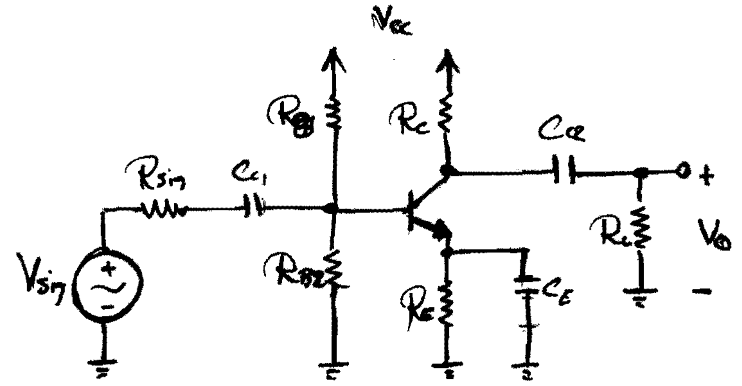
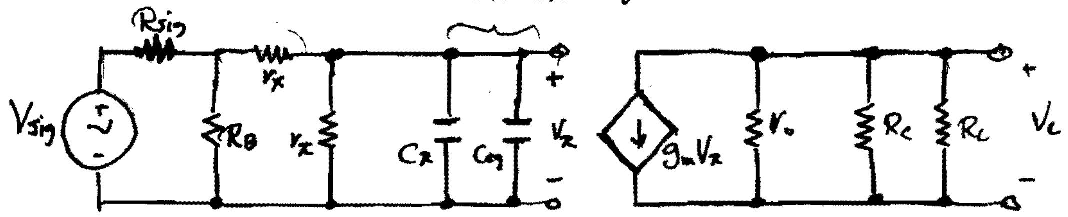
EE320 Homework #11

(11.1) Problem (10.38)



Small Signal Ckt



$$GB = |A_M| f_H = \beta \frac{R_i'}{R_{sig}} \frac{1}{2\pi C_H \beta R_i'} = \frac{1}{2\pi C_H R_{sig}} = \frac{1}{2\pi \cdot 1\times10^{-12} \times 25\times10^3} = 6.37\,\text{MHz}$$

for $I_C = 1\,\text{mA}$ and $\beta = 100$

(i) $R_i' = 25\,\text{k}\Omega$, $A_M = -\beta \frac{R_i'}{R_{sig}} = -100 \times \frac{25k}{25k} = -100\,\text{V/V}$

$GB = |A_M| \cdot f_c \longrightarrow f_c = \frac{GB}{|A_M|} = \frac{6.37\,\text{MHz}}{100} = \underline{63.7\,\text{kHz}}$

(ii) $R_i' = 2.5\,\text{k}\Omega$, $A_M = -\beta \frac{R_i'}{R_{sig}} = -100 \times \frac{2.5k}{25k} = -10\,\text{V/V}$

$f_c = \frac{GB}{|A_M|} = \frac{6.37\,\text{MHz}}{10} = \underline{637\,\text{kHz}}$

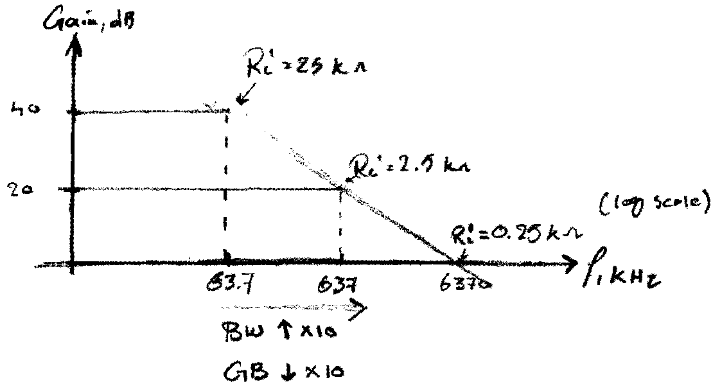
if midBand gain is unity

$f_H = GB = 6.37\,\text{MHz}$

This is obtained when R_i' is

$1 = 100 \times \frac{R_i'}{25}$

$R_i = 0.25k = 250\,\Omega$



GB · B is constant

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(11.2) PROBLEM (10.39)

