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Geological Effect on GPR System Due to Soil Properties in Malaysia

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Abstract: This paper present the measurement of dielectric properties of soil in Malaysia in three differences condition which are normal condition (ambience), heated (up to 50 ^{O}C) and wet condition (10 % water content). Eight (8) samples of soil have been collected in the local region and was measured in the frequency range from 0.5 GHz to 3.5 GHz for Ground Penetrating Radar (GPR) applications. The measurement of the dielectric properties has been conducted using Agilent high temperature probe (Model) integrated with Performance Network Analyzer (PNA E8362B). The uncertainties in measurement process, especially dealing with measurement data have been considered in order to eliminate the probability of error during the measurement. The measured result for permittivity and loss factor of the measured samples are tabulated in graphs and the analysis of the measured data are discussed in this paper.

Keywords: Dielectric properties, Ground Penetrating Radar, GPR, Soil Properties.

1. Introduction

Materials characterization has increased much interest, especially in many research fields such as materials engineering, microwave engineering, archaeologies, science, etc. In radio and microwave engineering such as in Ground Penetrating Radar (GPR) application, the requires of knowledge based on electromagnetic properties of materials are very important since it can show the electric or magnetic behavior of the materials. In the application of GPR systems, the transmit signal will propagate through the ground and reflect the signal when it hit the object. This is due to the differentiation of the dielectric properties between soil and the buried object and the illustration of the working principle of the GPR for bi-static radar system is shown in Fig. 1. Thus, the condition of the medium is very important to know before begin the measurement since it will have a significant effect on the overall performance of GPR systems.

The humidity of soil is different from one to another region. In [1], shows the GPR suitability map to conduct a measurement based on humidity in the selected regions in United State. This is very important because every region in the world have differences kind of soil properties. In Malaysia, as known as rainforest country which have many kind of soil types which produces different kind of properties. Thus, it is important to characterize the soil properties in order to obtain accurate data before performing any GPR measurement. In this paper, eight (8) samples of soil from local region (Perlis state) have been collected and characterized the properties of soil using Agilent High Temperature Dielectric probe incorporated with Agilent Performance Network Analyzer (PNA) E8562B.

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Measurement of dielectric properties involves complex relative permittivity εr and complex relative permeability μr of the materials. A complex dielectric permittivity consists of a real part and an imaginary part. The real part of the complex permittivity, also known as dielectric constant is a measure of the amount of energy from an external electrical field stored in the material. The imaginary part is zero for lossless materials and is also known as loss factor. It is a measure of the amount of energy, loss of the material due to an external electric field. There are few methods that have been developed for measuring the complex permittivity and permeability and each method have their own limitation to specific frequency, materials, applications and etc. The widely used and famous methods such as transmission line method, open ended coaxial probe method, free space method and resonant method [2], [3]. In this paper, the open ended coaxial probe method is used to measure the different types of soil in Malaysia for Ground Penetrating Radar applications in three differences conditions which is the normal condition, the wet and heated condition was measured. The Agilent dielectric probe is available at research cluster at UniMAP and it can be integrated with Agilent Performance Network Analyzer (PNA) E8562B with a valid licence which cover form 10 MHz until 20 GHz. The selection of the dielectric probe method are alos based on [3], [4] which can give a significant and reliable results. However, the repetition of the measurement need to be done in order to reduce the number of uncertainties reading as suggested in [5].

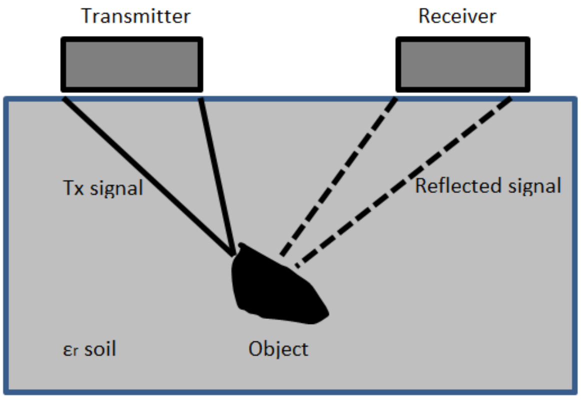

Fig. 1 - Bi-Static GPR System

2. Permittivity of Materials

This section discussed the definition and principles of permittivity of materials. Besides, the characterize properties of soil in local region, especially for Ground Penetrating Radar (GPR) application are elaborated.

