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In Situ Measuring of Relative Dielectric Permittivity to Calculate Electromagnetic Wave Velocity

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Abstract

The relative dielectric permittivity (dielectric constant) values for various materials are measured on site. The calculated values that are derived from measuring the ratio of the electrical capacitance of a cell when the sample of the material is placed. Parallel plate technique that consists of two parallel circular metallic plates is used. The instrument made up of aluminum which acts as electrodes and stuffed inside the PVC cylinder. Then the thin sheet of material (models) sandwiched between the two plates. Calculation of dielectric constant (ε_r) through this new technique gives a new velocity value of electromagnetic wave that propagates underground. These measured velocity values will utilize in Ground Penetration Radar (GPR) data acquisition and interpretation in order to increase the resolution of the obtained radargrams.

Keywords: Relative Dielectric Permittivity, Dielectric Constant, Ground Penetrating Radar, Electromagnetic Wave Velocity.

القياس الموقعى لثابت العزل الكهربائى لحساب سرعة الموجة الكهرومغناطيسية

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الخلاصة:

لقد تم قياس قيم سماحية العازل النسبية (ثابت العزل الكهربائي) لمختلف المواد في الموقع . القيم الجديدة تعتمد على قياس نسبة السعة الكهربائية الى الخلية للمادة المراد قياس ثابت العزل الكهربائي لها. تم في هذا العمل ألأعتماد على تقنية اللوحة المتوازية والتي تتألف من لوحتين معدنيتين دائريتين متوازيتين .أما الجهاز فيتكون من الألومنيوم الذي يعمل بمثابة أقطاب محشوة داخل اسطوانة بلاستيكية، ويتم وضع طبقة رقيقة من المادة المراد قياس ثابت العزل الكهربائي لها بين ألأسطوانتين.أن حساب ثابت العزل الكهربائي من خلال التقنية الجديدة يعطي قيمة جديدة لسرعة الموجات الكهرومغناطيسية للمواد تحت سطح الأرض. هذه القيم للسرعة سوف تستخدم في القياس والتفسير للبيانات الجيورادارية وذلك لزيادة القدرة التحليلية .

Introduction:

The dielectric properties of the subsurface are the primary control on both the amplitude and the arrival time of the received energy in a GPR survey. The image of GPR survey is thus largely determined by the variation in dielectric properties of the subsurface [1]. Measurement of relative dielectric permittivity (ε_r) of a material is very important for both practical applications and scientific research. Relative dielectric permittivity of a material is a dimensionless measure that indicates the degree to which the medium can resist the flow of electric charge or indicates the capacity of a material to store a charge [2].So, the high value of this property indicates that the material will absorb

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the radar waves, while the low value indicates reflection of waves and a clear radar image [3-5].It is defined as $\varepsilon_r = \varepsilon/\varepsilon_0$ where ε_r represents the relative dielectric permittivity, ε ($F.m^{-1}$) is the permittivity relative to free space as calculated by absolute permittivity, and ε_0 (8.854×10^{12} $F.m^{-1}$) is free space permittivity [6].

In this research, The relative dielectric permittivity (ε_r) of a sample is defined as the ratio of the electrical capacitance of a cell when the sample forms the dielectric medium (Cs) to the capacitance of the cell when air forms the dielectric medium in vacuum (C_0) at a given temperature, which is represented by the following equation [7, 8]:

$$\varepsilon_r = (Cs) / (C_0) \quad (1)$$

There are several techniques to measure relative dielectric permittivity (ε_r) in literature as stated by [9,10]. The choice of the technique depend on the frequency of interest, the expected value of $\varepsilon_{r,}$ the required measurement accuracy, material properties (i.e., homogeneous, isotropic), the material form (i.e., liquid, powder, solid, sheet), sample size restrictions, destructive or non-destructive, contacting or non-contacting and temperature. Figures-1 and 2 represent the summary of the published measuring techniques.

