Progress In Electromagnetics Research Letters, Vol. 111, 1–7, 2023

Detection of Water Content in Honey by Electromagnetics Characterization Measurements

Floriane Sparma, Sarah Sennoun, and Pierre Sabouroux*

Abstract—The quality of a honey can be affected by adulteration through the addition of often unauthorized substances such as sugar syrups or water. The water content in honeys is restricted to 20% according to CODEX ALIMENTARIUS. This research proposes a method which will allow to detect the water content in the honey directly in the jar. The method uses electromagnetic probing with several antennas around the jar. This method is based on the knowledge of the dielectric contrast between a pure honey and a honey containing different water contents. To validate this contrast, a campaign of dielectric measurements has been investigated on two different commercial honeys (H1 and H2) with arbitrary and controlled added water. The added water content in the honey has been varied from 0% to 15%. The experimental setup uses a coaxial transmission line with a sample holder. The frequency range extends from 100 MHz to 5000 MHz. The mixtures of honeys with water have been measured at an ambient temperature (25°C).

1. INTRODUCTION

In the food industry, honey is a victim of frauds that deceive the consumer on the quality of this product. A honey produced in a hive, remains a product without transformation. However, some producers or industrialists add cheaper substances to increase the financial margin. This practice is called adulteration. The added substances are usually syrups or simply water. If too much water is added, the honey can be of poor quality, ferment, and become unfit for consumption. The water content of honey therefore directly affects its taste, keeping quality, storage, and crystallization. The legal limit established by the Council Directive 2001/110 EC and the **CA**(**C**ODEX **A**LIMENTARIUS) [1] is maximum 20% in general and 23% for a heather honey (*Calluna*). It is therefore important to be able to measure this water content.

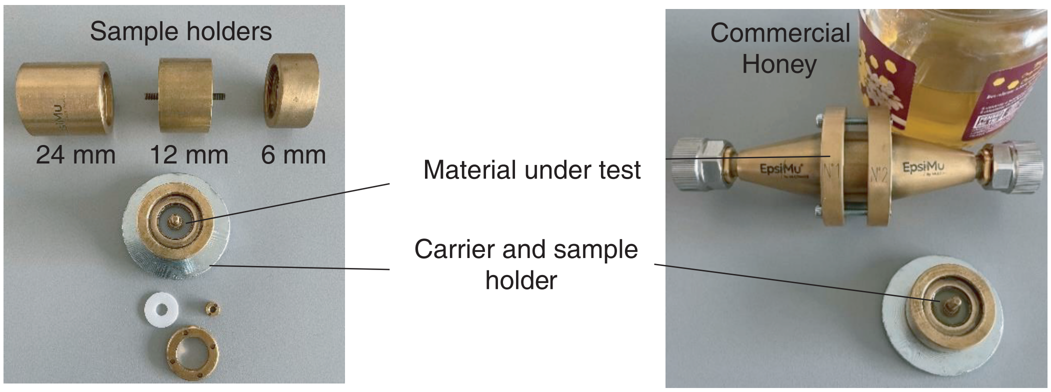
Thus, a reliable and traceable noninvasive method of honey's characterization is necessary. In this context, an approach using a microwave probing is proposed in this article. The setup uses a cylindrical system surrounded by antennas placed around a honey jar. Through these antennas, electromagnetic waves are emitted into the material in the microwave range between 100 MHz and 5000 MHz. The aim of this study is to propose a system that performs nondestructive measurement. The system will measure the transmission between two antennas. The transmission data is related to the dielectric values of the honey. Thus, if we observe variations in permittivity as a function of water content, the variation of the transmission parameter also varies as a function of this water content.

To determine the dielectric permittivity, there are different technics to measure this dielectric value. First, there are technics using cavity resonator [2]. For a liquid material, the permittivity value can be measured by reflection method [3, 4], or transmission method also [5]. In our case, we use a reflection and transmission method [6]. Two commercial honeys are characterized by the coaxial line method, available under the industrial name *EpsiMu*® coaxial line.

