Tristan Denning

107/100+

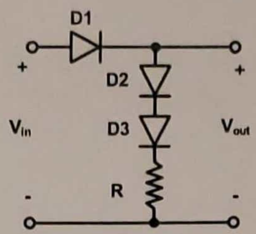
ECE 310 – Microelectronics I

Prof. Suat Ay **Homework #3** *Fall 2021*

(Due Date: 10/01/2021, 8.30am)

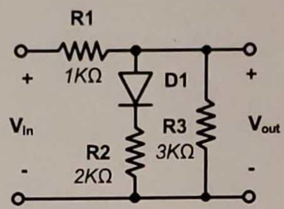
1. (20pts) For the circuit shown, where $I_S=2\times10^{-12}$ (A) for the diodes and R=10KΩ. Calculate V_{out}, and I_R for a) V_{in}=3.3V, and for b) V_{in}=5V. Assume room temperature, and V_T=26mV.

20



2. (30pts) For the circuit shown below, where $I_S=5\times10^{-15}$ (A) for the diodes, calculate V_{out} and I_D for a) V_{in}=1.5V and for b) V_{in}=3V. Assume room temperature, and V_T=26mV.

30



3. (30 pts) For the circuit shown, assume diodes are identical and $V_{D,ON}$=0.75V.

   a. (20pts) Find I/O curve of the circuit for V_1=0V, V_2=1V
   b. (10pts) Find V_1 and V_2 voltages that allow circuit to pass only input signals between 0 and 3V and draw the new I/O curve.

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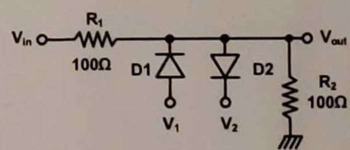
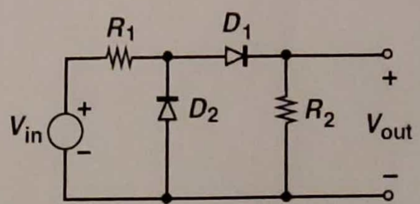


4. (30pts) Use R_1 = 500 Ω, and R_2 = 1kΩ for the circuit shown below. a) Use SPICE (Cadence) simulator to plot the input/output characteristic of the circuit for $-5V<V_{in}<+5V$. b) Also, plot the current flowing through R_1 as a function of V_{in}. c) Explain the function of the circuit based on your simulations. Use 1N4002 diode model (one you use in ece311 labs) for your simulations.

30



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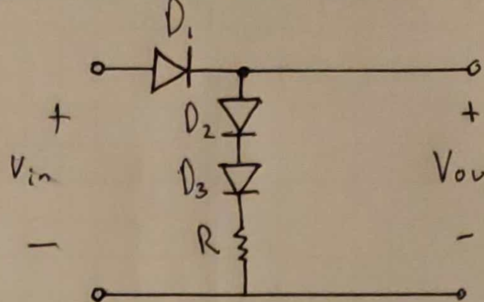
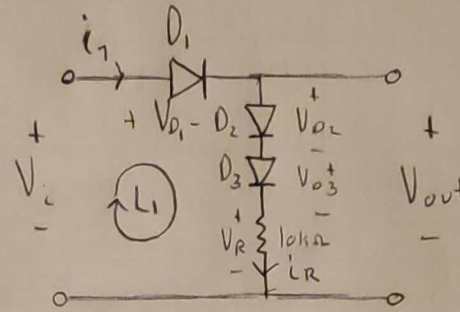
1 **Situation:** For the given circuit, $I_S = 2\times10^{-12}$ (A) for the diodes, and $R = 10k\Omega$. Calculate V_{out} and I_R for a.) $V_{in} = 3.3V$, and b.) $V_{in} = 5V$. Assume room temperature, and $V_T = 26mV$.



2 **Goal:** To calculate the output voltage and resistor current I_R given $V_{in} = 3.3V$ and $V_{in} = 5V$ at room temperature with a resistor value $R = 10k$ for the above circuit.

3 **Plan:** To use KVL along with known equations for diode current and voltage to evaluate the output voltage for the two given input voltages.

4 **Solution:** Redraw



Observe: $i_1 = i_R$

$V_{D_1} = V_{D_2} = V_{D_3}$ * Same I_S

Given: $i_s = 2\times10^{-12}$ $V_T = 26mV$

$R = 10000\ \Omega$

KVL on L_1: $V_i - V_{D_1} - V_{D_2} - V_{D_3} - V_R = 0$

$V_i - 3V_D - 10000\, i_R = 0$ ① * V_R Ohm's law

Known Eqn: $V_{out} = V_T \ln\left(i_R / i_s\right)$

$V_{out} = 26\times10^{-3} \ln\left(\frac{i_R}{2\times10^{-12}}\right)$ ②

② → ① $V_i - 3\left(26\times10^{-3} \ln\left(\frac{i_R}{2\times10^{-12}}\right)\right) - 10000\, i_R = 0$ ③

a.) $V_{in} = 3.3V$

$\Rightarrow$ $3.3 - 3\left(26\times10^{-3} \ln\left(\frac{i_R}{2\times10^{-12}}\right)\right) - 10000\, i_R = 0$

