AMB Laboratories Mini³ Headphone Class-T Amplifier

News

- Mini³ circuit boards are available.
- Pre-drilled and engraved Mini³ front and rear panels are now available on a made-to-order basis from AMB audio shop.
- Custom-built, ready-to-use Mini³ amplifiers are available from some professional builders.
- Use this headwize.com forum thread for Mini³ build-related discussions. AMB and the community provides assistance to builders there.
- Use this bbs.audiohall.net forum thread for Mini³ build-related discussions in traditional Chinese.

Overview

Mini³ ("Mini cubed") is a high-quality DIY portable stereo amplifier for dynamic headphones. Designed to be a small battery-powered unit with built-in charging circuit, Mini³ provides high performance and excellent sound that belies its size and cost. Its footprint is almost exactly the size of a credit card, and about 0.9" (23mm) thick.

A perfect companion with portable media players such as the Apple® iPod®, Mini³ offers dramatically improved sound when driven from the player's line output, and used with high quality headphones. The performance of Mini³ is so good, it could also serve as a headphone amplifier with dedicated home CD players and other sources without taking up much desk or shelf space. In conjunction with an off-the-shelf enclosure solution and wire-free board mounting of all components, Mini³ is easy and inexpensive to build. The only surface-mount parts are the two opamps, all other parts are through-hole. See the Tech highlights section for details.

Mini³ version 1 was never released. Version 2 is the current offering, featuring a smaller, sturdier and more attractive aluminum case. The technical difficulties with version 1 were solved in version 2, and the battery run-time has been greatly increased. See the History section for details. Unless otherwise noted, all information in these pages pertain to Mini³ version 2.

There are two variants of Mini³, the "high performance" and the "extended runtime" editions. The high performance edition has higher output current capability and offers superior measured benchmarks especially with low impedance headphones. The extended runtime edition provides decent output current capability while giving much longer run-times between battery charges. Both editions offer excellent sound. The only parts difference between the two editions is the choice of opamps. See the Parts list section for details.

To obtain the blank printed circuit board and some related parts, visit the AMB audio shop. Other parts are available from online vendors. See the Parts list section.

Please be sure to read every section of this site carefully before attempting to build the Mini³ amplifier. If you don't thoroughly understand everything, please consider having someone more experienced to build the amplifier for you.

The scope of the Mini³ project

The Mini³ project is primarily centered around the main headphone amplifier board, which incorporates a battery-charging circuit. To make a working amplifier, you will also need a 9V NiMH rechargeable battery, an AC-to-DC adapter "wallwart" (for battery charging), and a Hammond 1455C801 or 1455C802 enclosure. The Mini³ circuit board was designed to slide into these cases without additional mounting hardware.

Some photos of the Mini^3


mini3_1.jpg
640x480, 30KB


mini3_2.jpg
640x480, 35KB


mini3_3.jpg
640x480, 32KB


mini3_4.jpg
640x480, 24KB


mini3_5.jpg
640x480, 30KB


mini3_6.jpg
640x480, 55KB

mini3_7.jpg
640x480, 33KB

mini3_8.jpg
640x480, 43KB

What skills and tools are needed

You should know how to read a schematic diagram and correlate it to the circuit board layout, identify electronic parts and their pin-outs, have decent soldering skill, and be proficient with a multimeter. You need at least a basic set of tools for electronics work, such as a good soldering iron (with a fine tip) and accessories, screw drivers, needle nose plier, diagonal cutter, a sharp tweezer (for positioning the SOIC-8 opamps), etc. For the front and rear panels, you will also need to be able to accurately drill the holes needed for the input, output and DC power jacks, volume control, and indicator LEDs (unless you opted for the pre-drilled and engraved panel set).

Why not offer a full kit

AMB is not prepared to stock all the needed parts and offer them as a full kit. This amplifier is AMB's contribution to the DIY community rather than a for-profit product, AMB cannot assume the commercial support role that might be implicit with a full kit. However, to make sourcing parts easier, AMB includes the PCB-mount battery contacts and the ferrite beads with each board. The opamps, 3.5mm stereo mini jacks, DC power jack, the volume control potentiometer with integral power switch, and other parts are also available from AMB.

Why not offer completed amplifiers

This is intended to be a project for DIYers, and AMB is not set up to manufacture completed amplifiers.

Where to get help

Be sure you read all the information at this site. If you cannot find an answer to a question, or encounter a problem you cannot solve, the best place to get support is on the DIY forum at headwize.com. Search the forum for an answer before asking a question. Your question may have already been asked and answered. Tangent's articles are also excellent sources of information.

Technical Highlights

Ultra-portable, battery-powered headphone amplifier

- The Mini³ is almost the same size as a credit card, and about 0.9" (23mm) thick. The diminutive dimensions makes the amplifier very pocket-friendly.
- The extruded aluminum Hammond 1455C80x case, available in black or silver anodized finishes, is attractive and sturdy.
- Rechargeable NiMH 9V battery gives long playing times and good voltage swing, while allowing a small case form factor.
- Big, high-end sonics from a tiny package -- the Mini³ is carefully designed for excellent performance, rivaling amplifiers many times its size and cost.

3-channel active ground topology

- Similar in concept to the celebrated M³ and the reference class β22 (3-channel version), the Mini³ is also a 3-channel active ground design.
- In addition to the left and right channels, the "ground" wire of the headphone is actively driven by a third channel. The ground channel amplifier sources or sinks the return current from the transducers, which would otherwise have been dumped into signal ground or power supply ground. This shifts responsibility for the high current reactive load of the headphones from signal ground to the power supply rails, thus removing the primary source of signal ground contamination. The headphone transducers "see" active amplifiers on both sides, rather than an amplifier on one side and a capacitor bank of the power supply ground on the other. This results in lower output impedance, greater linearity and reduced stereo crosstalk.

Precision virtual ground reference

- Also similar to the M³, rather than using a conventional dual rail power supply with positive, ground and negative outputs (which, in the Mini³, would require two batteries and resulting in a larger, less portable case), a single 9V battery is employed, and a virtual signal ground is synthesized by using a TLE2426 precision rail splitter chip. This simplifies the power supply, yet provide the advantage of a dual-tracking split supply without associated complexity. The result is improved common-mode rejection ratio (CMRR).
- The TLE2426 ensures that as the battery drains down, the power supply rails to the opamps remain evenly-split.
- The signal ground quality is not affected by the return current from the headphone transducers due to the 3-channel active ground topology.

Two Mini³ variants to suit all needs

- There are two variants of this amplifier, the "high performance" edition and the "extended runtime" edition.
- The two editions are identical except for the choice of opamps.
- The high performance edition utilizes an Analog Devices AD8397 dual opamp for the left and right channels, and a Texas Instruments/Burr-Brown OPA690 opamp for the ground channel. These opamps have very high output current capability (~190-250mA), and could drive low and high impedance headphones with authority.
- The extended runtime edition use a National Semiconductor LMH6643 dual opamp for the left and right channels, and a LMH6642 opamp for the ground channel. This edition has respectable output current capability (75mA), but draws only 40% of the quiescent current compared to the high performance edition. This gives approximately twice the runtime between battery charges (up to 20+ hours).
- The high output current characteristics of the opamps allows them to drive headphones directly without the use of additional output buffer stages, simplifying the circuit and allows the amp to be made smaller.

- In both editions, the left and right channel opamps are rail-to-rail, capable of swinging output voltage to within 0.5V of each supply rail. This makes maximum use of the available battery voltage, providing improved output clipping/overload headroom.
- The opamps in all variants have very high slew rate, wide bandwidth, low output impedance and low distortion.
- All resistor values are chosen to reduce DC offset, minimize stray capacitance and inductance (which may cause opamp instability), and to maintain low noise.
- Low value resistors at the output of the left and right channel opamps offer short circuit protection. These resistors are wrapped within the global feedback loop so that they do not cause the effective output impedance to be compromised.
- Ferrite beads at the output of each opamp isolate headphone cable capacitance, and keeps the opamps stable.

Fully direct-coupled

- There are no signal-degrading coupling capacitors at the input, output or negative feedback loop.
  This is a true DC amplifier. Care should be taken to ensure that the input source does not have DC offset at its output.

Suitable for a wide variety of headphones

- Can be used with low-impedance and most high-impedance headphones.

Versatile power supply/battery charging circuit

- Both 7-cell ("8.4V") and 8-cell ("9.6V") rechargeable NiMH battery types are supported. A battery capacity of 230mAH or greater is recommended for long run times.
- A 7812 voltage regulator allows the use of an AC-to-DC adapter ("wallwart") that outputs anywhere between 15V DC to 24V DC (actual voltage) with a minimum current rating of 300mA for battery charging and for running the amplifier. Onboard voltage regulation allows a low cost unregulated linear AC-to-DC adapter to be used, while protecting the opamps from being damaged by over-voltage.
- The charging circuit, utilizing a LM317L voltage regulator wired as a constant current source, safely charges the battery at 16mA without risk of damage. A depleted battery can be charged back to capacity overnight.
- A zener diode protects the amplifier from damage if the battery becomes disconnected while the AC-to-DC adapter is plugged in.
- A power-on indicator LED is on the front panel, and a battery charging LED is on the rear panel.
- Ni-Cd batteries are not recommended due to the poorer charge capacity and memory effect. Li-Po, Li-Ion, or any non-rechargeable battery should not be used to avoid an explosion hazard.
- Two 470µF reservoir capacitors (for a total of 940µF) provide ample charge to feed the current demands from the amplifier. These capacitors are *before* the power switch, so they are always charged as long as the battery is connected. This avoids a large surge current during power-on, preserving the integrity of the switch contacts. It also ensures that the opamps' supply rails turn on and off instantaneously, eliminating noise.

