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RESEARCH ARTICLE

Analysis of Dielectric Absorption in Capacitors

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Abstract

This study proposes a method of studying and modeling the dielectric absorption in capacitors. Dielectric absorption is a well known phenomenon in capacitors which manifests as a slow recovery of a part of its lost voltage after the capacitor is completely discharged by shorting its terminals momentarily. The Ceramic NP0 100pF capacitor of Johnson Technology (Capacitor type: R05L series) is used for analyzing this effect using a standard model where a network of parallel RC branches in parallel to the actual capacitance provides satisfactory explanation for the observations. The measurement result shows a dielectric absorption effect of the order of 2% in the capacitor.

Keywords: Dielectric absorption, capacitors, Johnson technology, parallel RC branches, capacitance.

Introduction

The DC Standards division at CSIR NPLI is concerned with maintaining the national standards of dc voltage and dc resistance and provides calibration service for dc voltage, dc current and dc resistance and conducts research and development work to improve and upgrade the calibration and measurement capability for these parameters. The main objective of this study is to analyze the effect of dielectric absorption in capacitors. Dielectric absorption is known as soakage (Pease, 1982, 1998) and studied for more than hundred years and is a well known phenomenon in capacitors which manifests as a slow recovery of a part of its lost voltage after the capacitor is completely discharged by shorting its terminals momentarily. Dielectric absorption has its origin in the polarisation and depolarisation processes occurring in the dielectric material during the charging of the capacitor. It causes errors in applications based on the charging and discharging of capacitors. The amount of dielectric absorption depends upon the property of the dielectric material present between the conducting plates of the capacitor and the residual charges obtained in measurements provide a direct quantitative measure of this effect. Keeping the above points in view, this study proposes a method of studying and modeling the dielectric absorption in capacitors.

Materials and methods

Description of the analysis method: The proposed analysis method is based on the measurement of charge itself after momentarily shorting the terminals of capacitor. A capacitor is a passive device that store electric charge. It consists of two conducting plates separated by an insulating medium, i.e., dielectric. The charging of a capacitor with DC voltage source follows the charging equation given below.

$$V_t = V_0(1- e^{-t/RC}) \quad (1)$$

Where V_t = Capacitor voltage, V_0 = Charging voltage, t = Charging time.

Charging of a capacitor involves two components: the charge deposited on the electrodes and the charge acquired by the dielectric. These two charges can be identified separately in charge amplifier measurements by their widely differing time constants. The charge on the capacitor plates will discharge almost instantaneously to transfer all its charge to the charge amplifier whereas the dielectric charge will take much longer time to do so during the measurement. This results in the response characteristic of the charge amplifier to have two very distinct regions. The type of response curve obtained is shown in Fig. 1.

Fig. 1. Measurement of charge: Typical response characteristic of the charge amplifier.

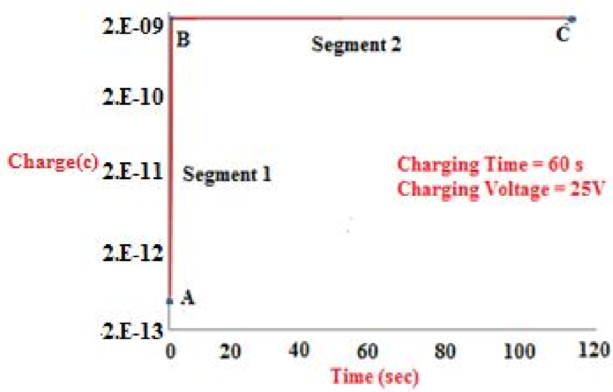
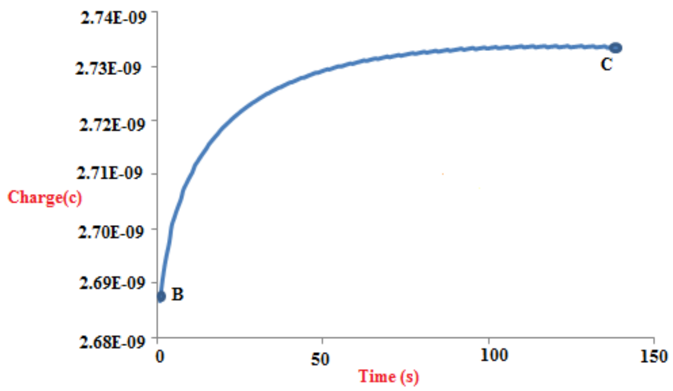


Fig. 2. Segment 2 (BC) of Fig. 1 shown-expanded Y-scale.



