Design of 4-bit Digital to Analog Converter

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Abstract - A digital to analog converter (DAC) converts digital code to analog signals to be used in analog devices such as speakers or headphones. Our design is a 4-bit binary weighted resistor DAC, but there are several other kinds of DACs that use different methods to convert signals from digital to analog. Our design is fairly simple and intended for educational purposes related to circuit design and manufacturing. This document will describe the process of how we designed and simulated our DAC, designed the PCB, assembled and tested the PCB, and used the DAC in a practical application.

Keywords - DAC (digital to analog converter), PCB (printed circuit board)

I. Introduction

A DAC takes a digital signal and changes it into an analog signal [1]. Digital signals are made of binary code (ones and zeros) and are very portable and convenient due to electronic devices such as smartphones and computers [1][2]. Meanwhile, analog signals are continuous and can have infinite values [1]. DACs are very useful for things like audio and video systems or controlling motors because these devices require analog signals, and DACs allow them to be operated by digital code [1]. Some other applications of DACs include data acquisition systems, data distribution systems, calibration, and digital potentiometers [3].

The DAC in our design is a 4-bit binary weighted resistor DAC. Binary weighted resistor DACs take each bit of the digital code as a separate input and pass each of them through a resistor before summing the bits with an operational amplifier. The resistors are weighted differently for each bit depending on the order of the bits [4]. Another common type of DAC is a R-2R ladder DAC. This kind of DAC is similar to a binary weighted resistor DAC because they both use resistors and a summing operational amplifier. However, most of the resistors in a R-2R ladder DAC only have resistance values of some value R and 2R and are arranged somewhat differently [4]. Other types of DACs include sigma-delta DACs which use oversampling to increase the resolution of the analog signal and pulse width modulation DACs which use a series of pulses to create an output [1].

Our design for a 4-bit digital to analog converter is made for educational purposes. The circuit is relatively simple and provides the opportunity to learn about some of the basics of circuit design and manufacturing. The simplicity of the design also contributes to a lower cost of manufacturing, which allows it to be more accessible and cost-effective for students

Section II of this document describes the specifications of our design and how it was simulated. Section III discusses the process of designing the PCB of the 4-bit DAC. Section IV provides an overview of assembling and testing the PCB as well as the cost of manufacturing. Section V describes the practical application of our design. Finally, Section VI gives our concluding statements on this project.

II. Circuit Design and Simulation

The schematic of our design was made with LTspice and can be seen in Figure 1. The circuit consists of an inverting summing amplifier with four input voltages followed by an inverting amplifier. The four input voltages represent each of the four bits of the binary input (V1 = bit 0, V2 = bit 1, V3 = bit 2, V4 = bit 3). The on voltage of each bit is 3.2 volts while the off voltage is 0 volts. Since each input is one bit of a 4-bit binary number, bit 3 has twice the weight of bit 2 which has twice the weight of bit 1 which has twice the weight of bit 0. In other words, bit 0 is multiplied by 1/8, bit 1 is multiplied by 1/4, bit 2 is multiplied by 1/2, and bit 3 is multiplied by 1. To achieve this, we selected a resistor with a value of 2.55k ohms to be the feedback resistor (R5). We then picked out the values of the other resistors so that each input voltage would be multiplied by the appropriate amount. This resulted in R1 = 20k ohms, R2 = 10k ohms, R3 = 5.1k ohms, and R4 = 2.55k ohms. R1 and R2 are not exactly four times or eight times the value of R5 because these values had to be picked out of a list of available resistors and they are reasonably close enough to the actual values needed. The output voltage of the summing amplifier is then passed through an inverting amplifier with resistors R6 = 10k ohms and R7 = 1k ohms. The purpose of this second operational amplifier is to invert the output back to a positive voltage and multiply it by a gain of 1/10. The power rails of both operational amplifiers are set to +12 volts and -12 volts.

