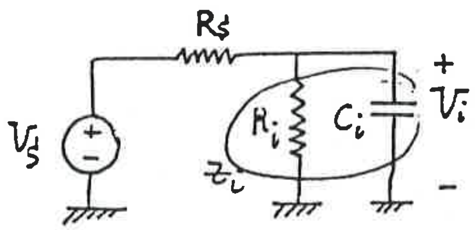
Test 1 - Winter 1995 - M. Cahay

Name: KEY

ELECTRONICS I

January 23, 1995

I. The figure below shows a voltage source connected to the input of an amplifier. R_s is the source resistance. R_i and C_i are the input resistance and input capacitance of the amplifier, respectively. Derive an expression for $V_i(s)/V_s(s)$ and show that it is a low-pass STC type. Find the 3-dB frequency for the case where $R_s = 5k\Omega$, $R_i = 200k\Omega$, and $C_i = 20pF$. (25 pts).



5pts $\frac{V_i}{V_s} = \frac{Z_i}{R_s + Z_i}$

Z_i? $\quad Y_i = \frac{1}{R_i} + sC_i = \frac{1 + sR_iC_i}{R_i}$

$$Z_i = \frac{1}{Y_i} = \frac{R_i}{1 + sR_iC_i}$$

$$\frac{V_i}{V_s} = \frac{R_i}{1 + sR_iC_i} \cdot \frac{1}{\left[R_s + \frac{R_i}{1 + sR_iC_i}\right]}$$

5pts

$$\frac{V_i}{V_s} = \frac{R_i}{R_s + R_i + sR_iR_sC_i} = \frac{R_i/R_s + R_i}{1 + \frac{sR_iR_sC_i}{R_s + R_i}} = \frac{K}{1 + \frac{s}{\omega_b}}$$

$$\boxed{\omega_b = \frac{R_s + R_i}{R_iR_sC_i} = \frac{1}{(R_i//R_s)C_i}}$$ 10pts

$R_s = 5k\Omega$

$R_i = 200k\Omega$

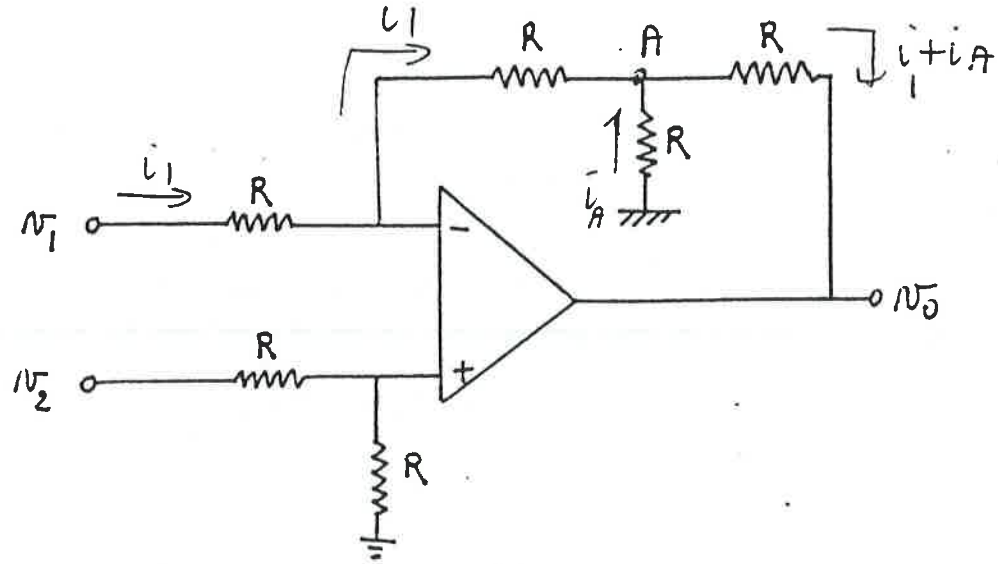
$C_i = 20pF$

$$\omega_b = \frac{205k\Omega}{200k\Omega\, 5k\Omega\, 20pF} = \frac{205}{20{,}000\ 10^3\ 10^{-12}}$$

$$f_b = \frac{205}{20{,}000} 10^9 \frac{1}{2\pi} = 1.63\ 10^6 Hz$$

$$\boxed{f_b = 1.63 MHz}$$ 5pts

II. In the diagram below the op-amp is assumed to be ideal and all resistors are assumed to be equal to 1Ω for simplicity. Find an expression of v_0 in terms of v_1 and v_2. Hint: Use the principle of superposition. (30pts)



