# Classification of treated and untreated water using Artificial Neural Network (ANN) based on Microwave Non destructive Testing (MNDT) method approach at 18-26GHz frequency range.

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*Abstract* – The main objective of this project is to introduce a technique to characterize treated and untreated water and developed a system that can classify these two types of water. In order to classify the water types, four stages of processes are involved. There are process of collecting water samples, measurement by using Microwave Non Destructive Testing method, finding parameter of dielectric constant and loss factor using FORTRAN software based on S11 parameters and classification process. The classification task is performed by using Artificial Neural Network (ANN) and the classification program was developed using MATLAB R2008a. The characteristic of the water samples was conducted using equipment known as Free Space Microwave Testing (FSMT) via the method of Microwave Non-Destructive Testing (NDT) at frequency 18GHz to 26GHz. Non-destructive testing is a method for determining the characteristics of materials without permanently changing its properties. There are 14 water samples was selected as a training samples for ANN .In order to see whether the developed system is successful or not another 28 samples have been tested. From the result obtained the ANN can classify all the testing samples correctly.

*Keywords*- Free space Measurement System (FSSM), and Vector Network Analyzer (VNA), Microwave Nondestructive Testing, Thru, Reflect, Line (TRL), and Artificial Neural Network (ANN)

## I. INTRODUCTION

Recently, many construction activities whether indoor or outdoor have been done in most of the area in Malaysia. Sometimes, there is a problem that arises from their activities such as water is flowing or coming out from the unknown source which can bring them a trouble. In construction site, normally there are only two sources of water, whether it came from leaking piping system itself or from underground. Therefore, this project is proposed to solve this kind of problem. In this paper, underground water is defined as untreated water whereas the pipe water is defined as treated water.

### Microwave Nondestructive Testing (MNDT)

Permittivity and permeability of materials at microwave frequencies can be measured in many ways [1]. For this project, these parameters of materials were measured by using free space measurements. Free space measurements of microwave reflection and transmission of materials has been performed for some years [2]. For microwave techniques, it has been used in a large number of applications that can be classified as nondestructive testing applications [3]. MNDT techniques have advantages over other NDT methods (such as radiography, ultrasonic and eddy current) regarding low cost, good penetration in nonmetallic materials, good resolution and contactless feature of the microwave sensor (antenna) [4]. However, MNDT still have errors [4] which are due to diffraction from the sample which is minimized by using spot focusing horn lens antennas. And also, errors due to multiple reflections between antennas were minimized by using free space TRL, (Thru, Reflect, Line) calibration technique and time domain gating which is a feature of VNA.

The samples of water are contained in a plexiglass container which has two plates of materials with known dielectric properties. Metal back method is used in a measurement of dielectric properties of treated and untreated water. Complex reflection coefficient ($S_{11}$) is measured for Plexiglas container backed by metal plate [5]. Dielectric constants and loss factors were measured for treated and untreated water in the frequency range f 18 to 26 GHz. Pipe water is the sample for treated water whereas underground water is the example for untreated water.

## II. THEORY

### Microwave Nondestructive Testing (MNDT)

The metal back method only used the value of reflection coefficient (S11) to calculate the complex permittivity of the sample. Figure below shows the diagram of metal back method for liquid sample.

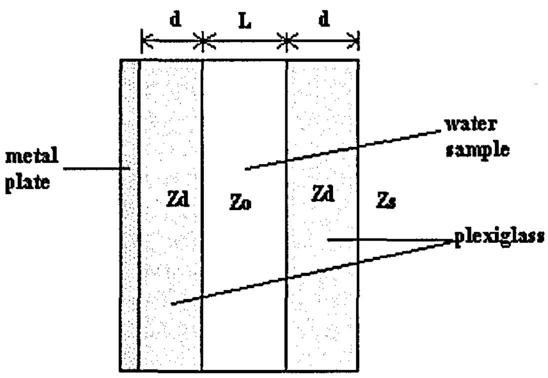


Figure 1: Diagram of metal back method

Where d is the thickness of plexiglass layer and L is the thickness of water sample. Reflection coefficient (S11) was measured by inserting the metal plate at the receiver side. The thickness, d of the plexiglass was quarter wavelength that is determined by equation (1) and (2) below.

