Circuit Symbols for MOSFETS

Four Terminal [Enhancement]

N Channel

P Channel

Three Terminal [Enhancement]

Body Connected to Source

N Channel

P Channel
MOSFETs versus BJTs
as analog amplifiers

NPN BJT

\[ i_c = g_m \cdot V_{be} \]

\[ g_m = \frac{\delta i_c}{\delta V_{be}} \mid V_{CE} = \text{constant} \]

\[ g_m = \frac{I_c}{V_T} \]

\[ I_C = 1 \text{ mA} \]

\[ V_T = 25.9 \text{ mV} \]

\[ g_m = 38.6 \text{ mS} \]

\[ g_m = 0.894 \text{ mS} \]

IV Channel Enhancement Mode MOSFET

\[ i_d = g_m \cdot V_{gs} \]

\[ g_m = \frac{\delta i_d}{\delta V_{gs}} \mid V_{DS} = \text{constant} \]

\[ g_m = 2 \sqrt{I_T} I_D \]

\[ I_D = 1 \text{ mA} \]

\[ V_T = 25.9 \text{ mV} \]

\[ I_T = 0.2 \text{ mA} / V^2 \]

\[ g_m = 0.894 \text{ mS} \]

Thus, \( g_m \) is 43.2 larger for the BJT.
Terminal Equations for 3 terminal N Channel Enhancement Mode MOSFET

\[ i_D = \begin{cases} 
0 & \text{if } V_{GS} \leq V_{TO} \\
2 It \left[ (V_{GS} - V_{TO}) V_{DS} - \frac{V_{DS}^2}{2} \right] & \text{if } V_{GS} - V_{TO} > V_{DS} \\
It (V_{GS} - V_{TO})^2 & \text{if } V_{GS} - V_{TO} < V_{DS}
\end{cases} \]

\[ H = \frac{k'}{2} (1 + \lambda V_{DS}) \frac{W}{L} \]

\[ k' = \text{SPICE parameter } \kappa \]
\[ V_{TO} = \text{SPICE parameter } V_{TO} \]
\[ \lambda = \text{SPICE parameter } \lambda \]

If in saturation region

\[ g_m = \left. \frac{\partial i_D}{\partial V_{GS}} \right|_{V_{DS}} = 2 It (V_{GS} - V_{TO}) = 2 \sqrt{\lambda} \ I_D \]
COMMON SOURCE AMPLIFIER

\[ I_D = K \left[ V_{GS} - V_{TO} \right] = I_S, \quad I_G = 0 \]

- \( K \) = transconductance parameter
- \( V_{TO} \) = threshold voltage

DC gate voltage \( V_G = \frac{R_2 V^+ + R_1 V^-}{R_1 + R_2} \)

DC source voltage \( V_S = V^- + I_S R_S \)

Given \( I_D \) and the parameters of the transistor, determine \( V_{GS} = V_G - V_S \)

Pick \( V_G \) and then select \( R_S \) to obtain desired \( V_{GS} \)

Small Signal Analysis
Small Signal Model for the N Channel Enhancement Mode MOSFET

T Model

\[ g_m = 2 \sqrt{I_D} \]

\[ r_a = \frac{1}{g_m} \]

\( r_a \) is the intrinsic source resistance
\[ l_a = i_d = g_m V_{gs} = \frac{V_{gs}}{r_A} \]

In the midband frequency range

\[ V_{gs} = V_i \frac{r_A}{r_A + R_s \parallel R_3} \]

\[ i_a = i_d = \frac{V_{gs}}{r_A} = V_i \frac{1}{r_A + R_s \parallel R_3} \]

\[ V_o = -i_d (R_D \parallel R_L) \]

\[ \frac{V_o}{V_i} = -\frac{R_D \parallel R_L}{r_A + R_s \parallel R_3} \]

\[ 3_i = R_1 \parallel R_2 \quad , \quad 3_o = R_D \]
\[ G_{cm} = \frac{1}{g_m + 2R_T} \]

\[ G_d = \frac{g_m}{2} \]

\[ g_m = 2 \sqrt{H T I_D} \]

\[ V_{id} = V_{i1} - V_{i2} \]

\[ V_{icm} = \frac{V_{i1} + V_{i2}}{2} \]

\[ V_{d1} = \left[ -G_d V_{id} + G_{cm} V_{icm} \right] R_D \]

\[ V_{d2} = \left[ G_d V_{id} + G_{cm} V_{icm} \right] R_D \]

\[ A_d = \text{differential gain} = \frac{V_{od}}{V_{id}} = -2G_d R_D \]

\[ A_{cm} = \text{common mode gain} = \frac{V_{ocm}}{V_{icm}} = -G_{cm} R_D \]

\[ CMRR = \frac{A_d}{A_{cm}} = 1 + 2 g_m R_T \]
Current Mirror Active Load \( i_{D3} = i_{D4} \)