$\boxed{A=\infty}$

(I) Solution

$v_+ = \frac{v_2}{2}$

$v_- = v_+ = \frac{v_2}{2}$

$i_1 = \frac{v_1 - \frac{v_2}{2}}{1} = v_1 - \frac{v_2}{2}$

at A: $v_A = v_- - R i_1 = \frac{v_2}{2} - v_1 + \frac{v_2}{2} = v_2 - v_1$

$i_A \overset{?}{=}$ $\quad \frac{-v_A}{R} = i_A = v_1 - v_2$

$\rightarrow v_0 = v_A - R[i_A + i_1] = v_2 - v_1 - [v_1 - v_2 + v_1 - \frac{v_2}{2}]$

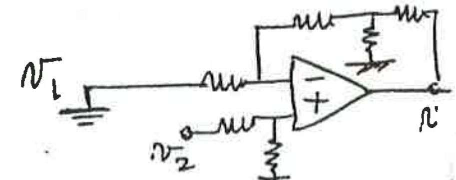
$\boxed{v_0 = v_2 - v_1 - [2v_1 - \frac{3}{2}v_2] = \frac{5}{2}v_2 - 3v_1}$

(II) Principle of Superposition (Solution)

$v_2 = 0$ $\rightarrow v_+ = v_- = 0 \rightarrow i_1 = v_1 \rightarrow v_A = -v_1$

$\rightarrow i_A = v_1$

$\rightarrow v_{01} = -v_1 - 2v_1 = -3v_1$



$v_1 = 0$ $\rightarrow v_+ = v_- = \frac{v_2}{2} \Rightarrow i_1 = -\frac{v_2}{2}$

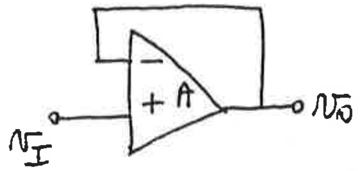
$\Rightarrow v_A = \frac{v_2}{2} + \frac{v_2}{2} = v_2$

$\Rightarrow i_A = -v_2$

$\rightarrow v_{02} = v_A - R(i + i_A) = v_2 - \left(\frac{-3v_2}{2}\right) = \frac{5}{2}v_2$

$\rightarrow \boxed{v_0 = v_{01} + v_{02} = \frac{5}{2}v_2 - 3v_1}$

IV. Consider a voltage follower (buffer amplifier) built with an ideal op-amp except for having a finite voltage gain A. Calculate the value of the close-loop gain for A=10,100, and 1000. In each case calculate the % error in gain magnitude compared to the gain obtained with an ideal op-amp. (15pts).



$$\left.\begin{array}{l} v_o = A(v_I - v_-) \\ v_- = v_O \end{array}\right\} \rightarrow \frac{v_O}{A} = v_I - v_O$$

or

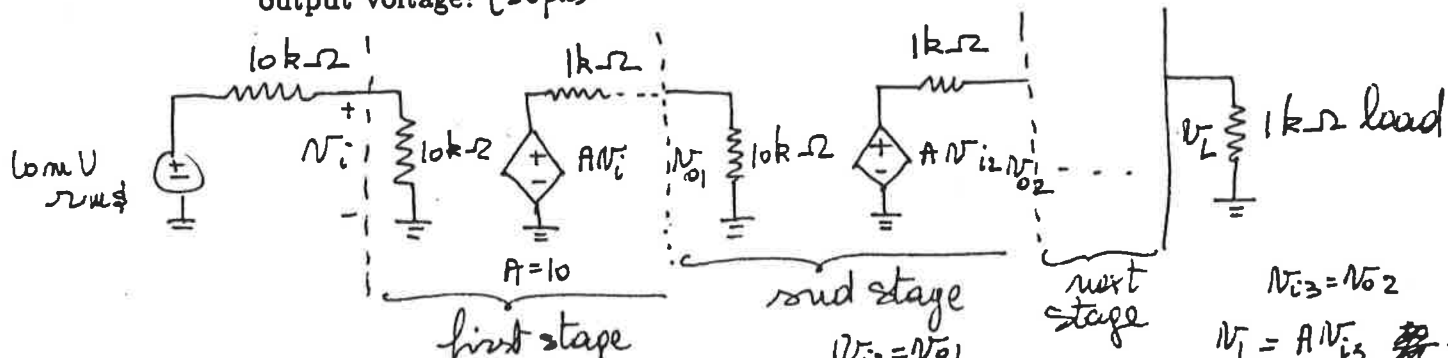
$$v_o\left[1+\frac{1}{A}\right] = v_I$$

Close-loop Gain $\longrightarrow$ $\boxed{G = \frac{v_O}{v_I} = \frac{1}{\left[1+\frac{1}{A}\right]}}$

A	$G(A=\infty)$	G	% error
10	1	0.909	9.1%
100	1	0.990	1%
1000	1	0.999	0.1%

$$\%\ \text{error} = \left|\frac{G - G(A=\infty)}{G(A=\infty)}\right| = \left|\frac{\frac{1}{1+\frac{1}{A}} - 1}{1}\right| = \frac{1}{A}\,\frac{A}{A+1} = \frac{1}{1+A}$$

