The Measurement of Dielectric Properties of Leucaena Leucocephala Biocomposite Antenna Substrate in Water Immersion Condition

A.A.Azlan [1], M.T.Ali[1], and M.F Jamlos [2]

***Abstract*— This paper contributes the dielectric properties measurements on five mixture of biocomposite antenna substrates in water immersion condition. The fabrications process of the biocomposite antenna substrate uses the compounding flat press method between the Polypropylene acting as laminator and stem three of Leucaena Leucocephala as a filler. The dielectric properties measurements conducted by using the KEYSIGHT 85070E coaxial probe method, with the observe frequency range of 1 GHz to 20 GHz and ASTM D570 procedure for water immersion process. The percentages of the water absorption rate reported 0.026 % (PP100), 0.18 % (PB9010), 0.22 % (PB8020), 0.28% (PB7030) and 0.35 (PB6040), while the changes of the dielectric properties reported increase 10.31 % (PP100), 11.16 % (PB9010), 15.48 % (PB8020), 23.60 % (PB7030) and 36.35 % (PB6040) when compared with the dielectric properties measurements before 24 Hours ASTM D570 water immersion procedure. The changes of the water absorption rate and dielectric properties percentages in line with the increments of filler composition mixture. The data from this measurement useful to observe the aging shielding capability of the material against water and moisture content absorption for antenna substrate material.**

***Index Terms*— Biocomposite substrate, Water Immersion, coaxial probe method, Flat pressed method**

I. INTRODUCTION

In this research, the observation of water content affected the Dk changes conducted. As elaborated by V. Komarov et al. [1], the moisture content (MC) inside MUT influence the Dk changes. By inspiring from this research paper B. K. Diefenderfer [2], the conduction of the measurement of the MC affected the substrate. The main experiment objective is to observe the guarding behavior of the substrate from the water content of the proposed substrate by observing the changes of the Dk using the coaxial probe method for twenty-four (24) hour period as stated in ASTM D570 [3]. The measurement of the dielectric constant (Dk) and loss tangent (Tan δ) are conducted by using a dielectric probe from KEYSIGHT 85070E Dielectric probe kit with the software of 85070 to be installed with PNA-L N5232A 300KHz to 20 GHz Vector network analyzer (VNA). The probe test is indicated as one of the most popular and easy to use the method to obtained the dielectric properties [4]–[6], with the testing method considered as a non-destructive test that unaffected the measuring substrate with the capability of the probe method measurement is up to 20 GHz [7].As stated in [8], the previous researchers discovered that the water absorption rate for wood plastic composite (WPC) that used (oil palm decanter cake) with polypropylene (PP) alias between the average of 0.16 to 0.44 (different composition). In that previous research also, the conclusion discovered that the water absorption rate proportionates with composition increments. The five different compositions antenna substrate used PP (PD943, Lotte Chemical Tian (M) Sdn. Bhd) as a material to laminate the Leucaena Leucocephala (L.Leucocephala) filler. The lamination process adapted to minimize the water absorption rate and enhanced the stiffness of the proposed antenna substrate [9]. Next, the research continues with the fabrication of five composition substrates as indicated in Table I with the thickness fixed to 1.6 mm and the filler size of 150µm inspired on the previous fabrication process [10]. The fabrications method used a flat pressed method that contained hot pressed and cold pressed method with the mold size of 150 x 150 x 1.6mm. The mold can be at any size but at this moment the dimension fixed at this dimension due to the capability of the flat pressed machine dimension 280 x 280 mm. The test significantly contributes to the determination of the worst case of moisture absorption to the proposed substrate since as previously proven [11], that water content is one of the most parameters that degrades the performance of the antenna substrate.

TABLE I
COMPOSITIONS MIXTURE FOR FIVE PROPOSED SUBSTRATE

Samples	Composition	
	PP (%)	L.Leucochephala filler (%)
PP100	100	0
PB9010	90	10
PB8020	80	20
PB7030	70	30
PB6040	60	40

This paper was submitted for review on 24th November 2016. Accepted on 30th December 2016.

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II. SUBSTRATES FABRICATION

As per mention in ASTM D570 for the purpose of testing [12], three specimens needed for each composition, but since this water immersion test classified as a destructive test, the specimen prepared in five substrates on each composition with the total substrates fabricated 25 substrates. The process of the standard operating procedure (SOP) for the substrate fabrications process distributed by Fig. 1.

