GLASSWARE AUDIO DESIGN

Aikido LV

USER GUIDE

08/12/2010

Warning!

Although this PCB was designed for use with a low-voltage power supply (24V or 48V), caution is still required. For example, even 24 volts shorted to ground will make big sparks and 48V, under worst-case conditions, could prove lethal; thus, a real shock hazard can also exist. Moreover, the large valued electrolytic capacitors may burst upon being energized if inserted incorrectly. Once the power supply is powered up, be cautious at all times.

If you are not an experienced electrical practitioner, before applying any voltage supply, have someone who is experienced review your work. There are too few tube-loving solder slingers left; we simply cannot afford to lose any more.

PCB Overview

Thank you for your purchase of the LV Aikido stereo PCB. This FR-4 PCB is extra thick, 0.094 inches (inserting and pulling tubes from their sockets won't bend or break this board), double-sided, with plated-through 2oz copper traces, and the boards are lovingly and expensively made in the USA. The boards are five inches by ten inches, with five mounting holes, which prevents excessive PCB bending while inserting and pulling tubes from their sockets. The PCB holds two Aikido line-stage amplifiers. Thus, one board is all that is needed for stereo unbalanced use or one board for one channel of balanced amplification.

Low-Voltage Operation The key advantage of the LV Aikido is that it can operate under relatively low B+ voltage. Where the typical tube-based line-stage amplifier requires a B+ of 200V to 400V, the LV Aikido can get by with only 24Vdc with 6GM8/6N27P/ECC86 tubes; or 48Vdc with 12BH7 or ECC99. The heaters are all placed in series and this heater string is placed in parallel with the B+ and ground. Thus, a single power supply voltage is all that is required.

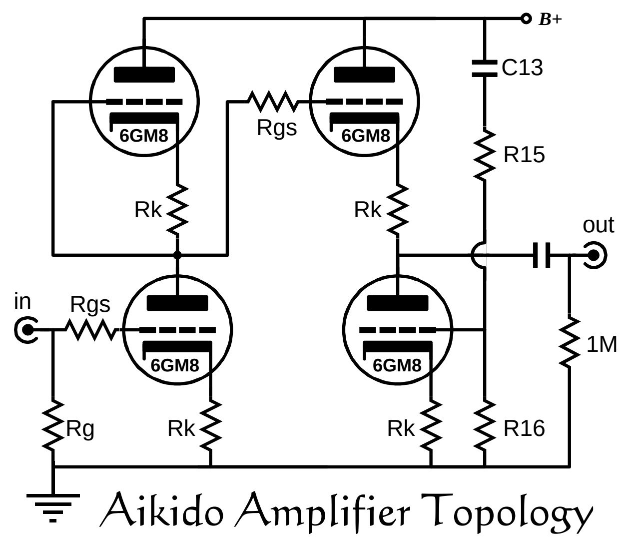
PS RC Filter The LV Aikido PCB holds an RC (resistor-capacitor) filter to smooth away power-supply ripple. Switch-mode regulated power supplies are readily available with 24V and 48V DC output voltages. These small desktop power supplies are both inexpensive and cool running. They usually put out less than 0.5V of ripple at full output current. Fortunately, the ripples tends to be supersonic, say over 40kHz, so the RC filter has less work to do. For example, an RC filter made up from a 1-ohm resistor and 1000µF capacitor would perform poorly with the typical power supply's 100Hz or 120Hz. But with a 40kHz ripple frequency, such an RC filter would offer wonderful ripple reduction, as the capacitor's reactance would equal only 0.004 ohms.

Redundant Solder Pads This board holds two sets of differently-spaced solder pads for each critical resistor, so that radial and axial resistors can easily be used (bulk-foil resistors and carbon-film resistors, for example). In addition, most capacitor locations find many redundant solder pads, so wildly differing-sized coupling capacitors can be placed neatly on the board, without excessively bending their leads.

Introduction to the Aikido Topology

The Aikido amplifier delivers the sonic goods. It offers low distortion, low output impedance, a great PSRR figure, and feedback-free amplification. The secret to its superb performance— in spite not using global feedback— lies in its internal symmetry, which balances imperfections with imperfections. As a result, the Aikido circuit works at least a magnitude better than the equivalent SRPP or grounded-cathode amplifier.

For example, the Aikido circuit produces far less distortion than comparable circuits by using the triode's own nonlinearity against itself. The triode is not as linear as a resistor, so ideally, it should not see a linear load, but a corresponding, complementary, balancing non-linear load. An analogy is found in someone needing eyeglasses; if the eyes were perfect, then perfectly flat (perfectly linear) lenses would be needed, whereas imperfect eyes need counterbalancing lenses (non-linear lenses) to see straight. Now, loading a triode with the same triode— under the same cathode-to-plate voltage and idle current and with the same cathode resistor— works well to flatten the transfer curve out of the amplifier.



Aikido Amplifier Topology

In the schematic above, the 6GM8 triodes are so specified for example only. Although they would never fit on the printed circuit board (PCB), 211 and 845 triodes could be used to make an Aikido amplifier. In other words, the Aikido circuit does not rely on 6GM8 triodes or any other specific triodes to work correctly. It's the topology, not the tubes that make the Aikido special.