We can divide the response curve into two segments:

1. The segment 1 of the curve (AB in Fig. 1) shows that the charge amplifier output is rising steeply immediately on applying the input indicating an almost instantaneous transfer of charge from the capacitor to the charge amplifier.
2. Segment 2 (BC in Fig. 2) begins from point B indicating that there is abrupt change to an almost steady output suggesting the completion of the charge transfer. However on closer examination, it is observed that the charge transfer is not completed at point B. This can be seen from the plot of the curve BC on an expanded scale shown in Fig. 2. As can be seen in Fig. 2, the charge transfer in this particular case takes more than 100s to complete.

Measurement setup: The experimental set up consists of a voltage source, charge amplifier, relay, charging and discharging resistance and the capacitor. It involves charging capacitor of known values to known voltages using a voltage source and the charge developed during the charging process is measured using a charge amplifier. For this experiment, the Fluke 5720A multi-function calibrator is used as the voltage source and the electrometer Keithley's 6517A (2009) used for the charge amplifier. The functional circuit diagram of the experimental set up is shown in Fig. 3. Relay acts as an electronic switch used to connect capacitor to the voltage source during charging and to the charge amplifier during measurement after disconnecting from the voltage source.

Fig.3. Functional circuit diagram: Switch position in charging mode.

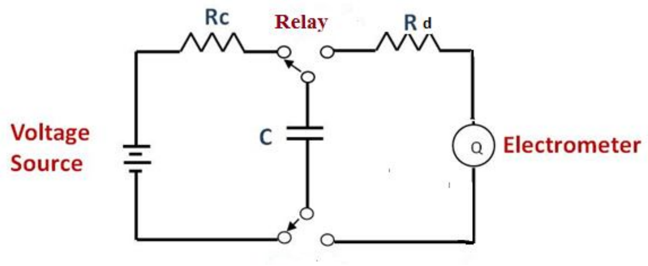
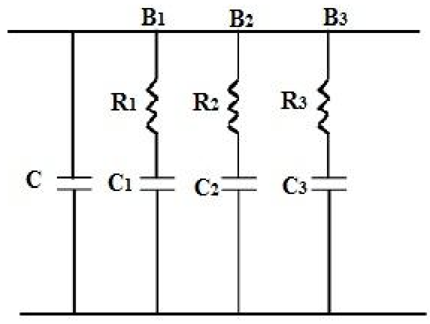


Fig. 4. Equivalent circuit model of a capacitor for explaining the dielectric absorption. C is the ideal capacitor and the RC components simulate the effect of dielectric absorption.



Equivalent circuit and mathematical model: The equivalent circuit model of a capacitor is normally used for explaining the dielectric absorption. In this model, a parallel network of RC circuits is introduced in parallel to the main capacitor. The network can have many RC branches, but normally three branches are sufficient to explain the measurements and accordingly we will use the three RC branch models for analyzing our measurements. Each RC branch has a different time constant. According to this model shown in Fig. 4, dielectric absorption is the result of charge stored on the capacitors C_1, C_2 and C_3 through R_1, R_2 and R_3 during the capacitor charging. This is the charge Q_R we measured as the residual charge in our measurements i.e. $Q_R = Q_{1r}+Q_{2r+} Q_{3r}$ where Q_{1r} is the charge stored on C_1, Q_{2r} is the charge stored on C_2 and so on. During charge measurement these capacitors have to discharge through their resistances and that is the reason for the delays observed in charge transfer (Buchman *et al.*, 1999). In the charge amplifier measurements is in fact the discharge characteristic of the charging capacitor and the measured residual charge data can be analyzed to derive the time constants of the RC network, viz., T_1, T_2 and T_3. However this analysis cannot provide the individual values of R and C in the network. But we can derive these values using the measurements at a given voltage for different charging times. The measured residual charge $Q_R= Q_{1r}+Q_{2r+} Q_{3r}$ can be expressed in terms of the charging of the three RC components as:

$$Q_R = Q_1\,(1-e^{-t/T1}) + Q_2\,(1-e^{-t/T2}) + Q_3\,(1-e^{-t/T3})$$

Where $T1=R_1C_1$, $T2=R_2C_2$, t=Charging time, Q_1= Saturation charge of C_1 for the charging voltage V, Q_2=Saturation charge of C_2 for the charging voltage V and so on.

