Establishing A Novel Technique for the Detection of Water Contamination Using Terahertz Waves

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***Abstract*—This paper presents preliminary results obtained through the measurements of the distinguished method for sensing the contaminants in the water using terahertz (THz) wave leveraging a commercially available THz material characterization kit (MCK) based on vector network analyzer (VNA) techniques and Swissto 12 system. The primary goal of this work is to highlight transmission response of THz wave through the frozen sugar-water and salt-water over the frequency range 0.75 THz to 1.1 THz. The different concentrations of mixed solution were frozen and measured to observe the transmission responses of corresponding solutions at different frequency regions since each additive in water induces a unique transmission response that can be examined to detect specific substances that caused water contamination. The results presented in this paper pave the way for applicability of THz technology for sensing the water contamination detection.**

***Index Terms*—terahertz, contamination, transmission response, detection, path loss.**

I. Introduction

The unique properties of terahertz (THz) radiation range from 0.3 THz to 3 THz make it particularly attractive for various applications including biomedical imaging, packaged goods inspection, food inspection, and water contamination detection [1]. The recent research work on the spectroscopic and imaging tools opens up new ventures by applying the particular technology for water food and contamination detection [2]. The core idea is that the food or the substance dissolved in water exhibit unique physical features and maybe inhere a particular spectral imprint when radiated in the THz wave field [3]-[5]. Studies on the food quality and safety inspection using THz technology has become popular since 2000. Several researchers have focused on the applications of particular technology such as microbiological contamination detection [6]-[8] and food additives identification [9][10]. Nevertheless, the terahertz detection for food and water contamination is limited by the strong absorbing nature of THz radiation due to the small energetic liberations available to terahertz absorption spectroscopy [12]. With the development of the THz spectroscopy technology, this limitation does not pose challenge to the applications of THz technique in the detection of moisture or humidity in different materials.

In this study, a novel technique is presented for detecting contaminated water by examining a very low concentration of salted and sugar water applying THz waves. As far as the experimental campaign is concerned, the data was collected by exposing the frozen samples that include frozen-pure-water, frozen-salt-water and frozen-sugar-water. The preliminary results indicate the identification of contaminated water (with additives) by examining particular imprints in the context of transmission response at specific THz frequencies. The results are obtained using vector network analyzer connected to the Swissto12 system operating at frequencies ranging between 0.75 THz to 1.1 THz [12], which lays the foundation for future studies in the field of water contamination detection.

II. Materials and Methods

A. Samples Preparation

Three various types of liquids (10 ml for pure-water, salt-water and sugar-water each) were used in the experimental campaign at laboratory. The concentration, c, of the mixture liquid can be calculated as

$$c = \frac{m}{m + 10ml} \times 100\% \qquad (1)$$

Here m is the mass of the salt or sugar. In this experiment, the mass of salt and sugar was weighed 0.2g (the minimum weight), and each time added by 0.2g until up to 2.4g respectively, using a digital scale as shown in Fig. 1(a). The additives were then fully dissolved into 10 ml of pure water. Moreover, a 2.6 ml salt-water solution and sugar-water solution were transferred into two different ice cubes frozen moulds by syringe as shown in Fig. 1(b). The length of one lattice was 32 mm, and the width was 22 mm. Therefore, the thickness of the frozen solution was approximately 3.7 mm. All samples including pure water, different concentrations of salt-water and sugar-water were prepared with extreme

(a) (b)

Fig. 1: Samples preparation for experiment. (a) weighing the salt and sugar. (b) Syringe was used for pouring the solution into frozen mould.

