EE 115A

Final Exam
Fall 2004

Your Name:

Solutions

Name of Person to Your Left: ____________________

Name of Person to Your Right: ____________________

Time Limit: 3 Hours

Use all approximations specified in each problem.

1.

2.

3.

4.

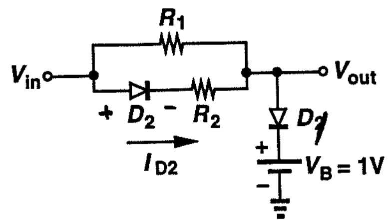
5.

6.

Total:

1. Plot V_{out} and I_{D2} as a function of V_{in} as V_{in} goes from $-\infty$ to $+\infty$. Determine the coordinates of each break point in the plot. Assume a constant-voltage diode model and $R_1 = R_2 = 1\ \text{k}\Omega$.

10



① when V_{in} is negative infinity,

D_1, D_2 both turn off. $V_{out} = V_{in}$ $I_{D2} = 0$

② When V_{in} increase at the point that D_1 ~~turn~~ begins turning on.

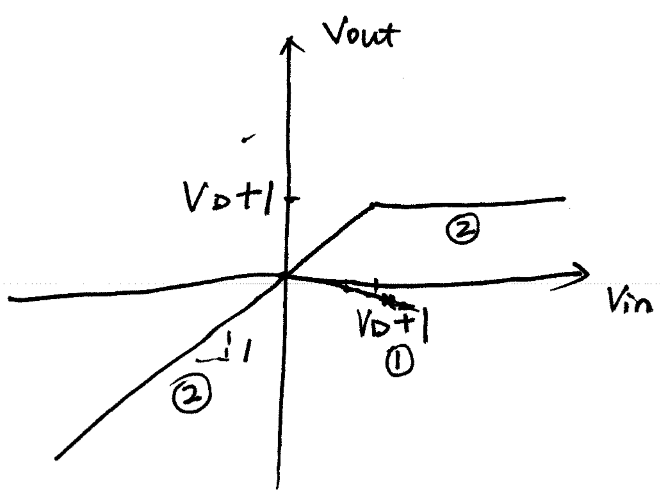
$V_{out} = V_D + 1$, Since D_2 still keeps off, $I_{D2} = 0$

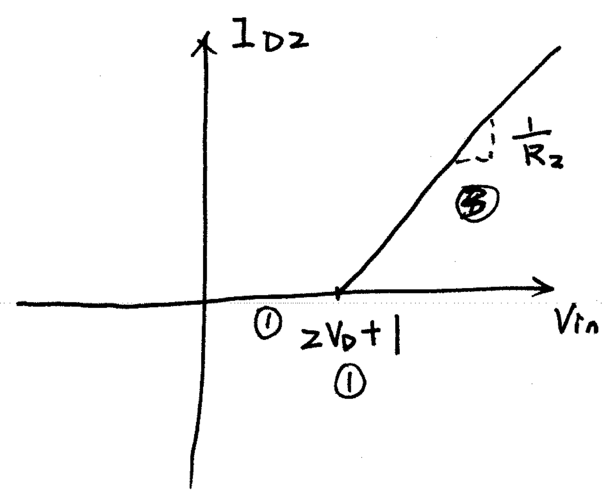
③ As V_{in} keeps increasing, the breakpoint that D_2 turns on and off is the $I_{D2} = 0$, $V_{in} - V_{out} = V_D$.

So. $V_{in} = V_D + V_{out} = 2V_D + 1$. Beyond that, I_{D2} increases,

$$I_{D2} = \frac{V_{in} - V_{out} - V_D}{R_2} = \frac{V_{in} - 2V_D - 1}{R_2}$$

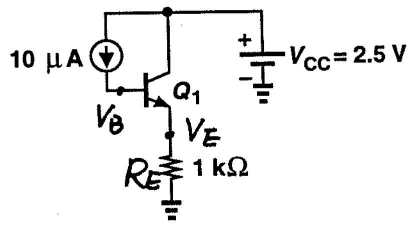
$$V_{out} = V_D + 1$$





2. Determine the maximum allowable value of β if Q_1 must not enter saturation. Assume the current source is ideal, $V_A = \infty$, and $I_S = 8 \times 10^{-16}$ A.

