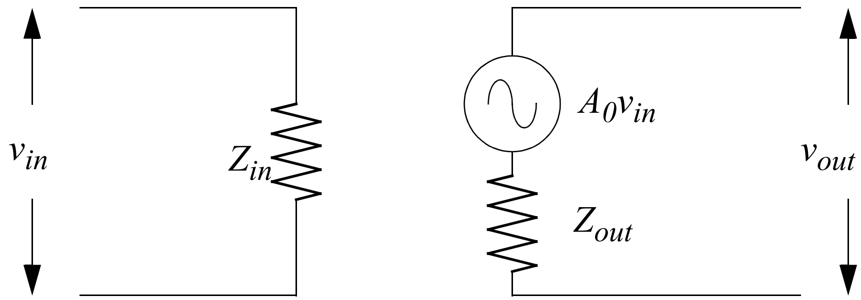
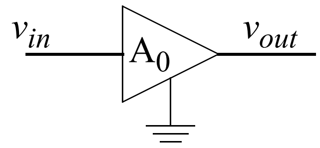
Transistor Amplifiers

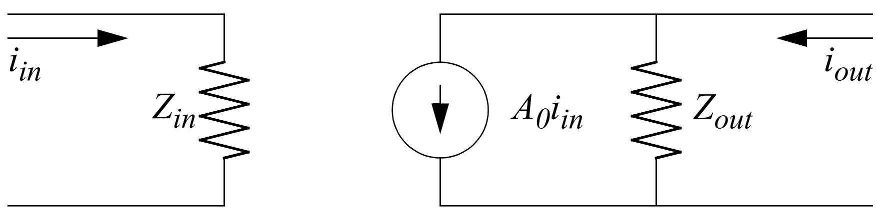
- An amplifier is a four connection device
- Voltage amplifier (Thevenin equivalent)



Schematic symbol:



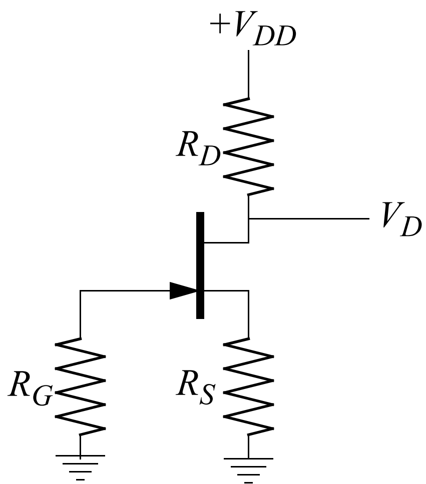
- Current amplifier (Norton equivalent)



- Amplifiers can also have current in and voltage out or voltage in and current out.

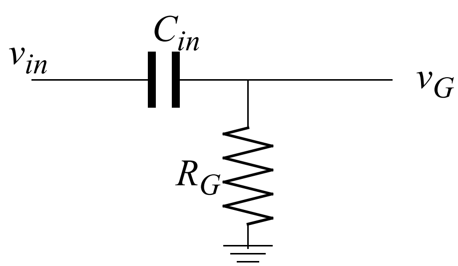
Common Source FET

- DC voltage source



The FET conducts and there is a voltage divider from V_{DD} to ground.

