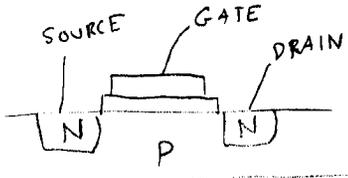


"Field effect" transistors

10A
①

Basic operation:



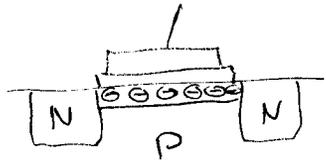
← N-channel MOSFET.

For now, assume V_{DS} is small ----

When $V_{GS} = 0$ -

No conduction drain to source.
- like a pair of diodes in series.

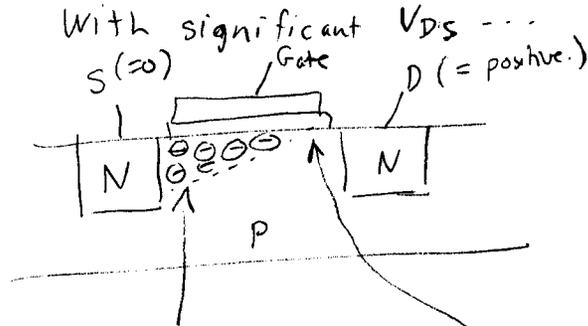
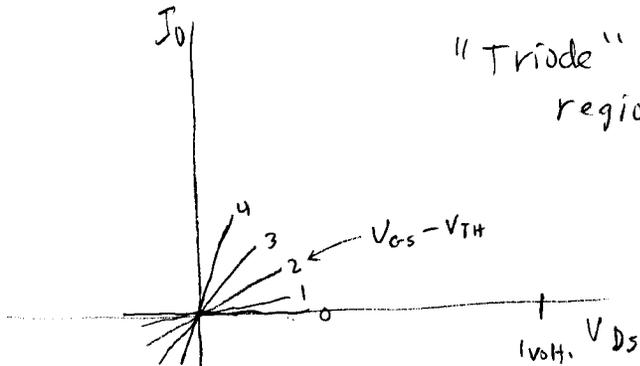
Positive bias on gate, above a threshold V_{TH}



Negative carriers attracted to gate.

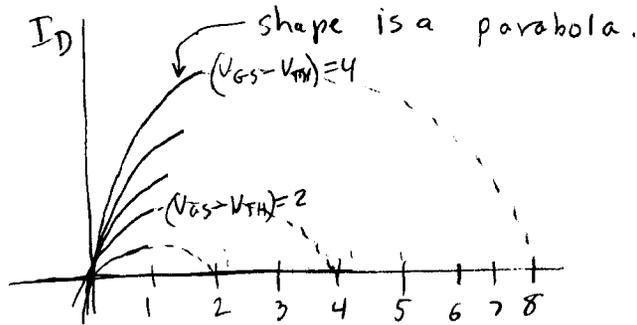
More bias \Rightarrow more conduction:

"Triode" or "ohmic" region.



lots of carriers here.
($V_{GS} - V_{TH}$) is positive

Few carriers here
($V_{GD} - V_{TH}$) ≈ 0
or maybe negative.



$$i_D = K \left(2(V_{GS} - V_{TH})V_{DS} - V_{DS}^2 \right)$$

$K =$ "process transconductance" = $\frac{\text{Amps}}{(\text{Volts})^2}$

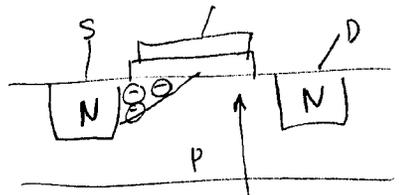
$(V_{GS} - V_{TH}) =$ "excess gate voltage"

