ELEG 312
Homework #9
Solutions

Problems 10.52, 10.55, 10.59, 10.63, 10.66, 10.79, and 10.84

Problem 10.52a

An amplifier with a dc gain of 60 dB has a single-pole high-frequency response with a 3-dB frequency of 100 kHz.

(a) Give an expression for the gain function $A(s)$.

(b) Sketch Bode diagrams for the gain magnitude and phase.

(c) What is the gain–bandwidth product?

(d) What is the unity-gain frequency?

(e) If a change in the amplifier circuit causes its transfer function to acquire another pole at 1 MHz, sketch the resulting gain magnitude and specify the unity-gain frequency. Note that this is an example of an amplifier with a unity-gain bandwidth that is different from its gain–bandwidth product.

$$60\text{ dB} = 10^{60/20} = 10^3 = 1000$$

$$A(s) = \frac{1000}{1 + \dfrac{s}{2\pi \cdot 100\text{ kHz}}}$$

$$A(s)=\frac{1000}{1+\dfrac{s}{2\pi\cdot 100\text{ kHz}}}$$

Problem 10.52b

zeros: $s = \infty$

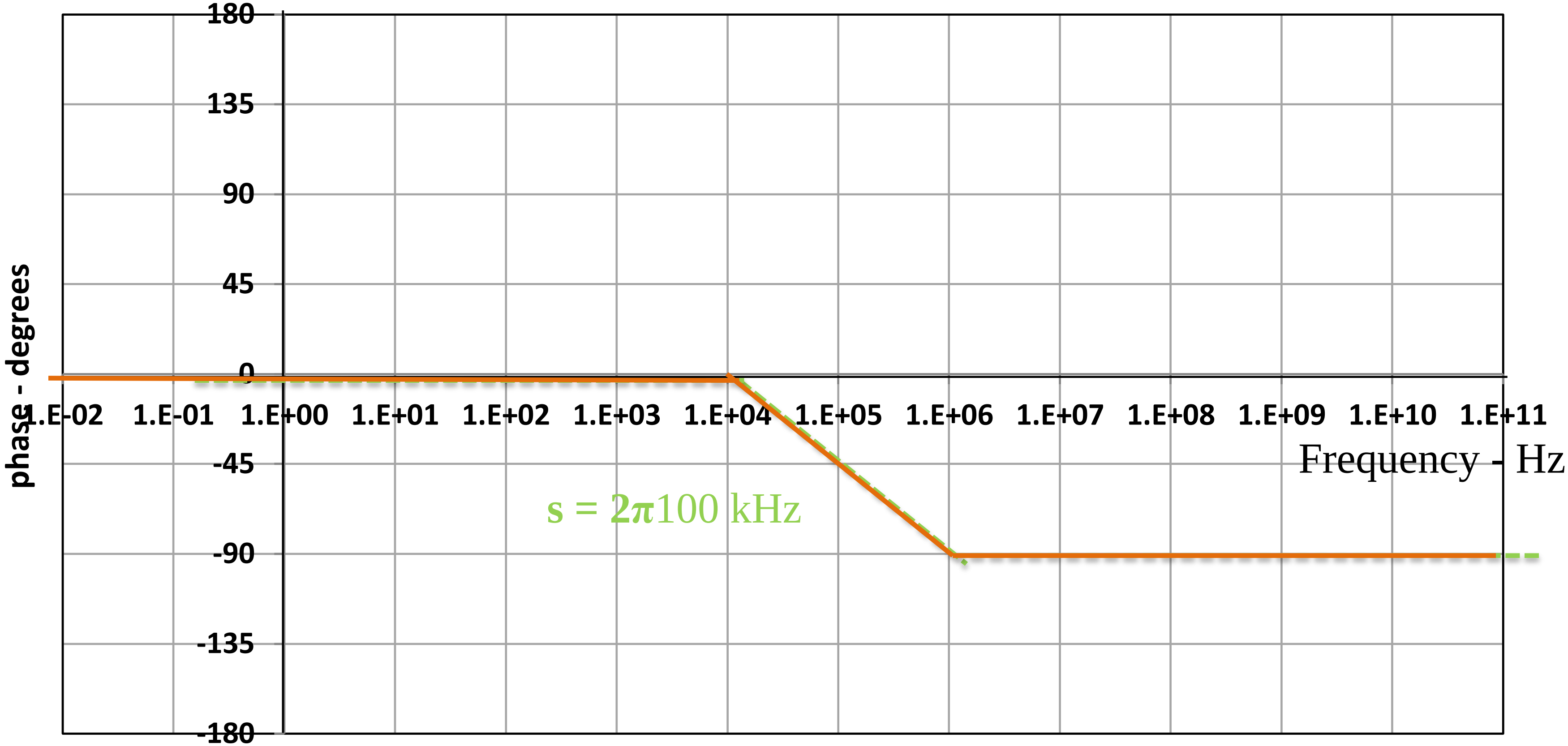
poles: $f = 100$ kHz

$$A(s) = \frac{1000}{1 + \dfrac{s}{2\pi \cdot 100\ \text{kHz}}}$$

Problem 10.52b

zeros: $s = \infty$

poles: $f = 100$ kHz



Problem 10.52c,d

An amplifier with a dc gain of 60 dB has a single-pole high-frequency response with a 3-dB frequency of 10 kHz.

(c) What is the gain–bandwidth product?

(d) What is the unity-gain frequency?

