# RYERSON UNIVERSITY

Department of Electrical & Computer Engineering

## MID-TERM
## Examination

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|---|---|
| **Course Name:** | Electronic Circuits |
| **Course Number:** | ELE 404 |
| **Examiners:** | Prof. D. Androutsos<br>Prof. A. Kabbani |

**DATE:** *Wednesday February 28, 2007*
**DURATION:** 110 Minutes
**TOTAL MARKS:** 100

**EXAMINATION INSTRUCTIONS**:

1. This is a closed-book examination. No aids other than basic calculators are permitted.
2. The examination paper contains 9 pages and is comprised of FOUR questions worth 100 marks, *and are not equally weighted.*
3. No questions are allowed during the examination time. *If in doubt, state your assumptions.*

**INFORMATION:**

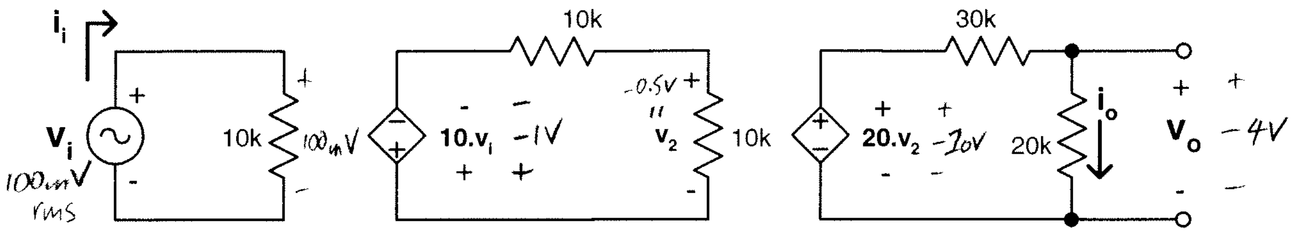
(a) OP-AMPS are assumed to be ideal, unless stated otherwise. The maximum output voltage of any OP-AMP is limited by its power-supply voltages, +/- Vcc.
(b) Note:- Symbols "V" or "v' stand for Volts; "k" stands for kilo-Ohms; and "mA" stands for milli-Amps.
(c) The diode current ($I_D$) in the forward-bias mode is given as: $I_D = I_S \exp(V_D/nV_T)$ , and the voltage difference between two operating points for a forward-bias diode can be expressed as:
$\mathbf{V_{D2} - V_{D1} = 2.3nV_T \log(I_{D2}/I_{D1})}$.

**NAME:** SOLUTION **NUMBER:**______________

**SECTION #:**______________

| Q1 | Q2 | Q3 | Q4 | TOTAL |
|---|---|---|---|---|
| /25 | /28 | /20 | /27 | /100 |

**Q1(a).** **[15 marks]** An amplifier has the small-signal a.c. equivalent circuit as shown below. **(i)** Find the voltage gain $\mathbf{A_v}$, $(\mathbf{v_o/v_i})$ and current gain $\mathbf{A_i}$, $(\mathbf{i_o/i_i})$ of the amplifier; and **(ii)** if this amplifier draws 1mA from a single 10V d.c. supply when $\mathbf{v_i}$ = 100mV r.m.s., determine the signal input power, $\mathbf{P_{in}}$, signal output power, $\mathbf{P_{out}}$, and the power efficiency, $\boldsymbol{\eta}$, of the amplifier.




$$\frac{V_o}{V_i} = \frac{-4V}{100mV} = -40\,V/V$$

$$i_o = \frac{-4V}{20k} = -0.2mA \text{ rms}$$

$$i_1 = \frac{100mV}{10k} = 0.01mA \text{ rms}$$

$$\frac{i_o}{i_1} = \frac{-0.2mA}{0.01mA} = -20\,A/A$$

$$P_{IN} = (0.01mA)(100mV) = 0.001\,mW$$

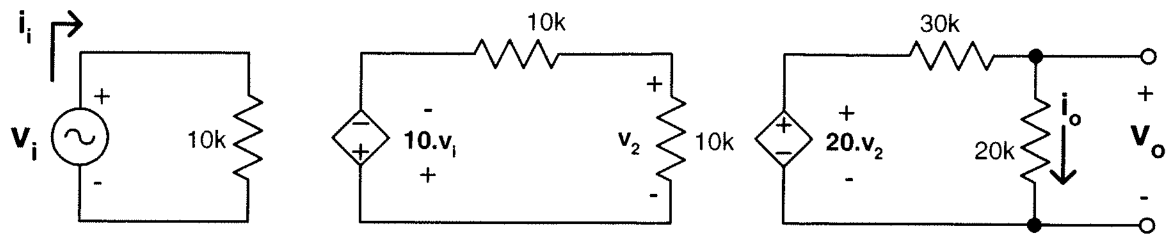
$$P_{DC} = (1mA)(10V) = 10mW$$

$$P_{OUT} = (0.2mA)(4V) = 0.8mW$$

$$\eta = \frac{P_{OUT}}{P_{IN} + P_{DC}} \times 100\% = \frac{0.8mW}{0.001mW + 10mW} = 0.079998 \times 100\% = 8\%$$

