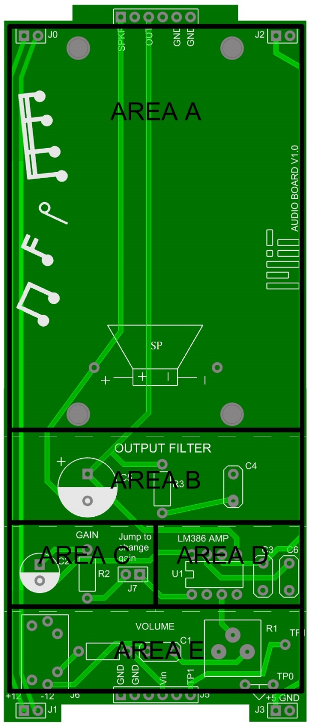
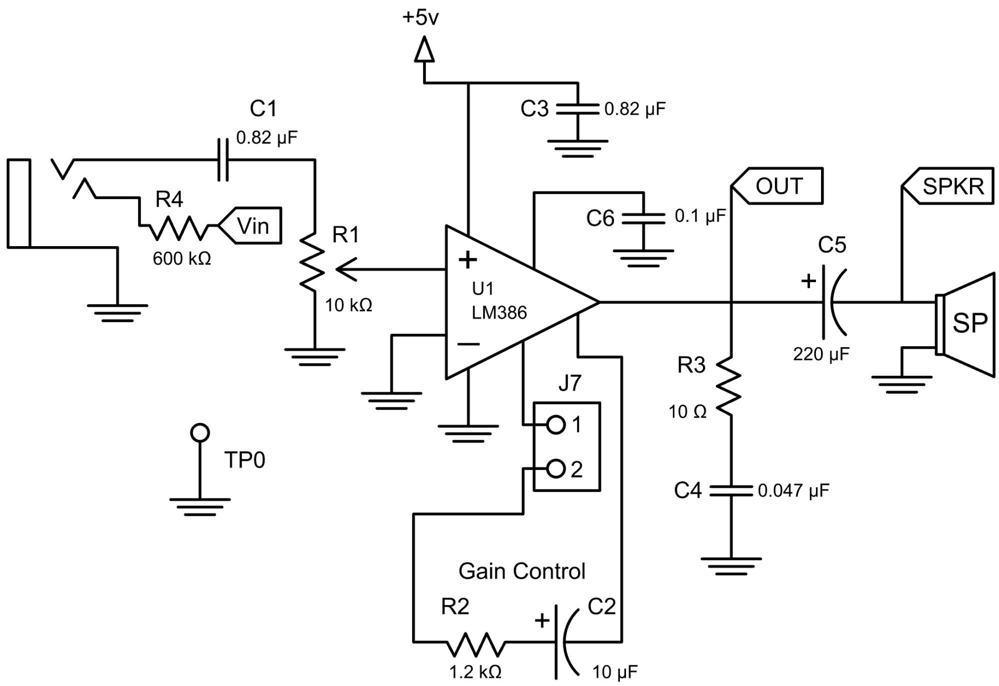
Massachusetts Institute of Technology
Electromechanical Systems Group
Electronics First: AMPLIFIERS

Board and **Circuit Schematic:**





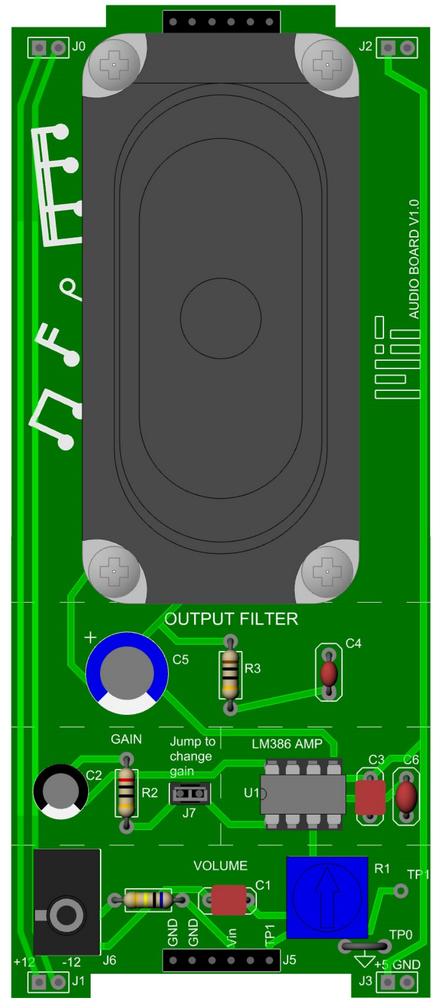
Materials:

