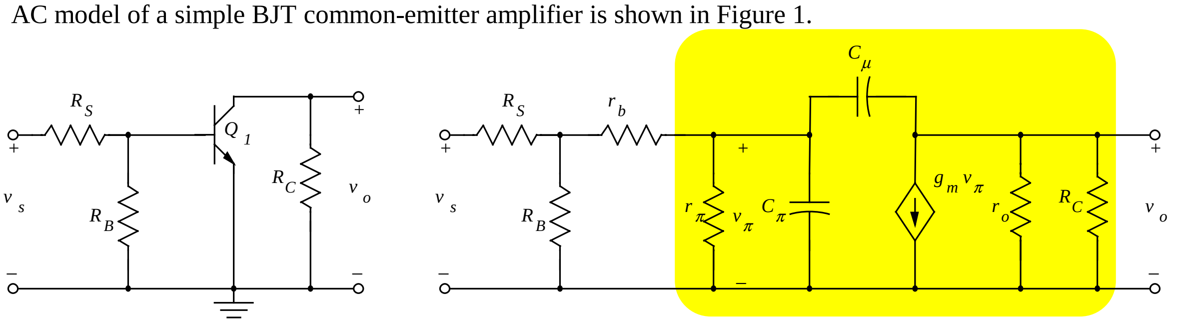
HIGH-FREQUENCY RESPONSE OF SIMPLE BJT AMPLIFIERS

At high frequencies, the amplifier response is characterized by midband and high-frequency poles. Single BJT amplifiers are analyzed.

Common-emitter amplifier high-frequency response

- AC model of a simple BJT common-emitter amplifier is shown in Figure 1.



(a) (b)

Figure 1. Common-Emitter Equivalent Circuits
(a) Midband AC Equivalent, (b) High-Frequency Equivalent

- The input portion of the high-frequency equivalent circuit is simplified for analysis as shown in Figure 2.

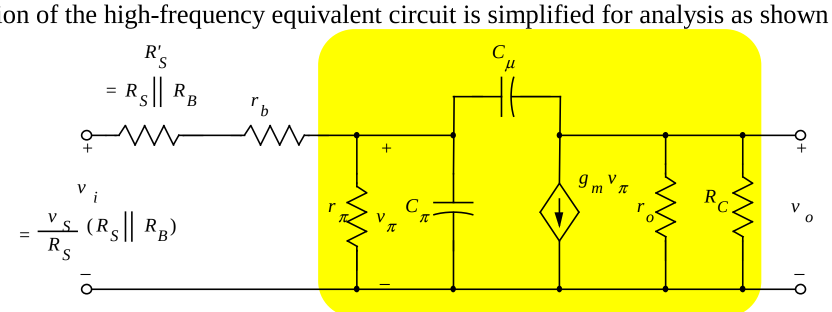
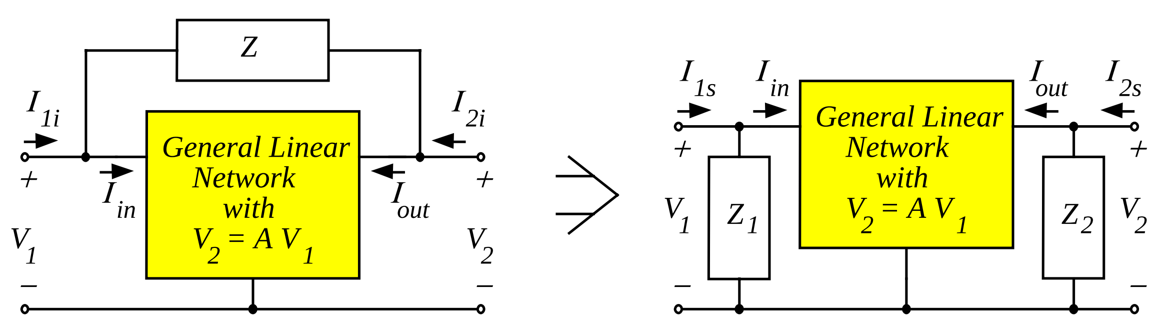


Figure 2. Simplified Input Portion of High-Frequency Equivalent Circuit

- Miller's Theorem is used to simplify the high-frequency equivalent circuit made complex by the presence of C_μ which interconnects the input and output sections of the circuit.
- The two-port network accentuated by the shaded area has a midband voltage gain of

$$A = \frac{v_o}{v_\pi} = -g_m\left(r_o \| R_C\right) = -g_m R_C\,',$$

which is used in Miller's Theorem, $Z_1 = \dfrac{Z}{1-A}$ $\qquad Z_2 = \dfrac{AZ}{A-1}$. (10.5-2)



