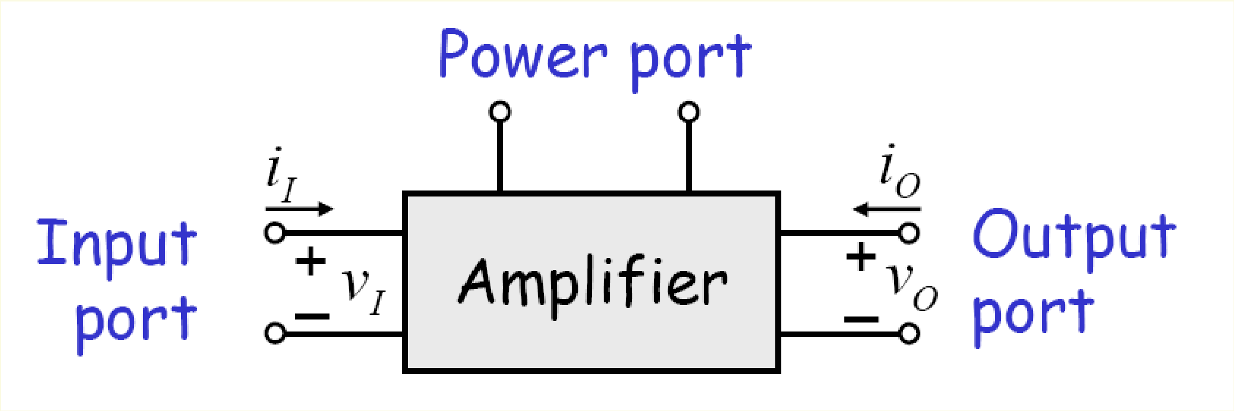
Chap. 7 The MOSFET Amplifier

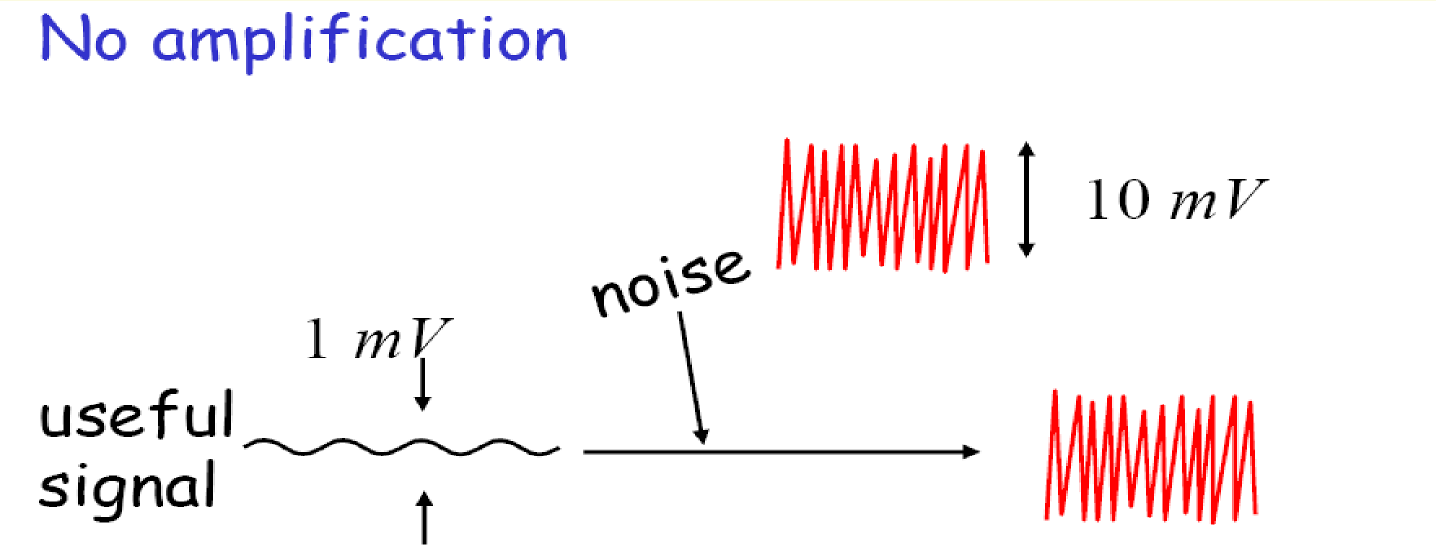
Signal Amplification
Actual MOSFET Characteristics
MOSFET Amplifier
Large Signal Analysis
Bipolar Junction Transitor (BJT)

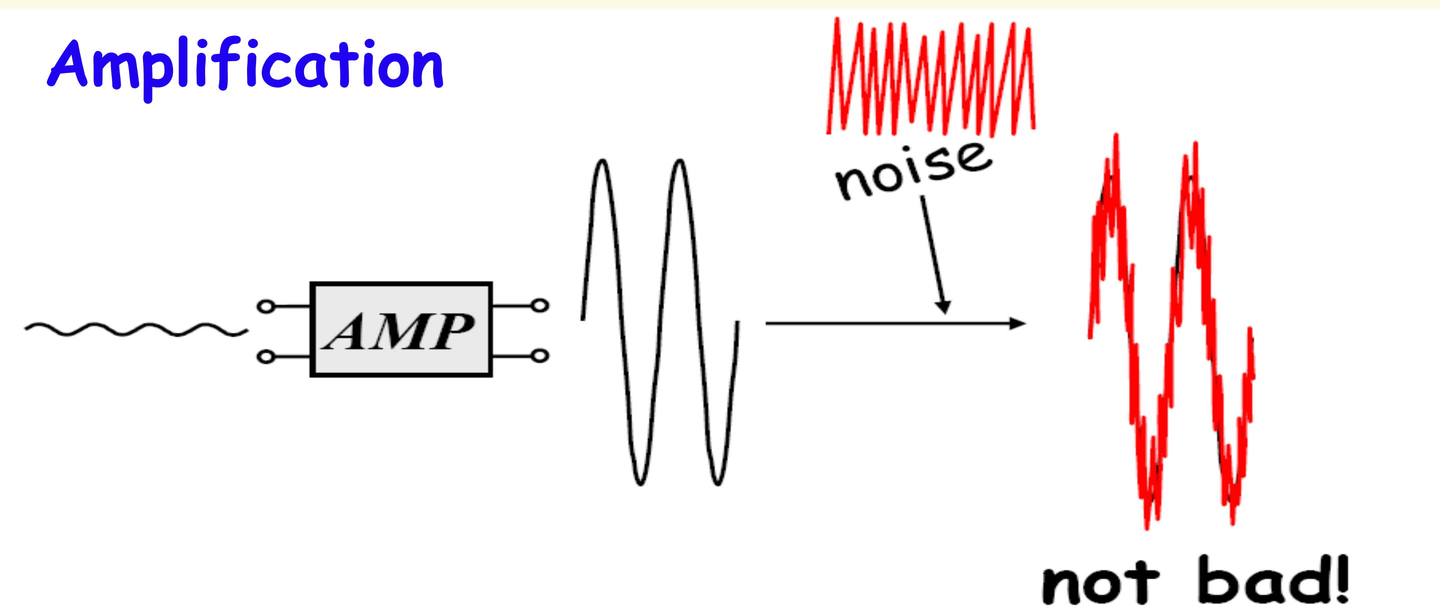
Signal Amplification



- Amplifier: power gain
  - noise tolerance
  - buffering

Why Amplify? (Analog)

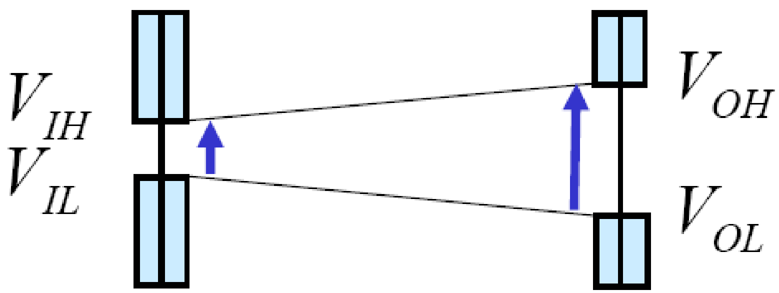




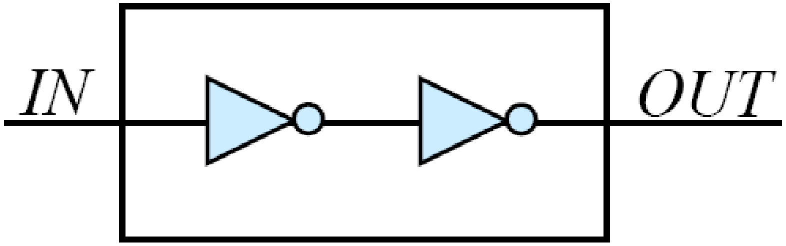
Why amplify? (Digital)

Static discipline requires amplification!

