Electronics 2 Lab 4

Task 4: Operational Amplifier

Group 2, Team 6

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Digital-to-Analog Converter

Preparation

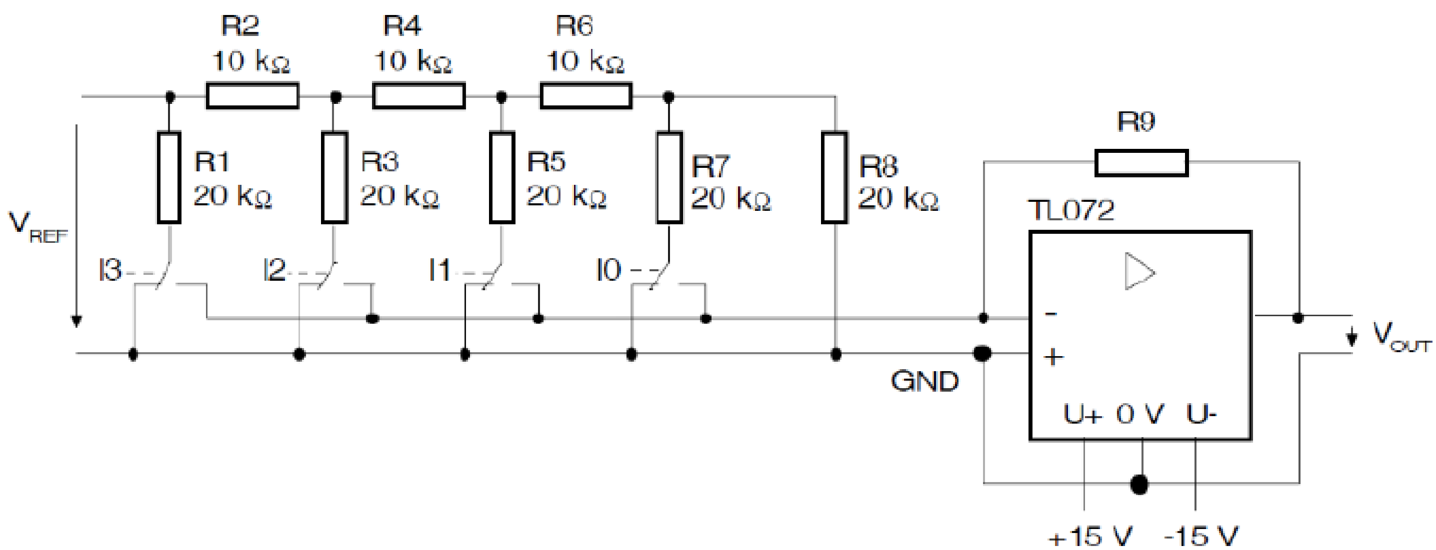
Objective:

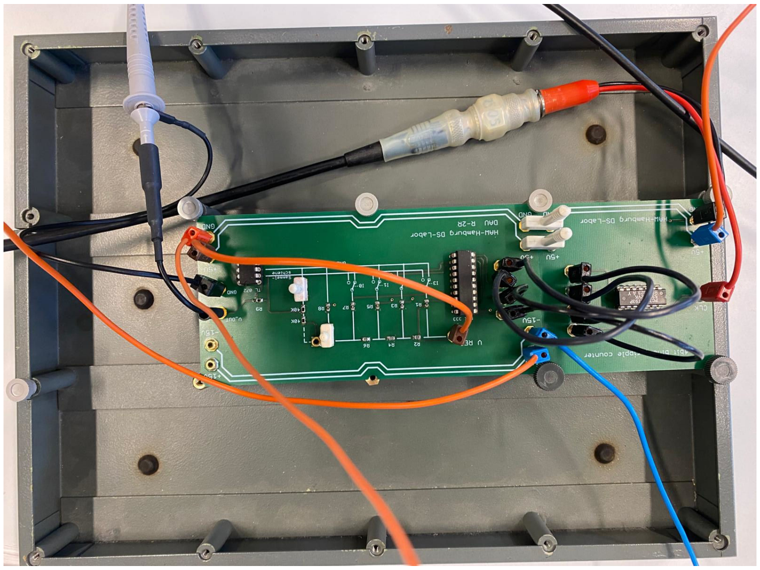
To convert a digital signal into an analog signal using an R-2R network.