Designed to be easy to build

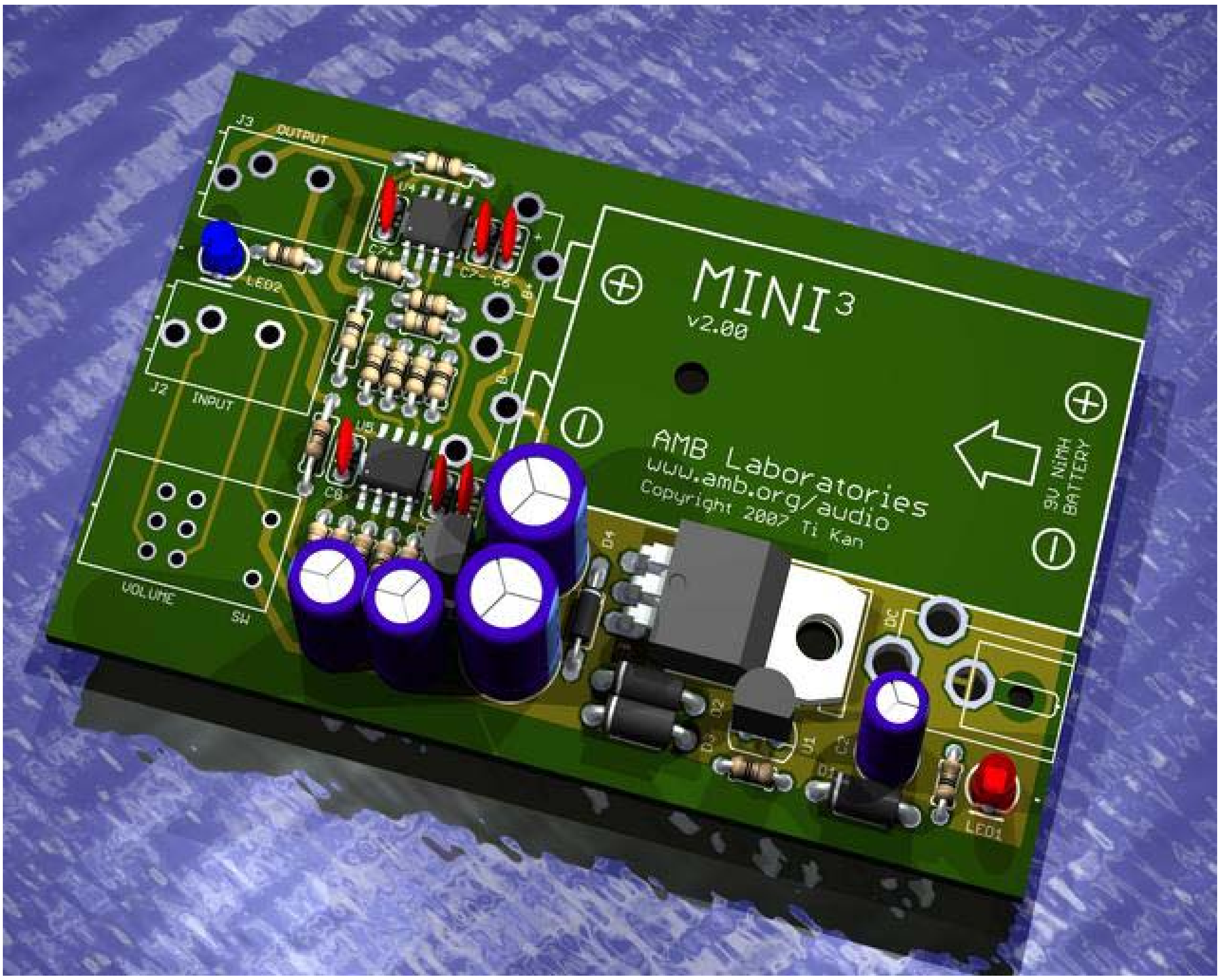
- A specific target case, DC power jack, input and output jacks, volume control, battery contacts and other parts make this a highly integrated design.
- All parts are through-hole except for the two SOIC-8 opamps, making the amplifier very easy to solder and assemble.
- All parts are board-mounted, there are no wires to connect.

- There are no trimpots to adjust after assembly.

High quality circuit board

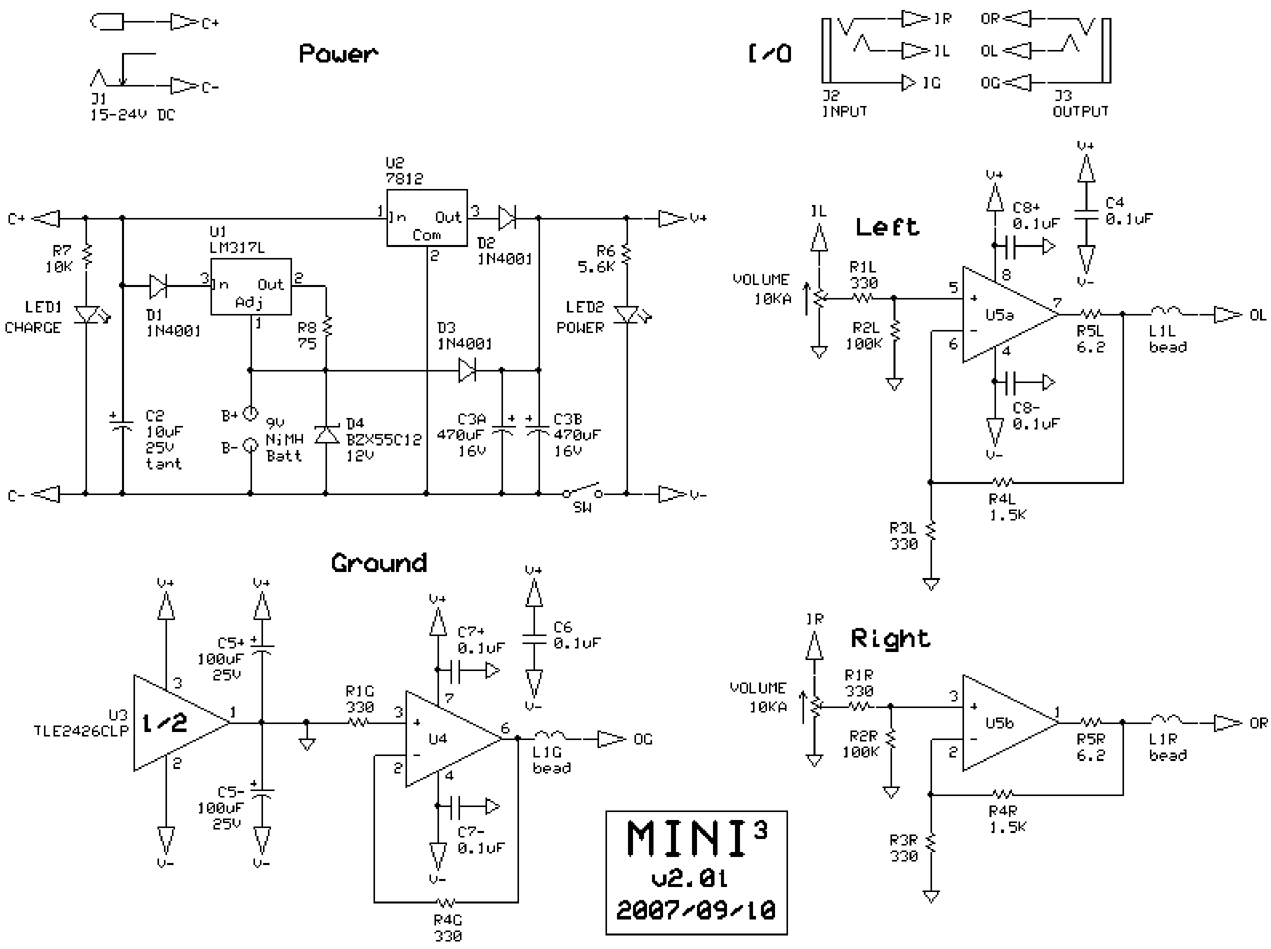
- Glass epoxy 3.1375"x1.9875" printed circuit board, double-layer with plated-through holes, silkscreen and solder mask.
- The layout of all parts and traces have been carefully considered for maximum performance.
- A low-impedance ground plane covers the entire surface of the bottom side. The top side has a partial V- plane that doubles as the heatsink for the 7812 voltage regulator.
- Exposed copper islands beneath the SOIC-8 opamps allows improved heat dissipation when a small amount of heatsink compound is applied, especially for the AD8397ARDZ opamp which has a thermal "E-pad" at the bottom.
- A strip of the ground plane is exposed along each bottom side, allowing the amplifier's signal ground to be electrically connected to the case (via the board slots) without the need to add any wires. The grounded case improves RFI shielding without additional wiring.
- The board is designed to slide perfectly into a Hammond 1455C80x series extruded enclosure, making the casing of this amplifier very easy.

A 3D rendering of a partially-populated Mini³ circuit board.



Schematic diagram

The following is the schematic diagram of the Mini³ amplifier. See the Parts list section for more details.



Mini3 Variant	U5	U4
"High-performance"	AD8397ARDZ	OPA690ID
"Extended run-time"	LMH6643MA	LMH6642MA

Gain	R1L/R	R4L/R	R3L/R
2x	470	1K	1K
3x	430	1.2K	620
5x (default)	330	1.5K	330
8x	240	1.8K	240

Here is the same schematic diagram in PDF format (34KB).

Circuit Description

Power supply/Battery charger

The 9V NiMH battery connected across the B+ and B- terminals supply DC power to the circuit via the D3 diode. When the AC-to-DC adapter is connected, the external power is regulated by U2 down to 12VDC which is then routed to the D2 diode. D2 and D3 protects the battery from "seeing" the output of the U2 regulator and vice-versa, and acts as an "or" gate, selecting the power source with the higher voltage to supply the amplifier.

C3a and C3b are the main reservoir capacitors, which are always charged when the battery is installed. The power switch acts on the V- line *after* the reservoir caps, so that when the switch is turned on and off, the voltage to the amplifier opamps rise and fall virtually instantaneously, virtually eliminating noise. Placing the switch after the reservoir caps also prevents a large turn-on surge through the switch, preserving the switch contacts. R6 is the current-limit resistor for LED2, the "power on" indicator lamp.

The AC-to-DC adapter input is also connected to the U1 voltage regulator, which is wired as a constant-current source for charging the battery. The R8 resistor sets the charging current. Capacitor C2 is a decoupling capacitor to aid the stability of both the U1 and U2 voltage regulators. R7 is the current-limit resistor for LED1, the battery "charging" indicator lamp. The D1 diode blocks any battery voltage from leaking through U1 and lighting up LED1 when the AC-to-DC adapter is not plugged in. The D4 zener diode protects the amplifier from over-voltage damage, in case the battery becomes disconnected while the AC-to-DC adapter is plugged in.

