Problem Set #5

1) Common-Source (CS) Stage

For the CS amplifier circuit shown below, \( \frac{W}{L} = 10 \) for both \( M_1 \) and \( M_2 \), \( \mu_n C_{ox} = 100 \, \mu A/V^2 \), \( \mu_p C_{ox} = 50 \, \mu A/V^2 \), \( \lambda_n = 0.05 \, V^{-1} \) for NMOS and \( \lambda_p = 0.01 \, V^{-1} \) for PMOS, \( V_{in} = 1 \, V \) for NMOS and \( V_{g} = -1 \, V \) for PMOS, \( V_{DD} = 5 \, V \).

1. Find the DC bias voltages, \( V_b \) and \( V_G \), such that the bias current is 100 \( \mu A \). Use \( \lambda = 0 \) for this part.
2. What is the voltage gain \( A_v = v_{o}/v_i \) of this amplifier, both symbolically and numerically?
3. What is the input (\( R_i \)) and output resistance (\( R_o \)) of this amplifier, both symbolically and numerically?
4. What determines the output voltage swing? Find the maximum and the minimum output voltages.
5. How does the voltage gain and the output resistance change if the gate of \( M_1 \) is connected to the output directly (no \( V_b \) is applied)?

2) Common-Gate (CG) Stage

Write an expression for the voltage gain \( G_v = \frac{v_{out}}{v_{in}} \), input resistance \( R_i \) and output resistance \( R_o \) of the CG amplifier shown below. Assume \( \lambda = 0 \) for each of the transistors. Your answer should be expressed in terms of the circuit resistances (\( R_s \), \( R_1 \)) and the transistor small-signal parameters (\( g_{m1} \), \( g_{m2} \)).

3) Source Follower
Consider the source follower circuit shown below, for which \( V_{DD} = 1.8 \) V. For \( M_1 \), 
\( \mu_n C_{ox} = 200 \) \( \mu A/V^2 \), \( V_t = 0.4 \) V, and \( \lambda = 0 \). Design the circuit to achieve a voltage gain 
\[ A_v = \frac{v_{out}}{v_{in}} = 0.8 \) V/V for a power budget \( (I_D \times V_{DD}) \) of 2 mW, and input resistance of \( R_i = 10 \) k\( \Omega \).

(Specify numerical values for \( R_G \), \( R_S \), and \( W/L \) for \( M_1 \).)

4) Show that the unity-gain or transition frequency of an n-channel MOSFET can be written as
\[ f_T = \frac{g_m}{2\pi(C_{gs} + C_{gd})} \geq 1.5 \frac{\mu I_D}{\pi L} \geq 3\mu_n V_{OV}. \]