Jurnal Teknologi

Full Paper

INITIAL STUDY ON MICROWAVE TECHNIQUE TO FIND THE RELATIONSHIP BETWEEN ATTENUATION OF MICROWAVE AND THICKNESS OF A SUBJECT

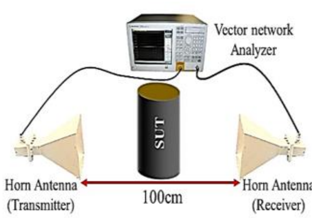
Article history
Received
28 June 2015
Received in revised form
1 September 2015
Accepted
15 October 2015

Thomas Tan Wan Kiat[a], Mohd Hafiz Fazalul Rahiman[a*], Soh Ping Jack[b], Ruzairi Abdul Rahim[c]

[a]Tomography Imaging and Instrumentation Research Group, School of Mechatronic Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia
[b]Advanced Communication Engineering (ACE) CoE, School of Computer and Communication Engineering, Universiti Malaysia Perlis, Pauh Putra Campus, 02600 Arau, Perlis, Malaysia
[c]Process Tomography and Instrumentation Research Group, Faculty of Electrical Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia

*Corresponding author
hafiz@unimap.edu.my

Graphical abstract



Abstract

This paper presents the initial study of microwave tomography in agriculture to investigate the effect of microwave signal on the thickness of a medium. In this project, a pair of antennas is used non-invasively where one of it acts as a transmitter and the other one as a receiver. The investigation was based on the transmission and reception of antennas in a transversal direction while several samples of mediums with different thickness are put between those antennas. The result obtained throughout this initial study had shown that the attenuation of microwave will vary with the diameter of the medium. The information and analysis of the preliminary results can be used as a reference for further investigation on the selected medium.

Keywords: Microwave tomography, non-destructive testing, diameter, attenuation

1.0 INTRODUCTION

Microwave is a region in the electromagnetic (EM) wave spectrum in the frequency range from 0.3GHz to 300GHz [1]. The EM wave consists of electric field and magnetic field. At microwave frequencies the line parameters are scattered along the whole length of the line in the z-direction but energy is lost due to radiation. Since the common characteristics of the EM wave propagation in all these lines are identical, the fundamental transmission line theory involving voltage standing waves, reflection and impedance [2]. A microwave system is usually based on transmission and reflection concepts. Meanwhile, a system based on microwave tomography is actually evaluating the total of the incident and the scattered field. Therefore, in microwave tomography, transmission concept is more practical, but with a condition that more than one antenna is used to measure the sum of the incident and the scattered field [3].

When the EM field reaches a medium, a forward and reflected wave from the surface of the medium and absorption of microwave signal will take place as the times goes on. In this paper, an experiment had been done to determine how the thickness of the medium can affect the attenuation of microwave. The results of the experiment obtained through the proposed system are reported. Since there is an interest to apply microwave tomography in agriculture product especially in valuable wood, the sample under test (SUT) for this experiment are water, wood shaves and air. It is relevant because the surrounding is humid.

2.0 THEORY

Microwave reading can be measured through insertion loss and return loss. Figure 1 illustrates the concept of insertion loss (IL) and return loss (RL). Both of them are all in dB terminology as shown in (1) and (2).

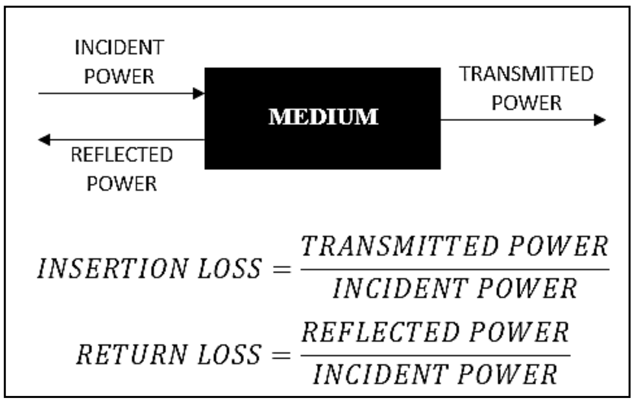


Figure 1 Insertion loss and return loss [2]

$$IL(dB) = 10log\frac{P_o}{P_i} \quad (1)$$

$$RL(dB) = 10log\frac{P_r}{P_i} \quad (2)$$

Microwave power is sent down by a transmitting antenna from the left and it reaches the medium. The power is the incident power. When it reaches the medium, a portion is reflected back down to the transmission line where it came from and never enters the medium. The power that is not reflected gets into the medium. There some of it gets absorbed and the remainder passes through the medium into a receiving antenna. The power that actually comes out of the component is called the transmitted power.