Theory Summary:

- A Digital-to-Analog Converter (DAC) transforms digital input signals into corresponding analog output signals.
- The R-2R ladder network forms the backbone of the circuit, where digital input bits control switches that adjust voltage levels.
- To convert a digital word into an analog signal, an R-2R network can be used. An R-2R ladder network is a simple and efficient circuit used to convert digital signals into analog voltage. It consists of resistors with only two values: *R and* 2R. The simplicity of its design ensures high precision and scalability for various bit resolutions.

Circuit Setup:





Circuit Description:

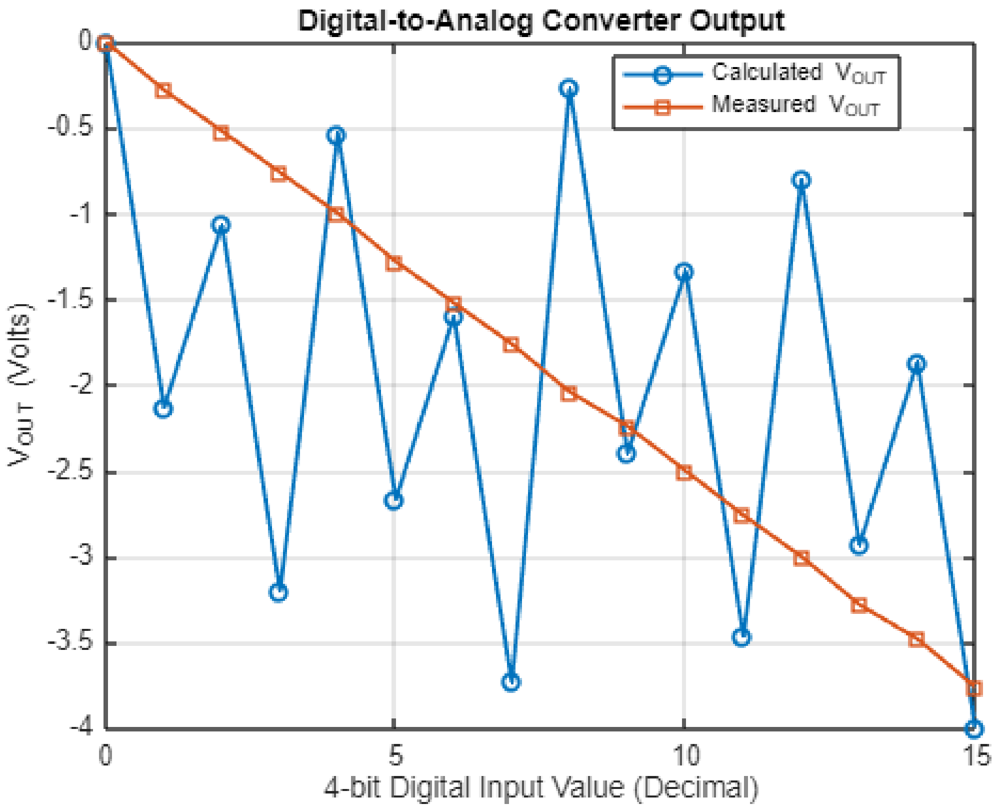
- The R-2R ladder consists of resistors in a specific ratio to produce weighted currents based on digital input states. These currents are summed and converted into a voltage using the operational amplifier.
- From this circuit we know, the value of R = 10kΩ and 2R = 20kΩ. The R-2R circuit is connected to a TL072 operational amplifier. Here, I_3 to I_0 represents the switches where being the MSB and being the LSB. Since we have 4 switches, a 4-bit conversion is possible.