III. A designer has available voltage amplifiers having an input resistance of $10k\Omega$, an output resistance of $1k\Omega$, and an open-circuit voltage gain of 10. The signal source has a $10k\Omega$ resistance and provides 10 mV rms signal. If it is required to provide a signal of at least 2V rms to a $1k\Omega$ load, how many amplifier stages are required? For this number of amplifiers, what is the actual output voltage? (30pts)



$v_{i3} = v_{o2}$

$v_L = A v_{i3} \cdot \frac{1}{2}$

$v_{i2} = v_{o1}$

$v_{o2} = A v_{i2} \frac{10}{11}$

$v_{o1} = A v_i \frac{10k\Omega}{11k\Omega}$

$v_i = \frac{10}{20} v_s = \frac{v_s}{2}$

$v_{o2} = A v_{o1} \frac{10}{11}$

$$v_L = \frac{A}{2} v_{i3} = \frac{A}{2} v_{o2} = \frac{A^2}{2} v_{o1} \frac{10}{11} = \frac{A^3}{2} v_i \left(\frac{10}{11}\right)^2$$

$$v_L = \frac{A^3}{2}\left(\frac{10}{11}\right)^2 \frac{v_s}{2}$$

$$v_L = \frac{1}{2} A^n \left(\frac{10}{11}\right)^{n-1} \frac{v_s}{2} \quad \text{where } n = \text{\# of stages}$$

we want

$$\frac{v_L}{v_s} = \frac{2}{10m} = 200 = \frac{1}{2} A^n \left(\frac{10}{11}\right)^{n-1} = \frac{1}{2}\frac{10^n\, 10^{n-1}}{11^{n-1}} = \frac{11}{20}\frac{10^{2n}}{11^n}$$

$$\frac{v_L}{v_s} = 200 = \frac{11}{20}\left(\frac{100}{11}\right)^n \Rightarrow \boxed{\text{solve for minimum } n \text{ needed}}$$

$$\left(\frac{100}{11}\right)^n = \frac{4000}{11} = 363.6$$

$\Rightarrow$ for $n=3$, $\left(\frac{100}{11}\right)^n = 751$
for $n=2$, $\left(\frac{100}{11}\right)^2 = 83$
$\Big\}\rightarrow$ 3 stages needed

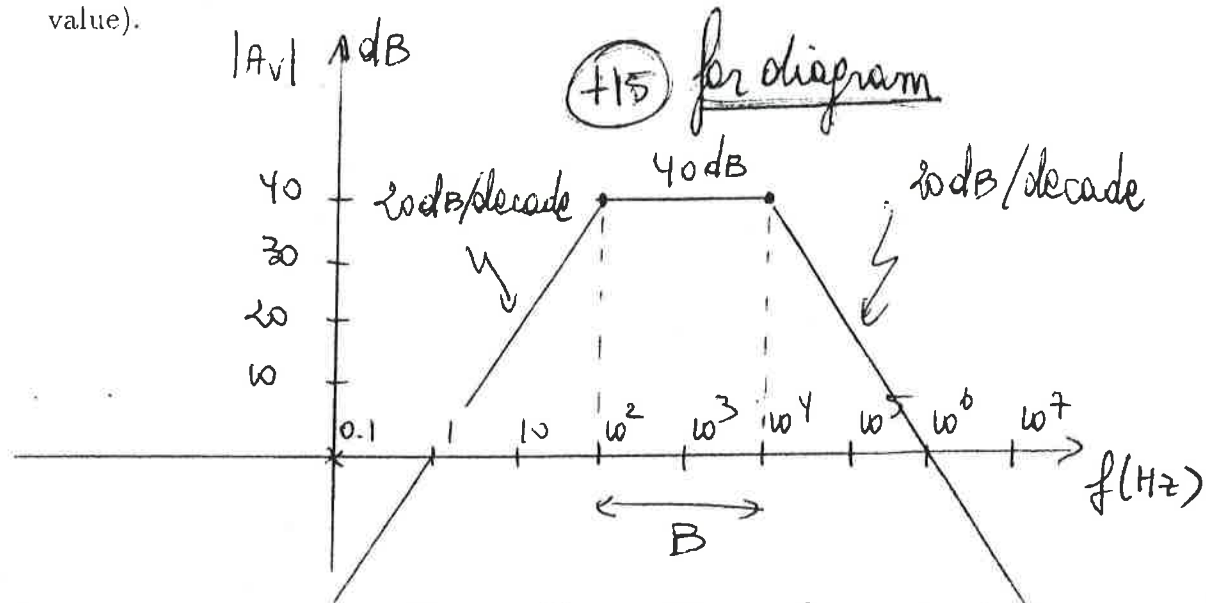
Test 1 - Fall 1997 (100pts max) - M. Cahay
Name:

ELECTRONICS I
October 14, 1997

I. (25 pts) A voltage amplifier has the transfer function

$$A_v = \frac{100}{(1 + \frac{jf}{10^4})(1 + \frac{10^2}{jf})} \tag{1}$$

Using the Bode plots for low-pass and high-pass filters, sketch the Bode plot for $|A_v|$. Give approximate values for the gain amplitude at f = 10, 10^2, 10^3, 10^4, 10^5, 10^6, and 10^7 Hz. Find the bandwidth of the amplifier (defined as the frequency range over which the gain remains within 3 dB of the maximum value).