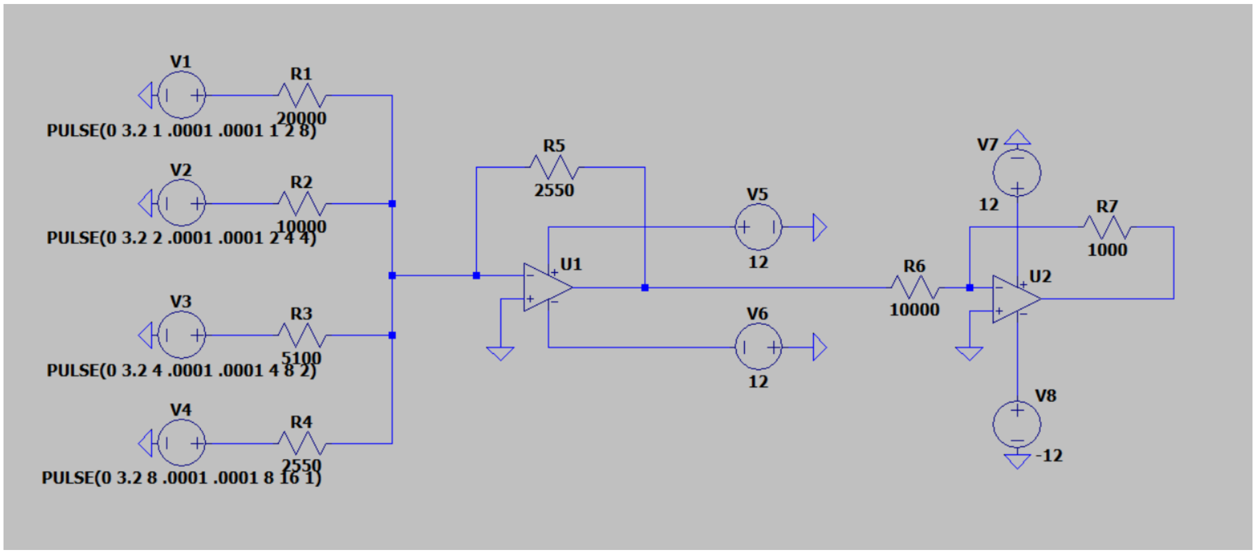

Figure 1: LTspice Schematic of 4-bit DAC

To simulate our design in LTspice, each of the input voltages was set to be a pulse function. The pulse settings were then configured as seen in Figure 1 so that the overall binary input would increase by one every second in the simulation. Figure 2 shows the simulation graph of the output voltage over 16 seconds. The graph increases by roughly the same amount every second (about 40 mV). This is to be expected because as the binary input increases linearly, so too should the output voltage.