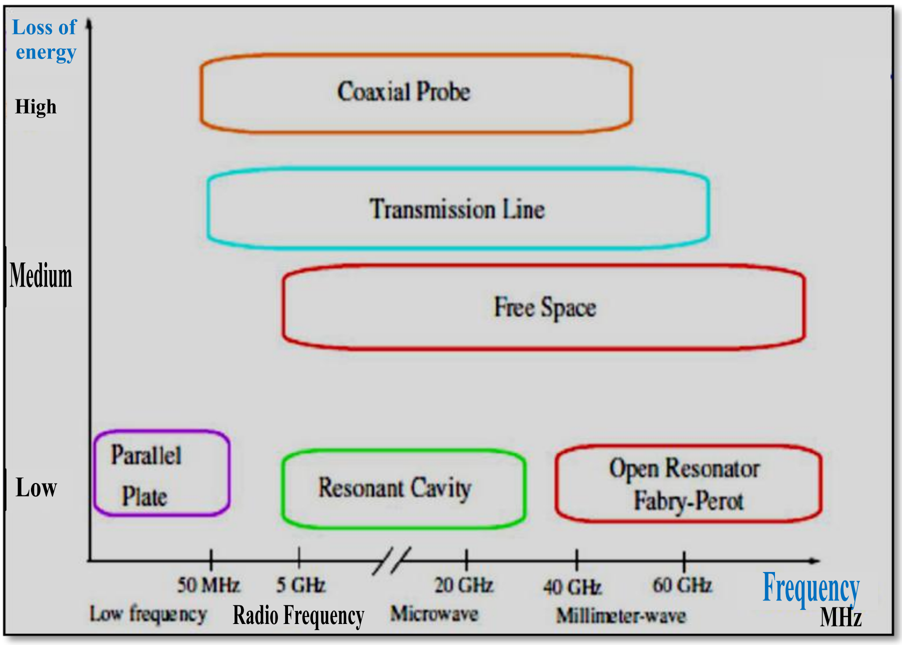

Figure 1- Shows different measurement techniques relying on applied frequency value [9].

Depending on the Figure-1, the frequency band of less than 5.0 GHz has the most suitable measurement technique which is the parallel plate method or the capacitor method. The transmission line method for low-frequency band requires the large size of the material sample. For the coaxial probe technique, the sample should be precisely prepared. In the current study, it is used the parallel plate technique Figure-2, which is best for low frequencies, thin, and flat sheets.