2.1 Definition and Principles

The fundamental electrical characteristics of materials have been defined in term of electrical field concept and parallel-equivalent circuit concepts by Nelson [4]. In practical use, the dielectric properties of usual interest are the dielectric constant ε' and the dielectric loss factor ε" the real and imaginary parts, respectively, of the relative complex permittivity.

$$\varepsilon = \varepsilon' - j\varepsilon'' = |\varepsilon|e^{-j\delta} \qquad (1)$$

where δ is the loss angle of the dielectric. Basically, the term loss tangent, $\tan\delta = \varepsilon''/\varepsilon'$ or so called dissipation factor and sometimes the power factor $(\tan\delta/\sqrt{(1+\tan^2\delta)})$ is used. The conductivity of the dielectric in S/m is

$$\sigma = \omega\varepsilon_o\varepsilon'' \qquad (2)$$

where $\omega = 2\pi f$ is the angular frequency, with frequency, f in Hz [4], [6].

2.2 Measurement Procedures

The characterization of the permittivity of soil begins with preparing the samples in three differences conditions. In this paper, the samples of soil (material under test, MUT) have been collected in the local region (Perlis, Malaysia) such as asphalt, hill soil, red soil, clay, concrete, granite, fine sand and coarse sand as depicted in Fig. 2. The measurement has been conducted using Agilent High Temperature Dielectric probe incorporated with Agilent

Performance Network Analyzer (PNA) E8562B to measure the dielectric constant and loss tangent of the samples. The amounts of the samples are measured in biker in order to ensure the amount of the soil are similar to each other's and the level of water content in wet condition measurement is only about 10 % from the amount of soil. The flow chart of the dielectric properties measurement is shown in Fig. 3. The characterization process of dielectric properties begins with understanding its principles and preparation of the samples. Then, the measurement of dielectric properties begins with a calibration of the system by placing the standard calibration kits which is a short, open and a referenced liquid at the end of the probe. The reference liquid is used as a calibration standard and must be a liquid with known dielectric properties. In this case, plain water has been used as a referred liquid which have a dielectric constant of ε_r= 80-86. The repetition of calibration is done until a good calibrated result obtained.

Fig. 2 - Samples of soils

The measurement of dielectric properties of soil is done in three difference conditions which are in normal condition around 25^o C to 35^o C, dried which been heated up to 50^{o}C in special oven and wet condition with 10% water content. The reason behind this experiment is to investigate the effect of soil properties towards these three condition. The soils was heated up to 50 ^{o}C due to summer season in Malaysia which normally reach up to 40 ^{o}C, however in this work, the temperature was setup until 50^{o}C to investigated the reaction in heated condition. Infrared thermometer was used to measure the temperature of soil during the measurement and the repetition of the measurement is done to reduce the uncertainties in measurements. There are few factor which contributes to the uncertainties in measurement such as impurities of MUT, the air gap between probe and sample MUT, connector mismatch etc. The repetition of measurement is carried out for five reading data and the mean or average data are plotted and analysed. Fig. 4 shows the Agilent dielectric probe, RF cable, stand that was integrated with Agilent network analyser.

Fig. 5(a) shows the measurement of sand (normal condition) while Fig. 5(b) sand in wet with 10% water content. The measurement is done in five times at differences point location for the sample of MUT is heterogeneous medium. Then, the measured data are recorded and plotted for comparison and analyzed. The same method was applied to the others samples of MUT and all the measured results are shown and discussed in Section 3.