* Solve 1 eqn for 1 unknown with calculator

$\boxed{1}$ (continued)

For $V_{in} = 3.3V$, Solving eqn ③ for i_R yields:

$$i_R = 0.000187 \text{ A}$$

$$\boxed{i_R = 0.187 \text{ mA}}$$

$V_{out}\big|_{V_{in}=3.3V}$

KVL Right Side:
$$V_{out} = V_{D3} + V_{D2} + V_R$$
$$V_{out} = 2V_D + 10000\, i_R$$
$$V_{out} = 2V_T \ln\left(\frac{i_R}{i_S}\right) + 10000\, i_R \quad ④$$

Plug in $i_R = 0.12\text{mA}$

$$V_{out} = 2\left(26\times10^{-3} \ln\left(\frac{0.187\times10^{-3}}{2\times10^{-12}}\right)\right) + 10000(0.187\times10^{-3})$$

$$\boxed{V_{out} = 2.824 \text{ V}}$$

b.) $V_{in} = 5V$

Solve $I_R\big|_{V_{in}=5V}$.

Solve eqn ③ for I_R with $V_{in} = 5V$.

$$\Rightarrow 5 - 3\left(26\times10^{-3}\left(\frac{i_R}{2\times10^{-12}}\right)\right) - 10000\, i_R = 0$$

$$\therefore \boxed{i_R = 0.352 \text{ mA}}$$

Solve $V_{out}\big|_{V_{in}=5V}$

Plug $i_R = 0.352\text{mA}$ into eqn ④:

$$V_{out} = 2\left(26\times10^{-3} \ln\left(\frac{0.352\times10^{-3}}{2\times10^{-12}}\right)\right) - 10000(0.352\times10^{-3})$$

$$\boxed{V_{out} = 4.507 \text{ V}}$$

$\boxed{1}$ (continued)

s Sanity Check:

Check KVL's with calculated Values

a.) $V_o = V_i - V_{out}$

$V_o = 3.3 - 2.824$

$V_o = 0.46 \ V$

$V_R = 10000 \ i_R$

$= 10000(0.187 \times 10^{-3})$

$V_R = 1.87 \ V$

KVL on L_1: $V_i - 3V_o - V_R = 0$

$3.3 - 3(0.46) - 1.87 \cong 0$

$0.05 \cong 0$

∴ Reasonable answers for i_R, V_{out} with slight error.

b.) $V_o = 5 - 4.507$

$V_o = 0.493 \ V$

$V_R = 10000(0.352 \times 10^{-3})$

$V_R = 3.52 \ V$

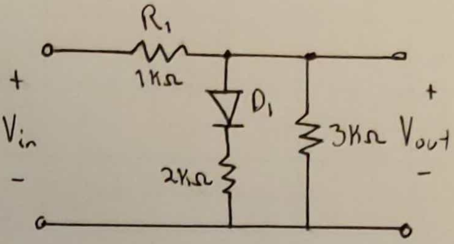
KVL on L_1: $V_i - 3V_o - V_R = 0$

$5 - 3(0.493) - 3.52 = 0$

$0.001 \cong 0$

∴ Reasonable answers for i_R, V_{out} with Very Small error

2. 1 Situation For the given circuit, $I_S = 5\times10^{-15}(A)$. For the diode, calculate V_{out} and I_D for:
a.) $V_{in} = 1.5V$ and for
b.) $V_{in} = 3V$. Assume Room temperature and $V_T = 26mV$



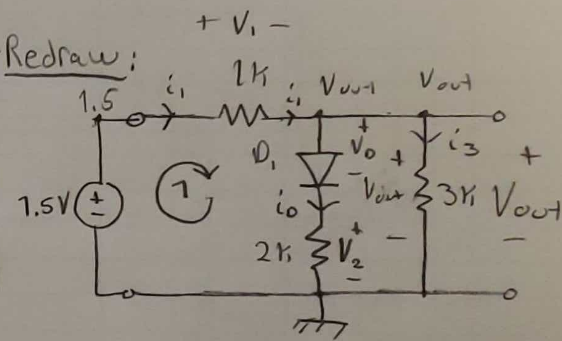
2 Goal: To calculate the output voltage, V_{out}, and Diode current I_D for $V_{in} = 1.5V$ and $V_{in} = 3V$ at room temperature.

3 Plan To use fundamental circuit analysis techniques along with known equations for diode current and voltage to solve for V_{out} and I_D for the given parameters for part a.) and b.)