Rail Splitter/Ground output channel

The V+ and V- supply rails are connected to U3, the precision rail-splitter chip. It derives a virtual ground IG which is centered halfway between V+ and V- (it ensures maximum possible output voltage swing and symmetrical clipping when the amplifier is driven into overload). In effect, the rail-splitter offers the characteristics of a tracking dual-rail power supply from a single battery at a low cost and with minimum parts count. Capacitors C5+ and C5- provide filtering and decoupling, reducing noise and enhancing rail-splitter stability.

The U4 opamp is the ground channel output amplifier. It operates as a DC-coupled unity gain amplifier, and takes its input voltage reference from IG. It swings no voltage but acts to sink and source the return current from the headphone's common "ground" return wire. This active-ground output scheme provides a very low-impedance reference and removes signal ground contamination (see the Tech highlights section for details.

The R1G and R4G resistors help with opamp stability, and the L1G ferrite bead isolates headphone cable capacitance, which helps improve opamp stability and performance without incurring extra output impedance in the audio frequency range.

The C6, C7+ and C7- capacitors provide decoupling across the rails as well as from each rail to ground. They are located immediately next to the U4 opamp for best performance.

Left and right channels

The U5 dual opamp serve as the main left and right channel amplification stages. Each operate in a classic DC-coupled non-inverting topology with gain. The R4L/R4R and R3L/R3R resistors set the voltage gain, while the values of R1L/R1R and R2L/R2R, in conjunction with the volume control potentiometer, are chosen for low DC offset and low noise characteritics.

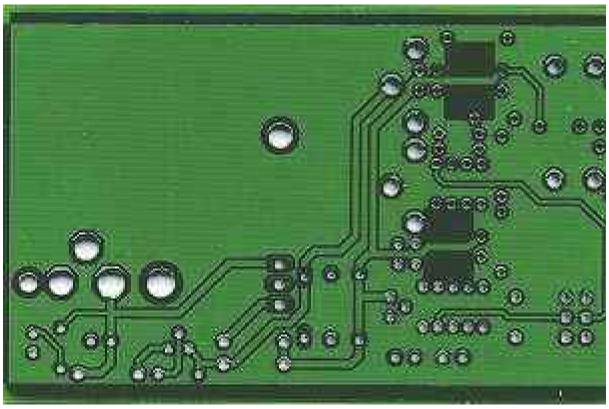
The R5L/R5R resistors protect the output of the opamp from damage from short circuits (which could occur when the headphone plug is withdrawn while the power is on). This resistor is wrapped within the global negative feedback loop, so its resistance does not cause an increase in the effective amplifier output impedance. The L1L/L1R ferrite beads, similar to L1G, isolates headphone cable capacitance.

Like their counterparts at the ground channel opamp U4, the C4, C8+ and C8- capacitors provide supply rail decoupling for the U5 opamp.

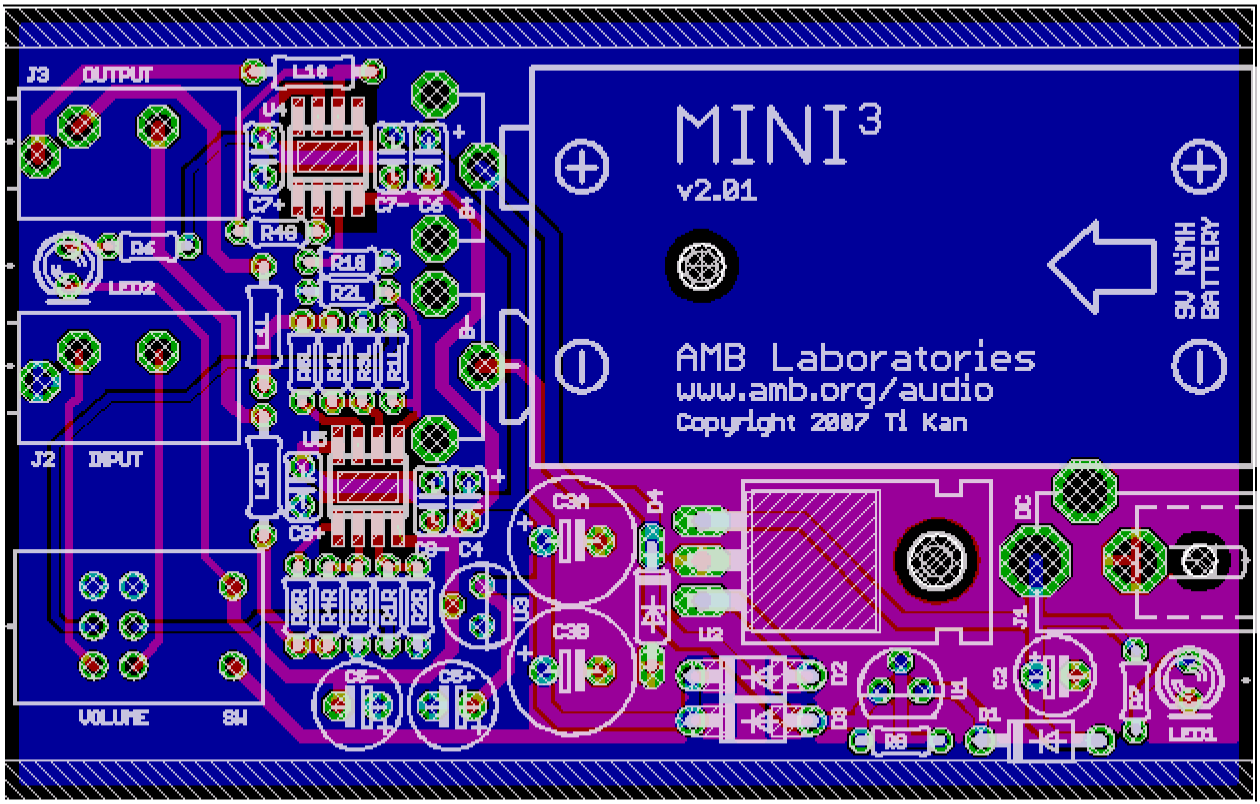
The circuit board

The Mini³ circuit board is made of high quality FR-4 glass epoxy, double-layer with plated-through holes as well as silkscreen and solder mask. It is intended to slide into the bottom slot of a Hammond 1455C801 or 1455C802 extruded aluminum case. The board dimensions are 1.9875" x 3.1375" (50.48mm x 79.69mm) and is 0.062" (1.58mm) thick.

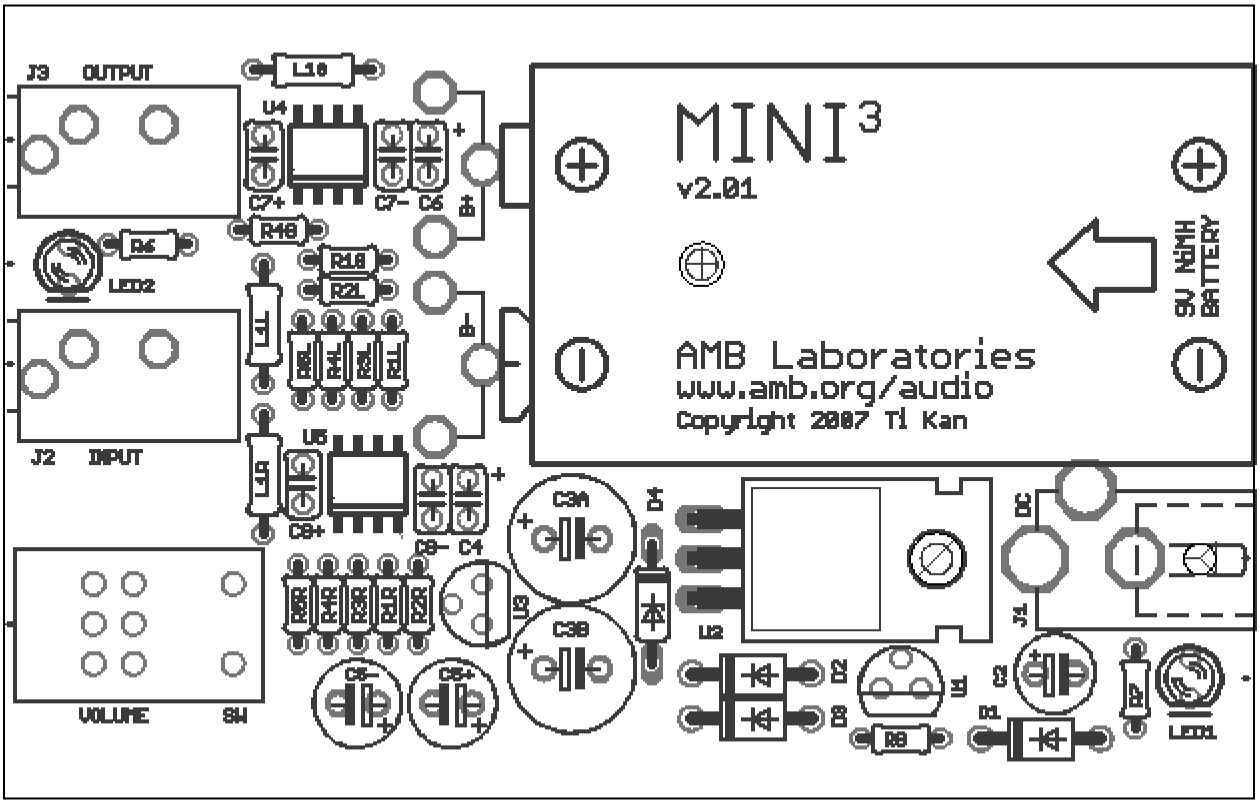
Photos of the top and bottom side of the circuit board are shown below. They are not in actual size.



The circuit board layout is shown below. The top layer is shown in red, the bottom layer is in blue, areas where there are traces in both the top and bottom layers are in lavender, and the top silkscreen is in light grey.



The following is a view of the silkscreen layer.



