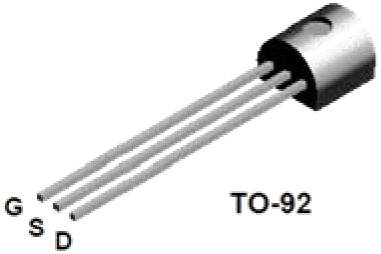
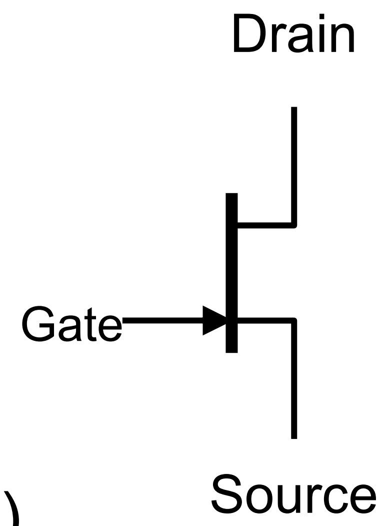
Transistors III: FETs

- 3-terminal device like a BJT

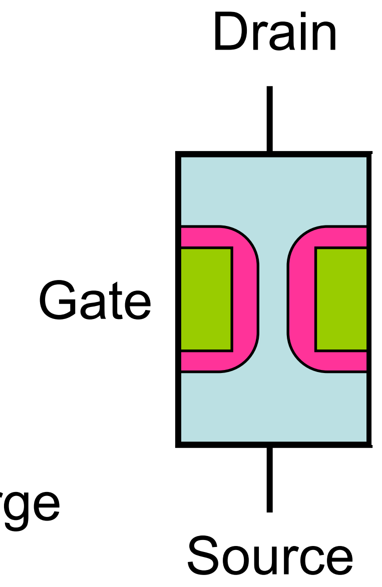
- New names for the connections
  - **Drain** (input) …sort of like collector
  - **Source** (output) … sort of like emitter
  - **Gate** (controls flow) … sort of like base





- 2 broad types
  - Junction FETs (JFETs)
  - Metal-oxide-semiconductor (MOSFETs)

Principle of Operation



- Made from a conducting piece of silicon
  - This is called the ***channel***
  - ***Drain*** on one end
  - ***Source*** on the other
  - In the middle a **gate** is embedded
- Current regulation
  - If the gate is at a negative voltage there is a charge **depletion zone** around the gate
    - Current cannot flow in this zone
    - Expands as the gate becomes more negative
  - Controls the conductivity of the channel
- At a **pinch off voltage** the current stops (V_p)
  - Think of pinching a hose to cut off the flow of water

JFETs vs. MOSFETs

- JFET gate forms a diode junction with the channel. Input impedance ~ $10^{12}\ \Omega$.

- MOSFET has a insulating layer for better input impedance (up to $10^{14}\Omega$).

- MOSFETs have an extra terminal called the **body.**
  - → Usually just connected to the source to drain charge

- MOSFETs are generally used for power circuits and digital circuits.

- Many other types now available.

FETs vs. BJTs

FET Pros

- ➢ The gate of a FET draws almost no current (i.e. pA range).
- ➢ FETs have almost infinite input impedance.
- ➢ Can frequently make a better amplifier circuit with a FET.
- ➢ Can operate bi-directionally sometimes.

FET cons

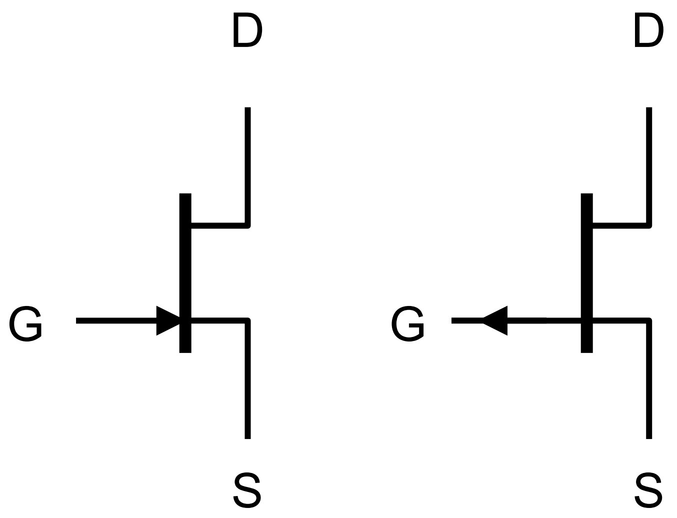
- ➢ FETs are more complicated than BJTs

  → complicated operational model.