4 Solution

Part a.) $V_{in} = 1.5V$

Redraw:



given: $I_S = 5\times10^{-15}$ (A)
$V_T = 26\ mV$

Assume: $n = 1$

Known: $V_D = V_T \ln\left(\frac{i_D}{i_S}\right)$

$I_D = I_S\, Exp\left(\frac{V_D}{nV_T}\right)$

Nodal Analysis:

$$i_1 = i_D + i_3$$

$$\frac{(1.5 - V_{out})}{1000} = i_S Exp\left(\frac{V_D}{V_t}\right) + \frac{V_{out}}{3000}$$

$$\frac{(1.5 - V_{out})}{10000} = 5\times10^{-15} exp\left(\frac{V_D}{26\times10^{-3}}\right) + \frac{V_{out}}{3000} \quad (1)$$

KVL Right Loop: $V_{out} - V_D - V_2 = 0$

$V_{out} - V_D - 2000\,i_D = 0$ $\quad\because$ ohm's law R_{2k}

$$V_{out} - V_D - 2000\left(5\times10^{-15} exp\left(\frac{V_D}{26\times10^{-3}}\right)\right) = 0 \quad (2)$$

* 2 eqn's (1) and (2) with 2 unknowns V_{out}, V_D

$\boxed{2.}$ (continued)

Part a.) (continued)

Solve eqn's ① and ② with calculator yields:

$$V_{out} = 0.991 \text{ V}$$
$$V_D = 0.6319 \text{ V}$$

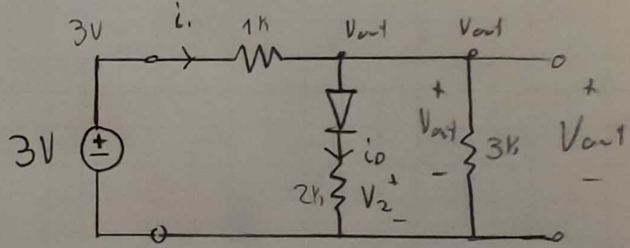
Plug $V_D \rightarrow I_D$ eqn:

$$I_D = 5\times10^{-15} \exp\left(\frac{0.6319}{26\times10^{-3}}\right)$$
$$I_D = 0.179 \text{ mA}$$

$V_{out}, I_D \Big|_{V_{in}=1.5V}$: $\boxed{\begin{array}{l} V_{out} = 0.991 \text{ V} \\ I_D = 0.179 \text{ mA} \end{array}}$

Part b.)

New Circuit:



Solve eqn's ① and ② for V_{out}, V_D. Exchange V_{in} in eqn ① from $1.5 \text{ V} \rightarrow 3 \text{ V}$

$$\Longrightarrow \frac{(3 - V_{out})}{10000} = 5\times10^{-15} \exp\left(\frac{V_D}{26\times10^{-3}}\right) + \frac{V_{out}}{3000} \quad ①$$
$$V_{out} - V_D - 2000\left(5\times10^{-15} \exp\left(\frac{V_D}{26\times10^{-3}}\right)\right) = 0 \quad ②$$

yields:
$$V_{out} = 1.817 \text{ V}$$
$$V_D = 0.6623 \text{ V}$$
$$I_D = 5\times10^{-15}\left(\exp\left(\frac{0.6623}{26\times10^{-3}}\right)\right)$$
$$I_D = 0.577 \text{ mA}$$

$V_{out}, I_D \Big|_{V_{in}=1.5V}$: $\boxed{\begin{array}{l} V_{out} = 1.817 \text{ V} \\ I_D = 0.577 \text{ mA} \end{array}}$

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2. (continued)

5 Sanity Check:

Check $V_D = V_T \ln\left(\frac{I_o}{I_S}\right)$

For diode in a.) and b.), then KVL Right side.

a.)

$$V_D = 26\times10^{-3} \ln\left(\frac{0.179\times10^{-3}}{5\times10^{-15}}\right)$$

$$V_D = 0.6318\ V$$

$$V_2 = 2000\,(0.179\times10^{-3})$$

$$V_2 = 0.358\,V$$

KVL: $V_{out} = V_D + V_2$

$$V_{out} = 0.9898$$

$$0.991 \cong 0.9898$$

∴ Reasonable calculations with low % difference.

b.)

$$V_D = 26\times10^{-3} \ln\left(\frac{0.577\times10^{-3}}{5\times10^{-15}}\right)$$

$$V_D = 0.6623$$

$$V_2 = 2000\,(0.577\times10^{-3})$$

$$V_2 = 1.154$$

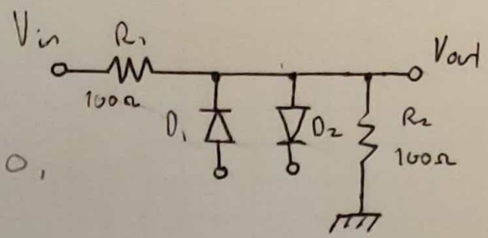
$$V_{out} = V_D + V_2$$

$$V_{out} = 1.8163$$

$$1.817 \cong 1.8163$$

∴ Reasonable calculations with low % difference.

