Signal Conditioning Problems

Conceptual

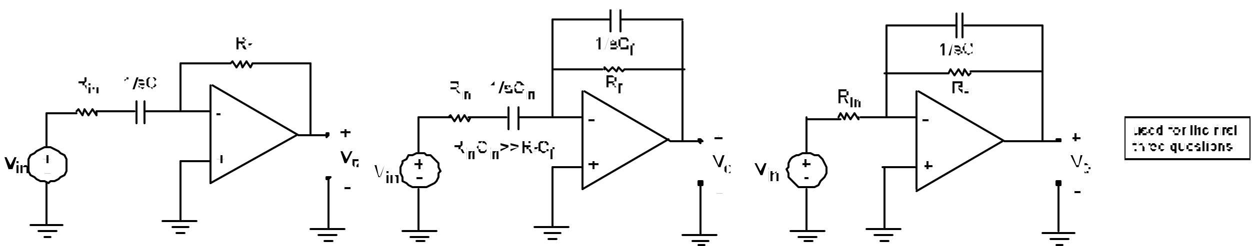

Fig. P9.1

1. ***T/F*** Circuit on **left**: $R_f = 10k\Omega$, $R_{in} = 5\ K\Omega$, $C = 0.01\mu F$. The circuit is a high-pass filter with a high-frequency gain of 2 and a break frequency of $2(10^4)$Hz.
2. ***T/F*** Circuit in **middle**: $R_f = 20k\Omega$, $R_{in} = 4K\Omega$, $C_{in} = 0.1\mu F$, $C_f = 10$ pF. For $V_{in} = 20\cos(10^5 t)$ mV, $|V_o|$ is approximately 100 mV.
3. ***T/F*** Circuit on **right**:. $R_f = 10k\Omega$, $R_{in} = 5K\Omega$, $C = 0.1\mu F$. The circuit is a low-pass filter with a lowpass gain of 2 and a break frequency of 1000 r/s.
4. ***T/F*** Time and frequency domain. Lowering the time constant of a 1st-order low-pass filter will result in a lower break frequency.
5. ***T/F*** Time and frequency domain. Lowering the break frequency of a low-pass filter will allow it, in its time-domain response to a step function input, to reach its steady-state value more quickly.
6. ***T/F*** A low-pass filter with $\omega_b = 1000$ r/s and a DC gain of 10 has a transfer function of 10/(s+1000) and its time-domain response to an input of 1u(t) V is $10\left(1 - e^{-t/1000}\right)$ V.

   Why or why not?

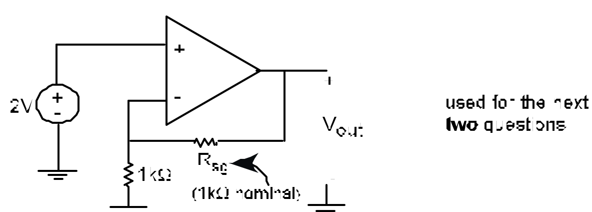

Fig. P9.2

7. An ideal op-amp is used to measure strain as shown above. Given a nominal 1kΩ resistance for the strain gage, and a strain gage factor of 2, $v_{out} = 4.004$V if the strain, $\varepsilon = 0.001$.
8. Given the same strain gage, $v_{out} = 4\cos 10t$ mV if the strain, $\varepsilon = 0.001\cos(10t)$.

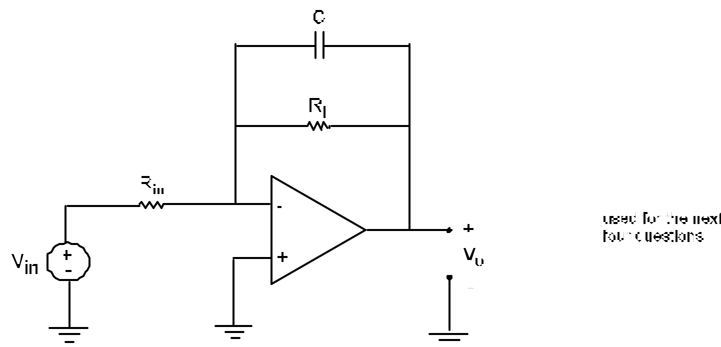

Fig. P9.3

9. ***T/F*** Time-domain response. Increasing C will lower the magnitude of the static gain coefficient.
10. ***T/F*** Time-domain response. Increasing R_f will increase the time constant.
11. ***T/F*** Frequency-domain response. Lowering R_{in} will lower the break frequency.
12. ***T/F*** Frequency-domain response. Increasing R_f will increase magnitude of the DC gain.

For the next two questions, $TF(s) = \frac{V_o(s)}{V_{in}(s)} = \frac{1000}{s + 20}$

13. ***T/F*** If $v_{in-1} = 5 \cos(10t)$ V and $v_{in-2} = 50 \cos(100t)$ V, the steady-state amplitude of v_{out-1} will be greater than v_{out-2}. *Why or why not?*

14. ***T/F*** If $v_{in-1} = 1000 \cos(10^4 t)$ V and $v_{in-2} = 10 \cos(500t)$ V, the steady-state amplitude of v_{out-2} is greater than v_{out-1}. *Why or why not?*

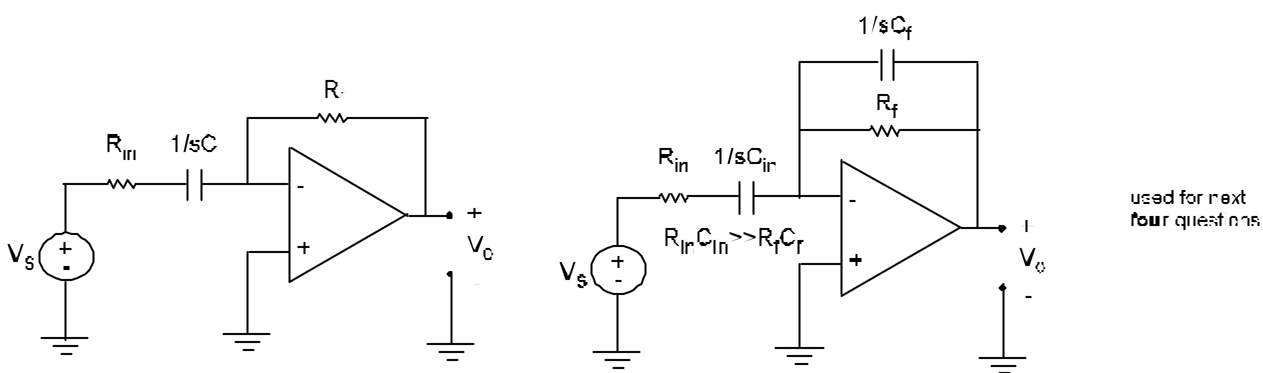

Fig. P9.4

15. ***T/F*** Increasing C in the *high-pass* filter will lower its break frequency.
16. ***T/F*** Increasing R_{in} in the *bandpass* filter has no effect on its lower break frequency .
17. ***T/F*** Increasing C in the *high-pass* filter has no effect on its high-frequency gain.
18. ***T/F*** Increasing C_{in} in the *bandpass* filter has no effect on its passband gain.
19. ***T/F*** The gain of an op-amp amplifier is independent of frequency.

