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Phantom development for In-Vitro measurements of MICS band telemetry antenna

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Abstract. The paper presents the development of a liquid phantom and In-Vitro testing of Compact Meander Line Telemetry Antenna (CMLTA) by using the developed phantom at 402.5 MHz. A liquid phantom for 402.5 MHz has been developed, and the dielectric properties of the developed liquid phantom have been characterized for verification by using an open-ended probe method. Various composite samples of the solution are developed to characterize material properties for comparison with the theoretical properties at 402.5 MHz (ε_r= 58.2, σ = 0.82). The comparison between simulated and theoretical permittivity as well as tangent loss is presented. The measured dielectric properties are verified by using open-ended coaxial dielectric kit. Simulated and measured results can be observed in terms of frequency and return loss performance with a deviation of 0.004 MHz and 2.7 dB, respectively.

1. Introduction
Implantable antenna in medical devices is commonly implanted in the patient body, which can be used for a number of applications in the biomedical field such as for diagnostic, monitoring and therapy applications [1]. In one of the previous research works [2], Ultra-Wide Band (UWB) antenna has been developed for breast cancer detection using simple homogenous breast phantom. In some published experimental work studies, soybean oil is commonly used as the breast phantom material due to easy availability [3]. A number of implantable antennas were proposed which study different factors crucial for implantable antennas such as miniaturization, exhibited radiation performance, patient safety and the effect by the implantation in the human body [4]. Prototype fabrication of the proposed design is highly important due to potential experimental and inconsistencies. Finally, in vitro testing of implantable antennas is one of the methods to verify the implantable antenna performances. In the paper, an implantable CMLTA has been simulated in the phantom environment and fabricated using FR-4 as a dielectric material. The proposed antenna is shown in Figure 1 and the details of the design were discussed in [5]. In vitro testing (using liquid phantom) is considered highly intriguing given the requirements for phantom formulation. Therefore, the liquid phantom has been developed in order to be utilized for experimental measurements of the proposed implantable antennas in the Medical

Implant Communication System (MICS) band. Liquid phantom for the research project is developed for 402.5 MHz, which is the resonant frequency of the proposed antenna. The phantom has to be developed at the same frequency as of the antenna under test in order to maintain the density of the medium, so that when the electromagnetic waves are transmitted to the phantom, the boundary conditions does not change due to the changes of the medium. Hence the maximum transmission of electromagnetic waves can take place with minimum reflection [6].

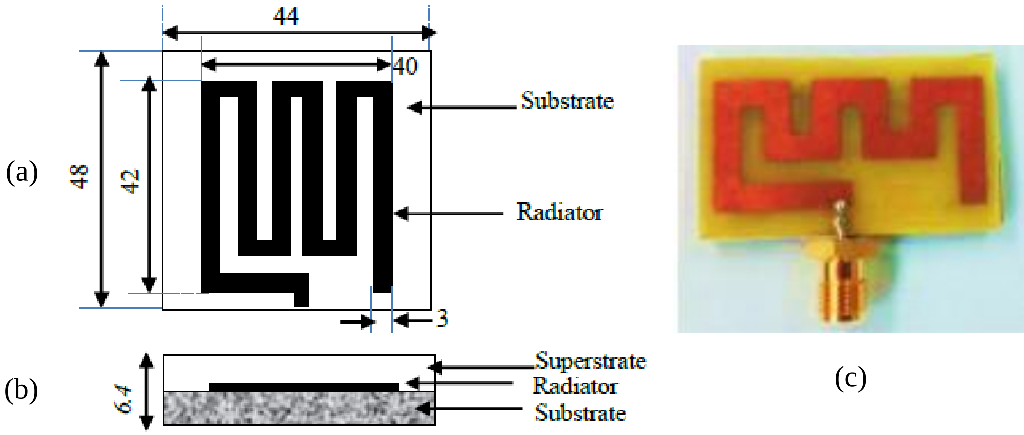

Figure 1. The proposed CMLTA (a) top view, (b) bottom view and (c) fabricated

2. Phantom Development and Verification

The development of liquid phantom and its material characterization is presented in this paper. For measurement purposes, a homogenous liquid phantom is developed practically using the composition of water (51.3%), sugar (47.3%) and salt (1.4%) to achieve phantom properties at 402.5 MHz. The dielectric measurements of the developed phantom have been performed by using an open-ended coaxial probe method to obtain dielectric properties such as permittivity and tangent loss. The dielectric properties, permittivity (ε_r) and conductivity (σ) can be calculated from the measurement of the output impedance of the probe against an unknown sample by using Equation (1).

$$\varepsilon' = \varepsilon_r \quad \text{and} \quad \varepsilon_r = \frac{\sigma}{\omega \varepsilon_o} \tag{1}$$

where σ, ω, and ε_r are conductivity, angular frequency, and permittivity, respectively. The complex conductivity is related by Equation (2).

$$\sigma' = j\omega\varepsilon' = j\omega\varepsilon_o\varepsilon_o' \tag{2}$$

The calibration has been carried out prior to the measurement process in order to obtain the accurate properties of the liquid phantom. The measured properties are then verified with the theoretical values provided by the FCC [6]. The calibration of the equipment is very crucial in order to provide precise results [8], [9]. Calibration is defined as the set of operations that establish, under specified conditions, the relationship between values of quantities indicated by reference material and the corresponding values realized by the standard [10].

