Electrical Characterization of *Bambusa Vulgaris* as a New Microwave Substrate

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***Abstract*— This study investigates the electrical properties of the bamboo scientifically named as *Bambusa Vulgaris* (BV) and its utilization potential to communication field as a new microwave substrate. The main objective of this paper is to reveal the performance of BV as a new bio-composite substrate in term of dielectric constant and loss tangent values. These two electrical parameters are the most important element for designing a patch antenna. The focus is to discover the proposed board capability to replace the conventional board, for example, Flame Retardant type 4 (FR-4) and Rogers. The BV substrate was developed through several processes such as chipping, heating and compressing before it became a thin board which suitable to be used as new microwave substrate. Then, this BV substrate electrical characteristic was examined by using the Vector Network Analyzer (VNA) with its special measurement tools (probe). All the measurements are completed through several experiments. All the experimental results are presented and discussed in this paper.**

***Index Terms*— *Bambusa Vulgaris*; Composite; Measure Dielectric Constant; Loss Tangent.**

I. Introduction

Bamboo is categorized as woody grass which belongs to angiosperm group [1].There are around 1500 species of bamboo around this planet such as *Dendrocalamus Giganteus*, *Phyllostachys Aurea* and *Bambusa Sinospinosa*. Each group of bamboos has their specific characteristics and usefulness for humankind. In addition, most of bamboos need a good moisture, humid environment and fertile soil in order to become larger. Therefore, many bamboos are easily grown in rainforest tropical countries. Most of the bamboos are well grown in Southeast Asia, especially in China [1-2]. It is naturally grown abundantly in these areas without the need for a careful supervision. It is easy to be found at high moisture or wet area such as in the bushes or close to the river. Under normal condition, the bamboos are considered mature and ready for harvest after 3 years of growing [3].

Bamboo has been used extensively for many applications such as musical instruments, building construction applications [3] and household properties [4]. Nowadays, the usages of bamboo are reaching out to numerous manufacturing applications because of advances in handling new innovation. According to [5], an innovation has been made in robotic arena where a group of researchers has developed a robot arm by using bamboo. In their research, bamboo is utilized as a part of request to embody a supportable material. Further, there was a study which produces a presspaper by using bamboo in order to replace conventional presspaper approach using softwood [6]. This is good since it can increase the utilization of bamboo in the industry.

Additionally, there are a lot of studies had been made onto bamboo as toxic or chemical adsorbents. For example, in [7] the toxic adsorbents have been made from *Bambusa Vulgaris* leaves. By having, an eco-green toxic adsorbent it can reduce the chemical pollution. This kind of pollution is capable of affecting other living things or creatures that can cause diseases such as alimentary canal cancer [7].

In this study, BV that provincially named as “Buluh Minyak” was chosen to be exploited as new material for antenna substrate. This is because of its quick maturation rate and high yearly re-maturation rate. Incidentally, bamboo also has high prospective for carbon storage, which good for extending the duration of its lifespan [2]. BV is one of the popular bamboos in South East Asia [1]. In the beginning, this BV was planted in Southern China before it spread out around Asia. It is also among the largest species of bamboo and easy to be identified.

For this research, the BV was mixed up with a polymer which called High Density Polyethylene (HDPE). The function is to grant strengths to the proposed substrate. Then, the mixture will go through several processes in wood plastic composite (WPC) procedure to combine them together to become a thin board that can be used as substrate.

Essentially the mixture of bamboo and polymer are not new to the current life industry. Many applications and studies such as in wood technology and manufacturing [8, 9] have been accomplished by using this kind of mixture. However, the usage of this mixture in microwave applications is not commonly used yet. Only a few researchers have explored this mixture such as in [10]. Thus, this study will reveal the potential of this mixture in a microwave field.

Generally, WPC is a composite based that mix two main materials which are wood and plastic (polymer). WPC technique includes a few steps such as heating, mixing and compress. Currently, WPC is one of the composite techniques. It is fast developing utilization in current real life. WPC has become popular because of its good properties such as low costing, satisfactory strength and stiffness, high durability and low maintenance [11]. In addition, the cost of manufacturing this substrate by using local material (BV) can be reduced. WPC is not stiff as solid as wood, but it is stiffer than pure polymer. Furthermore, WPC does not require any fasteners to bond them (wood and polymer) together.

II. Methodology

A. Bambusa Vulgaris Board Development

At the beginning, full-grown (three years old and above) BV were selected and harvested. Then, the harvested BV would be cleaned to remove any unwanted material such as dirt. This cleaning process is important because want to ensure that no any undesirable material will affect the electrical performance of the proposed substrate. Figure 1 below shows the harvested BV used in this investigation.