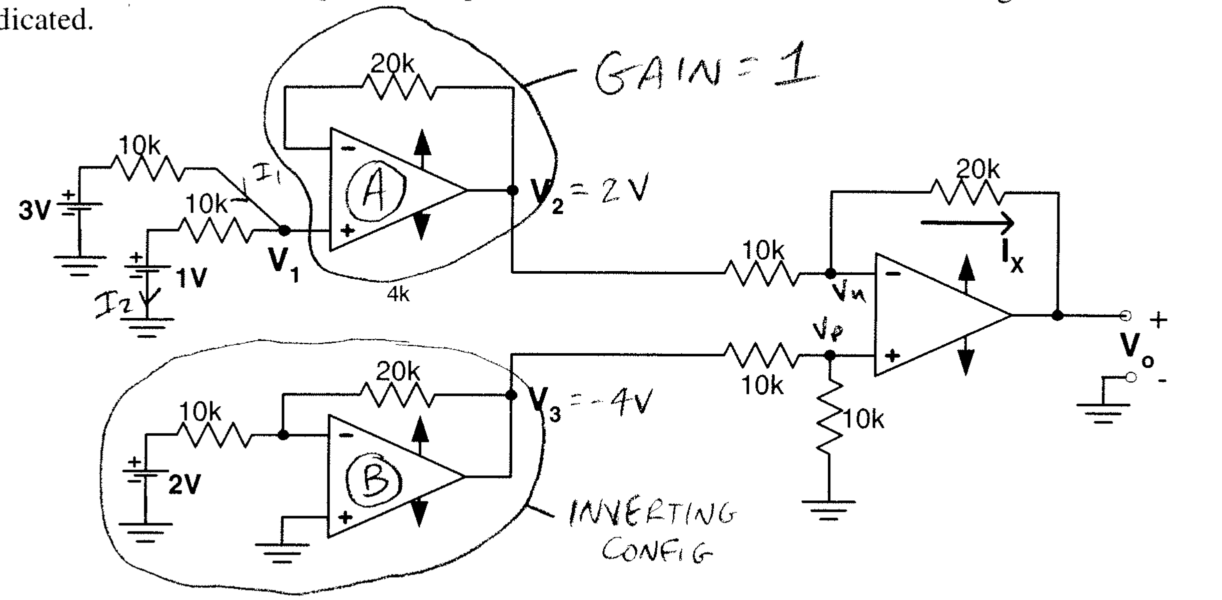
| $A_v$ | $A_i$ | $P_{in}$ | $P_{out}$ | $\eta$ |
|---|---|---|---|---|
| $-40\,V/V$ | $-20\,A/A$ | 0.001mW | 0.8mW | 8% |

**Q1(a).** **[15 marks]** An amplifier has the small-signal a.c. equivalent circuit as shown below. **(i)** Find the voltage gain $\mathbf{A_v}$, ($\mathbf{v_o/v_i}$) and current gain $\mathbf{A_i}$, ($\mathbf{i_o/i_i}$) of the amplifier; and **(ii)** if this amplifier draws 1mA from a single 10V d.c. supply when $\mathbf{v_i}$ = 100mV r.m.s., determine the signal input power, $\mathbf{P_{in}}$, signal output power, $\mathbf{P_{out}}$, and the power efficiency, $\boldsymbol{\eta}$, of the amplifier.




| $\eta$ | $P_{out}$ | $P_{in}$ | $A_i$ | $A_v$ |
|---|---|---|---|---|
| 8% | 0.8mW | 0.001mW | -20 A/A | -40 V/V |

**Q1(b).** **[10 marks]** For Op-AMP amplifier circuit shown, determine the voltages and current as indicated.




$I_1 = I_2$

$\frac{3 - V_1}{10k} = \frac{V_1 - 1}{10k}$

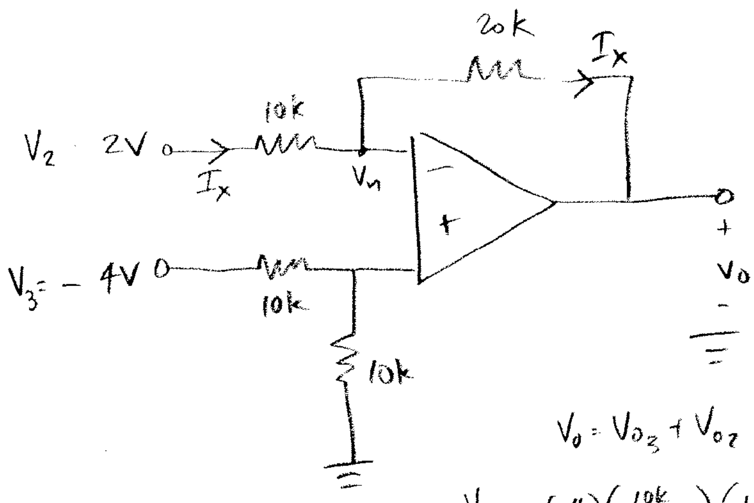
$V_1 = 2V$

Since op-Amp (A) has gain = 1

$V_2 = V_1 = 2V$

$V_3 = 2V\left(-\frac{20k}{10k}\right) = -4V$

Can now solve the following using superposition:




$V_o = V_{o3} + V_{o2}$

$V_{o3} = (-4)\left(\frac{10k}{10k+10k}\right)\left(1 + \frac{20k}{10k}\right) = -6V$

$V_{o2} = (2)\left(-\frac{20k}{10k}\right) = -4V$

$\therefore V_o = -10V$

$\frac{V_2 - V_n}{10k} = \frac{V_n - V_o}{20k}$

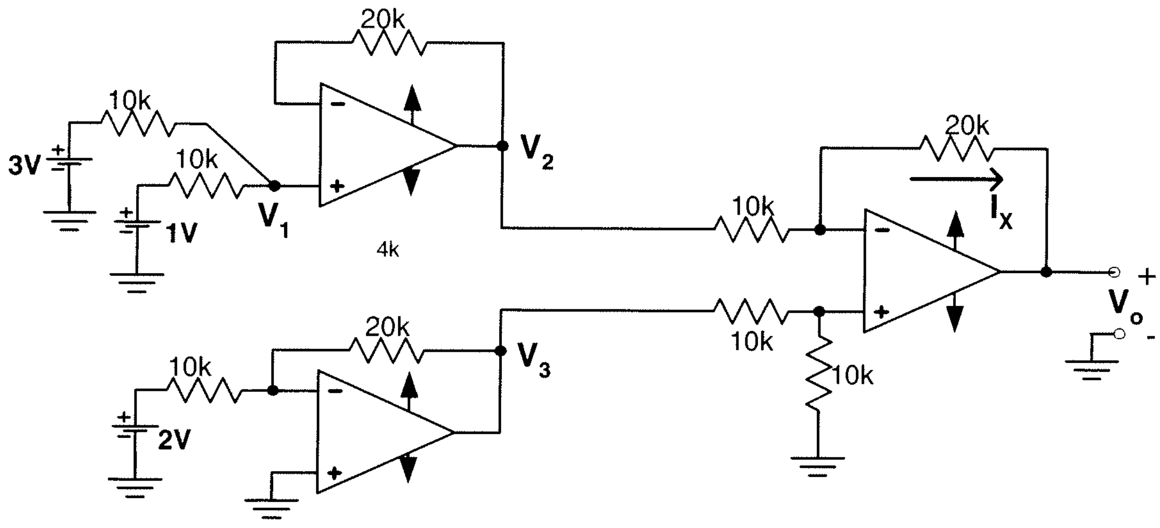
$\frac{2 - V_n}{10k} = \frac{V_n + 10}{20k}$

$V_n = -2$

$I_x = (V_n - V_o)/20k = 0.4mA$

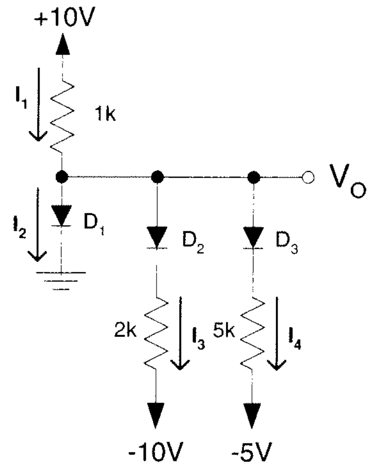
| $V_1$ | $V_2$ | $V_3$ | $I_X$ | $V_O$ |
|---|---|---|---|---|
| 2V | 2V | -4V | 0.4mA | -10V |

