II.6.4 TEMPERATURE DEPENDENCE OF THE CAPACITANCE OF A CERAMIC CAPACITOR

VERIFICATION OF CURIE-WEISS LAW FOR THE ELECTRICAL SUSCEPTIBITY OF A FERROELECTRIC MATERIAL

1. INTRODUCTION

The electrical susceptibility χ of a material is the ratio of change of the electric polarization P in the material to the change in the applied electric field E. **For an isotropic material the vector P is in the direction of E and the susceptibility is a number**

$$\varepsilon_0 \chi = dP/dE \qquad \text{(II.6.4.1)}$$

For a linear dielectric material, P is proportional to E, and χ is independent of the field as long as the field is not very high. This behaviour is seen in all materials at high temperatures. Such behaviour is called paraelectric in analogy with paramagnetic behaviour. In these materials there is no electric polarization in the absence of an electric field.

There is a class of solid materials called ferroelectric materials. Below a temperature T_C characteristic of a ferroelectric material, the material exhibits a spontaneous electric polarization even in the absence of an electric field. Above T_C these materials show paraelectric behaviour. The variation of P with E above and below T_C in the para- and ferro- electric states are shown in figures II.6.4.1 (a) and 1(b). In the paraelectric state the material shows no hysteresis while in the ferroelectric state the material shows hysteresis. The P vs. E curve in a ferro-electric material is similar to the Magnetization vs magnetic field curve for a ferromagnetic material. Hence these materials are called ferroelectric. Examples of ferroelectric materials are Potassium di-hydrogen phosphate (T_C = -151^0 C), Triglycine sulphate (47^0 C), Rochelle salt (it is ferro-electric between -18^0 C to 24^0 C), and Barium titanate (T_C 128^0 C).

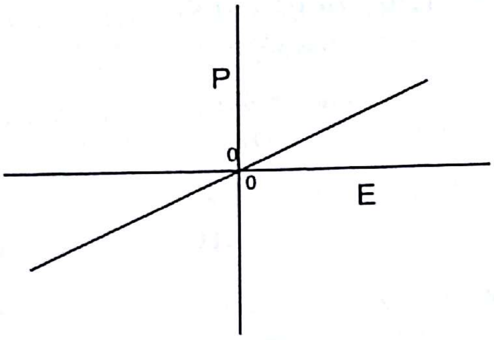

Figure II.6.4.1 (a) Variation of P with E in the paraelectric state of a material

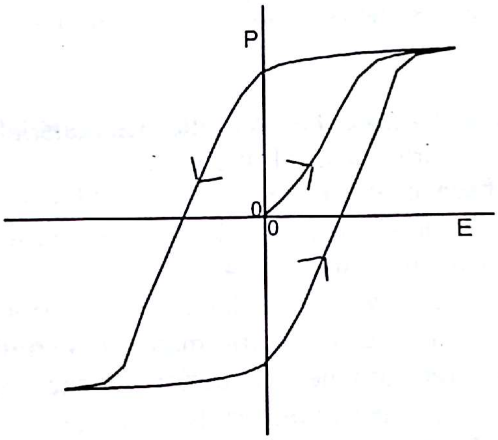

Figure II.6.4.1 (b) Variation of P with E in the ferroelectric state of a material

Above T_C (i.e.in the paraelectric state), the susceptibility of a ferroelectric material varies strongly with temperature following the Curie-Weiss law

$$\chi = C/\,(T-\Theta) \qquad \text{(II.6.4.2)}$$

Here C and Θ are constants characteristic of a given material. Θ has a value close to the transition temperature T_C. This law, derived in the mean field approximation of Landau, is valid at temperatures not too close to T_C (i.e. not closer than about 10^0 C). Near T_C fluctuations will play a dominant role. For a ferroelectric material with a T_C close to room temperature the susceptibility will have a very high value (of the order of hundreds and thousands). The dielectric constant

$$\varepsilon = 1+\chi = 1+C/(T-\Theta) \approx C/(T-\Theta) \qquad \text{(II.6.4.3)}$$

for a ferroelectric material. Because of the large dielectric constant a capacitance made of such a material will have a relatively small size.

