

GlassWare
AUDIO DESIGN

Aikido

24V Aikido
Stereo HPA & LSA PCB

USER GUIDE

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Overview
Schematics
Recommended Configurations
Assembly Instructions

01/29/2008

👉 **Warning!** 👈

Although this PCB was designed for use with a low-voltage power supply (24V), caution is still required. For example, 24 volts shorted to ground will make big sparks; and the large valued electrolytic capacitors must be inserted correctly according to their polarity, or they may burst upon being energized. Moreover, these capacitors can hold quite a wallop that lingers after the power has been switched off. In fact, always assume that capacitors will have retained their charge even after the power supply is disconnected or shut down. In addition, this PCB can also be configured to work with a high-voltage power supply; thus, a real shock hazard can also exist. Once a high-voltage power supply is attached, 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 TCJ 24V 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 eight mounting holes, which also helps to prevent excessive PCB bending while inserting and pulling tubes from their sockets. The PCB holds two Aikido line-stage amplifiers with two single-ended output buffers for driving headphones. Thus, one board is all that is needed for stereo unbalanced use or one board for one channel of balanced amplification.

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.

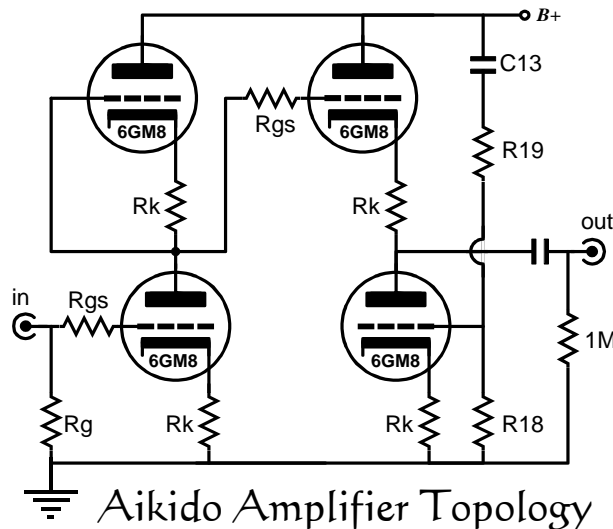
Dual Outputs The boards hold two output stages, one for driving interconnect and power amplifiers, and a second one for driving low-impedance headphones (32 to 600-ohms), with each headphone output holding its own class-A, single-ended, solid-state, unity-gain buffer and large coupling capacitor (with bypass option).

Unity-Gain Buffer This stage makes use of two solid-state, three-pin voltage regulators per channel, which greatly simplifies the circuit's construction, while retaining the advantages inherent in the regulators, such as thermal and short-circuit current limits. One way to view these regulators is as hot-rodged NPN power transistors, with the added feature is being depletion-mode devices. In other words, with an LM317 or LT1085 for example, the adjust pin can and must be more negative than the output voltage. One regulator sits atop another, with the top regulator acting as single-ended buffer/follower. The bottom regulator functions as a constant-current source—and not a bad one at that.

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.



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. (Far too many believe that a different triode equals a different topology; it doesn't. Making this mistake would be like thinking that the essential aspect of being a seeing-eye dog rested in being a Golden Lab.)

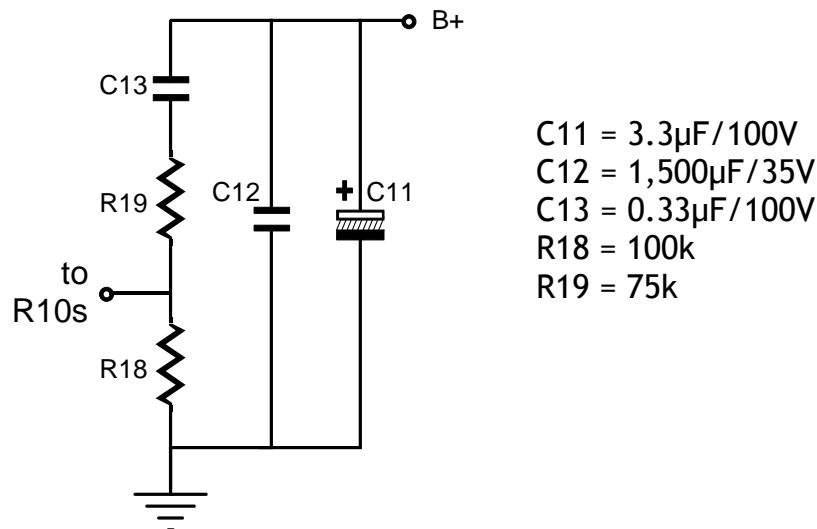
The secret to the Aikido circuit is that sidesteps power supply noise by anticipating and adjusting for that noise so that noise is eliminated from the output. This improved PSRR advantage is vital, for it greatly unburdens the power-supply. With no tweaking or tube selecting, you should easily be able 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 R19'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, 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. So the fresh 6GM8 is not the same as that same 6GM8 after 2,000 hours of use. But as long as the two triodes 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 swings 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.

