CMPE 110 Lab 6: ADC and DAC Circuits

Leonardo Blas

***Abstract*—The purpose of this lab project is to learn about analog-to-digital and digital-to-analog converter circuits (ADCs and DACs, respectively).**

I. INTRODUCTION

This lab project is based on the implementation of a 3-bit flash analog-to-digital and a 3-bit digital-to-analog converter circuits (ADCs and DACs, respectively) via operational amplifiers. Furthermore, we are given questions in the lab handout with each circuit's procedure, which we will try to answer throughout our discussion section.

A. Parts List

- Resistors
- Universal operational amplifiers
- Grounding components
- Generators (see each circuit for further details)

II. DESCRIPTION OF THE CIRCUITS' SCHEMATICS

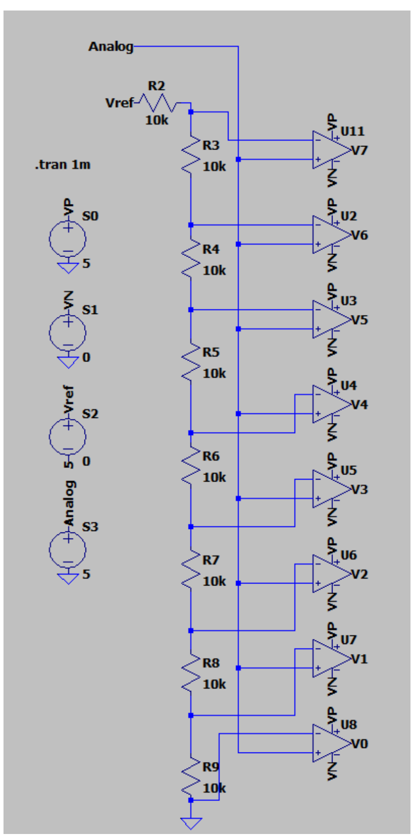

Figure 1. ADC without flash encoder branch (Part 1).

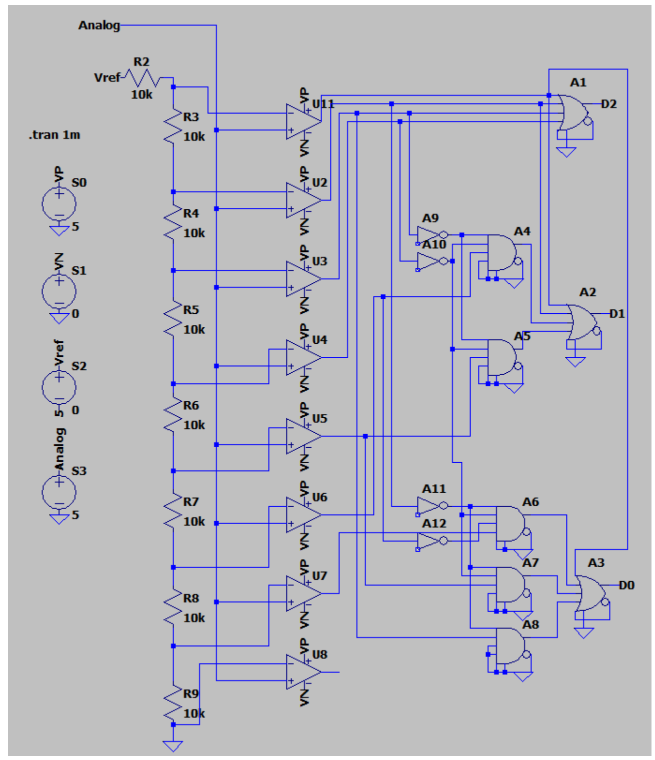

Figure 2. ADC with flash encoder branch (Part 1).

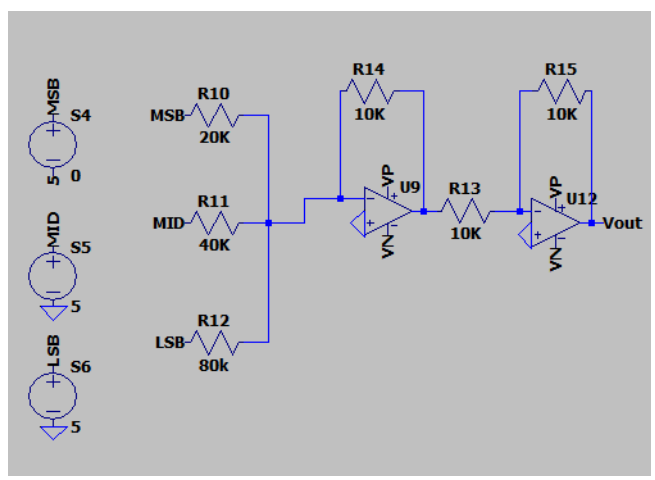

Figure 3. DAC (Part 2).