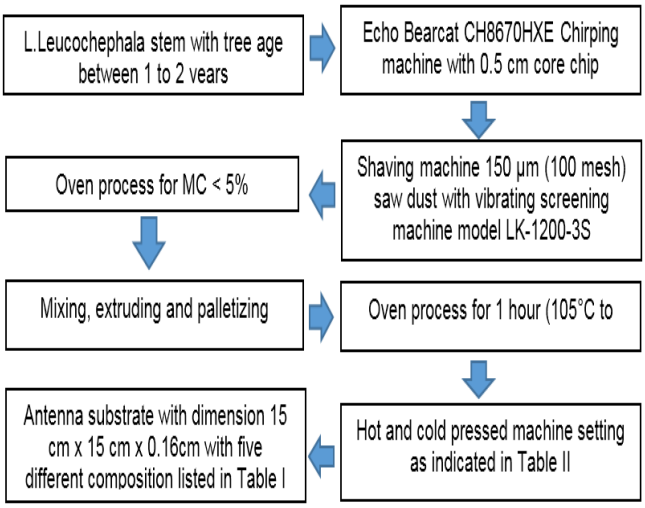

Fig. 1. Biocomposite substrates fabrications process

The reorganization of the tree age is based on the ring develop inside the wood stem and the second method is the diameter of the stem itself. The visibility of the ring reveal the age of the tree; one black line visible ring indicated that tree is one year as elaborated by E. Jayamani et al. in their research paper [13]. The expected diameter of the tree is between 48 to 58 mm which is considered as sufficient age. The measurement of the diameter and the visibility of the ring develop inside the stem tree are indicated in Fig. 2 The tree grows in the location situated in Taiping Perak Malaysia with the grid coordinate 4°47'01.4'' North and 100°45'54.4'' East. The age of the tree is controlled for one year with the diameter between 48 to 58 mm

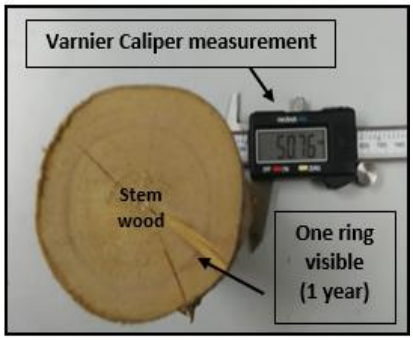

Fig. 2. Estimating Tree Age

After the selection of the three according to the age and diameter, the stem of the three then going for chirping process by Echo Bearcat CH8670HXE machine to produce the 0.5 cm core chip and shaving machine to produce the filler of 150µm (100 mesh) sawdust by using the vibrating screening machine model LK-1200-3S. The selection of the 150µm filler size inspired by the previous research conducted by A.A Azlan et al. [10]. In order to minimize the moisture content (MC) developed inside the wood filler the Oven process with 5% MC controlled introduce before preparing the palletizing process by using 2.6cm maxi compounder twin screw machine. Then, before fabricating the biocomposite substrate by using the flat pressed method the pallet then applied the ASTM D570 to discard the remaining MC developed inside the pellet. The calculation for the mixture for the biocomposite substrate is indicated in equation 1 and equation 2 [14]. The target of the calculation is to find the mass in gram (g) desired for both saw dust wood filler and PP according to the compositions mixture, whereby the density of the PP is fixed to 0.9 g/cm-3.

$$Density\ (gcm^{-3}) = (Mass/Volume) \quad (1)$$

$$Mass(g) = (density \times Volume) \quad (2)$$

The dimension of the mold (mild steel) is fixed at 170mm x 170 mm x 1.6 mm which allow of the actual dimension of the substrate 150 mm x 150 mm x 1.6mm to expand while heating process conducted. The selection of mild steel is due to cost effective and local availability compared to aluminum. The overall dimension of the mold is given in Fig. 3, whereas the palette placements situated at the center of the mold.

TABLE II
FLAT PRESS MACHINE SETTING

Hot Press Setting	Cold Press Setting
Temperature: TABLE III Pressure: 1000 psi (6.9 Mpa) Duration: 300 seconds	Temperature : 20°C (RT) Pressure: 500 psi (3.45 Mpa) Duration: 150 seconds
Venting: 2 seconds	**Venting: 2 Seconds**
Oven process 110^{0}C (1 Hours) for discard moisture after final substrate fabricated (size substrate 150 x150 x 1.6 mm) (ASTMD570)	

As indicated in Table II the setting divided into two processes that consist of hot (melting process) and cold pressed (preservation). The temperature conduction on each material differently distributed by using a small amount of material sample by using differential scanning calorimetric (DSC). The testing to get the actual melting point of the proposed material tabulated in Table III below. The cold press is setting conduction handled in the room temperature (RT) surrounding for preservation process.

