Final Project Application Note

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1 Design Overview

The goal of this project was to create a digitally controlled audio amplifier. The audio amplifier would have 3 band audio control and volume gain controlled by a microprocessor. The project has a analog and digital PCB. The analog PCB was used to control the audio and the digital PCB was used to control the audio gain and the interface.

1.1 Design Features

These are the design features:

- Volume Control
- 3 Band Control
- USB Communication
- Capacitive Touch Sensor
- USB Communication
- Internal Temperature Sensor
- Aux Audio Input
- Speaker Driver Output
- LCD Display

1.2 Block Diagrams

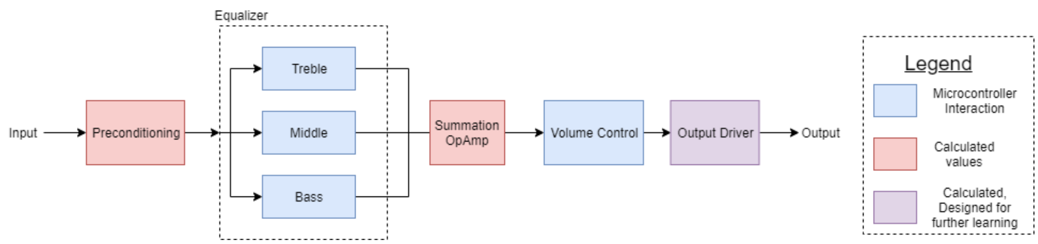

Figure 1: Audio PCB High Level

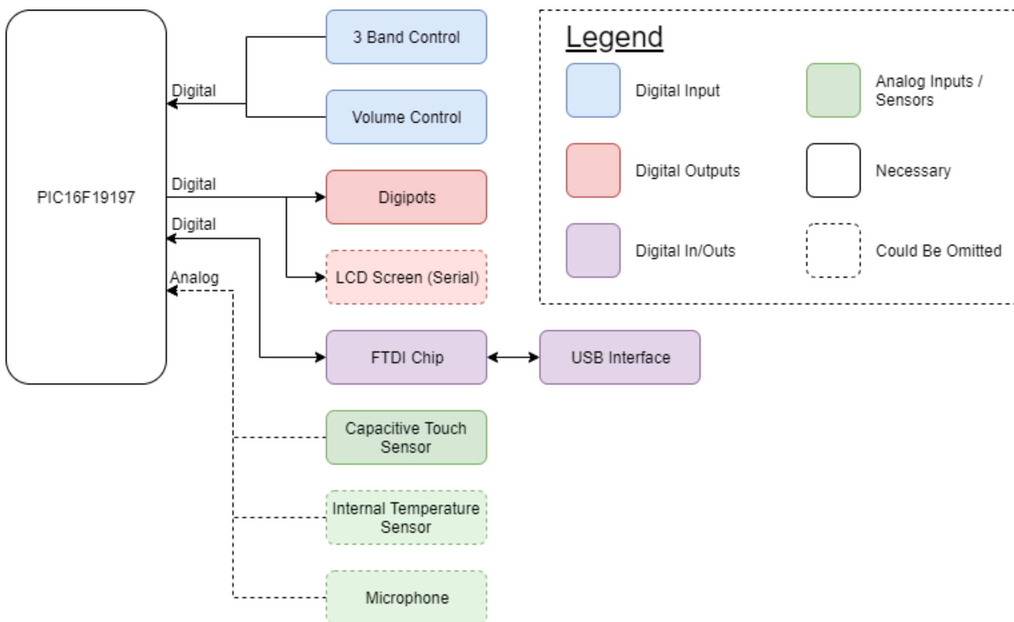

Figure 2: Control PCB High Level

1.3 Schematic Documents

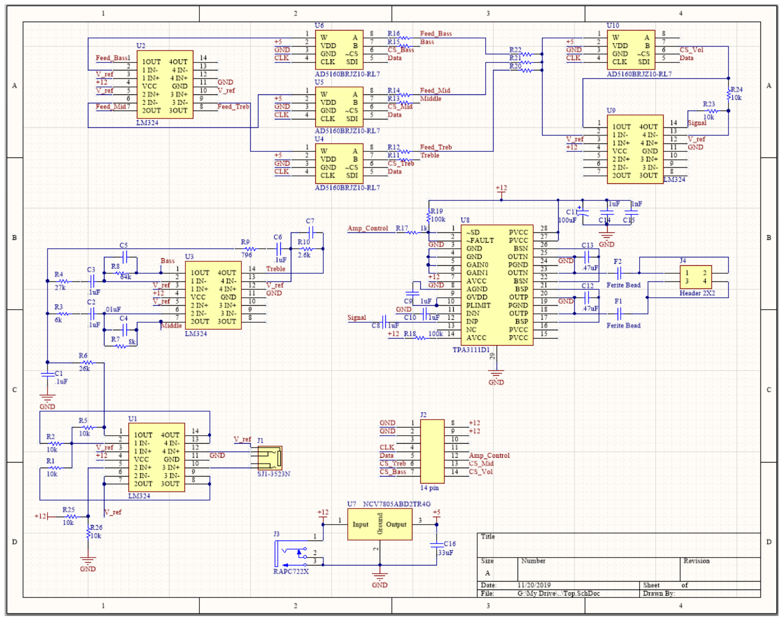

Figure 3: Audio PCB Schematic

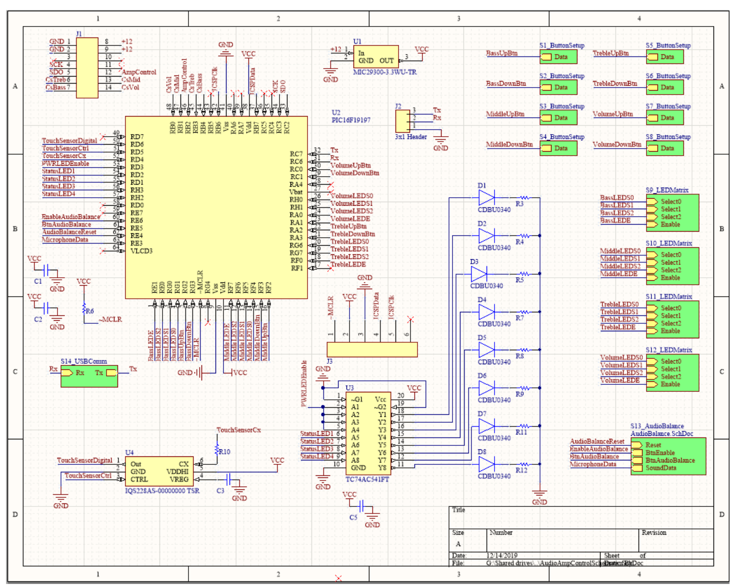

