Daniel Diamont

EE 445L

Lab 6 Report

A) Objectives (Requirements Document from Lab 5 below):

Requirements document

1. Overview

1.1. Objectives: Why are we doing this project? What is the purpose?

The objectives of this project are to design, build and test a music player. Educationally, students are learning how to interface a DAC, how to design a speaker amplifier, how to store digital music in ROM, and how to perform DAC output in the background. Your goal is to play your favorite song.

1.2. Process: How will the project be developed?

The project will be developed using the TM4C123 board. There will be three switches that the operator will use to control the music player. One switch will play/pause the song; one switch will rewind the song; one switch will change the instrument that the microcontroller is "using" to play the song. The system will be built on a solderless breadboard and run on the usual USB power. The system may use the on board switches or off-board switches. A hardware/software interface will be designed that allows software to control the player. There will be at least three hardware/software modules: switch input, DAC output, and the sound controller. The process will be to design and test each module independently from the other modules. After each module is tested, the system will be built and tested.

1.3. Roles and Responsibilities: Who will do what? Who are the clients?

EE445L students are the engineers and the TA is the client. Students are expected to make minor modifications to this document in order to clarify exactly what they plan to build. Students are allowed to divide responsibilities of the project however they wish, but, at the time of demonstration, both students are expected to understand all aspects of the design.

- Tasks:
  - Requirements document – Daniel Diamont
  - PCB Artist schematic – Robert Noe
  - Switch input software – Robert Noe
  - DAC Output software – Daniel Diamont
  - Sound controller software – Daniel Diamont
  - Checkout – Daniel Diamont and Robert Noe

1.4. Interactions with Existing Systems: How will it fit in?

The system will use the TM4C123 board, a solderless breadboard, and the speaker as shown in Figure 5.1. It will be powered using the USB cable. You may use a +5V power from the lab bench, but please do not power the TPA731 or the speaker with a voltage above +5V.

1.5. Terminology: Define terms used in the document.

- SSI – device to transmit data with synchronous serial communication. The clock is shared on both sides. Same as Serial Peripheral Interface (SPI).
- Linearity – the Digital to Analog converter must abide by the principle of linearity where its output is monotonic.
- Frequency response
- Loudness – Amplitude of the sound wave
- Pitch – 1/period of the sound wave
- Instrument – produces a particular sound wave according to its type
- Tempo – speed of the song
- Envelope – Amplitude vs. time. For notes to taper off, we can apply an exponentially decreasing envelope.
- Melody - a sequence of single notes that is musically satisfying.
- Harmony – the combination of simultaneously sounded musical notes to produce chords and chord progressions having a pleasing effect.
- Decibel (dB) – measure of the relative magnitude of two signals.
- Spectrum Analyzer – equipment that displays signal amplitude vs. frequency
- SNR - the ratio of the strength of an electrical or other signal carrying information to that of interference, generally expressed in decibels.

Definitions for the terms SSI, linearity, frequency response, loudness, pitch, instrument, tempo, envelope, melody and harmony can be found in the textbook. *(Note to students: add any addition terms you feel are needed)*

1.6. Security: How will intellectual property be managed?

The system may include software from and from the book. No software written for this project may be transmitted, viewed, or communicated with any other EE445L student past, present, or future (other than the lab partner of course). It is the responsibility of the team to keep its EE445L lab solutions secure.

2. Function Description

2.1. Functionality: What will the system do precisely?

If the operator presses the play/pause button the music will play or pause. If the operator presses the play/pause button once the music should pause. Hitting the play/pause again causes music to continue. The play/pause button does not restart from the beginning, rather it continues from the position it was paused. If the rewind button is pressed, the music stops and the next play operation will start from the beginning.

There must be a C data structure to hold the music, which will be an array containing the notes of the song and the time that each note must be held for. There must be a music driver that plays songs. The length of the song should be at least 30 seconds and comprise of at least 8 different frequencies. Although you will be playing only one song, the song data itself will be stored in a separate place and be easy to change. The player runs in the background using interrupts. The foreground (main) initializes the player, then executes **`for(;;){}`** do nothing loop. If you wish to include LCD output, this output should occur in the foreground. The maximum time to execute one instance of the ISR is xxxx *(note to students: replace the xxxx with performance measure of your solution).* You will need public functions **`Rewind`**, **`Play`** and **`Stop`**, which perform operations like a cassette tape player. The **`Play`** function has an input parameter that defines the song to play. A background thread implemented with output compare will fetch data out of your music structure and send them to the DAC.

There must be a C data structure to store the sound waveform or instrument. You are free to design your own format, as long as it uses a formal data structure (i.e., **`struct`**). The generated music must sound beautiful utilizing the SNR of the DAC. Although you only have to implement one instrument, it should be easy to change instruments.

2.2. Scope: List the phases and what will be delivered in each phase.

Phase 1 is the preparation; phase 2 is the demonstration; and phase 3 is the lab report. Details can be found in the lab manual.

2.3. Prototypes: How will intermediate progress be demonstrated?

A prototype system running on the TM4C123 board and solderless breadboard will be demonstrated. Progress will be judged by the preparation, demonstration and lab report.

2.4. Performance: Define the measures and describe how they will be determined.

The system will be judged by three qualitative measures. First, the software modules must be easy to understand and well-organized. Second, the system must employ an abstract data structures to hold the sound and the music. There should be a clear and obvious translation from sheet music to the data structure. Backward jumps in the ISR are not allowed. Waiting for SSI output to complete is an acceptable backwards jump. Third, all software will be judged according to style guidelines. Software must follow the style described in Section 3.3 of the book *(note to students: you may edit this sentence to define a different style format)*. There are three quantitative measures. First, the SNR of the DAC output of a sine wave should be measured. Second, the maximum time to run one instance of the ISR will be recorded. Third, you will measure power supply current to run the system. There is no particular need to optimize any of these quantitative measures in this system.

2.5. Usability: Describe the interfaces. Be quantitative if possible.

There will be three switch inputs. The DAC will be interfaced to a 32-ohm speaker. *(note to students: you could use 8 ohm speaker)*

2.6. Safety: Explain any safety requirements and how they will be measured.

If you are using headphones, please verify the sound it not too loud before placing the phones next to your ears.

3. Deliverables

3.1. Reports: How will the system be described?

A lab report described below is due by the due date listed in the syllabus. This report includes the final requirements document.

3.2. Audits: How will the clients evaluate progress?

The preparation is due at the beginning of the lab period on the date listed in the syllabus.

3.3. Outcomes: What are the deliverables? How do we know when it is done?

There are three deliverables: preparation, demonstration, and report.

