# Investigation on Dielectric Variation Factors in Materials for Brain Phantom

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*Abstract*— **This paper presents the investigation on variation factors in phantom material study, which observed through dielectric measurement that is performed from 1 to 6 GHz. Water and ancillary substances are used in the investigation. The study focuses on dielectric variation due to the water sources, the addition of ancillary substances and temperature. The obtained results in this study are useful for the development of realistic human head phantom.**

**Keywords—phantom; microwave; imaging; wideband**

## I. INTRODUCTION

Other than breast cancer, brain cancer also has been noted as the most common cause of cancer-related deaths around the world. Currently, magnetic resonance imaging (MRI) mostly used for the screening process. But this MRI is too costly and not widely available [1] especially in rural medical centre. Early cancer diagnosis and detection are very important to increase cancer survival rates. Nowadays, microwave imaging has gain attention among researcher due its potential in breast cancer detection [1-3]. These scenarios then lead to the motivation for development of microwave imaging with the purpose for brain cancer detection.

Synchronize with the microwave imaging development, the study of realistic head phantom is also required for this brain cancer detection system. This phantom can be used to simulate the interaction of electromagnetic wave with biological tissues [4]. Although there are availability of phantom in the market, but it is not specifically meet the requirements of the system and too costly. These reasons motivate the development of cost effective head phantom with specific requirements for this system.

Many researchers developed their own phantom for their system as reported in [5-7] using simple and cheap material such as polyacrylamide, dough (consisting flour and oil) and also gelatin. Gelatin based material is seen as potential material as reported in [4] since it can mimic properties of human tissues. Because of that matter, few factors must be considered to customize the dielectric properties of proposed material in order to obtain required dielectric properties for certain tissues or cells. This paper presents the variation of dielectric properties of materials against the addition of sugar and the effects of temperature. In this study, water has been used as main material. The dielectric properties of water from different sources will be measured to observe their properties of dielectric variations.

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## II. MATERIALS AND METHOD

To achieve the purpose of this paper, experimental study must be conducted. The experimental study is divided into four scopes, which are to study properties of tap waters taken from different location, properties of waters that taken from different sources, the effects of temperature and the addition of sugar to dielectric measurements.

For the first scope, five samples of tap water from different locations are measured to obtain their electrical properties. These tap water samples are taken from five locations of Johor Bahru (UTM JB), Machap, Pagoh, Port Dickson, and Negeri Sembilan (Enstek) as listed in Table I. All measured data then analyzed and compared.

TABLE I. FIVE SAMPLES OF TAP WATER FROM DIFFERENT LOCATIONS

| No. of sample | Source |
|---|---|
| Sample 1 | Johor Bahru (UTM JB) |
| Sample 2 | Machap |
| Sample 3 | Pagoh |
| Sample 4 | Port Dickson (batu 4) |
| Sample 5 | Negeri Sembilan (Enstek) |

For the second scope as listed in Table II, five samples of different water sources taken from different sources are measured to obtain their electrical properties. These samples are tap water (taken in UTM Johor Bahru), distilled, mineral, reverse osmosis (RO) and ceramic filtered water. Then, all samples measurement result for each sample is plotted in graph form and compared to each other to observe any different properties and behaviors.

TABLE II. FIVE WATER SAMPLES FROM DIFFERENT SOURCES

| No. of sample | Source |
|---|---|
| Sample 1 | Tap water (UTM JB area) |
| Sample 2 | Distilled water |
| Sample 3 | Mineral water (underground) |
| Sample 4 | RO (Reverse Osmosis) water |
| Sample 5 | Ceramic filtered water |

To study the effect of temperature for the third scope, three samples of water from same source, which is tap water from UTM JB have been used. This is to ensure any variations are only from the effect of temperature level. Each sample presents different temperature level as shown in Table III. The temperature of first sample is at the room temperature level around 23ºC, while the second sample at temperature of 37ºC, which close to body temperature and the third sample at temperature of 70ºC, which near to boiling temperature. The measured results of these three samples are then compared and analyzed.

TABLE III. THREE WATER SAMPLES MEASURED AT DIFFERENT TEMPERATURE LEVEL

| No. of sample | Temperature |
|---|---|
| Sample T1 | 23ºC |
| Sample T2 | 37ºC |
| Sample T3 | 70ºC |

Then, to study the effects of sugar and salt as ancillary substances, three samples of water from same source of tap water added with different amount of sugar or salt are tested. The water samples with different amount of sugar are listed in Table IV. Then, the measured data are plotted and compared to observe the dielectric variation due to the addition of sugar.

