Homework 3

Thursday, October 17, 2024 4:24 PM

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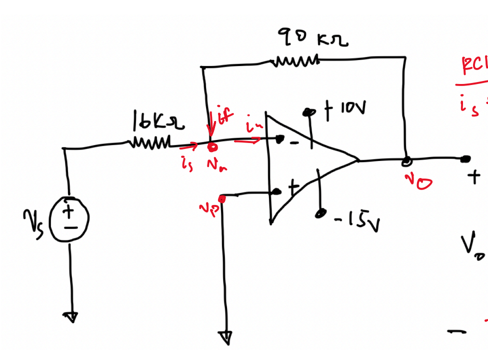
ECE 2040 Homework 3

Due Date: October 31st, 2024

Topic Covered: Operational Amplifiers

Problem 1. Assume that the op amp in the circuit shown in Fig. 1 is ideal.
1) Calculate V_o for the following values of V_s: $0.4, 2.0, 3.5, -0.6, -1.6$, and -2.4 V.
2) Specify the range of V_s required to avoid amplifier saturation.



KCl @ A

$i_s + i_f - \cancel{i_n} = 0$ (≈ 0)

$i_s + i_f = 0$

$\frac{V_s - V_n}{16k} + \frac{V_o - V_n}{90k} = 0$

$V_n = 0 = V_p$

$\frac{V_s}{16k} + \frac{V_o}{90k} = 0$

$V_o = \left(-\frac{90k}{16k}\right) V_s$

Fig. 1.

1) $V_o = -\frac{90}{\ } \cdot \begin{bmatrix} .4 \\ 2 \end{bmatrix} \rightarrow \begin{bmatrix} -2.25 \\ -11.25 \end{bmatrix}$

1) $V_0 = \quad 16 \begin{bmatrix} 2.5 \\ -.6 \\ -1.6 \\ -2.4 \end{bmatrix} = \begin{bmatrix} -15.0 \\ 3.375 \\ 9.0 \\ 10.0 \end{bmatrix} V \Rightarrow -\frac{R_F}{R_S} \cdot V_S$

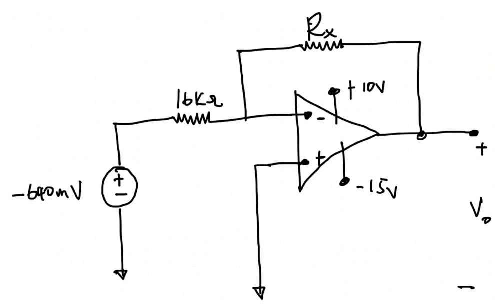
2) Since the max an ideal op amp can amplify is determined by the supply voltges the bounds of V_s are

$$-15 \leq V_0 \leq 10$$

$$-15 \leq 5.625\, V_s \leq 10$$

$$2.67 \geq V_s \geq 1.77\, V$$

Problem 2**.** With a source voltage of -640 mV, what range of R_x allows the inverting amplifier (see Fig. 2) to operate in its linear region?



$$-15 \leq V_0 \leq 10$$

$$-\frac{R_f}{R_S} V_s$$

Fig. 2.

V_0 is bounded by 10 and -15 as that is what its V_{cc+} and V_{cc-} supplies are.

$V_0 \leq 10$ $\qquad V_0 = -\left[\frac{R_f}{R_s}\right] \cdot V_s$

$$+\frac{R_x}{16k}(640\,mV) \leq 10$$

$$\left(\frac{R_x}{16k}\right)(.64) \leq 10 \qquad V_0 = -\left[\frac{R_x}{16k}\right](-.640)$$

$$\boxed{R_x \leq 250k\Omega} \qquad = R_x\left(\frac{.64}{16k}\right)$$

Problem 3**.**

1) Find V_o in the circuit shown below if $V_a = 0.1$ V and $V_b = 0.25$ V.
2) If $V_b = 0.25$ V, how large can V_a be before the op amp saturates?
3) If $V_a = 0.10$ V, how large can V_b be before the op amp saturates?
4) Repeat (a), (b), and (c) with the polarity of V_b reversed.

KCL @ A

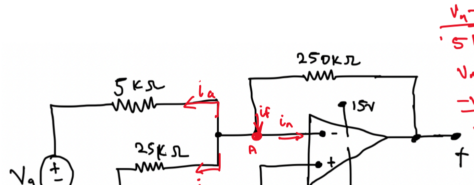
$i_a + i_b + \cancel{i_n}^{0} - i_f = 0$

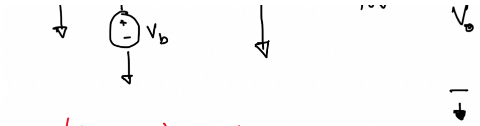
$\frac{V_n - V_a}{5k} + \frac{V_n - V_b}{25k} - \frac{V_0 - V_n}{250k} = 0$

$V_n = 0 = V_p$

$\frac{-V_a}{5k} - \frac{V_b}{25k} - \frac{V_0}{250k} = 0$

$V_0 = \left(\frac{V_a}{5k} + \frac{V_b}{25k}\right)(-250k)$





① $V_0 = \left(\frac{.1}{5k} + \frac{.25}{25k}\right)(-250k)$
$\boxed{= -7.5\ V}$

② $V_0 = \left(\frac{V_a}{5k} + \frac{.25}{25k}\right)(-250k)$

Fig. 3.