$\boxed{3(a)}$ 1 **Situation:** For the circuit shown, assume diodes are identical, and $V_{D,on} = 0.75V$. a.) Find the I/O Curve for the circuit for $V_1 = 0$, $V_2 = 1V$.

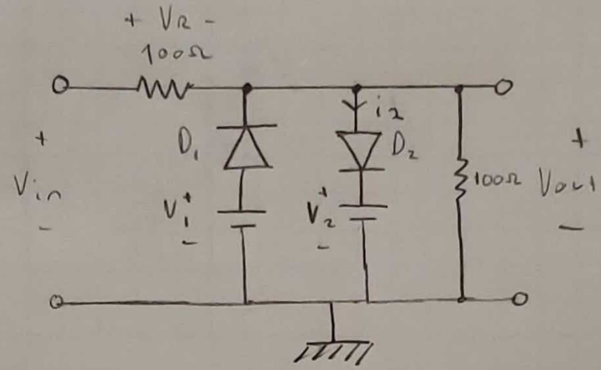


2 **Goal:** Find the input/output characteristics for the given circuit, then determine the I/O Curve.

3 **Plan:** Utilize the Constant Voltage Model (CVM) for diodes along with fundamental circuit analysis techniques to determine the input/output behavior.

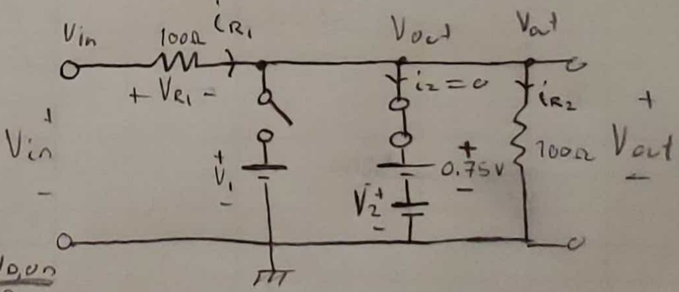
4 **Solution:**

Redraw:



State ① $D_1 = \text{OFF}$, $D_2 = \text{On}$

The instant D_2 turns on:



$i_{D2} = 0$

$V_{D_2,on} = 0.75V$

$V_2 = 1V$

$$\therefore i_{R_2} = \frac{(1+0.75)}{100\Omega} = \frac{1+V_{D,on}}{R}$$

$$i_{R_2} = \frac{1.75}{100} = i_{R_1} \qquad \because i_2 = 0$$

$$\therefore V_{in} = V_{out} + V_{R_1}$$

$$= i_{R_2}(R) + i_{R_1}(R)$$

$$= 2\left(\frac{1.75}{100}\right)100$$

$V_{in} = 3.5$ for D_2 to turn on

$\boxed{3(a)}$ (continued)

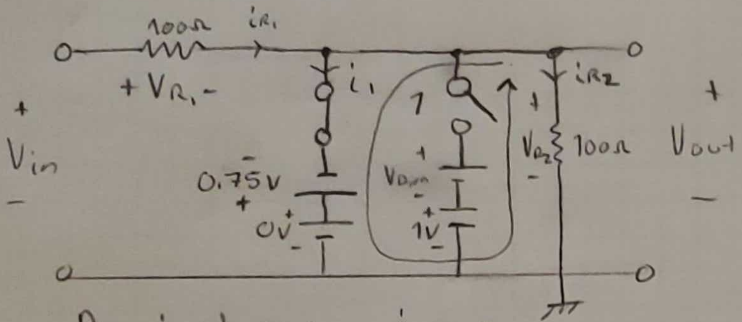
KUL Outside Loop: $V_{out} = V_{in} - V_{R_1}$

$$V_{out} = 3.5 - 100\left(\frac{1.75}{100}\right)$$

$$V_{out} = 1.75$$

$\therefore$ For $V_{in} \geq 3.5V$: $D_1 = \text{OFF}$, $D_2 = \text{on}$, $V_{out} = 1.75 V$ (*)

State (2) $D_1 = \text{on}$, $D_2 = \text{OFF}$



D_1 just on: $i_1 = 0$

$V_{out} = V_{R_2} = 0V - 0.75V$ $\because$ KVL 1

$V_{out} = -0.75 V$

$$i_{R_1} = i_{R_2} = \frac{-0.75}{100}$$

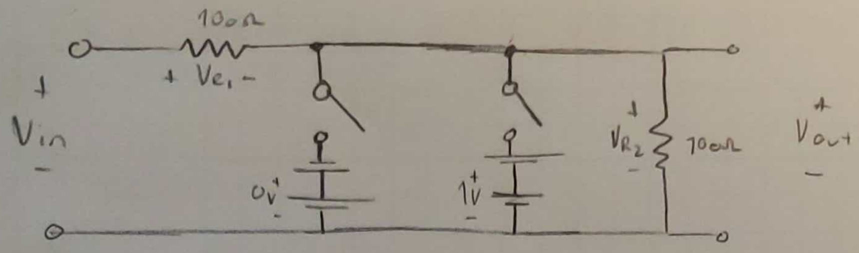
$$\therefore V_{in} = V_{out} + V_{R_1} = -0.75 + \left(-\frac{0.75}{100}\right)\cdot 100$$

