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Fabrication of Human Body Phantom for Body Centric Communication Systems at 2.4 GHz

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Abstract: This research is intending to investigate the human skin phantom's dielectric constant. The phantom will be used to test the electromagnetic compatibility later on since it can be harmful if it is directly tested on real human body. The human body phantom is made to have similar property as a skin tissue, at the operating frequency of 2.4 GHz. A methodology of the process is discussed. The phantom is fabricated, tested and measured. A fabricated phantom with the desired permittivity of ε_r and conductivity of σ values; are controlled by the amount of polyethylene powder and sodium chloride. The information on dielectric constant of the phantom based on measured values of ε_r and σ will be determined. The factors in making a good phantom is discussed. A good level of agreement is observed between simulation and measurement results.

Keywords: Human body phantom, skin tissue, permittivity, conductivity, dielectric constant

1. Introduction

The requirement to investigate the interaction performance of microwave systems and devices which produce electromagnetic field, with the human body is needed. It is because many technologies such as mobile phone, breast imaging system and implantable medical device exposed to electromagnetic are used widely by human. In order to make sure the safety of those devices or systems, the performance in all types of position need to be validate [1].

According to [1], the utilization of artificial tissue-emulating or human body phantom is highly recommended for testing a device or system instead of using live human being. A lot of criterion needs to verify and taken care before testing it to human being, including the safety concern of new device.

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The electrical properties (permittivity of ε_r and conductivity of σ) of the phantom are necessary to mimic the real environment for testing purpose later on. The electrical properties of different tissues of human body are varied depending on their types such as muscle, fat, stomach and et cetera. It is also varied according to the operating frequency. Summary of the electrical properties for different tissues of human body, with operating frequency at 0.5 GHz to 10.0 GHz is shown in Table 1.

Table 1 - The electrical properties of different tissues of human body at 0.5 GHz to 10.0 GHz [1].

Tissues	ε_r	σ (S/m)
Muscle	56.5 to 42.8	0.80 to 10.60
Fat	5.54 to 4.60	0.04 to 0.60
Blood	63.3 to 45.1	1.38 to 13.10
Stomach	66.7 to 49.0	1.04 to 13.30
Dry Skin	45.0 to 31.3	0.73 to 8.00

Human body phantom materials can be divided into several types according to their appearance. There is liquid, gel, semisolid and solid materials. Most of reported human body phantom materials are using gel and semisolid [2-7]. Phantom of solid material using agar-based is studied in [2] to operate from 0.9 GHz to 10.0 GHz. Human muscle tissue using gel material is reported in [3]. This phantom is operated at 2.45 GHz. Meanwhile, semisolid water-based phantom is fabricated mimicking of a human torso in [4]. The phantom is able to operate at 2.45 GHz. Multi-function phantoms including muscle, fat, skin, bone-tissues are also reported in [5-7]. The phantoms are made to suit the operating frequency of the microwave systems and devices. According to [2], the phantom can be used in wide range of frequency by altering the composition or ingredient ratios.

The amount of chemical substances ratios determines the dielectric constant of a phantom. A total number of six chemical substances are required to produce a good phantom. Among them, polyethylene powder and sodium chloride are an important ingredient. Right amount of polyethylene powder and sodium chloride is needed to offer a phantom with similar electrical properties as in real environment. According to [8], the amount of polyethylene powder affects the permittivity value of the phantom while the concentration of sodium chloride affects the conductivity value of the phantom. In addition, agar is used to hold the phantom's shape. However, agar and polyethylene powder are not suitable to be blend directly. Which is why, TX-151 is used as a thickener to thicken or harder the mold. In [9], xanthan gum is used instead of TX-151 because of easier to obtain and cheaper. Meanwhile, sodium dehydro-acetate is used as an antiseptic together with the deionized water as a main material.

In this paper, the human body phantom is presented mimic the physical properties of human skin tissue, as well as the electrical properties. The human body is fabricated and tested. The results are compared between calculated and measured data or values. The phantom is useable in many applications such as body area network, body centric wireless communication and biomedical systems.