(e) If a change in the amplifier circuit causes its transfer function to acquire another pole at 1 MHz, sketch the resulting gain magnitude and specify the unity-gain frequency. Note that this is an example of an amplifier with a unity-gain bandwidth that is different from its gain–bandwidth product.

$$GB = |A_M| f_H = 1000 \text{ V/V} \times 100 \text{ kHz} = 100 \text{ MHz}$$

unity-gain frequency from the plot = 100 MHz

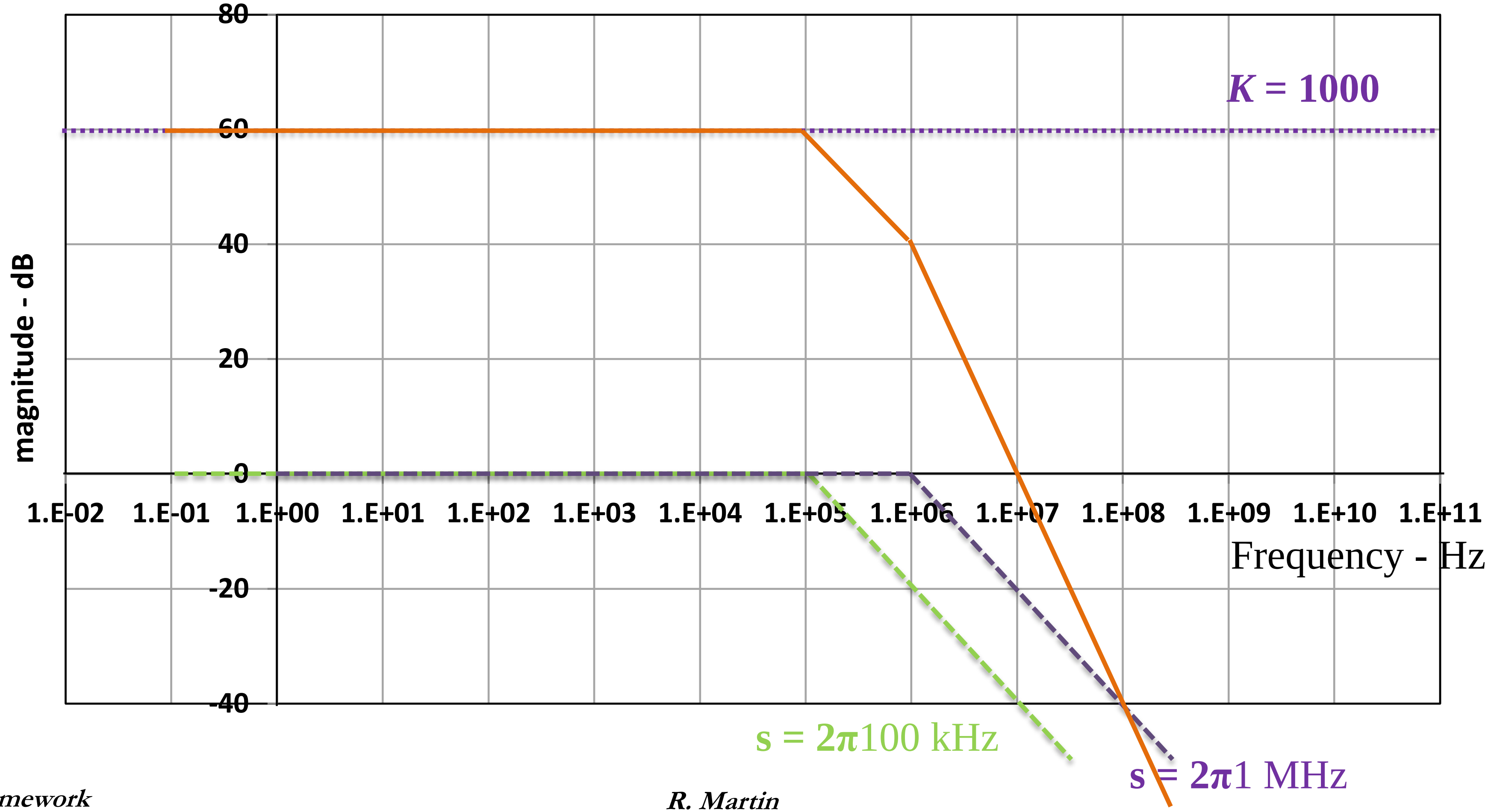
$$A_{new}(s) = \frac{1000}{\left(1 + \dfrac{s}{2\pi \cdot 100 \text{ kHz}}\right)\left(1 + \dfrac{s}{2\pi \cdot 1000 \text{ kHz}}\right)}$$

unity-gain frequency from the new plot = 10 MHz

$$A_{new}(s) = \frac{1000}{\left(1+\dfrac{s}{2\pi \cdot 100 \text{ kHz}}\right)\left(1+\dfrac{s}{2\pi \cdot 1000 \text{ kHz}}\right)}$$

Problem 10.52e

zeros: $s = \infty, \infty$ poles: $f = 100$ kHz, 1 MHz



Problem 10.55

A direct-coupled amplifier has a dominant pole at 1000 rad/s and three coincident poles at a much higher frequency. These nondominant poles cause the phase lag of the amplifier at high frequencies to exceed the 90° angle due to the dominant pole. It is required to limit the excess phase at $\omega = 10^7$ rad/s to 30° (i.e., to limit the total phase angle to −120°). Find the corresponding frequency of the nondominant poles.