$$\text{Quarter wavelength} = \frac{\lambda}{4} \quad (1)$$

$$\text{where } \lambda = \frac{c}{f} \quad (2)$$

$\lambda$ is the wavelength, c is the speed of light in free space ($3X10^8$) and f is the mid band frequency (22GHz)

Zs is the characteristic impedance for sample which is defines as [3]

$$Z_s = \frac{Z_o}{\sqrt{\varepsilon'}} \quad (3)$$

The characteristics impedance for plexiglass was defined as below;

$$Zd = \frac{Zo}{\sqrt{\varepsilon_d{}'}} \quad (4)$$

Characteristic impedance for free space, Zo;

$$Zo = \sqrt{\frac{\mu_o}{\varepsilon_o}} = 377\ \Omega \quad (5)$$

Complex phase constant for sample and Plexiglas can be defined as

$$\beta_s = \frac{2\pi}{\lambda_o}\sqrt{\varepsilon_s} \quad (6)$$

$$\beta_d = \frac{2\pi}{\lambda_o}\sqrt{\varepsilon_d{}^*} \quad (7)$$

Xd and Xs were defined as below equations;

$$X_d = \tan(\beta_d d) \quad (8)$$

$$X_s = \tan(\beta_s L) \quad (9)$$

Then, by using transmission line theory, it can be shown that input impedance Z1 for metal back Plexiglas and the sample layer as shown in figure 1 is given by;

$$Z_1 = \frac{j(X_d Z_d + X_s Z_s)}{\left[1-\left(\frac{X_s}{Z_s}\right)X_d Z_d\right]} \quad (10)$$

Denoted that Z1 as some function f1 ($\varepsilon_s{}'$).

$Z_2$ is the input impedance of the metal-plexiglass-sample-plexiglass assembly as shown in figure 1. The relationship of $Z_2$ and the S11 is as shown in equation below;

$$Z_2 = Z_o \frac{1+S_{11}}{1-S_{11}} \quad (11)$$

From transmission line theory, the following relationship has been found;

$$Z_1 = Z_d \left[\frac{Z_2 - jX_d Z_d}{Z_d - jX_d Z_2}\right] \quad (12)$$

Denoted that $Z_1$ as $f_2(\varepsilon_s')$ .

Then, the error function E is defined as given below.

$$E = f_1(\varepsilon_s') - f_2(\varepsilon_s') \quad (13)$$

It is necessary to find $\varepsilon_s'$ iteratively by finding zeros of the error function.

Loss factor refers to the imaginary part of the complex permittivity and denoted by ε". Loss tangent is comparison between loss factor and dielectric constant. Loss tangent can be referring to a measure of the energy loss in the form of heat. The formula for loss tangent is

$$\text{Loss tangent} (\tan \delta) = \left|\frac{\varepsilon''}{\varepsilon'}\right| \quad (14)$$

ε" is refer for loss factor and ε' is dielectric constant.

**Artificial Neural Network (ANN)**

The implementation of a neural network system was developed to classify the treated and untreated water samples. The classification process between these two water samples being made based on their loss factor and loss tangent since both parameter are distinguishable.

**Network Architecture**

Figure 1 below shows the neural network architecture. A typical feed forward neural network consists of three layers network which are input layer, hidden layer and the output layer. In this network, three layers of sigmoid neuron in the hidden layers and two layers of neuron in output layers were set to train with multi-vector input.

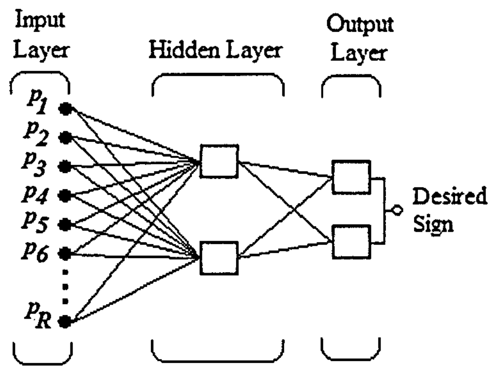


Figure 2: Feed Forward Neural Network architecture

**Neuron Layer model**

Figure 2 shows a neuron layer model in the hidden layer of the network. The input vector ($P_1$, $P_2$... $P_R$) were multiplied by weights ($W_{1,1}$, $W_{1,2}$,..,$W_{1,R}$) and fed to the summing junction. The bias *b*, on the neuron were summed with the weighted input to form *n*, this argument are represented in (4).

