

# ANALOG CIRCUITS : PROBLEM SET 6

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## Problem 1

This problem is intended to illustrate the effect of voltage-series feedback on the input and output impedances of an amplifier. The model to be used for the opamp is shown in Figure 1. Assume that  $k = 10000$ ,  $R_{ia} = 10\text{ K}\Omega$ ,  $R_{oa} = 1\text{ K}\Omega$ .

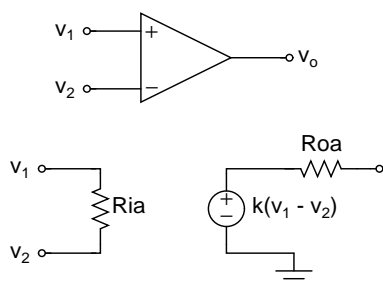


Figure 1: Opamp Model with input and output resistances

An amplifier is built using the above opamp, as shown in Figure 2.

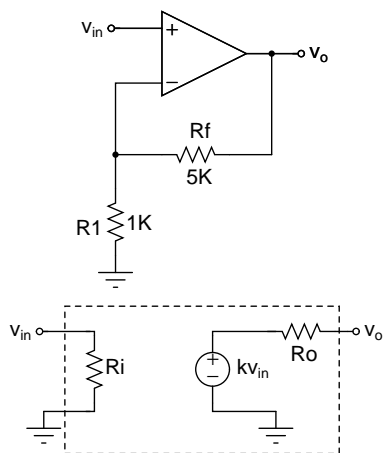


Figure 2: Model for the closed loop amplifier.

The closed loop amplifier is represented as shown in the lower part of the figure. Compute the input resistance, output resistance and gain of the closed loop amplifier. Since you will be doing this for many values of  $R_f$  and  $R_1$ , compute the required quantities in terms of  $R_{ia}$ ,  $R_{oa}$ ,  $k$ ,  $R_f$  and  $R_1$ .

- Does the closed loop gain depend on  $R_{ia}$  and  $R_{oa}$  ? What does this reduce to when  $R_{ia} \rightarrow \infty$  and  $R_{oa} \rightarrow 0$  ?
- Find the input and output resistances of the closed loop amplifier. What do you observe ? Can you intuitively justify your results ?

- Repeat the above calculations for  $R_f = 50\text{ K}\Omega$  and  $R_1 = 10\text{ K}\Omega$ . What do you notice ?
- Repeat the same calculations for  $R_f = 500\text{ K}\Omega$  and  $R_1 = 100\text{ K}\Omega$ . What happens now?
- Based on the answers to the questions above, what can you say about choosing the feedback resistor values ?

## Problem 2

For the circuit shown in Figure 3, determine  $R_{in}$ . Assume an ideal operational amplifier.

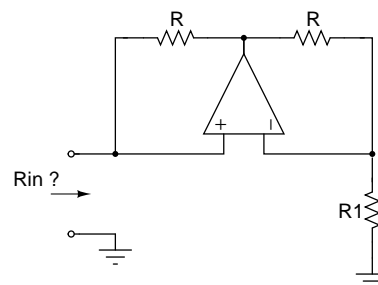


Figure 3: Find  $R_{in}$

## Problem 3

In the circuits shown in Figure 4, determine the signs of the opamp input terminals to ensure negative feedback operation.

## Problem 4

A loop gain function is of the form  $\frac{A_o}{(1 + \frac{s}{\omega_1})(1 + \frac{s}{2\omega_1})(1 + \frac{s}{6\omega_1})}$ . Using the approach discussed in class, find the permissible range of  $A_o$  for the closed loop system to be stable.

## Problem 5

In class, we saw that if we took a circuit ( consisting of resistors and ideal operational amplifiers ) with a gain  $G1$ , and interchanged the input and ground connections, we obtained a circuit with a gain of  $(1 - G1)$ . The purpose of this problem is to examine if this is true of circuits with nonideal operational amplifiers. To make matters simple, assume that the only nonideality of the opamp is its finite gain. Find the gains of the circuits in Figure 5. Is their sum unity ? If not, what is the difference ?

