Charge Amplifiers

Objective: Study signal conditioning for sensors with high output impedance and find the piezoelectric strain constant d_{31} of PVDF.

Preparation: Oscilloscope, Charge amplifier, Dual power supply, Cables, PMMA strip

Mechanical to Electrical Conversion

The PVDF film behaves like a dynamic strain gage except that it requires no external power source and generates signals greater than those from conventional foil strain gages *after* amplification. Frequency response is thus free from any limitations imposed by the need for high gains and will extend up to the wavelength limit of the given transducer. The extreme sensitivity is largely due to the format of the PVDF. Operation down to fractions of Hz can be achieved using either conventional **charge amplifiers** or, since signal levels are relatively high, simple high impedance FET buffer circuits.

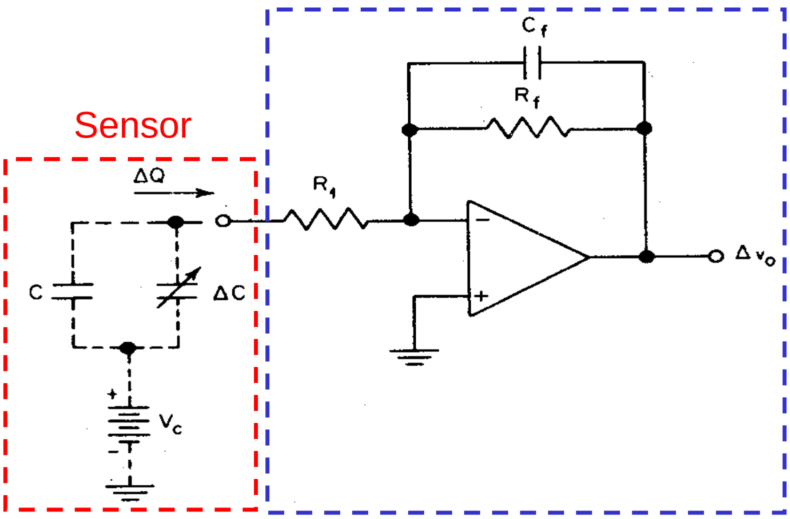
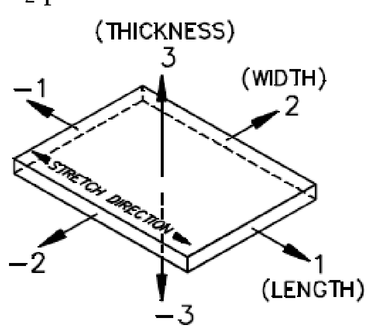


Fig. 1

$$\Delta v_o = \frac{-\Delta Q}{C_f}$$

Material constants

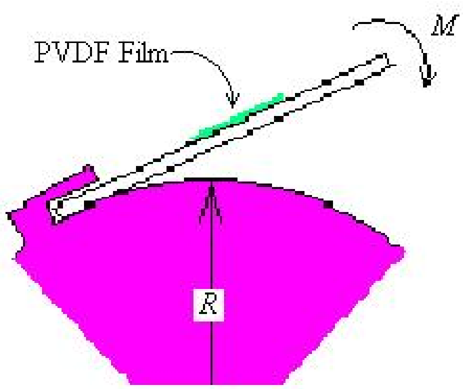
PVDF is a transversely isotropic material. If the x_3 axis is the poling axis, the material properties are isotropic in the x_1-x_2 plane.



The constitutive equations of PVDF are

$$\begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \end{bmatrix} = \begin{bmatrix} s_{11}^E & s_{12}^E & s_{13}^E & 0 & 0 & 0 \\ s_{12}^E & s_{11}^E & s_{13}^E & 0 & 0 & 0 \\ s_{13}^E & s_{13}^E & s_{33}^E & 0 & 0 & 0 \\ 0 & 0 & 0 & s_{44}^E & 0 & 0 \\ 0 & 0 & 0 & 0 & s_{44}^E & 0 \\ 0 & 0 & 0 & 0 & 0 & s_{66}^E = 2\left(s_{11}^E - s_{12}^E\right) \end{bmatrix} \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \\ T_6 \end{bmatrix} + \begin{bmatrix} 0 & 0 & d_{31} \\ 0 & 0 & d_{31} \\ 0 & 0 & d_{33} \\ 0 & d_{15} & 0 \\ d_{15} & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ E_3 \end{bmatrix}$$

$$\begin{bmatrix} D_1 \\ D_2 \\ D_3 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & d_{15} & 0 \\ 0 & 0 & 0 & d_{15} & 0 & 0 \\ d_{31} & d_{31} & d_{33} & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \\ T_6 \end{bmatrix} + \begin{bmatrix} \epsilon_{11} & 0 & 0 \\ 0 & \epsilon_{11} & 0 \\ 0 & 0 & \epsilon_{33} \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ E_3 \end{bmatrix}$$