$$A(s) \simeq \frac{1000}{1+\dfrac{s}{1000\ \text{rad/s}}}$$

$$\varphi(\omega) = -\tan^{-1}(\omega/\omega_0)$$

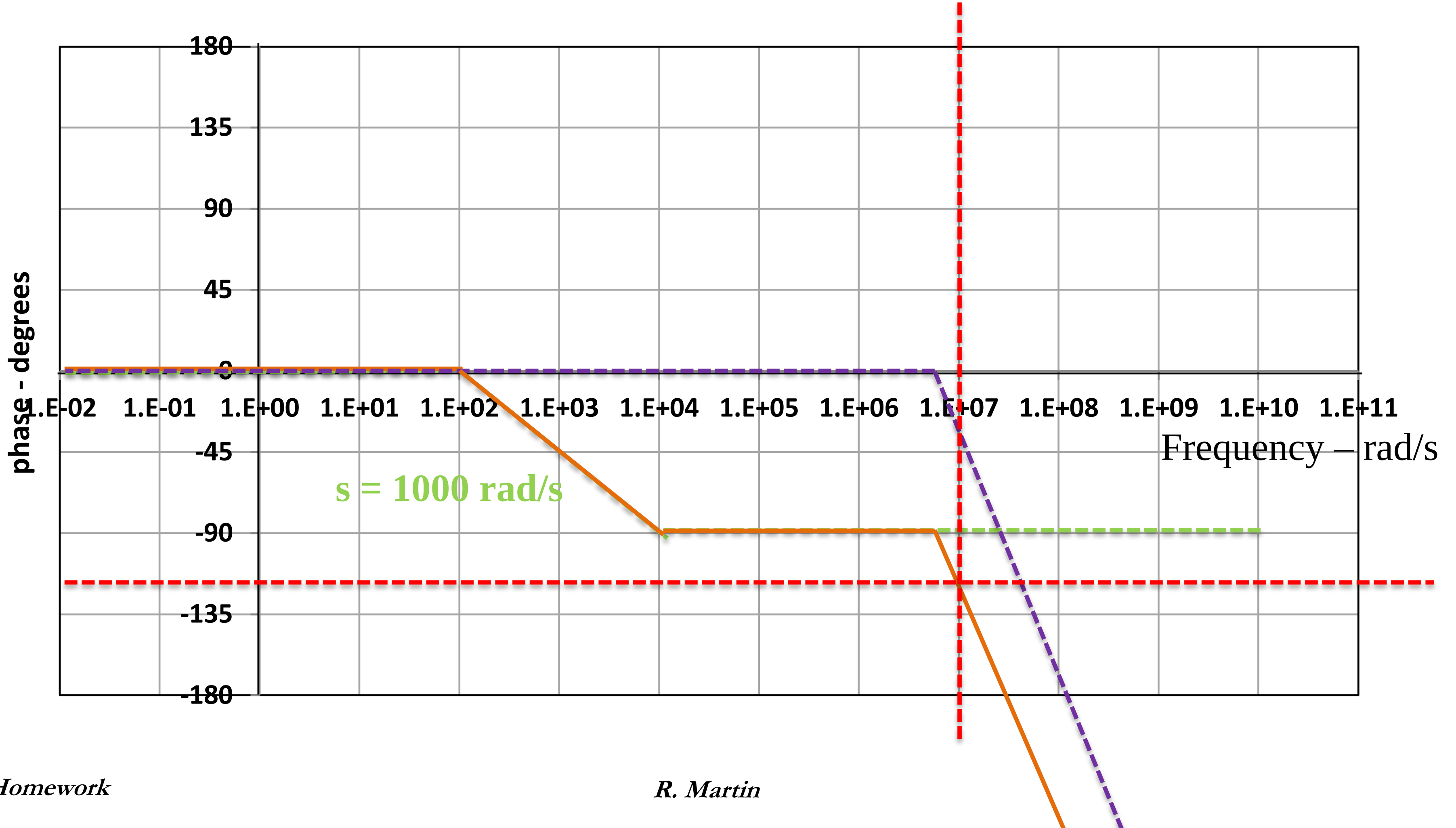
$$\varphi(10^7\ \text{rad}/s) = -3\tan^{-1}\left(\frac{10^7\ \text{rad}/s}{\omega_p}\right) = -30°$$

$$\tan^{-1}\left(\frac{10^7\ \text{rad}/s}{\omega_p}\right) = 10°$$

$$\omega_p = \frac{10^7\ \text{rad}/s}{\tan(10°)} = 5.671\times10^7\ \text{rad}/s = 56.71\ \text{Mrad}/s$$

Problem 10.55

poles: f = 1000 rad/s, (x3) 5.671×10^7 rad/sec



Problem 10.59a

A CS amplifier that can be represented by the equivalent circuit of Fig. 10.24 has C_{gs} = 2 pF, C_{gd} = 0.1 pF, C_L = 2 pF, g_m = 4 mA/V, and $R'_{sig} = R'_L$ = 20 kΩ. Find the midband gain A_M, the input capacitance C_{in} using the Miller approximation, and hence an estimate of the 3-dB frequency f_H. Also, obtain another estimate of f_H using open-circuit time constants. Which of the two estimates is more appropriate and why?