Measurements have been carried out to check for the liquid lifetime until additional particles are observed on the surface of developed phantom. First, second and third measurements have been repeated as there is no additional particles appear on the phantom surface, and the consistency of the dielectric properties. After day 8, it was observed that dark particles appeared on the surface of the liquid phantom and significant changes on its dielectric properties due to contamination caused. The results of the investigation are tabulated in Table 1.

Table 1. Measurements of the developed liquid phantom

Measurement	Period (day)	Phantom quality
First	1	Ok / Clean
Second	3	Ok / Clean
Third	7	Ok
Fourth	8 onwards	Contaminated

The material characterization process of the developed phantom is shown in Figure 2. Three different types of water sources which are tap water, deionized water and distilled water have been considered in order to investigate the suitable material for the liquid phantom. Tap water is the water taken directly from the tap without any further processing while deionized (DI) water is the water that has been treated to remove all ions. On the other hand, distilled water is the purified water that has many of its impurities removed through distillation. In order to investigate the stability of the developed liquid phantom, measurements have been carried out three times for each of the samples. This has been done so that it can be assured that the lifetime of the solution and the environmental temperature does not have any significant effect on the dielectric properties of the developed phantom. Based on the three different water sources, the tap water is chosen for the final liquid phantom development as the results show consistency and stability of the measured permittivity and tangent loss in the three measurement series, and the values are in close agreement to the theoretical values. Figure 3 shows comparisons between the measured and theoretical properties of the developed phantom at 402.5 MHz using tap water. A close agreement is observed with the theoretical values provided by the FCC for MICS band, which are ε_r = 57.95 and *tan* δ = 0.622.

Table 2, summarizes the comparison between the permittivity and conductivity of the developed phantom to the reference values provided by the FCC and authors in [7]. The comparison between the developed phantom and FCC values provided a very small discrepancy of 0.43% and 11.11% for permittivity and conductivity, respectively. Whereas, a previous work [7] reported the values with higher discrepancy of 2.15% and 16.05% for permittivity and conductivity, respectively. especially for implantable applications. Furthermore, the proposed CMLTA is used to further verify the reliability of the developed phantom for MICS Band.

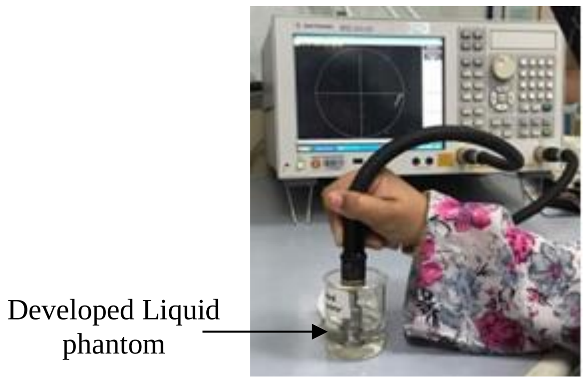

Figure 2. Material characterization of the developed liquid phantom

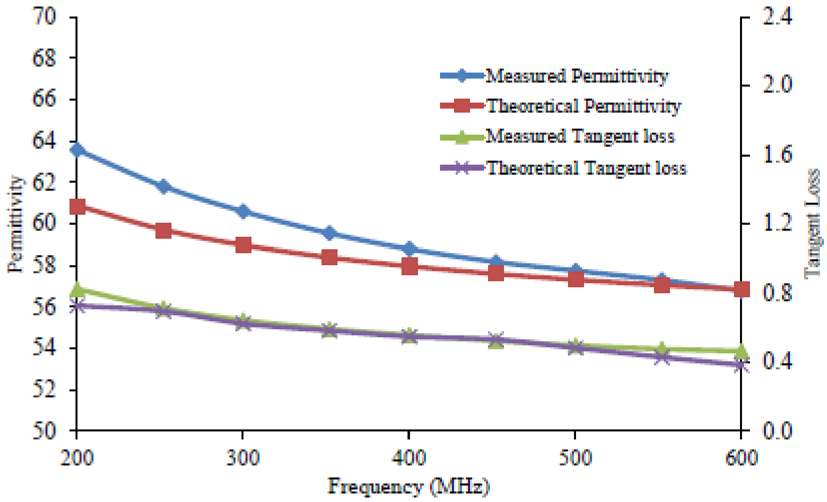

Figure 3. Comparison between measured and theoretical permittivity and tangent loss