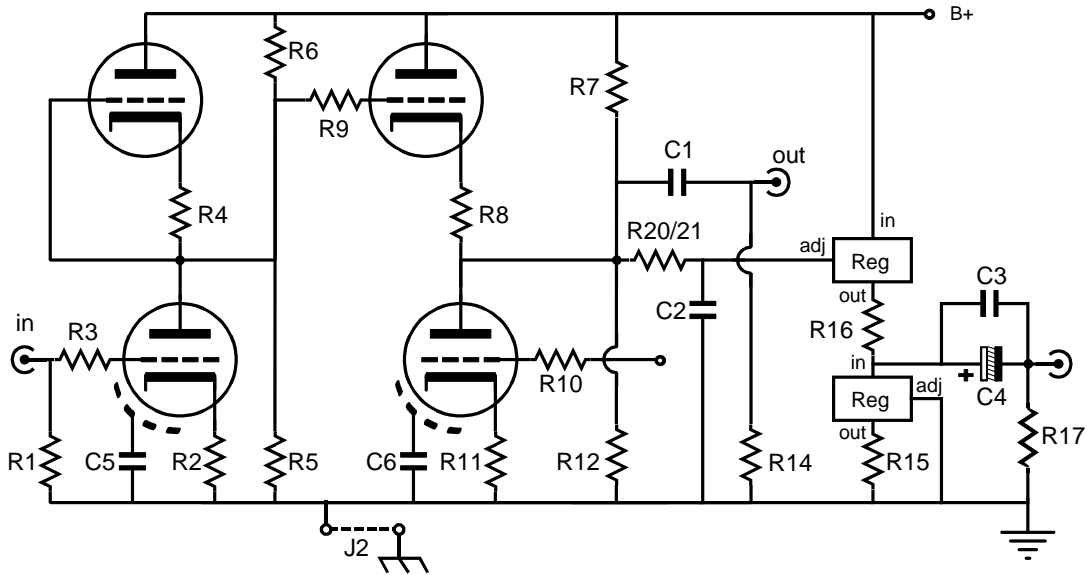
This circuit eliminates power-supply noise from the output, by injecting the same amount of PS noise at the top and bottom of the two-tube cathode follower circuit. The way it works is that the input stage (the first two triodes) effectively defines a 50% voltage divider, so that 50% of the PS noise is presented to the CF's grid; at the same time the voltage divider resistors also define a voltage divider of 50%, so the bottom triode's grid also sees 50% 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). The actual ratio is a little bit off from 50%, as the triode's own r_p influences the outcome; the exact ratio is equal to, in the case of 6GM8s, 57%. In other words, 57% of the B+ noise must be presented to the bottom triode's grid. The formula for determining resistor R19's value is as follows:

$$R19 = R18(\mu - 2) / (\mu + 2)$$

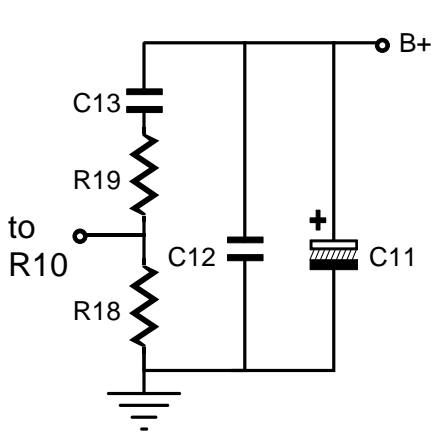
If the output connection were taken from the output cathode follower's cathode, rather than from the bottom triode's plate, then the balance would be broken. The same holds true if the cathode follower's cathode resistor were removed. Besides, this resistor actually makes for a better sounding cathode follower, as it linearizes the cathode follower at the expense of a slightly higher output impedance. If low-impedance line driver is needed, then the headphone output can be used instead.