2. Methodology

The fabrication of skin tissue phantom involves three stages. The first stage is to prepare the chemical substances which are deionized water, agar, sodium chloride, sodium dehydro-acetate, xanthan gum and polyethylene powder with the right amount.

The next stage is mixing all the ingredients by following several procedures and the solution is pour into a container. The solution will conform to the shape of its container when it is cooled or harden. Lastly, the final step is to measure the dielectric constant of the fabricated phantom using Vector Network Analysis (VNA) at the desired frequency which gives the value of real, ε' and imaginary, ε" parts of related permittivity.

Total of eight steps or procedures are shown in Fig. 1. In Fig. 1(a), all the ingredients are weight and put aside. The model or container is prepared earlier because the procedure is done quickly. This step is fall on the first stage. Second step until seventh step in Fig. 1(b)-(g), are the steps taken for second stage. The steps including stirring, cooking, mixing and cooling. The last step is shown in Fig. 1(h), for measurement process is the final stage in this study. If the results of electrical properties are not satisfied between calculated and measured data, we need to re-do the fabrication process from the first step.

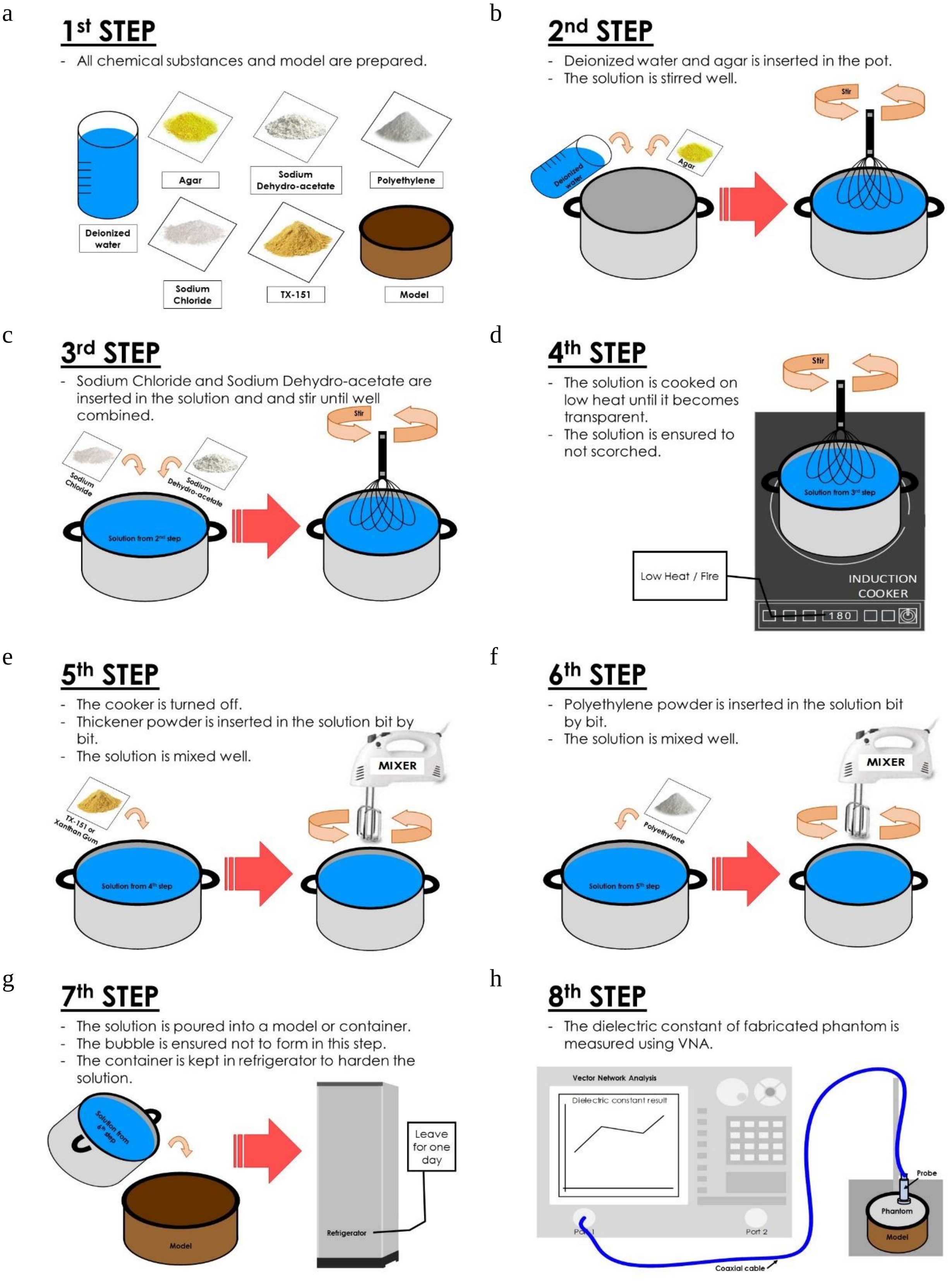

Fig. 1 - (a) First step; (b) second step; (c) third step; (d) fourth step; (e) fifth step; (f) sixth step; (g) seventh step; (h) eighth step

The relative permittivity, ε_r and conductivity, σ of phantom is obtained by calculating it using the formula given in (Eq. 1). Targeted permittivity and conductivity for skin-tissue phantom at 2.4 GHz is $\varepsilon_r = 46.7$ and $\sigma = 0.69$, respectively [8].

$$\varepsilon_r = \sqrt{(\varepsilon')^2 + (\varepsilon'')^2} \qquad (1)$$

