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EE 438 - Fundamentals of Electric Circuits I Laboratory
Lab Section: Friday @ 12PM
22 April 2022

LAB REPORT - LAB 7: DESIGN OF A MULTI-STAGE MOSFET LINEAR LED DRIVER

INTRODUCTION

The intended goal of this lab is for MOSFETs to design a multi-stage amplifier to drive a LED and also learn how to set up the correct DC bias points for an amplifier, determine current drive requirements for a LED and characterize the AC small-signal performance of an amplifier.

COMPONENTS

The same components listed in the lab instructions were used.

PROCEDURE

The same components listed in the lab instructions were used.

TASK 1 QUESTIONS

(a) What material property of a PN-junction determines the color output of a LED?

The semiconductor compound forms in the PN junction during manufacturing (i.e. Gallium, Arsenic, and Phosphorous).

(b) Identify the anode and cathode of your LEDs and setup them up using a test circuit consisting of a DC voltage source and a resistor of 100 Ω.

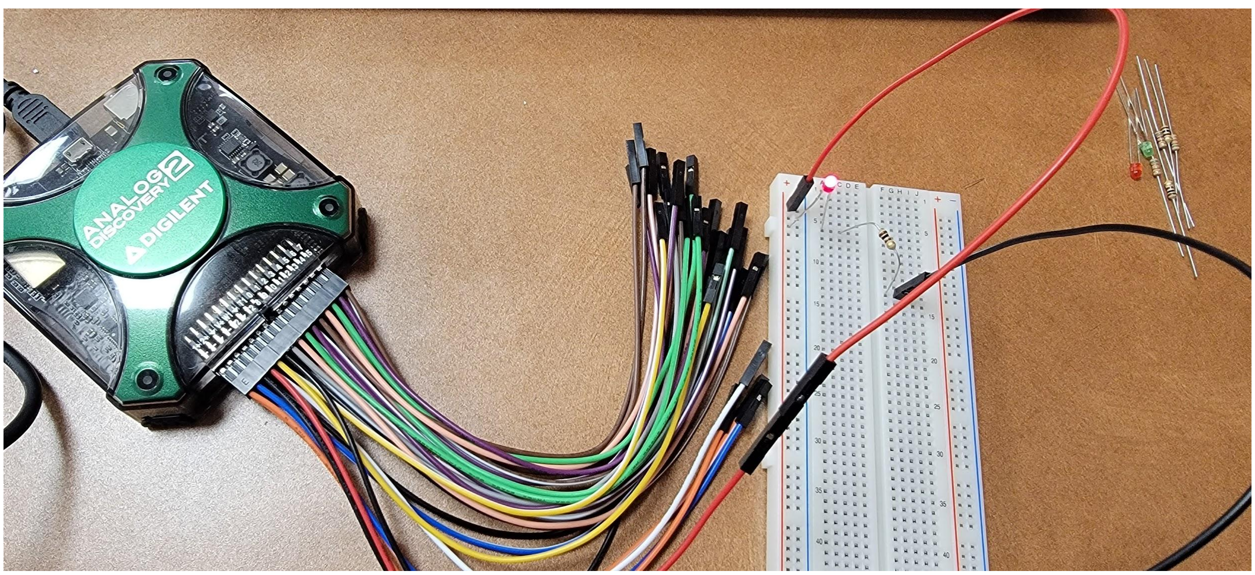


Figure 1: Test Circuit with Red LED and 100 Ω resistor.

(c) Determine a rough value of the forward-ON voltage of the red LED to determine the minimum anode voltage to turn it ON. Check if increasing the voltage beyond this value increases the brightness of the LED (as best as your eye can perceive). Replace the resistor by a larger value, say around 500 Ω, or the nearest standard to see if this reduce the brightness of the LED. Why does this happen?

By experimenting with various DC voltage values, the estimated forward-ON voltage of the red LED is ~1.745 V.

Increasing or decreasing the DC voltage, it results in the brightness of the LED either increasing or decreasing, respectively. When the resistor is replaced from 100Ω to 500Ω, the brightness of the LED decreases.
As the resistor value increases, the current through the circuit decreases, according to Ohm's Law. With a lower current flowing through the circuit, there is a lower amount of power through the LED, thus resulting in lower brightness.

