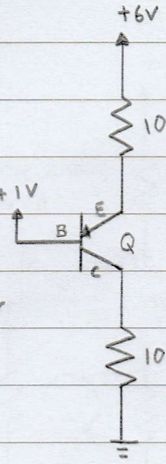
Esmund Lim A.E Tutorial 5

1)

a) pnp

$|V_{BE}| = 0.7V$

$\beta = 100$



arrow always point between base and emitter terminal

Assume Q is active

$V_E = V_{EB} + V_B$

$= 0.7V + 1V$

$= 1.7V$

$I_E = \frac{6V - 1.7V}{10k\Omega}$

$= 0.43mA$

$I_C = \beta I_B$

$= \alpha I_E$

$= \frac{\beta}{\beta+1} I_E$

$= \frac{100}{100+1}(0.43mA)$

$= 0.425742574 \times 10^{-3} mA$

$V_C = I_C R_C$

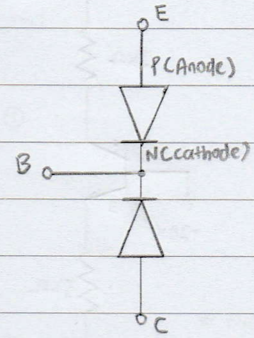
$= 0.425742574 \times 10^{-3} (10k\Omega)$

$= 4.257425743V$

$\approx 4.3V$

Since $V_C > V_B$, device will be saturated

$\therefore$ Assumption is invalid



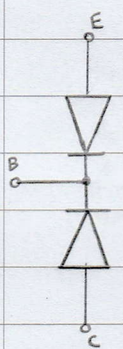
Forward active region

$V_E > V_B$ (forward bias)

$|V_{BE}| \approx 0.7V$

$V_C < V_B$ (Reverse bias)

$I_C = \beta I_B = \alpha I_E$, $\alpha = \frac{\beta}{\beta+1}$



Saturation region

$V_E > V_B$ (forward bias)

$|V_{BE}| \approx 0.7V$

$V_C > V_B$ (forward bias)

$V_{BC} = 0.4V \sim 0.5V$

$V_{CE(SAT)} = 0.2 \sim 0.3V$

With $V_{CE(SAT)} \approx 0.3V$ $V_{EB} = 0.7V$

$V_E = V_{EB} + V_B$

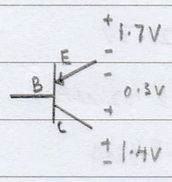
$= 0.7V + 1V$

$= 1.7V$

$V_C = V_E - V_{CE(SAT)}$

$= 1.7V - 0.3V$

$= 1.4V$



$I_C = \frac{V_C}{R_C}$

$= \frac{1.4V}{10k\Omega}$

$= 0.14mA$

KCL

$I_E = I_B + I_C$

$I_B = I_E - I_C$

$= 0.43mA - 0.14mA$

$= 0.29mA$

$\therefore V_C = 1.4V$

$V_E = 1.7V$

$I_B = 0.29mA$

$I_C = 0.14mA$

$I_E = 0.43mA$

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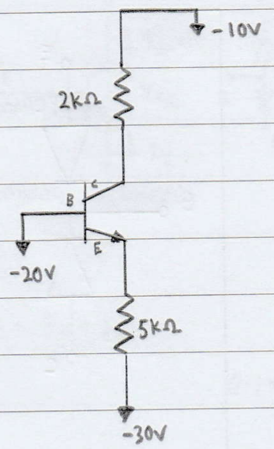
b)



Assume Q is active

$V_E = V_B - V_{BE}$

$= -20V - 0.7V$

$= -20.7V$

$I_E = \frac{V_E - V_{EE}}{R_E}$

$= \frac{-20.7V - (-30V)}{5k\Omega}$

$= 1.86mA$

$I_C = \alpha I_E$

$= \left(\frac{\beta}{\beta+1}\right)(I_E)$

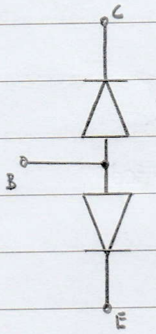
$= \frac{100}{101}(1.86mA)$

$= 1.841584158\,mA$

$V_C = V_{CC} - I_C R_C$

$= -10V - (1.841584158mA)(2k\Omega)$

$= -13.68316832\,V$



since $V_C > V_B$ (Reversed Bias)

