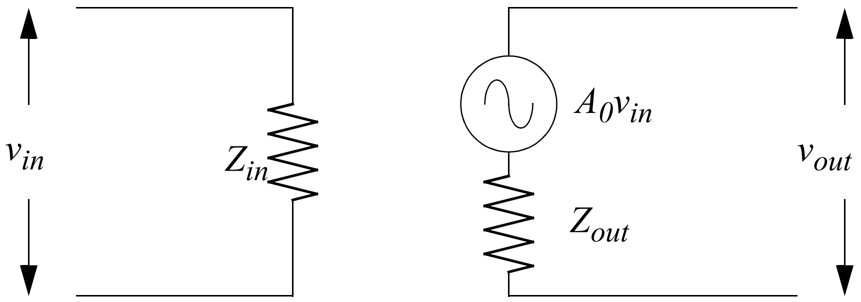
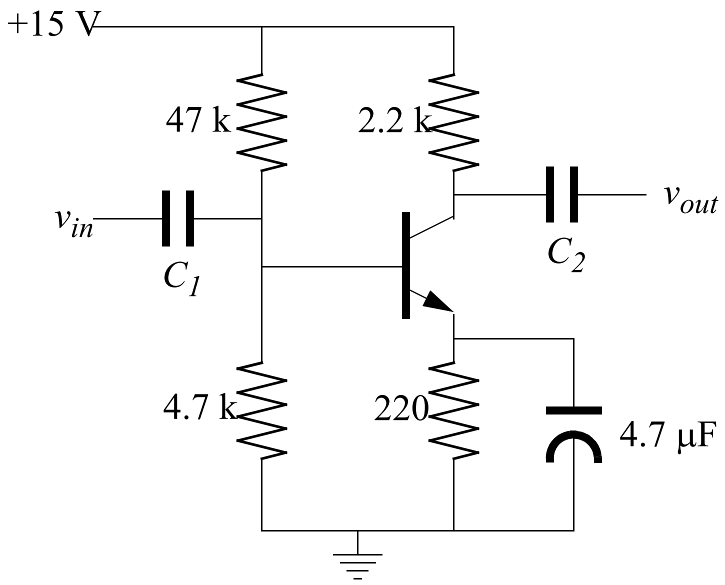
Amplifier Impedance

- Amplifier circuits have impedance at both the input and output.

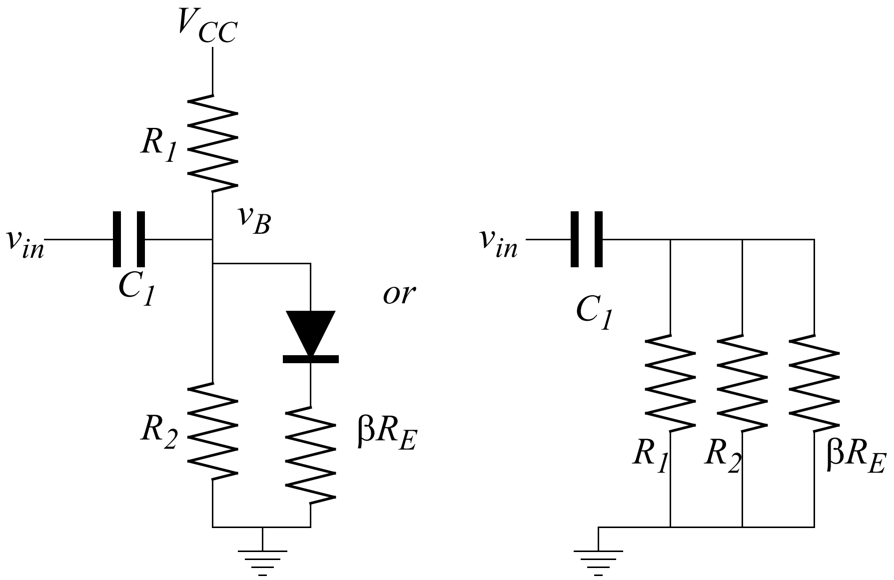


- AC common emitter



Input Impedance

- The input signal to a common emitter amplifier sees this circuit:

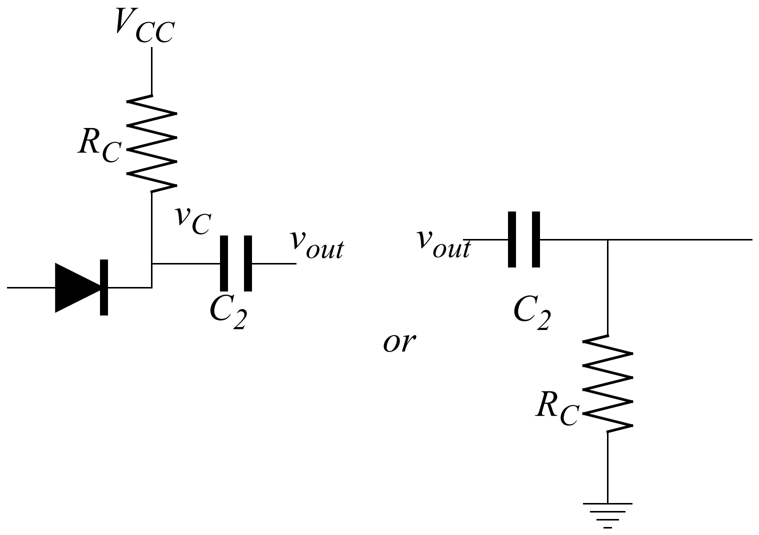


- This is a high-pass filter with $\omega_b = 1/RC$, where R is the parallel resistance.
- R_E is shorted at high frequency by C_E, but there is an internal resistance of about 2.6 kΩ mA/ I_C = 870 Ω.
- For a break frequency of 1 kHz, R_{in} = 0.71 kΩ.

$$C_1 \gg \frac{1}{2\pi f R_{in}} = 0.22\mu F$$

Output Impedance

- The output signal from a common emitter amplifier sees this circuit:

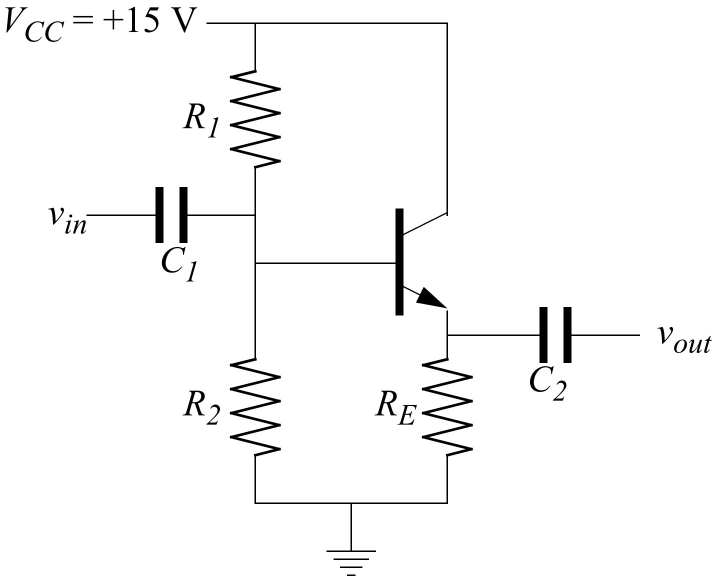


- This is a high-pass filter with $\omega_b = 1/R_C C_2$

$$C_2 \gg \frac{1}{2\pi f R_C} = 0.069\mu F$$

Follower Amplifier

- The common collector or emitter follower circuit:



- The emitter is a constant diode drop below the base.

$$v_E = v_B - V_{BE}$$

$$v_e = v_b$$

- The output voltage follows the input.