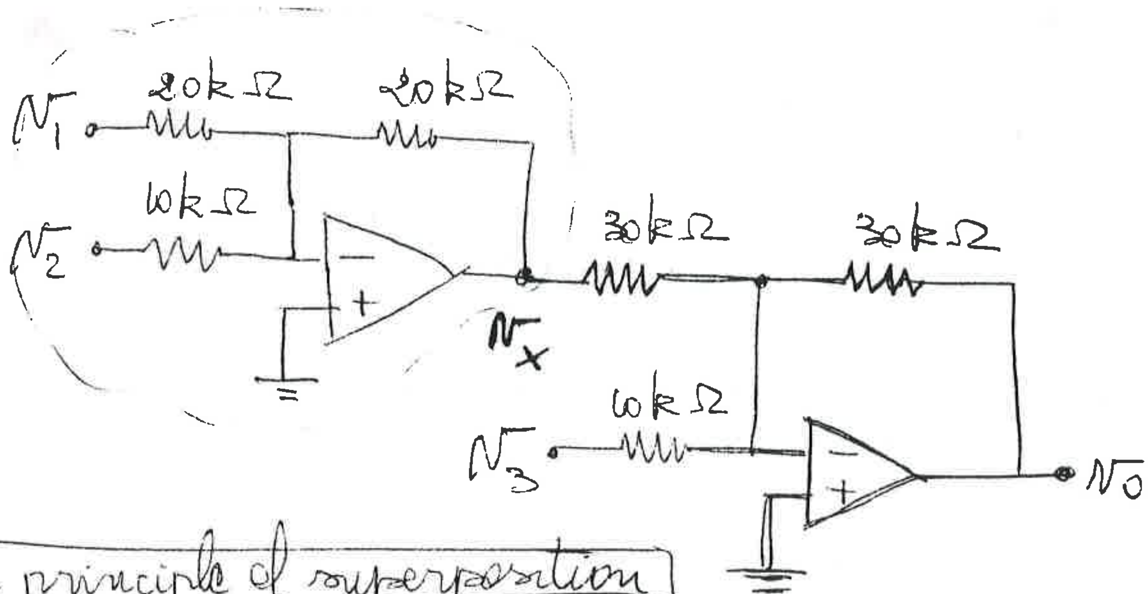
f =	10	10^2	10^3	10^4	10^5	10^6	10^7 (Hz)
$\lvert A_v \rvert$ =	20 +1	40 +1 (37dB)	40+1	40 +1 (37dB)	20+1	0+1	−20 +1

Better approximation

+3

Bandwidth $B = 10^4 - 10^2 =$ 9900 Hz

Calculate v_o in terms of v_1, v_2, v_3 for the circuit below. Assume ideal op-amps.



Use principle of superposition

$$v_x = -v_1 - 2v_2$$

$$v_o = -(-v_1 - 2v_2) - 3v_3$$

$$\boxed{v_o = v_1 + 2v_2 - 3v_3}$$

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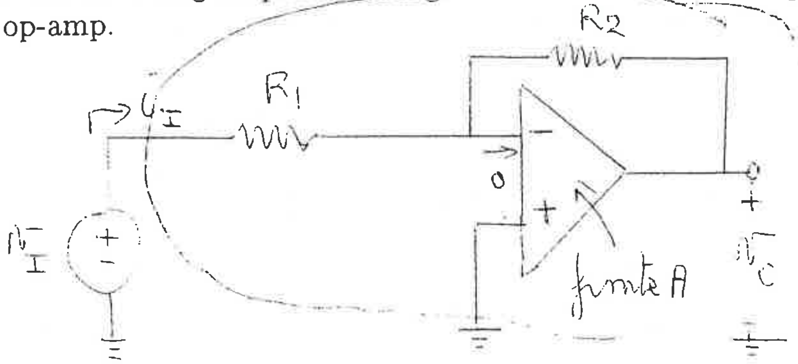
IV. (25 pts) For the circuit shown below, derive an expression for the input resistance of the inverting amplifier taking into account the finite open-loop gain of the op-amp.