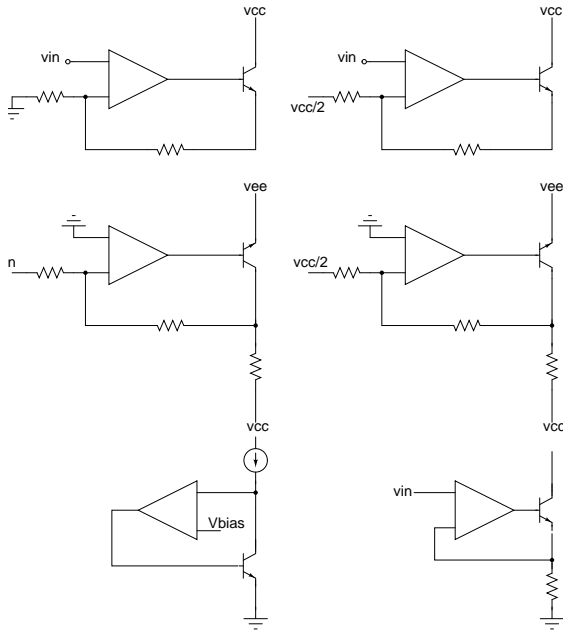


Figure 4: What are the signs of the opamp inputs ?

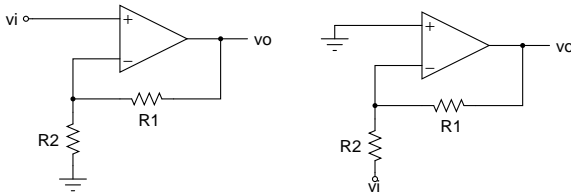


Figure 5: Input and ground as complements

### Problem 6

This problem discusses bandwidth in cascaded amplifiers. The topology of the basic amplifier stage is shown in Figure 6, where the only deviation of the operational amplifier from the ideal is its frequency dependent gain, given by  $\frac{A_o}{1 + \frac{s}{\omega_d}}$ . Further, assume  $A_o$  is very large compared to unity, and denote the product  $A_o\omega_d$  by  $GB$ .

- It is desired to realize an amplifier with a gain of  $k$ . This could be done using one amplifier stage like that shown in the figure, or by cascading  $n$  such stages, each with a gain of  $k^{1/n}$ . Find an expression for the bandwidth of the realized amplifier as a function of  $n$ . For a given  $k \gg 1$ , is there an optimum value of  $n$  ?
- Specifically, for  $n = 2$  evaluate the amplifier bandwidth. Consider now another way of realizing the amplifier

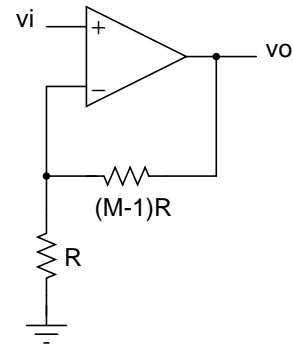


Figure 6: Basic Amplifier Stage

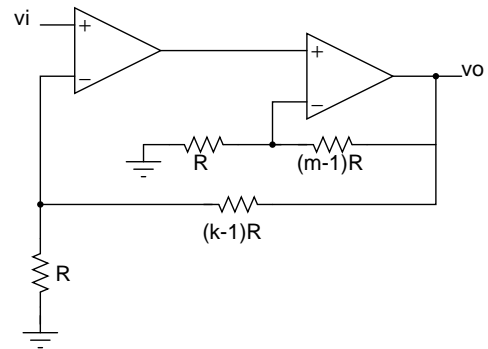


Figure 7: Amplifier with overall feedback

- this topology uses overall feedback, rather than cascading two identical stages with local feedback and is shown in Figure 7. Notice that we still use 2 opamps and 4 resistors. First, find the transfer function, assuming the same opamps as in the previous part. What should the value of  $m$  be, to assure a Butterworth response for the overall amplifier ? What is the bandwidth for this specific value of  $m$  ? How does this compare with the bandwidth of the cascade ?

### Problem 7

This problem illustrates the bandwidth penalty associated with inverting a signal. Both amplifiers are shown in Figure 8. Assuming nonideal opamps of the kind in Problem 1, find the respective bandwidths. Which amplifier has a higher bandwidth ? At what values of  $M$  is the difference in bandwidth more pronounced ?