(d) Comment on the purpose of the series resistor (whether 100 Ω or 500 Ω) in this circuit.
Resistors are important when designing LED circuits because the resistor limits the current flowing through the LED and prevents any damage to the LED or circuit.

(e) Replace the red LED by a green LED and include your observations in the report. What changes do you need to make to have a comparable response to the results in part (c) above?
When a green LED is implemented in a simple series resistor circuit, the estimated forward-ON voltage of the green LED is ~1.745 V, higher than that of the estimated forward-ON voltage of the red LED. In order for the circuit to have comparable results to that of the results with the red LED, the resistor should be removed from the circuit to increase the current through the green LED. As such, the brightness of the green LED is comparable to that of the brightness of the red LED.

(f) Now identify the topology of each of the two stages of the amplifier in the circuit shown in the figure. Explain why this combination of stages are used for driving the LED.
In the figure, stage 1 (circled in blue), the topology is the common-source configuration, with an added coupling capacitor. In stage 2 (circled in red), the topology is the common-drain configuration.

For the first stage, the common-source configuration with the coupling capacitor is necessary to essentially render the impedances insignificant, and allow for high currents to be driven through specific DC signals.

In the second stage, the common-drain configuration is used to drive a large current through the load (i.e. a bright LED). The common-drain configuration is ideal in situations where it needs to conduct large amounts of current and present low output impedances at the load.

(g) Assuming you use the 2N7000 MOSFET, calculate what the DC current in the load is if the output DC voltage is chosen equal to the voltage to keep a red LED ON with reasonable brightness. Use your answers from part (c) above to estimate this. Do this for resistor values 100 Ω and 500 Ω and include it in your report. It is recommended you use a different MOSFET from the one used in Lab 6, and perform a quick characterization as needed to obtain information about its properties.

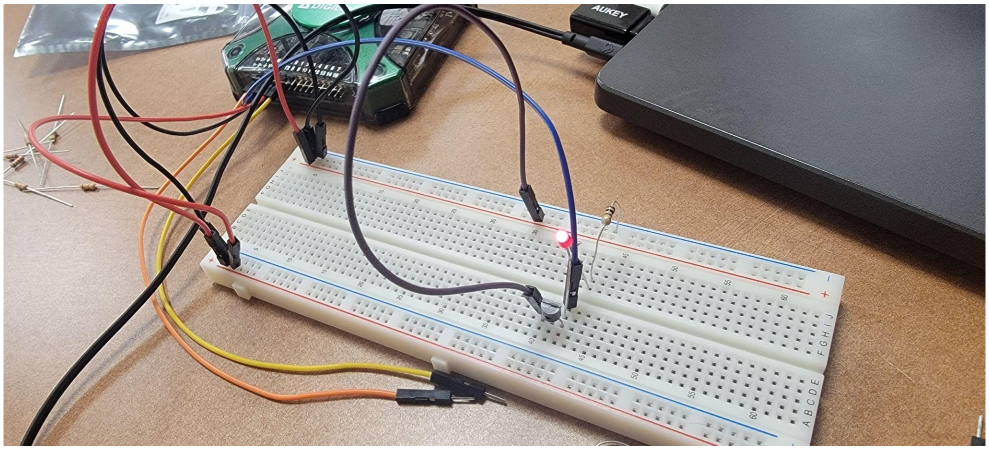


Figure 2: Stage 2 Test Circuit with MOSFET (Common-Drain Comfiguration)