20. ***T/F*** An amplifier have a gain of G is needed. Using identical op-amps, a two-stage amplifier (each stage having a gain of $\sqrt{G}$) will maintain its gain at higher frequencies than a single-stage amplifier.

21. ***T/F*** A 1st-order low-pass filter has a high-frequency slope of -20 dB/dec, and a 2nd-order filter would have a high-frequency slope of -40 dB/dec.

22. ***T/F*** The voltage at which an op-amp circuit saturates increases as the power supply voltage, V_{cc}, increases.

23. ***T/F*** An op-amp buffer circuit is useful when a signal source has a very high Thevenin impedance. *Why or why not?*

24. ***T/F*** An instrumentation amplifier can be described as a differential amplifier with buffered inputs.

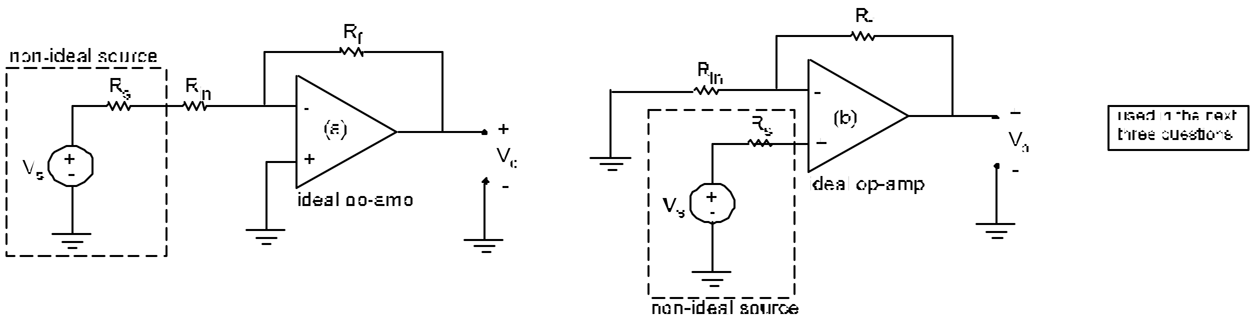

Fig. P9.5

25. ***T/F*** The gain, $|V_o/V_s|$, for the circuit on the left varies with R_s.

26. ***T/F*** The gain, $|V_o/V_s|$, for the circuit on the right is not a function of R_s.

27. ***T/F*** The gain, $|V_o/V_s|$, for the circuit on the left cannot be less than one, whereas the gain for the circuit on the right can be less than one.

Workout

1. i) Classify the amplifier model shown below.
   ii) Express V_o as a function of V_s.
   iii) Given V_s, what is the maximum possible amplification?
   iv) To obtain the amplification given in iii), what how must R_i be related to R_s? How must R_o be related to R_L?

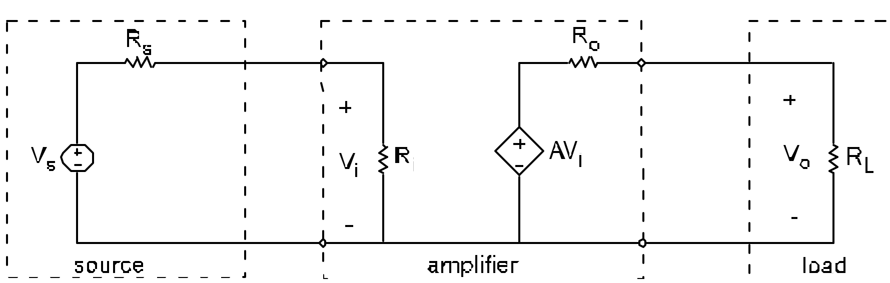

Fig. P9.6

2. i) Classify the amplifier model shown below.
   ii) Express V_o as a function of V_S.
   iii) Given V_S, what is the maximum possible amplification?
   iv) To obtain the amplification given in iii), what how must R_i be related to R_S? How must R_o be related to R_L?

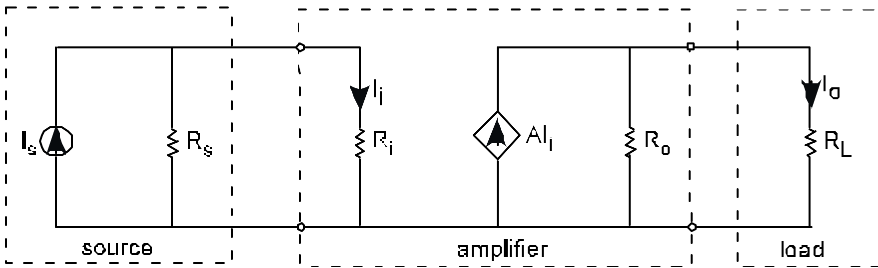

Fig. P9.7

3. i) Classify the amplifier model shown below.
   ii) Express V_o as a function of V_S.
   iii) Given V_S, what is the maximum possible amplification?
   iv) To obtain the amplification given in iii), what how must R_i be related to R_S? How must R_o be related to R_L?

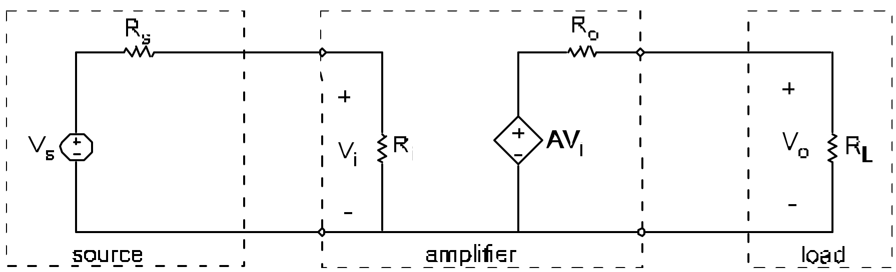

Fig. P9.8

4. i) Classify the amplifier model shown below.
   ii) Express V_o as a function of V_S.
   iii) Given V_S, what is the maximum possible amplification?
   iv) To obtain the amplification given in iii), what how must R_i be related to R_S? How must R_o be related to R_L?

