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Detection of Diseased Tissues with Open-Ended Coaxial Probes

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Abstract

This work presents analysis of open-ended coaxial probes having four different aperture sizes. The probes are simulated in CST. S-parameters collected from simulations and the dielectric properties of the material under test is retrieved with an in-house algorithm. The probes are fabricated and the measurements are performed with the known materials to evaluate the performance of the probes. A good agreement is obtained between the performance of the fabricated and commercially available probes.

1 Introduction

Open-ended coaxial probes have been widely utilized to measure the dielectric properties of materials with high relative permittivity and high conductivity in laboratory environment. The technique is widely used to quantify the dielectric properties of biological tissues with commercially available kits that are available for laboratory use with the motivation to provide the groundwork for various microwave therapeutic and diagnostic applications. Despite being widely used for gathering dielectric property data, the research on the best measurement practices and dielectric property retrieval have been stagnated for over a decade. Currently, microwave dielectric measurements with open-ended coaxial probes are suffering from high error and low repeatability rates [1]. Due to the high error rates, envisioned applications have not been realized [2]. Therefore, the dielectric property measurements currently can only be performed in laboratory environment; the error is reported as 5% for commercial probes [3]. This error can originate from the dielectric property retrieval algorithm, microwave cable connections, and calibration errors. By using the current commercial measurement kits the dielectric properties of a material can not be quantified with high certainty with a simple measurement. The practical applications of the technique can only be possible when a single measurement with high accuracy is achieved. One such example of a practical application is given in [4] where the technique is used for classification of the hepatic malignancies. Towards this goal, among many other contributing error sources, the effect of probe aperture to the microwave dielectric property measurements were investigated. The probe aperture along with the dielectric properties of the material under test and frequency of operation are two factors determining the sensing depth of the probe. In this work, probes with varying aperture diameters were simulated in Computer Simulation Technology (CST, Framingham, MA, USA) program and the S-parameters were evaluated to compute the relative dielectric properties with an in-house algorithm. The probes were fabricated, then tested with known materials such as 2-propanol and methanol. Also, in-vitro dielectric properties of rat skin tissue were collected under different circumstances. This work is useful to understand the relationship between the aperture size and sensing depth. Thus, it enables the possibility of using probes with appropriate apertures for a designated application such as classification of tissue anomalies.

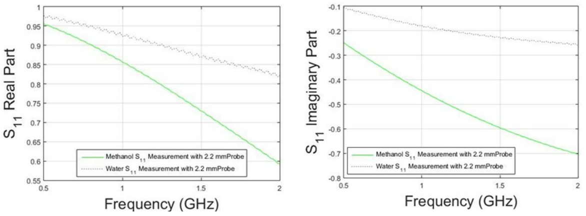
2 Materials and Methods

2.1 Probe Design

Open-ended coaxial probes were simulated with different apertures in CST and simulated S-parameter responses were collected when the probe was calibrated with open, short, and deionized water. Also, it was simulated with methanol as a known material. The probes were immersed 5 mm inside the liquid material under test. Next, simulated S-parameter responses were fed to the in-house dielectric property retrieval algorithm. Once the probe design was finalized, the probes with different aperture dimensions were fabricated. Copper was used for conductors and Teflon was used for the dielectric material. A total of four probes were fabricated with aperture diameters of 0.5 mm, 0.8 mm, 0.9 mm and 2.2 mm. The commercial probes are known to have an aperture diameter of 2.2 mm. Thus, this probe was used as reference to validate the simulations and the in-house algorithm.

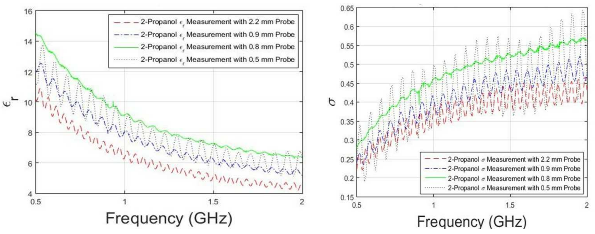
2.2 Dielectric Property Measurements

The dielectric property measurements were collected from known materials including 2-propanol and methanol to verify the proper functioning of the fabricated probes. Prior to the measurements, the probe was calibrated with the standard open, short, and known material measurements. Distilled water was used as a known material since the Cole-Cole parameters of the distilled water is well-established in the literature. Note that during the dielectric property measurements, S-parameter response of the probes were col-



(a) (b)

Figure 1. S_{11} measurements performed with probe having outer aperture diameter of 2.2 mm (a) real part of S_{11} collected from methanol and distilled water (b) imaginary part of S_{11} collected from methanol and distilled water.



(a) (b)

Figure 2. Dielectric property measurements performed with probes having outer aperture diameters of 0.5 mm, 0.8 mm, 0.9 mm, and 2.2 mm (a) relative permittivity measurements with 2-propanol (b) conductivity measurements with 2-propanol.

lected and the dielectric properties were retrieved with the in-house algorithm after measurements. S-parameters collected with 2.2mm-diameter probe from methanol and distilled water are shown in Fig. 1(a) and Fig. 1(b) for real and imaginary part, respectively. Note that the measurements were collected from 0.5 GHz to 2 GHz due to simulation limitations. Once the proper functioning of the probes are verified, the measurements can be performed at higher frequencies.

3 Results

Median dielectric property measurements calculated via in-house algorithm by using S-parameters collected from 2-propanol with fabricated probes is shown in Fig. 2. The difference between the measured values could stem from the calibration error and other factors such as cable loss. In order to eliminate the cable loss is to connect the probe directly to network analyzer or to use a low loss cable. The calibration procedure can be standardized; especially during the shorting of the probes. One important problem is the inability to short the probe properly, therefore, we are currently working towards standardization of the applied pressure during the shorting of the probe.

4 Conclusion

The accurate measurement of dielectric properties with open-ended contact probes have been suffering from low accuracy and low measurement repeatability rates. Open-ended coaxial probe method can be utilized as a diagnostic technology if the drawbacks, such as high measurement error rates, are eliminated with different approaches. In this work, we are looking into customization of these probes by changing the probe aperture to control the sensing depth of the probes. Customized probes can be utilized for applications requiring different sensing depth measurements such as skin cancer detection. By minimizing the sensing depth we intend to increase the accuracy of the measurement data in heterogeneous tissue. Other endeavours of the authors in this area include application of machine learning algorithms to the dielectric property data to eliminate the systematic measurement errors.

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