Received 12 April 2023, Accepted 23 May 2023, Scheduled 15 June 2023
* Corresponding author: Pierre Sabouroux (pierre.sabouroux@fresnel.fr).
The authors are with the Aix Marseille Univ., CNRS, Centrale Marseille, Institut Fresnel, Marseille, France.

2. DIELECTRIC MATERIAL AND METHOD

The *EpsiMu*® coaxial cell for characterizing electromagnetic parameters as the complex permittivity [7] is based on the measurement of reflection and transmission on a guided coaxial propagation line [8]. The dielectric permittivity values are calculated with the Nicolson-Ross method [9]. The external diameter of the *EpsiMu*® cell is 13 mm. This coaxial cell uses some sample holders with different lengths: 6, 12, and 24 mm (Fig. 1(a)). For the tests of this study, the length of the sample zone is 6 mm. The 6 mm length sample holder has been used in these campaigns in order to avoid numerical singularities when the electrical length of the sample is close to half wavelength [10–12].



(a) (b)

Figure 1. (a) Sample holders of the *EpsiMu*® cell. (b) *EpsiMu*® cell and honey sample.

The honey sample [Fig. 1(b)] fills completely the sample holder positioned between the two tapered coaxial cells [13–16]. All parts are screwed together allowing the cell to be fully assembled.

The cell is connected between the two ports of the **V**ector **N**etwork **A**nalyzer (**VNA**) *Anritsu MS2038C* [Fig. 2]. The frequency range is between 100 MHz and 5000 MHz. The measurements are performed by using the *EpsiMu 5.0* software. The experimental data processing is performed with the *Nicolson and Ross* method [9] to calculate the permittivity value from the reflection and transmission data measured with Vector Network Analyzer (VNA).

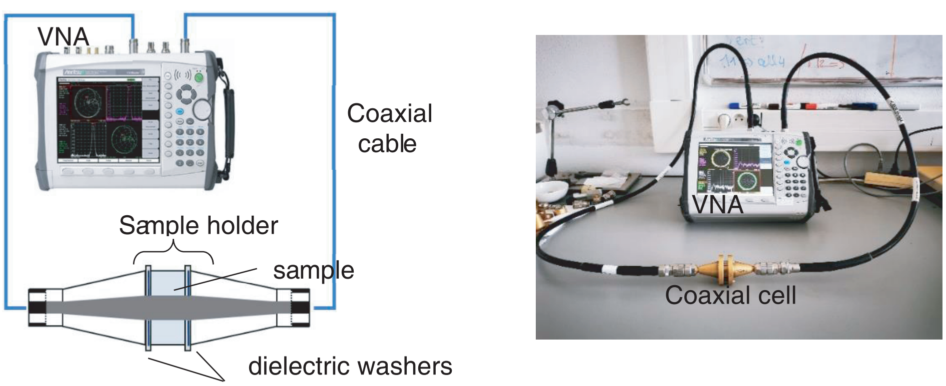


Figure 2. Schema of dielectric measurement bench.

3. RESULTS OF PERMITTIVITY OF HONEY WITH WATER

Permittivity measurements have been carried out on two different commercial honeys: **H1** (**H**oney **1**) and **H2** (**H**oney **2**) with different **a**dded **w**ater (a.w.). The two honeys that have been selected are two classic liquid honeys very consumed in supermarkets. H1 is a brown honey of Acacia, and H2 is a rather clear jaunty honey of flowers. Each sample of honey and water mixture was prepared according to mass fractions (m_{water}/m_{total}). The samples were mixed with a stirrer with low rotation speed in order not to introduce air into each mixture. The selected honeys were very liquid which simplified the viscous homogeneity of each preparation. For the measurements, the data varied from natural honey (0% a.w.) to honey with 15% a.w. Before each measurement, the **M**oisture **C**ontent (**%MC**) have been measured. Several techniques can be possible like refractometer or loss on drying method. For these measurements, we use the second method with a moisture analyzer (*Mettler Toledo HB43*). The honey samples were spread thinly over the entire surface of a 100 mm diameter aluminum sample holder to extract most water. Each sample was spread to have a mass of 1.5 grams. The procedure was performed four times for each honey at 130°C for 30 minutes.

