

Prof. Neureuther

EECS 42
Fall 2003

Homework 8 Solutions

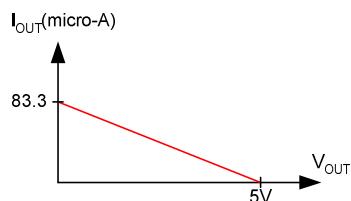
Problem 8.1. Three-Terminal Devices

(a)

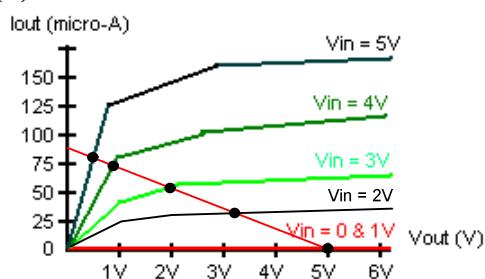
$$I_{OUT} = \frac{5V}{60k} = 83mA \text{ for the resistor-voltage network on the top.}$$

$$V_{TH} = V_{DD} = 5V$$

The plot is shown below:



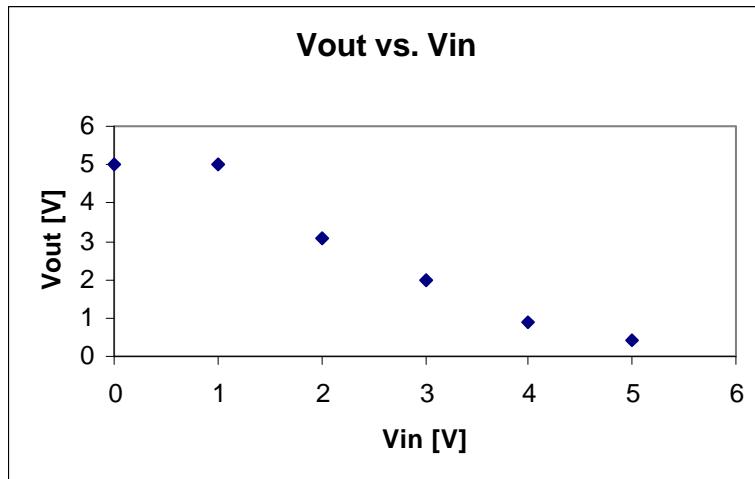
(b)



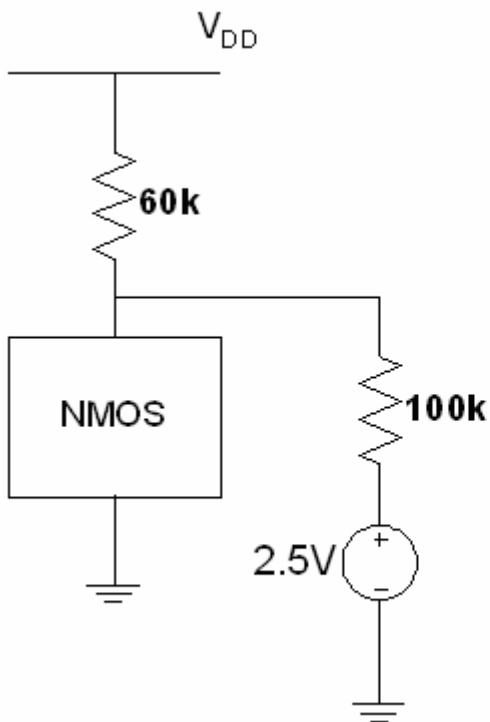
V_{IN}	V_{OUT}
0V	5V
1V	5V
2V	3.1V
3V	2V
4V	0.9V
5V	0.4V

(Note: full credit will be given if the V_{IN} operating point for $V_{IN} = 2V$ is not shown – it was accidentally left out of the graph handed out)

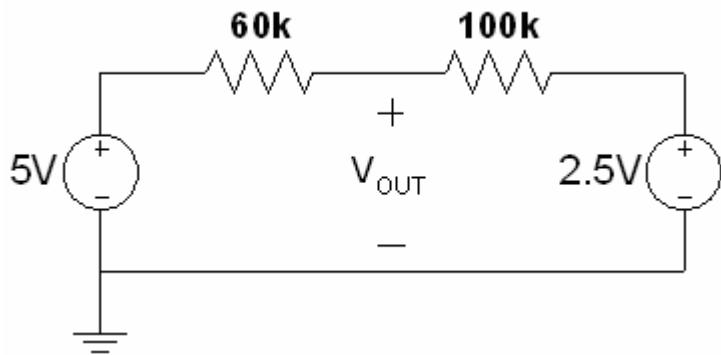
(c)



Problem 8.2. General Load

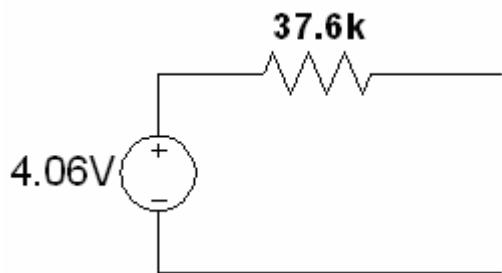


The thevenin equivalent circuit is now solved by removing the NMOS device and just considering the resistor-voltage network.

