DESIGN OF A MULTI-STAGE MOSFET LINEAR LED DRIVER

IN-LAB DEMO: FRIDAY APR 15 2022 (Signup required)
REPORT DUE: FRIDAY APR 15 2022, 11:59 PM on Canvas

LEARNING OBJECTIVES

The goal of this lab is use the MOSFETs you characterized in the previous lab to design a multi-stage amplifier to drive a LED. You will learn how to setup 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.

WORKSTATION

- Analog Discovery 2 (AD2)
- Laptop/PC
- Digital Multimeter

COMPONENTS

- Resistors - Values as needed from your kit and/or the lab checkout counter.
- 2 x 2N7000 MOSFETs (N-channel enhancement), TO-92 package (datasheet available in Canvas, refer to your characterization data from Lab 6)
- 1 µF/10 µF electrolytic capacitors from your kit.
- 2 Red LEDs and 1 Green LED from the checkout counter.

Task 1

The purpose of this lab is to design a two-stage linear MOS amplifier to drive a LED. In order to give you some direction in the design, you will work on the specific circuit shown in Fig 1. Each stage of the amplifier is highlighted for clarity. You will perform some reading and answer the questions that follow so that you have the necessary background material needed to complete the design. The background material is in a file called Lab7-Background.pdf on Canvas.

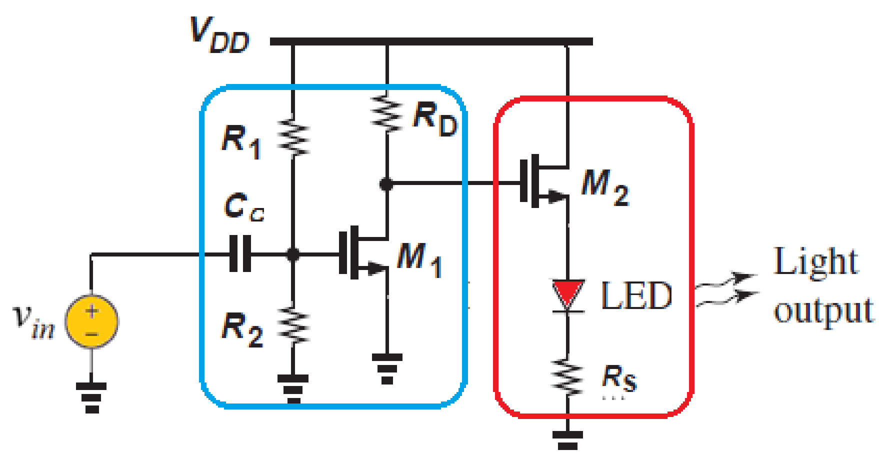

Figure 1: Two-stage MOS LED driver

Read the sections corresponding to LEDs and answer the following questions.

(a) What material property of a PN-junction determines the color output of a LED?
(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.
(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?
(d) Comment on the purpose of the series resistor (whether 100 Ω or 500 Ω) in this 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?
(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.

Read the section corresponding to common-drain stages and answer the following questions:

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

Read the section corresponding to Common-Source gain stages, voltage divider biasing and capacitive coupling and answer the following questions:

(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 R_D would you need. Pick the nearest available standard resistor values and state it in your report.
(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 R_1 and R_2. 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.
(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?
(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.
(o) Provide an estimate of the small-signal gain of this stage of the amplifier.

Task 2

In this part of the lab, you will put together the two stages of the amplifier based on the analysis and design choices in Task 1.

(a) First, setup only the 1st stage of the amplifier without the input voltage, v_{in}. Measure the DC operating point of the circuit viz. V_{GS}, V_{DS} and I_D. Tabulate and compare these values with the ones you designed for in Task 1.

(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.

(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.

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

Next we will connect the 2nd stage of the amplifier to the 1st stage as shown in Fig. 1.

(e) Measure the DC operating point of the 2nd circuit by measuring the source voltage of M_2, as well as the current through M_2. Tabulate and compare these values with the ones you designed for in Task 1. Do this for 100 Ω and 500 Ω resistor values.

(f) 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.
(*Troubleshooting tips: If you find you are far from the design target, the first thing you want to check is the value of V_{GS2} to make sure that is correct. Check with your transistor I_D-V_{GS} curves if the value of V_{GS} you are using will give you the desired LED current. The value of current in the 2nd stage will be anywhere between 3x to 10x the current in the 1st stage. You must have sufficient V_{GS} for M_2 to sink this much current into the LED. If your V_{GS} is too small, one way to increase it is by pulling the drain voltage of M_1 higher. Make small adjustments to the resistor value R_D to reduce the voltage dropped across it, which will increase V_{D1} and hence V_{G2}. Ensure that the operating point of the 1st stage is not disturbed too much by doing this*).

(g) Compare the brightness of the LED by switching resistor R_S between 100 Ω and 500 Ω resistor values. Now with this resistor chosen as 100 Ω, decrease the resistor R_D by approximately 30-50% in value, and observe if the LED brightness increases upon doing so. For each of the cases above, tabulate the DC operating points of both two stages of the circuit. (*We do this so that we have a quick snapshot for how the different design choices affect the brightness of the LED)*

(h) Now with R_S 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.

(i) Finally, to measure gain of the complete amplifier, measure the peak-to-peak AC voltage at the source of M_2 and the peak-to-peak AC current at the output of the 2nd stage. From these measurements, calculate the voltage gain and the trans-resistance gain (which is simply the output current over the input voltage)