NANYANG TECHNOLOGICAL UNIVERSITY

MA2011 MECHATRONICS SYSTEMS INTERFACING

Tutorial 5

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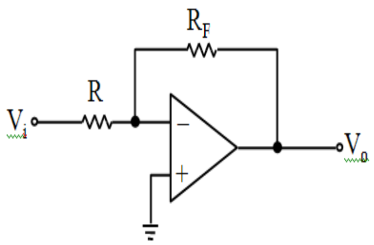
Q1

Operational amplifier:
- Very large (infinite) impedance
- Very small (zero) current



Finite Loop Gain A of Inverting Amplifier

A). Show that the closed loop gain G is a function of A, R and R_F

$$G = \frac{-AR_F}{AR+R+R_F} \qquad (1)$$

B). For large value A, G can be approximated by

$$G' = \frac{-R_F}{R} \qquad (2)$$

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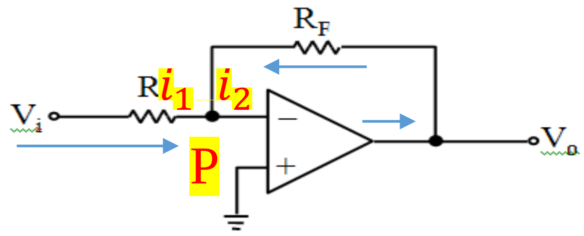
A). Show that the closed loop gain

$$G = \frac{-AR_F}{AR+R+R_F} \quad (1)$$



SOLUTION: At point P

$$-\ i_1 = \frac{(V_i - V_P)}{R} \qquad -\ i_2 = \frac{(V_P - V_o)}{R_F}$$

For an op-amp with infinite input resistance and zero output resistance, $i_1 = i_2$.

So, $$\frac{(V_i - V_P)}{R} = \frac{(V_P - V_o)}{R_F}$$

And $R_F\,(V_i - V_p) = R\,(V_p - V_o)$

$$V_P(R_F + R) = V_0 R + V_i R_F$$

But $V_P = - V_o / A$ Because Finite loop gain $A = - V_o/V_P$

So $$\frac{-V_o(R+R_F)}{A} = V_o R + V_i R_F$$

$$-V_o (R + R_F + AR) = V_i A R_F$$

$$\frac{V_0}{V_i} = \frac{-AR_F}{AR + R + R_F}$$

Therefore, closed loop (op-amp) gain G

$$G = \frac{V_0}{V_i} = \frac{-AR_F}{AR + R + R_F}$$

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Therefore, the closed loop gain