Figure 1: Harvested *Bambusa Vulgaris*

After the BV has been cleaned and dried out, they would be chipped and grinded into sawdust. Next, the sawdust was passed through a sieving process which purposely to separate them into several groups based on each particle size. This is important to allow an almost similar particle size of sawdust into the board mixture.

Table 1 below illustrates the obtained tabulation (mean value) of BV in 100g of sawdust. Table 1 indicates the smallest particle size is found in the smallest value of the sawdust. Meanwhile, the largest particle size is found in the largest amount of sawdust.

Table 1
Tabulation of BV in 100g of Sawdust

Particle Size (µm)	WEIGHT (GRAMS)	Percentage (%)
177 and smaller	12.10	11.98
177 to 250	11.40	11.28
250 to 425	26.03	25.77
425 and larger	51.50	50.97

Before the process of mixing BV and HDPE were conducted, the moisture content of sawdust needs to be verified as below than 10%. Ensuring minimal water existence in sawdust is important to avoid the formation of bubble occurring during the compression process. If the moisture content is more than 10%, the sawdust would need to be dried by using an appropriate machine such as an oven. Then, the BV sawdust would be merged together with HDPE in a hot mixer and before being extracted out from the machine. One of the machines which were used in this investigation is as shown in Figure 2 below.

Finally, the extracted mixture was cut into small pieces to become granules or pellet of composite. In order to make a thin board, the pellet would then be compressed by using hot and cold press machine. Figure 3 shows the sequence of processes in developing BV board as a summarization of procedures stated before.

Figure 2: Hot mixer for WPC method

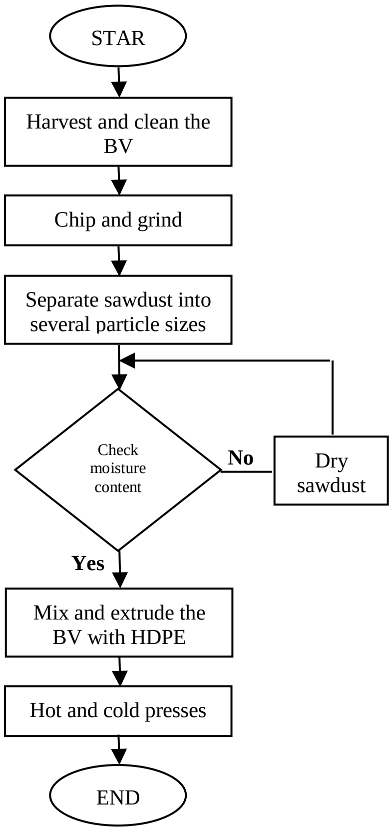

Figure 3: Processes of developing BV board

B. *Electrical Properties Measurement Method*

Many methods can be used to measure the electrical properties of substrate. One of the techniques has presented in [10]. In their investigation, they have combined many materials for instance bamboo charcoal, Titania, and ferrites to produce a new microwave absorber. They used ferrites because it has a good ferromagnetic property which is suitable to be used in microwave applications. They have also measured the electrical properties (complex permittivity and dielectric loss) of their microwave absorber. Meanwhile, in [12] a group of researchers has measured dielectric constant, loss tangent, electron mobility and many other parameters for their new microwave material. They developed an antenna based on their designed substrate and measured the performance in term of return loss, gain and radiation pattern as well as other parameters.

An experiment has been set up on the proposed substrate with the purpose of getting the targeted properties which are dielectric constant and loss tangent. Table 2 shows the example of electrical properties for Flame Retardant type 4 (FR-4) and RT/Duroid 5870 substrates. Meanwhile, Figure 4 shows the configuration of the experiment that has been applied to measure the electrical properties of proposed substrate.

Table 2
Electrical Properties of FR-4 and BV Substrate

Parameter	Value	
	FR-4	RT/Duroid 5870
Height, *h* (mm)	1.6	1.6
Dielectric constant, ε_r	4.7	2.35
Loss tangent, δ	0.015	0.0012

