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Dielectric properties of complete oil palm trunk sample (healthy and unhealthy)

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ABSTRACT
Microwave technology is utilized in many fields, especially in measuring the dielectric properties. In this study, the dielectric properties of a complete Oil Palm Trunk (OPT) log are investigated for both healthy and unhealthy (has hollow inside) samples to be used for imaging purpose (to reconstruct an image of the hollow in an unhealthy sample). An open-ended coaxial probe technique is used for measurement. Both Dielectric loss and loss tangent follow the same trend through most of the frequency band. Although the current sample is bigger than recent similar works, the dielectric constant and dielectric loss are positively harmonized with its moisture content. Furthermore, the results are more realistic than recent related works since a complete sample with all its layers is used not only the core as presented in the literature.

I. INTRODUCTION
Oil palm is a tropical tree which is cultivated for industrial production of vegetable oil, rubber, and many other purposes. Most of the countries in Southeast Asia and some parts of Africa, exported oil palm plantation and their associated products. Malaysia, as an Asian country, is not an exception, and it is one of the most significant exporters of oil palm plantation in the world. For instance, till December 2012, it covered more than 15 percent of lands in Malaysia. The total life span of an oil palm trunk is about 25 years, which can be productive. In replanting period, almost 13.6 million OPT logs collected from every 100,000 hectares. Most of these cut logs prepared to be applied in the wood industry to make furniture, plywood, and so on. Furthermore, to make plywood only the outer part of a tree is used and the rest of it, is considered as waste. The internal parts used as either food for dairy cattle or biofuel. During the process of biomass fuel, microwave showed promising assistance in the drying process.

One of the challenges in the oil palm industry, especially oil palm wood is basal stem rot (BSR) that creates hollow in the oil palm trunk. The earliest visible symptoms of basal stem rot of oil palms occur in the foliage, generally after at least half of the cross-sectional area of the stem base has been destroyed. Decay leads to a restriction of water and nutrient supply to the aerial parts, causing symptoms resembling those of water stress and malnutrition. Visual symptoms alone are thus not necessarily diagnostic of basal stem rot, as other factors leading to water stress, such as drought, high soil water salinity, or hyperacid soils also cause similar foliar symptoms. To avoid the loss and the hollow created by BSR, the BSR should be detected in its early stage. Microwave imaging is non-invasive and fast that can help us to fulfill that goal and obtain an image with high resolution. The dielectric properties of the OPT should be known to reconstruct the image of the hollow in the trunk using microwave imaging. As compared to the usual heating procedure, microwave heating shows some certain advantages such as volumetric heating which is perfect for the bulky and high moisture content samples. Microwave energy can change the direction of the ion in biomass. This reorientation is done based on the electric field direction. In addition to that, microwave energy makes biomass’s molecules to move faster. The Dielectric properties of materials are achieved with the investigation on the reflected, transmitted, and even absorbed energy.
This study utilizes the coaxial probe dielectric measurement technique. The current study uses the coaxial probe technique because of being convenient and non-destructive. Besides, this method is excellent for applications which required broadband such as ultrawide-band (UWB) and microwave imaging of biomaterials (the primary purpose and the future work of this study is to detect and reconstruct the defects and hollow in OPT log). The sample (OPT) is considered a high loss mass due to the high percentage of its moisture content. Therefore, the coaxial probe technique can be a reliable choice for our purpose.

Some studies were performed to measure the dielectric properties of biomass. These works are dielectric properties of oil palm shell, empty fruit bunch, pine wood, softwood, sapwood, Solid Asphaltenes, Australian wood species (Slash pine and Spotted gum), sugarcane stalks, hardwood. Some other studies presented the other material evaluations and characterization of agricultural products such as bamboo, tomato, and Rapeseed.

The present study demonstrates the required knowledge about dielectric properties of OPT log along with the importance of some factors when the OPT sample exposes in the microwave field. This paper presents the effect of frequency, sample size, probe location on sample, moisture content, and fiber directions on the dielectric properties of OPT chump. This fundamental knowledge of dielectric properties significantly gives further insight in describing the behavior of OPT log biomass of different moisture content when subjected to a frequency range of microwave electric fields.