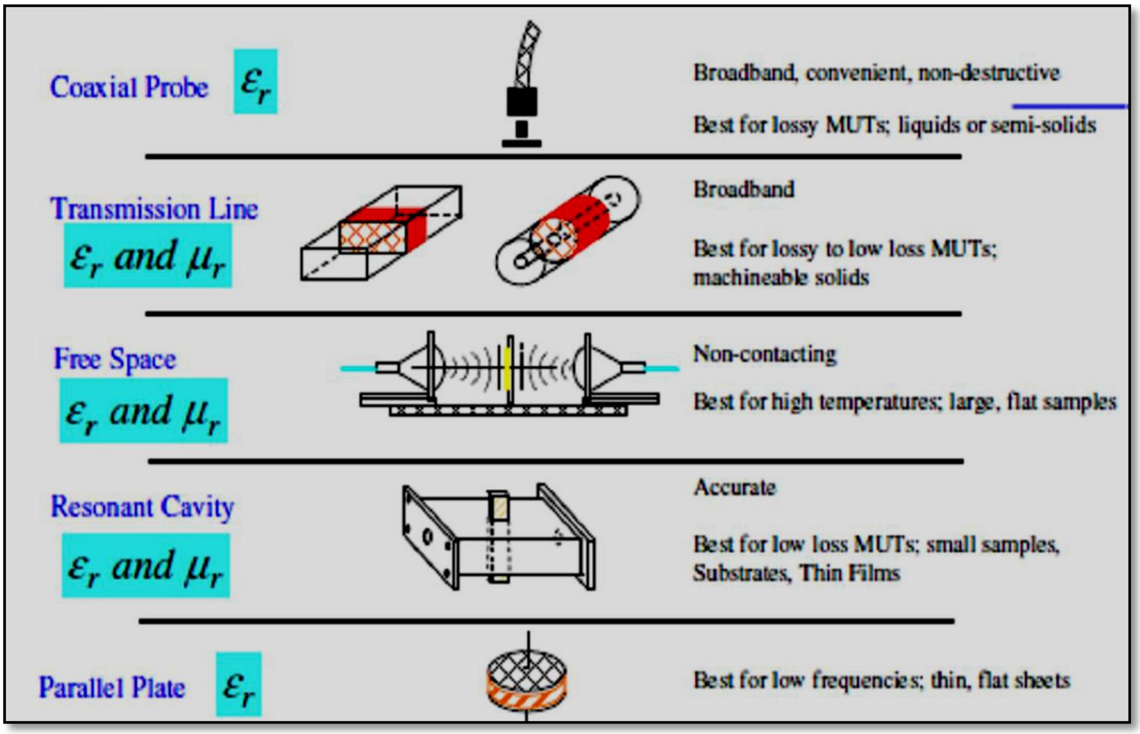

Figure 2- Shows the parallel plate technique and other available techniques (μ_r) is the magnetic permeability; (ε_r) is the relative permeability [9].

Materials and Experiment Procedure:

The instrument of parallel plate technique consists of two parallel circular metallic plates made up of aluminum which acts as electrodes and stuffed inside the PVC cylinder Figure-3, the thin sheet of material (six samples) sandwiched between two parallel circular metallic plates , as shown in Figure-4.

The diameter and thickness of the circular metallic plates are 5.0 cm and 2.0 cm respectively [Personal contact with Fariq, F. 2014. Interview by Bakir, H., Department of Physics, Faculty of Science and Health, Koya University]. Both circular metallic plate electrodes plugs directly into the live terminals of the LCR meter Figure-5.

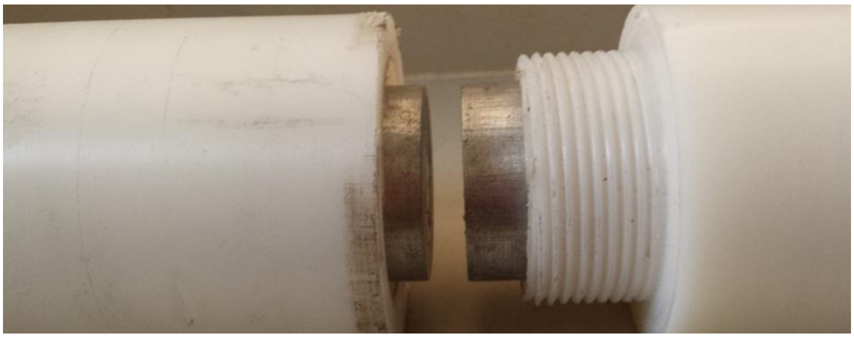

Figure 3- Shows two parallel circular metallic plates made up of aluminum and stuffed inside the PVC cylinder.

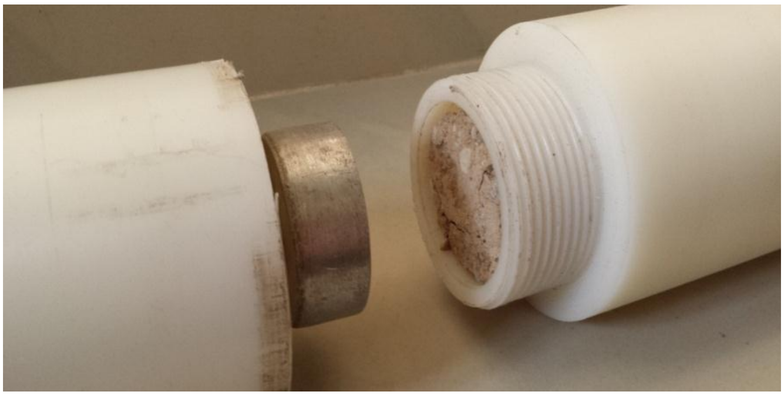

Figure 4- Shows the thin sheet of material (models) sandwiched between the two plates.