The secret to the Aikido circuit is that sidesteps power supply noise by anticipating and adjusting for that noise so that noise is eliminated from the output. This improved PSRR advantage is vital, for it greatly unburdens the power-supply. With no tweaking or tube selecting, you should easily be able to get a -30dB PSRR figure (a conventional grounded-cathode amplifier with the same tubes and current draw yields only a -6dB PSRR); with some tweaking of resistor R15's value, -60dB or more is possible. Additionally, unless regulated power supplies are used for the plate and heater, these critical voltages will vary at the whim of the power company and your house's and neighbors' house's use, usually throwing the once fixed voltage relationships askew. Nevertheless, the Aikido amplifier will still function flawlessly, as it tracks these voltage changes symmetrically.

Remember, tubes are not yardsticks that never change; instead, being more like car tires, they wear out. Just as a tire's weight and diameter decrease over time, so too the tube's conductance. Thus a fresh 6GM8 is not the same as the same 6GM8 after 2,000 hours of use. But as long as the two triodes with the tube envelope age in the same way—which they are inclined to do, as they do the same amount of work and share the same materials and environment—the Aikido amplifier will always bias up correctly, splitting the B+ voltage between the triodes. Moreover, the Aikido amplifier does not make huge popping sounds at start up, as the output does not start at the B+ and then swing down a hundred or so volts when the tube heats up, as it does in a ground-cathode amplifier.

By injecting the a portion of power-supply noise into the bottom triode of the two-triode-follower circuit, this circuit eliminates most of the power-supply noise from the output. The way it works is that the input stage (the first two triodes) define a voltage divider of 50%, so that 50% of the PS noise is presented to the CF's grid; at the same time resistors R15 and R16 also define a voltage divider, so the bottom triode's grid also sees about half of the PS noise. Since both of these signals are equal in amplitude and phase, they cancel each other out, as each triodes sees an identical increase in plate current (imagine two equally strong men in a tug of war contest). So, shouldn't resistors R15 and R16 share the same value, thereby also splitting the power-supply noise at 50%? No. If triode did not present a low plate resistance, then the 50% ratio would apply. Because of the low rp, the correct relationship between resistors R15 and R16 is given by the following formula:

R15 = R16[(mu - 2)/(mu + 2)]

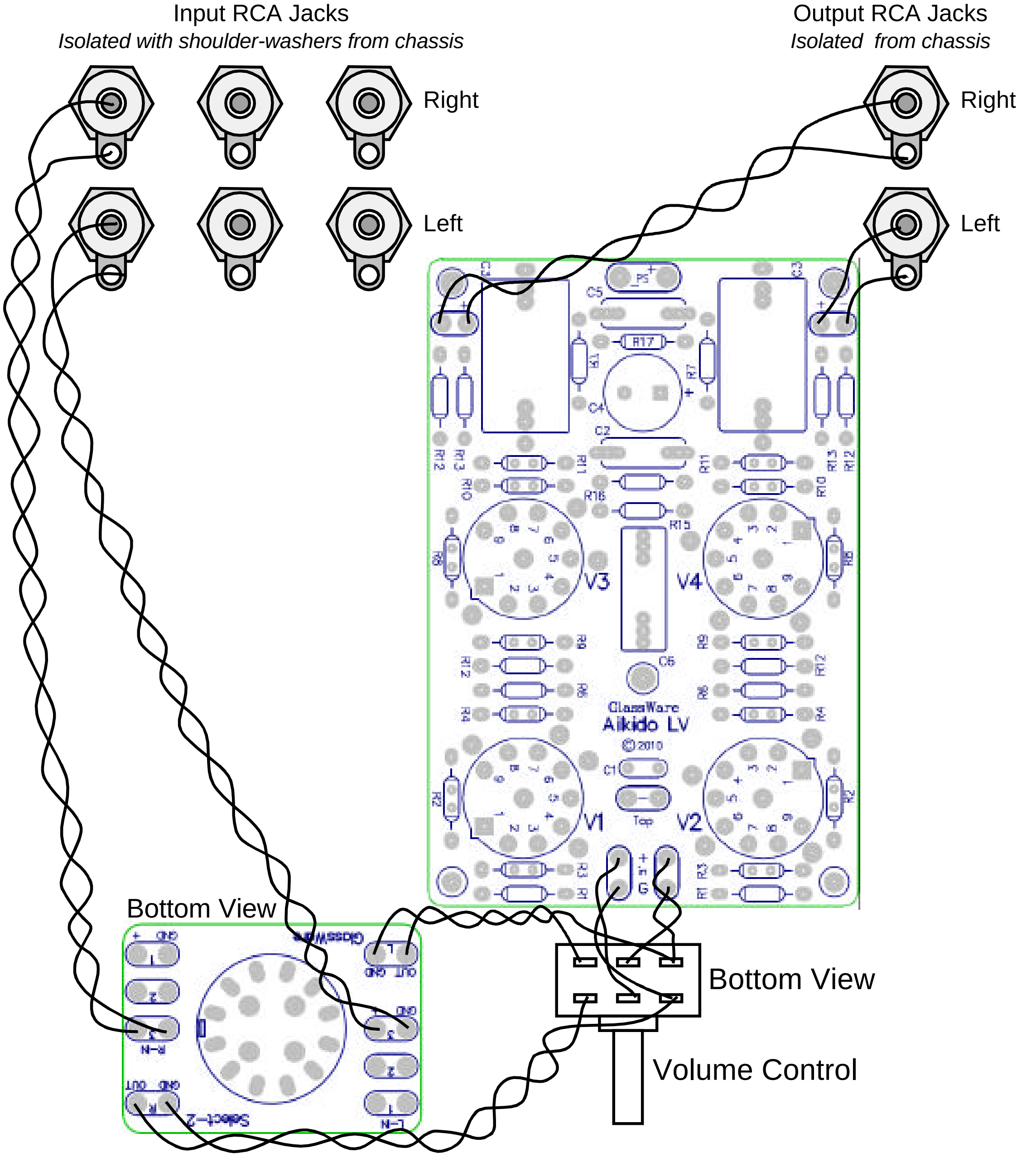
Furthermore, the Aikido amplifier—like other Aikido techniques I have tried—seems to bypass much (but not all) of the power supply squirrelliness, making the circuit sound as if it were attached to batteries or a well-regulated power supply. (This includes the sonic traces left by imperfect power supply capacitors.)