$R_{in} = \frac{v_I}{i_I}$



$v_O = A(v_+ - v_-)$; $v_+ = 0$

$\Rightarrow v_O = -A v_-$ +5

$= v_- - i_I R_2$ +5

$\Rightarrow i_I R_2 = (A+1) v_-$

$\Rightarrow v_- = i_I R_2/(1+A)$ +5

Now, $v_I = i_I R_1 + v_-$

$= i_I R_1 + \frac{i_I R_2}{A+1}$ +7

$$\Rightarrow \boxed{R_{in} = \frac{v_I}{i_I} = R_1 + \frac{R_2}{A+1}}$$ +3

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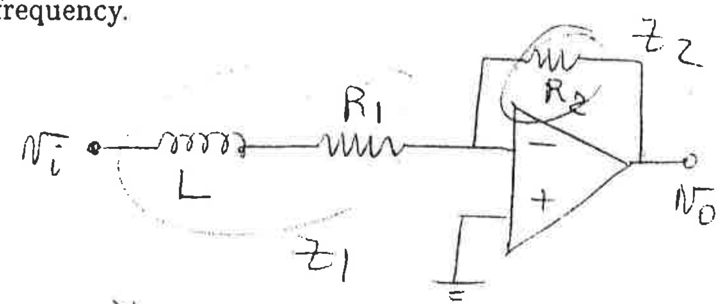
IV. (25 pts) For the circuit below, calculate the transfer function T(s) = $v_0(s)/v_i(s)$. Is it of the low-pass or high-pass type? Give an expression for the 3 dB frequency.



$$\frac{v_o}{v_i} \overset{+5}{=} \frac{-R_2}{R_1 + j\omega L} = \frac{-R_2/R_1}{1 + j\omega\frac{L}{R_1}} = \frac{-R_2/R_1}{1 + \frac{s}{(R_1/L)}} \quad +5$$

$$\Rightarrow \quad K = -R_2/R_1 \quad (+5)$$

$$\omega_{3dB} = R_1/L \quad (+5)$$

$\boxed{\text{Low-pass filter}}$ (+5)

III. (25 pts) For the circuit shown below, find v_o in terms of v_1 and v_2 assuming an ideal op-amp. For

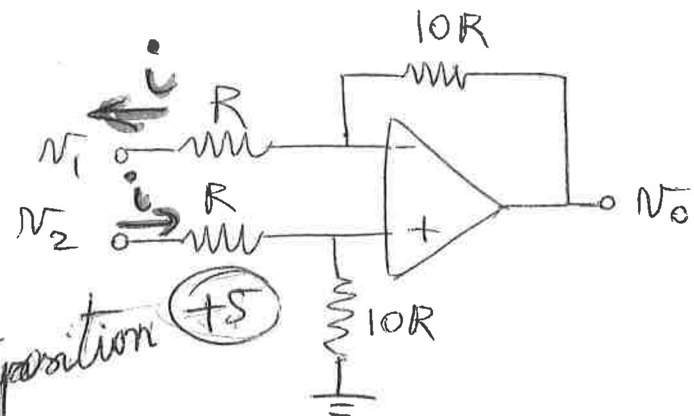
$$v_1 = 10sin(2\pi X60t) - 0.1sin(2\pi X1000t), volts \tag{2}$$

and

$$v_2 = 10sin(2\pi X60t) + 0.1sin(2\pi X1000t), volts \tag{3}$$

Find v_O.

Find the input resistance seen by the differential input signal $v_2 - v_1$.



principle of superposition +5

$$\boxed{\begin{array}{l} v_2 = 0 \\ v_1 = 0 \end{array}}$$

$v_2 = 0 \rightarrow v_{o1} = -10 v_1$ +5

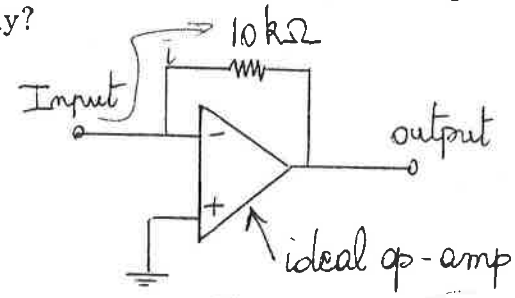
$v_1 = 0 \rightarrow v_{o2} = \underbrace{v_2\left(\frac{10R}{R+10R}\right)}_{v_+}\left(1 + \frac{10R}{R}\right) = 10 v_2$ +5

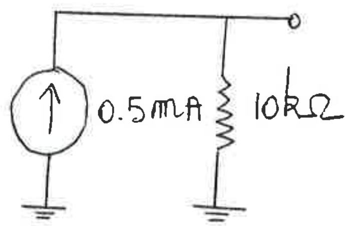
$\rightarrow v_o = v_{o1} + v_{o2} = 10(v_2 - v_1)$ +3

$\Rightarrow \boxed{v_o = 2 \sin(2\pi \times 1000t)}$ +2

$R_{in} = \frac{v_2 - v_1}{i} = 2R$ +5

II. (25 pts) The circuit shown below (left) can be used to implement a transresistance amplifier. Find the value of the input resistance R_i, the transresistance R_m, and output resistance of the transresistance amplifier R_O. If the signal source shown on the right below is connected to the input of the transresistance amplifier, find its output voltage. Does it depend on the load resistance? Why?

