EEE 51: Second Semester 2017 - 2018

Lecture 5

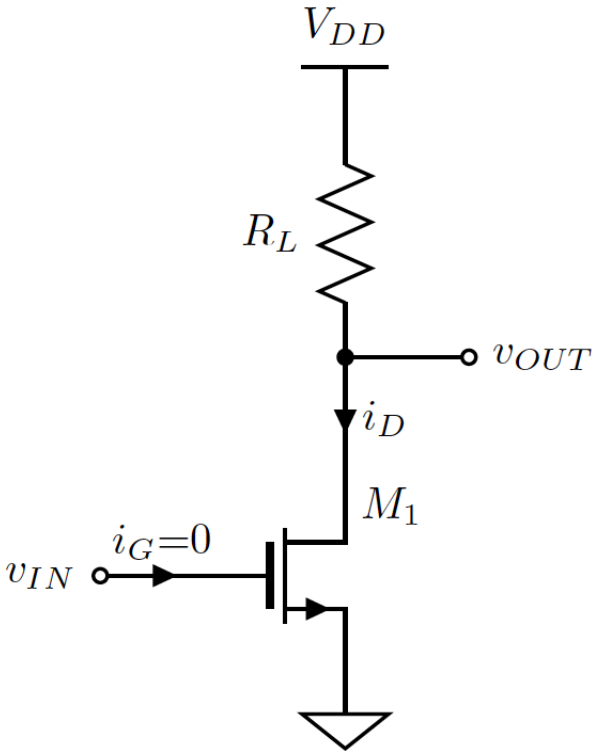
Single-Stage Amplifiers

Today

- Single-Stage Amplifiers

The Common-Source Amplifier

- Implications of using a MOSFET?



DC Analysis: Assume the MOSFET is in saturation

$$V_{DD} - I_{D,Q}R_L - V_{DS,Q} = 0$$

$$I_{D,Q} = k\left(V_{IN} - V_{TH}\right)^2\left(1 + \lambda V_{DS,Q}\right)$$

In most cases, we will deal with: $\lambda V_{DS,Q} << 1$

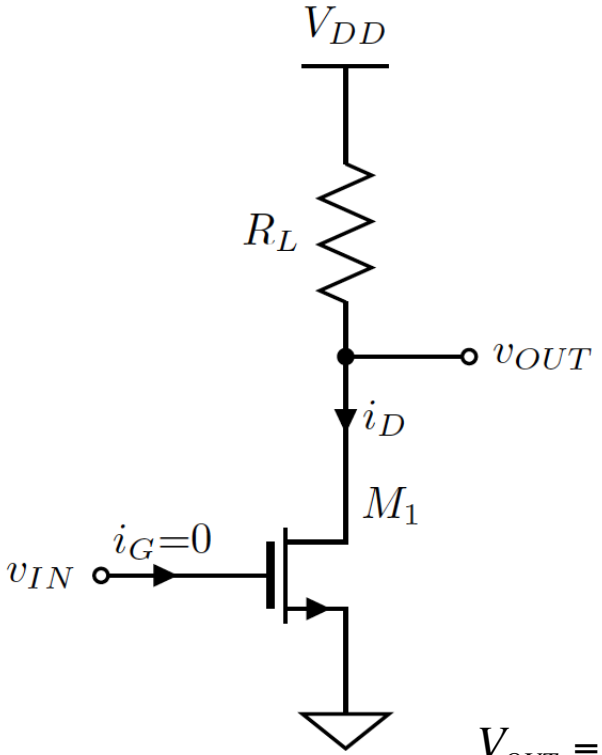
Thus,

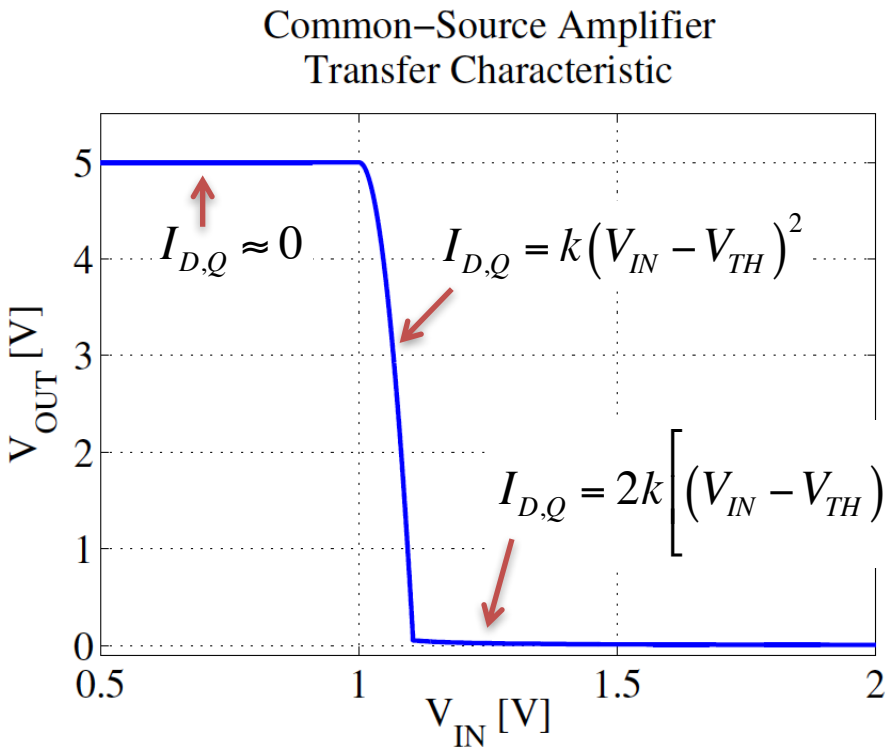
$$I_{D,Q} = k\left(V_{IN} - V_{TH}\right)^2$$