Design Parameters

- Design for audio, $f = 20$ Hz - 20 kHz, $I_C = 1$ mA.
- Set $V_E = 0.5\ V_{CC} = 7.5$ V to have the maximum dynamic range. Set $R_E = V_E / I_C = 7.5$ kΩ.
- Find $V_B = V_E + 0.6$ V = 8.1 V
- R_1 and R_2 form a voltage divider, $V_B = \frac{R_2}{R_1 + R_2} V_{CC}$ $\qquad \frac{R_2}{R_1} = 1.17 = r$
- The impedance due to the base bias should be small compared to the impedance into the base-emitter junction

$$\frac{R_1 R_2}{R_1 + R_2} = \frac{\beta R_E}{10} \qquad \frac{10 r R_1^2}{(1 + r) R_1} = \beta R_E$$

$$R_1 = \frac{\beta R_E (1 + r)}{10 r} = 139 k\Omega \approx 130 k\Omega$$

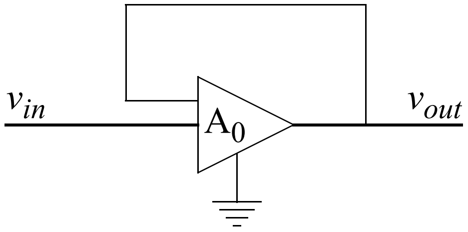
$$R_2 = 162 k\Omega \approx 150 k\Omega$$

- Total input impedance is 63 kΩ. Select $C_1 = 0.5\ \mu\text{F} > 1 / 2\pi f Z_{out} = 0.13\ \mu\text{F}$.
- Total output impedance > $R_E / 2 = 3.8$ kΩ. Select $C_2 = 4.7\ \mu\text{F} > 1 / 2\pi f Z_{in} = 2.1\ \mu\text{F}$.
- The amplifier provides **high input impedance** and **low output impedance**.

Feedback

Generalized Feedback

- In an amplifier output is a function of input
- It is difficult to design an amplifier with constant gain, and impedance
- Feedback allows the input to be a function of output

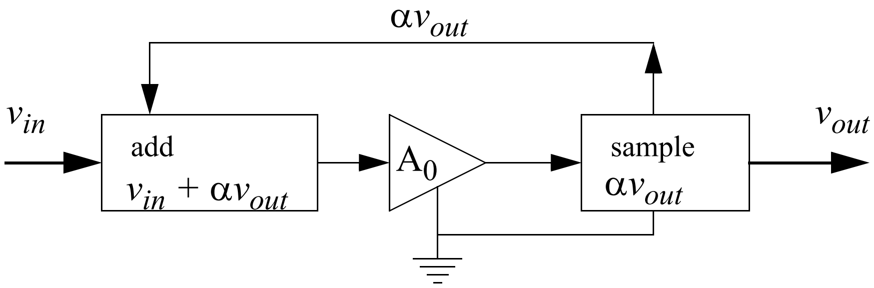


Types of Feedback

Sample output	Type of input	Name
Voltage	Voltage	Voltage feedback
Current	Voltage	Current feedback
Voltage	Current	Operational voltage feedback
Current	Current	Operational current feedback

Voltage Feedback

- Sample output voltage and add it to input:



- Input to amplifier: $v_{in} + \alpha v_{out}$
- Output of amplifier: $A_0(v_{in} + \alpha v_{out})$
- Output of the circuit:

$$A_0(v_{in} + \alpha v_{out}) - \alpha v_{out}$$

- If A_0 is very large:

$$A_0(v_{in} + \alpha v_{out}) = v_{out}$$

$$A_0 v_{in} = (1 - A_0\alpha) v_{out}$$

- The effective gain A is:

$$A = \frac{v_{out}}{v_{in}} = \frac{A_0}{(1 - A_0\alpha)}$$

High Gain

- If αA_0 is near 1: $A = \frac{A_0}{(1 - A_0\alpha)} \Rightarrow \infty$

  But there will be oscillations

- If αA_0 is negative: $A = \frac{A_0}{(1 - A_0\alpha)} < A_0$
- And if $-\alpha A_0 >> 1$: $A = \frac{A_0}{(1 - A_0\alpha)} \cong \frac{1}{|\alpha|}$

Amplifier Stability

- Small changes in gain A_0 affect the effective gain:

$$\frac{dA}{A} = \frac{dA_0}{A_0} - \alpha\frac{dA_0}{(1 - A_0\alpha)} = \frac{A}{A_0}\frac{dA_0}{A_0}$$