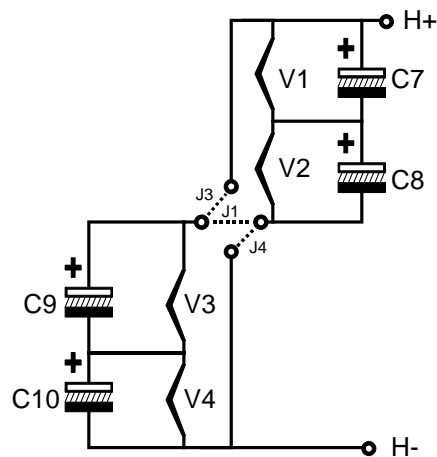
- C11 = 3.3 μ F/100V
- C12 = 1,500 μ F/35V
- C13 = 0.33 μ F/100V
- R18 = 100k
- R19 = 75k



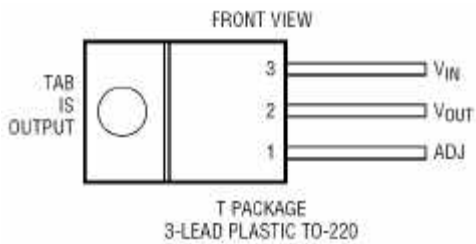
24V Aikido Schematic (one channel shown)



Power Supply Schematic
Common to both channels



Heater Schematic



Three-Pin Voltage Regulator

CAUTION

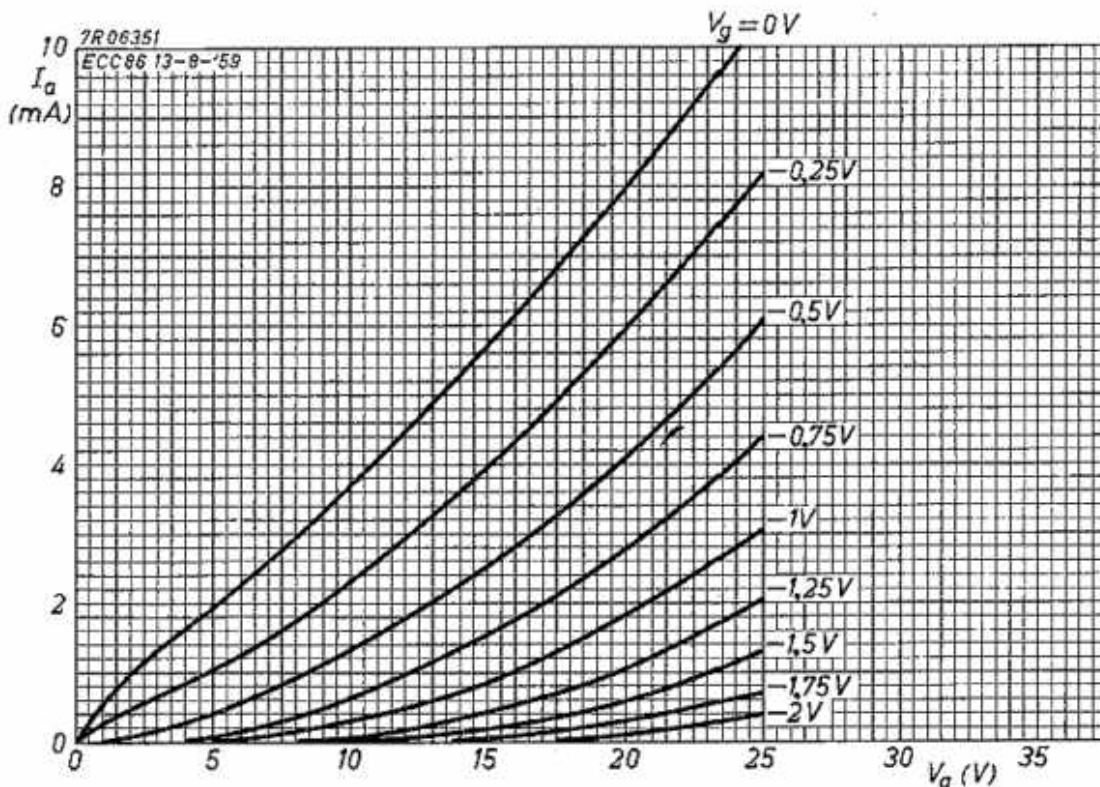
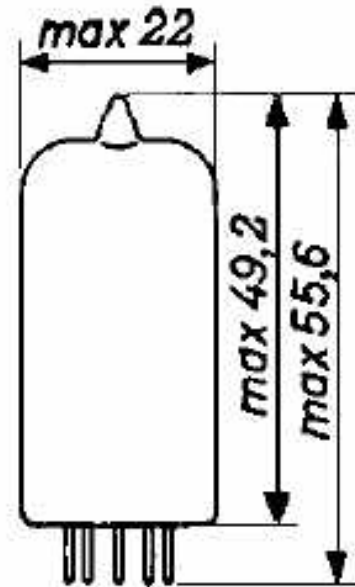
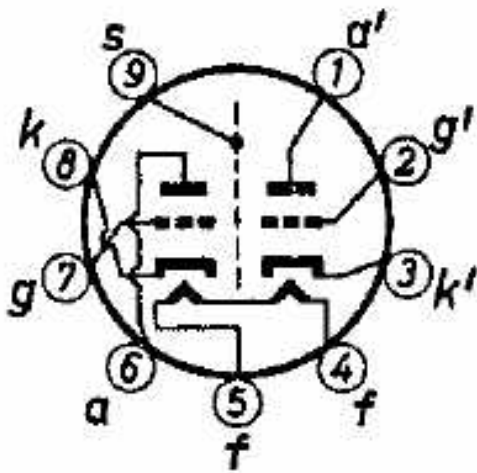
Heater bypass capacitors must be rated for the full B+ voltage, when wired in series and share the B+ connection, say a 25V capacitor with B+ of 24V.

