Rockin World of Transistor Amplifier Design
Ignite Their Future 2024

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Contents

Course Description

Get ready to embark on an exciting journey into the world of electronics. Hands-on activities will teach you how to prototype electronic circuits and construct a Rockin Transistor Amplifier. This projects will teach you about voltage regulation and audio amplification and introduce you to essential skills such as circuit design and design considerations, troubleshooting, and soldering. By the end of the camp, you will have gained practical hands-on experience and a sense of accomplishment in creating your own functional amplifier.

Keywords:

Electronics, Test Equipment, Breadboard, Bluetooth, Amplifier Design and Development, Soldering.

Welcome

Welcome, esteemed students, to the "Rockin World of Transistor Amplifier Design"! We’re thrilled to have you join us on this electrifying journey into the dynamic realm of electronics. Whether you’re a seasoned veteran or just starting your adventure in electronics, this course promises to invigorate your passion and expand your knowledge to new heights.

Led by an experienced instructor with nearly three decades of expertise in electronics, including a decade of teaching at Idaho State University, this course is designed to provide a comprehensive understanding of Transistor Amplifiers. Together, we’ll explore the intricacies of amplifiers, circuits, and hands-on learning experiences, culminating in the creation of your very own Rockin Transistor Amplifier.

This course will focus on project-based learning. Project-based learning offers invaluable opportunities for students to actively engage in their education, fostering deep understanding and long-term retention of concepts. By immersing students in real-world, hands-on projects, they develop critical thinking, problem-solving, and collaboration skills essential for success in both academic and professional settings. Moreover, project-based learning promotes creativity and autonomy, empowering students to take ownership of their learning journey and cultivate a lifelong love for learning.

So, prepare to rock the classroom as we embark on this exciting journey. Welcome aboard, and let’s dive into the world of electronics together!

Objectives:

- Design a Class AB stereo amplifier that will provide, at minimum, double the power to the speakers compared to Project 1 AND be loud enough, when playing Mr. Roboto by Styx, to hear down the hall at the principal's office.
- The amplifier will use Bluetooth for an input signal.
- Design for full visibility of all electronic parts will showcase the artistic nature of PCB design and component soldering skills.

Power Requirements

Class AB or Push-Pull amplifiers can achieve a maximum efficiency of 78.5%. However, I like to design at 50% efficiency which will result in components capable of handling more than what will be asked. The amplifier efficiency is equal to Power Out divided by Power Total.

$$Efficiency = \frac{P_{Out}}{P_{Total}}$$

$$0.5 = \frac{P_{Out}}{P_{Total}}$$

A stereo amplifier or two-channel amplifier, with a desired 10 watts of output power per channel will equal approximately 20 watts of needed power. Substituting the output power into the previous formula will allow us to calculate the approximate total power needed to run the amplifier.

$$0.5 = \frac{20w}{P_{Total}}$$

$$P_{Total} = \frac{20w}{0.5}$$

$$P_{Total} = 40w$$

40w represents the maximum power needed from our power supply.

Voltage Requirements

To find the needed voltage we must consider the load. Typically, speaker resistances are either 8Ω or 4Ω. For our example, we will use 4Ω speakers. The design power for each speaker is 10w.

$$Power(W) = Current(I) \times Voltage(V)$$

$$Current(I) = \frac{Voltage(V)}{Resistance(\Omega)}$$

$$Power(W) = \frac{Voltage(V)}{Resistance(\Omega)} \times Voltage(V)$$

$$Power(W) = \frac{Voltage(V) \times Voltage(V)}{Resistance(\Omega)}$$

$$Power(W) = \frac{Voltage(V) \times Voltage(V)}{Resistance(\Omega)}$$

$$Power(W) = \frac{Voltage^2(V)}{Resistance(\Omega)}$$

$$10W = \frac{Voltage^2(V)}{4\Omega}$$

$$10W \times 4\Omega = Voltage^2(V)$$

$$Voltage^2(V) = 10W \times 4\Omega$$

$$Voltage(V) = \sqrt{10W \times 4\Omega}$$

$$Voltage = 6.325v$$

The 6.325v is an RMS voltage. RMS voltage is required for calculating power. The Push-Pull amplifier will need to have the capability to swing the voltage to a positive and negative peak, this is known as Peak or Peak-to-Peak voltage. The RMS voltage must be converted to Peak to Peak voltage to determine the maximum DC voltage needed for the amplifier.

$$V_P = \frac{V_{RMS}}{0.707} \text{ OR } V_P = V_{RMS} \times \sqrt{2}$$

$$V_P = \frac{6.325V}{0.707} \text{ OR } V_P = 6.325V \times \sqrt{2}$$

$V_P = 8.95vp$ OR $V_P = 8.95vp$

$V_P = 8.95vp$

$V_{PP} = V_P \times 2$

$V_{PP} = 8.95vp \times 2$

$V_{PP} = 17.9vpp$

With the output swing voltage $17.9vpp$, we will need a minimum of 17.9 VDC for the amplifier. Using the minimum VDC will may cause distortion problems in the amplifier. Headroom provides more voltage swing potential than what will be needed, allowing the amplifier's voltage gain to control the maximum power out. This means that the power supply voltage for our amplifier will need to be 17.9V plus the headroom voltage.

$VDC_{Supply} = 17.9V + V_{Headroom}$

Operational Amplifier

Typically general-purpose operational amplifiers are capable of more than $\pm$ 15V or 0 to 30V. Most operational amplifiers are not capable of providing peak voltage at the rails and will need an internal headroom of around 1.4v. This means that a general-purpose operational amplifier with +15V and -15V supplied will be capable of providing a maximum output of approximately $27.5vpp$. This is more than enough headroom for our 10-watt amplifier. Additionally, we will have some space to raise the output power above 10 watts if needed.

TL071 Operational Amplifier

1 Features

- High slew rate: 20 V/μs (TL07xH, typ)
- Low offset voltage: 1 mV (TL07xH, typ)
- Low offset voltage drift: 2 μV/°C
- Low power consumption: 940 μA/ch (TL07xH, typ)
- Wide common-mode and differential voltage ranges
  - Common-mode input voltage range includes V_{CC+}
- Low input bias and offset currents
- Low noise: V_n = 18 nV/$\sqrt{\text{Hz}}$ (typ) at f = 1 kHz
- Output short-circuit protection
- Low total harmonic distortion: 0.003% (typ)
- Wide supply voltage: ±2.25 V to ±20 V, 4.5 V to 40 V

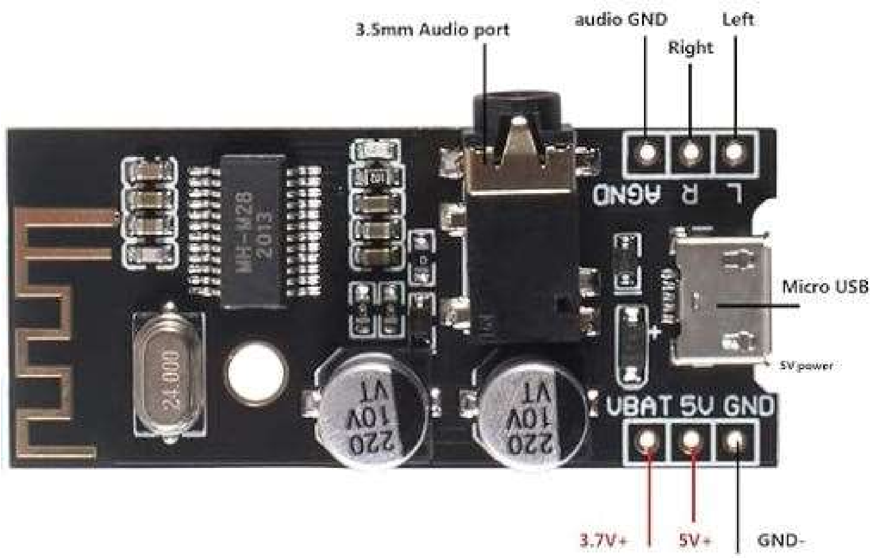
TL071 Data Sheet Excerpt

Observe the supply voltage can be up to $\pm 20V$ or $40V$. This means that the plus supply can be set to +20V while the minus supply is at -20V OR the plus supply can be set to 40V as long as the minus supply is at 0V. Operationally, the plus and minus supply differential voltage cannot exceed 40V.

M28 Bluetooth module

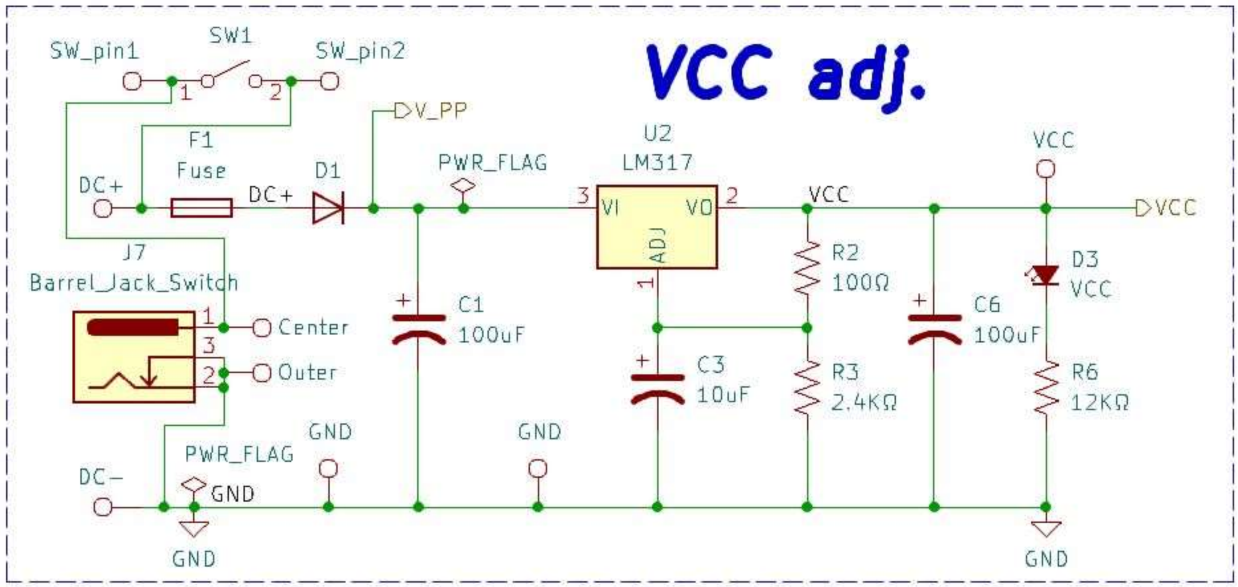
	M18	M28	M38
MICRO USB (power supply)	×	√	√
Audio headphone jack	×	√	×
Built-in amplifier	×	×	√ (5W+5W)
Lithium battery powered	√	√	√
Support USB sound card(free drive)	×	×	√
Volume memory/adjustment	√	×	×
MUTE interface	√	×	×
Button extension	√	×	×
Bluetooth version	Bluetooch V4.2		
Support Bluetooth protocol	HFPV1.7、 A2DPV1.2、 AVRCPV1.5、 AVCTPV1.2、 AVDTPV1.2		
Format support	WAV/WMA/FLAC/APE/MP3 lossless decoding, stereo dual channel output		
Operating Voltage	5V/3.7V-4.2V		
Not connected broadcast status	5.5MA		
Connection work status	20MA		
Deep sleeping	3UA		
Transmission distance	20M (MAX)		
Operating temperature	"-40°C-+85°C		
Sensitivity	"-87dbm		

M28 Features



M28 PCB

Schematic Review



30VDC Voltage Regulation circuit

Power for this project is supplied via a 36V DC wall adapter power supply using a center pin positive barrel jack connector.

SW1 is the power on/off switch.

Fuse **F1** provides primary current protection for the circuit.

Diode **D1** protects the circuit if someone uses the wrong polarity barrel jack power supply.