Had an SRPP circuit been used instead as the input stage or had the output connection had been taken from the output cathode follower's cathode, the equilibrium would be broken, resulting in a much poorer performance. The same holds true if the cathode follower's cathode resistor is removed. (Besides, this resistor actually makes for a better sounding cathode follower, as it linearizes the cathode follower at the expense of a slightly higher output impedance.) In other words, the Aikido topology trades away the higher gain and lower output impedance for lower distortion and much-lower noise. The formula for the Aikido's output impedance is the following:

Zo = [rp/(mu +1) + R8] || R13 || [rp + (mu + 1)Rk]

where "||" stands for in "parallel with."

Phase Like a grounded-cathode amplifier, the LV Aikido inverts its input signal's phase at the Aikido's output. This is not the tragedy that many assume. All that is required is that the speaker leads that connect to the power amplifier be reversed, assuming that the power amplifier does not itself invert the signal phase.



In this preferred physical setup, each input RCA jack gets its own pair of hot and ground wires; and the same holds true for the output RCA jacks. The six sets of twisted wire or coaxial cable travel from the input RCA jacks to a GlassWare Select-2 selector switch and then to the volume control and, finally, to the LV Aikido PCB. All RCA jacks must be isolated from the chassis with non-conducting shoulder washers. Test each jack's ground tab for shorts to the chassis, before soldering the ground wires in place. In addition, make sure that only absolutely necessary ground wires that are soldered in place. (If the volume potentiometer presents only one ground tab, then tie both of the incoming ground wires from the selector switch to this connection and send one ground wire from the potentiometer to the PCB.) Attach B+ voltage power supplies wires at the bottom of the PCB and twist these wires into to a tight bundle that hugs the bottom of the chassis to its power source. If an external power supply is used, ground the chassis at the negative tab of the power supply jack.

Configuring a Line Amplifier

The Aikido topology makes a perfect line amplifier, as it offers low distortion, low output impedance, and excellent power-supply noise rejection—all without a global feedback loop. For guidance on part values, look below, which lists several line-amplifier design examples. Calculating R15's value is easy; it's value equals R16 against [(mu -2)/(mu + 2)]. For example, a triode with a mu of 14, such as the 6GM8, results in R15 = 100k x (14 – 2)/(14 + 2) = 75k.

Typical Part Values () Parentheses denote recommended values

V1, V2, V3, V4 =	6GM8/6N27P/ECC86	12BH7	ECC99
B+ Voltage =	24V	48V	48V
Heater Voltage =	Same as above	Same as above	Same as above
Current Draw =	350mA	350mA	450mA
R1,5,6,7,12,13 =	1M	1M	1M
R2,4 =	100 - 240 (180)*	200 - 300 (249)*	200 - 470 (300)*
R3,9,10 =	100 - 1k (300)*	100 - 1k (300)*	100 - 1k (300)*
R8,11 =	100 - 240 (180)*	200 - 300 (249)*	200 - 470 (300)*
R15 =	75k	78k	82.5k
R16 =	100k	100k	100k
R17 =	1 ohm 1W	1 ohm 1W	1 ohm 1W