$$n = w_{11}P_1 + w_{12}P_2 + \cdots + w_{1R}P_R + b \quad (15)$$

The output *a*, in the output layer can be represent as equation below;

$$a = f(w_R P_R + b) \quad (16)$$

*F* is an activation function using tan-sigmoid transfer function which generates output between 0 and 1.

$$f(x) = 1 \text{for} x > 0 \quad (17)$$

$$f(x) = 0 \text{for} x < 0 \quad (18)$$

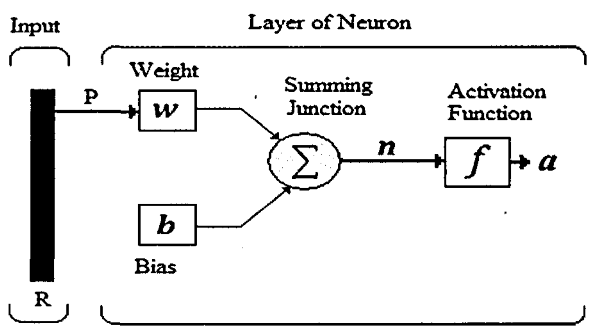


Figure 3: Neuron Layer diagram

A specific target were set and trained to perform the particular function of neural network for a classification system until the output of the network matched the target. The neural networks are trained based on the target output.

TABLE I
Target vector for both samples

| Samples | Target |
|---|---|
| Treated water | 0 1 |
| Untreated water | 1 0 |

## III. METHODOLGY

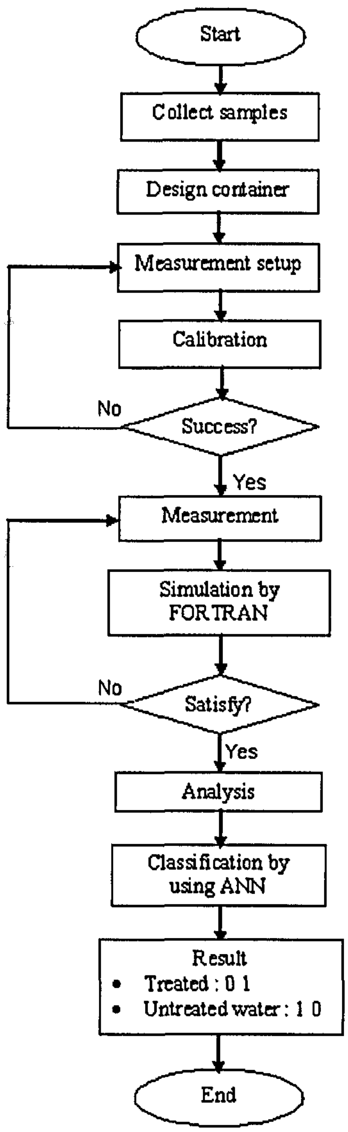


Figure 4: Methodology process

## IV. MEASUREMENT SETUP

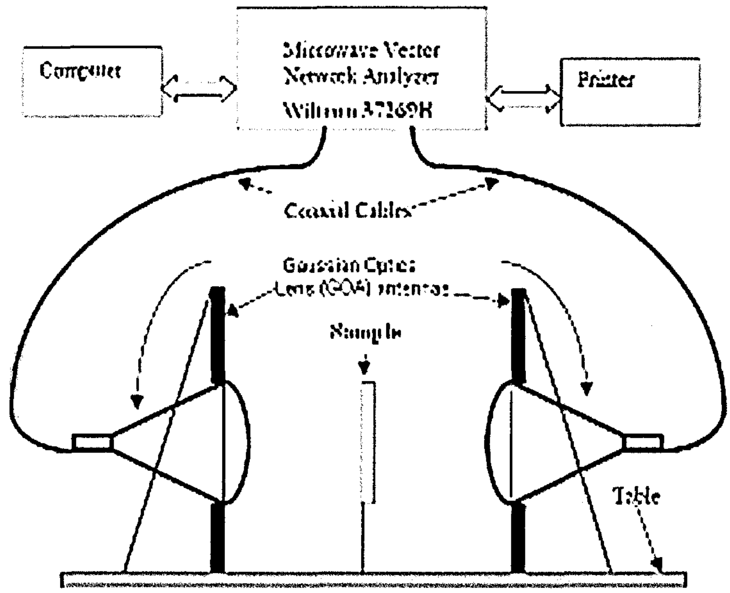

Figure 5: Schematic diagram of free space microwave measurement system

Figure 5 above shows the complete schematic diagram of the free-space microwave measurement system.

