Progress In Electromagnetics Research M, Vol. 43, 157–164, 2015

Improved Reflection Loss Performance of Dried Banana Leaves Pyramidal Microwave Absorbers by Coal for Application in Anechoic Chambers

Rajanroop Kaur[1, *], Gagan D. Aul[2], and Vikas Chawla[3]

Abstract—Agricultural waste is produced at agricultural premises as a result of an agricultural activity. Agriculture residue is made up of organic compounds from the living plants like rice straw, oil palm empty fruit bunch, sugarcane bagasse, coconut shell, banana leaves and others. This research has highlighted their eco-friendly nature and high microwave absorption properties, developing a new and improved form of pyramidal absorbers including high carbon content coal in it. Software simulation is done using CST Microwave studio. Samples are developed using a new technique by adding cobalt as an accelerator, and its performance is analyzed in terms of its reflection loss performance using free space measurement method in the frequency range of 8.2 to 12.4 GHz.

1. INTRODUCTION

This research gives a different definition to microwave absorbers as it is based on environmental and eco-friendly materials unlike commercial absorbers which use polyurethane and polystyrene plastic based materials that pose harm to the surroundings as well as human beings by releasing toxic gases when operating under high temperatures [1]. Basic material used is dried banana leaves which comes under the category of agricultural wastes and have a great potential of being used as a good microwave absorber. They are the most essential elements of an anechoic chamber to reduce signal interference. In order to increase the absorption properties of the basic material, finely powdered coal is added due to its high porosity and carbon content. A comparison is shown between banana leaves and banana plus coal as microwave absorbers enhancing the absorption capacity of basic material. The results for these unique types of absorbers are even better than the commercial absorbers.

Abandoned agricultural wastes pose a risk to the environmental and public health. While effectively absorbing microwave signals, polyurethane material particulates over time adding contaminants to clean rooms and reducing absorber lifetime. An alternative to these absorbers is found using agricultural wastes like banana leaves, sugarcane bagasse, rice husk etc. for the same purpose. These absorbers are composed of renewable materials and eliminate the toxic gas release problem for polyurethane materials under high power test conditions. They are cost effective materials and can be used to make environment friendly microwave absorbers with desired results. India is the largest producer of the bananas in the world contributing to 28% of world's banana production. Around 20–30% of the by products including banana leaves get wasted every year [9]. This waste can be effectively utilized in development of microwave absorbing materials due to presence of high amounts of carbon content (43.5%) in it [2]. Macro pores in carbon help in absorption. Table 1 shows weight percentages of different elements in banana leaves.

Received 26 July 2015, Accepted 8 September 2015, Scheduled 8 September 2015
* Corresponding author: Rajanroop Kaur (rajanroop29@gmail.com).
[1] DAV University, Jalandhar, Punjab, India. [2] Electronics and Communication Engineering, DAV University, Jalandhar, Punjab, India. [3] Mechanical Engineering, FCET, Ferozepur, Punjab, India.

Table 1. Elemental analysis of banana leaves.

Elemental Analysis	**Weight Percentage (%)**
Carbon	43.5 ± 0.04
Hydrogen	6.28 ± 0.03
Nitrogen	1.31 ± 0.09
Sulphur	0.36 ± 0.05
Oxygen	41.3 ± 0.05

Table 2. Weight percentages of chemical compounds present in coal.

Chemicals compounds	**Weight Percentage (%)**
Ash	10
Oxygen	8
Hydrogen	5
Nitrogen	1.5
Sulphur	0.5
Carbon	75

Coal originates from vegetal matter and forms from the compression of peat over millions of years. The organic component of coal consists of chemical compounds from carbon, hydrogen, oxygen, sulphur, and nitrogen [10]. Due to 75% of carbon content in it, coal is used to enhance microwave properties of banana leaves. Table 2 shows weight percentages of chemical compounds present in it naturally.