$\therefore$ First assumption is valid, Q is active

$I_C = \beta I_B$

$I_B = \frac{I_C}{\beta}$

$= \frac{1.841584158mA}{100}$

$= 18.41584158 \times 10^{-6}\,\mu A$

$= 18.42\,\mu A$

$\therefore V_C = -13.68V$

$V_E = -20.7V$

$I_B = 18.42\,\mu A$

$I_C = 1.84mA$

$I_E = 1.86mA$

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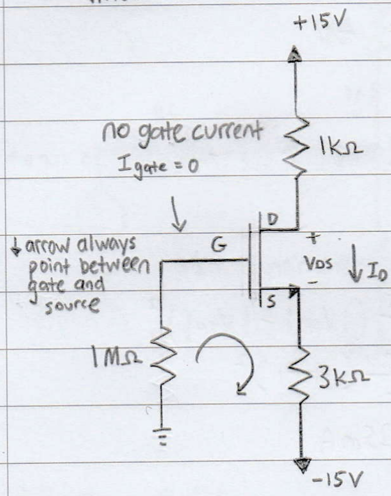
2)

a) NMOS



$K_n = 0.5mA$

$V_{TN} = 1V$

Threshold voltage

Assume saturation mode

$$I_D = \frac{K_n}{2}(V_{GS} - V_{TN})^2$$
$$= \frac{0.5m}{2}(V_{GS} - 1)^2 \quad \text{— ①}$$

KVL

$$V_{GS} + I_D R_S + (-15) = 0$$
$$V_{GS} + I_D R_S = 15$$
$$V_{GS} + 3k I_D = 15 \quad \text{— ②}$$

* Note since $I_g = 0$, $I_D = I_S$

$$②: V_{GS} = 15 - 3k I_D \quad \text{— ③}$$

Sub ③ into ①

$$I_D = \frac{0.5m}{2}(15 - 3k I_D - 1)^2$$
$$= 0.25m(14 - 3k I_D)^2$$
$$= 0.25m(14 - 3k I_D)(14 - 3k I_D)$$
$$= 0.25m[196 - 84k I_D + 9M I_D^2]$$
$$= 0.049 - 21 I_D + 2250 I_D^2$$

$$2250 I_D^2 - 22 I_D + 0.049 = 0$$

$$I_D = 6.34609745mA \text{ or } 3.431680328mA$$

For $I_D = 6.34609745mA$

$$V_{GS} = 15 - 3k(6.34609745mA)$$
$$= -4.03829235V$$

Since $V_{GS} < V_{TN}$

This answer is unacceptable

For $I_D = 3.431680328mA$

$$V_{GS} = 15 - 3k(3.431680328mA)$$
$$= 4.704959016V$$

$$V_{GS} > V_{TN}$$

KVL

$$-15 + I_D R_D + V_{DS} + I_D R_S + (-15) = 0$$
$$V_{DS} = 30 - I_D R_D - I_D R_S$$
$$= 30 - 3.43mA(1k\Omega + 3k\Omega)$$
$$= 16.28V$$

For saturation mode

$V_{DS} \geq V_{GS} - V_{TN}$ $\quad$ $16.28V \geq 4.7V - 1V$ $\quad$ (First assumption is correct)

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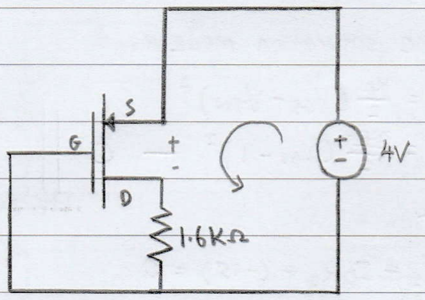
b) Pmos



$V_{TP} = -1V$

$k_p = 250\mu A/V^{-1}$

$|V_{GS}| = |-4V|$
$= 4V$

$|V_{TP}| = 1V$

since $|V_{GS}| > |V_{TP}|$, it is not cut-off

Assume saturation mode

$I_D = \frac{k_p}{2}(|V_{GS}| - |V_{TP}|)^2$
$= \frac{250\mu}{2}(4-1)^2$
$= 1.125mA$

KVL

$-4 + |V_{DS}| + 1.6k(I_D) = 0$
$|V_{DS}| = 4 - 1.6k(I_D)$
$= 4 - 1.6k(1.125mA)$
$= 2.2V$