(10)



For Q_1 not in saturation mode, "BC" should. reverse biased.

So. $V_B \leq V_{cc} = 2.5V$.

Based on equation $I_c = I_s \exp \frac{V_{BE}}{V_T}$, we get

$$\beta I_B = I_s \exp \frac{V_B - (\beta+1) I_B \cdot R_E}{V_T}$$ (5) Assume $V_T = 26mV$. $V_B = 2.5V$.

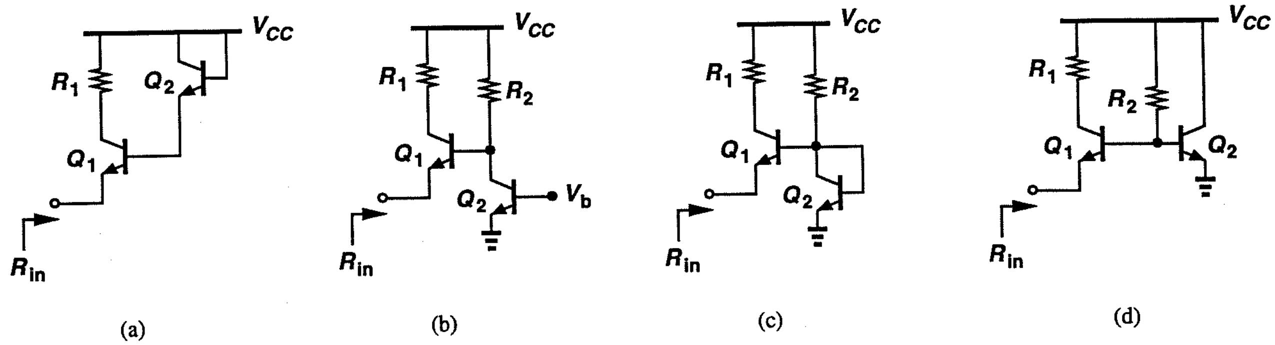
$$\beta \times 10 \times 10^{-6} = 8 \times 10^{-16} \exp \frac{2.5 - (\beta+1)\, 10 \times 10^{-6} \times 1 \times 10^{3}}{26 \times 10^{-3}}$$ (2)

Solve above equation, we can get maximum $\beta = 175.12$

(3)

3. Compute the input impedance of each circuit assuming $V_A = \infty$.

(10)



2.5 (a) $R_{in} = \dfrac{r_{\pi 1} + \dfrac{r_{\pi 2}}{1+\beta_2}}{1+\beta_1}$ if. consider β_1, β_2 is big enough. $R_{in} \approx \dfrac{1}{g_{m1}}$

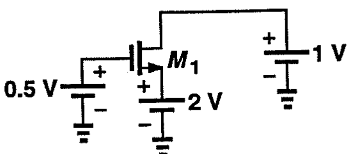
2.5 (b) $R_{in} = \dfrac{r_{\pi 1} + R_2}{1+\beta_1}$

2.5 (c) $R_{in} = \dfrac{r_{\pi 1} + R_2 // \frac{1}{g_{m2}} // r_{\pi 2}}{1+\beta_1} = \dfrac{r_{\pi 1} + R_2 // \frac{r_{\pi 2}}{1+\beta_2}}{1+\beta_1}$

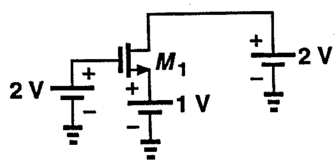
2.5 (d) $R_{in} = \dfrac{r_{\pi 1} + R_2 // r_{\pi 2}}{1+\beta_1}$

4. Determine the region of operation of each transistor. Assume a threshold voltage of 0.5 V for NMOS devices and −0.5 V for PMOS devices.

