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ECE 10BL- Lab 3

Introduction:
In this lab, we learn about MOSFET transconductance and how common-source and common-drain circuits work. We also learn to develop formulas for a MOSFET's transconductance and the relationship of gain in circuits. We use LTspice simulations to confirm the accuracy of the derived expressions, and then we construct the corresponding circuits to measure and analyze the outcomes.

Prelab 1:
Transconductance

$g_m = \frac{i_d}{v_{in}}$ **[RP1]**

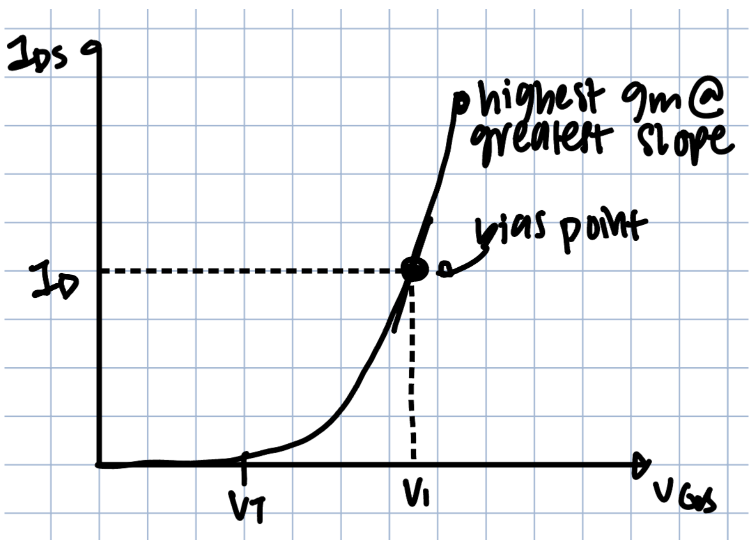

Figure 1. NMOS I_{DS} vs. V_{GS} **[RP2][RP3]**

The highest g_m value is given by V_{in} = 3V and I_{ds} = 9.533mA, because the ratio of $\frac{i_d}{v_{in}}$ is the greatest. **[RP4]**

V_{in}= 2.5V-2V = 0.5V
$g_m = \Delta I_{ds} / \Delta V_{gs}$ = ((7.225 – 3.6) x 10^{-3}) / (2.5 – 2) = 7.25 x 10^{-3} mhos **[RP5]**

V_{in}= 3V-2.5V = 0.5V
$g_m = \Delta I_{ds} / \Delta V_{gs}$ = ((9.533 – 7.225) x 10^{-3}) / (3 – 2.5) = 4.62 x 10^{-3} mhos **[RP6]**

Transconductance of an NMOS in Saturation

$g_m = \frac{i_d}{v_{in}}$, $i_d = K_n(V_{GS} - V_T)v_{in}$

$$g_m = \frac{K_n(V_{GS} - V_T)v_{in}}{v_{in}}$$

$g_m = K_n(V_{GS} - V_T)$ **[RP7]**

Common Source Amplifier

$v_O = V_{dd} - i_D R_L$

$(V_o + v_o) = V_{dd} - (I_D + i_d)R_L$

$V_o + v_o = V_{dd} - I_D R_L - i_d R_L$

$V_o = V_{dd} - I_D R_L$

$v_o = -i_d R_L$

$v_o = -(g_m v_i)R_L$

$v_o / v_i = -g_m R_L$

small signal gain = $-g_m R_L$ **[RP8]**

$v_o / v_i = -K_n (v_{gs} - v_T)R_L$, $V_{in} = V_{gs}$, $V_T = 1$ V

$v_o / v_i = -K_n (2.25 - 1)400$

gain = $-500K_n$ **[RP9]**

$v_o / v_i = -K_n (v_{gs} - v_T)R_L$, $V_{in} = V_{gs}$, $V_T = 1$ V

$v_o / v_i = -K_n (2.75 - 1)400$

gain = $-700K_n$ **[RP10]**

V_{in} = 2.75V gives a higher small-signal gain for the common source amplifier, because $|-700K_n| > |-500K_n|$. **[RP11]**

Common Drain Amplifier (Source Follower)

$v_{gs} = v_{in} - v_{out}$

$v_{out} / R = i_d = g_m v_{gs} = g_m(v_{in} - v_{out})$

$v_{out} / R = g_m v_{in} - g_m v_{out}$

$v_{out}(1 / R + g_m) = g_m v_{in}$

$v_{out} / v_{in} = g_m R / (g_m R + 1)$

Small-signal gain = $g_m R / (g_m R + 1)$. **[RP12]**

If R is much larger than $1/g_m$, the small signal gain converges to 1. **[RP13]**

