

## A Comparative Study of Material *Leucaena Leucocephala* Stem Wood Plastic Composite (WPC) Substrate with FR4 Substrate throughout Single Patch Antenna Design

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**Abstract**—The fabrication of single square patch antenna for proposed *Leucaena Leucocephala* (“*Petai Belalang*”) Wood Plastic Composite (WPC) substrate board (PB Substrate board) and FR4 substrate board is presented in this paper. The experiment objective is to measure the performance of an antenna fabricated on the FR4 and PB substrate (proposed substrate) by comparing the performance in terms of material’s dielectric constant and electron mobility and antennas’ loss tangent, return loss ( $S_{11}$ ), radiation pattern and practical antenna transmitting performance. The new substrate compositions of *Leucaena Leucocephala* stem and polypropylene (PP) are 30% and 70% consecutively. The result for 150  $\mu\text{m}$  (sample B) indicates stability on most dielectric constant ( $\epsilon_r = 3.02$ ), loss tangent ( $\tan \delta = 0.029$ ) and electron mobility ( $5.31 \times 10^3 \text{ cm}^2/\text{Vs}$ ), with the consistency of antenna result, between simulation and measurement. All results obtained will be analyzed and displayed in the form of data and graphs.

### 1. INTRODUCTION

“Green Technology Product” evolves from various kinds of techniques, methodologies and enhancement of various materials conserve the natural environment and resources, which minimizes and reduces the negative impact of human activities. The implementation of green technology especially on developing new material product will be an option to the industry and also the government in driving new economic growth by contributing to fiscal consolidation, enhancing productivity through greater efficiency in the use of natural and reusable resources [1–4]. Green technology product development, sustainability, cradle to cradle design and its viability are the major issues of this technology, whereby the product development can last indefinitely into the future without damaging or depleting natural resources, hence it can be fully reclaimed or reused [5–8]. The research of green technology product not only is related to energy saving, renewable energy and building material fabrication, but also can be expanded to the fabrication of Printed Circuit Board (PCB) which is now widely used as the substrate of planar antenna [9–12]. Existing substrate product, for example substrate from the Rogers Corporation Company and Taconic Company, is widely used as a substrate to fabricate high-end planar antenna system [13–16]. Existing substrate products, such as substrates from the Rogers Corporation Company and Taconic Company, are widely used to fabricate high end planar antenna system [13–16]. The fabricated antennas on both of these commercially available substrates seem to be very stable and highly efficient. However, the drawback is that it is very expensive if the antenna design is in mass production.

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In order to get cheaper substrates while not compromising the antenna performance, fiber glass material substrate (FR4) is the alternative solution, and relatively excellent results are obtained in spite of using cheaper FR4 material substrate [17, 18]. The goal for this research is to find other potential materials that can be used as antenna substrate with additional value, following the green technology product criteria and with better antenna performance than FR4 substrate material. The proposed substrate board used undergoes the process of Wood Plastic Composite (WPC) technique with hot and cold press machine fabrication method. The elaboration of the method will be discussed in the substrate fabrication method setup section. WPC can be obtained from a mixture of thermoplastic polymer and saw dust wood. The thermoplastic polymer can be Acrylic (methyl methacrylate), Polyethylene (PE), Polystyrene (PS), Polyvinyl chloride (PVC), polytetrafluoroethylene (PTFE) or Teflon and Polypropylene (PP). In this research paper, the fabrications are focused on PP since the melting point and resistance to temperature is high compared to other thermoplastic polymers. The melting point of PP is about 180°C.

The saw dust wood filler for this research paper will be from leucaena leucocephala stem. In Malaysia, leucaena leucocephala tree is known as “Petai Belalang”, and the popular tropical tree especially on the leaf is traditionally known to cure high blood pressure. These wild trees were originally found in Central America and Mexico; they spread all around the world including Asia and Malaysia. The tree can be harvested after 1 to 2 years of growth, and the application of the tree is still neglected and under-utilized [19]. WPC has currently become an important research that has gained popularity over the last decade especially with its properties and advantages. Among them are the high durability, low maintenance, acceptable relative strength and stiffness, low price relatives to other competing materials, and the fact that it is a natural resource or eco green technology. The high water content affects the whole board performance not only on mechanical properties, but also on its electromagnetic properties [20], compared to the used whole wood contents. Other advantages of the usage of WPC are their resistance towards biological deterioration especially for outdoor applications.

In order to verify the usage of the proposed substrate in the surrounding of electromagnetic and antenna substrate, the measurements of dielectric constant ( $\epsilon_r$ ) and loss tangent ( $\tan\delta$ ) seem very significant. Dielectric properties of a material define the physical-chemical properties related to the storage and loss of energy contained in a material or substance. The knowledge of a material’s dielectric property is necessary in determining its suitability for a specific application. FR4 material is widely used as a substrate on most of the antenna designs, and the dielectric constant of the material is between 4.3 to 4.9 [21, 22]. The dielectric constant and tangent loss value will be used to design single patch antenna in order to obtain the performance of each design. The overall antenna design parameters are given in Table 1, whereby the proposed leucaena leucocephala stem substrate board is noted as PB substrate board. As indicate in Table 1, the thickness of the copper sheet used was 0.35 mm (350  $\mu\text{m}$ ). The copper sheet was then cut by using laser cutter machine to square shape and attached to the material by using the epoxy (VT-146 rapid 3 Ton 4 minute non-conductive).