II. NUMERICAL CONSIDERATIONS

Each type of energy can be categorized with its term as the dielectric constant ($\varepsilon'$) is the ability of a material to store electric energy, and dielectric loss ($\varepsilon''$) is the ability of a material to convert the electromagnetic energy into heat. The related complex equation which presents the relation between dielectric constant ($\varepsilon'$) and dielectric loss ($\varepsilon''$) showed in Ref. 14. Furthermore, loss tangent is the ratio of dielectric loss to dielectric constant, and it defines how much microwave power is attenuated in a material which resulted in heating. In this section, the microwave considerations and principles of a lossy multilayer media are applied to OPT. For a better understanding of the wave propagation specifications in a multilayer media, four adjacent dielectric layers, three boundary surfaces, and the wave propagation models use.

The optional m-layered medium investigated in Ref. 31, is applied for the samples under test. According to the trunk sample shown in Figure 4 of Ref. 30 and Figure 3, both samples under test have four layers with both radius $l=0.15$m and $l=0.125$m. The numerical considerations assume the radial direction of the sample. Then it is located on the XOY plane when the wave touches the surface of the sample. The electric field ($E$) is propagating on Z direction, and the magnetic field is on the Y direction presented with equations 1 and 2.

$$E_z(x_m) = (A_m e^{-jK_{mz}x_m} + B_m e^{jK_{mz}x_m}) e^{-jK_{mz}y} \tag{1}$$

$$H_y(x_m) = -K_{mx}/\omega\mu_m(A_m e^{-jK_{mx}x_m} - B_m e^{jK_{mx}x_m}) e^{-jK_{mx}y} \tag{2}$$

$x_m$ is the interface between every two layers. Since there are four layers, $m$ is 4, and four interfaces exist as well. Also, both $A_m$ and $B_m$ are the wave amplitudes along the X direction. If the length of each layer given by $l_m$, then for each of the above equations, the field equation can be rewritten replacing $x_m$ with $(x_m + l_m)$ (Figure 1). In the end, by combining these four equations, a general matrix equation can be derived to attain the fields of each layer.

The magnitude matrix calculates by multiplying the matrix of each layer to each other. Both reflection and transmission coefficient of 4 layered sample can be extracted from the last matrix and then shown in Ref. 31.

Each layer has a different dielectric constant, and since the sample is nonmagnetic material, the permeability considers as 1. Thus, in the previous equations, only the permeability of free space is considered. Since the trunk sample is a lossy medium, the equations for a low loss medium can be used to obtain the phase constant, attenuation constant and intrinsic impedance to analyze the wave propagation with the help of equation (3-5). 31

III. PROCEDURE

Figure 2 shows the diagram of dielectric properties measurement.

The OPT chump received from a local farm in Perak, Lumut, Malaysia. This study uses a 10-year-old healthy OPT, and after cutting the branches and the other unwanted part of it, the trunk biomass cut into cylinders. Afterward, two samples apply for testing. The dimensions of these two samples are 25 cm × 12 cm (diameter, height) and 30 cm × 15 cm. Based on what is shown in Figure 2, almost 70 percent of the OPT clog in a cross-section consist of the central part which has more moisture content, more mass density, and less vascular bundles. Besides, the clog has some vascular bundles which scattered all over the log, and they located closer to each other next to the edge, and more space exists between them when they are getting close to the center of the clog (Figure 2). Therefore, due to the OPT physical structure (in terms of having more/less vascular bundles), the investigations are performed in three structural directions such as cross-section, radial, tangential to analyze the impacts of these directions on dielectric specifications of the samples.

Before starting the measurements, each of the cylinders is polished with sandpaper to make the samples’ surface smooth and reduce any possibility of air bubble existence between the sample
FIG. 2. The measurement setup (a) and diagram (b) of the dielectric properties.

and the probe. Because the presence of an air gap between the sample surface and the probe can lead us to an incorrect and false measurement result; moreover, the moisture content investigation of the samples is another critical parameter that should be considered to show how it affects the dielectric properties of the log. Hence, to prepare the samples with different moisture content, the OPT clog biomass is dried in an oven (humidity chamber model: DSW0520S-S316EX) at 60 ± 10 °C at different time intervals by following the method presented in Ref. 33. For example, if the sample has the moisture content of 87 % initially, the sample is getting heat in this chamber with different time intervals until the sample dries almost completely. The percentage of moisture content is checked calculating the sample’s weight differences throughout the drying procedure.