Ignoring Common Mode

\( i_{d1} = G_d \cdot V_{id} \quad i_{d2} = -G_d \cdot V_{ic} \)

\( i_{d4} = G_d \cdot V_{ic} \)

\( i_o = i_{d2} - i_{d4} = -2G_d \cdot V_{id} \)

\( V_o = -2G_d \cdot R_F \cdot V_{id} \)
Experiment 16: MOSFET Amplifiers

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To be permitted to complete the experiment during the open lab hours, you must complete at least three procedures during your scheduled lab period or spend your entire scheduled lab session attempting to do so. A signature below by your lab instructor, Dr. Brewer, or Dr. Robinson permits you to attend the open lab hours to complete the experiment and receive full credit on the report. Without this signature, you may use the open lab to perform the experiment at a 50% penalty.

SIGNATURE: ___________________________________________ DATE: ___________________________________________
Make sure you have made all required measurements before requesting a check-off. For all check-offs, you must demonstrate the circuit or measurement to a lab instructor. All screen captures must have a time/date stamp.

3. Common Source Amplifier
   ✓ Measurement of drain current with dc ammeter.
   ✓ Screen capture displaying 1kHz 1Vpp input sine wave and output. Display the Vpp measurements for both channels.
   ✓ Calculation of the midband gain.
   ✓ Plot of gain versus frequency with Labview or VEE. Use the cursors to determine the upper and lower -3dB frequencies. Set the input voltage to 0.1 Vrms to prevent clipping.
   ✓ Screen capture displaying 1kHz 1Vpp input SQUARE wave and output. Display the Vpp measurements for both channels.

4. Design of JFET Current Source
   • Build the circuit shown in Fig. 15.5 (a) using the 2N5457 JFET. Adjust the potentiometer until the specified bias current for the diff amp is obtained. The tail current through the JFET is twice that through each MOSFET in the diff amp.
   • Disconnect the grounded end of the dc ammeter and connect it to the sources of the diff amp transistors and verify that the current is still correct.
   ✓ Measurement of JFET current.

4. MOSFET Diff Amp with Resistive Load
   ✓ Screen capture displaying drain voltages for a 1kHz 1Vpp input sine wave and \( v_{i2} \) grounded. Display the Vpp measurements for both channels.
   ✓ Calculation of the single ended gain \( (v_{d2} - v_{d1})/v_{in} \)
   ✓ Screen capture displaying the input and output showing the output hard clipped. Display the max and min measurements.
   ✓ Screen capture displaying drain voltages for a differential input. Use the circuit of Fig. 15.4(b) to apply 1kHz 1Vpp sine wave to \( v_{i2} \) and this signal inverted to \( v_{i2} \). Display the Vpp measurements for both channels.
   ✓ Calculation of the differential gain \( (v_{d2} - v_{d1})/(v_{i2} - v_{i1}) \)
   ✓ Screen capture showing common mode output and input.
   ✓ Measurement of the common mode gain.
   ✓ Calculation of the CMRR.

5. MOSFET Diff Amp with Active Load
   • For \( V_{b} \) use 7.5V. Generate this voltage at the output of a two resistor voltage divider having equal resistor values of 10k connected between +15V and ground.
   ✓ Screen capture displaying output voltage and one input for a differential input. Apply 1kHz 1Vpp sine wave to \( v_{i1} \) and this signal inverted to \( v_{i2} \) again using the circuit of Fig. 15.4(b). Display the Vpp measurements for both channels.
   ✓ Calculation of \( G_{m(d)} \).
   ✓ Screen capture displaying one input and output showing the output hard clipped. Display the max and min measurements.
   ✓ Screen capture showing common mode output and input.
   ✓ Measurement of the common mode gain.
   ✓ Calculation of the CMRR.