Do not use capacitors, C7, C8, C9, or C10 with an AC heater power supply

Jumper J2 connects the PCB's ground to the chassis through the top centermost mounting hole. If you wish to float the chassis or capacitor couple the chassis to ground, then either leave jumper J2 out or replace it with a small-valued capacitor (0.01 to 0.1µF). Warning: if rubber O-rings are used with PCB standoffs, then the ground connection to the chassis is not likely to be made.

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



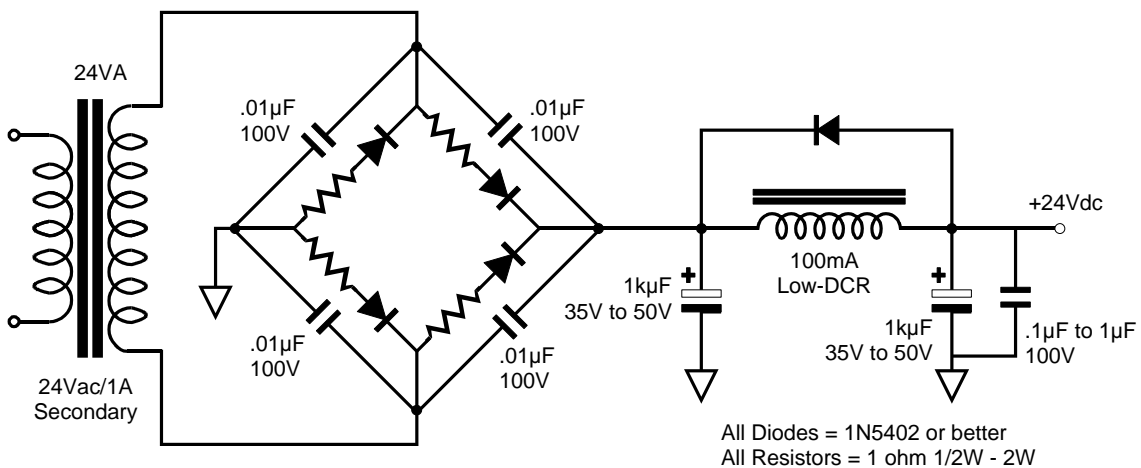
Power Supply

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 solid, choke-filtered tube or fast-diode rectified power supply. If you insist on going the cheap route, try the circuit below, as it yields a lot of performance for little money. FRED rectifiers are expensive, but make an excellent upgrade to the lowly 1N400X rectifier.