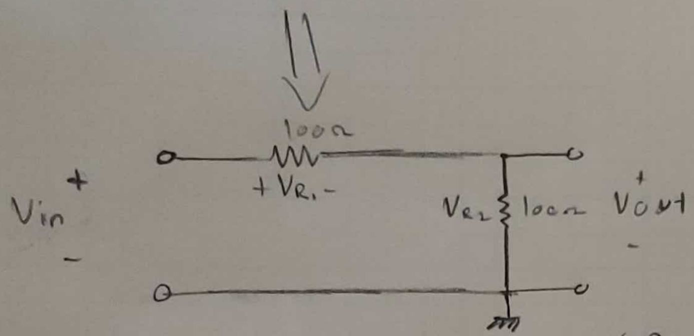
$V_{in} = -1.50 V$ for D_1 to turn on

$\therefore$ For $V_{in} \leq -1.50 V$: $D_1 = \text{on}$, $D_2 = \text{OFF}$, $V_{out} = -0.75 V$ (*)

$\boxed{3(a)}$ (continued)

State (3) D_1 = OFF, D_2 = OFF



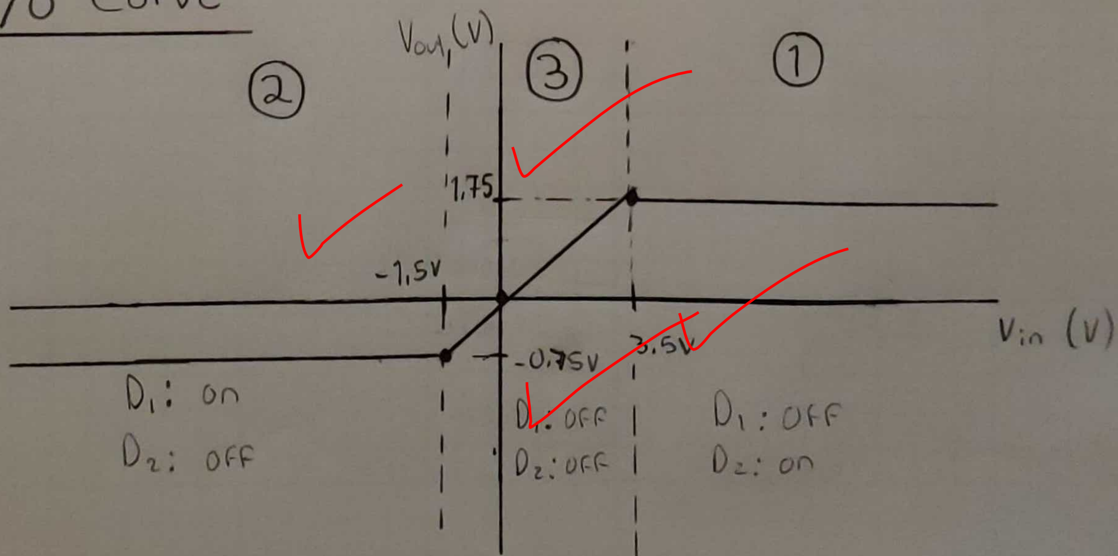


Voltage Division: $V_{out} = \left(\frac{R_2}{R_1+R_2}\right) V_{in}$

$V_{out} = \frac{100}{200} V_{in}$

$V_{out} = \frac{1}{2} V_{in}$ $\therefore$ Slope of I/O curve from [-1.5, 3.5]

I/O Curve



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$\boxed{3(a)}$ (continued)

5 Sanity Check

The process was intuitive and the results are reasonable and make sense.

3(b)

1. Situation: For the same situation outlined in 3(a), find V_1 and V_2 voltages that allow the circuit to pass only input signals between 0 and 3V. Then draw the new I/O curve.

2. Goal: Find the values for V_1 and V_2 that allow the circuit to pass only input values of 0 to 3V. Then draw the corresponding curve for i/o.

3. Plan:
To use the slope of ½ from part 4(a) to calculate which values of V_{out} shift the input voltage at D_1 and D_2 to 0 and 3 V respectively.