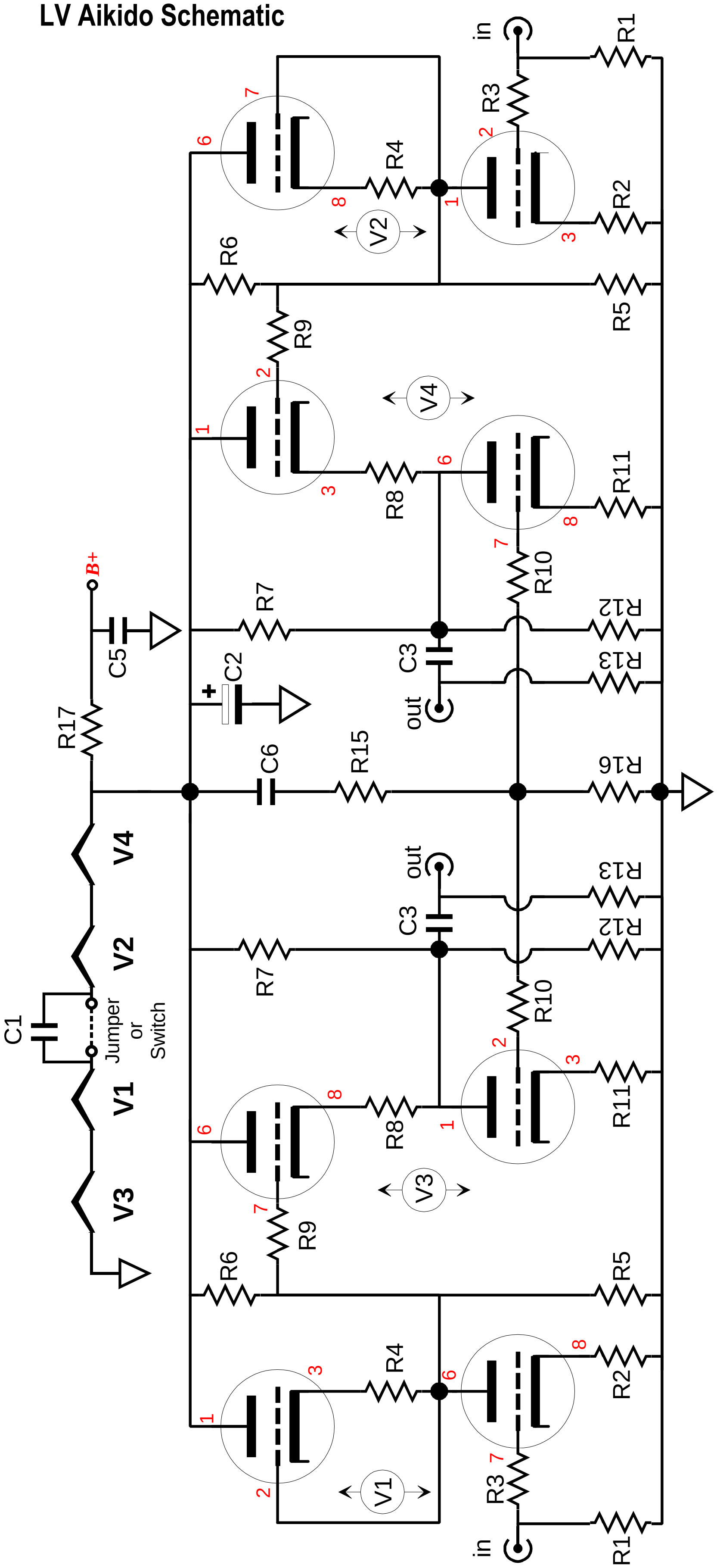
R5 mislabeled R12 on PCB.
All resistors (except R17) 1/2W or higher
**High-quality resistors essential in this position.*

C1 =	100pF - 0.01µF 100V	Same	Same
C2 =	0.1µF - 1µF 50V	0.1µF - 1µF 100V	0.1µF - 1µF 100V
C3 =	0.1 - 3µF 100V - 400V	Same	Same
C4 =	330µF - 1kµF 35V	330µF - 1kµF 63V	330µF - 1kµF 63V
C5 =	0.1µF - 1µF 100V	Same	Same
C6 =	0.1 - 1µF 50V	0.1µF - 1µF 100V	0.1µF - 1µF 100V

Power Switch The LV Aikido can switched on in two ways. The first is to place a switch in series with the heater string (two eyelets are provided below C1 on the PCB), leaving the LV Aikido's power supply constantly on (which works well with external power supplies, such as wallwart and switch-mode power supplies).The triodes cannot conduct until the heaters are hot but the capacitors will remain charged at all times. Or the unit can be switched on at either the power supply or the connection to the power supply; just use a jumper wire to bridge the heater series.

RFI Radio frequency interference can be a hassle to track down and eliminate. The air is filled with RFI from light dimmers, switching power supplies, cordless phone cradles, computers... First make sure that all contacts are clean. Second, make sure that the source of the problem actually resides in the line-stage amplifier. For example, if only one signal source suffers from RFI noise, make sure that it is normally RFI free. In other words, attach it to another line-stage amplifier and see if the RFI persists. If it does pass this test, then try soldering small capacitors, say 100pF, from this signal source's RCA jacks to the chassis, as close as possible to the jacks: if it fails, fix the source. Ferrite beads can also help; try using beads on the hot lead as it leaves the input RCA jack and then again at the selector switch. Increasing the grid-stopper resistor's (R3, R9, R10) value, say to 1k or 10k, can also work wonders (use a carbon-composition or bulk-foil resistor or some other non-inductive resistor type).

LV Aikido Schematic



Assembly

Before soldering, be sure to clean both sides of the PCB with 90% isopropyl alcohol, wiping away all fingerprints. First, solder the shortest parts (usually the resistors) in place, then the next tallest parts, and then the next tallest... Make sure that both the solder and the part leads are shiny and not dull gray. Steel wool can restore luster and sheen by rubbing off oxidation.

As the PCB is doubled sided, parts can be soldered in place from either side. In fact, many of the parts can be positioned on the bottom side of the PCB; the exceptions being the tube sockets, as they must always be positioned on the top of the board.

Important: Be sure to observe the electrolytic capacitors' polarity and glue or double-sided tape or tie-wrap heavy coupling capacitors to the PCB.

Volume Control An audio-taper potentiometer or stepped attenuator can be placed in front of the Aikido amplifier. Of course, a volume control may not be needed, if the signal source already provides the means of volume adjustment, such as an MP3 player or a line stage amplifier.

External Power Supply

The genius of the Aikido circuit is found in both its low distortion and great PSRR figure. Nonetheless, a good power supply helps (there is a practical limit to how large a power-supply noise signal can be nulled). I recommend you use at least a robust, fast-diode rectified power supply. A regulated power supply is the obvious upgrade. The LM317HV can be used with B+ voltages up to 48Vdc, as long as the raw DC power supply voltage feeding the regulator is not over 57Vdc.

