Design of a 4-bit Digital to Analog Converter

Hunter Pinkstaff
Department of Electrical Engineering
California Polytechnic State University
San Luis Obispo, CA USA
hpinksta@calpoly.edu

Mark Negus
EE
California Polytechnic State University
San Luis Obispo, CA USA
mnegus@calpoly.edu

***Abstract*— Digital to Analog converters convert digital electronic signals into analog signals. For our lab, we used a summing amplifier DAC with Op Amps and resistors. This paper will explain how we created our DAC boards using a simulated output via modeling software, the design process, and eventually testing/troubleshooting and using the DAC to apply it by taking in digital information (in the form of music) and converting it to 16 possible analog bits in the form of lower resolution music.**

Keywords—DAC

I. Introduction

Digital to Analog converters or DACs are used to convert digital signals into an analog signal to control analog devices[1]. This is useful especially in audio applications where audio files are stored digitally but need to be converted into analog so that the sound quality is improved [3].

There are a multitude of different DACs. For our lab we used a summing amplifier DAC [4]. Another popular DAC would be the PWM DAC that turns the voltage on and off so rapidly and at different frequencies so that it is interpreted as an analog signal[2]. However, PWM DACs have the undesirable tradeoff: that there is often a “hiss” or noise floor that is audible, and as you raise the carrier frequency that the PWM operates at to counteract this, you lose resolution, becoming less precise [5].

The purpose of this paper is to explain how we developed our DAC from the ground up using basic Op Amps to simulate, test, design then assemble our own DAC boards.

Our first section is the introduction to our essay, the second section is about our draft design in LTspice and our simulations. Section III is about our Design in LTspice. Section IV is about our testing of the PCB to see how it compares to the simulated models. Section V is about our application and Section VI is our conclusion.

II. 4-BIT DAC DESIGN AND SIMULATION

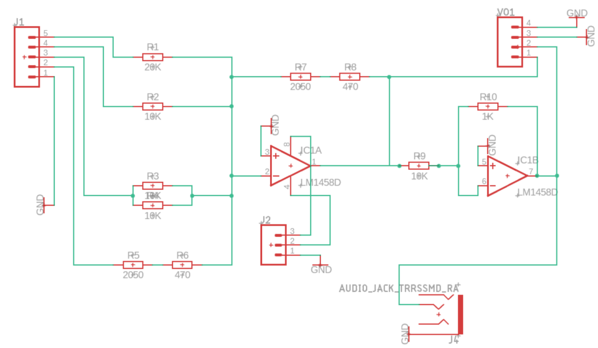
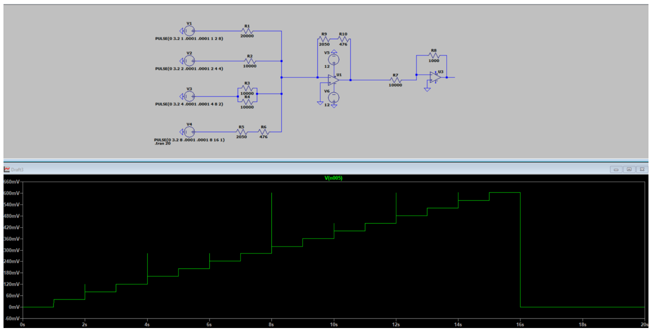


Figure 2: 4-bit DAC Schematic

The design has two op amps. The first one is an inverting summing amp which sums up the voltages of all the sources. Due to the resistors, each voltage is weighted differently. This outputs a large, negative voltage. To fix this, there is an inverting op amp that inverts the voltage and then inverts it so that it is positive. To ensure that the voltages add up correctly, the resistance values have to increase by x2 per voltage source. Because of this I made my resistors 20k, 10k, two 10k in parallel (5k), and 2050 and 470 in series (2.53k). I chose larger values so that the feedback resistor could have a resistance of 2.53k ohms, this is because if the feedback resistor doesn’t have enough resistance, the op amp might not work properly (according to the data sheet, 5.6mA max current) [6]. The figure below is the simulated output voltage. Each “step” is related to an increase in the value in binary. The voltage sources can not instantaneously be turned off, but they take 0.0001 seconds to turn on/off. Although it is almost instantaneous, there is a short moment of time where more voltage sources are on than should be. This is why there are spikes in the chart. As you can see each binary step is associated with a 40mV rise in voltage peaking at 600mV.

Figure 1: DAC 16 step Simulation Output



III. PCB Design

We used Fusion 360 to design the PCB for the 4-bit DAC circuit. The Fusion 360 DAC schematic is shown in Figure 2. To be able to fit the whole design in a 1” x 1” square, we selected to use surface mount 1206 resistors. We also selected surface mount components for the ICs so we could utilize both sides of the board.

To power the circuit, we created a three pin header for +/- 12V and ground. We created a five pin header for the four Digital inputs and ground. Finally we had a four pin header so we could record the two voltage outputs and a ground.