TABLE IV. WATER SAMPLES IN CONJUCTION WITH DIFFERENT AMOUNT OF SUGAR

| No. of sample | Water (g) | Sugar (g) |
|---|---|---|
| Sample S1 | 30 | 0 |
| Sample S2 | 30 | 5 |
| Sample S3 | 30 | 10 |

The measurement in this experimental study is obtained using coaxial probe in conjunction with a vector network analyzer (VNA). Before the measurement is performed using the dielectric probe, calibration of the probe is needed to be implemented using three standards. The first standard is using distilled water, where the tip of probe is immersed in distilled water. Then, second and third standard are 'open' where the tip of probe leaved in the air and 'short' where the tip of the probe connected to short circuit stub, accordingly. All measurement is conducted at room temperature, which is approximately 23ºC.

To ensure the precision of the measurement device, a measurement is performed on distilled water sample to observe its permittivity plots. Smooth curve of permittivity plots indicates that calibration is done correctly and the device is precise. Then, several more measurements taken on same distilled water sample and the results are compared to ensure repeatability and precision of performed measurement using calibrated dielectric probe and vector network analyzer (VNA).Sample data on three measurements with regard to the precision of each measurement can be observed in Fig. 1.Three measurements are taken for each sample to ensure its accuracy then the averaged results are plotted. The measurements data in this paper are plotted in form of relative permittivity ($\varepsilon_r$) and conductivity (σ).

## III. MEASUREMENT RESULTS AND DISCUSSION

Measurement data to prove the repeatability and precision of the used measurement instrument as stated in part II is plotted as in Fig. 1. From the plotted data in Fig. 1, it can be seen that similar values of measured data of complex permittivity for each measurement confirm the required precision. The different on each measurement actually is very small, which less than 0.1unit that almost cannot be noticed in the figure.

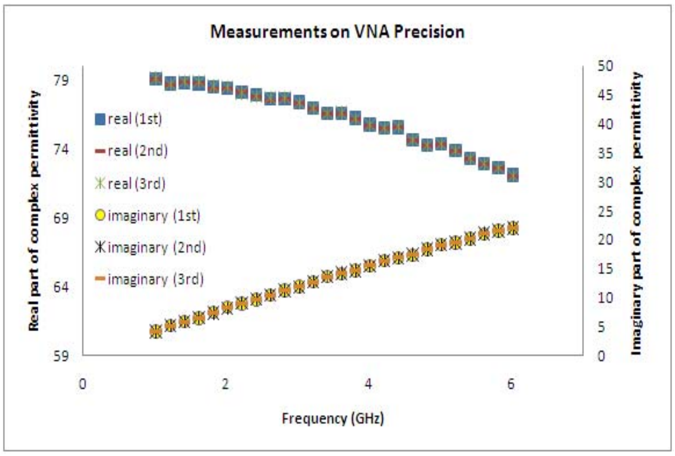


Fig. 1: Precision measurement data of the used measurement instrument.

All measurement results in experimental study is aiming on complex permittivity, $\varepsilon^*$ over wideband frequency from 1 to 6 GHz. Then, the measured data is analyzed to obtain its relative permittivity (ε⍰) and conductivity (σ).As noted in [8], the complex permittivity $\varepsilon^*$ is shown as a relation between conductivity (σ), angular frequency (ω),real part of permittivity ($\varepsilon'$) and imaginary part of permittivity ($\varepsilon''$) as in equation (1):

$$\varepsilon^* = \varepsilon_r - j\frac{\sigma}{\omega\varepsilon_o} = \varepsilon_r' - j\varepsilon_r'' \quad (1)$$

From the measured complex permittivity value in (1), the conductivity value could be obtained using equation (2):

$$j\frac{\sigma}{\omega\varepsilon_o} = j\varepsilon_r^{"} \quad (2)$$

Referring to equation (2), it shows the conductivity is related with the imaginary part of complex permittivity. Therefore, the conductivity can be computed using the derived equation (3):

$$\sigma = \varepsilon_r^{"}\omega\varepsilon_o \quad (3)$$

Relative permittivity plots of tap water from several different locations as listed in Table I are shown in Fig. 2. The purpose of this measurement is to investigate the electrical properties of tap water from different locations. From the observation on plotted data in Fig. 2, it clearly shows that tap water from different locations have almost similar relative permittivity. Furthermore, the conductivity plots in Fig. 3 also show that each sample of tap water does not have significant different in term of its dielectric properties. This data justified that the location of tap water taken is not a factor of dielectric variation.

