EE 115A

Midterm Exam
Fall 2006

Your Name:

Solutions

Name of Person to Your Left: ____________________

Name of Person to Your Right: ____________________

Time Limit: 2 Hours

1. 10
2. 10
3. 10
4. 10
5. 10
Total: 50

1. Assuming a constant-voltage model,

(a) plot V_{out} as a function of V_{in} if $I_1 = 0$. Show the details of your calculations.

(b) plot V_{out} as a function of V_{in} if I_1 is a constant, positive, ideal current source. Show the details of your calculations. Assume $I_1 R_1 > V_{D,on}$.

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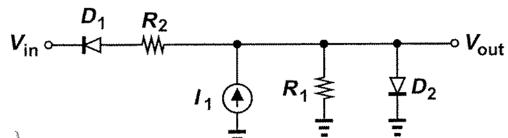
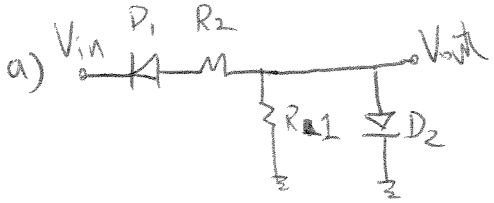
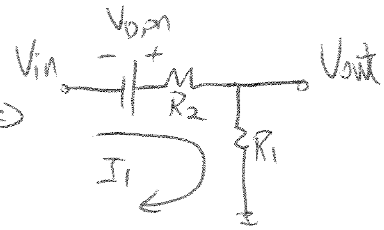


a)

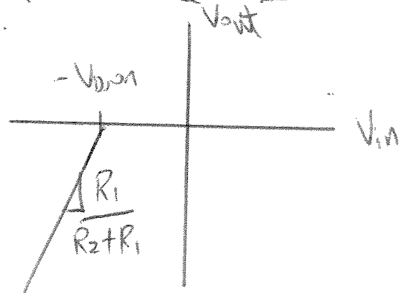


when $V_{in} = -\infty$
D_2 off, D_1 on $\Rightarrow$

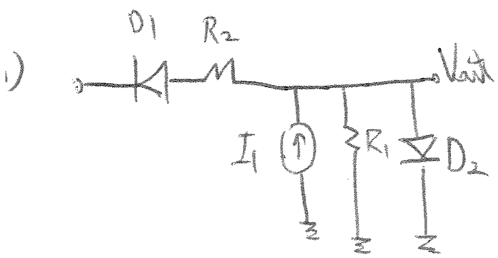


$$I_1 = \left(\frac{V_{in} + V_{D,on}}{R_2 + R_1}\right), \quad V_{out} = \left(\frac{V_{in} + V_{D,on}}{R_2 + R_1}\right) R_1$$

As $V_{in} \uparrow$ and hits $-V_{D,on}$ $I_1 = 0$ hence D_1 turns off and stays off so $V_{out} = 0$.



b)



For $V_{in} > 0$, D_1 is off and I_1 flows into R_1 and D_2 so $V_{out} = V_{D,on}$

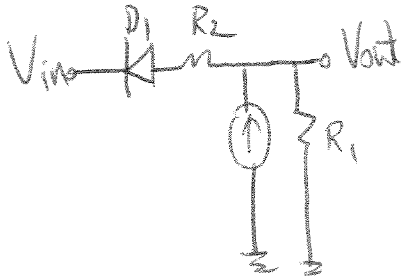
As $V_{in} \downarrow$ and hits 0 D_1 turns on and D_2 is still on.

So let's see when D_2 turns off. Writing a KCL at output we have

1) $I_1 = \frac{V_{out}}{R_1} + \frac{V_{out} - (V_{D,on} + V_{in})}{R_2} + I_{D_2}$, since when D_2 is on $V_{out} = V_{D,on}$ so 1) becomes

$I_1 = \frac{V_{D,on}}{R_1} + \frac{(-V_{in})}{R_2} + I_{D_2} \Rightarrow I_{D_2} = I_1 + \frac{V_{in}}{R_2} - \frac{V_{D,on}}{R_1}$, when $I_{D_2} = 0$ D_2 is off and this happens @ $\frac{V_{in}}{R_2} = -I_1 + \frac{V_{D,on}}{R_1} \Rightarrow V_{in} = \frac{R_2 V_{D,on}}{R_1} - I_1 R_2$

b) when D_2 turns off we have the following circuit.