The power supply is external to the LV Aikido PCB and can be mounted in, or outside, the chassis that houses the PCB. The optimal power supply voltage depends on the tubes used. Four 6GM8s (6N27P/ECC86) can be used with a low 24V power supply, with 12BH7 or ECC99, 48Vdc—either a switch-mode or a linear power supply. After dealing with 400-volt power supplies, it is a joyful relief to work with relatively low voltages. We must address, however, a few important issues. For example, although we do not need much voltage, the heaters add a heavy current burden on the power supply. With 6GM8, the heater string requires 330mA and the four tubes require a total of 8mA, for a grand total of 338mA or (rounding up) 350mA. So, 0.35A against 24V equals 8.4W of dissipation. With the ECC99, the heater string requires 400mA and the four tubes require a total of about 10mA, for a grand total of 410mA or (rounding up) 450mA. So, 0.45A against 48V equals 21.6W of dissipation. (In other words, expect a good deal of heat and provide plenty of ventilation, in spite of the low B+ voltage.)

The LV Aikido is a perfect candidate for a wall-wart power supply. Both linear and switch-mode wall-warts are available with a 24V output voltage and both cost less than $30 USD. A medical-grade switch-mode power supply cost about $45 and it will be both safer and more quiet. On the other hand, a simple non-regulated power supply can be built from a power transformer, diode bridge, and a few capacitors. It just might sound good as well.

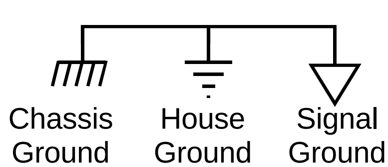
Grounding

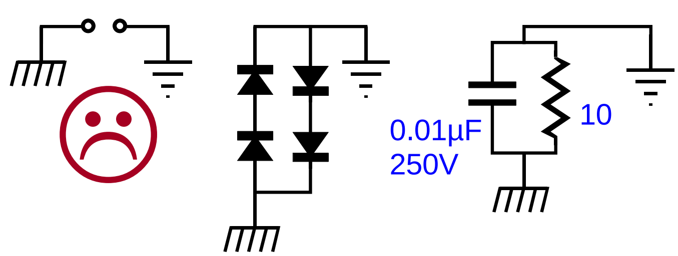
The LV Aikido PCB holds a star ground at its center. Ideally, this will be the only central ground in a line-stage buffer. A ground-loop is created when a device finds more than one connections to ground. Ground loops, unfortunately, are extremely easy to introduce. For example, if the input and output RCA jacks are grounded at the chassis, then the twisted pair of wires that connect the PCB to the jacks will each define a ground loop, as the chassis will attach to the PCB's central ground through at least four wires. The solution is either to isolate the jacks or use only a single hot wire from each jack to PCB (the wire can be shielded, as long as the shield only attaches at one end). Thus, the best plan is to plan. Before assembling the line-stage amplifier, stop and decide how the grounding is going to be laid out, then solder.

Three different schools of thought hold for grounding a piece of audio gear. The Old-School approach is to treat the chassis as the ground; period. Every ground connection is made at the closest screw and nut. This method is the easiest to follow and it produces the worst sonic results. Steel and aluminum are poor conductors.

The Spur-Star ground method uses several ground "stars," which then terminate in a single star ground point, often a screw on the chassis. This system can work beautifully, if carefully executed. Unfortunately, often too much is included in each spur connection. For example, all the input and output RCA jacks share ground connection to a long run of bare wire, which more closely resembles a snake than a spur ground. In other words, the spurs should not be defined just physical proximity, but signal transference. Great care must be exercised not to double ground any spur point. For example, the volume control potentiometer can create a ground loop problem, if both of its ground tabs are soldered together at the potentiometer and twisted pairs, of hot and cold wires, arrive at and leave the potentiometer, as the two cold wires attaching to the PCB will define a ground loop. The Absolute-Star grounding scheme uses a lot of wire and is the most time consuming to lay out, but it does yield the best sonic rewards. Here each input signal source and each output lead gets its own ground wire that attaches, ultimately, at one star ground point; each RCA jack is isolated from the chassis. The LV Aikido PCB was designed to work with this approach, although it can be used with any approach.