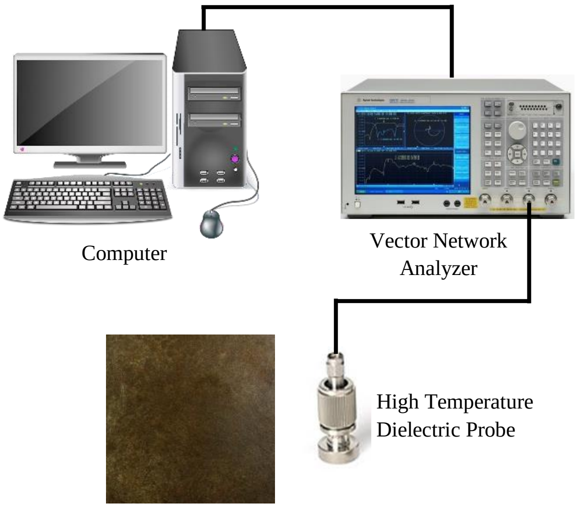

Figure 4: Configuration of experimental apparatus

The measurement of dielectric constant, ε_r and loss tangent, δ of the proposed board were determined by using an electrical instrument called as Agilent Technologies E5071C Network Analyzer. It is capable to measure electrical properties in the frequency range from 300 kHz up to 20 GHz. This feature allows the device competently evaluate Super High Frequency (SHF). At this frequency band, it is suitable to be used in radar, microwave and satellite applications. Hence, by using this device, a coaxial probe measurement technique has been applied to the proposed substrate to measure its electrical properties as mentioned before. The measurement has been completed by using a high temperature dielectric probe connected to the E5071C Network Analyzer.

Subsequently to measure the electrical properties of the proposed substrate, the high temperature dielectric probe was placed on the BV board. In order to check the accuracy of the obtained values, several points on the board were picked randomly. The measurements made depended on the return loss or reflected signal. The return loss is associated with standing wave ratio (SWR) and reflection coefficient. Accordingly, by using 85070 Dielectric Probe software which installed in the computer, the obtained return loss values were converted to dielectric constant, ε_r and loss tangent, δ.

III. EXPERIMENTAL RESULTS

Sample of BV boards were fabricated as stated in the methodology section. Four samples with different composition of materials have been developed in order to determine the variation of dielectric constant and loss tangent. The compositions of all developed BV boards are as stated in Table 3 below.

Table 3
Composition of BV Substrate

Substrate	Composition	
	HDPE (%)	BV (%)
Sample 1	100	0
Sample 2	90	10
Sample 3	80	20
Sample 4	70	30

All of these BV boards have been measured in term of its dielectric constant, ε_r and loss tangent, δ values by using the experiment setup as mentioned before. Furthermore, for reference and comparison, the FR-4 board electrical properties were also measured. FR-4 was selected due to the fact of its price not too expensive compared to the other existing substrates [13].

Figure 5 shows the experimental result for measured dielectric constant. The graph shows the value of dielectric constant from 1 GHz to 10 GHz. It consists of four line graph which indicates the result for four different compositions of developed substrate as mentioned in the Table 3.

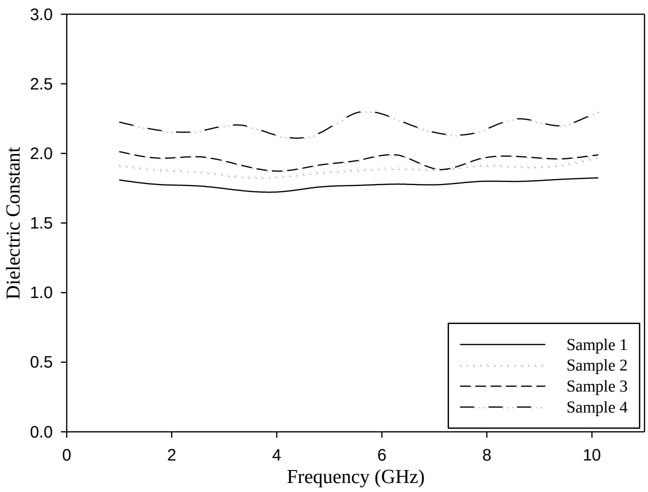

Figure 5: Dielectric constant graph for different composition of material

Based on the graph in Figure 5, it seems that the values of dielectric constant were increased if the total of BV was increased in the substrate. Basically, the dielectric constant value is an expression of the capability of the material to concentrate the electrical flux through it. Thus, from the graph in Figure 5, it means lesser signal can pass through in the substrate with the highest quantity of BV.

Furthermore, a comparison was made between one of BV board with common antenna substrate named FR-4. Noting the fact that this research is trying to produce a low cost substrate, Sample 4 (70% HDPE & 30% BV mixture) is selected. This decision is derived from the observations that large amount sawdust in a mixture will reduce the cost of raw material. Figure 6 illustrates the comparison between the BV substrate (Sample 4) and FR-4 substrate in term of dielectric constant value.