$$V_{OUT} = V_{DD} - I_{D,Q}R_L$$

$$= V_{DD} - R_L k\left(V_{IN} - V_{TH}\right)^2$$

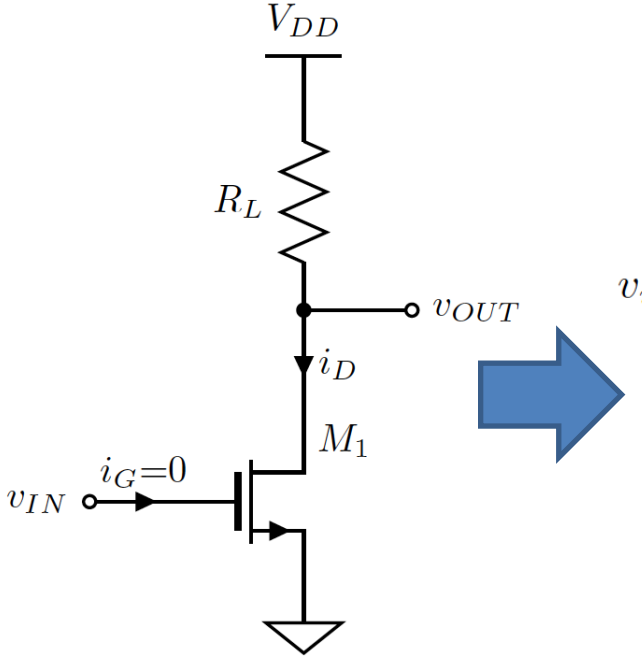
Common-Source Amplifier Transfer Curve

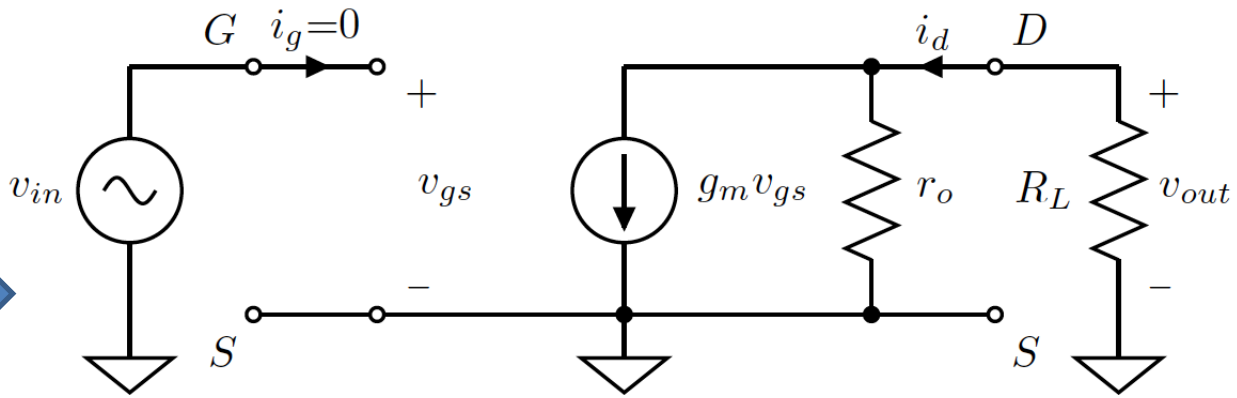




$V_{OUT} = V_{DD} - R_L k(V_{IN} - V_{TH})^2$ → Only in saturation: $V_{DS} > V_{GS} - V_{TH}$

Common-Source Amplifier Small Signal Model



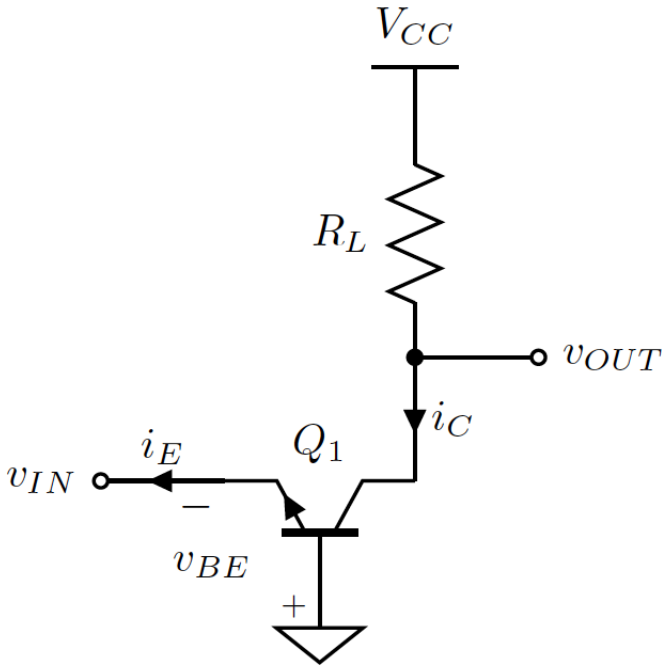


$$g_m = \sqrt{4k \cdot I_{D,Q}} \qquad r_o = \frac{1}{\lambda I_{D,Q}}$$

$$G_m = g_m$$
$$R_i \rightarrow \infty$$
$$R_o = r_o \parallel R_L$$
$$A_v = -G_m R_o = -g_m \left(r_o \parallel R_L \right)$$

The Common-Base Amplifier

- DC Analysis:



$$I_{C,Q} = I_S\left(e^{\frac{-V_{IN}}{V_T}} - 1\right)\left(1 + \frac{V_{OUT} - V_{IN}}{V_A}\right)$$

$$\approx I_S \cdot e^{\frac{-V_{IN}}{V_T}}$$

KVL at the output loop:

$$V_{OUT} = V_{CC} - I_{C,Q}R_L$$

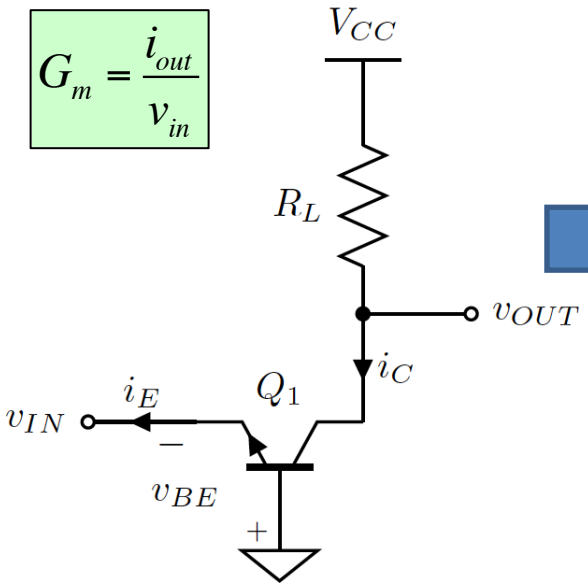
$$= V_{CC} - R_L I_S \cdot e^{\frac{-V_{IN}}{V_T}}$$ ← Non-inverting!

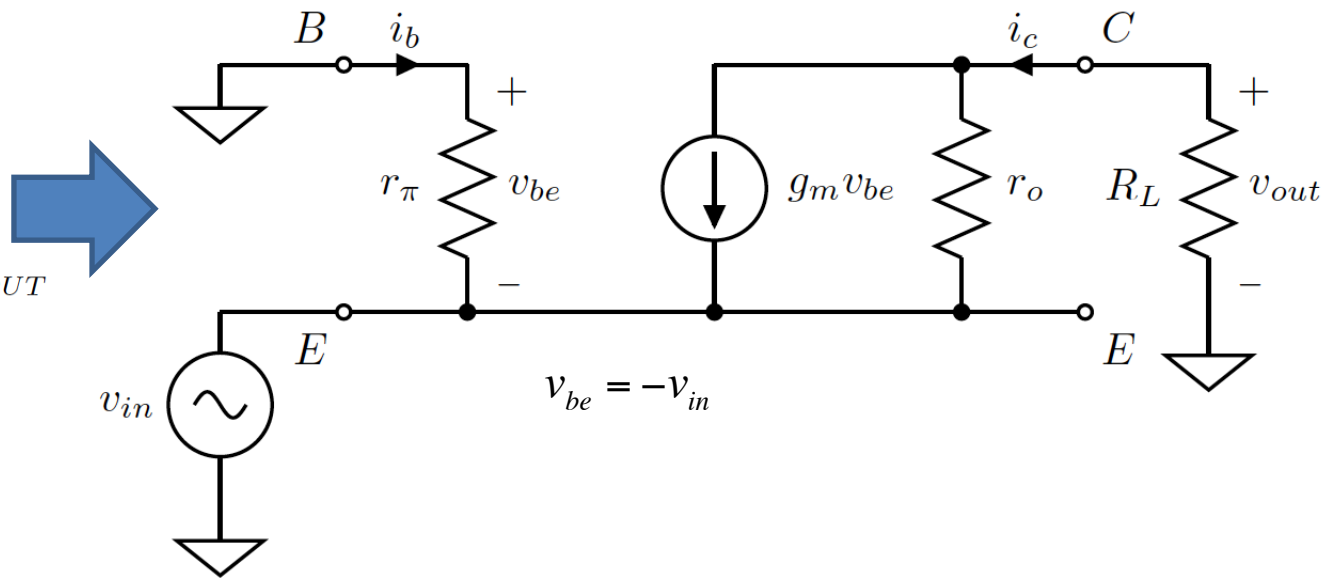
Forward-active region check:

$$V_{CE} = V_{OUT} - V_{IN} > V_{CE,sat}$$

Common-Base Amplifier Small Signal Analysis (1)

$$G_m = \frac{i_{out}}{v_{in}}$$



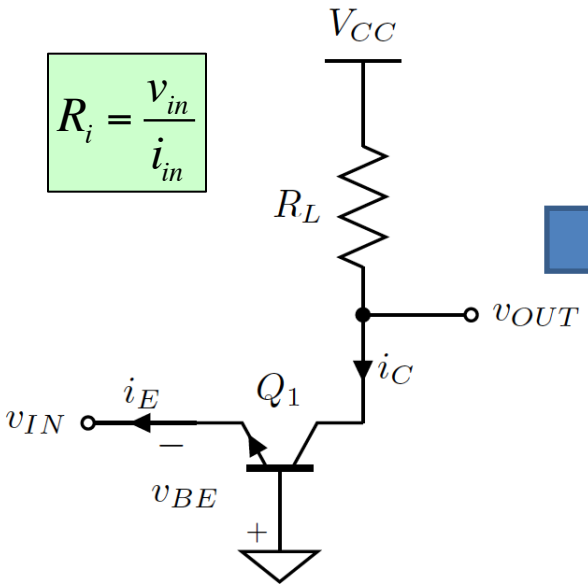


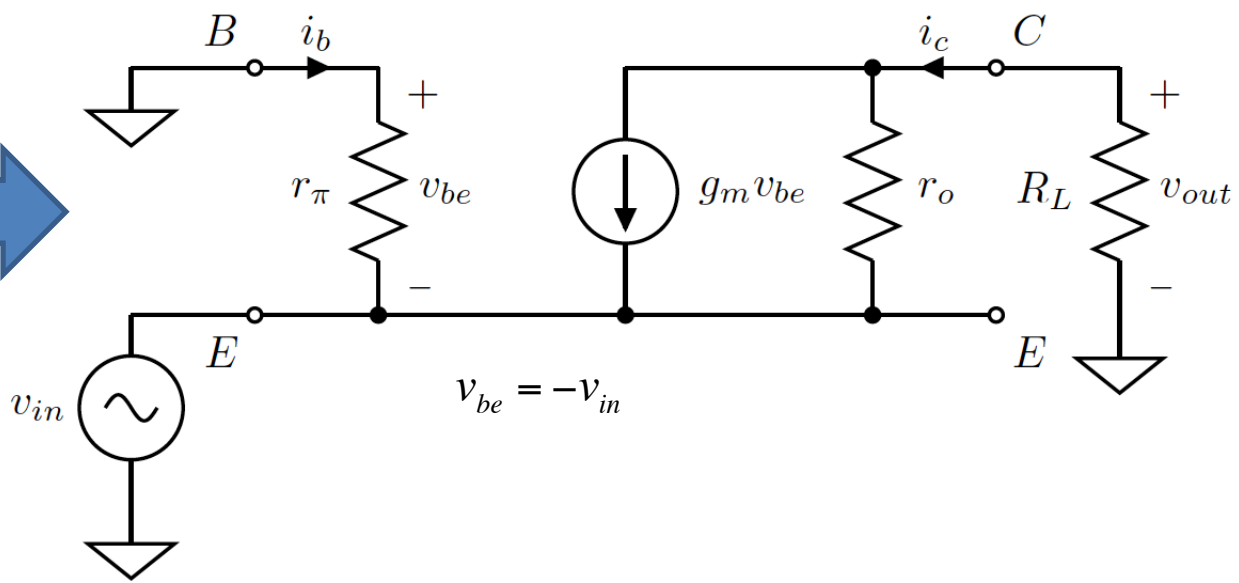
Short the output to ground: $i_{out} = -g_m v_{in} - \frac{v_{in}}{r_o}$

$$G_m = \frac{i_{out}}{v_{in}} = -g_m - \frac{1}{r_o} \approx -g_m$$

Common-Base Amplifier Small Signal Analysis (2)

$$R_i = \frac{v_{in}}{i_{in}}$$





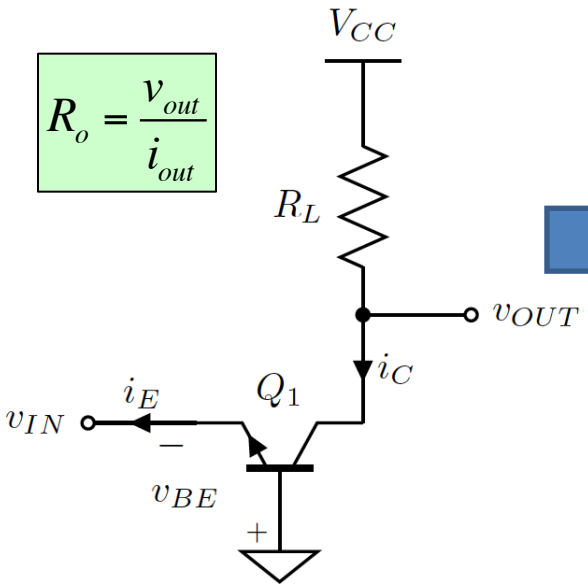
Short the output to ground:

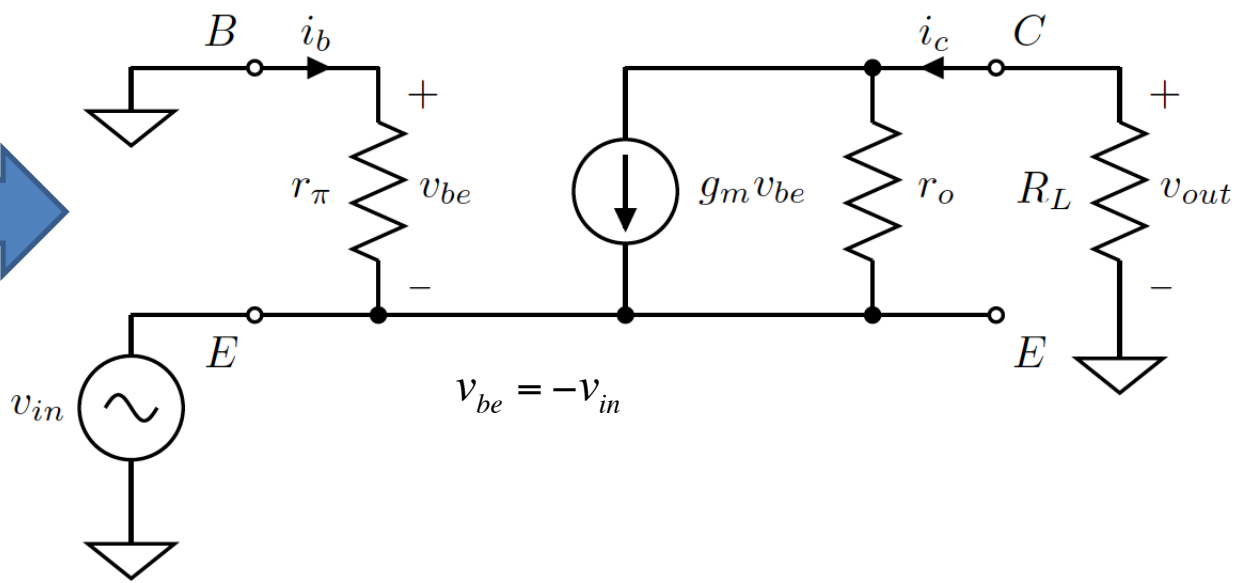
$$i_{in} = \frac{v_{in}}{r_\pi} + g_m v_{in} + \frac{v_{in}}{r_o}$$

$$R_i = \frac{v_{in}}{i_{in}} = \frac{1}{\frac{1}{r_\pi} + g_m + \frac{1}{r_o}} = r_\pi \parallel r_o \parallel \frac{1}{g_m} \approx \frac{1}{g_m}$$

Common-Base Amplifier Small Signal Analysis (3)

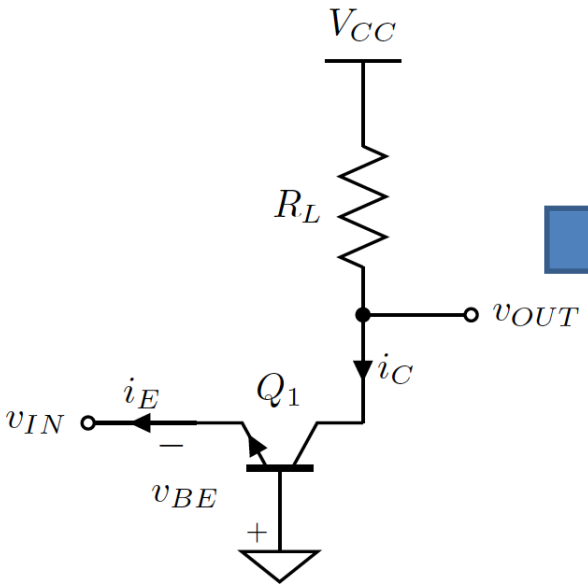
$$R_o = \frac{v_{out}}{i_{out}}$$

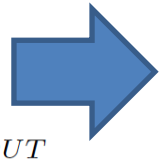


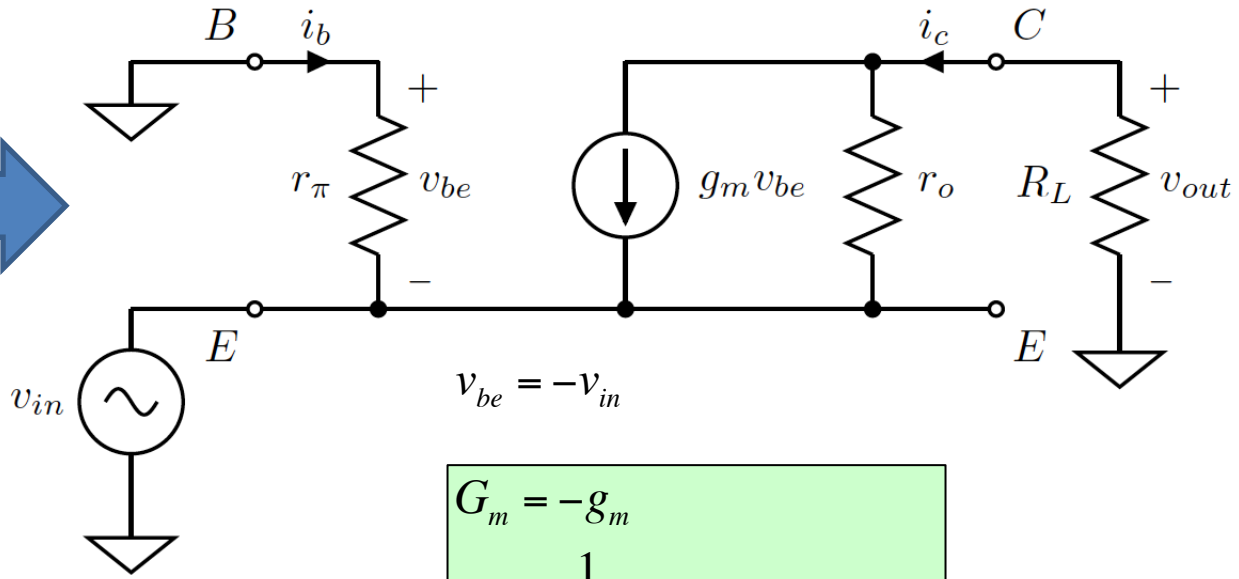


Zero out the input: $$R_o = \frac{v_{out}}{i_{out}} = r_o \parallel R_L$$

Common-Base Amplifier Small Signal Analysis (4)







$$G_m = -g_m$$

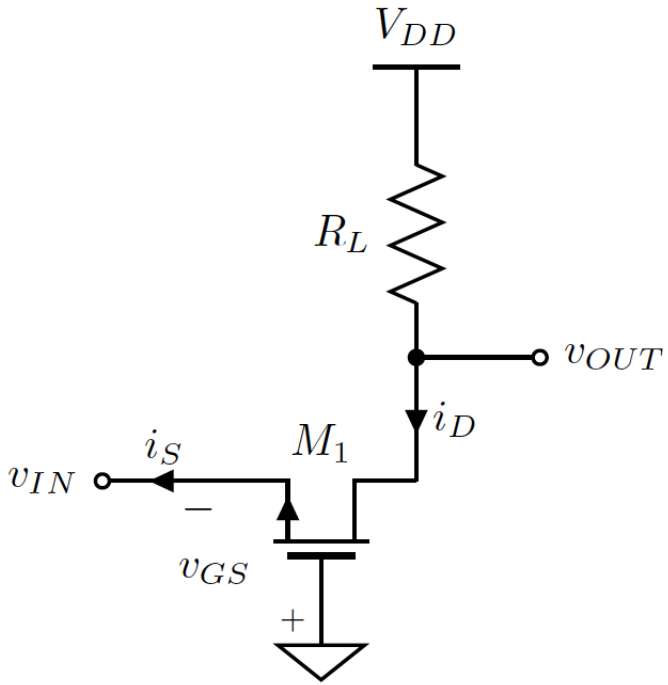
$$R_i \approx \frac{1}{g_m}$$

$$R_o = r_o \parallel R_L$$

$$A_v = -G_m R_o = g_m \left(r_o \parallel R_L \right)$$

The Common-Gate Amplifier

- DC Analysis:



$$I_{D,Q} = k\left(-V_{IN} - V_{TH}\right)^2\left(1 + \lambda\left(V_{OUT} - V_{IN}\right)\right)$$
$$\approx k\left(-V_{IN} - V_{TH}\right)^2$$

