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Lab 12: Digital to Analog Converter

Introduction

The purpose of this lab was to learn how to construct and analyze a digital to analog converter, as well as an analog to digital converter. A 7493 chip was used in the circuit as the counter. The DAC circuit for this lab is shown in Figure 1. The ADC circuit for this lab is shown in Figure 2. The ADC configuration incorporated the DAC set up. Knowledge of logic gates, op amps, and the 7493 chip were needed to understand how each factor worked together.

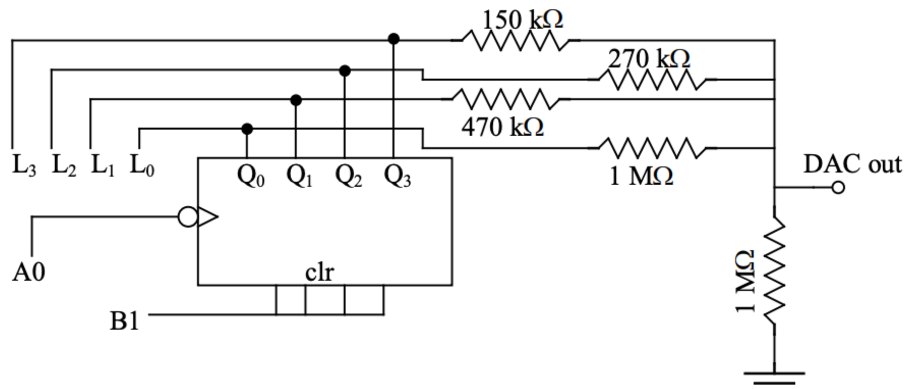

Figure 1. DAC circuit schematic (Gannett, lab handout, 2019)

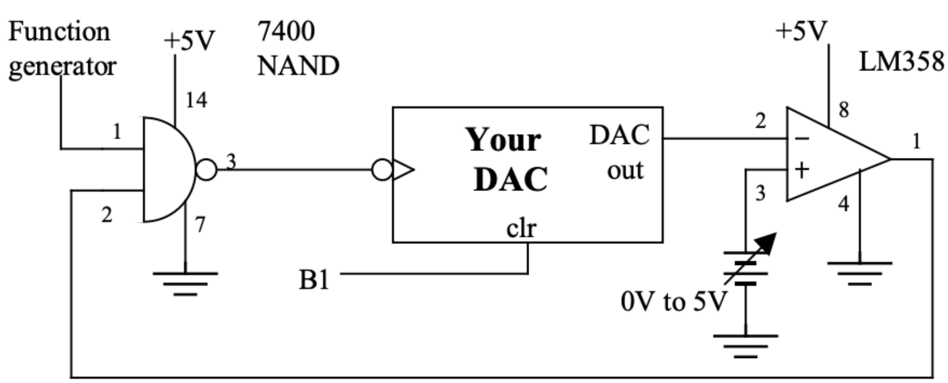

Figure 2. ADC circuit schematic (Gannett, lab handout, 2019).

Methodology

Most of our work this semester has involved analog circuitry, which deals with continuous voltage values. Recently we began studying digital circuitry as well, which involves binary logic and voltage values of either “high” or “low.” In this lab, we explored tools used for interfacing between these two types of circuits, called digital-to-analog converters (DACs) and analog-to-digital converters (ADCs).

These devices are very important in real-world electronics. As an example, an ADC can be used to convert an analog signal, such as the output from a microphone, into a digital signal that can be transmitted or stored. When this digital signal is retrieved, it is fed into a DAC and restored to its original form, which can be sent to an analog device such as a speaker.

The key concept beyond DACs and ADCs is a mapping between binary numbers and analog voltage values. A given voltage range is partitioned into bins, each associated with a binary number; when a voltage in that bin is received by an ADC, it outputs the corresponding number in binary. Similarly, a DAC receiving that number will output the lowest voltage in that bin.

Because multiple analog voltages can assigned to the same bin, there is an inherent loss of precision in this process. Increasing the resolution allows for greater precision by increasing the number of bins. This is accomplished by changing the number of binary digits in the ADCs output and the DACs input. For example, a 4-bit number gives only $2^4 = 16$ bins, whereas an 8-bit number yields $2^8 = 256$.

The DAC circuit we constructed is shown in Figure 1. The inputs Q0, Q1, Q2, and Q3, representing the digits of a 4-bit binary number, are each connected to a resistor, the value of which decreases by about a factor of 2 in order of increasing digit significance. The effect of this is to weight the output current of each digit according to its place value. For example, if the first digit’s output passes 1.33mA in the high state, then the second will pass 2.66mA; the currents sum to 4mA, which in this contrived example corresponds to the number $(11)_2 = (4)_{10}$. In practice, the output is measured as the voltage drop caused by this summed current through a resistor.

Unlike the ideal device, the output of a real DAC may not consist of smooth, even steps; this is partly because the ratio between neighbouring weighting resistors will not be precisely two. Adding a appropriately-sized capacitor in parallel with the output helps to interpolate between the steps, resulting in a cleaner waveform that is hopefully more true to the original analog signal.