Part	Quantity	Part Number	Vendor	Part	Quantity	Part Number	Vendor
Breadboard	1	377 − 2646 − *ND*	DigiKey	3.5 mm Audio Cable	1	1175 − 1449 − *ND*	DigiKey
Breadboard Power Supply Module	1	-	-	Speaker	1	*B00BYE92G4*	Amazon
Multimeter	1	*MN35* − *ND*	DigiKey	R_1 10 kΩ Potentiometer	1	3386*P* − 103*TLF* − *ND*	DigiKey
6-pin Header Pins	2	609 − 3263 − *ND*	DigiKey	R_2 1.2 kΩ Resistor	1	*CF14JT1K00CT* − *ND*	DigiKey
2-pin Rail Connector Pins	6	952 − 2262 − *ND*	DigiKey	R_3 10 Ω Resistor*	1	*RNF14FTD10R0CT* − *ND*	DigiKey
2 Pin Jumper	1	*S9337* − *ND*	DigiKey	R_4 600 kΩ Resistor	1	*RN55D6003FB14* − *ND*	DigiKey
12 Volt Adapter (if needed)	1	102 − 4123 − *ND*	DigiKey	C_1, C_3 0.82 µF Capacitor	1	399 − 9831 − *ND*	DigiKey
Soldering Iron and Solder Wire	1 ea	*T0052918199N* − *ND*	DigiKey	C_2 10 µF Capacitor	1	$1572 - 1648_N D$	DigiKey
LM386 Audio Amplifier	1	296 − 44414 − 5 − *ND*	DigiKey	C_4 0.047 µF Capacitor	1	399 − 13939 − 1 − *ND*	DigiKey
8 Pin DIP Socket	1	*ED3108* − *ND*	DigiKey	C_5 220 µF Capacitor	1	*P5183* − *ND*	DigiKey
Round Standoff	1	36 − 1846 − *ND*	DigiKey	C_6 0.1 µF Capacitor	1	490 − 8814 − *ND*	DigiKey
Machine Screw	4	36 − 9900 − *ND*	DigiKey	Audio Jack	1	*WM17366* − *ND*	DigiKey

The Build:

Amplifiers are devices that use a low power signal to control a higher power flow. An analogy to an electronic amplifier is a water faucet. With a water faucet, a low-power mechanical motion from your hand can control a more powerful flow of water. Ideally, electronic amplifiers enhance the available output power while otherwise copying characteristics of the input signal like a waveshape. For example, if we are trying to amplify a music signal from an audio player or phone, we want to increase the power available to drive a speaker without distorting or changing the music if possible. An important characteristic of an amplifier is its frequency range or *bandwidth*. In this lab, you will build an **audio amplifier**, a circuit designed to operate inside the frequency range of human hearing (e.g., 20 Hz to 20,000 Hz).

ENERGY IS THE ABILITY TO DO WORK, e.g., to move something. In this lab, we want to move the cone of a speaker to push air and make sound. All engineers are essentially united in the study of energy. The world of designing and constructing machines that convert energy from one form to another - a motor that converts electrical energy to rotational energy, a speaker that converts electrical energy to acoustic energy, a piston that converts thermal energy to mechanical energy, a lamp that converts electrical energy to light (radiated energy) - offers a huge collection of exciting, intellectually fascinating, and commercially relevant challenges. These machines can involve elements that are mechanical, electrical, chemical, and from other disciplines. Even mathematical engineering problems that seem divorced from such considerations can often be cast as energy problems. For example, a computer scientist seeking a "faster algorithm" for computing something on a particular computer is essentially seeking a computation that requires less energy to complete.



Audio Amplifier Board

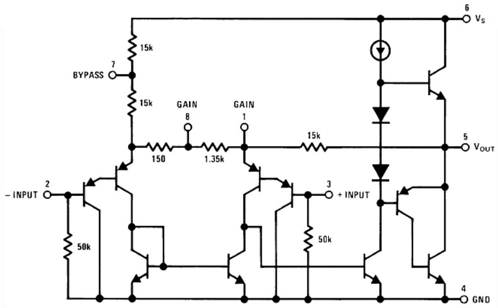
In modern scientific (SI) units, we often measure energy in units called Joules (J). Many conceptual frameworks for studying energy in any given setting break the contributions of work into a "push" or force and a "flow" that occurs in response to and in the direction of the push. Energy is force multiplied by distance, specifically, the distance that the force moves an object. In SI units, when we choose to measure force as our "push" variable, we quantify the force in units of Newtons (N). In this case, "flow" is the velocity of the object being pushed, measured in meters per second $(\frac{m}{s})$. The product of a "push" and a "flow" variable has the units of $\frac{N \cdot m}{s}$, the rate at which energy is delivered, also recognizable as Joules per second, Joules having the units of Newtons times meters. The flow of energy, or Joules per second, is called "power" and is measured with another unit, Watts (W).