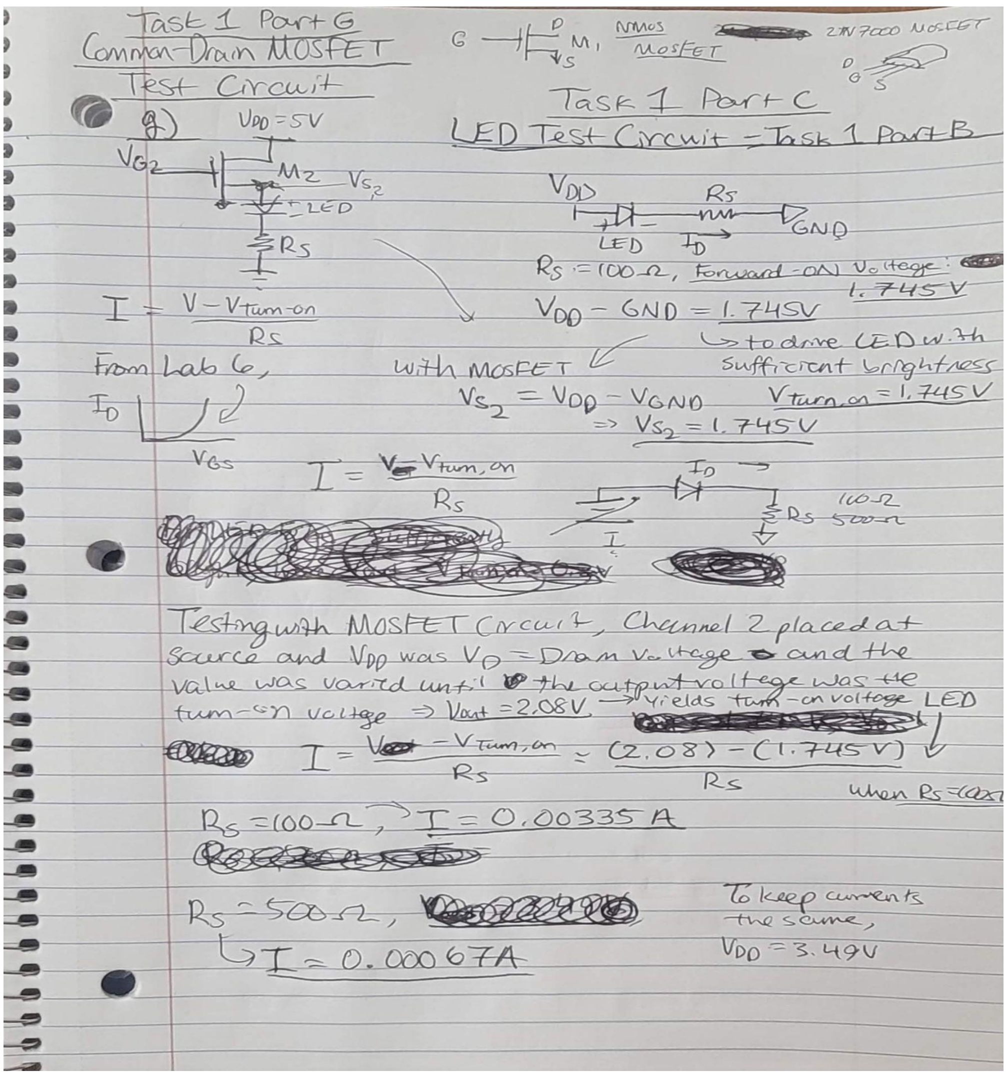


Figure 3: The formulas used and the calculations made to calculate the DC currents

Testing with the MOSFET circuit pictured in *Figure 2*, Channel 2 was placed at the source of the MOSFET to measure the output voltage with a varying drain voltage, Vdd. When the output voltage equals the turn-on voltage (Vout = Vturn-on = 1.745 V), the voltage at the drain, Vdd, differs when using the 100 Ω and 500 Ω resistor values, easily correlating with the I-V characteristics of the MOSFET that were originally calculated in Lab 6.

When testing with the 100 Ω resistor, Vdd = 2.08 V in order to obtain an output voltage equal to that of the turn-on voltage of the LED. Using the same process with the 500 Ω resistor, the Vdd = 3.49 V, as shown in *Figure 3*.

(h) Next, estimate what the DC bias must be on the gate of the transistor in order that it may conduct the currents calculated above. Do this for resistor values 100 Ω and 500 Ω and include it in your report.