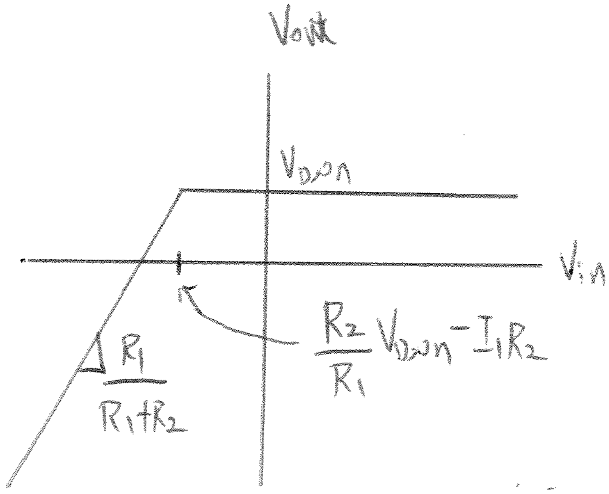
KCL @ output gives us

$$I_1 = \frac{V_{out}}{R_1} + \frac{V_{out} - (V_{D,on} + V_{in})}{R_2}$$

$$\Rightarrow \frac{V_{out}}{R_1} + \frac{V_{out}}{R_2} = I_1 + \frac{(V_{D,on} + V_{in})}{R_2}$$

$$V_{out} = I_1 (R_1 // R_2) + \frac{(V_{in} + V_{D,on})}{R_2} (R_1 // R_2)$$

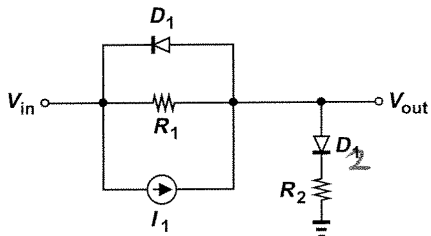
$$V_{out} = \frac{I_1 R_2 R_1}{R_1 + R_2} + \frac{(V_{in} + V_{D,on}) R_1}{R_1 + R_2}$$



2. Assuming a constant-voltage model, 10

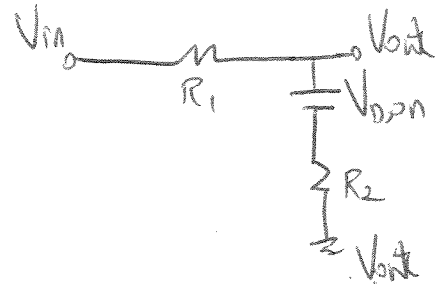
(a) plot V_{out} as a function of V_{in} if $I_1 = 0$. Show the details of your calculations.

(b) plot V_{out} as a function of V_{in} if I_1 is a constant, positive, ideal current source. Show the details of your calculations. Assume $I_1 R_1 > V_{D,on}$.



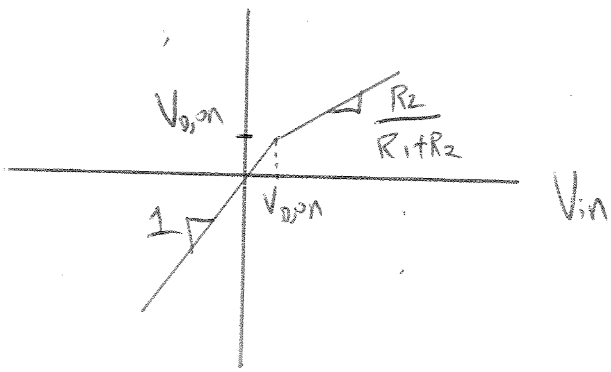
a) When V_{in} is at $-\infty$ D_2 off and D_1 off So $V_{out} = V_{in}$

As $V_{in} \uparrow$ and hits $V_{D,on}$ D_2 turns on and we have the situation below



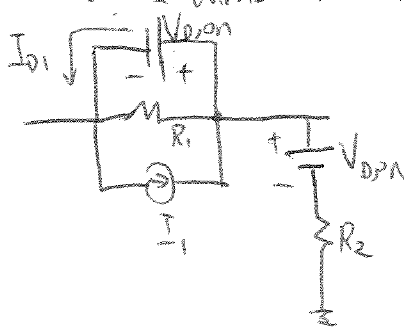
So $V_{out} = V_{D,on} + \left(\frac{V_{in} - V_{D,on}}{R_1 + R_2}\right) R_2$

D_1 will never turn on.



b) When V_{in} is at $-\infty$ D_2 off but D_1 is on since I_1 provides a current, so $V_{out} = V_{in} + V_{D,on}$

As $V_{in} \uparrow$ and hits zero D_2 turns on and we have the circuit below.



