Lecture 15: Emitter Follower and Common Gate

ECE3110J, Electronic Circuits

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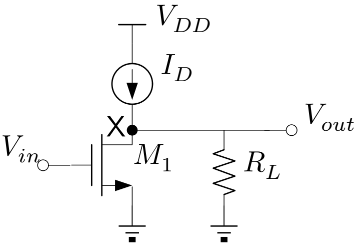
Recap of Last Lecture

- Source Follower

Topic to be covered

- Source Follower
- Emitter Follower
- Common Gate

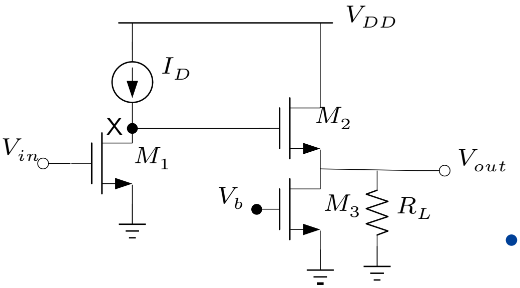
CS + Source Follower



$$A_v = -g_{m1} \left(r_{o1} \parallel R_L \right) \tag{1}$$

- Voltage gain severely reduced when R_L very small

CS + Source Follower



$$A_v = -g_{m1} r_{o1} \times g_{m2}\left(r_{o2} \parallel \frac{1}{g_{m2}+g_{mb2}} \parallel r_{o3} \parallel R_L\right) \quad (2)$$

- Voltage gain maintained when R_L very small

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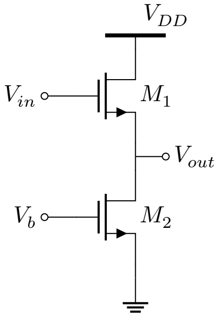
Source Follower Example

$(W/L)_1 = 20/0.5, I_D = 0.2\ mA,\ V_{THo} = 0.6\ V,$
$2\Phi_F = 0.7\ V, \mu_n C_{ox} = 50\mu A/V^2, \gamma = 0.4\ V^{1/2}, \lambda = 0$

- Calculate V_{out} for $V_{in} = 1.2V$.

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(V_{in} - V_{out} - V_{THO}\right)^2 \quad (3)$$

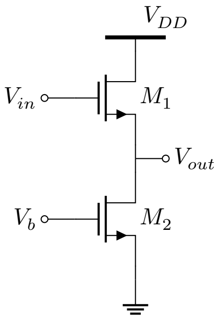
$$\rightarrow V_{\text{out}} = 0.153\ V \quad (4)$$



Source Follower Example

$$V_{TH1} = V_{THO} + \gamma\left(\sqrt{2\Phi_F + V_{\text{out}}} - \sqrt{2\Phi_F}\right) = 0.635\ V \quad (5)$$

$$\rightarrow V_{out} \approx 0.118\ V \quad (6)$$

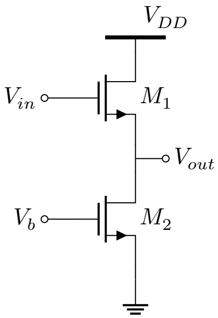


Source Follower Example

- Minimum $(W/L)_2$ for which M_2 remains saturated.

$$V_{out} = 0.118\ V \geq V_{GS2} - V_{TH2} \tag{7}$$

$$I_D = \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(V_{GS2} - V_{TH2}\right)^2 \rightarrow \left(\frac{W}{L}\right)_2 \geq \frac{283}{0.5} \tag{8}$$



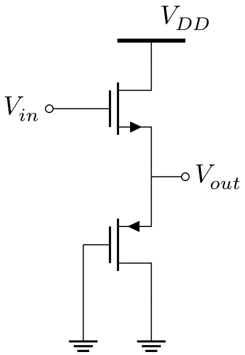
Source Follower Example

Calculate the small signal voltage gain of the circuit below.

