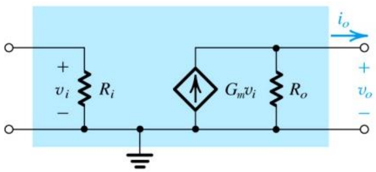
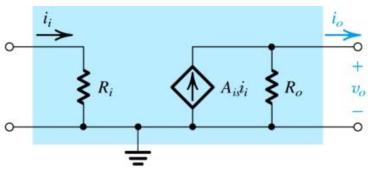
Exam #1
Chapters 1 and 2
Solutions

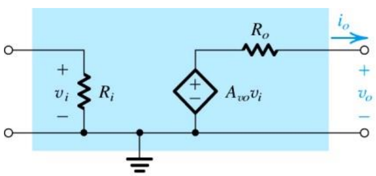
I. Amplifier Types



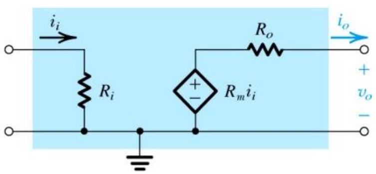
In V Out I
Type Transconductance
Ideal Characteristics
R_i = ∞ Ω
R_o = ∞ Ω



In I Out I
Type Current
Ideal Characteristics
R_i = 0 Ω
R_o = ∞ Ω

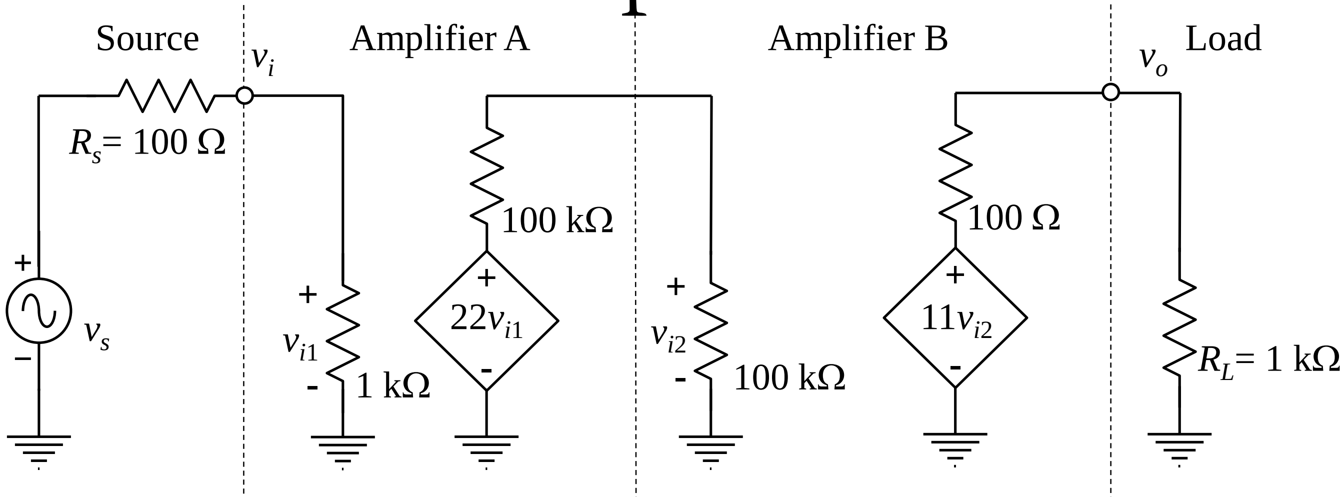


In V Out V
Type Voltage
Ideal Characteristics
R_i = ∞ Ω
R_o = 0 Ω



In I Out V
Type Transresistance
Ideal Characteristics
R_i = 0 Ω
R_o = 0 Ω

II. Amplifier Gain



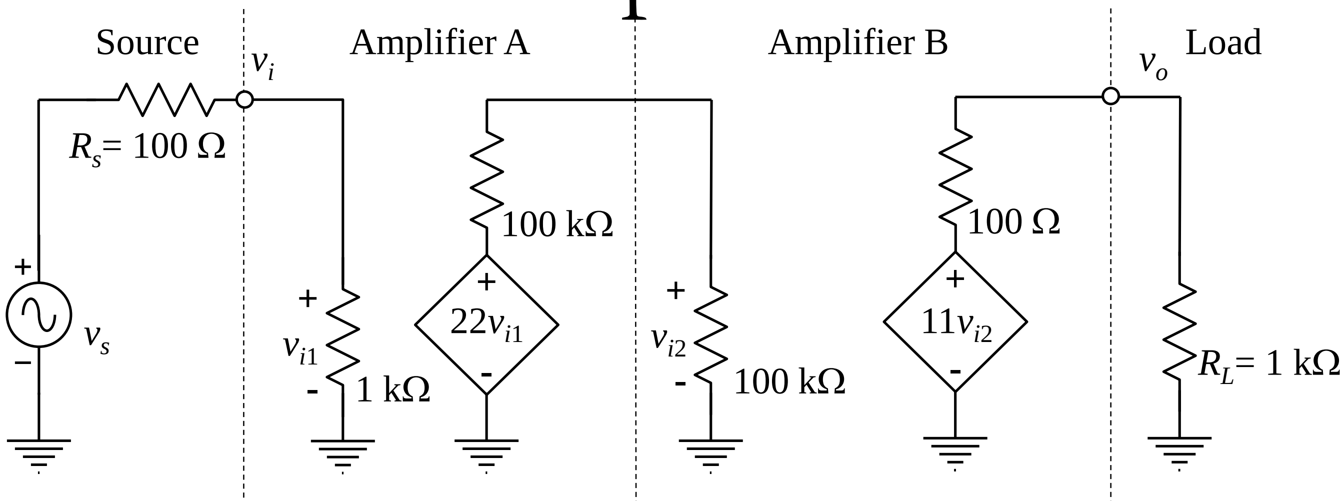
Find the cascaded amplifier voltage gain, A_v, as well as the overall circuit voltage gain both as V/V ratios and in dB. Show your work!

$$v_{inB} = v_i(22)\left(\frac{100\text{k}\Omega}{100\text{k}\Omega + 100\text{k}\Omega}\right) = 11v_i$$

$$v_o = 11v_{inB}\left(\frac{1\text{k}\Omega}{1\text{k}\Omega + 0.1\text{k}\Omega}\right) = 10v_{inB} = 10(11v_i) = 110v_i$$

$$\Rightarrow A_v \equiv \frac{v_o}{v_i} = 110\text{ V/V} = 40.83\text{ dB}$$

II. Amplifier Gain



Find the cascaded amplifier voltage gain, A_v, as well as the overall circuit voltage gain both as V/V ratios and in dB. Show your work!

