Problem 1 – (25 points) An amplifier has the following transfer function:

\[ H(s) = \frac{10s(s+1)}{(s/7+1)(s/5+1)(s/10,000+1)(s/50,000+1)} \]

List the low-frequency 3dB point in rad/s (round to 1 decimal place (e.g., 1.3)): \( \omega_L = \sqrt{7^2 + 5^2 - 2(1)^2} \)

\( \omega_L = 8.5 \)

List the high-frequency 3dB point in rad/s: \( \omega_H = 10,000 \)

What is the midband gain in dB (round to nearest integer)? \( A_M = 20 \log(10.57) \approx 51 \text{dB} \)

Sketch the magnitude (not phase) Bode plot for this system, labeling frequencies, gains, and slopes of interest.

What would you expect the phase of this transfer function to be at very, very high frequencies? \(-180^\circ\)
Problem 2 - (20 points) An uncompleted circuit consisting of two differential pairs is shown below. We wish to create a biasing network so that the NMOS differential pair transistors each have a differential gain equal to 100V/V, and the pnp differential pair transistors each have a $g_m$ of 6 A/V. Assume that $\beta$ is very large, $|V_{BE}| = 0.7$ V, $V_T = 25$ mV, $|V_t| = 1$ V, and $k'(W/L) = 1$ mA/V$^2$ for this entire problem. You may neglect the Early effect.

What value of $I_1$ is required? $A_d = g_{m}(10k) = 100 \Rightarrow g_m = \frac{2k'V_T}{2}\frac{1}{I_D} = 10mA$  
What value of $I_2$ is required? $g_m = \frac{I_c}{V_T} = 6 \Rightarrow I_c = 6(25mA) = 150mA$  
$I_D = 50mA$

Now, on the schematic below, draw a current mirror biasing network to provide the required dc currents. You may use no more than 5 npn transistors, 2 pnp transistors, and one resistor of any value. Assume all transistors are identical in size. You may only use the +5 V power supply shown.

(Don’t worry about connecting anything to the inputs or outputs of the differential pairs; we’re only concerned with the biasing network in this problem. Assume that the MOSFET’s are biased to a saturation region. Also, don’t worry about the value of the collector resistors shown.)
Problem 3 - (20 points) Short questions:

(a) Using the short-circuit time constant technique, what is the resistance seen by $C_1$?

\[
R_C = \frac{(1 \Omega + 2 \Omega)}{3} + 100
\]

(b) A circuit has a voltage gain of 0.707 V/V. Convert this to dB (round to nearest integer):

\[
-3 \text{dB}
\]

(20 \log (0.707))

(c) A circuit has a voltage gain of 35.56dB. Convert this to V/V (round to nearest integer):

60 V/V

(\frac{35.56}{20})

(d) Draw in the schematic below the parasitic capacitor that causes the Miller Effect.

(e) As a general rule of thumb (discussed in lecture), if your high frequency poles are 1,000, 2,000, and your high frequency zeros are 10,000 rad/sec, then $\omega_H \approx \sqrt{\frac{1}{1k^2} + \frac{1}{2k^2} - \frac{2}{10k^2}} \approx 9.02 \text{ rad/sec}$
Problem 4 - (15 points) Resistance reflection rule. Assume the transistors below have a finite $\beta$ and an infinite Early voltage.

Write an expression for the input resistance $R_{in}$ in the circuit shown below. Your expression should include only real resistances ($R_1$, $R_2$, $R_3$, or a subset of these) and possibly $\beta$, $r_{e1}$ or $r_{e1}$, and $r_{e2}$ or $r_{e2}$. (Assume both transistors have the same $\beta$.) Circle your answer.

$$R_{in} = R_{in1} + R_3 (\beta H) + \left[ R_4 \parallel \left( \frac{R_{in2}}{\beta H} \right) \right] (\beta H)$$

Or

$$R_{in} = [r_{e1} + R_3 + R_4 \parallel r_{e2}] (\beta H)$$
Problem 5 - (20 points) For the circuit shown below, derive expressions for:
- the midband gain $A_m$
- the low-frequency poles and/or zeros (if any; state if none)
- the high-frequency poles and/or zeros (if any; state if none)

Circle your answers. To keep the expressions readable, express any parallel resistances as $R_A \parallel R_B$ for example, not $R_A R_B / (R_A + R_B)$.

\[
\begin{align*}
V_o &= \frac{g_m v_1 \left( \frac{1}{C_2 S} + R_3 \right) C_2 S}{\frac{1}{C_2 S} + R_3 + R_2} = \frac{g_m v_1 \left( 1 + R_3 C_2 S \right)}{1 + \left( R_2 + R_3 \right) C_2 S} \\
V_1 &= \left[ \frac{R_1 V_S}{R_1 + R_S + \frac{1}{C_1 S}} \right] \frac{C_1 S}{C_1 S} = \frac{R_1 V_S C_1 S}{(R_1 + R_S) C_1 S + 1} \\
V_i &= \frac{R_i C_i V_S}{(R_i + R_S) C_i S \left( 1 + \frac{1}{(R_i + R_S) C_i S} \right)} \\
\frac{V_o}{V_S} &= \frac{g_m \left( 1 + R_3 C_2 S \right)}{1 + \left( R_2 + R_3 \right) C_2 S} \frac{R_1 C_i}{(R_1 + R_S) \left( 1 + \frac{1}{(R_i + R_S) C_i S} \right)} \\
A_n &= 20 \log \left[ \frac{g_m R_i}{(R_1 + R_S)} \right] \\
\text{Low pole} &= \frac{1}{(R_1 + R_S) C_i}
\end{align*}
\]