In PVDF film:

$S_1 = \dfrac{y}{R}$: strain in the x_1 direxction

R : radius of curvature

$y = t/2$: distance from neutral axis

t: thickness of the PMMA strip.

Known quantities:

$$E_1 = E_2 = 0, \quad T_3 = T_4 = T_5 = T_6 = 0, \quad S_2 = S_4 = S_5 = S_6 = 0 \tag{1}$$

Constitutive equations give

$$S_1 = s_{11}^E T_1 + s_{12}^E T_2 + d_{31} E_3 = \frac{y}{R} \tag{2}$$

and

$$D_3 = d_{31}(T_1 + T_2) + \varepsilon_{33} E_3 = \frac{Q}{A} \tag{3}$$

where Q is measured with a charge amplifier at the instant of deformation and A is the effective area of the PVDF film. The condition

$$S_2 = s_{12}^E T_1 + s_{11}^E T_2 + d_{31} E_3 = 0$$

gives

$$T_2 = -\frac{s_{12}^E}{s_{11}^E} T_1 - \frac{d_{31}}{s_{11}^E} E_3 \tag{4}$$

E_3 will drop to zero in a short time and the stress will change accordingly. Eqs. (2) and (3) become

$$[s_{11}^E - \frac{1}{s_{11}^E}(s_{12}^E)^2]T_1 = \frac{y}{R} \tag{5}$$

and

$$d_{31}(1-\frac{s_{12}^E}{s_{11}^E})T_1 = \frac{Q}{A} \tag{6}$$

If material constants are $\varepsilon_{33} = 110\times10^{-12} F/m$, the Young's modulus in the x_1-x_2 plane $Y = 2\times10^9 Pa = \frac{1}{s_{11}^E}$, and the corresponding Poisson's ratio $\nu = 0.35 = -\frac{s_{12}^E}{s_{11}^E}$, the piezoelectric strain constant d_{31} can be calculated .

Experiment 1: Characteristics of high output impedance sensors

Procedures:

1. Switch on the oscilloscope, turn the voltage scale of CH1 to 2*V*/division. Press the ground button of CH1 and turn the ground to the middle of the screen. Switch to DC coupling after this.
2. Select "Single sweep" mode for trigger. Set trigger level to 4*V* and slope to "-".
3. Turn the time base to 500*ms*/Div.
4. Connect the output cable of the PVDF film attached on the PMMA strip to the CH1 of the oscilloscope.
5. Press "Run/Stop"button such that the "Run Trigger?" is displaced on the screen.
6. Insert one end of the PMMA strip into the slot of the template then press the other end of the strip down to the edge of the template.
7. Observe the trace on the oscilloscope.
8. Use cursors to measure the time constant.

Experiment 2: Measure piezoelectric strain constant d_{31} with a charge amplifier

Procedures:

1. Follow all procedures of Experiment 1 except hook up the output cable to a charge amplifier in step 4.
2. Measure the charge generated from the PVDF film.
3. Employ Eqs. (5) and (6) to calculate d_{31} and the stresses of the PVDF film in the final state.

Report:

The report should contain the following works at least.
1. Calculate the discharge time constants of Experiment 1.
2. Compare the discharge time constants of Experiment 2 with that measured in Experiment 1. Discuss the reason for the discrepancy.

3. Calculate d_{31} in the unit of *m*/*V*. [strain/(*V*/*m*)]
4. Find the stresses of the PVDF film in the final state.
5. Why do the stresses in the PVDF change with time?

Appendix: Discharge time constant for the circuit shown in Fig. 1

$$V_o = \frac{-Q}{C_f} = R_f \frac{dQ}{dt}$$

$$\frac{dQ}{dt} + \frac{1}{R_f C_f} Q = 0$$

$$Q = A \exp\left(-\frac{t}{\tau}\right)$$

$$\tau = R_f C_f \text{ : time constant}$$