V_PP is the supply voltage for the Push-Pull amplifier $\approx 35.3VDC$.

C1, C3, and C6 are filter capacitors.

U2 LM317 is a linear voltage regulator. **R2 and R3** are used to set the regulation voltage as follows.

The LM317 will do whatever it can to keep 1.25VDC from pin2 to pin1.

No output current flows into pin 1 ADJ of the LM317.

The voltage at pin2 can be calculated using Ohm's Law.

$$V_{R2} = 1.25V$$

$$I_{R2} = \frac{V_{R2}}{R2} = \frac{1.25V}{100\Omega} = 12.5mA$$

$$I_{R3} = I_{R2}$$

$$V_{R3} = I_{R3} \times R3 = 12.5mA \times 2.4K\Omega = 30VDC$$

$$VO_{Pin2} = V_{R2} + V_{R3} = 1.25V + 30V = 31.25VDC$$

$$VCC = VO_{Pin2} = 31.25VDC$$

D3 is the green power on VCC LED indicator.

R6 is the current limiting resistor for the LED.

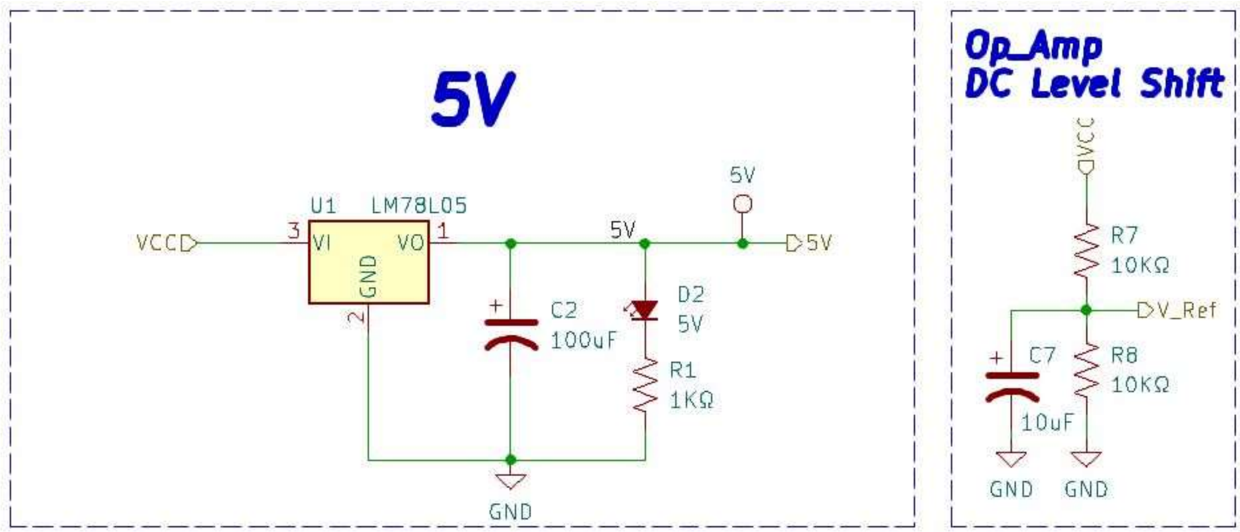
$$V_{R6} = VCC - V_{D3}$$

$$V_{D3} \approx 3V$$

$$V_{R6} = 31.25VDC - 3VDC = 28.25VDC$$

$$I_{R6} = \frac{V_{R6}}{R6} = \frac{28.25VDC}{12K\Omega} = 2.354mA$$

$$I_{D3} = I_{R6} = 2.354mA$$



5VDC Voltage Regulation and Level Shift circuits

The M28 Bluetooth module requires 5VDC to operate. The LM7805 is a 5V linear regulator. The maximum differential voltage between pin1 and pin3 is 30V. This means that the maximum input voltage on pin 3 is 35VDC. VCC is regulated at 31.25VDC, just under the maximum specification.

U1 is a linear 5VDC Regulator.

C2 is a filtering capacitor.

D2 is the green power on 5V LED indicator.

R1 is the current limiting resistor for the LED.

$V_{R1} = 5V - V_{D2}$

$V_{D2} \approx 3V$

$V_{R1} = 5VDC - 3VDC = 2VDC$

$I_{R1} = \frac{V_{R1}}{R1} = \frac{2VDC}{1K\Omega} = 2mA$

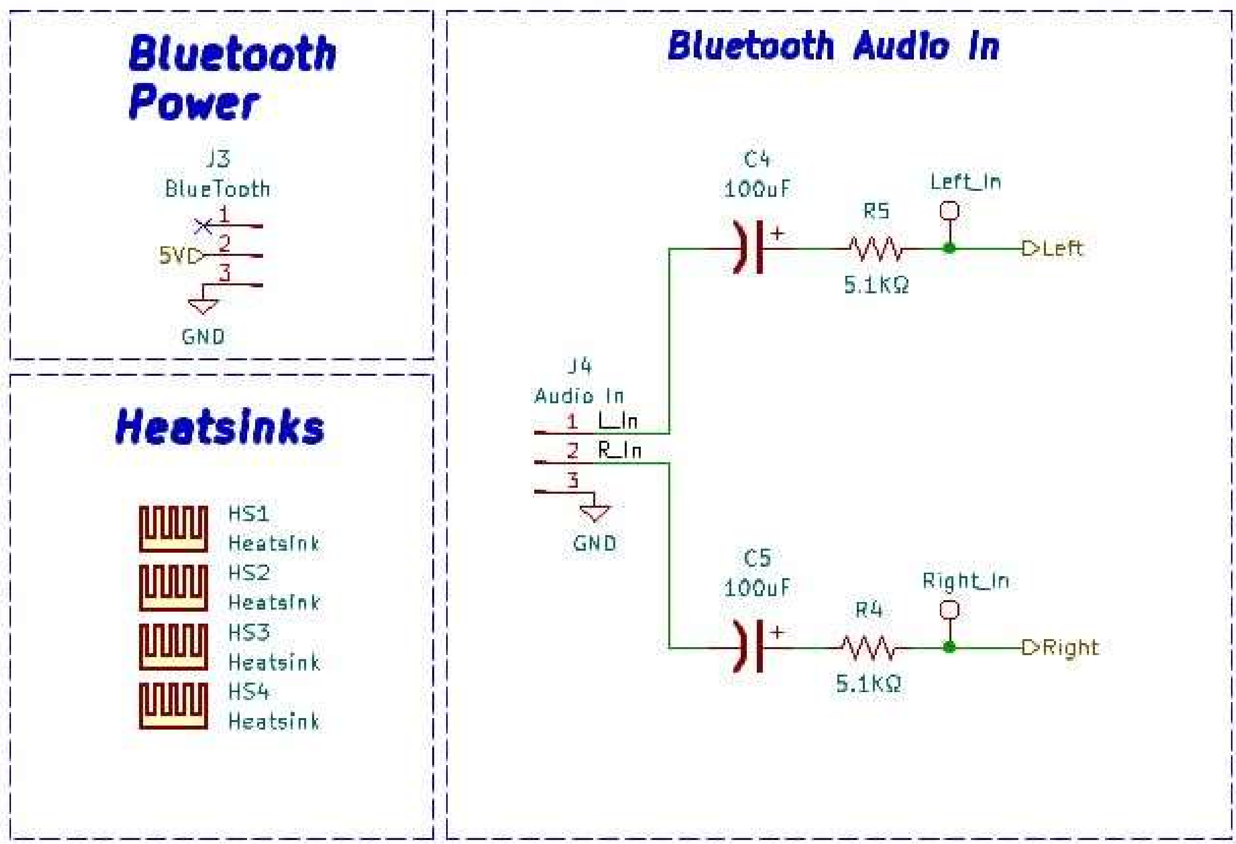
$I_{D3} = I_{R1} = 2mA$

The Op_Amp DC Level Shift will provide a DC level for the input analog signal to for the Operational Amplifier. The V_Ref voltage is equal to VCC divided by two.

C7 is a filtering capacitor.

R7 & R8 form a voltage divider network.

V_Ref $= \frac{VCC}{2} = \frac{31.25VDC}{2} = 15.625VDC$

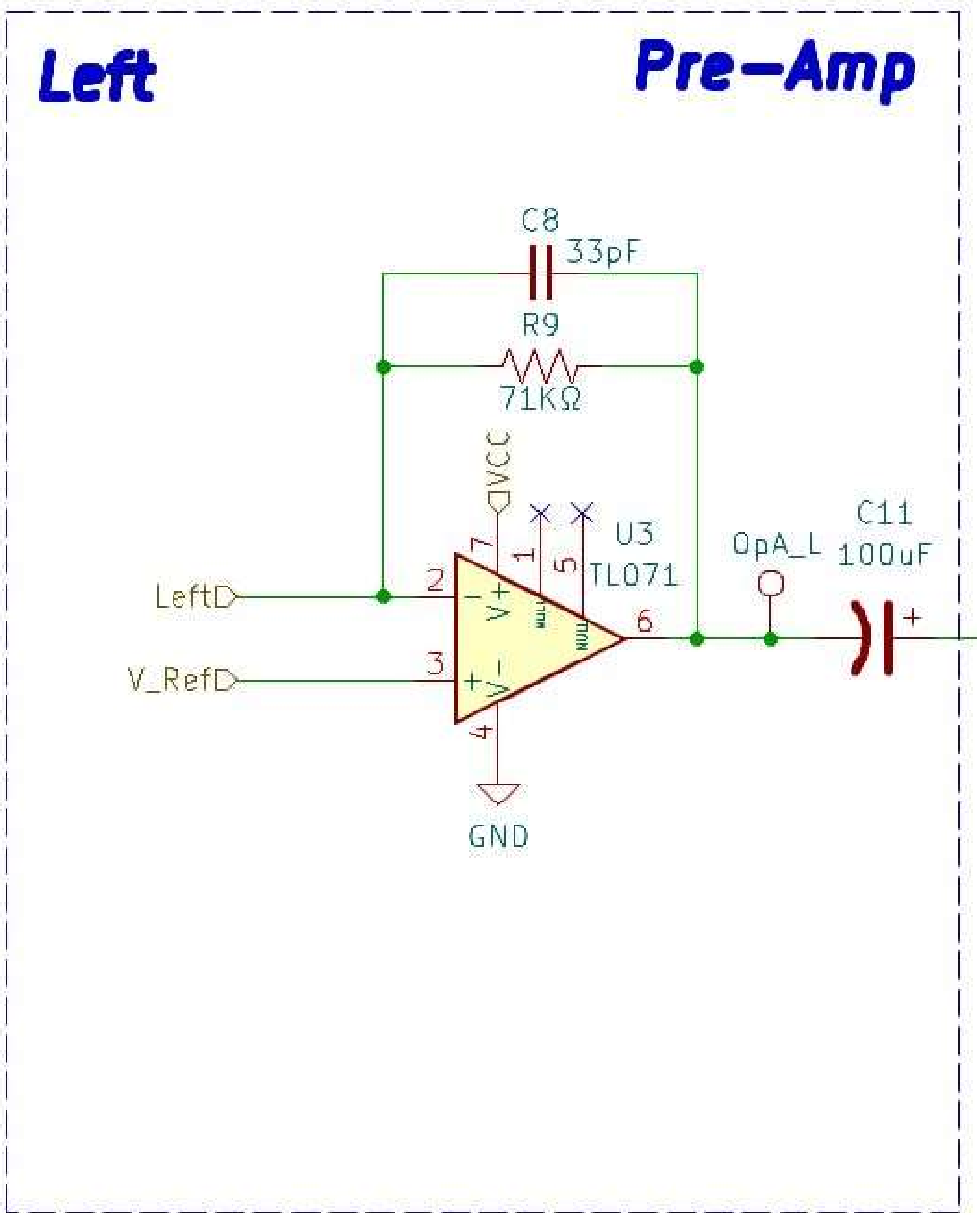


Bluetooth Power and Audio, plus the Heat-sinks for the Push-Pull amplifier

The Bluetooth M28 module is powered with the 5VDC and ground and will provide the low-level analog audio signal to the left and right channel pre-amps. The Heat-sinks are used to dissipate heat from the Push-Pull amplifier power transistors Q5-Q8.