$$A_M = -\left(\frac{R_G}{R_G + R_{sig}}\right) g_m R'_L \simeq -4\text{mA/V} \times 20\text{k}\Omega = -80\text{V/V}$$

$$C_{in} = C_{gs} + C_{eq} = C_{gs} + C_{gd}\left(1 + g_m R'_L\right) = 2\text{pF} + 0.1\text{pF}\left(1 + 80\right) = 10.1\text{pF}$$

$$f_H = \frac{\omega_H}{2\pi} = \frac{1}{2\pi C_{in} R'_{sig}} = \frac{1}{2\pi\left(10.1\text{pF}\right)\left(20\text{k}\Omega\right)} = 787.9\text{kHz}$$

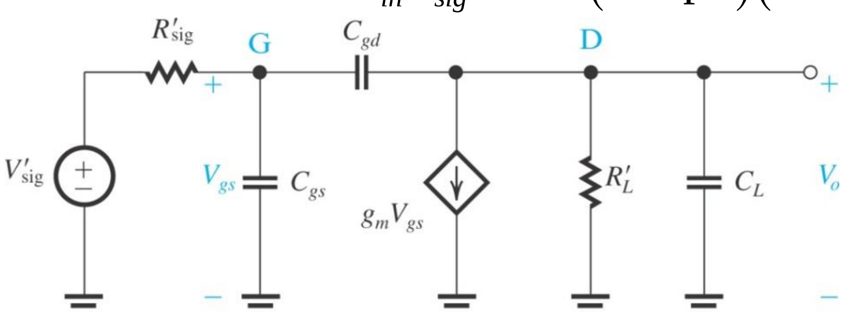


Figure 10.24 Generalized high-frequency equivalent circuit for the CS amplifier.

Problem 9.59b

A CS amplifier that can be represented by the equivalent circuit of Fig. 10.24 has C_{gs} = 2 pF, C_{gd} = 0.1 pF, C_L = 2 pF, g_m = 4 mA/V, and R'_{sig} = R'_L = 20 kΩ. Find the midband gain A_M, the input capacitance C_{in} using the Miller approximation, and hence an estimate of the 3-dB frequency f_H. Also, obtain another estimate of f_H using open-circuit time constants. Which of the two estimates is more appropriate and why?

$R_{gs\_eff} = R'_{sig} = 20\text{k}\Omega$ $\quad R_{L\_eff} = R'_L = 20\text{k}\Omega$

$$R_{gd\_eff} = R'_{sig}\left(1 + g_m R'_L\right) + R'_L = 20\text{k}\Omega \times (1+80) + 20\text{k}\Omega = 1.64\text{M}\Omega$$

$$\tau_H = C_{gs}R_{gs\_eff} + C_{gd}R_{gd\_eff} + C_L R_{L\_eff} = (2\text{pF}\times 20\text{k}\Omega) + (0.1\text{pF}\times 1.64\text{M}\Omega) + (2\text{pF}\times 20\text{k}\Omega) = 244\text{ns}$$

$$f_H \simeq \frac{1}{2\pi\tau_H} = \frac{1}{2\pi 244\text{ns}} = 652.3\text{kHz}$$

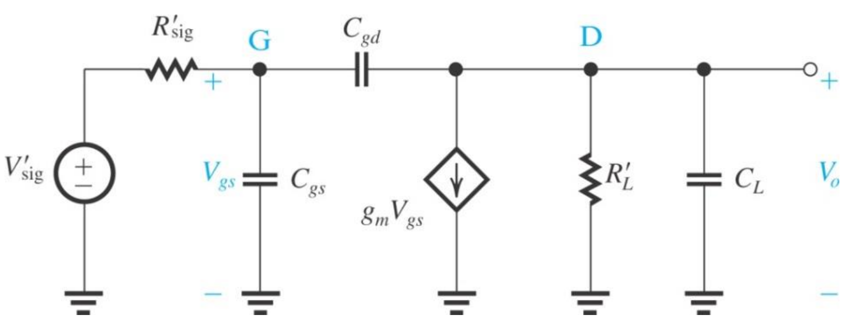


Figure 10.24 Generalized high-frequency equivalent circuit for the CS amplifier.

Problem 9.59c

A CS amplifier that can be represented by the equivalent circuit of Fig. 10.24 has C_{gs} = 2 pF, C_{gd} = 0.1 pF, C_L = 2 pF, g_m = 4 mA/V, and $R'_{sig} = R'_L$ = 20 kΩ. Find the midband gain A_M, the input capacitance C_{in} using the Miller approximation, and hence an estimate of the 3-dB frequency f_H. Also, obtain another estimate of f_H using open-circuit time constants. Which of the two estimates is more appropriate and why?

Miller approximation: $$f_H = \frac{1}{2\pi C_{in} R'_{sig}} = 787.9\text{kHz}$$

Open Circuit TCs: $$f_H = \frac{1}{2\pi \tau_H} = 652.3\text{kHz}$$

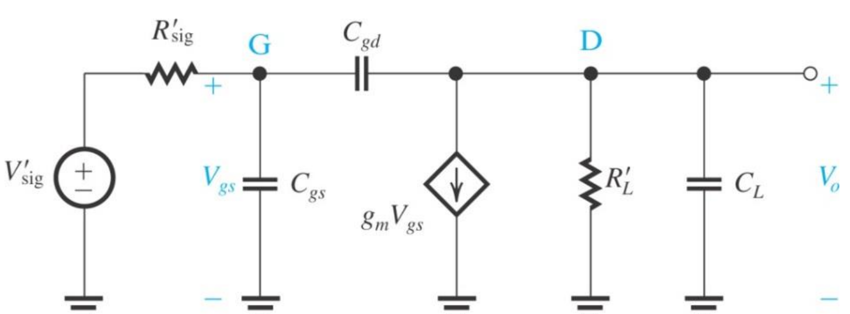


Figure 10.24 Generalized high-frequency equivalent circuit for the CS amplifier.