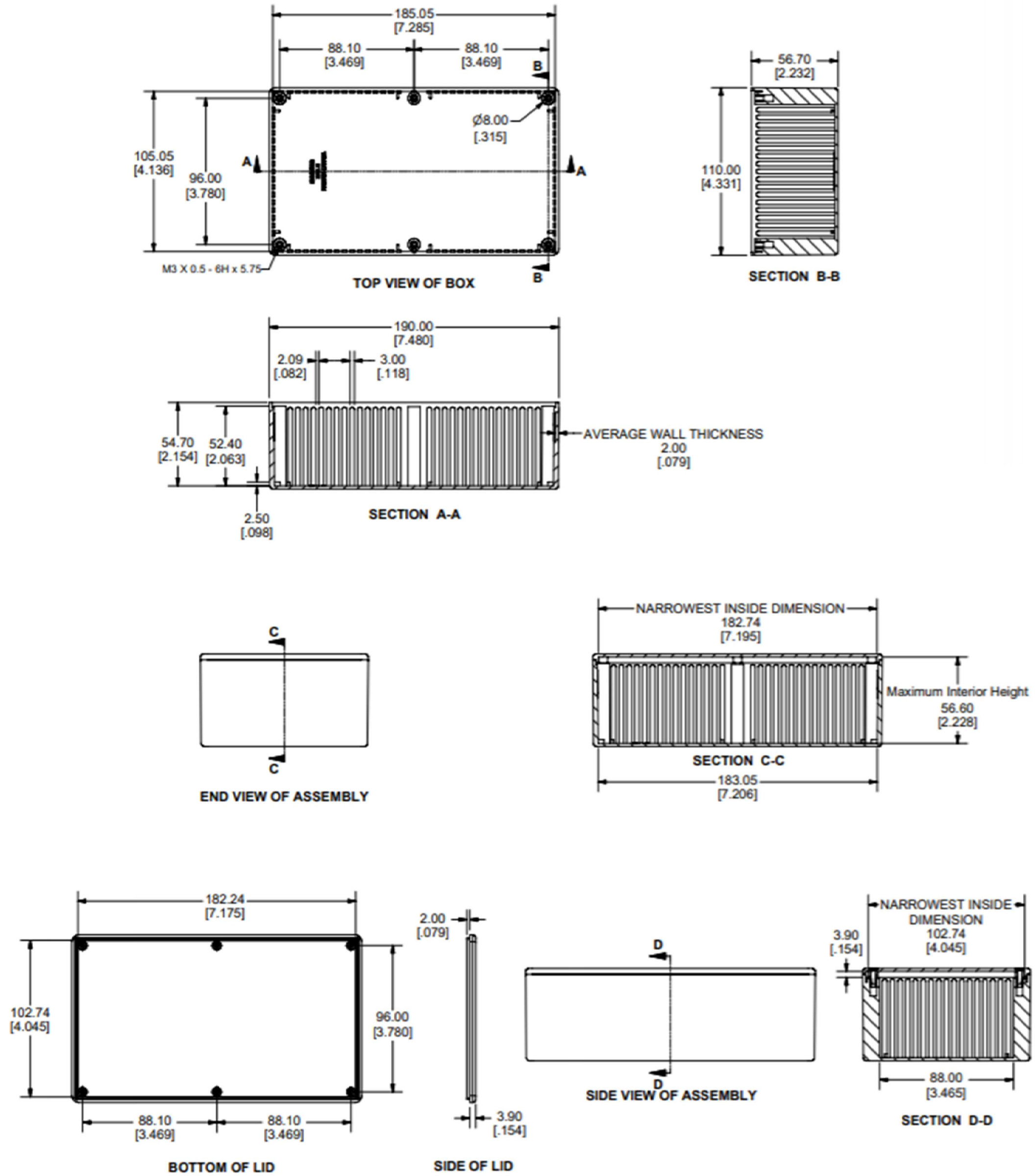
B) Hardware Design

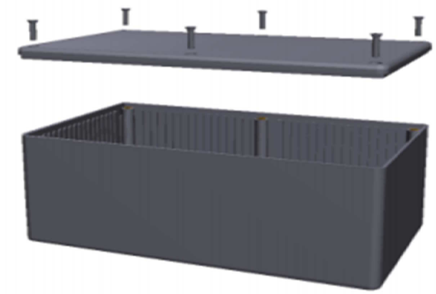
a. Description of Battery

Model	Pilot 2GS Black
Capacity	10000mAh
Input	2.1A
Output	3.4A
Times To Charge iPhone 6S	3.8
Size	5.43 x 2.91 x 0.54
Weight	8.8 oz
Accessories	Micro cable

- Plug and Charge - Auto detect your device and deliver its fastest possible charge speed once connected
- Keep Your Phone's Battery from Dying - 10,000mAh capacity provide 4 charges to an iPhone 6, or 2.5 Charges to a Galaxy S6
- SAFEST PROTECTION - built in Li-Polymer battery(the safest battery type so far) and the multi-protect system provide complete protection
- Compact Design - Aluminum body plus the built-in Li-polymer battery, not only increase safety but also make it easy to carry
- Industry-Leading Warranty: 24 months limited product warranty and 24*7 easy-to-reach customer service

b. Description of Box





Note:
Enclosures can be Factory Modified (Milling, Drilling, Printing etc.)
Contact Factory mjm@hammondmfg.com for quotes
Solid models of this enclosure available in STEP or IGES Format.

PART NUMBERS

1591E Enclosures		
Material	**Colour**	**Part Number**
FR ABS UL94 - V0	Beige	1591EBG
	Black	1591EBK
	Blue	1591EBU
	Grey	1591EGY
GP ABS UL94 - HB	Black	1591ESBK
	Grey	1591ESGY
Translucent Polycarbonate	Ice Blue	1591ETBU
	IR Red	1591ETRD
	Crystal Clear	1591ETCL
Accessories		
	Description	**Part Number**
Universal Use	PC Board Card Adapters	See Accessories Section
	Clear Lids - clear, flame retardant polycarbonate - Lid ONLY	1591EC
FR ABS	Replacement Screws, Flat Head Phillips Nickel Plated Pkg of 100	1591MS100 1591MS100BK (Black)
GP ABS	Self Tapping Pkg of 100	1591TS100 1591TS100BK (Black)
Recomended Torque on Fasteners (no lubrication)		
	M3 - 0.5 x 10mm Screws	30-40 cN*m
	#4 x 0.5 Screws	30-40 cN*m

HAMMOND MANUFACTURING™
1591E

c. **Component I created a schematic symbol and footprint for: INA188ID (Instrumentation Amplified from Texas Instruments)**

i. **Description of component:**

3 Description

The INA188 is a precision instrumentation amplifier that uses TI proprietary auto-zeroing techniques to achieve low offset voltage, near-zero offset and gain drift, excellent linearity, and exceptionally low-noise density (12 nV/√Hz) that extends down to dc.

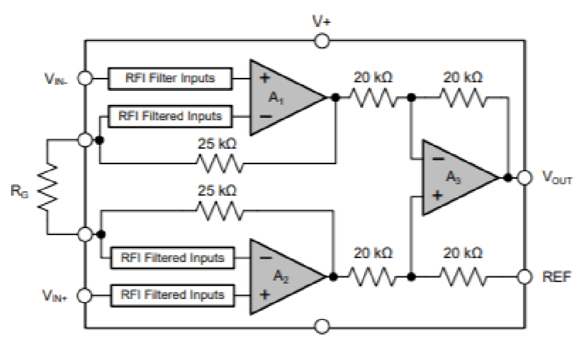
The INA188 is optimized to provide excellent common-mode rejection of greater than 104 dB (G ≥ 10). Superior common-mode and supply rejection supports high-resolution, precise measurement applications. The versatile three op-amp design offers a rail-to-rail output, low-voltage operation from a 4-V single supply as well as dual supplies up to ±18 V, and a wide, high-impedance input range. These specifications make this device ideal for universal signal measurement and sensor conditioning (such as temperature or bridge applications).

