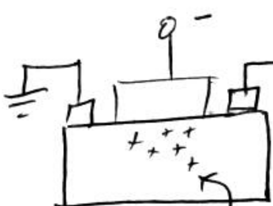
<u>FET's</u> come in <u>several</u> flavours. Look first at an n-channel depletion mode junction FET (JFET) ---

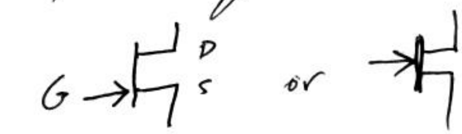
/// → conductor.

(source, gate, drain)

If $V_G = 0$, get limited conduction depending on V_{DS}.

If $V_G < 0$,
(no gate current!)
$Z_{in} \to \infty$!



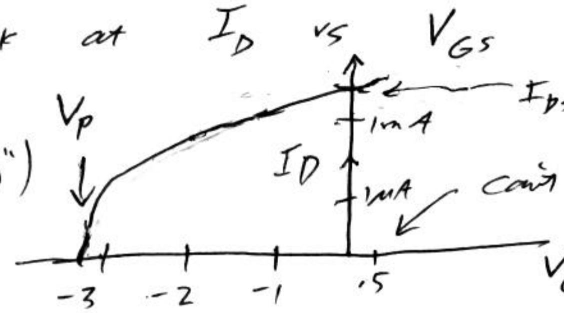


depleted region -- e^- are driven away.

If V_{DS} small, effect is to vary resistance R_{DS} with V_G
If V_{DS} large (> few V), get complete depletion ⇒ I_{DS} is limited to a value determined by V_G (good for amplifier use)

So we need two types of plot:

1) Look at I_D vs V_{GS} for a fixed V_{DS} ---

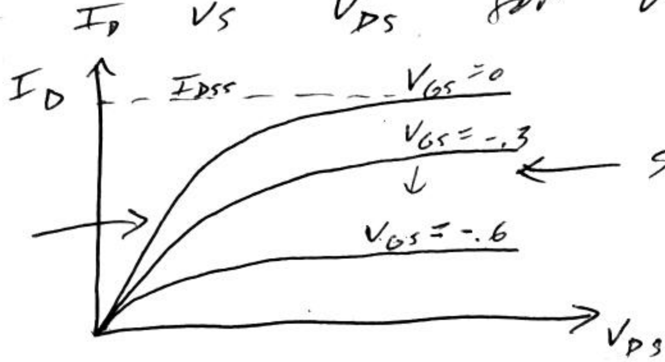


I_{DSS} = current for $V_{GS} = 0$

Can't exceed ~ .5 V or S-G conducts!

(Note semi-log scale.)

2) look at I_D vs V_{DS} for various V_{GS}



saturated region,
$I_D(\text{sat}) \propto (V_{GS} - V_P)^2$

$I \propto V_{DS}$. Like a resistor with $R \propto V_{GS}$!

Saturation occurs when depletion blocks the channel completely. So we can use device either as a variable resistor,

moral: look at curves!

$$I_D = 2K\Big(\underbrace{(V_{GS} - V_P)}_{\text{resistance}} V_{DS} - \frac{V_{DS}^2}{2}\Big) \quad ① \ \text{(low } V_{DS}) \text{ "linear"}$$

(or V_T for enh. mode)

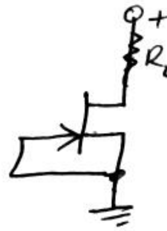
or

$$I_D = K\,(V_{GS} - V_P)^2 \quad ② \ \text{"saturation" (high } V_{DS})$$

(or V_T)

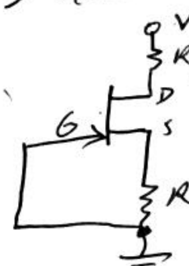
finally, for very small I_D (< 1mA), and high V_{DS}, $I_D = K' e^{V_{GS} - V_P}$ ③

Simple <u>current</u> <u>source</u>:



Operate in sat. region. Then $I_L = I_{DSS}$, apparently $(= K V_P^2)$ set by device.

To vary, use "self-biasing"



Since $I_G = 0$, quite accurately, ~~$V_{GS} = 0$~~ have $I_S = I_D$.

Also $V_{GS} = -I_S R = -I_D R$

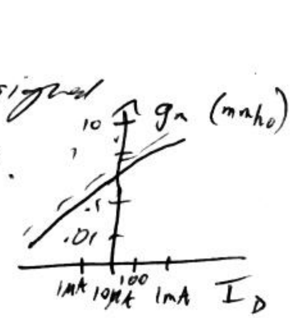
So we have a (−) bias.

Current will be $I_D = K(I_D R - V_P)^2$

(still indep. of V_{DS}.) ~~or $I_D = \frac{1}{KR^2}$~~.