The estimate obtained using the open-circuit time constants is more appropriate as it takes into account the effect of C_L.We note that τ_{CL} is 16.4% of τ_H , thus C_L has a significant effect on the determination of f_H .

Problem 10.63a

A common-emitter amplifier has C_π = 10 pF, C_μ = C_L = 0.3 pF, g_m = 40 mA/V, β = 100, r_x = 100Ω, R'_L = 5 kΩ, and R_{sig} = 1kΩ. Find the midband gain A_M, and an estimate of the 3-dB frequency f_H using the Miller approximation. Also, obtain another estimate of f_H using open-circuit time constants. Which of the two estimates would you consider to be more realistic, and why?

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{40\text{mA/V}} = 2.5\text{k}\Omega$$

$$A_M = \frac{V_o}{V_{sig}} = -\frac{R_B}{R_B + R_{sig}} \frac{r_\pi}{r_\pi + r_x + \left(R_{sig} \,||\, R_B\right)}\left(g_m R'_L\right)$$

If R_B (unspecified) is assumed to be very large then:

$$A_M = -\frac{r_\pi}{r_\pi + r_x + R_{sig}}\left(g_m R'_L\right)$$

$$A_M = -\frac{2.5\text{k}\Omega}{2.5\text{k}\Omega + 100\Omega + 1\text{k}\Omega}\left(40\text{mA/V} \times 5\text{k}\Omega\right) = -138.9\text{V/V}$$

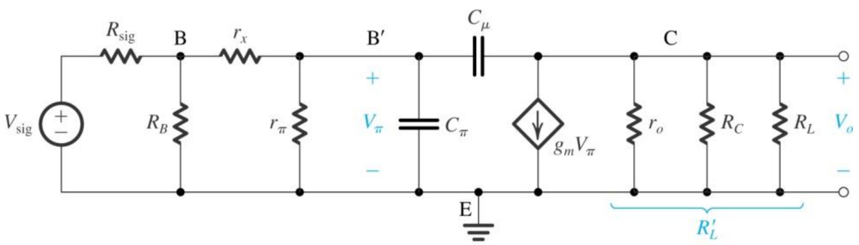


Figure 10.19 Determining the high-frequency response of the CE amplifier: **(a)** equivalent circuit

Problem 10.63b

A common-emitter amplifier has C_π = 10 pF, C_μ = C_L = 0.3 pF, g_m = 40 mA/V, β = 100, r_x = 100Ω, R'_L = 5 kΩ, and R_{sig} = 1kΩ. Find the midband gain A_M, and an estimate of the 3-dB frequency f_H using the Miller approximation. Also, obtain another estimate of f_H using open-circuit time constants. Which of the two estimates would you consider to be more realistic, and why?

$$R'_{sig} = \left(R_{sig} + r_x\right) || r_\pi = \frac{(1\text{k}\Omega + 0.1\text{k}\Omega) \times 2.5\text{k}\Omega}{(1\text{k}\Omega + 0.1\text{k}\Omega) + 2.5\text{k}\Omega} = 763.9\Omega$$

$$C_{in} = C_\pi + C_\mu\left(1 + g_m R'_L\right) = 10\text{pF} + 0.3\text{pF}(1 + 200) = 70.3\text{pF}$$

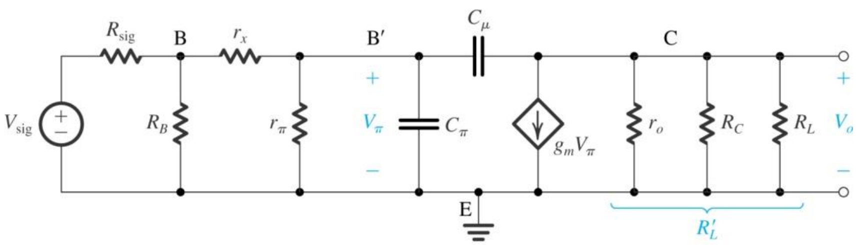


Figure 10.19 Determining the high-frequency response of the CE amplifier: **(a)** equivalent circuit

$$f_H = \frac{1}{2\pi C_{in} R'_{sig}} = 2.96\text{MHz}$$

Problem 10.63c

A common-emitter amplifier has C_π = 10 pF, C_μ = C_L = 0.3 pF, g_m = 40 mA/V, β = 100, r_x = 100Ω, R'_L = 5 kΩ, and R_{sig} = 1kΩ. Find the midband gain A_M, and an estimate of the 3-dB frequency f_H using the Miller approximation. Also, obtain another estimate of f_H using open-circuit time constants. Which of the two estimates would you consider to be more realistic, and why?

$$R_\pi = R'_{sig} = 763.9\Omega \qquad R_\mu = R'_{sig}\left(1+g_m R'_L\right)+R'_L = 763.9\Omega\left(1+200\right)+5\text{k}\Omega = 158.54\text{k}\Omega$$

$$R_{C_L} = R'_L = 5\text{k}\Omega$$

$$\tau_H = C_\pi R_\pi + C_\mu R_\mu + C_L R_{C_L} = \left(10\text{pF}\times 763.9\Omega\right)+\left(0.3\text{pF}\times 158.54\text{k}\Omega\right)+\left(0.3\text{pF}\times 5\text{k}\Omega\right) = 69.9\text{ns}$$

$$f_H = \frac{1}{2\pi\tau_H} = \frac{1}{2\pi\left(69.9\text{ns}\right)} = 2.28\text{MHz}$$