Figure 3 and Figure 4 demonstrate the differences between the applied sample and the similar study (the red cube), and the directions when the sample is under test, respectively. Furthermore, the dielectric properties of OPT chump are measured applying an open-ended coaxial probe which is connected to a Vector Network Analyzer (VNA) model HP 85070-D, as shown in Figure 2. As aforementioned, the microwave heating and microwave imaging are non-destructive measuring method. Besides, their low power measurements do not cause any harm and alteration in neither the biomass characteristics nor the human body during the test. Thus, a 3.5 mm diameter open-ended probe is touched the sample surface based on the previous method. The applied method of the measurement relies on the reflection coefficient of the coaxial probe when it reaches the sample surface.32 Hence, the dielectric properties of the log are measured concerning the magnitude and the phase of the reflection coefficient at each frequency of the band.33 Besides, all the locations on the sample are under test from the central part to the edge of the bark and cortex; however, the sample is divided into five parts and five points of these parts shown in the result section (All part of

FIG. 3. The samples in different dimensions in cross section view.

FIG. 4. Structural directions of OPT with Probe sensor positions in a: radial, b: cross section, c: tangential (P1−P5 are the chosen points).
sample surface in each direction are examined. Then they are divided into five parts and the most significant result of each part presented as P₁-P₅).

Although, an open-ended probe frequency range can be set for a broad range of frequency between 0.5 GHz and 110 GHz; the frequency range of the VNA set from 500 MHz to 6 GHz. Furthermore, this frequency range validates for ISM (Industry, Scientific, Medical) frequency bands, which are 0.915 GHz and 2.45 GHz, plus the materials with loss factors higher than 1. After setting the frequency range of the VNA, the probe calibrates with distilled water. Therefore, the probe is inserting into the glass container content of distilled water, and then the calibration procedure is continued. The calibration must be done to have no error and false result during the measurement. Based on the previous explanations, the analysis of the sample is performed several times to validate the high accuracy results; then, their average significant values use for evaluation and investigation. Both dielectric constant (ε') and dielectric loss (ε") are achieved by direct measurement while the formula (ε"/ε') obtains the loss tangent.

Since two independent parameters are considered in each evaluation step, for example evaluating of dielectric constant and frequency; therefore, two-way ANOVA test is used for the mean values to determine the significant difference between all variables and parameters considered in this study. The first thing in the ANOVA test is to be sure that our data can be analyzed using ANOVA test. Thus, the data should pass the first six assumptions, which might take a bit more time. The ANOVA test shows us if the effect of one of the independent parameters on an independent variable is the same, for all values of the other independent parameters will be the same. Furthermore, if any significance finds it is required to find out if there is any simple impact caused by them and then they should be defined. To perform the ANOVA test, SPSS and Excel are used.

IV. RESULTS AND DISCUSSION

The results are considered and investigated in terms of the sensor’s (probe) locations, samples’ size (for the unhealthy sample), frequency range, and the moisture content for both the healthy and unhealthy trunk sample.

A. Healthy trunk sample

The impacts described above on OPT sample present as follows:

1. Sensor locations

Figure 5, Figure 6, and Figure 7 show the dielectric constant, dielectric loss, and loss tangent in terms of the sensor locations along with the frequency. In this section, due to the data volume, the result of the healthy sample with the almost initial 87 % moisture is presented only. Moreover, all three directions (cross-section, radial, tangential) are considered for each of these variables shown from Figure 5 to Figure 7. As depicted in Figure 5, the dielectric constant decreases when the sensor is moving from the center to the edge of the sample from point 1 to point 5 (as shown in Figure 4 as P₁ to P₅). This decrement is due to the density of the moisture, the higher density of the mass, a smaller number of vascular bundles at the center as compared to the edge of the trunk.

2. Effect of frequency

The experiment is fulfilled at the frequency of range from 0.5 GHz to 6 GHz to analyze and investigate the frequency effect.
on dielectric properties of OPT log just for the sample with smaller dimensions (0.3 m diameter), and then the results are shown in Figure 8 and Figure 9. These results show the frequency relevance and how the fiber direction alteration can modify it (the results present in this part are their maximum and most significant at each direction). The dielectric constant ($\varepsilon'$) is declined with the enhancement of frequency from 0.5 GHz to 6 GHz in all directions of fiber. Therefore, the results demonstrate that the electric field (E) produced by microwave can affect the reciprocal action of OPT log with electromagnetic waves. Plus, raising the frequency from 0.5 GHz to 6 GHz develops a simultaneous variable electric field.