Figure 4: Control PCB Schematic

1.4 PCB 3D Representation

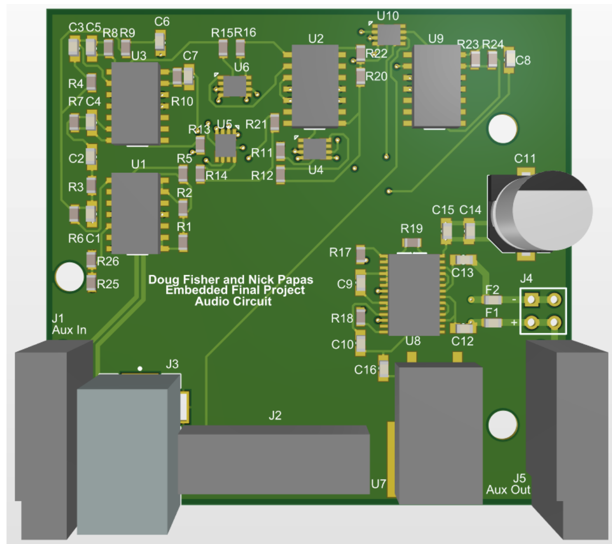

Figure 5: Audio PCB

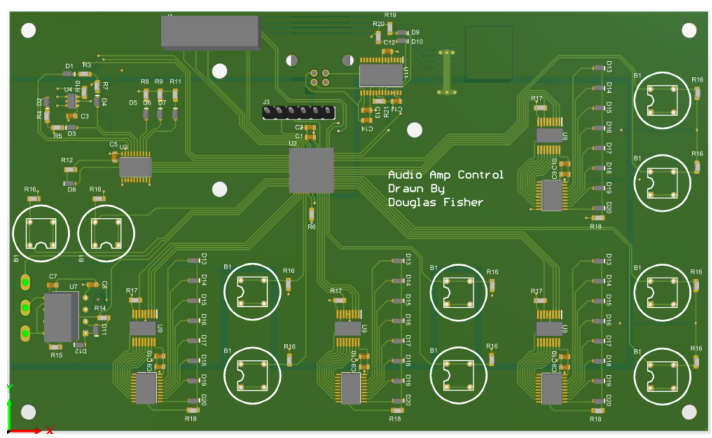

Figure 6: Control PCB

2 Key System Specifications

1. 3 Db Band Control
   - Gain ranges from 2 to 1/2
   - Bass: 60 - 250Hz

- Middle: 350 - 2kHz
- Treble: 2k - 6kHz

2. Volume Control
   - Gain ranges from 0 to 10
   - Logarithmic Steps Via Software
3. USB Communication
   - Processor outputs UART
   - System interfaces over USB-B 2.0
4. Autimatic Audio Balance
   - Reads peak voltage out of analog microphone
   - Adjusts volume steps to match readings
5. Internal Temperature Sensor
   - Uses PIC16F Series internal temperature sensor
   - Cuts-off operation at 80 C
6. Capacitive Touch Sensor
   - Activates 0.25 inches or less away
   - Enables and disables processor sleep mode
7. Audio Input
   - Uses 3.5mm audio jack
   - Vpp ranges from 500mV to 1.2V
8. Audio Output
   - 10W 12V Output Driver