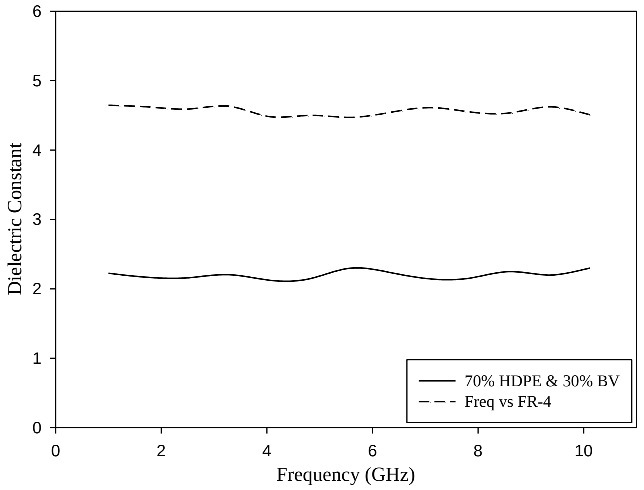

Figure 6: Comparison of dielectric constant value between BV and FR-4

It can be observed that the dielectric constant of BV board is lesser than the FR-4 board. For 70% HDPE merged with 30% BV board, the value of dielectric constant is around 2.2, while for FR-4 substrate is approximately 4.6. Thus, according to this dielectric constant value, BV board can allow more signal to pass through it as compared to the FR-4 substrate.

In addition, 9 random points on the board were measured. Then, it was summarized with the average values of every point. The details of mean values for measuring dielectric constant, ε_r and loss tangent, δ onto FR-4 and BV boards are presented in Table 4 below. The values are applicable for frequency start from 1 GHz to 10 GHz. It consists of 13 points of frequency with 0.76 GHz step values.

From the obtained results in Table 4, there are several divergences among the values of dielectric constant and loss tangent. However, the average value of dielectric constant of BV board is lesser than the FR-4 board. It shows the lower value of dielectric constant is good for better performance because many microwave signals would be able to store and pass through the board. Nevertheless, for the obtained loss tangent value, it is not as good as a FR-4 board because the loss tangent value of BV board is higher than the FR-4 board. In fact, the lower loss tangent value is the better performance of the board. This is because higher values of loss tangent will lead to more signal or power losses occurred on the board.

Additionally, Table 5 shows the summarization of data obtained in Table 4. The most important parameter in Table 5 is the standard deviation. It indicates the amount of difference of a set data value. A lower standard deviation is better for data measurement. This is because by having low value of standard deviation specifies the set of data is closer to its mean value or expected value. Therefore, for this investigation the standard deviation of BV boards for both electrical properties is less than a FR-4 board. It means the measured values for BV board were more precise compared to FR-4 board.

Table 4
Dielectric Constant and Loss Tangent Values of FR-4 and BV Substrate

Frequency (GHz)	FR-4 Substrate		BV Substrate	
	ε_r	δ	ε_r	δ
1.00	4.6450	0.0365	2.2242	0.0701
1.76	4.6194	0.0468	2.1652	0.0675
2.52	4.5898	0.0371	2.1591	0.0605
3.28	4.6302	0.0374	2.2034	0.0574
4.04	4.4798	0.0476	2.1244	0.0646
4.80	4.4994	0.0579	2.1433	0.0571
5.56	4.4693	0.0532	2.2959	0.0619
6.32	4.5398	0.0450	2.2368	0.0572
7.08	4.6103	0.0470	2.1442	0.0668
7.84	4.5476	0.0589	2.1528	0.0660
8.60	4.5350	0.0459	2.2482	0.0656
9.36	4.6223	0.0478	2.1974	0.0625
10.12	4.5057	0.0398	2.2997	0.0733

Table 5
Summarization of Electrical Properties for FR-4 and BV Substrate

Parameter	FR-4 Substrate		BV Substrate	
	ε_r	δ	ε_r	δ
Max	4.6450	0.0589	2.2997	0.0733
Min	4.4693	0.0365	2.1244	0.0571
Mean	4.5610	0.0462	2.1996	0.0639
Std. Deviation	0.0591	0.0071	0.0559	0.0049

IV. CONCLUSION

A new potential substrate named BV board was developed. The characteristics of electrical properties were measured, analyzed and presented in this paper. Furthermore, the obtained results for BV board were compared with familiar existing substrate which is a FR-4 substrate. The results show BV board has more consistencies as compared to the FR-4 substrate. It is suggested to use BV in microwave application such as designing a patch antenna. For further study, other characteristics such as strength, breakdown voltage and water absorption of BV board will be evaluated. This is important in order to determine prospect of the board to be used in other applications such as insulation of electrical devices. In addition, a patch antenna would be developed onto this BV substrate in order to observe the real performance of this substrate in microwave application.

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