KVL at the output loop:

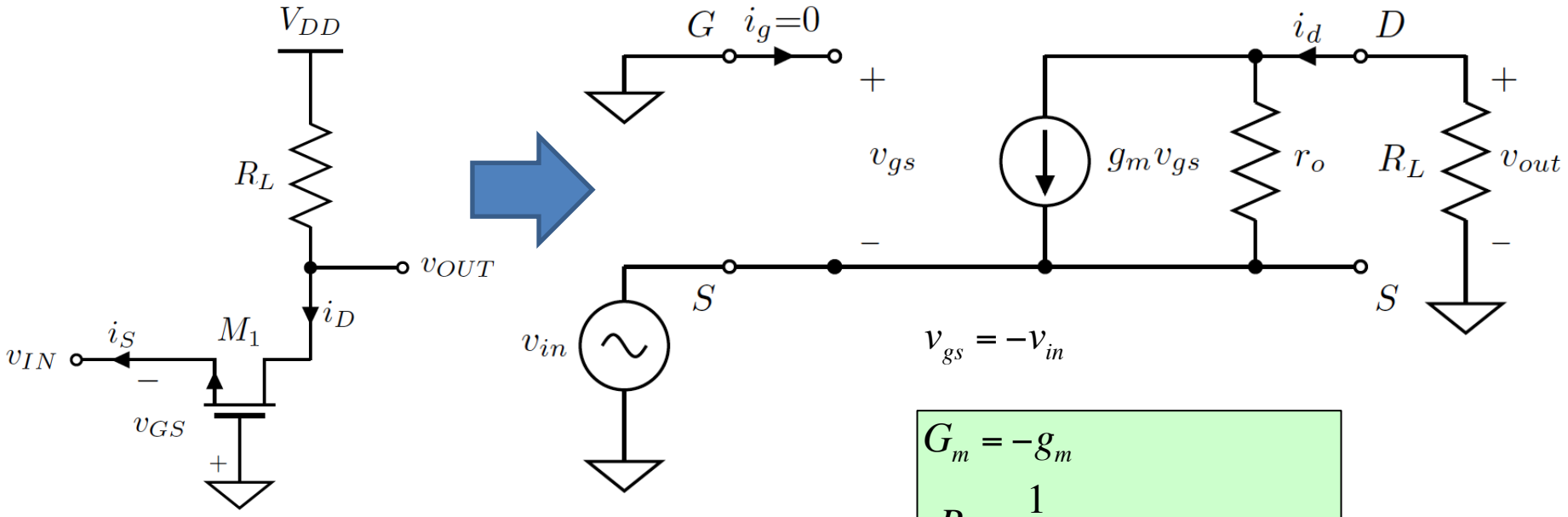
$$V_{OUT} = V_{DD} - I_{D,Q}R_L$$
$$= V_{CC} - R_L \cdot k\left(-V_{IN} - V_{TH}\right)^2$$

Saturation region check:

$$V_{DS} = V_{OUT} - V_{IN} > V_{GS} - V_{TH} = -V_{IN} - V_{TH}$$

$$V_{OUT} > -V_{TH}$$

Common-Gate Amplifier Small Signal Analysis



$$G_m = -g_m$$

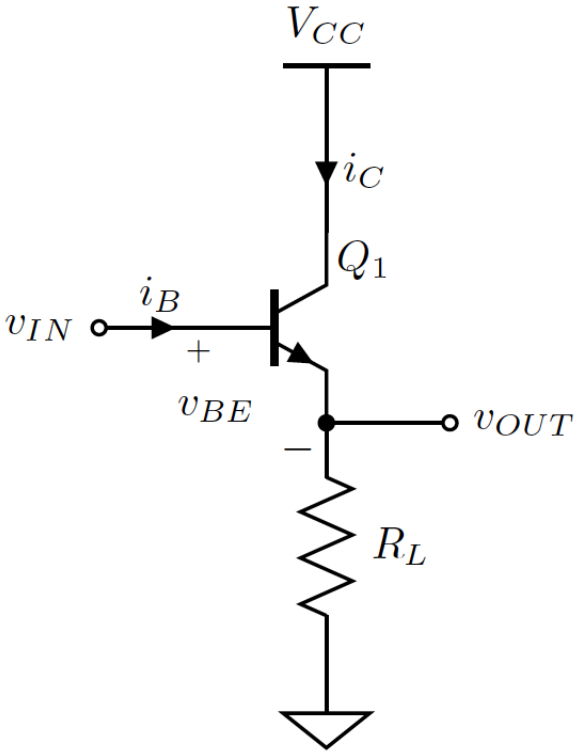
$$R_i \approx \frac{1}{g_m}$$

$$R_o = r_o \parallel R_L$$

$$A_v = -G_m R_o = g_m \left(r_o \parallel R_L \right)$$

The Common-Collector Amplifier

- DC Analysis:



$$V_{IN} - V_{BE,Q} - I_{E,Q}R_L = 0$$

$$V_{IN} - V_T \ln\left(\frac{I_{C,Q}}{I_S}\right) - I_{C,Q}\left(1+\frac{1}{\beta}\right)R_L = 0$$

Non-linear!

Simplify? $V_{BE,Q} = 0.7\text{V}$

$$I_{C,Q} = \frac{V_{IN} - 0.7\text{V}}{\left(1+\frac{1}{\beta}\right)R_L} \approx \frac{V_{IN} - 0.7\text{V}}{R_L}$$

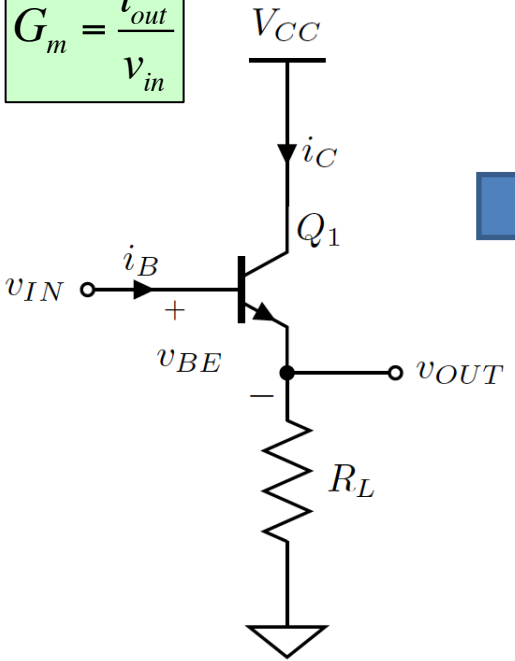
$$V_{OUT} = I_{E,Q}R_L \approx I_{C,Q}R_L = V_{IN} - 0.7\text{V}$$