### Problem 8

A *voltage regulator* which you use to generate necessary DC supplies in a laboratory is usually designed as shown in Figure 9. The output DC voltage is approximately  $M V_{ref}$ . The opamp has a frequency dependent gain, given by  $\frac{A_o}{(1 + \frac{s}{\omega_{d,reg}})}$ . Denote  $A_o\omega_{d,reg}$  by  $GB_{reg}$ .

- Find the output impedance of the regulator as a function of frequency. Can this impedance be modelled using lin-

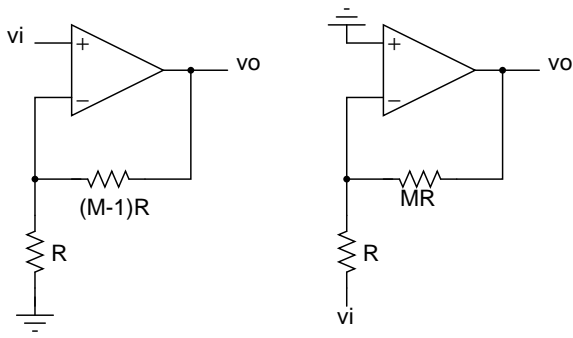


Figure 8: Noninverting versus inverting amplifiers.

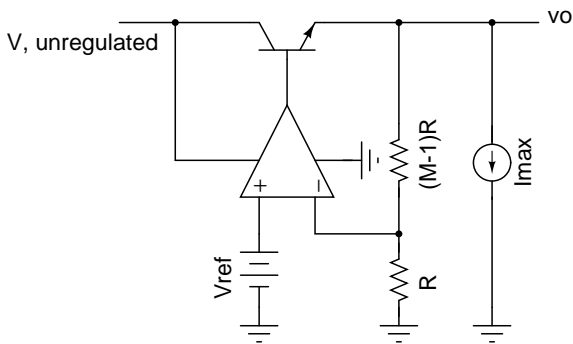


Figure 9: Simplified schematic of a voltage regulator.

ear passive elements? Draw a Thevenin equivalent circuit for the output of the regulator.

### Problem 9

A second order lowpass filter has a transfer function given by  $H(s) = \frac{1}{(\frac{s}{\omega_p})^2 + \frac{s}{\omega_p Q_p} + 1}$ . Assuming  $Q_p > \frac{1}{\sqrt{2}}$ , find the frequency at which maximum transmission occurs, and the value of the  $|H(j\omega)|$  at this frequency.

### Problem 10

A lowpass voltage transfer characteristic is desired, as shown in Figure 10.  $|H_{min}| = 10$  and  $|H_{max}| = 10.5925$ . Determine the required  $H(s)$  in terms of  $\frac{s}{\omega_c}$ , with the constant in the denominator polynomial set to one. The transfer function is to be realized using the circuit shown in Figure 11. Identify which of the three outputs gives the response wanted. Determine  $RC$ ,  $b$  and  $a$ .

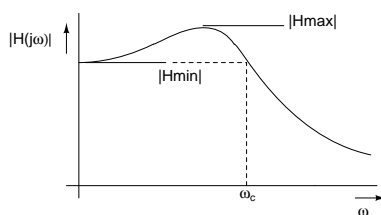


Figure 10: Desired voltage transfer characteristic.

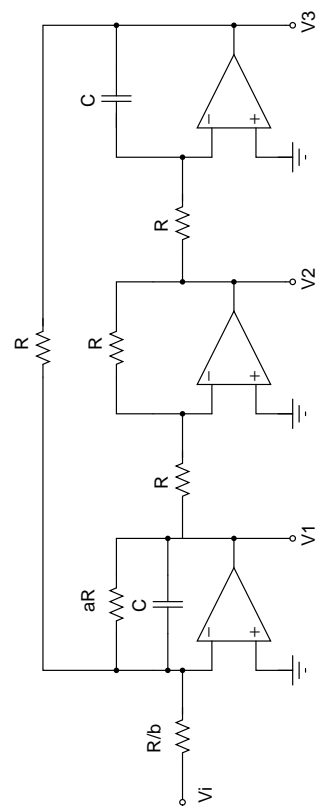


Figure 11: Filter topology.