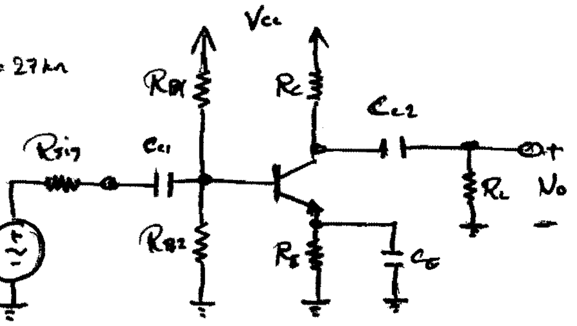
$R_{sig} = 10k\Omega$, $R_{B1} = 68k$, $R_{B2} = 27k\Omega$

$R_E = 2.2k\Omega$, $R_C = 4.7k\Omega$

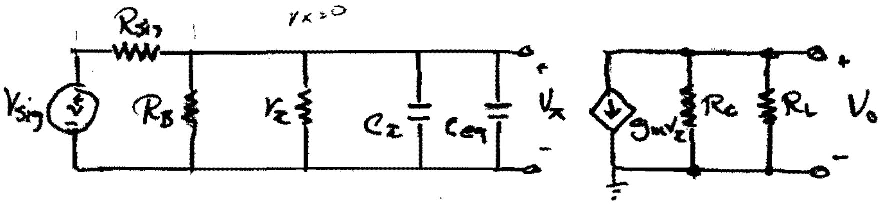
$\beta = 200$, $f_T = 1GHz$

$C_\mu = 0.8\,pF$,

$I_C = 0.8mA$



(Fig 10.9 (a))



$$R_B = R_{B1} \| R_{B2} = 68k\Omega \| 27k\Omega = 19.3k\Omega$$

$$g_m = \frac{I_C}{V_T} = \frac{0.8mA}{0.025V} = 32\ mA/V$$

$$r_\pi = \frac{\beta}{g_m} = \frac{200}{32\ mA/V} = 6.25k\Omega$$

$$R_{sig}' = r_\pi \| R_B \| R_{sig} = 6.25k\Omega \| 19.3k\Omega \| 10k\Omega = 3.2k\Omega$$

(10.54) when $r_x = 0$
$$A_M = -\frac{R_B}{R_B + R_{sig}} \frac{r_\pi}{r_\pi + (R_{sig} \| R_B)} g_m R_L'$$

$$= -\frac{19.3k}{19.3k + 10k} \frac{6.25k}{6.25k + (10k \| 19.3k)} \times 32m \times 3.2k = -32.8\ V/V$$

$$f_T = \frac{g_m}{2\pi(C_\pi + C_\mu)}$$ — f_T given, solve for $(C_\pi + C_\mu) = \frac{g_m}{2\pi \cdot f_T} = \frac{32 \times 10^{-3}}{2\pi \cdot 10^9}$

$\therefore (C_\pi + C_\mu) = 5.1\ pF$ — With $C_\mu = 0.8pF \longrightarrow C_\pi = 5.1p - 0.8p = 4.3pF$

(10.58) $$C_{in} = C_\pi + (g_m R_L' + 1) C_\mu = 4.3p + (32m \times 3.2k + 1) \times 0.8p = 87\ pF$$

(10.57) $$f_H = \frac{1}{2\pi C_{in} R_{sig}'} = \frac{1}{2\pi \times 87 \times 10^{-12} \times 3.2k} = 572\ kHz$$

(11.3) PROBLEM (5.14)