**Table 1.** Basic antenna design parameter.

Substrate	PB Board	FR4 Board
Substrate Thickness (mm)	1.6	1.6
Design Center Frequency (GHz)	2.45	2.45
Copper thickness (mm)	0.35	0.35

**Note: PB Board (Petai Belalang Board).**

## 2. SAMPLE PB SUBSTRATE FABRICATION SETUP

Five PB material samples composed of 70% PP and 30% wood filler were prepared and fabricated earlier before the measurement began. For the purpose of testing, four different samples were already fabricated with 30% of wood filler mix with 70% of PP. The moisture content of the filler was controlled and maintained at < 16% according to American Society for Testing and Materials (ASTM) D5456 standard. The thickness and dimension of the sample were fixed to 1.6 mm and 150 mm  $\times$  150 mm. The

**Table 2.** Sample parameter of material mixing.

Sample	% Filler	% Polypropylene (PP)	Particle size	Substrate thickness
A1	0	100	0	1.6 mm
A	30	70	100 $\mu\text{m}$	1.6 mm
B	30	70	150 $\mu\text{m}$	1.6 mm
C	30	70	250 $\mu\text{m}$	1.6 mm
D	30	70	500 $\mu\text{m}$	1.6 mm

**Note:**

- Sample A1:** Pure PP substrate board with 0% of Sawdust Wood;
- Sample A:** PB substrate board 100  $\mu\text{m}$  sawdust wood particle;
- Sample B:** PB substrate board 150  $\mu\text{m}$  sawdust wood particle;
- Sample C:** PB substrate board 200  $\mu\text{m}$  sawdust wood particle;
- Sample D:** PB substrate board 500  $\mu\text{m}$  sawdust wood particle.

parameter that varies between these four samples was only the particle size of the sample. Table 2 below shows the five sampled parameters.

The proposed PB board was fabricated with the ratio of 70 percent of PP and 30 percent of *Leucaena Leucocephala* sawdust filler. The main filler is taken from the tree trunk with 2 years of growth age. The filler is cut into different particle sizes to vary the wood behavior. The different particle sizes were also shown in Table 2. Figure 1 below shows the raw material of wood plastic composite (WPC) fabrication.



**Figure 1.** Wood plastic composite raw material: (a) PP crystalline, (b) *Leucaena Leucocephala* stems Sawdust filler.

Preparation of the sample of WPC is in accordance to the ASTM D1238 standard, and the melting point for the fabrication is set to 180°C with melting index of 12 g/10 min [23]. The melting process occupied two main machines that were hot press machine and cold press machine. The hot and cold press machines are shown in Figure 2. Most of the fabrication method of WPC can be obtained in [25, 26].

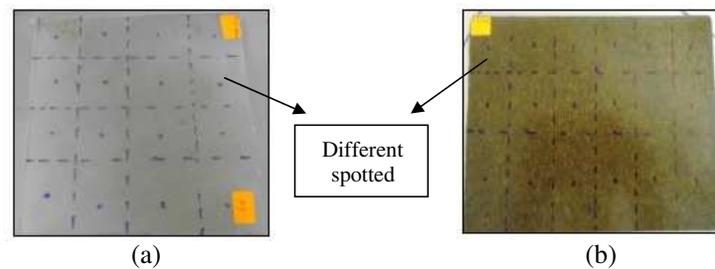
Transferring the WPC sample from hot pressing machine to cold pressing machine has to be done immediately in order to preserve the molecule of PP structure and hence the rigidity of the sample. The temperature of the cold press machine is set to 20°C with duration of 120 second [26]. The overall setting of hot and cold press machines can be viewed in Table 3.

**Table 3.** Hot and cold press machine setting.

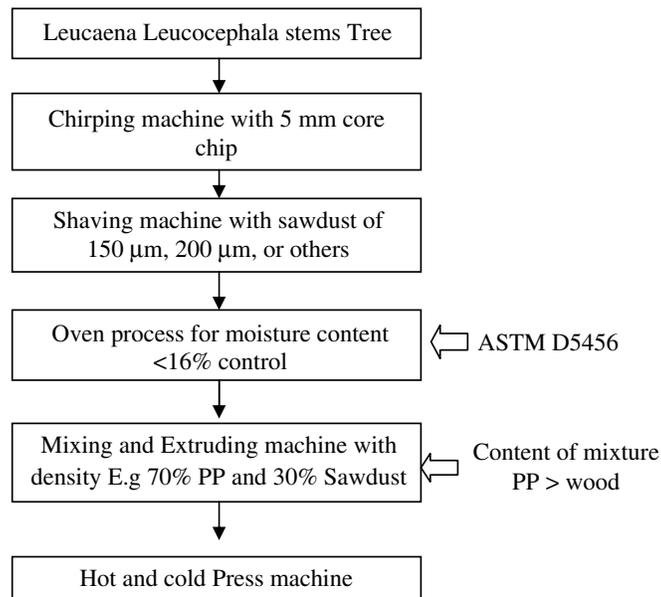
Hot Press Setting	Cold Press Setting
Temperature: 180°C	Temperature: 20°C
Pressure: 1000 psi	Pressure: 500 psi
Duration: 330 Seconds	Duration: 120 Seconds



**Figure 2.** Wood plastic composite machine: (a) hot press machine, (b) cold press machine.



**Figure 3.** Fabricated substrate board: (a) pure PP board, (b) PB board.



**Figure 4.** Overall process for proposed substrate board.

Overall, sample fabrication was made under room temperature of 26°C and about 30% to 50% at relative humidity. Samples of fabricated WPC substrate board are shown in Figure 3. The proposed fabricated board name was noted as ‘*Petai belalang*’ board (PB substrate board). The overall processes of proposed substrate board are shown in Figure 4.

The process used 70% of PP and 30% of sawdust wood. The composition must follow PP > wood to make sure that there is no need for others adding materials such as chemical lubricant to hold the structure.

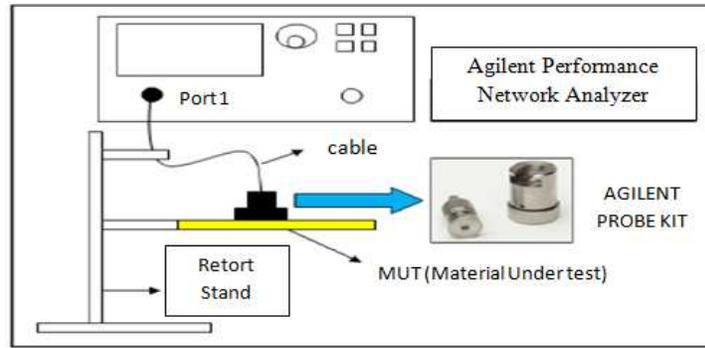


Figure 5. Probe test method setup.