The so called ceramic capacitances available in the market at low cost are made of materials with T_C around 10 to 20 C. These materials can be used to verify the Curie-Weiss law. The capacitance, being proportional to the dielectric constant, will show a strong dependence on temperature, the capacitance decreasing as the temperature increases.

On the other hand one can also get capacitances in the market with a polymer dielectric material. The dielectric constant of these polymer materials is not large and the dielectric constant shows a very weak dependence on temperature. Capacitances with such materials as dielectrics show a weak dependence on temperature.

2. AIM

To measure the capacitances of a ceramic capacitor and a polymer capacitor as a function of temperature in the range 40 to 130 C; to show that the capacitance of the ceramic capacitor shows a strong dependence on temperature while that of a polymeric capacitor shows a weak dependence and to verify the Curie-Weiss law for the ceramic capacitor.

3. APPARATUS REQUIRED

A regulated DC power supply, temperature controller, furnace, insert with ceramic and polymeric capacitors, a signal generator and a DMM to measure AC volts to three decimal places in the range of 2 Volts.

4. EXPERIMENTAL SET UP

A ceramic capacitor and a polymeric capacitor, each of a nominal value of 0.1 μfd, are pasted with Araldite on two faces of an aluminium block which also carries a Pt 100 sensor. Leads from the capacitor are brought to a circular disc carrying eight small banana terminals as shown in Figure II.6.4.2. The two central unmarked terminals are for the leads of Pt 100 thermometer. The ceramic capacitor leads are connected to the terminals R_1 (Red) and G_1 (Green) marked Ceramic. Similarly the terminals R_2 and G_2 are connected to the leads from the capacitance with polymeric dielectric. Between G_1 and B_1 (Black) is connected a 1 k resistor at the top disc Similarly between G_2 and B_2 is connected a 1 k resistor at the disc. Terminals R_1 and R_2 are shorted at the disc (as shown by the dotted line). So also, terminals B_1 and B_2 are shorted. If a signal generator is connected between R_1 and B_1 the same AC voltage is applied to both the RC combinations as shown in Figure II.6.4.3.

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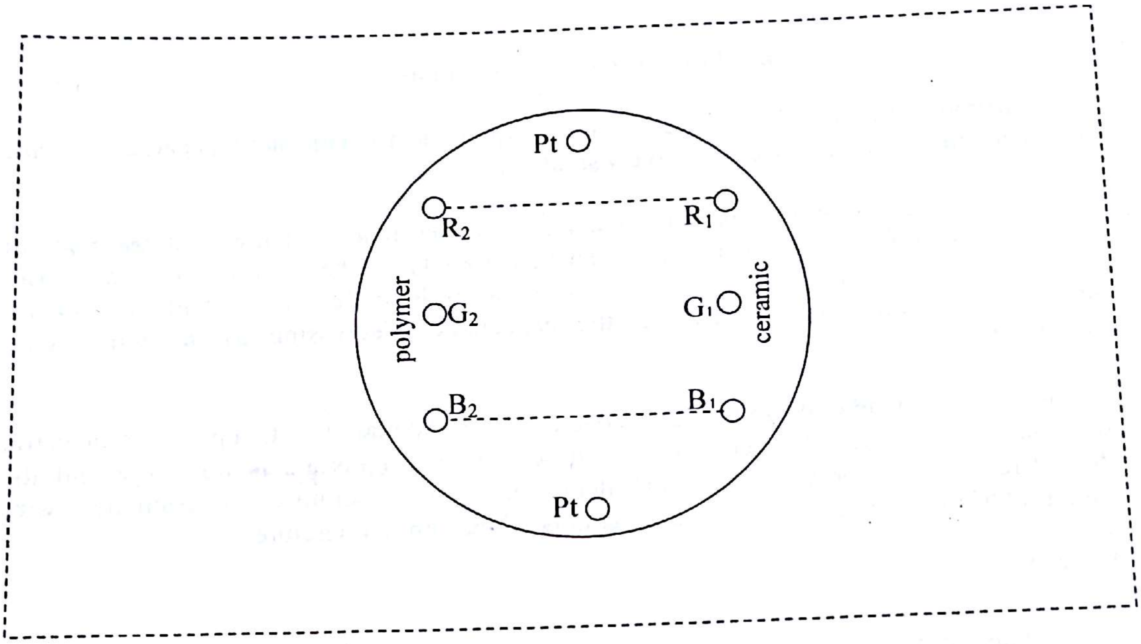