$v_{out} / v_{in} = g_m R / (g_m R + 1)$

$v_{out} / v_{in} = (7.25 \times 10^{-3})(400) / ((7.25 \times 10^{-3})(400) + 1)$

small signal gain = 0.743 **[RP14]**

Prelab 2
Common Source Amplifier

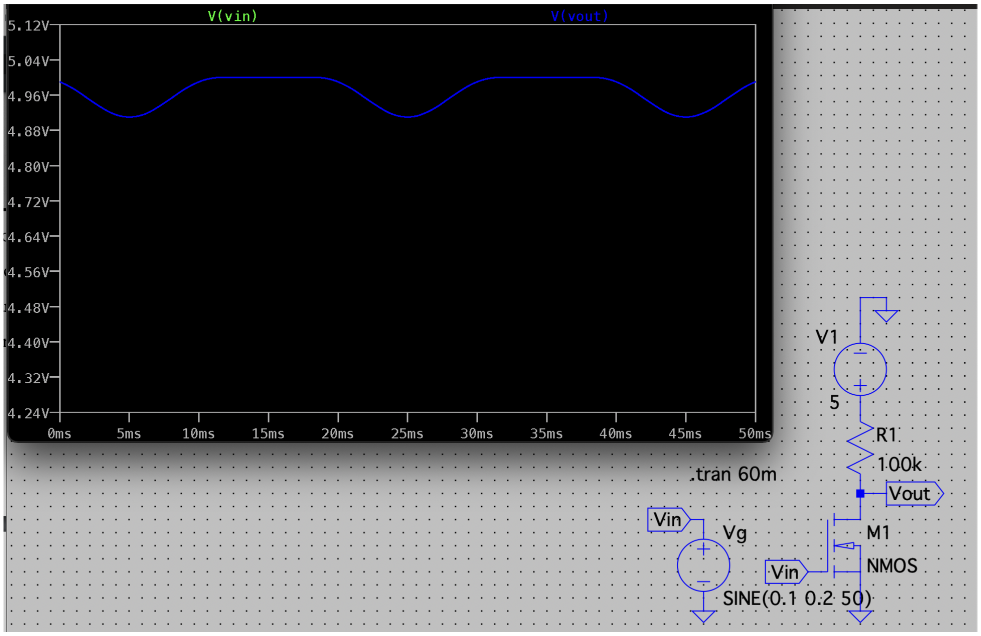

Figure 2. Common-source Amplifier with Clipping in LTspice **[RP15]**

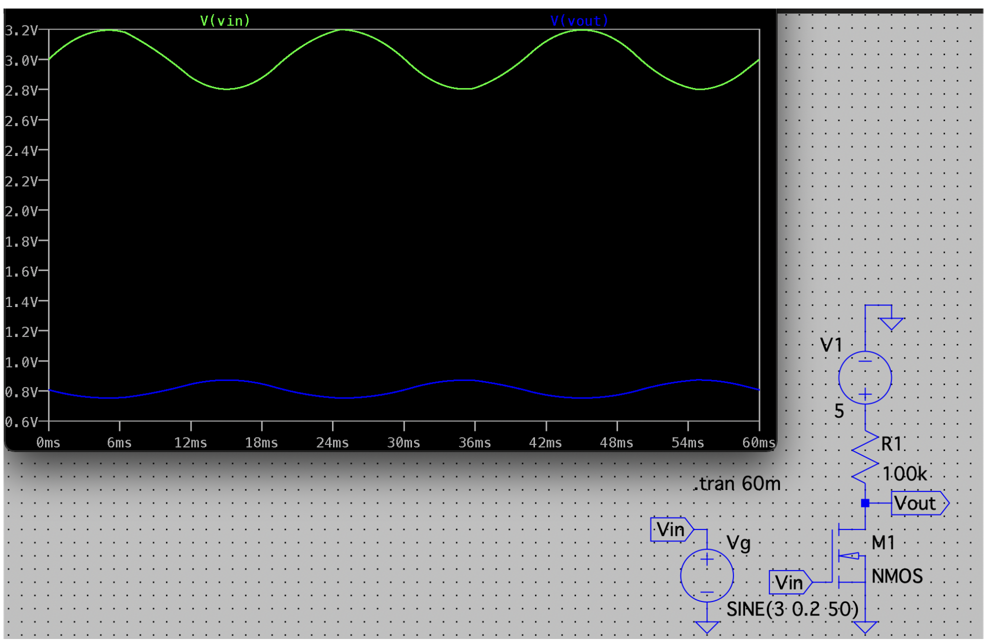

Figure 3. Common-Source Amplifier with compression in LTspice **[RP16]**

Since the NMOS enters cutoff when $V_{gs} < V_T$, supplying a low DC bias will result in clipping. Since the NMOS enters triode when $V_{ds} < V_{gs} - V_T$, supplying too high of a DC bias will result in compression. **[RP17]**