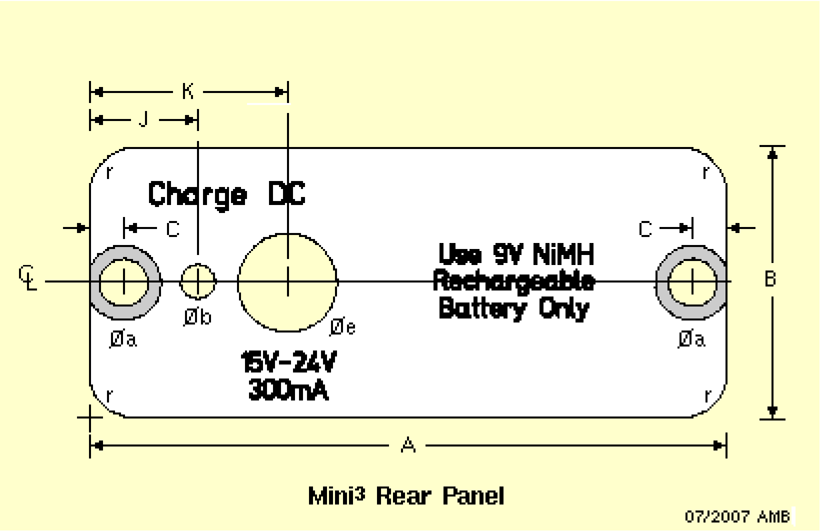
You may also view the following:

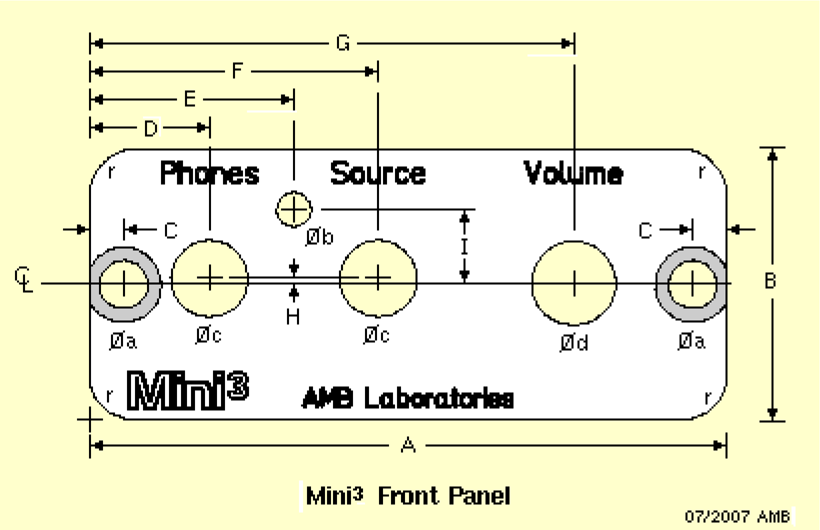
- A larger image of the board layout (PNG format, 96KB)
- An larger image of the silkscreen (PNG format, 49KB)
- An image of the silkscreen layer (PDF format, 162KB)

The front and rear panels

If you purchase the pre-drilled and engraved panel set from AMB, then you may skip this section and read the Notes below. The information here is relevant if you will be drilling your own panels.

Since all Mini³ panel components (DC power jack, input/output jacks, LED indicators and volume control potentiometer) are board-mounted, it is important that the holes on the front and rear panels be drilled accurately to match. The following diagrams and table shows the dimensions.





Dimensions	
A	2.1230" (53.924mm)
B	0.9030" (22.936mm)
C	0.1135" (2.883mm)
D	0.4000" (10.160mm)
E	0.6813" (17.305mm)
F	0.9625" (24.448mm)
G	1.6125" (40.958mm)
H	0.0200" (0.508mm)
I	0.2500" (6.350mm)
J	0.3600" (9.144mm)
K	0.6600" (16.764mm)

Hole diameters	
Φa	0.1600" (4.064mm), countersink cone diameter: 0.2500" (6.35mm)
Φb	0.1142" (2.900mm)
Φc	0.2550" (6.477mm)
Φd	0.2800" (7.112mm)
Φe	0.3300" (8.382mm)
Corner radius	
r	0.155" (3.937mm)
Panel thickness	
t	0.0591" (1.500mm) to 0.0787" (2.000mm)

The following PDF files may be printed and used as drilling templates, but their accuracy depends on the resolution of your printer. You should use a good, calibrated digital caliper to verify all measurements.

- Front panel drilling template (PDF format, 12KB)
- Rear panel drilling template (PDF format, 12KB)

Notes about the front and rear panels

You may use the listed dimensions to drill the panels provided by Hammond, or fabricate custom panels. If you use a Hammond 1455C801 case (with metal end panels), it is recommended that you discard the plastic bezels provided, and mount the panel directly to the case. The bezel pads the panel about 0.065" (1.65mm) away from the edge of the circuit board, causing the front 3.5mm stereo mini jacks to become recessed, possibly preventing the plugs from seating properly. The plastic bezel also creates an unsightly gap around the rear DC power jack, and possibly preventing the DC power plug from making proper contact.

It is important that the panel screw holes be countersunk (see *Φa* in the diagrams above), so that flat-head screws could be used to secure the panel to the case. This assures that the screw head will not interfere with a large headphone plug. You may use the self-tapping flat-head screws provided with the Hammond case, or tap the case and use imperial #6-32 or metric M3.5 flat-head machine screws. A minimum screw length of 0.375" (9.5mm) is recommended.

In the Mini^3, the case is connected to input ground via strips of exposed ground plane (along the bottom of the circuit board) against the case slots. If you have a metal front panel, you should use "isolated" 3.5mm stereo mini jacks as specified in the parts list. This type of jack's sleeve contact is electrically insulated from the front panel, and prevents a short circuit from the output ground to the input ground.

The DC power jack hole should be large enough to prevent the plug's outer conductor (which is V-) from touching the edge of the hole. Since the case is input ground, if the panel is metal and V- shorts to input ground (even for a short moment), the onboard TLE2426 rail splitter chip will be damaged.

You may omit the volume control potentiometer panel nut. Some knobs would rub against the nut unless mounted with a large gap to the panel. The potentiometer is securely attached to the board via eight solder joints and does not need additional reinforcement. Similarly, if you have a plastic front panel and are using non-isolated 3.5mm stereo jacks with a threaded collar, you may omit the panel nuts.

The indicator LEDs should be mounted with their leads bent 90° and soldered on the board. Measure the the amount of needed lead length carefully prior to soldering, in order for the LED to fit properly in their respective panel holes. Only T-1 (3mm) should be used for the hole sizes listed above.

Parts recommendations & options

To obtain the blank Mini³ circuit board and some related parts, visit the AMB audio shop. You can get almost everything else from the vendors listed on the AMB Audio DIY Page.

The following is a list of recommendations and options. Please read through this carefully before you order any parts.

Resistors

- All except R5: miniature 1% metal film type
  Lead spacing 0.200" (5mm)
  - Xicon MF-RC 270 series (Mouser)
  - Panasonic EROS2 series (Digi-Key)
  - Vishay-Dale RN50 series (Mouser)
  - Vishay-Dale CMF50 series (Digi-Key)
  - Multicomp MF12 series (Farnell)
  - other similar

- R5: miniature 1% or 5% metal film or carbon film type
  Lead spacing 0.200" (5mm)
  - Xicon CF-RC 299 series (Mouser)
  - Panasonic ERDS2 series (Digi-Key)
  - Multicomp MF12 series (Farnell)
  - other similar

Notes about all resistors

The Mini³ circuit board is designed for miniature through-hole axial-lead 1/8W or 1/4W resistors with a body length no longer than 4mm (the recommended Xicon, Panasonic and Multicomp resistors are 3.5mm or 3.2mm), and no wider than 1.9mm. Do not use oversized resistors, in particular do not mount resistors vertically ("tombstone style"). The extra lead length adds unwanted inductance which could affect the stability of the amplifier.

Notes about R3 and R4

The voltage gain of the amplifier is determined by the ratio of R4L and R3L (as well as R4R and R3R). The default values of 1.5KΩ and 330Ω, respectively, results in a gain of 5, which is a good for a wide array of low and high impedance headphones. The following table shows optimized resistor values for several other voltage gain settings. Please do not use other values than listed to maintain low output DC offset and ultrasonic stability.

Gain	R1L, R1R	R4L, R4R	R3L, R3R
2x	470Ω	1KΩ	1KΩ
3x	430Ω	1.2KΩ	620Ω
5x (default)	330Ω	1.5KΩ	330Ω
8x	240Ω	1.8KΩ	240Ω

In terms of decibels:

$$dB = 20 * \log(Gain)$$

Notes about R6 and R7:

The optimum value of these resistor depends on your choice of LED. Use this online LED resistor value calculator to determine what value your resistor values should be. The default resistor values work well for LEDs with rated intensity of about 15mcd to 400mcd. If you have LEDs with much higher intensity than that, you should increase the resistances.

Notes about R8

This resistor sets the battery charging current. The default value of 75Ω charges at a gentle 16mA, so that it will wear down the battery cells as minimally as possible, and is safe to leave connected to the AC-DC adapter for extended periods of time (even when the battery is fully charged). The drawback is longer time to charge the battery from a totally drained state back to full charge. Depending on the capacity of the battery, it may take 15 hours or more.

You could decrease the value of this resistor to increase the charge current. The formula is:

$$I = 1.25V / R$$

where I is the charge current in Amperes, and R is the value of the resistor in Ohms.

For example, if you use a 47Ω resistor, the charge current will be increased to 27mA. This will reduce the charge time, but will increase wear on the battery slightly. Also, depending on how high the current is and the capacity of the battery, it may no longer be prudent to leave the AC-DC adapter connected indefinitely after the battery is fully charged.

The charge current should not exceed ~35mA to prevent U1 from overheating.

Potentiometer

Volume/Power: 10KΩ stereo potentiometer with SPST switch

- Alps RK0971221Z05 (AMB audio shop)

Capacitors

- C2: solid dipped tantalum capacitor 10µF 25V
  Lead spacing 0.100" (2.5mm), radial
    - Kemet T350 series (Mouser, Digi-Key)
    - Multicomp CB series (Farnell)
    - other similar

- C3a, C3b: aluminum electrolytic capacitor 470µF 16V low-ESR high-reliability
  Lead spacing: 0.138" (3.5mm) radial, diameter: 0.315" (8mm), maximum height 0.59" (15mm)
    - Panasonic FC (Digi-Key)
    - Panasonic FM (Digi-Key, Farnell)
    - Nichicon HE (Mouser)
    - Nichicon PW (Mouser)

- C4, C6, C7+, C7-, C8+, C8-: multilayer ceramic capacitor (X7R) 0.1µF 50V
  Lead spacing 0.100" (2.5mm) radial
    - Kemet Golden-max C320 series
      (Mouser, Digi-Key)
    - Vishay-BC Mono-Kap series (Farnell)
    - other similar

- C5+, C5-: aluminum electrolytic capacitor 100µF 25V low-ESR high-reliability
  Lead spacing: 0.100" (2.5mm) radial, diameter: 0.250" (6.3mm), maximum height 0.59" (15mm)
    - Panasonic FC (Digi-Key)
    - Panasonic FM (Digi-Key, Farnell)
    - Nichicon HE (Mouser)
    - Nichicon PW (Mouser)

Notes about C4 and C6:

If you prefer, you may use 10µF 16V solid dipped tantalum capacitors (0.100" lead spacing, radial) in these locations. Please note that tantalum capacitors are polarized, and there is a "+" label located next to each of these capacitors on the circuit board denoting the positive pin.