$$G = \frac{-AR_F}{AR+R+R_F} \qquad (1)$$

$$= \frac{-R_F}{R+\frac{R+R_F}{A}}$$

$$A \gg R + R_F\text{, or } \frac{R+R_F}{A} \to 0$$

$$G \to G' \equiv \frac{-R_F}{R}\text{, or } \frac{G'}{G} \to 1$$

B). For large value A, G can be approximated by

$$G' = \frac{-R_F}{R} \qquad (2)$$

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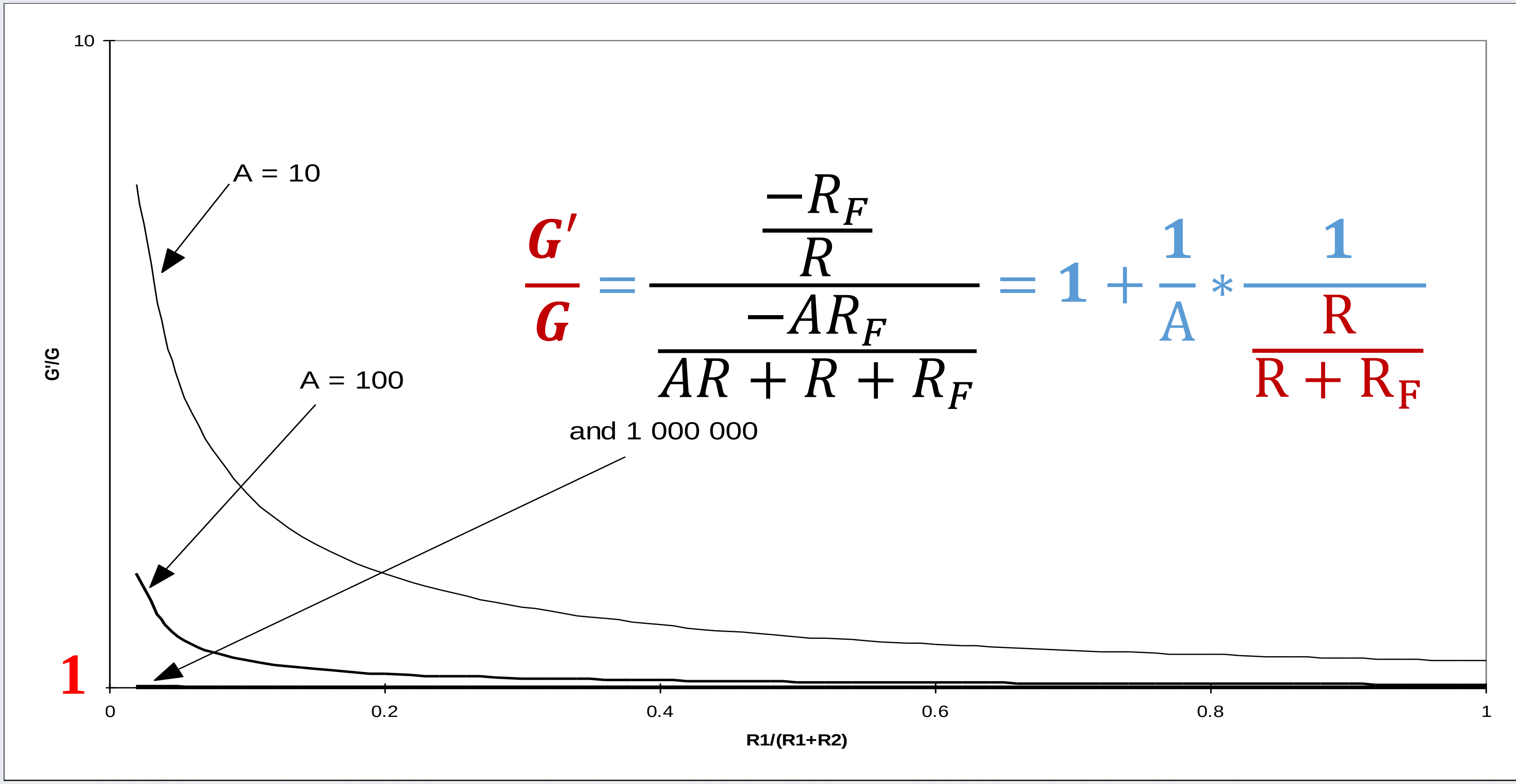
ANSWER TO Q1



$$\frac{G'}{G} = \frac{\frac{-R_F}{R}}{\frac{-AR_F}{AR+R+R_F}} = 1 + \frac{1}{A} * \frac{1}{\frac{R}{R+R_F}}$$

For high open-loop gain A ($10^5 \sim 10^6$), and the values of R **and** R_F(k**Ω**~M**Ω**), G can be approximated by $G' = \frac{-R_F}{R}$

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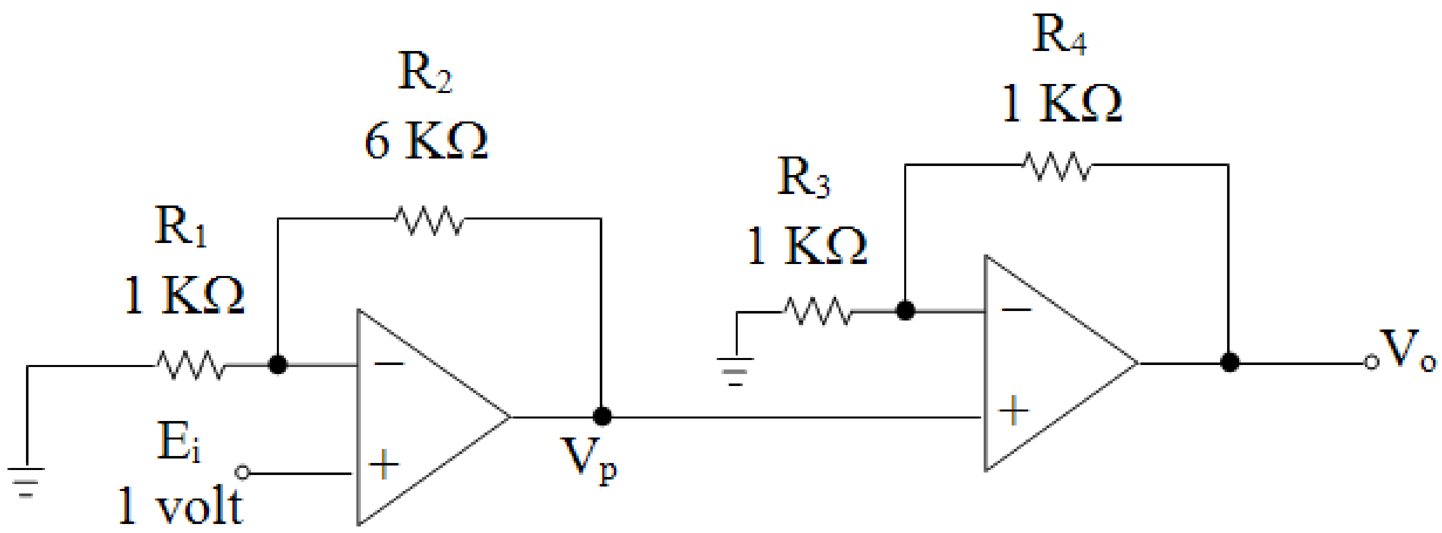
Q2