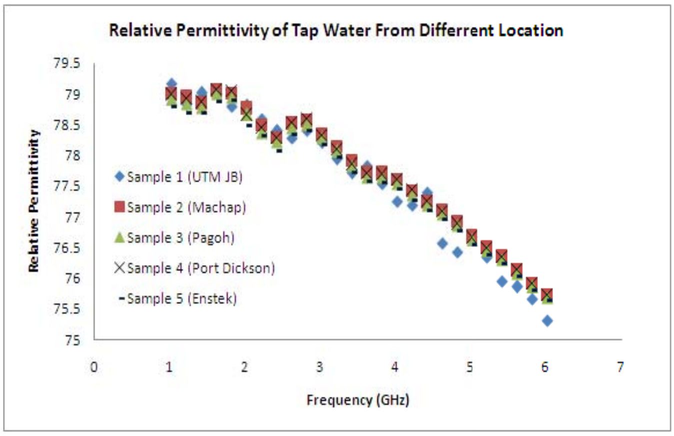


Fig. 2: Relative permittivity of tap water from different locations.

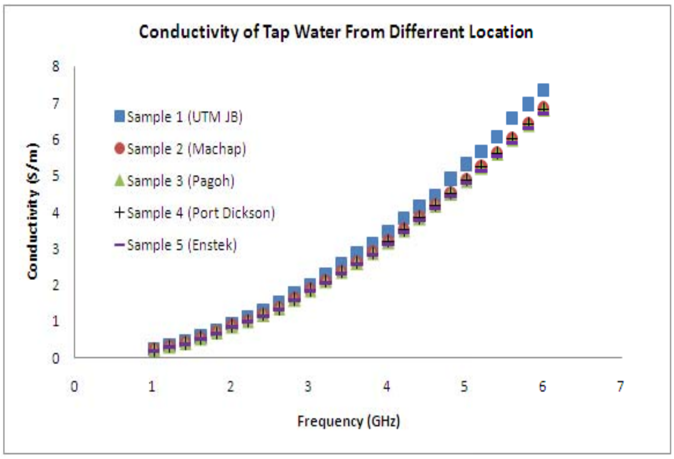


Fig. 3: Conductivity of tap water from different locations.

Fig. 4 shows the measurement data for the relative permittivity of water that taken from few different sources as presented in Table II. The purpose of this measurement is to obtain electrical characteristics of the water samples that have different mineral content in term of permittivity and conductivity.

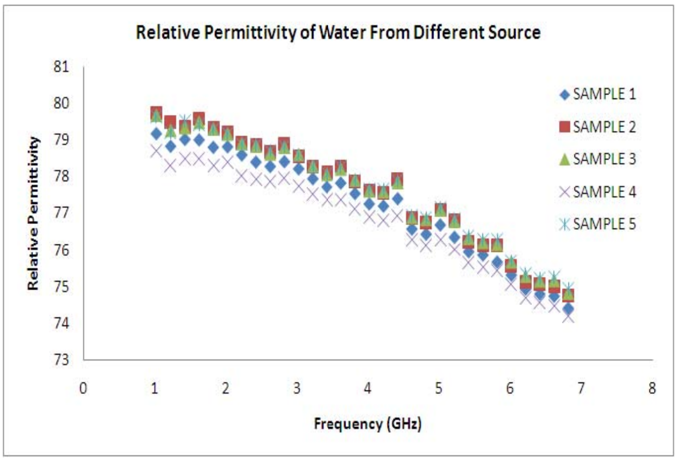


Fig.4: Relative permittivity of water samples from different source.

From the observation in Fig. 4, each sample resulting almost similar measurement data, this means the samples that taken from different sources will only provide small variations of permittivity level. From the relative permittivity plot, measured data for sample 2, 3 and 5 shows very small different, which is less than 0.1. While, sample 1 and 4 results demonstrate the variation of 0.5 and 0.9, respectively. This small variation for sample 1 and 4 are probably due to some interference, which could be from human or instrument errors and small temperature changes during measurement.