**Q1(b).** **[10 marks]** For Op-AMP amplifier circuit shown, determine the voltages and current as indicated.

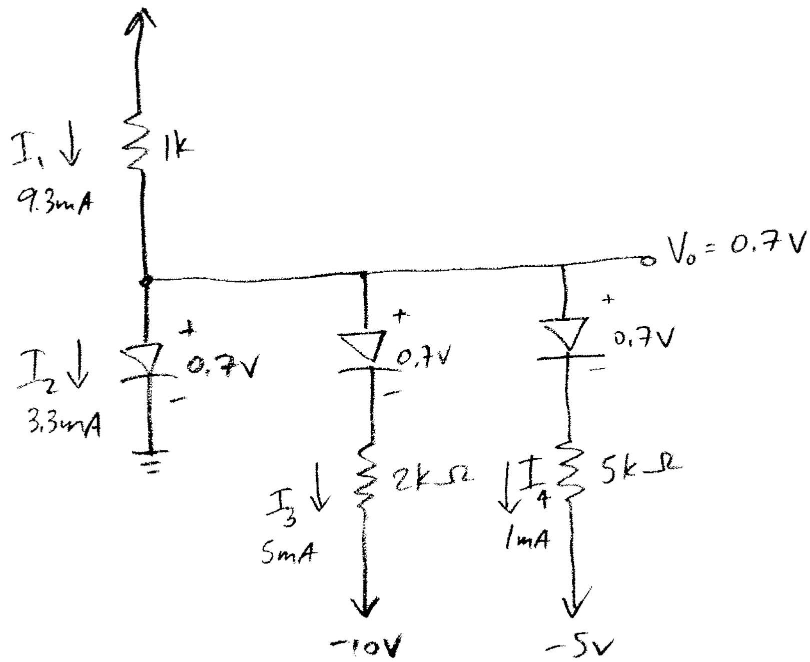



| $V_O$ | $I_X$ | $V_3$ | $V_2$ | $V_1$ |
|---|---|---|---|---|
| -10V | 0.4mA | -4V | 2V | 2V |

**Q2(a).** **[13 marks]** Assume all diodes exhibit a *constant 0.7 volt drop in forward bias mode*. Find $\mathbf{I_1}$, $\mathbf{I_2}$, $\mathbf{I_3}$, $\mathbf{I_4}$ & $\mathbf{V_o}$ as indicated and the state of the diodes.




ALL DIODES ARE ON.




$$I_1 = \frac{10-0.7}{1k} = 9.3mA$$

$$I_3 = \frac{0.7-0.7-(-10)}{2k} = 5mA$$

$$I_4 = \frac{0.7-0.7-(-5)}{5k} = 1mA$$

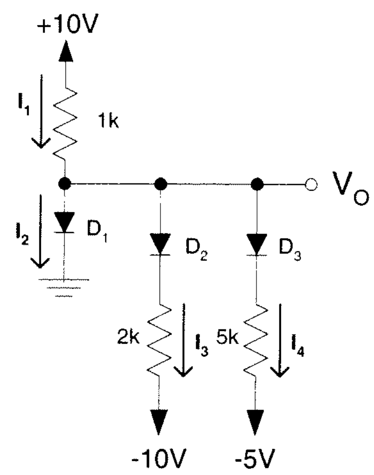
$$I_1 = I_2 + I_3 + I_4$$

$$\therefore I_2 = 3.3mA$$

All diodes are forward biased and all currents are flowing into the anodes of all diodes.

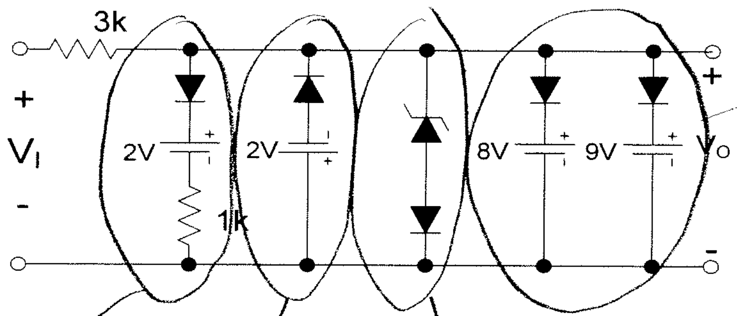
| $I_1$ | $I_2$ | $I_3$ | $I_4$ | D1 | D2 | D3 | $V_o$ |
|---|---|---|---|---|---|---|---|
| 9.3mA | 3.3mA | 5mA | 1mA | On<br>Off | On<br>Off | On<br>Off | 0.7V |

**Q2(a).** **[13 marks]** Assume all diodes exhibit a *constant 0.7 volt drop in forward bias mode*. Find $\mathbf{I_1}$, $\mathbf{I_2}$, $\mathbf{I_3}$ , $\mathbf{I_4}$ & $\mathbf{V_o}$ as indicated and the state of the diodes.




| $V_o$ | D3 | D2 | D1 | $I_4$ | $I_3$ | $I_2$ | $I_1$ |
|---|---|---|---|---|---|---|---|
| 0.7V | On<br>Off | On<br>Off | On<br>Off | 1mA | 5mA | 3.3mA | 9.3mA |

**Q2(b).** **[15 marks]** For the circuit shown, **a**ssume all diodes to be ***ideal***. The Zener diode has a reverse breakdown voltage, $\mathbf{V_z = 4V}$, and acts as an ideal diode in forward bias. Determine, and neatly sketch on the graph provided, the transfer characteristic ($\mathbf{V_O}$ **vs** $\mathbf{V_I}$) of the circuit. Label all the *breakpoints* on both axes and *slopes* of the transfer characteristic.