4. Solution.

Known from 4(a): Between regions ② and ①,

$$V_{out} = \frac{1}{2} V_{in}$$

For left bound: V_1 on D_1:

$$V_{out} = -0.75\text{ V} = -V_{o,on} \quad \because \text{From } ②$$

We want $V_{in} = 0$ on left bound:

$$\therefore \quad V_{out}' = \frac{1}{2}(0)$$

$$V_{out}' = 0$$

$$V_{out}' - V_{out} = V_1 \quad * \text{ to correct left bound}$$

$$0 - (-0.75) = V_1$$

$$\therefore \boxed{V_1 = 0.75\text{ V}}$$

For Right bound V_2 on D_2:

$$\therefore \quad V_{out}' = \frac{1}{2}(3)$$

$$V_{out}' = 1.5\text{ V}$$

$$V_{out} = 1.75 \quad \because \text{From } ①$$

$$V_2 = V_{out}' - V_{out}$$

$$V_2 = 1.5 - 1.75$$

$$\boxed{V_2 = -0.25\text{ V}}$$

−3

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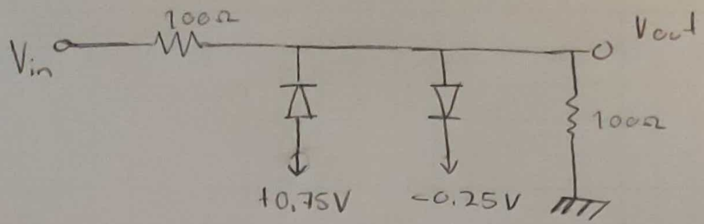
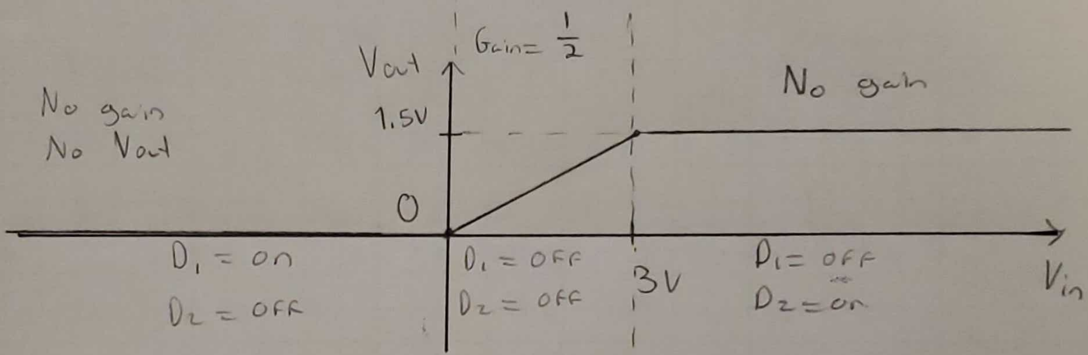
$\boxed{3(b)}$ (Continued)

New Circuit

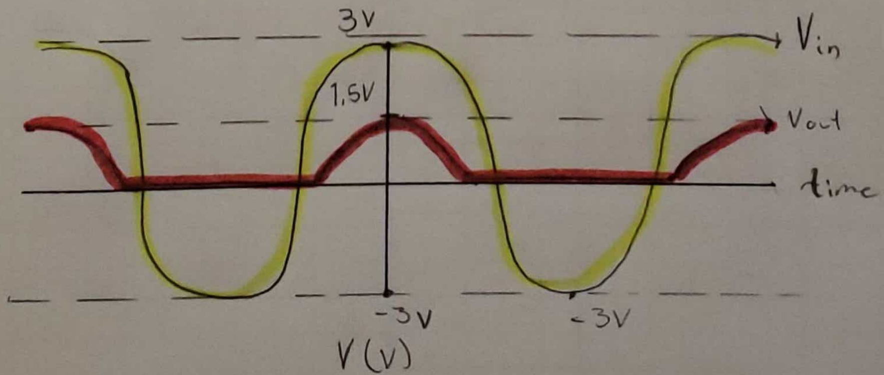


I/O Curve



<u>Sanity Check</u>

Example Input / output vs t



V_{in}
V_{out}

V_{out} only "Senses" V_{in} between $0 < V_{in} < 3$ V then V_{out} can only reach a peak of 1.5 Volts.

* For any $V_{in} > 3$V, V_{out} will <u>flatline</u> on the V vs t graph

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4(a)

[1]**Situation:** Use Cadence simulator to plot the i/o characteristic for the circuit below for -5 < V_{in} < 5.