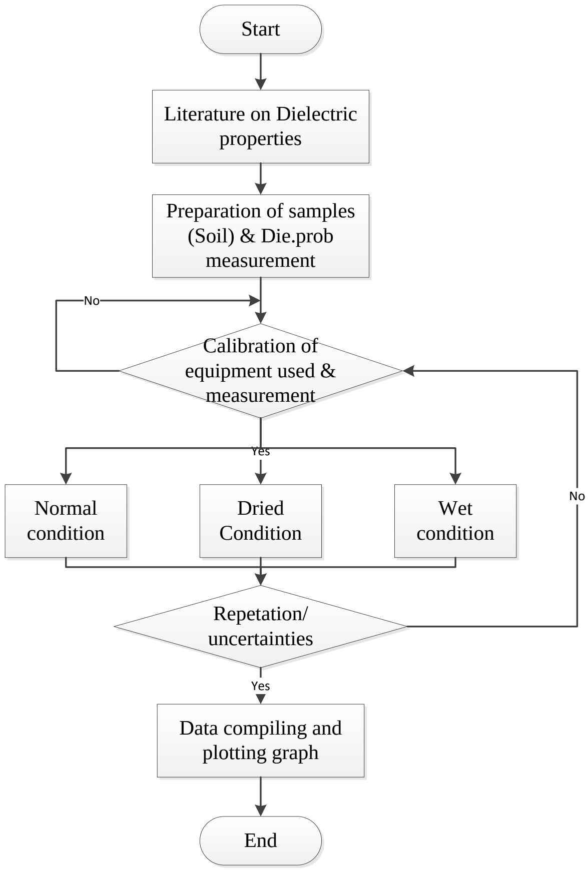

Fig. 3 - Measurement process of dielectric characterization of soil.

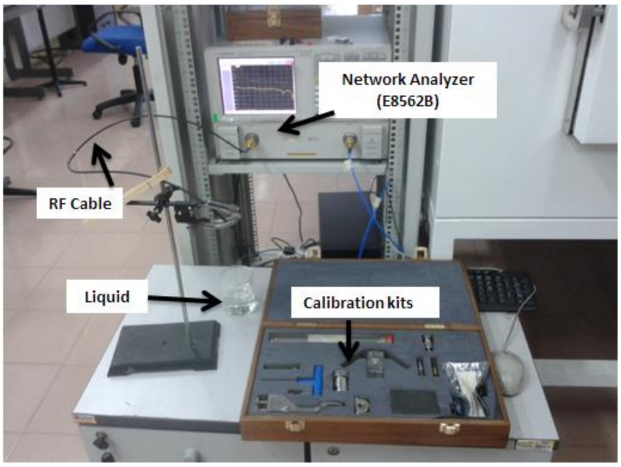

Fig. 4 - Dielectric Coaxial Probe and Calibration Kits

(a)

(b)

Fig. 5 - Measured samples, (a) Dried sand (b) Wet sand

3. Results and Discussion

In this section, the measured data for soil properties in presented. The dielectric constant and loss factor of the measured samples of soil is plotted in graph.

3.1 Structure

The dielectric properties of soils have been measured in three differences condition as explained in the previous section. Fig. 6 until Fig. 13 shows the measured results for dielectric constant (ε') and loss factor (ε") for clay, asphalt, fine sand, coarse sand, concrete, granite, red soil and hill soil. The measurement of the dielectric properties is conducted in the frequency range from 0.5 GHz to 3.5 GHz and all data have been plotted and shown in details with a blue color refer to dielectric constant and black color refer to loss factor. Two samples which are asphalt and sand from [7] and [8] have been selected as references data in order to validate the measurement of dielectric properties.

Fig. 6 shows the dielectric properties of asphalt from 0.5 GHz until 3.5 GHz. As can be seen, the dielectric constant for asphalt in normal and heated condition have almost similar values obtained from the measurement (εr=4-6) compared to the [7] which have εr=4.5 to 6.5, while, in wet condition, the dielectric permittivity reach up to 32. Other than that, the dielectric permittivity of sand from the measurement is 2.0 to 3.0 as compared to the [8] which have 2.0 to 4.0. These two data where obtained from the measurement are comparable with the data from literatures such as in [7], [8]. Therefore, the measured data for other types of soil should be considered as reliable since only small variation around +/- 0.5 to 1.0 between reference and measured samples for a normal condition. However, the data for heated and wet condition is not available in the previous literature or experiment.