Minimum amplification needed:

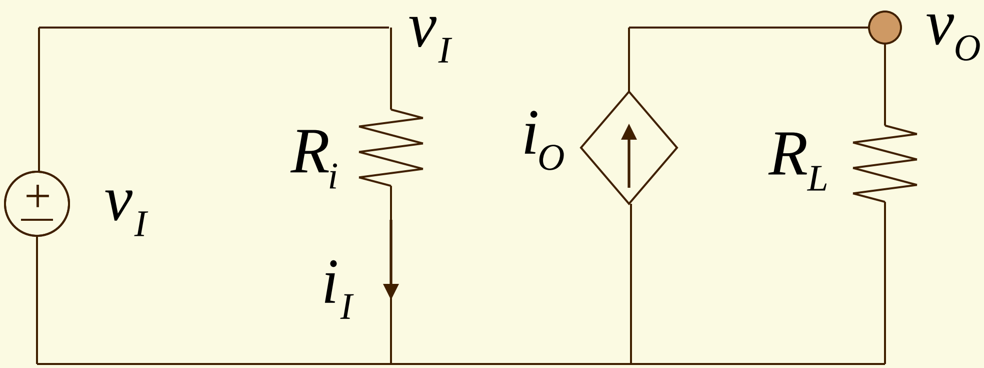


$$\frac{V_{OH} - V_{OL}}{V_{IH} - V_{IL}}$$



Digital System

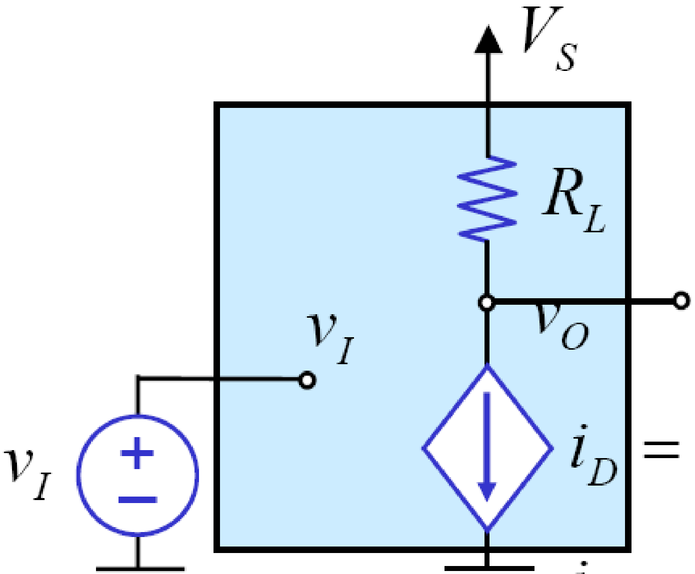
VCCS Circuit: Linear Amplifier



$$i_O = f(v_I) = -g_m v_I$$

$$\frac{v_O}{v_I}? \quad \frac{i_O}{i_I}? \quad \frac{P_O}{P_I}?$$

Example

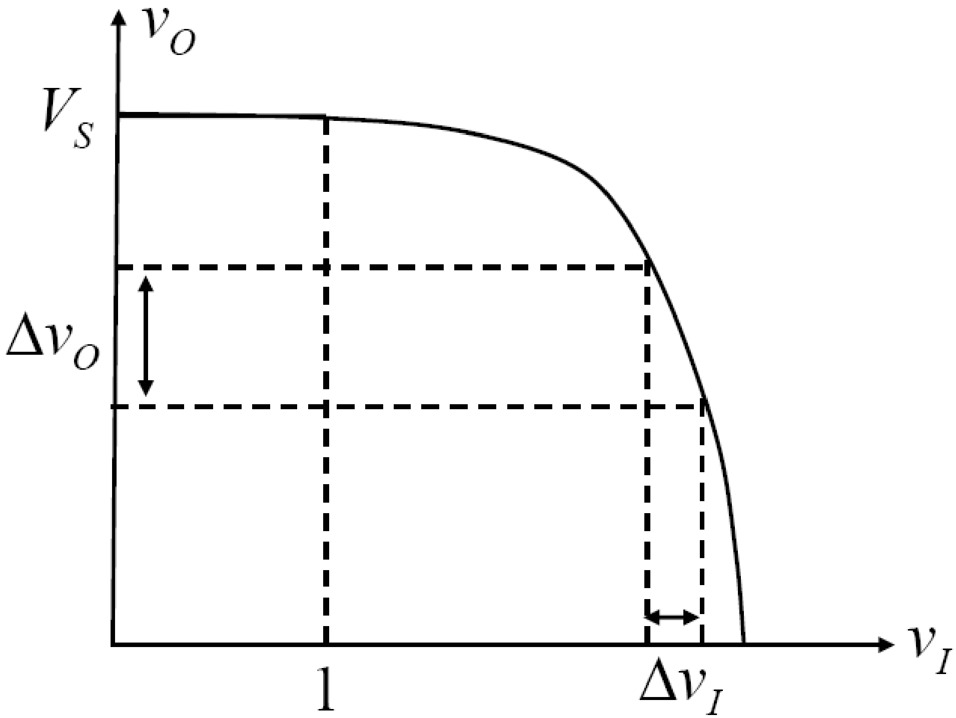


$$V_S = 10V, \quad K = 2\frac{mA}{V^2}, \quad R_L = 5k\Omega$$

$$i_D = \frac{K}{2}(v_{IN} - 1)^2 \quad \text{for } v_{IN} \geq 1$$

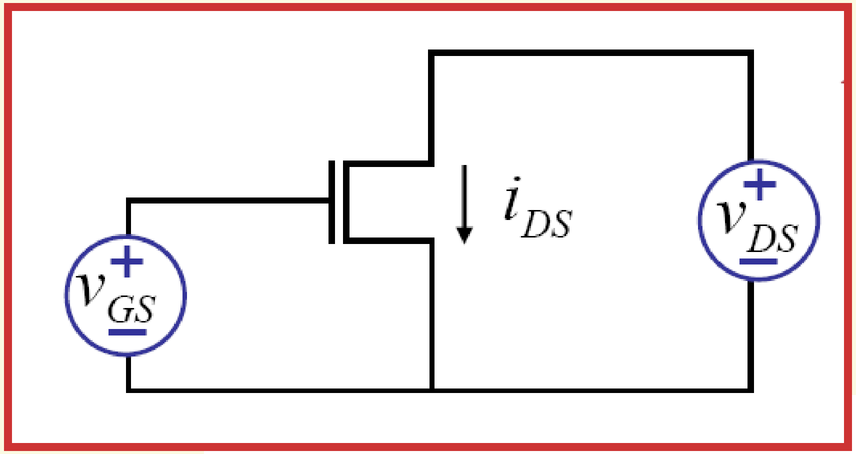
$$i_D = 0 \quad \text{otherwise}$$

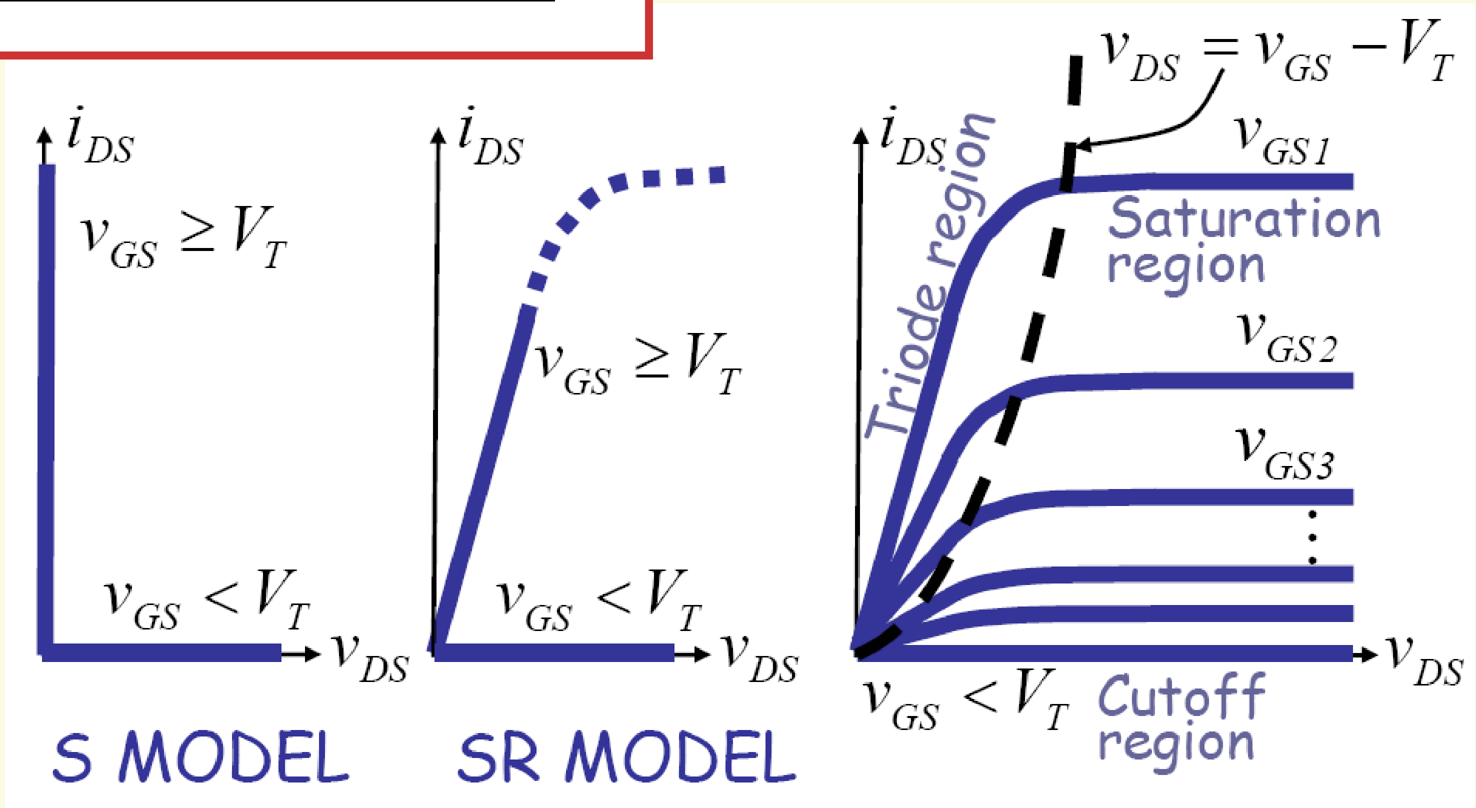
Example – cont'd