Find V_o for the following op-amp circuits:

a) Two non-inverting amplifiers in series.



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ANSWER TO Q2

SOLUTION:

$$G = \frac{R + R_F}{R} = 1 + \frac{R_F}{R} \text{ (General equation)}$$

$$V_p = \left(1 + \frac{R_2}{R_1}\right) V_i = \left(1 + \frac{6}{1}\right) \times 1 = 7 \text{ V}$$

$$V_o = \left(1 + \frac{R_4}{R_3}\right) V_p = \left(1 + \frac{1}{1}\right) \times 7 = 14 \text{ V}$$

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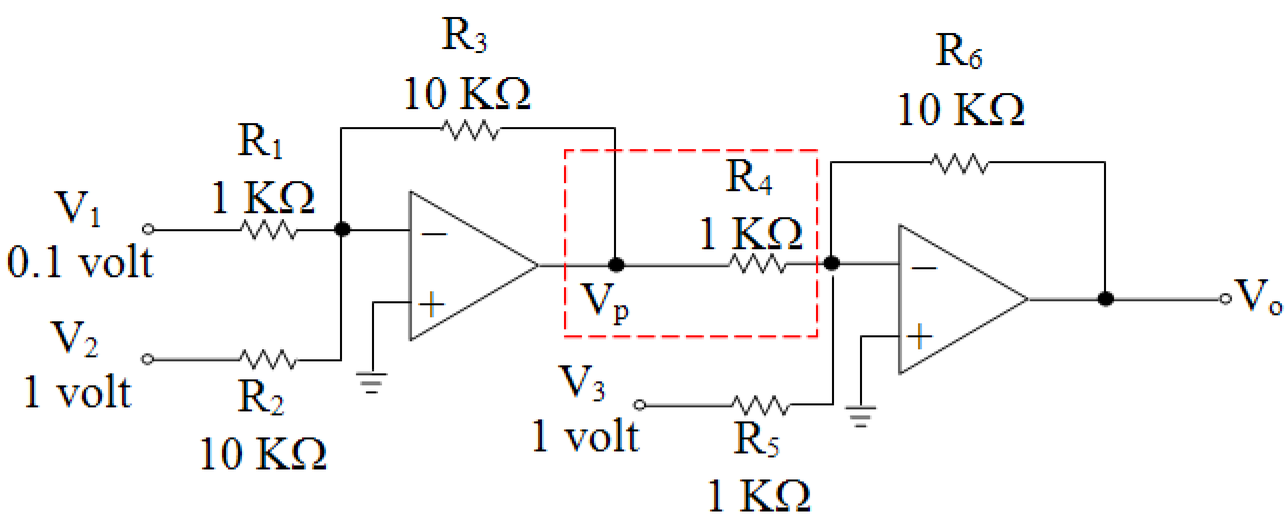
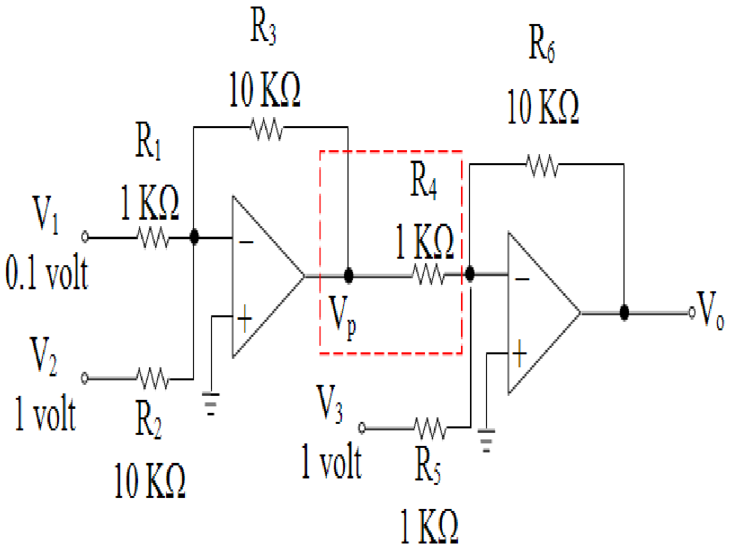
ANSWER TO Q2