3.1. The Moisture Content (%MC) Measurements of Honey

With the moisture analyzer, the %MC measurement is based on the weight loss after the heating of the material. It is the loss on drying method. We assume that water predominates over VOCs (volatile organic compounds) in honey. Thus, the %MC is obtained by a relation between the **W**et **W**eight (**WW**) and the **D**ry **W**eight (**DW**) of material (1). We have an accuracy of 0.01% with our moisture analyzer.

$$\mathbf{MC}\,[\mathbf{0}\ldots\mathbf{100}\%] = \frac{Wet\,Weight\,(\mathbf{WW}) - Dry\,Weight\,(\mathbf{DW})}{Wet\,Weight\,(\mathbf{WW})} * 100\% \tag{1}$$

First, these measurements of moisture content allowed to estimate the amount of water in these two natural honeys. Secondly, check if the addition of water content is in accordance with the %MC measured.

Thus, the percentage of added water content in honey has been traceable with the %MC [Fig. 3]. Both H1 and H2 have a %MC value around 15% in natural state without added water. Besides, the linearity of the added water with the %MC proves the logical amount of water in the honey and validates the values of %MC for natural honeys.

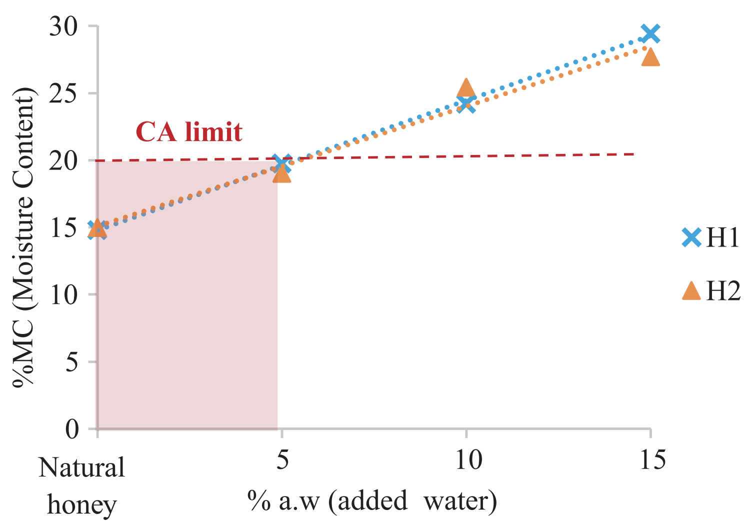
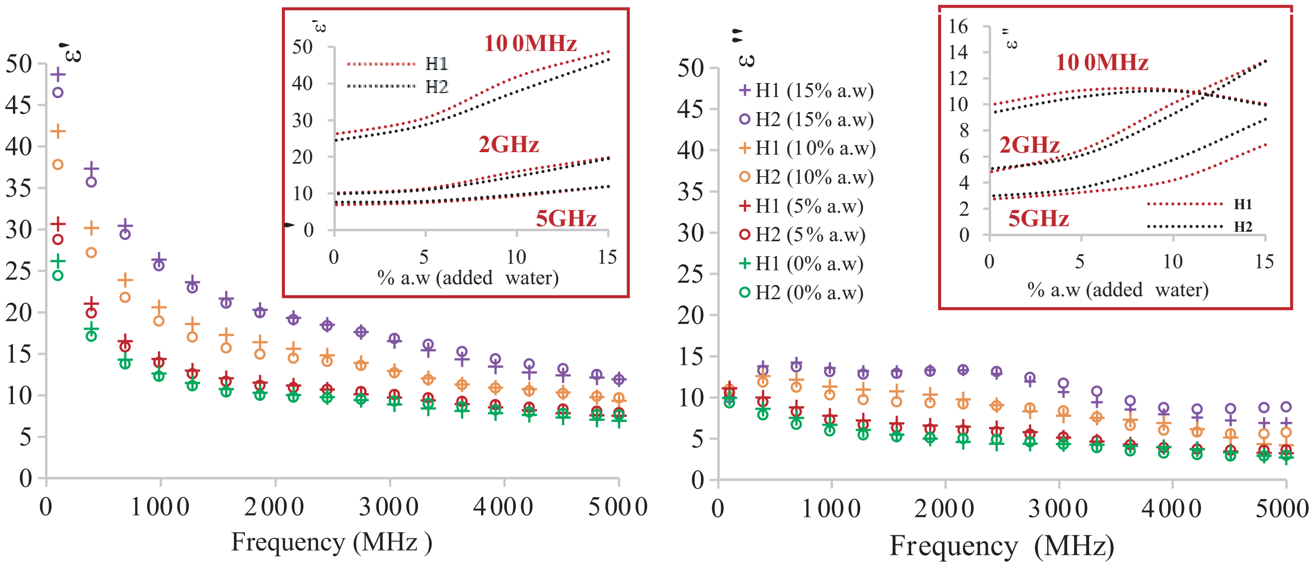