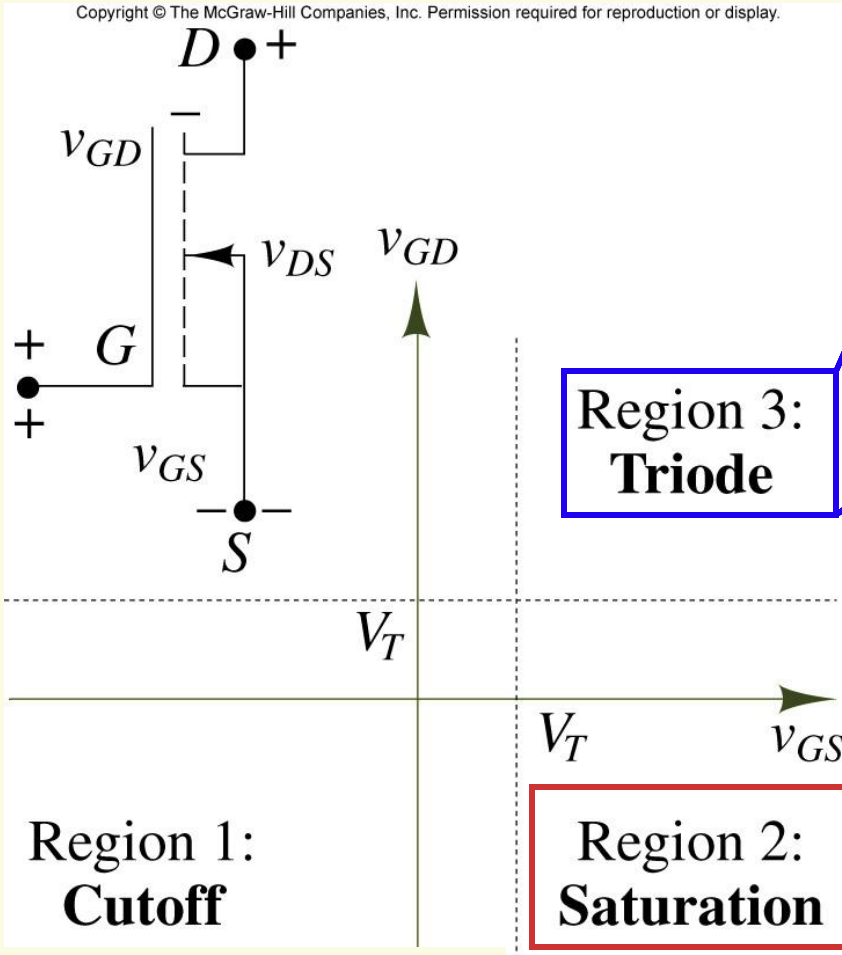
$$\frac{\Delta v_O}{\Delta v_I} > 1$$ → amplification

Actual MOSFET Characteristics





Remind: Region of Operation of NMOS



$$V_{GS} \geq V_T, \quad V_{GD} \geq V_T$$

$$i_D = K[2(V_{GS} - V_T)V_{DS} - V_{DS}^2]$$

$$V_{GS} \geq V_T, \quad V_{GD} < V_T$$

$$i_D = K(V_{GS} - V_T)^2(1 + \frac{V_{DS}}{V_A})$$

$$\approx K(V_{GS} - V_T)^2$$

$$V_{GS} < V_T, \quad V_{GD} < V_T$$

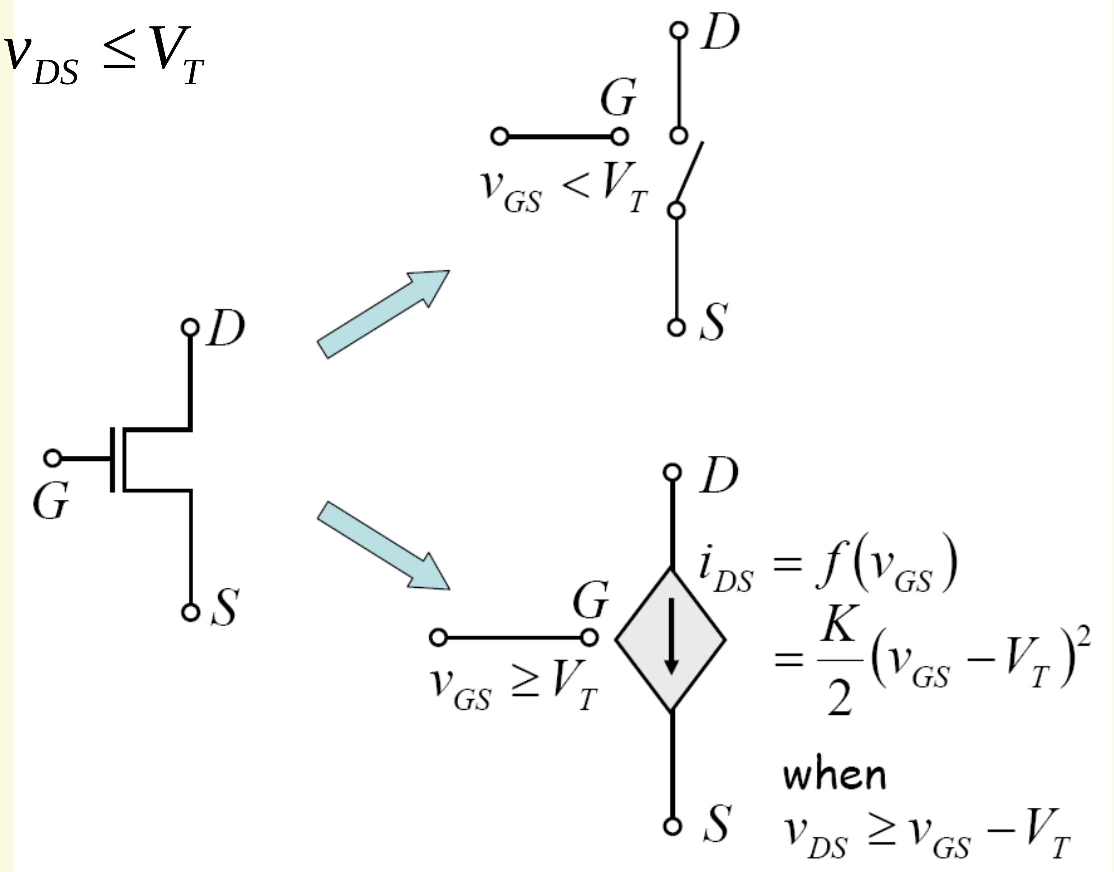
$$i_D = 0$$

MOSFET SCS Model

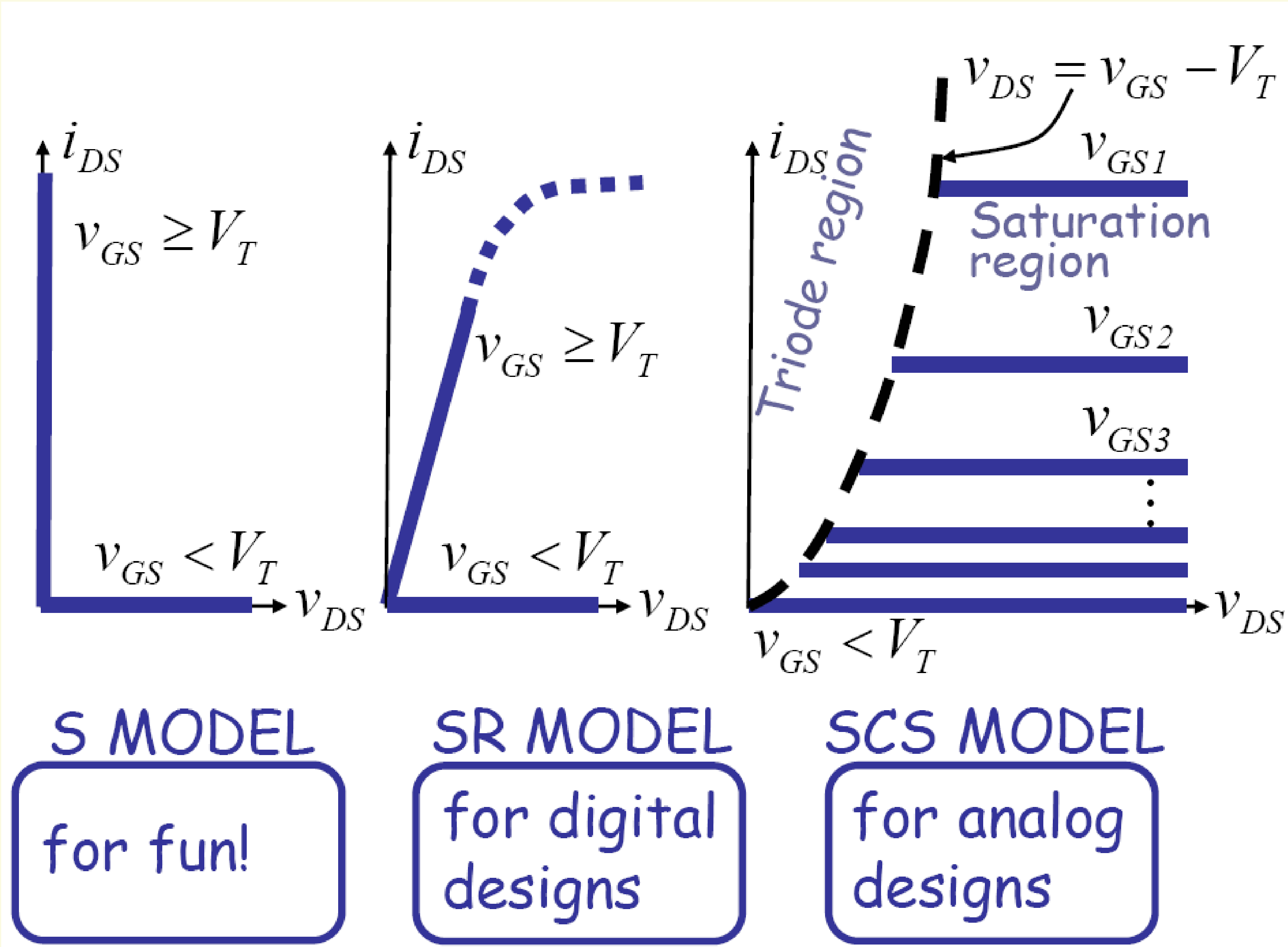
- SCS Model: Switched Current Source Model
  - Saturation region of operation: "**saturation principle**"

