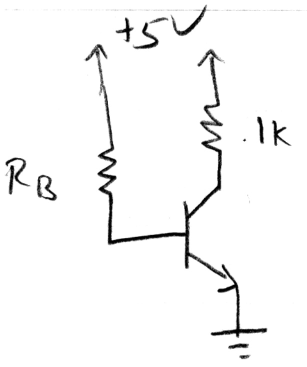
EE 321

Fall 2002

Homework #11

Solutions

4.97



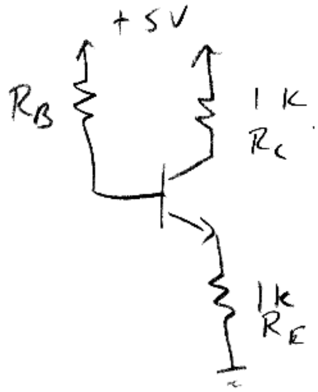
$$I_C = \frac{5V - V_{CEsat}}{R_C} = \frac{5V - 0.2V}{1k} = 4.8mA$$

$$I_{B_{EOS}} = \frac{I_{Csat}}{\beta} = \frac{4.8mA}{30} = 0.16\ mA$$

Want overdrive factor of 10, so $I_B = 10\ I_{B_{EOS}} = 1.6\ mA$

$$R_B = \frac{5V - V_{BE}}{I_B} = \frac{5V - 0.7V}{1.6mA} = 2.7k\Omega$$

4.99



Assume active

$5V = I_B R_B + V_{BE} + (\beta+1) I_B R_E$

$I_B = \dfrac{5V - 0.7V}{R_B + (\beta+1) R_E}$

$V_E = I_E R_E = (\beta+1) I_B R_E$

$V_C = 5V - I_C R_C = 5V - \beta I_B R_E$

$V_{CE} = V_C - V_E$

R_B	100 K	10 K	1K
I_B	0.021 mA	0.039	0.042
V_E	2.2 V	3.9 V	4.3 V
V_C	2.9 V	1.1 V	0.8 V
V_{CE}	0.7 V	−2.8 V	−3.5 V

For $R_B = 100k$, Q is active

$V_E = (\beta+1) I_B = 2.2V$

$V_B = V_{BE} + V_E = 2.9V$

For $R_B = 10k$ and 1K, Q is in saturation, so $V_{CE} = 0.2V$

$5V = I_C R_C + V_{CE} + I_E R_E$ $\quad$ $4.8V = I_C + I_E$ $\quad$ $R_C = 1k$

$5V = I_B R_B + V_{BE} + I_E R_E$ $\quad$ $4.3V = I_B R_B + I_E$ $\quad$ $R_E = 1k$

$I_E = I_C + I_B$

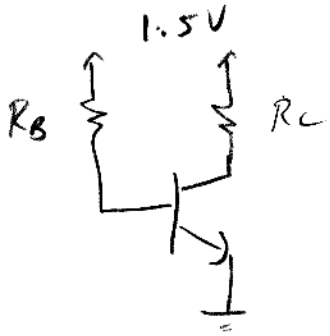
For $R_B = 10k$: $\quad I_B = 0.18\ mA \quad I_C = 2.31\ mA \quad I_E = 2.49\ mA$

$V_E = 2.49\ V \quad V_C = 2.69V$

For $R_B = 1k$: $\quad I_B = 1.27\ mA \quad I_C = 1.77\ mA \quad I_E = 3.03\ mA$

$V_E = 3.03V \quad V_C = 3.23V$

4.114



$$I_{C_{sat}} = \frac{1.5 - V_{CEsat}}{R_C} = \frac{1.3V}{R_C}$$

$$I_B = \frac{1.5V - V_{BE}}{R_B} = \frac{0.8V}{R_B}$$

$$\beta_f = \frac{I_{C_{sat}}}{I_B} = 10$$

$$P = VI = 1.5V\,(I_B + I_{C_{sat}}) = 1mW$$

4 eqns, 4 unkns

$$\frac{I_{C_{sat}}}{I_B} = 10 \Rightarrow \frac{\frac{1.3V}{R_C}}{\frac{0.8V}{R_B}} = 10 \Rightarrow \frac{R_B}{R_C} = 6.2 \Rightarrow R_B = 6.2R_C$$

