

Aikido

Aikido Stereo PCB

Octal

USER GUIDE

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- Assembly Instructions

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AUDIO DESIGN

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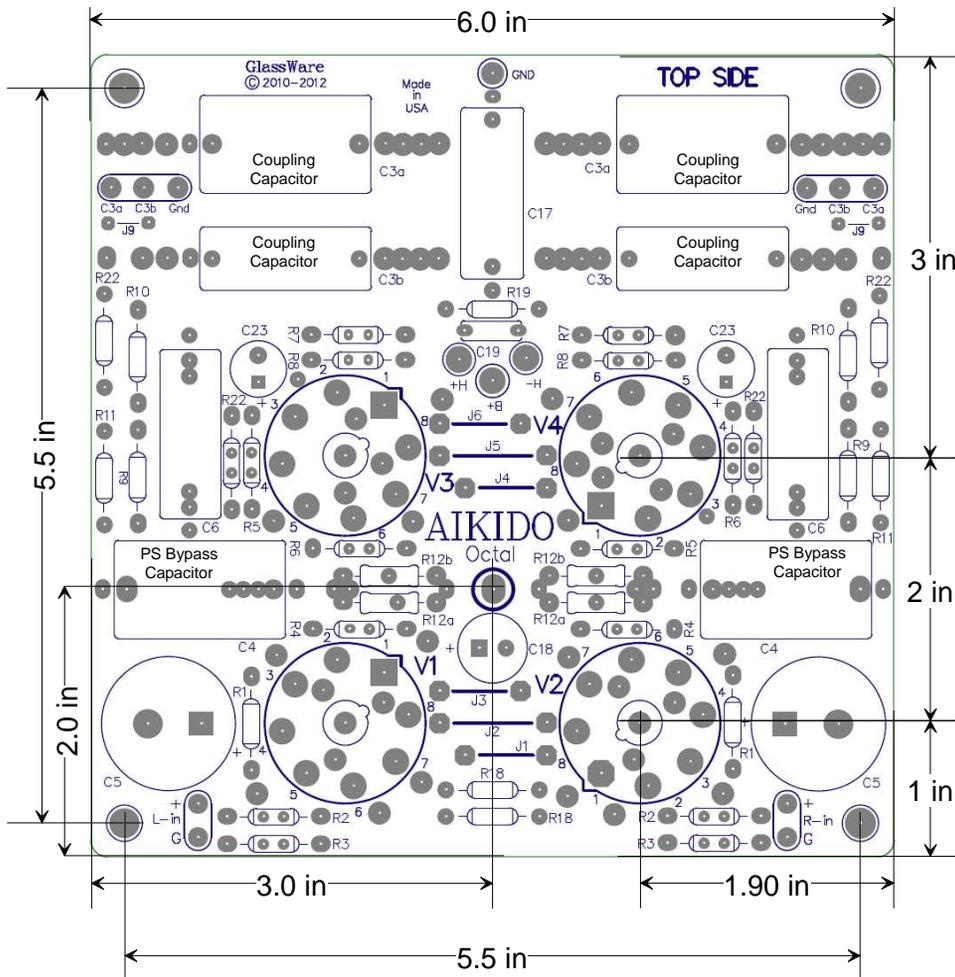
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GLASSWARE
AUDIO DESIGN

Top Side PCB Mechanical Layout



NOTE: Resistors R5 & R6 are not symmetrically laid out from side to side.

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 the heater jumper settings or cathode resistor values, drop me a line by e-mail to sales@glass-ware.com (begin the subject line with either "Aikido" or "tube").

Overview

Thank you for your purchase of the Aikido Octal 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 heavy 2oz copper traces. In addition, the PCB is lovingly and expensively made in the USA. The boards are 6 by 6 inches, with six mounting holes, which helps to prevent excessive PCB bending while inserting and pulling tubes from their sockets. Each 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).

PCB Features

Aikido PP The Aikido Octal PCB allows either the original single-ended Aikido or the new Aikido push-pull topology to be implemented. The single-ended Aikido topology is perfect for line stage use. Aikido push-pull topology is perfect for high-impedance headphones, 250 to 600 ohms, as it allows up to twice the idle current to be delivered into the headphones, while still delivering the Aikido's famous low noise and distortion operation.

Dual Coupling Capacitors The boards hold two coupling capacitors, each finding its own 1M resistor to ground. The idea here is that you can select (via a rotary switch) between C3a or C3b or both capacitors in parallel. Each type of capacitor has its virtues and failings. So use the one that best suits the music; for example, one type of coupling capacitors for old Frank Sinatra recordings and the other for Beethoven string quartets. Or the same flavor capacitor can fill both spots: one lower-valued capacitor would set a low-frequency cutoff of 80Hz for background or late night listening; the other higher-valued capacitor, 5Hz for full range listening.