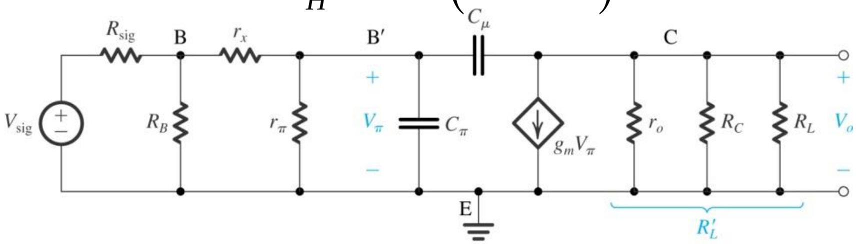


Figure 10.19 Determining the high-frequency response of the CE amplifier: **(a)** equivalent circuit

Problem 10.63d

A common-emitter amplifier has C_π = 10 pF, $C_\mu = C_L$ = 0.3 pF, g_m = 40 mA/V, β = 100, r_x = 100Ω, R'_L = 5 kΩ, and R_{sig} = 1kΩ. Find the midband gain A_M, and an estimate of the 3-dB frequency f_H using the Miller approximation. Also, obtain another estimate of f_H using open-circuit time constants. Which of the two estimates would you consider to be more realistic, and why?

Miller approximation:

$$f_H = \frac{1}{2\pi C_{in} R'_{sig}} = 2.96\text{MHz}$$

Open Circuit TCs:

$$f_H = \frac{1}{2\pi\tau_H} = \frac{1}{2\pi\left(69.9\text{ns}\right)} = 2.28\text{MHz}$$

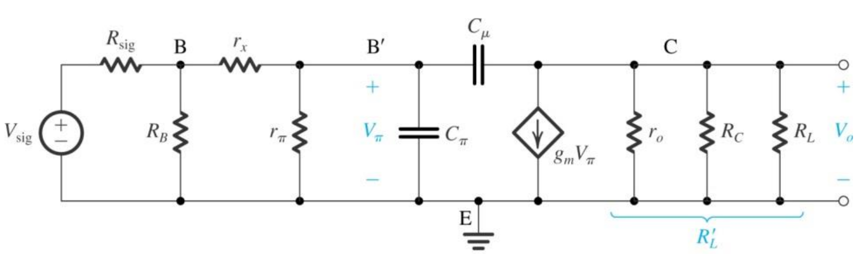
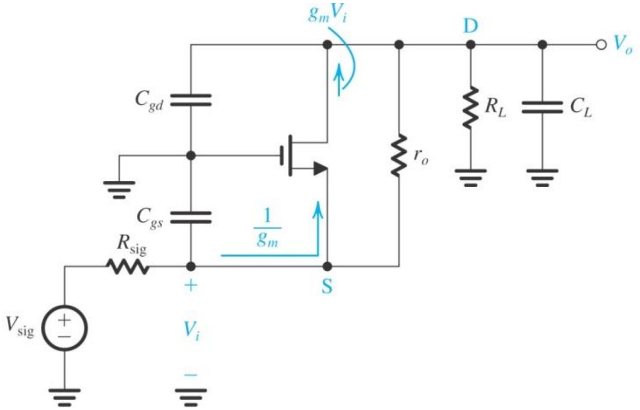


Figure 10.19 Determining the high-frequency response of the CE amplifier: **(a)** equivalent circuit

OCTC method is a more realistic estimate of f_H as it takes into account the effect of C_L.

Problem 10.66

A CG amplifier is specified to have C_{gs} = 4 pF, C_{gd} = 0.2 pF, C_L = 2 pF, g_m = 5 mA/V, and R_{sig} = 1 kΩ, R_L = 10 kΩ. Neglecting the effects of r_o find the low-frequency gain V_o/V_{sig}, the frequencies of the poles f_{P1} and f_{P2}, and hence an estimate of the 3-dB frequency f_H.



$$\frac{V_o}{V_{sig}} = \frac{R_L}{R_{sig} + R_{in}} = \frac{R_L}{R_{sig} + 1/g_m} = \frac{10\text{k}\Omega}{1\text{k}\Omega + 0.2\text{k}\Omega} = 8.33\text{V/V}$$

$$f_{P1} = \frac{1}{2\pi C_{gs}\left(R_{sig} \,||\, \frac{1}{g_m}\right)} = 239\text{MHz}$$

$$f_{P2} = \frac{1}{2\pi\left(C_{gd} + C_L\right)R_L'} = 7.23\text{MHz}$$

$$f_H \simeq f_{P2} = 7.23\text{MHz}$$

Problem 10.79a

A source follower has g_m = 5 mA/V, r_o = 20 kΩ, R_{sig} = 20 kΩ, R_L = 2 kΩ, C_{gs} = 2 pF, C_{gd} = 0.1 pF, and C_L = 1 pF. Find A_M, R_o, f_Z, the frequencies of the two poles, and an estimate of f_H.