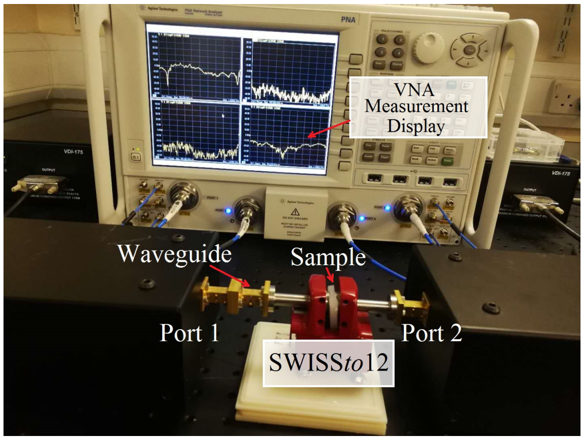


Fig. 2: Experimental equipment setup for measuring the transmission response using Swissto 12 THz system.

care and ensured that no solution should be mixed with each other during experimental campaign. Lastly, the samples were transferred gently into the refrigerator for 2 hours where the temperature was set to -77 degrees Celsius.

B. Experimental Apparatus Settings

As shown in Fig. 2, the THz transmission measurements were obtained using Swissto12 system after performing careful calibration process. The Swissto 12 system can measure the transmission response in the frequency range of 0.75 THz to 1.2 THz for the sample of thickness between the range of 40 μm to 4 mm. In order to minimize the measurement errors produced by the system or any other external factors, a fully two-port calibration (wR-1.0) was performed which is known as Short-Open-Load-Through prior to start of the THz transmission measurements based on the VNA where the range of frequencies was set into the THz region. Both the reflection coefficients (S_{11}, S_{22}), and transmission coefficients (S_{12}, S_{21}) were measured whilst performing experiments and obtained THz data. After freezing the samples, frozen pure water and different concentrations of both frozen salted and sugar water were placed in the material characterization kit (MCK) Swissto 12 system for measurements. For each case, measurements were performed and carefully three times at the same location of frozen samples to obtain the transmission responses (i.e. S_{21}) [13]. The average transmission response was measured using the following equation (2).

$$\tilde{S}_{21(k)} = \frac{\sum_{i=1}^{3} S_{21(k)}^{(i)}}{3} \tag{2}$$

where $S_{21(k)}^{(i)}$ is the measurement of the i-th time of the k-th sample. $\tilde{S}_{21(k)}$ is the average transmission response of three times measurements of the k-th sample.

III. Results and Discussions

The transmission responses of frozen pure water and three concentrations of frozen sugar-water are shown in Fig. 3. It can be observed that there are three peaks in the response curve of frozen pure water from 0.8-1.05THz. In the responses of three concentrations of sugar-water, three downward peaks centered at 0.87 THz, 0.95 THz and 1.04 THz are observed clearly in the same frequency range, which classify the different concentrations of the sugar-water (shown as the top embedded curve in Fig. 3). These results are obtained by curve fitting showing the recognition of sugar water in the whole sweeping frequency range, shown as the bottom embedded curve in Fig.3.

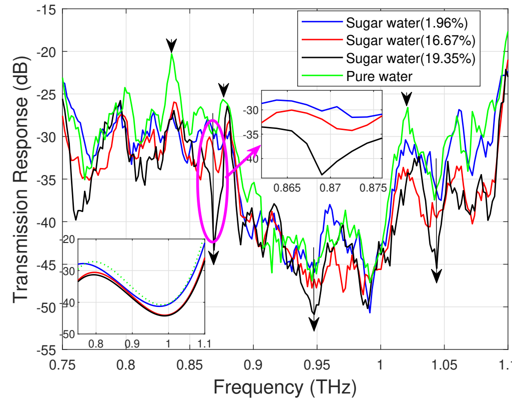


Fig. 3: THz transmission response of different concentrations in frozen sugar water at various frequencies.

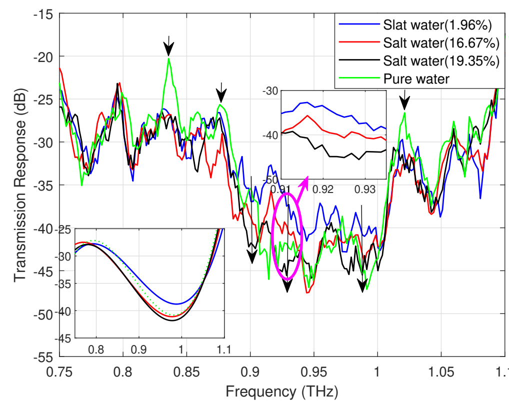
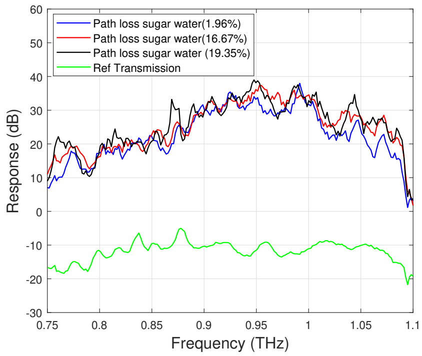