The transmitted power will be less than the incident power due to three reasons. The first reason is some of the power got reflected back to the source and never got into the medium which is the reflection losses. Reflection losses can by denoted by [4]

$$Reflection\ losses = 20log\left|\frac{Z-1}{Z+1}\right| \quad (3)$$

where Z is the normalized impedance which can be defined by:

$$Z = \frac{Z_{in}}{Z_{out}} = \sqrt{\frac{\mu}{\varepsilon}}tanh\left(j\frac{2\pi d}{\lambda_o}\sqrt{\mu\varepsilon}\right) \quad (4)$$

where Z_{in} is the input impedance, Z_{out} is the impedance of free space, μ is the relative complex permittivity, $\boldsymbol{\varepsilon}$ is the permeability, d is the thickness of the medium and λ_o is the wavelength of the incident wave in free space. Thus, there are six parameters that can affect the reflection losses which are $\varepsilon', \varepsilon'', \mu', \mu'', f$ and d. This can be explained from the point that microwave tomography is based on the relationship between attenuation of microwaves and the medium of propagation is absolutely determined by the relative permittivity of the medium [1]. However, the dielectric properties is affected by the capability of material attracting and holding water molecules in the air, frequency, density, temperature, the composition and structure of material, the bulk density of the air-particle mixture and chemical composition [1]. The second reason is some of the power that entered the component was absorbed inside the medium which is the dielectric losses. Last but not least results from absorption by atmospheric molecules or scattering by aerosols in the atmosphere [5].

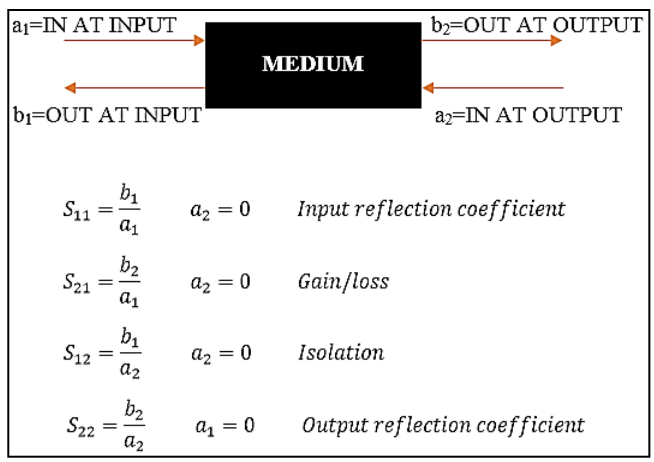


Figure 2 S-parameters [1]

RL and IL can be identified in S-parameters. The S-parameters are defined in Figure 2. It shows that microwave signal penetrating and leaving a medium in both directions. As stated before, when a microwave signal is incident on the input side of the medium, some portion will reflected and some is penetrated into the medium. The reflection coefficient is denoted by the ratio of the reflected electric field to the incident electric field where as the transmission coefficient can be defined by the ratio of the transmitted electric field to the incident electric field.

S_{11} is the electric field reflected at the input divided by the electric field inserting the input with the situation that no signal enters into the output. Their ratio is a reflection coefficient as b_1 and a_1 are the electric fields. Meanwhile, when no signal enters into the output, S_{21} is the electric field leaving the output divided by the electric field entering the input. Therefore, S_{21} is a transmission coefficient. It is related to the insertion loss or the gain of the medium whereas S_{12} is a transmission coefficient related to the isolation of the medium. It specifies the amount of the power leaks back through the medium in incorrect direction. S_{22} is similar to S_{11} but looks in the other way into the medium.

When measuring a medium at far field, the signal needs to pass through the free space before entering the medium. The free space attenuation (FSA) is known by the loss factor term of the Friis transmission equation [6], which can be denoted by:

$$FSA = \left(\frac{\lambda}{4\pi R}\right)^2 \quad (5)$$

where λ is the free space wavelength, and R is the distance between the source antenna and the desire point. Besides this quantity also depends on the frequency since frequency related to wavelength where:

$$f \propto \frac{1}{\lambda} \quad (6)$$

3.0 EXPERIMENTAL SETUP

The measurement setup used for this study consists an Agilent/HP E5062A 3GHz ENA-L VNA Network Analyzer and two horn antennas as shown in Figure 3. Figure 4 shows the used VNA, Figure 5 shows the dimension of the horn antenna and Figure 6 shows the specification for the horn antennas. The SUT is filled into different diameter of polyvinyl chloride (PVC) pipe. The selected SUT and the different diameter of PVC pipe are shown in Table 1.