KCL at output gives us:

$$I_1 = \frac{V_{out} - V_{D,on}}{R_2} + \frac{V_{D,on}}{R_1} + I_{D_1}$$

$$I_{D_1} = I_1 + \frac{V_{D,on} - V_{out}}{R_2} - \frac{V_{D,on}}{R_1}$$

$$0 = I_1 + \frac{V_{D,on}}{R_2} - \frac{V_{D,on}}{R_1} - \frac{V_{out}}{R_2}$$

2.)

b)

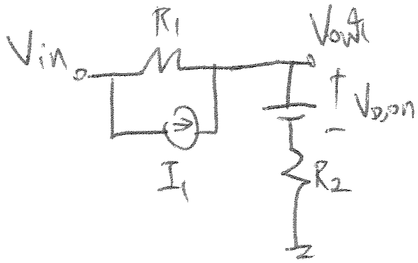
Solving for V_{out} gives us

$$V_{out} = I_1 R_2 + \frac{V_{D,on}(R_1 - R_2)}{R_1}, \quad D_1 \text{ turns off.}$$

Since $V_{out} = V_{D,on} + V_{in}$, $V_{in} = I_1 R_2 + \frac{V_{D,on}(R_1 - R_2)}{R_1} - V_{D,on}$

$$V_{in} = I_1 R_2 - \frac{V_{D,on} R_2}{R_1}$$

Afterwards we have this circuit and



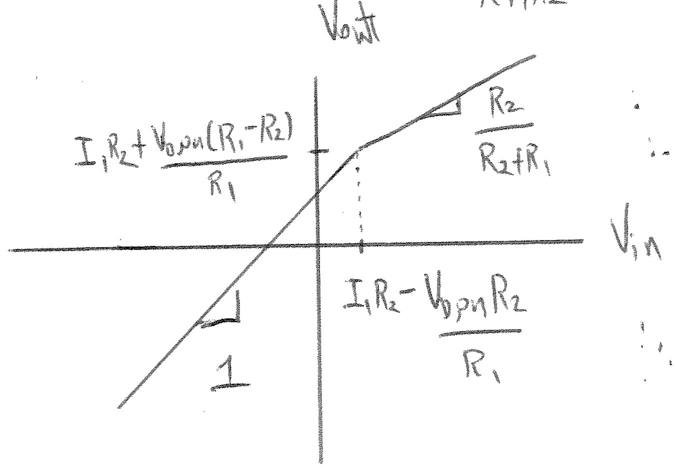
KCL at V_{out} gives us:

$$I_1 = \frac{V_{out} - V_{D,on}}{R_2} + \frac{V_{out} - V_{in}}{R_1}$$

$$V_{out}\left(\frac{1}{R_2} + \frac{1}{R_1}\right) = I_1 + \frac{V_{D,on}}{R_2} + \frac{V_{in}}{R_1}$$

$$V_{out} = (R_2 // R_1) I_1 + \frac{(R_2 // R_1)}{R_2} V_{D,on} + \frac{(R_2 // R_1)}{R_1} V_{in}$$

$$V_{out} = \frac{R_2}{R_2 + R_1} V_{in} + \frac{R_1}{R_1 + R_2} V_{D,on} + \frac{R_2 R_1 I_1}{R_1 + R_2}$$



3. Determine the region of operation of Q_1 in each of the circuits shown below. Assume $I_S = 5 \times 10^{-16}$ A, $\beta = 100$, $V_A = \infty$. You need only show whether the transistor is in active region, saturated, or off. Simply indicate which region and why.