A single external resistor sets any gain from 1 to 1000. The INA188 is designed to use an industry-standard gain equation: $G = 1 + (50\ k\Omega / R_G)$. The reference pin can be used for level-shifting in single-supply operation or for an offset calibration.

The INA188 is specified over the temperature range of –40°C to +125°C .

The buffer amplifiers on the inputs eliminate the need for impedance matching and can reject noise that is common on both input lines and can amplify the difference (which is the value of interest to the engineer) between them. Because of this instrumentation amplifiers have useful applications in measuring equipment.

Simplified Schematic

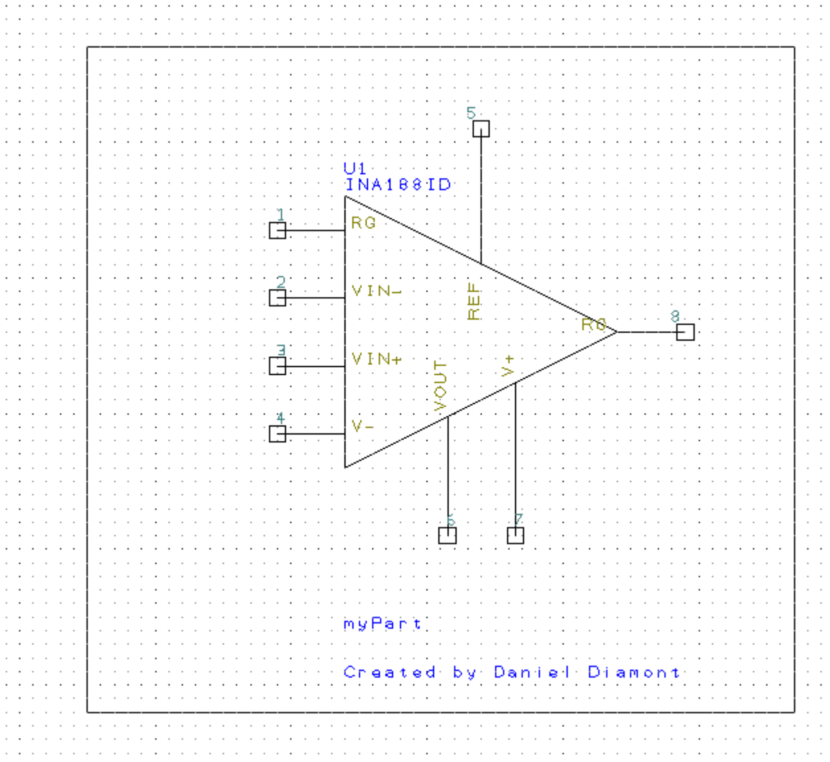


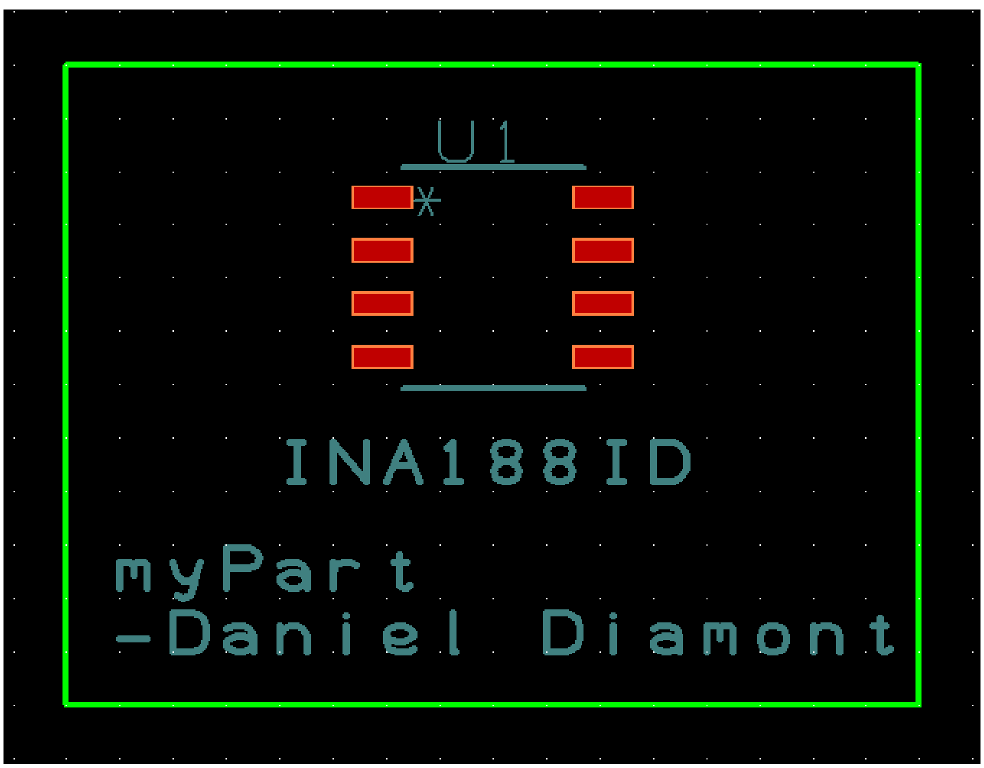
$$V_{OUT} = (V_{IN+} - V_{IN-}) \times G + V_{REF} \qquad G = 1 + \frac{50\ k\Omega}{R_G}$$

2 Applications

- Bridge Amplifiers
- ECG Amplifiers
- Pressure Sensors
- Medical Instrumentation
- Portable Instrumentation
- Weigh Scales
- Thermocouple Amplifiers
- RTD Sensor Amplifiers
- Data Acquisition