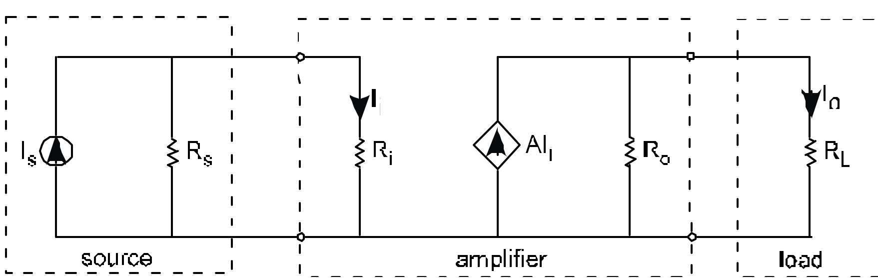

Fig. P9.9

5. The example below uses a photoconductor as part of an optical detector. Assume the photoconductor's resistance, R_{pc}, varies as shown. A current source is intended to convert changes of resistance into changes of voltage.

   i) Design an amplifier circuit which amplifies V_{pc} so that, when the light power is 100 mW, the output voltage is 10 V.
   ii) Design the amplifier to have a very high input resistance (i_{in} very small). Explain why this is desirable.
   iii) Give the overall sensitivity of the detector (photoconductor circuit + amplifier in V/mW).

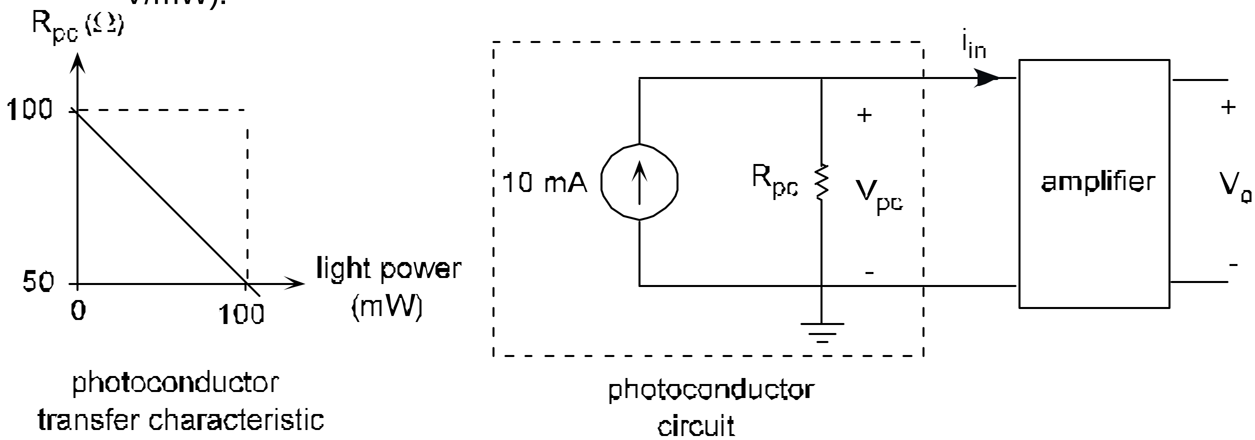

Fig. P9.10

6. Choose R_1, R_2, R_3, and R_4 so that:

   i) $V_{o\text{-}1st\ stage}$ = 0.4 V when the temperature is 1250 °C.
   ii) $V_{o\text{-}2nd\ stage}$ = -8 V when the temperature is 1250 °C.
   iii) Plot $V_{o\text{-}2nd\ stage}$ as a function of temperature for 500 °C < temp < 1250 °C.

   Use resistance value between 1 kΩ and 100 KΩ.

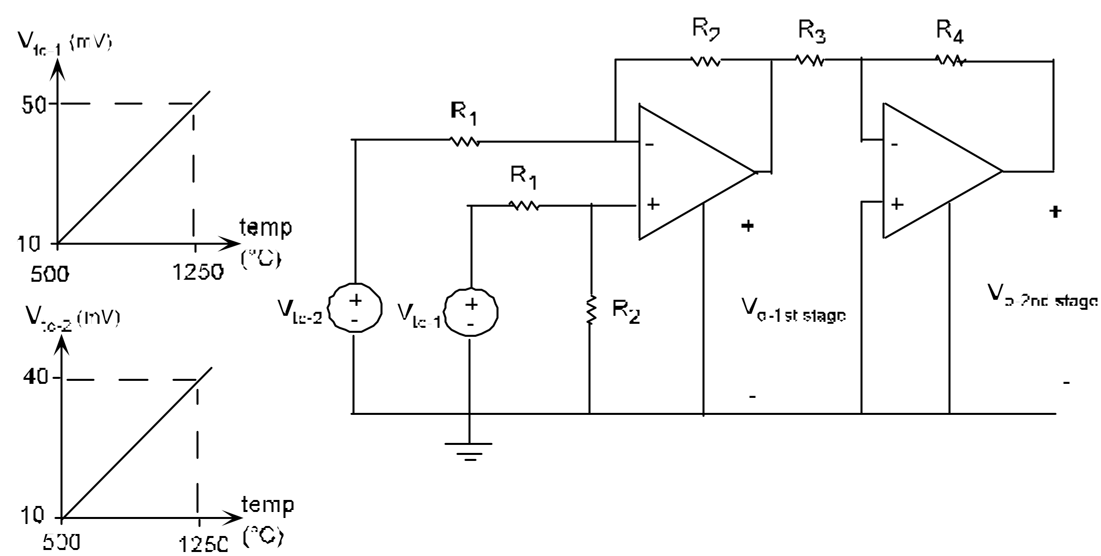

Fig. P9.11

7. A system for monitoring the effectiveness of a process in removing a compound from a product stream. Design for V_o to vary from -5 V to 5 V as the concentration difference C1-C2 varies between -200 and 200 ppm.

Find:

i) The sensitivity of the sensor probes (in mV/ppm).

ii) The values for the resistances (choose between 2 kΩ and 200 kΩ).

iii) The sensitivity of the resulting detector (in mV/ppm).