TABLE III
TEMPERATURE SETTING FOR EACH SUBSTRATE

Substrate	Temperature (°C)
PP100	170.36
PB9010	171.22
PB8020	171.82
PB7030	171.95
PB6040	172.71

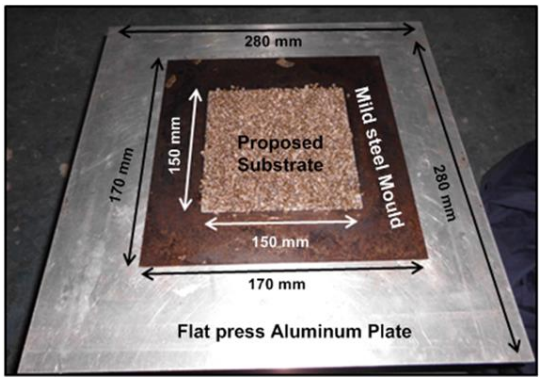

Fig. 3. Mild Steel Biocomposite molding dimension

The dimension of the mold and the placement of the palette before going for flat pressed process indicated in fig. 3. The final product of the proposed substrates given by Fig. 4 with five variation composition of the biocomposite antenna substrate. For the purpose of the water immersion testing, each substrate undergoes for five substrates for each composition with the distribution of 25 substrates for this water immersion dielectric properties measurement

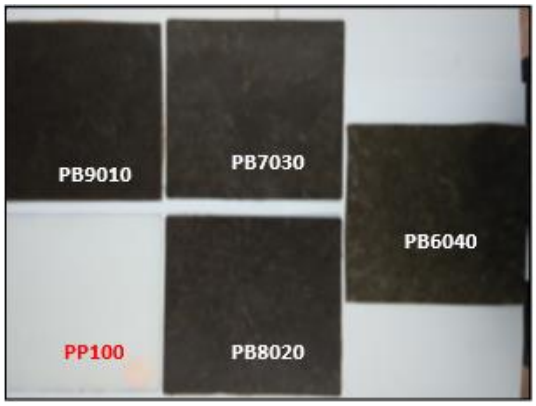

Fig. 4. Five variations composition of fabricated antenna substrate

III. DIELECTRIC PROBE MEASUREMENT

The testing process starts by doing the open, short and 25 ccs sterile water calibration procedure. The setting of the dielectric probe measurement system distributed in Fig. 5 and Fig.6 with the Keysight Dielectric Probe model 85070E connected to the performance network analyzer (PNA-L) model N5232A up to 20GHz via high-temperature coaxial cable. The substrate under test (SUT) placed in the middle between proposed JIG to hold the SUT with consist of nine-hole of the measurement point. This nine hole purposely dedicated to providing an equally reading point on all the substrate surface. This method also provides substrate control procedure acceptance procedure. The substrate with the standard deviation (SD) of more than 5 percent [15] will be rejected and the new substrate batch fabrication must be conducted. The SUT placed in the middle of the proposed JIG as indicated in Fig. 7, whereby the placement will provide a better mechanically holding mechanism so that more reliability data obtained.

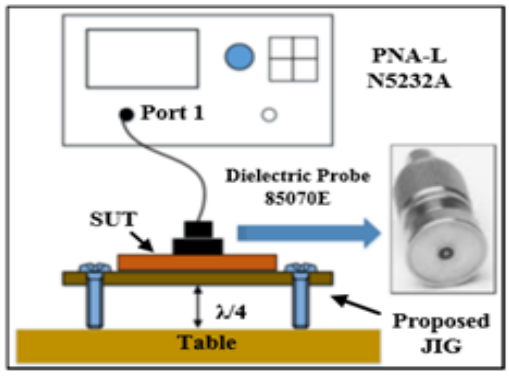

Fig 5. Arrangements of dielectric probe measurements

Since the method of dielectric properties used reflection method, it must be placed in a flat condition to avoid the graph plotting of the dielectric properties creates multiple reflections. The dimension of the proposed substrate distributed by Fig. 5 with the placement of the nylon screw must not less than λ/4 of the measurement frequency, or multiple reflections will occur.