ii. **My Part on PCB Artist**





iii. **Example Circuit and PCB:**

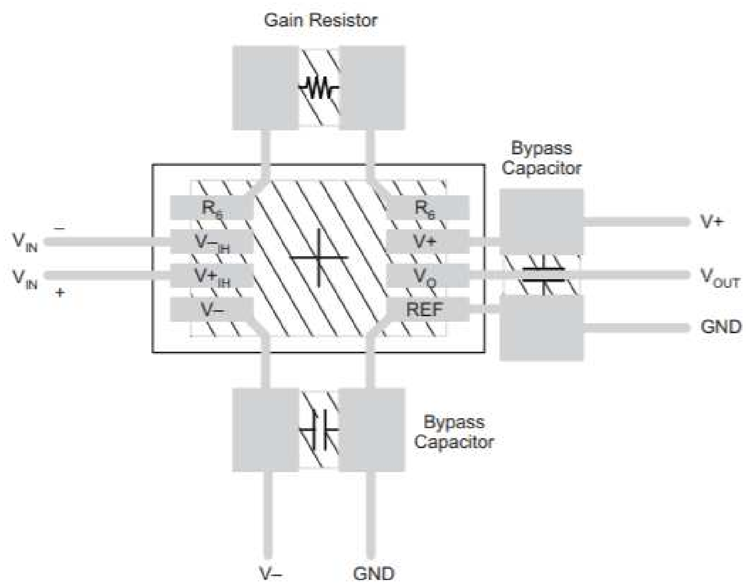
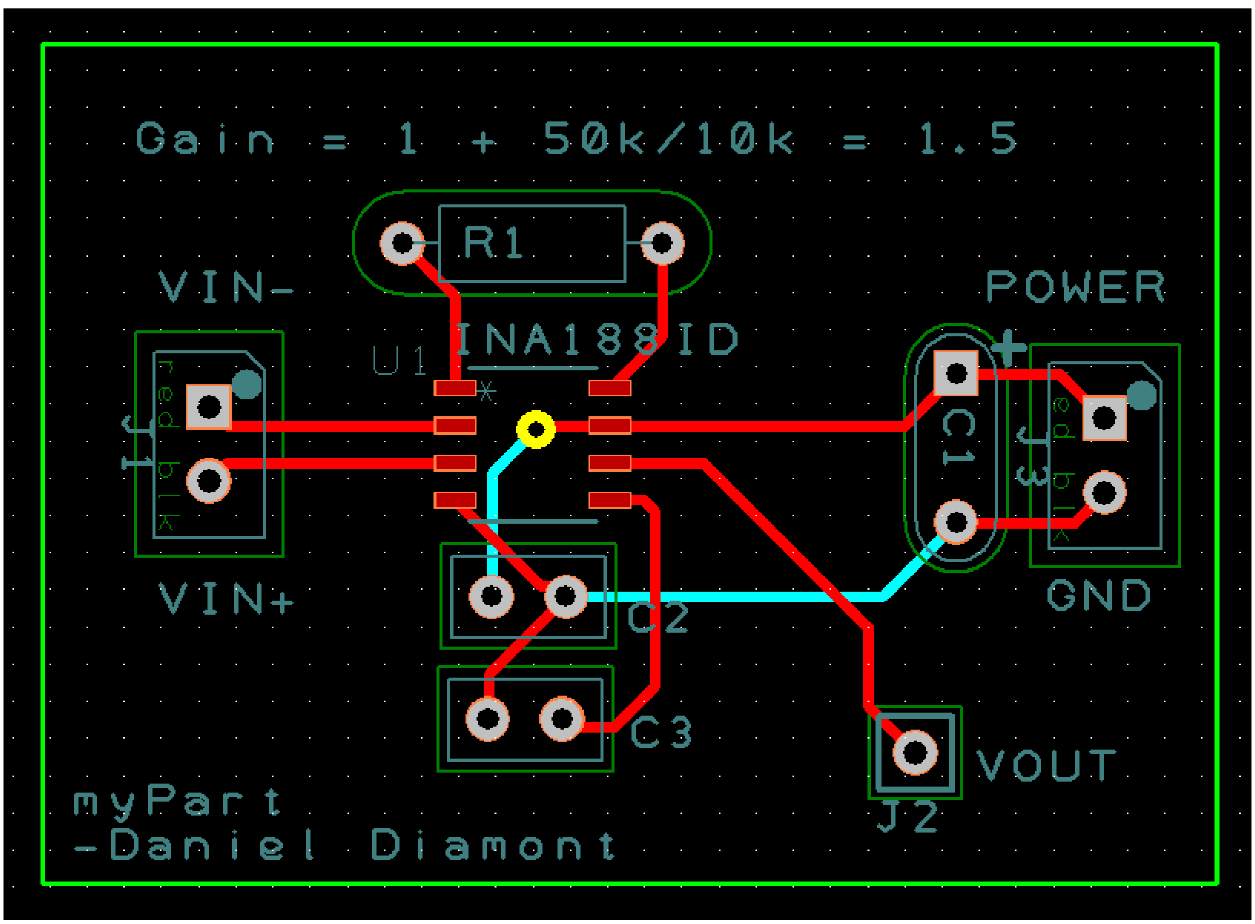
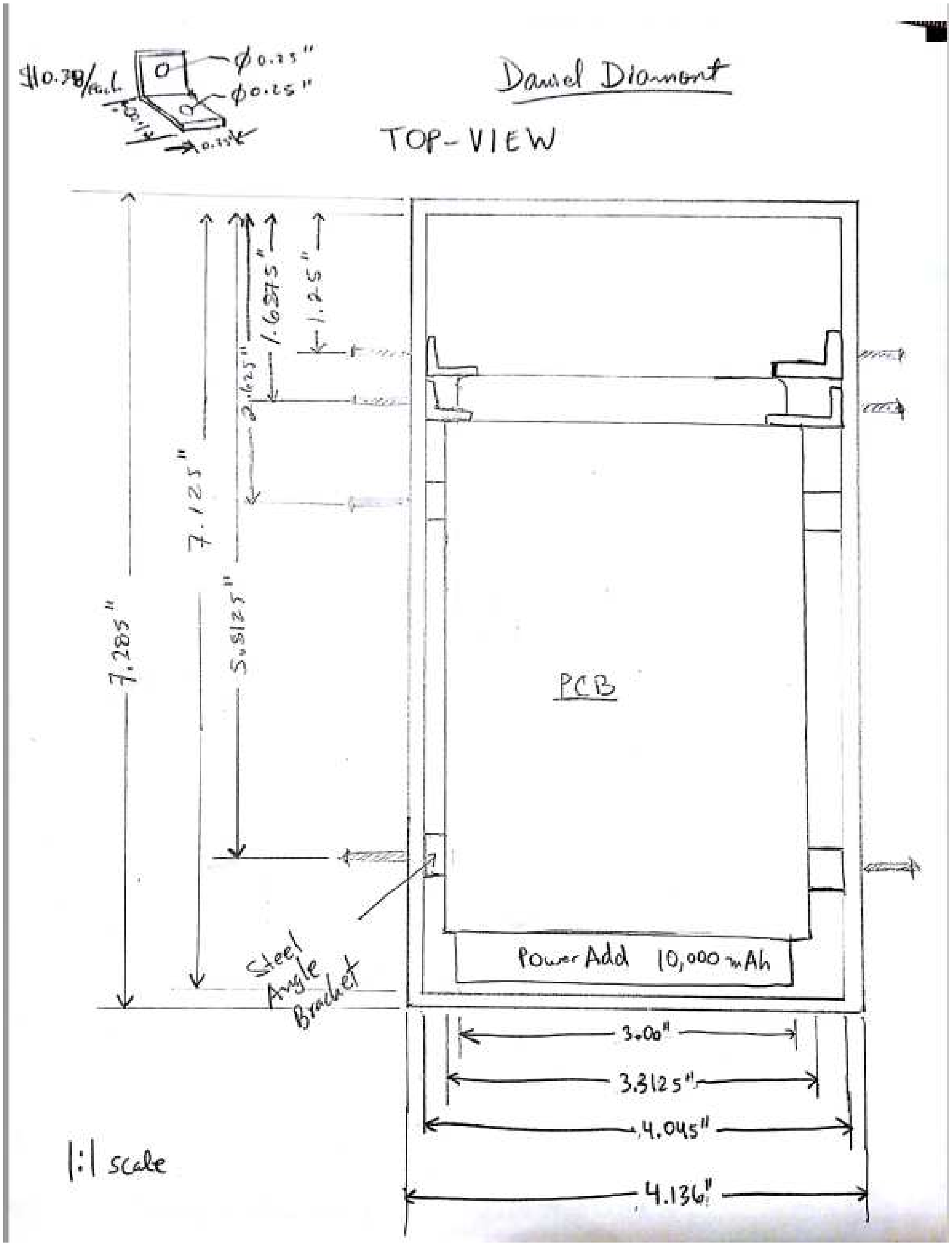