All engineers study power and energy, but with push and flow variables tailored to their applications or domain. Different pairs of push and flow variables for sample engineering disciplines are summarized in Table 1. All of the "push" variables, including voltage, contain the units of force, Newtons. But finding the force buried in the different definitions for push variables (pressure, voltage, etc.) can be more or less easy depending on the discipline.

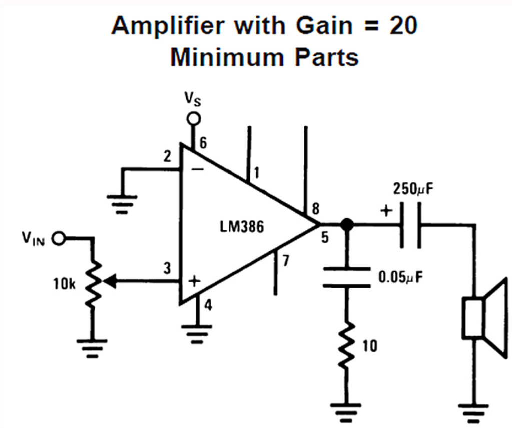
Table 1: Push and flow variables in different engineering disciplines. (See text.)

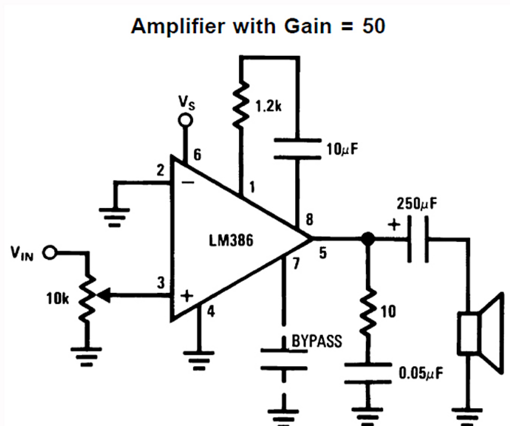
Engineering Discipline	Push	Flow	Product = Power
Mechanical Engineer (ME)	Force (N)	Velocity (m/s)	$\frac{N \cdot m}{s} = Watts$
Acoustics Engineer Aero-Astro Engineer Ocean Engineer	Pressure $(\frac{N}{m^2})$	Volume Flow $\frac{m^3}{s}$	$\frac{N \cdot m}{s} = Watts$
Rotary ME	Torque $(N \times m)$	Angular Velocity $\frac{rads}{s}$	$\frac{N \cdot m}{s} = Watts$
Electrical Engineer	Voltage $(V = \frac{N \cdot m}{Coulomb})$	Current $(I = \frac{Coulombs}{s})$	$V \cdot I = Watts$

An **amplifier** uses a low-power input to control a larger flow of output power. Generally, amplifiers are not direct sources of energy. Amplifiers require a



Internal Schematic of the LM386 IC





LM386 Specification Sheet Details

source of power, e.g., a battery, to operate. The job of an amplifier is to control the flow of power from a source based on the information in a power-restricted input signal. An audio-amplifier like the one you will construct for this build boosts low-power electronic audio signals. The sound-wave generating components (speakers) of most sound systems require a relatively high-powered signal to function. The input audio signals must therefore be "amplified" to an appropriate level so that they can drive these components.

The extent to which an amplifier amplifies a signal is called the *gain*. Gain is a unitless factor found by taking the ratio of the output over the input. An amplifier can work by increasing the “push” variable in the output with respect to the input, or by increasing the amount of flow, or by increasing both push and flow. In an electrical amplifier like our audio amplifier, this corresponds, respectively, to increasing output voltage with respect to the input, or increasing output current, or increasing both output voltage and current. In every case, output power is increased with respect to the input. We therefore refer to three components of gain: *voltage gain*, *current gain*, and *power gain*, summarized by the following equations:

$$\text{Voltage Gain } (A_v) = \frac{V_{out}}{V_{in}}$$
$$\text{Current Gain } (A_i) = \frac{I_{out}}{I_{in}}$$
$$\text{Power Gain } (A_p) = A_v \cdot A_i$$

Our audio amplifier offers both voltage and current gain.