The variable electric field creates a polarization in the log sample. Furthermore, when biomass positioned in this electric field, the dipole moments in it is reduced by frequency increment. Hence, these dipoles do not have enough time to change their direction based on the electric field direction. Besides, the conductive impact of microwave heating shrinks with frequency increase. Thus, the dielectric constant, which depicted the capability of the material to save electric energy, is degraded. Regression for each of the fiber directions is more than 0.9, where the regression lines firmly fit with the actual data of dielectric constant. The decrement orientation of dielectric constant when the frequency was increasing is almost the same and similar to some
other biomass trunk which presented previously such as rubberwood, softwood included Black spruce, Balsam fir, and Tamarack, empty fruit bunch of oil palm, oil palm shell, oil palm fiber, biochar from oil palm shell, green pea flour, lentil flour, and soybean flour. Also, Figure 8 and Figure 9 show a similar tendency in all directions and for each of dielectric constant, dielectric loss and loss tangent (since the center position of each direction has a significant result as compared to the other locations, only the center position’s result shown as $P_1$ in Figure 4 presented in Figures 8 and 9). In comparison with the other two fiber directions (radial and tangential), cross-section direction indicates a dramatic increase in dielectric constant with the highest value. This peak in dielectric constant is due to the high percentage of the moisture content in the cross-section direction when the sensor touches the sample surface. In addition to that, the Standard error of the experiment replication is small, too ($<0.55$). Furthermore, both frequency and the fiber directions are strongly harmonized with dielectric constant since the significant value of $e'$ is less than 0.05.
Both factors, the standard error, and the significant value, calculate for all the directions. For both radial and cross-section, they show promising results. Therefore, it concludes that cross-section and radial directions of the log have enough capability of storing energy rather than tangential direction. Another item that might have affected the differences in dielectric constant in different directions is their fiber structure.

3. Effect of moisture content

The impact of moisture content on dielectric properties is studied at 2.45GHz (this frequency band is known as ISM band and widely used for the same purposes). The original moisture content of the OPT log is 87 % for the bigger sample and 82 % for the smaller one. Based on the known fact that water can absorb too much energy, it is not difficult to understand that the moisture content affects the dielectric properties of the biomass sample in interaction with the electromagnetic wave energy.

In this study, dielectric constant, dielectric loss and loss tangent of the OPT chump in all three fiber directions show a positive correlation with the moisture content presented in Figure 10, Figure 11, and Figure 12, respectively (same as Figures 8 and 9, only the center position’s result shown as $P_1$ in Figure 4 presented in Figures 10–12.

**FIG. 11.** The effect of moisture content (%) on dielectric loss (a: Cross section, b: Radial, c: Tangential).

**FIG. 12.** The effect of moisture content (%) on loss tangent (a: Cross section, b: Radial, c: Tangential).
due to the significance of its outcome in comparison with other positions). However, the regression evaluation of dielectric constant in tangential direction created smaller $R^2$ ($R^2 = 0.458$). Besides, regression evaluation dielectric loss and the loss tangent become smallest in tangential ($R^2 = 0.357$) and radial direction ($R^2 = 0.199$). As mentioned before, due to the perfect absorption of the microwave by water, the moisture content produces a high polarization when it encounters with microwave power. Thus, when there is more moisture content, more amount of energy stored in the OPT sample. In addition to that, the dielectric constant as a factor which illustrates the ability to direct the molecules in the presence of the electric field enhances with moisture content increase. Besides, Figure 10 depicts that the dielectric constant is low when the percentage of moisture is low, and it's high when it gets to a higher level. These correlation trends are similar to other biomass reported previously, such as empty fruit bunch31, hard red winter wheat, and yellow dent field corn.

Figure 11 shows the dielectric loss versus the moisture content. The dielectric loss increases until it gets the peak at almost 30 percent of moisture content for the cross-section direction. Then, it suddenly declines to 10 at 50 percent moisture. Afterward, it keeps reducing to 6. Finally, it dramatically increases to the peak of it at 82 %. Furthermore, for both radial and tangential directions, it is growing gradually except at 82 %, which reduces. In an overall trend, it shows that the dielectric loss is increasing with moisture content.

Based on the amount of microwave and electric energy that the OPT sample receives, it gets warmer. Since the input power of the wave generator is constant for the signal that is sent by the VNA, the percentage of the moisture content controls the time interval that the sample gets heat to lose the moisture percentage and get dried.