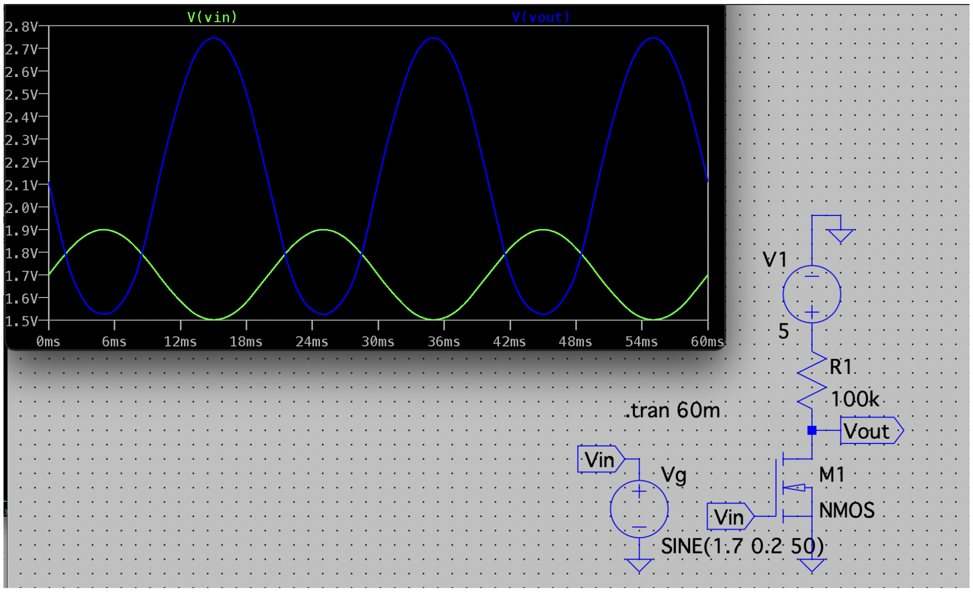

Figure 4. Common-Source Amplifier with a gain greater than 3 in LTspice **[RP18]**

$$gain = \frac{v_o}{v_i} = \frac{0.65}{0.2} = 3.25$$ **[RP19]**

Based on the derivation we can conclude that increasing V_{gs} (the DC bias) increases $g_{m.}$ When the NMOS is in saturation the gain is proportional to V_{gs}. **[RP20]**

Source Follower

R	Gain	$V_{out,DC}$	g_m
1kΩ	0	0.09 V	0
10kΩ	0.33	0.59 V	-3.25×10^{-5}
100kΩ	0.71	1.69 V	-7.10×10^{-6}
1MΩ	0.9	2.50 V	-9.0×10^{-7}

Table 2. NMOS Source Follower R vs. Gain, $V_{out,DC}$ vs. g_m **[RP21]**

The Gain vs. R relation is consistent with the small-signal gain $v_o / v_i = -g_m R_L$ calculated in Part 1, as increasing R_L increases the gain. **[RP22]**

$v_o / v_i = -g_m R_L$
$g_m = -(v_o / v_i) / R_L$ **[RP23]**

$g_m = K_n(V_{gs} - V_T)$
$V_{gs} = V_{in} - V_{out,DC}$

∴ $g_m = K_n(V_{in} – V_{out,DC} – V_T)$.
As $V_{out,DC}$ increases, $(V_{in} – V_{out,DC} – V_T)$ decreases. K_n is a constant, so g_m will decrease when $V_{out,DC}$ increases. **[RP24]**

Lab 3

$V_{IN\ peak\ to\ peak}$ = 167.5 V
$V_{OUT\ peak\ to\ peak}$ = 1062.5 V
gain = $V_{OUT\ peak\ to\ peak}$ / $V_{IN\ peak\ to\ peak}$ = 6.34 **[RP25]**