### 3. DIELECTRIC MEASUREMENT SETUP

There are a few techniques used to measure the dielectric properties of material. The elaborations of the techniques were discussed extensively in research papers [27–30]. Among them, the dielectric probe method was chosen due to its simpler technique and considered as non-destructive test method. The probe has the capability of measuring the material properties up to 50 GHz [31]. The setup contains Agilent EB 362B Performance network analyzer (PNA) 10 MHz to 10 GHz which means that the material test is mainly for X band applications. In order to hold the material and measuring coaxial cable, retort stand was used to make sure minimize the output variation. The test occupied only port 1 in PNA, and in all testing procedures, the Agilent 85070E dielectric probe kit was used to read all dielectric property values including dielectric constant and loss tangent value. The beauty of this technique is that all the measurement and graph were directly visible inside the PNA network analyzer screen with Agilent 85070B software. The fabricated proposed PB substrate board and FR4 substrate were analyzed by using the probe method. Figure 5 shows the setup of the technique.

The procedure was done by contacting the probe end into the material. The measurement mostly relies on the reflected signal ( $S_{11}$ ), and by using a software  $\epsilon_r$  (dielectric constant) and  $\tan \delta$  (loss tangent) can be obtained. The results from the software were visible in the form of graph. In order to increase accuracy, each material was divided into different spots of measurement. The measurement was done on all spots on the material, and results from these spots would be analyzed to find the best reading on all spots created. Not all spots would give the same reading since each sport created different reflections depending on density and moisture of the material. Figure 5 shows the different places of spotted positions of the probe on both 100% of pure propylene board and PB board.

#### 3.1. Electron Mobility Measurement Setup

The measurement of electron mobility of the material will give the researcher some basic information and idea on the penetrations of the electron via material [32–34]. The higher value of the electron mobility indicates that the material absorb the electron less than small value of electron mobility. The



Figure 6. Hall effect measurement HMS 3000 setup.



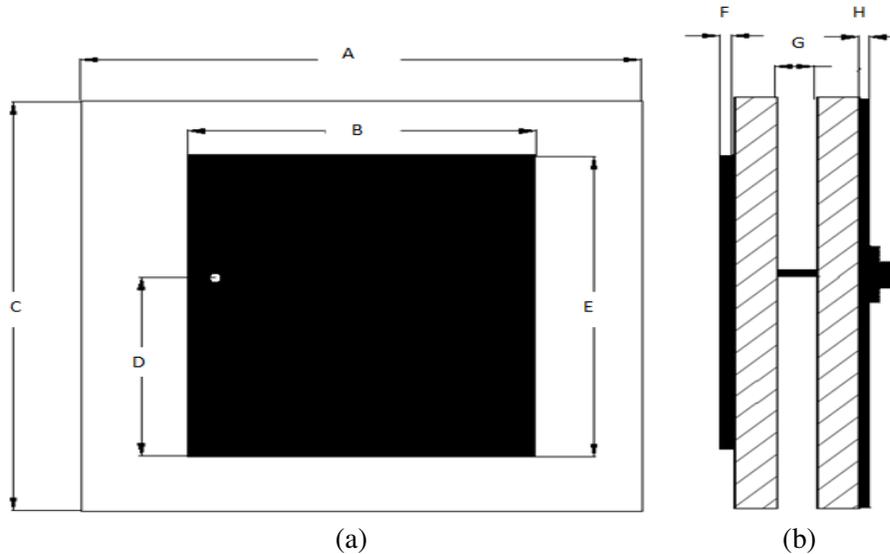
Figure 7. Sample PB board placement inside of jig.

higher value of electron mobility will tend to give lower value of dielectric constant value, and it is good for wider bandwidth application especially on ultra wideband application, whereby higher bandwidth has priority. Most of the design of wide band antenna by using low dielectric constant value can be obtained in [36, 37]. The test was conducted by using the hall measurement system by ECOPIA model HMS-3000. The arrangement of the setup is shown in Figure 6. In this measurement setup, there are three main components involved, and all the setup will integrate with Hall effect measuring software. This software directly giving the value of electron mobility with the changes of the current is applied with constant injected temperature 300 K (26.85°C). The temperature control and different currents applied were distributed by HMS 3000 device, and the magnetic control for the Hall Effect test was control by North and South Pole magnetic applied by device jig.

The sample with the dimension of 1 cm × 1 cm was placed and measured inside the jig. The placement of the sample is shown in Figure 7.

#### 4. ANTENNA DESIGN

The antenna design is based on the parameter value of the dielectric constant and loss tangent value obtained while using the probe test method. The design is based on single-patch antenna with air-gap technique fabricated onto both proposed PB and FR4 substrate boards with coaxial feed through type. The overall design of the triangular single-patch antenna design on both PB board and FR4 board was shown in Figure 8, while all the parameter values for both antennas are presented in Table 4.



**Figure 8.** Square patch antenna: (a) front view, (b) side view.

The design utilizes a 0.35 mm copper plate with square-patch antenna arrangement on top of the substrate, while the ground patch situated behind the single patch with the air gap fixed to 4.6 mm on both designs.

The antenna structure was initially inspired by [37], and the differences between the existing design was the usage of the thick 0.35 mm copper plate onto the proposed PB and FR4 substrate boards with air-gap technique to enhance the existing gain. The fabricated antenna structure onto the proposed PB and FR4 substrate boards is shown in Figure 9.

#### 5. PRACTICAL ANTENNA MEASUREMENTS

An indoor practical antenna measurement setup is illustrated in Figure 10. The transmitter ( $T_X$ ) is aligned with the receiver ( $R_X$ ) to ensure a proper establishment of the point-to-point communication.