$$1.5V(I_B + I_{C_{sat}}) = 1mW \Rightarrow 1.5V\left(\frac{0.8}{R_B} + \frac{1.3}{R_C}\right) = 1mW$$

$$1.5V\left(\frac{0.8}{6.2R_C} + \frac{1.3}{R_C}\right) = 1mW \Rightarrow R_C = 2.1K$$

$$R_B = 13.2K$$

5.4 $k_n' = 50\,\mu A/V^2$ $V_t = 0.8V$ $W/L = 20$ $v_{GS} = 5V$

$$r_{DS} = \left[k_n' \frac{W}{L}(v_{GS}-V_t)\right]^{-1} = \left[(50\,\mu A/V^2)(20)(5V-0.8V)\right]^{-1}$$

$$r_{DS} = 240\,\Omega$$

$$r_{DS} = \frac{v_{DS}}{i_D} \Rightarrow v_{DS} = r_{DS}\, i_D = (240\,\Omega)(1mA) = 0.24V$$

$$\mu_p \cong 0.4\,\mu_n \Rightarrow k_p' \cong 0.4\,k_n'$$

To get same performance need $k_p'(W/L)_p = k_n'(W/L)_N$

$$(W/L)_p = \frac{k_n'}{k_p'}(W/L)_N = \frac{k_n'}{0.4\,k_n'}\left(\frac{W}{L}\right)_N = 2.5\left(\frac{W}{L}\right)_N$$

5.6

$k_n' = \mu_0 C_{ox} = 100\,\mu A/V^2$ for $t_{ox} = 20\,nm$ (Table 5.1)

$V_t = 0.8V \qquad W/L = 10$

(a) $v_{GS} = 5V \qquad v_{DS} = 1V \qquad v_{GS} - V_t = 4.2V$

$v_{DS} < v_{GS} - V_t$, so triode

$i_D = k_n' \frac{W}{L}\left[(v_{GS} - V_t)v_{DS} - \frac{1}{2}v_{DS}^2\right)$

$= (0.1mA/V^2)(10)\left[(4.2)(1) - \frac{1}{2}(1)^2\right)$

$= 3.7\,mA$

(b) $v_{GS} = 2V \qquad v_{DS} = 1.2V \qquad v_{GS} - V_t = 1.2V$

$v_{DS} = v_{GS} - V_t$; between triode and saturation

$i_D = \frac{1}{2}k_n' \frac{W}{L}(v_{GS} - V_t)^2$

$= \frac{1}{2}(0.1mA/V^2)(10)(2-0.8)^2 = 0.72\,mA$

(c) $v_{GS} = 5V \qquad v_{DS} = 0.2V \qquad v_{GS} - V_t = 4.2V$

$v_{DS} < v_{GS} - V_t$, so triode

$i_D = (0.1mA/V^2)(10)\left[(4.2)(0.2) - \frac{1}{2}(0.2)^2\right)$

$= 0.82\,mA$

(d) $v_{GS} = 5V \qquad v_{DS} = 5V \qquad v_{GS} - V_t = 4.2V$

$v_{DS} > v_{GS} - V_t$, so saturation

$i_D = \frac{1}{2}k_n' \frac{W}{L}(v_{GS} - V_t)^2$

$= \frac{1}{2}(0.1mA/V^2)(10)(5-0.8)^2$

$= 8.82\,mA$

5.13 $i_D = k_n' \frac{W}{L} \left[(v_{GS} - V_t) v_{DS} - \frac{1}{2} v_{DS}^2 \right]$