$\frac{-10}{-250k} = \left(\frac{V_a}{5k} + \frac{.25}{25k}\right) \Rightarrow V_a = \left(\frac{10}{250k} - \frac{.25}{25k}\right)5k$

$\boxed{V_a = .15\ V\ max}$

③ $V_0 = \left(\frac{.1}{5k} + \frac{V_b}{25k}\right)(-250k)$

$\frac{-10}{-250k} = \left(\frac{.1}{5k} + \frac{V_b}{25k}\right) \Rightarrow V_b = \left(\frac{10}{250k} - \frac{.1}{5k}\right)(25k)$

$\boxed{V_b = .5\ V\ max}$

④ Reversing the polarity of V_b results in the original eqn to be ① $V_0 = \left(\frac{V_a}{5k} - \frac{V_b}{25k}\right)(-250k) \Rightarrow \left(\frac{.1}{5k} - \frac{.25}{25k}\right)(-250k) = \boxed{2.5V}$

② $V_a = \left(\frac{10}{250k} + \frac{.25}{25k}\right)(5k) = \boxed{.25V}$

③ $V_b = \left(\frac{10}{250k} - \frac{.1}{5k}\right)(-25k) = \boxed{-2\ V\ max}$

$\left(\frac{15}{-250k} - \frac{.1}{5k}\right)(+25k) = V_b$

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Problem 4**.** A realistic (non-ideal) non-inverting operational amplifier model has been provided in the Fig. 4.

(a) Express the output voltage V_0 as a function of the source voltage V_g.

(b) Define conditions upon which the relationship between the output voltage and source voltage in this realistic op amp model will be similar to that of the ideal op amp model studied in class.

$i = \frac{V}{R}$

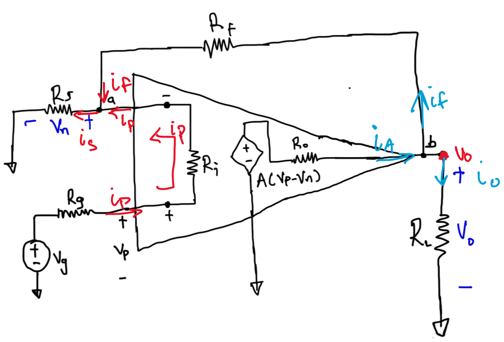

Fig. 4. A non-inverting amplifier circuit

Hint: Note that the input-output voltage relationship for an ideal non-inverting amplifier (as studied in class) can be expressed as:

$$V_0 = \frac{R_s + R_f}{R_s} V_g \qquad (1)$$

KCL @ A

$i_p + i_f - i_s = 0$

$\frac{V_g - V_n}{R_g + R_i} + \frac{V_0 - V_n}{R_f} - \frac{V_n}{R_s} = 0$

$\left(\frac{1}{R_g + R_i}\right)V_g + \left(-\frac{1}{R_g + R_i} - \frac{1}{R_s} - \frac{1}{R_f}\right)V_n + \frac{1}{R_f}V_0 = 0$

$\frac{V_g}{R_g + R_i} + \frac{V_0}{R_f} = \left(\frac{1}{R_g + R_i} + \frac{1}{R_s} + \frac{1}{R_f}\right)V_n \quad (i)$

KCL @ B

$i_a - i_f - i_0 = 0$

$\frac{A(V_p - V_n) - V_0}{R_0} - \left(\frac{V_0 - V_n}{R_f}\right) - \frac{V_0}{R_L} = 0$

$\frac{A(V_p - V_n)}{R_0} + \frac{V_n}{R_f} = \frac{V_0}{R_0} + \frac{V_0}{R_L} + \frac{V_0}{R_f} \quad (ii)$

$V_p - V_g = (V_n - V_g)\left(\frac{R_g}{R_g + R_i}\right) \quad (iii) \rightarrow$ FROM voltage divider

$$V_P = \frac{(V_n - V_g) R_g}{R_g + R_i} + V_g \Rightarrow \frac{V_n R_g - V_g R_g}{R_g + R_i} + V_g \Rightarrow \frac{V_n R_g}{R_g + R_i} - \frac{V_g R_g}{R_g + R_i} + V_g$$

$$\frac{A\left(\left[\frac{(V_n - V_g) R_g}{R_g + R_i} + V_g\right] - V_n\right)}{R_0} + \frac{V_n}{R_f} = \left(\frac{1}{R_0} + \frac{1}{R_L} + \frac{1}{R_f}\right) V_o \quad (\text{IV})$$

By solving for V_n in eqn (IV) we can plug V_n in terms of V_g and Gain A into eqn (i) to solve for V_o in terms of V_g.

$$V_n = \ldots$$

$$\frac{V_g}{R_g + R_i} + \frac{V_o}{R_f} = \left(\frac{1}{R_g + R_i} + \frac{1}{R_s} + \frac{1}{R_f}\right) V_n \quad (i)$$

$$\Rightarrow V_o = \left[\left(\frac{1}{R_g + R_i} + \frac{1}{R_s} + \frac{1}{R_f}\right) V_n - \frac{V_g}{R_g + R_i}\right] R_f$$

$$V_o = \left[\frac{V_n - V_g}{R_g + R_i} + \left(\frac{1}{R_s} + \frac{1}{R_f}\right) V_n\right] R_f$$

$$\boxed{V_o = \frac{(V_n - V_g) R_f}{R_g + R_i} + \frac{R_f}{R_s} V_n + V_n}$$

b) The positive and negative terminals will have no current flowing through them and their voltages will be equal. In other words, R_i must be $> 2\,M\Omega$ and R_o must be very small for this op amp to be considered ideal.