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Microwave characterization of pandanus atrocarpus as potential organic-based dielectric substrate

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ABSTRACT

This study investigated the microwave characterization of a potential organic-based substrate pandanus atrocarpus. Pandanus atrocarpus, also known as "pandan mengkuang", is easily found at riverside and beach areas in Penisular Malaysia. The experiment's objective was to measure dielectric constant and tangent loss using the dielectric coaxial probe method by employing vector network analyzer (VNA) and dielectric probe. Dielectric constant and tangent loss are the crucial parameter in the microwave design. Three different samples of pandanus atrocarpus were measured and analyzed. The result showed that the dielectric constant of the pandanus substrate material depended on the leaves' water content. All experimental results obtained were analyzed, presented, and discussed in this paper.

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1. INTRODUCTION

Organic substance material is composed of a carbon-based compound originally derived from living organisms such as plants and animals. An implementation of eco-friendly technology on developing new material will ensure the environment's safety because non–toxic natural ingredients are used plus it does not deplete and damage the ecosystem too. Eco-friendly technology has become a burgeoning industry that attracts a significant amount of investors due to the rising awareness on the impact of climate changes and as initiative to protect the environment and repair the damage inflicted on the environment in the past due to [1].

Currently, most patch antennas are designed on many commercial substrates that are costly and involve many chemical processes due to a combination of several substances. For example, Rogers, Taconic, FR4, and polyethylene terephthalate (PET) [2]–[8]. Based on these limitations, the organic substance has been explored intensively in order to propose an optional substrate that is low cost, degradable, and environment friendly [9], [10]. As reported in [11]–[13], dielectric substrate has been developed from the botanical plant, i.e., bambusa vulgaris and leucaena leucocephala. These two species have been chosen because they are easy to harvest and grow widely in many tropical countries, including Malaysia. However, due to environment concern and efforts to sustain the balance ecosystems, the harvesting activity involves bambusa vulgaris and leucaena leucocephala is limited. Another organic substrate material is banana fiber pulp that are made up from the banana fiber and recycled new papers was proposed in [14].

Pandanus atrocarpus has been chosen and investigated as the new material for antenna substrate. Pandanus is a tropical plant genus in the family of pandanaceae with more than 600 species, including pandanus atrocarpus, pandanus tectorius, and pandanus amarylloifolius. In Malaysia, pandanus atrocarpus is known as "pandan mengkuang." It is grown widely and easily found in the highland areas in Pahang, Kelantan, and Terengganu riverside, Perak and Terengganu rubber plantation, and Kedah beach areas. Their leaves were used as woven materials to make hats, mats, baskets, and traditional handcrafts. It also provides ecological services range including carbon sequestration and soil binding at the river and seaside area. Due to its elegant and predictable shapes, the plant is also used for landscaping area such as hotel compounds and roadsides [15]. Pandanus atrocarpus is also used as a source of natural fiber due to its versatile characteristics, and it has less impact on the environment than synthetic fiber [16]. However, no extensive research was conducted to determine its electrical properties in the microwave region to estimate its dielectric properties respond to electromagnetic signal, and finally to propose as an antenna substrate. Therefore, this research paper focused on investigating and analyzing the effect of leave moisture on dielectric constant and tangent loss values. Using vector network analyzer (VNA) and a specifically designed jig platform, the sample of pandanus atrocarpus was categorized into several levels and measured based on the moisture content in the leaves.

2. RESEARCH METHOD

Dielectric is an insulating material or a poor electric conductor and as the energy storage of the devices. Every material's electrical property, including living organisms and agricultural products, are different depending on their dielectric properties [17]. Material characterization is a critical and vital issue that can provide precious data and information for researchers and engineers in the material production, monitoring process, quality of bioengineering, food engineering, medial, and agriculture. Knowledge of the microwave properties is essential and vital in microwave engineering technology and developments.

$$\varepsilon_r = \varepsilon_r' - \varepsilon_r'' \quad (1)$$

$$\tan\delta = \frac{\varepsilon_r''}{\varepsilon_r'} \quad (2)$$

Commonly, each material has a different value of dielectric constant. Scientifically, the dielectric value depends on each material's storage capacity and the energy stored when the external electrical field is applied. Dielectric properties can be presented in a complex form that consists of dielectric constant (ε_r) and tangent loss ($\tan\delta$). From (1) real part, ε_r' is the absolute dielectric constant related to the material capacitance that measures the amount of electric field energy stored in the material. Meanwhile, the imaginary part, ε_r'' is the loss factor that represents how much energy dissipate. Tangent loss indicates the ratio of the energy lost (imaginary part) to the energy stored (real part) of the material, as shown in (2) [18].

