ELEG 312
Homework #8
Solutions

Problems 10.29, 10.32, 10.34, and 10.39

Problem 10.29a

A design is required for a CS amplifier for which the MOSFET is operated at g_m = 5 mA/V and has C_{gs} = 5 pF and C_{gd} = 1 pF. The amplifier is fed with a signal source having R_{sig} = 1 kΩ, and R_G is very large. What is the largest value of R'_L for which the upper 3-dB frequency is at least 6 MHz? What is the corresponding value of midband gain and gain–bandwidth product? If the specification on the upper 3-dB frequency can be relaxed by a factor of 3, that is, to 2MHz, what can A_M and GB become?

$$R'_{sig} = R_{sig} \,||\, R_G \simeq R_{sig} = 1\text{k}\Omega$$

$$R'_L = r_o \,||\, R_D \,||\, R_L$$

$$f_H = \frac{1}{2\pi C_{in} R'_{sig}} = \frac{1}{2\pi C_{in} 1\text{k}\Omega} \geq 6\text{MHz}$$

$$C_{in} \leq \frac{1}{2\pi f_H R'_{sig}} = \frac{1}{2\pi \times 6\text{MHz} \times 1\text{k}\Omega} = 26.5\text{pF}$$

$$C_{in} = C_{gs} + C_{eq} = C_{gs} + C_{gd}\left(1 + g_m R'_L\right)$$

$$R'_L \leq \frac{\dfrac{C_{in} - C_{gs}}{C_{gd}} - 1}{g_m} = \frac{\dfrac{26.5\text{pF} - 5\text{pF}}{1\text{pF}} - 1}{5\text{mA/V}} = 4.1\text{k}\Omega$$

Problem 10.29b

A design is required for a CS amplifier for which the MOSFET is operated at g_m = 5 mA/V and has C_{gs} = 5 pF and C_{gd} = 1 pF. The amplifier is fed with a signal source having R_{sig} = 1 kΩ, and R_G is very large. What is the largest value of R'_L for which the upper 3-dB frequency is at least 6 MHz? What is the corresponding value of midband gain and gain–bandwidth product? If the specification on the upper 3-dB frequency can be relaxed by a factor of 3, that is, to 2MHz, what can A_M and GB become?

$$R'_{sig} = 1\text{k}\Omega$$

$$R'_L = 4.1\text{k}\Omega \qquad A_M = -g_m R'_L = 5\text{ mA/V} \times 4.1\text{ k}\Omega = -20.5\text{ V/V}$$

$$C_{in} = 26.5\text{pF}$$

$$GB = |A_M| f_H = 20.5\text{ V/V} \times 6\text{ MHz} = 123\text{ MHz}$$

Problem 10.29c

A design is required for a CS amplifier for which the MOSFET is operated at g_m = 5 mA/V and has C_{gs} = 5 pF and C_{gd} = 1 pF. The amplifier is fed with a signal source having R_{sig} = 1 kΩ, and R_G is very large. What is the largest value of R'_L for which the upper 3-dB frequency is at least 6 MHz? What is the corresponding value of midband gain and gain–bandwidth product? If the specification on the upper 3-dB frequency can be relaxed by a factor of 3, that is, to 2MHz, what can A_M and GB become?

$$f_H = \frac{1}{2\pi C_{in} R'_{sig}} \geq \frac{6\text{ MHz}}{3} = 2\text{ MHz}$$

$$C_{in} = 3\times 26.5\text{ pF} = 79.5\text{ pF}$$

$$R'_L \leq \frac{\dfrac{C_{in}-C_{gs}}{C_{gd}} - 1}{g_m} = \frac{\dfrac{79.5\text{pF}-5\text{pF}}{1\text{pF}} - 1}{5\text{mA/V}} = 14.7\text{k}\Omega$$

$$A_M = -g_m R'_L = 5\text{ mA/V}\times 14.7\text{ k}\Omega = -73.5\text{ V/V}$$

$$GB = |A_M|\, f_H = 73.5\text{ V/V}\times 2\text{ MHz} = 147\text{ MHz}$$

Problem 10.32a,b

A discrete MOSFET common-source amplifier has R_G = 2 MΩ, g_m = 5 mA/V, r_o = 100 kΩ, R_D = 20 kΩ, C_{gs} = 3 pF, and C_{gd} = 0.5 pF. The amplifier is fed from a voltage source with an internal resistance of 500 kΩ and is connected to a 20-kΩ load. Find:

(a) the overall midband gain A_M

$$R_L' = r_o \,||\, R_D \,||\, R_L = 100\text{k}\Omega \,||\, 20\text{k}\Omega \,||\, 20\text{k}\Omega = 9.1\text{k}\Omega$$

$$A_M = -\left(\frac{R_G}{R_G + R_{sig}}\right)(g_m R_L') = -\left(\frac{2\text{M}\Omega}{2\text{M}\Omega + 500\text{k}\Omega}\right)(5\text{mA/V} \times 9.1\text{k}\Omega) = -36.4\text{V/V}$$