Various parameters are required to define the properties of microwave absorbers. Dielectric constant is ratio of permittivity of a substance, ε to the permittivity of free space, ε_o. It shows the extent up to which a material concentrates electric flux and hence is related to storage of electrostatic energy. Tangent loss, $\tan\delta$ is frequency dependent and it determines the amount of energy being dissipated. The formula for tangent loss is given by the Equation (1):

$$\delta \tan = \varepsilon''/\varepsilon' \tag{1}$$

where ε'' is the complex permittivity of the material and ε' the real permittivity of the material.

Reflection loss is another parameter which is important to calculate the amount of signal absorbed by the microwave absorber. It is ratio of amount of reflected power from the absorber to the amount of incident power into the absorber. It is usually expressed as a negative number in dB. The formula for reflection loss is given by Equation (2):

$$R = 10 \log_{10} P_r/P_i \tag{2}$$

where P_r = reflected power density and P_i = incident power density.

Reflection loss is calculated by observing plot of S_{11} given by vector network analyzer.

2. MICROWAVE ABSORBER FABRICATION

Shape is an important and sensitive issue that affects the reflectivity performance of a good microwave absorber. Various shapes can be pyramidal, wedge, convoluted, oblique, honeycomb, truncated and flat absorbers. Mostly, pyramidal shaped absorbers are used in development of anechoic chambers because they have least amount of open surface area and hence provide maximum microwave absorption [3, 4]. The frequency range considered for the analysis of absorbers in this research work is 0 to 20 GHz. Because of equipment limitation, the frequency being used for testing of 3×3 array is 8.2 to 12.4 GHz. For obtaining comparison between 'banana leaves' and 'mixture of banana leaves & coal' as microwave absorbers through CST Microwave studio in the frequency range of 0 to 20 GHz, two small rectangular samples are prepared separately of the same size as WR90 waveguide, that can get fixed in it for testing of its dielectric properties. The material for array consists of mixture of the basic material, porous material and chemicals. Banana leaves are taken and dried for a week under direct sun. They are blended using a mixer to a fine powder. Coal is used as to enhance the absorption due to high carbon content and porosity [5, 6]. Figure 1 shows preparation of basic material.

Figure 1. Drying and blending of banana leaves.

The chemicals used are polyester resin as a binding agent, methyl ethyl ketone peroxide (MEKP) as a hardening agent and cobalt as an accelerator. Resin binds the material together, maintains the shape of the sample, imparts strength to it and protects it from degradation due to abrasion or environmental attack. As MEKP mixes with the resin, a chemical reaction occurs, creating heat which hardens the resin. The chemical formula for MEKP is $C_8H_{16}O_4$. Dilute solutions of MEKP are used as the catalyst which initiates the Cross linking of polyester resins. A liquid polymer, where the chains are freely flowing can be turned into a "solid" or "gel" by cross-linking the chains together. Cross links can be formed by chemical reactions that are initiated by heat, pressure, change in pH, or radiation. Cobalt acts as an accelerator/promoter that increases the reactivity by reducing the gel time of the process and hence speeding up the reaction [7]. Figure 2 shows steps for developing and testing microwave absorbers.

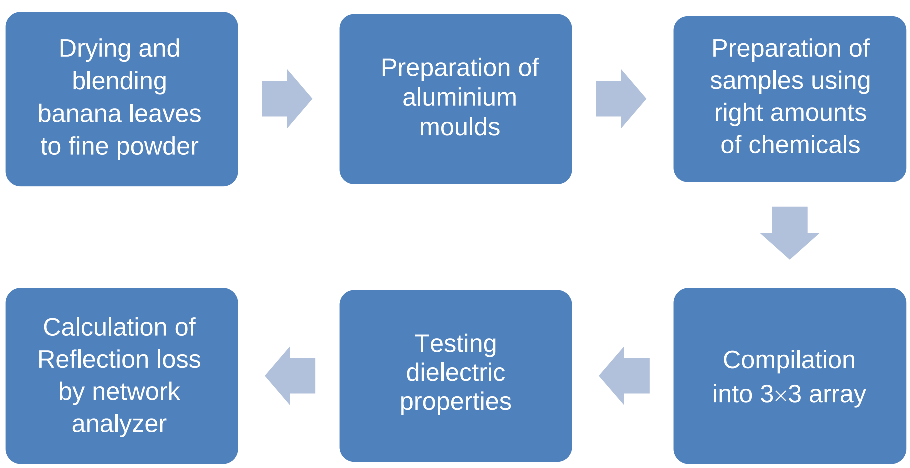

Figure 2. Steps for developing and testing microwave absorbers.