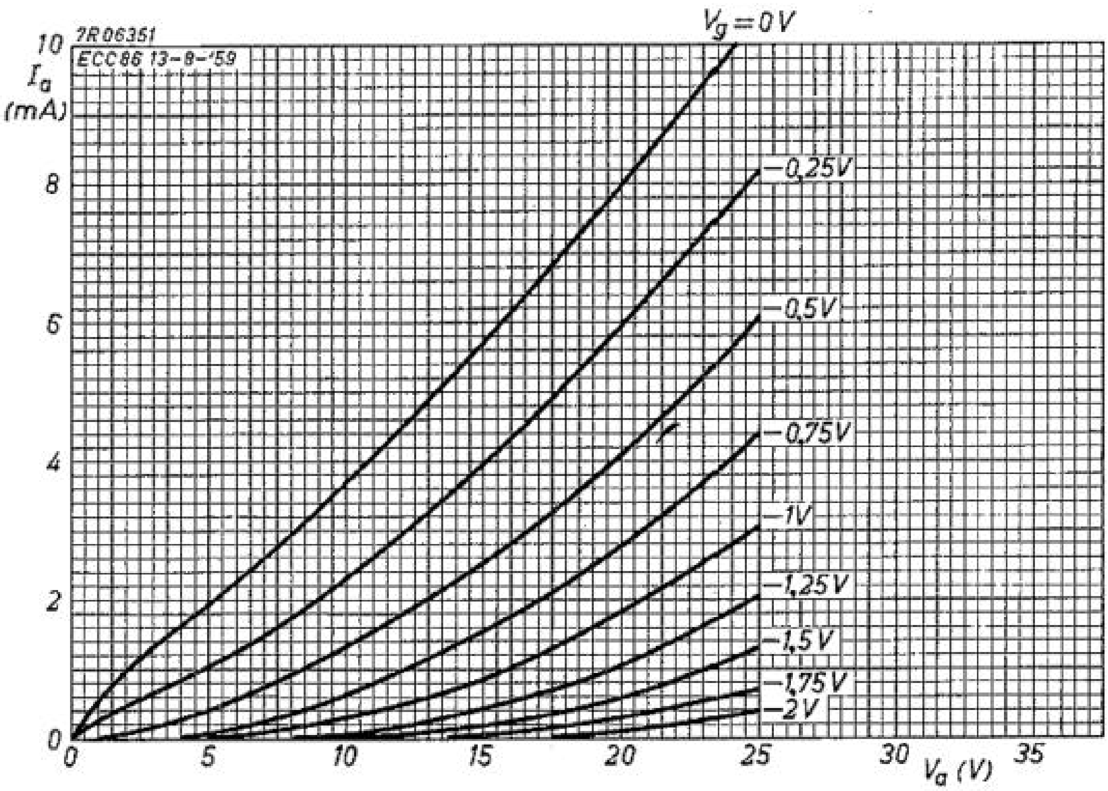
House Ground The third prong on the wall outlet attaches to the house's ground at the service panel and usually the cold water pipe. The line-stage buffer can also attach to this ground connection, which is certainly the safest approach, as it provides a discharge path should the high voltage short to the chassis. Unfortunately, this setup often produces a hum problem. Some simply float the chassis (not safe!), others use several solid-state rectifiers in parallel to attach the chassis ground to the house ground (**NOT NEUTRAL**) via the third prong, and others still use a power 10-ohm resistor shunted by a small capacitor, say 0.001µF to 0.1µF/250V.



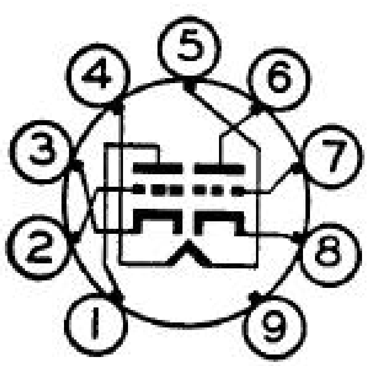


6GM8/6N27P/ECC86 Specifications

Heater Voltage	6.3V
Heater Current	330mA
Maximum Plate Voltage	30V
Maximum Plate Dissipation	0.6W
Maximum Cathode Current	20mA
Maximum Grid Resistor	1M
Maximum Cathode-to-heater Voltage	30V
Maximum Cathode-to-heater Resistance	20k
Amplification Factor	14
Transconductance	2.4mA/V
Plate Resistance	5800 Ohms



BASING DIAGRAM



RETMA 9AJ

TERMINAL CONNECTIONS

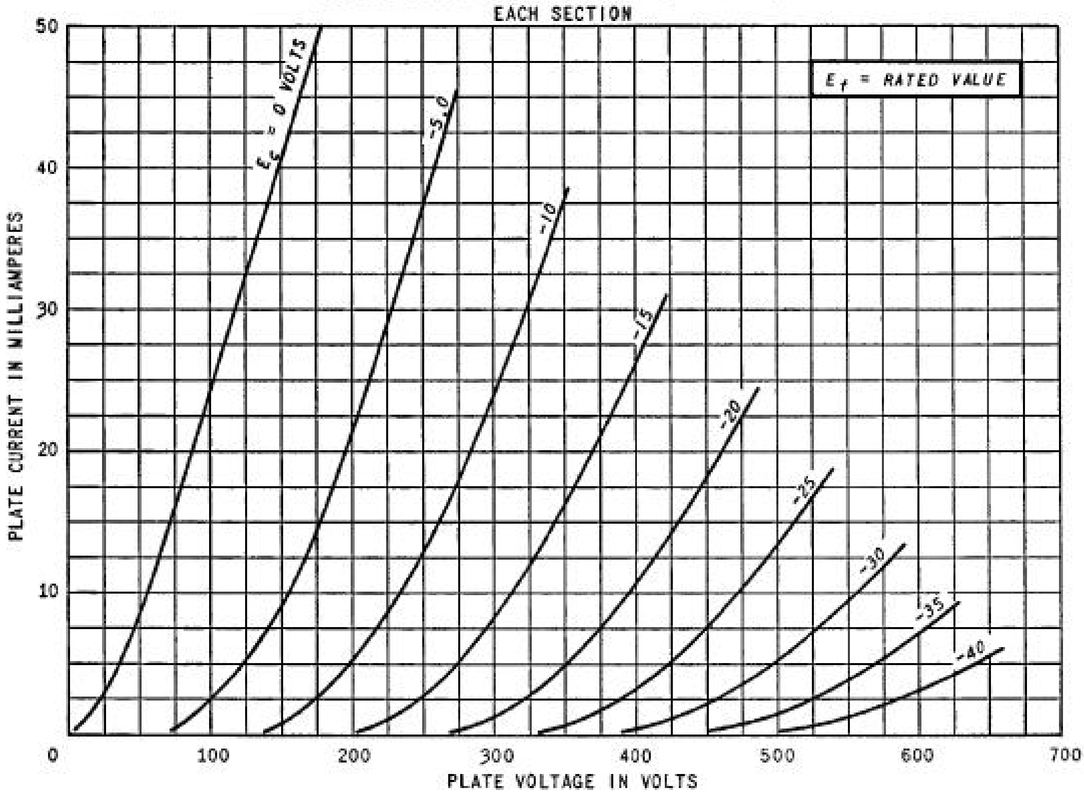
Pin 1—Plate (Section 2)
Pin 2—Grid (Section 2)
Pin 3—Cathode (Section 2)
Pin 4—Heater
Pin 5—Heater
Pin 6—Plate (Section 1)
Pin 7—Grid (Section 1)
Pin 8—Cathode (Section 1)
Pin 9—Internal Shield‡

‡ It is recommended that pin 9 be grounded.