C4 & C5 are coupling capacitors. Coupling capacitors will block DC voltages and pass AC signals. The value of the capacitance will determine the Low Critical Frequency.

R4 & R5 represent the input impedance of the operational amplifiers U3 and U4. Additionally, R4 and R5 will be used to calculate the gain of the Operational amplifiers.



Left Channel Operational Amplifier

The TL071 is an operational amplifier used to amplify the signal voltage coming from the Bluetooth module. Our desired maximum output signal amplitude is 8.95vp. The Bluetooth M28 module has an approximate maximum output amplitude of 0.6vp. This means the Operational Amplifier should have a gain $\Delta V = \frac{8.95vp}{0.6vp} = 14.916$.

Left is the left channel signal coming from the M28 Bluetooth module.

V_Ref is the reference voltage for the input signal which is necessary to lift the signal reference DC voltage because pin 7 is set to 30VDC and pin 4 is set to ground.

R9 is the Feedback resistor used to control the gain of the operational amplifier.

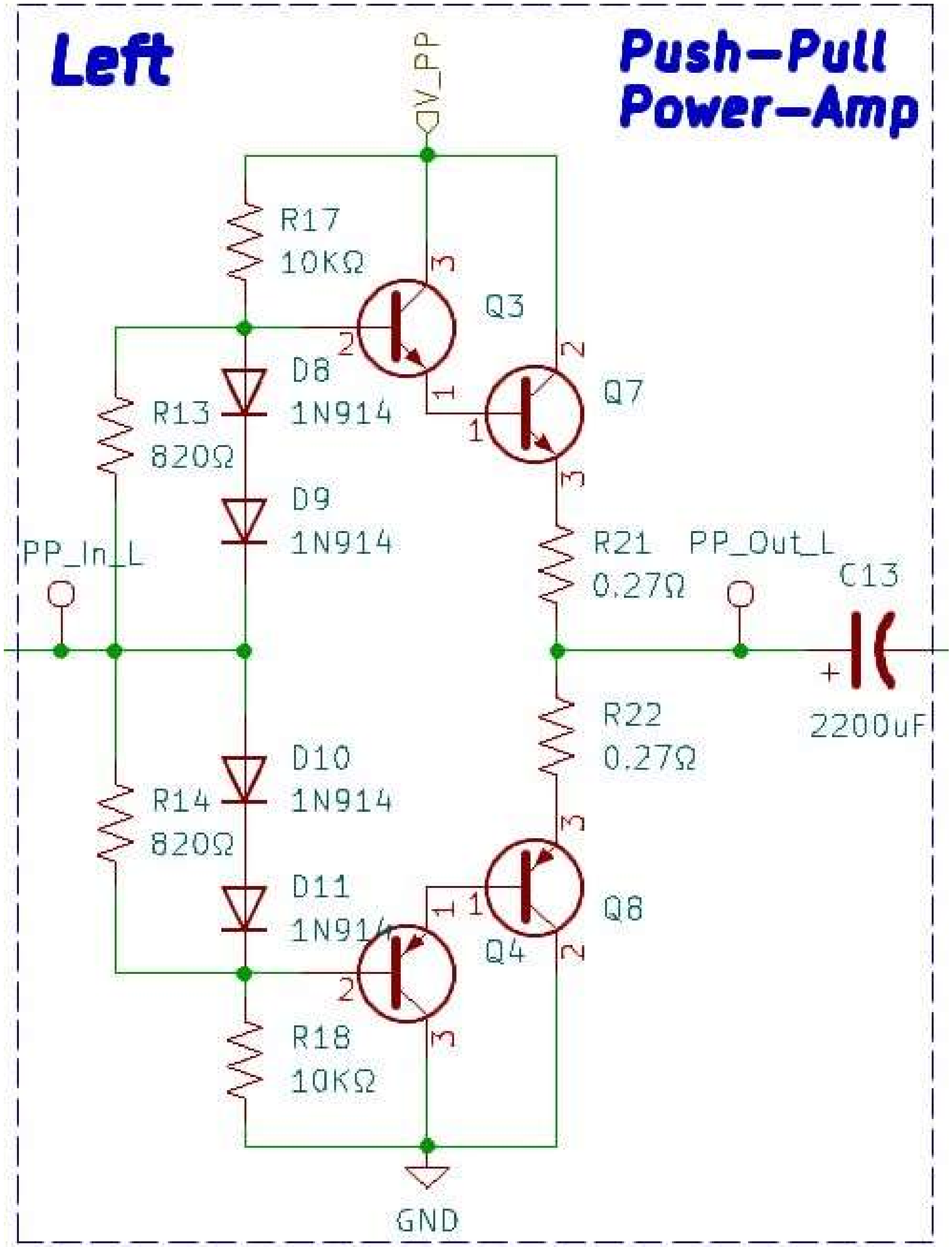
C8 is a bypass capacitor which is used to reduce the gain of the amplifier at frequencies above the audio range. This helps prevent high-frequency oscillations which could damage the Push-Pull amplifier.

C11 is a coupling capacitor.

U3 Voltage Gain ΔV

$$\Delta V_{U3} = \frac{R9}{R5} = \frac{75K\Omega}{5.1K\Omega} = 14.706$$

$$\Delta V_{U4} = \Delta V_{U3} = 14.706$$



Left Channel Push-Pull Amplifier

The maximum current that the op-amp can supply is around 30-50mA. This is not enough current to drive our 4Ω speaker. We will need a peak current of $\frac{Vp}{R} = \frac{8.95vp}{4\Omega} = 2.238Ap$

The Push-Pull amplifier is used to provide current gain.

R17 & R18 are biasing resistors.

R13 & R14 are also biasing resistors. Ideally, the Push-Pull will have a very small amount of shoot-through *mA* to avoid cross-over distortion. However, too much shoot-through will cause circuit problems (blown fuse, damage to Q7 and Q8). If the circuit is experiencing too much shoot-through, R13 and R14 values can be lowered. If the circuit is experiencing cross-over distortion R13 and R14 values can be raised.

D8, D9, D10, D11 diodes are used to set a maximum bias voltage of 1.4V for the Darlington Pair and Swamper resistor. These are used to prevent shoot-through current run away.

V_PP is our 36VDC input which provides even more headroom.

Q3 & Q7 are a NPN Darlington Pair. Together, these two transistors will provide current gain for the upper or positive portion of the signal. Q3 is a 2N3904 and Q7 is a TIP41, both are general-purpose bipolar junction transistors. Beta is the ratio of the transistor's collector current (Ic) to its base current (Ib). The Beta of the 2N3904 is ≈ 200 and the Beta for the TIP41 is ≈ 40. This means the Darlington Pair will have a potential current amplification capability of $\approx 200 \times 40 \approx 8000$.

Q4 & Q8 are a PNP Darlington Pair. Together, these two transistors will provide current gain for the lower or negative portion of the signal. Q4 is a 2N3906 and Q8 is a TIP42, both are general-purpose bipolar junction transistors. Beta is the ratio of the transistor's collector current (Ic) to its base current (Ib). The Beta of the 2N3906 is ≈ 200 and the Beta for the TIP42 is ≈ 40. This means the Darlington Pair will have a potential current amplification capability of $\approx 200 \times 40 \approx 8000$.

R21 & R22 are Swamping resistors used to limit shoot-through current. These resistors are small because they are in series with the 4Ω load (speaker), ideally $R_{Swamp} \leq 4\Omega$.

C13 is a coupling capacitor. To accomplish full-range frequency amplification, the Critical Frequency for the amplifier will be below 20hz.

Frequency Response for C13

$X_{C13} = \frac{1}{2\pi \times F \times C}$

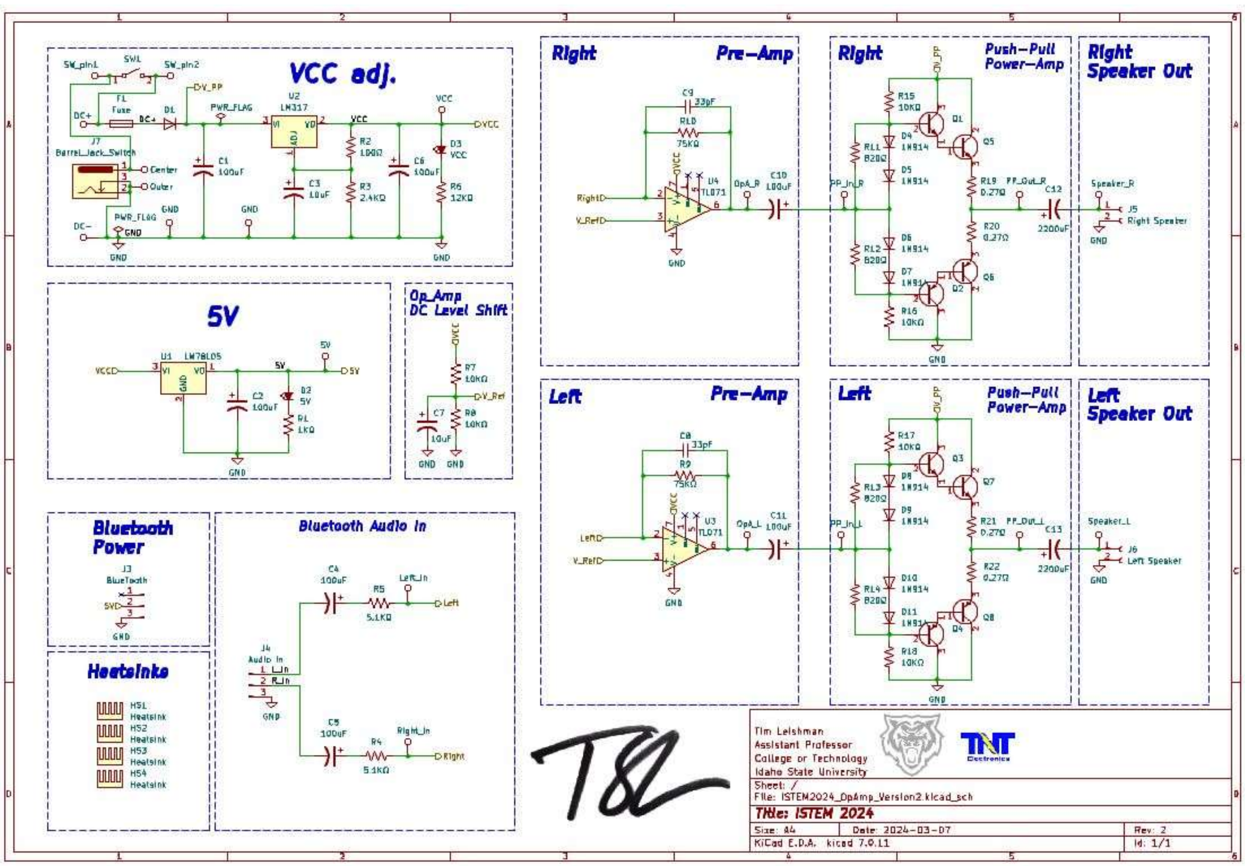
at Critical Frequency (FC), $X_{C13} = Rth_{C13}$

