Lab 5 Report

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1 Introduction

Through paper calculation, computer simulation, and physical measurements we will analyze the DC behavior of three similar circuits featuring an NMOS transistor. The first is an NMOS biased in the saturation region, as well as an NMOS biased in the triode region, and finally a diode connected NMOS transistor.

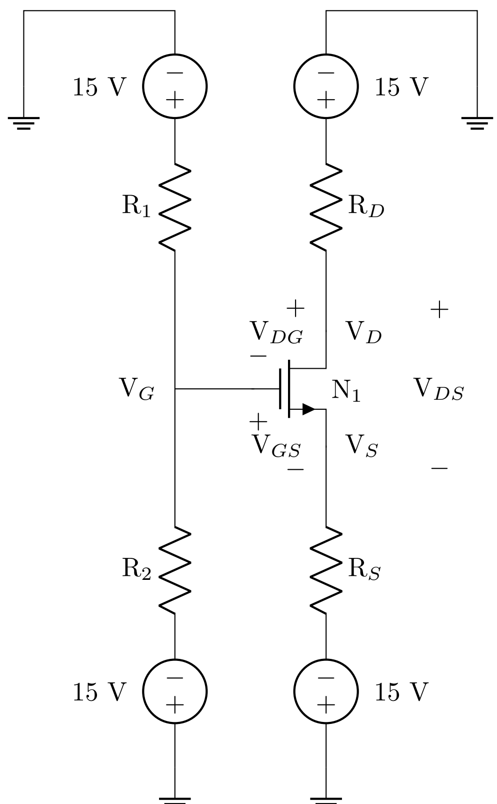


Figure 1: The Circuit we Analyze in this Lab

The transistor labeled N_1 is the same transistor as we used in the last lab, of the type 2N7000. For the first circuit we were tasked with designing the circuit such that $I_D = 1$ mA, $V_G = 0$ V, and $V_D = +5$ V. We need to select the resistor values that will satisfy such a circuit. The rail and drain voltages that we used were +15 V and -15 V.

2 Saturation Region Analysis/Experiment

2.1 Hand Calculations

The calculations are made for the circuit shown in Figure 1.

While searching for a data sheet of the 2N7000G on the internet we found this source on Microchip's website. From this data sheet we were able to find that the threshold voltage of the 2N7000 transistor is around 2.1 V. We also found from the documentation that at a V_{GS} of 5 V, the current I_D was 1 A. We can find k_n from this state using the equation $I_D = \frac{1}{2}k_n(V_{GS} - V_{TH})^2$. The value of k_n that we found from that equation was $k_n = 0.237812$.

With that value of k_n, we were able to use that same equation, but with a current of $I_D = 1$ mA to solve for a new V_{GS} of 2.1917 V. Knowing that $V_{GS} = 2.1917$ V, we can find V_S. Using the equation $V_S = V_G - V_{GS}$, we found that $V_S = 0 - 2.1917 = -2.1917$.

To finally solve the circuit, we need to select the resistor values that will give the specified values. R_1 and R_2 need to be the same value so that V_G can equal 0, and with a higher resistance there will be less power used in the circuit. The largest resistors available in the lab were 100 kΩ resistors, so we used those.

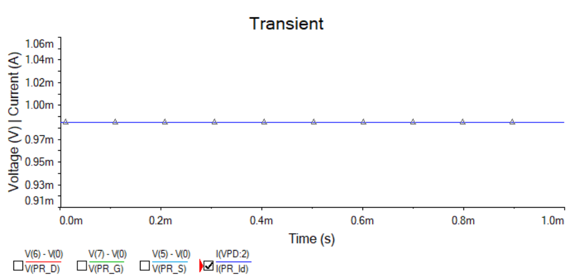
To find the value of R_D, we used Ohm's law. The voltage over that resistor was $15 - 5 = 10$ V, and the current through the resistor was 1 mA, so using $R = \frac{V}{i}$, we found that the resistor we needed to use was 10 kΩ. Likewise, we used Ohm's law to find the value of the resistor R_S, the difference in voltage was $-15 - (-2.1917) = 12.8083$ V. With just 1 mA of current, the resulting resistor value was 12.808 kΩ.

To match those specific resistor values I wrote a python script which takes a list of available resistors and shows a combination of resistors which can be combined in a resistor network to get near that resistor value. We were able to get within 1% of the resistor value by combining a 15 k, 100 k, and 680 k resistors in parallel.

Based on this specification, V_{OV} is $V_{GS} - V_{TH} = 2.1917 - 2.1 = 0.0917$ V.

2.2 Simulation

As shown in Figure 2, we simulated the circuit and found that the current I_D was just shy of 1 mA, and the voltages V_G, V_D, and V_S were very similar to our calculated values.



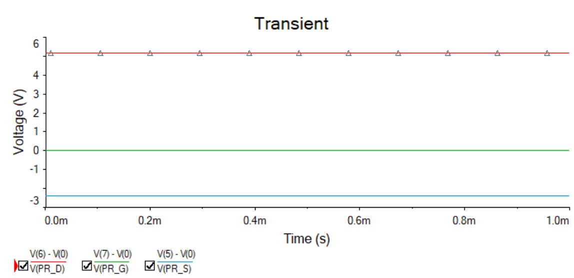


Figure 2: Results from the Simulation 1

2.3 Prototyping and Measurement

After building the circuit we measured several values, shown in Figure 3.