both have NO EFFECT

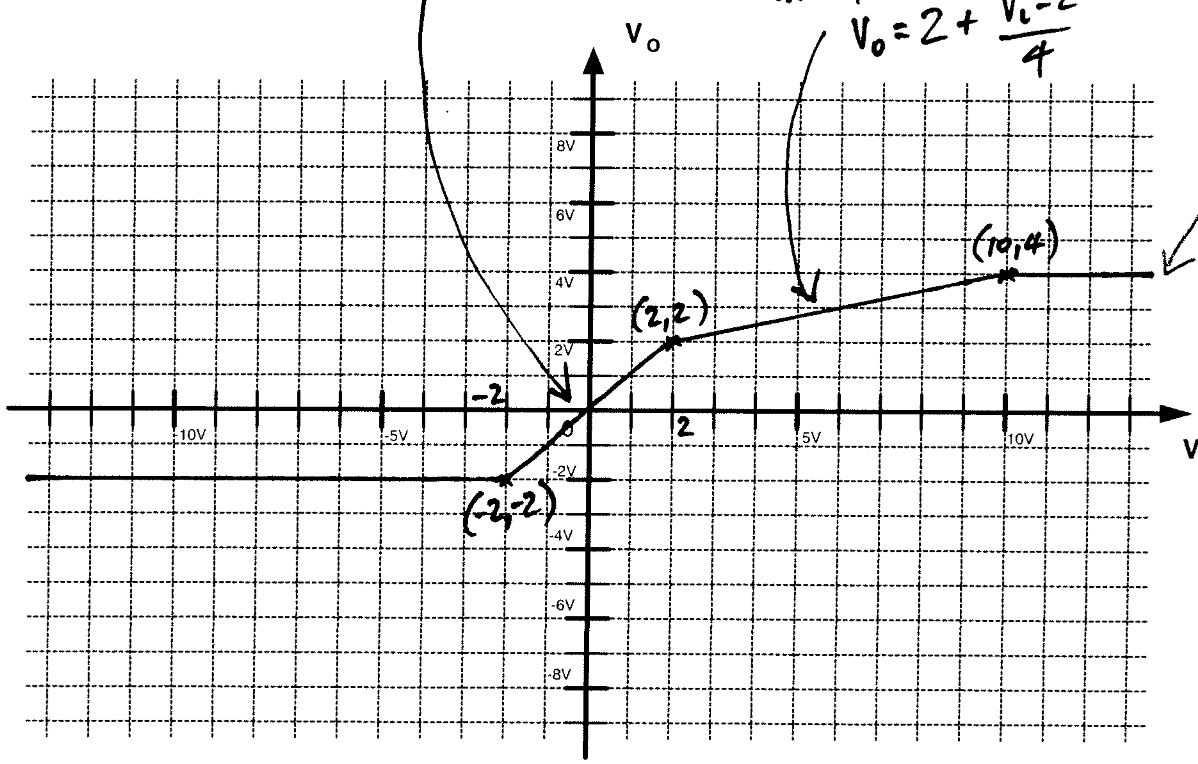
limits @ -2V

limits @ 4V

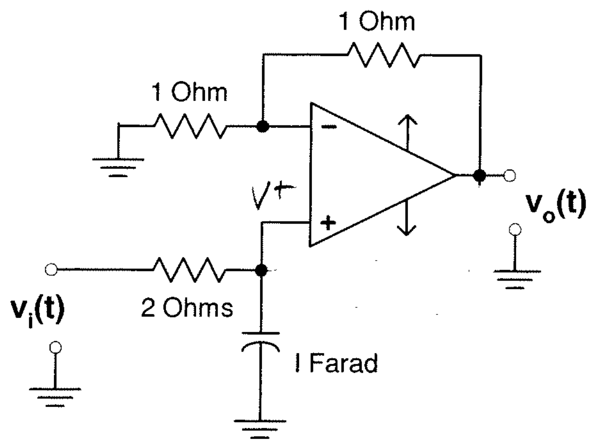
$m = 1/1$

$m = 1/4$

$V_o = 2 + \frac{V_i - 2}{4}$



**Q3(a).** **[8 marks]** For the circuit shown below, assume the Op-AMP and all components to be ideal. Develop the expression for the transfer function, **T(jω)** [= $v_o(j\omega)/v_i(j\omega)$]. What function does this circuit perform?




$$V^+ = V_i(j\omega)\left(\frac{\frac{1}{j\omega}}{2+\frac{1}{j\omega}}\right)$$

$$V_o = V^+\left(1 + \frac{1\Omega}{1\Omega}\right) = 2V^+$$

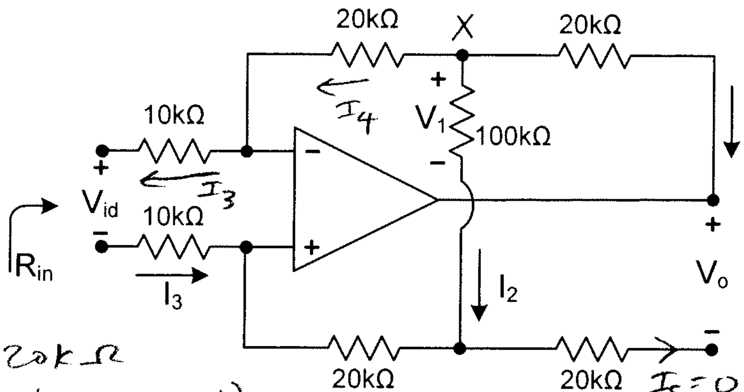
So,

$$V_o(j\omega) = 2\left(V_i(j\omega)\left(\frac{\frac{1}{j\omega}}{2+\frac{1}{j\omega}}\right)\right)$$