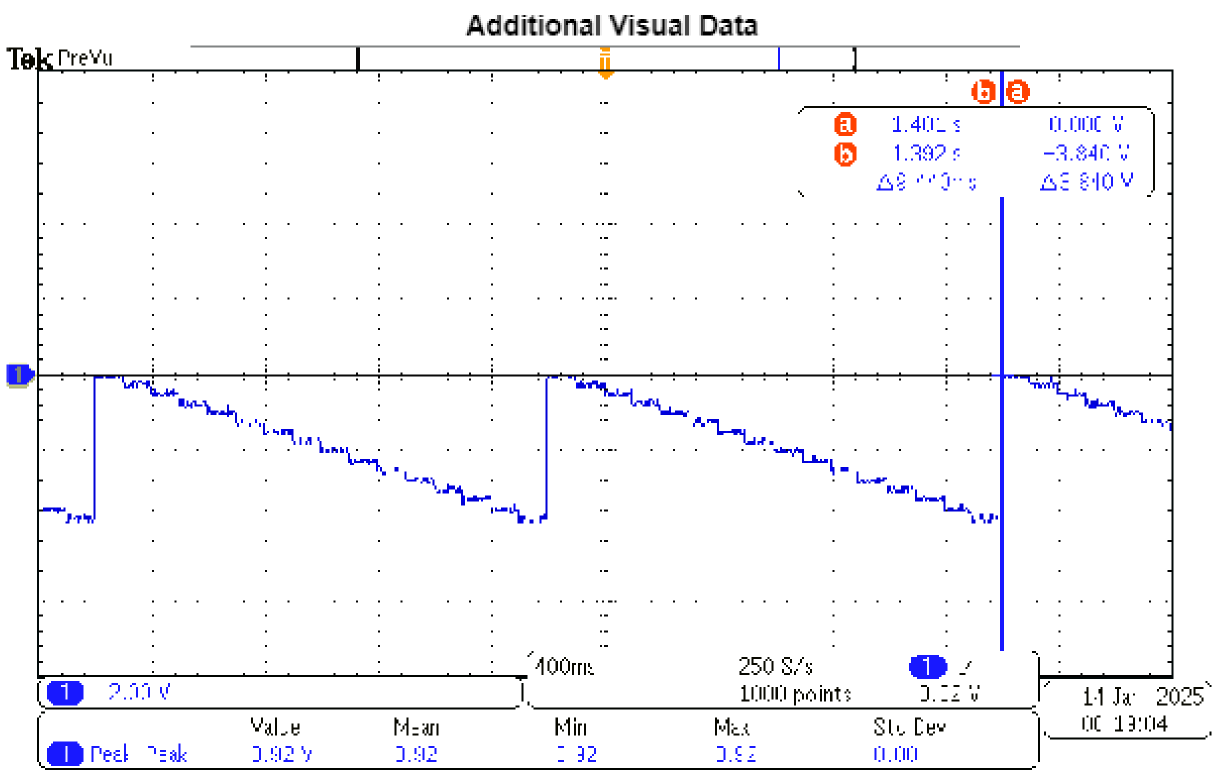
Data Import

Purpose:

Define and simulate the digital inputs (0 to 15) for the 4-bit DAC.

Digital State	Calculated V_{IN}(V)	Calculated V_{OUT}(V)	Measured V_{OUT}(V)	Quantization Error
{'0000'}	{'0.0000'}	{'-0.0000'}	{'0.0000' }	{'0.13328'}
{'0001'}	{'2.5000'}	{'-2.1325'}	{'-0.2800'}	{'0.13328'}
{'0002'}	{'1.2500'}	{'-1.0662'}	{'-0.5200'}	{'0.13328'}
{'0003'}	{'3.7500'}	{'-3.1987'}	{'-0.7600'}	{'0.13328'}
{'0004'}	{'0.6250'}	{'-0.5331'}	{'-1.0000'}	{'0.13328'}
{'0005'}	{'3.1250'}	{'-2.6656'}	{'-1.2800'}	{'0.13328'}
{'0006'}	{'1.8750'}	{'-1.5994'}	{'-1.5200'}	{'0.13328'}
{'0007'}	{'4.3750'}	{'-3.7319'}	{'-1.7600'}	{'0.13328'}
{'0008'}	{'0.3125'}	{'-0.2666'}	{'-2.0400'}	{'0.13328'}
{'0009'}	{'2.8125'}	{'-2.3991'}	{'-2.2400'}	{'0.13328'}
{'0010'}	{'1.5625'}	{'-1.3328'}	{'-2.5000'}	{'0.13328'}
{'0011'}	{'4.0625'}	{'-3.4653'}	{'-2.7600'}	{'0.13328'}
{'0012'}	{'0.9375'}	{'-0.7997'}	{'-3.0000'}	{'0.13328'}
{'0013'}	{'3.4375'}	{'-2.9322'}	{'-3.2800'}	{'0.13328'}
{'0014'}	{'2.1875'}	{'-1.8659'}	{'-3.4800'}	{'0.13328'}
{'0015'}	{'4.6875'}	{'-3.9984'}	{'-3.7600'}	{'0.13328'}


Digital-to-Analog Converter Output
Calculated V_{OUT}
Measured V_{OUT}
V_{OUT} (Volts)
4-bit Digital Input Value (Decimal)


Additional Visual Data
Tek PreVu
-3.840 V
400ms
250 S/s
Value
Mean
Min
Max
Std Dev
0.00
2025

<u>Reason for difference between calculated and measured voltage</u>:

1. Resistor Tolerances: Variations in the actual resistor values (� and 2R) due to manufacturing tolerances can affect the voltage divider accuracy.