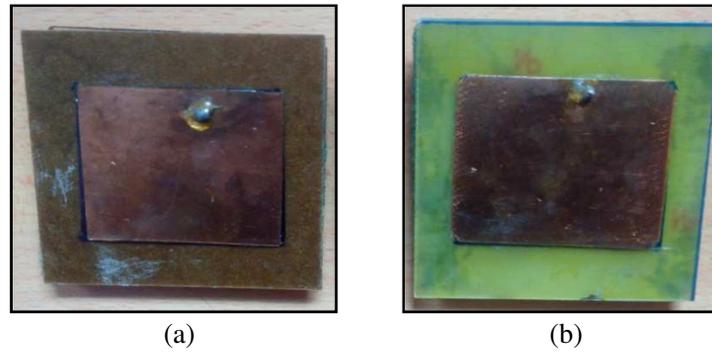


Figure 9. Fabricated square patch antenna structure: (a) for PB board while (b) for FR4 board.

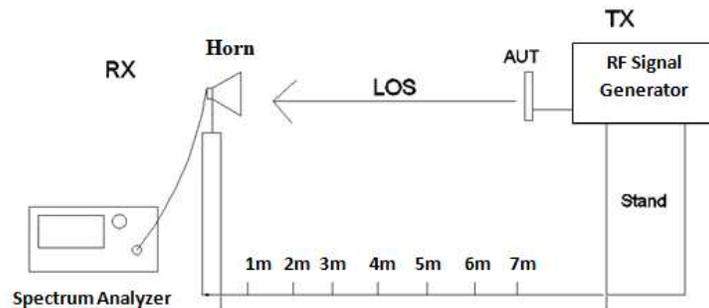


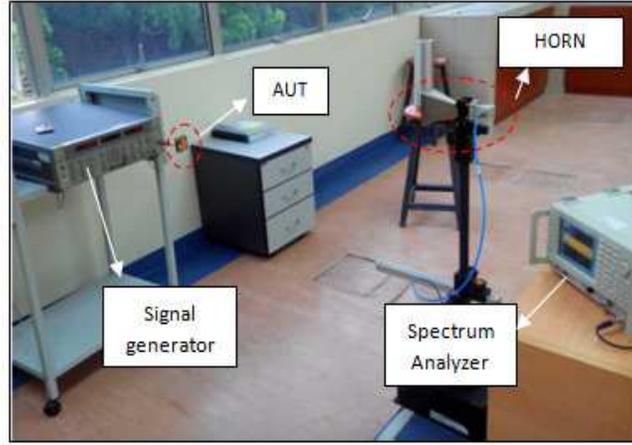
Figure 10. Measurement equipment setup.

Therefore, a similar height for the horn and proposed antenna (AUT) must be maintained for a good line of sight (LOS), and the transmitter and receiver were critically spaced to get the most reliable data. The test was conducted at the “Universiti Teknologi Mara” (UiTM) antenna research group (ARG) lab with maximum spaced of 7 meter. The overall block diagram setup of the test is shown in Figure 10.

The equipment involved in this test consists of signal generator model WILTRON 6647B that has the capability to inject the RF signal from 10 MHz to 20 GHz as a transmitter ( $T_X$ ). Then, on the receiving side ( $R_X$ ) spectrum analyzer will read the power level received via HORN antenna. The gain of the horn antenna is reported to be 10 dBi, while the spectrum analyzer model is Advantest U3751, capability of sweeping frequency from 9 kHz to 8 GHz. The objective of this test is to verify that the rectangular patch antenna on both PB substrate and FR4 substrate can act as transmission antenna. The setting of the equipment is based on a distance of 7 meter Line Of Sight (LOS), lab maximum length, and the power from the signal generator has to be calibrated and adjusted so that the received signal at spectrum analyzer will be leveled at 0 dBm. The injection frequency through the AUT antenna is based

Table 4. Antenna design parameter.

Parameters	FR4 antenna design (in mm)	PB antenna design (in mm)
Width substrate ( $A$ )	66.0	66.0
Height substrate ( $C$ )	65.6	65.9
Width patch ( $B$ )	40.9	41.1
Height patch ( $E$ )	47.9	48.3
Feed position ( $D$ )	28.7	28.1
Copper thickness ( $F$ ) and ( $H$ )	0.4	0.4
Air Gap ( $G$ )	4.6	4.6



**Figure 11.** Indoor practical antenna arrangement.

on measured return loss ( $S_{11}$ ) reading of square patch antenna. For PB-board-substrate antenna, the injection frequency is at 2.487 GHz, while for FR4-substrate antenna, the injection frequency aliases at 2.479 GHz. The actual setup of practical antenna is shown in Figure 11, with the measurement distance started at 1 meter.

The Two Ray propagation model in [38–41] is shown in Figure 8, considering the effect of ground, in order to predict the path loss attenuation as given in Equation (1). The building parameter coefficients were taken into account in this equation, and the parameter is defined as  $T_{\text{floor}} = 13$  dB,  $T_{\text{glass}} = 0.25$  dB,  $T_{\text{wall}} = 2.2$  dB [42].

$$L_{PL} = 32.44 + [20 \log d (\text{km})] + [20 \log f (\text{MHz})] - [G_T (\text{dBi}) - G_R (\text{dBi})] + T_L \quad (1)$$

where

$$T_L = T_{\text{floor}} + T_{\text{Glass}} + T_{\text{wall}} \quad (2)$$

The received signal can be written as in Equation (3), as a result of the combination of Equation (1) and Equation (2). In this research, the values of  $P_t$ ,  $G_T$ ,  $G_R$  and  $d$  are available.  $P_t$  is set to 1.8 dBm (since this value suites 7 meter room power  $T_X$  calibration), while  $G_T$  is 7.535 dBi for FR4 antenna, and PB antenna is 7.98 dBi obtained from CST simulation cad software. The idea of this setup is to find the Power Received ( $P_R$ ) of the AUT and make a comparison between the calculated and measured received powers of the AUT antenna hence to prove that the antenna under test (AUT) can be used as transmitting antenna for some distance. Based on Equation (3),  $P_R$  is inversely proportional to  $d$  value. Therefore, the signal

$$10 \log \frac{P_T}{P_R} = L_{PL} \quad (3)$$

Received powers are measured at various distances between transmitter ( $T_X$ ) and receiver ( $R_X$ ), from 1 meter to 7 meter, as shown in Figure 7.