III. WAVEFORMS AND RESULTS

Part 1:

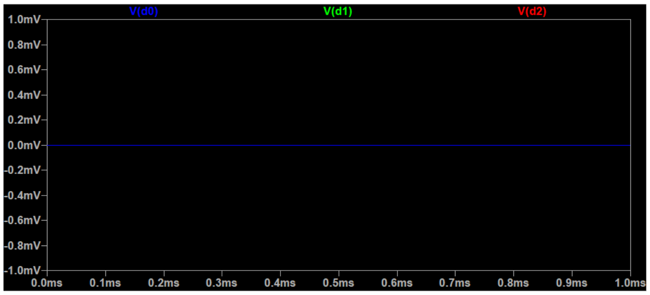

Figure 4. ADC with Analog at 0 V.

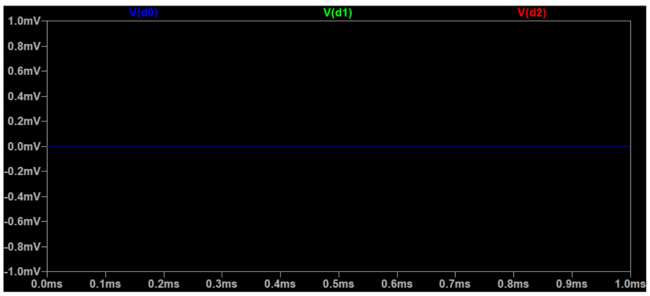

Figure 5. ADC with Analog at 0.5 V.

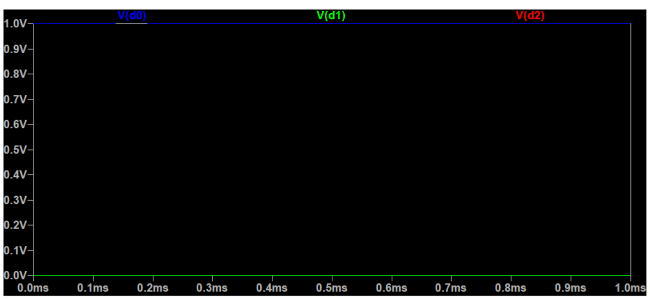

Figure 6. ADC with Analog at 1 V.

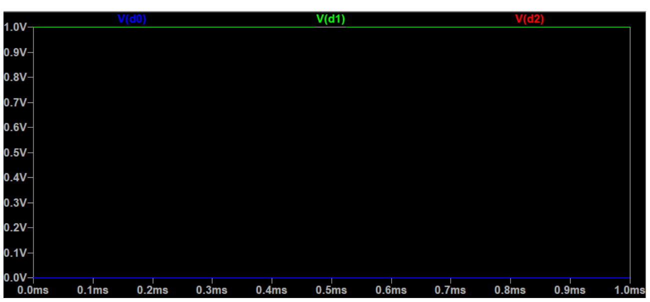

Figure 7. ADC with Analog at 1.5 V.

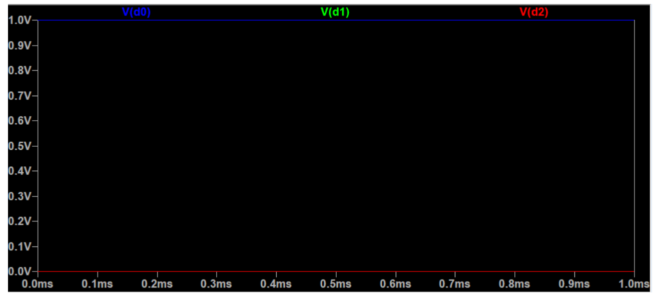

Figure 8. ADC with Analog at 2 V

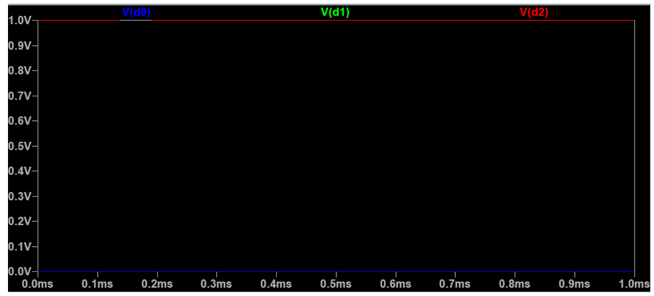

Figure 9. ADC with Analog at 2.5 V.