$$\Rightarrow G_v \equiv \frac{v_o}{v_s} = A_v \frac{1\text{k}\Omega}{1.1\text{k}\Omega} = 110\left(\frac{1}{1.1}\right) = 100 \text{ V/V} = 40.0 \text{ dB}$$

III. Definitions (10 points)

Answers:

A. Bipolar
B. Decade
C. Decibel
D. Discretization
E. Fourier Transform
F. Frequency Spectrum
G. Fundamental Frequency
H. Linearity
I. Norton
J. Octave
K. Thevenin
L. Transducer
M. Transfer Characteristic
N. Transfer Function
O. Unilateral

_J__ Change in frequency by a factor of 2; i.e. a doubling or halving of the frequency.

_C__ Log based ratio or measurement of gain

_E__ Mathematical tool for converting between time domain and frequency domain.

III. Definitions (10 points)

Answers:

A. Bipolar
B. Decade
C. Decibel
D. Discretization
E. Fourier Transform
F. Frequency Spectrum
G. Fundamental Frequency
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I. Norton
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K. Thevenin
L. Transducer
M. Transfer Characteristic
N. Transfer Function
O. Unilateral

_L_ Device that converts real world, or physical, signals into electrical signals.

_F_ The frequency components that make a signal.

_O_ Signal flow is unidirectional, from input to output.

_B_ Change in frequency by a factor of 10; i.e. an order of magnitude increase or decrease in frequency.