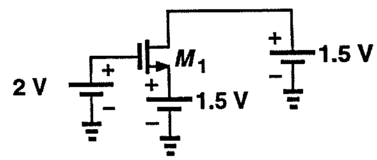
10



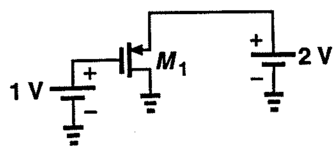
(a)



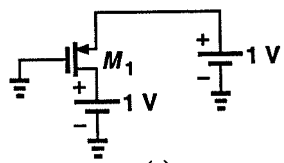
(b)



(c)



(d)



(e)

(a) $V_{GS} < 0$ $V_{GD} < 0$. off

(b) $V_{GS} = 1\,V > 0.5\,V$ $V_{GD} = 0 < V_{th}$ SAT

(c) $V_{GS} = 0.5 = V_{th}$ $V_{GD} = 0.5 = V_{th}$

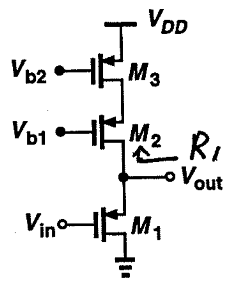
Current is zero. But since $V_{GS} = V_{th}$, the device is in SAT.

(d) $V_{SG} = 1V > |V_{thp}|$ $V_{DG} = -1V < V_{thp}$. SAT.

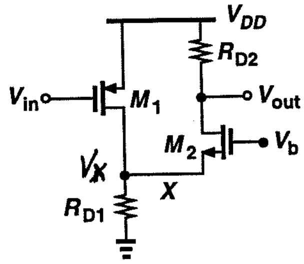
(e) $V_{SG} = 1V > |V_{thp}|$ $V_{DG} = 1V > V_{thp}$ Triode

5. Calculate the voltage gain of each circuit. Assume $\lambda \neq 0$ for (a) but $\lambda = 0$ for (b).

10



(a)



(b)

(a) The impedance of $R_1 = r_{o2} + (1 + g_{m2} r_{o2}) r_{o3}$

This circuit is basically a source follower.

$$A_v = \frac{g_{m1}(R_1 // r_{o1})}{1 + g_{m1}(R_1 // r_{o1})}$$

$$= \frac{g_{m1}[(r_{o2} + (1 + g_{m2} r_{o2}) r_{o3}) // r_{o1}]}{1 + g_{m1}[(r_{o2} + (1 + g_{m2} r_{o2}) r_{o3}) // r_{o1}]}$$

(b) $$\frac{V_{out}}{V_{in}} = \frac{V_{out}}{V_X} \cdot \frac{V_1}{V_{in}}$$

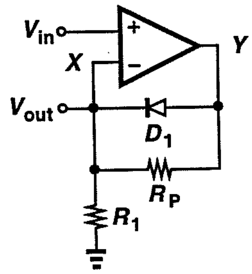
$$\frac{V_X}{V_{in}} = -g_{m1} \cdot \left(R_{D1} // \frac{1}{g_{m2}}\right)$$

$$\frac{V_{out}}{V_X} = g_{m2} \cdot R_{D2}$$

so. $$\frac{V_{out}}{V_{in}} = -g_{m1} g_{m2} R_{D2} \left(R_{D1} // \frac{1}{g_{m2}}\right)$$

6. Plot V_{out} and V_Y as a function of V_{in} as V_{in} goes from $-\infty$ to $+\infty$. Assume $R_P = 3\ \text{k}\Omega$ and $R_1 = 1\ \text{k}\Omega$, and use a constant-voltage model for the diode. Also, assume an ideal op amp.

10



Since the opamp is ideal, $V_{out} = V_{in}$.

① When V_{in} is $-\infty$. V_{out} is also $-\infty$. D_1. off.

$$V_Y = \frac{R_1+R_P}{R_1} V_{out} = \frac{R_1+R_P}{R_1} V_{in}$$

② when $V_{in} = 0$, $V_{out} = 0$. V_Y is also 0. D_1 still turns off.

~~when~~ $V_Y = \frac{R_1+R_P}{R_1} V_{in} = 4V_{in}$

when $V_Y - V_{out} = V_D$, D_1 begins turning on. So the point to turn on D_1 is:

$$V_Y - V_{out} = \frac{R_1+R_P}{R_1} V_{in} - V_{in} = V_D \Rightarrow V_{in} = \frac{R_1}{R_P} V_D = \frac{1}{3} V_D$$

After D_1 turns on, $V_Y = V_{out} + V_D = V_{in} + V_D$