The power supply is external to the 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, either a switch-mode or a linear power supply.

24-Volt Power Supplies After dealing with 400-volt power supplies, it is a joyful relief to work with non-lethal voltages. However, we must address a few important issues. For example, although we do not need much voltage, the heaters add a heavy current burden on the power supply. The heater string requires 330mA and the four 6GM8 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.

The 24V 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 an 18V-20Vac power transformer, a diode bridge, and a few capacitors. It just might sound good as well.



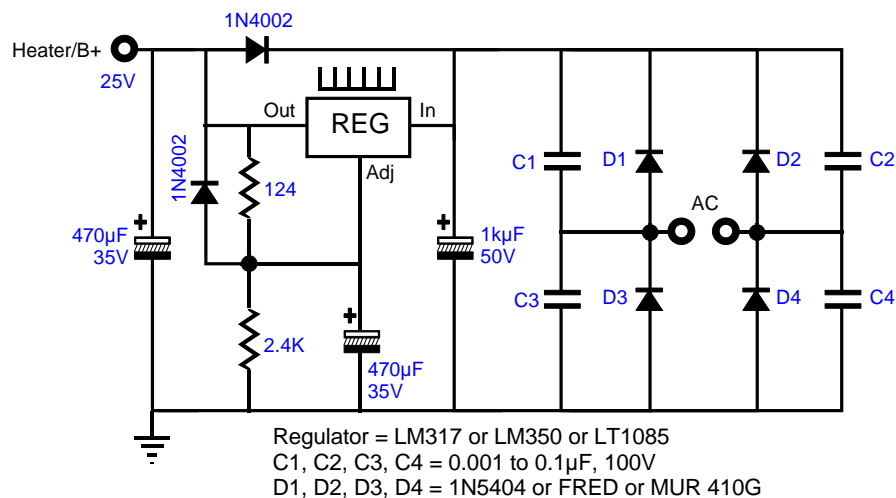
Simple Choke-Based 24V Power Supply

However, I would prefer to be a bit more nervous. For although the Aikido boasts an excellent PSSR figure, I don't want to tax it any more than necessary. Even if the power supply isn't regulated, a few small tricks will deliver big sonic gains. For example, chokes perform wonders in stripping away power supply blemishes.

I have found that just about any choke, of any inductance or DCR, is better than not using a choke in a power supply, even if that power supply terminates in a voltage regulator. One inductor and one extra capacitor added to the simple power supply will make a big difference in performance. In fact, a bigger difference than might be expected in normal tube gear. Why? Inductors work best working into a dead short. As the terminating resistance increases, the inductor loses effectiveness, just the opposite of a capacitor. Fortunately, for this inductor-based power supply, the heater string represents a 76-ohm resistive load, whereas the tubes alone represent a 3k load. Therefore, what started out as a liability (having to power the heater string) becomes an advantage to the inductor-filled power supply.

Because the current draw is so high, the inductor's DCR becomes an important circuit element, as the voltage drop across the inductor will steal a much larger percentage of the available B+ voltage than it would in the normal tube line amplifier, which might only draw 20mA. In other words, a low DCR is critical. I would place a DCR limit of 10 ohms, as a 10-ohm DCR will displace 3.4V, which will demand a 22Vac transformer winding to yield 24V for the B+.

Rectifiers I recommend ultra-fast rectifiers, such as the popular HEXFREDs or the unpopular Schottky diodes. (Developed by International Rectifier, in the 1970s, "FRED" stands for Fast Recovery Epitaxial Diode, thus the trade name "HEXFRED." Today, manufacturers include Harris, International Rectifier, IXYS and others. Tube folk do not know about Schottky diodes because, until recently, it was not possible to buy a high-voltage Schottky diode. But these fast rectifiers also make for cleaner power supplies.) IXYS DSEI8-06A rectifiers cost less than a dollar, so no one will have to take out a loan. The worse choice, other than a WE275 rectifier (too much current draw), is the cheap and ubiquitous 1N4001. This rectifier works well in many non-audio applications, but it spurs too much switching-induced noise into an audio power supply. Still I know that many readers will opt for them, as they already own several dozen. If you insist on using them, then build the circuit above. Paradoxically, the added capacitors actually slow the diodes, while the 1-ohm resistors help soften the transitions between conduction and non-conduction. And the choke filters away the ripple. A low-voltage, linear-regulated power supply is easy to build, as shown below. Care must be taken not to exceed the regulator's maximum input voltage and adequate heat-sinking is required.