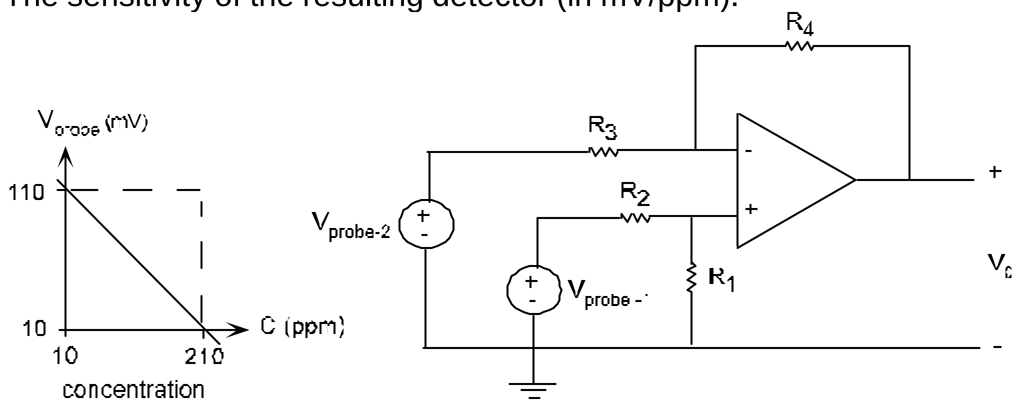

Fig. P9.12

8. In the circuit below, $R = R_o + \Delta R$ is the resistance of a resistive sensor.

i) Show that V_o may be expressed as $V_s(-\Delta R)/(R_1 + R_o)$.

ii) Find the sensitivity of V_o with respect to ΔR. That is, find $dV_o/d\Delta R$

iii) In a practical op-amp circuit, could R be a 120 Ω strain gage? *Why or why not?*

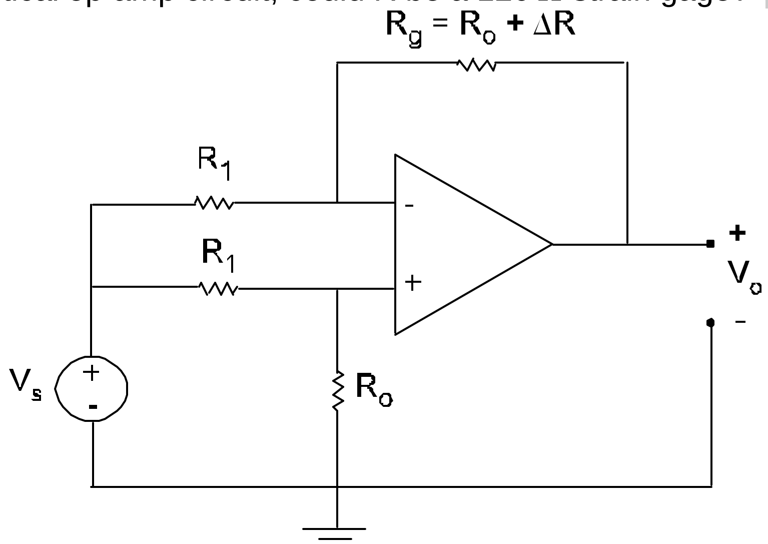

Fig. P9.13

9. Using the ideal op-amp model, find i_o.

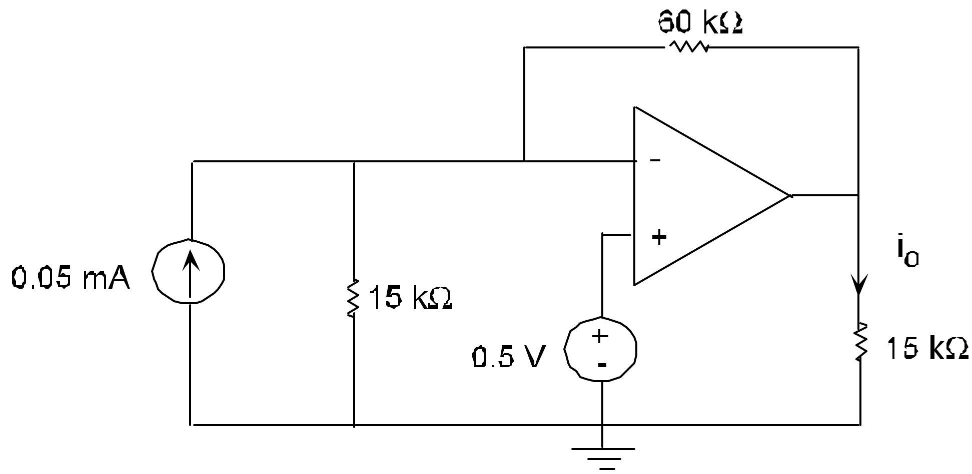

Fig. P9.14

10. Find V_o.

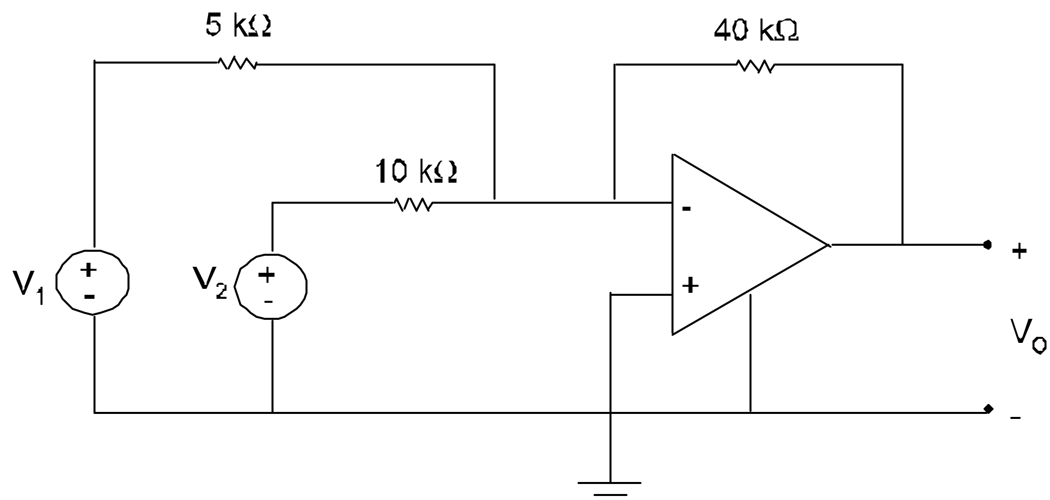

Fig. P9.15

11. Using an op-amp in the inverting configuration, design a low-pass filter with a break frequency of 1000 rad/sec and a low-pass gain magnitude of 10. Use R_{in} = 10 kO.
    i) Sketch the circuit showing the calculated values of R_f and C.
    ii) Given the transfer function.
    iii) Using semilog paper, give the straight-line Bode magnitude plot

12. When a given load is placed on a **four-active arm** cantilever load cell, ε=0.0004.
    i) What is V_b?
    ii) Specify R_b in the amplifier below to give an output of V_0=60 mV. Use R_a= 2 kΩ and

assume S=2, V_s=15V, and R_1,R_2,R_3, and R_4 to all be 350Ω strain gages.