(a) (b)

Figure 3. Miller's Equivalent Circuits : (a) Interconnecting Impedance, (b) Port-Shunting Impedance

- The use of Miller's Theorem results in the following equivalent circuit:

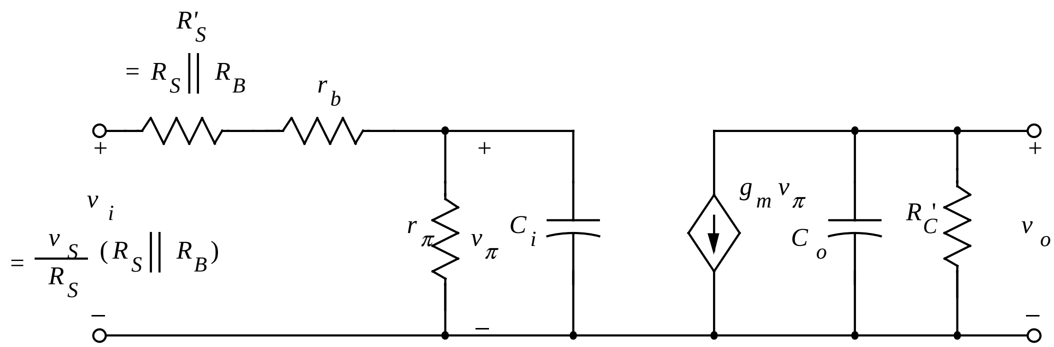


Figure 4. Miller's Theorem Applied to a Common-Emitter Amplifier

where $$\frac{1}{j\omega C_i} = \frac{\frac{1}{j\omega C_\mu}}{1-A} = \frac{1}{j\omega C_\mu\left[1-\left(-g_m R_C^{'}\right)\right]} \Rightarrow C_i = C_\mu\left(1+g_m R_C^{'}\right)$$

and $$\frac{1}{j\omega C_o} = \frac{\frac{A}{j\omega C_\mu}}{A-1} = \frac{-g_m R_C^{'}}{j\omega C_\mu\left(-g_m R_C^{'}-1\right)} \Rightarrow C_o = C_\mu \frac{\left(1+g_m R_C^{'}\right)}{g_m R_C^{'}}$$

- The voltage gain of the circuit is therefore:

$$A_V = \left(\frac{v_o}{v_S}\right) = \left(\frac{v_o}{v_\pi}\right)\left(\frac{v_\pi}{v_i}\right)\left(\frac{v_i}{v_s}\right)$$

$$= \left[-g_m\left(R_C^{'} \left\| \frac{1}{j\omega C_o}\right.\right)\right]\left[\frac{r_\pi \left\| \frac{1}{j\omega C_i}\right.}{R_S^{'} + r_b + \left(r_\pi \left\| \frac{1}{j\omega C_i}\right.\right)}\right]\left[\frac{R_S \| R_B}{R_S}\right]$$

Simplifying this expression to yield an expression for the gain which clearly shows the poles of the amplifier:

$$A_V = \left[\frac{-g_m R_C^{'} R_B r_\pi}{R_S\left(R_B + r_b + r_\pi\right) + R_B\left(r_b + r_\pi\right)}\right]\left[\frac{1}{1+j\omega C_o R_C^{'}}\right]\left\{\frac{1}{1+j\omega C_i\left[r_\pi \left\| \left(R_S^{'} + r_b\right)\right.\right]}\right\}$$

- The high frequency poles for the common-emitter amplifier as shown in Figure 1 are:

$$\omega_{P1} = \frac{1}{1+j\omega C_o R_C^{'}} \quad \text{and} \quad \omega_{P2} = \frac{1}{1+j\omega C_i\left[r_\pi \left\| \left(R_S^{'} + r_b\right)\right.\right]} .$$

- Simply put, the voltage gain characteristics of the amplifier at high frequencies is composed of the midband voltage and the lowpass transfer characteristics of the input and output portions of the high-frequency equivalent circuit: $$A_V = \left[A_{Vm}\right]\left[\frac{1}{1+j\omega C_o R_C^{'}}\right]\left\{\frac{1}{1+j\omega C_i\left[r_\pi \left\| \left(R_S^{'} + r_b\right)\right.\right]}\right\} .$$

Common-collector amplifier high-frequency response

- AC model of a simple BJT common-collector amplifier is shown in Figure 5.

