**ES 330 Electronics II Homework # 10 Solutions**
(Fall 2017 – Due Wednesday, December 30, 2017)

**IMPORTANT NOTE:** The first four problems, Problem 1 through Problem 4, make use of the common-source NMOS amplifier shown schematically immediately below. This is Figure 10.3(a) in Section 10.1 of Sedra and Smith (refer to pages 699 to 707 for definitions and additional information).

![Schematic Diagram](image_url)

**Problem 1** (20 points)
For the common-source amplifier in the above schematic assume the following component values:

\[ R_{G1} = 2 \, \text{M}\Omega, \quad R_{G2} = 1 \, \text{M}\Omega, \quad R_{\text{sig}} = 200 \, \text{k}\Omega \]

Find the value of the coupling capacitor \( C_{C1} \) (calculate its value to only one significant figure) placing an associated pole frequency at 10 Hz, or slightly lower.

Consider Figure 10.3(b) in Sedra and Smith which we reproduced immediately in the homework:
For Problem 1 we are concerned only with the input circuitry surrounding capacitor $C_{C1}$.

\[
\frac{V_s}{V_{sg}} = \frac{R_G}{R_G + R_{sg} + \frac{1}{sC_{C1}}} ; \quad \text{where} \quad s = j\omega \\
R_G = R_{G1} || R_{G2} = 2 \, \text{M}\Omega \| 1 \, \text{M}\Omega = 667 \, \text{k}\Omega \quad \text{and} \quad R_{sg} = 200 \, \text{k}\Omega \\
\frac{V_s}{V_{sg}} = \frac{R_G}{R_G + R_{sg}} \cdot \frac{s}{s + \frac{1}{C_{C1}(R_G + R_{sg})}} , \quad \text{thus}
\]

Pole frequency \( f_{p1} = \frac{1}{2\pi C_{C1} (R_G + R_{sg})} \) \( \text{and requiring} \ f_{p1} \leq 10 \, \text{Hz} \)

\[
\frac{1}{2\pi C_{C1}(R_G + R_{sg})} \leq 10 \, \text{Hz} \quad \text{means that} \quad C_{C1}
\]

\[
C_{C1} \geq \frac{1}{2\pi(10)(667 + 200) \times 10^9} = 18.4 \, \text{nF} ; \quad \Rightarrow \quad C_{C1} = 20 \, \text{nF} = 20 \times 10^{-9} \, \text{F}
\]

**Problem 2 (20 points)**

For the common-source amplifier in the above schematic assume the following component values:

\[
R_D = 10 \, \text{k}\Omega , \quad R_L = 10 \, \text{k}\Omega , \quad \text{and} \quad r_0 \text{ is very large; } r_0 \to \text{infinite}
\]

Find the value of the coupling capacitor $C_{C2}$ (calculate its value to only one significant figure) placing an associated pole frequency at 10 Hz, or slightly lower.

For problem 2 we again refer to Figure 10.3(b) shown above and focus upon the output circuitry surrounding capacitor $C_{C2}$. 
Problem 3 (25 points)

For this common-source amplifier assume the transistor’s transconductance value to be \( g_m = 5 \text{ mA/V} \) and the series source resistor \( R_S = 1.8 \text{ k}\Omega \). Determine the value of the bypass capacitor \( C_S \) (again calculate to only one significant figure) that places its associated pole frequency at 100 Hz or slightly lower. What are the frequencies of the pole \( f_p \) and the zero \( f_z \) using the value for \( C_S \) you calculated?

For problem 3 we again refer to Figure 10.3(b) shown above and focus upon the bypass circuitry involving capacitor \( C_S \). We begin by writing the transfer function for \( I_s/V_g \).

\[
V_o = -I_d \frac{R_D}{R_D + R_L + \frac{1}{sC_{c2}}} \times R_L; \quad \text{which can be written as}
\]

\[
\frac{V_o}{I_d} = -\frac{R_D R_L}{R_D + R_L + \frac{s}{C_{c2}}} \times \frac{s}{s + \frac{1}{C_{c2}(R_D + R_L)}}
\]

where the pole frequency \( f_{p3} \) is

\[
f_{p3} = \frac{1}{2\pi C_{c2}(R_D + R_L)}; \quad \text{For } R_D = 10 \text{ k}\Omega \text{ and } R_L = 10 \text{ k}\Omega
\]

To make \( f_{p3} \leq 10 \text{ Hz} \), \[
\frac{1}{2\pi C_{c2}(R_D + R_L)} \leq 10 \text{ Hz}
\]

\[
\Rightarrow C_{c2} \geq \frac{1}{2\pi \times 10 \times (10 + 10) \times 10^3} = 0.8 \mu\text{F} = 800 \text{ nF}; \quad \text{Select, } C_{c2} = 0.8 \mu\text{F}
\]

Now we know \( g_m = 5 \text{ mA/V} \) and \( R_S = 1.8 \text{ k}\Omega \)