3 System Description

The system uses two PCBs, an analog board and a digital board. The digital board uses buttons to get user input. The user can increase or decrease the gain for each controlled band and the overall volume gain. The button presses are read by the on board PIC processor and then the outputs are updated. The first output is to the MSP430FR6989 which then controls its on board LCD screen. The second is the LED Matrix next to each set of buttons, which displays the current level of the gain. Finally, the PIC will then output the new value over SPI to the digit pots on the analog board, changing the gain of the related op amp. The PIC processor also gets input from a microphone for the audio balance circuit. The microphone goes into a peak detector circuit to find the max voltage. The theory behind this was that the value would change the max volume gain of the circuit, but this subsystem was never tested. The PIC processor also gets data from two other sensors, the on chip temperature sensor, and a capacitive touch sensor. The capacitive touch sensor enables lights and volumes to signify the device as ”on”, and the temperature sensor makes sure the board doesn't accidentally overheat, turning off all LEDs and volume if the processor gets above a certain threshold. Finally, the system also communicates using Uart over a USB connecting. This is used to manually set the gain of any digipot, as well as indirectly communicate with the MSP430FR6989 previously mentioned.

3.1 Detailed Block Diagram

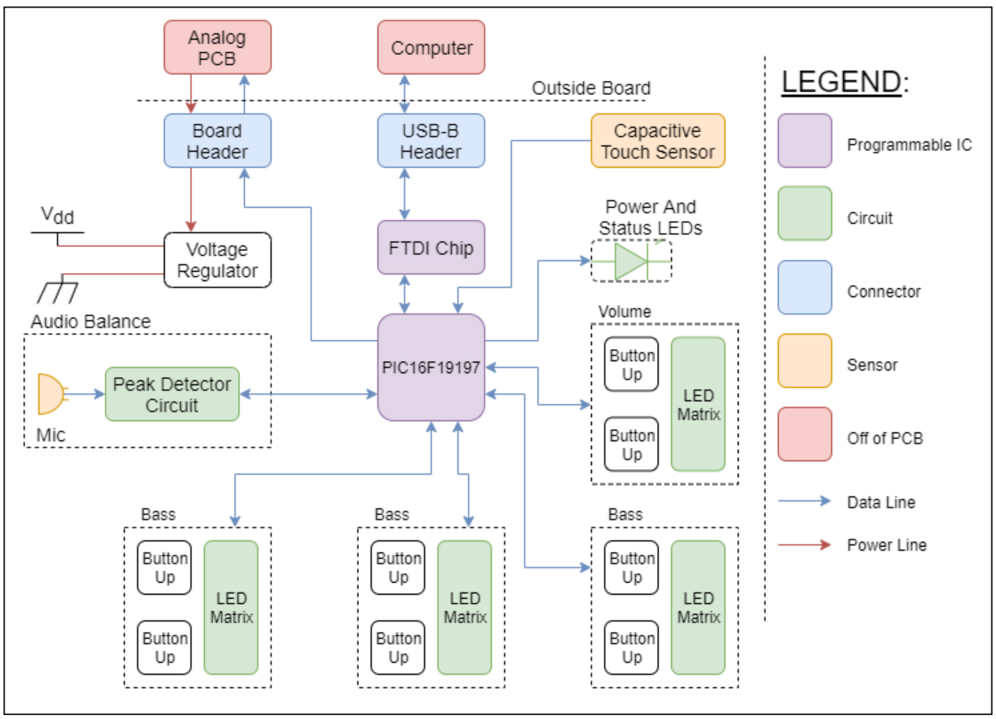

Figure 7: Detailed Digital Circuit Block Diagram

3.2 Highlighted Devices

- MSP430FR6989

  This micro controller was used for its LCD screen. The LCD screen was used to display to the user the systems current volume, bass, treble and mid level.

- AD5160BRJZ10-RL7

  This component is a digitally controlled potentiometer. Four of these potentiometers are used in the feedback loop of inverting op-amp configurations to control the gain of each of the three audio bands and the overall volume.

- FT232R

  This component is an FTDI chip that converts USB to UART. It is used on the control board to allow a computer to communicate with the PIC microcontroller with UART over USB.

- PIC16F19197

  This is the microcontroller used on the control board. It takes input from the buttons and UART interface, and sends serial data over SPI to the digipots to control the audio board.