For an amplifier with $A_0 = 1000$, and $\alpha = -0.1$

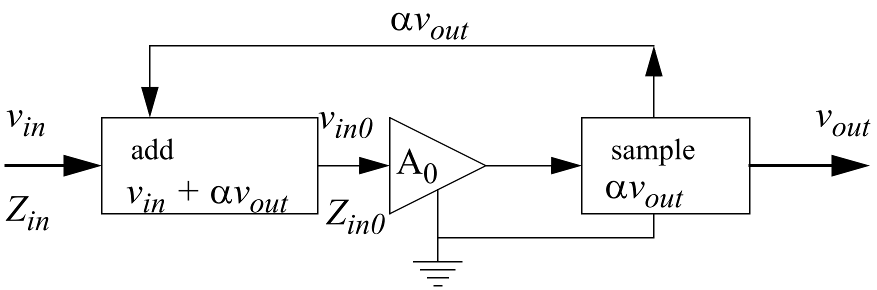
$A = 1/|\alpha| = 10$, $A/A_0 = 0.01$

100% change in A_0 results in 1% change in A.

Impedance with Feedback

- Input impedance changes with feedback: $Z_{in} = \frac{v_{in}}{i_{in}} = \frac{v_{in0}}{(1+\alpha A)i_{in}} = \frac{A_0}{A} Z_{in0}$

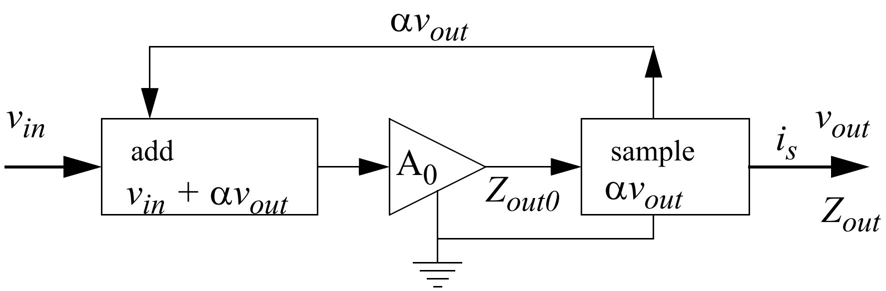
  This is an increase for negative feedback



- Output impedance also changes:

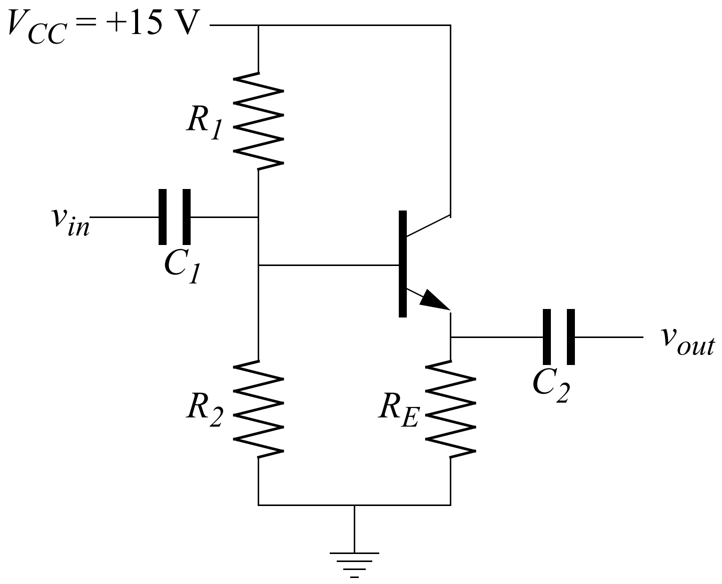
$$Z_{out} = \frac{v_{out}}{i_s} = \frac{A v_{in}}{i_s} = \frac{A}{i_s}\frac{i_s Z_{out0}}{A_0} = \frac{A}{A_0} Z_{out0}$$

  This is a decrease for negative feedback



Follower with Feedback

- The emitter follower circuit:



- The base is one diode drop above the emitter, so $v_{be} = 0$.