$$v_{GS} \geq C, \quad v_{GD} = v_{GS} - v_{DS} \leq V_T$$

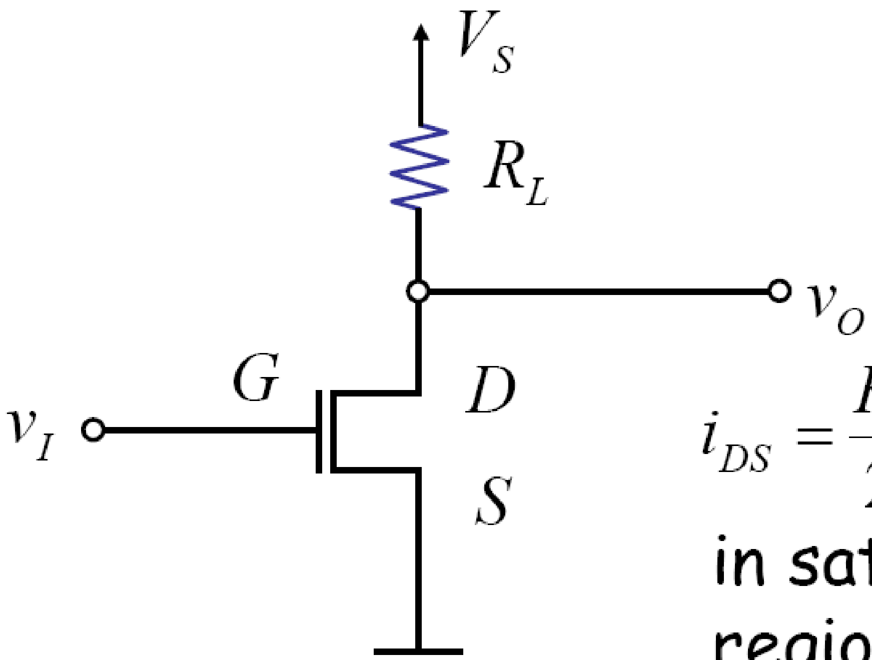
$$i_{DS} = \frac{1}{2} K (v_{GS} - V_T)^2$$



Reconciling the Models



MOSFET Amplifier

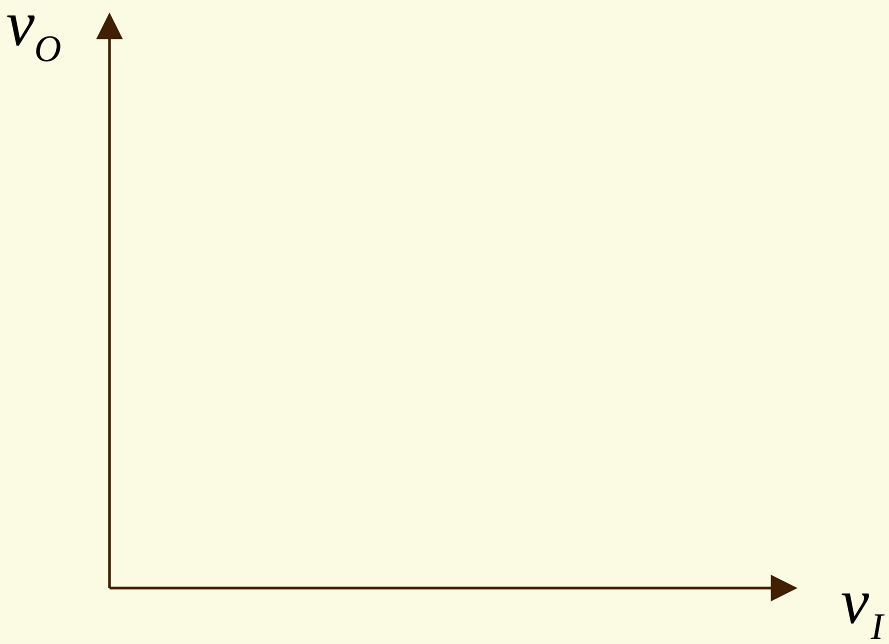


$$i_{DS} = \frac{K}{2}\left(v_I - V_T\right)^2$$

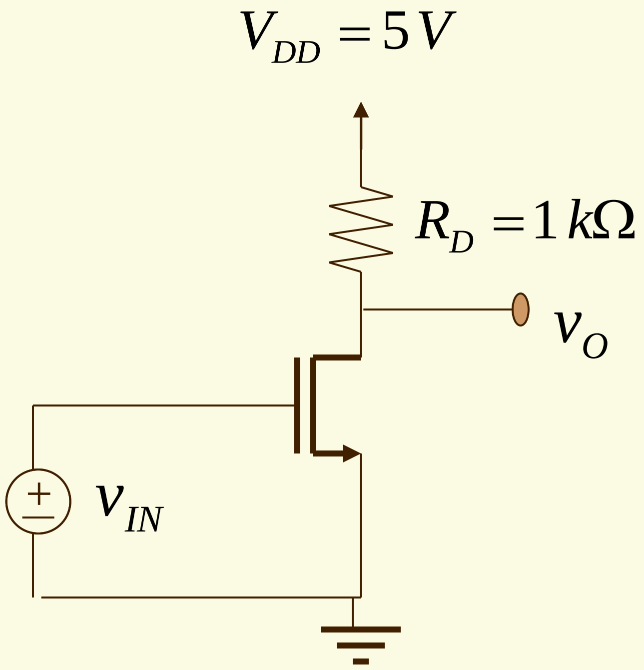
in saturation region

- What is the voltage gain?