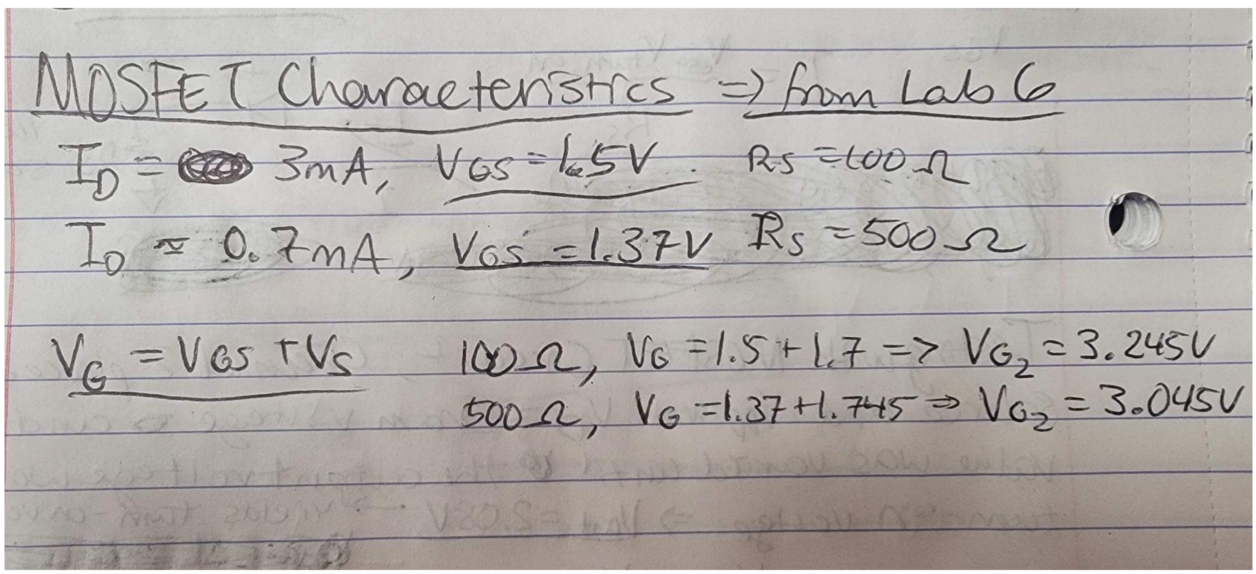
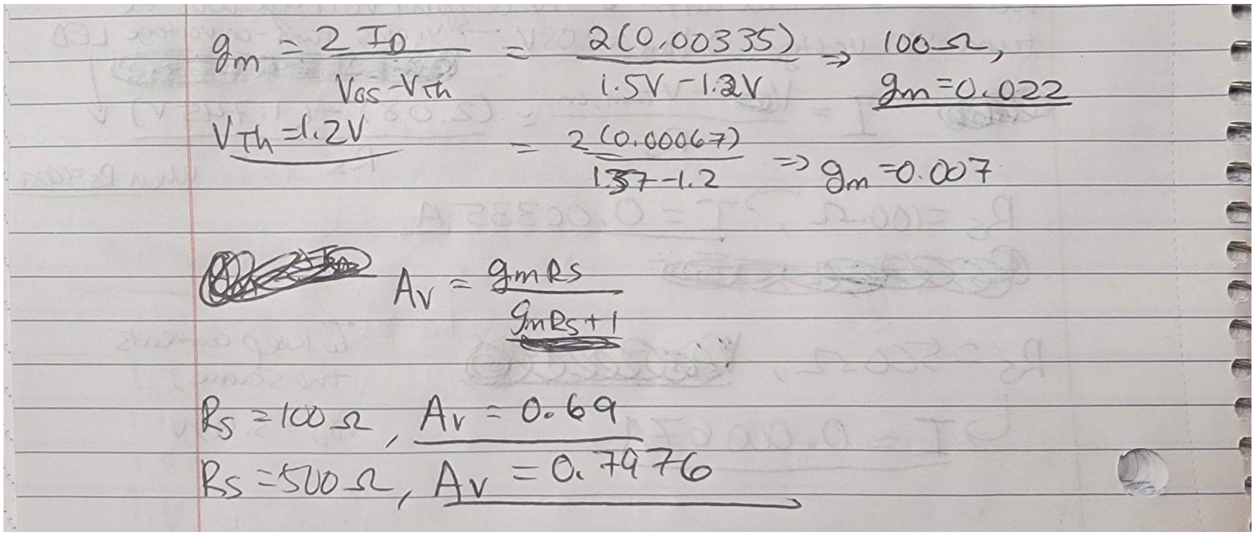