Many dielectric constant measurement methods have been reported, such as coaxial probe method, transmission line method (waveguide), free space method, resonant cavity method, and planar transmission line method [19]–[22]. In this paper, the technique used to measure the value of the dielectric constant and tangent loss of pandanus leaves was the coaxial probe method. This testing method is considered as a nondestructive test because the measurement is conducted without affecting and damaging the substrate material [23].

The plant leaves' dielectric properties are essential and valuable for monitoring and managing the earth's resources [24]. Figure 1 shows the picture of the pandanus atrocarpus tree and leaves. In this preliminary research, the dielectric properties of pandanus leaves were analyzed based on three categories; freshly picked pandanus (sample A), 7-day-dried pandanus (sample B), 30-day-dried pandanus (sample C). All these samples are shown in Figure 2. Other processes have been conducted to prepare sample B and C. Since there was no standard method in preparing sample B and C, the traditional step was chosen. Figure 3 shows the process in the dielectric constant and tangent loss of pandanus atrocarpus measurement. The leaves were boiled and submerged in water for 2 days to get a smooth surface. Besides, this process increased the leaves' durability and flexibility so that the leaves would not break easily. After that, sample B and C were dried under the sun for 7 days and 30 days respectively to remove the water content before they were tested. Then, the samples were compressed with a press machine to produce flat surface leaves for dielectric measurement. Dielectric and tangent loss of sample B and C, which had different drying times, have been measured.

The dielectric constant and tangent loss measurement were performed as depicted in Figure 4 where; Figure 4(a) Keysight 85070E coaxial dielectric probe that was connected to the Keysight PNA-L N5232A vector network analyzer as shown in Figure 4(b). The VNA can measure from 300 kHz up to 20 GHz. The dielectric probe used in the measurement setup can measure up to 20 GHz and capable of measuring the dielectric properties of liquid, semi-solid, and solid. In the research, the dielectric constant and tangent loss of pandanus samples were measured at 5.8 GHz that was intended for 5G wireless device antenna.

Figure 1. Pandanus atrocarpus tree

Figure 2. Three different sample of pandanus atrocarpus, i.e., sample A (freshly picked), sample B (7 days after picked), and sample C (30 days after picked)

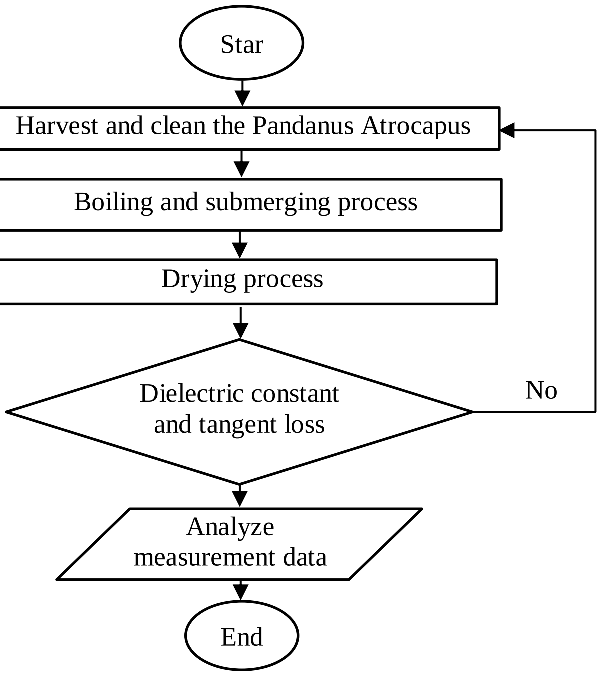

Figure 3. Flowchart of the dielectric constant and tangent loss pandanus atrocarpus leaves

(a) (b)

Figure 4. The dielectric constant and tangent loss measurement (a) Keysight PNA-L N5232A vector network analyzer and (b) keysight 85070E coaxial dielectric probe

The measurement setup of dielectric constant and tangent loss is depicted in Figure 5. The calibration of the dielectric probe and VNA was conducted with Keysight 85070E calibration kit. Before measurement, pandanus leave was sandwiched between two plywood jigs with nine measurement holes of 15 mm diameter that can cover 9 points of the measured substrate. The distance between the table and the measured substrate (height of the jig) must be $\lambda/4$ to avoid the signal from radiating to the air and increase the accuracy of measured reflection signal reading. A jig was used to hold the pandanus leaves sample to ensure the samples stiffness remained consistent. Furthermore, by using jig, the bending issues can be avoided if excessive force is applied to the material under test (MUT) [25]. The coaxial dielectric probe touched the flat surface of the MUT, and the dielectric constant and tangent were measured. The reflection method was applied at the coaxial dielectric probe measurement in which only one port of the vector network analyzer was used as the transmitting and receiving port. The reflected signal from the MUT was measured, and the measurement output gave a dielectric constant and tangent loss value at 5.8 GHz.