$$\sigma = \omega\varepsilon''\varepsilon_0$$

where,

$$\omega = 2\pi f$$

$$\varepsilon_0 = \frac{(10)^{-9}}{36\pi}$$

3. Result and Discussion

Table 2 shows the ingredients required to make a skin phantom. Modification has been done on the amount of sodium chloride which is from 2.1 grams to 1.8 grams, in order to lower the conductivity value based on previous research paper. It is because it can affect conductivity value based on concentration of sodium chloride itself.

Table 1 - Ingredients amount in skin phantom

Ingredient	Amount
Polyethylene powder	47.00 g
Sodium chloride	1.80 g
Agar	20.00 g
Xanthan gum	6.25 g
Sodium dehydro-acetate monohydrate	0.25 g
Deionized water	420 ml

Fig. 2 shows the fabricated human skin-tissue phantom. Fig. 3 illustrates the position during measurement of dielectric constant of human skin phantom. The measured values are taken at 11 different positions on the bottom surface of fabricated phantom. Later, average value is calculated to be set as a final measured data. Position is changing on the surface to ensure that fabricated phantom obtained same results of electric properties on all area of the surface.

Fig. 2 - Fabricated human skin phantom

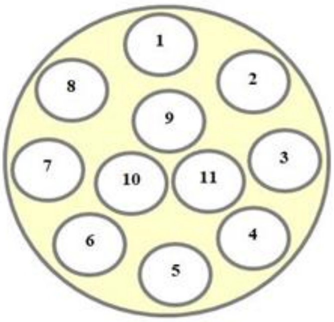

Fig. 3 - Position of measurement of dielectric constant

Fig. 4 shows the measured data for real part (ε') and imaginary part (ε") at frequency of 2.4GHz. The data is taken at 11 different position as shown in Fig. 3. As noticed in the figure, there is a big difference value at position 1 due to uneven surface of the phantom or small bubble which cannot be seen by naked eyes, the measured value affected a lot compared to others position. Average values of real and imaginary parts are 48.3 and 5.12, respectively. Both of the measured value will be compared with the theoretical value in Fig. 5 and Fig. 6.