$Rth_{C13} = R_{Swamp} + RL = 0.27\Omega + 4\Omega = 4.27\Omega$

$Rth_{C13} = \frac{1}{2\pi \times FC_{C13} \times C}$

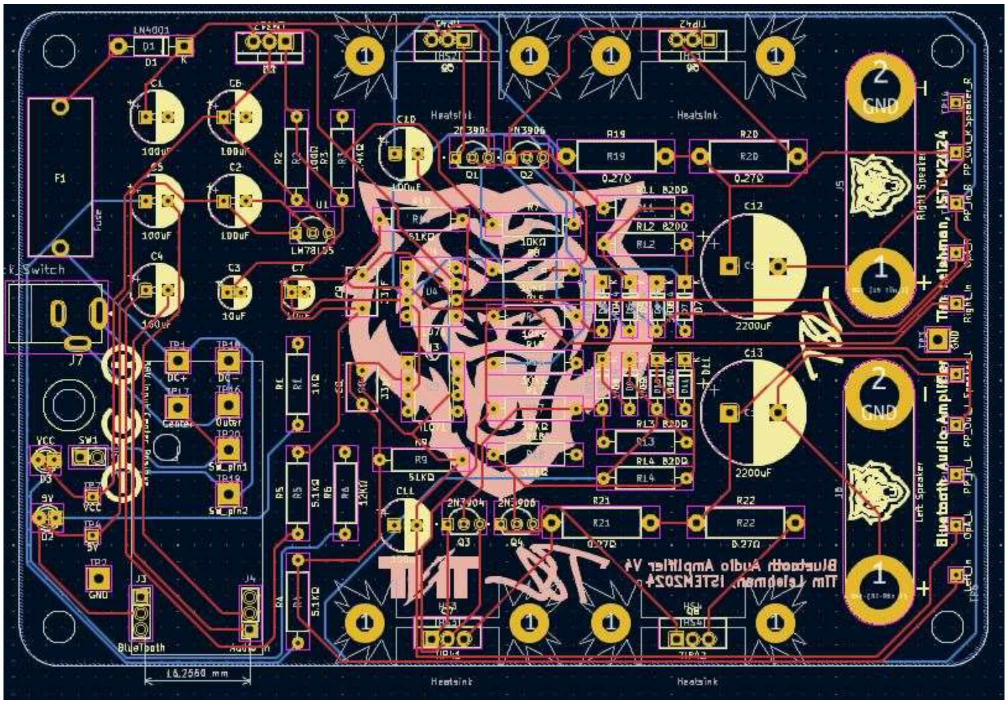
$FC_{C13} = \frac{1}{2\pi \times Rth_{C13} \times C} = \frac{1}{2\pi \times 4.27\Omega \times 2200\mu F} = 16.942hz$

Schematic

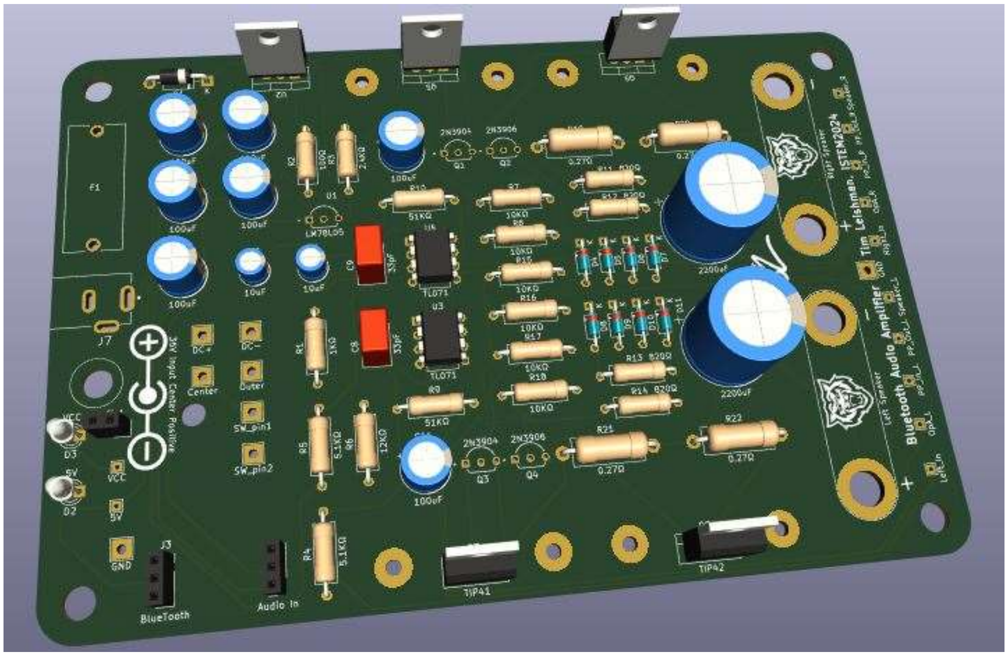


Full Schematic

PCB



PCB Design

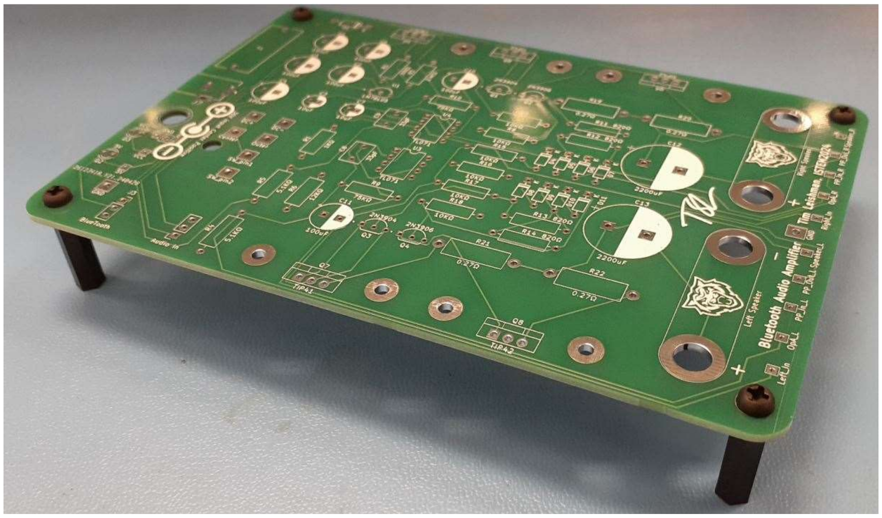


PCB 3D Top View

PCB 3D Bottom View

10-watt Amplifier, Assembly Instructions

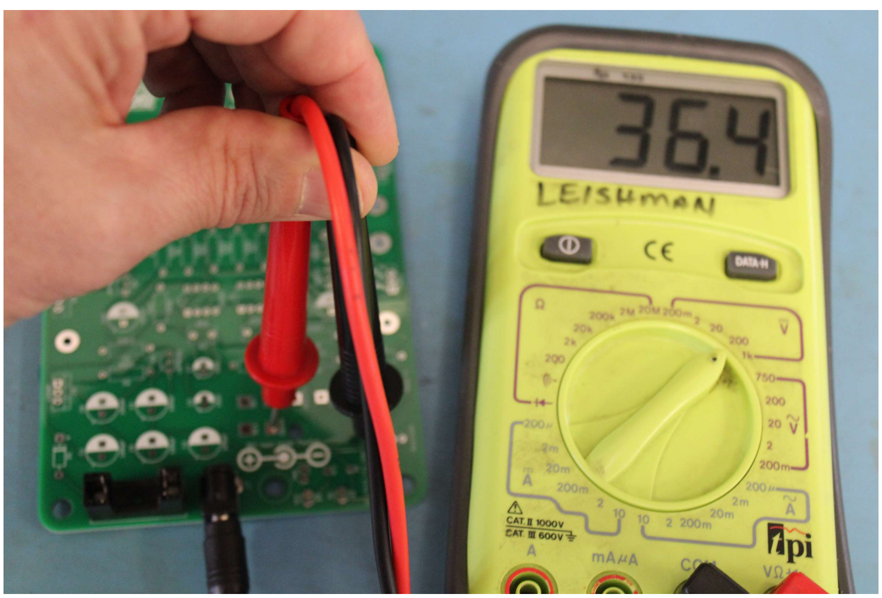
10-watt Amplifier Power Supply



Standoffs

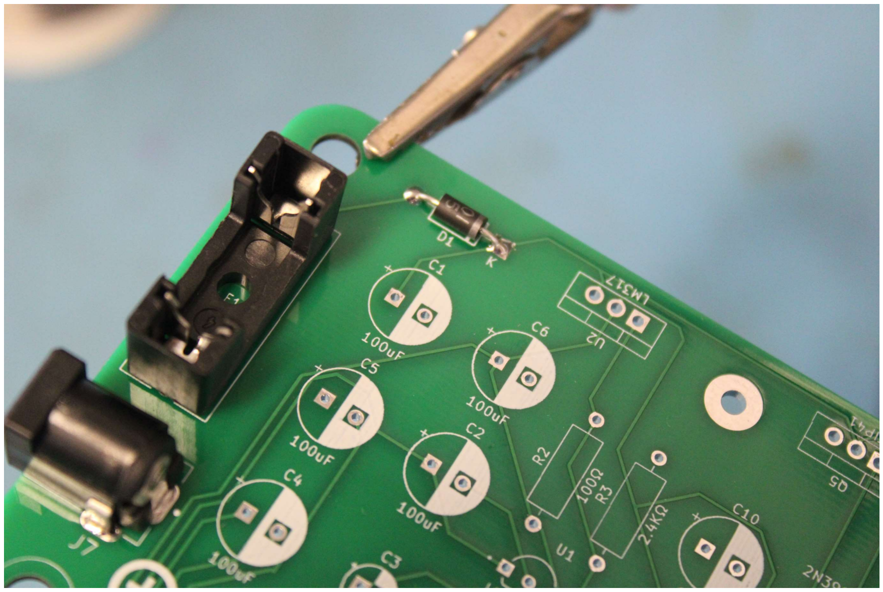
☐ Install stand-offs at the four corners of the PCB.

☐ Solder the Barrel Jack Connector J7 onto the PCB.



DC voltage test - test point Center to test point GND

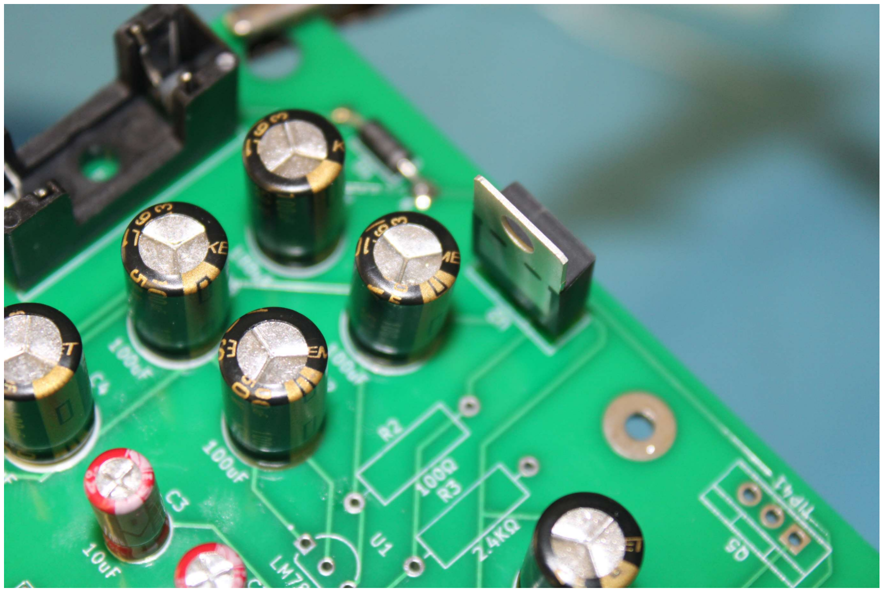
☐ Plug in the 36V power adapter into the Barrel Jack Connector. Using a DMM, verify the voltage at the test points labeled Center (red lead) and Outer & GND (black lead).



Fuse Holder F1 and Diode D1

☐ Solder the Fuse Holder F1.

☐ Solder Diode D1, this part is polarity-sensitive! Make sure the anode and cathode (k) are properly oriented.