Transconductance --

Most commonly, amps are ~~def~~ designed using $\boxed{g_m \equiv \frac{i_d}{v_{gs}}}$ ← change in drain current. Measured in "mhos".

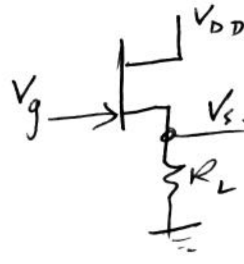


It's <u>smaller</u> than for junction transistors

⇒ high input Z is main FET virtue.

$g_m \sim 2\sqrt{K I_D}$

One common use is FET input circuit ---
simplest is <u>source follower</u> --



(V_{DD} high enough to be in sat. region)

$v_s = i_d R_L$, since $I_s = I_D$.

Using $i_d = g_m v_{gs} = g_m (v_g - v_s)$,

$$v_s = \left(\frac{R_L g_m}{1 + R_L g_m} \right) v_g$$

(but note that $g_m \simeq 2\sqrt{k I_D}$ depends on operating point!)

$$\cong v_g \quad \text{if} \quad R_L g_m >> 1$$

Output impedance is $\frac{1}{g_m}$, like emitter follower, but less impressive ($\sim 100\ \Omega$). However, Z_{in} is <u>very</u> large, especially with MOSFETs.

Another common use is <u>variable</u> <u>resistor</u>.

When ① applies -

$$\frac{I_D}{V_{DS}} = \frac{1}{R_{eff}} = 2K \left(\underbrace{(V_{GS} - V_P)}_{\text{linear}} - \frac{V_{DS}}{2} \right)$$

run with this small, obviously. (Can also compensate by circuit design - see H&H.)

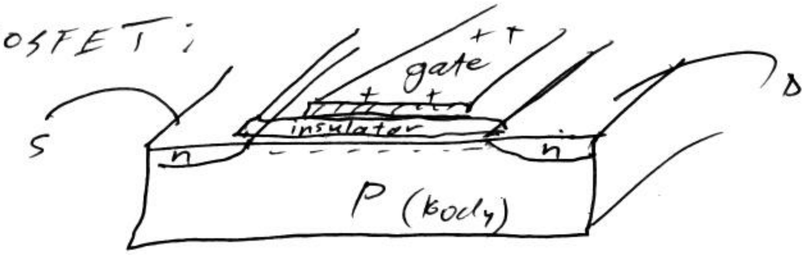
Usable values --- few Ω to ∞.

Suggest use for: modulators
gain control
→ analog switch

But usually we use MOSFET's for this ---

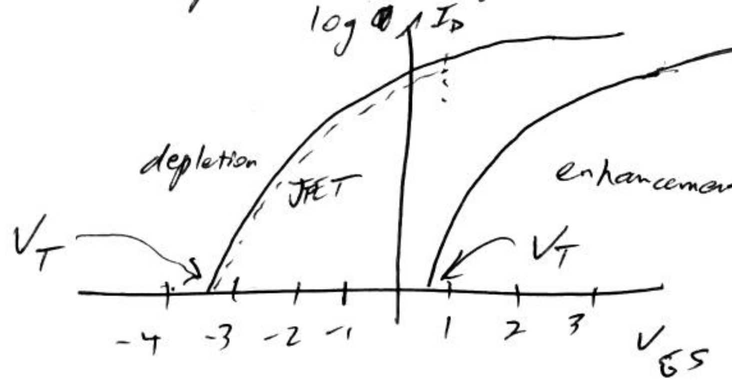
Typical MOSFET:

(NMOS)



Enhancement mode: make gate (+) to create an n-type channel for conduction.

Depletion ~~type~~ mode: vary doping so a (−) voltage discourages conduction. (fairly rare)

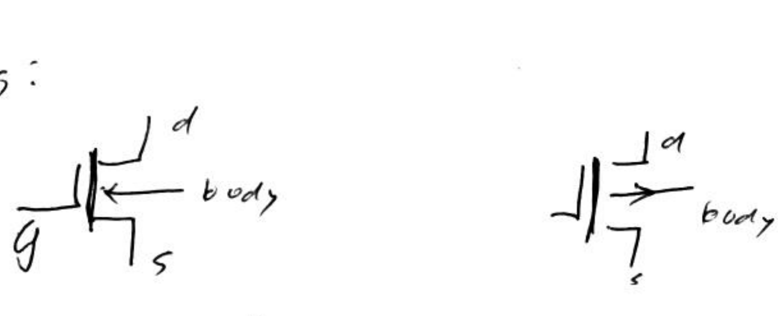


p-channel: mirror image.

So, we usually use MOSFET's as switches.