III. Definitions (10 points)

Answers:

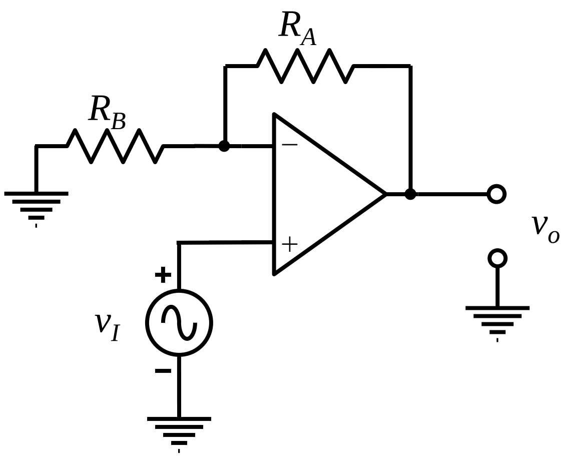
A. Bipolar
B. Decade
C. Decibel
D. Discretization
E. Fourier Transform
F. Frequency Spectrum
G. Fundamental Frequency
H. Linearity
I. Norton
J. Octave
K. Thevenin
L. Transducer
M. Transfer Characteristic
N. Transfer Function
O. Unilateral

__H__ Measurement of how close the output signal is to a scaled version of the input.

__M__ The output voltage as a function of input voltage.

__N__ Relation between the input and output of a linear time-invariant system with respect to frequency

IV. Solve for the closed loop gain



$$v_{Id} = \frac{v_O}{A} \approx 0$$

$$i_{R_B} = \frac{v_I}{R_B}$$

$$v_O = v_I + i_{R_B} R_A = v_I + \frac{v_I}{R_B} R_A = v_I \left(1 + \frac{R_A}{R_B}\right)$$

$$A_v \equiv \frac{v_O}{v_I} = 1 + \frac{R_A}{R_B}$$

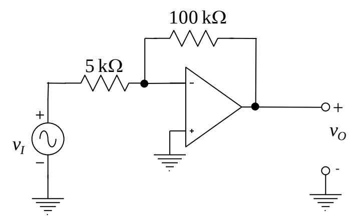
Alternate derivation – voltage divider

$$v_- = v_O \left(\frac{R_B}{R_B + R_A}\right) = v_I \quad \Rightarrow A_v \equiv \frac{v_O}{v_I} = \left(\frac{R_B + R_A}{R_B}\right) = 1 + \frac{R_A}{R_B}$$

V. Ideal Op Amp

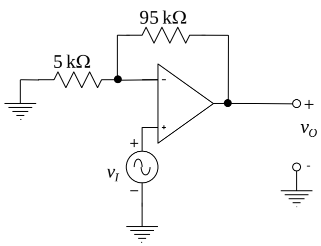
1. input impedance __infinite Ω______
2. output impedance ____zero Ω ______
3. common-mode gain __zero V/V_______
4. common-mode rejection ___ infinite V/V or dB_
5. open-loop gain, *A* _ infinite V/V_____
6. bandwidth __ infinite Hz_____

VI. Calculate the Voltage Gain



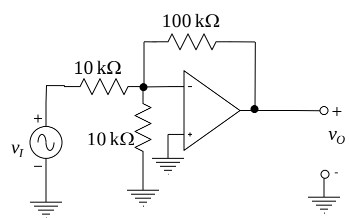
-100k/5k=-20

A_v = ___-20______ V/V __26.0___dB



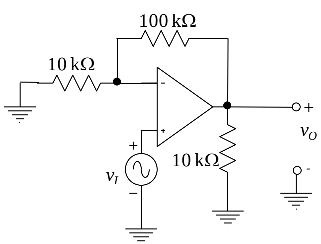
1+95k/5k = 20

A_v = __20_______ V/V ___26.0___dB



-100k/10k = -10

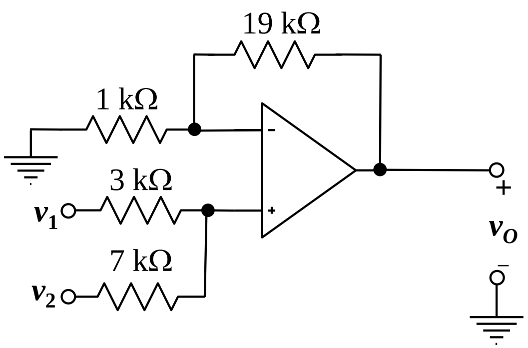
A_v = ___-10______ V/V __20____dB



=1+100k/10k = 11

A_v = __11_____ V/V __20.83____dB

VII. Superposition principle



Use the superposition principle to find the output voltage as a function of the two input voltages of the circuit shown.

