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Human Brain Phantom Modeling Based on Relative Permittivity Dielectric Properties

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Abstract— **This study aims to investigate the clinical outcomes of human brain dielectric properties in order to build a human-like brain phantom using simple material. This artificial intelligence human brain was developed according to the dielectric properties of a real human brain. The regions cover grey matter and white matter tissues. Elements used for phantom building demonstrate adequate internal consistency of $\mathcal{E}_r$ (relative permittivity) within 60-80 for a range of frequency from 1-6 GHz. A surprisingly finding, quantity of element sugar is the main reason of affecting the permittivity. The findings give a big step closer for building an artificial human brain without defect.**

Keywords-dielectric; relative permittivity; brain; phantom

I. INTRODUCTION

The electric properties or the dielectric properties of biological tissues at radio and microwave frequencies have been the subject of research for over four decades [1]. The response of a material to an electromagnetic field was determined by dielectric properties. The dissipation of electromagnetic energy was led by the inability of the molecules to instantaneously align with the applied electromagnetic field.

The dielectric properties refer to a complex number consisting of a real part of the permittivity (e' or $\mathcal{E}_r{}'$) and an imaginary part of the permittivity (e" or $\mathcal{E}_r{}''$). The dielectric constant (κ or $\mathcal{E}_r$) is an indication of the polarizability of the molecules and their ability to store electric energy. The dielectric loss factor (e" or $\mathcal{E}_r{}''$) is related to the energy absorption and dissipation of electromagnetic energy from the field [2].

II. LITERATURE REVIEW

The human brain has the same general structure as the brains of other mammals, but is larger than expected on the basis of body size among other primates [3, 4]. Grey matter (or gray matter) is a major component of the brain which consists of neuronal cell bodies such as neuropil (dendrites and unmyelinated axons), glial cells (astroglia and oligodendrocytes) and capillaries. White matter is contrast with grey matter, which does not consists of neuronal cell bodies but mostly contains myelinated axon tracts [5].

Same as other biological tissues, different part of human brain have its own dielectric properties. The dielectric properties of human body tissues can obtain from the online application, International Federation of Automatic Control (IFAC) which founded by Italian National Research Council. The application provides the dielectric properties of single tissues in the frequency range 10 Hz to 100 GHz.

The dielectric properties measurement been done by employing the HP 8720B Vector Network Analyzer (VNA) with the use of HP 85070B open-ended coaxial sensor as shown in Figure 1.

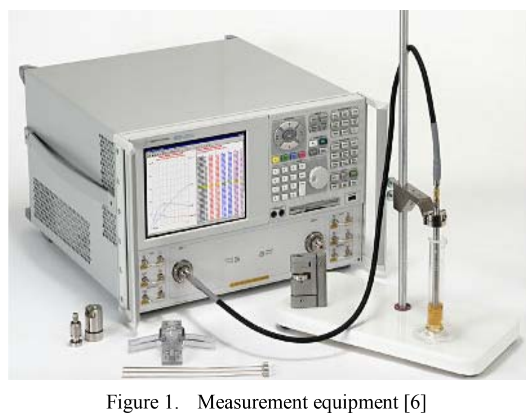

Figure 1. Measurement equipment [6]

Permittivity describes the interaction of a material with an electric field E and is a complex quantity. In (1), dielectric constant, κ is equivalent to relative permittivity, $\mathcal{E}_r$ or the absolute permittivity, $\mathcal{E}$ relative to the permittivity of free space, $\mathcal{E}_0$. The real part of permittivity, $\mathcal{E}_r{}'$ is a measure of how much energy from an external electric field is stored in a material. The imaginary part of permittivity, $\mathcal{E}_r{}''$ is called the loss factor and is a measure of how dissipative or lossy a material is to an external electric field [6].

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$$\kappa = \frac{\varepsilon}{\varepsilon_0} = \mathcal{E}_r = \mathcal{E}_r - j\mathcal{E}_r'' \quad (1)$$

The imaginary part of permittivity ($\mathcal{E}_r''$) is always greater than zero and is usually much smaller than ($\mathcal{E}_r'$). The loss factor includes the effects of both dielectric loss and conductivity.

When complex permittivity is drawn as a simple vector diagram shown in Figure 2, the real and imaginary components are 90° out of phase. The vector sum forms an angle δ with the real axis ($\mathcal{E}_r'$). As shown in (2) the relative "lossiness" of a material is the ratio of the energy lost to the energy stored [6].

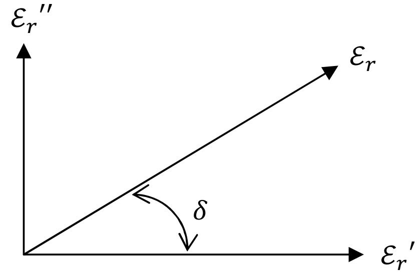

Figure 2. Loss tangent vector diagram

$$\tan\delta = \frac{\mathcal{E}_r''}{\mathcal{E}_r'} = D = \frac{1}{Q} \quad (2)$$

$$= \frac{Energy\ Lost\ per\ cycle}{Energy\ Stored\ per\ Cycle}$$

III. METHODOLOGIES

The research framework and methodology complies with ADDIE model [7]. ADDIE model is the generic process traditionally used by instructional designers and training developers. The five phases—Analysis, Design, Development, Implementation, and Evaluation — represent a dynamic, flexible guideline for building effective training and performance support tools. The study starts with conducting a preliminary pilot test on several elements. It aims to compare the actual value of brain tissues from the experimental result.

