ECE 2100 Lecture Notes 4/7/03

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4/6/03

Stuff

Exam 3 Wednesday 4/9/03

Primarily Ch.4 (BJTs), but may include any earlier material.
Old exams are available on the HW web page.

MOSFET Lab today: Bring lab card with at least \$4.50.

Bring your textbook to lab

Spice #S2, due: M, 4/7 2 handouts

HW #20, due: W, 4/9 Ex4.45, Ex4.46
Problems 4.120, 4.119, The transistor of HW 19, problem 1 has C_π = 11pF, C_μ = 2pF & 1pF of stray capacitance between the base & collector, find f_{CH} due to these.

ans 4.120 $r_o || \dfrac{r_\mu + r_\pi}{\beta + 1}$ last problem: $1.82\cdot\text{MHz}$

HW # 21, due: F 4/11 Ex5.1 - Ex5.8
ans: Ex5.7: V_{SB}=4V, i_D=0.182mA, r_o=578ohm

HW # 22, due: W 4/16 Ex5.9 - Ex5.16
Check assumptions, esp saturation on 15 & 16

Depletion-type MOSFET Continued

Equations are often rewritten in terms of I_{DSS}, because I_{DSS} is so easy to measure

$$\frac{2\cdot I_{DSS}}{V_t^2} = k'_n\cdot\frac{W}{L}$$

Small v_{DS} $\quad r_{DS} = \dfrac{V_t^2}{2\cdot I_{DSS}\cdot\left(V_{GS} - V_t\right)}$

Triode: $i_D = I_{DSS}\cdot\left[2\cdot\left(\dfrac{v_{GS}}{V_t} - 1\right)\cdot\dfrac{v_{DS}}{V_t} - \left(\dfrac{v_{DS}}{V_t}\right)^2\right]$

Saturation: $i_D = I_{DSS}\cdot\left(1 - \dfrac{v_{GS}}{V_t}\right)^2$

$$i_D = I_{DSS}\cdot\left(1 - \frac{v_{GS}}{V_t}\right)^2\cdot\left(1 + \lambda\cdot v_{DS}\right)$$

Transconductance: $g_m = \dfrac{2\cdot I_{DSS}}{V_t^2}\cdot\left(V_{GS} - V_t\right) = \sqrt{\dfrac{4\cdot I_{DSS}\cdot I_D}{V_t^2}}$

OR, the old equations still work fine

$$r_{DS} = \frac{1}{k'_n\cdot\frac{W}{L}\cdot\left(v_{GS} - V_t\right)}$$

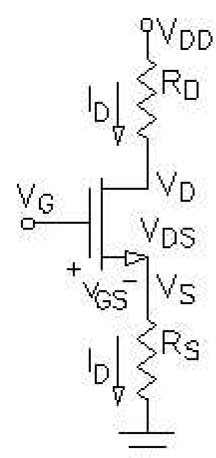
$$i_D = k'_n\cdot\frac{W}{L}\cdot\left[\left(v_{GS} - V_t\right)\cdot v_{DS} - \frac{1}{2}\cdot v_{DS}^2\right]$$

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

$$i_D = \frac{1}{2}\cdot k'_n\cdot\frac{W}{L}\cdot\left(v_{GS} - V_t\right)^2\cdot\left(1 + \lambda\cdot v_{DS}\right)$$

$$g_m = k'_n\cdot\frac{W}{L}\cdot\left(V_{GS} - V_t\right) = \sqrt{k'_n\cdot\frac{W}{L}\cdot 2\cdot I_D}$$

DC Circuits (bias)



You need to know the important parameters of the MOSFET: V_t and $k'_n\cdot\dfrac{W}{L}$

In reality, these are not that well known, and you may have to repeat calculations for max and min values

Important circuit parameters are: V_G , R_S & I_D Need to know 2

Any single one of these could be unknown.

Next you need to assume a region of operation.

<u>Cutoff Region</u> If $V_G < V_t$, you're done. There's no way the MOSFET will turn on at all

$I_D = 0$ $\quad R_S$ can be anything

<u>Saturation Region</u>

Assume R_D is small enough that the FET is in saturation (active) region

If I_D is known (often a design parameter): $I_D = \dfrac{1}{2}\cdot k'_n\cdot\dfrac{W}{L}\cdot\left(V_{GS} - V_t\right)^2$

These equations are for the circuit above. If your circuit is different, modify the equations accordingly.

$$\frac{2}{k'_n\cdot\frac{W}{L}}\cdot I_D = \left(V_{GS} - V_t\right)^2 \qquad V_{GS} = \sqrt{\frac{2\cdot I_D}{k'_n\cdot\frac{W}{L}}} + V_t$$

Now, depending on which other variable is known: If V_G is known: $V_S = V_G - V_{GS}$ $\quad R_S = \dfrac{V_S}{I_D}$