- ➢ FET have even larger parameter spreads than BJTs.

FET properties

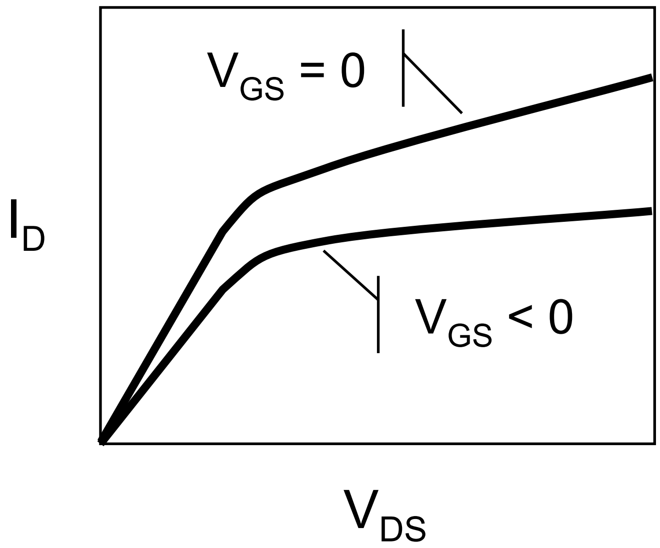
- Can be a n-channel or a p-channel
  - **N-channel** like *npn*
  - **P-channel** like *pnp*
- Gate may be centered on some diagrams
  - Have to figure out it which is which from "context"
  - Source & drain are nearly identical
  - Can be used backwards with almost same performance
- **N-channel** usually faster than **P-channel** due to higher mobility of electrons vs holes moving in the channel.



n-channel JFET (left)
p-channel JFET (right)

Gate Voltage Rules

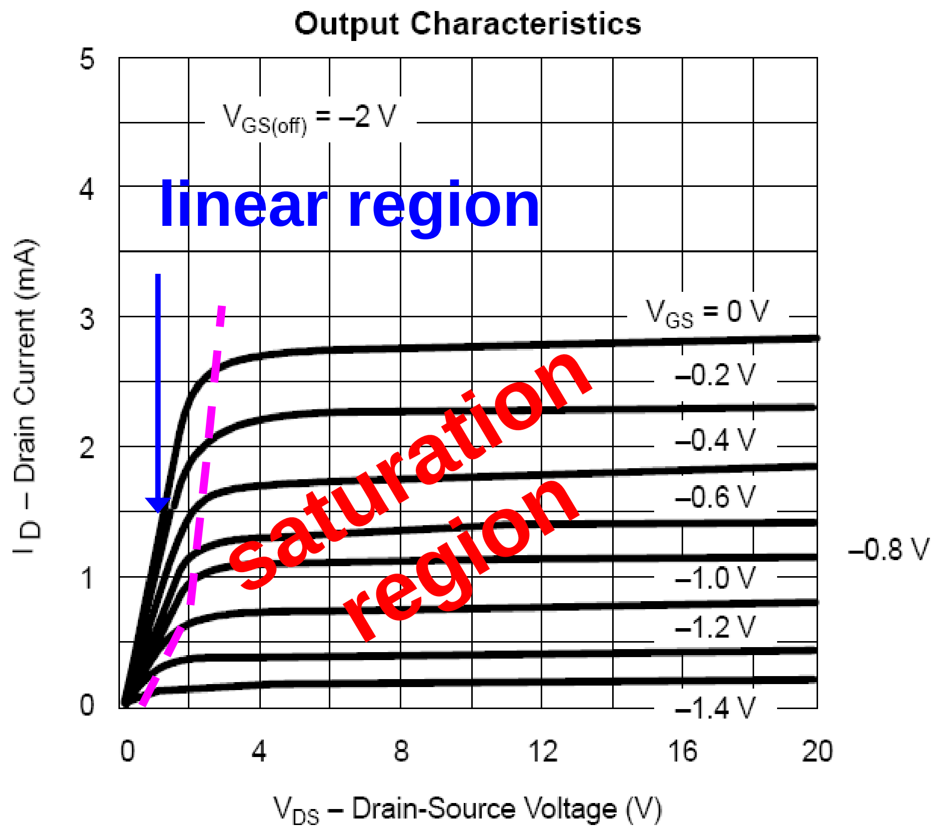
- $V_{GS} < V_p$
  → $I_D = 0$
- For $V_{GS} > 0.6$ V
  → Device Fails!!!
  → Try to keep $V_{GS}<0$
- $V_p < V_{GS} < 0.6$ V
  → I_D depends on both V_{GS} & V_{DS}
  → A complete description would require a 2D function: $I_D\ (V_{GS}, V_{DS})$



