Soil Moisture Dielectric Measurement Using Microwave Sensor System

[1]Yi Lung Then, [1]Kok Yeow You and [1]Mohamad Ngasri Dimon
[1]Department of Communication Engineering, Faculty of Electrical Engineering,
Universiti Teknologi Malaysia, 81300 UTM Skudai, Malaysia.

***Abstract* – A microwave sensor system has been developed to operate from 2.2 GHz to 4.4 GHz and used to determine the change of soil dielectric constant with various values of gravimetric moisture content from 0% to 26%. Soil samples are placed on a microstrip ring resonator (MRR) sensor and the respective incident and reflected voltages are measured and converted into magnitude of return loss, $|S_{11}|$. The calculated return loss, $|S_{11}|$ is then correlated with corresponding soil moisture content obtained from oven drying method and also the soil permittivity obtained from commercial dielectric probe with vector network analyzer.**

***Index Terms* — Soil moisture, microstrip ring resonator, return loss, permitivity.**

I. INTRODUCTION

Recently, microwave electronic components have become relatively common for agricultural testing and are produced at a more affordable price. Microwave ring sensor for soil moisture and dielectric measurement was first introduced by Kamal Saramandi [1], followed by monopole sensor [2], antenna patch [3], resonator cavity [4], , and coaxial probe [5]. Time domain reflectometry (TDR) and currently the most popular, frequency domain reflectometry (FDR) which is used in this paper are significant operating system for microwave aquametry measurement. The advantage of using microwave sensor system is because of fine precision and good sensitivity in respect to the moisture content in sample under test (SUT). The moisture content in the sample is strongly affecting its dielectric properties, since normally the value of dielectric constant of water is far higher than its dry substrate of the sample. Thus, soil dielectric measurement is significant to determine soil quality. In this paper, we introduce a portable microwave sensor system, which operates as an actual vector network analyzer which was previously used to determine soil moisture and dielectric constant.

II. FABRICATED MICROWAVE SENSOR SYSTEM

The full architecture of this microwave sensor system with 13 cm in length, 6.5 cm in width, and 11.5 cm in height consists of ***A***: a microwave controllable synthesizer, ***B***: a microstrip S-band microwave directional coupler [6], ***C***: two power detectors, ***D***: a cooling fan, ***E***: power source, and a National Instrument X-Series USB multifunction data acquisition unit (DAQ), which interacts with a personal computer for control and display usage. For measuring part, a MRR is designed and fabricated. The MRR is available in [7]. The schematic diagram for the full set of microwave sensor system is shown in Fig. 1. The microwave controllable synthesizer is able to generate sweeping signal frequency from 2.2 GHz to 4.4 GHz. The output of the system is interpreted in magnitude of return loss, $|S_{11}|$ (dB) parameter, which computed from raw measured reflected voltage, V_A and measured incident voltage, V_B, as:

$$S_{11} = -20\times\log_{10}\left(\frac{V_A}{V_B}\right) \tag{1}$$

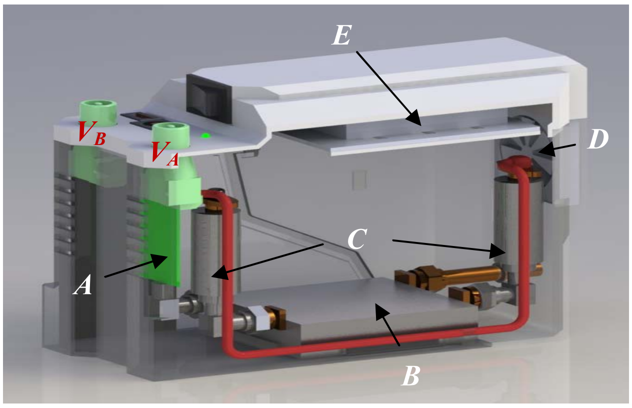


Fig. 1. Configuration structure of microwave sensor system in application.

III. RESULTS AND DISCUSSION

A. Moisture Measurements

The full system in Fig. 2 was constructed and used in resonance measurement for various moisture content, *m.c.* in soil sample. 50 grams of dry soil sample, $m_{drysoil}$ was mixed with various amount of water content, m_{water}, respectively. The gravimetric moisture content, *m.c.* of the soil-water mixture from 0 % to 26 % was calculated by using (2) (dry basis). The $|S_{11}|$ of the sample was computed from measured voltages (V_A and V_B) using two power detectors via (1). Fig. 3(a) shows the $|S_{11}|$ versus frequency, *f*. From broadband measurement of $|S_{11}|$, the resonant condition of the system at certain frequency can be determined. In this study, as expected, the resonance of the measurement encounters frequency shifting with changes in gravimetric moisture content, *m.c.* at room temperature.