Then, with the information of complex permittivity obtained from the measurement, conductivity of five water samples can be computed from equation (3). Fig. 5 shows the conductivity data of water that taken from different sources. As relative permittivity, the conductivity of these samples also shows that all samples from different sources will provide almost similar conductivity. Observation on conductivity plots show that all sample results have same pattern and only little variations occur at 5 GHz towards higher end of frequency range (6 GHz).

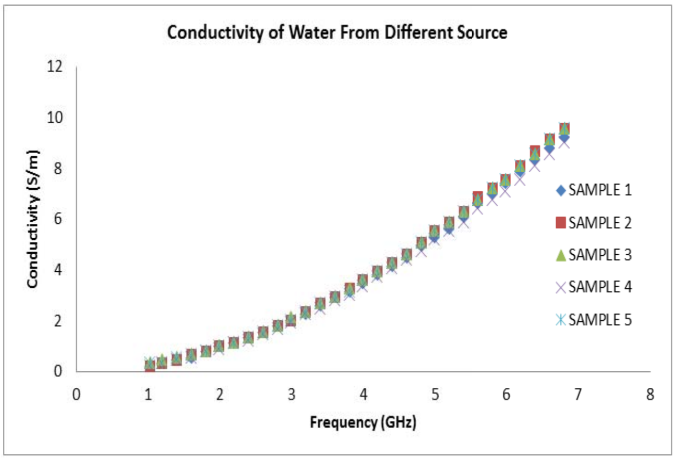


Fig.5: Conductivity of water samples from different source.

Fig. 4 and 5 prove that different water sources will not affect the permittivity and conductivity. Another concerned condition is the effect of temperature in dielectric properties measurement. Fig. 6 shows the relative permittivity plots of water samples at different temperature level. Sample T1 measurement is taken at temperature of 23ºC while the measurements for sample T2 and sample T3 are conducted at temperature of 37ºC and 70ºC, respectively as shown in Table III. It clearly shows that the dielectric properties of water are affected by temperature change. Sample with higher temperature level produces highest permittivity compared to the lower one. Although there is small different, it is important to consider the temperature level for the sample and surrounding during the measurement.

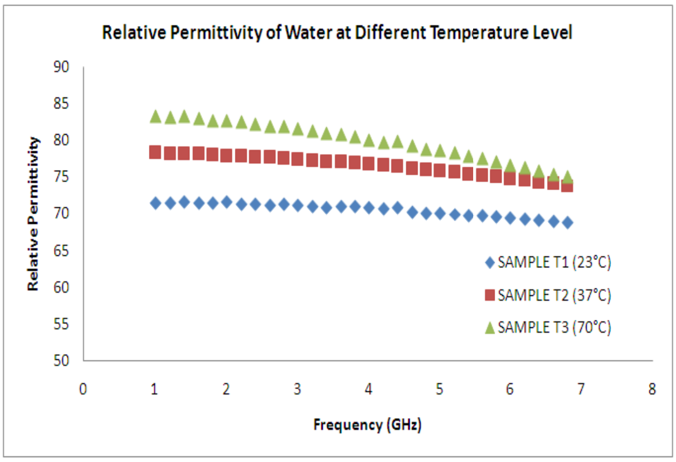


Fig.6: Relative permittivity of water samples at different temperature level.

As the measurement results of the relative permittivity, the conductivity plots for water samples also demonstrate the higher temperature level results higher conductivity. This scenario can be noted as in the Fig. 7. From the plotted measurement results, we can observe the same trend in both parameters, where these relative permittivity and conductivity will increase depending in the increasing of temperature.

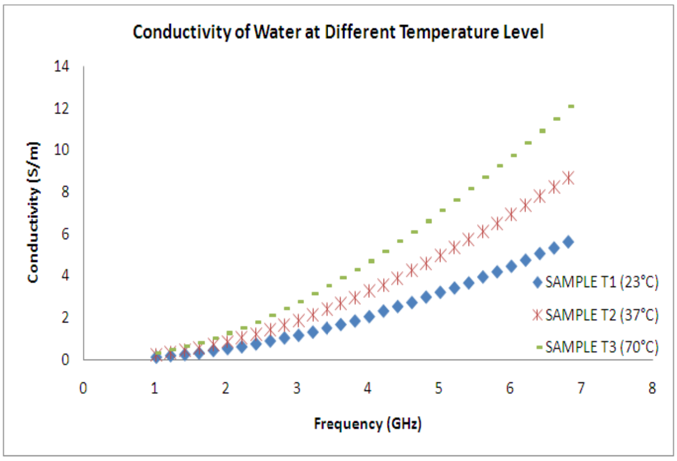


Fig.7: Conductivity of water samples at different temperature level.