Measurement setup is consisting of GOA antennas, coaxial cables and WILTRON 37269B Vector Network Analyzer (VNA) as shown in figure above. The transmitting and receiving antennas are spot focusing horn lens antennas which are laid on a large table (1.83m by 1.83m). The spot-focusing antennas are connected to the two ports of S-parameter test set by using circular-to rectangular waveguide adapters, rectangular waveguide to coaxial line adapters , (Agilent K281C Coaxial Waveguide Adapter) and precision coaxial cables. The S-parameter measurements in free space were measured by WILTRON 37269B Vector Network Analyzer. FORTRAN PROGRAM was used to implement the equations (3) to (13).

## V. CALIBRATION SETUP

The TRL (Thru, Reflect, Line) calibration techniques for free space measurement system of S-parameters must be done to eliminate errors due to multiple reflections between coaxial-to-rectangular waveguide adapters, rectangular-to-circular waveguide transitions and the antennas. These calibration errors are minimized by using time-domain gating which is a feature of VNA.

Free-space TRL calibration is implemented by establishing three standards, namely, a through connection, and a short circuit connected to each port and a transmission line connected between the test ports. For thru calibration concept, devices are set to be 0.00mm which means there is no sample is located at the middle of sample holder. Line calibration concept involves the mid band frequency which is 22GHz. The distance of the antennas is changed by changing the gauge meter to 3.409mm from the center of the middle reference plates. For reflect calibration technique, the distance must be moved behind depends on the thickness of the metal plate that used (3.18mm). The process of calibration technique must be done after ensure that the focal distance to antenna diameter (F/D) of the lens is equal to one and D is approximately 30.5cm. S-parameter measurements in free space were measured by WILTRON 37269B Vector Network Analyzer (VNA) system. Vector network analyzer measures amplitude and phase of reflected or transmitted signal in transmission media such as coaxial line, rectangular waveguide, microstrip line and free-space. Wiltron 37269B network analyzers also can perform rationed measurements (including phase), which require multiple receivers.

After TRL calibration, the thru connection was measured for $S_{11}$ readings and the reflect connection was measured for $S_{21}$ readings. The amplitude and phase of $S_{11}$ were 0.0±0.2dB and 180°±1° while the amplitude and phase for $S_{21}$ were 0.0±0.1dB dB and 0°±1° respectively.

After calibration has been done, for the verification purposes, Teflon and Plexiglas materials were measured for the dielectric properties at 22GHz. measured dielectric constants of Teflon and Plexiglas sample are 2.03 and 2.67 respectively. The standard values of Teflon and Plexiglas is 2.08 and 2.65 as reported data from Von Hippel [6]. There is a good match in dielectric constant values.

## VI. RESULT

The calibration errors can be further reduced by using time domain gating or smoothing function of VNA. From calibration results, it is observed that magnitude and phase of S11 are within ±0.1dB and ±1° of the theoretical value of 0dB and 180° for the reflect calibration. For the thru calibration technique, S21 are within ±0.05dB and ±0.5° of the theoretical values of 0dB and 0°.

The measured value of the complex permittivity of Teflon and Plexiglas at 22GHz are 2.03 and 2.67 respectively. Quarter wavelength for a Plexiglas was 3.409mm.

The complex permittivity, loss factor and loss tangent of the treated and untreated water have been calculated using the computer simulation based on the equation (3) to (14). The tabulated results were selected from 19.3GHz to 23.98GHz because of the inconsistency of the dielectric properties at the lower and upper K band frequencies.

