# MECH 420 SENSORS AND ACTUATORS
# Assignment 2

**Problems 2.4, 2.7, 2.10, 2.17, 2.25, Read Section 2.8, then 2.40, 2.41, and 2.48 from the textbook**

## Problem 1 (Problem 2.4 from Textbook)

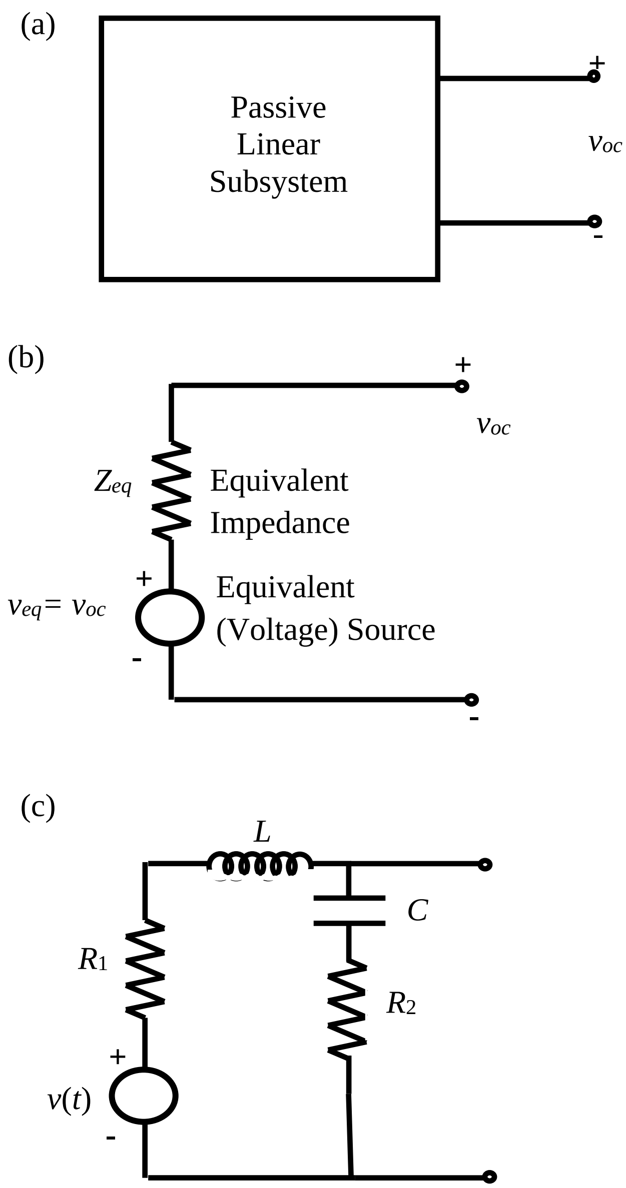


**Figure P2.4: Illustration of Thevenin's theorem. (a) Unknown linear subsystem; (b) Equivalent representation; (c) Example.**

Thevenin's theorem states that with respect to the characteristics at an output port, an unknown subsystem consisting of linear passive elements and ideal source elements may be represented by a single across-variable (voltage) source $v_{eq}$ connected in series with a single impedance $Z_{eq}$. This is illustrated in Figures P2.4(a) and (b). Note from Figure P2.4(b) that:

1. $v_{eq}$ = open-circuit across-variable $v_{oc}$ at the output port because the through-variable (current) through $Z_{eq}$ is zero
2. $Z_{eq}$ is the equivalent impedance of the circuit when the across-variable source is shorted.

*Note*: This is true for any circuit (mechanical, fluid, etc.) not just electrical.
Consider the circuit shown in Figure P2.4(c). Determine the equivalent source voltage $v_{eq}$ and the equivalent series impedance $Z_{eq}$, in the frequency domain, for this circuit.

## Problem 2 (Problem 2.7 from Textbook)

Indicate a suitable impedance for the connected component in the following two applications:

(a) A pH sensor of output impedance 10 MΩ is connected to a conditioning amplifier

(b) A power amplifier of output impedance 0.1 Ω is connected to a passive speaker.

In each case estimate a possible percentage error in the transmitted signal.

## Problem 3 (Problem 2.10 from Textbook)

A machine of mass *m* has a rotating device, which generates a harmonic forcing excitation $f(t)$ in the vertical direction. The machine is mounted on the factory floor using a vibration isolator of stiffness *k* and damping constant *b*. The harmonic component of the force that is transmitted to the floor, due to the forcing excitation, is $f_s(t)$. A simplified model of the system is shown in Figure P2.10. The corresponding force transmissibility magnitude $|T_f|$ from *f* to $f_s$ is given by $|T_f| = \sqrt{\dfrac{1+4\zeta^2 r^2}{\left(1-r^2\right)^2 + 4\zeta^2 r^2}}$ where, $r = \omega/\omega_n$, $\zeta$ = damping ratio, $\omega_n$ = undamped natural frequency of the system, and $\omega =$ excitation frequency (of $f(t)$).