Figure 57. PCB Layout Example



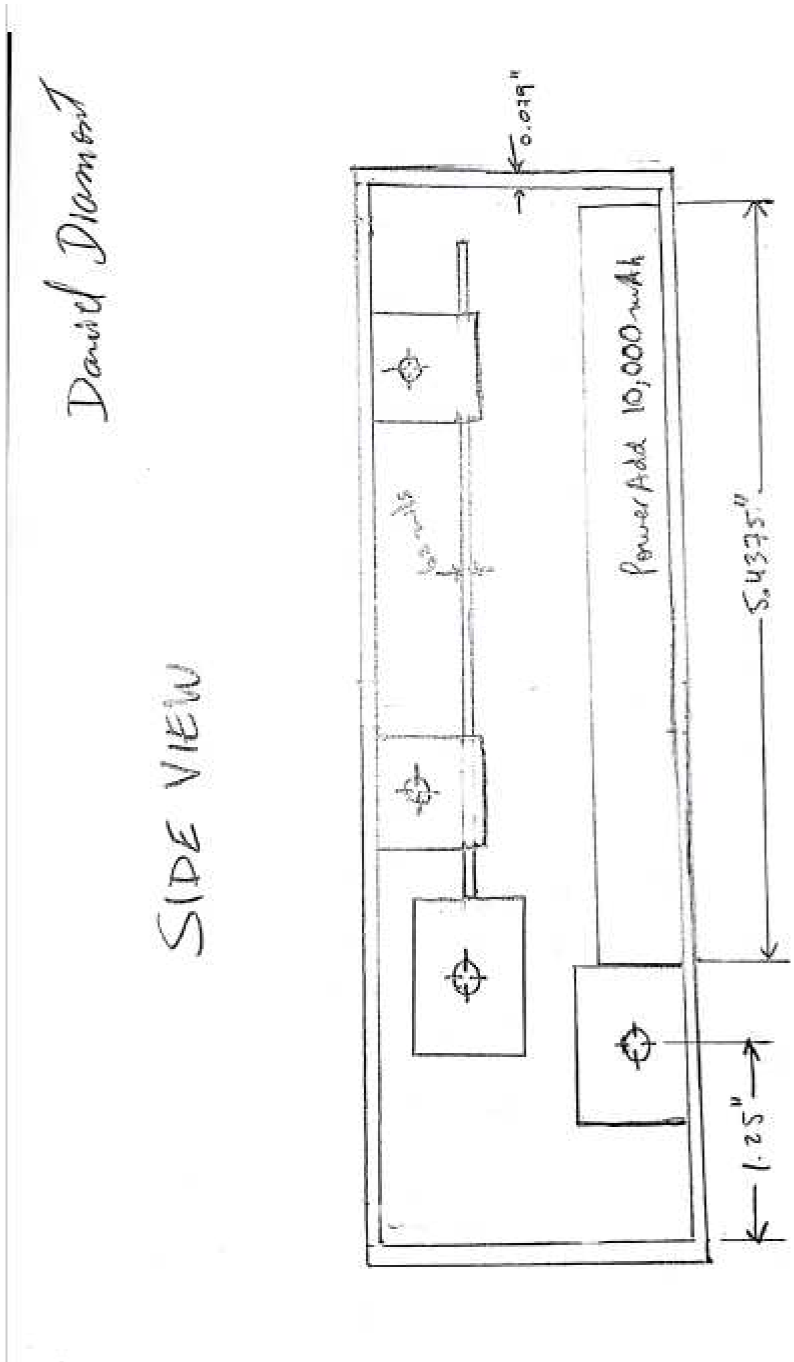
d. Two Mechanical Drawings

i. **Top View**



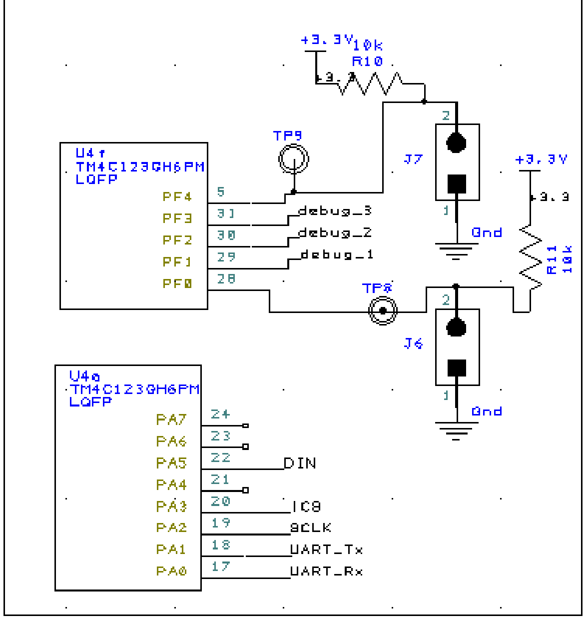
$0.78/each
ϕ0.25"
ϕ0.25"
0.75"
Daniel Diamont
TOP-VIEW
1.25"
1.6875"
2.625"
7.125"
5.8125"
7.285"
PCB
Steel Angle Bracket
Power Add 10,000 mAh
3.00"
3.3125"
4.045"
4.136"
1:1 scale

ii. **Side View**

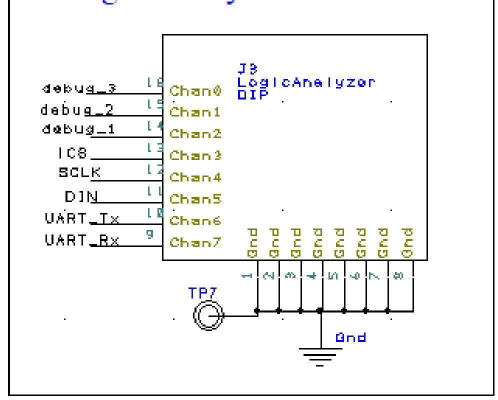


e. **Final Circuit Diagram of the Embedded System (check attached files/see below)**