- no gate leakage (But there is capacitance!)
- 0V is "off"

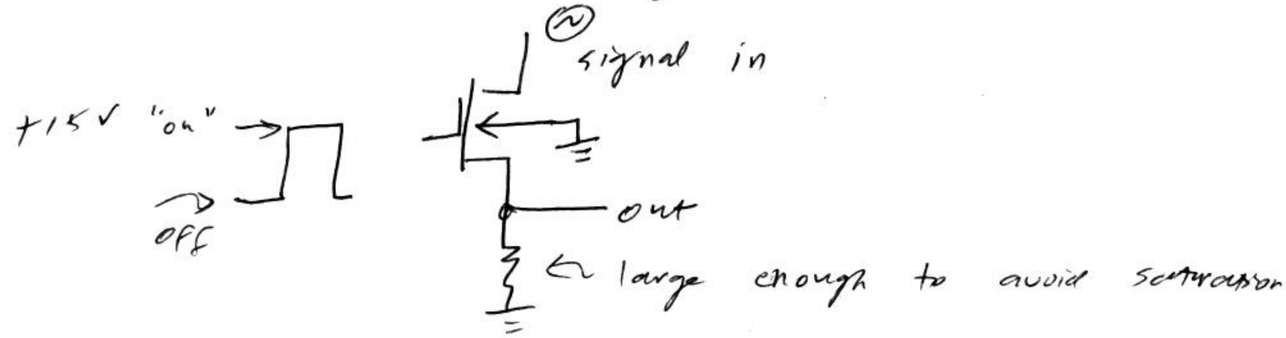
Symbols:



n-channel p-channel

body usually connected to S, or ground, in power MOSFETs.

Typical switch -- analog:



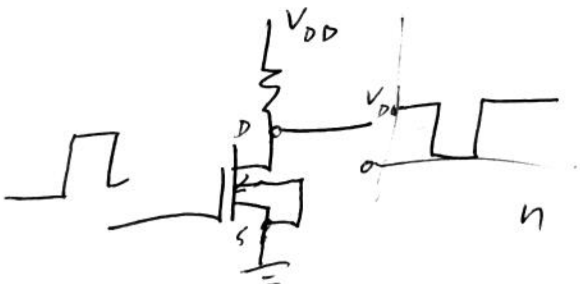
R_{DS} varies from $\sim 10^{10}\ \Omega$

to $25-100\ \Omega$

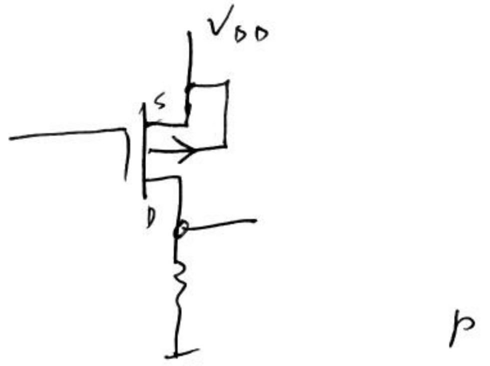
Can be used for multiplexor, reset, etc.

Nice integrated switches available.

logic & power switching: common-source inverter

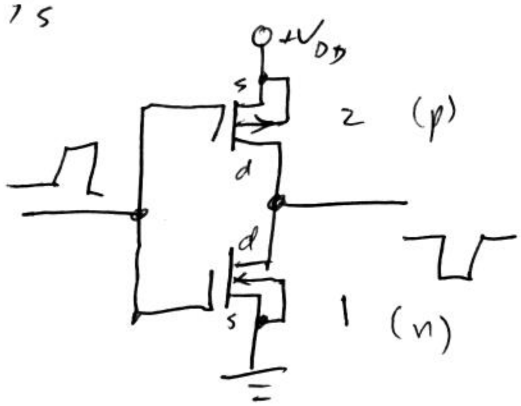


← For power designs, can have $R_{on} \gtrsim 0.01\ \Omega$!!



Good for driving loads.

Better is



CMOS inverter

input grounded --- $V_{gs1} = 0$ (off)

$V_{gs2} = -15V$ (~~off~~ on)

Basis of logic chips

Power FET's -- same with big gates (high C, low R_{on})

- Can have on-state R of $< 0.005\ \Omega$
- Currents up to > 100 A
- Voltages " " > 1000 V
- thermally stable - can use in //.

But,

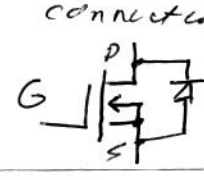
1) Large capacitance -- high gate currents needed to switch rapidly

2) Static - sensitive

3) Easily damaged by reverse gate bias outside spec's.

4) Need $\gtrsim$ 10 V to fully switch on, in some cases.

5) Body connected to source; forms a diode:



← internal but often not shown!