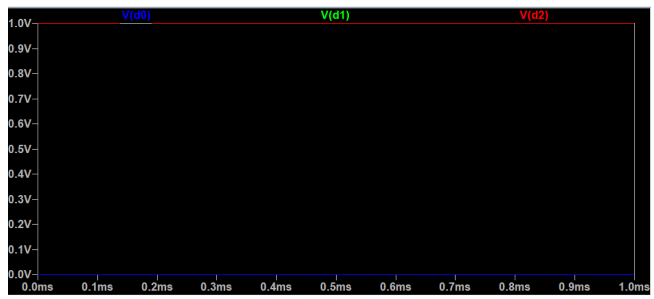

Figure 10. ADC with Analog at 3 V.

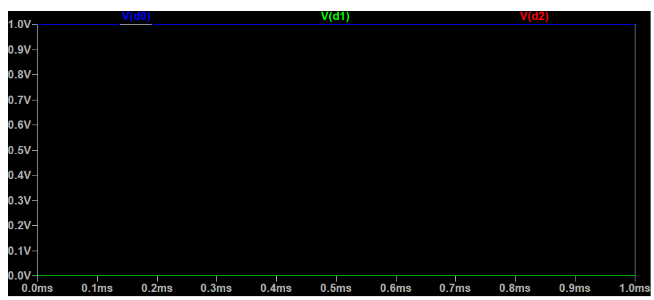

Figure 11. ADC with Analog at 3.5 V.

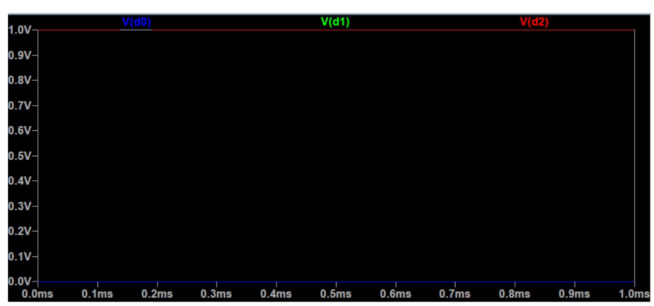

Figure 12. ADC with Analog at 4 V.

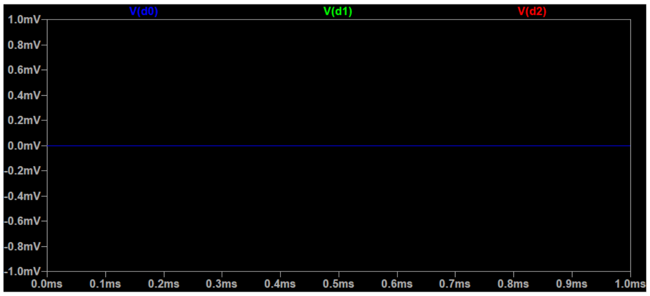

Figure 13. ADC with Analog at 4.5 V.

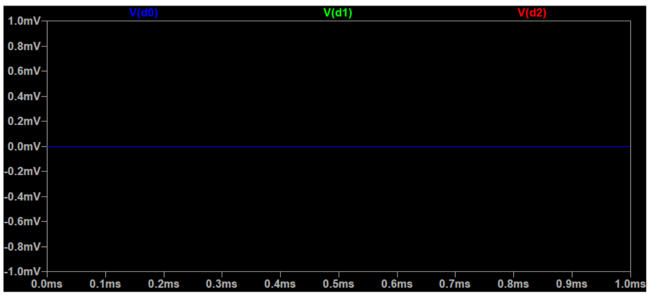

Figure 14. ADC with Analog at 5 V.

	(V)							
Analog	**V7**	**V6**	**V5**	**V4**	**V3**	**V2**	**V1**	**V0**
0	0	0	0	0	0	0	0	2.5
0.5	0	0	0	0	0	0	0	5.0
1.0	0	0	0	0	0	0	5.0	5.0
1.5	0	0	0	0	0	5.0	5.0	5.0
2.0	0	0	0	0	5.0	5.0	5.0	5.0
2.5	0	0	0	2.5	5.0	5.0	5.0	5.0
3.0	0	0	0	5.0	5.0	5.0	5.0	5.0
3.5	0	0	5.0	5.0	5.0	5.0	5.0	5.0
4.0	0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
4.5	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0
5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0	5.0

Table 1. ADC input and Vout voltages.