100uF & 10uF capacitors, LM317 U2

☐ Solder all seven of the 100uF capacitors. The electrolytic capacitors are polarity-sensitive! Make sure the + and - are properly aligned.

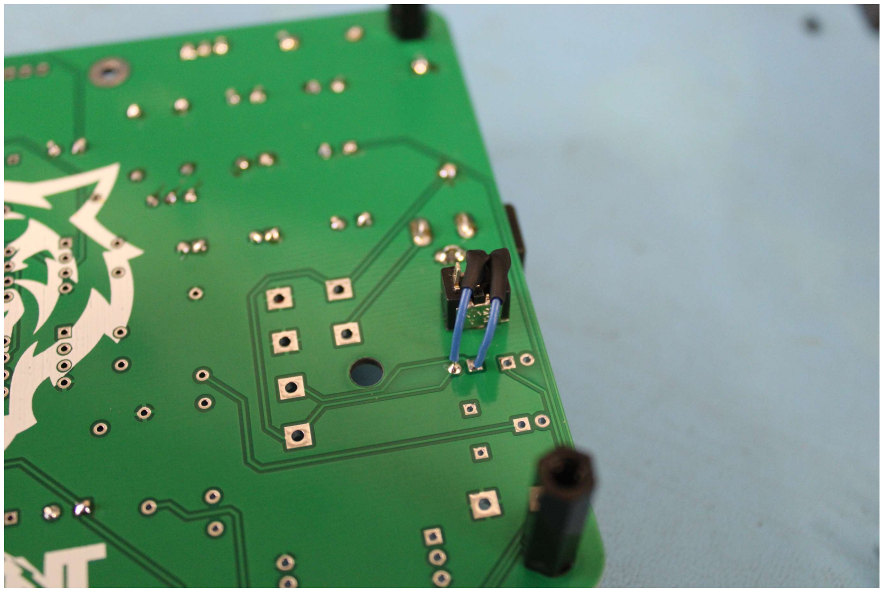
☐ Solder the two 10uF capacitors. Make sure the + and - are properly aligned.

☐ Solder the LM317 U2. The part faces out away from the PCB, the back **metal part is toward the capacitor C6**.

☐ Solder the 100Ω resistor R2. For uniform aesthetics, all horizontal resistors should be oriented in the same direction with the gold band to the right. Orient the vertical resistors with the gold band down.

☐ Solder the 2.4KΩ resistor R3 with the same orientation as R2.

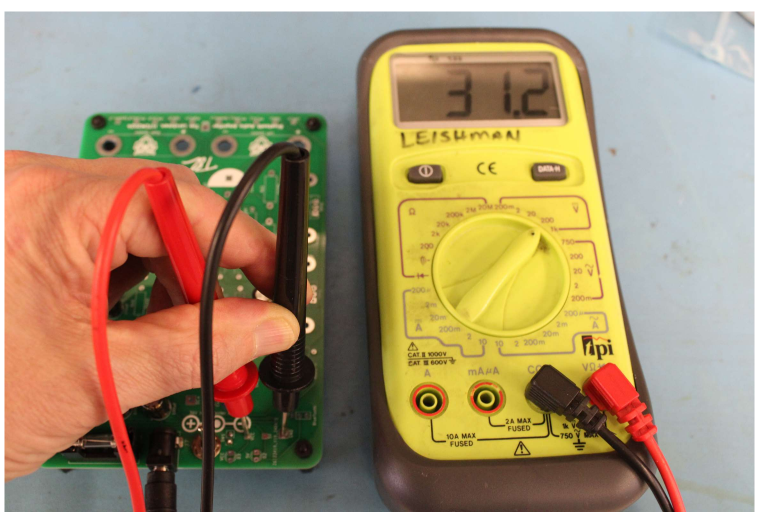
☐ Solder the LM7805 5V linear regulator U1. The orientation should match the silkscreen.



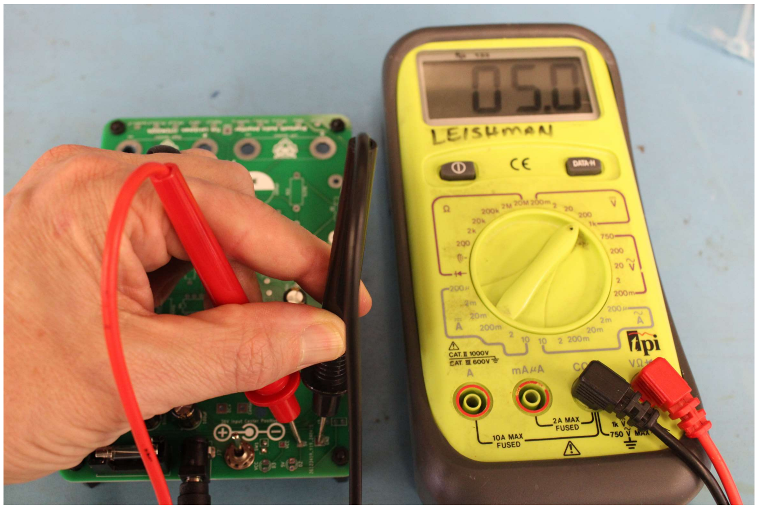
Switch S1

☐ Mount the switch to measure continuity (zero resistance) (on position) when the switch is away from the PCB.

☐ On the underside of the board solder small 1" wire jumps from the switch to SW1. Use heat shrink to protect the switch contacts.



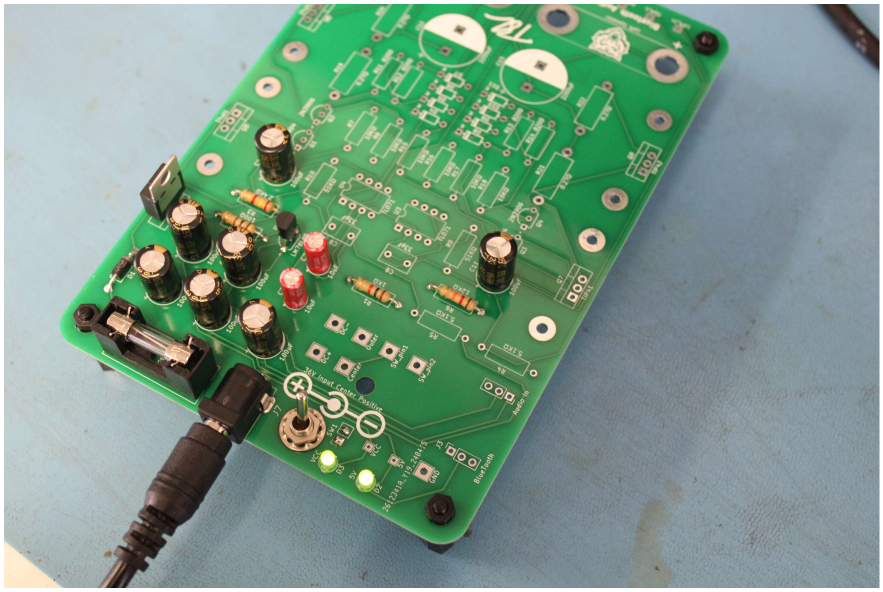
$VCC \approx 30V\,DC$



5VDC

With the switch in the off position, install the Fuse F1 and connect power to the PCB. Using a DMM measure the test points labeled VCC (red) and GND (black). First, verify that there is no voltage and switch the power on. Verify that VCC is $\approx 30VDC$. Move the red lead to 5V and verify the voltage is $5VDC$.

- ☐ Switch OFF, no voltage at test points.
- ☐ Switch ON, $\approx$ 30V measured at 30V test point.
- ☐ Switch ON, 5V measured at 5V test point.



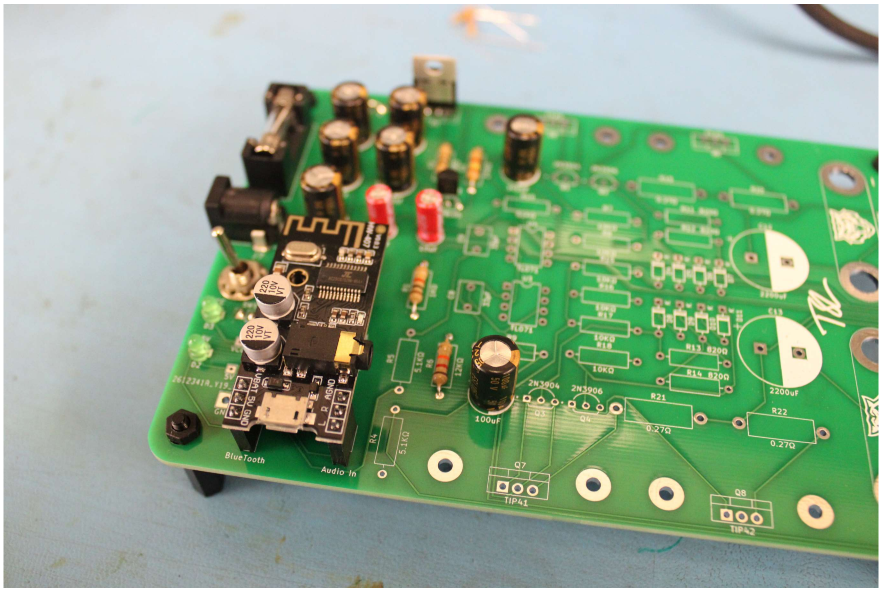
LED Test (Light Emitting Diode)

☐ Remove power and solder the 1KΩ resistor R1.

☐ Solder the 12KΩ reistor R6.

☐ Solder the LED diodes D2 and D3. These parts are polarity-sensitive, the flat part of the LED goes toward the square pad.

☐ Connect power to the PCB. Observe that the VCC and 5V LEDs light and turn off when the switch is turned on and off.



M28 Bluetooth Module

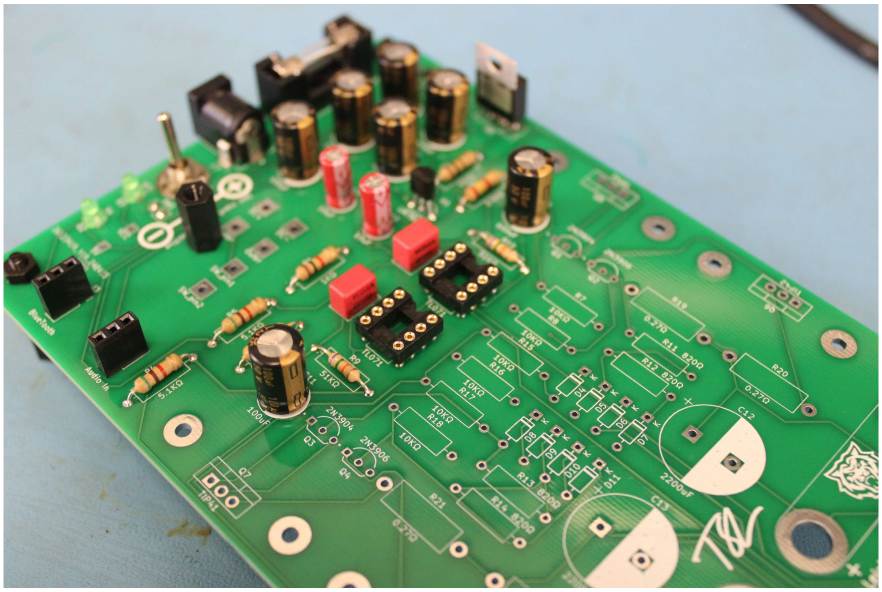
☐ Locate the M28 Bluetooth module and the, two each, 2.54mm Header Pins and Header Receptacles.

☐ Attach the M3 10mm stand-off support to the PCB for the M28.

☐ Without soldering! Place the female 2.54 header receptacles into J3 (Bluetooth) and J4(Audio In). Press the long end of the male 2.54mm header pins into the female 2.54 receptacles. Place the M28 Bluetooth module onto the smaller side of the 2.54 male header pins that are pressed into the female 2,54 header receptacle.