If R_S is known: $V_S = I_D\cdot R_S$ $\quad V_G = V_S + V_{GS}$

If I_D is unknown, things get a little harder: $V_{GS} = V_G - R_S \cdot I_D$

$$I_D = \frac{1}{2} \cdot k'_n \cdot \frac{W}{L} \cdot \left(V_{GS} - V_t\right)^2 = \frac{1}{2} \cdot k'_n \cdot \frac{W}{L} \cdot \left(V_G - R_S \cdot I_D - V_t\right)^2 = \frac{1}{2} \cdot k'_n \cdot \frac{W}{L} \cdot \left[\left(V_G - V_t\right) - R_S \cdot I_D\right]^2$$

$$\frac{2}{k'_n \cdot \frac{W}{L}} \cdot I_D = \left[\left(V_G - V_t\right) - R_S \cdot I_D\right] \cdot \left[\left(V_G - V_t\right) - R_S \cdot I_D\right] = \left(V_G - V_t\right)^2 - 2 \cdot \left(V_G - V_t\right) \cdot R_S \cdot I_D + R_S^2 \cdot I_D^2$$

Solve for I_D:

$$0 = \underbrace{R_S^2}_{a} \cdot I_D^2 - \underbrace{2 \cdot \left[\left(V_G - V_t\right) \cdot R_S + \frac{1}{k'_n \cdot \frac{W}{L}}\right]}_{b} \cdot I_D + \underbrace{\left(V_G - V_t\right)^2}_{c}$$

$$I_{D1} = \frac{-b + \sqrt{b^2 - 4 \cdot a \cdot c}}{2 \cdot a} \qquad I_{D2} = \frac{-b - \sqrt{b^2 - 4 \cdot a \cdot c}}{2 \cdot a}$$

Of these two answers, only one will make sense. ($V_{GS} > V_t$).

Finally, you MUST check to see that the MOSFET is actually in the saturation region. If not, you' ll have to start over or modify your design.

Go through the examples in your book, p381 - 387

Triode Region If R_D is too big, the FET is in triode region

If I_D is known:

$$I_D = k'_n \cdot \frac{W}{L} \cdot \left[\left(V_{GS} - V_t\right) \cdot V_{DS} - \frac{1}{2} \cdot V_{DS}^2\right]$$

$$\frac{1}{k'_n \cdot \frac{W}{L}} \cdot I_D = \left[\left(V_{GS} - V_t\right) \cdot V_{DS} - \frac{1}{2} \cdot V_{DS}^2\right]$$

$$\frac{1}{k'_n \cdot \frac{W}{L} \cdot V_{DS}} \cdot I_D = \left(V_{GS} - V_t\right) - \frac{1}{2} \cdot V_{DS} \qquad V_{GS} = \frac{I_D}{k'_n \cdot \frac{W}{L} \cdot V_{DS}} + V_t + \frac{1}{2} \cdot V_{DS}$$

Where: $V_{DS} = V_{DD} - R_D \cdot I_D - R_S \cdot I_D = V_{DD} - \left(R_D + R_S\right) \cdot I_D$

Now, depending on which other variable is known:

If V_G is known: $V_S = V_G - V_{GS}$ $\qquad R_S = \frac{V_S}{I_D}$

If R_S is known: $V_S = I_D \cdot R_S$ $\qquad V_G = V_S + V_{GS}$

If **I_D is unknown**, things get downright messy: Define: $K = k'_n \cdot \frac{W}{L}$ & $R_T = R_D + R_S$

$$I_D = k'_n \cdot \frac{W}{L} \cdot \left[\left(V_{GS} - V_t\right) \cdot V_{DS} - \frac{1}{2} \cdot V_{DS}^2\right] \qquad V_{GS} - V_t = V_G - R_S \cdot I_D - V_t \qquad V_{DS} = V_{DD} - R_T \cdot I_D$$

$$= K \cdot \left[\left(V_G - R_S \cdot I_D - V_t\right) \cdot \left(V_{DD} - R_T \cdot I_D\right) - \frac{1}{2} \cdot \left(V_{DD} - R_T \cdot I_D\right)^2\right] =$$

$$K \cdot \left(V_G \cdot V_{DD} - V_G \cdot R_T \cdot I_D - R_S \cdot I_D \cdot V_{DD} + R_S \cdot I_D^2 \cdot R_T - V_t \cdot V_{DD} + V_t \cdot R_T \cdot I_D - \frac{1}{2} \cdot V_{DD}^2 + V_{DD} \cdot R_T \cdot I_D - \frac{1}{2} \cdot R_T^2 \cdot I_D^2\right)$$

$$0 = \underbrace{\left(R_S \cdot R_T - \frac{1}{2} \cdot R_T^2\right)}_{a} \cdot I_D^2 + \underbrace{\left[V_{DD} \cdot R_D - \left(V_G - V_t\right) \cdot R_T - \frac{1}{K}\right]}_{b} \cdot I_D + \underbrace{\left[\left(V_G - V_t\right) \cdot V_{DD} - \frac{1}{2} \cdot V_{DD}^2\right]}_{c}$$

$$I_{D1} = \frac{-b + \sqrt{b^2 - 4 \cdot a \cdot c}}{2 \cdot a} \qquad I_{D2} = \frac{-b - \sqrt{b^2 - 4 \cdot a \cdot c}}{2 \cdot a}$$

Of these two answers, only one will make sense. ($V_{GS} > V_t$).