$i_D \cong k_n' \frac{W}{L} (v_{GS} - V_t) v_{DS}$ for small v_{DS}

$i_{D1} = k_n' \frac{W}{L} (v_{GS1} - V_t) v_{DS}$

$i_{D2} = k_n' \frac{W}{L} (v_{GS2} - V_t) v_{DS}$

$$\frac{i_{D2}}{i_{D1}} = \frac{(v_{GS2} - V_t)}{(v_{GS1} - V_t)}$$

Solve for V_t: $V_t = \dfrac{i_{D1} v_{GS2} - i_{D2} v_{GS1}}{i_{D1} - i_{D2}}$

$$= \frac{(40\mu A)(3V) - (80\mu A)(2V)}{40\mu A - 80\mu A}$$

$$\underline{\underline{V_t = 1V}}$$

$$\frac{W}{L} = \frac{i_{D1}}{k_n' (v_{GS1} - V_t) v_{DS}} = \frac{40\mu A}{(40\mu A/V^2)(2V - 1V)(0.1V)}$$

$\underline{\underline{\frac{W}{L} = 10}}$

$v_{DS} = 1.5V$ $\quad v_{GS} = 2.5V$ $\quad v_{GS} - V_t = 1.5V$

$v_{DS} < v_{GS} - V_t$, so triode mode

$i_D \cong k_n' \frac{W}{L} \left[(v_{GS} - V_t) v_{DS} \right] = 90\mu A$

Pinchoff when $v_{DS} = v_{GS} - V_t = 2.5V - 1V = 1.5V$

$i_D = \frac{1}{2} k_n' \left(\frac{W}{L}\right) (v_{GS} - V_t)^2$

$i_D = 450\mu A$

5.15 $r_{DS} = \left[k_n' \frac{W}{L} (V_{GS} - V_t) \right]^{-1}$

For $V_{GS} = 1.1V$, $r_{DS} = [(20\mu/V^2)(100/5)(1.1V - 1V)]^{-1} = 25k\Omega$

For $V_{GS} = 11V$, $r_{DS} = [(20\mu A/V^2)(100/5)(11V - 1V)]^{-1} = 250\Omega$

r_{DS} range: $25k\Omega \leftrightarrow 250\Omega$

(a) W is in the denominator of r_{DS}, so halving W doubles r_{DS}

r_{DS} range: $50k\Omega \leftrightarrow 500\Omega$

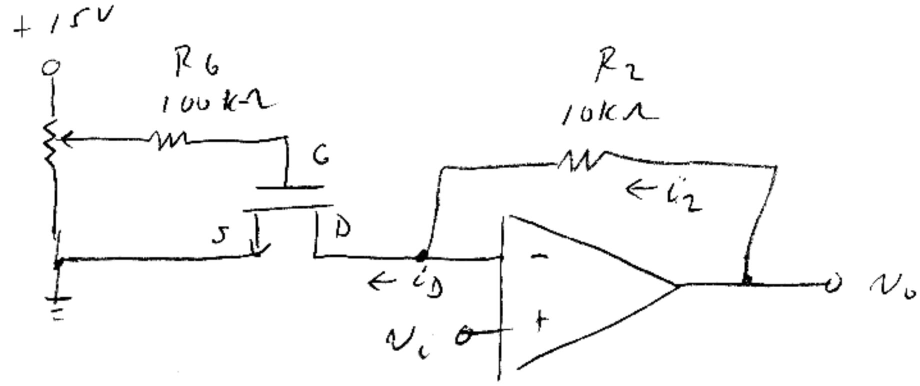
(b) L is in the numerator of r_{DS}, so halving L halves r_{DS}

r_{DS} range: $12.5k\Omega \leftrightarrow 125\Omega$

(c) W/L does not change so r_{DS} does not change

r_{DS} range: $25k\Omega \leftrightarrow 250\Omega$

8.