## 6. RESULT AND DISCUSSION

Five samples have been fabricated and measured and verify the measurement method for the TEFLON and FR4 materials used as calibrated material and it will be compared with existing value reported by other researchers [43–46]. The measured values of TEFLON and FR4 substrates were then revealed in a form of graph in Figure 9. Since the application of PB substrate board will be focused on ISM band antenna application occupying 2.45 GHz, the measurement will be focused only for the frequency of 2.08 GHz to 3.7 GHz even though the capability of the measurement method can go up to 50 GHz. The technique of using Teflon and FR4 as a verification dielectric measurement method was discussed in [44]. The result in Figure 12(a) shows agreement with the existing research value which is about

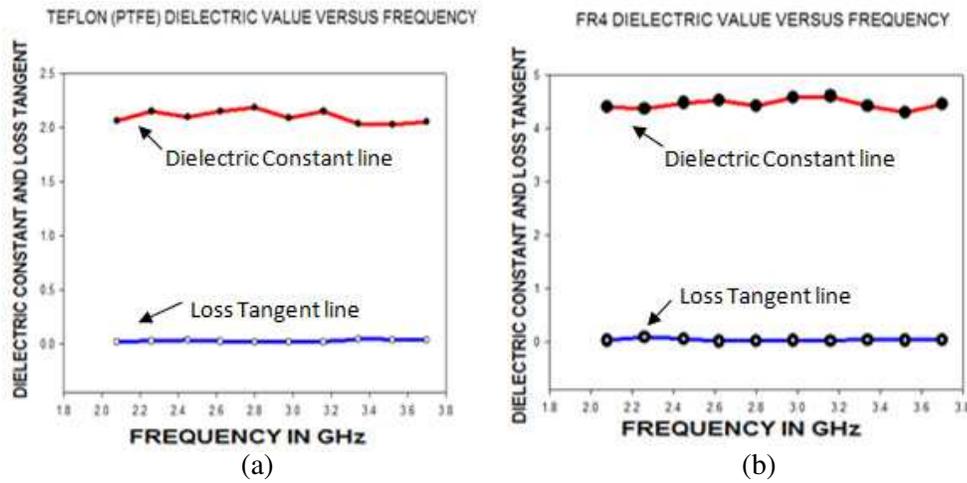


Figure 12. (a) TEFLON dielectric properties graph; (b) FR4 dielectric properties graph.

Table 5. Dielectric constant and loss tangent value for four PB substrate board.

Frequency	A1		A		B		C		D	
	$\epsilon_r$	tan								
2.08	2.22	0.0868	3.35	0.0637	2.92	0.0114	3.02	0.0687	3.72	0.0472
2.26	2.52	0.0605	3.33	0.0915	3.02	0.0132	3.02	0.0213	3.13	0.0300
2.44	2.57	0.0352	3.38	0.0596	3.06	0.0082	3.07	0.4362	3.89	0.0945
2.62	2.39	0.0662	3.30	0.0023	3.06	0.0778	3.09	0.0955	3.51	0.0196
2.8	2.47	0.0332	3.30	0.0468	3.05	0.0375	3.05	0.0239	3.78	0.0461
2.98	2.58	0.0142	3.38	0.0618	3.01	0.0357	3.05	0.0559	3.75	0.0958
3.16	2.47	0.0791	3.53	0.0654	2.92	0.0108	3.03	0.0722	3.75	0.0385
3.34	2.51	0.0868	3.37	0.0067	3.03	0.0236	3.01	0.0491	3.89	0.0810
3.52	2.28	0.0605	3.30	0.0348	3.09	0.0106	3.03	0.0573	3.80	0.0410
3.7	2.69	0.0352	3.36	0.0165	3.06	0.0608	3.01	0.0668	3.78	0.0571

Note:

- A1: Pure PP substrate board with 0% of Sawdust Wood;
- A: PB substrate board 100  $\mu\text{m}$  sawdust wood particle;
- B: PB substrate board 150  $\mu\text{m}$  sawdust wood particle;
- C: PB substrate board 200  $\mu\text{m}$  sawdust wood particle;
- D: PB substrate board 500  $\mu\text{m}$  sawdust wood particle.

2.0–2.1 and loss tangent of 0.0029 as reported in [46]. The method of dielectric probe to measure the dielectric constant ( $\epsilon_r$ ) and loss tangent ( $\tan \delta$ ) value for Teflon substrate tabulated in Table 5 indicates that the variation is aliased between minimum value of 2.03 at 3.52 GHz and maximum value of 2.19 at 2.8 GHz, and this can be clearly shown in Figure 12(a), with the frequency in GHz versus the variation of dielectric constant and loss tangent, while Figure 12(b) indicates the dielectric constant (4.5) and loss tangent (0.035) for FR4 material.

The purpose of this measurement is to see whether there is any possibility that the proposed PB substrate board can be used as antenna or any electromagnetic substrate based on its performance on dielectric constant and loss tangent value and also to find the suitable particle filler size that has stability in dielectric constant and loss tangent value. For the purpose of the antenna and other electromagnetic

usages, the verification mostly relies on dielectric constant and loss tangent of proposed materials. The overall value of dielectric constant and loss tangent value for a variation of filler mixture particle size are given in Table 5. Before any claim can be made based on result of which particle mixture is better in term of stability the variation, a pure PP board has to be tested, and in this research the substrate board noted as A1 was fabricated. In this fabrication, the substrate boards were based on 100% mixture of pure PP as shown in Figure 3(a). The results of pure PP board are also given in Table 5.