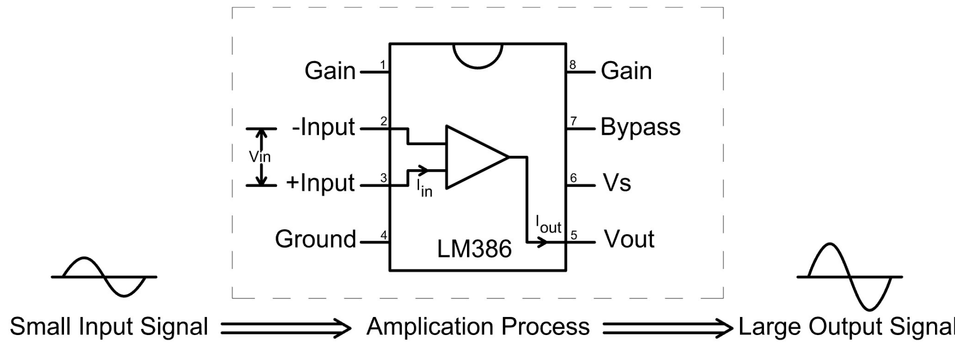
Operation and Predictions

THIS BUILD USES AN LM386 AUDIO AMPLIFIER TO BOOST A LOW-POWER INPUT SIGNAL INTO A HIGH-POWER OUTPUT. This output is sufficient to drive a speaker and create audible sound. You can control the volume of the speaker sound by controlling the voltage of the input signal through a voltage divider and also by controlling the amplifier gain with a jumper on the board.

The LM386 Audio Amplifier

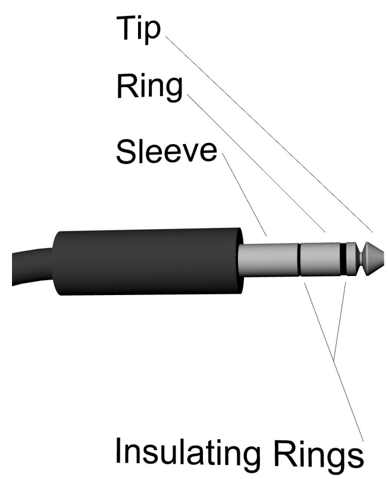
The core of this build is an *LM386 Audio Amplifier*. An LM386 is a specific kind of power amplifier specially designed to handle signal frequencies within the range of human hearing, which is about 20 to 20,000 Hz. The amplifier processes a small input signal composed of an input voltage (V_{in}) and input current (I_{in}) and produces an output voltage (V_{out}) and output current (I_{out}). This integrated circuit has several values for gain that the end user (you) can select. Depending upon how you have wired the circuit, you can produce a voltage gain of any value between 20 and 200.

This build starts with a gain of 50. We select this value by adding components around the LM386 IC. If you look at the schematic on the cover page, you will



LM386 Basic Operation

see a section of the circuit labeled "Gain Control." It is isolated from the rest of the circuit board by a jumper, **J7**. With the jumper installed at **J7**, a 10 μF capacitor in series with a 1.2 kΩ resistor is inserted into this leg of the circuit, setting the LM386 gain at 50. If you do not install the 2-pin jumper at **J7**, that leg of of the circuit becomes an open and sets the LM386 to a minimum gain of 20. You will be able to see what affect this has on the system when you test your completed board. Additionally, if you were to replace the 1.2 kΩ resistor with a short, i.e., a piece of wire, but keep the 10 μF capacitor in place, you would achieve a maximum gain of 200. We will not be using that much gain for this build, but the LM386 provides the capability.

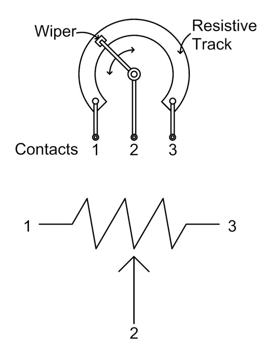


Audio Jack Structure

Input Signal

You can bring an input signal onto the audio amplifier board in two different ways. You can plug in an audio cable, or you can connect a signal (e.g., from another board like the piano board) between ground (GND) and input (Vin) on the **J5** jumper. The finished circuit board includes a 3.5 mm input audio jack in **J6** of **AREA E**. This jack will accept a double-ended 3.5 mm stereo audio cable to connect your board to a cell phone or MP3 player. Plugging in an audio cable to the board automatically disconnects the connection to the Vin jumper pin with a mechanical switch built into the jack.