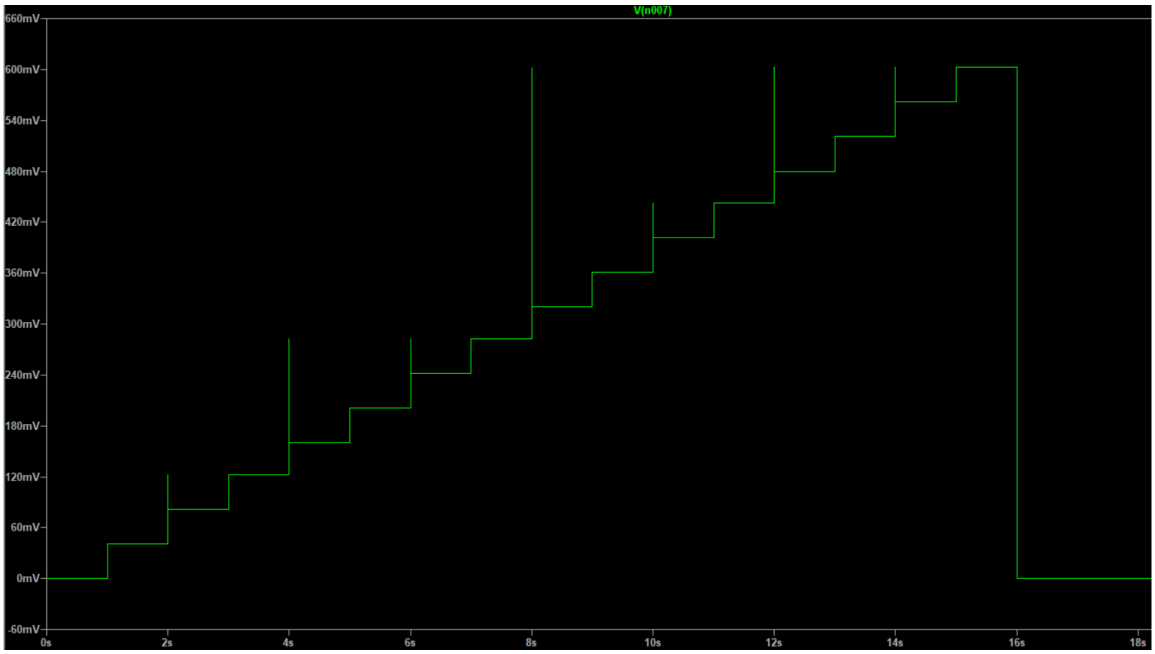

Figure 2: LTspice simulation of 4-bit DAC

III. PCB Design

We used Fusion 360 to design the PCB for the 4-bit DAC design, as well as the circuit corresponding to the PCB. The 4-bit DAC PCB circuit schematic is shown in Figure 3. In order to meet the size requirements of the assignment, we made the PCB board 1” x 1” and used 1206 resistors. We also selected all surface mount components for the PCB. As seen in Figure 3, to power the circuit we employed a three pin header. One port being GND, the next being Vcc1, and the last being Vcc2. The Vcc ports connect to the IC and provide the power rails for the op amps. They will be +12v and -12 volts respectively. The voltages are first amplified, summed, and inverted by the first op amp, then inverted and amplified by the second op amp, as explained above. These two op amps are housed in the IC surface component (LM1458D).