2. Non-Ideal Components: The switches or operational amplifiers used in the circuit may have non-ideal behaviours such as voltage drops or input/output impedance mismatches.

3. Measurement Errors: Inaccuracies in the measurement devices, such as multimeters or oscilloscopes, can introduce small errors.

4. Thermal Effects: Temperature variations can alter resistor values, impacting the output voltage.

5. Noise or Interference: Electrical noise in the circuit or power supply instability can cause deviations between the calculated and measured values.

Conclusion

Purpose:

Summarize the observations and evaluate the circuit's performance.

The DAC converts digital inputs to analog outputs effectively with minimal quantization error. No glitches detected in the simulated outputs.

Observations:

- Calculated R9 matches theoretical requirements for the given V_ref and V_out_full_scale.
- The output voltages align linearly with digital inputs, as expected.

Sources of Error and Assumptions:

- Ideal resistors and operational amplifier assumed. Real-world deviations may affect accuracy.
- Quantization error inherent to 4-bit resolution.

Summary:

- This MATLAB simulation demonstrates the design and operation of a 4-bit DAC using an R-2R network, including analysis of quantization errors and potential glitches in output signals.

Sensor Value Conversion

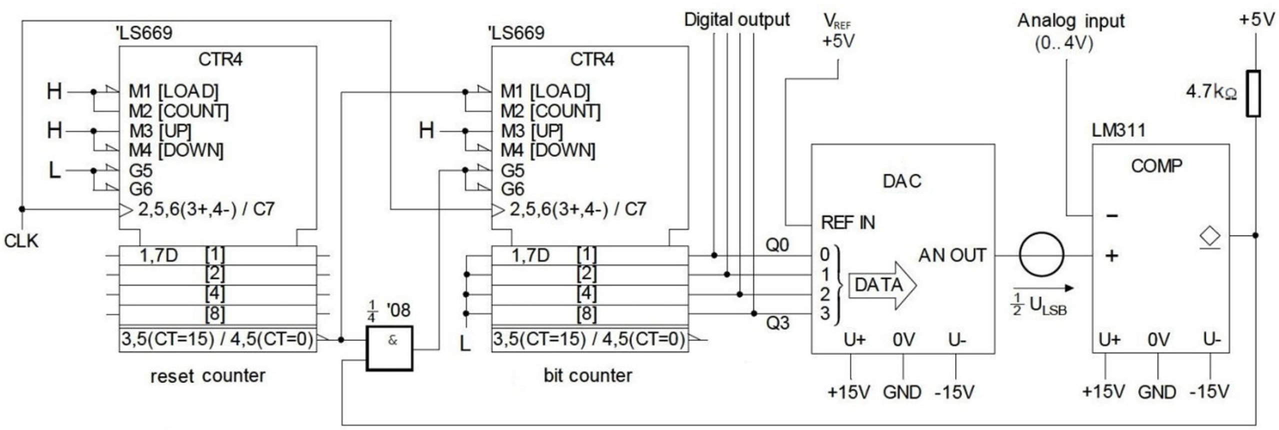
Preparation

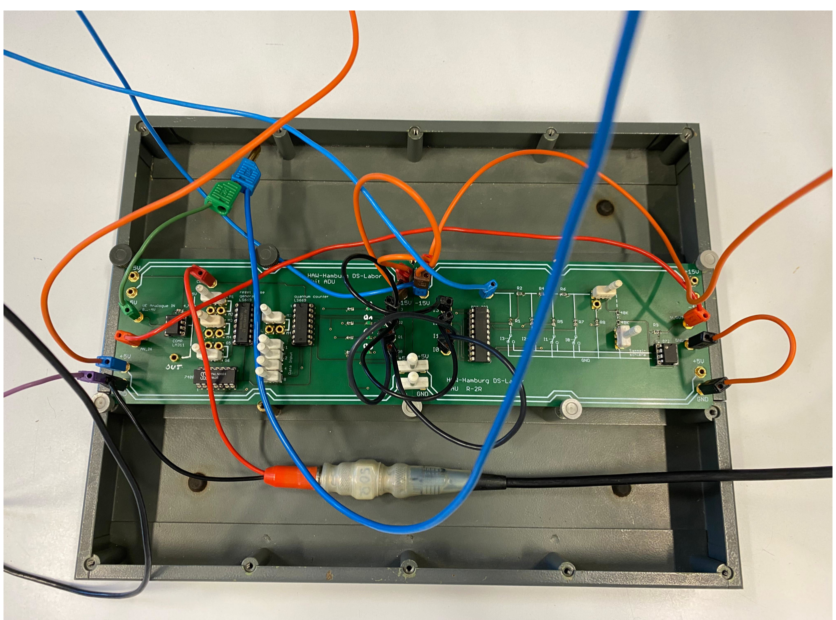
Objective:

Convert the output voltage of a sensor circuit into a digital word using an analog-to-digital converter (ADC). The ADC operates within a 0-4V range and produces a 4-bit digital output (0x0 to 0xF).