To compute the quantization error at the input, we subtract our reference voltage 5V from the operational amplifiers' negative terminal's voltage:

Op Amp #	Negative terminal (V)	5 V – Neg. terminal (V)
7	4.375	0.625
6	3.75	1.25
5	3.125	1.875
4	2.5	2.5
3	1.875	3.125
2	1.25	3.75
1	0.625	4.375
0	0	5

Table 2. Quantization error at the input computations.

Analog (V)	D2 (V)	D1 (V)	D0 (V)
0	0	0	0
0.5	0	0	0
1.0	0	0	1
1.5	0	1	0
2.0	0	1	1
2.5	1	0	0
3.0	1	0	0
3.5	1	0	1
4.0	1	1	0
4.5	1	1	1

Table 3. ADC input and output voltages.

Part 2:

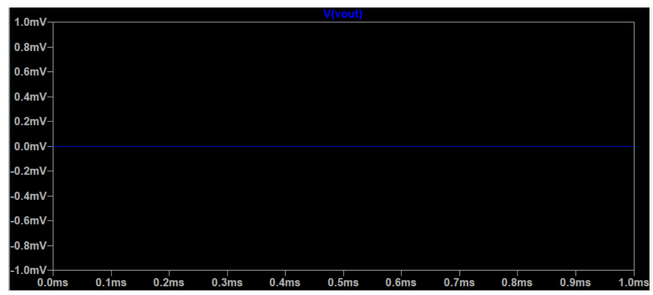

Figure 15. DAC case 0.

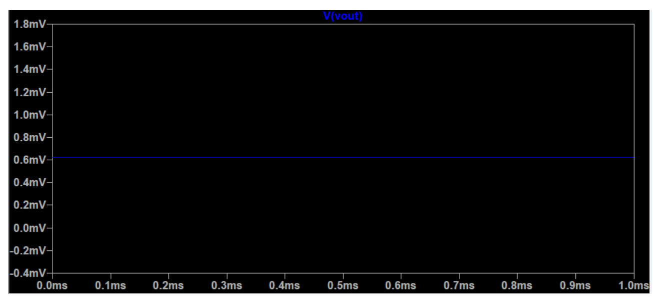

Figure 16. DAC case 1.

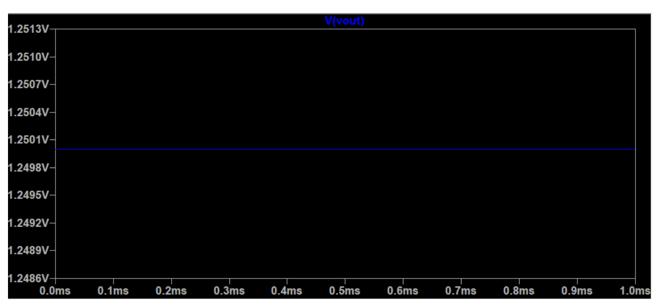

Figure 17. DAC case 2.

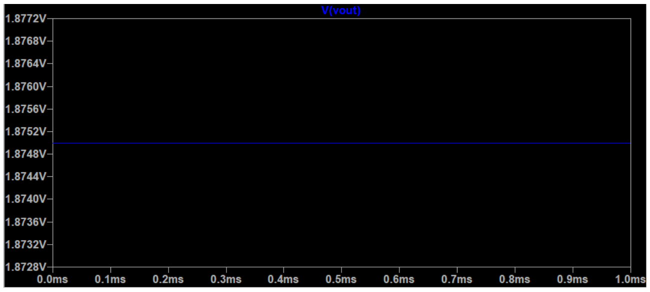

Figure 18. DAC case 3.

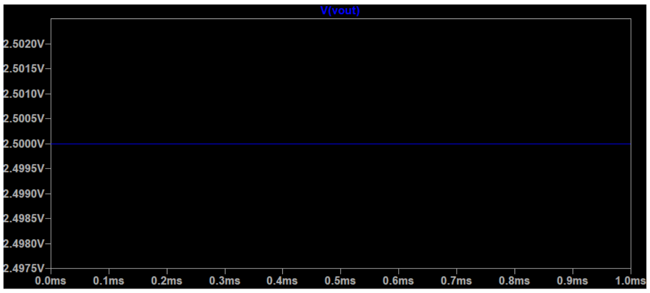

Figure 19. DAC case 4.