Other than that, based on measurement results as shown in Fig. 8 until Fig. 12, the properties of soils have similar characteristic in normal and heated condition except red soil and hill soil, which have a small variation when the heated soil give a bit higher dielectric constant compared to normal condition. However, with 10 % water content, all the types of soil give a very different value for dielectric properties and loss factor. It's shows that, when the soil moisture content higher, the value of dielectric properties will arise. Consequently, the absorption rate will be higher, thus in the wet condition, the measurement of GPR is strongly not recommended since most of the transmitted signal will absorb by the soil or medium. On the other hand, the amount of air in sample also can give an effect to the measured data, thus, the sample need to be compressed first to ensure no air may affect the reading of the measurements.

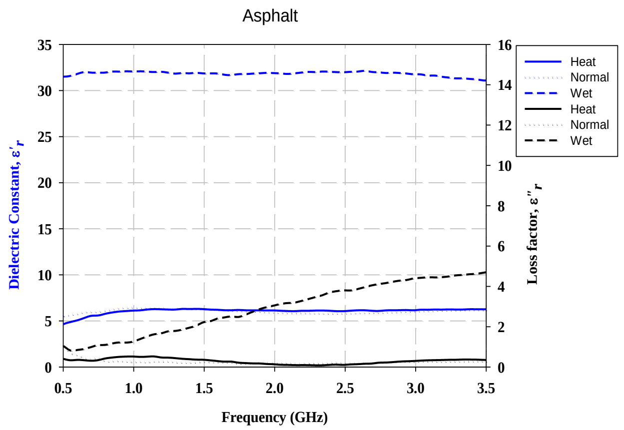

Fig. 6 - Dielectric properties for asphalt

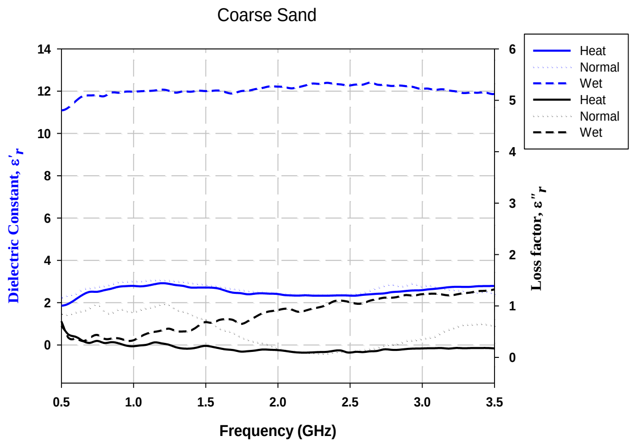

Fig. 7 - Dielectric properties of coarse sand

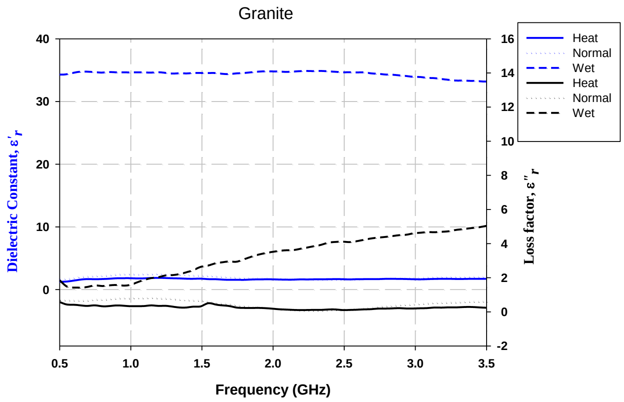