For sample of microwave absorbers, nine pieces of pyramidal shape of 13 cm height are made and compiled in 3×3 array, having base dimensions of $15\times15\,\text{cm}^2$ [8]. Pyramid is made by making aluminium moulds of required dimensions, adding proper amounts of banana leaf powder, coal and chemicals to it and preserving it for some time. Banana leaves and coal is added in 60:40 ratios. For a single pyramid, 26 g of powdered leaves are taken and mixed with 14 g of powdered coal thoroughly. 16 g of resin, 0.16 g of cobalt and 1.32 g of MEKP is added to strengthen and solidify it in pyramid form. Resin required to strengthen only banana leaves is comparatively a little less because coal being very porous requires

(a)

(b)

Figure 3. (a) Preparation of aluminium moulds. (b) Preparation of samples.

Figure 4. 3×3 pyramidal microwave absorber.

more resin for getting bound. Figure 3 shows preparation of aluminium moulds and samples [11, 12]. Figure 4 shows 3×3 array structure of dried banana leaves and coal.

3. MEASUREMENT TECHNIQUE

At microwave frequencies, various measurement techniques like free space measurement technique, resonant cavity technique, transmission line technique, dielectric probe technique are available. In this work, dielectric probe technique is used to measure dielectric constant and tangent loss of the material. It includes a 50 GHz Agilent network analyzer having Agilent Technologies 85071 measurement software to define the dielectric properties. The sample is loaded in WR 90 waveguide in the shape which exactly fits inside it. Two co-axial cables are required for the measurement. Figure 5(a) shows WR 90 waveguide and coaxial cables (b) shows rectangular sample of banana leaves for measurement.

The method works best for the sample loaded in the waveguide, although transverse electromagnetic guide such as co-axial line can also be used. Before Measurement, Calibration of VNA is required. It is done to eliminate the systematic (stable and repeatable) measurement errors caused by the imperfections of the system. The difference between the predicted and actual values is used to remove the repeatable errors from the measurement. For calibration, the empty WR 90 Waveguide is inserted between the two port co-axial cables of VNA and then the dielectric constant of air is made to real at value 1. After that a waveguide filled with the material is tested to check for its material properties. Dielectric constant and tangent loss value appears in network analyzer. Measurement is done in the frequency range of 8.2 to 12.4 GHz [13]. Table 3 shows dielectric constant and tangent loss for both the samples.

Figure 6 shows the values that network analyzer shows on the software. Reflection loss is the most important parameter which tells us about the amount of energy being reflected or absorbed by

(a) (b)

Figure 5. (a) WR 90 waveguide and coaxial cables. (b) Rectangular sample of banana leaves for measurement.

Table 3. Dielectric constant and tangent loss values for banana leaves and mixture of banana leaves & coal.

Sample	Dielectric Constant	Tangent loss
Banana leaves	1.99	0.0246
Mixture of banana leaves & coal	2.1098	0.0715

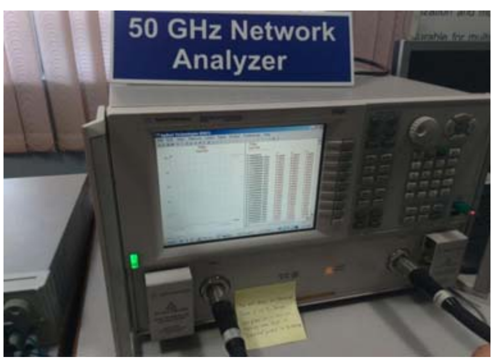

Figure 6. Dielectric properties measurement.