Voltage Characteristics

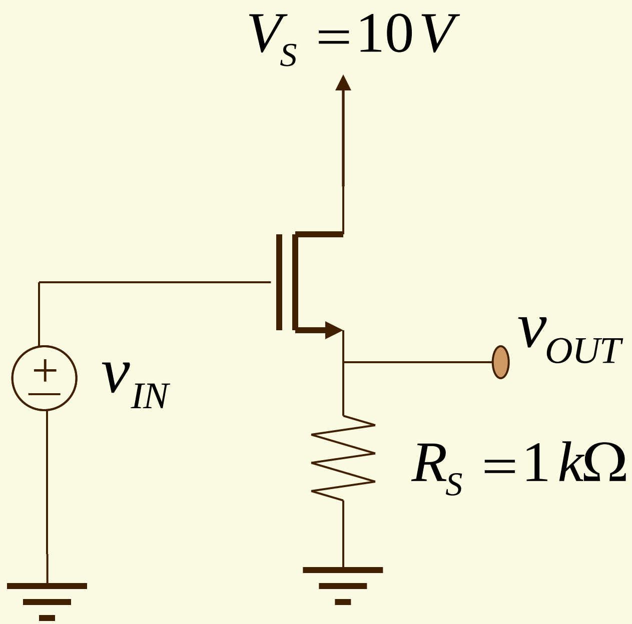


Example 7.7



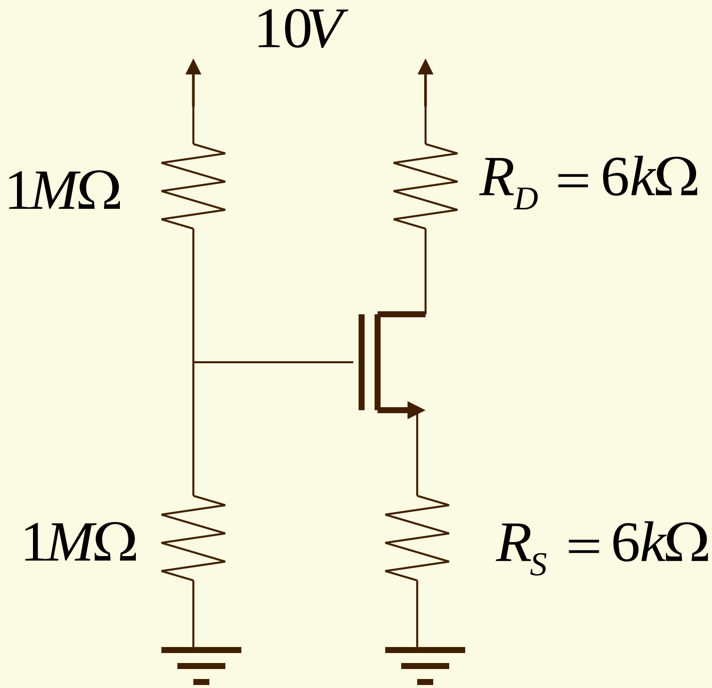
$V_T = 0.8V,\ K = 0.5mA/V^2$

Example 7.8: Source Follower Circuit



$$V_T = 1V,\ K = 2\,mA/V^2$$

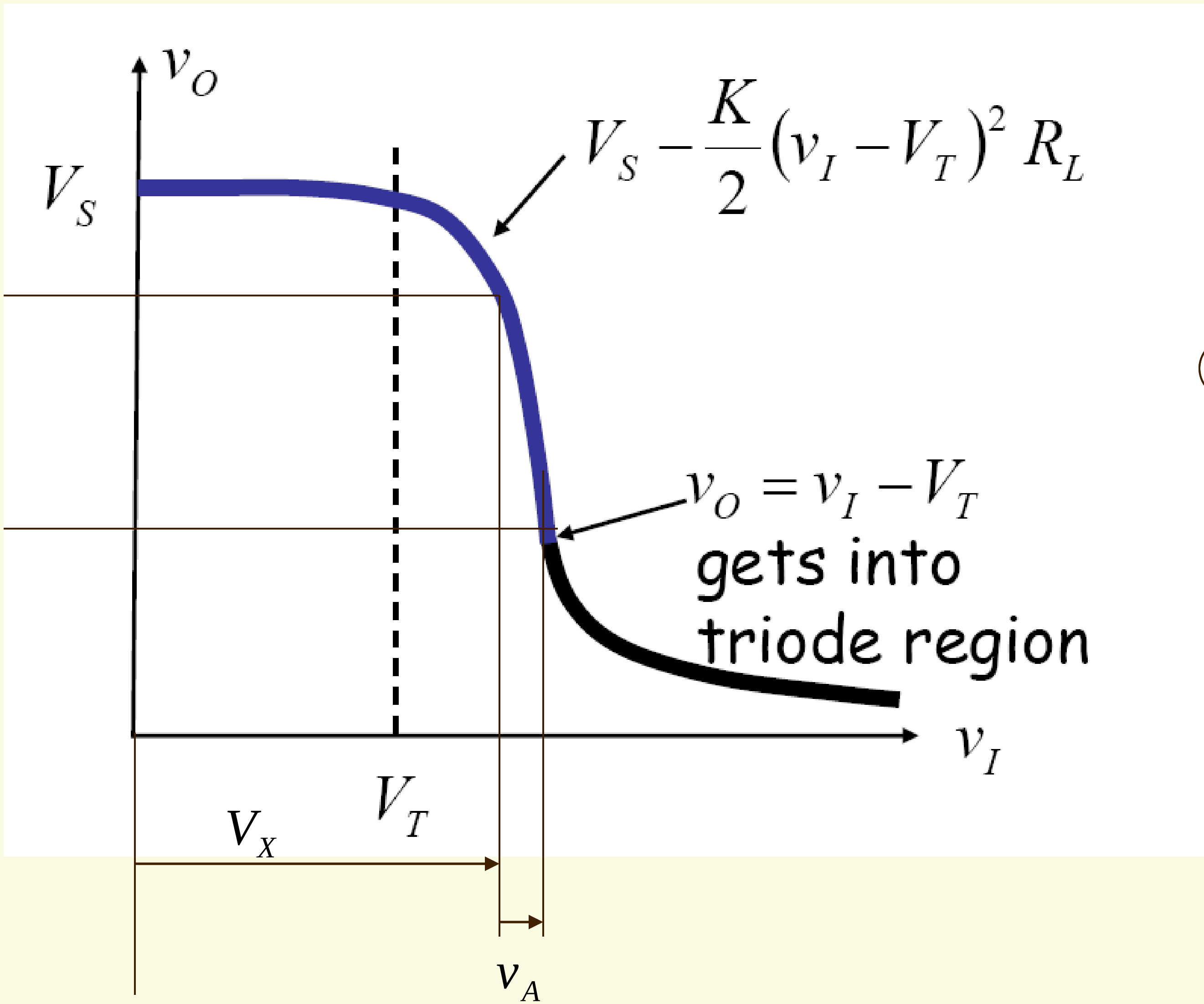
Exercise

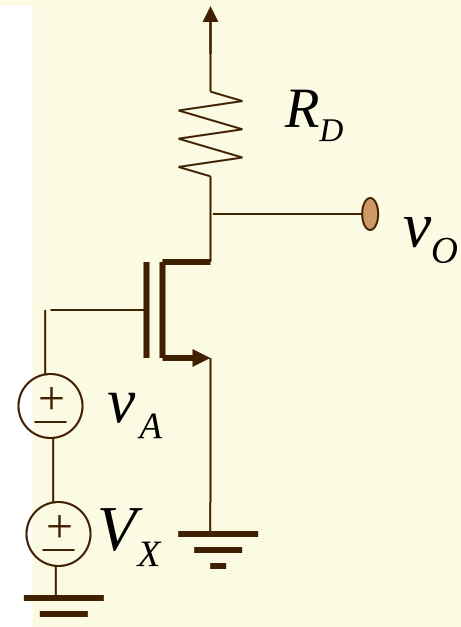


$V_T = 1.0V,\ K = 0.5mA/V$

i_D ?

Biasing the Circuit

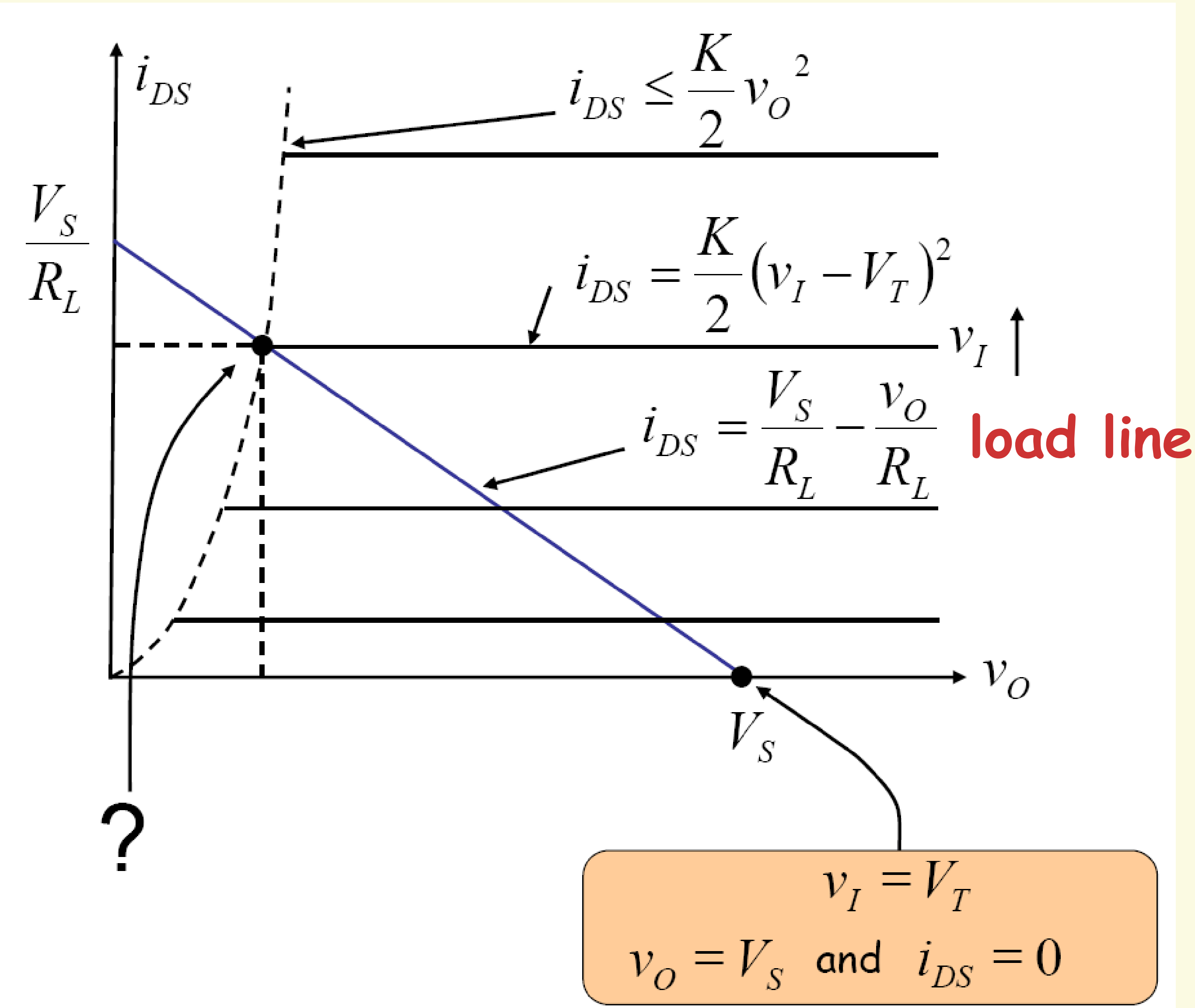




Large Signal Analysis

- Relationship between v_O *and* v_{IN}
- What is the range of valid input values under the saturation discipline? What is the corresponding range of output values?