b) Two summing amplifiers in series.



ANSWER TO Q2



SOLUTION:

General equation: $V_o = -\left(\frac{V_1}{R_1} + \frac{V_2}{R_2} + \cdots\right)R_F$

$$V_p = -\frac{R_3V_1}{R_1} - \frac{R_3V_2}{R_2} = -10 \times 0.1 - 1 \times 1$$

$$= -2\ V$$

$$V_o = -\frac{R_6V_p}{R_4} - \frac{R_6V_3}{R_5} = -\{10 \times (-2)\} - (10 \times 1)$$

$$= 10\ V$$

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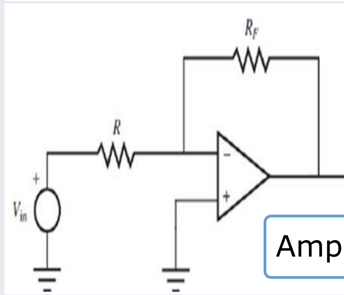
COMPARISON OF INVERTING AND NONINVERTING AMPLIFIER

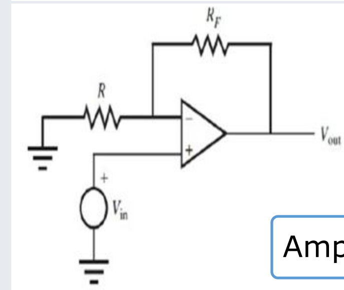
Inverting	Non-inverting

Inverting



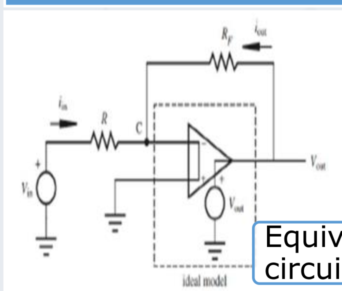
Amplifier

Non-inverting



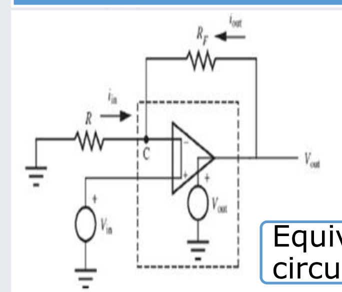
Amplifier

Inverting



Equivalent circuit

Non-inverting



Equivalent circuit

Inverting

$$V_{out} = -\frac{R_F}{R} V_{in}$$

Equation & negative gain

Non-inverting

$$V_{out} = \left(1 + \frac{R_F}{R}\right) V_{in}$$

Equation & positive gain

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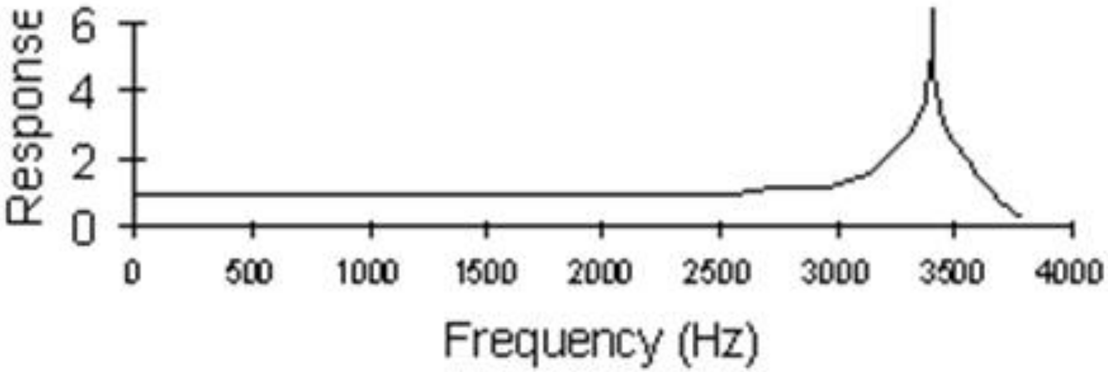
T5 Q3

3. An accelerometer that is used to measure the vibration of a machine has a frequency response as shown in the figure below:



The vibration signal is filtered to ensure that the vibration signal beyond 2.5 kHz does not affect the recording of the measurements.