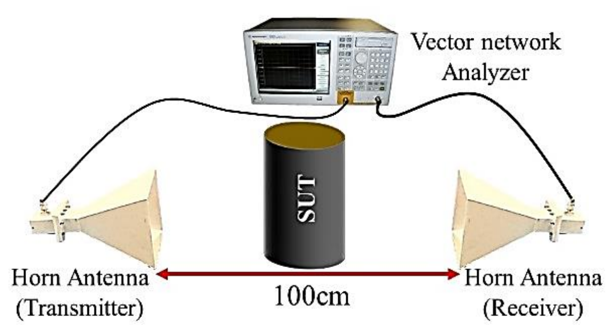


Figure 3 Experimental setup

VNA Specification	
Frequency Range	300 kHz to 3 GHz
Max. Output Power	10dBm

Figure 4 Specification of VNA

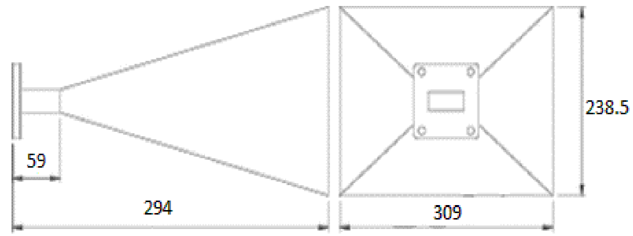
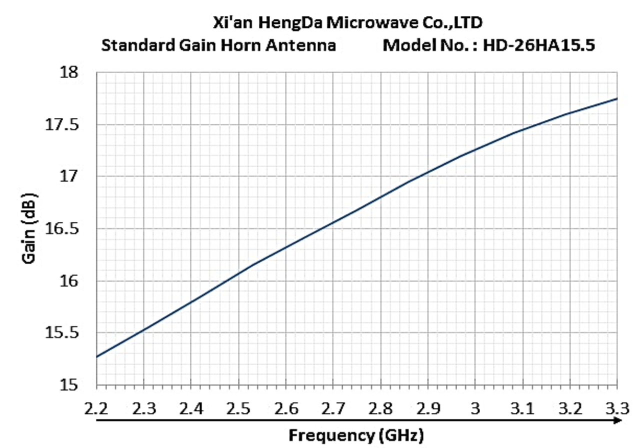


Figure 5 Dimension of the horn antenna



f(GHZ)	G(dB)
2.20	15.27
2.31	15.55
2.42	15.85
2.53	16.15
2.64	16.42
2.75	16.68

N0. 50322

f(GHZ)	G(dB)
2.86	16.95
2.97	17.20
3.08	17.42
3.19	17.60
3.30	17.75

Figure 6 Specification of horn antenna

Table 1 Experiment's parameter

Parameter			
f	2.2GHz		
DTA	100cm		
SUT	Air	Wood Shaves	Water
d (inches)		d1 – 0.75" d2 – 1.25" d3 – 2.00" d4 – 3.00" d5 – 4.00"	d1 – 0.75" d3 – 1.25" d2 – 2.00" d4 – 3.00"

The constant variables in this experiment are the frequency (f), the distance between the transmitting and receiving antenna (DTA), the location where the SUT is put which is the midpoint of the distance between both antennas and the environment which the experiment is conducted. The manipulated variables are the size of the PVC pipe (d) and the SUT. Table 1 shows parameters that had been used in this experiment in detail. The responding variable in this experiment is the attenuation of microwave.

Thus, the experiment started by measuring S_{21} in the free space as a calibration before measuring the

S_{21} for air, wood shaves and water in different diameter of PVC pipe for every test. 21 times measurement has been made for each SUT. The value shows on VNA for S_{21} is in dB terminology is due to two measurement ports operate at the identical reference impedance, the insertion loss (IL) is defined as [7, 8]:

$$IL(dB) = -20log_{10}|S_{21}| \tag{7}$$

After obtaining the calibrated value and the measured value, the attenuation of microwave in this experiment is denoted by:

$$Attenuation\ of\ microwave = \frac{1}{n}\sum_{i=1}^{n}(A_{cal} - A_{mea}) \tag{8}$$

where n is the number of test, A_{cal} is the value of S_{21} measured in air and A_{mea} is the value of S_{21} measured when SUT with different diameter is allocated between the transmitting and receiving antenna.

4.0 RESULT AND DISCUSSION

The antenna transmits 2.2GHz towards to the SUT which are air, wood shaves and water to obtain reference graphs for investigating the relationship between the attenuation of microwave and the diameter of SUT. The attenuation of microwave increases with the increasing of the diameter of the pipe with air, wood shaves and water and this can be illustrated by Figures 7, 8 and 9 respectively. From the figures, the gradient of the graph for PVC pipe with water is higher than PVC pipe with air and wood shaves. Besides, for each diameter of PVC pipe, the attenuation of microwave in PVC pipe filled with water has the highest value.