Figure II.6.4.2: Circular disc containing the banana terminals

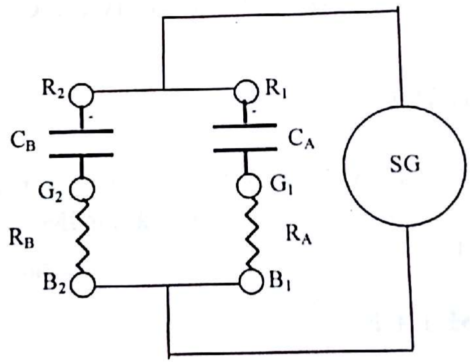

Figure II.6.4.3: C_A Ceramic capacitor, R_A = 1 k;
C_B Polymer capacitor, R_B = 1k
SG Signal generator

If we measure the voltage V_{RA} across R_1 and G_1 and the voltage V_{CA} across G_1 and B_1 then

$$V_{CA}/V_{RA} = Z_{CA}/R_A \tag{II.6.4.4}$$

where Z_{CA} is the impedance of the capacitor C_A and is equal to

So

$$Z_{CA} = 1/(2\pi f C_A) \quad (II.6.4.5)$$

$$C_A = 1/(2\pi f\,(V_{CA}/V_{RA})R_A) \quad (II.6.4.6)$$

Knowing f the frequency of the signal generator, and R_A, one can calculate the capacitance C_A.

Similarly

$$C_B = 1/(2\pi f\,(V_{CB}/V_{RB})R_B) \quad (II.6.4.7)$$

where V_{RB} is the voltage across G_2 and B_2 and V_{CB} is the voltage across R_2 and G_2.

Connect the furnace to the regulated power supply. Close the open ends of the ceramic tube of the furnace loosely with plugs of cotton to prevent convection currents. Start with a DC voltage of 7.5 V so that the furnace temperature rises at the rate of 1 to1.5 degrees/minute. As the temperature increases, increase the DC voltage gradually. At 120 C the DC voltage should not exceed 12 V. Connect the signal generator terminals to R_1 and B_1. Set the signal generator frequency to 1 kHz as measured at the terminals R_1 and B_1 with a DMM. Set the output voltage at 1 V. Connect the two Pt 100 terminals to the corresponding terminals on the temperature indicator.

At a given value of temperature as indicated on the temperature indicator, measure with a DMM, set in AC 2 Volts range, V_{RA}, V_{CA}, V_{RB} and V_{CB}. Carry out the measurements at intervals of 10 C from 40 to 110 C. A sample set of readings is given below.

Table II.6.4.1

Temperature dependence of capacitor
C_A is a ceramic capacitor and C_B is a polymeric capacitor
R_A and R_B are 1 kΩ resistors
Frequency of signal generator is 1 kHz

	Ceramic capacitance				Polymer capacitance			
Temp C	V_C	V_R	Z_c	C_A in μfd	V_C	V_R	Zc	C_B in μfd
40	0.887	0.409	2168.7	0.0734	0.814	0.533	1527.2	0.1042
50	0.875	0.284	3080.9	0.0517	0.773	0.507	1524.6	0.1044
60	0.89	0.232	3836.2	0.0415	0.771	0.508	1517.7	0.1049
70	0.897	0.191	4696.3	0.0339	0.766	0.507	1510.8	0.1053
80	0.9	0.164	5487.8	0.029	0.761	0.506	1503.9	0.1058
90	0.903	0.14	6450	0.0247	0.752	0.511	1471.6	0.1082
100	0.905	0.129	7015.5	0.0227	0.751	0.517	1452.6	0.1096
110	0.855	0.106	8066	0.0197	0.701	0.493	1421.9	0.1119

From the ratio V_C/V_R, the impedance Z_C is calculated using

$$Z_C = (V_C/V_R)*1000$$

From Z_C, the capacitance C is calculated from

$$C = 1/(2\pi f Z_C)$$

with f=1000 Hz.