Fig. 8 - Dielectric properties of granite

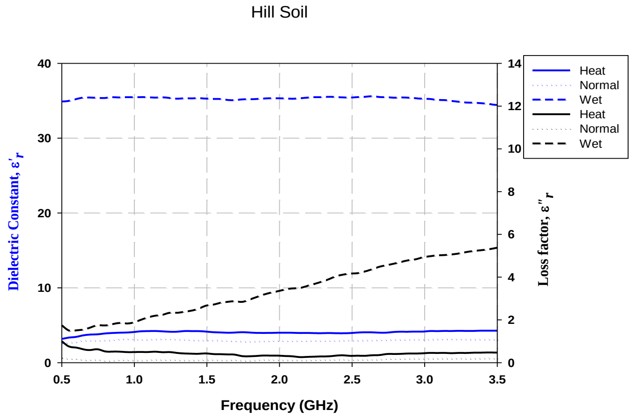

Fig. 9 - Dielectric properties of hill soil.

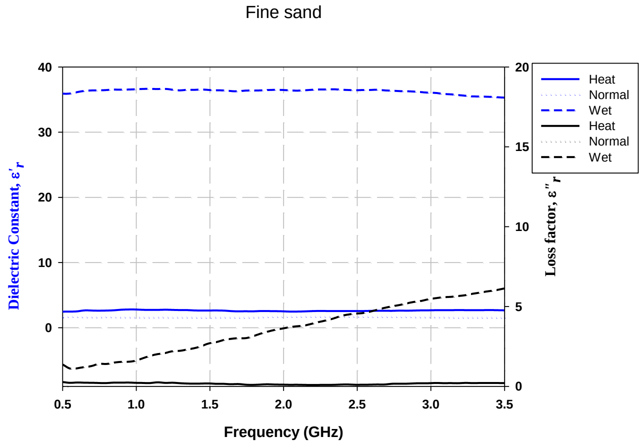

Fig. 10 - Dielectric properties of fine sand

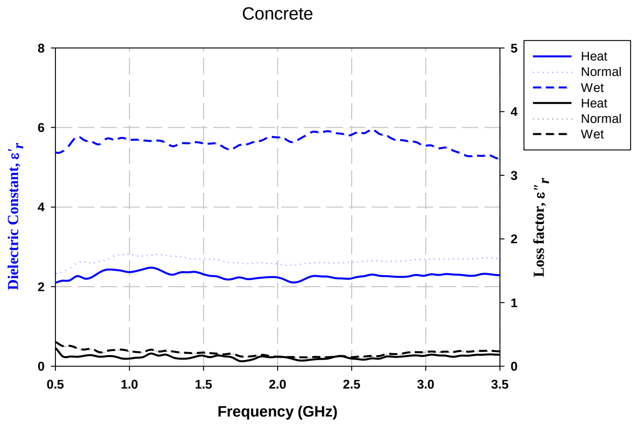

Fig. 11 - Dielectric properties of concrete

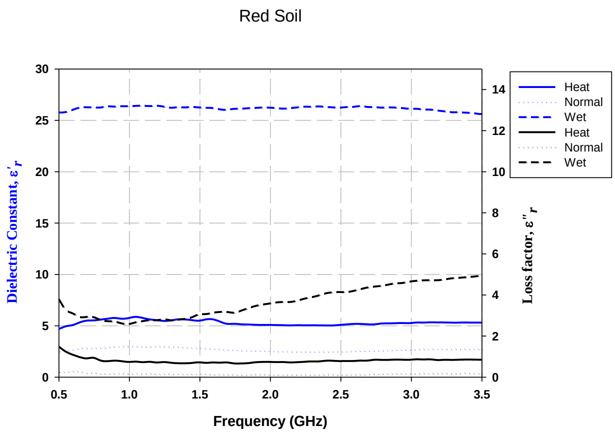

Fig. 12- Dielectric properties of red soil

4. Summary

In conclusion, the characterization of dielectric properties of soil from local region has been measured using a high temperature dielectric probe with three differences conditions. The measured data have been plotted in graphs and its shows that the measurement results have a similar properties in dried (heated) and normal condition, but the value of permittivity for all MUT slightly increase in wet condition with 10% water content. Thus, it can be said that, in the wet condition, the experimental work for GPR system since the depth of penetration will be low. In summaries, all these data can be used for references during performing any nondestructive exploration for underground object detection.

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