TABLE 2
Dielectric Constant, Loss Factor and Loss Tangent for untreated water

| Frequency | Dielectric Constant | Loss Factor | Loss Tangent |
|---|---|---|---|
| 19.3 | 114.2429 | -0.714 | 0.00625 |
| 19.48 | 83.3726 | -0.6937 | 0.00832 |
| 19.84 | 80.3619 | -0.6793 | 0.008453 |
| 20.02 | 78.9154 | -0.6721 | 0.008517 |
| 20.2 | 77.5062 | -0.6648 | 0.008577 |
| 20.38 | 84.4665 | -0.6613 | 0.007829 |
| 20.74 | 81.5371 | -0.6442 | 0.007901 |
| 20.92 | 80.1275 | -0.6345 | 0.007919 |
| 21.1 | 78.753 | -0.624 | 0.007924 |
| 21.28 | 77.4127 | -0.6126 | 0.007913 |
| 21.64 | 82.6005 | -0.5903 | 0.007146 |
| 21.82 | 81.2293 | -0.5763 | 0.007095 |
| 22 | 79.8917 | -0.5617 | 0.007031 |
| 22.18 | 78.5869 | -0.5466 | 0.006955 |
| 22.72 | 82.2507 | -0.5034 | 0.00612 |
| 22.9 | 80.9513 | -0.4887 | 0.006037 |
| 23.08 | 79.6824 | -0.4746 | 0.005956 |
| 23.26 | 78.443 | -0.4613 | 0.005881 |
| 23.8 | 81.9398 | -0.4286 | 0.005231 |
| 23.98 | 80.7021 | -0.4191 | 0.005193 |

TABLE 3
Dielectric Constant, Loss Factor and Loss Tangent for treated water

| Frequency | Dielectric Constant | Loss Factor | Loss Tangent |
|---|---|---|---|
| **19.3** | 111.1957 | -0.9414 | 0.008466 |
| **19.48** | 77.8297 | -0.9033 | 0.011606 |
| **19.84** | 82.1036 | -0.8932 | 0.010879 |
| **20.02** | 80.6298 | -0.8857 | 0.010985 |
| **20.2** | 86.3251 | -0.8849 | 0.010251 |
| **20.38** | 77.795 | -0.8729 | 0.011221 |
| **20.74** | 81.8663 | -0.8671 | 0.010592 |
| **20.92** | 80.4533 | -0.8614 | 0.010707 |
| **21.1** | 79.0748 | -0.8554 | 0.010818 |
| **21.28** | 77.7298 | -0.8488 | 0.01092 |
| **21.64** | 81.6145 | -0.8374 | 0.01026 |
| **21.82** | 80.2577 | -0.8278 | 0.010314 |
| **22** | 78.9336 | -0.8171 | 0.010352 |
| **22.18** | 77.6411 | -0.8051 | 0.01037 |
| **22.72** | 80.0636 | -0.7666 | 0.009575 |
| **22.9** | 78.7951 | -0.7509 | 0.00953 |
| **23.08** | 77.5569 | -0.7349 | 0.009476 |
| **23.26** | 81.1296 | -0.7626 | 0.0094 |
| **23.8** | 78.6784 | -0.6772 | 0.008607 |
| **23.98** | 77.4898 | -0.664 | 0.008569 |

Table 2 and 3 shows the average value for dielectric constant, loss factor and loss tangent from 21 samples at each frequency.

Figure 6 below shows the measured value of dielectric constant for treated and untreated water. The average of dielectric constant for treated water is 81.3582 in the range of 77.4898 to 111.1957 whereas the average of dielectric constant for untreated water is 82.1487 in the range of 77.4127 to 114.2429. Both dielectric constants for treated and untreated water were quite similar and not distinguishable. The measured dielectric constants were quite similar with the reported data which is 80 [10].