Graphical Analysis



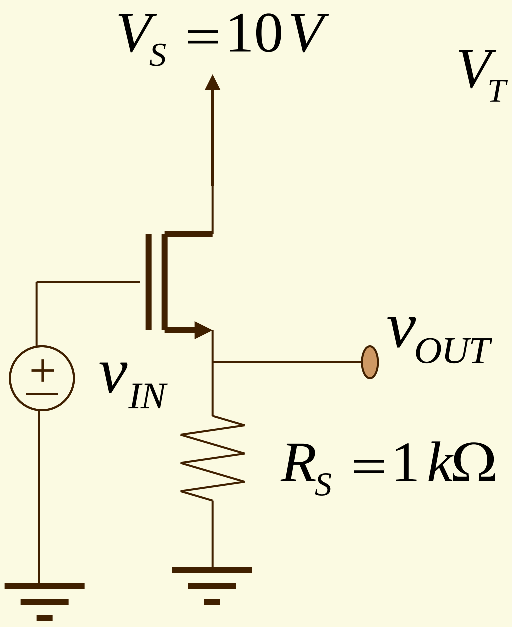
$$v_I = V_T + \frac{-1 + \sqrt{1 + 2KR_L V_S}}{KR_L}$$

$$v_O = \frac{-1 + \sqrt{1 + 2KR_L V_S}}{KR_L}$$

$$i_{DS} = \frac{V_S}{R_L} - \frac{v_O}{R_L}$$

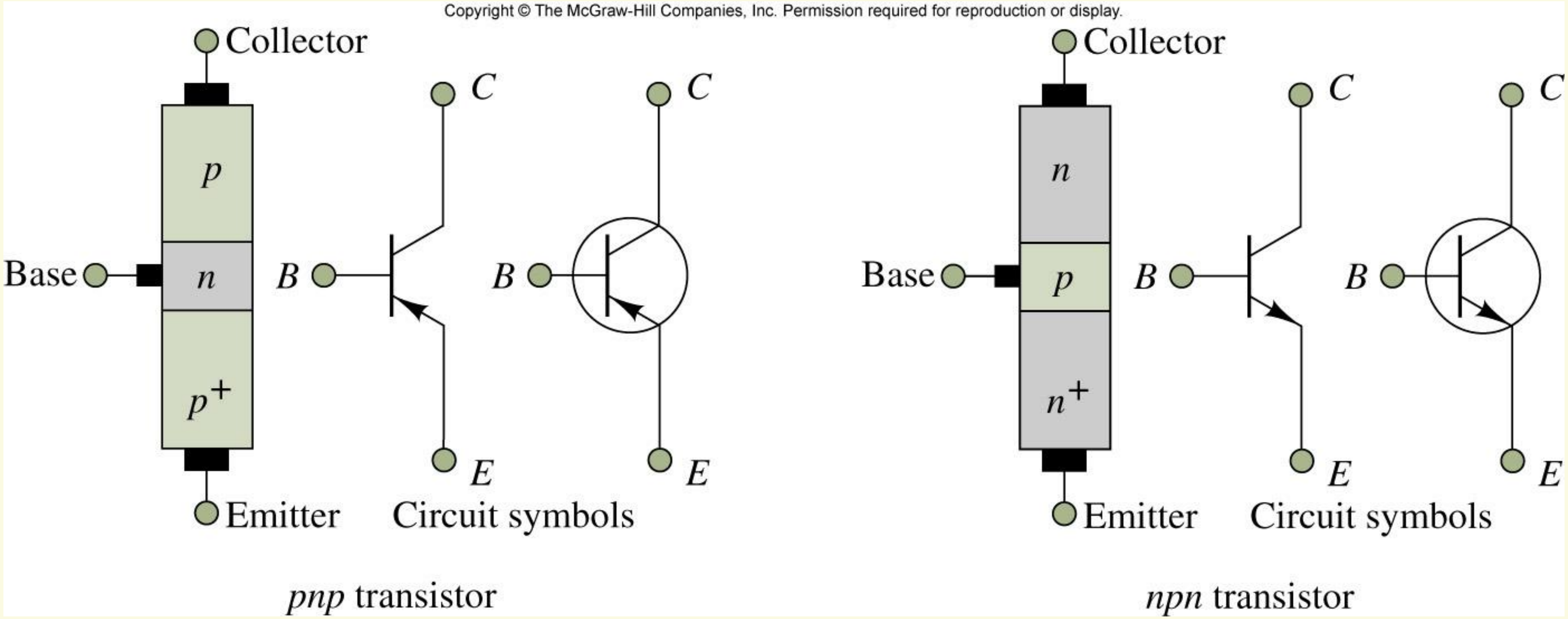
Example 7.10, 7.11

- Valid ranges for the source follower circuit.
- Operating point for maximum input swing

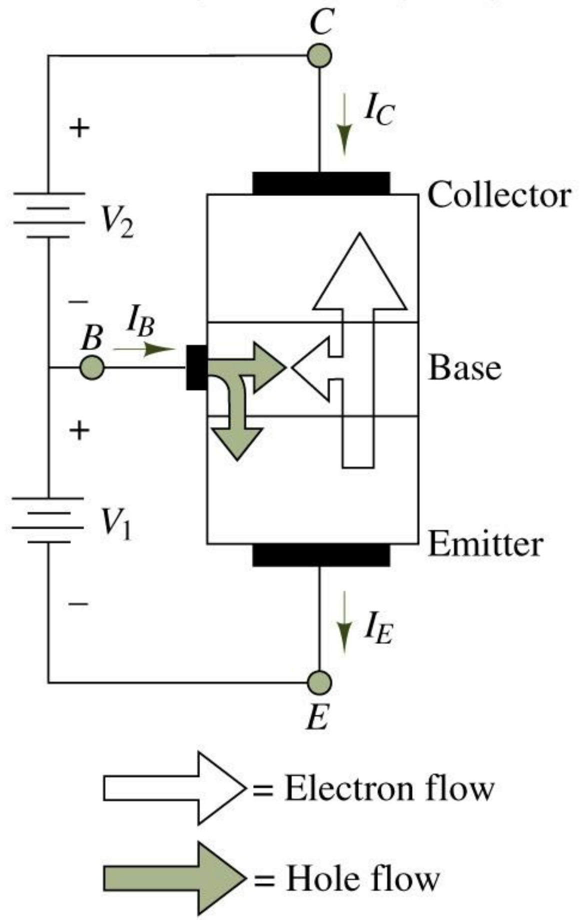


$V_T = 1V, K = 2\ mA/V^2$

Bipolar junction transistors



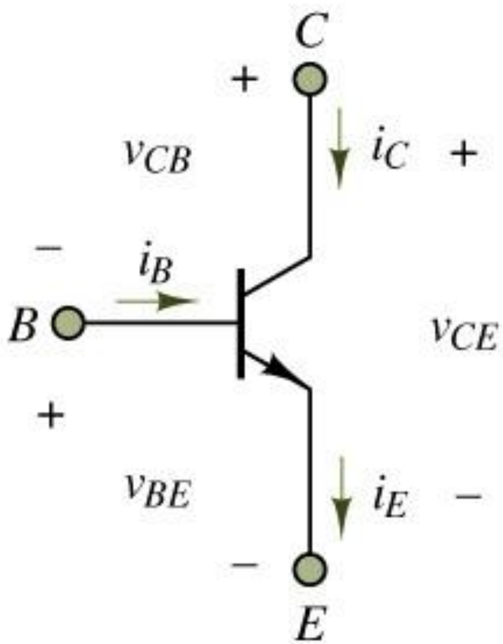
Operation Principle



When the *BC* junction is reverse-biased, the electrons from the emitter region are swept across the base into the collector.

Definition of BJT voltages and currents

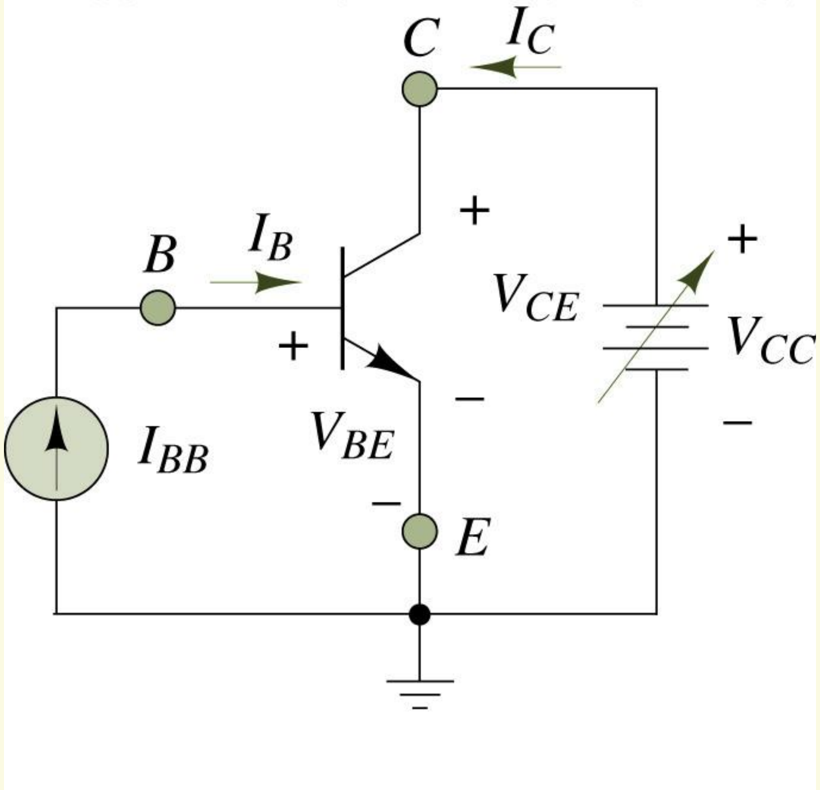
The operation of the BJT is defined in terms of two currents and two voltages: i_B, i_C, v_{CE}, and v_{BE}.