Figure 3. %MC (Moisture Content) measurements of H1 and H2.

3.2. Dielectric Measurements of Honey at 25°C

For the water, *Codex Alimentarius* (CA) has defined the water content's limit at 20% [1] for commercial honeys. Both honeys already have a water content value at 15% naturally and at 5% under the CA limit. In order to highlight a contrast dielectric with the circular system, the choice of variation of **a.w**



(a) (b)

Figure 4. (a) Real and (b) imaginary part of permittivity of mixtures honey with added water: from 0% to 15%.

(**a**dded **w**ater) content in the honey, in this dielectric campaign, was from 0% up to 15% [Fig. 4]. In both cases, the value of permittivity changes with frequency and water. In the real part of permittivity, the values decrease with frequency and increase with water. For example, at 100 MHz the permittivity increases by 20 from 5% to 15% a.w. whereas it increases by 10 at 2 GHz and 5 at 5 GHz on the same band of added of water. Indeed, the real part of permittivity of honey seems less sensitive to water when it does not exceed more 5% of added and all the more in the high frequencies (5 GHz).

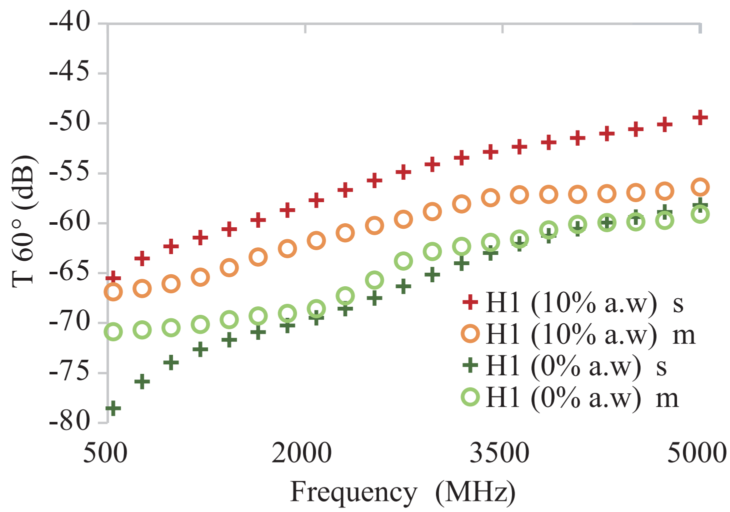
For the imaginary part of permittivity [Fig. 4(b)], at 100 MHz there is almost no variation even with 15% a.w. It increases by less than 7 at 2 GHz and by 0.5–2 at 5 GHz between 5% and 15% a.w. The variation of value between pure honey and the honey with 5% dry extract is small. The difference is less than 1.5–2 over the entire frequency band.