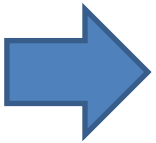
Emitter follower

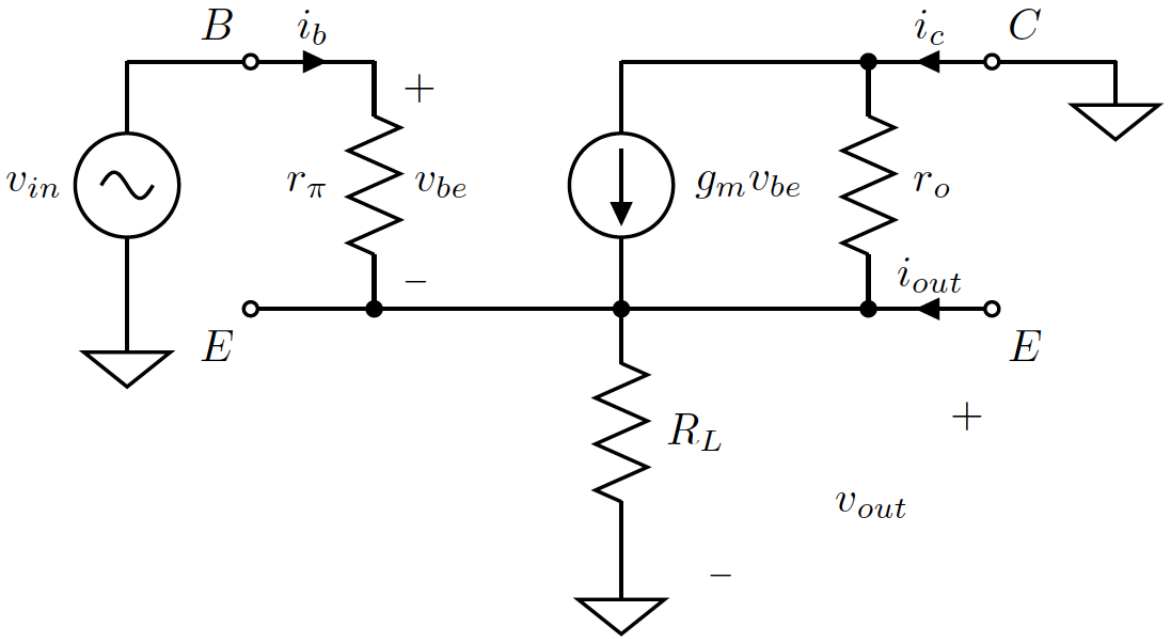
Forward-active region check: $V_{CE} = V_{CC} - V_{OUT} > V_{CE,sat}$

Common-Collector Small Signal Analysis (1)

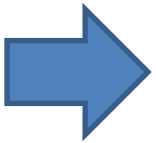
$$G_m = \frac{i_{out}}{v_{in}}$$







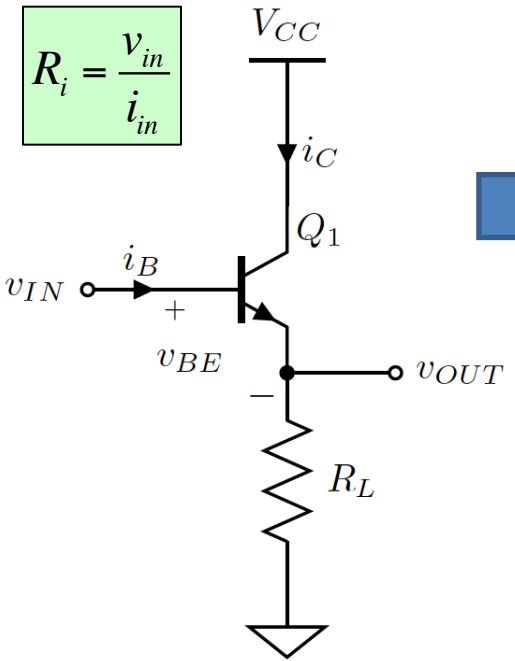
Short the output to ground: $i_{out} = -g_m v_{in} - \frac{v_{in}}{r_\pi}$

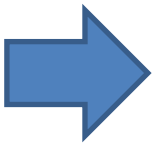


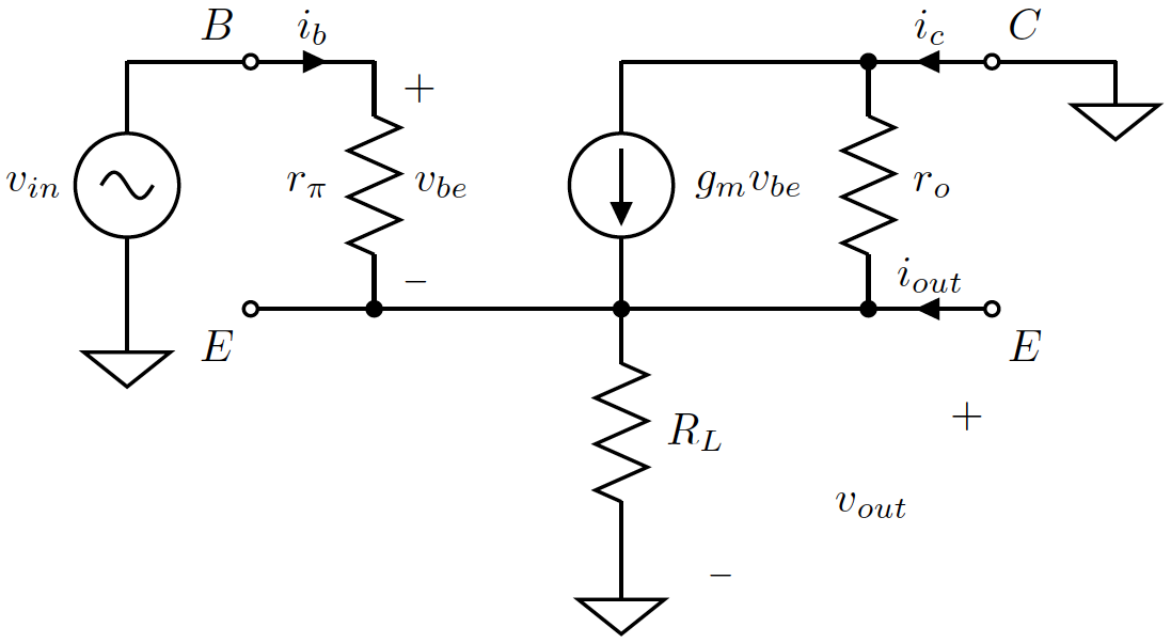
$$G_m = \frac{i_{out}}{v_{in}} = -g_m - \frac{1}{r_\pi} \approx -g_m$$