Schematic

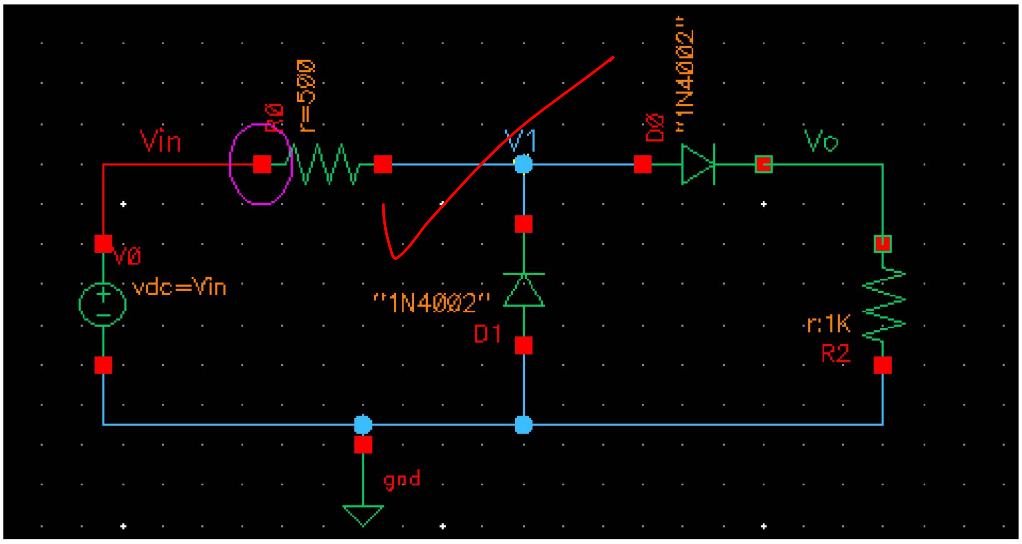

Figure 1: Schematic

DC Response Simulation Results – V_{out} vs V_{in}

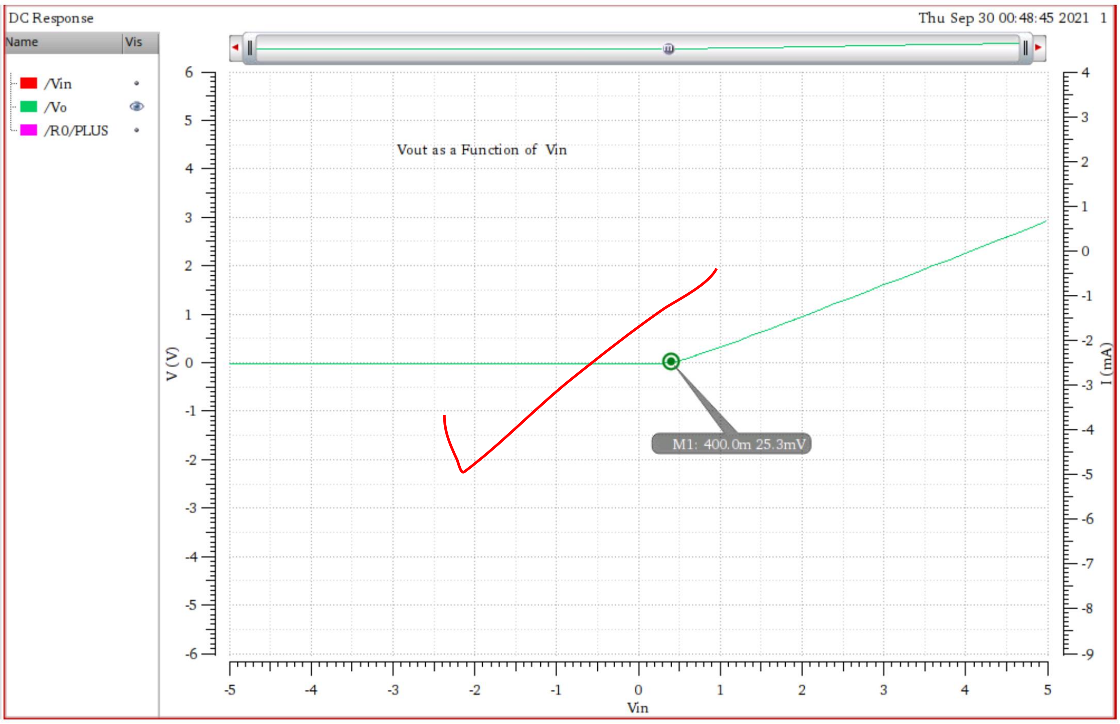

Figure 2

4(b)

[1]Situation: Plot the current flowing through R_1 as a function of V_{in}.