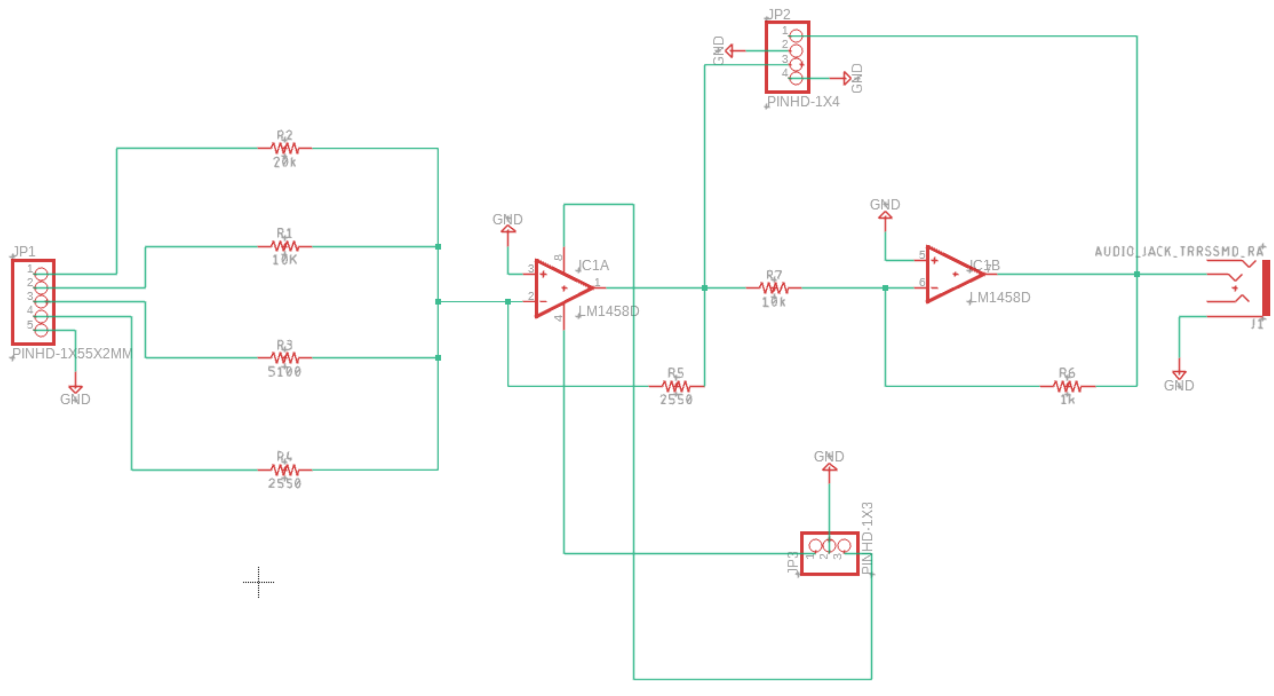

Figure 3: Circuit Schematic of 4-Bit DAC

Our four pin header is used to get the output voltages of the first IC op amp and the second IC op amp. While the other two ports are GND. The five pin header's purpose is to input the voltages to the IC. Each of the 4 voltage inputs represents one bit of the 4-bit DAC converter. As said above all seven resistors are of the 1206 variety and are surface mounted. One 1k ohm resistor, two 2.55k ohm, one 5.1k ohm, two 10k ohm, and one 20k ohm. Finally we have our audio jack; that inputs the final amplified voltage, outputted from our IC, and later used to create a pitched sound. After creating the 4-bit DAC circuit and fitting all components on the 1" x 1" board, we utilized auto-routing to make the traces. These traces can be seen in Figure 4. The generated traces use a total of nine vias to navigate and interconnect the components; thus occupying the top and bottom of the PCB. We chose not to use a ground pour because a 4-bit DAC is not extremely complicated so there was no need for a common node or greater heat dissipation. There are four large mountain holes and two smaller mounting holes. The four larger holes will be used to mount the PCB on a chassis that will secure the PCB and an Arduino. The two smaller holes will be used to mount and secure the audio jack to the PCB.

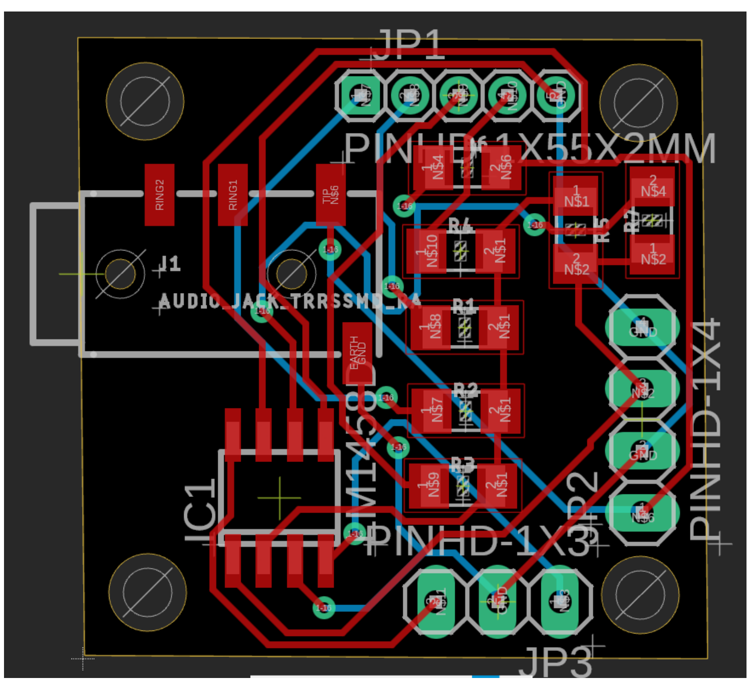

Figure 4: PCB Board Layout of 4-Bit DAC

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