Common-Collector Small Signal Analysis (2)

$$R_i = \frac{v_{in}}{i_{in}}$$



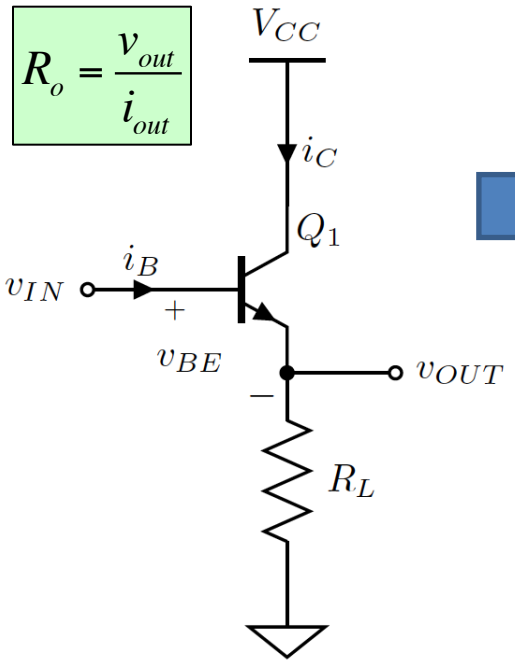


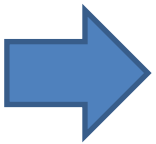


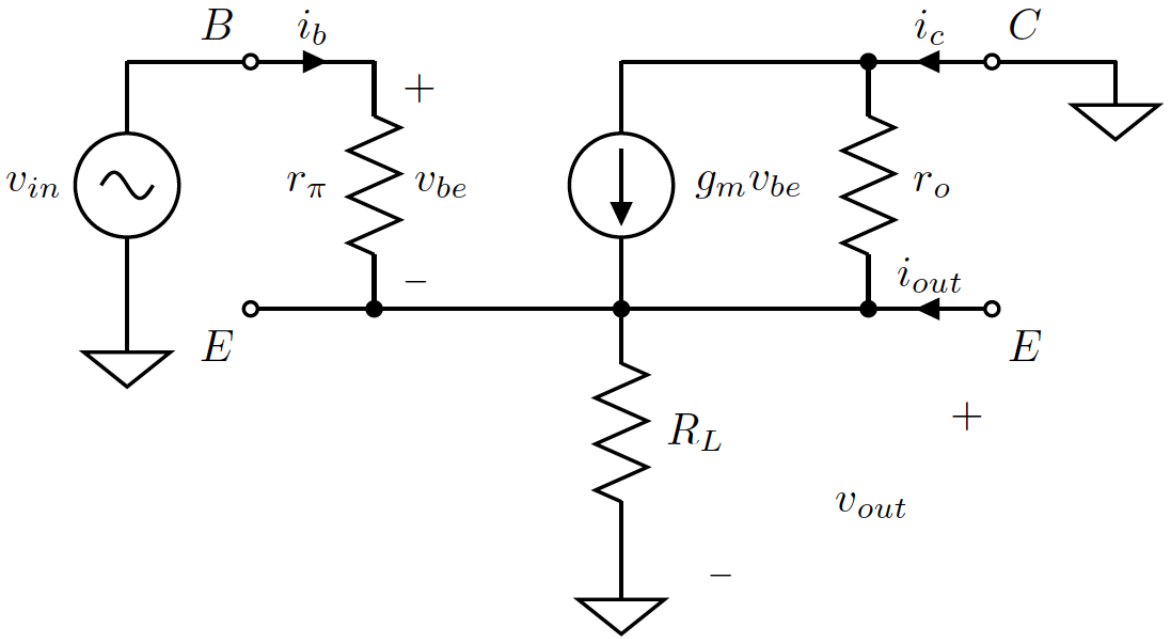
Short the output to ground: $R_i = r_\pi$

Common-Collector Small Signal Analysis (3)

$$R_o = \frac{v_{out}}{i_{out}}$$



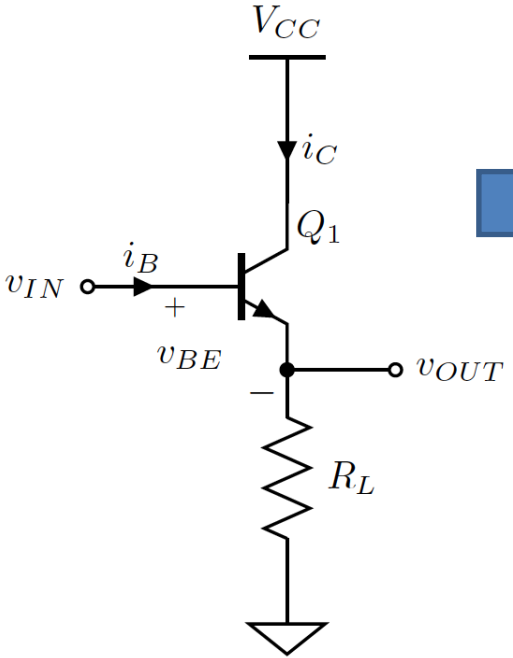


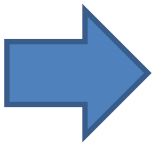


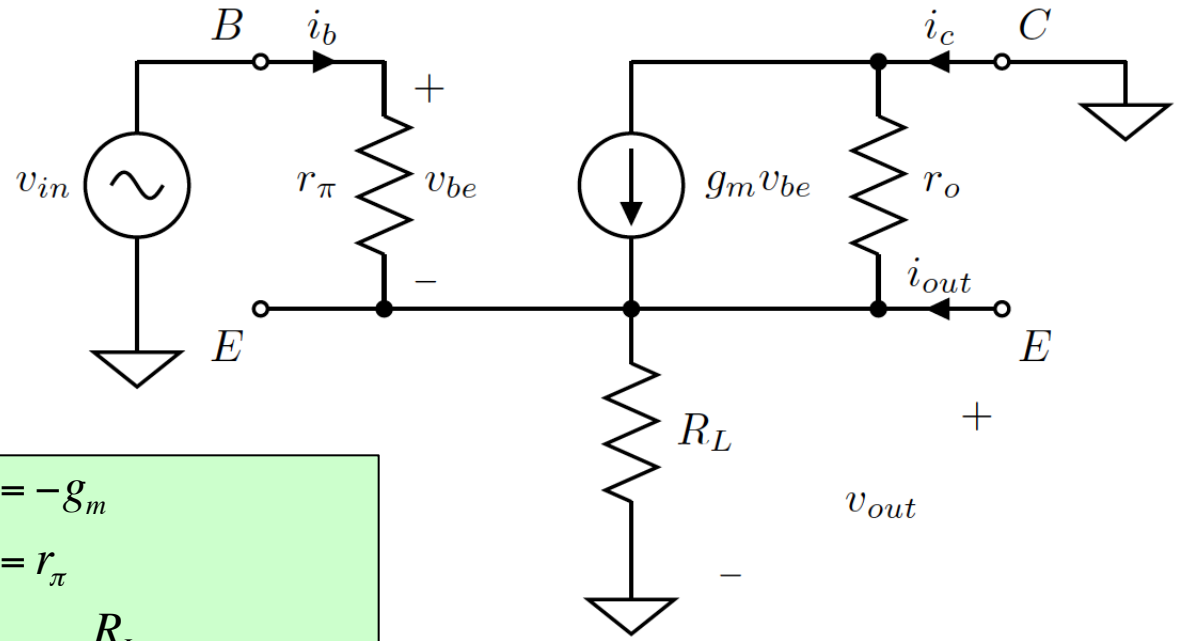
Zero out the input:

$$R_o = \frac{v_{out}}{i_{out}} = r_\pi \,\|\, r_o \,\|\, \frac{1}{g_m} \,\|\, R_L \approx \frac{1}{g_m} \,\|\, R_L = \frac{R_L}{1 + g_m R_L}$$