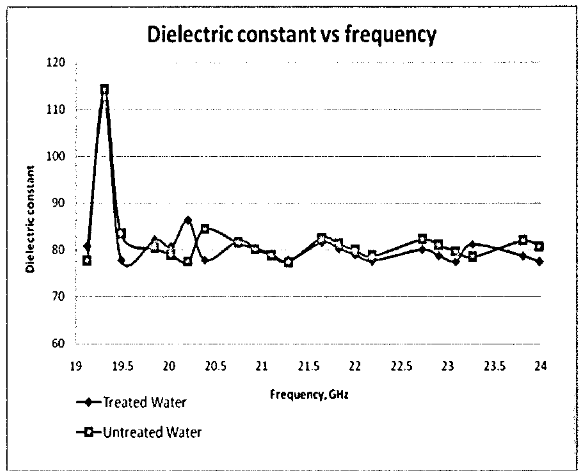


Figure 6: Dielectric Constant vs. frequency

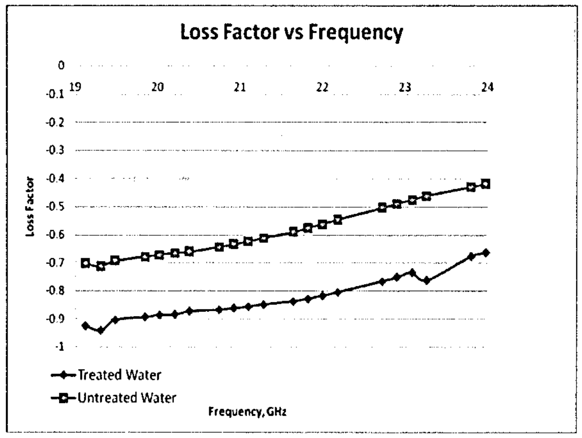


Figure 7: Loss Factor vs. Frequency

Figure 7 gives the loss factor results for both types of water. Both types of water are directly proportional to the frequency. However, the treated water has a low loss factor compared to the untreated water. The impurities in the untreated water make the water more dissipative than the treated water.

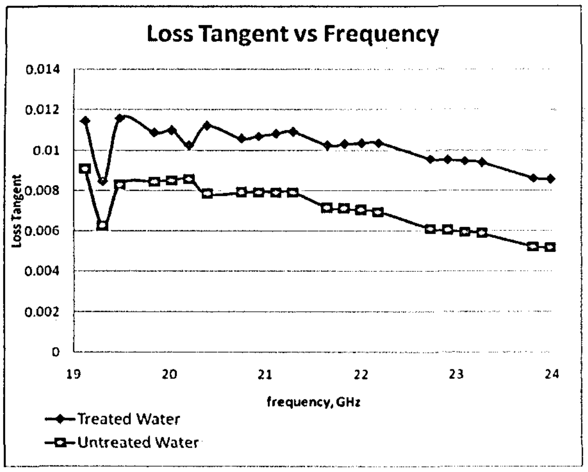


Figure 8: Loss Tangent vs. Frequency

Figure 8 gives the results of loss tangent for both types of water. Loss tangent for both types of water are indirectly proportional to the frequency. However, the loss tangent of treated water is higher than the untreated water. This result is depending on dielectric constant and the loss factor of the samples.

**Classification using ANN system**

Table 4 and 5 below show the results of dielectric constant, loss factor and loss tangent for 21 samples for both types of water at mid band frequency of 22GHz. The first seven samples for each type of water were selected as training samples. Therefore, the remaining sample data were used as a testing.

TABLE 4
Dielectric Constant, Loss Factor and Loss Tangent for untreated water

| Sample | Dielectric | Loss Factor | Loss Tangent |
|---|---|---|---|
| 1 | 79.8833 | -0.6296 | 0.007881497 |
| 2 | 79.9109 | -0.5305 | 0.006638644 |
| 3 | 79.8918 | -0.5583 | 0.006988202 |
| 4 | 79.8885 | -0.5589 | 0.006996001 |
| 5 | 79.8883 | -0.5626 | 0.007042333 |
| 6 | 79.8854 | -0.5616 | 0.007030071 |
| 7 | 79.8852 | -0.5597 | 0.007006304 |
| 8 | 79.8849 | -0.5659 | 0.007083942 |
| 9 | 79.8821 | -0.5722 | 0.007163057 |
| 10 | 79.9052 | -0.5448 | 0.006818079 |
| 11 | 79.9075 | -0.5435 | 0.006801614 |
| 12 | 79.882 | -0.5732 | 0.007175584 |
| 13 | 79.9051 | -0.546 | 0.006833106 |
| 14 | 79.9048 | -0.547 | 0.006845646 |
| 15 | 79.9053 | -0.5472 | 0.006848106 |
| 16 | 79.8776 | -0.5754 | 0.007203521 |
| 17 | 79.8918 | -0.5605 | 0.007015739 |
| 18 | 79.8908 | -0.5542 | 0.006936969 |
| 19 | 79.8783 | -0.5782 | 0.007238512 |
| 20 | 79.8922 | -0.5674 | 0.007102070 |
| 21 | 79.888 | -0.565 | 0.007072401 |