The input audio jack and cable you will be using in this build has three connections and is designed to accept two audio signals, left and right stereo channels. The LM386 is a “mono” amplifier, so it will only amplify one of the two channels, left or right, whichever is present on the “tip” connection of your 3.5 mm audio cable.



Reminder - Potentiometer Function

Volume Control

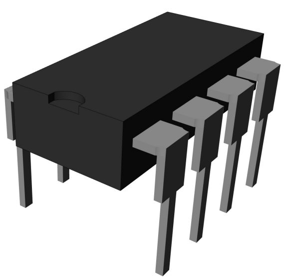
A potentiometer on the board acts as a variable voltage divider that serves as a volume control for the signal entering your board from the audio cable. This means that you can reduce, or *attenuate*, the voltage of the input signal before it

V_{out}:

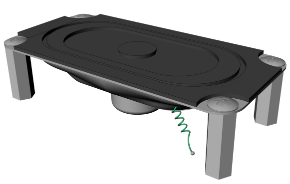
Prediction 1

V_{out}:

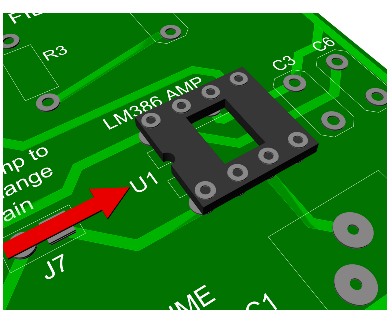
Prediction 2



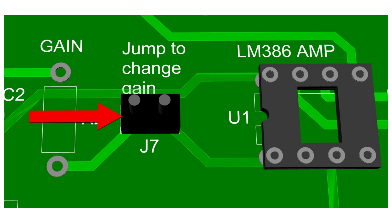
LM386 Audio Amplifier



Speaker



DIP Socket Location



Jumper Pin Installation

reaches the amplifier simply by turning the knob of the potentiometer.

For volume control, it is useful to have a continuum of gains that we can select. The LM386 can provide a range of gain. For this build, we choose a fixed gain from the LM386 and control the volume with a potentiometer R_1 to attenuate or adjust the input voltage from the sound source. The more you decrease the resistance between pins 2 and 3, the more you reduce the output voltage. The net gain of the audio amplifier board comes from the *attenuation* provided by the divider and the *gain* of the LM386.

1.) Assume the jumper at **J7** is installed, C_2 = 10 μF, R_1 is a 10 kΩ potentiometer, R_2 = 1.2 kΩ, and V_{in} is a sine wave with a 100 mV peak voltage. If you turned the knob of the potentiometer so that the resistance between pins 2 and 3 was at it's maximum, and the resistance between points 1 and 2 was negligible, what would you expect the peak of V_{out} of the amplifier to be? (Assume that C_1 looks like a "short" or wire for the sine wave frequency input to V_{in}.)

2.) Now, assume the same conditions except that you turned the knob of the 10 kΩ potentiometer to the middle position, so that the wiper was precisely half-way between pins 1 and 3. What would V_{out} of the amplifier to be?

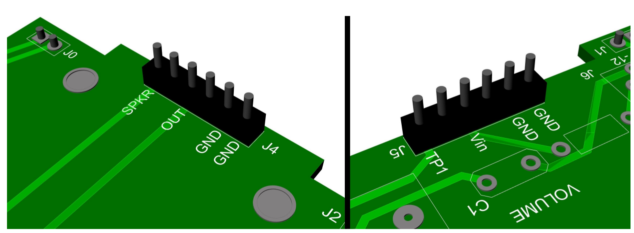
Assembly

THE LM386 AUDIO AMPLIFIER PROVIDES THE CORE AMPLIFICATION FUNCTION FOR THIS BOARD. Additionally, you have a speaker and the other necessary components to make the board function. For ease of installation, the board has been divided into separate areas shown on the cover page.

DIP Socket and Pin Installation

Install the 8-pin DIP socket in **AREA D**. Orientation matters! Ensure the semi-circular notch at the top of the socket lines up with the corresponding notch illustrated in **U1** of the board. **AREA D** has two rows of 4 contact points. Press the 8 socket wire pins through the corresponding pads on the board. Make good solder connections between each of the 8 socket pins and the pads located on the underside of the circuit board. *Do not insert the LM386 yet.*

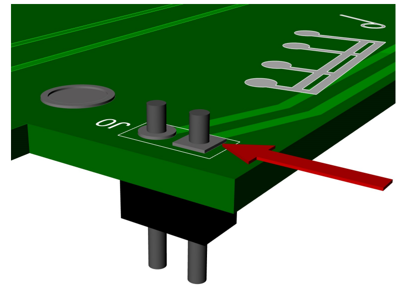
Install one 6-pin header into **J4** at the top of your board. Insert the other 6-pin header into **J5**. Make soldered joints on the underside of the board.