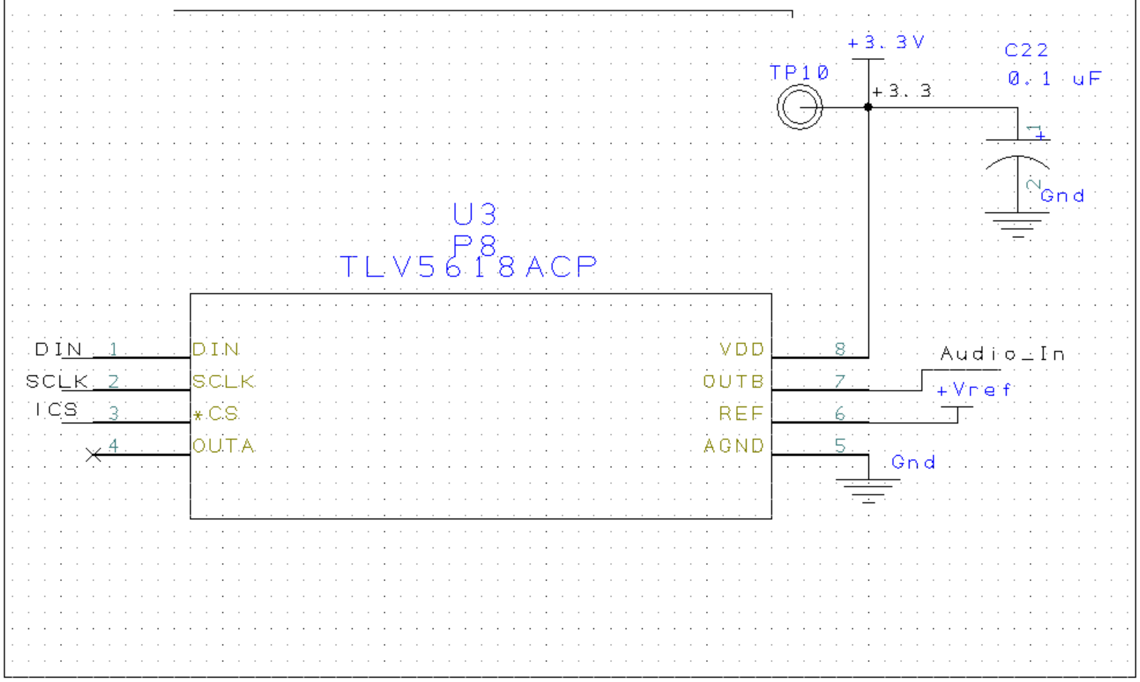
TM4C Peripheral Connections

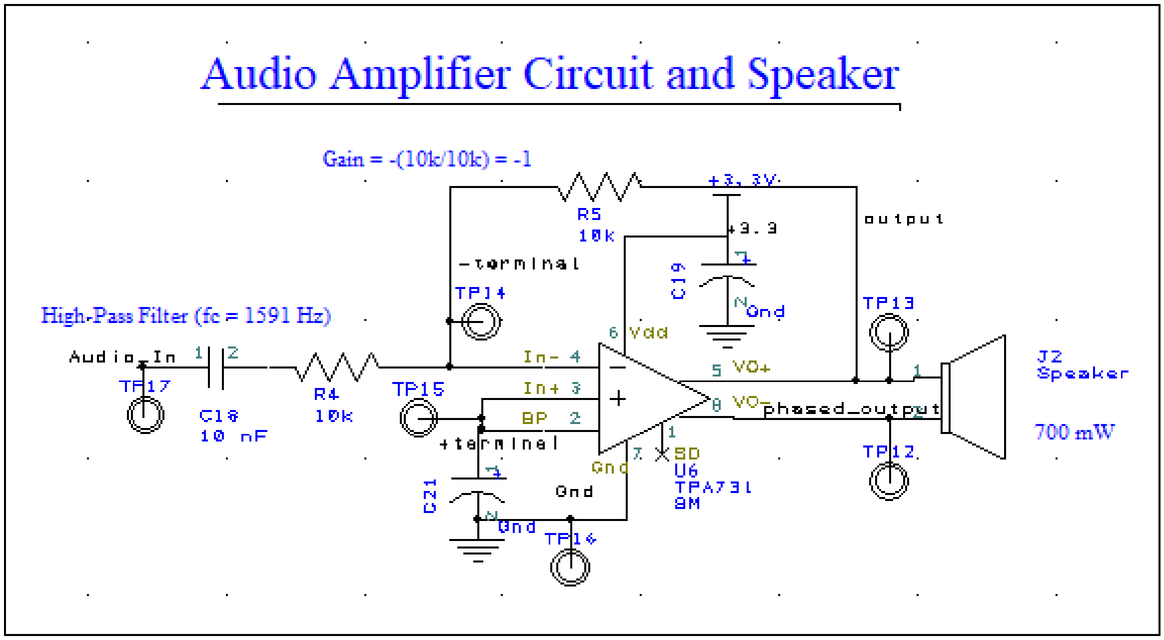


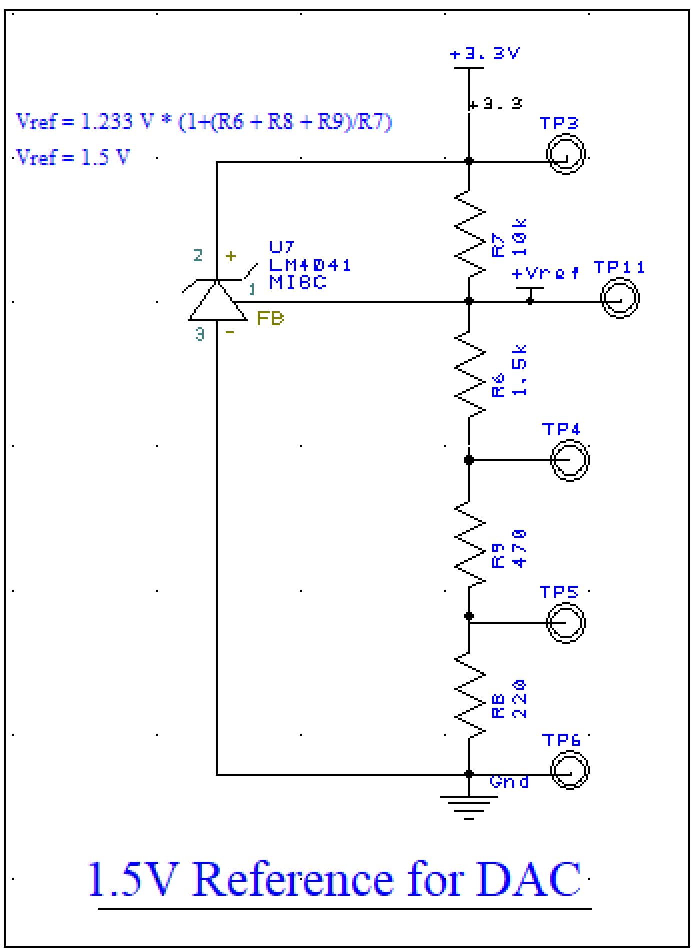
Logic Analyzer Connections



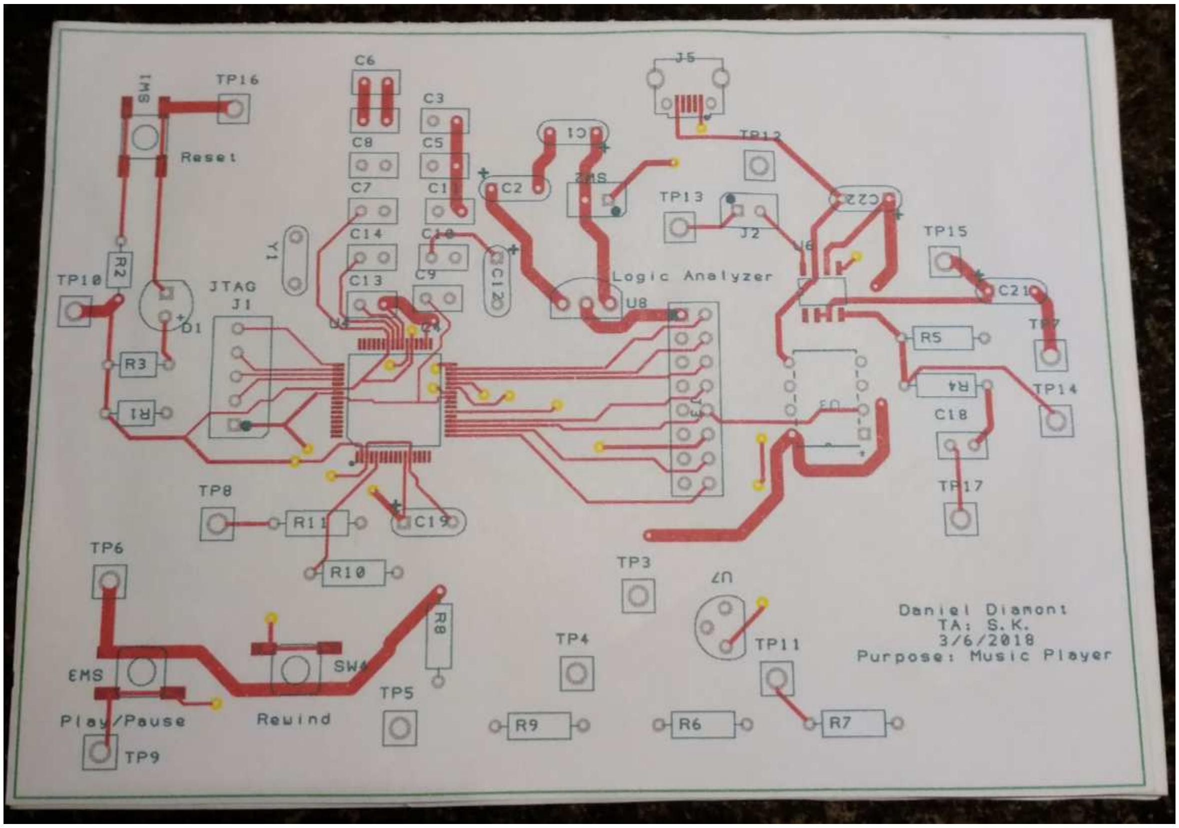
Digital to Analog Converter

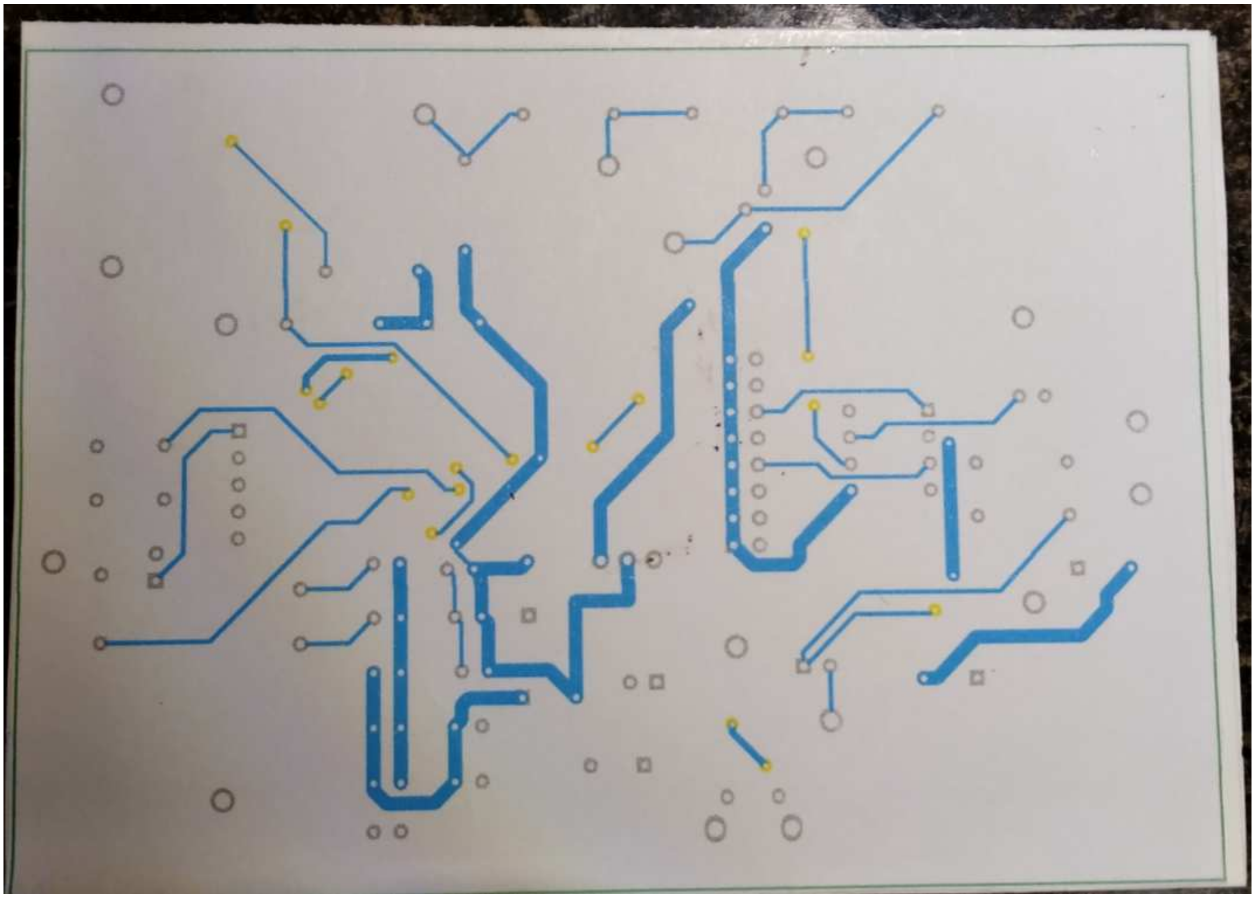



Audio Amplifier Circuit and Speaker
Gain = -(10k/10k) = -1
R5
10k
+3.3V
+3.3
output
-terminal
C19
Gnd
TP14
TP13
High-Pass Filter (fc = 1591 Hz)
Vdd
Audio_In
In- 4
J2
Speaker
TP17
C18
10 nF
R4
10k
TP15
In+ 3
BP 2
5 VO+
8 VO-
phased_output
+terminal
700 mW
SD
U6
TPA731
8M
C21
Gnd
TP16
TP12


+3.3V
+3.3
Vref = 1.233 V * (1+(R6 + R8 + R9)/R7)
Vref = 1.5 V
TP3
R7
10k
U7
LM4041
MIBC
+Vref
TP11
FB
R6
1.5k
TP4
R9
470
TP5
R8
220
TP6
Gnd
1.5V Reference for DAC

f. Cardboard Mockup of PCB Layout





C) Software Design (none)

D) Measurement Data

a. Bill of Materials (see attached files/see below)