Common abbreviation: V_{GS}

10A
②

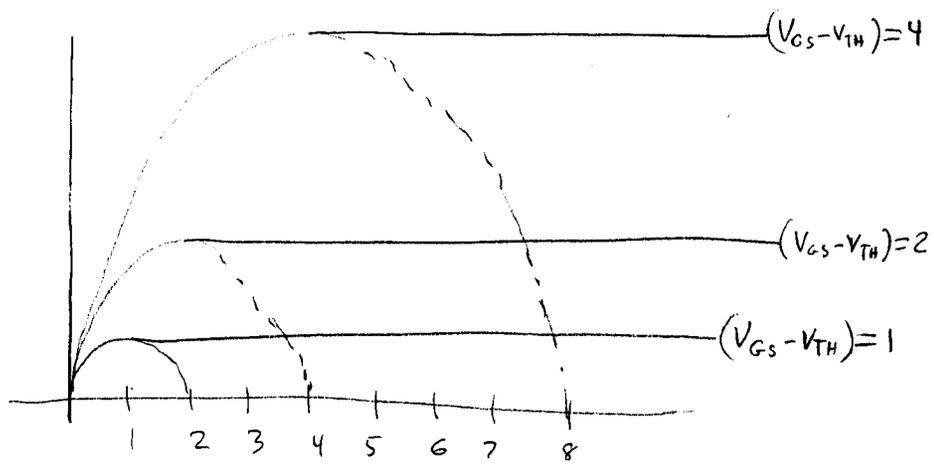
10A
3

Even bigger V_{DS} --



channel is "pinched off" --

It acts like constant current -
"saturation region"



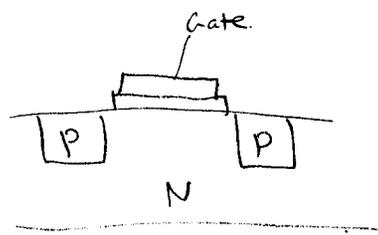
$$i_D = K(V_{GS} - V_{TH})^2$$

Confusion warning:
 FET "saturation" means active region.
 BJT "saturation" is more like FET "ohmic" region.

10A
4

P-channel MOSFET

It is the same except that polarity is reversed --

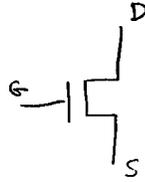
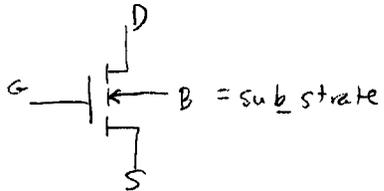
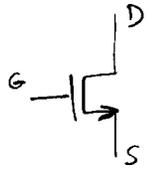


$V_{DS} < 0$
 $(V_{GS} - V_{TH}) < 0$
 for conduction.

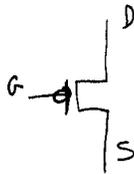
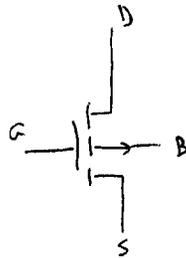
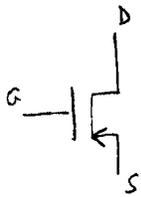
FET Symbols --

You will see all of these ...

N channel



P channel



5

Large signal model of FET.

6

Triode region -- $(V_{GS} - V_{TH}) > V_{DS}$

$$I_D = K (2 (V_{GS} - V_{TH}) V_{DS} - V_{DS}^2)$$

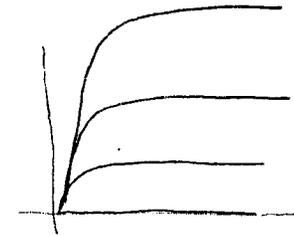
← depends on both V_{GS} and V_{DS}



Saturation region -- $(V_{GS} - V_{TH}) < V_{DS}$

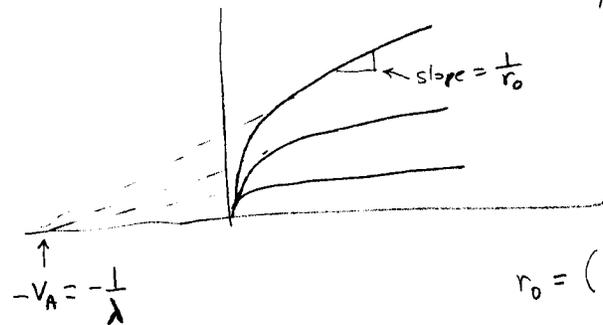
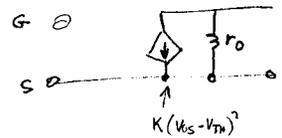
$$I_D = K (V_{GS} - V_{TH})^2$$

← does not depend on V_{DS}



in more detail (5.1.7)

$$i_D = K ((V_{GS} - V_{TH})^2 (1 - \lambda V_{DS}))$$



"channel length modulation"

results in a finite output resistance

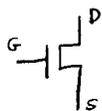
$$r_o = \left(\frac{\partial i_D}{\partial V_{DS}} \right) \Big|_{V_{GS} = \text{const}}$$

$$r_o = \frac{1}{\lambda K_n (V_{GSQ} - V_{TH})^2}$$

Examples:

Device specs:

$K = 2 \frac{\text{mA}}{\text{V}^2}$ $\lambda = 0$ $V_{TH} = 1$



(a) $V_{GS} = 3$, $V_{DS} = 5$

Region = saturation ($V_{GS} - V_{TH} < V_{DS}$)

$$I_D = K(V_{GS} - V_{TH})^2$$

$$= 2(3-1)^2 \text{ mA}$$

$$= 2(2)^2 \text{ mA}$$

$$= 8 \text{ mA}$$

(b) $V_{GS} = 2$, $V_{DS} = 5$

Region = saturation ($V_{GS} - V_{TH} < V_{DS}$)

$$I_D = K(V_{GS} - V_{TH})^2$$

$$= 2(2-1)^2$$

$$= 2(1)$$

$$= 2 \text{ mA}$$

(c) $V_{GS} = 1$, $V_{DS} = 5$

Region = cutoff ($V_{GS} - V_{TH} = 0$)

$$I_D = K(V_{GS} - V_{TH})^2$$

$$= 2(1-1)$$

$$= 0$$

cutoff

(d) $V_{GS} = 3$, $V_{DS} = 1$

Region = triode ($V_{GS} - V_{TH} > V_{DS}$)

$$I_D = K(2(V_{GS} - V_{TH})V_{DS} - V_{DS}^2)$$

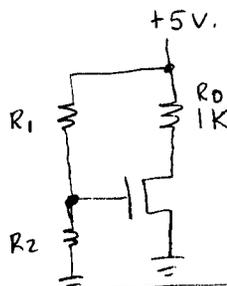
$$= 2(2(3-1)1 - 1^2)$$

$$= 2(2(2) - 1)$$

$$= 2(4 - 1)$$

$$= 2(3)$$

$$= 6 \text{ mA}$$



$K = 2 \frac{\text{mA}}{\text{V}^2}$ $V_{TH} = 1$

$R_1 = 4 \text{ meg}$ $R_2 = 1 \text{ meg}$
 $V_{GS} = 1 \Rightarrow V_{GS} - V_{TH} = 0 \Rightarrow \text{cutoff}$

$R_1 = 3 \text{ meg}$ $R_2 = 2 \text{ meg}$

$V_{GS} = 2 \Rightarrow V_{GS} - V_{TH} = 1$

Try saturated:

$$i_D = K(V_{GS} - V_{TH})^2$$

$$= 2(2-1)^2$$

$$= 2(1)^2$$

$$= 2 \text{ mA}$$

$V_{RD} = I R = (2 \text{ mA})(1\text{K}) = 2 \text{ volts}$

$\Rightarrow V_D = 3$ $V_{DS} = 3$

$V_{DS} > V_{GS} - V_{TH}$ - so it really is in saturation

HW - Reed 5.0 - 5.1 (understand)

pre-read 5.2 on

| P | # | Overview only: |
|----------------|--------------|----------------|
| 252 | 1, 2, 3 | subthreshold |
| 257 | 4 | breakdown |
| 260 | 5 | body effect |
| 261 | 6 | |

$$R_1 = 2 \text{ meg} \quad R_2 = 3 \text{ meg}$$

⑨

$$V_{GS} = 3 \Rightarrow V_{GS} - V_{TH} = 2$$

Try saturated:

$$I_D = K (V_{GS} - V_{TH})^2$$

$$= 2 (2)^2$$

$$= 8 \text{ mA}$$

$$V_{RD} = I_D R = (8 \text{ mA})(1 \text{ k}) = 8 \text{ volts ???}$$

↑
Bad assumption.

Try triode:

$$I_D = K (2 (V_{GS} - V_{TH}) V_{DS} - V_{DS}^2)$$

2 unknowns - need another equation -

$$V_{RD} = I_D R_D \Rightarrow I_D = \frac{V_{RD}}{R_D}$$

$$V_{RD} = 5 - V_{DS} = \frac{5 - V_{DS}}{R_D}$$

Substitute:

$$\frac{5 - V_{DS}}{R_D} = K (2 (V_{GS} - V_{TH}) V_{DS} - V_{DS}^2)$$