Header Pin Installation

Use the same procedure to install a 2-pin header into **J7**. This is a *jumper point*. You can add a 2-pin jumper over the pins to change the gain of the circuit.

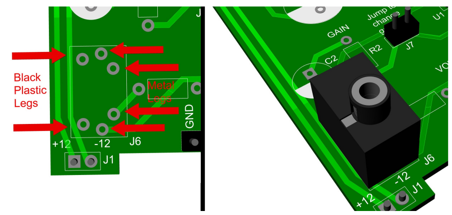
Next, install 2-pin rail connectors into **J0, J1, J2, and J3**. These are installed in the reverse direction, with the base of the pin on the underside of the board, and the location of the soldered joint on the top of the board. *BEFORE SOLDERING*, insert the bottom of the pins into your breadboard, and *then* make your soldered connections on the top of the circuit board to ensure proper alignment.



Rail Connector Pin Installation

Audio Jack Connection

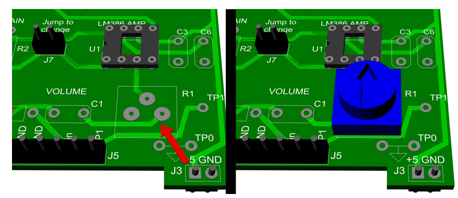
Add the audio jack in **AREA E**. There are 6 pads located in **J6**. Examine the pictures carefully – position the audio jack so that the 2 black plastic pins go into the upper and lower holes on the left, and the 4 metal pins are inserted into the 4 corresponding holes on the right. Push the pins through the contacts and make soldered joints on the underside of the board. *Solder only the metal pins. Do NOT solder the plastic pins!*



3.5 mm Audio Jack Location

Variable Voltage Divider

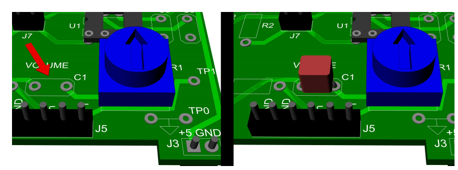
Construct the variable voltage divider in **AREA E**. Install the blue, rotating-knob potentiometer into the section labeled for R_1. Ensure its three triangularly-positioned pins are aligned with the three corresponding PCB pads. Make soldered connections at the proper locations on the bottom side of the board.



Variable Voltage Divider R_1 Location

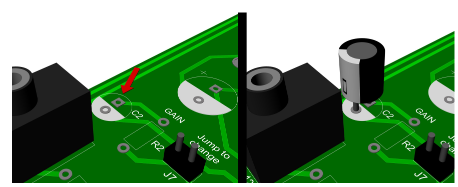
Capacitor and Resistor Installations

Construct the input audio coupling capacitor in **AREA E**. This capacitor blocks any DC signals and only permits AC to pass into the amplifier. Install one 0.82 μF capacitor into **C1**. Pull the leads through until the capacitor is on the surface of the board. Solder in the proper locations beneath the board, and when your joints have cooled, trim any excess wire. *Save your trimmed pieces of wire - you will use them to construct test points later.*



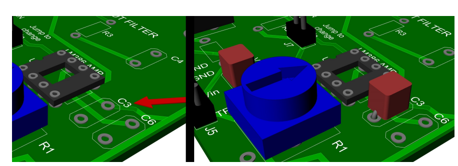
Input Coupling Capacitor C_1 Location

Add the gain control capacitor in **AREA C**. This capacitor is part of the circuit path that sets the amplifier gain. Install one 10 μF capacitor into the pads for C_2 which contains a circle inscribing two pads. *Polarity matters.* Position your capacitor so that the side with the negative pin (marked with a negative sign and white stripe on the body) aligns with the part of the circle that is shaded white. Make the necessary soldered connections beneath the board.



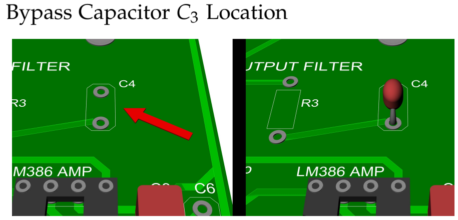
Gain Control Capacitor C_2 Location

Add the bypass capacitor in **AREA D**. This capacitor effectively "smooths out" the power supply. Solder one 0.82 μF capacitor into the pads for C_3.