3.3 MSP430FR6989

The MSP430FR6989 was the micro controller used to run the LCD. The MSP430FR6989 has a LCD that can be used to show the change in volume, bass, treble, and mid. The code for this program was written in C. The RXD and TXD jumpers are switched from connecting vertically to connecting horizontally. This enables the UART function of the processor. The coded used an interrupt and when that interrupt is triggered the values are loaded to an array package and then another integer is turned on to let the main function know the package is ready. The main function takes this package and then sees whats in it and displays it to the on board LCD.

3.4 AD5160BRJZ10-RL7

This component is a digitally controlled potentiometer (digipot). Four of these digipots are used in the feedback loop of inverting op-amp configurations to control the sound level of each of the three audio bands and the overall volume. These digipots communicate with the microcontroller on the control board over an SPI interface. To control the position of the wiper on the digipot, send it a byte over SPI, and the wiper will move to that position. Sending it 0 (0x00) will move the wiper to A, and sending it 255 (0xFF) will move the wiper to B, and any value in-between will move it to that relative position. The default position of the wiper on startup is in the middle, right between A and B. The resistance from A to B is 10K ohms, and this is only valid when the device is powered on.

3.5 FT232R

This component is an FTDI chip that converts USB to UART. It is used on the control board to allow a computer to communicate with the PIC microcontroller with UART over USB. The purpose for wanting a computer to interface with the control board is to allow for a secondary control method of the audio board, besides the buttons, and for debugging purposes.

3.6 PIC16F19197

This is the microcontroller used on the control board. It takes input from the buttons and UART interface, and sends serial data over SPI to the digipots to control the audio board. Also, based on the state of the volume and band control, it turns on LEDs to indicate that state to the user.

4 SYSTEM DESIGN THEORY

4.1 Design Requirement 1

The first design requirement is to have the audio circuit be controlled digitally. The audio PCB should be able to receive SPI data and adjust resistance accordingly. This should then affect the audio output of the device.

4.2 Design Requirement 2

The digital PCB needs to be able to be able to send SPI data to the audio PCB to control the digipots. The PIC processor doesn't need to receive any data back, just send the positions of the digipots to the audio PCB.

4.3 Design Requirement 3

The digital PCB needs to be able to communicate over Euart through a USB-B. This will all for a user to send a package of data to the PIC detailing which gain to change an the value to change it to.

4.4 Design Requirement 4

The digital PCB needs to be able to interface with the user using buttons and LEDs. The user will be able to individually control the gain of each band and volume. The user will also be able to tell the current level of each based on an LED matrix. Each LED matrix will have a single light on to signify the current level.

4.5 Design Requirement 5

The device will use an algorithm adjust the linear digipots. Since the ear hears logarithmicly, a function will mimic a logrithmic curve and assign values to a number of steps evenly distributed along that curve. The digipots will then be set to those values as the user increased and decreases the gain of audio op amps.

4.6 Design Requirement 6

The digital PCB will also get data from a on chip temperature sensor and a on board capacitive touch sensor. The touch sensor will enable and disable the device, while the temperature sensor monitors the processor and disables the device if it rises above a threshold.

4.7 Design Requirement 7

The digital PCB will also use a microphone connected to a peak detector circuit, getting the maximum value for a set of time. This will be used to limit the max volume for the audio based on the maximum value received.

4.8 Design Requirement 8

The final design requirement was the communication to the MSP430FR6989 to utilize the on board LCD display. When the user changes the volume, bass, treble, or mid level a signal is sent to the micro processor.

5 Testing

5.1 Case 1

5.1.1 Procedure

The control PCB was connected to the Audio Board and the voltage regulator was getting very hot very fast. Decided to power the control board with a power supply. An average of 350mA were being pulled through the control board. Found that an op amp designed for a bipolar supply was pulling a large amount of current because it was receiving single supply. When measured approximately 100 ohms of resistance was found between power and ground.

5.1.2 What Was Done

The op amp was removed from the circuit and the current draw was reduced but was still too substantial. Since there was nothing else on the PCB that could have been creating a partial short except the MCU, it was removed. The resistance between power and ground immediately returned to the double digit kilo-ohms so a new processor was soldered in its place.

5.2 Case 2

5.2.1 Procedure

With the new processor the board was then powered from the power supply and functionality was verified. After connecting the two boards together and further testing the same issue as earlier arises. Noticed the voltage regulator was getting extremely hot and the processor was also getting hot.

5.2.2 What Was Done

Realised there may be a problem with the design. Blamed the problem on insufficient ESD protection. Tested Digital PCB independently to make sure the board design wasn't faulty.

5.3 Case 3

5.3.1 Procedure

A new board was assembled with all new parts. The digital PCB behaved normally on startup and was working initially when connected to the audio board. After some time the impedance between power and ground was measured and found to be below 200 ohms. The processor was removed and the impedance returned to normal, meaning our last processor was killed.

5.3.2 What Was Done

Measured the power and ground with an oscilloscope and saw spikes on both signals. Assumed a spike in the power line would be the culprit, so the SPI code was redone to be compatible with the MSP430FR6989 and started testing.