Figure 4: Formulas and calculations used to calculate the gate bias of MOSFET

(i) Based on the estimate of gm you have for the MOSFET, estimate the small-signal gain of the 2 nd stage of the amplifier. Do this for resistor values 100 Ω and 500 Ω and include it in your report.



$$g_m = \frac{2 I_D}{V_{GS} - V_{th}} = \frac{2(0.00335)}{1.5V - 1.2V} \Rightarrow 100\,\Omega, \quad g_m = 0.022$$

$V_{Th} = 1.2V$

$$= \frac{2(0.00067)}{\cancel{1.37}-1.2} \Rightarrow g_m = 0.007$$

$$A_v = \frac{g_m R_S}{g_m R_S + 1}$$

$R_S = 100\,\Omega$, $A_v = 0.69$

$R_S = 500\,\Omega$, $A_v = 0.7976$

Figure 5: Formulas and calculations for small-signal gain of common-drain amplifier

(j) Comment on the design tradeoffs you encounter when deciding to choose between 100 Ω and 500 Ω (Think about the LED current rating, output signal swing, DC operating point considerations etc.)

Having 500 ohms reduces the current but increases the voltage gain.

(k) If you were to design a common source amplifier with an operating point current of ~ 1 mA and with an output operating point voltage equal to the voltages obtained in part (g) above, what values of drain resistor RD would you need. Pick the nearest available standard resistor values and state it in your report.

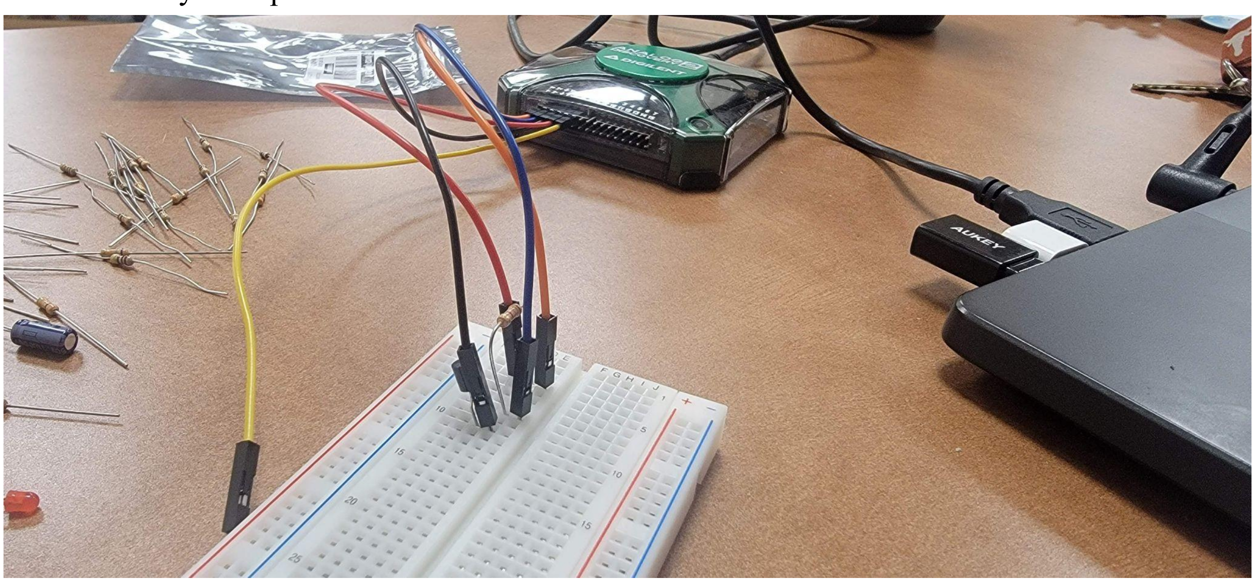


Figure 6: Stage 1 Test Circuit with MOSFET (Common-Source configuration)