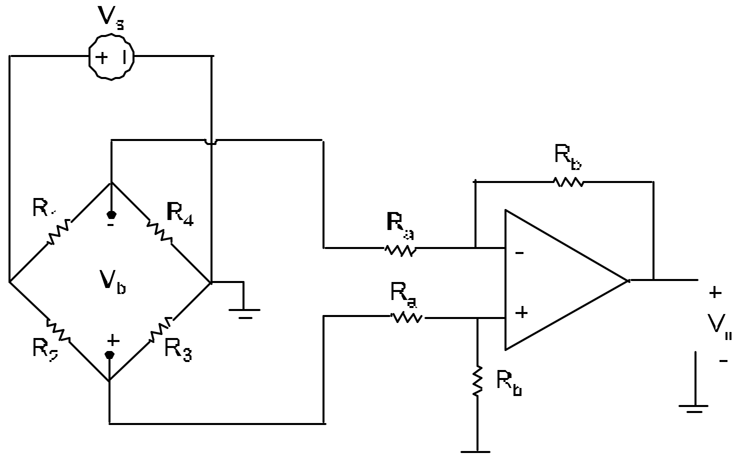

Fig. P9.16

iii) A filtering stage is needed. Design an active ***bandpass*** filtering stage to filter V_0 with ω_L=100 r/s, ω_u=5000 r/s and a gain at resonance of 10. **Use R_{in} = 10kW.**
Neatly add this stage to the above schematic.

iii) Using semilog paper, neatly sketch the straight line Bode magnitude plot for $|V_{out\text{-}bp\ filter}/V_b|$

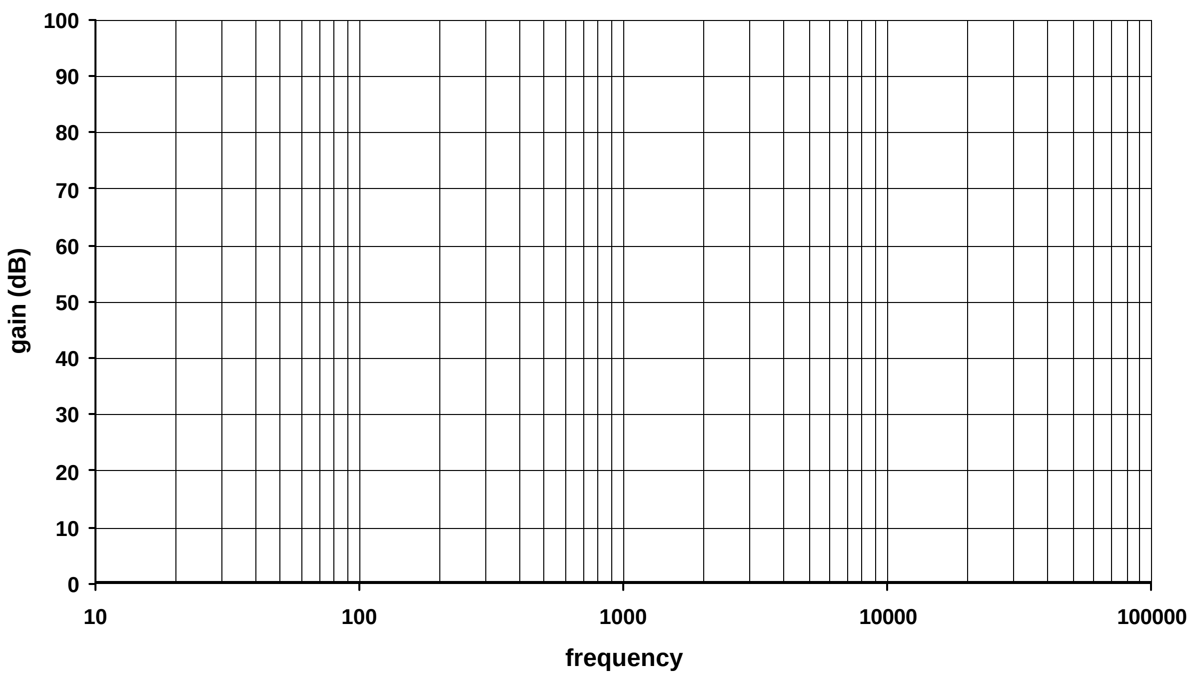

Fig. P9.17

13. i) Design a low-pass filtering stage to the amplifier below so that the ***overall system*** transfer function has a DC gain of 100 and a break frequency of 10000 r/s.
ii) Neatly sketch the LP filtering stage in the space provided below. *For the filter use R_f = 100 kW.*

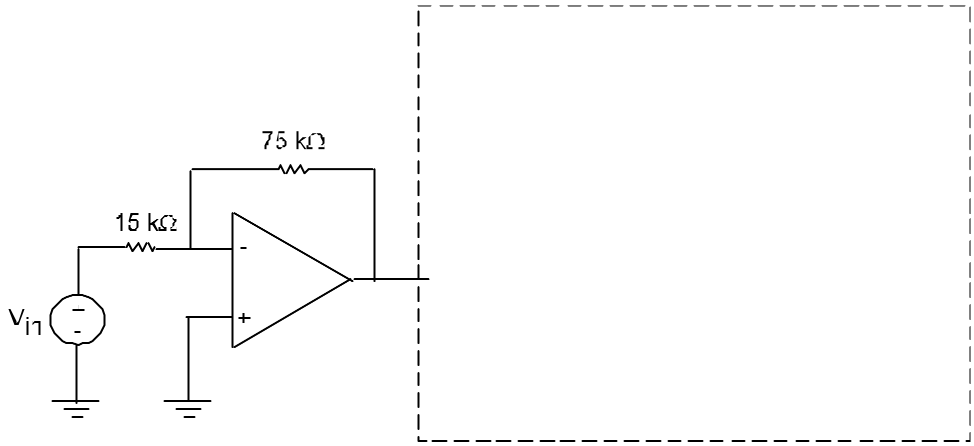

Fig. P9.18

iii) Give the overall transfer function in Bode form.

iv) Using semilog paper, plot the straight-line Bode magnitude plot for the overall system.