5.4 Case 4

5.4.1 Procedure

The MSP430FR6989 was programmed and the SPI functionality was verified. After connecting to the analog board, the MSP430 seemed to be behaving incorrectly. When attempting to reprogram, Code Composer couldn't't recognize the MSP430 programmer.

5.4.2 What Was Done

Tried to isolate which part of the board was damaged by using a different launchpad's programmer on the processor. Used the programmer on a different launchpad's chip, and since both cases failed, its assumed that the programmer and microprocessor were both inoperable.

5.5 Final Testing

To isolate potential issues optoisolaters were used to electrically separate the two subsystems. An opto isolator is an electronic component that transfers electrical signals between two isolated circuits by using light. Opto isolators prevent high voltages from affecting the system receiving the signal. Used the oscilloscope to test all the data lines, and the opto isolators were working correctly.

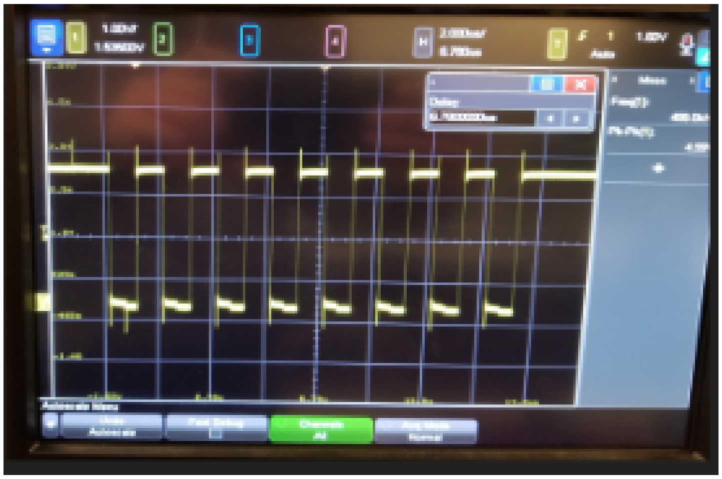

Figure 8: SPI Data Line from MSP

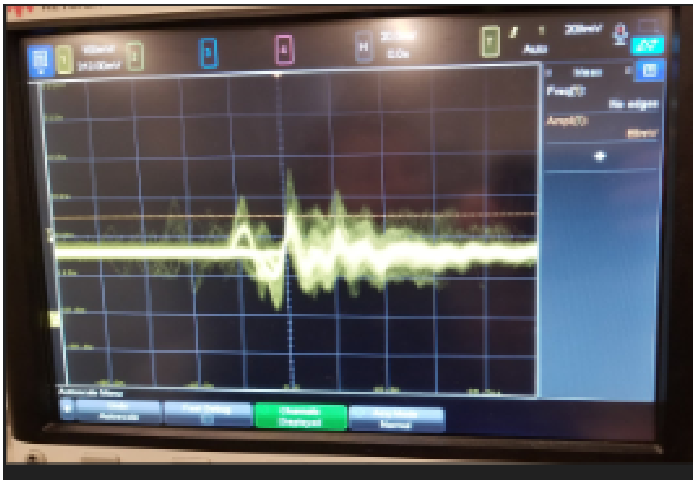

Figure 9: SPI Data Line on Audio Circuit

Figure 10: Ground of Audio Circuit

Figure 11: Clk Line on Audio Circuit

6 Appendix

6.1 Bill of Materials

Part #:	Description:	Vendor:	# of Parts:	Price:	Total:
PIC16F19197	Processor	PIC	1	$1.87	$1.87
IQS228AS	Capacitive Touch Sensor	Mouser	1	$0.72	$0.72
MM74HCT138MTC	3 to 8 Decoder	Mouser	4	$0.45	$1.80
	0603 LED	Resource Center	36	$0.00	$0.00
TC74AC541FT	Line driver	Mouser	4	$0.69	$2.76
ICS-40180	Microphone	Mouser	1	$1.41	$1.41
FT232R	FTDI Chip	Mouser	1	$4.50	$4.50
USB-B-S-F-B-VT	USB-B female port	Mouser	1	$0.98	$0.98
MIC29300-3.3WU	Voltage Regulator	Digikey	1	$3.48	$3.48
D6R00F2LFS	Button	Mouser	10	$0.90	$9.00
NE5532	Op amp	Resource Center	1	$0.00	$0.00
TIP35CW	NPN-Transistor	Resource Center	1	$0.00	$0.00
SJ1-3523N	3.5mm Female Aux Jack	Mouser	1	0.73	0.73
555-LM324DRG4	General Purpose Op Amp	Mouser	4	0.36	1.44
HIF3FC14PA2.54DS	Male 14 Pin Ribbon Cable Connector	Mouser	1	2.51	2.51
HIF3FC14PA2.54DSA	Female 14 Pin Ribbon Cable Connector	Mouser	1	1.94	1.94
NCV7805ABD2TR4G	Linear Voltage Regulators ANA 1A 5V VREG	Mouser	1	0.8	0.8
RAPC722X	Power Jack, 5 A, 3-Pin	Mouser	1	1.02	1.02
AD5160BRJZ10-RL7	Digital Potentiometer ICs IC 8-Bit SPI	Mouser	4	1.84	7.36
BLM18SG331TN1D	Ferrite Beads 330ohms	Mouser	2	0.13	0.26
TPA3111D1	Mono Class-D Audio Power Amplifier	Mouser	1	1.99	1.99
UCL1V101MNL1GS	Aluminum Electrolytic Capacitor, 100 uF	Mouser	1	0.79	0.79
AC0603FR-0726K7L	26.7k resistor	Mouser	1	0.1	0.1
RT0603FRE0763K4L	63.4k resistor	Mouser	1	0.19	0.19
RT0603DRE07796RL	796 ohm resistor	Mouser	1	0.11	0.11
RN731JTTD2641B50	2.64k resistor	Mouser	1	0.35	0.35