To make \( f_{p2} \leq 100 \text{ Hz} \), \[
\frac{g_m + (1/R_S)}{2\pi C_S} \leq 100 \text{ Hz}; \quad \text{Therefore,}
\]

\[
\Rightarrow C_S \geq \frac{5 \times 10^{-3} + ((1/1.8) \times 10^3)}{2\pi \times 10 \times 10^{-6} \times 1.8 \times 10^3} = 8.8 \mu\text{F}; \quad \text{We select } C_S = 10 \mu\text{F}
\]

Next we calculate the values of the pole and the zero using these values.

\[
f_{p2} = \frac{g_m + (1/R_S)}{2\pi C_S} = \frac{5 \times 10^{-3} + ((1/1.8) \times 10^3)}{2\pi \times 10 \times 10^{-6} \times 1.8 \times 10^3} = 88.4 \text{ Hz}, \quad \text{and}
\]

\[
f_z = \frac{1}{2\pi \times 10 \times 10^{-6} \times 1.8 \times 10^3} = 8.84 \text{ Hz}
\]
Problem 4 (35 points)
Again using the common-source amplifier, we now have a new set of values for the components in the amplifier:

\[
\begin{align*}
R_{\text{sig}} &= 100 \, \text{k}\Omega, & R_{G1} &= 47 \, \text{M}\Omega, & R_{G2} &= 10 \, \text{M}\Omega, \\
C_{C1} &= 0.01 \, \text{\mu F}, & R_S &= 2 \, \text{k}\Omega, & C_S &= 10 \, \text{\mu F}, \\
R_D &= 4.7 \, \text{k}\Omega, & R_L &= 10 \, \text{k}\Omega, & C_{C2} &= 1 \, \text{\mu F},
\end{align*}
\]

and the transistor’s transconductance is \( g_m = 5 \, \text{mA/V} \) and ignore \( r_0 \).

Calculate the following parameters: \( A_M, f_{p1}, f_{p2}, f_z, f_{p3} \) and \( f_L \). Note: The parametric notation is defined in Section 10.1 of Sedra and Smith. Note: For example, see page 704 of Sedra & Smith for the definition of \( f_L \).

Midband gain

\[
A_M = -\frac{R_g}{R_{G1} + R_{\text{sig}}} \times g_m \left( R_g \left| R_L \right| \right)
\]

where

\[
R_g = \left( R_{G1} \left| R_{G2} \right| \right) = 47 \, \text{M}\Omega \left| 10 \, \text{M}\Omega \right| = 8.246 \, \text{M}\Omega
\]

\[
R_{\text{sig}} = 100 \, \text{k}\Omega; \quad g_m = 5 \, \text{mA/V}; \quad R_D = 4.7 \, \text{k}\Omega; \quad R_L = 10 \, \text{k}\Omega
\]

Hence,

\[
A_M = -\frac{8.246}{8.246 + 0.1} \times 5 \left( 4.7 \left| 10 \right| \right) = -15.8 \, \text{V/V}
\]

Input-stage pole:

\[
f_{p1} = \frac{1}{2\pi C_{C1} \left( R_g + R_{\text{sig}} \right)} = \frac{1}{2\pi \times 0.01 \times 10^{-6} \left( 8.246 + 0.1 \right) \times 10^6}
\]

Therefore, \( f_{p1} = 1.9 \, \text{Hz} \)

Source bypass pole and zero:

\[
f_{p2} = \frac{g_m + \left( 1 / R_S \right)}{2\pi C_S R_S} = \frac{\left( 5 \times 10^{-3} \right) + \left( 0.5 \times 10^{-3} \right)}{2\pi \times 10 \times 10^{-6}}
\]

Therefore, \( f_{p2} = 87.5 \, \text{Hz} \)

For the zero, \( f_z = \frac{1}{2\pi C_S R_S} = \frac{1}{2\pi \times 10 \times 10^{-6} \times 2 \times 10^3} = 8 \, \text{Hz} \)

Output-stage pole:

\[
f_{p3} = \frac{1}{2\pi C_{C2} \left( R_D + R_L \right)} = \frac{1}{2\pi \times 1 \times 10^{-6} \times \left( 4.7 + 10 \right) \times 10^3}
\]

Therefore, \( f_{p3} = 10.8 \, \text{Hz} \)

\[
\begin{align*}
A_M &= -15.8 \, \text{V/V} & \text{Clearly, we see that } f_{p2} &\gg f_{p1} \text{ or } f_{p3} \text{ or } f_z \\
f_{p1} &= 1.9 \, \text{Hz} & \text{Therefore, } f_L &\approx f_{p2} = 87.5 \, \text{Hz} \\
f_{p2} &= 87.5 \, \text{Hz} & \text{Thus, } f_{p2} &\text{ is a dominant pole and we don't} \\
f_z &= 8.0 \, \text{Hz} & \text{have to use equation (10.12) in Sedra and Smith.} \\
f_{p3} &= 10.8 \, \text{Hz} \\
f_L &= 87.5 \, \text{Hz} \text{ which is approximately equal to } f_{p2} \text{ (so it is a dominant pole)}
\end{align*}
\]