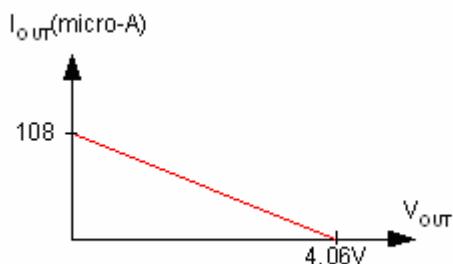


$$V_{\text{OUT}} = V_{\text{OC}} = 4.06 \text{V}$$

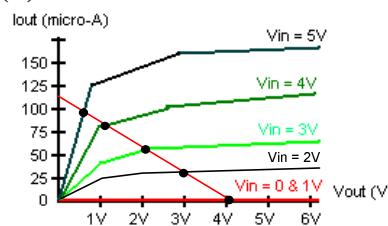
$$R_{\text{TH}} = 60\text{k} \parallel 100\text{k} = 37.6\text{k}$$



(a)



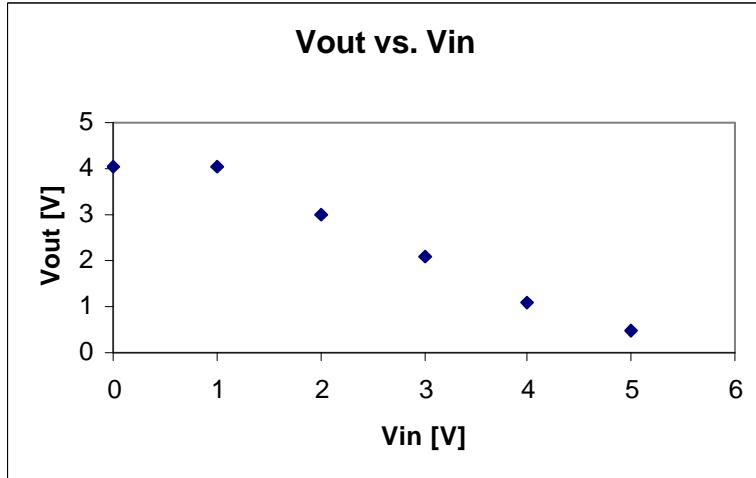
(b)



(c)

V _{IN}	V _{OUT}
0V	4.06V
1V	4.06V

2V	3V
3V	2.1V
4V	1.1V
5V	0.5V



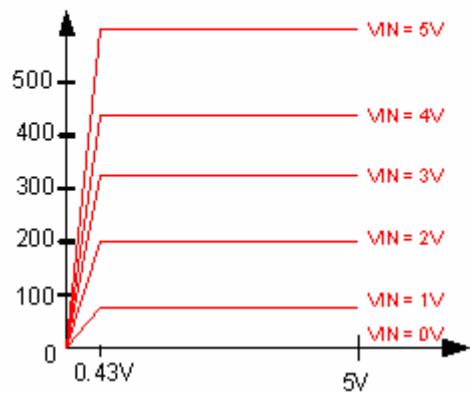
Problem 8.3. CMOS

(a) $I_{OUT-SAT-n} = k_n \left(\frac{W}{L} \right)_n (V_{IN} - V_{Tn}) V_{OUT-SAT-n}$

	V _T (V)	V _{OUT-SAT} (V)	k' (μA/V ²)
NMOS	0.43	0.63	100
PMOS	0.4	1	25

V _{IN}	I _{OUT-SAT-n} [mA]
0	0
1	71.82
2	197.82
3	323.82
4	449.82
5	575.82

I_{OUT} (micro-A)



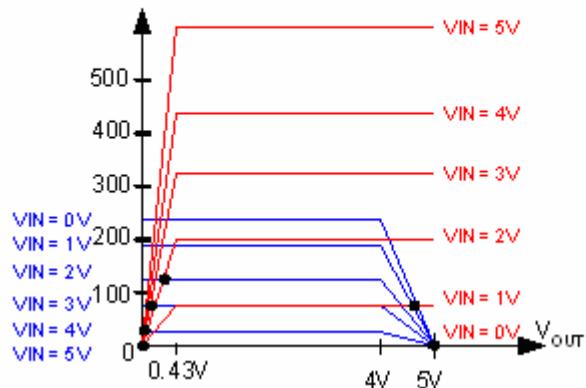
(b)

$$I_{OUT-SAT-p} = k_p \left(\frac{W}{L} \right)_p \left(V_{DD} - V_{IN} - |V_{TP}| \right) V_{OUT-SAT-p}$$