$$G_m = g_{m1} \tag{9}$$

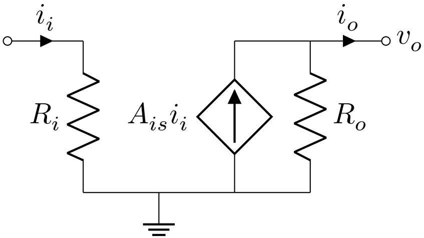
$$R_{out} = \frac{1}{g_{m1} + g_{mb1}} \parallel r_{o1} \parallel \frac{1}{g_{m2} + g_{mb2}} \parallel r_{o2} \tag{10}$$

$$A_v = G_m R_{out} \tag{11}$$



Emitter Follower (Common Collector)

Current Amplifier

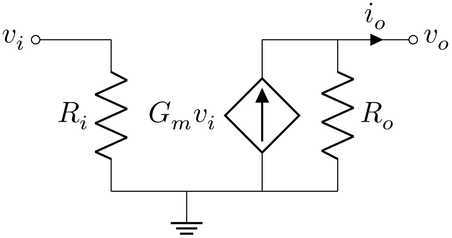


Short-Circuit Current Gain
$(R_i = 0, R_o = \infty)$

$$A_{ix} \equiv \frac{i_o}{i_i}\Big|_{v_o=0} \; (A/A) \qquad (12)$$

- Reading: Sedra & Smith, 8th Ed.: 7.3 (BJT CC)

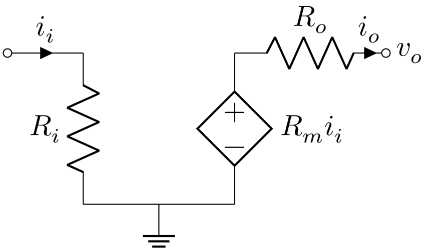
Transconductance Amplifier



Short-Circuit Transconductance
$(R_i = \infty, R_o = \infty)$

$$G_m \equiv \frac{i_o}{v_i}|_{v_o=0} \; (A/V) \tag{13}$$

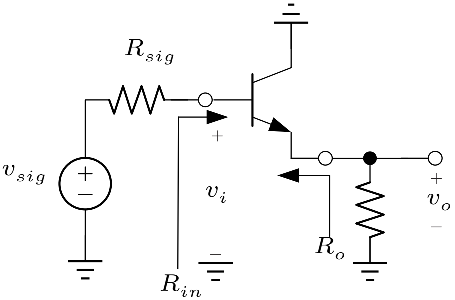
Transresistance Amplifier



Short-Circuit Transresistance
$(R_i = 0, R_o = 0)$

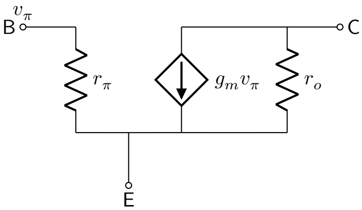
$$R_m \equiv \frac{v_o}{i_i}|_{i_o=0}\ (V/A) \tag{14}$$

Emitter Follower

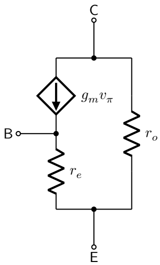


- Transistor is biased to be in the FAR using the same biasing technique for CE amplifier.