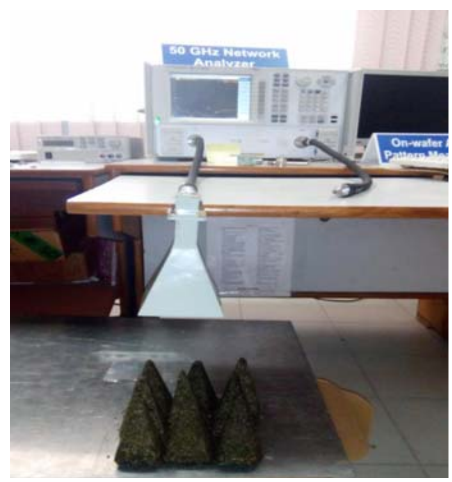

Figure 7. Set up for testing 3×3 array by RCS method [15].

the microwave absorber. It is calculated by a free space measurement technique, i.e., Radar Cross Section (RCS) method. The RCS is a measure of power scattered in a direction being considered when a target is illuminated by an electromagnetic plane wave. VNA measures S parameters in the frequency domain. The frequency range for which the complete 3×3 array is tested is from 8.2 to 12.4 GHz. A horn antenna and a co-axial cable is used for the testing process which are further attached to VNA. It is calibrated first using a conducting aluminium sheet to remove the repeatable errors and obtain maximum reflection. A complete set up is made which includes placing the array on an aluminium sheet directly under the horn antennas at 90 degrees so that maximum reflections from the array can be observed and a transparent picture of the potential of the material to absorb the energy can be seen clearly. A graph between S_{11} and frequency is displayed on the VNA. Figure 7 shows set up for testing 3×3 array by RCS method.

4. RESULTS

Result from the RCS measurement shows a good reflection loss performance as it gives an average value better than −10 dB. VNA gives a plot for S_{11} against frequency which gives the reflection loss. Figure 8 shows the reflection loss performance for 3×3 array in the frequency range of 8.2 to 12.4 GHz as shown by VNA.

It gives an average reflection loss value of −38.4 dB with highest reflection loss of −49 dB at 12 GHz. The absorber gives better results above 10 GHz with −45 dB as an average reflection loss value. Although fluctuations are found in the reflection loss values, it can be considered to give higher value when the frequency is increased. Due to limitation of equipments the testing is done in the smaller frequency range, whereas to get results for the range of 0 to 20 GHz, simulation is performed on CST Microwave studio [14]. The value of dielectric constant and tangent loss from VNA are given to the software and simulation is performed in the frequency range of 0 to 20 GHz keeping aluminium sheet as back plate for

Figure 8. Reflection loss performance of 3×3 array by Network Analyzer.

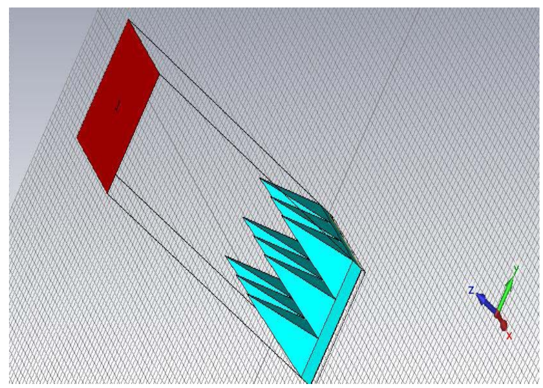

Figure 9. Simulation of array in CST Microwave Studio.