4. DISCUSSIONS

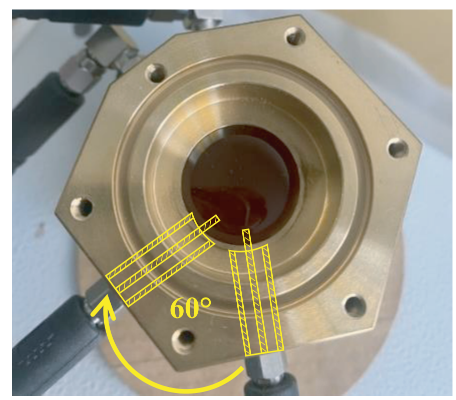
We have verified with two different commercial honeys that the dielectric permittivity of honey depends on the water content. The coaxial cell method is one of the many techniques that efficiently and accurately prove this variation. In fact, the real and imaginary parts of permittivity (ε' and ε'') increase with the total percentage of water content and decrease with the frequency in the studied range [100 MHz; 5000 MHz]. The values obtained are consistent with other dielectric measurement techniques [3] which validate our results. Moreover, the study of the dielectric contrast on two different commercial honeys emphasizes the validation of this system. We notice that the increase of the permittivity value is not proportional to the water content in the honey. Indeed, the difference between 0% and 5% of added water (i.e., between 15% and 20% of total water content) remains weak, lower than 2 for the real part and imaginary part. Nevertheless, the principle of detecting the water content by electromagnetic characterization measurements remains interesting as long as the expected variations can be observed. Indeed, beyond 5% of added water (i.e., beyond 20% of the total water content), we are able to detect if the water content of the honey is lower or higher than 20%MC simply by the knowledge of the permittivity value.

5. AN APPROACH OF AN INDUSTRIAL ELECTROMAGNETIC SYSTEM

Instead of using a coaxial cell to determine the permittivity of honey, we have developed a measurement a new cell using a circular guide section associated with monopole antennas. In this first realization, the angle between the two monopole antennas is equal to 60° [Fig. 5(a)]. The monopole antennas are based on a straight SMA flange mount connector with 4.10 mm diameter for the dielectric part, 1.3 mm diameter for the inner conductor, and 2.80 mm for the monopole length. The circular guide section has 20 mm diameter and 50 mm height. The two monopole antennas are coaxial with 2 mm of diameter which allow to measure the transmission [Fig. 5]. Electromagnetics simulations of this system were carried out on samples of both honeys, H1 (0% a.w) s and H1 (10% a.w) s, then verified directly in experimental (H1 (0% a.w) m and H1 (10% a.w) m) [Fig. 5(b)]. The simulations are performed with the 3D EM simulation software *CST Microwave Studio*.



(a)



(b)

Figure 5. (a) Transmission simulations (s) and measurements (m) of two samples honeys (H1 (0% and 10% a.w)) in the (b) circular guide section with two monopole antennas with a 60 degrees' angle.

Simulations (+) and measurements (o) show a variation of the transmission between two monopole antennas as a function of the water content of the honey samples [Fig. 5]. In the microwave range [500 MHz, 5000 MHz], a significant variation between 7 dB and 12 dB is found between the simulation with 0% (natural honey) and that with 10% a.w. The differences between the simulations and experimental measurements are due to the different high frequency connection components such as coaxial cables and adapters. Indeed, these elements are not taken into account in the simulations. However, we have the same relative variations with the water content both in simulation and experiments.

Consequently, through the support of results of this system used for other applications, we propose an all new system where the model is a little different from *Fig. 5(a)* and is more adapted for industrial applications. Thus, simulations of a model of electromagnetic system have been done on these two samples of honeys (H1 (0% a.w) and H1 (10% a.w)) at the microwave range of the dielectric campaign [500 MHz–5000 MHz]. For simulation setup, we use one emitter probe and two receiver probes located at two different angular positions: 30 and 60 degrees [Fig. 6]. The tubular setup with probes around the glass jar of 3 mm of thickness is in perfectly electrical conductor (PEC) [17].