Linear and Saturation Region Performance

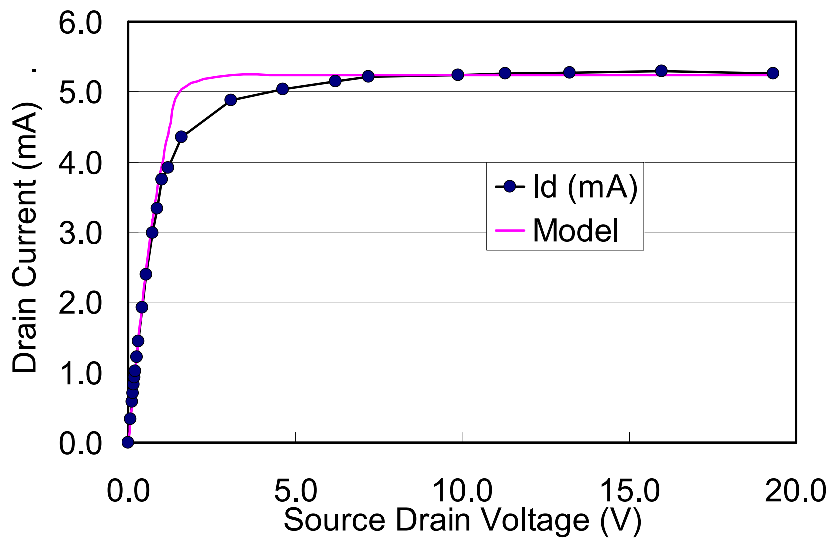
$$\text{Linear Region}: V_{DS} < V_{GS} - V_P$$
$$\rightarrow I_D = k\,[2(V_{GS} - V_P)V_{DS} - V_{DS}^2]$$

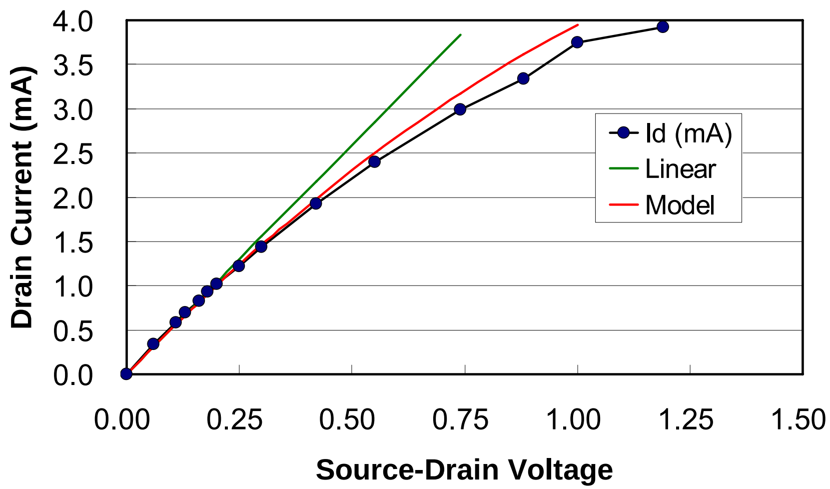
$$\text{Saturation Region}: V_{DS} > V_{GS} - V_P$$
$$\rightarrow I_D = k\,(V_{GS} - V_P)^2$$



- V_p is the **pinch-off** voltage
  → It's negative for n-channel.
  - Voltage where conductance stops
  - **Huge** manufacturing spread
- *k* is a constant
  - Depends on the physical size of the channel (length/width)
  - Depends on the manufacturing details

Ideal Performance vs. Reality





Transconductance in the Saturation Region

- There is a quiescent current given by I_D.
- Use lower case symbols to represent small changes around the quiescent values
  - Transconductance: $g_m = i_d/v_{gs}$
    → Just the slope of I_D vs V_{GS} in the saturated region.
    → Depends on I_D.
  - Smaller variation for $V_{GS} < 0$ V.
  - Units: Ω^{-1} = mho (pronounced “Moe
    → μmho or umho for 10^{-6} mho.
    → mmho for 10_{-3} mho.
    → Sometimes see ℧