DC Response Simulation Results – I_{R1} vs V_{in}

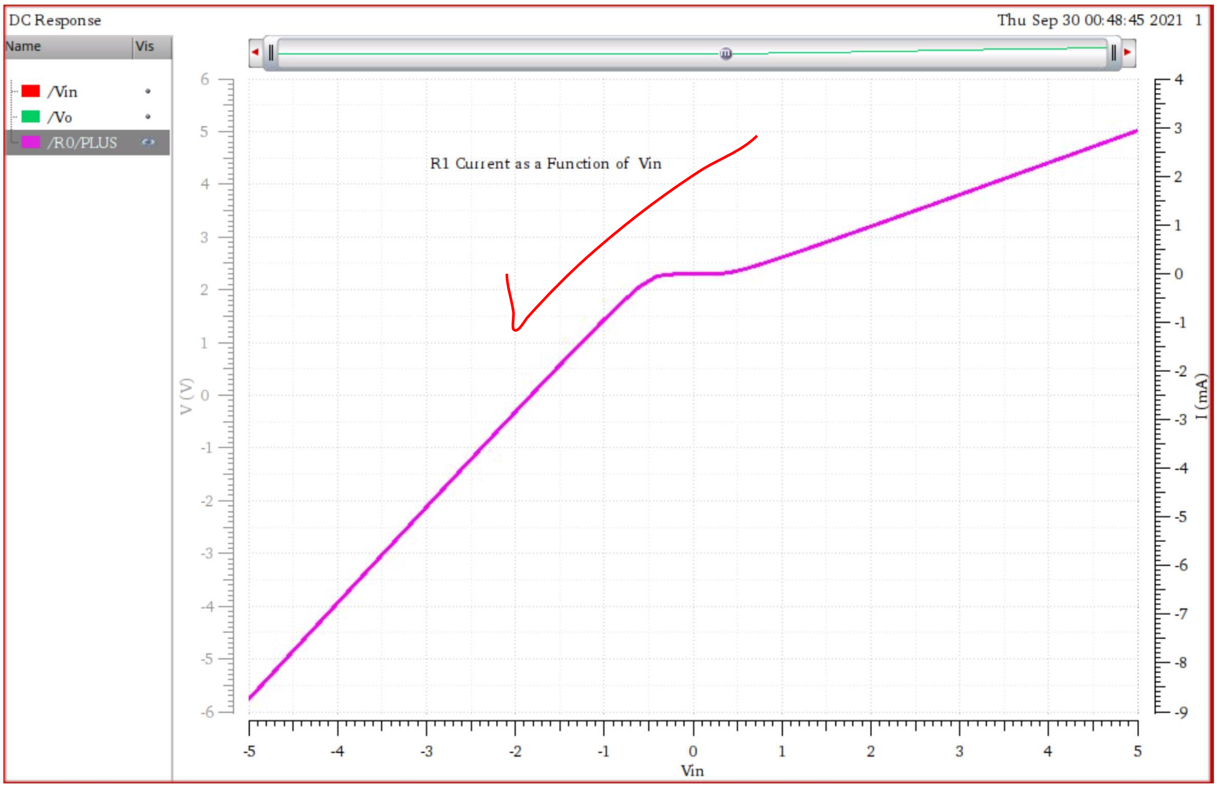

Figure 3

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4(c)

1 **Situation:** For the Circuit illustrated in 4(a) Figure 1, Use the results from the I/O and I_R vs V_{in} Simulations to Explain the function of the Circuit.

2 **Goal:** Understand and explain the function of the given circuit.

3 **Plan:** " "

4 **Solution:**

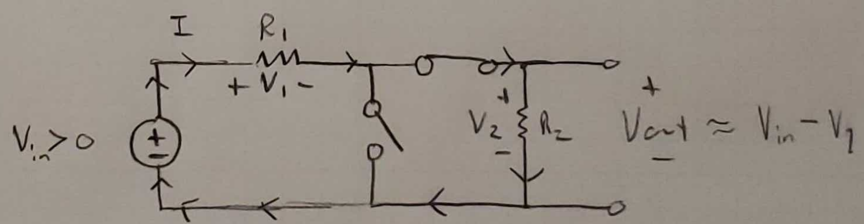
When V_{in} reaches a value of about 0.4 V, D_1 turns on and allows current to flow through to V_{out} Node. This is shown in Figure 1 of 4(a) with a marker where V_{out} just barely begins to gain voltage. After this value, V_{out} approaches a linear relationship with V_{in} including voltage drops across R_1, R_2, and D_1. This voltage drop results in a slope of less than 1 for $V_{in} > 0.4$.

For V_{in} slightly less than 0 and beyond, D_2 turns on, D_1 is OFF. Then No voltage is transfered to V_{out}.

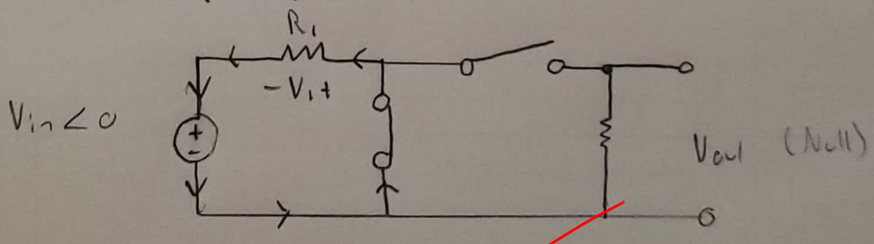
To the left of $V_{in} = 0$, the I/O curve has a slope closer to 1, because less voltage drops across resistance. Here, the current through R_1 is Negative

5 **Sanity Check.** Quasi-Ideal Model to illustrate operation:

$V_{in} \gtrsim 0.4$ V



$V_{in} \lesssim 0$



The circuit works as a half-wave rectifier with voltage drops across R_1 and R_2.

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