Diodes

- D1, D2, D3: 1A rectifier diode
  Lead spacing 0.300" (7.5mm)
  1N4001 to 1N4007 series (DO-41) (Mouser, Digi-Key, Newark, Farnell)

- D4: 12V 500mW zener diode
  Lead spacing 0.300" (7.5mm)
  BZX55C12 or 1N5242B (DO-35) (AMB audio shop, Mouser, Digi-Key, Newark, Farnell)

- LED1, LED2: T-1 (3mm)
  Lead spacing 0.100" (2.5mm)
  Your choice of size and color (affects value of R6 and R7)

Notes about D2 and D3:

You may use STPS1L30U schottky diodes (surface mount, SMB/DO-214AA) in these locations. The circuit board has pads to accommodate this option. These schottky diodes have lower forward voltage drop than standard diodes.

Voltage Regulators

- U1: Adjustable 100mA positive voltage regulator TO-92 LM317L (Mouser, Digi-Key, Newark, Farnell)
- U2: Fixed 12V 1A positive voltage regulator TO-220
  - 7812 (Mouser, Digi-Key, Newark, Farnell)
  - LM340T-12 (Digi-Key, Newark, Farnell)

Rail splitter

- U3: Texas Instruments TLE2426CLP TO-92. (AMB audio shop, Mouser, Digi-Key, Newark, Farnell)
  There is no substitute part for this.

Opamps

The recommended opamps for Mini³ "high performance" edition is as follows:

- U4: Texas Instruments/Burr Brown OPA690ID (SOIC-8) (AMB audio shop, Mouser, Digi-Key, Farnell)
- U5: Analog Devices AD8397ARDZ (SOIC-8) (AMB audio shop)

The recommended opamps for Mini³ "extended runtime" edition is as follows:

- U4: National Semiconductor LMH6642MA (SOIC-8) (AMB audio shop, Digi-Key, Farnell)
- U5: National Semiconductor LMH6643MA (SOIC-8) (AMB audio shop, Digi-Key, Farnell)

Notes about opamps:

AD8397ARZ may be substituted for the AD8397ARDZ with a degradation of heat dissipation performance. Other opamp substitutions are not recommended.

Connectors

- J1: DC power jack, barrel type, 2.5mm center pin, board-mount
  - Kycon KLDX-0202-B (AMB audio shop, Mouser)
  - Kobiconn 163-5003 (Mouser)
  - CUI PJ-002B (Digi-Key)
  - other similar

- J2, J3: 3.5mm stereo mini phone jack, board-mount, isolated

- CUI SJ1-3533NG (AMB audio shop, Digi-Key)

Notes about J2 and J3:

If your front panel is non-conductive (i.e., plastic), you may use non-isolated jacks such as Kycon STX-3150-3N or CUI SJ1-3533NS.

Heatsink thermal compound

This is used to help conduct heat from the U2 voltage regulator and U4/U5 opamps to the board, improving the power dissipation. Only a very small amount is needed. Be sure to use an electrically non-conductive compound to prevent the opamp pins from being shorted by it.

- Radio Shack 276-1372
- Wakefield 120-SA (Mouser, Digi-Key)
- other similar

Chassis / case

The Mini³ is designed specifically for the Hammond 1455C80x series extruded aluminum cases.

- 1455C802 clear anodized with plastic end-caps (Mouser, Digi-Key, Newark, Farnell)
- 1455C802BK black anodized with plastic end-caps (Mouser, Newark, Farnell)
- 1455C801 clear anodized with aluminum end-panels (Mouser, Digi-Key, Newark, Farnell)
- 1455C801BK black anodized with aluminum end-panels (Mouser, Digi-Key, Newark, Farnell)

A precision-drilled, engraved aluminum front and rear panel set is available from AMB audio shop. Use these for ease of build, upgraded appearance, and to assure a perfect fit. The Mini³s shown in the Overview section are equipped with these panels.

Volume knob

The Alps volume control used in the Mini³ has a 6mm (0.236") "D" shaft, so the volume knob should be made for this and have a single set-screw. Knobs made for a 0.25" shaft will be slightly eccentric. The diameter of the knob should be no larger than about 0.5" (13mm) due to the small size of the front panel and proximity to the nearby panel screw and input jack.

Kilo International ML-50 machined and anodized solid aluminum "soft-touch" knobs are recommended. These are high in quality and attractive. The usable variations are shown below, and are available from Digi-Key.

- Kilo ML-50-1-6MM gloss clear (Digi-key 226-2003-ND)
- Kilo ML-50-2-6MM gloss black (Digi-key 226-1003-ND)
- Kilo ML-50-3-6MM matte clear (Digi-key 226-3003-ND)
- Kilo ML-50-4-6MM matte black (Digi-key 226-4003-ND)

You may find other knob styles from different vendors usable as well.

Battery

The Mini³ has an onboard battery charger designed only to be used with a 9V NiMH (nickel metal hydride) rechargeable battery. No other battery types should be used to avoid possible battery explosion.

> **NOTE**: Do not, under any cirmcumstances, use a Li-Poly, Li-Ion, or non-rechargeable battery in the Mini³.

The battery is snapped in place by onboard battery contacts, and the case has just enough clearance for a standard size 9V battery. However, not all battery vendors adhere strictly to the standard, and some batteries may be too thick to fit.

The CTA 325mAH or 275mAH, and the Accupower 300mAH and Accupower 270mAH 9V NiMH batteries are recommended for Mini³. These have high capacity, providing long play times between charges, has an excellent 500-1000 cycles of recharge life, and are reasonably priced.

Note that some samples of these batteries have been found to be thicker than spec, and may not fit properly in the Mini³. In most cases peeling off the plastic film wrapping and sanding away a little of the largest flat surfaces of the battery will make them fit.

The Maha PowerEx 8.4V 300mAH or Maha PowerEx 9.6V 230mAH batteries are also favorites, but they are oversized and is a *very* tight fit.

The above batteries are available from various sources, including Thomas Distributing and zbattery.com in the US. You can try another brand of 9V NiMH battery, but you'll have to check the fitment.

AC-DC adapter

Due to Mini³'s onboard voltage regulation, the AC-DC adapter requirement is not very stringent. It should be a linear adapter (not switching) to avoid high-frequency noise, but does not need to be regulated. It must output somewhere between 15VDC and 24VDC. 24VDC is the absolute maximum. Do not trust the label, you should measure it with a DMM to be sure, because unregulated DC adapters usually output more voltage than specified). The minimum current rating should be 300mA to ensure that it could provide all the current the amp might need under all circumstances.

The AC-DC adapter should be fully isolated. That is, if it has a three-prong AC wall plug, the AC earth pin should not be internally connected to either the positive or negative outputs. Using your DMM, you should verify this by checking the resistance between them. The readings should both show infinity ("OL").

Many "12VDC" unregulated DC adapters actually output more than 15VDC, and are good to use with Mini³.

The AC-DC adapter's output plug should be a barrel-type with 2.5mm ID, 5.5mm OD female, the polarity is center-positive. The appropriate input AC mains voltage, frequency and plug style depends on your country.

Example adapters are listed in the parts list table above.

Miscellaneous

The L1, L2 and L3 leaded ferrite beads and the B+ and B- board-mount battery contacts are supplied with each Mini³ circuit board, so you do not have to purchase them separately. If, for any reason, you need to replace them in the future, you may contact AMB, or, you may purchase replacements elsewhere. Here are the specifics:

- L1, L2, L3: Panasonic EXC-ELSA35
- B+, B-: Keystone 593 and 594 or Eagle Plastic Devices 12BC210-GR and 12BC220-GR

Notes about the ferrite beads:

Do not substitute the ferrite beads with a different part number. These beads have been carefully tested and selected amongst many similar products for the best performance. Using different beads may impact the stability of the amplifier.

Assembly - Before you start

This section assumes that you have pre-drilled your front and rear panels (for the jacks, volume pot and LEDs). If you haven't done so, see the board and panels section for details and work on that first.

You can print out an image of the circuit board silkscreen layer (PNG format | PDF format), to use as a guide for installing components.

Do not remove the opamps from their sealed packaging until you're ready to solder them on the board. This is to protect them from electrostatic discharge and moisture.

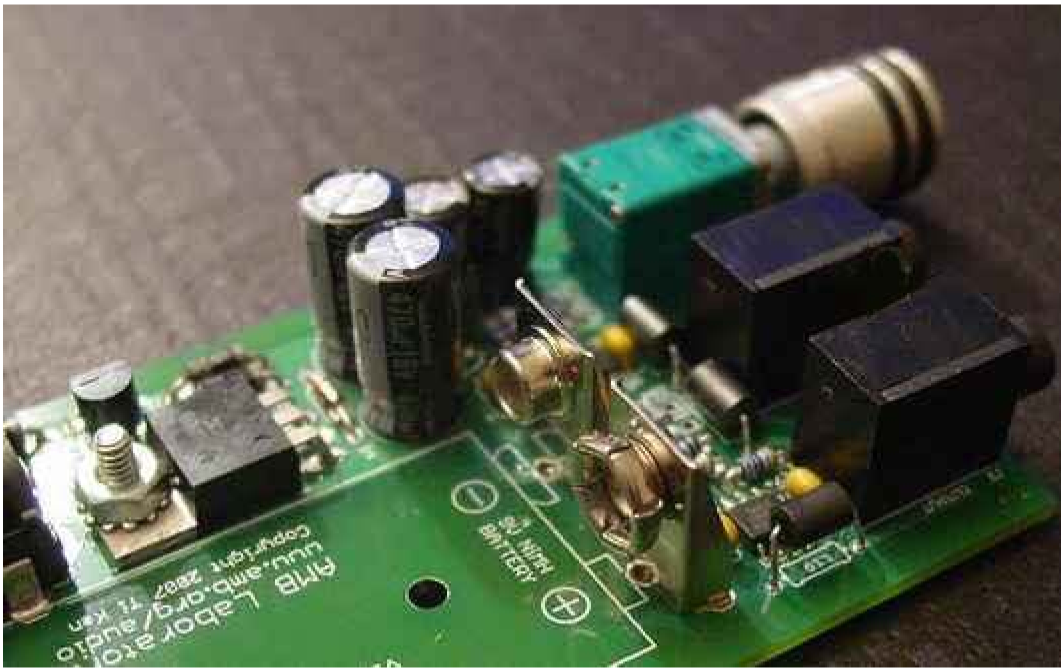
While you look at the board layout, please also take the time to look at the schematic diagram and associate each part with their location in the circuit. While this is not normally required to build a working amplifier, one of the opportunities of DIY is to learn about how the circuit works. Try to determine what each part does and why the particular part or value is chosen. There are many web resources to help you with this, including the Mini³ v2 project thread in the headwize.com DIY workshop forum. You will find the overall DIY experience more rewarding as a result.

