ECE 2100 Lecture Notes 4/4/03

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

A. Stolp
4/5/03

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.

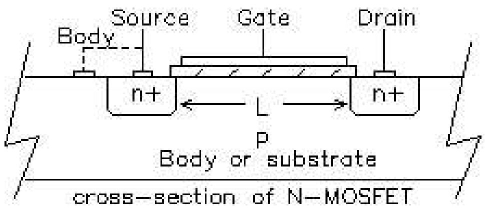
ans 4.120 $r_o || \frac{r_\mu + r_\pi}{\beta + 1}$ last problem $1.82 \cdot \text{MHz}$

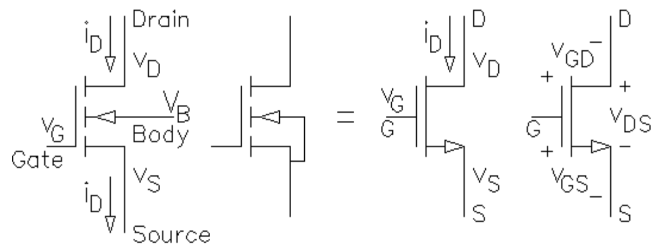
HW # 21, due: F 4/11 Ex5.1 - Ex5.8
ans: Ex5.7: V_{SB}=4V, i_D=0.182mA, r_o=578ohm

Start with MOSFET part of Wednesday's notes

MOSFETS

n-channel enhancement:





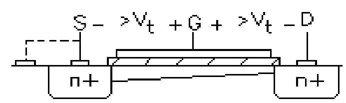
Threshold Voltage Minimum voltage to induce a channel (n) in the p substrate, called *inversion*

Ohmic region of operation (for small v_{DS}) $r_{DS} = \frac{1}{k_n \cdot \frac{W}{L} \cdot (v_{GS} - V_t)}$

Triode Region (aka, linear, also includes ohmic region)

Both ends of the channel are still open. $v_{GD} > V_t$ $v_{DS} < v_{GS} - V_t$

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

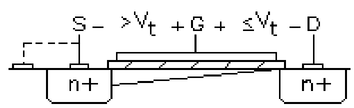


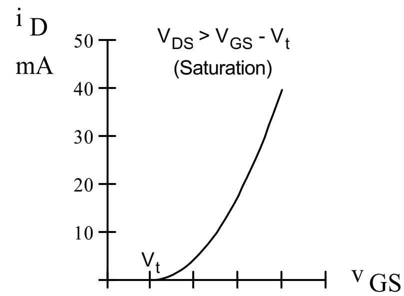
Saturation Region (Beware, this is nothing like the saturation region of a BJT)

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

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

Early voltage = $V_A = \frac{1}{\lambda}$ $r_o \simeq \frac{1}{\lambda \cdot I_D} = \frac{V_A}{I_D}$

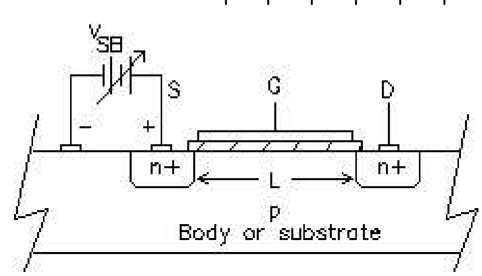




Body Effects (No such thing if the source and body are connected.)

Don't ever let the body become 0.7V more + than Source or the body-source diode will conduct. This can lead to unpredictable effects, including "latch-up" or total destruction. Same goes for Drain.

The best way to think of the body is as a second gate, which affects the channel a little like the regular gate. A + voltage on the body would tend to open up the channel and a - voltage would tend to close the channel.



A negative voltage on the body will effectively increase the gate voltage necessary to turn the MOSFET on. This is how you account for the body effect, by changing the V_t of the MOSFET.

See p. 374 in text.

$V_t = V_{t0} + \gamma \cdot \left(\sqrt{2 \cdot \phi_f + V_{SB}} - \sqrt{2 \cdot \phi_f} \right)$ typical: $\phi_f := 0.3 \cdot V$ $2 \cdot \phi_f = 0.6 \cdot V$

V_t with no V_{SB}

Body effect parameter: $\gamma = \frac{\sqrt{2 \cdot q \cdot N_A \cdot \varepsilon_s}}{C_{ox}}$ typical: $\gamma := 0.5 \cdot \sqrt{V}$

Permittivity of silicon: $\varepsilon_s := 1.035 \cdot 10^{-12} \cdot \frac{F}{cm}$

Electron charge: $q := 1.60 \cdot 10^{-19} \cdot \text{coul}$ doping of p substrate

Thermal effects

$\Delta V_t \approx -2\cdot\frac{mV}{degC}$ just like V_{BE} $\qquad k_n\cdot\frac{W}{L} = K$ is proportional to $T^{-\frac{3}{2}} = \frac{1}{\sqrt{T^3}}$

2nd effect dominates, so i_D decreases with temp, So MOSFETs can be hooked in parallel.