Emitter Follower Impedance



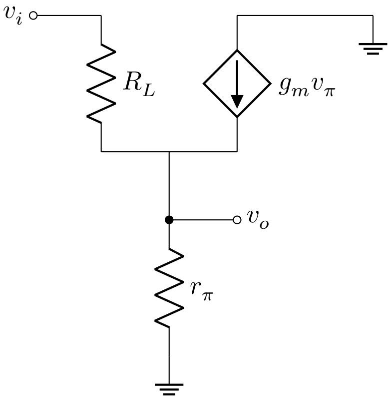
π-model



T-model

$$g_m = \frac{\alpha}{r_e} r_\pi = (\beta + 1) r_e \tag{15}$$

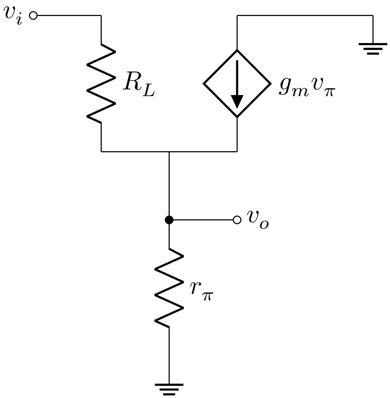
Emitter Follower Impedance



$$R_{\text{in}} = r_\pi + (\beta + 1)R_L \tag{16}$$

$$R_{\text{out}} = r_\pi \parallel (1/g_m) \tag{17}$$

Emitter Follower Gain

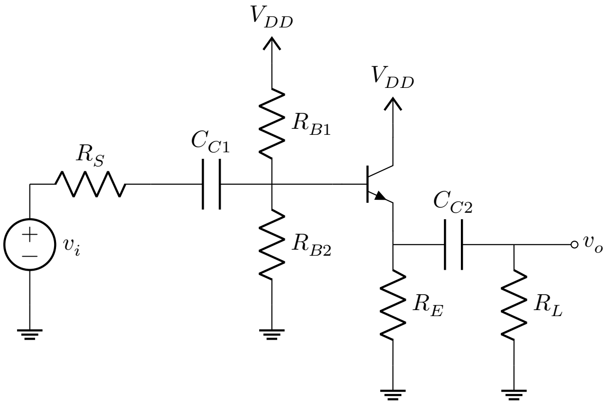


$$\frac{v_o}{v_i} = \frac{R_L}{\frac{1}{g_m + 1/r_\pi} + R_L} \tag{18}$$

CC Amplifier with Biasing Circuit

- No collector resistor
- no bypass capacitor
- Biasing scheme remains the same.
- Output taken out at the emitter.

CC Amplifier with Biasing Circuit



CC Amplifier with Biasing Circuit

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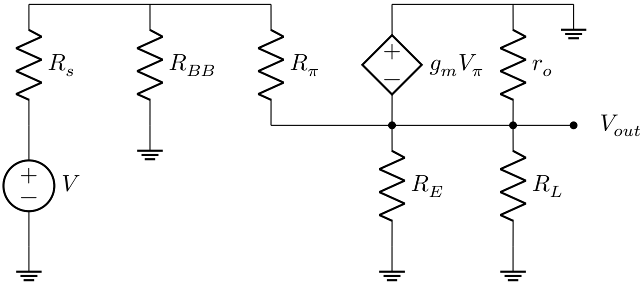
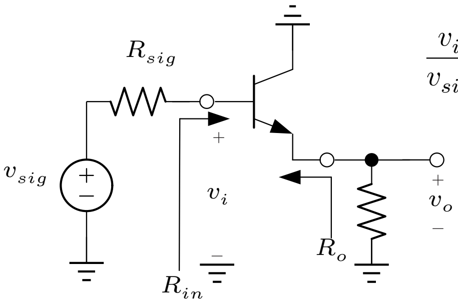
Use the current relationship of i_b and i_c



CC Amplifier with Biasing Circuit

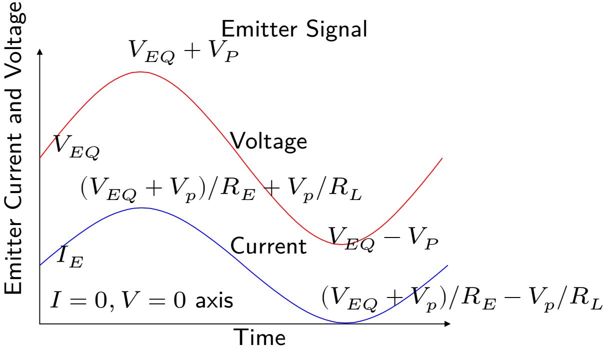


$$\frac{v_i}{v_{sig}} = \frac{R_{in}}{R_{in} + R_{sig}} = \frac{(\beta+1)(r_e + R_L)}{(\beta+1)(r_e + R_L) + R_{sig}} \tag{19}$$

$$G_v \equiv \frac{v_o}{v_{sig}} = \frac{v_i}{v_{sig}} \times A_v \tag{20}$$

$$G_v = \frac{(\beta+1)R_L}{(\beta+1)R_L + (\beta+1)r_e + R_{sig}} \tag{21}$$

CC Amplifier Swing



- Assume output is a sinusoid with peak voltage of V_P
- Emitter voltage can get to within $V_{CE,sat}$ of the supply voltage, therefore the maximum output voltage is $V_{CC} - V_{CE,sat} - V_{EQ}$.