Ground v_1 first

$$v_o = v_2\left(\frac{3\text{k}\Omega}{3\text{k}\Omega + 7\text{k}\Omega}\right)\left(1+\frac{19\text{k}\Omega}{1\text{k}\Omega}\right) = v_2\left(\frac{3}{10}\right)(20) = 6v_2$$

Then ground v_2

$$v_o = v_1\left(\frac{7\text{k}\Omega}{7\text{k}\Omega + 3\text{k}\Omega}\right)\left(1+\frac{19\text{k}\Omega}{1\text{k}\Omega}\right) = v_1\left(\frac{7}{10}\right)(20) = 14v_1$$

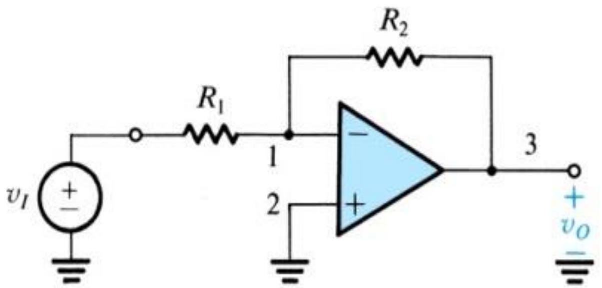
Then add the two outputs

$$v_o = 14v_1 + 6v_2$$

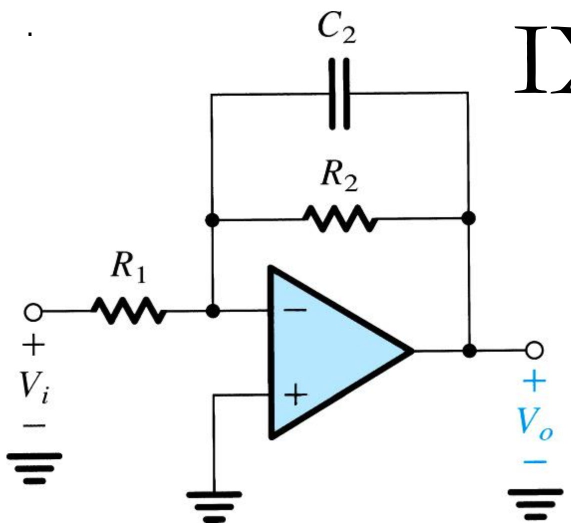
VIII. Inverting Amplifier Solutions

You are provided with an ideal op amp, one 10-kΩ, and two 40-kΩ resistors. ***Using all three resistors*** with series and parallel resistor combinations there are 8 different inverting-amplifier circuit topologies possible. Fill in the table below for all 8 configurations.

Config	R_1	R_2	v_o/v_i	R_{in}
1	10kΩ	40kΩ+40kΩ	-8 V/V	10 kΩ
2	10kΩ	40kΩ||40kΩ	-2 V/V	10 kΩ
3	40kΩ	10kΩ+40kΩ	-1.25 V/V	40 kΩ
4	40kΩ	10kΩ||40kΩ	-0.2 V/V	40 kΩ
5	40kΩ+40kΩ	10kΩ	-0.125 V/V	80 kΩ
6	40kΩ||40kΩ	10kΩ	-0.5 V/V	20 kΩ
7	10kΩ+40kΩ	40kΩ	-0.8 V/V	50 kΩ
8	10kΩ||40kΩ	40kΩ	-5 V/V	8 kΩ



Assuming that you want the magnitude of the gain to be more than 4x, which is the best configuration and why?



IX. Miller Integrator

For the Miller Integrator with feedback resistor circuit shown, answer the following questions:

Don't forget proper units.

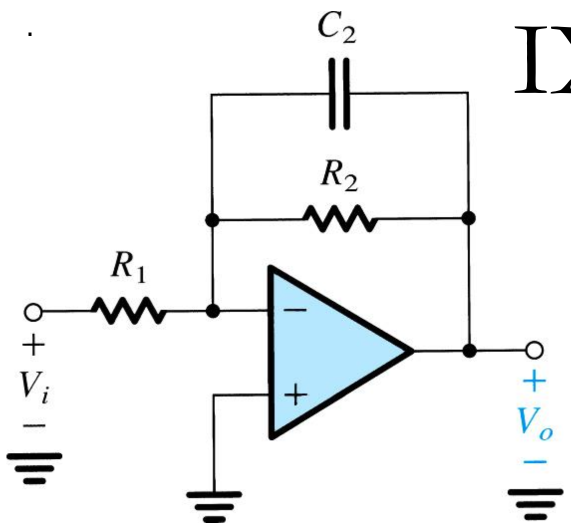
Derive an expression for the low pass transfer function $V_o(s)/V_i(s)$ in the form