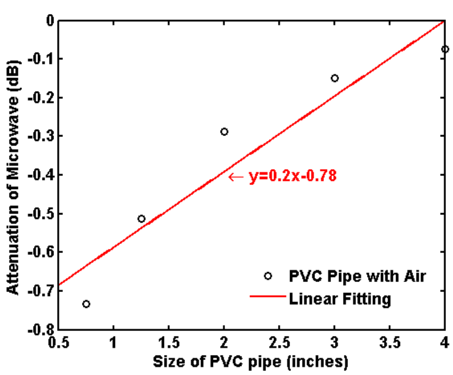


Figure 7 Graph of attenuation of microwave against size of PVC pipe with air

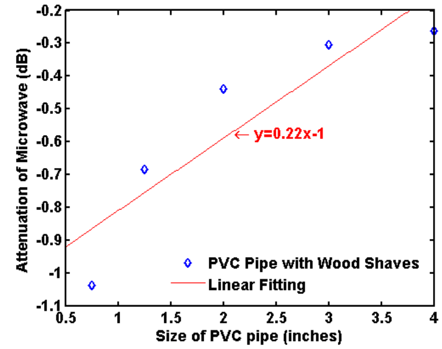


Figure 8 Graph of attenuation of microwave against size of PVC pipe with wood shaves

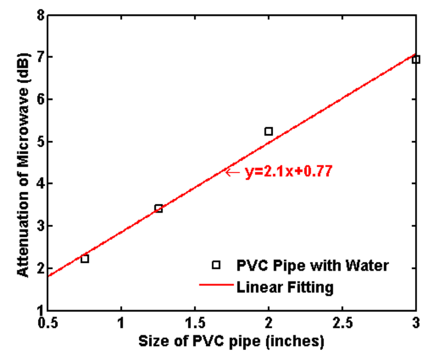


Figure 8 Graph of attenuation of microwave against size of PVC pipe with water

5.0 CONCLUSION

In conclusion, there is a relationship between the size of SUT and the attenuation of microwave. There are two factor can be look into which are the dielectric constant and the penetration depth. Different dielectric constant will give different attenuation of microwave at each size of the SUT. Besides, another factor which causes different attenuation of microwave as the size increases is the penetration depth. The penetration depth also known as 'skin depth'. It is defined as the distance that a wave must propagate to reduce its amplitude to the factor of 1/e=36.8%. The penetration depth is the reciprocal of the attenuation constant [9]. Since there is an attenuation of microwave signal in different medium, it is possible to apply in microwave tomography to find out the attenuation of microwave in a scattering field. Future work will involve evaluating the wave of microwave through simulation and to observe the result with phantom and without phantom.

Acknowledgement

Authors are grateful for the funding from the Ministry of Education (MOE) under RACE Grant 2013 (9017-00016), RACE Matching Grant (Q.J130000.3013.00M17), UTM GUP Grant (03H96) and

MyMaster via MyBrain15 program under 10th Malaysia Plan for the financial support.

References

[1] M. H. Fazalul Rahiman, W. K. Thomas Tan, P. J. Soh and R.A. Rahim. 2015. *Jurnal Teknologi Microwave Tomography Application and Approaches-A Review.* 3: 133-138.

[2] A.W. Scott. 2005. *Understanding of Microwave.* Hoboken, NJ: John Wiley & Sons, Inc. 53-68.

[3] R. D. Monleone, M. Pastorino, S. Poretti, A. Randazzo, A. Massimini, and A. Salvade. 2012. Nondestructive Evaluations by Using a Prototype of a Microwave Tomography.

[4] J. Guo, Y. Duan, L. Liu, L. Chen, and S. Liu. 2011. Electromagnetic and Microwave Absorption Properties of Carbonyl-Iron/$Fe_{91}Si_9$ Composites in Gigahertz Range. *J. Electromagn. Anal. Appl.* 03(05): 140-146.

[5] Japan Association of Remote Sensing. 1996. Remote Sensing Note. Available: http://wtlab.iis.u-tokyo.ac.jp/~wataru/lecture/rsgis/rsnote/cp3/cp3-2.htm.

[6] C. A. Balanis. 2005. *Antenna Theory: Analysis and Design.* 3rd Edition. Hoboken, NJ: Wiley-Interscience.,

[7] Pozar, David M. 2012. *Microwave Engineering.* Fourth Edition. United Stated: John Wiley & Sons, Inc.

[8] Collin, Robert E. 2001. *Foundations for Microwave Engineering.* Second Edition. New York: John Wiley & Sons, Inc.

[9] C. A. Balanis. 1989. *Advanced Engineering Electromagnetics.* New York: John Wiley & Sons, Inc.