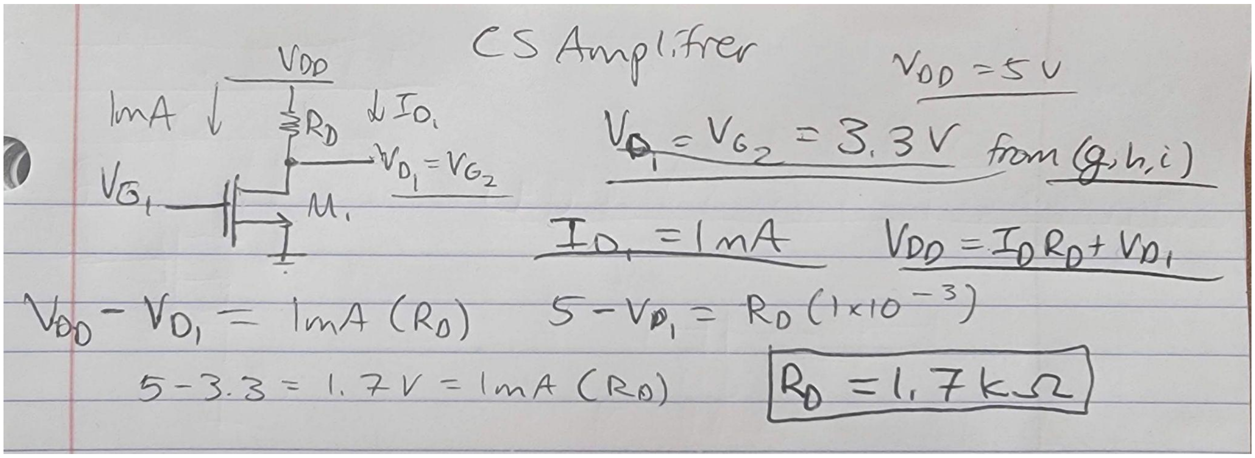


Figure 7: Formulas and calculations for estimating drain resistance value Rd

(l) Based on the current of 1mA chosen above, determine what DC gate bias is needed at the input of the Common-Source stage. It is recommended you use the same MOSFET as the one from Lab 6, since you have already characterized its properties. Once you determine this voltage, design the voltage divider network by calculating appropriate values of R1 and R2. You can freely choose these values based on the ratio you need, but respecting good design principles, choose resistor values in the range 10 kΩ to 100 kΩ.