The transmission (T_{60° and T_{30°) between the two probes increases with the added water in the honey at the same frequency band as the campaign studied before [Fig. 7]. A variation around 3–4 dB is raised between the measure with 0% and the one with 10% a.w. Consequently, this first version of this simulated model validates the use of this method on honeys.

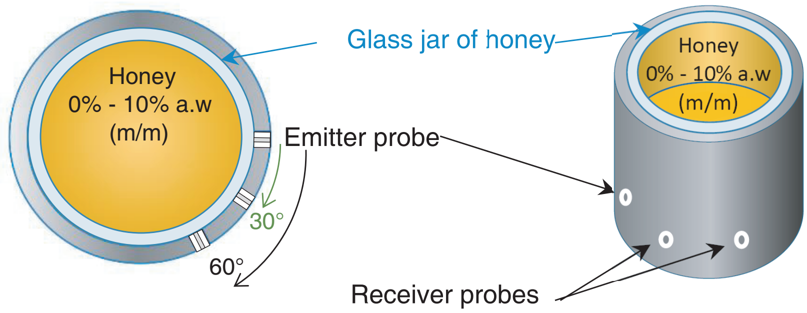


Figure 6. Simulated model for electromagnetic characterization applications of honey.

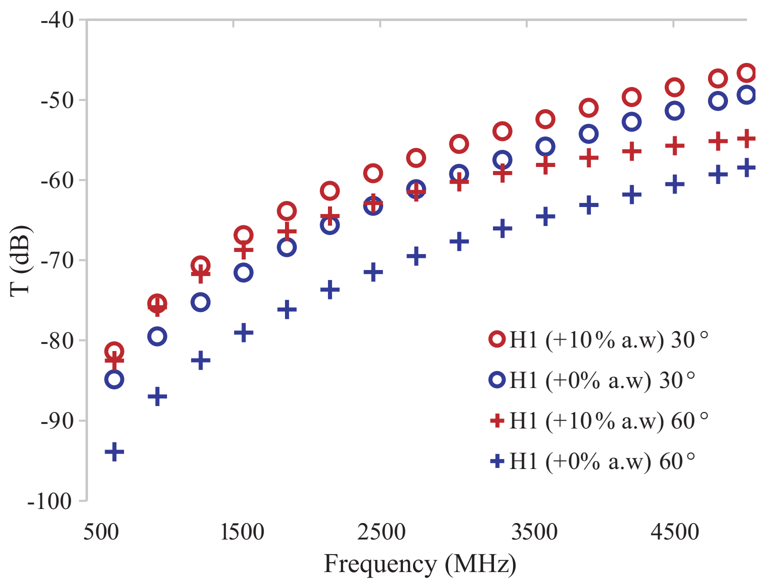


Figure 7. Simulation of transmission T_{60° and T_{30° (dB) between two probes around the jar of honey.

6. CONCLUSION

In this research, the study of dielectric contrast on different mixtures of honey with water is verified using a coaxial line transmission system on a frequency range from 100 MHz to 5000 MHz. These contrasts become less important and visible between 15% and 20% of total water content in the honey. Nevertheless, the variations are presents. In order to develop an industrial system to detect the water content in the honey, a simulation study was done with several probes covering a jar of honey. The system focuses only on transmission coefficients measurements between two probes. The principle is that the detection of water content is based on the variation obtained from these transmission measurements. Thus, variations of the signal as a function of the water content have been obtained. This allows us to propose a first potential solution to be used in an industrial environment to detect water adulteration directly in a honey jar.

ACKNOWLEDGMENT

This work carried out in the European project ***BIOFMET*** funded by the *European Metrology Programme for Innovation and Research (EMPIR)* from *the European Association of National Metrology (EURAMET)*. The prototype used in this work derivate from a setup studied in BIOFMET Project. It is a new and important application in agrifood aera.