$t_{ox} = 6nm$, $\mu_n = 460 cm^2/V\cdot s$,

$V_t = 0.5V$, $W/L = 10$), $C_{ox} = \frac{\epsilon_{ox}}{t_{ox}}$ (5.3) $\rightarrow \epsilon_{ox} = 3.9\epsilon_0$

(5.12b) $k_n = \mu_n C_{ox} \frac{W}{L} = 460 \times 10^{-4} \times \frac{3.9 \times 8.854 \times 10^{-12}}{6 \times 10^{-9}} = 2.645 \, mA/V^2$

(a) $v_{GS} = 2.5V$ and $V_{DS} = 1\ V \rightarrow V_{GS} > V_t$
(2.5 > 0.5)

$V_{OV} = v_{GS} - V_t = 2V \longrightarrow v_{DS} < v_{OV} \longrightarrow$ triode region

(5.16) Triode $I_D = \underbrace{k_n' \frac{W}{L}}_{\equiv k_n} \left[v_{DS} v_{OV} - \frac{1}{2} v_{DS}^2 \right] = 2.645 \left[1 \times 2 - \frac{1}{2} \times 1 \right] = \underline{4\ mA}$

(b) $v_{GS} = 2V$ and $v_{DS} = 1.5\ V \longrightarrow V_{GS} > V_t$
2 > 0.5

$v_{OV} = v_{GS} - V_t = 2 - 0.5 = 1.5V$

Thus, $V_{DS} = v_{OV} \longrightarrow$ Saturation region

(5.20) $I_D = \frac{1}{2} k_n' \left(\frac{W}{L}\right) \underbrace{(V_{GS} - V_t)^2}_{\equiv V_o} = \frac{1}{2} \times 2.645 \times 1.5^2 = \underline{3\ mA}$

(c) $V_{GS} = 2.5V$ and $v_{DS} = 0.2V \longrightarrow V_{GS} > V_t$
2 > 0.5

$v_{OV} = 2.5 - 0.5 = 2V$

(5.16) $v_{DS} < v_{OV} \longrightarrow$ triode region

$i_D = k_n \left[v_{DS} v_{OV} - \frac{1}{2} v_{DS}^2 \right] = 2.645 \left[0.2 \times 2 - \frac{1}{2} 0.2^2 \right] = \underline{1\ mA}$

(d) $V_{GS} = V_{DS} = 2.5V \longrightarrow V_{GS} > V_t$

$v_{OV} = 2.5 - 0.5 = 2V$, $\longrightarrow v_{DS} > V_{OV} \longrightarrow$ Saturation region

(5.20) $i_D = \frac{1}{2} k_n v_{OV}^2 = \frac{1}{2} \times 2.645 \times 2^2 = \underline{5.3\ mA}$

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11.4 PROBLEM (5.18)

$V_{tn} = 0.5\,V$, $k_n = 1.6\,mA/V^2 = k_n'(\frac{W}{L})$, $I_D = 50\,\mu A$

(5.20) $I_D = \frac{1}{2} k_n'(\frac{W}{L})\underbrace{(V_{GS}-V_t)^2}_{= V_{OV}} \Rightarrow 50\,\mu A = \frac{1}{2} \times 1.6 \times 10^{-3} \times V_{OV}^2$

$\therefore V_{OV} = 0.25\,V$ and $V_{DS} \geq 0.25\,V$

for Saturation $V_{DS}|_{min} = 0.25\,V$

at min V_{DS}:

$V_{GS} - V_t = 0.25 \;, \rightarrow V_{GS} = V_t + 0.25 = \underline{0.75\,V}$

for $I_D = 200\,\mu A$

Using (5.20) $200\,\mu A = \frac{1}{2} \times 1.6 \times 10^{-3} \times V_{OV}^2 \longrightarrow V_{OV} = 0.5$ and $V_{DS} \geq 0.5$

for Saturation $V_{DS}|_{min} = 0.5\,V$

at min V_{DS}:

$V_{GS} - V_t = 0.5\,V \rightarrow V_{GS} = V_t + 0.25 = 0.5 + 0.5 = \underline{1\,V}$

