03.11 Problems for Chapter 03

03.11.1 Design problem

piezoelectric load sensor
pzt
load cells

Piezoelectric load sensors use the piezoelectric effect of certain materials, such as *pzt*, to transduce force applied to them into voltage across them. These sensors, sometimes called *load cells*, can be used to measure both compression and tension, and have characteristically "high frequency response," meaning they respond quickly to input forces, even those that change quickly.

A typical configuration is shown in Figure 03.17. A force is applid to a chassis that sandwiches two plates made of piezoelectric material, which sandwich an electrode.

Figure 03.18 shows a composite model for the devices. It is best to model the entire system with a single input-output differential equation or transfer function because it is not known *a priori* that the cable and charge amplifier systems will not load the load cell.

Let the load cell produce a source voltage V_p proportional to the input force f as

$$V_p = \alpha f \tag{03.55}$$

where the constant of proportionality is $\alpha = 20\ \text{mV/kN}$.

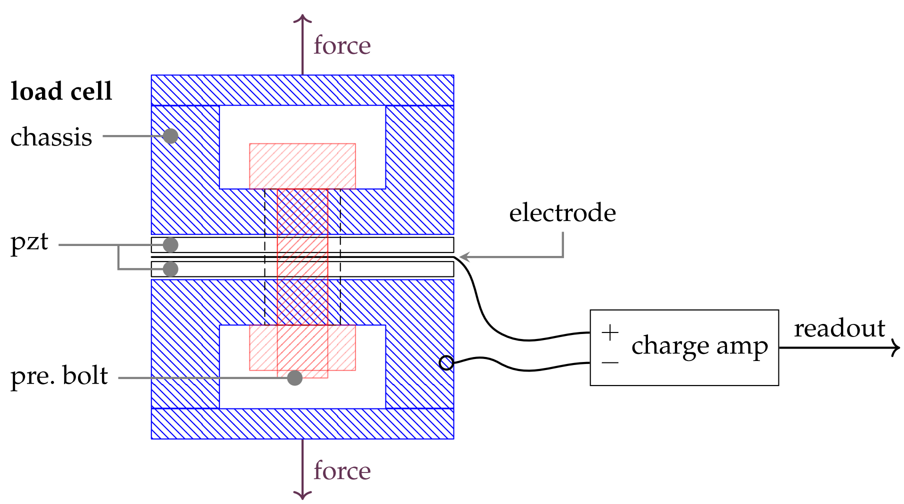

Figure 03.17

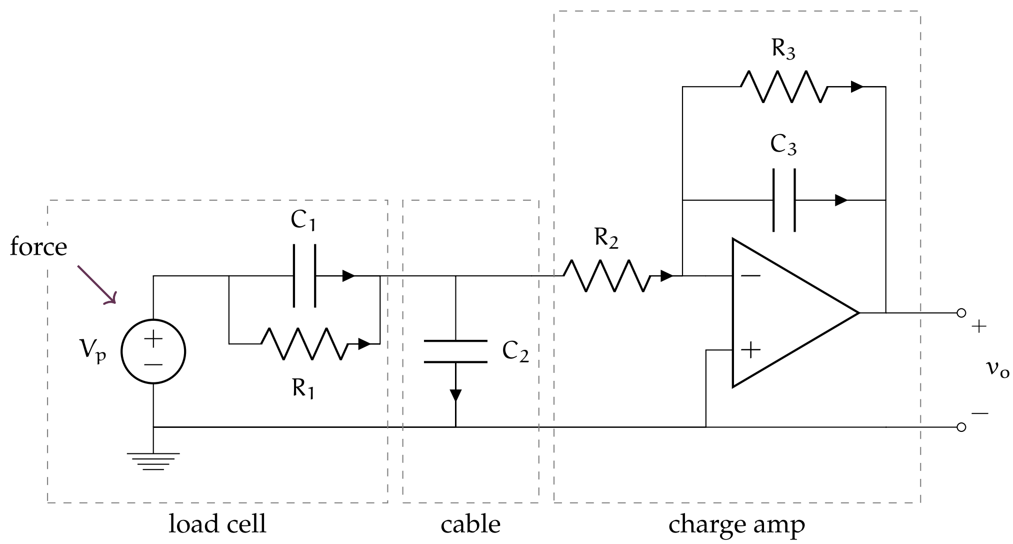

Figure 03.18

Let the piezoelectric material have capacitane $C_1 = 100\ \mu F$ and resistance $R_1 = 1\ M\Omega$. Let the cable have capacitance $C_2 = 30\ pF$.

1. Perform a circuit analysis and express the result as a single input-output differential equation relating the input force f to the output voltage v_o.
2. Define the transfer function from $F(s)$ to $V_o(s)$.
3. Define a MATLAB (or similar) model and plot the magnitude and phase of the frequency response function for the designs you develop, below (choose arbitrary R_2, R_3, and C_3 to get started).
4. Design the charge amp by tuning R_2, R_3, and C_3 such that the system responds to a force step input of 50 N with a settling time of less than 1/2 s. Plot the step response of the system. Hint: use MATLAB's `step` function to generate the step response. Note that this system has two time constants. Our primary concern in this problem is the "fast" response to a step and its initial settling time. The feedback capacitor C_3 will slowly discharge via R_3, so be careful not to be fooled by the "slow" decay. It helps to specify the simulation interval manually. For instance, a one-second time interval should be about right to simulate your system response. MATLAB's `step` function has an option for specifying the time interval or array.
5. Design the charge amp by tuning R_2, R_3, and C_3 such that the system

responds to a force sinusoidal input of 50 N at 1 Hz and at 1 kHz with a dynamic error of $< 10\%$. Consider the "flat" interval of the frequency response to be the $|H(j\omega)| = 1$ value for the purposes of the dynamic error formula. Sometimes a system like this would be characterized by a gain equal to the magnitude ratio of this flat interval.