As indicated in Table 5, there is no significant difference between sample A1 and previous PP substrate data reported by [45]. The dielectric constant for fabricated PP substrate varies from 2.22 to 2.69. The average dielectric constant for sample A (100  $\mu\text{m}$ ) was 3.4, while those for sample B (150  $\mu\text{m}$ ) and sample C (200  $\mu\text{m}$ ) were reported at 3.0 and for sample D (500  $\mu\text{m}$ ) at 3.7. From Table 5 it is clearly indicated that there is no significant difference among samples A to D in term of dielectric constant value. This result indicates that the dielectric constant value does not depend much on the particle size. From Table 5 it is clearly indicated that the pure PP substrate (sample A1) rises from average 2.2 to 3.0 of dielectric constant value. This situation occurs when the carbon content from the filler rises [47]. Table 5 shows the average of 0.04 loss tangent reported by sample A, while 0.02 for sample B, and 0.09 and 0.05 reported for sample C and Sample D. So it can be concluded that the most stable dielectric constant value and loss tangent value on most of the samples is shown by sample B. That is why sample B was chosen for antenna fabrication as shown in Figure 9(a). Figures 13(a)–13(e) indicate the graphs for all the substrates indicated in Table 5.

As indicated in Figures 13(a) to 13(e), the most stable values of dielectric constant and loss tangent value are reported by Figure 13(c), with 150  $\mu\text{m}$  sawdust particle. Even though Figure 13(d) gives a constant value for dielectric constant, there is a huge variation on loss tangent reported on frequency 2.4 GHz. In Figure 13(b), there is a constant value on both dielectric constant and loss tangent, but low dielectric constant value substrate with 150  $\mu\text{m}$  sawdust wood shows better result and fulfills our objective to get constant reading on both dielectric constant and loss tangent value while maintaining low value of dielectric constant value.

Besides measuring the dielectric properties of any proposed material, the overall parameter of any substrate can also be gauged by its electron mobility. The result later will show the differences in electron mobility between FR4 substrate board and PB substrate board with 150  $\mu\text{m}$  particle size since this proposed PB board shows stability in the dielectric parameter compared to other particle sizes.

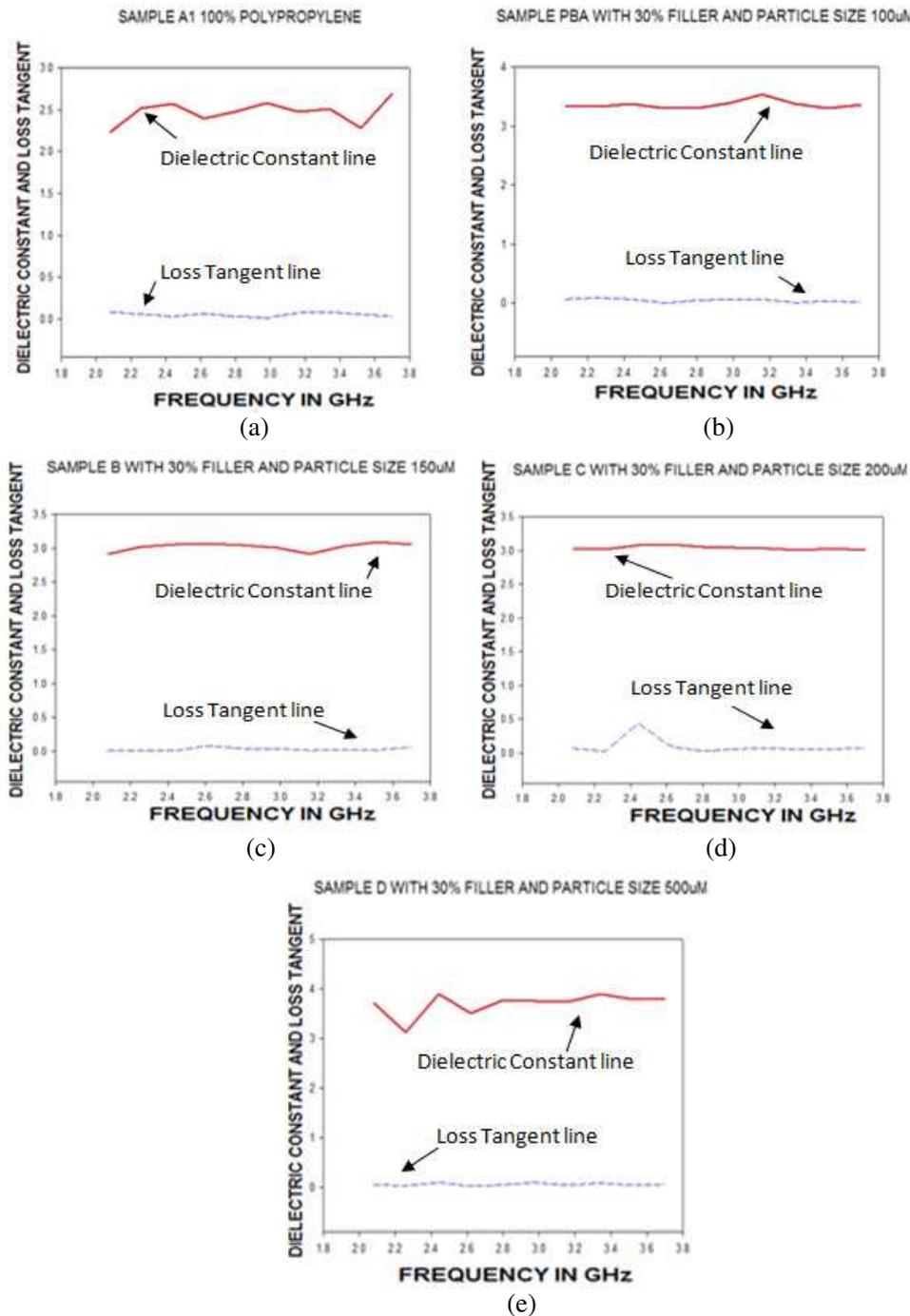
Figure 14(a) and Figure 14(b) indicate the electron mobility for FR4 substrate and proposed PB substrate. It is clear to conclude that by referring to Table 6 above, the proposed PB substrate board show higher electron mobility with  $5.31 \times 10^3 \text{ cm}^2\text{V}_s^{-1}$ , compared to FR4  $1.40 \times 10^3 \text{ cm}^2\text{V}_s^{-1}$ . The difference between these two substrates is about  $3.91 \times 10^3 \text{ cm}^2\text{V}_s^{-1}$ , but dielectric constant does not show significant difference on the two results. It is also confirmed that higher value of electron mobility will lead to low value of dielectric constant, and electron can easily pass through compared to the lower reading of electron mobility recorded by FR4 compared to PB board.