A. Phantom Probing

The open-ended coaxial probe is a cut off section of transmission line. The material is measured by immersing the probe into a liquid or touching it to the flat face of a solid (or powder) material.

Before measuring, calibration at the tip of the probe must be performed. It is important to allow enough time for the cable which connects the probe to the network analyzer to stabilize before making a measurement and to be sure that the cable is not flexed between calibration and measurement.

For solid materials, an air gap between the probe and sample can be a significant source of error unless the sample face is machined to be at least as flat as the probe face. For liquid samples, air bubbles on the tip of the probe can act as the same way of error. The sample must also be thick enough to appear "infinite" to the probe for transmission and receiving measurement [6]. The correct measuring technique is shown in Figure 3.

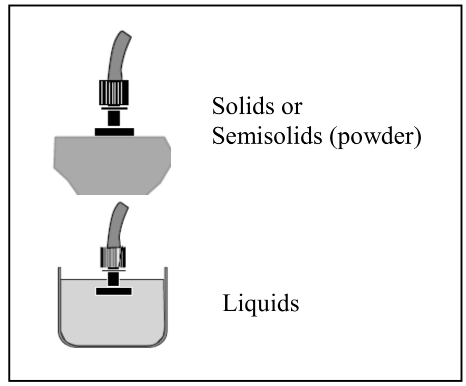

Figure 3. Coaxial probe measuring techniques. [6]

B. Phantom Model

The brain phantom model for this study comprised only grey matter and white matter region. The model consists of several elements like jelly, water and sugar mixing up randomly for a few samples. The phantom is in disc form with dimensions of 7 cm height in radius of 3 cm long. The tissue and the associated dielectric properties used as the referenced values were obtained from [8]. The $\mathcal{E}_r$ values obtained were literature support and much research had been done in order to get these exact values.

C. Phantom Element

The following samples are mixture of simple and low cost elements:

- Sample 1 = water
- Sample 2 = water + agar-agar
- Sample 3 = water + sugar
- Sample 4 = water + agar-agar + sugar

The samples were contained inside a small beaker for permittivity probing.

D. Intrument Revision

The relative permittivity of this study focus on frequency range 1-6 GHz. The experiment took place in a laboratory site and temperature was controlled under 25±1ºC.