Apart from sources and temperature, other ancillary substances also have been used to observe the changes of dielectric properties. Two basic substances that have been used are sugar and salt. And for the result, the added of salt in water cause the VNA unable to measure its permittivity. The reading from the VNA shows that water with salt results the permittivity at infinite level. This happens possibly because more than one ancillary substance required to tests the effects of salt. Theoretically, salt can be used in order to vary the conductivity of sample material which low conductivity tissues can be produced by reducing amount of salt as reported in [5]. Then, the measured permittivity of the water samples with added with sugar are shown in Fig. 8.

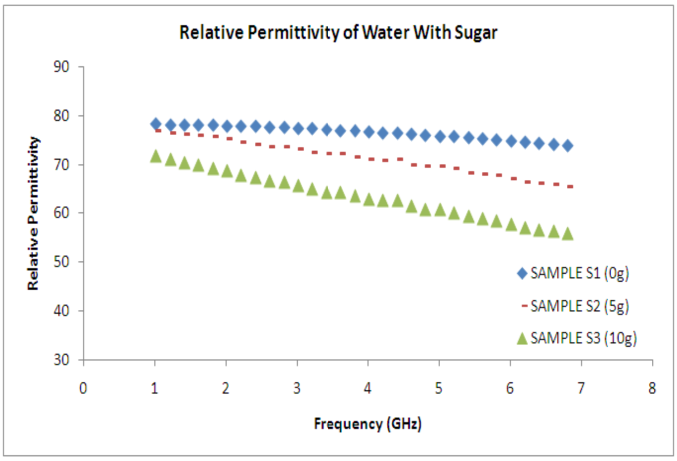


Fig.8: Relative permittivity of water samples with different amount of added sugar.

As noted from Fig. 8, Sample S1 is water with no sugar. Sample S2 and S3 have been added with 5g and 10g of sugar, respectively as stated in Table IV. Through the observation on Fig. 8, it can be noted that sugar could be used to reduce the dielectric permittivity of sample. This finding is very useful in order to optimize the permittivity of certain sample. Fig. 9then shows the conductivity plots for the water samples with sugar. A bit different with its permittivity result, the adding of sugar at first increased a bit of conductivity but, the higher amount of sugar added into the sample, there is no significant change to the conductivity.

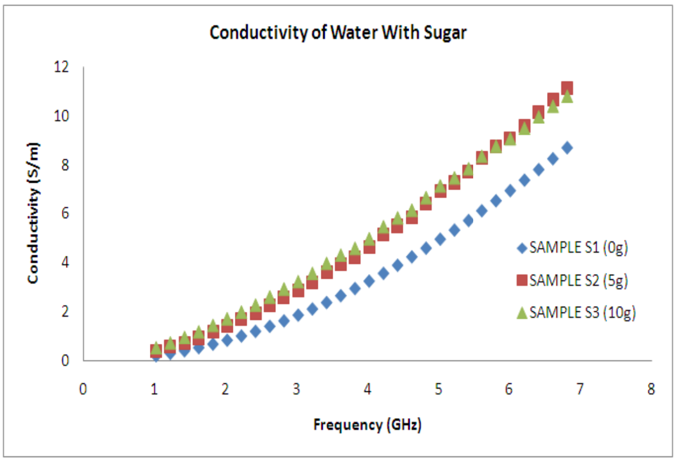


Fig.9: Conductivity of water samples with different amount of added sugar.

## IV. Conclusion

In the development of human head phantom, it is important to understand the characteristic of the material. In microwave imaging, dielectric is the most important point during phantom development. Any unwanted changes in dielectric value will drag to false image construction. From the finding in this paper, few factors discovered will affect the dielectric measurement, which are the temperature changes and contains of sugar. While, water which taken from different sources do not results a big change in dielectric value and. In addition, location of tap water alsohas not resulting a significant variation to electrical properties as been verified through the finding of this paper.The finding presented in this paper could be used to obtain the most suitable and accurate phantom material in the purpose of the realistic human head phantom development for microwave imaging system.

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