TABLE 5
Dielectric Constant, Loss Factor and Loss Tangent for treated water

| Sample | Dielectric | Loss Factor | Loss Tangent |
|---|---|---|---|
| 1 | 78.9135 | -0.8228 | 0.01042661 |
| 2 | 78.9138 | -0.8283 | 0.01049626 |
| 3 | 78.913 | -0.8327 | 0.01055213 |
| 4 | 78.9123 | -0.8396 | 0.01063966 |
| 5 | 78.913 | -0.8674 | 0.01099185 |
| 6 | 78.9527 | -0.7785 | 0.00986033 |
| 7 | 78.9666 | -0.7555 | 0.00956734 |
| 8 | 78.9659 | -0.759 | 0.00961174 |
| 9 | 78.9649 | -0.7592 | 0.00961440 |
| 10 | 78.9653 | -0.7618 | 0.00964728 |
| 11 | 78.9879 | -0.6968 | 0.00882160 |
| 12 | 78.9879 | -0.6968 | 0.00882160 |
| 13 | 78.9806 | -0.7108 | 0.00899968 |
| 14 | 78.9139 | -0.8708 | 0.01103481 |
| 15 | 78.9109 | -0.8829 | 0.01118857 |
| 16 | 78.9113 | -0.886 | 0.01122780 |
| 17 | 78.9095 | -0.8955 | 0.01134844 |
| 18 | 78.907 | -0.9003 | 0.01140963 |
| 19 | 78.9071 | -0.9029 | 0.01144257 |
| 20 | 78.9057 | -0.9054 | 0.01147446 |
| 21 | 78.9062 | -0.9084 | 0.01151240 |

After classification process using ANN, both treated and untreated water can be classified successfully as shown in table 6 below.

TABLE 6
Classification Result

| Sample | Dielectric | Loss Factor | Loss Tangent | Target | Result |
|---|---|---|---|---|---|
| 1 | 79.8849 | -0.5659 | 0.007083942 | 1 0 | 1 0 |
| 2 | 79.8821 | -0.5722 | 0.007163057 | 1 0 | 1 0 |
| 3 | 79.9052 | -0.5448 | 0.006818079 | 1 0 | 1 0 |
| 4 | 79.9075 | -0.5435 | 0.006801614 | 1 0 | 1 0 |
| 5 | 79.882 | -0.5732 | 0.007175584 | 1 0 | 1 0 |
| 6 | 79.9051 | -0.546 | 0.006833106 | 1 0 | 1 0 |
| 7 | 79.9048 | -0.547 | 0.006845646 | 1 0 | 1 0 |
| 8 | 79.9053 | -0.5472 | 0.006848106 | 1 0 | 1 0 |
| 9 | 79.8776 | -0.5754 | 0.007203521 | 1 0 | 1 0 |
| 10 | 79.8918 | -0.5605 | 0.007015739 | 1 0 | 1 0 |
| 11 | 79.8908 | -0.5542 | 0.006936969 | 1 0 | 1 0 |
| 12 | 79.8783 | -0.5782 | 0.007238512 | 1 0 | 1 0 |
| 13 | 79.8922 | -0.5674 | 0.007102070 | 1 0 | 1 0 |
| 14 | 79.888 | -0.565 | 0.007072401 | 1 0 | 1 0 |
| 15 | 78.9659 | -0.759 | 0.00961174 | 0 1 | 0 1 |
| 16 | 78.9649 | -0.7592 | 0.00961440 | 0 1 | 0 1 |

| | | | | | |
|---|---|---|---|---|---|
| 17 | 78.9653 | -0.7618 | 0.00964728 | 0 1 | 0 1 |
| 18 | 78.9879 | -0.6968 | 0.00882160 | 0 1 | 0 1 |
| 19 | 78.9879 | -0.6968 | 0.00882160 | 0 1 | 0 1 |
| 20 | 78.9806 | -0.7108 | 0.00899968 | 0 1 | 0 1 |
| 21 | 78.9139 | -0.8708 | 0.01103481 | 0 1 | 0 1 |
| 22 | 78.9109 | -0.8829 | 0.01118857 | 0 1 | 0 1 |
| 23 | 78.9113 | -0.886 | 0.01122780 | 0 1 | 0 1 |
| 24 | 78.9095 | -0.8955 | 0.01134844 | 0 1 | 0 1 |
| 25 | 78.907 | -0.9003 | 0.01140963 | 0 1 | 0 1 |
| 26 | 78.9071 | -0.9029 | 0.01144257 | 0 1 | 0 1 |
| 27 | 78.9057 | -0.9054 | 0.01147446 | 0 1 | 0 1 |
| 28 | 78.9062 | -0.9084 | 0.01151240 | 0 1 | 0 1 |