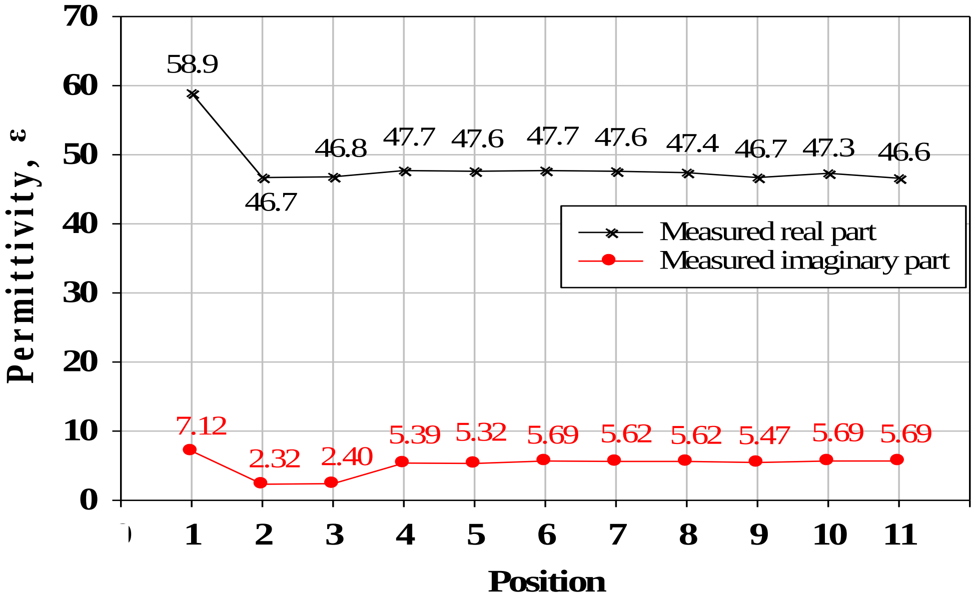

Fig. 4 - Measured value of real part, ε' (re) and the imaginary part, ε" (im) of permittivity on the bottom surface of skin phantom

Fig. 5 compares the desired permittivity, ε_r with measured data for real part (ε') at frequency of 2.4GHz. The black line shows the desired value for permittivity, ε_r which is 46.7 regardless of the position. Meanwhile, the red line indicates the real part data for 11 different positions. As mentioned earlier, the average value of real part of permittivity, ε' is 48.3. This result exhibits the skin phantom achieving the requirement for the relative permittivity value because of the acceptable value of the measured dielectric constant should be in the range of ±10% of the expected dielectric constant value.

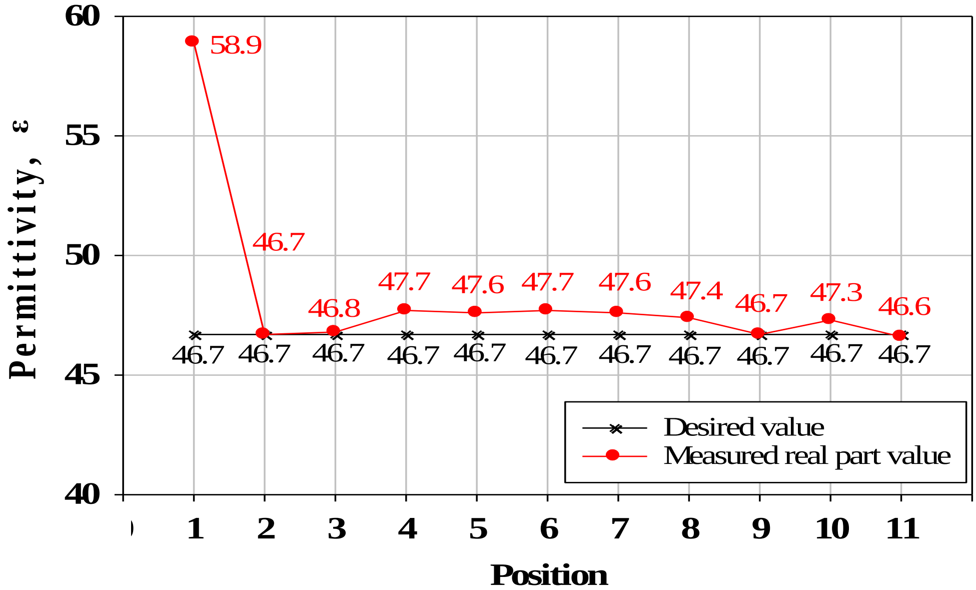

Fig. 5 - Comparison results of desired and measured permittivity, ε_r for the bottom surface of skin phantom