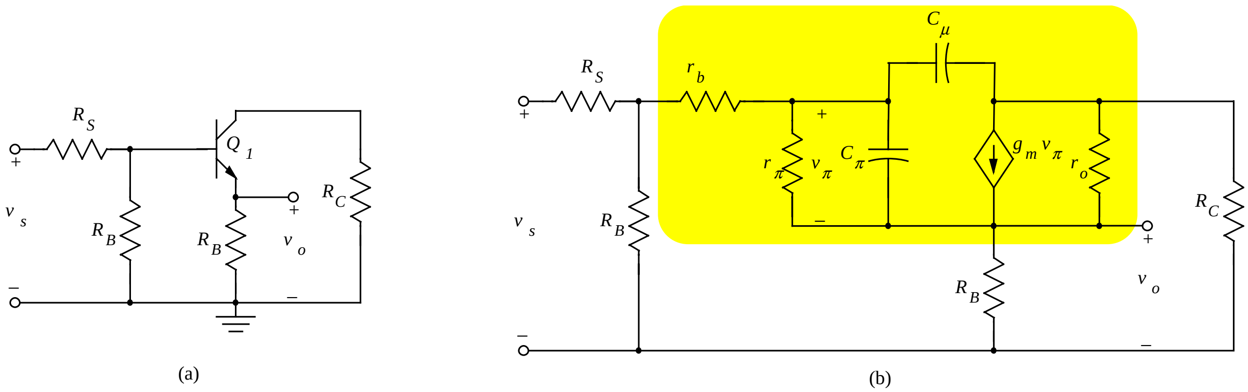


Figure 5. Common-Collector Equivalent Circuits
(a) Midband AC Equivalent, (b) High-Frequency Equivalent

- The input portion of the high-frequency equivalent circuit is simplified for analysis as shown in Figure 6. For simplicity, r_o is considered to be very large compared to R_C and R_E.

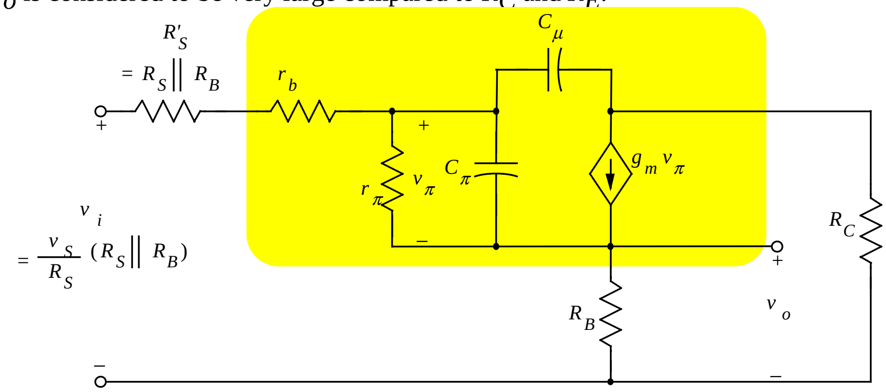


Figure 6. Simplified Input Portion of High-Frequency Equivalent Circuit

- The gain of the shaded two-port network is $A = \dfrac{v_{ec}}{v_\pi} = -g_m\left(R_C + R_E\right)$ which is used in Miller's Theorem,

$$Z_1 = \frac{Z}{1-A} \qquad\qquad Z_2 = \frac{AZ}{A-1} \quad . \tag{10.5-2}$$

- When Miller's Theorem is applied to the common-collector amplifier,

$$C_i = C_\pi + C_\mu\left[1 + g_m\left(R_C + R_E\right)\right] \text{ and } C_O = C_\mu\left[\frac{1 + g_m\left(R_C + R_E\right)}{g_m\left(R_C + R_E\right)}\right] \approx C_\mu$$

with the equivalent circuit shown in Figure 7:

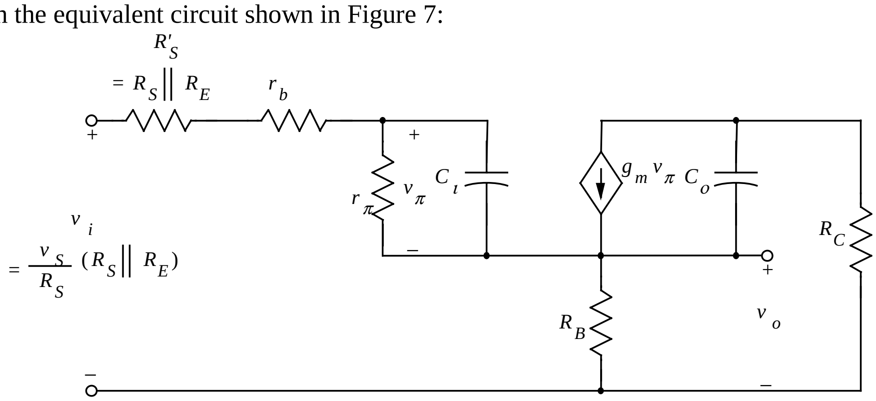


Figure 7. Miller's Theorem Applied to a Common-Collector Amplifier

- The pole introduced by the C_i is of primary interest since C_o is less than the input capacitance. Therefore, assume that the pole introduced by C_o is sufficiently high so that C_o can be replaced by an open circuit.
- The voltage gain of the common-collector amplifier is:

$$A_V = \frac{v_o}{v_s} \approx \frac{g_m r_\pi R_E}{R_S' + r_b + \left(1+g_m R_E\right) r_\pi + j\omega C_i r_\pi \left(R_S + r_b\right)} \frac{R_S'}{R_S}$$

- The dominant high-frequency pole is

$$\omega_{P1} \approx \frac{1}{C_i\left[r_\pi \left\| \left(\frac{R_S + r_b}{1+g_m R_E}\right)\right.\right]} = \frac{1}{\left\{C_\pi + C_\mu\left[1+g_m\left(R_C + R_E\right)\right]\right\}\left[r_\pi \left\| \left(\frac{R_S + r_b}{1+g_m R_E}\right)\right.\right]} \quad .$$

- Common-emitter amplifiers with emitter resistors have the same basic topology as the common-collector amplifier. The resultant pole location remains identical.

Common-base amplifier high-frequency response

- AC model of a simple BJT common-base amplifier is shown in Figure 8.

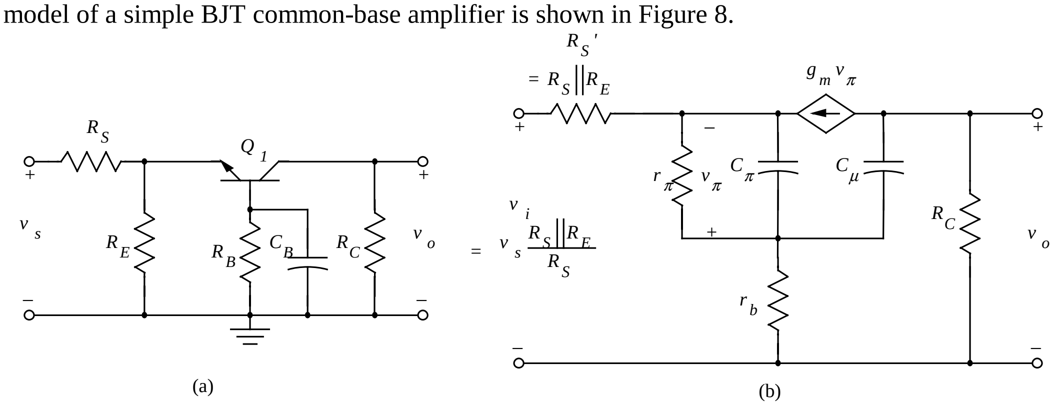


Figure 8. Common-Base Equivalent Circuits
(a) Midband AC Equivalent, (b) High-Frequency Equivalent

- Note that there are no capacitors bridging the input and output terminals: therefore, there do not exist Miller effect high valued capacitors. Therefore, the poles are at very high frequencies.
- To simplify the analysis, assume that the base current is small so the voltage across r_b is also small. Then r_b can be ignored: that is, let $r_b = 0$ and $v_e \approx -v_\pi$
- The poles are located at

$$\omega_{P1} = \frac{r_\pi + \left(1+g_m r_\pi\right)\left(R_S' \| R_E\right)}{C_\pi r_\pi \left(R_S' \| R_E\right)} \approx \frac{\beta_F}{C_\pi r_\pi} = \omega_T \quad \text{and} \quad \omega_{P2} = \frac{1}{C_\mu R_C} \quad .$$

- Both poles are at very high frequencies. Therefore, common-base amplifiers are not usually the frequency limiting elements in a multistage amplifier.