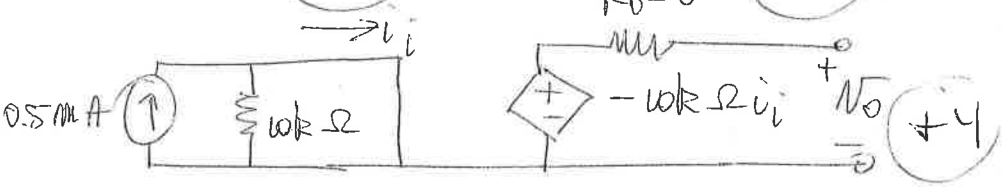




$R_i = \frac{v_i}{i_i} = 0$ +4 $\quad R_O = 0$ +4

$v_O = -10k\Omega\, i_i \Rightarrow R_m = -10\,k\Omega$ +4 +4

$R_O = 0$



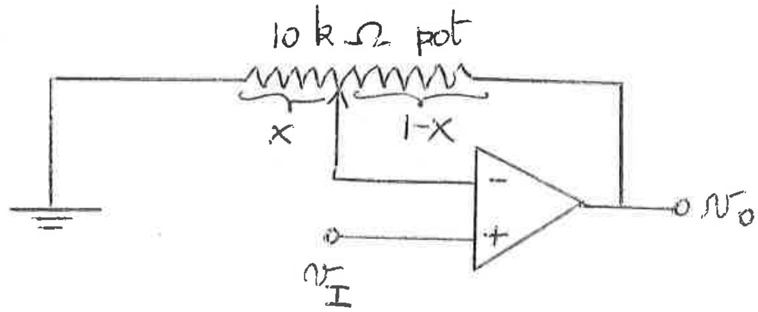
$i_i = 0.5\ mA$

$\Rightarrow \boxed{v_O = -10k\Omega \times 0.5\ mA = -5V}$ +3

v_O does not depend on R_L because $R_O = 0$. +2

EE 351 (Electronics I - Spring 1993 - Final), NAME:

- Problem 1: The circuit shown below utilizes a 10 kiloohms potentiometer to realize an adjustable-gain amplifier. Derive an expression for the gain as a function of the potentiometer setting x. Assume the op amp to be ideal. What is the range of gains obtained? Show how to add a fixed resistor so that the gain range can vary from 1 V/V to 11 V/V. What should the resistor value be?



$\boxed{35}$ Refer to fig. P2.35

$$v_O = v_I \left[1 + \frac{(1-x)\times 10}{x \times 10}\right]$$

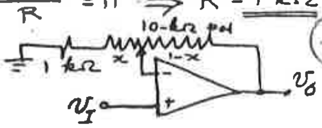
$$= v_I\left(1 + \frac{1}{x} - 1\right) = \underline{v_I / x}$$ (+10)

$$\underline{\frac{v_O}{v_I} = \frac{1}{x}}$$

The gain obtained ranges from +1 to ∞ (+15)

For gain range of +1 to +11, need to add a resistor R to ground end of pot so that with $x = 0$,

$$\text{gain} = 1 + \frac{10\text{ k}\Omega}{R} = 11 \Rightarrow \underline{R = 1\text{ k}\Omega}$$



(+10)

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Final Exam (200 pts: 25 pts each)- Spring 1996 - M. Cahay
Name: KEY

ELECTRONICS I
June 5, 1996

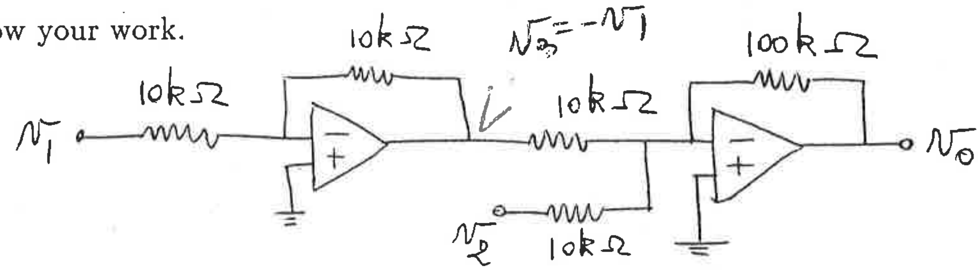
I. In the circuit below, express v_O in terms of v_1 and v_2. Assume the op-amps are ideal. Calculate v_O if

$$v_1 = 3sin(2\pi \times 60t) + 0.01sin(2\pi \times 1000t)Volts, \quad (1)$$

and

$$v_2 = 3sin(2\pi \times 60t) - 0.01sin(2\pi \times 1000t)Volts. \quad (2)$$

Show your work.



