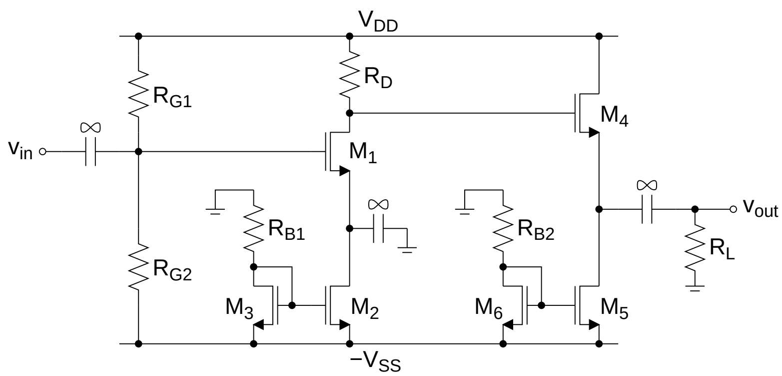
ECEN 326 Lab 3
Design of a Two-Stage MOSFET Amplifier

Circuit Topology

The following figure shows the two-stage dual-supply MOSFET amplifier circuit that will be designed in this lab.



DC drain currents of M_1 and M_4 are set by the two current mirrors as follows:

$$I_{D1} = I_{D2} = I_{D3} = \frac{V_{SS} - V_{GS3}}{R_{B1}} = \frac{k_n'}{2}\frac{W}{L}(V_{GS3} - V_{tn})^2 \tag{1}$$

$$I_{D4} = I_{D5} = I_{D6} = \frac{V_{SS} - V_{GS6}}{R_{B2}} = \frac{k_n'}{2}\frac{W}{L}(V_{GS6} - V_{tn})^2 \tag{2}$$

For M_1, M_2 and M_5, the following should be satisfied for the active operation:

$$V_{DS} \geq V_{ov} = V_{GS} - V_{tn} \tag{3}$$

The signal swing at the drain of M_1 is limited by V_{DD} and $-V_{SS} + V_{ov2} + V_{ov1}$, provided that the gate bias of M_1 is arranged to have the maximum possible swing. However, the minimum value at V_{d1} is usually limited by $-V_{SS} + V_{ov5} + V_{GS4}$, which is typically higher than $-V_{SS} + V_{ov2} + V_{ov1}$. In order to maximize the symmetrical swing, the DC bias at V_{D1} may be centered between the upper and the lower limit. However, centering the DC bias is not always necessary, since it may conflict with other specifications. Nevertheless, the difference between V_{D1} and the upper or lower limit should be greater than the desired swing at that node.

As in the case of BJT emitter-follower, MOS source follower bias current can be determined from

$$I_{D5} \geq \frac{\text{0-to-peak output swing}}{R_L} \tag{4}$$

AC small-signal parameters can be obtained as:

$$A_v = \frac{v_{out}}{v_{in}} \approx -\frac{R_D}{\frac{1}{g_{m1}}}\,\frac{R_L}{R_L + \frac{1}{g_{m4}}} = -g_{m1}R_D\,\frac{R_L}{R_L + \frac{1}{g_{m4}}} \tag{5}$$

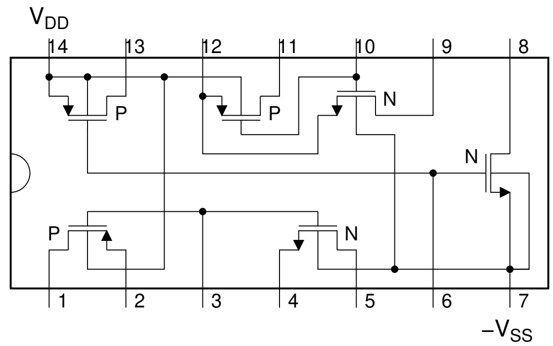
where

$$g_m = k_n'\frac{W}{L}V_{ov} = \sqrt{2k_n'\frac{W}{L}I_D} \tag{6}$$

CD4007 transistor array will be used for the implementation of the amplifier. Device parameters of CD4007 are approximately given as follows:

CD4007N	CD4007P
$k'_n = 70\ \mu A/V^2$	$k'_p = 15\ \mu A/V^2$
$V_{tn} = 1.4\ V$	$V_{tp} = -1.65\ V$
$W = 170\ \mu m$	$W = 360\ \mu m$
$L = 10\ \mu m$	$L = 10\ \mu m$
$\lambda_n = 0.016\ V^{-1}$	$\lambda_p = 0.01\ V^{-1}$

Connection diagram of the CD4007 chip (top view) is shown below.



Note that all P-channel substrates are connected to V_{DD} and all N-channel substrates are connected to $-V_{SS}$.

Calculations and Simulations

Design a common-source MOSFET amplifier with a source follower using the following specifications:

$V_{DD} = V_{SS} = 5\ V$	$R_L = 5\ k\Omega$	Operating frequency: 5 kHz
$R_{in} \geq 100\ k\Omega$	$\lvert A_v \rvert = 30$	Zero-to-peak un-clipped swing at $V_{out} \geq 2.5\ V$
$I_{supply} \leq 1.5\ mA$		

1. Show all your calculations, design procedure, and final component values.
2. Verify your results using a circuit simulator. Submit all necessary simulation plots showing that the specifications are satisfied. Also provide the circuit schematic with DC bias points annotated.
3. Using a circuit simulator, perform Fourier analysis and determine the input and the output signal amplitudes resulting in 5% total harmonic distortion (THD) at the output. Provide the simulation results.

Measurements

1. Construct the amplifier you designed.
2. Measure I_{D1}, I_{D4}, V_{D1}, V_{D2} and V_{D5}. If any DC bias value (especially I_D) is significantly different than the one obtained from simulations, modify your circuit (i.e. change R_{B1}, R_{B2}, R_{G1}, or R_{G2}) to get the desired DC bias before you move onto the next step.
3. Measure A_v, R_{in}, and I_{supply} (for both V_{DD} and $-V_{SS}$).
4. Measure the maximum un-clipped output signal amplitude.
5. Find the input signal amplitude resulting in 5% THD measurement at the output.

Report

1. Include calculations, schematics, simulation plots, and measurement plots.
2. Prepare a table showing calculated, simulated and measured results.
3. Compare the results and comment on the differences.

Demonstration

1. Construct the amplifier you designed on your breadboard and bring it to your lab session.
2. Your name and UIN must be written on the side of your breadboard.
3. Submit your report to your TA at the beginning of your lab session.
4. Measure A_v, R_{in}, and I_{supply} (for both V_{DD} and $-V_{SS}$).
5. Apply the input signal resulting in 5% THD at the output from your earlier measurements. Show the input and output waveforms, and THD measurement at the output.