Due to Mini³'s small size and close approximity of parts, as well as the two surface-mount (SMT) opamps, you should have the following tools and supplies to help you work on the board and case:

- A good soldering iron with fine tip, preferably with adjustable temperature. For example, a Weller WLC100 with ST6 tip. A more deluxe soldering station such as the Weller Weller WES51 or Hakko 936 is nice, but not necessary.
- Liquid flux or flux pen (e.g., this or this)
- Thin gauge solder, such as 0.025". Your choice of 60/40 or 63/37 tin/lead. Avoid silver solder as it requires high heat. Lead-free solders also require higher heat and their durability is still in question.
- Fine tweezer with sharp points, such as those from Wiha
- Desoldering braid
- Vision aid, such as magnifier lamp, loupe, magnifying eyewear (e.g., Fisherman Eyewear Flip-n-focus), etc.
- Needle nose pliers

- Diagonal cutter
- Cotton Q-tips
- Isopropyl alcohol
- Emery board or thin file (for black Hammond case only)
- Imperial #6-32 or metric M3.5 tap (optional, if not using stock Hammond screws)
- Multimeter with sharp probes

Circuit board assembly instructions

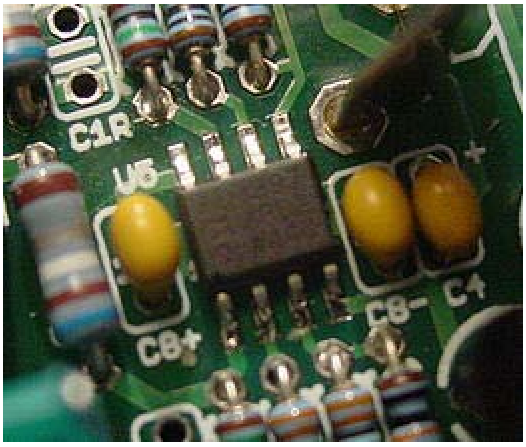


Solder the components to the board, beginning with the opamps for maximum access. Do the U5 opamp first, as described below.

Apply some liquid flux to the opamp pads. Optionally, apply a *very small* dab of heatsink thermal compound below the opamp (this is recommended especially for the AD8397ARDZ opamp). Place the opamp over the pads, use the tweezers to pick and nudge the opamp until it is centered and aligned perfectly over the pads. Be sure the thermal compound does not ooze out the sides and the pin orientation is correct. The side of the opamp with pin 1 is beveled, and usually has a dot denoting pin 1. Viewing the board with the "Mini³" logo proper side up, the pin 1 pad of both U4 and U5 are at the bottom left side.

Press the tweezer tip on the top of the opamp to keep it from shifting while soldering. Apply only a *tiny* amount of solder to the tip of your iron, and tack down one corner pin of the opamp. I find that it helps to use a "wiping" motion of the tip on the pin and pad. If necessary, make small adjustments while heating that pad and pin again. If all is well, do the pin on the diagonally-opposite side. Then, do the remaining pins one at a time, reflow any pin that needs a bit of touch-up. If necessary, use the desoldering braid to remove any excess solder, and be sure there are no solder bridges between the pins.

When done, your solder joints should look something like this:

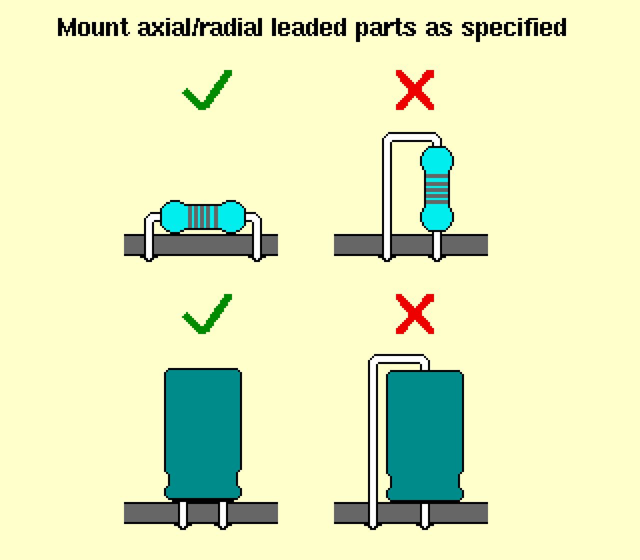


Use your multimeter and check the resistance between each pin of the opamp and the pad to make sure you don't have a cold solder joint (i.e., your meter should read close to zero ohms). Also check continuity between adjacent pins for solder bridges (meter should read infinity).

Repeat the above procedure for the U4 opamp. When you are done with the opamps, use a Q-tip and isopropyl alcohol, or specialized electronics flux remover to clean off the flux.

Now mount and solder the rest of the parts, starting with the lowest profile parts and work up, in the following order (see details below):

- Resistors
- Diodes
- Multilayer ceramic capacitors
- Voltage Regulators U1, U2
- Rail-splitter chip U3
- Ferrite beads L1L, L1R, L1G
- Tantalum capacitor C2
- Electrolytic capacitor C5+, C5-
- Volume control potentiometer
- DC power jack J1
- 3.5mm stereo mini phone jacks J2, J3
- Electrolytic capacitor C3a, C3b
- LEDs
- Battery contacts B+, B-

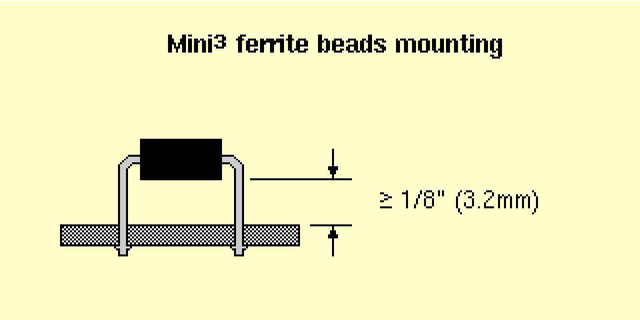


Set the volume control potentiometer to the power off position (rotate to fully counterclowise position until you feel a click) before you install it on the board.

Since the Mini³ circuit board holes are plated through, with the exception of the SMT opamps (or if you chose to use the SMT schottky diodes for D2 and D3), you only need to solder the parts from the bottom of the board. Do not drill or enlarge the holes because that would damage the through-plating.

Make sure the correct part goes into each position on the circuit board. Measure each resistor with your multimeter to ensure it's the proper value before installing it. Pay attention to the polarity of electrolytic and tantalum capacitors, diodes, voltage regulators and rail splitter chip. For electrolytic and tantalum capacitors, the positive lead should be the longer one.

The ferrite beads should be mounted elevated from the board surface, allowing at least 1/8" (3.2mm) clearance, as shown in the following picture:



The U2 voltage regulator should have its pins bent 90° downward for insertion into the board. You must check that the mounting hole is aligned properly while the pins are bent to fit their pads. Apply a small amount of heatsink compound to the bottom of the regulator to help it transfer heat to the board. No isolation pad or TO-220 mounting kit is needed. The imperial #4-40 or metric M3 mounting screw should have a low-profile pan head (so as not to touch the case when the board is installed), or you could use a nylon screw. The screw should be inserted from the bottom up. Secure the regulator using a hex nut from above (see photo above) before soldering the regulator's pins.

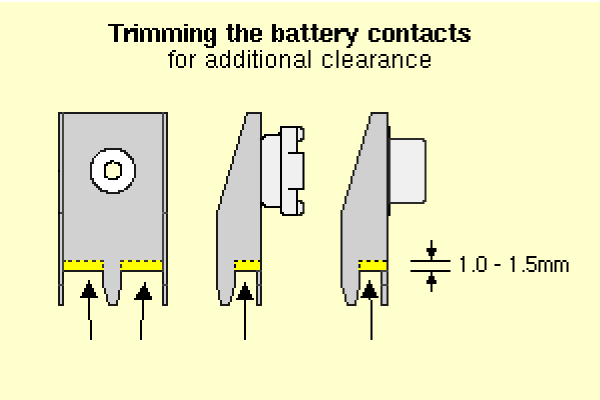
When soldering the DC power jack and 3.5mm stereo mini jacks, you should heat the solder tabs and pads sufficiently to allow solder to fill the entire hole. Remove heat immediately and cool the joint by blowing air at it as soon as you achieve a good fill. This assures that the jacks will be mechanically-secure.

For LED1, bend the LED leads 90°, paying attention to the polarity and which way it will face through the rear panel. Since the LED will be inline with the center of the DC power jack, insert the LED into the board until the LED is aligned properly. Solder one LED pin, then heat the pad and make small adjustments if needed. Then, solder the other pin.

For LED2, also bend the pins 90° (noting the polarity and direction), then install the front panel temporarily by placing it over the 3.5mm mini phone jacks and volume pot. Insert the LED into the board until the lens is aligned to the hole in the panel, and push it into the hole. Solder one LED pin, and make any adjustments as necessary. Solder the other pin.

The easiest way to solder in the battery contacts is to first attach them to a 9V battery (preferably a dead one), making sure that the two contacts do not touch, and then carefully insert the contacts into the board. Be sure the battery positive and negative contacts go into the correct locations! They are marked clearly on the board, and should match the labels on the battery (Also see the photo above).

Before soldering in the battery contacts, you should check the fitment into the case. When the battery is snapped into the contacts, there will usually be about 1mm to 1.5mm gap between the battery and the top surface of the board. If the battery is too thick, the whole assembly may not fit into the case. In that event, you can file away a portion of the bottom of the battery contacts to eliminate the gap and obtain additional clearance. See the following diagram.