$v_2 = 0$ $\quad v_{o1} = -10 v_3 = 10 v_1$

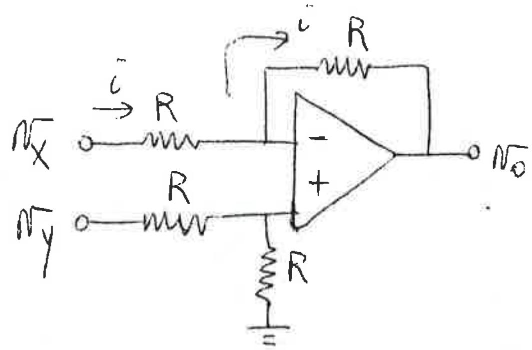
$v_1 = 0 = v_3$ $\quad v_{o2} = -10 v_2$

$v_o = v_{o1} + v_{o2} = -10(v_3 + v_2) = 10(v_1 - v_2)$

$v_1 - v_2 = +0.02 \sin(2\pi \times 1000t)$

$\longrightarrow \boxed{v_o = +0.2\,V \sin(2\pi \times 1000t)}$

III. (25 pts) In the circuit below, the op-amp is ideal except that it has a finite A. Express v_0 in terms of v_X, v_Y, and the open-loop gain A. If v_Y is grounded, What is the input resistance seen by v_X. Express your answer in terms of R and A.



(15 pts) a.

$$\boxed{v_+ = \frac{v_y}{2}} \quad (+3) \qquad v_- ? \qquad v_o = A(v_+ - v_-)$$

$$\boxed{\begin{aligned} v_+ - v_- &= \frac{v_o}{A} \\ v_- &= v_+ - \frac{v_o}{A} \end{aligned}} \quad (+3)$$

$$i = \frac{v_x - v_-}{R} = \frac{v_- - v_o}{R} \quad (+4)$$

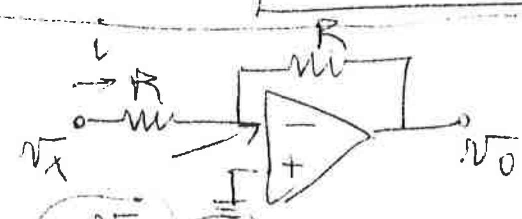
$$\Rightarrow v_o = 2v_- - v_x \ (+2) = 2\left(v_+ - \frac{v_o}{A}\right) - v_x$$

$$= 2\frac{v_y}{2} - 2\frac{v_o}{A} - v_x$$

$$v_o\left(1 + \frac{2}{A}\right) = v_y - v_x$$

$$\boxed{v_o = \frac{v_y - v_x}{\left[1 + \frac{2}{A}\right]}} \quad (+3)$$

(10 pts) b. $v_y = 0$



$$-\frac{v_o}{A} \quad (+2)$$

$$v_x + \frac{v_o}{A} = v_- - v_o = \frac{-v_o}{A} - v_o \quad (+4)$$

$$R_{in} = \frac{v_x}{i} \quad (+1)$$

$$\Rightarrow v_x = -\left(\frac{2}{A} + 1\right)v_o \rightarrow R_{in} = \frac{v_x R}{v_x + \frac{v_o}{A}}$$

$$v_o = \frac{-v_x}{(\ldots)} \quad (+3)$$

$$R_{in} = R\left(\frac{A+2}{A+1}\right)$$

$R_{in} = R$ as $A \to \infty$ ✓

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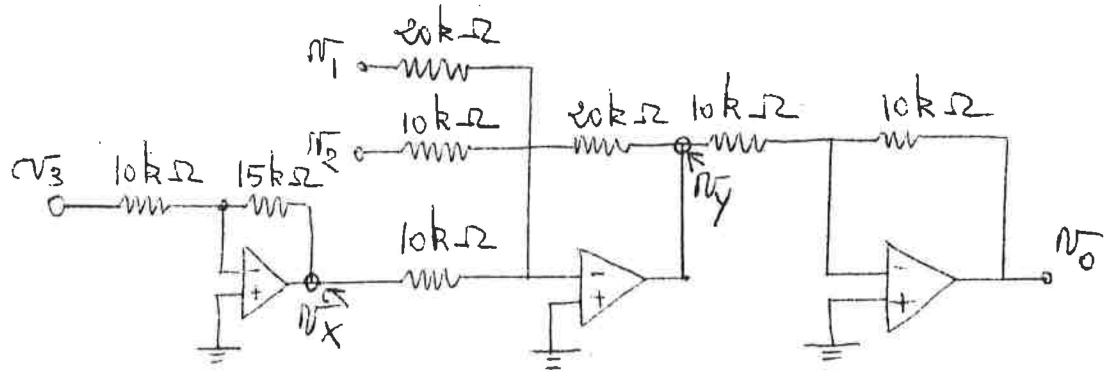
II. (25 pts) In the circuit shown below, assume that all op-amps are ideal. Give an expression for v_0 in terms of v_1, v_2, and v_3. Show all intermediate steps for full credit.