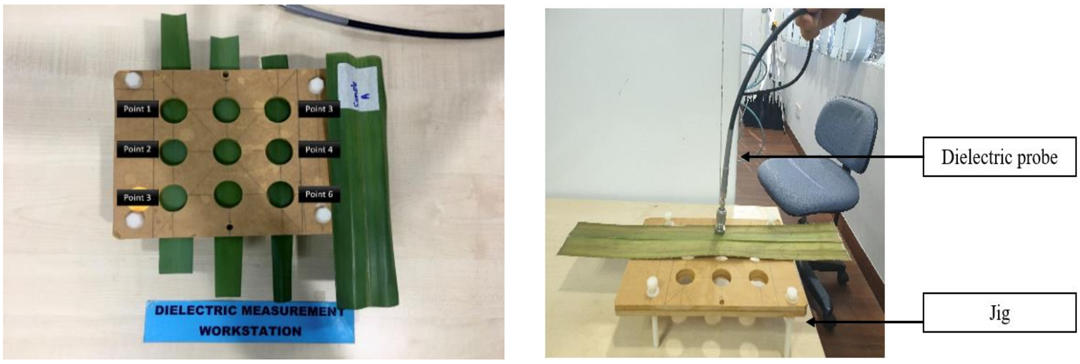

Figure 1. Measurement setup of dielectric constant and tangent loss

3. RESULTS AND DISCUSSION

Each sample of pandanus leaves was measured at six different points, as shown in Figure 4, and the test was repeated three times to increase the accuracy. Each piece has undergone a total of 18 dielectric properties measurements. However, the temperature effect during measurement was neglected due to limited devices. The temperature chamber was not available in the laboratory. Therefore, the testing was conducted at room temperature at approximately 26 °C to 28 °C. Three samples with different timelines have been analyzed to determine the variation value of the dielectric constant and tangent loss. As stated in the methodology section, sample A was freshly picked pandanus leaves while sample B and sample C were measured on day 7 and 30 of the drying process, respectively.

Dielectric constant and tangent loss value from sample A, B, and C for every 6 points are shown in Figures 6, 7 and 8, respectively. The measurement data of the dielectric properties for each was constant for six different points. As depicted in Figure 6, the value of dielectric constant of sample A for the three tests was between 1.53 to 2.45. The measured value of tangent loss was plotted between 0.104 and 0.237. The value of dielectric constant and tangent loss for sample B at the six points of the dielectric measurement point varied from 1.041 to 1.451 and 0.024 to 0.146, respectively. The measured dielectric constant value for sample C ranged from 0.906 to 1.068, while the tangent loss value for all six points was more consistent, which was 0.001 to 0.022.

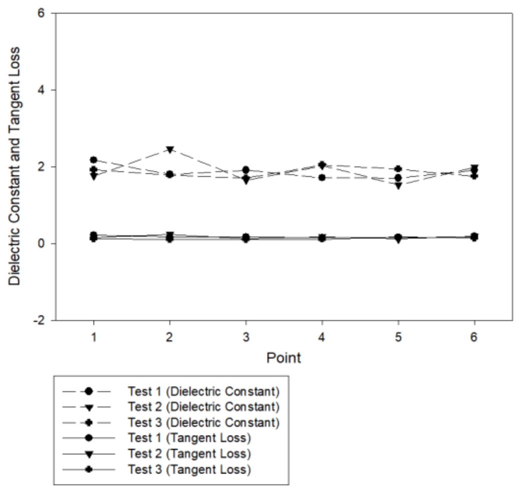

Figure 6. Graph of the dielectric constant and tangent loss of the pandanus leaves – sample A

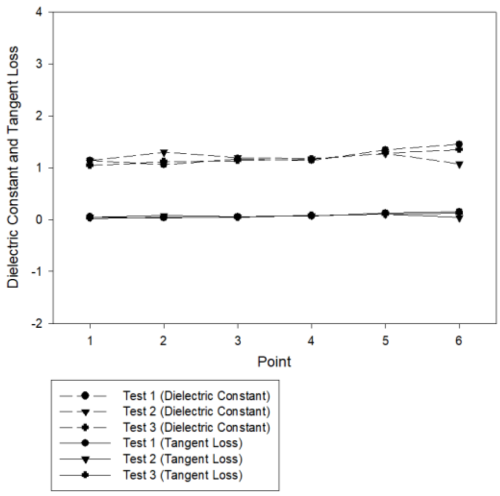

Figure 7. Graph of the dielectric constant and tangent loss of the pandanus leaves – sample B