Fig. 6 shows the measured value for imaginary part (ε''), measured and desired value for conductivity of the phantom. By applying Eq. 1, the simpler way to get conductivity by using equation σ = (ε''/7.5). Therefore, the measured conductivity can be calculated and plotted as shown in Fig. 6 using the imaginary data, ε'' as stated in the figure. For example, if the ε'' at position 1 is 7.12, the measured σ is 0.95. The red line indicates the desired skin conductivity of σ = 0.69 S/m while the measured conductivity is demonstrated by the blue line. Overall average conductivity of σ = 0.68 S/m which is close to the desired value. This result exhibits the skin phantom successfully achieving the requirement for the targeted conductivity value by modifying the sodium chloride proportion in the recipe from 2.1 g to 1.8 g.

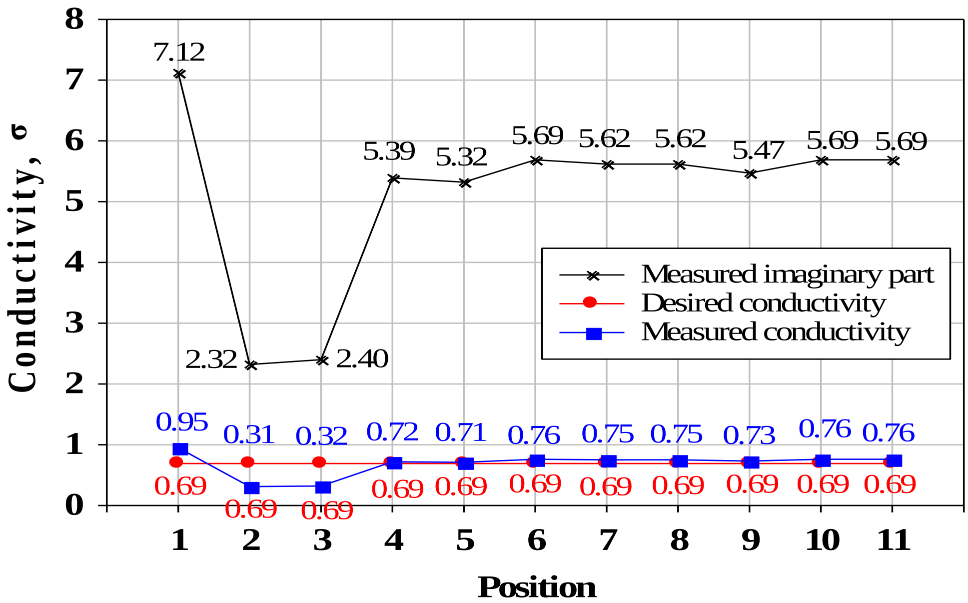

Fig. 6 - Comparison results of desired and measured conductivity, σ for the bottom surface of skin phantom

A lot of precaution needs to be taken care such as room temperature which need to be controlled during fabrication process, accurate ingredients composition ratio, as well as the cooking and mixing techniques to avoid the phantom became watery for example. Lastly, the precaution is made to reduce the air gap in the mixture when the phantom is solidified to increase the accuracy during measurement process. In addition, the thickness of the phantom need to verify if the phantom will be used for other measurement's application later on. It is to ensure that the human body phantom mimicking the real environment to reduce the error during the measurement process.

4. Conclusion

Based on this study, the fabrication of human skin phantom is done successfully. The methodology of the study is fully discussed and carried out. Fabrication process were done at Antenna Laboratory in Malaysia Japan International Institute of Technology-Universiti Teknologi Malaysia Kuala Lumpur. Meanwhile, the measurement setup was done using Network Analyzer N5224A from Keysight Technologies. The measured values for both permittivity and conductivity of the phantom are close to the desired value. The desired values for permittivity and conductivity are 46.7 and 0.69, respectively. Meanwhile the measured values are 48.3 and 0.68 for permittivity and conductivity, respectively. The precautions during fabrication need to be taken seriously to produce a good phantom. Overall, the phantom is in a good condition to be used in the on-body measurement with the antenna later on.

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