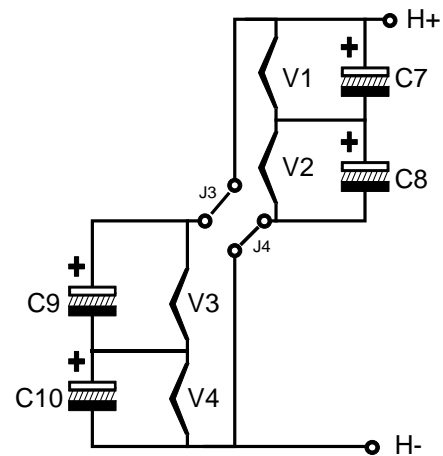


Heater Issues

The board assumes that a DC 18V to 26V power supply will be used for both the B+ voltage and the heaters, which will work well with the 6GM8/ECC86/6N27P dual triodes. Different tubes can be used, however, as long as heaters see the correct voltage. For example, four 12BH7s or ECC99s can be used with a 48V power supply for both the B+ voltage and the heater string. **AT ALL TIMES, ALL THE HEATERS MUST SHARE THE SAME CURRENT DRAW.** For example, 6CG7 and 6DJ8 tube cannot coexist on the board, as the heater current draws differ.

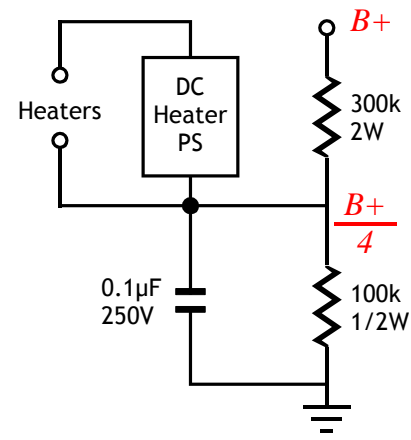
AC Heaters An AC heater power supply can be used, if the heater shunting capacitors C7, C8, C9, C10 are left off the board, or are replaced by 0.01 μ F ceramic capacitors, and if the heater power supply is independent of the B+ power supply. Not recommended in the least.

Alternate Heater Arrangement For the advanced practitioner, the heater string can be wired with the right and left channel heaters placed in series-parallel so that 12.6Vdc power supply can be used with 6.3V tubes. In this setup, jumper J1 is not used; instead, jumpers, J3 and J4 are used. This arrangement assumes that the heater power supply will be independent from the B+ power supply, which can now greatly exceed the usual 26V limit. For example, with a 12V heater power supply, a B+ voltage of 170V could be used with four 6922 or 6CG7 or 6H30 tubes; remember no mixing and matching with these tubes, as each holds a different heater current draw.



Alternate Heater Arrangement

If you think that you see a fatal flaw with this plan, you are right. The three-pin, solid-state voltage regulators, such as the LM317 or LT1085 are not high-voltage devices. The IXCY 10M45S constant-current source, on the other hand, is a high-voltage device. Thus the bottom regulator can be replaced with an IXCY 10M45S and the top solid-state voltage regulator, with an additional IXCY 10M45S or any high-voltage, low-wattage, N-channel MOSFET that can be had in the TO-220 package.



If the heater string and the B+ do not share the power supply, then a voltage relationship must be established between the heater power supply and the B+ power supply. Since one triode stands atop another, the heater-to-cathode voltage experienced differs between triodes. The safest path is to reference the heater power supply to a voltage equal to one fourth the B+ voltage; for example, 75V, when using a 300V power supply. The $\frac{1}{4}$ B+ voltage ensures that both top and bottom triodes see the same magnitude of heater-to-cathode voltage. The easiest way to set this voltage relationship up is the above circuit.

Heater Capacitors IMPORTANT!