Two ways ANOVA analysis assists in investigating how dielectric loss, moisture content, and fiber directions are related to each other. Dielectric loss is found to depend on moisture content and fiber directions with a significant value less than 0.05 (standard error on the replication of the experiment is less than 0.15). Both Figure 10 and Figure 11 depict that the dielectric constant and dielectric loss elevate with an increase in moisture content. However, this increment is less for dielectric loss. Since the loss tangent depends on both dielectric constant and dielectric loss, it augments with them as well as when they go up loss tangent raises as well. As shown in Figure 12, the tangent loss increases gradually for both radial and tangential directions except around 60 % of moisture content. In overall, the tangent loss starts degrading after almost 45 % of its moisture content. After all these outcomes, it concludes that the OPT log would be efficient enough in converting the microwave energy in
low moisture content, and consequently, efficiency reduces at higher moisture content.

The classification of material’s loss tangent organized into three groups demonstrated in Ref. 37. In this study, the loss tangent is presented in Figures 5–12 as it is measured and calculated in all directions in terms of the sample’s moisture content, size, and the sensor location. As noticed, the loss tangent’s range changes between 0.15 and 0.85. Hence, OPT log can be a medium which absorbs microwave energy. Furthermore, when the biomass has a higher tangent loss level, it shows the capability of the biomass in rapid heating since it can store more energy in it and convert the electromagnetic energy to heat.

**B. Unhealthy trunk sample**

The same procedure applied for the healthy sample is used to test the unhealthy sample in terms of sensor positions, size, and frequency. The unhealthy sample is dried when it encounters with the fungus. Thus, the effects of moisture content on the unhealthy sample does not consider in this study.
Figure 13 shows the dielectric properties results of the unhealthy sample for both dielectric constant and dielectric loss on various parts of the sample for radial direction. The dielectric constant of the unhealthy sample illustrates that when the sensor touches the spot near the center, its value is higher than when it is getting closer to the edge of the unhealthy sample (the unhealthy sample follows the same trend from the healthy sample). The points where the probe sensor touches the sample’s surface follow the spots shown in Figure 4 (P₁–P₅).

As aforementioned, Figure 13 follows Figure 4 in the investigation of dielectric constant and dielectric loss. Point 1 in Figure 13 shows the center of the sample in the radial direction shown as P₁ in Figure 4. In Figure 4, the sample is divided into five parts for each direction as P₁–P₅. P₁ is at the center of the sample and other four points are the points with significant result among the result of each section. For instances, the sample shown in Figure 4 has a thickness of 10 cm (radial direction). After dividing this 10 cm by 5, each testing section has two cm. Afterward, the probe surface touches each part of this two cm around the sample in a circle, and finally, the significant outcome for each 2 cm section (around the sample as a circle in the radial direction) is depicted in Figure 13.

2. Effect of size

Figure 14 demonstrates how the size of the sample affects and changes the dielectric properties of the unhealthy sample. The sample trunk diameters are 18 cm, and 25 cm, and the direction of the sensor probe is radial when the test is running. The probe position for both samples of different size (the 18 cm and the 25 cm diameter shown in Figure 14) is presented only for the center of the sample in the radial direction (Figure 4(a) shows this location as P₁). Furthermore, Figure 14 depicts that both dielectric constant and dielectric loss are higher for the sample with the bigger size. When the dielectric constant is low, it shows that the stored energy in the sample is too low due to the small percentage of the moisture content. When the sample is affected by the fungus and BSR, it loses most of its moisture content and cannot absorb and save enough microwave energy.

3. Effect of frequency

Figure 15 shows the effect of frequency variation on the dielectric properties of the unhealthy sample. Both dielectric constant and dielectric loss reduce when the frequency enhances. Same as the healthy sample, the unhealthy results illustrated in Figure 15, follow the same trend as the cross-section direction has the highest level, and then the tangential and radial directions follow the cross-section direction (the results presented in Figure 15, are the
results when the probe location is at the center known as $P_1$ for each direction).

In Figure 15, the decrement takes place in the radial direction is due to the layers that are on the way of the sensor (while sending wave) when it touches the sample. On the other hand, there are only some vascular bundles in cross-section and tangential directions which affect the wave propagation, but in the radial direction, the layers resist against the wave and the microwave power to penetrate the sample. Hence, the cross-section direction has the highest dielectric properties level among them.