$$\therefore \frac{V_o(j\omega)}{V_i(j\omega)} = \frac{2}{2j\omega + 1}$$

This circuit is a <u>low-pass filter</u>

**Q3(b).** **[12 marks]** For the circuit shown below, assume the Op-AMP and all components to be ideal. **(i)** Find the differential gain $A_{id} = V_o/V_{id}$, **(ii)** Find the labeled currents and voltages, $V_1$, $I_1$, $I_2$ and $I_3$, if $V_{id}$=6V (iii) Find $R_{in}$.




$R_{IN} = 10k\Omega + 10k\Omega = 20k\Omega$
(due to virtual short circuit)

$I_3 = -\frac{V_{id}}{20k} = -I_2$ (since $I_5 = 0$)

Thus, $I_2 = \frac{V_{id}}{20k} = \frac{6V}{20k} = 0.3mA$

$\boxed{I_3 = -0.3mA}$

Also, $I_4 = I_3$

KCL @ x gives:

$I_1 + I_2 + I_4 = 0$

$I_1 = -(I_2 + I_4)$

but $I_4 = I_3 = -I_2$

So, $I_1 = -(I_2 - I_4)$

$\boxed{I_1 = 0}$

Since $I_5 = I_1 = 0$,

$V_o = V_1$

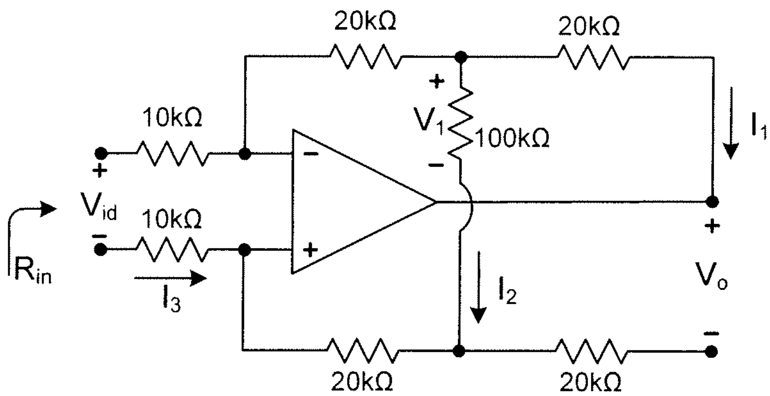
$V_1 = I_2(100k\Omega) = (0.3mA)(100k)$

$\boxed{V_1 = 30V = V_o}$

$A_{id} = \frac{V_o}{V_1} = \frac{30V}{6V} = 5\ V/V$

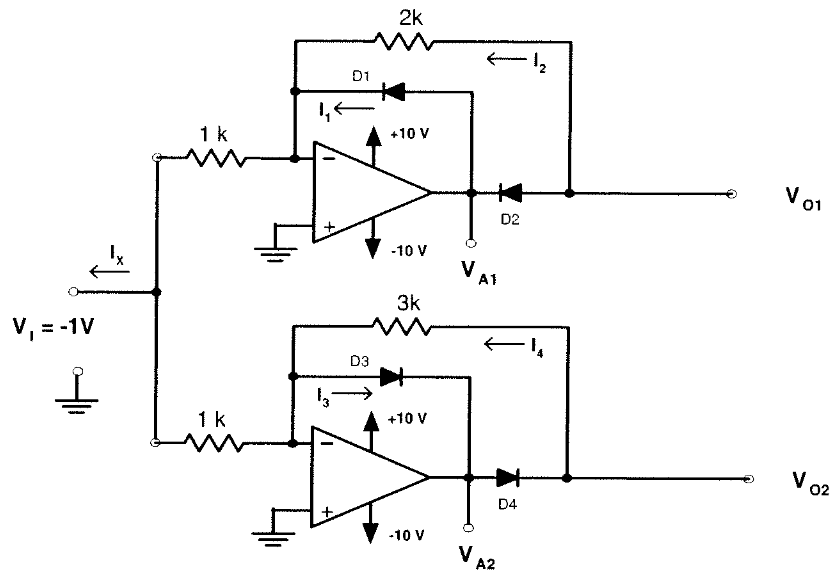
| $R_{in}$ | $I_3$ | $I_2$ | $I_1$ | $V_1$ | $A_{id}$ |
|---|---|---|---|---|---|
| 20kΩ | -0.3mA | 0.3mA | 0 | 30V | 5 V/V |