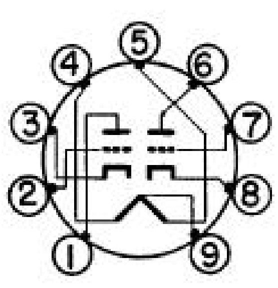
12BH7 Specifications

Heater Voltage	6.3V & 12.6V
Heater Current	600mA & 300mA
Maximum Plate Voltage	450V
Maximum Plate Dissipation	3.5W
Maximum Cathode Current	20mA
Maximum Grid Resistor	1M
Maximum Cathode-to-heater Voltage	100V
Amplification Factor	16.5
Transconductance	3.1mA/V
Plate Resistance	5300 Ohms
Grid-to-Plate Capacitance	2.6pF

AVERAGE PLATE CHARACTERISTICS



BASING DIAGRAM



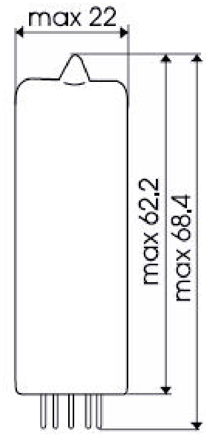
RETMA 9A

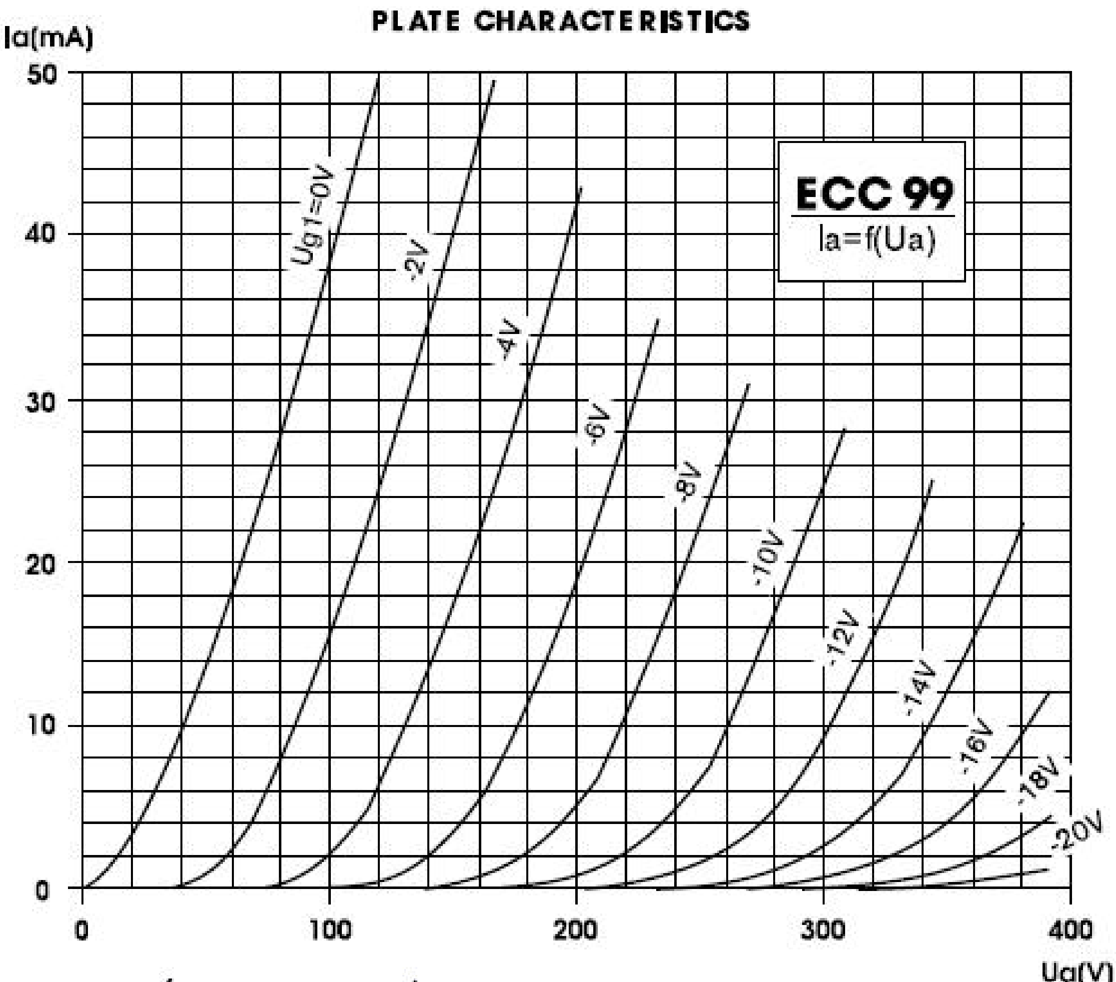
TERMINAL CONNECTIONS

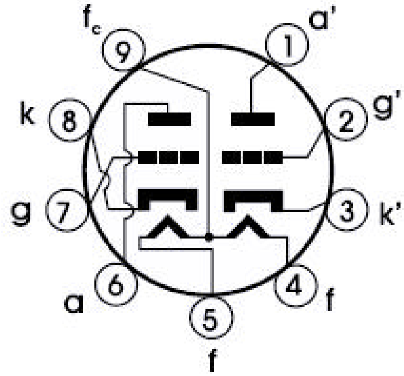
Pin 1—Plate (Section 2)
Pin 2—Grid (Section 2)
Pin 3—Cathode (Section 2)
Pin 4—Heater
Pin 5—Heater
Pin 6—Plate (Section 1)
Pin 7—Grid (Section 1)
Pin 8—Cathode (Section 1)
Pin 9—Heater Center-Tap