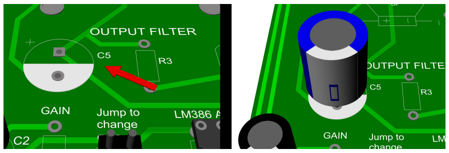


Bypass Capacitor C_3 Location

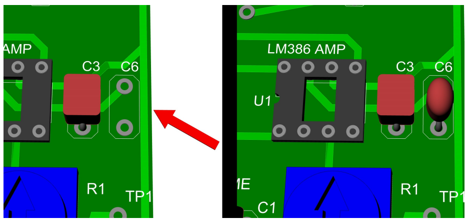
Add the high frequency damping capacitor in **AREA B**. This capacitor, along with resistor R_3, is part of what is known as a *compensation network*, which stabilizes the operation of the LM386 amplifier. The capacitor looks more and more like a short at high frequencies outside the audible range, effectively diverting or “shunting” high-frequency signals to ground. Install and solder one



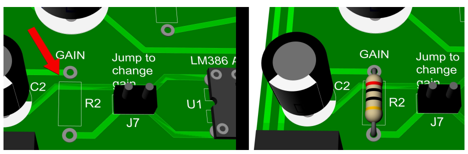
High Frequency (HF) Damping Capacitor C_4 Location



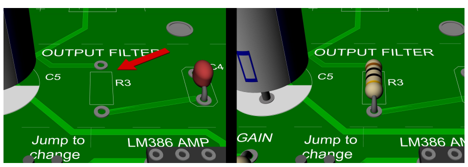
Speaker coupling Capacitor C_5 Location



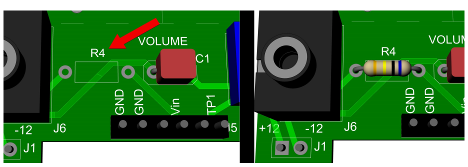
LM386 Bypass Capacitor C_6 Location



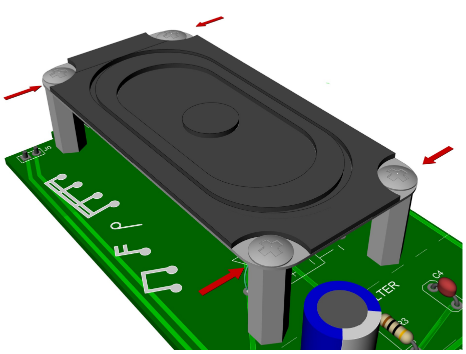
Gain Control Resistor R_2 Location

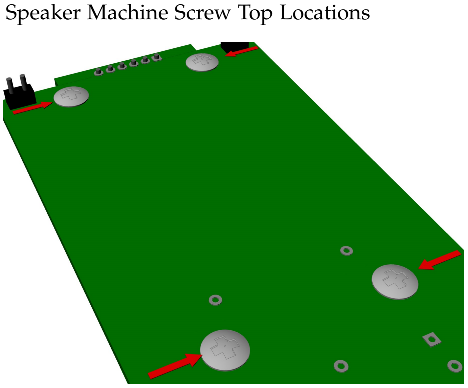


LM386 Compensation Resistor R_3 Location



Input Voltage Resistor R_4 Location


Speaker Machine Screw Top Locations


Speaker Machine Screw Bottom Locations

0.047 μF capacitor into the pads for C_4.

Construct the speaker coupling capacitor in **AREA B**. Similar to the input coupling capacitor, this output capacitor permits only AC signals to reach the speaker. Properly install and solder the 220 μF capacitor into the pads for C_5. Again, position your capacitor so that the side with the negative pin (marked with a negative sign and white stripe on the body) aligns with the part of the circle on the board that is shaded white.

Add the LM386 bypass capacitor in **AREA D**. This capacitor also filters out high frequency disturbances, smoothing the power supply for the amplifier. Install and solder one 0.1 μF capacitor into the pads for C_6.

