwave absorption properties of epoxy polyaniline composites. Composites Science and Technology, 74, pp.107-112.

Saini, P., V. Choudhary, B. Singh, *et al.* 2009. Polyaniline–MWCNT nanocomposites for microwave absorption and EMI shielding. Materials Chemistry and Physics, 113(2), pp.919-926.

Saini, P., V. Choudhary, B. Singh, *et al.* 2011. Enhanced microwave absorption behavior of polyaniline-CNT/polystyrene blend in 12.4–18.0 GHz range. Synthetic Metals, 161(15), pp.1522-1526.

Salimbeygi, G., K. Nasouri and A. M. Shoushtari. 2014. Fabrication of homogeneous multi-walled carbon nanotube/poly (vinyl alcohol) composite films using for microwave absorption application. Fibers and Polymers, 15(3), pp.583-588.

Sarkar, D., A. Bhattacharya, P. Nandy, *et al.* 2014. Enhanced broadband microwave reflection loss of carbon nanotube ensheathed Ni-Zn-Co-ferrite magnetic nanoparticles. Materials Letters, 120, pp.259-262.

Wang, L.-L., B.-K. Tay, K.-Y. See, *et al.* 2009. Electromagnetic interference shielding effectiveness of carbon-based materials prepared by screen printing. Carbon, 47(8), pp.1905-1910.

Wang, Z. and G.-L. Zhao. 2013. Microwave Absorption Properties of Carbon Nanotubes-Epoxy Composites in a Frequency Range of 2-20 GHz. Open Journal of Composite Materials, 3, pp. 17.