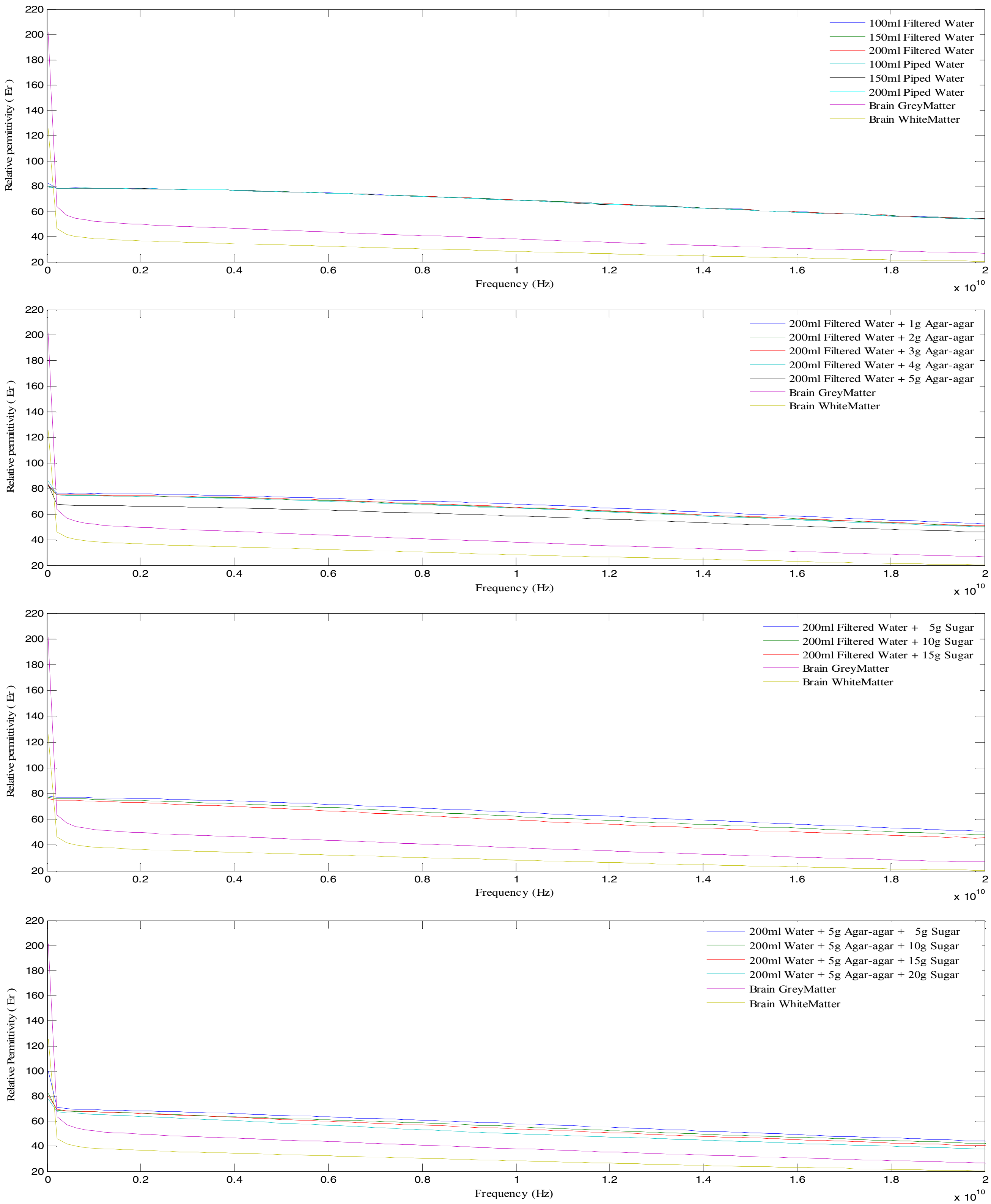

Figure 4. Graphical plot of relative permittivity($\mathcal{E}_r$) of sample 1-4

IV. RESULT

The study is still in a preliminary stage and yet we had conducted this pilot test as a fundamental testing and analysis on the collected data. The main goal of this study is to investigate and discover the most suitable mixture for building a human brain phantom with the closest relative permittivity to the real human brain. Data collected were compared with real human white matter and grey matter as shown in Figure 4.

A. Sample 1

Values collected show that either filtered water or piped water contributes relative permittivity $\mathcal{E}_r$= 74-78 for range 1-6 GHz. The values are still too far for building grey and white matter.

B. Sample 2

Sample 2 is a mixture from filtered water and agar-agar. The concentration of agar-agar is increased by 1g to the respective samples. As the concentration increasing, the values of relative permittivity are lowering. In order to lower the trend of relative permittivity to the desired values, the amount of agar-agar is increased, meanwhile the mixture was too hard and it is unable to dissolve more than 5g agar-agar in 200ml filtered water.

C. Sample 3

A mixture of filtered water and increasing quantity of sugar contribute relative permittivity $\mathcal{E}_r$= 66-76 for frequency range from 1-6 GHz. Increasing of quantity of sugar enable to increase the gradient of relative permittivity trend.

D. Sample 4

Meanwhile, Sample 4 can be labeled as the most optimum choice of material for building brain phantom. It has a slightly steady slope form with lower gradient changes. In section $\mathcal{E}_r$ (relative permittivity), the last part of the plot, the line plot is within $\mathcal{E}_r$= 60-80. The values collected are slightly higher than the targeted values of 52.282 for grey matter and 46.399 for white matter. Hence, further experiment will be conducted in order to optimize these values by increasing the quantity of element sugar in the model.

V. DISCUSSION

As the initial, the experiment took place in a normal laboratory environment, it was consider appropriate for the preliminary phase of the quantitative study to be conducted in a similar environment. Further work is planned to widen the sample and element to encompass different environments in temperature and pressure.

In Sample 1, the volume of water does not influence the measurement of relative permittivity. Either filtered water or piped water brings no difference for $\mathcal{E}_r$. In Sample 2, in order to reach the real relative permittivity of grey and white matter, increasing quantity of agar-agar is not applicable due to the mixture will become more harder and this does not fulfill the human brain characteristics. Hence, an idea was proposed to mix in element sugar rather than agar-agar as in Sample 3. Although the increasing of sugar quantity enable to lowering the relative permittivity trend but these values are still outside the desired range. Therefore, an advanced method was proposed by mixing agar-agar and increases sugar quantity to lower the $\mathcal{E}_r$ slope.

In this experiment, sugar element is playing an important role for stabilizing the permittivity values of the model. By increasing the quantity of sugar, the permittivity of sample is decreasing and vice-versa. Hence, further experiment is focusing on the effects of salt quantity in building a brain phantom.

Imagination is no limit and therefore, there is a lot we can do with this study. One but not the only one straight forward application is this real-like brain phantom can act as clinical study or medical instrument for disease or tumor research. It also can be applied on the incredible thing likes replacing wax as the main material for actual-size human modeling since the proposed model gives a more natural and real life-like sensing of touching.

VI. CONCLUSION

A brain phantom was built according to the data collected from an initial phase of experiment. The study accomplished all the objectives stated and had a surprisingly good start. The study aims to build a brain phantom with a few simple elements, and the findings indicate that sugar element able to stabilize and optimize the trends of slope. Results are presented in graphical form for better visual of revealed information.

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