ECC99 Specifications

Heater Voltage	6.3V & 12.6V
Heater Current	0.8A & 0.4A
Maximum Plate Voltage	400V
Maximum Plate Dissipation	5W
Maximum Cathode Current	60mA
Maximum Cathode-to-heater Voltage	200V
Amplification Factor	22
Transconductance	9.5mA/V
Plate Resistance	2300 Ohms
Grid-to-Plate Capacitance	5.1pF







TERMINAL CONNECTIONS

Pin 1—Plate (Section 2)
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Pin 5—Heater
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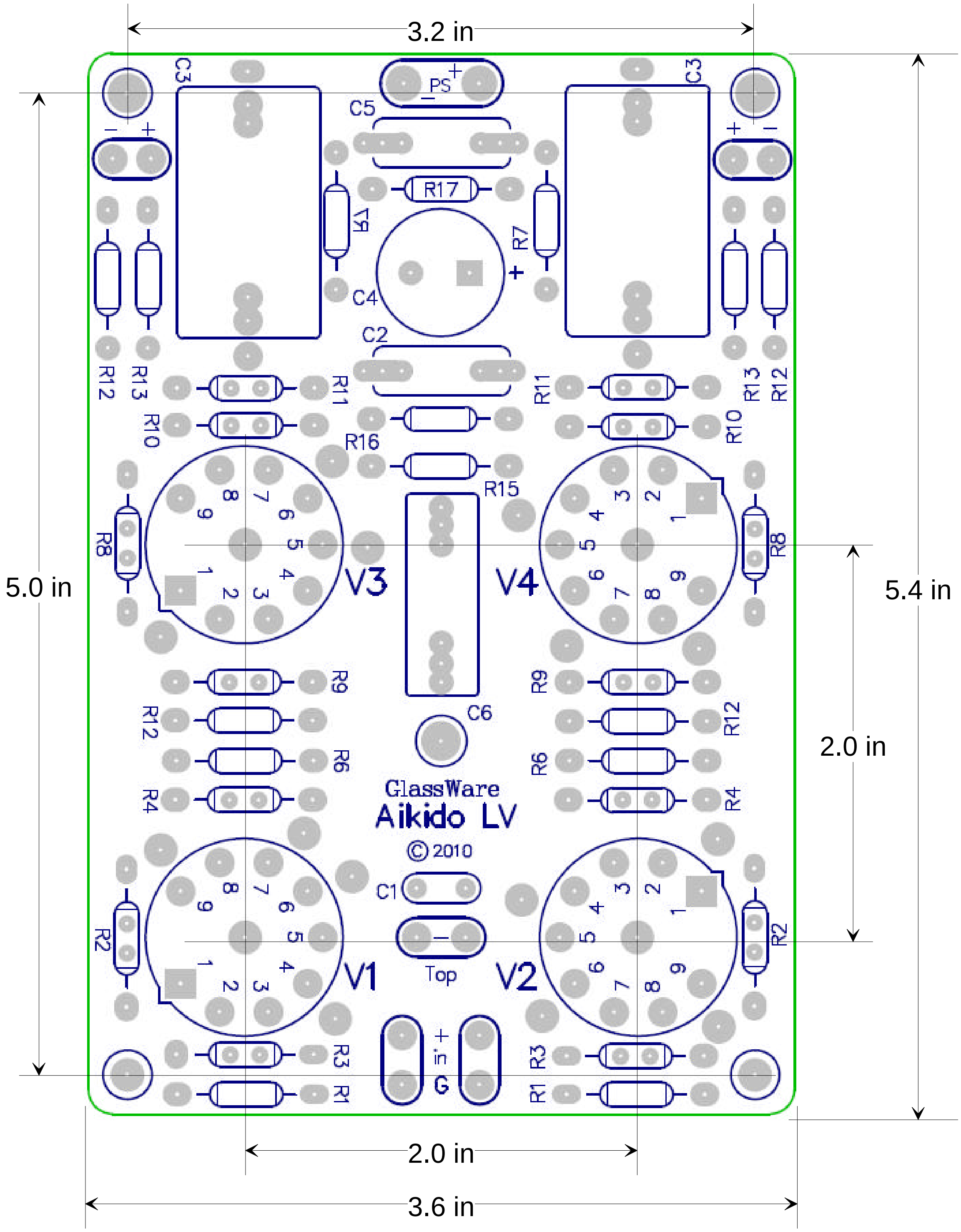
Pin 7—Grid (Section 1)
Pin 8—Cathode (Section 1)
Pin 9—Heater Center-Tap

PCB Dimensions



Let me know what you think

If you would like to see some new audio PCB or kit or recommend a change to an existing product or if you need help figuring out cathode resistor values, drop me a line by e-mail sales@tubecad.com (begin the subject line with either "Aikido" or "tube").