As shown in Figure 15(a), the return loss for simulation FR4 board occurred at 2.45 GHz with  $-25.8 \text{ dB}$ , while for the measured value the peak was reported at 2.47 GHz with  $-25.44 \text{ dB}$ . This  $S_{11}$  result indicates that the differences between measurement and simulation for FR4 board are frequency of 0.02 GHz and return loss of  $-0.36 \text{ dB}$ . The result shows that the board design is more stable on  $S_{11}$  reading since there is not much shifting in frequency between simulation and measurement. The target frequency of 2.45 GHz is still covered for measured FR4 antenna. The bandwidths reported for practical and simulated antennas were identical to bandwidth of 0.1809 GHz, which shows good reading on  $S_{11}$  result for FR4 board since the results on fabricated and simulated antennas seem identical. The only difference is only the frequency shifting a little bit but still in the range of desired operating frequency. As shown in Figure 15(b), the operating frequency for simulation PB board was set to 2.45 GHz with

**Table 6.** Electron mobility and resistivity of substrate.

Sample	Electron Mobility ( $\text{cm}^2/\text{V}_s$ )	Resistivity ( $\Omega \text{ cm}$ )
FR4 Board	$1.40 \times 10^3$	47.5
PB 150 $\mu\text{m}$ board	$5.31 \times 10^3$	10.8

a good return loss of  $-48.9$  dB, but the huge difference for the proposed fabricated PB board antenna occurred at frequency  $2.5$  GHz with only  $-27.96$  dB. Even though there is a huge difference between simulation and fabrication results, the return loss value was better than FR4 reading of  $-25.44$  dB. The shifting frequency between fabrication and simulation boards is at  $0.05$  GHz. Although the result is slightly different between simulated and fabricated antennas for PB board, the bandwidth of  $0.21$  GHz



**Figure 13.** (a) PP board; (b)  $100\ \mu\text{m}$  particle size PB board; (c)  $150\ \mu\text{m}$  particle size PB board; (d)  $200\ \mu\text{m}$  particle size PB board and (e)  $500\ \mu\text{m}$  particle size PB board.

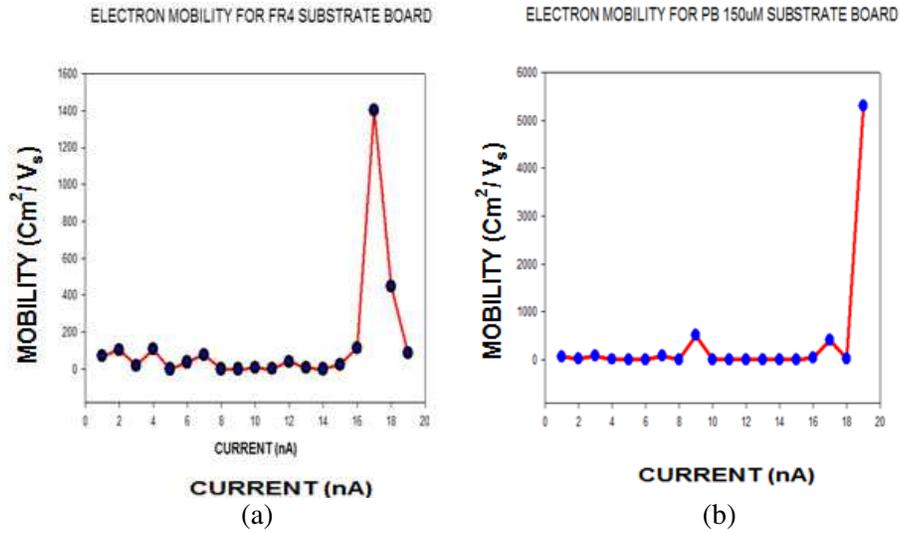


Figure 14. (a) Electron mobility for FR4 substrate; (b) electron mobility for PB substrate board.

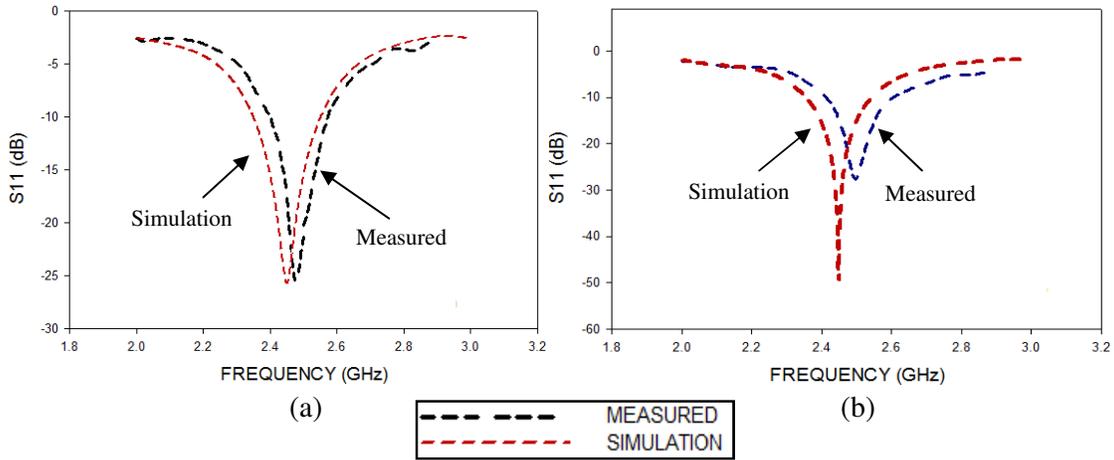


Figure 15. (a)  $S_{11}$  result for FR4 substrate board; (b)  $S_{11}$  result PB substrate board.