KCL: $i_E = i_B + i_C$
KVL: $v_{CE} = v_{CB} + v_{BE}$

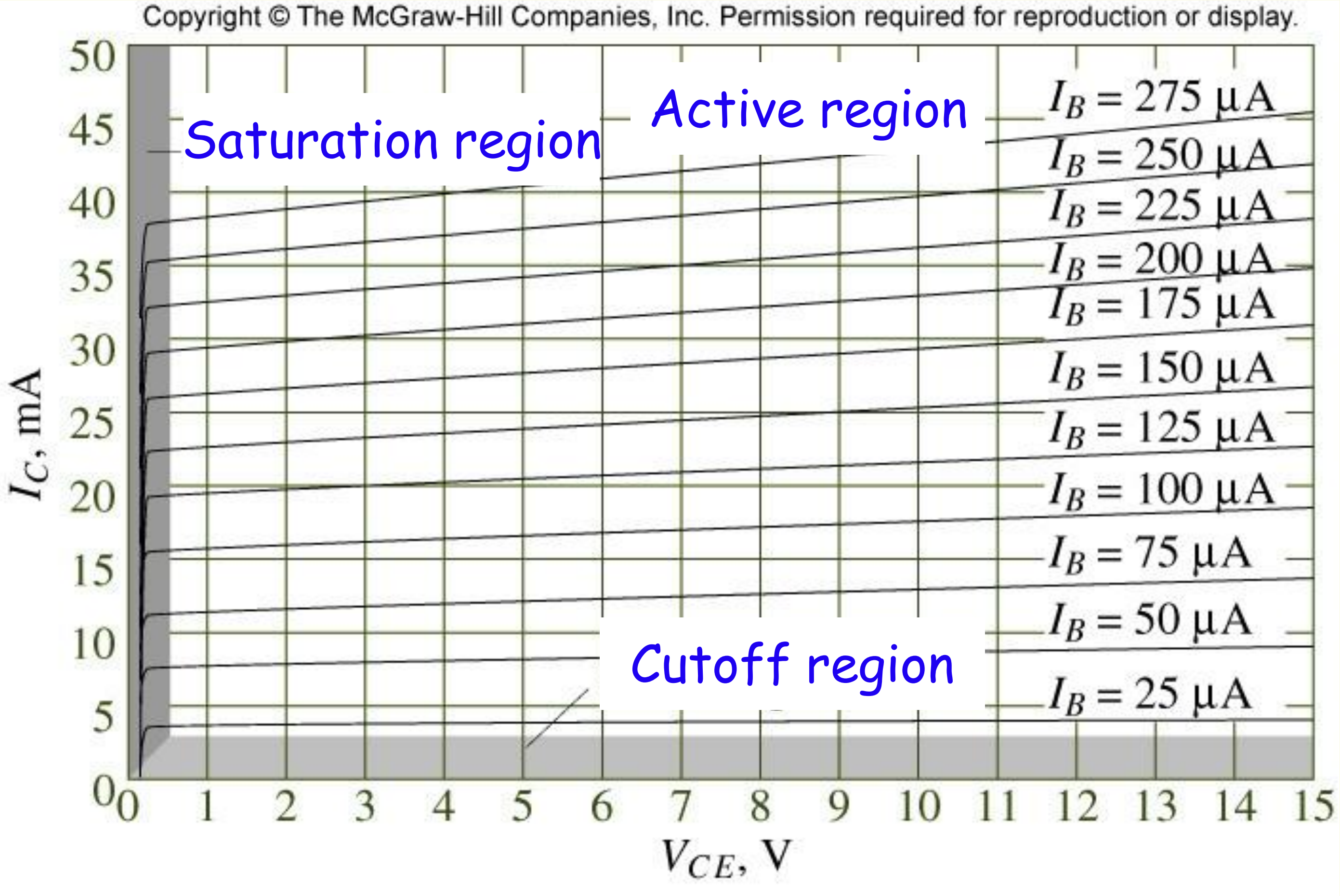
$$I_C = \beta I_B, \quad I_C = \alpha I_E, \quad I_E = I_C + I_B$$

Ideal test circuit to determine the i-v char acteristic



(a)