$$m.c. = \frac{m_{water}}{m_{drysoil}} \times 100\% \qquad (2)$$

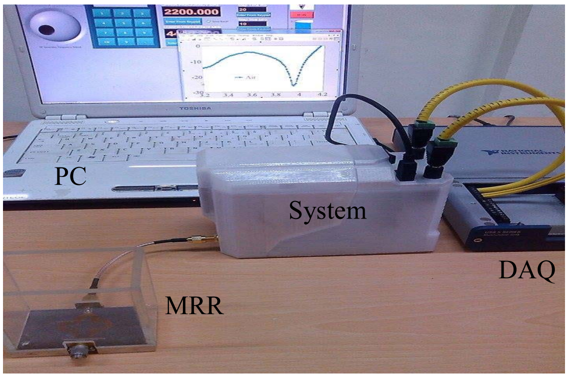
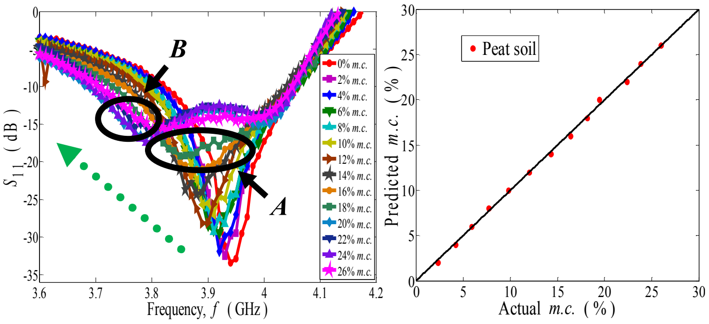


Fig. 2. Configuration of full sensor system for soil moisture measurement.

The green dotted arrow line illustrates the tendency of shifting curve of $|S_{11}|$ related to the moisture content contained in the mixture soil sample. The significant changes can be separated into two regions. The ***A*** region is the bound water condition (18-20% *m.c.*) in the soil-water mixture sample, while the ***B*** region is free water condition (22-26% *m.c.*), respectively as shown in Fig. 2. In fact, soil particles' with different shape and density may directly affect the soil's bound water fraction [7]. The measured $|S_{11}|$ were fitted with corresponding *m.c.* obtained from (2). The 5th order polynomial equation for the average *m.c.* as a function of $|S_{11}|$ is listed in (3). To verify the accuracy and reliability of the (3), the predicted *m.c.* for peat soil was compared with actual *m.c.* from (2) as shown in Fig. 3(b). The mean deviation between the predicted and actual *m.c.* are within ±0.02 *m.c.* The deviation is due to several factors such as soil-water mixture is not uniform during the preparation of samples as well as some water content has evaporated into air during experiment [2].

$$\begin{aligned}&\text{Predicted } m.c. = 3.8268\times10^{6} f_s^{5} - 1.3432\times10^{6} f_s^{4} + \ldots \\ &1.5526\times10^{5} f_s^{3} - 7022.3 f_s^{2} + 306.36 f_s - 0.19209\end{aligned} \qquad (3)$$



(a) (b)

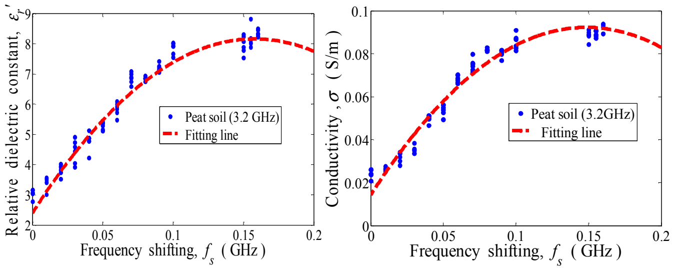
Fig. 3. (a) Variation in return loss, $|S_{11}|$ with frequency, f of various gravimetric moisture content, *m.c.* and (b) comparison between predicted and actual gravimetric moisture content, *m.c.* at room temperature (25±1) ˚C.

B. Dielectric Measurements

Relative dielectric constant, ε'_r and conductivity, σ (in Siemens/meter) measurements obtained from vector network analyzer via commercial HP85070D dielectric probe were correlated with the proposed microwave sensor system. Fig. 4 (a) shows the changes in ε'_r with frequency shifting, f_s for different *m.c* values. Conductivity, σ changes in variations with frequency shifting, f_s for different moisture changes as shown in Fig. 4 (b). Quadratic fitting lines were computed as functions in the data acquisition system for predicting both ε'_r and σ of tested soil samples. Both fitting equations for prediction were empirically expressed in (4) and (5).

$$\varepsilon'_r = -230.66 f_s^{2} + 72.864 f_s + 2.4011 \qquad (4)$$

$$\sigma = -3.5 f_s^{2} + 1.1 f_s + 0.014 \qquad (5)$$



(a) (b)

Fig. 4. Relationship between (a) relative dielectric constant, ε'_r and (b) conductivity, σ of various moisture content, *m.c.* and frequency shifting, f_s.

IV. CONCLUSION

The microwave sensor system was successfully developed. Its application on determining dielectric properties and moisture content, *m.c.* is based on scalar measurement stand-alone technique. This reflectometer technique is not only applicable for soil processing but its good reliability measurement can be used to perform testing on other agricultural products.

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