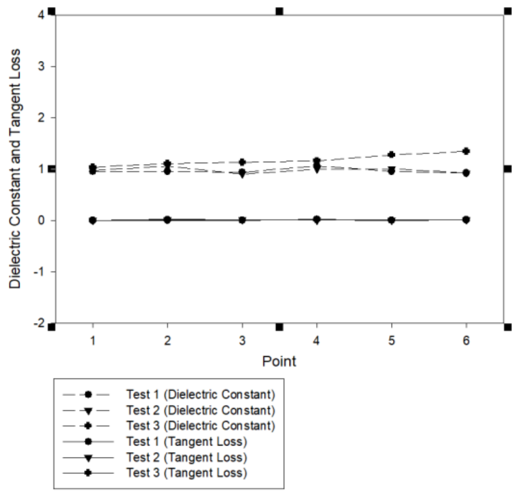

Figure 8. Graph of the dielectric constant and tangent loss of the pandanus leaves – sample C

Table 1 shows the tabulated data of the three samples, A, B, and C, respectively. These data were measured at 5.8 GHz operating frequency. The dielectric constant for sample A, B, and C were 1.873, 1.195 and 1.042, respectively. As the drying process increased, the value of the dielectric constant decreased from 1.873 to 1.042. Dielectric constant value is the capability of the substrate material to pass through the microwave signal and store the energy. It acts as the capacitor when the voltage is applied. The dielectric constant of sample C was 1.042, the lowest compared to the other samples. It showed more signal can pass through pandanus substrate. Sample A had the highest dielectric constant value, which was 1.873. This implies–that lesser signal can pass through the substrate and more microwave signal are stored in the pandanus substrate. Next, the value for the tangent loss for sample C was 0.009. The lowest compared to sample A and B. Lower value of tangent loss indicated that the substrate material had a good performance with more signal radiated and less power loss.

One of the crucial parameters in this measurement was standard deviation, which indicated the difference in the data set of dielectric constant and tangent loss. Sample B showed the lowest standard deviation, which was 0.109 compared to sample A and C in terms of dielectric constant. Meanwhile, tangent loss standard deviations for sample A, B, and C were 0.036, 0.035 and 0.06, respectively. The accuracy and reliability of the measurement data of pandanus substrate was established, as the value of standard deviation is lower and closer to zero. The low standard deviation showed that the measured data set of dielectric constant and tangent loss was more relative to the mean value.

Dielectric properties of plant material were strongly influenced by the water and moisture content in the substrate material. The dielectric constant of pandanus leaves was likely proportional to water content. Variation of pandanus leaves' dielectric constant was due to the different composition of a water composition for every sample. As the drying process increased, the pandanus leaves' water content decreased, and obtained values ranged between 1.873 to 1.042.

Table 1. Summarization of the microwave characterization for the pandanus atrocarpus substrate

Parameter	Sample A		Sample B		Sample C	
	Dielectric Constant (ε_r)	Tangent Loss ($\tan\delta$)	Dielectric Constant (ε_r)	Tangent Loss ($\tan\delta$)	Dielectric Constant (ε_r)	Tangent Loss ($\tan\delta$)
Mean	1.873	0.152	1.195	0.070	1.042	0.009
Min	1.529	0.104	1.041	0.024	0.906	0.022
Max	2.455	0.237	1.451	0.146	1.068	0.001
Standard Deviation	0.210	0.036	0.109	0.035	0.121	0.006

4. CONCLUSION

In this study, a new potential organic-based material from pandanus atrocarpus has been discovered. The microwave properties in terms of dielectric constant and tangent loss were measured, analyzed, and presented in this paper. The pandanus leaves were measured at 5.8 GHz at a different timeline. The measurement result showed that the change of water content inside the leaves would affect the dielectric constant and tangent loss value. Interestingly, the low values of dielectric constant at the proposed frequency that shown in the table indicates that, flexible substrate from will give the small effect if the substance is composed with additional substance in developing flexible dielectric substrate. In addition, the low dielectric properties of pandanus, as depicted from sample A, can contribute to shorter processing time in preparing or developing organic-based substrate for designing patch antenna. Consequently, it offers a newly based-organic dielectric substrate for antenna design. Lastly, future research can focus on creating a physical substrate layer and designing a patch antenna.

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