(11.5) Problem (5.21)

In triode region $V_{GS} > V_t$ & $V_{DS} < V_{GS} - V_t$

(5.16) $I_D = \underbrace{k_n'\left(\frac{W}{L}\right)}_{k_n} \left[(V_{GS}-V_t)V_{DS} - \frac{1}{2}V_{DS}^2\right]$

if $\frac{1}{2}V_{DS}^2 << (V_{GS}-V_t)V_{DS}$

$i_D \approx k_n (V_{GS}-V_t)V_{DS}$ "Linear resistance region"

case 1 $25\,\mu A = k_n(1-V_t) \times 0.05$ — ①

case 2 $50\,\mu A = k_n(1.5-V_t) \times 0.05$ — ②

by dividing Eq (2) by Eq (1)

$2 = \frac{1.5-V_t}{1-V_t} \longrightarrow V_t = 0.5\,V$

Substituting V_t in Eq. 1 $25\,\mu A = k_n \times 0.5 \times 0.05 \longrightarrow k_n = 1000\,\mu A/V^2$

for $k_n' = 50\,\mu A/V^2$ $\longrightarrow \frac{W}{L} = 20$

For $v_{GS} = 2V$ and $v_{DS} = 0.1\,V$ $\longrightarrow v_{GS} > v_t$ $(2 > 0.5)$ & $V_{GS} - v_t = 1.5$ $\therefore V_{DS} < V_{GS} - v_t \rightarrow$ triode

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

$= 1\left[(2-0.5)\times 0.1 - \frac{1}{2}\times 0.1^2\right] = 145\,\mu A$

For $v_{GS} = 2V$, Pinch-off will occur for $v_{DS} = v_{GS} - v_t = 2 - 0.5 = 1.5\,V$

the drain current will be

(5.20) for Saturation $i_D = \frac{1}{2}k_n(v_{GS}-V_t)^2 = \frac{1}{2}\times 1 \times (2-0.5)^2 = 1.125\,mA$

11.6 PROBLEM (5.22)

$v_{DS} \leq v_{GS} - V_t$

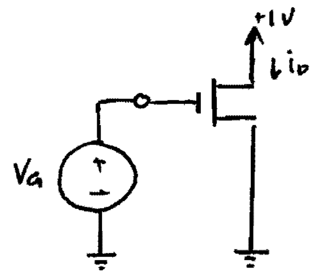
for $v_{GS} = 1.0V$ to $1.8V$ and $V_t = 0.4V$

for max V_{DS} use $v_{GS} = 1V$

$v_{DS} \leq 1 - 0.4$ so $V_{DS}|_{max} = \underline{0.6 V}$

(117) PROBLEM (5.28)