REFERENCES

1. Codex Alimentarius Commission, Revised Codex Standard for Honey, Codex Standard 12-1981, Rev. 1, 1987; Rev. 2, 2001.
2. Li, Z., Z. Meng, A. Haigh, P. Wang, and A. Gibson, "Characterisation of water in honey using a microwave cylindrical cavity resonator sensor," *Journal of Food Engineering*, Vol. 292, 110373, 2021.
3. Bakar, A. A., M. A. N. B. Rodzali, R. Radzali, et al., "Dielectric properties assessment of honey by using non destructive dielectric spectroscopy," *International Journal of Electrical and Computer Engineering*, Vol. 12, No. 1, 189–200, February 2022, ISSN: 2088-8708.
4. Yakubu, A., Z. Abbas, and A. Muhammed, "Determination of adulteration of honey syrup using open ended coaxial probe sensor at microwave frequency," *Open Access Library Journal*, Vol. 6, e5448, 2019.
5. Li, Z., A. Haigh, C. Soutis, A. Gibson, and R. Sloan, "Evaluation of water content in honey using microwave transmission line technique," *Journal of Food Engineering*, Vol. 215, 113–125, December 2017.
6. Ba, D. and P. Sabouroux, "EpsiMu, a toolkit for permittivity and permeability measurement in microwave domain at real time of all materials: Applications to solid and semisolid materials," *Microwave and Optical Technology Letters*, Vol. 52, No. 12, December 2010.
7. Georget, E., R. Abdeddaim, and P. Sabouroux, "A Quasi universal method to measure the electromagnetic characteristics of usual materials in microwave range," *C. R. Physique*, Vol. 15, 448–457, 2014.
8. Jarvis, J. B., M. D. Janezic, et al., "Measuring the permittivity and permeability of lossy materials: Solids, liquids, metals, building materials, and negative-index material," *NIST Technical Note 1536*, 2005.
9. Nicolson, A. M. and G. F. Ross, "Measurement of the intrinsic properties of materials by time-domain techniques," *IEEE Trans. on Instrumentation and Measurement*, Vol. 19, No. 4, Nov. 1970.
10. Boughriet, A. H., C. Legrand, and A. Chapoton, "Noniterative stable transmission/reflection method for low-loss material complex permittivity determination," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 45, No. 1, January 1997.
11. Jarvis, J. B., E. J Vanzura, and W. A Kissick, "Improved technique for determining complex permittivity with the transmission/reflection method," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 38, No. 8, August 1990.
12. Jarvis, J. B., M. D. Janezic, J. H. Grosvenor, and R. G. Geyer, Jr., "Transmission/Reflection and short-circuit line methods for measuring permittivity and permeability," *NIST Technical Note 1355-R*, 1993.
13. Park, H. H., "Design of compact transition from conical to coaxial transmission lines with a low return loss," *International Journal of Electronics*, DOI: 10.1080/00207217.2020.1870739.
14. Adous, M., P. Queffelec, and L. Laguerre, "Coaxial/Cylindrical transition line for broadband permittivity measurement of civil engineering materials," *Meas. Sci Technol.*, Vol. 17, 2241–2246, Institute of Physics Publishing, 2006.
15. Chew, W. C., K. J. Olp, and G. P. Otto, "Design and calibration of a large broadband dielectricmeasurement cell," *IEEE Transactions on Geoscience and Remote Sensing*, Vol. 29, No. 1, January 1991.
16. Bohleber, P., N. Wagner, and O. Eisen, "Permittivity of ice at radio frequencies: Part I. Coaxial transmission line cell," *Cold Regions Science and Technology*, Vol. 82, 56–67, October 2012.
17. Sparma, F., B. Tallawi, E. Georgin, and P. Sabouroux, "Multi-probe sensor for water content diagnosis of liquid biofuels," *Progress In Electromagnetics Research Letters*, Vol. 106, 1–6, 2022.