## VII. DISCUSSION

Calibration results were very important for every measurement since it can affect the dielectric properties. This is because the microwave equipment is very sensitive when operates at high frequency range. The thickness of the container also should be matched to quarter wavelength in order to allow the microwave signal passing through the sample.

Before measuring sample using the metal back method, measurement has been made without metal plate at the back side. The results of S-parameter that used were S11 and S12. However, the microwave signal cannot pass through the sample. This is because the water samples tend to absorb the microwave signals especially for the K band antennas. Therefore, metal back method has been proposed to calculate the dielectric properties.

Referring to table 4 and 5, the dielectric constant for both treated and untreated water was slightly the same and difficult to differentiate. Therefore, the classification for treated and untreated water has been made based on the value of loss factor and loss tangent.

Treated water passes through some of the treatment process like methods to kill the microorganisms including disinfection, oxidation with oxidizing chemicals or irradiation with UV radiation. This process makes the water has no more impurities. The impurities have causing the water become more dissipative or loss. That is why both types of water are very distinguishable in terms of their loss factor and loss tangent whereas the dielectric constant is not differing.

## VIII.CONCLUSION & FUTURE DEVELOPMENT

As a conclusion, the treated and untreated water can be characterize successfully using Microwave Nondestructive Testing (MNDT) technique and can be classified correctly using Artificial Neural Network (ANN). This approach presents a clearer classification. These two types of water have been classified clearly based on their loss factor and loss tangent.

Future study may focus on the various water sources and low frequency ranges used for Microwave Non Destructive Testing (MNDT) and make a comparison in terms of the dielectric properties in order to study more on the treated water and untreated water.

## IX. ACKNOWLEDGEMENT

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## X.REFERENCES

[1] A.Amiet, P.Jewsbury, "Free Space Microwave Permittivity and Permeability Measurements"Defence Science and Technology Organization, Melbourne.

[2] D. K. Ghodgaonkar et al, "A Free Space Method for Measurement of Dielectric Constants and Loss Tangents at Microwave Frequencies", IEEE Trans.Instrum. Meas., Vol. 37, n3, pp789-793, June 1989.

[3] Mohd Aris Aziz , D.K Ghodgaonkar," Nondestructive and Noncontact Dielectric Measurement Methods for High-Loss Liquids Using Free Space Microwave Measurements Systems in 8-12.5GHz Frequency Range"pp.169-176, October, 5-6, 2004, Subang Selangor, Malaysia

[4] Deepak Kumar Ghodgaonkar, Nor Azlin Ali, "Microwave Nondestructive Testing of composite Materials using Free Space Microwave Measurement Techniques", 2000

[5] Nur Elieya Che Muda," Measurement Dielectric Constant of new transformer oil at frequency 18 to 26 GHz (K Band)", 2008

[6] Arthur Von Hipple,"Dielectric Materials and Applications,"Artech House Boston London, P.18-19, 1995.

[7] Kamriah Ismail, Zaiki Awang, Noor Hashimah Baba and Mazlina Esa, "Microwave Characterization using Rectangular Dielectric Waveguide", 2006

[8] N.H.Baba, Z.Awang, and D.K. Ghodgaonkar, "Accuracy Consideration for Dielectric Measurements of Semiconductor Wafers Using Free Space Microwave System in 8-13Ghz range", pp.177-181, October, 5-6, 2004, Subang selangor, Malaysia

[9] H. Saad and A. Hussain, "Classification for the Ripeness of Papayas Using Artificial Neural Network (ANN) and Threshold Rule," 2006, pp. 132-136.

[10]Drake, F.H Pierce, G.W Dow, M.T, "Measurement of the Dielectric Constant and Index of Refraction of Water and Aqueous Solutions of KCl at High Frequencies," Physical Review, vol. 35, Issue 6, pp. 613-622, 03/1930.