From the schematic, we generated a 2-layer PCB layout as shown in Figure 3. After placing the components (within spacing requirements) on either side of the board (components shown in red are on one side, blue is the other side), we used Fusion 360’s auto-router with custom design rules (which governs the trace width, the drill size and the clearance between traces and components) to route the design so that there would be no shorts, crosstalk or other errors when parts are too close together. The red on Figure 3 represents the top of the PCB, the blue represents the bottom and all the green holes are the through holes in the PCB.

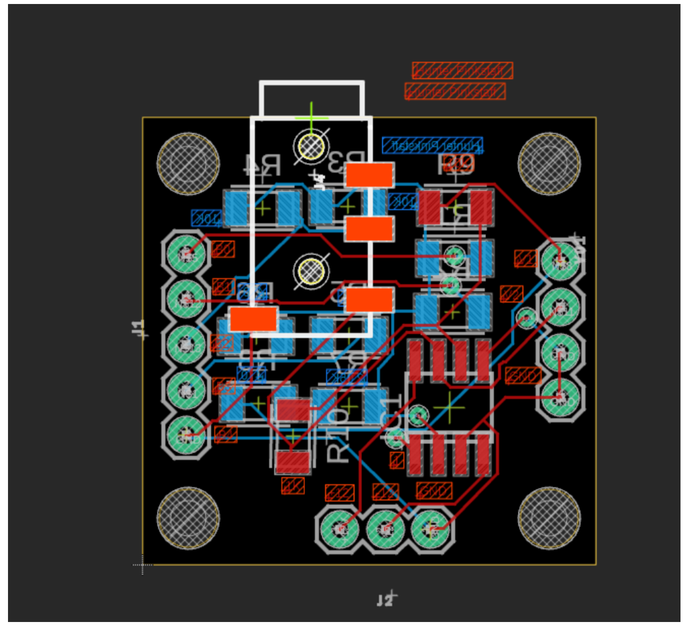


Figure 3: PCB Layout

Table 1: Bill of Materials

Part Description	Part Name	Part Description	Value	Unit Price
IC1	Lm1458 Op Amp	General purpose dual op amp	x	$1.16
J1	CONN_ 05	Connection point with 5 pins	x	
J2	CONN_ 03	Connection point with 3 pins	x	Top
J3	CONN_ 04	Connection point with 4 pins	x	top
J4	SMD Audio Jack	Audiojack input	x	$0.80
R1	1206 SMD	Surface Mount Resistor	20K	0.30
R2	1206 SMD	Surface Mount Resistor	10K	0.30
R3	1206	Surface Mount	10K	0.30

	SMD	Resistor		
R4	1206 SMD	Surface Mount Resistor	10K	0.30
R5	1206 SMD	Surface Mount Resistor	2.05K	0.30
R6	1206 SMD	Surface Mount Resistor	470	0.30
R7	1206 SMD	Surface Mount Resistor	2.05K	0.30
R8	1206 SMD	Surface Mount Resistor	470	0.30
R9	1206 SMD	Surface Mount Resistor	10K	0.30
R10	1206 SMD	Surface Mount Resistor	5K	0.30
PCB	PCB	Board to mount all parts onto	x	5.00

We added ground pours on both layers to help with heat dissipation and added additional vias around the board (shown as the unconnected green dots in Figure 3) to ensure a good connection between the ground pours on the two layers. The board is 1.00" x 1.00" within the set limitations.

After routing the design, we used Fusion 360's design rule check tool to make sure the routed design met all of the design rules.

IV. PCB Assembly and Testing

We used the electronic components provided to us in class and ordered the PCB from OshPark. They charge $5.00 for a 1"x1" PCB. The price for all the surface mount PCB components was $4.96. Luckily for us, all of these parts were provided by the lab instructor. To manufacture the board we used intrusive soldering to attach all of the surface mount resistors. We used a soldering iron to solder the IC and plastic terminal pins. To test our DAC, we put the outputs of a clock with 4 different cycles to our DAC inputs and powered the op amp with +/-12V. We only managed to get 8 of the 16 output voltages. The output from port 2 was also not inverted. On our final lab day, when we attached the 0.5V step up voltage to some analog input, converted it to digital signal with an arduino and back to analog with the DAC, we found that the DAC was reaching all 16 unique output frequencies. We concluded that the problem before must've been from how we assembled the timed output circuit.

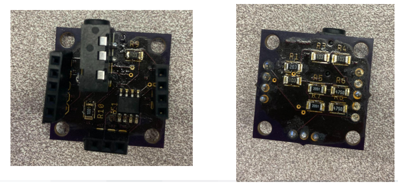


Figure 4: Assembled PCB.

V. 4-bit DAC Application

We used a 4 bit DAC to turn the digital output from the arduino into a rough analog signal that was hooked up to a speaker to play music. The code we used converted the 10 bits of input to 4 bits

```
// read the input on analog pin 0:
int sensorValue = analogRead(A0);
// Convert the analog reading (10 bits) to a 4 bit value:
int output = (int) (sensorValue * 0.014663) ; // 15/1023
```

by using the conversion factor 15/1023. Where 15 comes from 2^4 (4 bit) -1/ 2^10 (10 bits) - 1, where the "-1"s account for starting at 0 instead of at one. Alternatively, if we were making a 12 bit to 4 bit converter, the ratio to multiply sensor value (A0 output) would be 2^4 -1 / 2^12 - 1 = 15/4095. For a 6-4 bit, it would be 2^3 - 1 / 2^4 - 1 = 7/63. Each time you remove bits, you lose resolution and the "bins" that the music data gets put in get larger and larger.