$v_- = v_+ \Rightarrow v_- = v_i$ and $i_2 = i_D$

$v_o = v_i + R_2 i_2 = v_i + R_2 i_D$

$v_o = v_i + R_2 k_n' \frac{W}{L}\left[(v_{GS} - V_t) v_{DS} - \frac{1}{2} v_{DS}^2\right]$

$v_{DS} = v_D = v_- = v_i$, so

$v_o = v_i + R_2 k_n' \frac{W}{L}\left[(v_{GS} - V_t) v_i - \frac{1}{2} v_i^2\right]$

For $v_i \ll (v_{GS} - V_t)$, can ignore $\frac{1}{2} v_i^2$

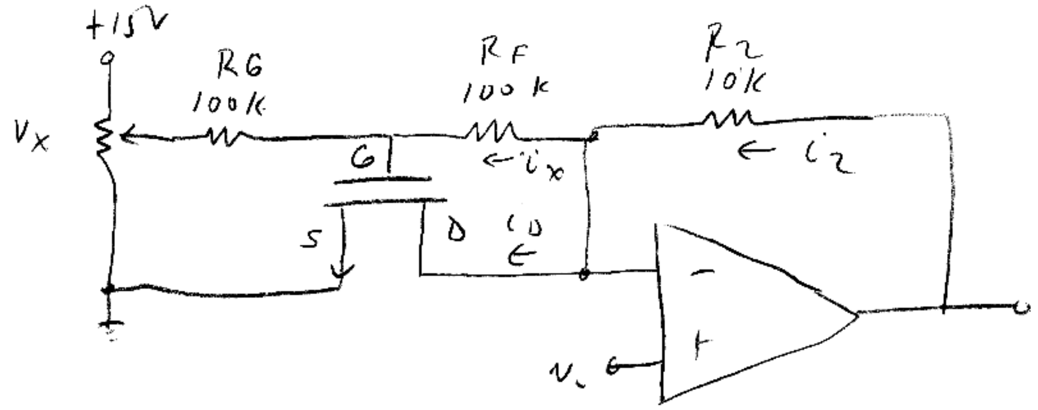
$v_o = v_i + R_2 k_n' \frac{W}{L} (v_{GS} - V_t) v_i$

$$\frac{v_o}{v_i} = 1 + R_2 k_n' \left(\frac{W}{L}\right)(v_{GS} - V_t)$$

$$= 1 + \frac{R_2}{r_{DS}}$$

v_{GS} is set by pot.

9.



$v_- = v_+ = v_i$ $\qquad i_2 = i_D + i_x$

V_x is set by pot

$$i_x = \frac{v_i - v_x}{200k}$$

$$i_D = \frac{v_i}{r_{DS}}$$ r_{DS} is a few kΩ, so $i_x \ll i_D$;

we will ignore i_x, so $i_2 \simeq i_D$

Note that $V_{GS} = V_G = \frac{1}{2} V_x + \frac{1}{2} v_i$

$$v_o = v_i + i_D R_2$$

$$= v_i + k_n' \frac{W}{L} \left[(v_{GS} - V_t) v_i - \frac{1}{2} v_i^2 \right) R_2$$

$$= v_i + k_n' \frac{W}{L} \left[\left(\frac{1}{2} V_x + \frac{1}{2} v_i - V_t \right) v_i - \frac{1}{2} v_i^2 \right) R_2$$

$$= v_i + k_n' \frac{W}{L} \left[\left(\frac{1}{2} V_x - V_t \right) v_i \right) R_2$$

$$\frac{v_o}{v_i} = 1 + k_n' \frac{W}{L} \left(\frac{1}{2} V_x - V_t \right) R_2$$

and output is linear.

Note: V_x set by pot.

Note also: $v_{DS} = v_i$. If $v_{DS} > v_{GS} - V_t$, the MOSFET leaves the triode region and enters the saturation region.

This circuit is linear only when $v_i < v_{GS} - V_t$.