$$R_o = \frac{1}{g_m} \,||\, r_o = \frac{1}{5\text{mA/V}} \,||\, 20\text{k}\Omega = 198.0\Omega$$

$$R_L' = R_L \,||\, r_o \,||\, \frac{1}{g_{mb}} \simeq 2\text{k}\Omega \,||\, 20\text{k}\Omega = 1.818\text{k}\Omega$$

$$A_M = \frac{R_L'}{R_L' + (1/g_m)} = \frac{1.818\text{k}\Omega}{1.818\text{k}\Omega + \dfrac{1}{5\text{mA/V}}} = 0.90\text{V/V}$$

$$g_m R_L' = (5\text{mA/V})1.818\text{k}\Omega = 9.091\frac{\text{V}}{\text{V}}$$

$$f_Z = \frac{g_m}{2\pi C_{gs}} = \frac{5\text{mA/V}}{2\pi(2\text{pF})} = 397.9\text{MHz}$$

$$b_1 = \left(C_{gd} + \frac{C_{gs}}{g_m R_L' + 1}\right) R_{sig} + \left(\frac{C_{gs} + C_L}{g_m R_L' + 1}\right) R_L'$$

$$= \left(0.1\text{pF} + \frac{2\text{pF}}{9.1+1}\right) 20\text{k}\Omega + \left(\frac{2\text{pF} + 1\text{pF}}{9.1+1}\right) 1.818\text{k}\Omega$$

$$= 6.505\text{ns}$$

$$b_2 = \frac{(C_{gs} + C_{gd})C_L + C_{gs}C_{gd}}{g_m R_L' + 1} R_{sig} R_L'$$

$$= \frac{(2\text{pF}+0.1\text{pF})(1\text{pF}) + (2\text{pF})(0.1\text{pF})}{9.1+1} 20\text{k}\Omega(1.818\text{k}\Omega)$$

$$= 8.288 \times 10^{-18}\text{s}^2$$

Problem 10.79b

A source follower has g_m = 5 mA/V, r_o = 20 kΩ, R_{sig} = 20 kΩ, R_L = 2 kΩ, C_{gs} = 2 pF, C_{gd} = 0.1 pF, and C_L = 1 pF. Find A_M, R_o, f_Z, the frequencies of the two poles, and an estimate of f_H.

$$b_1 = 6.505\text{ns} \qquad b_2 = 8.288\times10^{-18}\text{s}^2 \qquad Q = \frac{\sqrt{b_2}}{b_1} = \frac{\sqrt{8.22(\text{ns})^2}}{6.505\text{ns}} = \frac{\sqrt{8.22}}{6.505} = 0.443$$

$Q < 0.5$ therefore the poles are real – need to find the roots of :

$$1 + b_1 s + b_2 s^2 = \left(1 + \frac{s}{\omega_{P1}}\right)\left(1 + \frac{s}{\omega_{P2}}\right)$$

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \Rightarrow s_{P1} = \frac{-b_1 + \sqrt{b_1^2 - 4b_2}}{2b_2} = -2.099\times10^8 \frac{\text{rad}}{\text{s}}$$

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \Rightarrow s_{P2} = \frac{-b_1 - \sqrt{b_1^2 - 4b_2}}{2b_2} = -5.749\times10^8 \frac{\text{rad}}{\text{s}}$$

$$f_{P1} = \frac{\omega_{P1}}{2\pi} = \frac{2.099\times10^8 \frac{\text{rad}}{\text{s}}}{2\pi} = 33.4\text{MHz} \qquad f_{P2} = \frac{\omega_{P2}}{2\pi} = \frac{5.749\times10^8 \frac{\text{rad}}{\text{s}}}{2\pi} = 91.502\text{MHz}$$

Problem 10.79c

A source follower has g_m = 5 mA/V, r_o = 20 kΩ, R_{sig} = 20 kΩ, R_L = 2 kΩ, C_{gs} = 2 pF, C_{gd} = 0.1 pF, and C_L = 1 pF. Find A_M, R_o, f_Z, the frequencies of the two poles, and an estimate of f_H.

$$f_Z = \frac{g_m}{2\pi C_{gs}} = \frac{5\text{mA/V}}{2\pi(2\text{pF})} = 397.9\text{MHz}$$

$$f_{P1} = \frac{\omega_{P1}}{2\pi} = \frac{2.099\times10^8 \frac{\text{rad}}{\text{s}}}{2\pi} = 33.4\text{MHz}$$

$$f_{P2} = \frac{\omega_{P2}}{2\pi} = \frac{5.749\times10^8 \frac{\text{rad}}{\text{s}}}{2\pi} = 91.502\text{MHz}$$

Neither pole is dominant (> than a factor of 4 lower in frequency) therefore

$$f_H = \frac{1}{\sqrt{\frac{1}{f_{P1}^2} + \frac{1}{f_{P2}^2} - \frac{1}{f_Z^2}}} = 31.473\text{MHz}$$

Problem 10.84a

For an emitter follower biased at I_C = 1mA and having R_{sig} = R_L = 1 kΩ, and using a transistor specified to have f_T = 2 GHz, C_μ = 0.1 pF, r_x = 100 Ω, β = 100, and V_A = 20 V, evaluate the low-frequency gain A_M, the frequency of the transmission zero, the pole frequencies, and an estimate of the 3-dB frequency f_H.