R = 6kΩ **[RP26]**

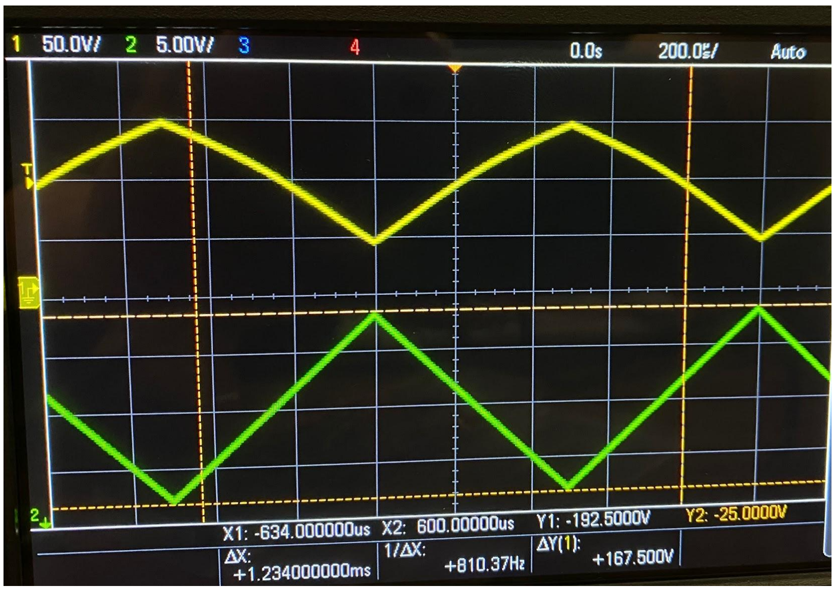

Figure 5. Oscilloscope of amplified signal **[RP27]**

Input bias voltage when the MOSFET just enters triode = 1.745 V **[RP28]**

Figure 6. Oscilloscope of output in triode **[RP29]**

Input bias voltage when the MOSFET just enters cutoff = 0.70 V **[RP30]**

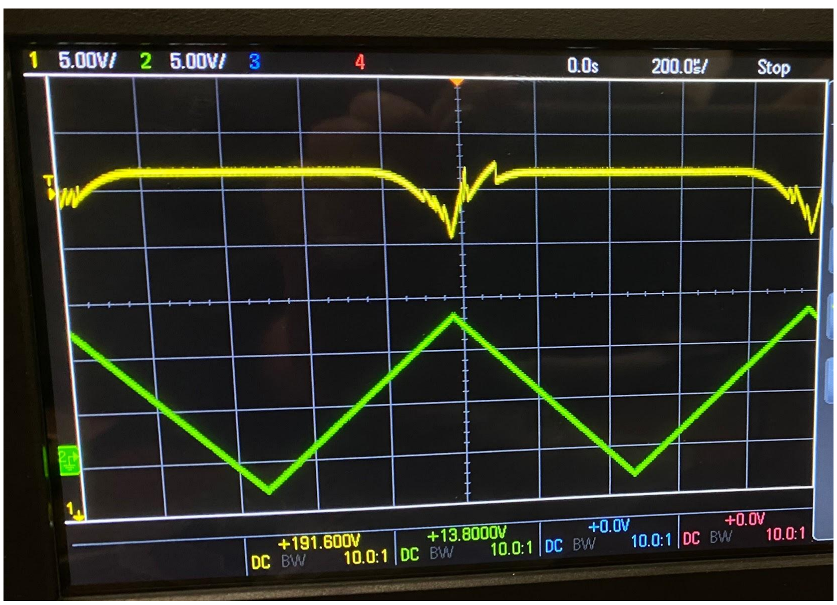

Figure 7. Oscilloscope of clipped signal **[RP31]**

R_L at 7kΩ pushes MOSFET into triode **[RP32]**

Varying R_L cannot push MOSFET into cutoff **[RP33]**

Since $V_{ds} = V_{dd} – i_dR_L$, i_d stays constant because V_{gs} is not changing. Therefore, increasing R_L will decrease V_{ds} and $V_{ds} < V_{gs} – V_T$, which is the condition for triode. On the other hand, cutoff cannot be reached since changing R_L does not affect V_{gs} and it will never be less than V_T.
[RP34]

Conclusion
The lab concludes that the common-source amplifier produces an amplified signal that is inverted when a signal is inputted. By analyzing expressions, simulations, and conducting physical tests, it was determined that the small signal gain relies on the load resistance and bias voltage. On the other hand, the source-follower produces an unamplified signal that is reduced. When the load resistance increases, the gain approaches one and the output resembles the input.