The measurements that we made were right in line with our calculations, and we didn't get any interesting results like we did in the lab last week.

2.4 Post-Measurement Exercise

Our measured values for V_{GS} and V_{DS} were very near the calculated values. Small discrepancies could be explained by slightly different resistors or the threshold voltage of the transistor not being exactly 2.1 V.

V_G	-24.1 mV
V_D	5.32 V
V_S	-2.30 V
V_{GS}	2.27 V
V_{DS}	7.6 V
I_D	0.994 mA
Resistor Values	
R_S	12.773 kΩ
R_D	9.74 kΩ
R_1	99.61 kΩ
R_2	99.94 kΩ

Figure 3: Table of Measured Values from Part 1

We directly measured the value of I_D in the circuit and got a value of 0.994 mA. If we use the V_D of 5.32 V, and R_D of 9.74 kΩ, with a V_{DD} of 15 V, we get a current of $\frac{15-5.32}{9740} = 1.004$ mA. That's close to our measured value, and very close to the calculated value as well.

3 Triode Region Analysis/Experiment

For this second part of the lab we're redesigning the circuit so that $I_D = 10$ mA, $V_D = 2$ V, and $V_{DS} = 0.1$ V. Once again we're using the same rail and drain voltages as the first part of the lab.

3.1 Hand Calculations

We are using the same circuit from Figure 1 for the calculation in this section as well. As opposed to the equation used in part 1, the equation we use to express I_D is $I_D = k_n(V_{OV} - \frac{1}{2}V_{DS})V_{DS}$. The k_n value remains the same as was calculated in the first section. Using this, we're able to find the value of V_{OV} from the I_D expression. The V_{OV} value that we found was 0.4705 V. We can then find $V_{GS} = 2.5705$ from the expression $V_{OV} = V_{GS} - V_{TH}$.

From the defined values of $V_D = 2$ V and $V_{DS} = 0.1$ V, we can find that $V_S = 1.9$ V. Using V_S and V_{GS} we find that $V_G = 4.4705$ V.

To finish designing the circuit we need to select resistor values, using a voltage divider to get $V_G = 4.4705$ V we got $R_1 = 100$ kΩ and $R_2 = 184.9$ kΩ. We were able to combine a network of resistors using the same script as above to get near to those values.

Using the same Ohm's law method as above we were able to find $R_D = 1.3$ kΩ and $R_S = 1.69$ kΩ.

3.2 Simulation

As shown in Figure 4, we simulated the circuit and found that the current I_D was just shy of 10 mA, and the voltages V_G, V_D, and V_S were very similar to our calculated values.

3.3 Prototyping and Measurement

We build the circuit and found these measurements, shown in Figure 5.

Those values were mostly right in-line with the calculated values.

3.4 Post-Measurement Exercise

Those values were aligned very well with the calculated values, aside from V_{DS} which was a little higher than it should've been. Overall, though, the values were very similar to our calculations for an NMOS transistor in the triode region.

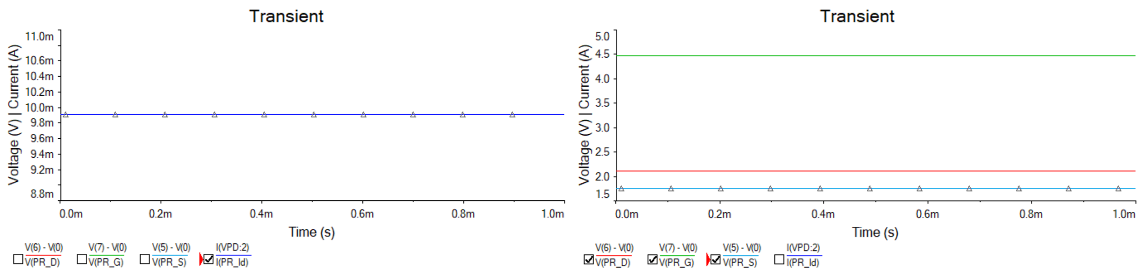


Figure 4: Results from the Simulation 2

V_G	4.731 V
V_D	1.885 V
V_S	1.836 V
V_{GS}	2.907 V
V_{DS}	48.32 mV
I_D	10.20 mA
Resistor Values	
R_S	1.653 kΩ
R_D	1.287 kΩ
R_1	99.95 kΩ
R_2	0.193 MΩ

Figure 5: Table of Measured Values from Part 1

4 Conclusion

Overall we were able to analyze the transistor in two different settings, both in the saturation region and the triode region. The most important part of the calculations was understanding the implementation of the equation that express I_D for the different operation regions. Without appropriately using those equations you can't fully analyze the circuit. I also thought it was interesting being able to read more information from the data sheets than I have in the past. The more we do these labs, the more I understand why transistors are so important in the worlds of electrical and computer engineering.