☐ Verify the alignment of the M28 Bluetooth module is square. Solder the M28 to the header pins. Finally, solder the female receptacle pins to the PCB.

☐ Remove the M28 Bluetooth module and set it aside for later.



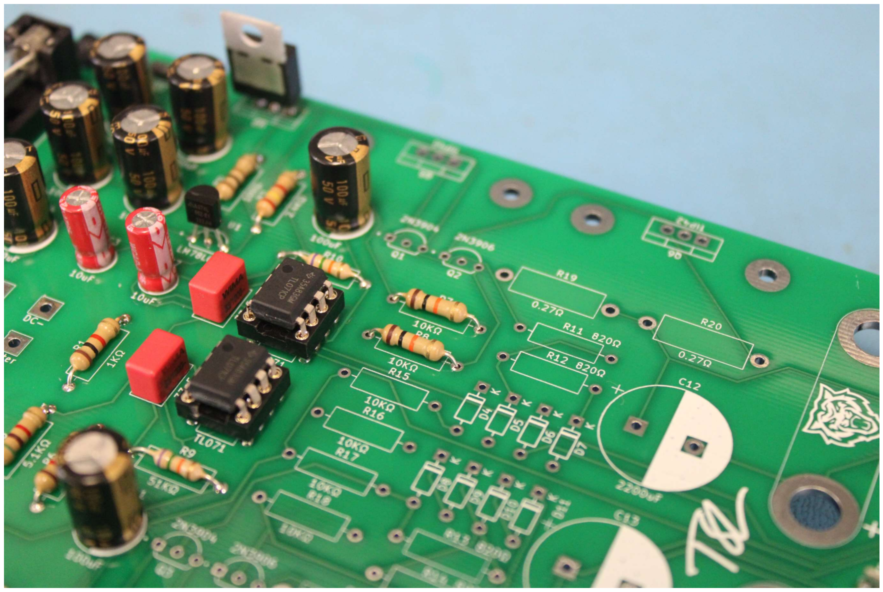
R4, R5, C8, C9, U4 and U5 DIP sockets, R9, and R10

☐ Solder the two 5.1KΩ resistors R4 and R5.

☐ Solder the two 33pF capacitors C8 and C9.

☐ Solder the two DIP sockets at U4 and U5.

☐ Solder the two 75KΩ resistors for R9 and R10.



U3, U4, R7, and R8

☐ Verify the correct orientation and press fit the two TL071 operational amplifiers into the U3 and U4 sockets.

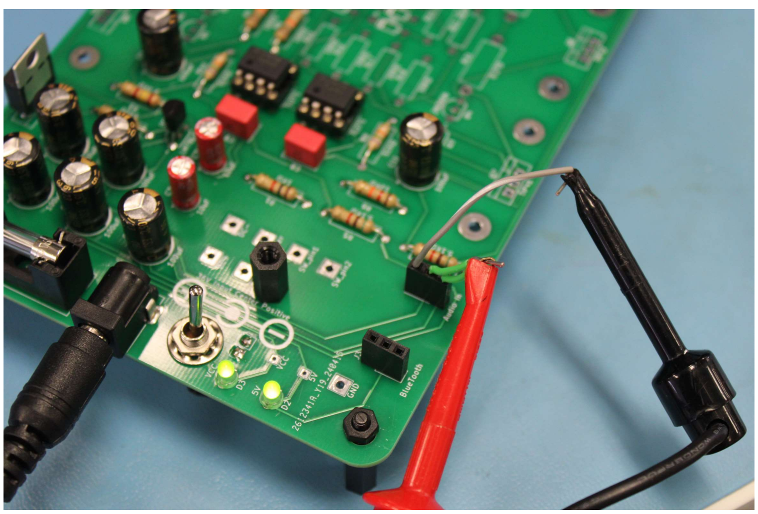
☐ Solder the two 10KΩ resistors R7 and R8.

☐ Solder the GND test point at the board's end between the two Bengal heads.

Pre-Amp Verification

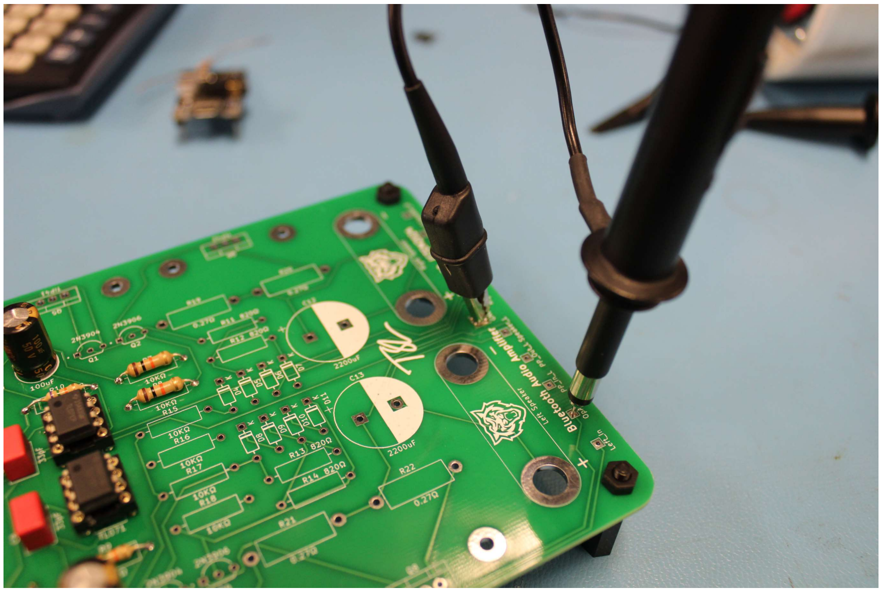
200mvpp 1Khz

☐ Set the function generator to produce a 200mVpp, 1Khz sine-wave output waveform.

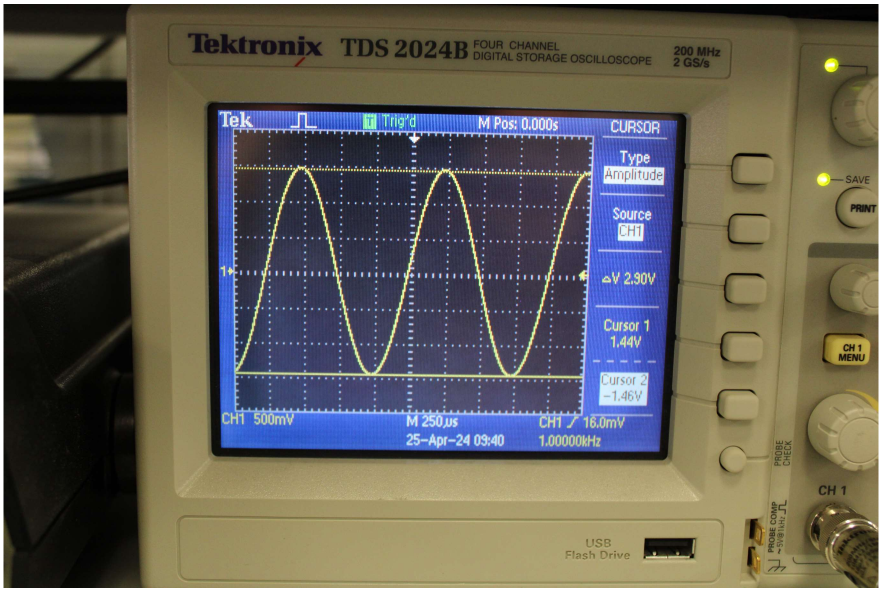


Pre-Amp Test - function generator connection

☐ Verify that the amplifier is off. Connect the red lead of the function generator to the audio left and audio right of J4 Audio In. Connect the black lead to GND.



Pre-Amp Test - oscilloscope connection



Pre-Amp Test - oscilloscope measurement

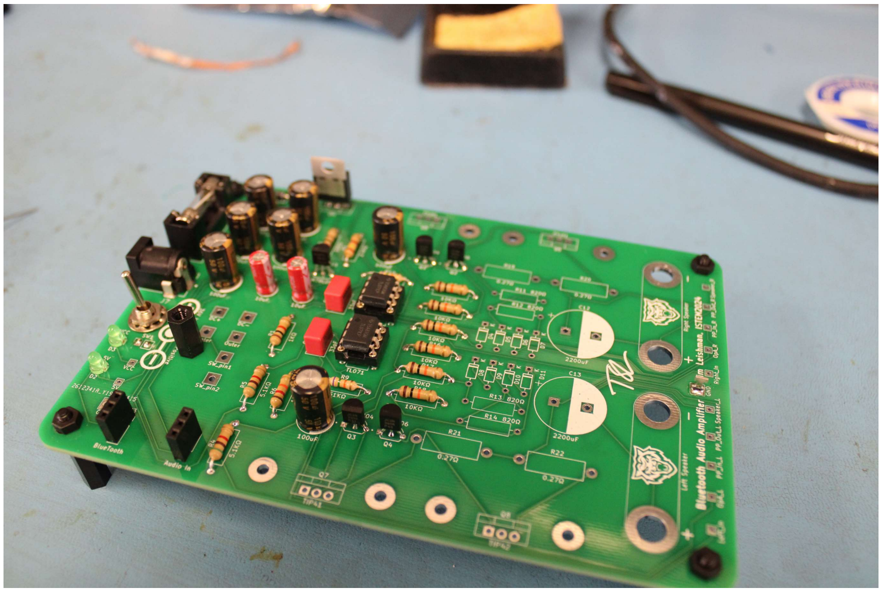
☐ Set CH1 of the Oscilloscope to 500mV per division and 250uS per division. Connect an Oscilloscope CH1 probe to GND. Turn on the amplifier and measure the waveforms at OpA_L and OpA_R.

☐ Verify the operational amplifier's voltage gain:

$$\text{Calculated } \Delta V_{OpAmp} = \frac{Rf}{Ri} = \frac{R9}{R4} = \frac{75K\Omega}{5.1K\Omega} = 14.706$$

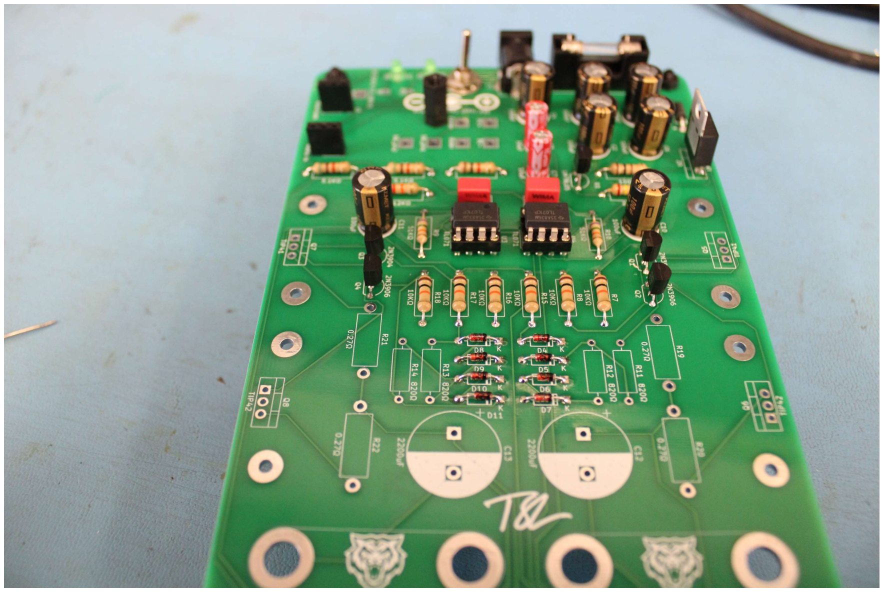
$$\text{Measured } \Delta V_{OpAmp} = \frac{Vout}{Vin} = \frac{2.90vpp}{200mvpp} = 14.5$$