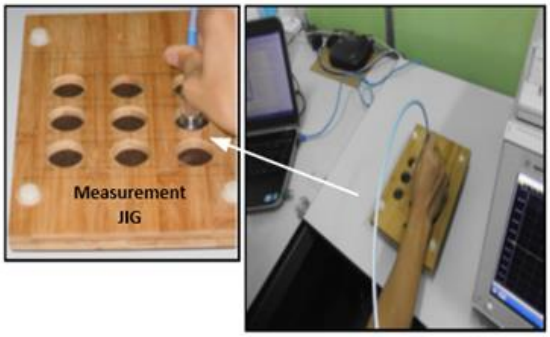

Fig. 6. Dielectric probe In-Situ measurement

The fabrication of the measurements tool (JIG) developed by using plane plywood material with the diameter of the measurement hole fixed to 15mm. The dimension of the JIG is fixed to 260mm x 180 mm x 30mm which SUT situated in the middle of the JIG. In order to hold and clamp the substrate under test (SUT) the nylon bolt and nut size 8cm x 0.5cm (diameter). The SUT placed in the middle between upper and lower JIG plates with the gap of 1.6mm, tighten with the nylon screws.

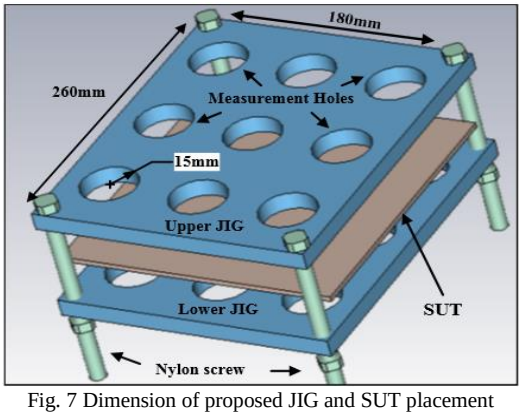

Fig. 7 Dimension of proposed JIG and SUT placement

The dielectric measurement software 85070 occupied only one port for the measurement. The measurement of dielectric properties is a combination of signal storage and loss created inside the material to perform Dk measurement. In antenna measurement most of the antenna designer using Dk value, as their main design parameter [16]. The output from PNA-L N5234A VNA will give two main parameters; that is signal storage (Dkr') and material loss (Dkr''). The permittivity value distributed by a complex number that contains real part (Dkr') represent dielectric constant value (Dkr) and imaginary part (Dkr''). So to convert the imaginary part to loss tangent (Tan δ) value the indicated in equation 3 and equation 4 [17].

$$Dk = Dk_r' - j\, Dk_r'' \quad (3)$$

$$\text{Tan } \delta = (Dkr''/ Dkr') \quad (4)$$

Inside the software, the calculation of both parameters of Dk and Tan δ can be accessed in the same graph whereby the measurement will indicate the both parameter together or part by part with the graph.

A. Water immersion process

The next measurement, which followed the ASTM D570 procedure on preparing the substrate for water aging immersion procedure, will focus on the observation of the substrate dielectric properties with the absorption of the water. The measurement tank setup developed by WITEG labor Technik Gmbh company model wisecrack wch-8, with the test followed ASTM D570 twenty-four hour immersion procedure. Before the SUT going for the water immersion procedure, initially, the SUT must undergo the ASTM D570 oven dry process to discard the existing water inside the SUT. The dry oven procedure will take one hour, and temperature control maintained at 105ºc to 110ºC.

(a) (b)

Fig. 8. Water immersion process (a) Upper view (b) side view of the Tank

After the oven dry process, as mention in the procedure, the conditioned SUT shall be placed in a compartment with sterile water with the controller set point can maintain the temperature of 23 ± 1ºC with SUT should entirely immerse inside the water. After the twenty-four-hour immersion had completed, the SUT will then pickup from the tank and wiped the water with the dry cloth and put the SUT in desiccator compartment before ongoing for dielectric probe measurements. The setup of the water aging process is indicated in Fig. 8 (a) and Fig. 8 (b). The purposes of the experiments to observe the water absorption behavior of the proposed substrate that degrades the performance of the substrate and sees the guarding properties of the proposed substrate to the water absorption that degrade the performance of the antenna later. The SOP of this water aging process followed the ASTM D570 procedure.

IV. RESULT AND ANALYSIS

The composition distributes different characteristic of Dk and Tan δ due to wood filler. The higher the wood filler content, contribute higher Dk and Tan δ due to increments of carbon content inside the wood, thus increase the intention of wood filler to absorb more humidity from the surrounding [18]. In this section experiments, five substrates with different composition are observed to see the dielectric properties variations on each composition substrates. The final average summarization average data are given in TABLE IV. The table indicated clearly that the Dk raise from 1.86 (PP100) to 3.45 (PB6040) and Tan δ 0.0066 (PP100) to 0.0754 (PB6040) on all five substrates. From the tabulated data, the increments of the mixture increase not only the Dk but also the Tan δ value that turns the substrate from the Low loss material to the lossy material in the final PB6040 mixture.