$V_t = 0.4V$



Cutoff - Saturation boundary is determined by $V_{GS} = V_t$

So $V_{GS} = 0.4V$ at the boundary

The Saturation - triode boundary is determined by

$V_{GD} = V_t$ and $V_{DS} = V_{DD} = 1V$ and since

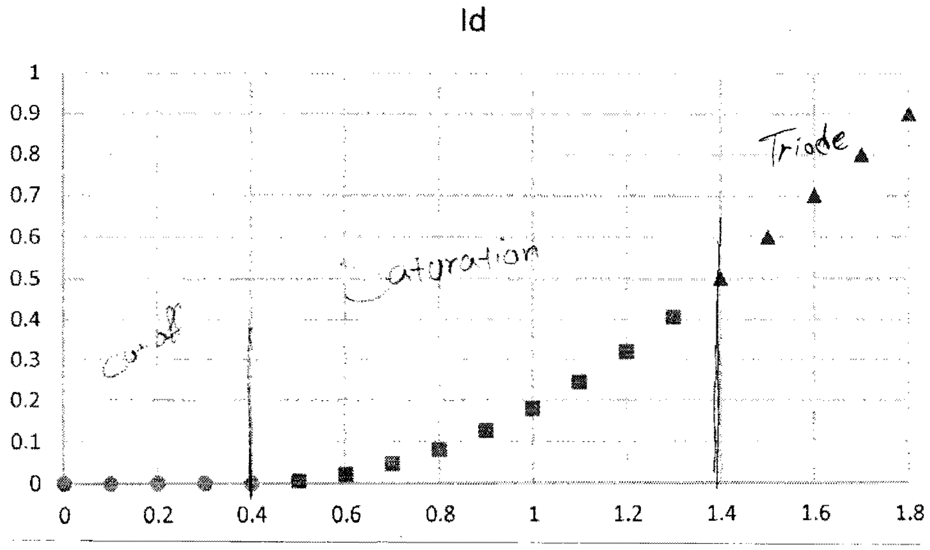
$V_{GS} = V_{GD} + V_{DS}$, one has

$V_{GS} = 0.4 + 1.0 = 1.4V$ at the boundary

So Cut off $i_D \frac{L}{k_n' W} = 0$ $\quad 0 \leq V_{GS} \leq 0.4$ V

Saturation $i_D \frac{L}{k_n' W} = \frac{(V_{GS} - 0.4)^2}{2}$ $\quad 0.4 \leq V_{GS} \leq 1.4$ V

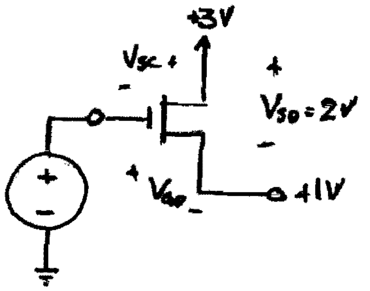
Triode $i_D \frac{L}{k_n' W} = V_{GS} - 0.9$ $\quad 1.4 \leq V_{GS} \leq 1.8$ V



(11.8) PROBLEM (5.41)

Refer to Table 5.2

And Lecture 27



For induced Channel

$V_{SG} \geq |V_{tp}|$

$= V_S - V_G = 3 - V_G \longrightarrow V_G$ range from 3 to 0 V

- V_G from $3 \to 2.5$ V : $V_{SG} \leq |V_{tp}|$ X^{tor} Cutoff

- At $V_G = 2.5V$, $V_S - V_G = 3 - 2.5 \geq |V_{tr}|$ X has induce channel

So, $V_{SD} = 3 - 1 = 2V$ & $V_{SD} \geq V_{SG} - |V_{tr}| \rightarrow (2 \geq 0.5 - 0.5)$ Saturation

As V_G decrease from 2.5V to 0.5V X^{tor} Stay Saturated

- At $V_G = 0.5V$, $V_{GS} - |V_{tp}| = 2V$ ∴ V_{SD} is no longer greater than $V_{SG} - |V_{tr}|$

Instead $V_{SD} \leq V_{SG} - |V_{tr}|$ triode region

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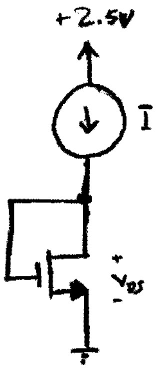
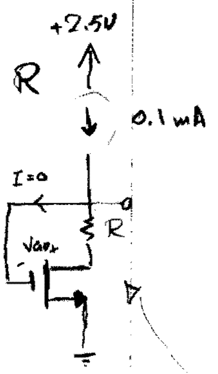
(11.9_1) PROBLEM (5.43).a



(a)

ⓐ $V_1 = V_{DS} = V_{GS} = 1V$

After adding R

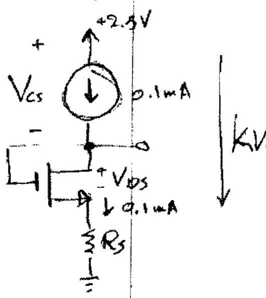


for saturation $V_{GD} \le V_t$

$V_{GD} = I \cdot R \le V_t$

$I \, R_{max} = V_t \longrightarrow R_{max} = \frac{V_t}{I} = \frac{0.5V}{0.1mA} = \underline{5k\Omega}$