**Q3(b).** [12 marks] For the circuit shown below, assume the Op-AMP and all components to be ideal. **(i)** Find the differential gain $\mathbf{A_{id}} = \mathbf{V_o/V_{id}}$, **(ii)** Find the labeled currents and voltages, $\mathbf{V_1}$, $\mathbf{I_1}$, $\mathbf{I_2}$ and $\mathbf{I_3}$, if $\mathbf{V_{id}}$=6V (iii) Find $\mathbf{R_{in}}$.




| $A_{id}$ | $V_1$ | $I_1$ | $I_2$ | $I_3$ | $R_{in}$ |
|---|---|---|---|---|---|
| 5V/V | 30V | 0 | 0.3mA | -0.3mA | 20kΩ |

**Q4(a).** [15 marks] For the circuit shown below, assume each diode exhibits a **0.7V** constant-voltage-drop in the forward-bias mode. For $V_I = -1V$, determine all voltages and currents as indicated, and the status of each diode (On or OFF).




D1 ON, D2 OFF, $I_1 = \frac{0-(-1)}{1k} = 1mA$, $I_2 = 0$

$V_{o_1} = 0$, $V_{A_1} = V_{D_1} = 0.7V$

D3 OFF, D4 ON, $I_3 = 0$, $I_4 = \frac{0-(-1)}{1k} = 1mA$

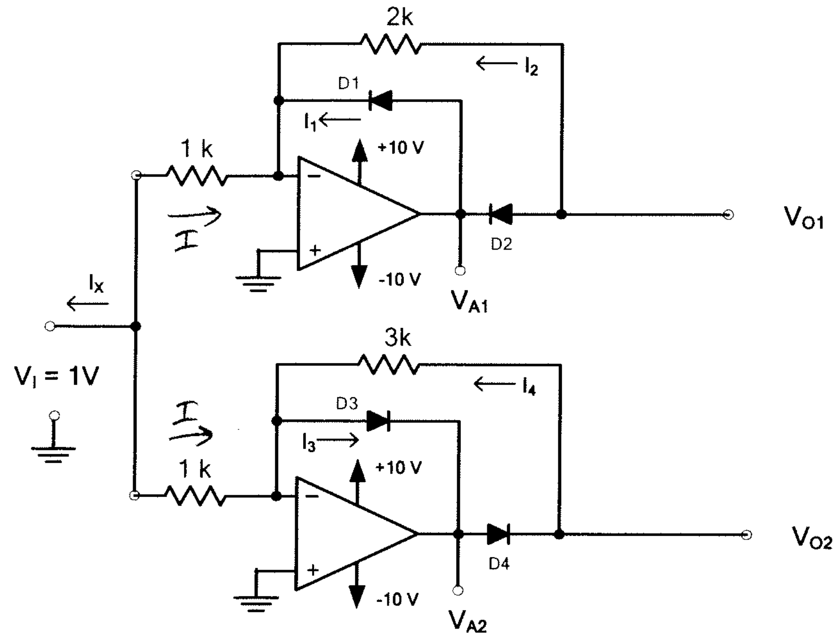
$$V_{o_2} = -1\left(-\frac{3}{1}\right) = 3V$$

$$V_{A_2} = V_{o_2} + V_D = 3.7V$$

$$I_x = 2\left(\frac{1}{1k}\right) = 2mA$$

| $V_I$ | $I_X$ | $I_1$ | $I_2$ | $V_{A1}$ | $V_{O1}$ | $I_3$ | $I_4$ | $V_{A2}$ | $V_{O2}$ | $D_1$ | $D_2$ | $D_3$ | $D_4$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| -1V | 2mA | 1mA | 0 | 0.7V | 0 | 0 | 1mA | 3.7V | 3V | On / Off | On / Off | On / Off | On / Off |

**Q4(a).** **[15 marks]** For the circuit shown below, assume each diode exhibits a **0.7V** constant-voltage-drop in the forward-bias mode. For $\mathbf{V_I = +1V}$, determine all voltages and currents as indicated, and the status of each diode (On or OFF).