CC Amplifier Swing

Total emitter current is given by:

$$i_E = \frac{V_{EQ}}{R_E} + \frac{v_p}{R_E} + \frac{v_p}{R_L} \tag{22}$$

$$i_E = \frac{V_{EQ}}{R_E} - \frac{V_P}{R_E} - \frac{V_P}{R_L} = 0 \tag{23}$$

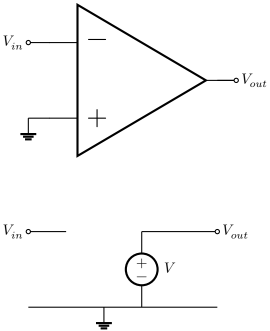
$$\frac{V_{EQ}}{R_E} - \frac{V_P\,(R_L + R_E)}{R_L R_E} = 0 \tag{24}$$

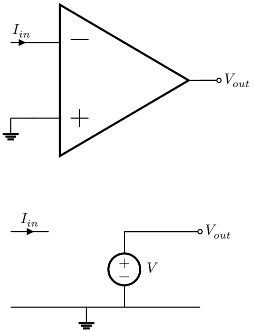
CC Amplifier Swing

$$V_P = \frac{V_{EQ}(R_L}{R_L + R_E} = \frac{V_{EQ}}{\left(1 + \frac{R_E}{R_L}\right)} \tag{25}$$

$$V_{E\,\mathrm{min}} = V_{EQ} - V_P = \frac{V_{EQ}\left(R_E\right)}{R_L + R_E} = \frac{V_{EQ}}{\left(1 + \frac{R_L}{R_E}\right)} \tag{26}$$

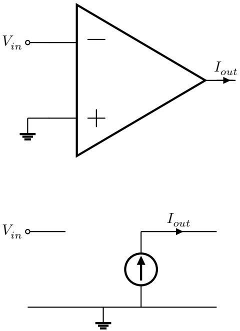
Ideal Amplifier: Voltage Amp. and Transimpedence Amp

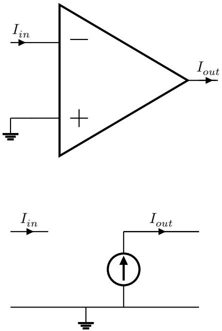




- For driving a low impedance load, source follower, as a buffer, provides no gain but large input impedance and low output impedance.

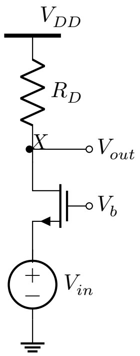
Ideal Amplifier: Transconductance Amp. and Current Amp.





- For driving a low impedance load, source follower, as a buffer, provides no gain but large input impedance and low output impedance.

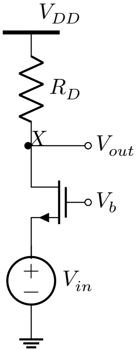
Common-Gate $(\lambda = 0, \gamma \neq 0)$



- $V_{\text{in}} > V_b - V_{TH} \rightarrow M_1$ Off
- $V_{\text{out}} = V_{DD}$
- $V_b - V_{TH} > V_{\text{in}} > V_{\text{in1}} \rightarrow M_1$ in Saturation

$$V_{\text{out}} = V_{DD} - R_D \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_b - V_{\text{in}} - V_{TH})^2 \tag{27}$$