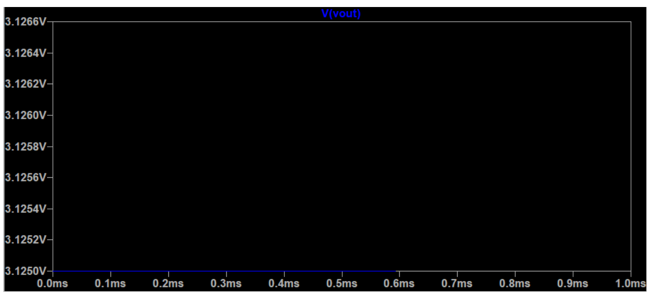

Figure 20. DAC case 5.

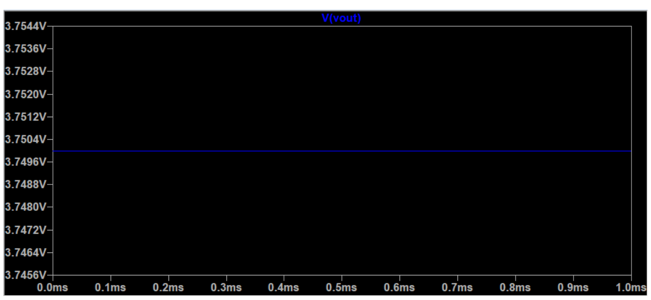

Figure 21. DAC case 6.

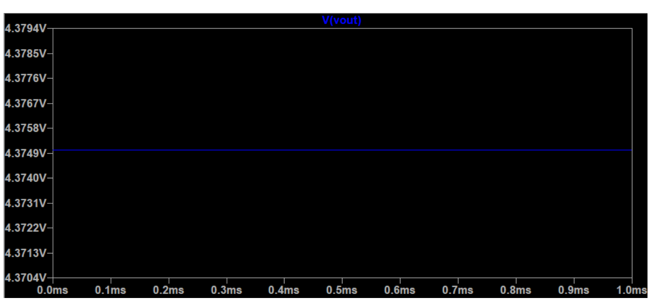

Figure 22. DAC case 7.

	Digital Input			Analog Input	
Case #	**MSB**	**MID**	**LSB**	**Theoretical Vout (V)**	**Experimental Vout (V)**
0	0	0	0	0.00	0
1	0	0	1	0.625	0.62499824
2	0	1	0	1.250	1.2499678
3	0	1	1	1.875	1.8749899
4	1	0	0	2.5	2.4999865
5	1	0	1	3.125	3.1249906
6	1	1	0	3.75	3.7499886
7	1	1	1	4.375	4.3749932

Table 4. DAC input and output cases.

Case #	% error (%)
0	0
1	0.0003
2	0.0026
3	0.0054
4	0.0005
5	0.0003
6	0.0003
7	0.0002

Table 5. DAC results % error computations.

IV. DISCUSSION

Part 1:

- No theoretical-practical inconsistencies found when implementing the ADC circuit.
- Out [7:0] relates to our analog input by its magnitude. Out [7] becomes 5V only when our analog input is within 0.5V from 5V. So, Out [7] = 5 V only when Analog = 4.5 and 5 V.
- Given the digital data we gathered from the experiments with our ADC circuit—see the truth table, **Table 3**—we can argue that not only our circuit but also our flash encoder are working properly.

Part 2:

- No theoretical-practical inconsistencies found when implementing the DAC circuit.
- Our error computations proved to be low enough for us to be able to disregard them.
- Given the analog data we gathered from the experiments with our DAC circuit—see **Table 4**—we can argue that our circuit is working properly.

V. DESCRIPTION OF THE LEARNING EXPERIENCE

While, overall, the lab handout contained instructions that were clear and well-defined, the most challenging part was designing the flash encoder. In my opinion, LTspice is a potent simulation software when dealing with analog circuits, but it’s not too friendly at the time of designing digital circuits—which other software, like LogicWorks, handle better.

The most valuable aspect of this experiment was not only to be introduced to the concept of converting analog into digital signals, and vice versa, but also learning how this is done, with which circuits and with which parts.

All in all, this was a fruitful experience where we were exposed to yet another use for op-amps, as well as an important concept in the topic of signals and signal processing.

VI. CONCLUSION

In conclusion, we learned how to transform analog into digital signals, and vice versa, which is a fundamental concept for any computer and electrical engineer. Furthermore, we chained our existing knowledge on operational amplifiers to explore yet another branch within the world of circuits and electronics.
Knowing how ADC and DAC circuits work, we know have more knowledge of how many of our day-to-day devices, like headphones, operate under the hood.