Push-Pull Amplifier



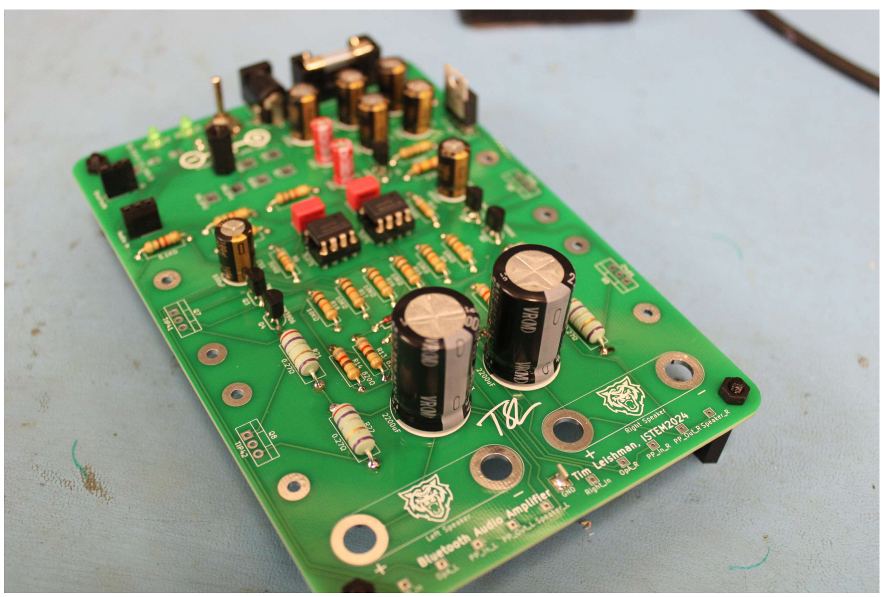
R15, R16, R17, R18, Q1, Q3, Q2, and Q4

☐ Solder 10KΩ resistors R15, R16, R17, R18, the 2N3904s Q1, Q3, and the 2N3906s Q2, Q4 (match the silk screen for transistor orientation.



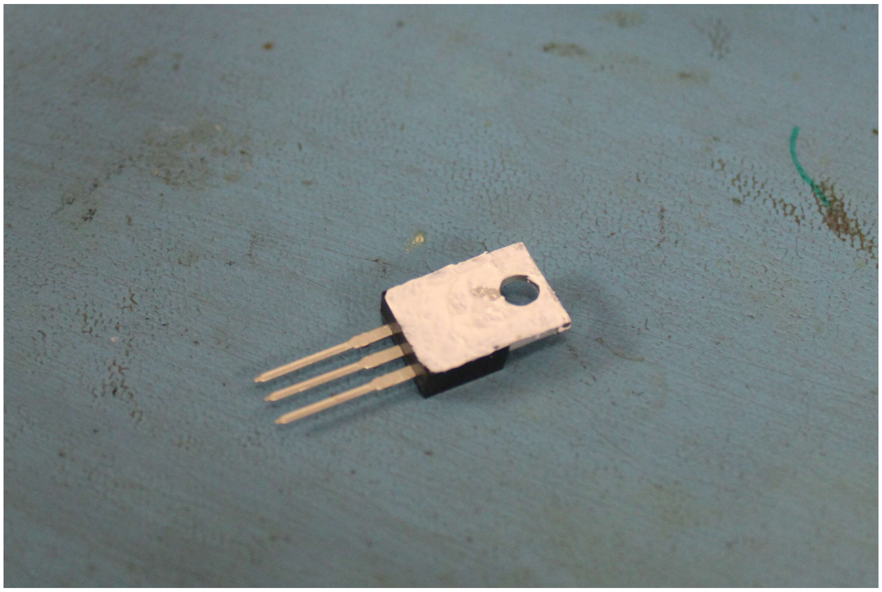
D4-D11

☐ Solder diodes D4-D11, note the cathode (k) has a black stripe.

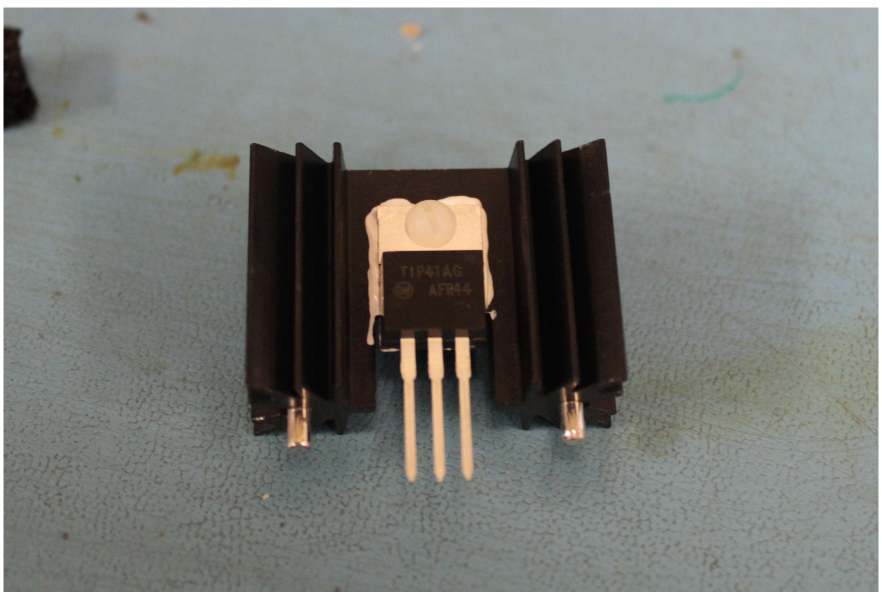


R11-R14, R19-R22 and C12-C13

☐ Solder the 820Ω resistors R11-R14, the 0.27Ω resistors R19-R22, and the 2200uF capacitors C12 and C13 with proper polarity (negative to white silk screen).

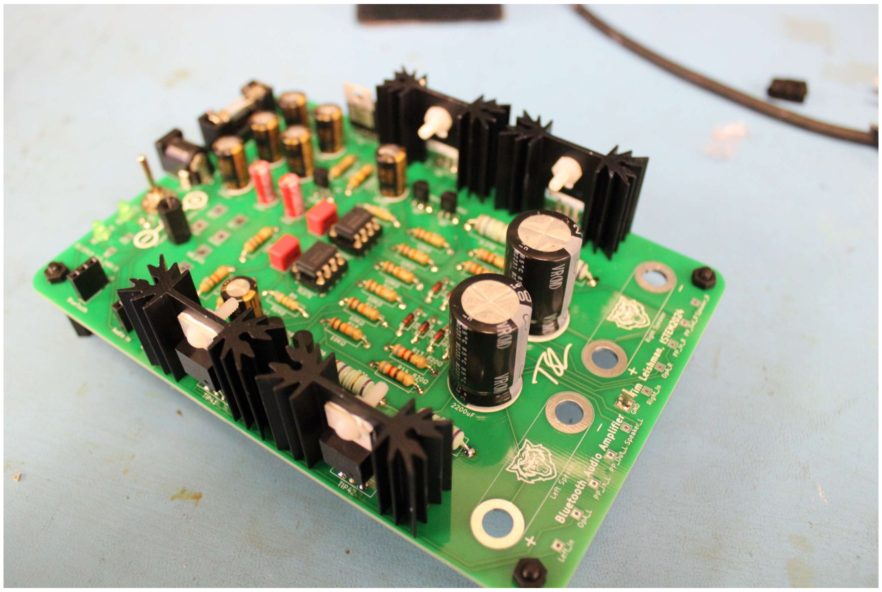


Heat Sink Compound Application



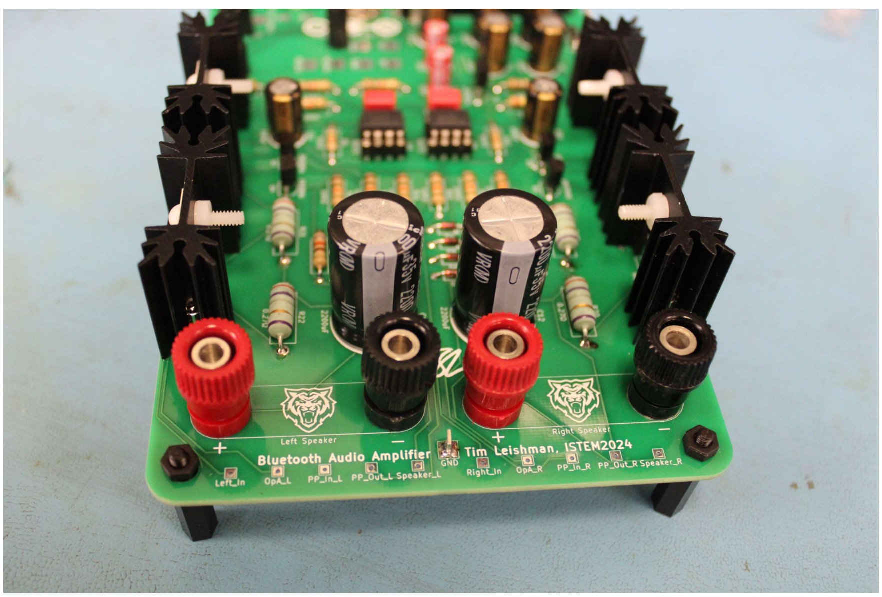
Heat Sink

☐ Locate the two each, TIP41 and TIP42 transistors and the four heat sinks. using a Q-tip apply heat sink compound to the back of each transistor. Bolt the transistor to the heat sinks using the nylon 4-40 hardware.



TIP41s and TIP42s

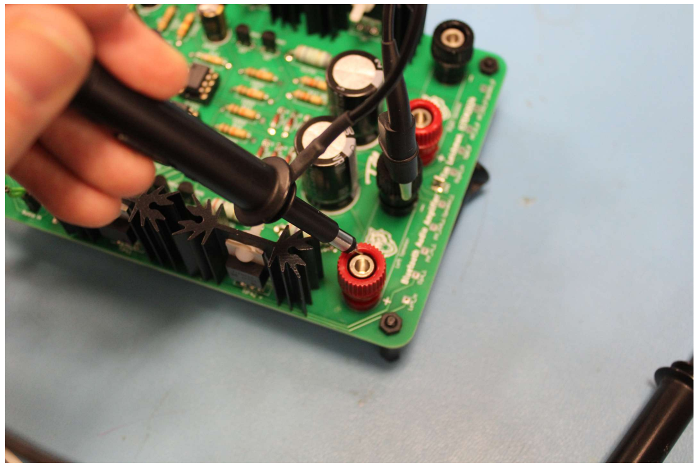
☐ Solder the TIP41s Q5 and Q7 and the TIP42s Q6 and Q8, the transistors face out and away from the center of the PCB.



Banana Socket Connectors

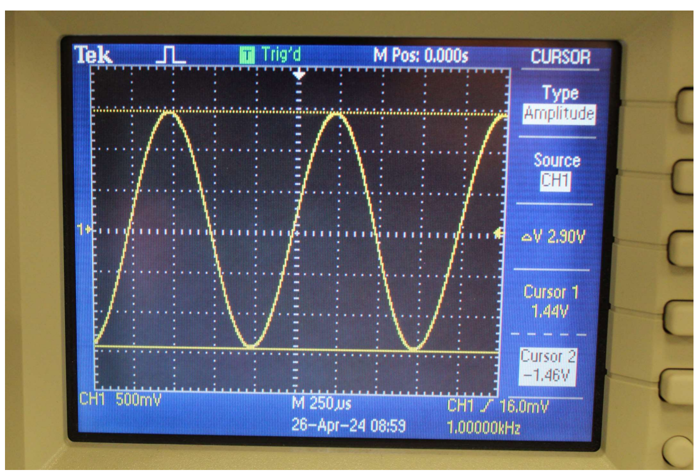
☐ Connect the banana socket connectors, red to + and black to -.