For saturation mode

$|V_{DS}| \geq |V_{GS}| - |V_{TP}|$

since

$|V_{DS}| \leq |V_{GS}| - |V_{TP}|$

$2.2V \leq 4V - 1V$

$\therefore$ It is not in saturation but it is in triode region, which is also known as ohmic or linear region

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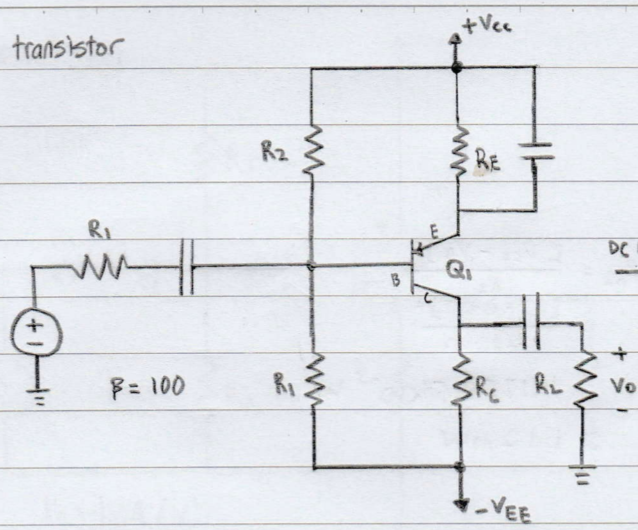
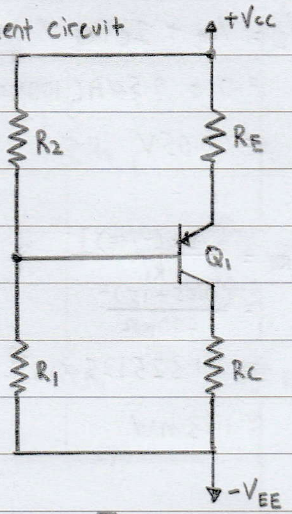
3) PnP transistor



DC Analysis →

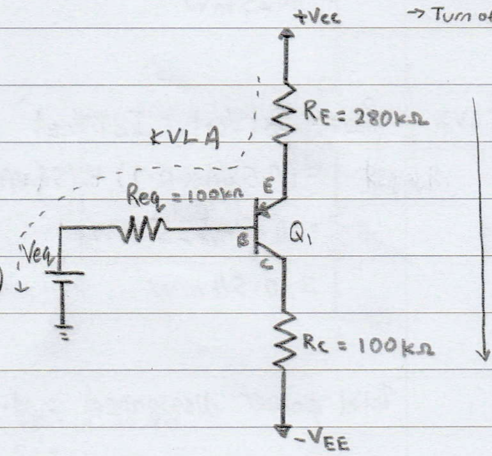
Capacitor o/c
inductor s/c

DC Equivalent circuit



Simplify by thevenin theorem

Find R_{TH}
→ Turn off source



$R_{eq} = R_{TH} = R_1 // R_2$

$= \dfrac{200k\Omega \times 200k\Omega}{200k\Omega + 200k\Omega}$

$= 100k\Omega$

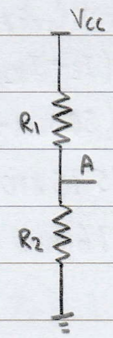
$V_{eq} = V_{TH} = \dfrac{R_1}{R_1+R_2}(15-15)$ or by superposition $V_{eq} = \underbrace{\dfrac{R_1}{R_1+R_2}V_{cc}}_{-V_{EE}\text{ ground}} + \underbrace{\dfrac{R_2}{R_1+R_2}(-V_{EE})}_{V_{cc}\text{ ground}}$

$= 0V$

$= \dfrac{200k\Omega}{200k\Omega+200k\Omega}(15V) + \dfrac{200k\Omega}{200k\Omega+200k\Omega}(-15V)$

$= 0V$

Thevenin Equivalent

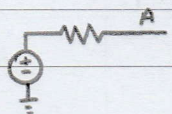


$R_{EQ} = R_{TH}$ (turn off source)

$= R_1 // R_2$

$V_{EQ} = V_{TH}$ (Voltage open circuit)