When soldering the battery contacts, it will help to first secure the battery and contacts to the board by wrapping several turns of rubberband around the whole assembly. As with the jacks, you should fill each hole with solder.

Please be aware that even a dead battery may have enough voltage to cause component damage if you accidently short circuit either battery contact to other points on the board, such as with DMM probes, pliers, or some other metallic tool. Handle the board carefully. After you're done soldering the battery contacts, remove the battery.

Clean up the solder flux residue from the board with isopropyl alcohol (or electronics flux remover) and a brush. Using your diagonal cutter, trim all protruding pins, leads, solder tabs, etc., on the bottom side as close to the board as possible to prevent a short circuit to the case after installation.

Inspect all solder connections carefully, using a magnifying glass, to make sure there are no solder bridges or cold solder joints. Use a multimeter in ohms scale to check for short circuits. Correct any mistakes before moving on to the next phase.

Proceed to the initial check section to test the amplifier before connecting any headphones. When you are done with testing, continue to the section below for preparing and mounting the board in the case.

Preparing the case

This section assumes that you have already done the initial checks of your assembled board.

You may use the panel screws provided with your Hammond case, but they aren't as attractive as socket cap screws. Also, the Hammond screws are self-tapping, and are not designed to be removed and installed for many cycles. Eventually the screw threads would wear out.

For this reason imperial #6-32 or metric M3.5 flat-head socket cap screws are recommended. These screws should be at least 3/8" (9.5mm) long but no longer than 3/4" (19mm). Flat-head screws are required for the front panel to avoid interfering with the volume knob or a large headphone plug.

Optionally, you could use thumb screws of similar specifications for the rear panel to make removal easier.

If you use #6-32 or M3.5 screws, you must first tap the case to match. Taps for your portable electric drill or drill press could be purchased from a tools and hardware store.

If you use the screws provided by Hammond, installing and then removing the screws before the final assembly keeps you from getting pieces of aluminum all over the board.

The circuit board has a hole beneath the battery, near the version number marking. You can optionally tie a ribbon in a knot to the bottom side, and run it through this hole and over the top of the battery, from between the contacts toward the rear of the case. Once installed in the case, pulling on the ribbon will pop the battery out easily (after the rear panel is removed).

If you have a black anodized Hammond case, you should grind away some of the anodizing from the board slot, in order for the exposed ground plane strips on the bottom of the board to make contact with the case. This provides RFI shielding. You do not need to do this with the clear anodized version.

The board will go into the bottom slot of the case. Using the emery board or thin file, carefully grind along the bottom surface of that slot on each side, until you could see bare aluminum showing through. Also, you should use the emery board or file to deburr the sharp inside edge of the case to prevent it from scraping the top of the battery as you slide the board into the case. When you're done, clean the case of all metal dust and shavings.

Insert the board into the slot (with a good battery installed), Be careful while doing this to prevent any part of the circuit from touching the case, especially the battery contacts and any protruding leads on the bottom of the board.

Use your multimeter to check the continuity between the sleeve ("input ground") of the inner 3.5mm stereo mini jack and a point where you could make good contact with the bare metal of the case (such as at the panel screw threads). You should get a low ohms reading. If not, remove the board, grind the slots further and repeat.

Install the front and rear panels (taking care to guide the LEDs into their respective holes), fasten the panel screws, install the volume knob, and you're done.

Connect your source and headphones, and enjoy the music!

Specifications and benchmarks

Measurements were done on Mini³ high performance edition and Mini³ extended runtime edition amplifiers with a default gain of 5. The parts selection are as specified in the parts list section.

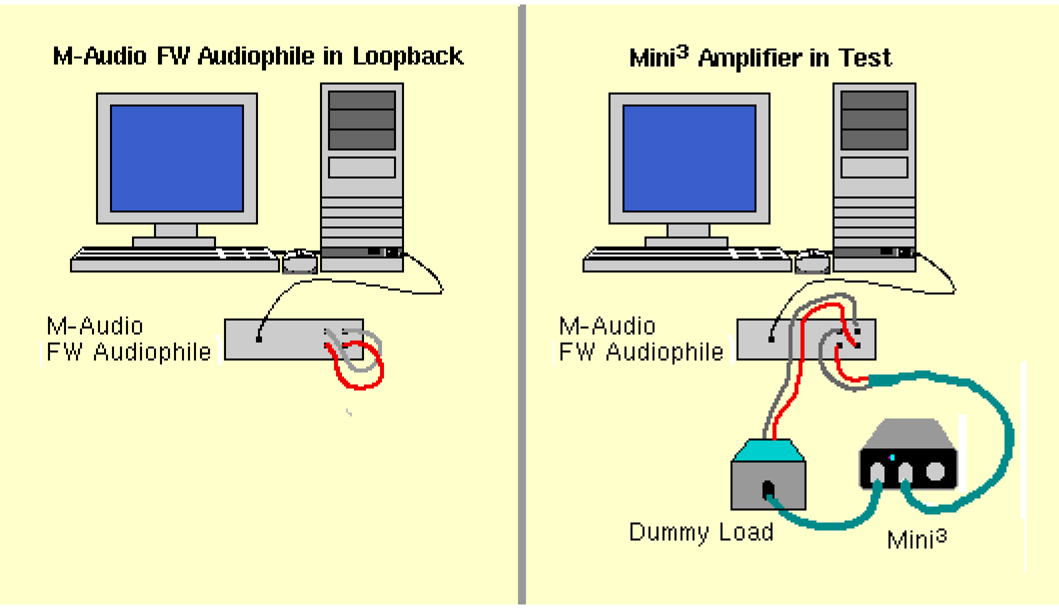
The tests were conducted using the following equipment:

1. Wavetek 188 4MHz sweep function generator
2. Tektronix TDS2014B 100MHz quad trace digital storage oscilloscope
3. Protek 6510 100MHz analog dual trace oscilloscope
4. Fluke 95 50MHz digital dual trace ScopeMeter
5. Fluke 187 digital multimeter
6. Toshiba Satellite A65 laptop computer with Celeron 2.8GHz CPU and 768MB RAM
7. M-Audio Firewire Audiophile mobile interface
8. RightMark Audio Analyzer 5.5 software
9. dummy loads 330Ω/33Ω/none
10. other custom test jigs, cables and software

Here are the measured results:

Measured Results	**Mini³ high performance edition**	**Mini³ extended runtime edition**
Opamps	L&R: AD8397ARDZ G: OPA690ID	L&R: LMH6643MA G: LMH6642MA
Input impedance	10KΩ nominal	
Output impedance	less than 0.1Ω	
Maximum output voltage per channel, 1KHz, prior to onset of clipping	9Vp-p (3.2Vrms) with battery power 11Vp-p (3.9Vrms) with external power	
Power output	300mWrms into 33Ω 30mWrms into 330Ω	180mWrms into 33Ω 30mWrms into 330Ω
Frequency response at 0dBV output	0Hz - >4MHz; +0, -3dB (limited by function generator)	
Rise time 100KHz square wave, at maximum output, 10% to 90%	166nS	54nS
Slew rate 100KHz square wave, at maximum output	52V/µS	162V/µS
Quiescent current (battery current draw while power on)	25mA	10mA
Noise level Dynamic range Total harmonic distortion Intermodulation distortion Stereo crosstalk	see RMAA test results below	

RMAA test results



Several tests were performed, one with the M-Audio Firewire Audiophile mobile interface running in loopback mode to establish the baseline (lowest limit of measurement resolution), and anothers with the Mini³ amplifier added to the chain with 330&Omega or 33Ω dummy loads connected to the Mini³'s output.

The Mini³'s volume control knob is set to maximum for these tests. This is worthy of mention because many others test their amplifiers with the volume set lower, which would give artificially low noise and distortion results.

Click on the following links to see the results.

- M-Audio Firewire Audiophile loopback baseline
- Mini³ high performance edition test results (330Ω load)
- Mini³ high performance edition test results (33Ω load)
- Mini³ extended runtime edition test results (330Ω load)
- Mini³ extended runtime edition test results (33Ω load)
- Mini³ high performance edition, 330Ω load vs. 33Ω load
- Mini³ extended runtime edition, 330Ω load vs. 33Ω load

Comments on the RMAA test results

The measured performance with 300Ω load is excellent for both Mini³ editions, exhibiting extremely low THD and IMD distortion, low noise floor and low stereo crosstalk through the entire audio frequency range. There is virtually no degradation of performance on the high performance edition when the load is decreased to 33Ω The extended runtime edition shows increased THD and IMD with 33Ω load (due to its lesser output current capability), but these results are still very good compared to many other amplifiers, particularly those of similar size to the Mini³.

The stereo crosstalk in the high frequency range for both editions was not impacted as the load is decreased from 330Ω to 33Ω illustrating the benefit of the 3-channel active ground topology. See the Tech highlights section for more details.

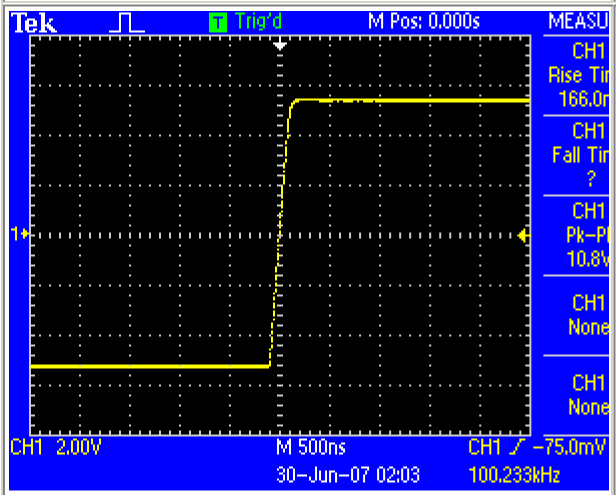
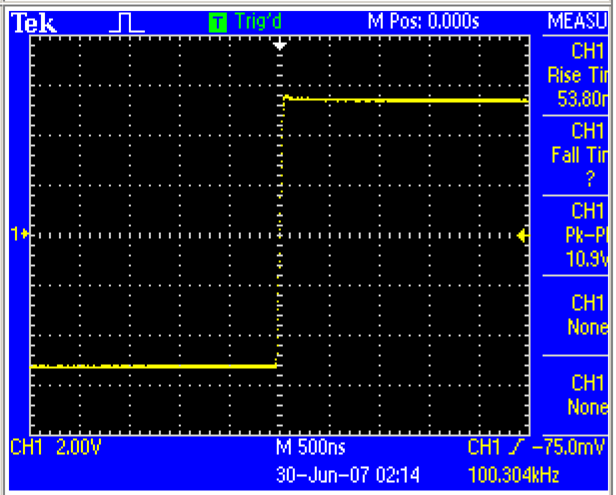
The slight rolloff at the low end in the frequency response graph is due to the M-Audio's coupling capacitor. The Mini³'s actual frequency response is flat down to 0Hz. Likewise, the high-end rolloff in the graph is due to the M-Audio's anti-aliasing filters. Both Mini³ editions have high frequency response that extends to 10MHz and beyond.