$$T(j\omega) = \frac{K}{1 + j(\omega/\omega_0)}$$

$$Z_1 = R_1, Z_2 = R_2 \,||\, (1/sC_2) = \frac{R_2}{1 + sC_2R_2}$$

$$\frac{V_o(s)}{V_i(s)} = -\frac{Z_2}{Z_1} = \frac{-R_2/R_1}{1 + sC_2R_2}$$

$$K = -\frac{R_2}{R_1} \qquad \omega_0 = \frac{1}{C_2R_2}$$



IX. Miller Integrator

For the Miller Integrator with feedback resistor circuit shown, answer the following questions:

Don't forget proper units.

$$\frac{V_o(s)}{V_i(s)} = -\frac{Z_2}{Z_1} = \frac{-R_2/R_1}{1+sC_2R_2}$$

Design the circuit to obtain a dc gain of 40 dB, a 3-dB frequency of 15.915 kHz, and an input resistance of 1 kΩ.

R_1 $$R_1 = 1\text{k}\Omega$$

R_2 $$K = -\frac{R_2}{R_1} = 40\text{dB} = 100\text{V/V} \Rightarrow \text{R}_2 = 100\text{k}\Omega$$

C_2 $$\omega_0 = \frac{1}{C_2R_2} = 2\pi f_0 = 2\pi \times 15.915\text{kHz} \qquad \Rightarrow C_2 = 100.0\text{pF}$$

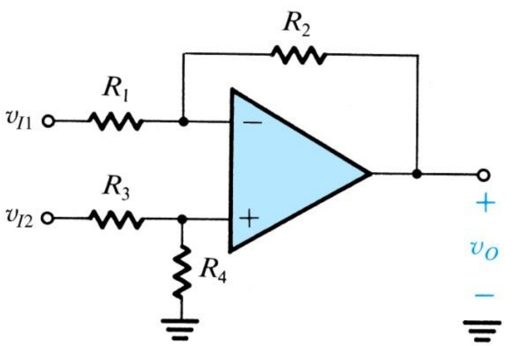
X. Difference Amplifier Circuit

For a difference amplifier as shown the differential and common mode gains are given by the following:

$$A_d \equiv \frac{v_0}{v_{id}} = \frac{R_2}{R_1} \text{ with the condition that } \frac{R_2}{R_1} = \frac{R_4}{R_3} \qquad A_{cm} \equiv \frac{v_0}{v_{icm}} = \frac{R_4}{R_4 + R_3}\left(1 - \frac{R_2}{R_1}\frac{R_3}{R_4}\right)$$

Analyze the difference amplifier shown to the right for the case $R_1 = R_3 = 4.7\ \text{k}\Omega$, and $R_2 = R_4 = 470\ \text{k}\Omega$.

What is the differential input resistance R_{id}? Find the common-mode gain, A_{cm}, the differential mode gain, A_d, and calculate the CMRR in dB. Don't forget proper units.



$R_{id} = 4.7\text{k}\Omega + 4.7\text{k}\Omega = 9.4\text{k}\Omega$

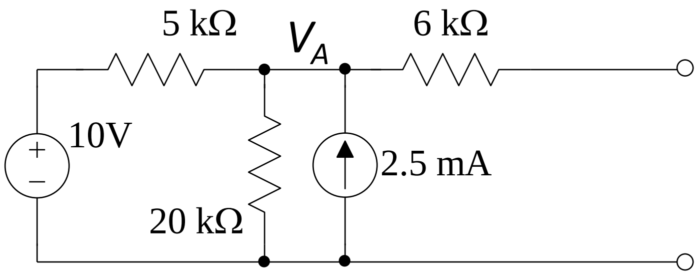
$A_d = 470\text{k}\Omega / 4.7\text{k}\Omega = 100\text{V/V}$