Now add R_s



$2.5 = V_{CS} + V_{DS} + I R_{s_{max}}$

$2.5 = 0.5 + 1 + I R_{s_{max}}$

$I R_{s_{Max}} = 2.5 - 1.5 \longrightarrow R_{max} = \frac{1V}{0.1mA} = \underline{10k\Omega}$

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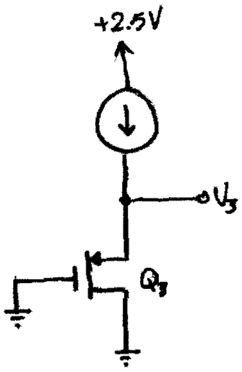
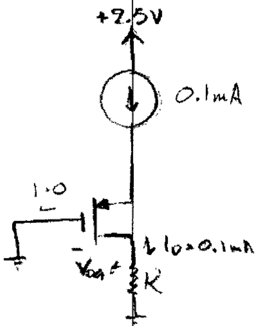
Cont (11.9) Problem (5.43).c



(c) $V_3 = V_{SD} = V_{SG} = 1V$

Adding R



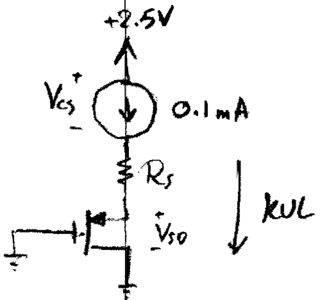
For Saturation $V_{DG} \leq |V_{tp}|$

$I_D R = V_D - \cancel{V_G}^{0} \leq |V_{tp}|$

$I R_{max} = |V_{tp}| = 0.5 \rightarrow R$

$\therefore R_{max} = \frac{0.5V}{0.1mA} = \underline{5k\Omega}$

Adding R_s



by KVL

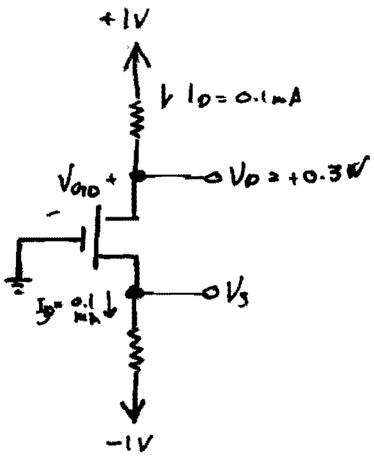
$2.5 = V_{CS} + IR_s + V_{SD}$

$2.5 = 0.5 + IR_{s_{max}} + 1$

$IR_{s_{max}} = 2.5 - 0.5 - 1 = 1V$

$R_{s_{max}} = \frac{1V}{I} = \frac{1V}{0.1mA} = \underline{10k\Omega}$

11.10 PROBLEM (5.44)



Assume $V_{GS} > V_t$ for induced channel

Since $V_{DG} > 0$ the MOSFET is in Saturation

CHECK *

$$V_{GD} = V_G - V_D = 0 - 0.3 = -0.3V < V_t$$

$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} V_{ov}^2$$

$$0.1 = \frac{1}{2} \times 0.4 \times \frac{5}{0.4} \times V_{ov}^2 \longrightarrow V_{ov} = 0.2V$$

$$V_{GS} = V_t + V_{ov} = 0.5 + 0.2 = 0.7$$

CHECK * $V_{GS} = V_G - V_S = 0 - (-0.7) = 0.7 > V_t$ induced channel

$$V_S = 0 - V_{GS} = -0.7V$$

$$R_S = \frac{V_S - (-1)}{I_D} = \frac{-0.7 + 1}{0.1mA} = \underline{3k\Omega}$$

$$R_D = \frac{1 - V_D}{I_D} = \frac{1 - 0.3}{0.1mA} = \frac{0.7}{0.1mA} = \underline{7k\Omega}$$