TABLE IV
DIELECTRIC PROPERTIES MEASUREMENTS FOR FIVE VARIATIONS COMPOSITION

	AVG PP100		AVG PB9010		AVG PB8020		AVG PB7030		AVG PB6040	
	Dk	Tan δ	Dk	Tan δ	Dk	Tan δ	Dk	Tan δ	Dk	Tan δ
AVG	1.86	0.0066	2.21	0.0129	2.57	0.0191	3.00	0.0404	3.45	0.0754
SD	0.02	0.0015	0.06	0.0023	0.03	0.0017	0.03	0.0012	0.05	0.0016
MAX	1.90	0.0098	2.28	0.0179	2.62	0.0227	3.05	0.0424	3.52	0.0784
MIN	1.80	0.0044	2.09	0.0089	2.52	0.0165	2.94	0.0383	3.36	0.0728
DIFF	0.10	0.0054	0.19	0.0090	0.10	0.0062	0.11	0.0042	0.16	0.0056
2.45 GHz	1.89	0.0047	2.28	0.0097	2.61	0.0169	3.04	0.0386	3.51	0.0732

There is not much research focusing on dielectric properties measurements for frequency ranging from 1 GHz to 20 GHz. The nearest frequency is available reported by [19], from 1 GHz to 10 GHz only. As stated in TABLE IV, the standard deviation (SD) reported on all proposed substrates alias between the values of 0.02 to 0.06 for the Dk. The Tan δ reported at lower value alias between values of 0.0012 to 0.0023. The differences (DIFF) value on all Dk is reported being maximum value at 0.19. Now, the observation of the dielectric properties across 1GHz to 20GHz has been observing before going for water immersion procedure to see the related increments changes for proposed biocomposite antenna substrate. Beside of the carbon content contains in the wood filler, water and moisture content (MC) also play an important part of the substrates Dk and Tan δ changes [20]. As stated in [8], the previous researchers discovered that the water absorption rate for wood plastic composite (WPC) that used (oil palm decanter cake) with polypropylene (PP) alias between the average of 0.16 to 0.44 (different composition). In that previous research also, the

conclusion discovered that the water absorption rate proportionates with composition increments.

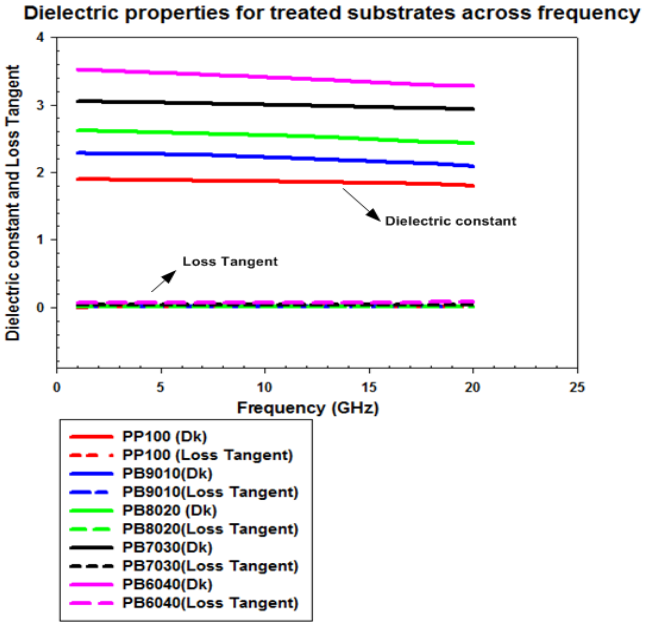

Fig. 9. Dielectric properties plot for propose substrate

The lamination process adapted to minimize the water absorption rate and enhanced the stiffness of the proposed antenna substrate. As indicated in TABLE V, the PP water absorption rate for 24hours as stated in American Society for Testing and Materials (ASTM) D570 standard [72], reported to be 0.026 % (PP100), 0.18 % (PB9010), 0.22 % (PB8020), 0.28 % (PB7030) and 0.35 % (PB6040). By referring to the PD 943 product specifications, the absorption of the product claimed to be 0.020% which deviates only 0.006% distribute from the roundup value from the weighing scale measurements. As the composition increase, the water absorption rate also increases, and the result is consistent with the previous finding that the amount of the filler influence the intensity of the water absorption. The important issue emerged from these finding indicated that the water infers of the increment of the Dk and loss of substrate. The experiments use the same procedure of ASTM D570 for dielectric measurements. Beside water content the moisture content (MC) also indicated the degradations of the substrate performance.