The output of the music from the DAC was obviously more rough sounding than the input music because it could only play one of 16 frequencies at a time. We know that our DAC was working properly because in figure 6 you can see the digital output from the arduinos pins can be combined to form 16 unique output levels.

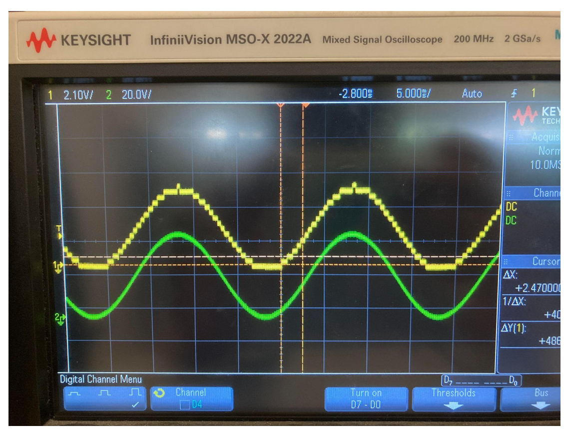


Figure 5: analog PCB output with a digital sine input

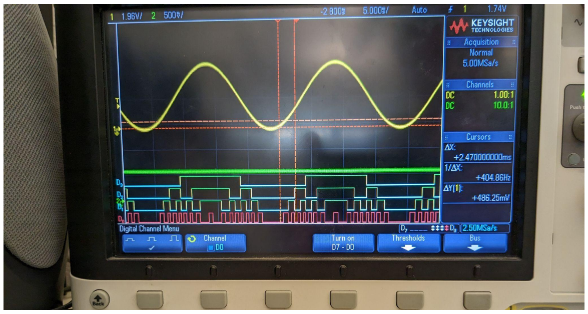


Figure 6: Digital output from arduino

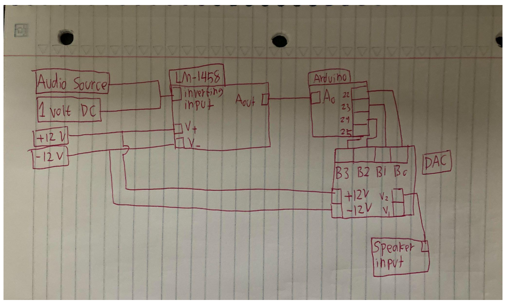


Figure 7: Block Diagram of audio conversion

VI. CONCLUSION

We used our Digital to Analog converter to turn some multiple digital input into a singular analog output. We used a summing amplifier DAC using only Op Amps and resistors. We created our DAC boards using a simulated output via modeling software, the design process, and eventually testing/troubleshooting and using the DAC by giving it an input in digital information (music) and converting it to 16 possible analog bits in the form of lower resolution music. If we were to do it again we would have been more gentle while soldering in order to ensure that no loose solder would short any connections. Additionally, the process could have gone smoother with more attention to detail with regards to connections e.g. wiring GND to -12V or making the power supply 13V and 11V instead of 12V each to account for the additional 1V.

Acknowledgment

The authors would like to thank Gary Perks for his instructional video on how to use Fusion360 and Clay Mckell for guiding us through every step of designing, manufacturing, assembling and testing our 4 bit DAC.

References

[1] "13.2.1: The R/2NR DAC- Binary-Weighted-Input Digital-to-Analog Converter." *Workforce LibreTexts*, 20 Mar. 2021, workforce.libretexts.org/Bookshelves/Electronics_Technology/Book%3A_Electric_Circuits_IV_-_Digital_Circuitry_(Kuphaldt)/13%3A_Digital-Analog_Conversion/13.02%3A_The_R/13.2.01%3A_The_R/2nR_DAC-_Binary-Weighted-Input_Digital-to-Analog_Converter.

[2] "Digital-to-Analog Converter." *Digital-to-Analog Converter - an Overview | ScienceDirect Topics*, www.sciencedirect.com/topics/engineering/digital-to-analog-converter. Accessed 13 May 2023.

[3] Says, Ig, and Brian says. "Digital to Analog Converters - an Introductory Tutorial: Circuit." *Circuit Crush*, 30 June 2021, www.circuitcrush.com/digital-analog-converters-tutorial/.

[4] Storr, Wayne. "Binary Weighted Digital to Analogue Converter." *Basic Electronics Tutorials*, 7 Jan. 2023, www.electronics-tutorials.ws/combination/digital-to-analogue-converter.html.

[5] "PWM DAC." *Open Music Labs*, www.openmusiclabs.com/learning/digital/pwm-dac.1.html. Accessed 9 June 2023.

[6] "LM1458 Data Sheet." *LM1458 Data Sheet, Product Information and Support | TI.Com*, www.ti.com/product/LM1458. Accessed 9 June 2023.