Table 2. Comparison of dielectric properties between theoretical and developed phantom

	FCC		Ref [7]		Developed phantom	
Phantom Properties	ε_r	σ	ε_r	σ	ε_r	σ
	57.95	0.81	56.7	0.94	58.2	0.72
Discrepancy (%)	-		2.15	16.05	0.43	11.11

3. Antenna Measurements

To further verify the validity of the developed liquid phantom, the comparison is made between the simulated CMLTA in homogeneous phantom and the measured CMLTA with the developed phantom. In the simulation, the phantom is modeled as a box filled with homogenous tissue as in [7] as shown in Figure 4. Meanwhile, the fabricated CMLTA antenna is immersed into a box which is filled with the developed liquid phantom as shown in Figure 5. The antenna is wrapped in plastic in order to avoid direct contact with the phantom. The fabricated antenna is connected to a Vector Network Analyzer (VNA) where the coaxial cable and SMA connector are kept carefully outside the liquid phantom. The comparison between the simulated and measured return loss is shown in Figure 6.

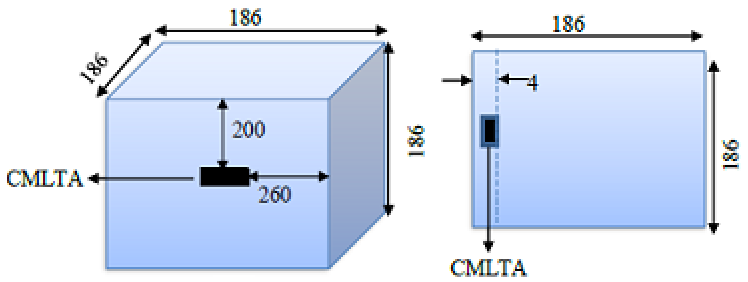

Figure 4. Simulation setup: CMLTA in homogeneous phantom

Figure 5. Measurement setup: CMLTA in developed phantom

Figure 6 illustrates the comparison between the simulated and measured results of the CMLTA antenna performance in homogenous phantom and in the developed liquid phantom, respectively. It can be observed that the measured results are in good agreement to the simulated results. A slight deviation is observed in terms of frequency and return loss performance with 0.004 MHz and 2.7 dB difference, respectively may be due to fabrication errors as well as approximations made in the development of liquid phantom.

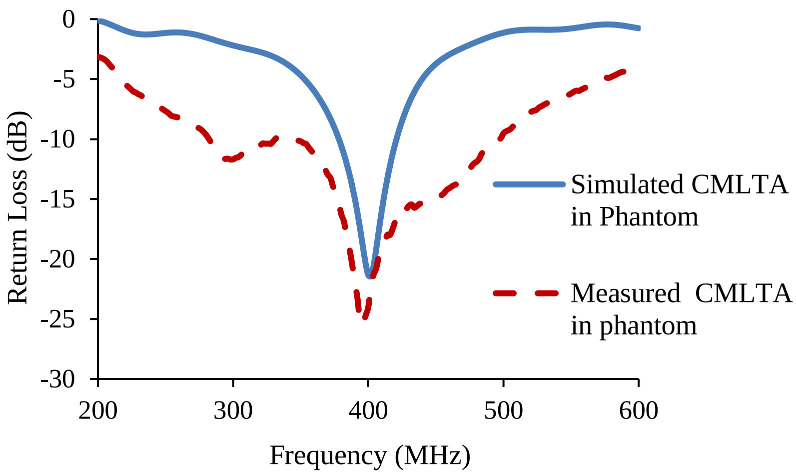

Figure 6. Simulated CMLTA in homogeneous box and measured CMLTA in developed phantom

4. Conclusions

The mixture of the liquid phantom to be used at 402.5 MHz MICS band has been developed and characterized using dielectric properties measurements. Return loss measurements of the designed antenna are carried out in the liquid phantom, which provided a close agreement with the simulated results in the homogeneous body model. From the investigation, it can be concluded that liquid phantom can be developed and used to mimic a human body. This could be useful to validate to antenna performance, especially for in-body and on-body health monitoring applications. A slight deviation between the simulated and measured results is be observed in terms of frequency and return loss performance with 0.004 MHz difference and 2.7 dB difference, respectively may be due to fabrication errors as well as approximations made in the development of liquid phantom, that can be improved in the near future.

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