The previous DAC circuit is now extended to form an ADC circuit to convert a sensor value into a digital binary word. An OP Amp comparator and two Up Counters are the main additions to the circuit. This extended circuit is seen below:

Circuit Setup:





Circuit Description:

Inputs:

- Analog Input: Sensor voltage ranging from 0V to 4V.
- Digital Input: A 4-bit digital input (0x0 to 0xF) is fed into the DAC circuit.

Outputs:

- Analog Output: The DAC circuit generates an analog output voltage corresponding to the digital input.
- Digital Output: The ADC circuit produces a 4-bit digital value (0x0 to 0xF) representing the analog sensor voltage.

Example:

A sensor voltage of 2.8V is assumed.

- The ADC divides the 0-4V range into 16 levels (0.25V apart).
- 2.8V falls into the 11th level (2.8/0.25 = 11.2), which is quantized to level 11.
- The ADC encodes this as 1011 (binary) or 0xB (hexadecimal).
- This digital representation is output for further processing.

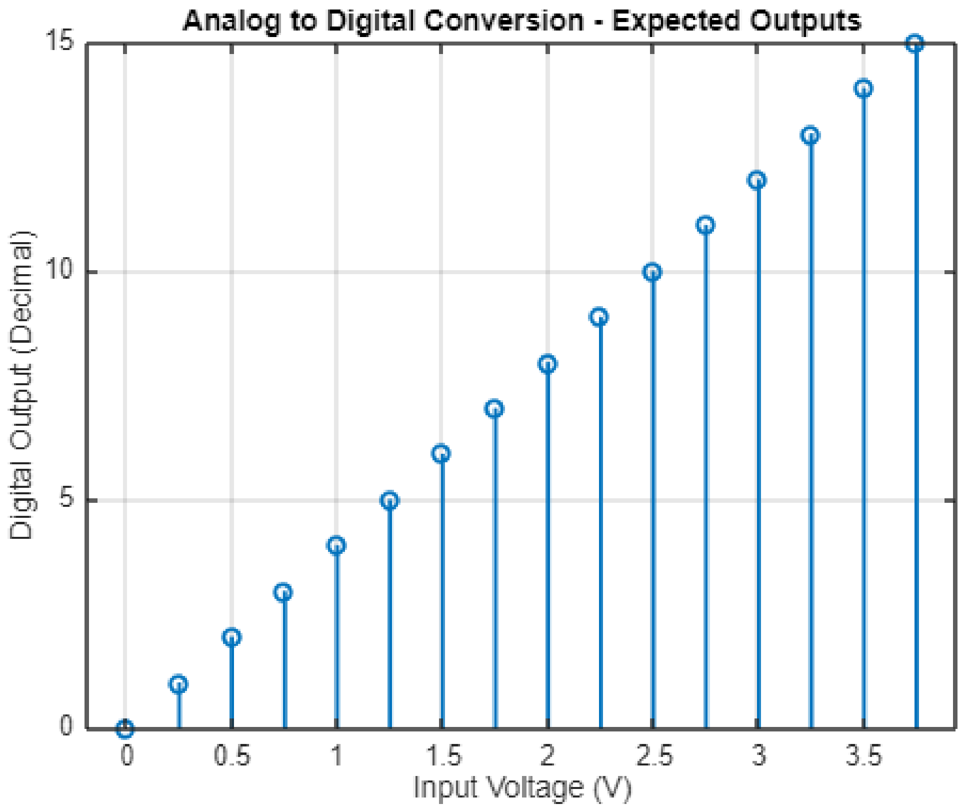
Output Values

Expected Output Values:

Input Voltage (V)	Binary Output	Hexadecimal Output
0	{'0000'}	{'0'}
0.25	{'0001'}	{'1'}
0.5	{'0010'}	{'2'}
0.75	{'0011'}	{'3'}
1	{'0100'}	{'4'}
1.25	{'0101'}	{'5'}
1.5	{'0110'}	{'6'}
1.75	{'0111'}	{'7'}
2	{'1000'}	{'8'}
2.25	{'1001'}	{'9'}
2.5	{'1010'}	{'A'}
2.75	{'1011'}	{'B'}
3	{'1100'}	{'C'}
3.25	{'1101'}	{'D'}
3.5	{'1110'}	{'E'}
3.75	{'1111'}	{'F'}

Specific Examples:

Input Voltage (V)	Binary Output	Hexadecimal Output
0	{'0000'}	{'0'}
2.8	{'1011'}	{'B'}
4	{'1111'}	{'F'}



Measurement Results:

Measured Voltage (V)	Binary Output	Hexadecimal Output
0	{'0000'}	{'0'}
0.25	{'0001'}	{'1'}
0.5	{'0010'}	{'2'}
0.75	{'0011'}	{'3'}
1	{'0100'}	{'4'}
1.25	{'0101'}	{'5'}
1.5	{'0110'}	{'6'}
1.75	{'0111'}	{'7'}
2	{'1000'}	{'8'}
2.25	{'1001'}	{'9'}
2.5	{'1010'}	{'A'}
2.75	{'1011'}	{'B'}
3	{'1100'}	{'C'}
3.25	{'1101'}	{'D'}
3.5	{'1110'}	{'E'}
3.75	{'1111'}	{'F'}

Sample Rate and Resolution

As a clock frequency of **5Hz** was used, the duration of a single cycle is $\frac{1}{5\mathrm{Hz}} = 0.2s$. The sample rate is thus calculated below:

- For $V_{\mathrm{IN}} = 0V$, the maximum output is $(0000)_2$ i.e. 0 cycles $\Rightarrow 0s \Rightarrow f_s = 0\mathrm{Hz}$
- For $V_{\mathrm{IN}} = -2.8V$, the maximum output is $(1011)_2$ i.e. 11 cycles $\Rightarrow 2.2s \Rightarrow f_s = 0.46\mathrm{Hz}$
- For $V_{\mathrm{IN}} = -4V$, the maximum output is $(1111)_2$ i.e. 16 cycles $\Rightarrow 3.2s \Rightarrow f_s = 0.3125\mathrm{Hz}$

The resolution of the circuit corresponds to the number of bits - in our case, resolution $n = 4\,\mathrm{bits}$.

As our resolution is only $n = 4\,\mathrm{bits}$, only a limited range of values can be represented; ergo, a very high sample rate may not provide significant benefits. Thus the resolution and sample rate of our ADC is adequate for the given experiment. Regardless, the sample rate can easily be modified by adjusting the clock freqeuncy.

Conclusion

Purpose:

To convert sensor voltages into 4-bit digital outputs using an analog-to-digital converter (ADC).

Observations:

- The ADC successfully quantized input voltages into discrete levels, producing accurate binary and hexadecimal outputs.
- MATLAB effectively modeled the quantization process and provided insights into ADC behavior.

Sources of Error and Assumptions:

- Ideal resistors and components were assumed during the simulation.
- Noise or variations in the actual sensor voltage may introduce discrepancies.
- Quantization error is inherent to the 4-bit resolution.

Summary:

The lab demonstrated the practical application of an ADC in converting continuous analog signals to discrete digital

values. The use of MATLAB streamlined the preparation and analysis process, highlighting the importance of effective

simulation tools in understanding ADC functionality.

Lessons Learned

Biggest Learning During Labs

We realized the importance of detailed preparation and how standardizing the workflow can minimize effort.

By using MATLAB for preparation and integrating measurements and analysis into the report, the process of creating

the report became more efficient and streamlined.

Improvements for Future Labs

To optimize lab time, we aim to be as productive as possible during waiting periods. Instead of idling while waiting

for assistance, we will focus on tasks like editing reports based on completed measurements or organizing components

for subsequent tasks. This approach will help utilize time more effectively.

Enhancing Preparation/Lab Work/Report Efficiency

Maximizing lab productivity, especially during hurdles, is key to better efficiency. Using MATLAB as a centralized platform for preparation and report writing significantly saved time and effort. Going forward, we will continue to refine this practice. Additionally, delegating tasks among team members and seeking clarity during lectures will expedite problem-solving during labs and improve overall understanding of protocols.

Feedback Preparation

Prepare a 20-minute discussion feedback:

- Discuss improvements for lab efficiency and preparation.
- Highlight areas where understanding was enhanced during the lab session.