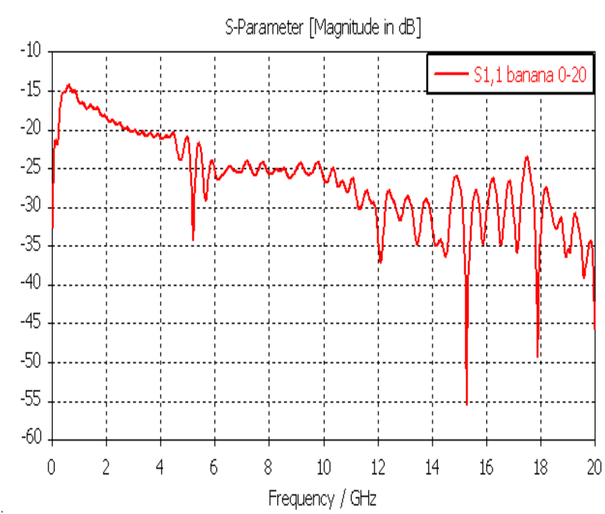

Figure 10. Reflection loss performance of banana leaves from 0 to 20 GHz.

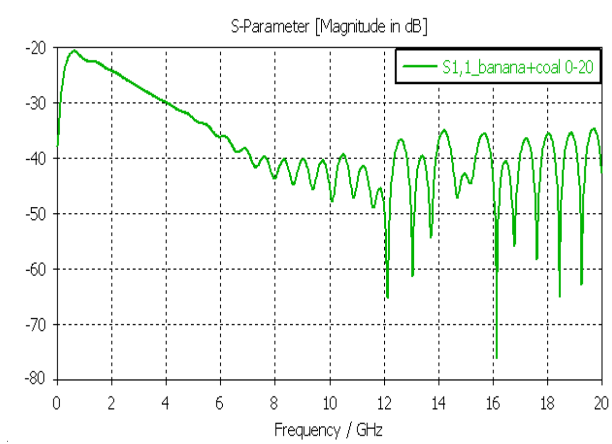

Figure 11. Reflection loss performance for mixture of banana leaves & coal from 0 to 20 GHz.

3×3 array. Simulation is done for both the samples of basic material and adding coal for comparison. Reflection loss values for both the samples are measured at ten frequencies at the interval of two for calculating average reflection loss. Figure 9 shows the simulation of array on CST Microwave Studio.

The reflection loss performance of pyramidal microwave absorber for ‘banana leaves’ and ‘mixture of banana leaves & coal’ is obtained through simulation in wide range of frequencies. Figure 10 shows reflection loss performance for banana leaves from 0 to 20 GHz.

Values of reflection loss are considered at various frequencies. Table 4 shows different values from 0 to 20 GHz. The average reflection loss for banana leaves is −32.7 dB. The maximum reflection loss obtained in the plot is −55 dB at 15 GHz. Similarly a S_{11} plot is obtained for mixture of banana leaves & coal as shown in Figure 11. Table 5 shows values of its reflection loss at different frequencies.

Table 4. Reflection loss values for banana leaves from 0 to 20 GHz.

S. No	Frequency (GHz)	Reflection loss (dB)
1.	2	−20
2.	4	−22
3.	6	−27
4.	8	−26
5.	10	−28
6.	12	−38
7.	14	−36
8.	16	−35
9.	18	−50
10.	20	−45

Table 5. Reflection loss values for banana leaves and coal from 0 to 20 GHz.

S. No	Frequency (GHz)	Reflection loss (dB)
1.	2	−28
2.	4	−30
3.	6	−38
4.	8	−42
5.	10	−48
6.	12	−63
7.	14	−44
8.	16	−76
9.	18	−40
10.	20	−43

The average value of reflection loss given by pyramidal microwave absorber is −45.2 dB. The highest value of reflection loss obtained in this plot is −76 dB at 16 GHz. There is a window seen in the graph from 12 to 20 GHz where they perform the best giving an average reflection loss of −63.33 dB. The results from 0 to 20 GHz show that mixture of banana leaves & coal is better than banana leaves by −12.5 dB which makes a big difference. Also, it is seen that by adding coal, response of banana leaves have become better by approximately −10 dB in the frequency range of 2 to 12 GHz.