You can't do that with BJTs or one may thermally run away. In BJTs, i_C increases with temp, so when two are in parallel, the hottest one takes the most current-- and gets even hotter...

Breakdown Mechanisms

Nondestructive (if power is not too great)

- Drain-Body diode breakdown, like zener diode, 50 to 100V
- Drain-Source "punch-through" in small devices, ~20V

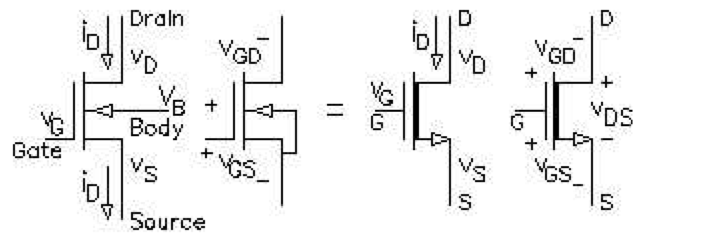
Destructive

- Gate insulation breakdown ("burn-through"), ~50V, easy to get with static electricity. Gate is usually protected by diodes, but is still easily hurt.

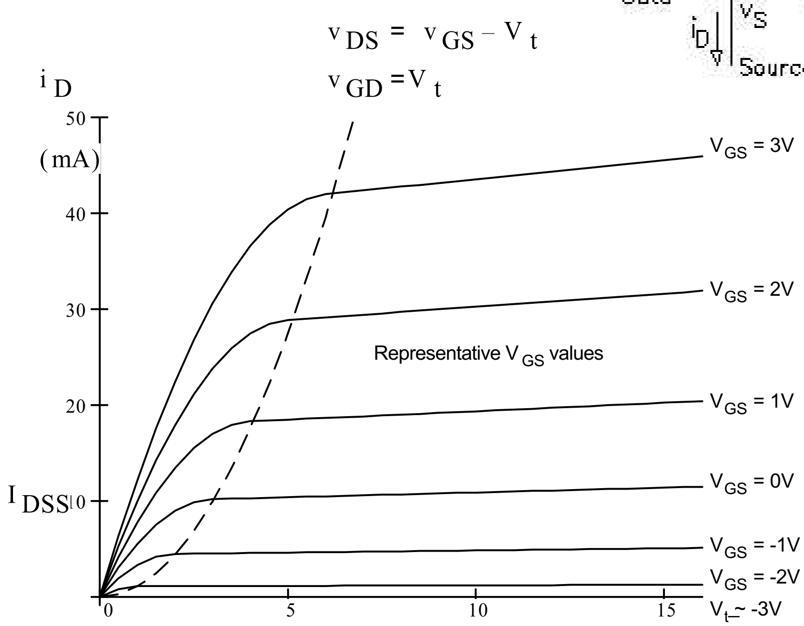
Depletion-type MOSFET

Channel already exists by doping, even with no v_{GS}.

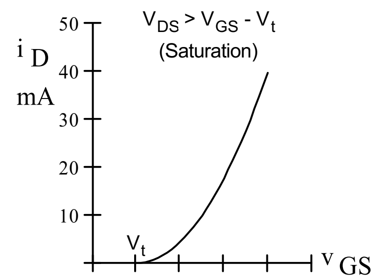
Everything is the same, except V_t is negative



Symbols try to show a channel



Representative i_D vs v_{DS} curves v_{DS} (volts)



Enhancement-mode MOSFET

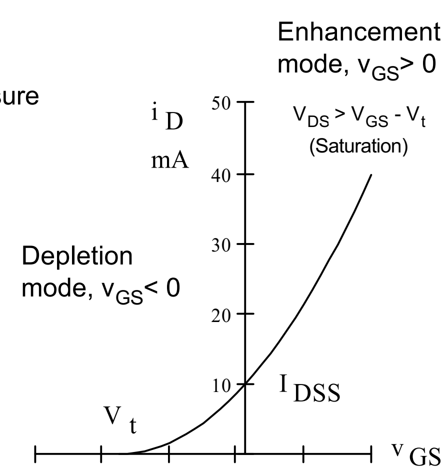
$$I_{DSS} = \frac{1}{2}\cdot k_n\cdot\frac{W}{L}\cdot V_t^2 \qquad k_n\cdot\frac{W}{L} = \frac{2\cdot I_{DSS}}{V_t^2}$$

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

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

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

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



Depletion-mode MOSFET