D1 OFF, D2 ON, $I_2 = -\frac{1}{1k} = -1mA$

$V_{O_1} = V_i\left(-\frac{R_2}{1}\right) = -2V$

$V_{A_1} + V_{D_2} - (I_2)2 = 0 \Rightarrow V_{A_1} = -0.7 - (1)(2) = -2.7V$

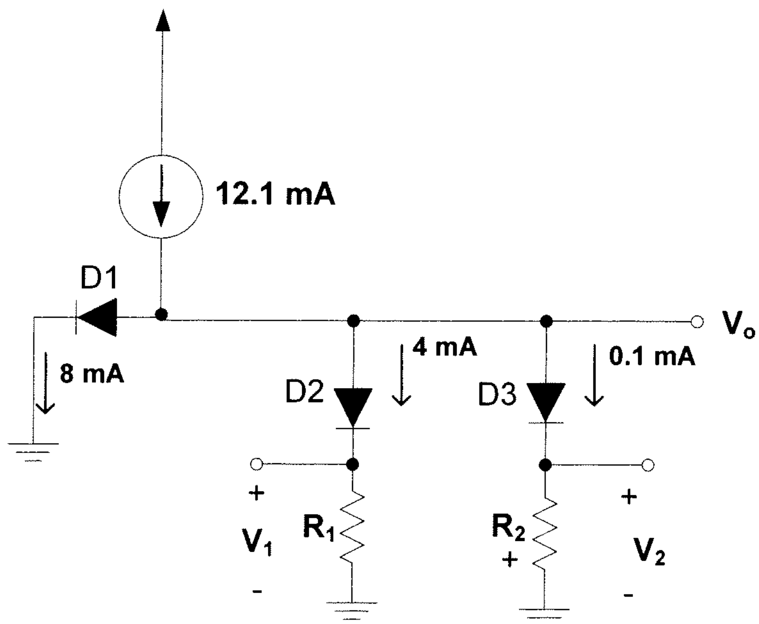
D3 ON, D4 OFF, $\Rightarrow V_{O_2} = 0$, $V_{A_2} = -V_{D3} = -0.7V$

$I_4 = 0$, $I_3 = I = \frac{1}{1k} = 1mA$

$I_x = -(2I) = -2mA$

| $V_I$ | $D_4$ | $D_3$ | $D_2$ | $D_1$ | $V_{O2}$ | $V_{A2}$ | $I_4$ | $I_3$ | $V_{O1}$ | $V_{A1}$ | $I_2$ | $I_1$ | $I_X$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1V | On<br>Off | On<br>Off | On<br>Off | On<br>Off | 0 | -0.7V | 0 | 1mA | -2V | -2.7V | -1mA | 0 | -2mA |

**Q4(b).** **[12 marks]** For the circuit shown below, assume the diodes to be *identical*. The diode characteristic is such that it has a forward-bias voltage of **0.7V** at **1mA** current and its voltage changes by **0.1V per decade** change in current (*note:* $2.3nV_T = 0.1V$). Find the voltages as indicated.




$V_o = V_{D1} = 0.7 + 0.1 \log \frac{8}{1} = 0.79V$

$V_1 = V_o - V_{D2}$ , $\Rightarrow$ $V_{D2} = 0.7 + 0.1 \log \frac{4}{1} = 0.76V$

So,

$V_1 = 0.79 - 0.76 = 0.03V$

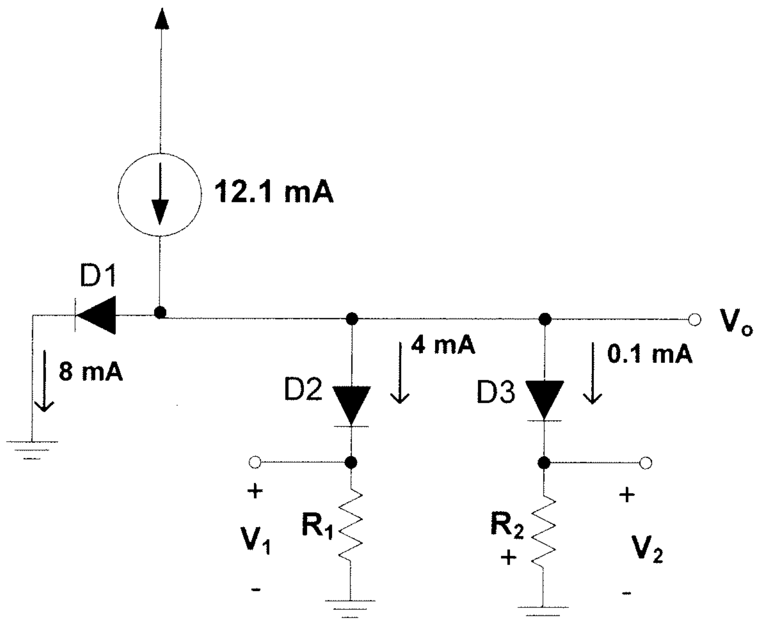
$V_2 = V_o - V_{D3}$ $\Rightarrow$ $V_{D3} = 0.7 + 0.1 \log \frac{0.1}{1} = 0.6V$

So

$V_2 = 0.79 - 0.6 = 0.19V$

| $V_o$ | $V_2$ | $V_1$ |
|---|---|---|
| 0.79V | 0.19 V | 0.03V |

**Q4(b).** **[12 marks]** For the circuit shown below, assume the diodes to be *identical*. The diode characteristic is such that it has a forward-bias voltage of **0.7V** at **1mA** current and its voltage changes by **0.1V per decade** change in current (*note:* $2.3nV_T = 0.1V$). Find the voltages as indicated.




| $V_1$ | $V_2$ | $V_o$ |
|---|---|---|
| 0.03V | 0.19V | 0.79V |

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