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ANSWER TO Q3

Select an appropriate filter consisting of a resistor, with resistance R, and a capacitor, with capacitance C, that will remove the error due to the frequency response of the accelerometer. Suggest appropriate values of R and C. Sketch the frequency response of the filter, indicating all relevant parameters on the sketch.

KNOWN: To filter off signal of 2.5 kHz or more.

FIND: (i) Filter type, values of R and C, and frequency response of filter

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ANSWER TO Q3

SOLUTION:

As frequencies below 2.5 kHz are required and those above have to be removed, a low pass filter is required.

Cut-off frequency must be at least 2.5 kHz (required) and less than about 3 kHz, (where the accelerometer response becomes > 1).

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ANSWER TO Q3

Impedance-based relationship between frequency, resistance and capacity.

If the cut-off frequency is 2.5 kHz, $f_c = \dfrac{1}{2\pi RC}$

Or $RC = \dfrac{1}{2\pi f_c}$

So, $RC = \dfrac{1}{2\pi \times 2500} = 6.37 \times 10^{-5}$ s

Choose any value of R and C such that the combination results in 6.37×10^{-5} s.

For example, R = 63.7 kΩ, C = 1 000 pF (1 pF = 10^{-12} F).

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ANSWER TO Q3

The frequency response of the filter, with the relevant parameters is:

$$M(f) = \frac{1}{\sqrt{1+(f/2500)^2}}$$

$$M(3400)_{filter} = \frac{1}{\sqrt{1+\left(\frac{3400}{2500}\right)^2}} = 0.592.$$

Magnitude ratio $M(\omega) = \frac{1}{\sqrt{1+(\omega\tau)^2}}$

Since $\omega = 2\pi f$, **and** $\tau = 1/(2\pi f_c)$, $M(f) = \frac{1}{\sqrt{1+(f/fc)^2}}$

For $f_c = 2500$, $M(2500) = \frac{1}{\sqrt{1+(1)^2}} = 0.707$

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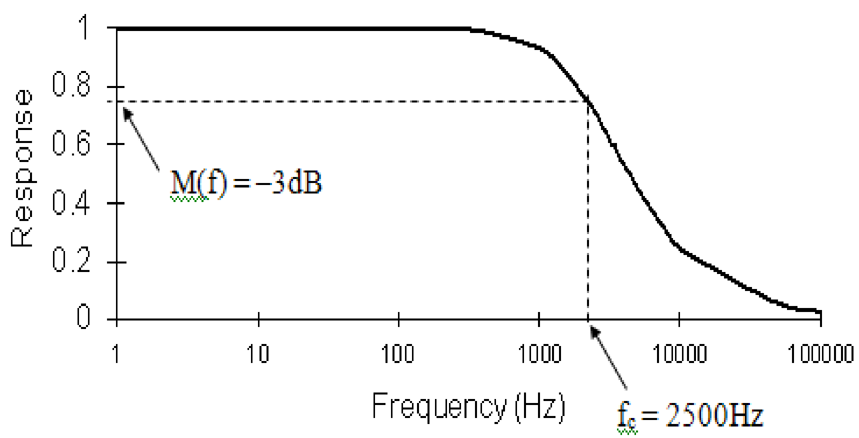
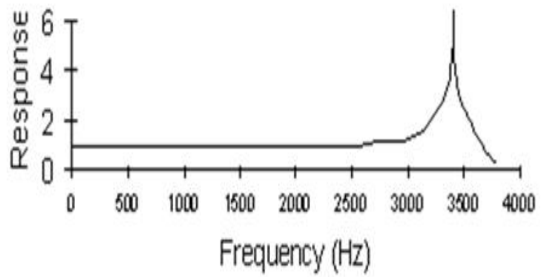
ANSWER TO Q3



The frequency response of the accelerometer-filter combination is:

An accelerometer that is used to measure the vibration of a machine has a frequency response as shown in the figure below:



The vibration signal is filtered to ensure that the vibration signal beyond 2.5 kHz does not affect the recording of the measurements.

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