- AC signal

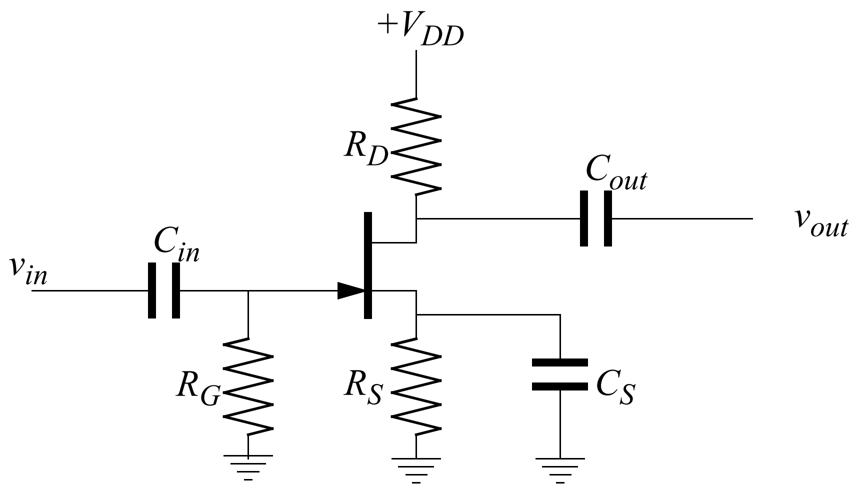


Input forms a high-pass filter.

No DC offset passes into v_G.

Common Source Amplifier

- AC voltage amplifier



DC separates from AC, V_{DS} = constant.

Forward transconductance g_m is about 10 mS.

$$g_m = \left(\frac{\partial i_D}{\partial v_{GS}}\right)_{V_{DS}} \qquad i_D = g_m v_{GS} \qquad i_d \cong g_m v_{gs}$$

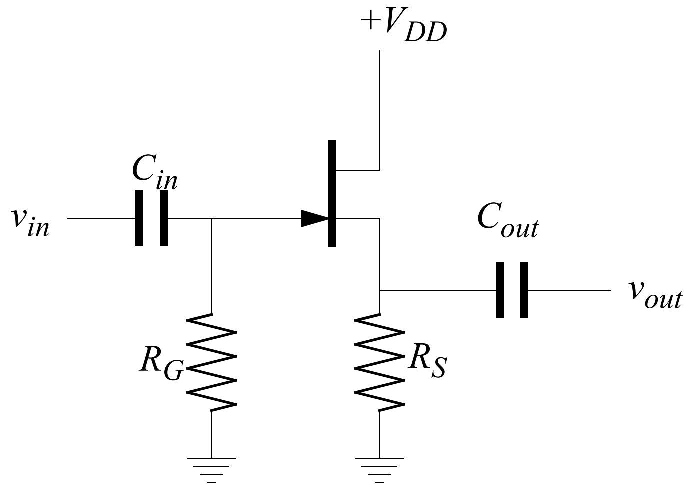
C_S provides an AC short, so $v_s = 0$, $v_{gs} = v_{in}$.

For the AC signal: $v_{out} = v_d = -i_d R_D$.

- Gain: $A = v_{out}/v_{in} = -g_m v_{gs} R_D / v_{gs} = -g_m R_D$

Common Drain Amplifier

- The common drain amplifier takes output at the source



- The input impedance is very high so little current flows into the gate

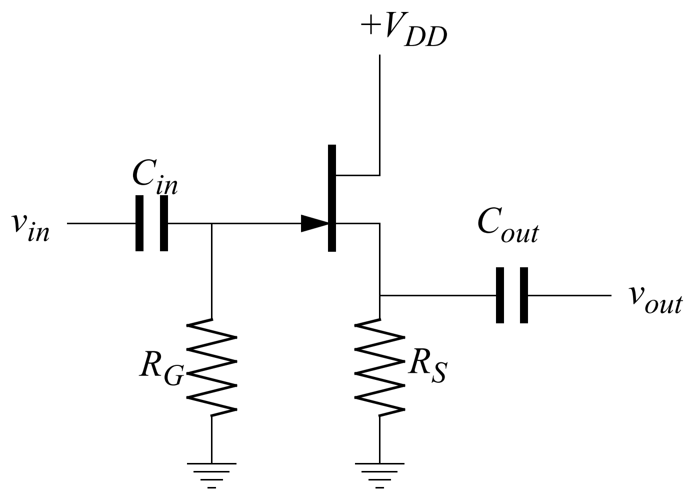
$$i_g \cong 0 \qquad i_s = i_d$$

- The FET has a transconductance g_m:

$$i_d = g_m(v_g - v_s)$$

Source Follower

- The circuit behaves like a voltage divider



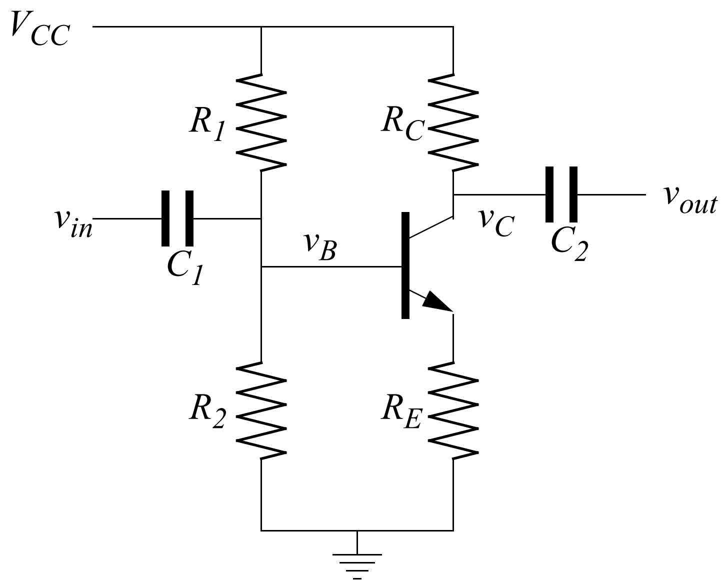
$$v_s = i_s R_S = i_d R_S = R_S g_m (v_g - v_s)$$

$$v_s = \frac{R_S g_m}{1 + R_S g_m} v_g$$

- R_S and $1/g_m$ form a voltage divider, if $g_m = 10$ mS, then $1/g_m = 100\ \Omega$.
- If $R_L >> 1/g_m$, $v_s = v_g$.
- The AC signal out has the same amplitude as the input - it is a “follower”.

Common Emitter

- The common emitter circuit:



- C_1, C_2 form high-pass filters for the signal, the DC bias remains for the transistor.
- The AC and DC behavior of the transistor can be separated

- Common emitter input is at the base: v_b.

$$v_B = V_B + v_b$$

- Common emitter output is at the collector: v_c.

$$v_C = V_C + v_c$$

Signal Amplification

- The base-emitter junction is like a diode (assume $V_{\text{diode}} = 0.6$ V)

$$v_B = V_B + v_b \qquad v_E = V_E + v_e$$

$$v_B = v_E + 0.6 \qquad V_B = V_E + 0.6$$

$$v_b = v_e$$

- The AC part of the emitter current is:

$$i_e = \frac{v_e}{R_E} = \frac{v_b}{R_E}$$

- The AC part of the collector current is:

$$i_c = -\frac{v_c}{R_C}$$

- Since β is large, $i_c = i_e$.

$$\frac{v_b}{R_E} = -\frac{v_c}{R_C}$$

$$v_c = -\frac{R_C}{R_E}v_b$$

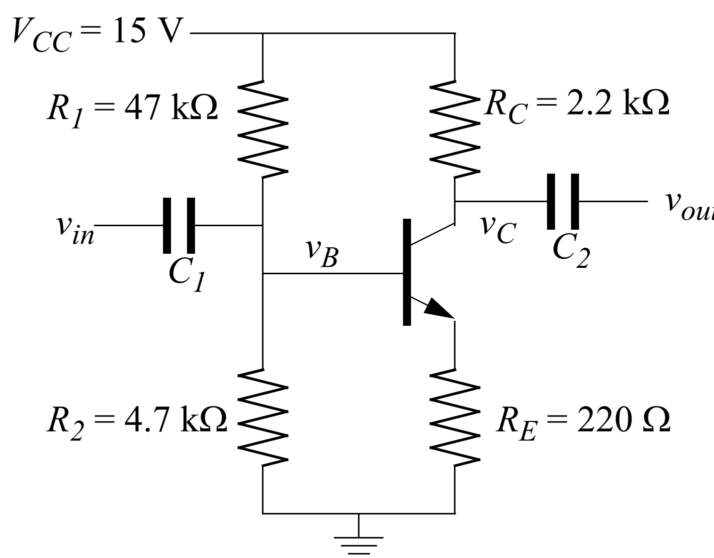
- This is a voltage amplifier, with gain $A = -R_C / R_E$.
- Negative gain means the output has inverted sign.
- Selecting the gain provides the remaining constraints to select the circuit bias resistors.