The heaters are all placed in series, so each heater sees one fourth of the B+ voltage. So, we might assume that each heater bypass capacitor will only see the same one fourth of the B+ voltage; and they do, when all the heaters are conducting. But what happens when one tube is removed from its socket or when one heater element becomes open? The answer is that the remaining three heaters become effectively dead shorts and the heater bypass capacitor that is now missing its heater element now see the full B+ voltage! In other words, each heater capacitor must be rated for the full B+ voltage to be safe.

Tube Selection

Unlike 99.9% of tube circuits, the Aikido amplifier defines a new topology without fixed part choices, not an old topology with specified part choices. In other words, an Aikido amplifier can be built in a nearly infinite number of ways. A low-voltage Aikido, on the other hand, offers greatly reduced choices. The perfect choice is the 6GM8/ECC86/6N27P, a small 9-pin, dual triode that designed to be used as an RF amplifier and as a self-oscillator mixer in a car radio, back when car radios held tubes. Unlike most triodes, it works quite well with only 12 volts on its plate (a maximum plate voltage of only 30V). Additionally, like the 6DJ8/6922 this little triode stows a grid frame, making it doubly rare. Fortunately, it shares the same pinout as the 6DJ8/6922, so in a pinch, the 6DJ8 can be used instead, for example the 6H30 or 12BH7 or ECC99. For the advanced practitioner, other dual triodes can be used. The only stipulations are that the two triodes within the envelope be identical and that the tube conforms to the 9A or 9AJ base pin-out and that input and output tube share the same heater current draw. (See the Heater section for details on using separate power supplies for the heater string and the B+ voltage.)

Line Stage Amplifier Gain & Zo

The total gain of a 6GM8-based Aikido line amplifier will be close to +15dB, which should work handsomely in most systems. The output impedance will be less than 600 ohms.

Cathode Resistor Values

The cathode resistor sets the idle current for the triode: the larger the value of the resistor, the less current. In general, high- μ triodes require high-value cathode resistors (1-2K) and low- μ triodes require low-valued cathode resistors (100-1k). A 24-volt B+ voltage means that each triode will have 12 volts (minus the voltage drop across its cathode resistor) to play with. Looking at the plate curves on page 5 reveals that a cathode resistor value between 160 to 200 ohms will set an idle current of about 2mA. 180 ohms is a good starting value. Now 2mA is not a lot of current. Nevertheless, as long as short, low-capacitance interconnects are driven, the bandwidth should not suffer too greatly.

(Driving capacitance at fast slew rates requires current. The faster you want to charge a capacitance, the more current you will need. A low-output impedance is nice, but without the ability to deliver current into a capacitance-laden load, it is not enough. In other words, although a line amplifier may not be voltage limit, it may current limited.)

Typical Part Values () Parentheses denote recommended values

V1, V2, V3, V4 =	6GM8/6N27P/ECC86	6CG7	6DJ8/6922	12BH7
B+ Voltage =	18V - 26V (24V)	200V - 300V (300V) ¹	24V - 25.2V (24V)	48V
Heater Voltage =	Same as above	12.6V ¹	Same as above	Same as above
R1,5,6,7,12,13,14 =	1M	same	Same	Same
R2,4 =	100 - 240 (180)*	470 - 2k (870)*	70 - 100 (100)*	200 - 300 (249)*
R3,9,10 =	100 - 1k (300)*	Same	Same	Same
R8,11 =	100 - 240 (180)*	270 - 680 (270)*	70 - 100 (100)*	200 - 300 (249)*
R15 =	10 - 40 (20)*	250	10 - 40 (20)*	10 - 40 (20)*
R16 =	0 - 20 (2)*	0 - 20 (2)*	0 - 20 (2)*	0 - 20 (2)*
R18 =	100k	Same	Same	Same
R19 =	75k	83.2k	87.5k	78k
All resistors 1/2W or higher				
*High-quality resistors essential in this position.				
1. Requires separate heater and B+ power supplies.				
C1 =	0.1 - 4μF* (Film or PIO)	Same	Same	Same
C2 =	100 - 200pF 100V	Same	Same	Same
C3 =	0.1 - 30μF 100V	Same	Same	Same
C4 =	330μF - 3,900μF 25V	Same	Same	Same
C5, C6 =	0.001 - 0.1μF 160V ²	Same	Same	None
C7, C8, C9, C10 =	10μF-1kμF*	10μF-1kμF/25V	10μF-1kμF*	10μF-1kμF*
C11 =	1kμf 35v	Same	Same	Same
C12 =	0.1 - 1μF 100V	Same	Same	Same
C13 =	0.1 - 1μF 100V	Same	Same	Same