Suppose that $m = 100$ kg and $k = 1.0\times10^6$ N/m. Also, the frequency of the excitation force $f(t)$ in the operating range of the machine is known to be 200 rad/s or higher. Determine the damping constant *b* of the vibration isolator so that the force transmissibility magnitude is not more than 0.5.

Using MATLAB, plot the resulting transmissibility function and verify that the design requirements are met.

*Note*: 2.0 = 6 dB; $\sqrt{2}$ = 3 dB; $1/\sqrt{2}$ = –3 dB; 0.5 = -6 dB.

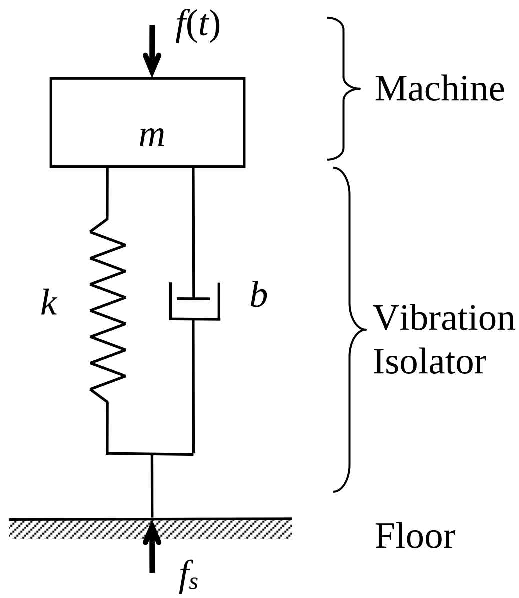


**Figure P2.10: Model of a machine mounted on a vibration isolator.**

## Problem 4 (Problem 2.17 from Textbook)

The speed of response of an amplifier may be represented using the three parameters: bandwidth, rise time, and slew rate. For an idealized linear model (transfer function), it can be verified that the rise time and the bandwidth are independent of the size of the input and the dc gain of the system. Since the size of the output (under steady conditions) may be expressed as the product of the input size and the dc gain, it is seen that rise time and the bandwidth are independent of the amplitude of the output, for a linear model.

Discuss how slew rate is related to bandwidth and rise time of a practical amplifier. Usually, amplifiers have a limiting slew rate value. Show that the bandwidth decreases with the output amplitude in this case.

A voltage follower has a slew rate of 0.5 V/μs. If a sinusoidal voltage of amplitude 2.5 V is applied to this amplifier, estimate the operating bandwidth. If, instead, a step input of magnitude 5 V is applied, estimate the time required for the output to reach 5 V.

## Problem 5 (Problem 2.25 from Textbook)

An active filter circuit is given in Figure P2.25.

(a) Obtain the filter transfer function. What is the order of the filter?
(b) Sketch the magnitude of the frequency transfer function. What type of filter does it represent?
(c) Estimate the cutoff frequency and the roll-off slope of the filter.

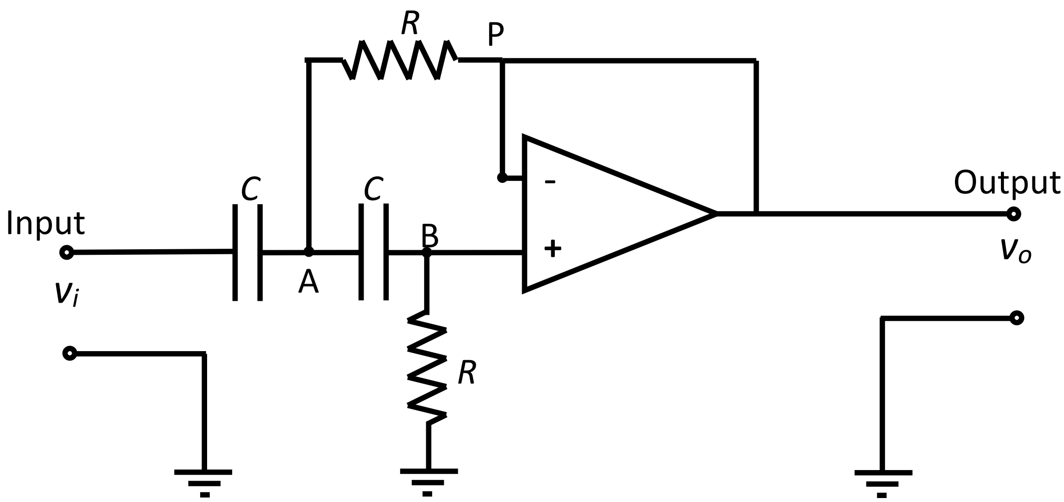


**Figure P2.25: An active filter circuit.**

**Please read Section 2.8 of the textbook. Then answer the following questions.**

## Problem 6 (Problem 2.40 from Textbook)

Suppose that in the constant-voltage (Wheatstone) bridge circuit shown in Figure 2.43(a) we have, $R_1 = R_2 = R_3 = R_4 = R$. Let $R_1$ represent a strain gage mounted on the tensile side of a bending beam element and $R_3$ represent another strain gage mounted on the compressive side of the bending beam. Due to bending, $R_1$ increases by $\delta R$ and $R_3$ decreases by $\delta R$. Derive an expression for the bridge output in this case, and show that it is nonlinear. What would be the result if instead $R_2$ represents the tensile strain gage and $R_4$ represents the compressive strain gage?