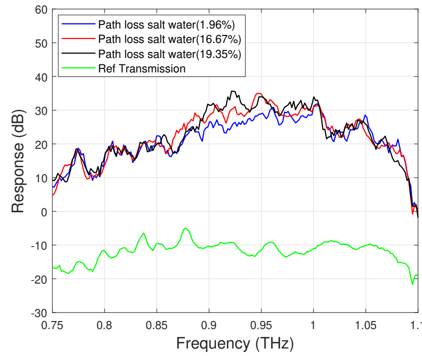
Fig. 4: THz transmission response of different concentrations in frozen salt water at different frequencies.

The transmission responses of frozen salt-water are shown in Fig. 4. Three downward peaks can be observed at the frequency of 0.9 THz, 0.93 THz, and 0.99 THz in the frequency range from 0.8-1.05THz. At these three frequency points, the concentrations of the salt-water can be distinguished clearly shown as the top embedded curve in Fig. 4. The recognition of the different concentrations of salt-water can be gained by curve fitting in this frequency range.

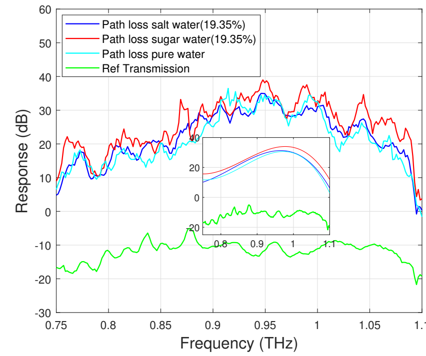
Fig. 5(a) and Fig. 5(b) show the path loss generated in different concentrations of both sugar and salt water, which can be observed that much loss has occurred in high concentration at the sensitive frequency region. The results demonstrate that



(a) Sugar water pathloss



(b) Salt water pathloss



(c) pure water pathloss

Fig. 5: Path loss response of frozen water with the effect of two impurities including sugar and salt.

TABLE I
CONCENTRATION AND PATH LOSS MEAN VALUE

Sample	Concentration (%)	Path Loss Mean (0.75-1.1 THz)
sugar water	1.96	-25.9716
	16.67	-27.7761
	19.35	-28.3946
salt water	1.96	-23.8532
	16.67	-25.7109
	19.35	-25.9442

the variation in transmission loss obtained from different concentration liquid is distinguished from each other indicating the higher concentration has the higher absorption. Fig. 5(c) shows the comparison of path loss responses of the highest concentration (i.e. 19.35%) in sugar water and salt water with path loss of pure water. The ingredients can be distinguished clearly from the same concentration in different water solutions, such as sugar and salt.The measurement results can also be verified from the Table I representing the path loss mean value of the different concentrations in sugar water and salt water. It clearly shows the relation between the concentration of liquid and path loss in specific terahertz wave region.

IV. CONCLUSION

In this paper, we have demonstrated a novel technique for sensing the contaminants such as sugar and salt in water using the THz wave exploiting VNA-based techniques and Swissto 12 system by examining the sweeping frequency range from 0.75 THz to 1.1 THz. Considering the measured results, it can be concluded that the different contaminants with very low concentration in water can be identified by analyzing specific THz frequency range. The future goal is to extend our work by introducing more substances into the water and taking more measurements from the samples used. Instead of analyzing the unique imprint induced due to specific substances (i.e. sugar and salt) in the context of transmission response, the large datasets obtained from the proposed method with various machine learning algorithms can be employed to classify and evaluate the performance in terms of percentage accuracy.

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