

An innovative approach to determine the dielectric constant of a solid

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Abstract

Determination of dielectric constant of a solid involves the measurement of capacitance of the capacitor with dielectric material, if one knows the physical dimensions. The simpler and easier to measure the dimensions of a capacitor is that of a parallel plate capacitor. Here we use commercially available aluminium panel sheet (APS), where the low density polyethylene (LDPE) is laminated using two thin aluminium sheets, which acts as a dielectric material. The capacitances of the different dimensions of the APS are measured and hence the dielectric constant of the LDPE is determined. We measured the time constant from charging curve by applying square waves using a cathode ray oscilloscope (CRO) and hence determined the capacitance. By measuring the dimensions of the samples the dielectric constant was calculated. Low cost, simplicity, and accuracy are the features of this experiment.

Keywords: Capacitance, Dielectric constant, time constant, charging and discharging.

Resumen

La determinación de la constante dieléctrica de un sólido implica la medición de la capacitancia del condensador con material dieléctrico, si se conocen las dimensiones físicas. El tipo de condensador más simple y fácil de medir en sus dimensiones, es el condensador de placas paralelas. Se utilizó panel de hoja de aluminio (APS) disponible comercialmente, en el que el polietileno de baja densidad (LDPE) se lamina usando dos hojas delgadas de aluminio que actúan como un material dieléctrico. Las capacitancias de los APS de diferentes dimensiones se miden, y consecuentemente se determina la constante dieléctrica del LDPE. Se midió la constante de tiempo de la curva de carga al aplicar ondas cuadradas utilizando un osciloscopio de rayos catódicos (CRO), y con ello se determinó la capacitancia. Midiendo las dimensiones de las muestras, se calculó la constante dieléctrica. Bajo costo, sencillez y precisión son las características de este experimento.

Palabras clave: Capacitancia, constante dieléctrica, constante de tiempo, carga y descarga.

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I. INTRODUCTION

The concept of capacitance involves the understanding of concentration of electric field between the two plates of a capacitor, which depends on the dielectric material between the plates of a capacitor. The relation which connects the character of the dielectric material (called dielectric constant, ϵ_r) with the capacitance is a simple, *i.e.*

$C = \frac{\epsilon_r \epsilon_0 A}{d}$. Hence several experiments are being done to

determine the dielectric constant of a solid dielectric [1, 2, 3, 4, 5, 6, 7, 8, 9, 10].

Most of these use thin sheet/s of paper as the dielectric material. The use of paper sheets introduces air gaps which affect the accuracy of the result to a larger extent. When this was discussed with the students, some of the students suggested the use of commercially available Aluminium Panel Sheet (APS) as capacitor and determine the dielectric constant of low density polyethylene (LDPE) which was laminated using two thin sheets of Aluminium. The capacitances of different dimensions of the APS are measured and hence the dielectric constant of the LDPE is

determined by measuring the dimensions of the samples. The method of experimentation not only yielded accurate result but also proved to be more effective in conveying the concept of variation of capacitance with area. This method was tried by other teachers of our University, and has been adopted in the colleges.

II. THEORY

According to Coulomb's law, the force between two charges is given by the equation:

$$F = C \frac{q_1 q_2}{r^2}. \quad (1)$$

The equation has the identical form as Newton's law of gravitation and the constant C is analogous to the gravitational constant which determines the force between two masses. The dielectric constant ϵ_0 measured here is related to C by:

$$C = \frac{1}{4\pi\epsilon_0} \tag{2}$$

A parallel plate capacitor consists of two parallel conducting plates. If we move an electric charge Q from one plate to the other at a potential ΔV , the capacitance of the pair may be calculated using the equation:

$$C = \frac{Q}{\Delta V} \tag{3}$$

The electric field which exists between the plates is simply:

$$E = \frac{\Delta V}{d} \tag{4}$$

Where d is the distance between the plates. If the surface charge density is σ , then Gauss's law says the potential difference and electric field between the plates is:

$$\Delta V = Ed = \frac{\sigma d}{\epsilon_0} \tag{5}$$

If the plate area is A , then the total charge on the plate is $Q = \sigma A$. The plate capacitance is now:

$$C = \frac{Q}{\Delta V} = \frac{\sigma A}{\sigma d / \epsilon_0} = \frac{\epsilon_0 A}{d} \tag{6}$$

If the medium between the two plates is something besides free space, then it is necessary to replace ϵ_0 with the dielectric constant of the material. Usually this is expressed using the term relative dielectric, $\epsilon_r = \frac{\epsilon}{\epsilon_0}$ where ϵ is the dielectric constant of the material and ϵ_r is its relative dielectric value. The relative dielectric is therefore a unit less number usually in the range of 1 to 20.

The capacitance with a dielectric medium of dielectric constant ϵ_r will then be:

$$C = \frac{\epsilon_r \epsilon_0 A}{d} \tag{7}$$

Commercially available capacitors are either cylindrical or disc type. In both the cases, it is not possible to study variation of capacitance with distance between the plates or determine the dimensions; area and distance between the plates, in order to calculate the dielectric constant of the medium. Here we use commercially available aluminium panel sheets¹ of different sizes as capacitors. By measuring the areas and noting the distance between the aluminium

¹These sheets are used for exterior decoration, wall cladding etc. and available in different sizes and thicknesses. We used Eurobond 3mm thick sheet. The thickness of aluminium foil was 0.25mm and thickness of LDPE core was 2.5mm.

sheets from the data available from the manufacturer, we can determine the dielectric constant of the material (which is low density poly ethylene, LDPE) if we determine the capacitance C between the aluminium sheets and core (LDPE).

The capacitances of these sheets are very small; of the order of nano-farad; it is difficult to record voltages at different intervals unless we have a resistor of Giga (10^9) Ohm.