Table 7. Parameter antenna performance between PB boards and FR4 board.

PB Substrate = 90°		FR4 Substrate = 90°	
GAIN	8 dBi	GAIN	7.5 dBi
Angular Width (3 dB)	77.8 deg	Angular Width (3 dB)	72.1 deg
Side lobe level	-14.2 dB	Side lobe level	-13.5 dBi
Main Lobe direction	0 deg	Main Lobe direction	0 deg

for fabricated antenna is still in the range of desired operating frequency of 2.45 GHz for Industrial Science and Medical (ISM) band antenna.

Figure 16(a) and Figure 16(b) illustrate that there is a huge difference on radiation pattern between simulated and fabricated results for both PB substrate board and FR4 board, and the results are tabulated in Table 7.

Figure 17(a) and Figure 17(b) show that there are not too much difference between calculated and

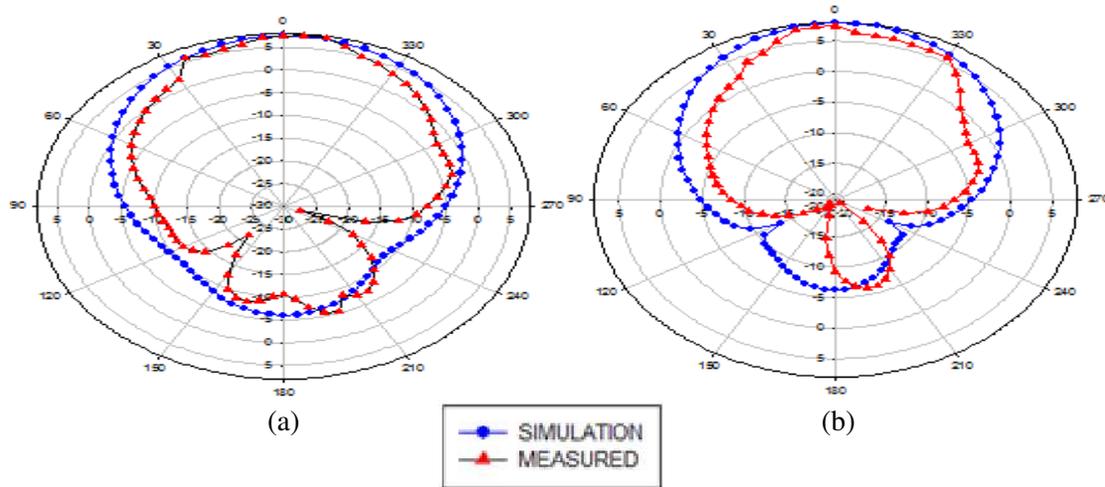


Figure 16. (a) Radiation pattern for FR4 substrate; (b) radiation pattern for PB substrate board.

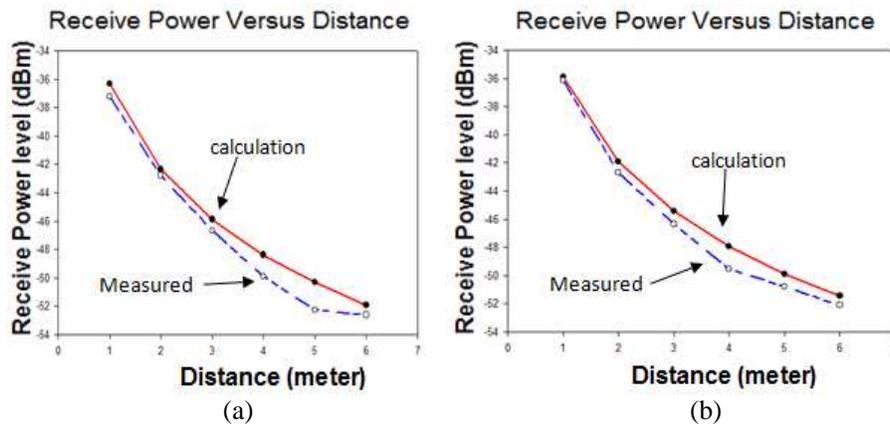


Figure 17. (a) Practical antenna measurement test for FR4; (b) practical antenna measurement test for PB substrate.

measured values on both antennas. The slight difference is only on the frequency about 4 to 5 GHz, but for other frequency, there is not much difference on performance of the antenna. Result shows that if distance of the Transmit ( $T_X$ ) antenna and Receive ( $R_X$ ) antenna is increased, the received power level will be decreased, which indicates that received power level is inversely proportional to the distance. Figure 17(b) shows better result in terms of agreement between measured and calculated data than Figure 17(a). This shows that PB board shows constant value of  $T_X$  power and more stable than FR4 board. The test is conducted with power  $T_X$  fixed at 1.8 dBm or 0.00151 Watt on both antennas.

In order to verify that both antennas can be used as transmitting antenna, the practical antenna measurements were carried out, and the results are shown in Figure 17(a) and Figure 17(b). The result indicates and verifies the Power Received ( $P_R$ ) Level recorded with spectrum analyzer while doing practical test measurement as Figures 10 and 11 with calculation of Power Received ( $P_R$ ) by using Equations (1), (2) and (3).

## 7. CONCLUSION

A new PB substrate board was fabricated and measured considering its dielectric constant, electron mobility and loss tangent value. The proposed PB substrate boards were then used as substrates for the single patch square shape antenna to verify its performance. The PB board design was then

compared with the existing FR4 material board in term of simulated gain, radiation pattern, return loss and practical antenna transmission test performance. Overall performance analysis shows some improvement for PB substrate board regarding simulated gain and back lobe reduction compared with FR4 substrate board. In conclusion, there is a possibility of using the proposed PB substrate board to serve as one of the options for designing antenna and electromagnetic usage, and beside that, it also supports green technology since the usage of bio-composite technology will be one of the frontier methods to the antenna designers later. The material can not only be reusable and reproduced, but also reduce some fabrication cost because the sawdust wood fillers are locally available.

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