$$g_m = \frac{I_C}{V_T} = \frac{1\text{mA}}{25\text{mV}} = 40\text{mA/V}$$

$$r_\pi = \frac{\beta}{g_m} = \frac{100}{40\text{mA/V}} = 2.5\text{k}\Omega$$

$$r_o = \frac{V_A}{I_C} = \frac{20\text{V}}{1\text{mA}} = 20\text{k}\Omega$$

$$r_e = \frac{r_\pi}{(\beta+1)} = \frac{2.5\text{k}\Omega}{101} = 24.75\Omega \simeq 25\Omega$$

$$R_L' = R_L \,||\, r_o = 1\text{k}\Omega \,||\, 20\text{k}\Omega = 952\Omega$$

$$R_{sig}' = R_{sig} + r_x = 1.1\text{k}\Omega$$

$$A_M = \frac{R_L'}{\dfrac{R_{sig}+r_\pi+r_x}{\beta+1} + R_L'} = \frac{952\Omega}{\dfrac{1\text{k}\Omega + 2.5\text{k}\Omega + 100\Omega}{100+1} + 952\Omega}$$

$$= 0.964\text{V/V}$$

Problem 10.84b

For an emitter follower biased at I_C = 1mA and having R_{sig} = R_L = 1 kΩ, and using a transistor specified to have f_T = 2 GHz, C_μ = 0.1 pF, r_x = 100 Ω, β = 100, and V_A = 20 V, evaluate the low-frequency gain A_M , the frequency of the transmission zero, the pole frequencies, and an estimate of the 3-dB frequency f_H.

$$f_T = \frac{g_m}{2\pi\left(C_\pi + C_\mu\right)} \quad \Rightarrow C_\pi + C_\mu = \frac{g_m}{2\pi f_T} = \frac{40\text{mA/V}}{2\pi 2\text{GHz}} = 3.183\text{pF}$$

$$C_\pi = 3.083\text{pF}$$

$$C_L = 0\text{pF}$$

$$f_Z = \frac{1}{2\pi C_\pi r_e} = \frac{1}{2\pi\left(3.083\text{pF}\right)25\Omega} = 2.065\text{GHz}$$

$$b_1 = \frac{\left[C_\pi + C_\mu\left(1 + \frac{R_L'}{r_e}\right)\right]R_{sig}' + \left[C_\pi + C_L\left(1 + \frac{R_{sig}'}{r_\pi}\right)\right]R_L'}{1 + \frac{R_L'}{r_e} + \frac{R_{sig}'}{r_\pi}} = 2.688\times10^{-10}\text{s}$$

$$b_2 = \frac{\left[\left(C_\pi + C_\mu\right)C_L + C_\pi C_\mu\right]R_L' R_{sig}'}{1 + \frac{R_L'}{r_e} + \frac{R_{sig}'}{r_\pi}} = 8.17\times10^{-21}\text{s}^2$$

Problem 10.84c

For an emitter follower biased at I_C = 1mA and having R_{sig} = R_L = 1 kΩ, and using a transistor specified to have f_T = 2 GHz, C_μ = 0.1 pF, r_x = 100 Ω, β = 100, and V_A = 20 V, evaluate the low-frequency gain A_M , the frequency of the transmission zero, the pole frequencies, and an estimate of the 3-dB frequency f_H.

$$b_1 = 2.688\times10^{-10}\text{s} \qquad b_2 = 8.17\times10^{-21}\text{s}^2 \qquad Q = \frac{\sqrt{b_2}}{b_1} = \frac{\sqrt{.00817(\text{ns})^2}}{0.296\text{ns}} = 0.336$$

$Q < 0.5$ therefore the poles are real – need to find the roots of :

$$1 + b_1 s + b_2 s^2 = \left(1 + \frac{s}{\omega_{P1}}\right)\left(1 + \frac{s}{\omega_{P2}}\right)$$

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \Rightarrow s_{P1} = \frac{-b_1 + \sqrt{b_1^2 - 4b_2}}{2b_2} = -4.275\times10^9 \frac{\text{rad}}{\text{s}}$$

$$\frac{-b \pm \sqrt{b^2 - 4ac}}{2a} \Rightarrow s_{P2} = \frac{-b_1 - \sqrt{b_1^2 - 4b_2}}{2b_2} = -2.863\times10^{10} \frac{\text{rad}}{\text{s}}$$

$$f_{P1} = \frac{\omega_{P1}}{2\pi} = \frac{4.275\times10^9 \frac{\text{rad}}{\text{s}}}{2\pi} = 680.442\text{MHz} \qquad f_{P2} = \frac{\omega_{P2}}{2\pi} = \frac{2.863\times10^{10} \frac{\text{rad}}{\text{s}}}{2\pi} = 4.557\text{GHz}$$

Problem 10.84d

For an emitter follower biased at I_C = 1mA and having R_{sig} = R_L = 1 kΩ, and using a transistor specified to have f_T = 2 GHz, C_μ = 0.1 pF, r_x = 100 Ω, β = 100, and V_A = 20 V, evaluate the low-frequency gain A_M , the frequency of the transmission zero, the pole frequencies, and an estimate of the 3-dB frequency f_H.

$$f_Z = \frac{1}{2\pi C_\pi r_e} = \frac{1}{2\pi(3.083\text{pF})25\Omega} = 2.065\text{GHz}$$

$$f_{P1} = \frac{\omega_{P1}}{2\pi} = \frac{4.275\times10^9 \frac{\text{rad}}{\text{s}}}{2\pi} = 680.442\text{MHz}$$

$$f_{P2} = \frac{\omega_{P2}}{2\pi} = \frac{2.863\times10^{10} \frac{\text{rad}}{\text{s}}}{2\pi} = 4.557\text{GHz}$$

pole 1 is dominant (> than a factor of 4 lower in frequency) therefore

$$f_H \simeq f_{P1} = 680.442\text{MHz}$$