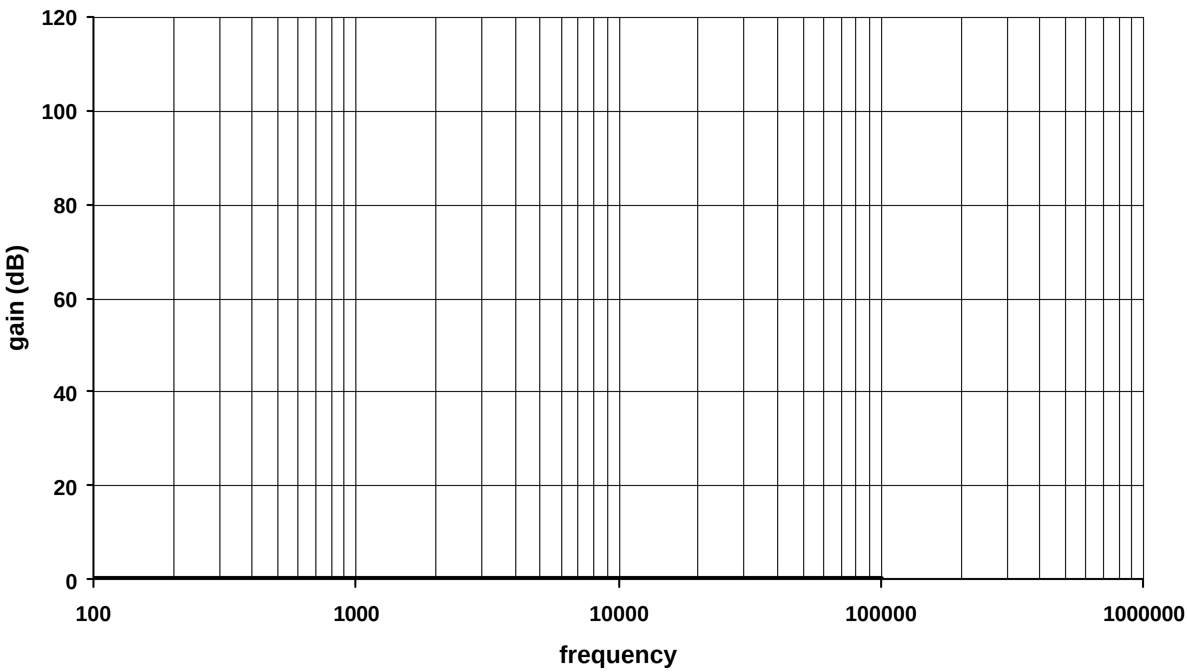

Fig. P9.19

14. A force measurement transducer has a voltage output and has an underdamped 2nd-order response (K_s = 4 mV/N, ζ = 0.2, ω_n = 100 r/s).

$$\frac{1}{w_n^2}\frac{d^2v}{dt^2} + \frac{2z}{w_n}\frac{dv}{dt} + v = K_s$$

Use phasor analysis to determine the actual steady-state force, f(t), when the measured steady-state voltage is v*(t) = [20 + 50 cos (150t)] mV.*

Hint: Review system dynamics.

15. The TC voltage plot below results when a thermocouple sensing junction, at t=4 seconds, is transferred from a temperature of 20°C to 100°C. (*For a temperature of 0°C, the steady-state voltage is 0V*)

Given that the TC behaves as a 1st-order system, extract the system parameters and give the differential equation that relates the input TC temperature and output TC voltage.

$$t\frac{dv}{dt} + v = K_s T$$

Hint: Review system dynamics.

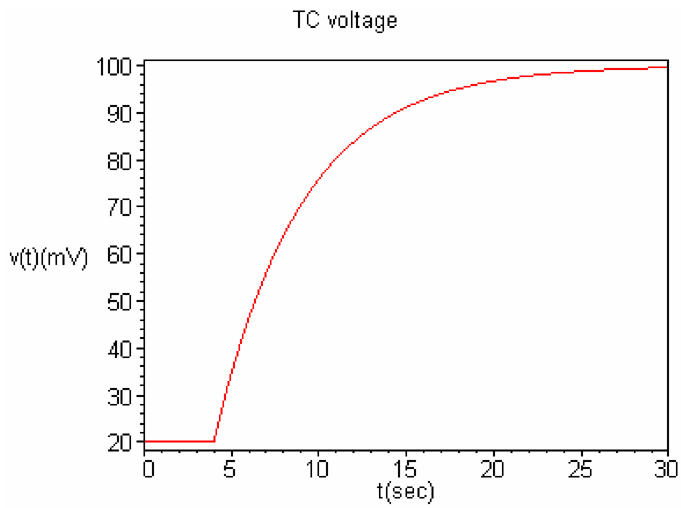

Fig. P9.20

16. A thermocouple is used to measure temperature. The output voltage for T=0°C is 0V. The plot below is taken as the thermocouple is taken from 400°C to 0°C at t=2s. Assume the TC behaves as a 1st-order system.

$$t\frac{dv}{dt} + v = K_s T$$

i) Find the approximate differential equation relating input temperature to thermocouple voltage. Identify the time constant, τ, and the static gain coefficient, K.
Don't forget units.

ii) For the same thermocouple, give the thermocouple voltage, in steady-state, if its surrounding temperature, in °C, is T = 400 + 20 cos t.