Push-Pull Amplifier verification



Output Measurement

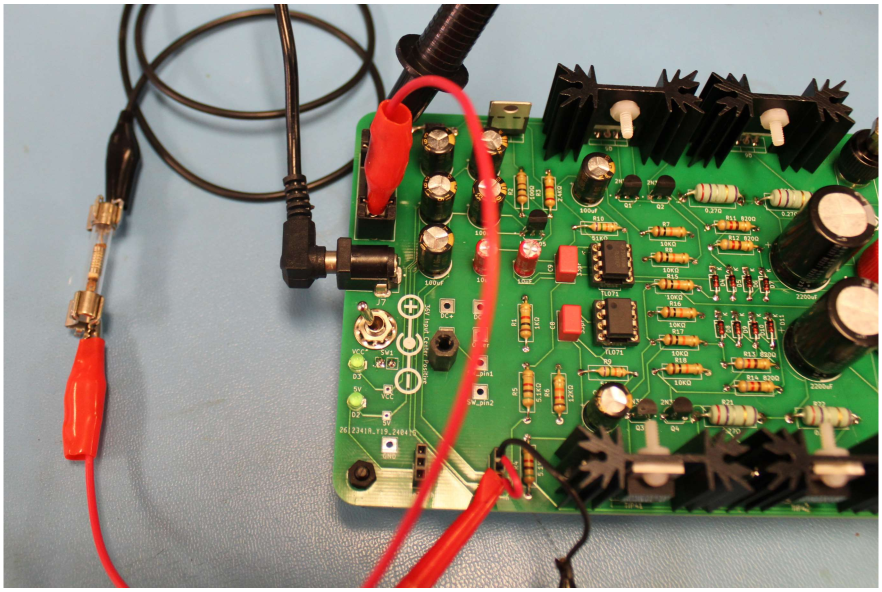
☐ With power off, connect the function generator to the PCB as previously done when testing the op-amps. Connect an oscilloscope probe to the left channel banana sockets. Turn on the function generator. Switch the toggle switch S1 to the on position and measure the output waveform.



Un-Loaded Output Oscope Measurement

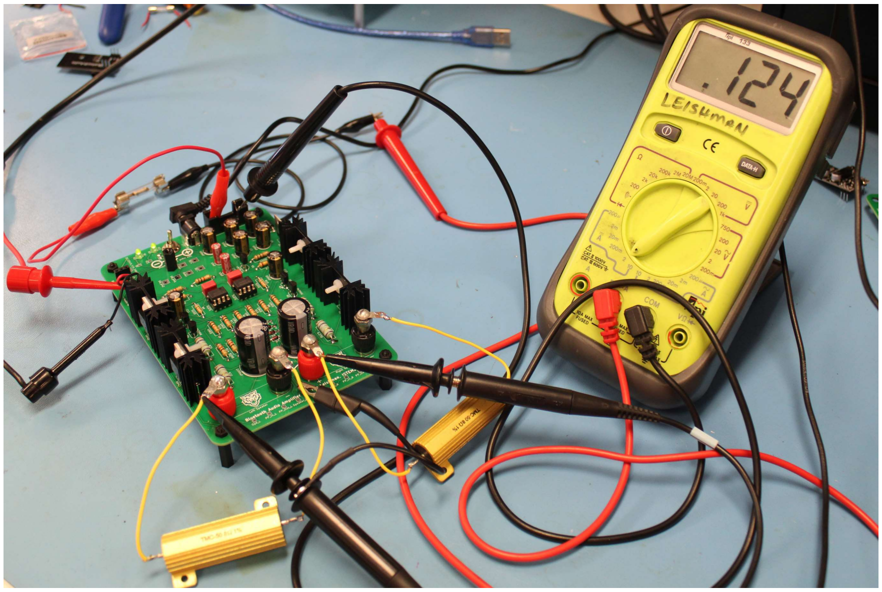
☐ The output should have no cross-over distortion and the amplitude should be the same as the previously measured op-amp amplitude. Repeat the test for the right channel output.

Load Testing



1A External Fuse to allow with Current Meter connected

☐ Remove the fuse from the fuse holder. Use a jumper wire to the DC side of the PCB fuse holder to a 1A external fuse. Connect the other side of the external fuse in series with a current meter and the PCB fuse holder (ask for help if needed).



Initial 8Ω *Load Test with a 200mVpp input*

☐ Connect two 8-Ω dummy loads to the speaker out banana sockets.

☐ Connect the 200mVpp function generator signal to the audio left and right in.

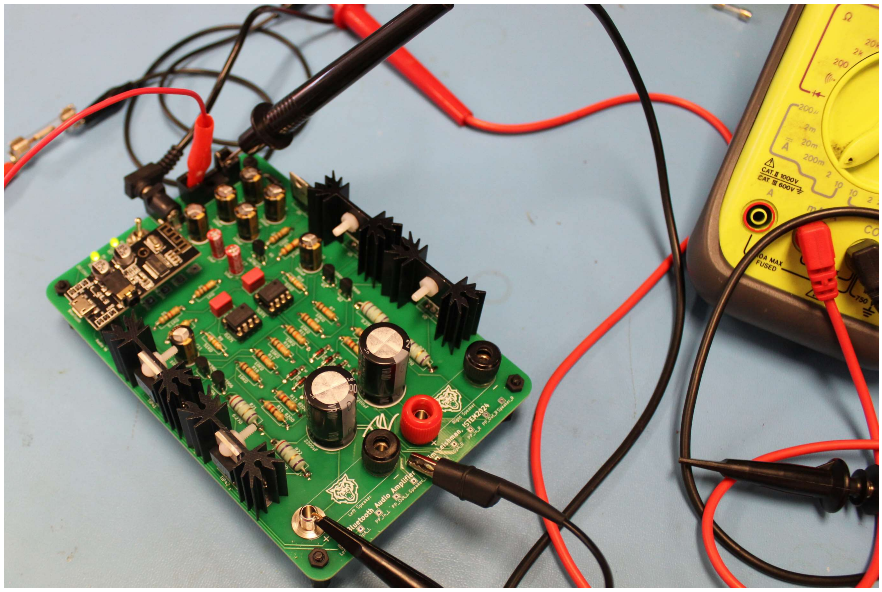
☐ Connect the oscilloscope probes across the 8Ω dummy loads.

☐ Turn on the function generator and the amplifier toggle switch SW1.

Table 8Ω Load Test Data

Input Voltage	Current Measured	Output Voltage Measured
200mVpp	124mA	2.4Vpp
300mVpp	174mA	3.68Vpp
400mVpp	222mA	4.92Vpp
500mVpp	271mA	6.24Vpp
600mVpp	320mA	7.52Vpp
700mVpp	374mA	8.64Vpp
800mVpp	426mA	10Vpp

Bluetooth Testing



Unloaded Bluetooth Audio Test

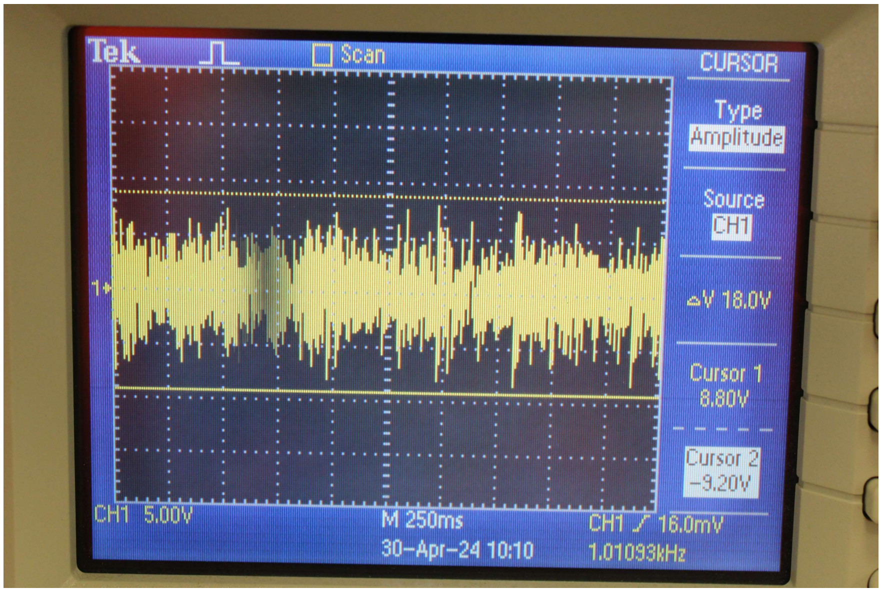
☐ Remove power by switching SW1 to the off position. Also, turn off the function generator and remove the wires connecting to the audio-in.

☐ Remove the 8Ω loads from the left and right outputs.

☐ Connect an oscilloscope probe to one of the outputs.

☐ Install the M28 Bluetooth module and turn on power.

☐ Verify the blue light on the M28 Bluetooth module will initially turn on and then flash. Pair your phone or device with the M28. Once a device is connected to the M28, the blue light will stop flashing and remain on.



Cursors Represent Extreme Audio Peaks

☐ Once paired, play a song (no actual sound will be heard). Turn up the volume to the max and measure the extreme peak voltages using the oscilloscope. (set the scope to 5V/Div and 250mS)

☐ Calculate the output power using the measured extreme peak-to-peak audio voltage and a 4Ω load:

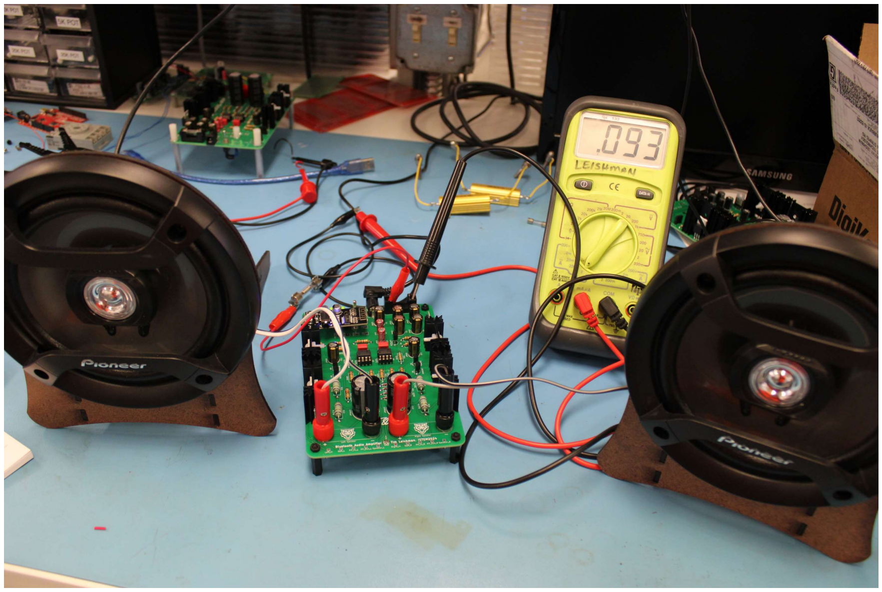
Convert peak to peak voltage to rms voltage:

$$v_{RMS} = \frac{Vpp}{2\times\sqrt{2}} = \frac{18vpp}{2\times\sqrt{2}} = 6.364v_{RMS}$$

Calculate the output power:

$$P_{OUT} = \frac{(V_{RMS})^2}{R} = \frac{(6.364V_{RMS})^2}{4\Omega} = 10.125W$$

Speaker Test



Audio Test with Speakers

☐ Remove power from the circuit and connect the 4Ω speakers to the Left and Right outputs.

☐ Turn the volume down to a moderate level on your phone and switch SW1 to the on position. The M28 should pair and play audio. Listen to your favorite song and observe the current meter at various volume levels.

☐ Turn SW1 to the off position and remove the current meter from the circuit. Install F1 into the fuse holder. Switch SW1 to the on position and test the amplifier at moderate volumes.