Results and Discussion

Table 1 consists of the resistors used and their measured value. The minimum and maximum output voltages for the DAC are shown in Table 2. Table 2 also has the number of steps of the DAC, which was determined by raising the number two to the fourth power because there were four lights. In order to determine an average voltage increase per step, multiple trials we ran. Table 3 contains the data collected that was used to obtain an average value. Pair levels one step from one another were recorded and subtracted to calculate the voltage increase for a specific step over multiple trials.The resulting average increase in voltage per step size and the theoretical voltage increase per step size is shown in Table 4. The two values had a percent difference of about 21% which is pretty significant. The theoretical value was calculated by taking the maximum output voltage and dividing it by the number of steps. This shows that there are some voltage losses through other components of the circuit. Table 5 has the voltage output value when the counter was manipulated until the number 12 was displayed.

The function generator was added to the clock input of the counter and different scenarios were conducted. Figure 3 displays the output of the DAC for when the frequency was set to 80 Hz, square wave, and the peak to peak voltage was 5 V. Figure 5 displays the output when the frequency was bumped up to 1000 Hz. Figure 3 displays the output when a 0.01 μF capacitor was added. From the figures, it can be seen that the output smooths out when the capacitor is present. This is because of the fundamentals of a capacitor which is that it stores charge and therefore the steps aren't as staggered. This occurs because it takes a significant amount of time for the capacitor voltage to increase.

Table 1. Theoretical and measured resistor values used in the circuits.

Theoretical resistance [Ω]	measured resistance [Ω]
1 M	0.986 M
470 k	470.0 k
270 k	293.6 k
150 k	148.1 k
1 M	0.995 M

Table 2. DAC minimum and maximum output voltage and number of steps.

$V_{min, out}$ [V]	$V_{max, out}$ [V]	number of steps
0.086	3.370	16

Table 3. Raw data for voltage increases per step.

v1	v2	Voltage increase per step
0.335	0.086	0.249
0.614	0.335	0.279

0.863	0.614	0.249
1.179	0.931	0.248
1.458	1.179	0.279

Table 4. Theoretical and average voltage increase per step.

Average voltage increase per step	Theoretical voltage increase per step	Percent Difference
0.261	0.211	21.3

Table 5. Output voltage when the DAC displays the number 12.

Voltage when the number 12 is displayed
2.602 V

Figure 3. DAC voltage output with a frequency of 80 Hz.

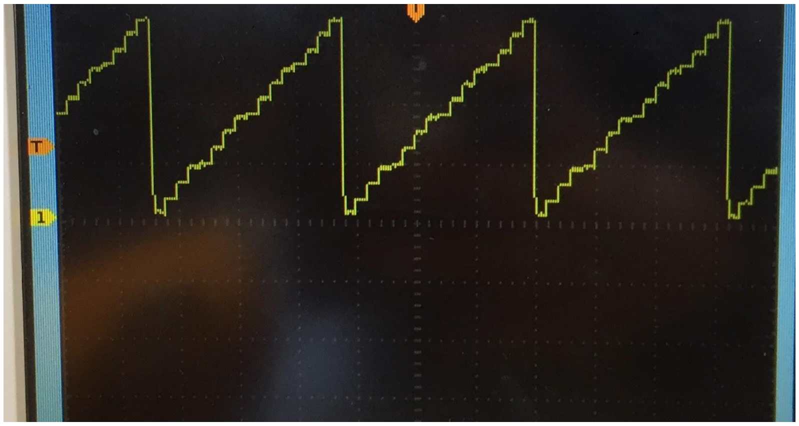

Figure 4. DAC voltage output with a frequency of 1000 Hz.

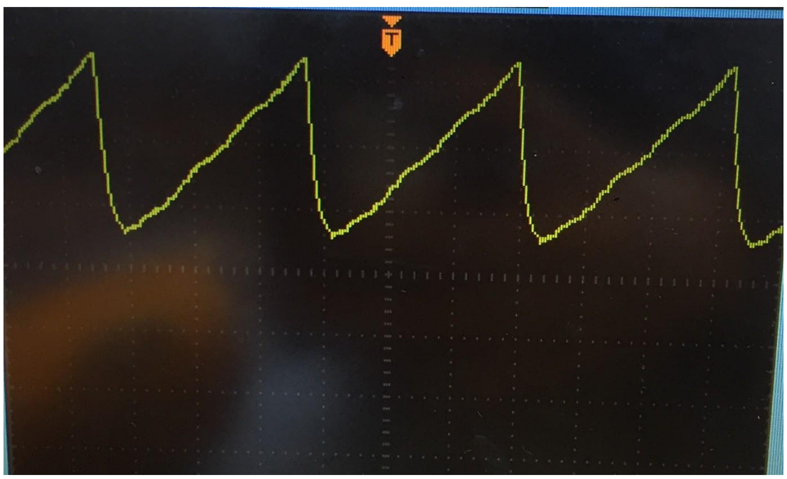

Figure 5. DAC voltage output with the addition of a 0.01 µF capacitor.

Conclusion

Digital-analog conversion is a crucial step in interfacing between the analog signals of the real world and the digital nature of computers. Using logic gates, integrated circuits, and general principles of circuitry, we constructed a digital-to-analog converter that takes in a binary number as an input and outputs an analog voltage value. Our counter circuit from the previous lab acted as the digital input, and as shown in the figures above, it produced a staircase pattern consisting of 16 steps, corresponding to the 16 states of the 4-bit input. Adding a smoothing capacitor to the output resulted in an approximation of a sawtooth waveform.