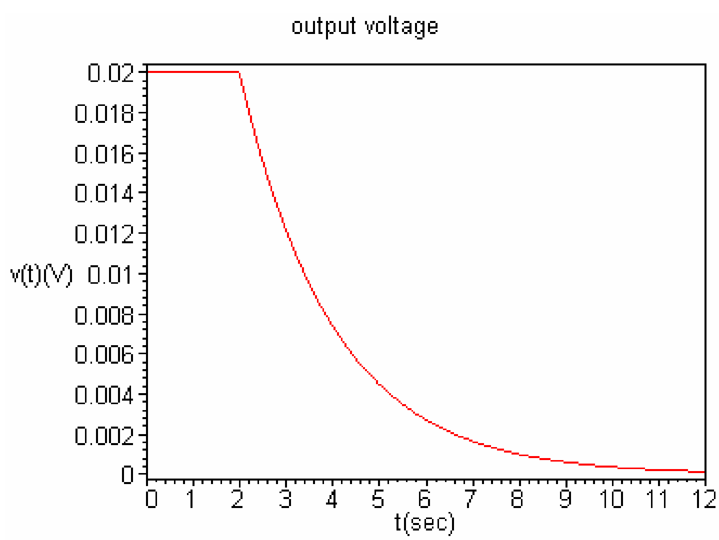

Fig. P9.21

17. i) Find the transfer function, V_o/V_S, of the circuit shown below.
    ii) Sketch the Bode magnitude plot for the circuit shown below given R_1 = 1 kΩ, R_2 = 100 Ω, C = 0.1 μF, and L = 10 μH.
    iii) What is $v_o(t)$, in steady-state, given $v_S(t) = 10 \cos 10^4 t$ V.
    iv) What is $v_o(t)$, in steady-state, given $v_S(t) = 10 \cos 10^6 t$ V.
    v) What is $v_o(t)$, in steady-state, given $v_S(t) = 10 \cos 10^8 t$ V.

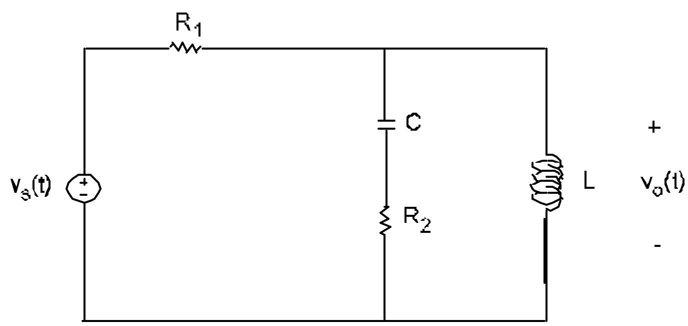

Fig. P9.22

17. Let V_S be a sinusoidal signal (2 V amplitude, with a frequency of 4000 r/s) corrupted by high frequency noise (1 V amplitude, frequency 32 kr/s).

    i) What is the signal-to-noise ratio of V_S.
    ii) Design an active first-order low-pass filter using an op-amp in the inverting configuration. Let the low-frequency gain be 1 and the break frequency be 8000 r/s. Use R_{in} = 10 kΩ.
    iii) If V_S is input to the op-amp circuit design in ii), what is the signal-to-noise ratio at the output?
    iv) Design an active second-order Sallen-Key low-pass filter. Let the low-frequency gain be 1 and the break frequency be 8000 r/s. Choose $\zeta = 0.7$.
    v) If V_S is input to the op-amp circuit in iv), what is the signal-to-noise ratio at the output?
    vi) Compare the filtering effectiveness of the 1st-order filter to the 2nd-order filter.

18. Let V_S be a sinusoidal signal (2 V amplitude, with a frequency of 5 kHz) corrupted by low frequency noise (1 V amplitude, frequency 60 Hz) and by high frequency noise (5 V amplitude, frequency 40 kHz).

    i) Design an active Sallen-Key band-pass filter. Let the center frequency be 5 kHz and let the quality factor be 10. Choose R = 10 kΩ.
    ii) Let V_S be input to the circuit designed in i). Compare the signal-to-noise ratios at the input to those at the output.

19. Let V_s be a sinusoidal signal (2 V amplitude, with a frequency of 5 kHz) corrupted by low frequency noise (1 V amplitude, frequency 60 Hz) and by high frequency noise (5 V amplitude, frequency 40 kHz).

    i) Design an active Sallen-Key band-pass filter. Let the center frequency be 5 kHz and let the quality factor be 10. Choose R = 10 kΩ.
    ii) Let V_s be input to the circuit designed in i). Compare the signal-to-noise ratios at the input to those at the output.

20. Let V_s be a sinusoidal signal (2 V amplitude, with a frequency of 6 kHz) corrupted by low frequency noise (1 V amplitude, frequency 60 Hz) and by high frequency noise (5 V amplitude, frequency 40 kHz).

    i) Design an active band-pass filter as described in Design Example 6.7.1. Let f_b = 1.5 kHz, f_u = 12 kHz, and the passband gain = 2. Choose R_{in} = 100 kΩ.
    ii) Let V_s be input to the circuit designed in i). Compare the signal-to-noise ratios at the input to those at the output.

21. For each of the areas below, discuss the associated limitations of op-amps.
    i) Current limitations of op-amps. What limits does this place on the resistances connected at the output of op-amps?
    ii) Limits for op-amp output voltages.
    iii) Limits associated with finite op-amp gain-bandwidth products.
22. i) Design an inverting amplifier, shown in Fig. with a |gain| of 10. Use R_{in} = 7.5 kΩ.
    ii) Given V_{cc} = 9 V, sketch V_o given the input is a 1 kHz triangle wave with a peak-to-peak amplitude of ½ V.
    iii) Given V_{cc} = 9 V, sketch V_o given the input is a 1 kHz triangle wave with a peak-to-peak amplitude of 2 V.
    iv) Given V_{cc} = 15 V, sketch V_o given the input is a 1 kHz sinusoid with an RMS voltage of 5 V.

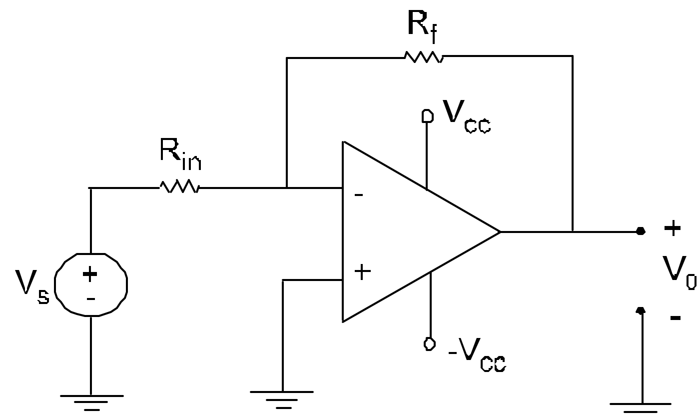

Fig. P9.23

23. Using the amplifier shown in Fig. , which shows the model accounting for finite gain-bandwidth product and non-ideal input-output op-amp resistances, determine $v_o(t)$ and the |gain| for the following frequencies.