Hence we apply square wave of suitable frequency and measure the time constant from the charging curve using an oscilloscope. If we apply a continuous square wave voltage waveform to the RC circuit whose frequency matches exactly to that of the $5RC$ time constant ($5T$) of the circuit, then the charging voltage waveform across the capacitor would look as in Figure 1.

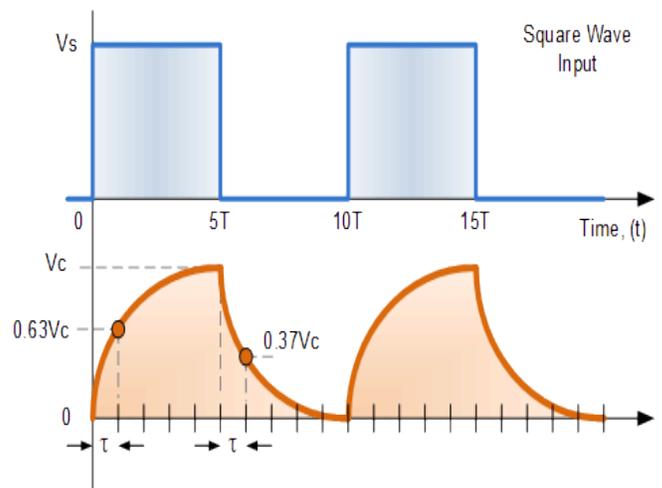


FIGURE 1. The voltage drop across the capacitor alternates between charging up to V_c and discharging down to zero according to the input voltage. Here the frequency (and therefore the time period, $f = 1/T$) of the input square wave voltage approximately matches that of the 5 times RC time constant, $f = 1/5RC$, and the capacitor is allowed to fully charge and fully discharge on every cycle resulting in a perfectly matched RC waveform.

II. THE EXPERIMENT

- Arrange the experimental setup as shown in Figure 2.

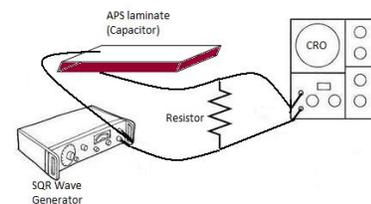


FIGURE 2. Description of capacitor connection to a SQR wave generator and the oscilloscope.

- Connect the Square wave generator alone to the oscilloscope and Set the Square wave voltage (V_{p-p}) to 20 volts.

- Make the connections as shown in Figure 2.
- Keep the frequency of Square wave a constant value (Between 6 to 8 KHz). Adjust resistance and time per division control on the oscilloscope, so that a clear and minimum one complete cycle of charging curve is displayed on the oscilloscope.
- Using X-shift control of the oscilloscope move the charging curve along the X-axis until the charging curve meets the $12.6V$ (which is 63% of the Square wave voltage) point on the Y-axis of the oscilloscope as shown in Figure 3.
- Note the number of horizontal divisions the charging curve has been moved.
- Calculate the time constant by multiplying with time per division on the CRO.
- Repeat the above steps for plates of different areas
- Dielectric constant is calculated using slope of the straight line(Figure 3) from the formula:
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$$\epsilon_r = \frac{d}{\epsilon_0} \times \text{Slope}. \quad (8)$$

The thickness of the APS is a standard one, can easily be found from the supplier or from technical data provided (we used 2.5mm thick sheet).

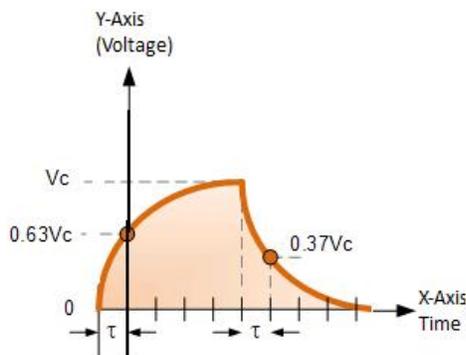


FIGURE 3. Wave shape detected in the oscilloscope.

III. RESULTS AND DISCUSSION

Typical value of dielectric constant of low density polyethylene ranges from 2.2 to 2.35.

The physical dimensions of commercially available capacitors, either parallel plate or cylindrical, being too small for the measurements, hence the difficulty of determining the value of dielectric constant. Many experiments have been done using two bigger metal plates and paper sheet or glass sheet as dielectric media, but the air gaps introduces the considerable error [11]. The APS

An innovative approach to determine the dielectric constant of a solid being well sealed and surfaces painted reduce these errors to a considerable extent. Somewhat subjectivity is introduced in the measurement of time constant from the charging curve; this can further be reduced using high quality L-C-R bridge capacitance meter. Where C is directly measured.

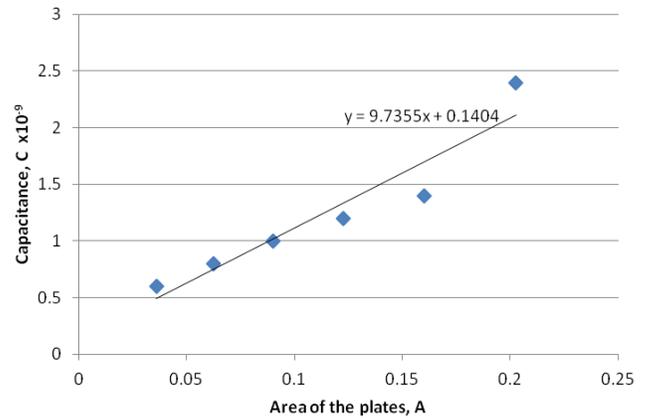


FIGURE 4. Graph of capacitance vs. area of the plates.

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