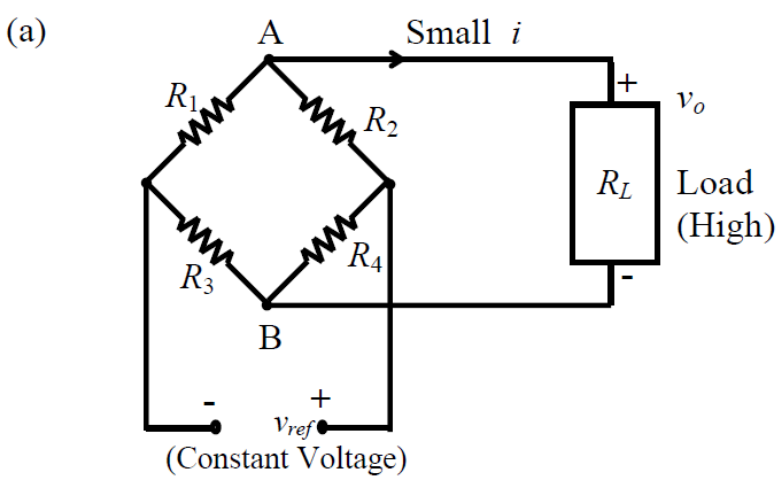


**Figure 2.43(a)**

## Problem 7 (Problem 2.41 from Textbook)

Suppose that in the constant-current bridge circuit shown in Figure 2.43(b) we have, $R_1 = R_2 = R_3 = R_4 = R$. Assume that $R_1$ and $R_2$ represent strain gages mounted on a rotating shaft, at right angles and symmetrically about the axis of rotation. Also, in this configuration and in a particular direction of rotation of the shaft, suppose that $R_1$ increases by $\delta R$ and $R_2$ decreases by $\delta R$. Derive an expression for the bridge output (normalized) in this case, and show that it is linear. What would be the result if $R_4$ and $R_3$ were to represent the active strain gages in this example, with the former element in tension and the latter in compression?

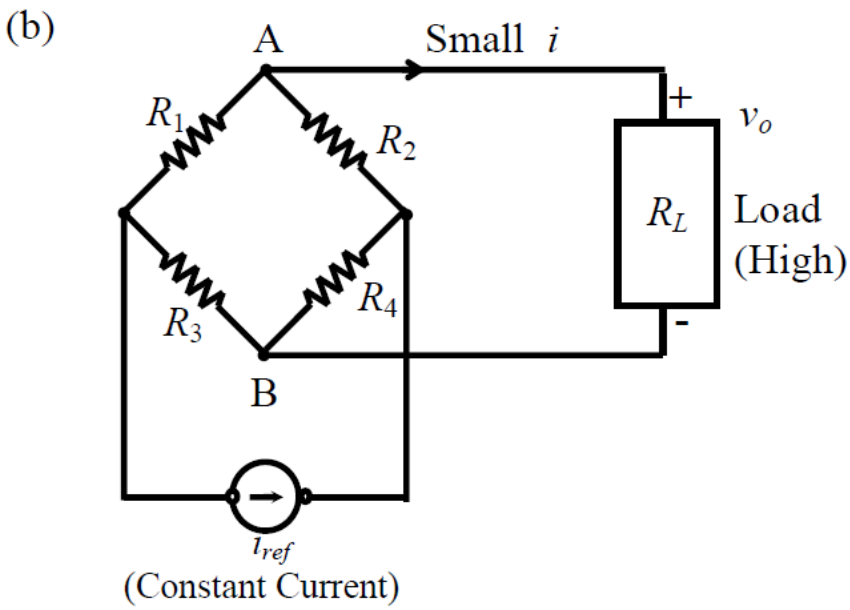


**Fig. 2.43(b)**

## Problem 8 (Problem 2.48 from Textbook)

Consider the strain-gage bridge shown in Figure 2.43(a). Initially, the bridge is balanced, with $R_1 = R_2 = R$. (*Note*: $R_3$ may not be equal to $R_1$.) Then $R_1$ is changed by $\delta R$. Assuming that the load current is negligible, derive an expression for the percentage error as a result of neglecting the second-order and higher-order terms in $\delta R$. If $\delta R/R = 0.05$, estimate this nonlinearity error.