In the above equation Q_1, Q_2 and Q_3 are the unknowns and the equation can be solved by using the measured values of Q_R for three properly chosen charging times.

Results and discussion

For the ceramic NP0 capacitor, the 3 RC branch time constants have been obtained as T_1= 3 sec, T_2= 18 sec, T_3= 25 sec.

Fig. 5. Charging curve showing an example for very close agreement between model generated curve and measured curve.

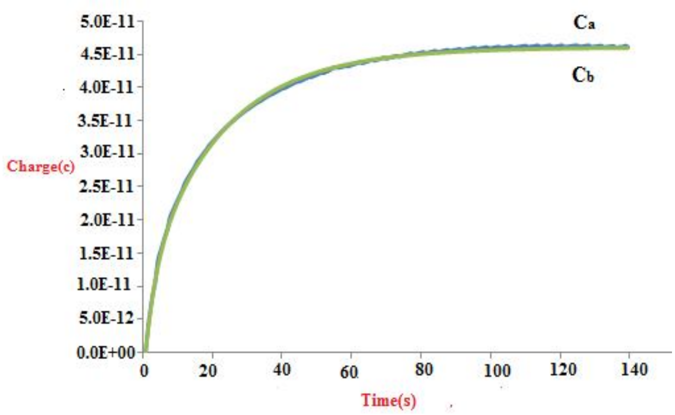


Table 1. Saturation charges Q_1, Q_2, Q_3 of the RC network and the estimated values of R and C of the three branches (CeramicNP0 capacitor).

Time Constant (sec)	Charging voltage= 25V		
	Charge (pC)	C= Q/V (pF)	R=T/C (T ohm)
T_1= 3	Q_1=16	C_1=0.64	R_1=4.7
T_2=18	Q_2= -6.27	C_2=0.252	R_2=71.4
T_3=25	Q_3=40.2	C_3=1.61	R_3=15.54

Fig. 6. Charging curves of the three RC branches for the ceramic NP0 capacitor. Only the RC branch with the lowest time constant has saturated during the 60s charging period.

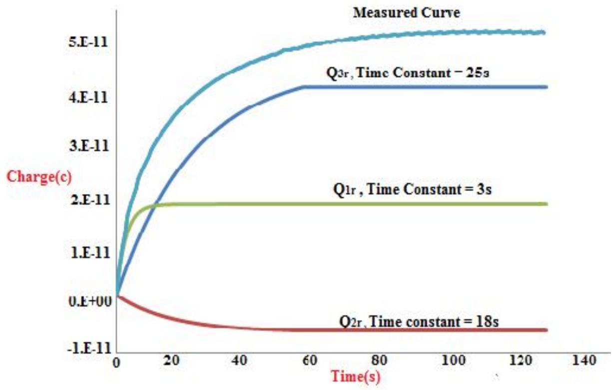


Figure 5 shows the calculated curve C_a based on these time constants plotted along with measured curve C_b for a charging voltage of 25 V and charging time of 60s. As can be seen, the two curves overlap indicating the correctness of the fit. The result obtained by solving equation for ceramic NP0 capacitor charged at 25 V is presented in Table 1. Figure 6 shows the resulting curves of Q_{1r}, Q_{2r} and Q_{3r} for the same for a charging time of 60s. The corresponding measured curve is also plotted in the same graph.

Conclusion

This study presents a general method of studying the dielectric absorption in capacitors and building the equivalent circuit model. The method based on the measurement of charge itself has advantages over the usual method (Lorga, 2000) of measuring the dielectric absorption by measuring the recovery voltage of the charged capacitor after it has been discharged by shorting its terminals. The measurements show a dielectric absorption effect of the order of 2% in the capacitor. The method presented here can be used to study and model any type and value of capacitor, at different charging periods.

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