V_{IN}	$I_{OUT-SAT-n}$ [mA]
0	230
1	180
2	130
3	80
4	30
5	0

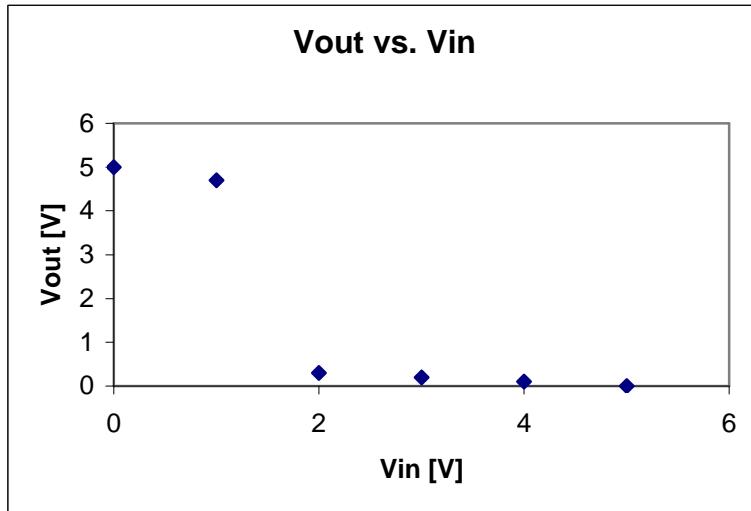
(d)

I_{OUT} (micro-A)



V_{IN}	V_{OUT}
0V	5V

1V	4.7V
2V	0.3V
3V	0.2V
4V	0.1V
5V	0V



Problem 8.4 Sized CMOS Circuits and V_M

The vertical portion of the voltage transfer characteristic occurs essentially when the saturation currents for both of the NMOS and PMOS transistors are set equal to each other with the condition that V_{IN} and $V_{DD} - V_{IN}$ are identical for the NMOS and PMOS transistors, respectively.

$$I_{OUT-SAT-n} = I_{OUT-SAT-p} = k_n \left(\frac{W}{L} \right)_n (V_{IN} - V_{Tn}) V_{OUT-SAT-n} = k_p \left(\frac{W}{L} \right)_p (V_{DD} - V_{IN} - |V_{Tp}|) V_{OUT-SAT-p}$$

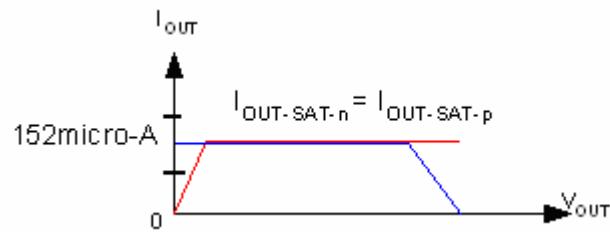
$$\frac{k_n}{k_p} \left(\frac{W}{L} \right)_n \frac{V_{OUT-SAT-n}}{V_{OUT-SAT-p}} (V_{IN} - V_{Tn}) = V_{DD} - V_{IN} - |V_{Tp}|$$

$$\text{Let } \alpha = \frac{k_n}{k_p} \left(\frac{W}{L} \right)_n \frac{V_{OUT-SAT-n}}{V_{OUT-SAT-p}} = \frac{100 \frac{mA}{V}}{25 \frac{mA}{V}} \frac{(2)}{(2)} \frac{0.63V}{1V} = 2.52$$

$$kV_{IN} - kV_{Tn} = V_{DD} - V_{IN} - |V_{Tp}|$$

$$V_{IN} = \frac{V_{DD} + \alpha V_{Tn} - V_{Tp}}{\alpha + 1} = \frac{5V + (2.52)(0.43V) - 0.4V}{2.52 + 1} \\ = 1.61V$$

(b)



(c)

$$aV_{IN} - aV_{Tn} = V_{DD} - V_{IN} - |V_{Tn}|$$

$$a = \frac{V_{DD} - V_{Tp} - V_{IN}}{V_{IN} - V_{Tn}} = \frac{5V - 0.4V - 2.5V}{2.5 - 0.43V} = 1.014$$

$$a = \frac{k_n'}{k_p'} \left(\frac{W}{L} \right)_n \frac{V_{OUT-SAT-n}}{V_{OUT-SAT-p}}$$

$$\left(\frac{W}{L} \right)_p = \frac{2.52}{1.014} = 2.48 = \left(\frac{W}{L} \right)_{p-new} \text{ since } \left(\frac{W}{L} \right)_{p-old} = \left(\frac{W}{L} \right)_n$$

$$\left(\frac{W}{L} \right)_p = 2(2.48) = 5$$