Qty Note	REF DES Note			"Box means in box in your McDermott's office (bring a print out of your SCH circuit)								
Quan	REF DE	Type	Description	Manufacturer	Mfg. P/N	Distributor	P/N	Unit co	Co	PCB Artist	Where?	Datasheets
1		ASM	32-ohm speaker			AllElectronics	SK-230	$0.50	$0.50	Speaker	Cabinet	
1		ASM	Poweradd 2nd Gen Pilot 2GS 10000mAh Powe	Poweradd	B00N2JBTEM	Amazon	Pilot 2GS	$15.99	$15.99	N/A	Amazon	
2		CAP	Ceramic, X7R, 20%, 1 uF			Jameco	81509	$0.35	$0.70	Ceramic0.2	Cabinet	Datasheet
6		CAP	Ceramic, Z5U, -20/+80%, 0.1 uF			Digikey	399-4151-ND	$0.05	$0.27	Ceramic	Cabinet	Datasheet
3		CAP	Ceramic, Z5U, -20/+80%, 0.01 uF			Digikey	399-4148-ND	$0.40	$1.20	Ceramic	Cabinet	Datasheet
2		CAP	Ceramic C0G, 10%, 10 pF	Murata 50V 5%	RDE5C1H100J0P1H03I	Digikey	490-8629-ND	$0.31	$0.62	Ceramic	Cabinet	Datasheet
2		CAP-Tant	Tantalum, 16V, 20% 2.2 uF	AVX Corporation	TAP225M016CCS	Mouser	581-TAP225M016CCS	$0.29	$0.58	tantalum	Cabinet	Datasheet
1		CAP-Tant	Tantalum, 16V, 10% 4.7 uF			Jameco	94035	$0.22	$0.22	tantalum	Cabinet	Datasheet
1		CAP-Tant	Tantalum, 35V, 10%, 0.47 uF			Jameco	33531	$0.19	$0.19	tantalum	Cabinet	Datasheet
1		CON	2 to 40 pin 0.1 in header (price per pin)			AllElectronics	SHS-40	$0.02	$0.02	Jumper2	Cabinet	
1		CON	2-pin header			AllElectronics	SBH-2	$0.10	$0.10	Jumper2	Cabinet	
1		CON	2-pin jumper			AllElectronics	SBC-2	$0.27	$0.27	goes with SBH-2	Cabinet	
1		CON	2-pin jumper			AllElectronics	SJ-1	$0.10	$0.10	goes with Jumper2	Cabinet	
10		CON	Test point, black	Keystone Electronics	5001	Digikey	36-5001K-ND	$0.23	$2.30	testpoint	Cabinet	
1		CON	Micro USB Type B, surface mount	Hirose Connector	ZX62D-B-5PA8(30)	Mouser	798-ZX62D-B-5PA830	$0.47	$0.47	USB_Micro-B	Cabinet	Datasheet
2		CON	Logic Analyzer connector	FCI	68021-208HLF	Digikey	609-3344-ND	$0.27	$0.54	LogicAnalyzer	Cabinet	
1		CPU	TM4C123GH6PM 64-pin LQFP	TI	TM4C123GH6PMI	Mouser	595-TM4C123GH6PMI	$11.55	$11.55	TM4C123GH6PM	we will s	Datasheet
1		CRYS	NX5032GA-16.000000	NDK	NX5032GA-16.000000	Digikey	644-1037-1-ND	$0.51	$0.51	XTAL/NX5032	Cabinet	Datasheet
1		IC	LM2937 3.3 V regulator TO220, 500mA	TI	LM2937ET-3.3/NOPB	Digikey	LM2937ET-3.3-ND	$1.17	$0.00	LM2937-3.3	Cabinet	Datasheet
1		IC	TLV5618 dual 12-bit DAC	TI	TLV5618	TI	TLV5618ACP	$4.30	$4.30	TLV5618	Cabinet	Datasheet
1		IC	TPA731 audio amp (pin 1 low) 700mW	TI	TPA731D	TI	TPA731D	$1.84	$1.84	TPA731	Cabinet	Datasheet
1		IC	LM4041CILPR shunt diode reference	TI	LM4041CILPR	TI	LM4041CILPR	$0.90	$0.90	LM4041	Cabinet	Datasheet
1		LED	Red 1.6V 1mA 5mm diffused	Avago Technologies	HLMP-D150	Digikey	516-1323-ND	$0.29	$0.29	LEDT1.75	Cabinet	Datasheet
1		PCB	PCB plus shipping	Advanced Circuits		Advanced Circuits		$53.00	$53.00		http://www.4pcb.com/	
1		RES	Carbon 1/6W, 5%, 220	Yageo	CFR-12JB-220R	Digikey	220EBK-ND	$0.02	$0.02	0.125Wresistor	Cabinet	Datasheet
2		RES	Carbon 1/6W, 5%, 470	Yageo	CFR-12JB-470R	Digikey	470EBK-ND	$0.02	$0.05	0.125Wresistor	Cabinet	Datasheet
1		RES	Carbon 1/6W, 5%, 1.5K	Yageo	CFR-12JB-1K5	Digikey	1.5KEBK-ND	$0.02	$0.02	0.125Wresistor	Cabinet	Datasheet
6		RES	Carbon 1/6W, 5%, 10K	Yageo	CFR-12JB-10K	Digikey	10KEBK-ND	$0.02	$0.14	0.125Wresistor	Cabinet	Datasheet
1		RES	Carbon 1/6W, 5%, 1M	Yageo	CFR-12JB-1M0	Digikey	1.0MEBK-ND	$0.02	$0.02	0.125Wresistor	Cabinet	Datasheet
1		SW	Tactile Switch, surface mount	C&K Components	KSC353JLFG	Mouser	611-KSC353JLFG	$0.86	$0.86	KSC353JLFG	Cabinet	Datasheet
1		SW	B3F tactile push button switch	Omron Electronics	B3F-1052	Digikey	SW405-ND	$0.17	$0.17	B3F-1050	Cabinet	Datasheet
1		SW	Black Off board momentary push buttom			AllElectronics	MPB-5	$0.35	$0.35	OffBoardSwitch	Cabinet	
1		SW	Red Off board momentary push buttom			AllElectronics	MPB-1	$0.35	$0.35	OffBoardSwitch	Cabinet	
1		SW	On/off power switch			BGMicro	SWT1010	$0.85	$0.85	OffBoardPowerSwitch	Cabinet	
1		Box	Hammond 1591E	Hammond Mfg.	1591ESBK	Mouser	546-1591ES-BK	$7.44	$7.44	N/A	Mouser	Datasheet
			Supply Current Sum (mA)									
		TM4C	40	per datasheet								
		Speaker	103	3.3/32Ohm = 103 mA								
		Total (mA)	143									

b. How I chose the battery

I experimentally determined the average current drawn by the system (~73 mA), and determined that the battery capacity must be at least 1,752 mAh in order to last a whole day playing music. My personal preference was to make the system last at least 5 days, so I chose a 10,000 mAh battery, which yields about 5.7 days worth of playing Ode to Joy.

E) Analysis and Discussion

a. Test Procedure

Test Procedure for Lab 6 PCB

Description: This procedure tests the functionality of the TM4C, DAC, and audio generation circuitry.

1. Connect two 8-channel Logic Analyzer ports to the Pin Header labeled *Logic Analyzer* on the PCB.
2. Connect two oscilloscope probes to the Pin Header labeled *O-Scope: Power*.
3. Connect the board to a +5V power supply through the micro-USB header (J5) and check if the red power LED turns on.
4. Check the +5V and +3.3V power rails (e.g. TP10 and TP3). Check the 1.5V shunt reference voltage for the TLV5618A (TP11).
5. If the appropriate voltages were found in step 4, evaluate TP10, TP3, and TP11 on the oscilloscope and check that the noise in the power rails is being successfully filtered by the smoothing capacitors on either side of the LP290CZ-3.3 regulator.
6. Connect an oscilloscope probe to the TP17 (the DAC output).
7. Disconnect the PCB from the +5V power supply and connect through the micro-USB port (J5) to a computer with test software.
8. Perform a full erase of the TM4C's flash memory via the micro-USB port (J5).
9. Given that step 8 is successful, flash software to generate a 440 Hz sine wave on the DAC.
10. Examine the DAC output on the oscilloscope, and examine the DAC's SCLK, ICS, DIN signals on the Logic Analyzer.
11. Connect two oscilloscope probes to TP12 and TP13 to check that the signals Vo- and Vo+ (speaker output) are exactly 180 degrees out-of-phase with each other.