Collector-Emitter Output Characteristics

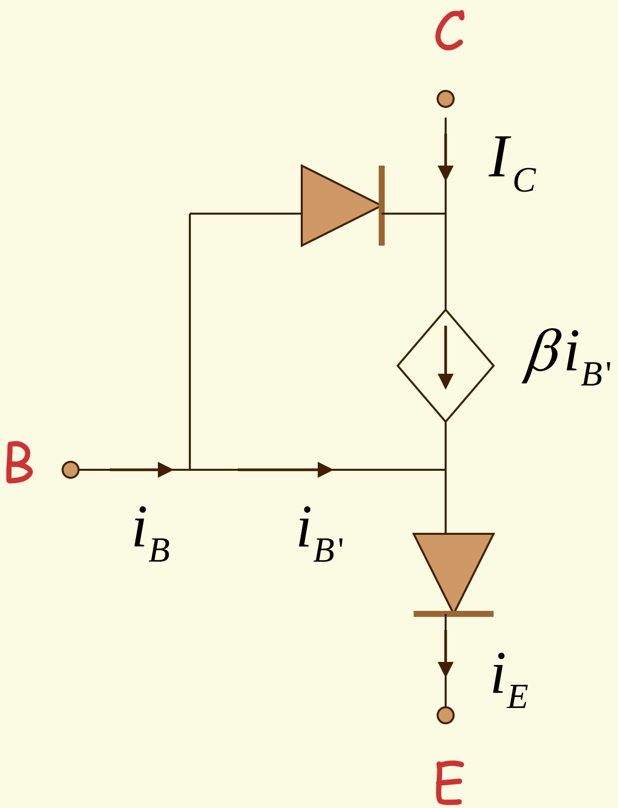


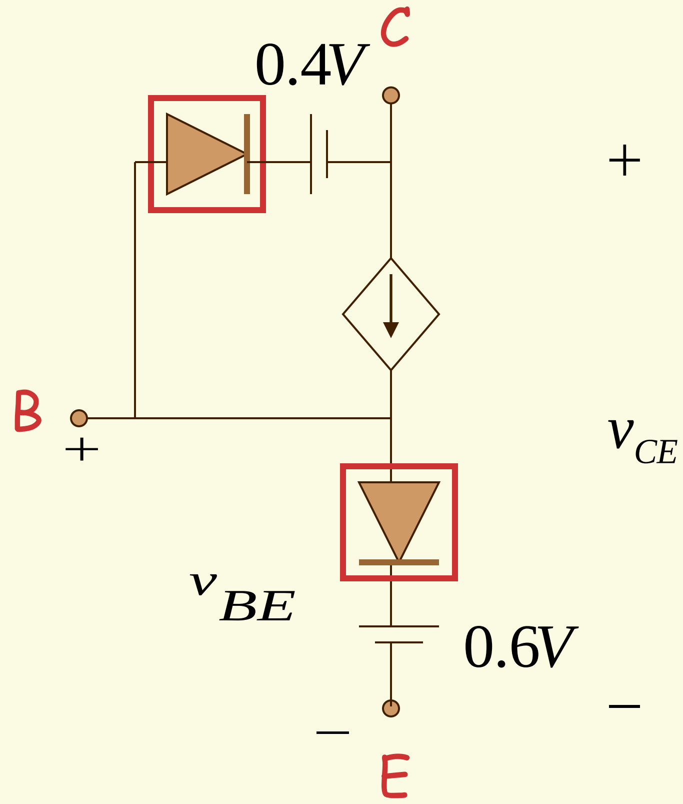
Breakdown region

Saturation region: $V_{CE} < 0.2$, almost constant

Active region: $V_{BE} = 0.6 \sim 0.7$, almost constant

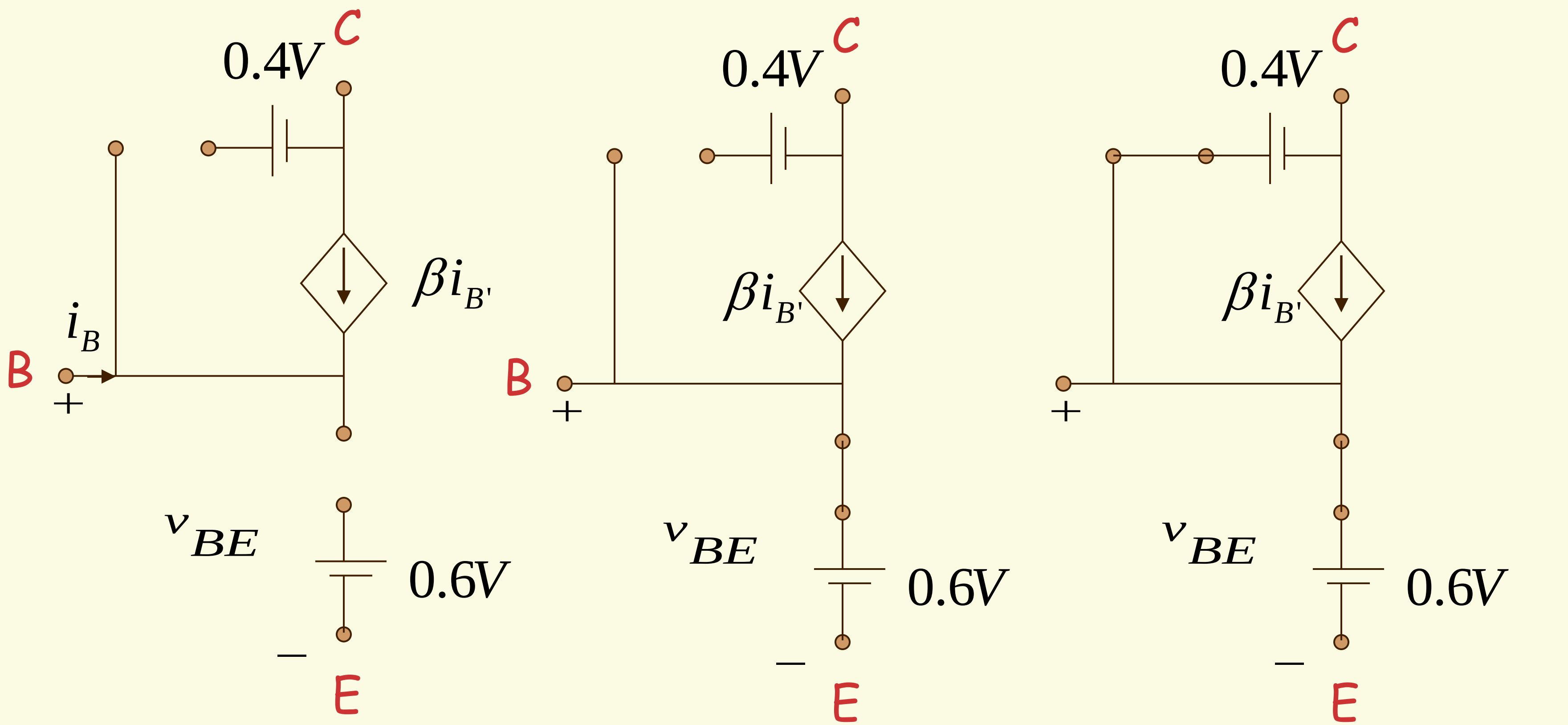
BJT Model





Piecewise-linear model

BJT Models in various regions of operation



cutoff region

$$i_B = 0$$

active region

$$i_B > 0$$

$$v_{CE} > v_{BE} - 0.4$$

$$(v_{CE} > 0.2)$$

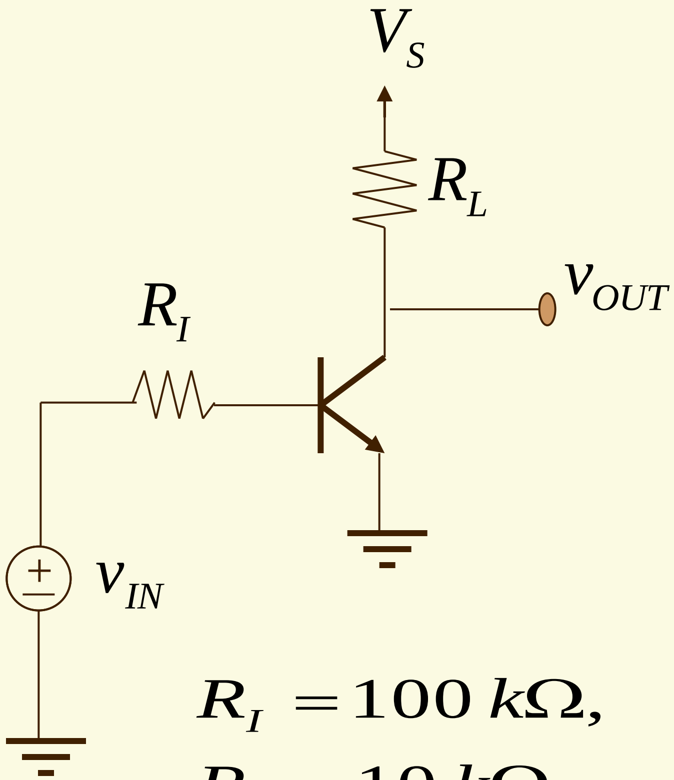
saturation region

$$i_B > 0$$

$$v_{CE} = v_{BE} - 0.4$$

$$(v_{CE} = 0.2)$$

Example 7.15 BJT Amplifier



$$v_O = ?$$

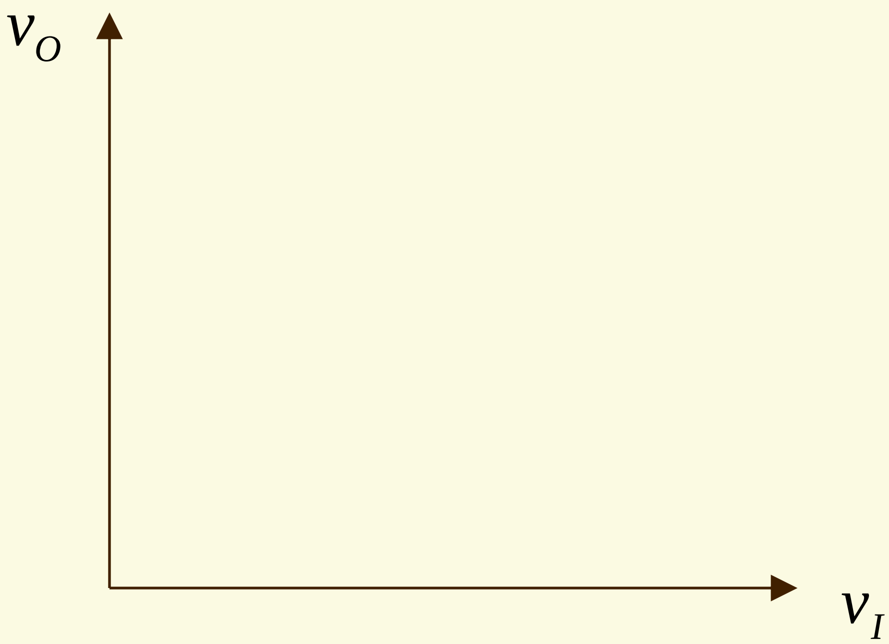
$$v_{IN} = 1, 1.1, 1.2\,V$$

$$R_I = 100\,k\Omega,$$
$$R_L = 10\,k\Omega,$$
$$\beta = 100,$$
$$V_S = 10\,V$$

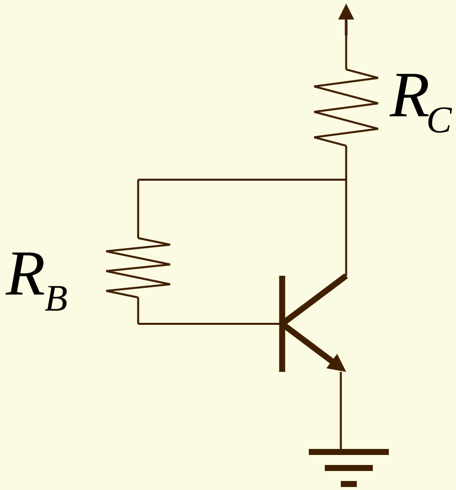
Large Signal Analysis

- 1. Relationship between v_O *and* v_{IN}
- 2. What is the range of valid input values for active region operation of the BJT ? What is the corresponding range of output values ?

Voltage characteristics of BJT Amplifier



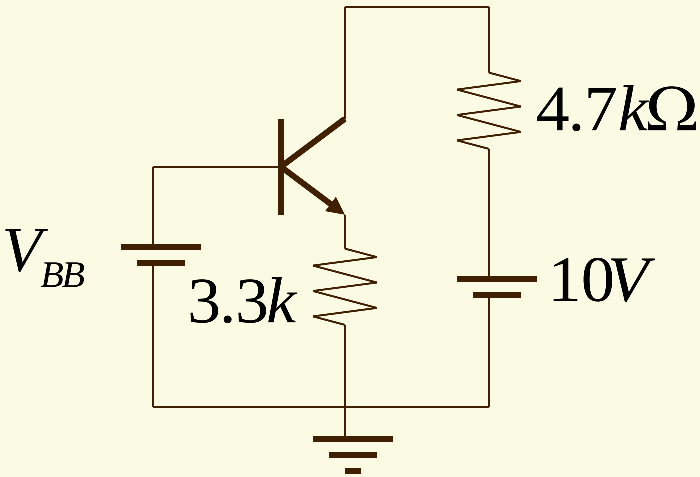
Exercise 1



$$R_C = 4k,\ R_B = 100k\Omega$$

$$V_{CC} = 15V,\ V_D = 0.7V,\ \beta = 99$$

Exercise 2: compute the bias condition

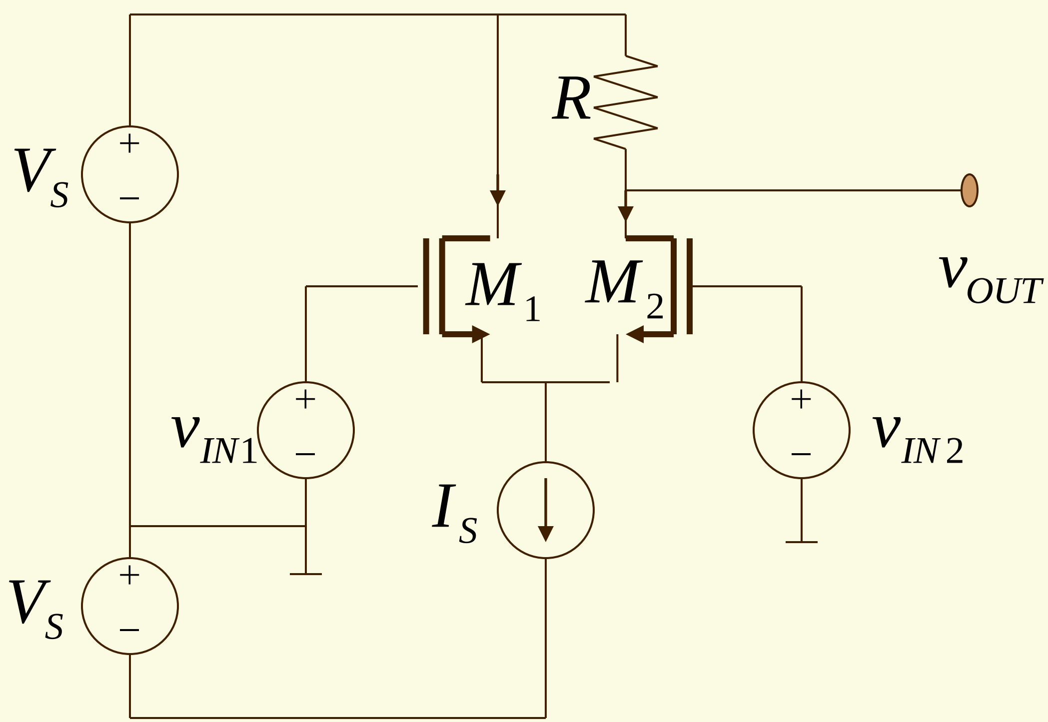


$V_{BE,on} = 0.7V, \quad V_{CE,sat} = 0.2V, \quad \beta = 100$

(1) $V_{BB} = 4.0V$

(2) $V_{BB} = 6.0V$

Example 7.19 Differential Amplifier



Conclusion

- MOSFET Amplifier
- MOSFET and SCS Model
- Large Signal Analysis
- BJT Amplifier
- Differential Amplifier