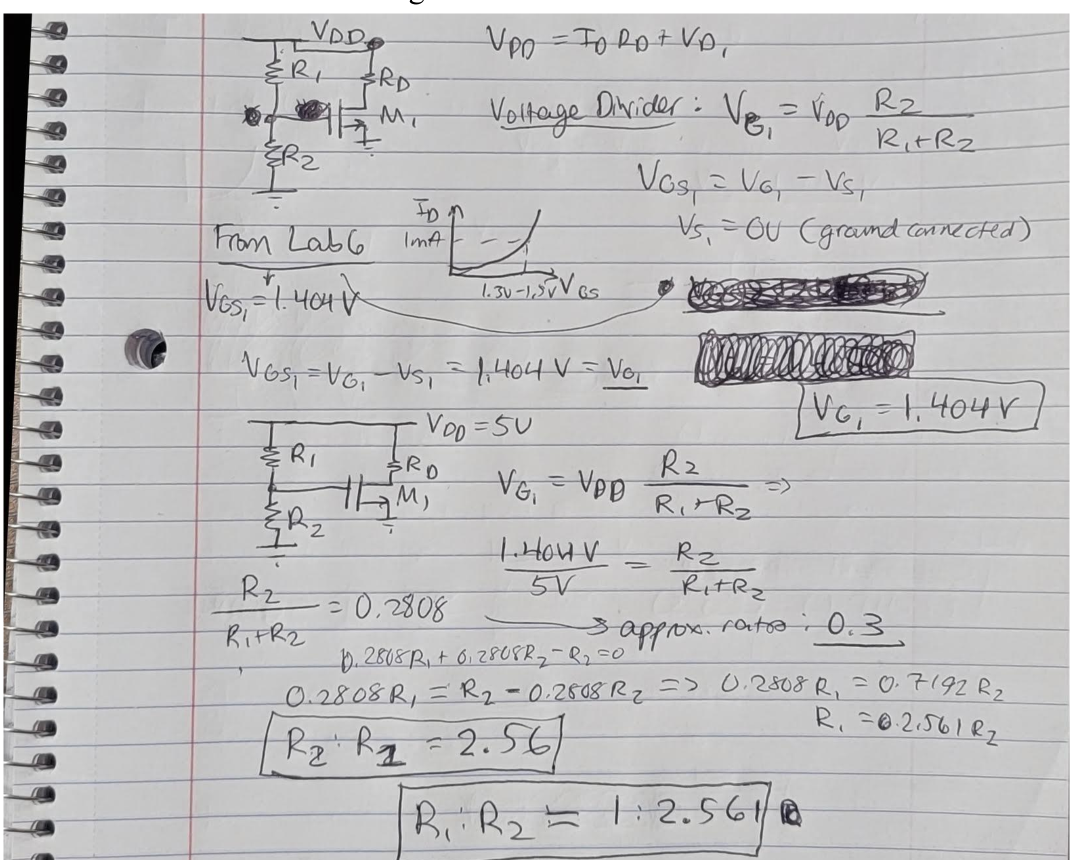


Figure 8: Formulas and Calculations for estimating gate bias and input resistance ratio at gate

With the calculated values, the ratio of the resistors between R2 and R1 is 2.56 to 1, or the ratio is approximately 5:2. With the available resistors for this lab, R1 = 20 kΩ and R2 = 47 kΩ.

(m) For a given resistor ratio, say 3:1, why is it good design practice to choose 30 kΩ and 10 kΩ as your resistor versus say 3 kΩ and 1 kΩ?
Resistances with smaller values have higher currents.
Higher resistance values allow for more degrees of freedom with the obtained voltage values and current values, providing more sense when designing amplifiers.

(n) Assuming we are dealing with input sine signals in 1 kHz range, choose an appropriate value of coupling capacitor, and justify your choice with the appropriate reasoning.
10 µF. From the Lab 7 background file, for EE 438 labs in general, C = 10 µF is typically chosen when dealing with 1 kHz.

(o) Provide an estimate of the small-signal gain of this stage of the amplifier
For the common-source amplifier topology, the small-signal gain is Av = -gm * Rd.

<u>TASK 2 QUESTIONS</u>
(a) First, setup only the 1st stage of the amplifier without the input voltage, vin. Measure the DC operating point of the circuit viz. VGS, VDS and ID. Tabulate and compare these values with the ones you designed for in Task 1.
From the circuit setup of the 1st stage of the amplifier,
Vgs = 3.468 V
Vds = 12 mV
Id = 2.77 mA
Using the formula, Vdd = IdRd + Vd (where Vd = Vds + Vs, Vs = 0V; Vd = Vds)

(b) If the values you measure in part (a) above are within 10% of what you designed for in Task 1, you can proceed to the next step. Otherwise, adjust your design to make sure you are within the 10% design target. State the changes you made in your report to achieve this.
The ratio between R2 and R1 was incorrectly calculated in my calculations as I had them flipped in the calculations. As such, the resistor values were changed, with R2 = 30kΩ and R1 = 68kΩ.

(c) Apply a small sine wave at the input of the circuit (small enough that you ensure small-signal operation) at a frequency of 1 kHz. Measure the peak-to-peak amplitude at the gate of the transistor as well as the drain and note these values in the report. Ensure for both these measurements, the signal you measure is a sine wave, and not distorted in anyway. From these measurements, estimate the small-signal gain of the 1st stage.