Figure 5- Shows circular metallic plate electrodes plugs directly into the Live terminals of the LCR meter.

The measurements are used at low frequencies, typically at 200 MHz; the material is stimulated by a DC source. The material test parameters are derived by measuring its capacitance. After putting a sample which is directly taken from the homogeneous material of the proposed area of the survey (see sample types in Table-1) into an internal scaled sample holder which has been numbered to obtain the mentioned dimension accurately Figure-4, a capacitor is formed. This method involves simple sample preparation and setup.

Calibration and Measurement:

The instrument is calibrated by circular PVC plate which it's ε_r value is 8.0 [14], and the measurement is carried out according to the following procedure that mentioned below.

1. Keep the dielectric cell in air.
2. Connect the cell to the circuit as shown in Figure-5.
3. Switch on the system.
4. The system measures the capacitance of the cell (C_0). Note down the values.
5. Keep the cell at infinite distance to measure the lead capacitance.
6. Repeat the steps from (2) to (4).
7. Keep the unknown sample in the cell.
8. Repeat the steps from (2) to (4).
9. Then calculate the dielectric constant of unknown sample using the equation (1).
10. Note down the readings of the dielectric constant of unknown samples.

Estimation of Velocity:

To convert two-way times to depths, it is necessary to estimate or determine the propagation velocity of the EM pulses. The relative permittivity of the material (ε_r) through which the EM pulse propagates mostly determines the propagation velocity of the EM wave. The propagation velocity through the material is approximated using the following relationship [11-13]:

$$\mathbf{V_m = c / \sqrt{\varepsilon_r}} \qquad \textbf{(2)}$$

Where:

c = propagation velocity in free space (30 cm/ns),

V_m = propagation velocity through the material, and

εr = relative permittivity.

Equation (2) has been used to find the accurate value of velocity. The goal of in situ calculated velocity is to use this parameter in the data gathering GPR software in order to obtain high resolution radargrams. The ground penetrating radar scientists interest to use exact calculated values of the velocity so as to avoid themselves from the popular or average velocity value which is equal to 10.0 cm/ ns.

Table 1- Shows the calculated relative dielectric permittivity and velocity using parallel plate technique.

Model Name (The sample of the materials)	Present work (Calculated by Researcher) Host rock Dielectric constant (ε_r)	Velocity cm/ns	Literature Velocity Values cm/ns	Reference Number
Dry Clay	4.42	14.3	4.0	[13]
			3.0	[14]
Wet Clay	10.85	9.11	10.0	[13]
			8.0-15.0	[14] , [15]
Dry Mixture	8.34	10.38	4.0-30.0	[5]
Wet Mixture	22.51	6.32	15.0	[14] , [15]
Dry Sand/gravel			4.0-10.0	[16]
	6.06	12.20	5.5	[13]
			3.5-6.5	[17]
Wet Sand/gravel	11.85	8.72	10.0-20.0	[16]
			15.5-17.5	[17]

Results and Discussion:

The results of in situ measuring of relative dielectric permittivity and subsequently calculation of velocity are presented in Table-1. Depending on these values of dielectric constant, the ground penetrating radar scientists and operators able to find the accurate velocity value of electromagnetic wave that propagate within its media. As illustrated in the table, the values of dielectric constant and electromagnetic wave velocities are changed due to the change in physical and chemical properties of different type of materials [18 ,19], and water content. Increasing the materials moisture or water content means rising of media conductivity and falling media resistivity, in the light of this consequence the values of electromagnetic waves properties are also changed. The dielectric constant values will increase with increasing the ratio of water content while the velocity value of electromagnetic waves are decreasing with the ratio of water content. Both of the parameters are directly relate to resolution of in situ obtained radargrams, especially the velocity of electromagnetic waves, because it is changed with changing the amplitude (power) of propagated waves. The high amplitudes simultaneously with the frequency assist the waves to penetrate more and more thereafter helps getting higher resolution for radargrams.

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