$= \dfrac{R_2}{R_1+R_2}(V_{cc})$



KVL A

$-15 + I_E R_E + V_{EB} + I_B R_{eq} = 0$

$I_E R_E + V_{EB} + I_B R_{eq} = 15$

$(\beta+1) I_B R_E + V_{EB} + I_B R_{eq} = 15$

$(101)(280k\Omega) I_B + 100k\Omega I_B = 15 - 0.7$

$28.38 \times 10^6 I_B = 14.3$

$I_B = 0.503875969 \times 10^{-6}$ A

$\approx 0.5 \mu A$

* $I_C = \beta I_B = \alpha I_E$

$\beta I_B = \alpha I_E$

$= \dfrac{\beta}{\beta+1} I_E$

$I_E = \beta I_B \div \dfrac{\beta}{\beta+1}$

$= \beta I_B \times \dfrac{\beta+1}{\beta}$

$= (\beta+1) I_B$

$I_C = \beta I_B$

$= 100(0.5\mu A)$

$= 50\mu A$

$I_E = (100+1) I_B$

$= 50.5\mu A$

KVL B

$-15 + I_E R_E + V_{EC} + I_C R_C + (-15) = 0$

$V_{EC} = 30 - I_E R_E - I_C R_C$

$= 30 - 50.5\mu A(280k\Omega) - 50\mu A(100k\Omega)$

$= 10.86V$

$\therefore$ Q-point (I_C, V_{EC})

$(50\mu A, 10.86V)$

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$$V_B = V_{eq} + I_B R_{eq}$$
$$= 0 + 0.5\mu A(100k\Omega)$$
$$= 0.05V$$

$$P_{R1} = \frac{[V_B - (-V_{EE})]^2}{R_1}$$
$$= \frac{(0.05+15)^2}{200k\Omega}$$
$$= 1.1325125 \times 10^{-3} W$$
$$\approx 1.13mW$$

$$P_{R2} = \frac{[V_{cc} - V_B]^2}{R_2}$$
$$= \frac{[15-0.05]^2}{200k\Omega}$$
$$= 1.1175125 \times 10^{-3} W$$
$$\approx 1.12mW$$

$$P_{R_C} = I_C^2 R_C$$
$$= (50\mu A)^2 (100k\Omega)$$
$$= 0.25mW$$

$$P_{R_E} = I_E^2 R_E$$
$$= (50.5\mu A)^2 (280k\Omega)$$
$$= 0.71407mW$$

$$P_{BJT} = I_B|V_{BE}| + I_C|V_{CE}|$$
$$= (0.5\mu A \times 0.7) + (50\mu A \times 10.86)$$
$$= 0.54335mW$$
$$\approx 0.54mW$$

Total power dissipated $= 1.13 + 1.12 + 0.25 + 0.71 + 0.54$
$= 3.75mW$

Power dissipated by source :

$$P_s = V_{cc}(I_E + I_{R2}) + |V_{EE}|(I_C + I_{R1})$$
$$= 15\left(50.5\mu A + \frac{15-0.05}{200k\Omega}\right) + 15\left(50\mu A + \frac{0.05-(-15)}{200k\Omega}\right)$$
$$= 3.7575 \times 10^{-3} W$$
$$\approx 3.76 mW$$

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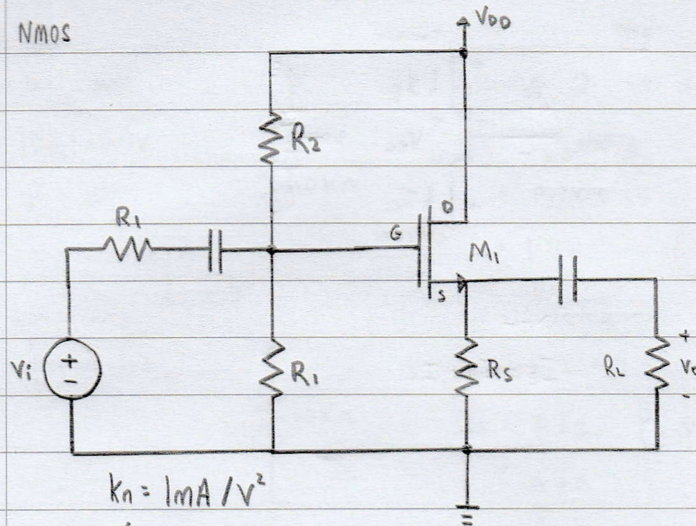
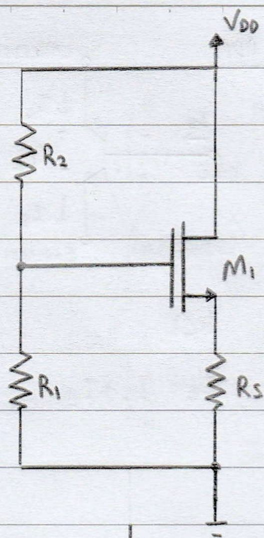
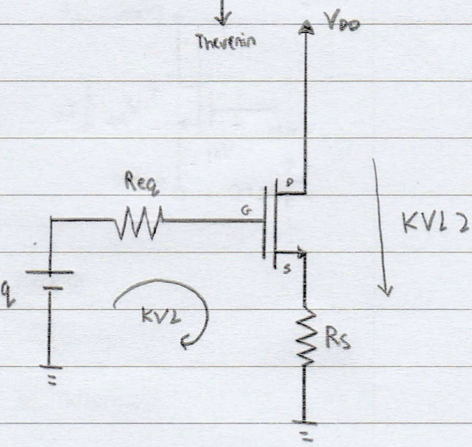
4) NMOS