(b) the upper 3-dB frequency f_H

$$R_{sig}' = R_{sig} \,||\, R_G = 500\text{k}\Omega \,||\, 2000\text{k}\Omega = 400\text{k}\Omega$$

$$C_{in} = C_{gs} + C_{gd}\left(1 + g_m R_L'\right) = 3\text{pF} + 0.5\text{pF}\left(1 + 5\text{mA/V} \times 9.1\text{k}\Omega\right) = 26.25\text{pF}$$

$$f_H = \frac{\omega_H}{2\pi} = \frac{1}{2\pi C_{in} R_{sig}'} = 15.2\text{kHz}$$

(c) the frequency of the transmission zero, f_Z.

Problem 10.32c

A discrete MOSFET common-source amplifier has R_G = 2 MΩ, g_m = 5 mA/V, r_o = 100 kΩ, R_D = 20 kΩ, C_{gs} = 3 pF, and C_{gd} = 0.5 pF. The amplifier is fed from a voltage source with an internal resistance of 500 kΩ and is connected to a 20-kΩ load. Find:

(c) the frequency of the transmission zero, f_Z.

$$f_Z = \frac{g_m}{2\pi C_{gd}} = \frac{5\text{mA/V}}{2\pi(0.5\text{pF})} = 1.6\text{GHz}$$

Problem 10.34a

Consider the integrated-circuit CS amplifier in Fig. P10.34 for the case I_{BIAS} = 100 μA, Q_2 and Q_3 are matched, and R_{sig} = 200 kΩ. For Q_1: $\mu_n C_{ox}$ = 90 μA/V^2, V_A = 12.8 V, W/L = 100 μm/1.6 μm, C_{gs} = 0.2 pF, and C_{gd} = 0.015 pF. For Q_2: $|V_A|$ = 19.2 V. Neglecting the effect of the capacitance inevitably present at the output node, find the low-frequency gain, the 3-dB frequency f_H, and the frequency of the zero f_Z.

$$I_{D1} = I_{D2} = I_{D3} = I_{BIAS} = I_D = 0.1\text{mA}$$

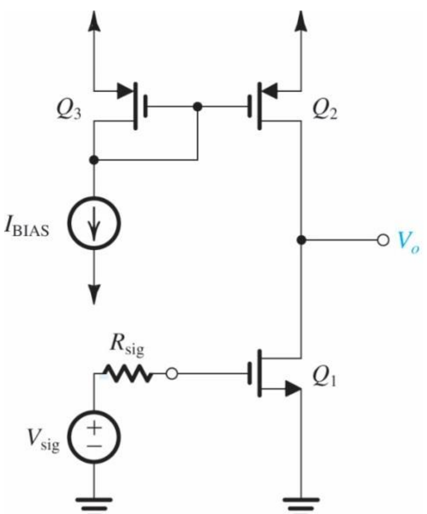

Figure P10.34

$$V_{OV1} = \sqrt{\frac{2I_D}{\mu_n C_{ox}(W/L)}} = \sqrt{\frac{2(0.1\text{mA})}{0.09\frac{\text{mA}}{\text{V}^2}\left(\frac{100\mu\text{m}}{1.6\mu\text{m}}\right)}} = 0.189\frac{\text{mA}}{\text{V}}$$

$$g_{m1} = \frac{2I_D}{V_{OV1}} = \frac{2(0.1\text{mA})}{0.189\text{V}} = 1.06\frac{\text{mA}}{\text{V}}$$

$$g_{m1} = \frac{2I_D}{V_{OV1}} = 2I_D\sqrt{\frac{\mu_n C_{ox}(W/L)}{2I_D}} = \sqrt{\frac{4I_D^2\mu_n C_{ox}(W/L)}{2I_D}} = \sqrt{2I_D\mu_n C_{ox}(W/L)} = 1.06\frac{\text{mA}}{\text{V}}$$

$$r_{o1} = \frac{V_{A1}}{I_D} = \frac{12.8\text{V}}{0.1\text{mA}} = 128\text{k}\Omega \qquad r_{o2} = \frac{|V_{A2}|}{I_D} = \frac{19.2\text{V}}{0.1\text{mA}} = 192\text{k}\Omega$$

Problem 10.34b

Consider the integrated-circuit CS amplifier in Fig. P10.34 for the case I_{BIAS} = 100 μA, Q_2 and Q_3 are matched, and R_{sig} = 200 kΩ. For Q_1: $\mu_n C_{ox}$ = 90 μA/V^2, V_A = 12.8 V, W/L = 100 μm/1.6 μm, C_{gs} = 0.2 pF, and C_{gd} = 0.015 pF. For Q_2: $|V_A|$ = 19.2 V. Neglecting the effect of the capacitance inevitably present at the output node, find the low-frequency gain, the 3-dB frequency f_H, and the frequency of the zero f_Z.