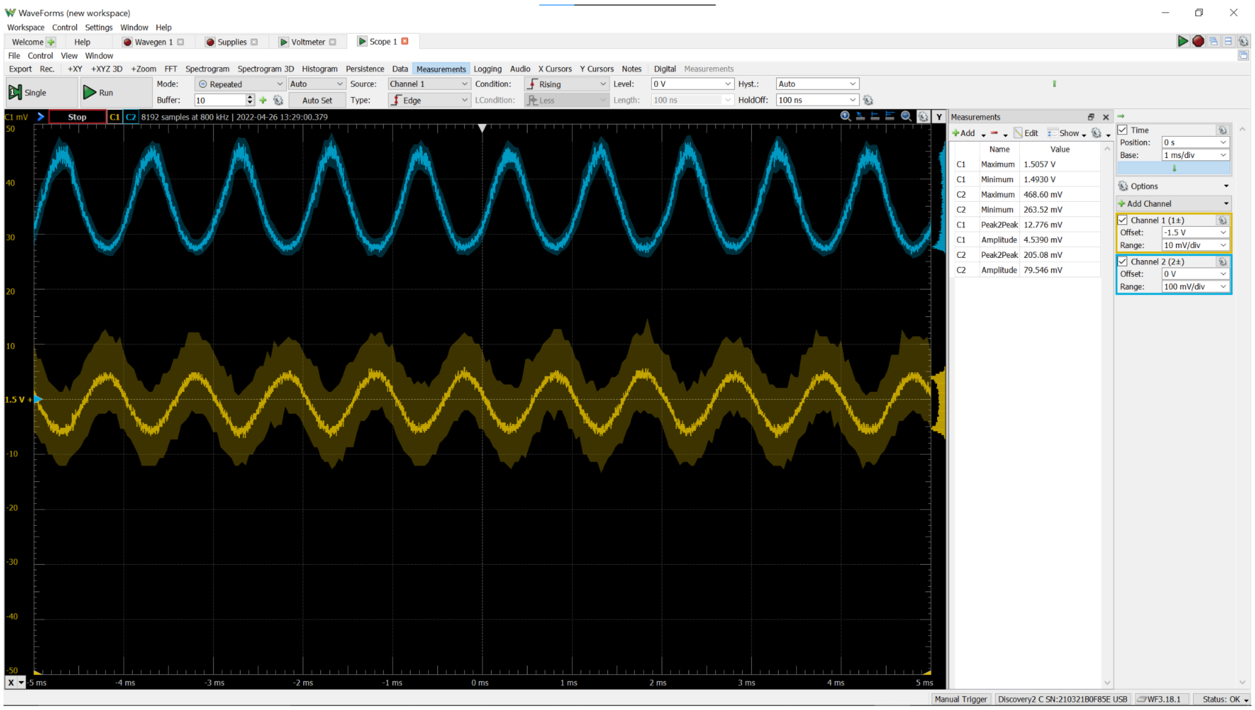


Figure 9: Measuring Peak-to-Peak Voltages at Drain and Gates of M1

In my case, my current through M1 was around 2 mA, which caused my gain to be abnormally high when measuring the peak-to-peak voltages. My peak to peak voltage at C2 was 200 mV and C2 was 12 mV, which puts the gain at around 16. As current increases, the gain is increased. As such, I had to decrease my input amplitude voltage to around 10 mV to adjust for the increased gain and currents. Referring to the small-signal model, when input is too high, we get distortions, as seen above.

(d) What is the maximum achievable signal swing at the output of stage 1?

20 mV

(h) Now with RS chosen as 100 Ω, replace the red LED with green LED. Compare the brightness of the LED with the red LED (for the same voltages and currents). Explain the change in brightness you observe.

The green LED is much dimmer than red LED.

CONCLUSION

In this lab, we have managed to successfully design a multi-stage MOSFET amplifier circuit driving an LED. We understood how DC biasing functions with different amplifier topologies and how LEDs are affected by the design of their internal components. Most importantly, we have learned how to characterize all of the currents and voltages (small signal DC and AC currents and voltages) according to the common-source and common-drain MOSFET amplifier topologies.