DC Analysis →



Thevenin



$K_n = 1mA/V^2$

$V_{TN} = 1V$

$R_{eq} = R_{TH}$
$= R_2 \| R_1$
$= \frac{1.2M\Omega \times 910k\Omega}{1.2M\Omega + 910k\Omega}$
$= 517.535545\ k\Omega$
$\approx 518\ k\Omega$

$V_{eq} = V_{TH}$
$= \frac{R_1}{R_1 + R_2}(V_{DD})$
$= \frac{1.2M\Omega}{1.2M\Omega + 910k\Omega}(15V)$
$= 8.530805687V$
$\approx 8.53V$

KVL

$-V_{eq} + V_{GS} + I_D R_S = 0$

$V_{eq} = V_{GS} + I_D R_S$

$V_{GS} = V_{eq} - I_D R_S$

$= 8.53V - 3000 I_D$ — ①

$I_D = \frac{k_n}{2}(V_{GS} - V_{TN})^2$ — ②

sub ① into ②

$I_D = \frac{1m}{2}(8.53V - 3000I_D - 1)^2$

$= 0.5m(7.53V - 3000I_D)^2$

$= 0.5m[(7.53 - 3000I_D)(7.53 - 3000I_D)]$

$= 0.5m[56.7009 - 22590I_D - 22590I_D + 9000000I_D^2]$

$= 4500I_D^2 - 22.59I_D + 0.02835045$

$4500I_D^2 - 23.59I_D + 0.02835045 = 0$

$I_D = 3.376176311mA$ or $1.866045911mA$

$\approx 3.38mA$ $\approx 1.87mA$

if $I_D = 3.38mA$

$V_{GS} = 8.53 - 3000(3.38mA)$

$= -1.61V$ (reject)

$V_{GS} < V_{TN}$

if $I_D = 1.87mA$

$V_{GS} = 8.53 - 3000(1.87mA)$

$= 2.92V$

$V_{GS} > V_{TN}$

Hence, $I_D = 1.87mA$

KVL2 :

$-V_{DD} + V_{DS} + I_D R_S = 0$

$V_{DS} = V_{DD} - I_D R_S$

$= 15 - (1.87mA)(3k\Omega)$

$= 9.39V$

$\therefore I_D = 1.87mA,\ V_{DS} = 9.39V$

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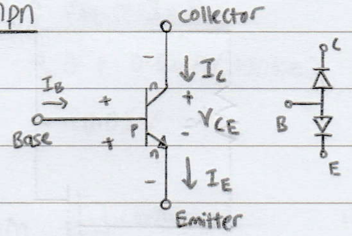
npn



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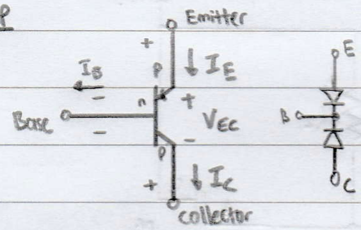


KCL

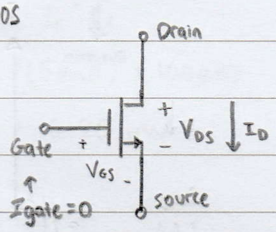
$I_E = I_C + I_B$

KCL

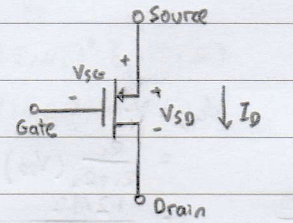
$I_E = I_B + I_C$

Q-point (I_C, V_{CE})

NMOS



PMOS



Q point (I_D, V_{SD})