$A_{cm} = 0\text{V/V}$

CMRR $= \infty\text{V/V}$

$$CMRR = 20 \log\left(\frac{|A_d|}{|A_{cm}|}\right)$$

E.C. Thevenin and Norton Equivalent Circuits – Nodal Solution



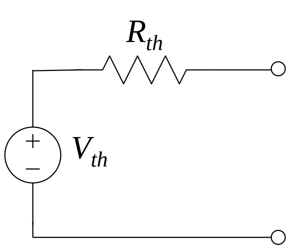
$$\frac{V_A - 10\text{V}}{5\text{k}\Omega} + \frac{V_A}{20\text{k}\Omega} - 2.5\text{mA} = 0$$

$$\frac{V_A}{5\text{k}\Omega} + \frac{V_A}{20\text{k}\Omega} - \frac{10\text{V}}{5\text{k}\Omega} - 2.5\text{mA} = 0$$

$$V_A\left(\frac{1}{5\text{k}\Omega} + \frac{1}{20\text{k}\Omega}\right) = V_A\left(\frac{5}{20\text{k}\Omega}\right) = 2\text{mA} + 2.5\text{mA} = 4.5\text{mA}$$

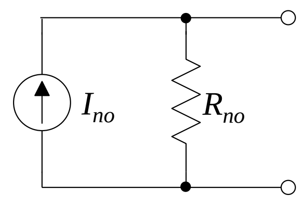
$$V_A = V_{th} = \left(4\text{k}\Omega \times 4.5\text{mA}\right) = 18\text{V}$$

$$I_{No} = \frac{V_{th}}{R_{th}} = \frac{18\text{V}}{10\text{k}\Omega} = 1.8\text{mA}$$



$V_{th} =$ 18 V

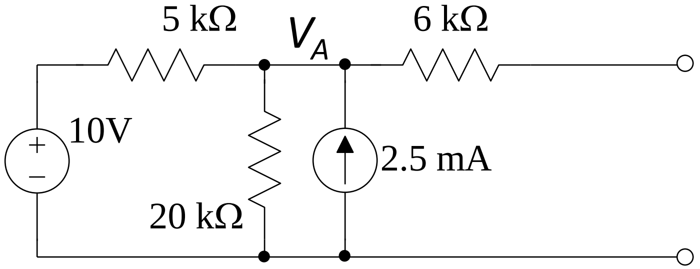
$R_{th} =$ 10 kΩ



$I_{No} =$ 1.8 mA

$R_{No} =$ 10 kΩ

E.C. Thevenin and Norton Equivalent Circuits-Superposition Solution



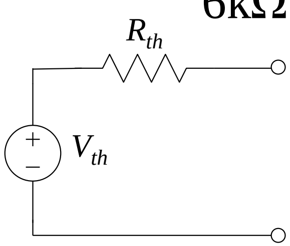
$$10\text{V}\left(\frac{20\text{k}\Omega}{20\text{k}\Omega+5\text{k}\Omega}\right)=8\text{V}$$

$$2.5\text{mA}\left(5\text{k}\Omega\,||\,10\text{k}\Omega\right)=2.5\text{mA}\left(4\text{k}\Omega\right)=10\text{V}$$

$$V_{th}=10\text{V}+8\text{V}=18\text{V}$$

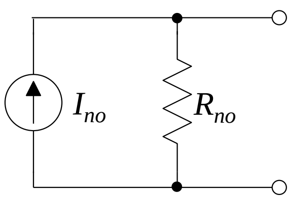
$$I_{No}=\frac{10\text{V}\left(\dfrac{20\text{k}\Omega\,||\,6\text{k}\Omega}{\left(20\text{k}\Omega\,||\,6\text{k}\Omega\right)+5\text{k}\Omega}\right)}{6\text{k}\Omega}+2.5\text{mA}\left(\frac{20\text{k}\Omega\,||\,5\text{k}\Omega}{\left(20\text{k}\Omega\,||\,5\text{k}\Omega\right)+6\text{k}\Omega}\right)$$

$$=\frac{10\text{V}\left(0.48\right)}{6\text{k}\Omega}+2.5\text{mA}\left(\frac{4\text{k}\Omega}{10\text{k}\Omega}\right)=0.8\text{mA}+1.0\text{mA}=1.8\text{mA}$$



V_{th} = 18 V

R_{th} = 10 kΩ



I_{No} = 1.8 mA

R_{No} = 10 kΩ

Exam #1 Results

# Tests	92
Average	87.9 %
High	104% (2)
Low	46.5%