6.2 PCB Design

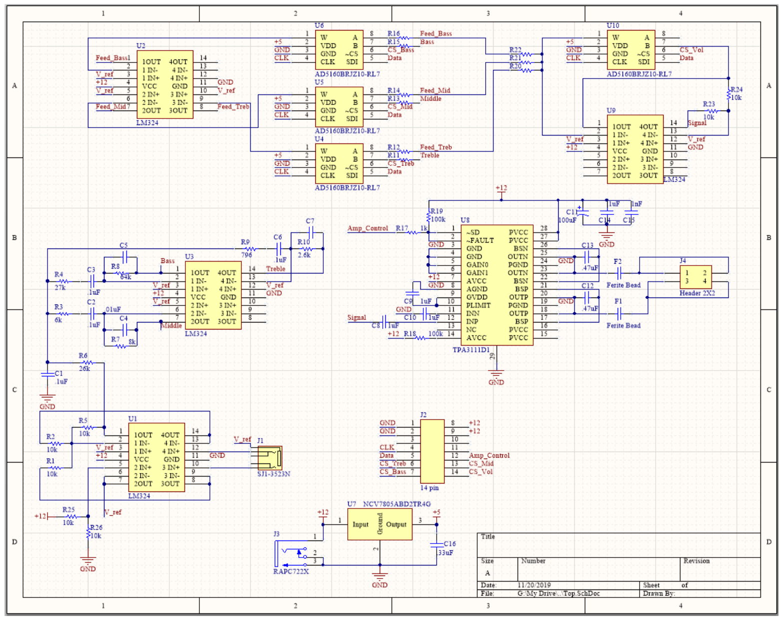

Figure 12: Audio PCB Schematic

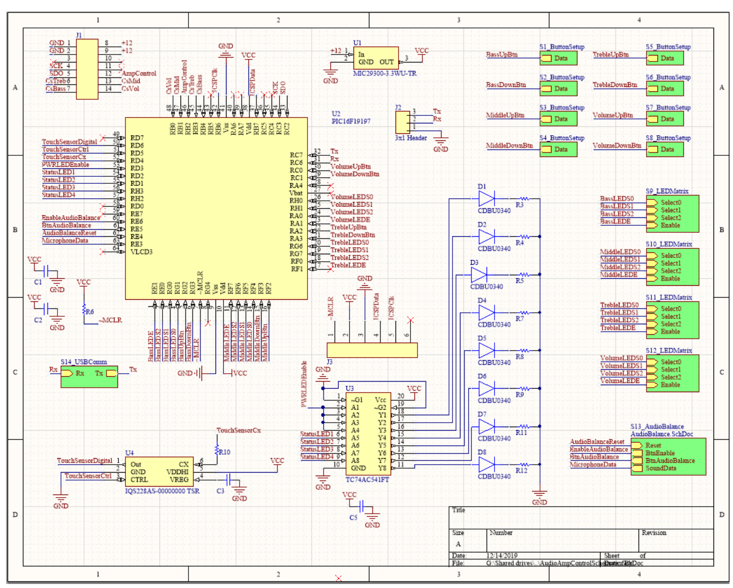

Figure 13: Control PCB Schematic

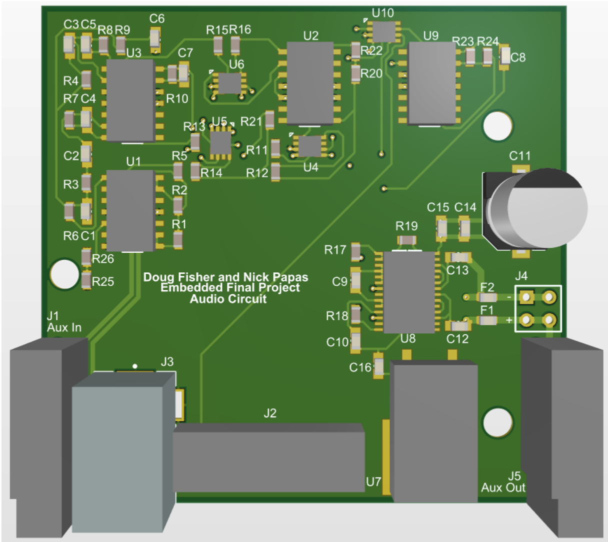

Figure 14: Audio PCB

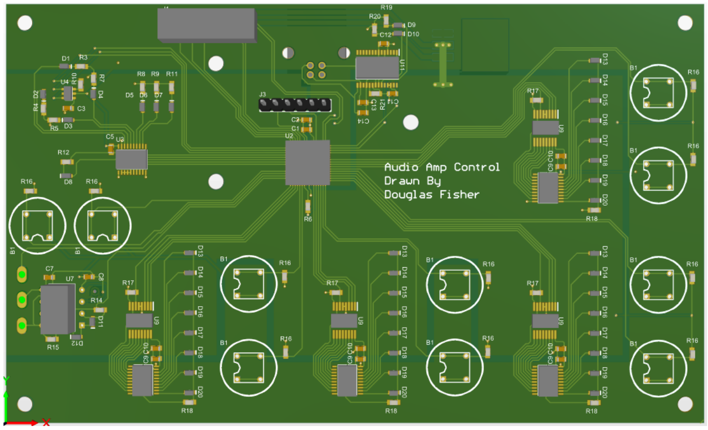

