Physics 120 Lab 7 (2018) Field Effect Transistors: Active Region

We now direct our studies to transistors as amplifiers, for which the Drain and Source operate as a current source whose value depends on the Gate-to-Source voltage, denoted $V_{GS}$.

7-1. FET saturation characteristics

![Figure 7.1: FET test circuit. Plot $I_D$ versus $V_{GS}$.](image)

Measure $I_{DSS}$ and $V_{GS(0)}$ for three or more samples of the 2N5485 n-channel JFET. Use the circuit in Figure 7.1 and be sure to use a DMM as a sensitive Ammeter. Record your results (3 pts).

Verify the relation between $I_D$ and $V_{GS}$ shown in manufacturers data specifications; show your data as semi-log plots ($\log_{10} I_D$ versus $-V_{GS}$, recalling that $V_{GS} \leq 0$) (3 pts). Notice the spread of values even in devices from the same manufacturer. Check that your values fall within the quoted maximum range and exclude outliers (1 pt):

$$4 \text{ mA} < I_{DSS} < 10 \text{ mA}$$
$$-4 \text{ V} < V_{GS(0)} < -0.5 \text{ V}$$

Keep track of $V_{GS(0)}$ for your different JFETs when building the circuits below.

7-2 Discreet FET current source

![Figure 7.2: FET current source.](image)

Let's determine how well the circuit in Figure 7.2 operates as a current source. Vary the resistance of the ‘load’, $R_L$, between 0 and 100 kΩ and monitor $V_{DS}$ with a DMM as a Voltmeter as you simultaneously monitor $I_{out} = I_{DS}$ with a second DMM as an Ammeter (use a sensitive range as the currents are below 1 mA). Plot your data (2 pts).
What is $V_{DS}$ when the constant current behavior starts to break down? Measure with a DMM as a Voltmeter or the difference between two oscilloscope inputs (2 pts). This value of $V_{DS}$ marks the boundary of the "active region" and "Ohmic region" and should occur when $V_{DS}$ is near $V_{GS}-V_{GS}(\text{off})$. Does your FET’s “active region” begin around this value of $V_{DS}$ (1 pt)?

Figure 7.3: Reminder: FET linear versus current-source regions depends on $V_{DS}$.

7.3. Improved current source

The single FET circuit of Figure 7.2 is a two-terminal current source that requires no external bias. It is also called "self leveling". Let's see if we can make a more general source, albeit with more parts.

Figure 7.4: Op-amp current source (repeat of Figure 5.8).

Recall the op-amp current source that you built in laboratory exercise 5.5 and repeated in Figure 7.4. This current source had the disadvantage of requiring a “floating” load, i.e., neither side of the load is connected to ground. The circuit in Figure 7.5 solves this problem and sources a current into a load that is connected to ground.

Figure 7.5: Current source for load returned to ground.

Build the circuit of Figure 7.5 using a VP0104 p-channel MOSFET; note that the position of Drain and Source are reversed for p-channel and $V_{GS} < 0$, i.e., the Source is at a higher potential than the Gate, which is at a higher potential than the Drain. What is the expected value of $I_{out}$, the current through the load (1 pt)? What do you measure for a low resistive load, $R_{load}$ (1 pt)?
Measure the variation in $I_{\text{out}}$ as you vary $R_{\text{load}}$. To understand why the current source eventually fails, it may help to use a Voltmeter (or the difference between two oscilloscope channels) to watch the voltage across the FET, i.e., $V_{DS}$. Present your result (2 pts). Briefly discuss if the FET’s Ohmic region, i.e., the region with $V_{DS}$ below $V_{GS} - V_{GS(\text{off})}$, restricts the range of circuit performance as it did for the discrete FET current source (section 7.2) (1 pt).

### 7-4. Source follower

*Figure 7.6: Source follower.*

Build the source follower shown in Figure 7.6 and drive the input with a small, i.e., 0.1 to 1.0 V sine wave at 1 kHz. By how much does the gain differ from unity; show a SCREENSHOT (2 pts). Why is there a difference (1 pt)?

**Extra credit (2 pts)**

Infer $g_m$, the transconductance at this $I_{DS\text{quiescent}}$, from this single observation of the follower’s attenuation. One way to think of the effect of $g_m$ is to draw it as an equivalent resistance in the source as shown in Figure 7.7. Report your result (1 pt) and compare the $g_m$ that you infer from you follower’s attenuation with $g_m$ shown on the transistor’s data sheet (1 pt).

*Figure 7.7: Effect of $g_m$ shown as series resistance forming voltage divider in a follower.*

Recall that $g_m$ varies with $I_D$ and that the data sheet specifies $g_m$ under the most favorable condition, i.e., $V_{GS} = 0$ V. Your follower runs with $V_{GS} < 0$ V, so the observed $g_m$ will always be lower than the data sheet’s value. This can be seen from curves for $I_D$ versus $V_{GS}$ (Figure 7.8) and a plot of

$$\text{Gain} = \frac{dI_S}{dV_{GS}} = \frac{dI_D}{dV_{GS}} \equiv g_m$$

versus $V_{GS}$. Since $I_{DS}$ varies as the square of $V_{GS}$, the gain curve looks like a straight line, reaching its maximum, and the specified value of $g_m$ at $I_{DSS}$, where $V_{GS} = 0$. 

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From your observation of the selected, quiescent value of \( V_{DS} \), denoted \( V_{DS\text{-quiescent}} \); you know \( V_{GS\text{-quiescent}} \); recall that \( V_G \) rests at ground through the 1 M\( \Omega \) pull-down resistor. Having measured \( V_{GS\text{(off)}} \) at the start of today’s laboratory, you can see where you must be on the FET’s curve. Make a sketch (2 pts).

7.5. Source follower with current source load

Modify the circuit of Figure 7.6 to include a current source load, as shown in Figure 7.9. Confirm that this follower performs much better than the simpler circuit.

Measure the gain with a 1 V, 1 kHz signal and document with a SCREENSHOT (1 pt). Is the gain closer to 1.0 than with simple follower of Figure 7.6 (1 pt)? Is the offset closer to zero volts than with simple follower of Figure 7.6 (1 pt)?

Attempt to measure the input impedance. Document your work and report at least a lower bound (2 pts). Hint: If you conclude that \( R_{in} \) is around 10 M\( \Omega \) ohms, you have likely fallen into a trap!

Measure the DC offset and document with a SCREENSHOT (1 pt). What accounts for the non-zero offset (1 pt)? Mismatch of FETs? Mismatch of resistors? Anything else? What easy circuit changes would let you find out, if you are in doubt (1 pt)?

30 points total
2 point bonus