Designing an Amplifier

- Select a gain of –10

$R_C = 10\ R_E$	$R_C + R_E = 2.5\ \text{k}\Omega$
$R_E = 230\ \Omega$	$R_C = 2.3\ \text{k}\Omega$
$R_2 = 10R_E + 2\ \text{k}\Omega$	$R_1 = 48\ \text{k}\Omega - 10R_E$
$R_2 = 4.3\ \text{k}\Omega$	$R_1 = 46\ \text{k}\Omega$

- The common emitter circuit with resistances rounded off:



- Double check values:

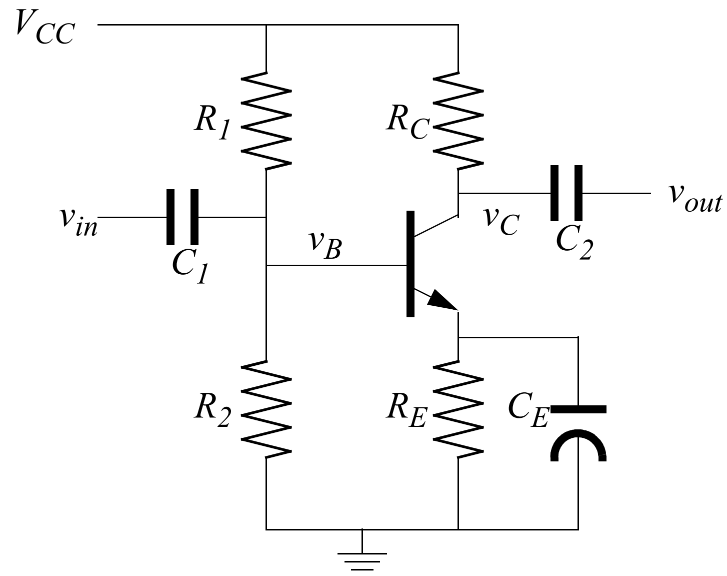
$V_B = 1.36\ \text{V}$ $\quad V_E = 0.8\ \text{V}$ $\quad I_E = 3.5\ \text{mA} = I_C$

$V_C = 7.4\ \text{V}$ $\quad V_{CE} = 6.6\ \text{V}$

$\text{Gain} = -R_C / R_E = -10$

Emitter Stability

- Without an emitter capacitor, the emitter voltage increases with increasing base voltage. This reduces the gain since V_{BE} doesn't increase enough.



- A capacitor C_E in parallel with R_E is a low-pass filter, and should block all signal frequencies.
- Assume for design signal frequencies from 1 kHz to 100 kHz.

$$\omega_b = \frac{1}{R_E C_E} \qquad C_E \gg \frac{1}{2\pi f R_E} = 0.69\mu F$$

- However this also effectively puts v_e at ground, since the capacitor looks like low impedance to AC.

Stabilized Amplifier

- There is a resistance from the base to the emitter that is inversely proportional to the collector current.

$$R_{BE} = \frac{2.6(k\Omega \cdot mA)}{I_C}$$

- The AC part of the base current is:

$$i_b = \frac{v_b}{R_{BE}}$$

- The AC part of the collector current is:

$$i_c = -\frac{v_c}{R_C}$$

- Since $i_c = \beta i_b$:

$$\frac{v_b}{R_{BE}} = -\frac{v_c}{\beta R_C}$$

$$v_c = -\frac{\beta R_C}{R_{BE}} v_b = -\frac{\beta I_C R_C}{2.6 V} v_b$$

- This is a voltage amplifier, with gain $A = -\beta I_C R_C / 2.6$ V.
- This gives a gain that is proportional to β for the transistor.