TABLE V
WATER ABSORPTION RATE FIVE PROPOSED SUBSTRATE

Parameter (Unit)	PP100	PB9010	PB8020	PB7030	PB6040
Weight before oven (g)	39.21	39.43	41.43	42.48	45.4
Weight after oven (g)	39.2	39.4	41.38	42.41	45.32
% of MC (%)	0.03	0.08	0.12	0.16	0.18
24H water immersion ASTM D570 (g)	39.22	39.47	41.47	42.53	45.48
% of water absorption 24H (%)	0.026	0.18	0.22	0.28	0.35

As tabulated in TABLE V, the MC increase while increasing the wood filler composition. The value for the five proposed substrate alias from 0.03 to 0.18 for composition PP100 to PB6040. This reveal that the value of MC increase with increasing the wood filler as mentioned in previous research by Jayamani et al.[13] . Even though using different wood filler material but the wood behavior outcome reveals the same result that more wood filler distributes more MC absorption. The testing then enhanced on 24Hours immersion with ASTMD570 standard. The result of dielectric properties measurement reveals that the average before and after the immersion process increase the Dk percentages of 0.87% for PP100, 1.83 % for PB9010, 2.66 % for PB8020, 4.55 % for PB7030 and 7.54 % for PB6040 as indicated in TABLE VI. The Plotting of the graph for five compositions of the substrate plotted in Fig 9. From tabulated data Table IV below.

TABLE VI
DIELECTRIC PROPERTIES MEASUREMENTS

SUBSTRATES (WATER IMMERSION)	AVG BEFORE		AVG AFTER		% DIFFERENCES	
	Dk	Tan δ	Dk	Tan δ	Dk	Tan δ
PP100	2.18	0.0137	2.20	0.0151	0.87%	10.31%
PB9010	2.19	0.0224	2.23	0.0249	1.83%	11.16%
PB8020	2.63	0.0155	2.70	0.0179	2.66%	15.48%
PB7030	3.17	0.0322	3.32	0.0398	4.55%	23.60%
PB6040	3.34	0.0638	3.59	0.0870	7.54%	36.35%

The Tan δ data for all proposed substrate proportionate with the increment of substrate content. The percentages of losses (Tan δ) more influent to the water content of the wood filler. As stated in TABLE VI, the percentages of Tan δ, calculated to be increasing compared to Dk values. The water immersion process increases the amount of losses about 10.31 % (PP100), 11.16 % (PB9010), 15.48 % (PB8020), 23.60 % (PB7030) and 36.35 % (PB6040). As a conclusion besides the carbon content, water and MC are the biggest contributor of substrate loss parameter based on data tabulated in TABLE V and TABLE VI. The conclusion from this experiment relates the output of the data to the worse case of the proposed substrate fully immerse with the water. The resistant of the proposed substrate towards water absorption indicates that there is less aging water affected the substrate.

V. CONCLUSION

The measurements of the five different compositions biocomposite antenna substrate for dielectric properties on water immersion condition indicate promising result on guarding the absorption of water. The experiment simulates the worst case behavior of the water effect on dielectric properties for proposed substrate. The proposed substrate is increasing on percentages of MC and water content at 24 Hour rate with synchronizing of increments of filler content. The increments of MC reported raising from 0.03% (PP100) to maximum of 0.18 only for PB6040 substrate, while the water absorption only involved 0.026% (PP100) to 0.35% (PB6040). Since this biocomposite does not use any additive, the result indicates

significant output with the higher the filler content absorb more water and moisture. The back to back comparison between the dielectric properties measurements before and after the water immersion indicated the differences occurs at the point between 10.31 -36.35% with the plotting increase with the increments of filler content. The increments still considered low since it only occurs below 50% of increments.

VI. ACKNOWLEDGEMENT

The authors would like to acknowledge Malaysian Timber Industry Board (MTIB), Fidec (Banting, Malaysia), especially En. Zulkepli bin Abd Rani, Director of Fibre and Bio-composite center (FIDEC), for allowing the author to use the facility in FIDEC lab that possible of accomplishment of this article.

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