$$I_{D1} = I_{D2} = I_{D3} = I_{BIAS} = I_D = 0.1\text{mA}$$

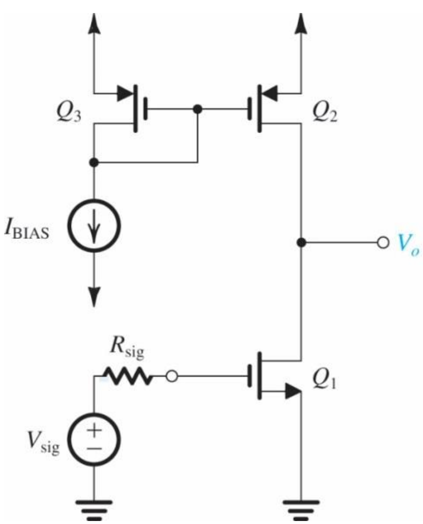

Figure P10.34

$$R_L' = r_{o1} \| r_{02} = 128\text{k}\Omega \| 192\text{k}\Omega = 76.8\text{k}\Omega$$

$$A_M = -g_{m1} R_L' = -\left(1.06\frac{\text{mA}}{\text{V}}\right) 76.8\text{k}\Omega = -81.46\frac{\text{V}}{\text{V}}$$

$$C_{in} = C_{gs} + C_{gd}\left(1 + g_{m1} R_L'\right) = 0.2\text{pF} + 0.015\text{pF}(1 + 81.46) = 1.437\text{pF}$$

$$R_{sig}' = R_{sig} = 200\text{k}\Omega$$

$$f_H = \frac{1}{2\pi C_{in} R_{sig}'} = 553.82\text{kHz}$$

$$f_Z = \frac{g_m}{2\pi C_{gd}} = \frac{1.06\text{mA/V}}{2\pi\left(0.015\text{pF}\right)} = 11.25\text{GHz}$$

Problem 10.39

For a version of the CE amplifier circuit in Fig. 10.9(a), R_{sig} = 10 kΩ, R_{B1} = 68 kΩ, R_{B2} = 27 kΩ, R_E = 2.2 kΩ, R_C = 4.7 kΩ, and R_L = 10 kΩ. The collector current is 0.8 mA, β = 200, f_T = 1 GHz, and C_μ = 0.8 pF. Neglecting the effect of r_x and r_o, find the midband voltage gain and the upper 3-dB frequency f_H.

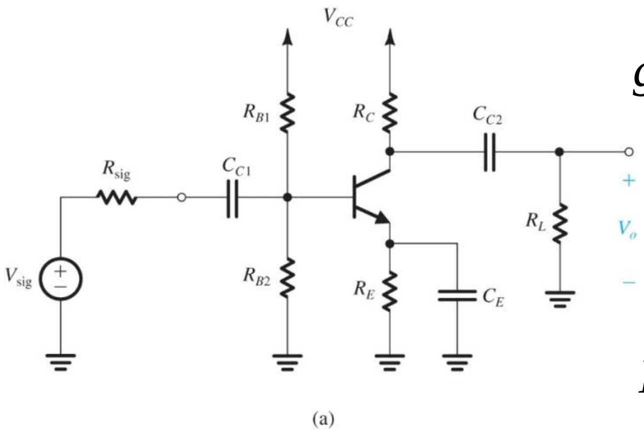

Figure 10.9 (**a**) A discrete-circuit common-emitter amplifier.

$$g_m = \frac{I_C}{V_T} = \frac{0.8\text{mA}}{25\text{mV}} = 32\text{mA/V} \qquad r_\pi = \frac{\beta}{g_m} = \frac{200}{32\text{mA/V}} = 6.25\text{k}\Omega$$

$$R_{in} = r_\pi \,||\, R_{B1} \,||\, R_{B2} = 4.72\text{k}\Omega$$

$$R'_{sig} = R_{in} \,||\, R_{sig} = 3.2\text{k}\Omega$$

$$R'_L = r_o \,||\, R_C \,||\, R_L = R_C \,||\, R_L = 3.2\text{k}\Omega$$

$$A_M = \frac{V_o}{V_{sig}} = -\frac{R_{in}}{R_{in}+R_{sig}}\left(g_m R'_L\right) = -32.8\text{V/V}$$

$$C_\pi = \frac{g_m}{2\pi f_T} - C_\mu = \frac{32\text{mA/V}}{2\pi \times 1\text{GHz}} - 0.8\text{pF} = 4.3\text{pF}$$

$$C_{in} = C_\pi + C_{eq} = C_\pi + C_\mu\left(1 + g_m R'_L\right) = 87\text{pF}$$

$$f_H = \frac{\omega_H}{2\pi} = \frac{1}{2\pi C_{in} R'_{sig}} = 572\text{kHz}$$