i) DC (f = 0)
ii) f = 1000 Hz
iii) f = 10 kHz
iv) f = 100 kHz
v) f = 1 MHz

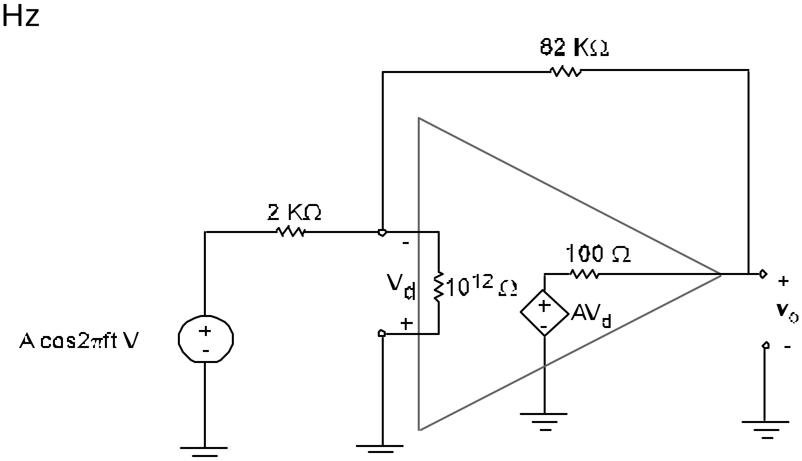

Fig. P9.24

24. Find $v_o(t)$ and the signal-to-noise ratio (the noise is the high frequency component) at the output. Design a first-order low-pass filter having a DC gain of 25 and a break frequency of 2ω. Use the ideal op-amp model and choose R_{in} = 10 kΩ.

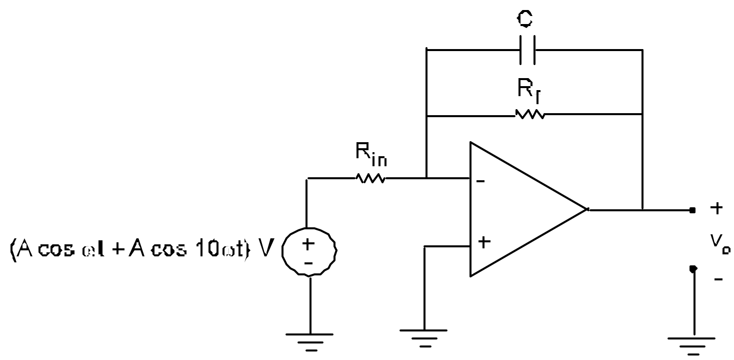

Fig. P9.25

i) DC (ω = 0)
ii) ω = 1000 r/s
iii) ω = 10 kr/s
iv) ω = 100 kr/s
v) ω = 1 Mr/s
vi) ω = 10 Mr/s

Now, using the component values determines in i) – iv), and using the amplifier model shown in Fig. , which accounts for finite gain-bandwidth product and non-ideal input-output op-amp resistances, determine $v_o(t)$ and the signal-to-noise ratio at the output for the same values of ω.

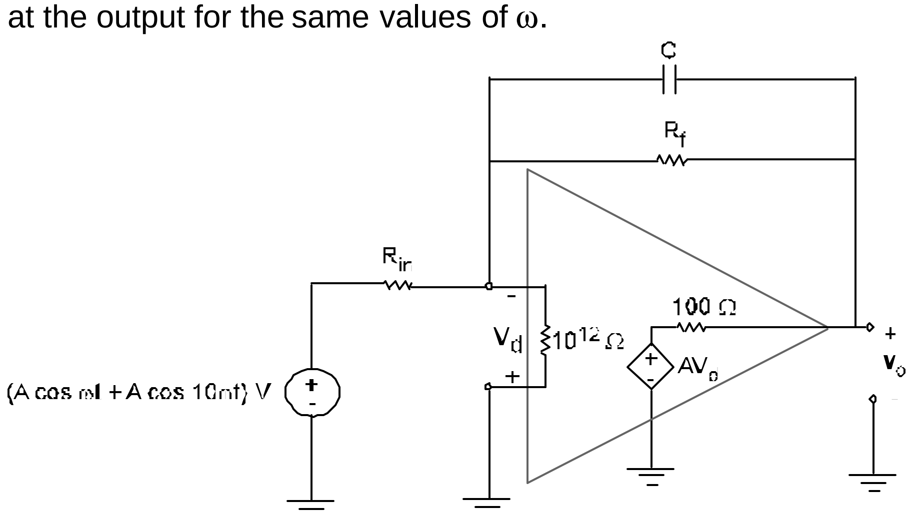

Fig. P9.26

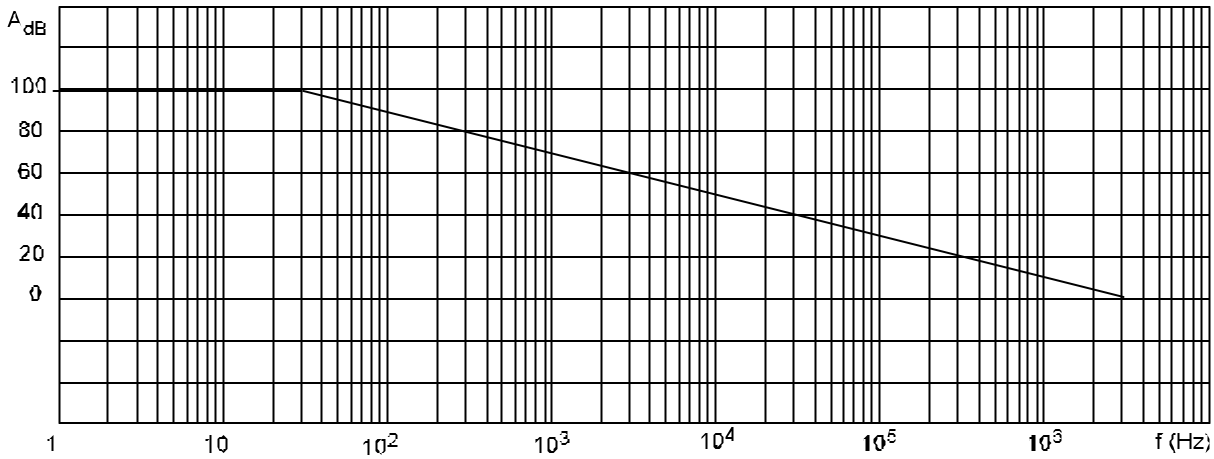

Fig. P9.27