In the following problems, if reference to a semiconductor process is needed, assume processes with the following characteristics: CMOS Process -- $\mu_{n}C_{OX}=100\mu A/V^2$, $\mu_{p}C_{OX}=\mu_{n}C_{OX}/3$, $V_{TNO}=0.5V$, $V_{TPO}=-0.5V$, $C_{OX}=2fF/\mu^2$, $\lambda_n=\lambda_p=0.01V^{-1}$, and $\gamma=0.4V^{-1/2}$, Bipolar Process -- $J_S=10^{-15}A/\mu^2$, $\beta=100$ and $V_{AF}=150V$.

Problem 1 A single-ended input, single-ended output voltage amplifier is shown.

a) Determine the number of degrees of freedom the designer has with this circuit. Assume $V_{DD}$ and $V_{SS}$ are fixed.

b) Derive expressions for the dc voltage gain, the 3dB bandwidth, and the GB for this operational amplifier (assume the devices are operating in the “right” region)

c) Derive an expression for the gain of the following circuit if the two-transistor amplifier is used as the op amp.

d) Show that the I/O relationship can be approximated by the expression
\[ V_{\text{OUT}} = -\frac{R_2}{R_1} V_{\text{in}} + V_{XQ} + \frac{R_2}{R_1} (V_{XQ} - V_{\text{inQ}}) \]

where \( V_{\text{in}} \) is the small-signal input, \( V_{XQ} \) is the quiescent value of the input voltage for the open-loop amplifier, and where \( V_{\text{inQ}} \) is the quiescent value of the input voltage.

Problem 2 Assume the amplifier shown below is designed in a 0.5\( \mu \) CMOS process. and that \( V_{\text{DD}}=5V \), \( V_{\text{SS}}=-1.5V \), and \( I_{\text{DQ}}=1mA \).

a) Analytically determine the \( W \) and \( L \) needed to establish a quiescent output voltage of 0V

b) Verify the transfer characteristics by Spice simulation.

c) Analytically determine the dc voltage gain at the Q-point established in a)

d) Using SPICE, obtain a plot of the small signal voltage gain versus the quiescent output voltage.

Problem 3 Assume the amplifier in Problem 2 is used as a single-input, single-output operational amplifier. With this op amp, analytically determine the small signal voltage gain and the quiescent output voltage for the circuit shown below if \( R_2=10M \) and \( R_1=5M \). Assume that the dc offset of \( V_{\text{IN}} \) is 0V. Verify the gain of this amplifier with SPICE simulation.
Problem 4   A transresistance amplifier with a gain $R_T$ is shown. Derive an expression for the voltage gain of the amplifier as a function of the transresistance gain $R_T$ and determine what that reduces to if $R_T$ is very large.

Problem 5   The gain of the following feedback amplifier was derived in class and it was shown that if the gain $G_M$ is large that the feedback gain approaches $-R_2/R_1$. Determine the gain of the feedback amplifier if the load resistor $R_L$ (shown in the second part of the figure) is included and determine how that load resistor affects the gain of the feedback amplifier if $G_M$ is large.

Problem 6   3.1 of Martin and Johns
Problem 7   3.2 of Martin and Johns
Problem 8   3.3 of Martin and Johns