Figure 15: Control PCB

6.3 Block Diagrams

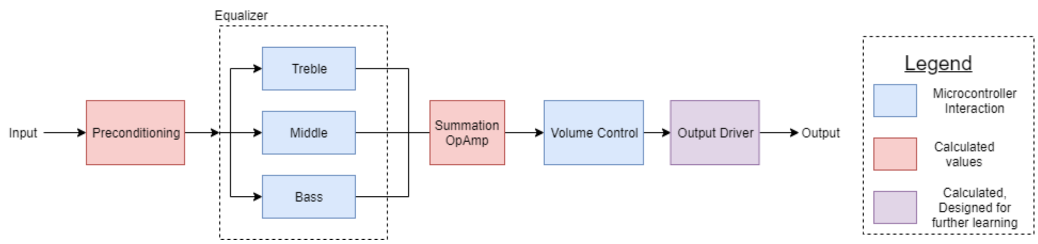

Figure 16: Audio PCB High Level

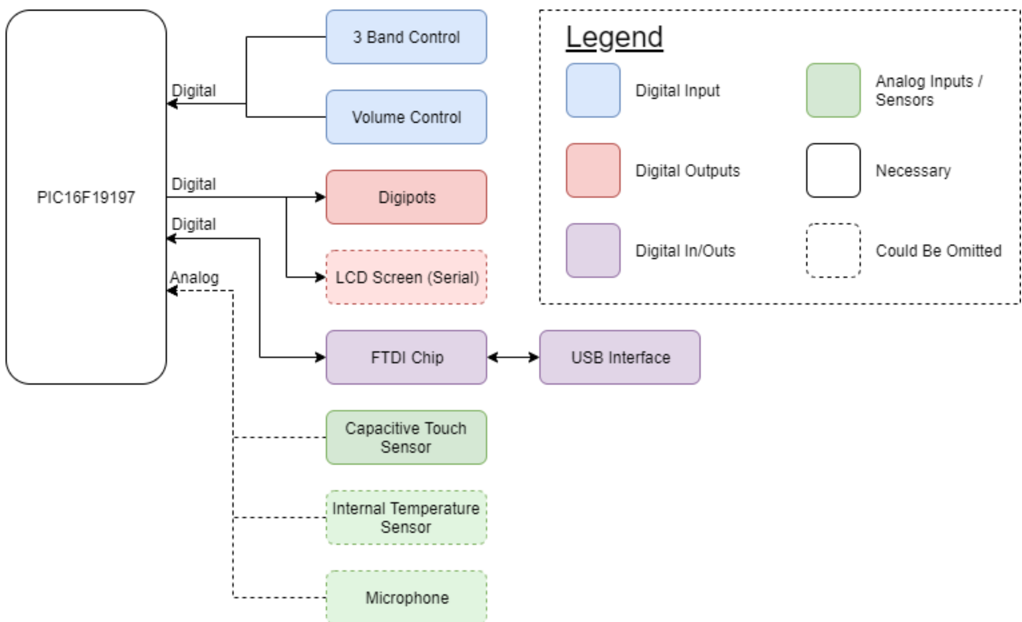

Figure 17: Control PCB High Level

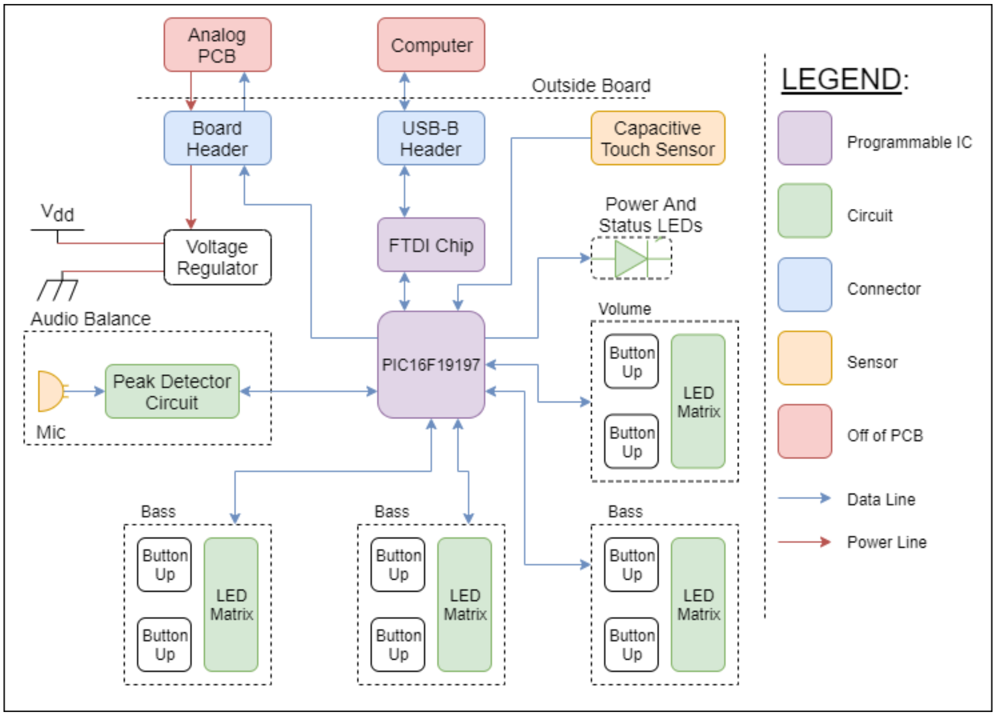

Figure 18: Detailed Digital Circuit Block Diagram