Common-Gate



At the boundary of triode/saturation:

$$V_{\text{out}} = V_b - V_{TH} \tag{28}$$

$$= V_{DD} - R_D \frac{1}{2} \mu_n C_{ox} \frac{W}{L} \left(V_b - V_{in1} - V_{TH}\right)^2 \tag{29}$$

$$V_{\text{in}} < V_{\text{in }1} \rightarrow M_1 \text{ in Triode} \tag{30}$$

Triode region equation as follows:

$$V_{\text{out}} = V_{DD} - R_D \mu_n C_{ox} \frac{W}{L} \left[\left(V_b - V_{in} - V_{TH}\right) \left(V_{\text{out}} - V_{in}\right) - \frac{1}{2} \left(V_{\text{out}} - V_{in}\right)^2 \right] \tag{31}$$

Common-Gate $(\lambda = 0, \gamma \neq 0)$

$$V_b - V_{TH} > V_{in} > V_{in1} \rightarrow M_1 \text{ in Saturation} \tag{32}$$

$$V_{out} = V_{DD} - R_D \frac{1}{2}\mu_n C_{ox}\frac{W}{L}\left(V_b - V_{in} - V_{TH}\right)^2 \tag{33}$$

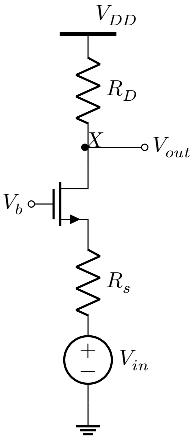
$$\frac{\partial V_{out}}{\partial V_{in}} = -R_D \frac{1}{2}\mu_n C_{ox}\frac{W}{L} 2\left(V_b - V_{in} - V_{TH}\right)\left(-1 - \frac{\partial V_{TH}}{\partial V_{in}}\right) \tag{34}$$

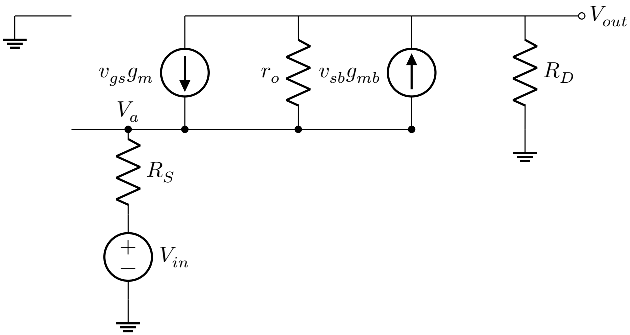
$$= R_D \mu_n C_{ox}\frac{W}{L}\left(V_b - V_{in} - V_{TH}\right)\left(1 + \frac{\partial V_{TH}}{\partial V_{in}}\right) \tag{35}$$

$$A_v = \frac{\partial V_{out}}{\partial V_{in}} = R_D g_m (1 + \eta) \tag{36}$$

- g_m is a function of I_D and η is a function of V_{SB}.
- A_v is not quite linear.

Common-Gate ($\lambda = 0, \gamma \neq 0$ Small-signal)





Common-Gate ($\lambda = 0, \gamma \neq 0$ Small-signal)

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$$G_m = \frac{(g_m + g_{mb})r_o + 1}{r_o + R_S + (g_m + g_{mb})r_o R_S} \tag{37}$$

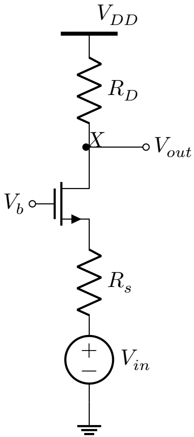
$$R_{\text{out}} = R_D \parallel [r_o + R_S + (g_m + g_{mb})r_o R_S] \tag{38}$$

$$A_v = \frac{(g_m + g_{mb})r_o + 1}{r_o + R_S + (g_m + g_{mb})r_o R_S + R_D} R_D \approx R_D g_m (1 + \eta) \tag{39}$$

$$\text{If} \quad R_S = 0 \quad \text{and} \quad r_o = \infty \tag{40}$$

Common-Gate SS gain

Transconductance gain: use Norton equivalent



Common-Gate SS gain

Output Impedance: SS model