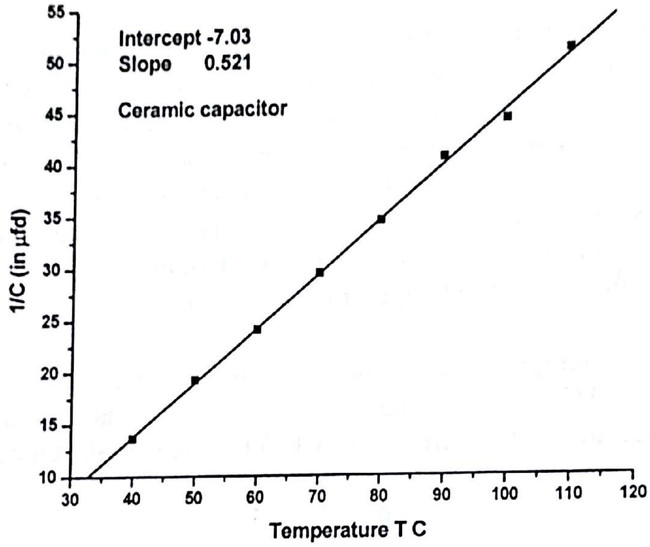

Figure II.6.4.4: A plot of $1/C_A$ vs. t.

Figure II.6.4.4 shows a plot of $1/C_A$ against temperature T in ^{0}C. The linear fit to the points is shown by the black line. The fit is very good. The intercept A = -7.03 and the slope B is 0.521. So the Curie temperature Θ is given by

$$\Theta = -A/B = 13.4 \text{ C}.$$

The equation to the straight line is

$$1/C_A(\text{in } \mu\text{fd}) = 0.521(T-13.4) \qquad \text{(II.6.4.8)}$$

or

$$C_A\ (\text{in } \mu\text{fd}) = 1.921/(T-13.4) \qquad \text{(II.6.4.9)}$$

The ceramic capacitance (and hence the dielectric constant of the ferroelectric material used in the capacitance) follows the Curie-Weiss law with $\Theta = 13.4\ ^0$ C.

Figure II.6.4.5 shows a plot of C_A and C_B with temperature. The black curve represents the fit of C_A to equation (II.6.4.9).

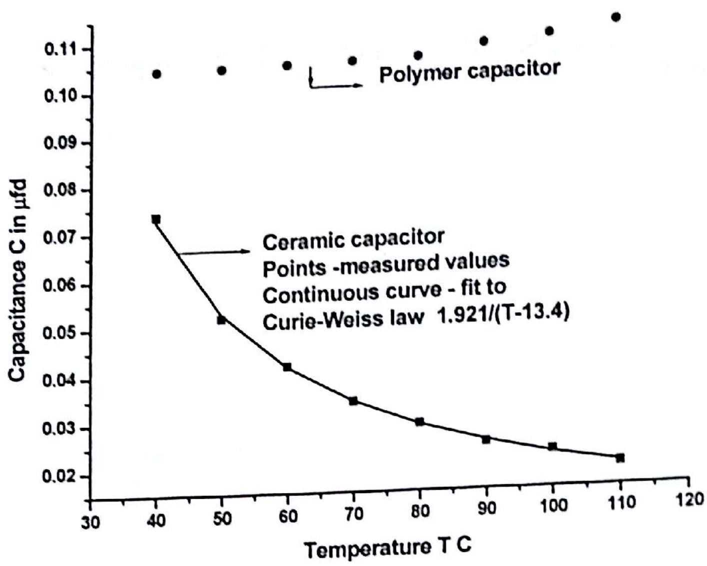

Figure II.6.4.5: Plot of the capacitance value C_A of the ceramic capacitor as a function of temperature T in ^{0}C. The continuous curve shows the fit to the experimental points for C_A from the Curie Weiss equation.

Thus this experiment demonstrates that

1. The capacitance of a ceramic capacitor decreases rapidly as temperature increases while the capacitance of a polymer capacitor increases slightly with increase of temperature.

2. The dielectric constant of the ferroelectric material used in the ceramic capacitor follows the Curie-Weiss law.

3. The dielectric constant of the material used in the polymer capacitor increases slightly as the temperature is increased.

Questions:

1. If we use a ceramic capacitor in the tank circuit of the oscillator how will the vary as the temperature changes, assuming the inductance in the circuit is independent of temperature.

2. Can you use a ferroelectric as a memory element to represent the binary states 0 and 1?