  The feedback voltage exactly cancels the input voltage

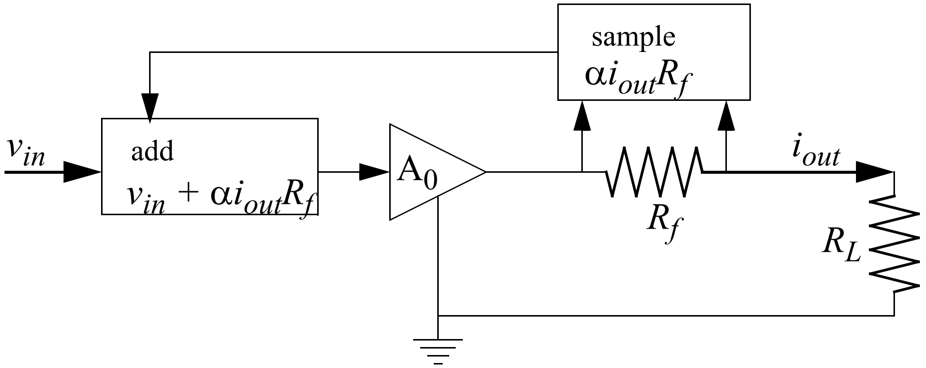
  $\alpha = -1$.

$$A = \frac{A_0}{(1 - A_0\alpha)} = \frac{A_0}{(1 + A_0)} \cong 1$$

- The gain $A = 1$ for an emitter follower.

Current Feedback

- Sample output current, convert to voltage, and add it to input:



- Input to amplifier:

$$v_{in} + \alpha i_{out} R_f$$

- Output of amplifier:

$$A_0 (v_{in} + \alpha i_{out} R_f) - i_{out} Z_{out0}$$

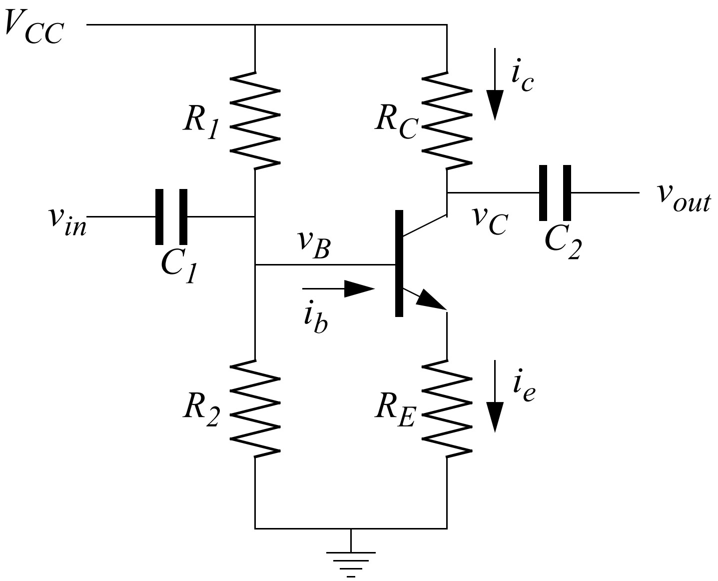
- Output of the circuit:

$$i_{out} = \frac{A_0 v_{in}}{R_L + Z_{out0} + (1 - A_0 \alpha) R_f}$$

- If $-A_0 \alpha R_f >> R_L + Z_{out0} + R_f$ (negative feedback):

$$i_{out} \cong \frac{v_{in}}{-\alpha R_f}$$

Common Emitter with Feedback



- The feedback is through the emitter

$$v_f = -R_E i_e = R_E i_b - R_E i_b - R_E i_e \qquad v_f = -R_E i_b - R_E i_c$$

$$v_f = -R_E i_b + R_E \frac{v_{out}}{R_C}$$

- The two terms correspond to current feedback and voltage feedback.
- The output impedance is $Z_{out} = \frac{v_{th}}{i_s} = \frac{-v_i(R_C/R_E)}{-v_i/R_E} = R_C$