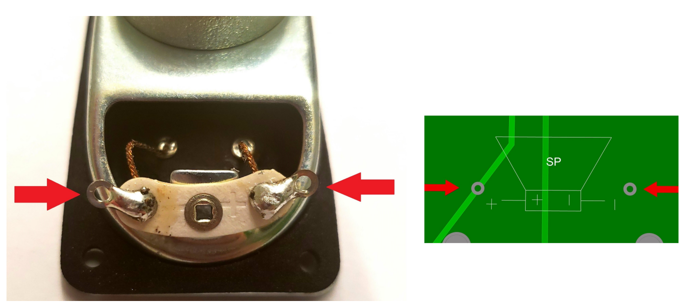
Construct the gain control resistor in **AREA C**. This resistor is part of the circuit path that sets the amplifier gain. Using the resistor band color code, identify and install the 1.2 kΩ resistor into the pads labeled for R_2. Make soldered connections at the proper locations on the bottom side of the board.

Add the LM386 compensation resistor in **AREA B**. This resistor, along with capacitor C_4 is part of the compensation network circuit path that filters out high frequency noise. Install and solder the 10 Ω resistor into the pads labeled for R_3.

Add the input voltage resistor in **AREA E**. This resistor limits the voltage applied to the LM386 by input voltages on V_{in}. Install and solder the 600 kΩ resistor into the slot labeled for R_4.

Speaker Assembly

Install the speaker in **AREA A**. Cut two lengths of shielded wire while measuring them against one metal speaker standoff, ensuring the wire segments are longer. Prepare the speaker leads first. Solder one wire end to one of the connections on the underside of the speaker body. Solder a second, different wire to the other connection on the underside of the speaker body. You should now have two wires connected to the speaker, and two free wire ends to insert into the PCB. Pull the ends of each wire through a small contact hole on the board directly beneath the speaker. *Ensure the ends of the wires are bent away from the metal speaker body - you want no contact between these wires and the metal casing.* Make your soldered joints on the bottom of the board.

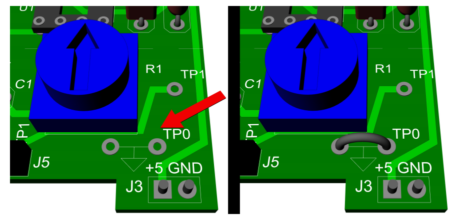


Wire Connections - Speaker and Board

Place the four metal speaker standoffs beneath the corresponding holes on the speaker body and install one screw in each of the four holes, fastening the standoffs to the speaker body. Place the bottoms of the standoffs above the corresponding screw holes on the board. Install a screw in each of the four holes from the bottom of the board, fastening the speaker to the board.

Ground Clip Construction

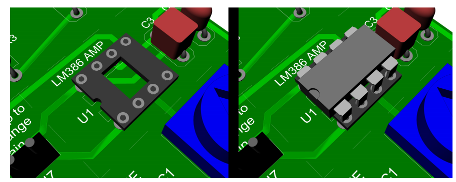
Construct the ground clip in **AREA E**. Take one of the wire cuttings you saved earlier and bend it into an arc, inserting each end into the pads in **TP0**. Trim the length of the wire as necessary. Make soldered joints on the bottom of the board. This is a ground clip.



Ground Clip Soldering Location

LM386 Amplifier Installation

Once all of your soldered joints are completely cooled, install the LM386 audio amplifier into the socket. *Orientation matters!* Ensure that the notch on the topside of the timer body aligns with the indent shown on the board.

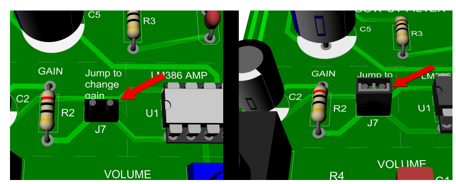


LM386 Amplifier Orientation

Testing

Add one 2-pin jumper to the pins you installed in **J7**. Remember, this connects the circuit path that sets the gain of the amplifier to 50. Removing this jumper sets the gain to the minimum value of 20.

Carefully connect your circuit board to the breadboard in line with the power supply module. Ensure that the pins of both boards are fully inserted into the breadboard contact holes. Ensure that your power cord is properly fitted into the correct port on the power supply module. Check that the power supply indicator light is illuminated.



Jumper Installation

Producing Sound

Connect one end of your audio cord into the 3.5 mm jack on your board and the other end into the 3.5 mm jack of an audio signal source such as a cell phone or MP3 player. From your device, select a song or audio file and play it. Sound should be emanating from the speaker you built on the board. Turn the potentiometer and listen for volume changes.

If you have an oscilloscope:

1.) Turn on your oscilloscope. Attach the probe tip to the **OUT** pin on the **J6** header at the top of your board. Attach the ground lead to the ground clip at **TP0**. Observe how the output of the LM386 changes as you alter the volume knob on the board. Compare the signal you measure at the test point **OUT** versus the signal at **SPKR**. How are these two signals different?