Common-Collector Small Signal Analysis (4)







$$G_m = -g_m$$

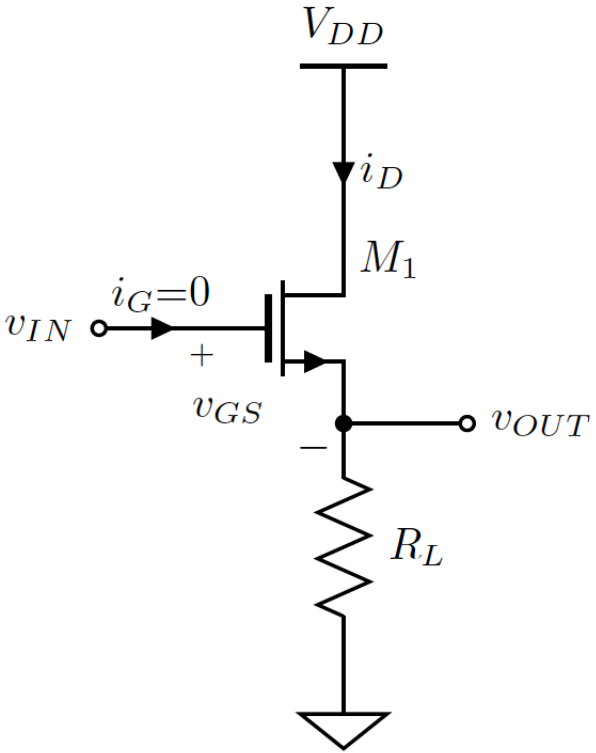
$$R_i = r_\pi$$

$$R_o = \frac{R_L}{1 + g_m R_L}$$

$$A_v = -G_m R_o = \frac{g_m R_L}{1 + g_m R_L}$$

The Common-Drain Amplifier

- DC Analysis:



$$V_{IN} - V_{GS,Q} - I_{S,Q}R_L = 0$$

$$V_{IN} - \left(V_{TH} + \sqrt{\frac{I_{D,Q}}{k}}\right) - I_{D,Q}R_L = 0$$

Quadratic

$$V_{OUT} = I_{D,Q}R_L = V_{IN} - V_{GS}$$

$$= V_{IN} - \left(V_{TH} + \sqrt{\frac{I_{D,Q}}{k}}\right)$$

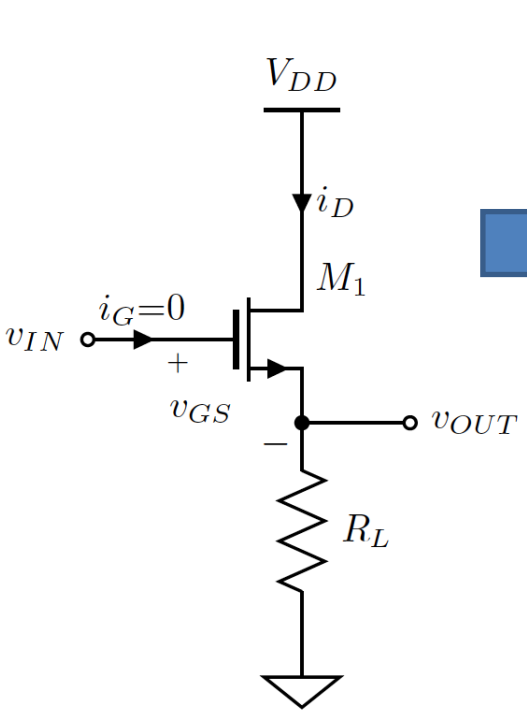
Source follower

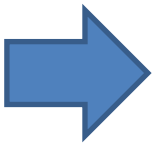
Saturation region check:

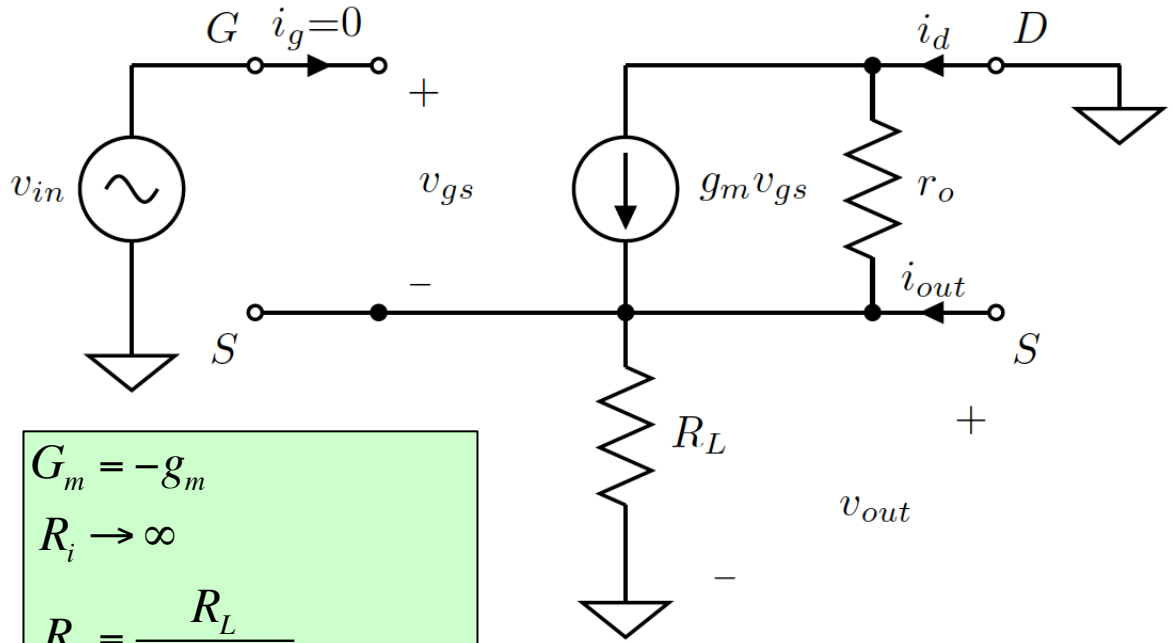
$$V_{DS} = V_{DD} - V_{OUT} > V_{GS} - V_{TH} = V_{IN} - V_{OUT} - V_{TH}$$

$$V_{DD} > V_{IN} - V_{TH}$$

Common-Gate Small Signal Model







$$G_m = -g_m$$

$$R_i \to \infty$$

$$R_o = \frac{R_L}{1 + g_m R_L}$$

$$A_v = -G_m R_o = \frac{g_m R_L}{1 + g_m R_L}$$

Next Meeting

- Wrap up single-stage amplifiers
- Current Sources