6.4 Testing Data

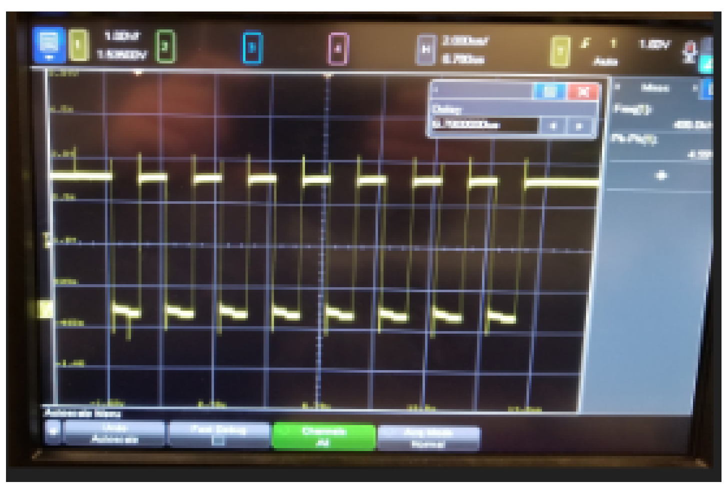

Figure 19: SPI Data Line from MSP

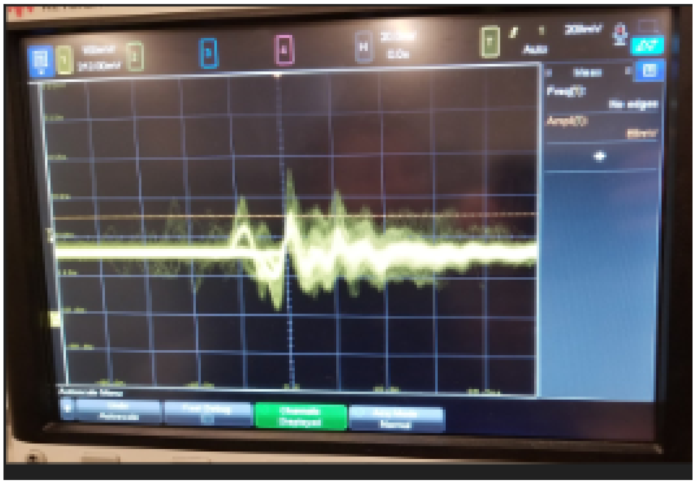

Figure 20: SPI Data Line on Audio Circuit

Figure 21: Ground of Audio Circuit

Figure 22: Clk Line on Audio Circuit