*Voltage rating must equal or exceed B+ voltage

2. Optional, otherwise use shorting jumper

Configuring the Line Amplifier Portion of the PCB

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 above, which lists several line-amplifier design examples. Calculating R19's value is easy; it's value equals R18 against $[(\mu - 2)/(\mu + 2)]$. For example, a triode with a μ of 14, such as the 6GM8, results in $R19 = 100k \times (14 - 2)/(14 + 2) = 75k$.

Internal Shields

If the triode's pin 9 attaches to an internal shield, as it does with the 6CG7, 6DJ8, 6GM8/ECC86, and 6H30, then capacitors, C5 and C6 can be replaced with a jumper wire, which will ground the shield. However, using capacitors will also ground the shield (in AC terms) and allow using triodes whose pin-9 attaches to the center tap of its heater, such as the 12AU7.

Configuring the Headphone Driver Portion of the PCB

The standard Aikido is a thoroughly single-ended affair, nothing pulls while something else pushes. Unfortunately, wonderful as single-ended mode is sonically, it cannot provide the larger voltage and current swings that a push-pull output stage can. Single-ended stages can only deliver up to the idle current into a load, whereas class-A push-pull stages can deliver up to twice the idle current; and class-AB output stages can deliver many times the idle current. For a line stage, such big voltage and current swings are seldom required; headphones, on the other hand, do demand a lot more power; really, a 32-ohm load is brutally low impedance for any tube to drive. Unfortunately, a heavy idle current is needed to ensure large voltage swings into low-impedance loads, something that the little 6GM8 (or any other tube) cannot do with just 12V on the plate.

The solid-state, class-A, unity-gain buffer receives its signal directly from the Aikido's output. Then, it delivers the needed high-current swings into the headphones. Two three-pin, adjustable voltage regulators are used per channel, one as a unity-gain follower and one as a constant-current source. LM317, LM350, LT1085 adjustable regulators can be used. Resistor R15 set the idle current through output stage and 20 to 40 ohms is a good value. Resistor R16 serves to buffer the output device from the load and helps linearize the transfer function, but at the cost of slightly greater output impedance; 1 to 10 ohms is a useful range of values. Heatsinks can be soldered to the PCB; the hole spacing is 1in; a good choice is from Aavid Thermalloy (Mouser Part # 532-531202B25G), which is 12.7mm deep, 35.052mm wide, and 50.8mm tall.

Coupling Capacitors A coupling capacitor of at least 33 μ F is required when driving 300-ohm headphones; 330 μ F for 32-ohm headphones. So why use a much larger capacitor? A larger capacitor value extends the low frequency cutoff and reduces the phase shift in the audio band. Use a high-quality, relatively small-valued bypass capacitor in C3's position, say 1 μ F to 10 μ F capacitors.

Power-Supply Capacitors

The PCB holds two positions for power supply capacitors, C11 and C12. Capacitor C11 should be rated for more than the power supply voltage and should be at least 1k μ F in capacity. Obviously, an electrolytic will be needed. This large capacitor should be bypassed with a high-quality plastic film or PIO capacitor. Because the B+ voltage is so low, low-voltage capacitors can be used that would not work in most tube projects.

Low-Pass Filter

The PCB also offers the provision for a low-pass filter going into the solid-state output buffer for headphones. This filter limits the high-frequency bandwidth, as a safety precaution. Resistors R20 and R21 (R21 should have been labeled R20 as well) can be 10k in resistance and capacitors C2 can be any value between 100pF to 300pF.

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. If some of the parts have gold-plated leads, remove the gold flash before soldering the part, as only a few molecules of gold will poison a solder joint, making it brittle; use sandpaper, steel wool, or a solder pot. NASA forbids any gold-contaminated solder joints; you should as well. (Yes, there are many quality parts with gold-flashed leads, but the use of gold is usually only a marketing gimmick.)

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

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 to the address above (begin the subject line with either "Aikido" or "tube").

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AUDIO DESIGN

www.glass-ware.com
www.tubecad.com

sales@glass-ware.com

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