5. CONCLUSION

A new proposed product has been successfully developed and produced into a low cost and environment friendly microwave absorber. Agricultural wastes are utilized very efficiently and effectively for development of pyramidal absorbers with least amount of chemicals added in it. By effective utilization of a high carbon content material 'coal', the performance of banana leaves has been greatly enhanced in the low frequency ranges of 2 to 12 GHz in addition to high frequency ranges making it a better and improved microwave absorber. The average reflection loss for pyramidal microwave absorber of mixture of banana leaves & coal 0 to 20 GHz is -45.2 dB which is almost comparable to commercial absorbers, also keeping the surroundings clean and pollution free. For future works, further new best filler materials with high carbon content can be added to the basic material for enhancement of microwave absorption.

REFERENCES

1. Smythe, B., S. Casserly, and D. Arakaki, "Organic-based microwave frequency absorbers using corn stover," *USA Antennas and Propagation Society, International Syposium Proceedings*, 920–921, 2011.
2. Fernandes, E. R. K., C. Marangoni, S. H. W. Medeiros, O. Souza, and N. Sellin, "Slow pyrolysis of banana culture waste: Leaves and pseudostem," *3rd International Conference on Industrial and Hazardous Waste Management*, 2012.
3. Mezan, M. S., M. F. B. A. Malek, M. S. Jusoh, F. S. Abdullah, and N. A. M. Affendi, "Reflection loss performance and performance assessment of pyramidal microwave absorber using agriculture waste," *PIERS Proceedings*, 142–145, Guangzhou, China, August 25–28, 2014.
4. Malek, F., P. J. Soh, A. A. H. Azremi, and H. Nornikman, "Reflection loss performance of hexagonal base pyramid microwave absorber using agricultural waste material," *Loughborough Antennas & Propagation Conference*, 2010.
5. Malek, M. F. B. A., E. M. Cheng, O. Nadiah, H. Nornikman, M. Ahmed, M. Z. A. Abdul Aziz, A. R. Osman, P. J. Soh, A. A. A.-H. Azremi, A. Hasnain, and M. N. Taib, "Rubber tire dust-rice husk pyramidal microwave absorber," *Progress In Electromagnetics Research*, Vol. 117, 449–477, 2011.
6. Hasnain, A., M. I. Imran, Z. S. Rohaiza, S. Roslan, A. A. Takiyuddin, A. Rusnani, and A. A. Azremiasia, "Preliminary development of mini anechoic chamber," *Pacific Conference on Applies Electromagnetic Proceedings*, 2007.
7. Raja, R., P. Kuppusamy, and S. Neogi, "Influence of curing agents on gelation and exotherm behaviour of anunsaturated polyester resin," *Indian Academy of Sciences*, 1217–1224, 2013.
8. Nornikman, H., P. J. Soh, and A. A. H. Azremi, "Performance of different polygonal microwave absorber designs using novel material," *The 2009 International Symposium on Antennas and Propagation (ISAP)*, Bangkok, Thailand, October 20–23, 2009.
9. http://www.fao.org/fsnforum/cfshlpe/sites/cfshlpe/files/files/Food_losses_waste/India%20banana-%20case_final.pdf, at 1:00 pm dated 25-05-2015.
10. http://f03.classes.colgate.edu/fsem037-coal/Coal/Default/composition_of_coal.htm,at 11:00 am dated 28-05-2015.
11. http://www.netcomposites.com/guide/polyester-resins/8, at 4:00 pm dated 28-05-2015.
12. http://www.chemicalland21.com/industrialchem/organic/COBALT%20OCTOATE.htm, at 10:00 am dated 29-05-2015.
13. Agilent Basics of Measuring the Dielectric Properties of Materials, http://www3.imperial.ac.uk-/pls/portallive/docs/1/11949698.PDF, at 9:00 pm dated 01-06-2015.
14. https://www.cst.com/Products/CSTmws/ResonantSolver, at 11:00 am dated 01-06-2015.
15. Set up for testing 3×3 array by RCS method at CARE Department, I.I.T Delhi, Hauz Khas, New Delhi.