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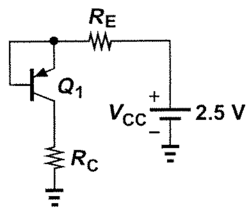
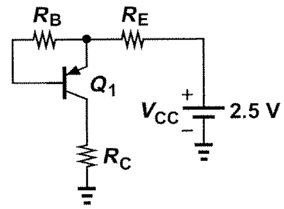
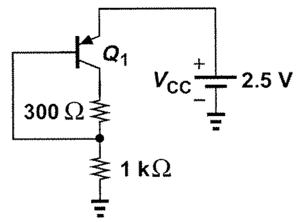


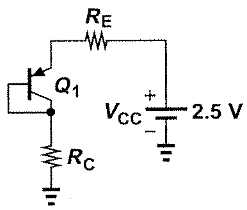
(a)



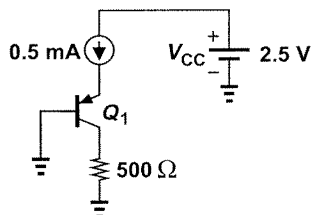
(b)



(c)



(d)



(e)

a) $V_{EB} = 0$ off

b) For $V_{EB} > 0$, I_B has to flow from emitter to base (into the base) which is impossible so, off

c) Collector is higher than base, Saturated (maybe in soft saturated, but doesn't matter still saturated.)

d) $V_{CB} = 0$, so Forward active

e) Collector higher than base, Saturated

4. (a) Consider the circuit shown below, where $I_S = 6 \times 10^{-16}$ A, $\beta = 100$, and $V_A = \infty$. Calculate the operating point of Q_1.

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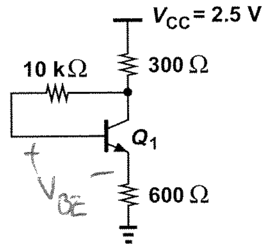

$$2.5 - I_E 300\Omega - I_B 10K - V_{BE} - I_E 600\Omega = 0$$

Since β is large, assume $I_C \approx I_E$ so

$$2.5 - I_C 300 - \frac{I_C}{\beta} 10K - V_{BE} - I_C 600\Omega = 0$$

$$I_C = \frac{2.5 - V_{BE}}{0.6 + \frac{10}{100} + 0.3}$$, guess $V_{BE} = 0.75$ and then iterates

I_C converges to 1.75 mA

$V_{BE} \approx 0.746$V

$V_{CE} \approx 0.925$ V

5. Compute the voltage gain and the input impedance of the circuits shown below. Assume $V_A = \infty$ and $\beta \gg 1$. Place your answers within the boxes.

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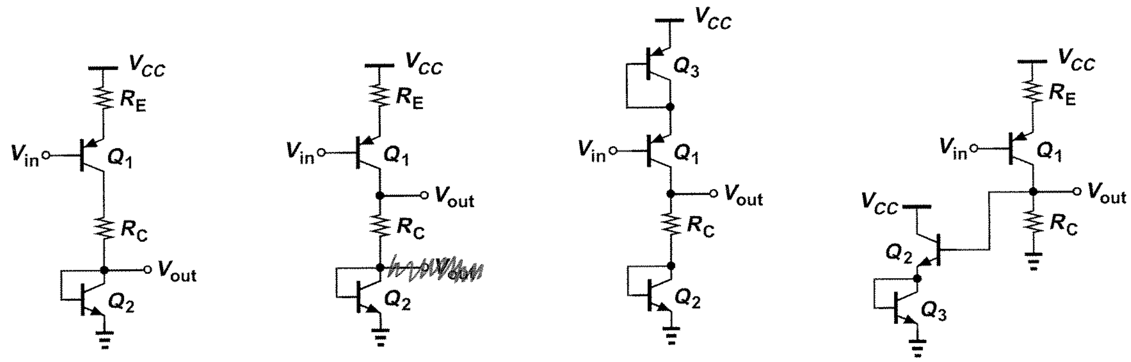

(a) (b) (c) (d)

(a): $A_v = \dfrac{-1/g_{m2}}{R_E + 1/g_{m1}}$

(a): $R_{in} = r_{\pi 1} + (1+\beta) R_E \approx r_{\pi 1} + \beta R_E$

(b): $A_v = \dfrac{-(R_C + 1/g_{m2})}{R_E + 1/g_{m1}}$

(b): $R_{in} = r_{\pi 1} + (1+\beta) R_E \approx r_{\pi 1} + \beta R_E$

(c): $A_v =$ $\frac{-(R_C + 1/g_{m2})}{1/g_{m3} + 1/g_{m1}}$

(c): $R_{in} =$: $r_{\pi_1} + \beta\left(\frac{1}{g_{m3}}\right)$

(d): $A_v =$ $\frac{-([r_{\pi_2} + \beta \frac{1}{g_{m3}}] // R_C)}{R_E + 1/g_{m1}}$

(d): $R_{in} =$: $r_{\pi_1} + \beta R_E$