Figure 16 illustrates a comparison between the healthy and unhealthy sample in the radial direction (only the results for the center position of the probe ($P_1$ in Fig. 4) is illustrated in Figure 16 because of its significance compared to other locations in radial

**FIG. 19.** Received signals in both Z direction (a) and X direction (b).
directions). It clearly shows that both healthy and unhealthy samples are following a similar tendency. Moreover, for all three parameters, the dielectric properties level for the healthy sample is higher than the unhealthy sample. The dramatic difference is because of the low moisture content (almost dry) of the unhealthy sample; besides, the unhealthy sample doesn’t consist of water molecules and cannot absorb the microwave electric field energy and get heat (according to the purpose of the paper “Imaging of the sample to detect the defects in oil palm trunk” to be used as the next step of paper presented in Ref. 42, only data in radial direction uses since the UWB antenna shown in Ref. 42 is going to be located around the sample in radial direction).

Figure 17 presents the electric field variations of a cube made of a material with the same dielectric constant as what achieved from a healthy OPT in a radial direction. A 3D wave simulator name CST is used to simulate the electric field of an OPT log. The total dimensions of this OPT log are 10 cm × 10 cm × 15 cm and the dielectric constant of 15 at center frequency of 3 GHz. Furthermore, the OPT log sample is exposed in a plane wave with an input power of 1 mW. It is evident that changes occur when the E-field penetrates and moves through the trunk sample. The electric field amplitude decreases when it permeates deep into the material until its faded. In addition to that, the maximum E-field magnitude in the first layer is almost 3 V/m, and this amount reduces to zero for the last layer. When the incident wave faces the first layer of the sample, part of this wave transmits to the next layer, and part of it reflects the same layer. Hence, the transmitted wave of the first layer is equal to the incident wave of the second layer, and the other layers follow the same trend. However, for the last layer, no reflected wave is detected due to the lowest amplitude that this layer receives. Hence, the final layer contains the incident wave only.

Based on the microwave principles presented in section II, any alterations in dielectric properties of the material changes the amplitude of the signal and the electric field. For instances, the variations in dielectric constant at the boundary between the healthy and unhealthy tissue change the amplitude of the transmitted signal and magnitude of the electric field. Therefore, for the imaging purpose of the OPT log, it would be a way to detect the defects and hollow in the sample.  

To validate the dielectric measurement of OPT presented in this study and show that these measurements can be applied for microwave imaging purpose, a UWB antenna is operated and designed at 3 GHz. A slice of healthy wood with the same permittivity achieved from section IV, imported in CST simulator with two antennas (presented in Ref. 42) in both sides of the wood slice (Figure 18). Figure 18 shows two antennas, antenna 1 as the transmitter (Tx) and antenna 2 (Rx) as the receiver. In this Figure, the Tx is kept fixed, and the Rx is moving around the sample based on the φ direction.

Figure 19 presents the received signals from Tx in two directions Z and X. It concludes that this slice of OPT with the achieved dielectric constant from section IV can be used for microwave imaging since the received signals’ shapes do not change (very similar or high percentage of fidelity) but their amplitude. In addition to that, the array arrangement presented in Ref. 42 applies to obtain the received signals in both X and Z directions. In Refs. 42, 45, 46 showed that the received signals from the arrays should be similar enough with a high percentage of fidelity. It is required to calculate the signal fidelity since signal distortion is a critical issue. Fidelity can be considered as the magnitude of the cross-correlation when it reaches its maximum between the transmitted and received pulse. Based on the high fidelity presented in Ref. 42, there is low distortion in the transmitted signal. Thus, the antenna depicted in Ref. 42 and the dielectric properties shown in this paper can cooperate to get an image of defects in OPT. Furthermore, the dielectric properties of the OPT are necessary for imaging, because it is required to calculate the delay in receiving signal between every two antennas.

V. CONCLUSION

This study investigates both healthy and unhealthy OPT in terms of OPT size, sensor location, frequency, and moisture content. The dielectric constant of the OPT log is decreased with frequency increase while this increase did not show a significant change in dielectric loss and follow the same trend. Furthermore, the dielectric constant and dielectric loss of the OPT log is altered with moisture content positively. Following the moisture impacts on dielectric measurement, OPT log can be categorized as a medium with the ability to absorb microwave energy and converting it to heat. Notably, at higher moisture content, it can save more energy when the loss tangent is high. Also, the electric field investigation of the sample shows that the electromagnetic principles meet the multi-layered sample conditions like OPT. In addition to that, the present study shows more realistic result since it is taking account a complete OPT log sample (not only core which was tested in previous similar work shown in Figure 3). Besides, after using two UWB antennas at both sides of the sample, it has noticed that the received signals from different angles around the antenna do not change their shape but the magnitude. Hence, this sample can be a suitable environment for microwave imaging.

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