$$v_x = -\frac{3}{2} v_3 \quad +7$$

$$v_y = -v_1 - 2v_2 - 2v_x = -v_1 - 2v_2 - 2\left(-\frac{3}{2} v_3\right) \quad +7$$

$$v_y = -v_1 - 2v_2 + 3v_3 \quad +7$$

$$v_0 = -v_y = v_1 + 2v_2 - 3v_3 \quad +4$$

IV: (25 pts) A measurement of the open-loop gain of an internally compensated op-amp at very low frequencies show it to be 4.2 X $10^4 V/V$. At 100 kHz, it is 76V/V. Estimate the values for A_o, f_b, and f_t. Remember that your answers must be in Hz for f_b and f_t.

5

$$A_o = 4.2 \times 10^4 \, V/V \quad (+5)$$

$$A = \frac{A_o}{1 + j\frac{f}{f_b}} \quad (+5)$$

$$|A| = \frac{A_o}{\sqrt{1 + (f/f_b)^2}}$$

$$76 = \frac{4.2 \, 10^4}{\sqrt{1 + (100/f_b)^2}} \Rightarrow f_b = 0.181 \, kHz = 181 \, Hz$$

But $f_t = A_o f_b = 4.2 \, 10^4 \times 0.181 \, kHz$ (+5)

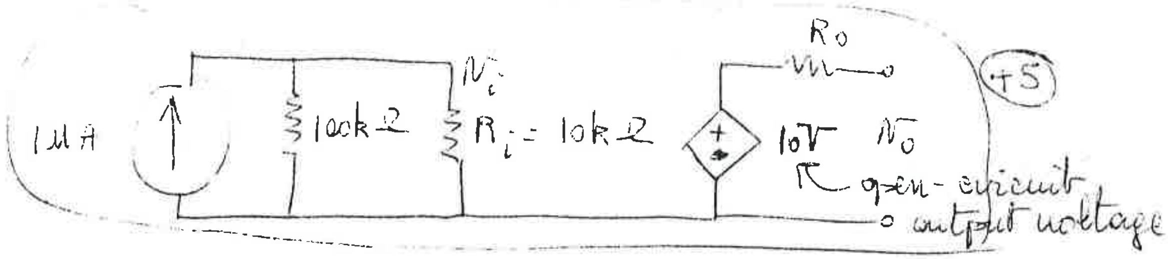
$$\boxed{f_t = 7.6 \, MHz}$$

(+5)

Test 1 - Fall 1998 (100pts max) - M. Cahay
Name:

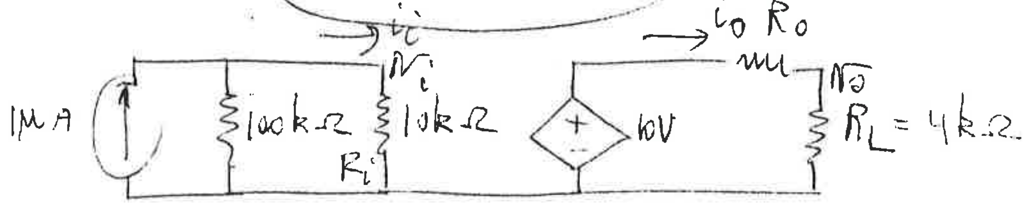
ELECTRONICS I
October 16, 1998

I. (25 pts) A voltage amplifier with an input resistance of 10 $k\Omega$, when driven with a current source of 1 μA and a source resistance of 100 $k\Omega$, has a short-circuit output current of 10 mA and an open-circuit output voltage of 10 V. When driving a 4 $k\Omega$ load, what are the voltage gain, current gain, and power gains expressed in dB?



short circuit output current = 10 mA

$$R_o = \frac{10V}{10mA} = 1k\Omega \quad (+5)$$



$$v_o = 10 \times \frac{4}{4+1} = 8\,V \quad (+3)$$

$$A_v = \frac{v_o}{v_i} = \frac{8 \;\; +3}{10^{-6}(100//10)10^3} = 888\,V/V \text{ or } 58.9\,dB \quad (+1)$$

$$A_i = \frac{i_o}{i_i} = \frac{v_o/R_L \;\; +3}{10^{-6}\left(\frac{100}{100+10}\right)} = \frac{8/4\,10^{-3}}{10^{-6}\,\frac{100}{110}} = 2200\,A/A \text{ or } 66.8\,dB \quad (+1)$$

$$A_p = \frac{v_o^2/R_L}{R_i i_i^2} \;\; 2+3 \;\; = 19.36\,10^8\,W/W = 62.9\,dB = \frac{1}{2}\left[A_v + A_i\right] \quad (+1)$$