These tests were run with the amplifier operating on battery power. The same results were obtained when the amplifier ran on external power via an unregulated AC-DC adapter. In particular, no change was observed in the noise floor, showing that the Mini³'s onboard voltage regulation is very effective.

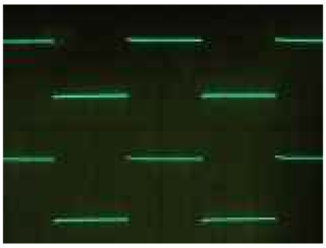
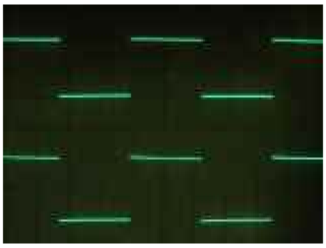
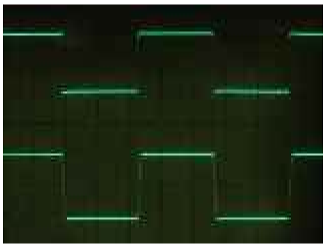
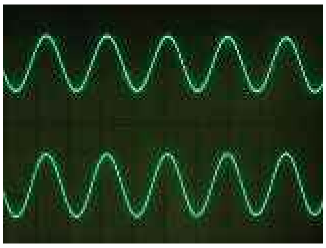
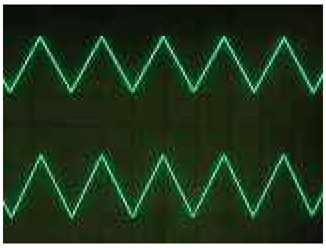
Oscilloscope waveforms

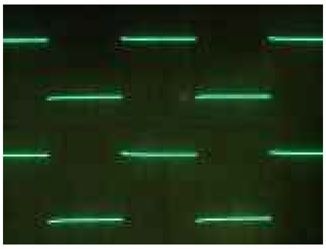
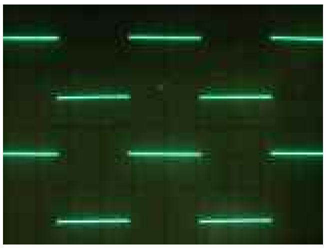
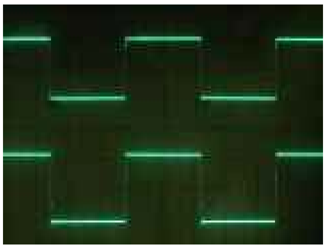
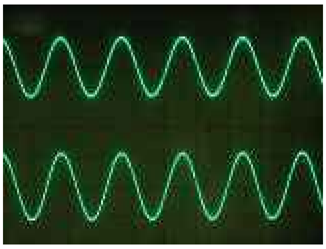
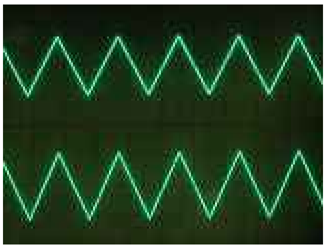
The oscillogram waveforms of the Mini³ amplifier are shown below. All input waveforms are produced by a Wavetek 188 4MHz sweep function generator.

The following are the 100KHz square wave rising edge response of the Mini³ high performance and extended runtime editions, as tested with a Tektronix TDS2014B 100MHz digital storage oscilloscope. The rise time as well as the peak-to-peak output amplitude is shown on the right hand side of the display. As could be seen, the extended runtime edition's rise time (and thus slew rate) is actually faster than the high performance edition.

Mini³ high performance edition	**Mini³ extended runtime edition**
	

Below are additional waveforms as measured with a Protek 6510 100MHz analog oscilloscope. In all graphs except the Lissajous waveform, the top trace is the input and the bottom is the output. The 100KHz square wave graphs show no overshoot or ringing. The lissajous (X-Y) graph shows no discernable phase shift.

Mini³ high performance edition		
 1KHz square wave	 10KHz square wave	 100KHz square wave
 100KHz sine wave	 100KHz triangle wave	 100KHz Lissajous

Mini³ extended runtime edition		
 1KHz square wave	 10KHz square wave	 100KHz square wave
 100KHz sine wave	 100KHz triangle wave	 100KHz Lissajous

Part	Quantity	Description	Mouser #	Digi-Key #	Other
Circuit board					
PCB, L1L, L1R, L1G, B+, B-	1	Mini³ printed circuit board (includes three ferrite beads and one set of board-mount battery contacts)	AMB audio shop		
Potentiometers					
Volume/Power	1	Alps RK0971221Z05 10KΩ stereo potentiometer with SPST switch	AMB audio shop		
Resistors					
R1L, R1R, R1G, R3L, R3R, R4G	6	miniature 1% metal film resistor 330Ω	270-330-RC	P330CACT-ND	Farnell 9343032
R2L, R2R	2	miniature 1% metal film resistor 100KΩ	270-100K-RC	P100KCACT-ND	Farnell 9342427
R4L, R4R	2	miniature 1% metal-film resistor 1.5KΩ	270-1.5K-RC	P1.50KCACT-ND	Farnell 9342621
R5L, R5R	2	miniature 5% or 1% carbon-film or metal-film resistor 6.2Ω	299-6.2-RC	P6.2BACT-ND	Farnell 9343504 (6.8Ω)
R6	1	miniature 1% metal-film resistor 5.6KΩ	270-5.62K-RC	P5.60KCACT-ND	Farnell 9343369
R7	1	miniature 1% metal-film resistor 10KΩ	270-10K-RC	P10.0KCACT-ND	Farnell 9342419
R8	1	miniature 1% metal-film resistor 75Ω	270-75-RC	P75.0CACT-ND	Farnell 9343555
Capacitors					
C2	1	solid dipped tantalum capacitor 10µF 25V	80-T350E106K025AT	399-3565-ND	Farnell 9708448
C3a, C3b	2	aluminum electrolytic capacitor 470µF 16V	647-UHE1C471MPD or 647-UPW1C471MPD6	P10247-ND or P12376-ND	Farnell 1219462
C4, C6, C7+, C7-, C8+, C8-	6	multilayer ceramic X7R capacitor 0.1µF 50V	80-C320C104K5R5CA	399-4264-ND	Farnell 1141775
C5+,C5-	2	aluminum electrolytic capacitor 100µF 25V	647-UHE1E101MED or 647-UPW1E101MED	P10269-ND or P12924-ND	Farnell 1219466
Integrated Circuits					
U1	1	LM317L voltage regulator TO-92	512-LM317LZ	LM317LZ-ND	Farnell 9488545
U2	1	7812 voltage regulator TO-220	512-LM7812CT	MC7812ECT-ND	Farnell 9666109
U3	1	TLE2426CLP precision rail-splitter TO-92	AMB audio shop		
U4	1	(For Mini³ "high performance" edition) OPA690ID operational amplifier SOIC-8	AMB audio shop		
U4	1	(For Mini³ "extended runtime" edition) LMH6642MA operational amplifier SOIC-8	AMB audio shop		
U5	1	(For Mini³ "high performance" edition) AD8397ARDZ dual operational amplifier SOIC-8	AMB audio shop		
U5	1	(For Mini³ "extended runtime" edition) LMH6643MA dual operational amplifier SOIC-8	AMB audio shop		
Diodes					
D1, D2, D3	3	1N4001 1A rectifier DO-41	512-1N4001	1N4001FSCT-ND	Farnell 9564993
D4	1	BZX55C12 12V 500mW zener diode DO-35	AMB audio shop		
LED1	1	T-1 (3mm) super-bright LED (red, for charge indicator)	(your choice)	(your choice)	(your choice)
LED2	1	T-1 (3mm) super-bright LED (blue, for power on indicator)	(your choice)	(your choice)	(your choice)
Miscellaneous					
J1	1	DC power jack 2.5mm pcb-mount	AMB audio shop		
J2, J3	2	3.5mm stereo mini phone jack, pcb-mount, isolated	AMB audio shop		
-	1	heat-sink thermal compound (electrically non-conductive)	567-120-SA	345-1006-ND	Radio Shack 276-1372
-	1	imperial #4-40 or metric M3 low-profile pan-head machine screw, 3/8" or 10mm long and matching hex nut (for U2 mounting)	-	-	local hardware store
Case	1	Hammond 1455C802 or 1455C802BK or 1455C801 or 1455C801BK	546-1455C802 546-1455C802BK 546-1455C801 546-1455C801BK	HM970-ND - HM969-ND -	Farnell 4272936 Farnell 9287906 Farnell 4272810 Farnell 9287787
Knob	1	volume knob, silver or volume knob, black	-	226-3003-ND 226-4003-ND	-
Battery	1	9V NiMH rechargeable battery CTA 325mAH or 275mAH recommended	-	-	Thomas Distributing or other vendors
Wallwart	1	AC-DC adapter, 15VDC-24VDC, 300mA minimum, 2.5x5.5mm barrel plug, center positive	412-112053 (for 120VAC 60Hz USA, rated 12V/500mA, actual ~17VDC unloaded)	-	Jameco 189982 (for 120VAC 60Hz USA), or Farnell 1217107 (for 230VAC 50Hz Euro), or Farnell 1217103 (for 230VAC 50Hz UK), or local electronics store
Optional items					
-	1 set	Precision drilled and engraved front/rear aluminum panel set	AMB audio shop		
-	4	imperial #6-32 or metric M3.5 flat-head socket cap screws (for front and rear panel)	-	-	McMaster-Carr or local hardware store
-	2	imperial #6-32 or metric M3.5 thumb screws (for rear panel)	534-2406	-	McMaster-Carr or local hardware store