On the other hand, each coupling capacitor can feed its own output, for example, one for low-frequency-limited satellites and one for subwoofers.

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 (radial bulk-foil resistors and axial 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.

Power-Supply-Decoupling Capacitors The Aikido Octal PCB provides space for two sets of capacitors to decouple both Aikido gain stages from the B+ connection and each other. This arrangement allows a large-valued electrolytic capacitor and small-valued film capacitor to be used in parallel, while a series voltage-dropping resistor completes the RC filter. In place of the RC series resistor, an off-board choke can be used (one per channel).

RC Power-Supply Filter

Resistors R12a and R12b are in parallel. Each resistor can be used in isolation or in parallel with one other resistor. Fifteen possible combinations are possible with five resistor values, with each channel gets its own pair of R12 resistors. (The resulting parallel resistance is shown in the top chart below.) For example, a line-stage amplifier might run each tube with 5mA of idle current, for a total of 10mA per channel. So by looking up the 10mA column, we can see the resulting voltage drops. Thus, one 3k resistor will drop 30V, so a 280Vdc raw DC power supply will deliver 250Vdc to the tubes.

| R | R12a | R12b | I max mA | V max | W attage | F3 150µF | F3 270µF |
|-------|-------|-------|----------|-------|----------|----------|----------|
| 889 | 1600 | 2000 | 78 | 69 | 5.4 | 1.19 | 0.66 |
| 1043 | 1600 | 3000 | 66 | 69 | 4.6 | 1.02 | 0.56 |
| 1135 | 1600 | 3900 | 61 | 69 | 4.2 | 0.94 | 0.52 |
| 1200 | 2000 | 3000 | 64 | 77 | 4.9 | 0.88 | 0.49 |
| 1295 | 1600 | 6800 | 53 | 69 | 3.7 | 0.82 | 0.46 |
| 1322 | 2000 | 3900 | 58 | 77 | 4.5 | 0.80 | 0.45 |
| 1379 | 1600 | 10000 | 50 | 69 | 3.5 | 0.77 | 0.43 |
| 1545 | 2000 | 6800 | 50 | 77 | 3.8 | 0.69 | 0.38 |
| 1600 | 1600 | none | 43 | 69 | 3.0 | 0.66 | 0.37 |
| 1667 | 2000 | 10000 | 46 | 77 | 3.6 | 0.64 | 0.35 |
| 1696 | 3000 | 3900 | 56 | 95 | 5.3 | 0.63 | 0.35 |
| 2000 | 2000 | none | 39 | 77 | 3.0 | 0.53 | 0.29 |
| 2082 | 3000 | 6800 | 46 | 95 | 4.3 | 0.51 | 0.28 |
| 2308 | 3000 | 10000 | 41 | 95 | 3.9 | 0.46 | 0.26 |
| 2479 | 3900 | 6800 | 44 | 108 | 4.7 | 0.43 | 0.24 |
| 2806 | 3900 | 10000 | 38 | 108 | 4.2 | 0.38 | 0.21 |
| 3000 | 3000 | none | 32 | 95 | 3.0 | 0.35 | 0.20 |
| 3900 | 3900 | none | 28 | 108 | 3.0 | 0.27 | 0.15 |
| 4048 | 6800 | 10000 | 35 | 143 | 5.1 | 0.26 | 0.15 |
| 6800 | 6800 | none | 21 | 143 | 3.0 | 0.16 | 0.09 |
| 10000 | 10000 | none | 14 | 170 | 3.0 | 0.11 | 0.06 |

| R | Voltage Drop Against Current | | | | | | | | | | | | | | | |
|-------|------------------------------|-----|-----|-----|-----|-----|----|----|-----|-----|-----|-----|-----|-----|-----|----|
| 889 | 9 | 11 | 12 | 14 | 16 | 18 | 20 | 21 | 23 | 25 | 27 | 28 | 30 | 32 | 34 | 36 |
| 1043 | 10 | 13 | 15 | 17 | 19 | 21 | 23 | 25 | 27 | 29 | 31 | 33 | 35 | 38 | 40 | 42 |
| 1135 | 11 | 14 | 16 | 18 | 20 | 23 | 25 | 27 | 29 | 32 | 34 | 36 | 39 | 41 | 43 | 45 |
| 1200 | 12 | 14 | 17 | 19 | 22 | 24 | 26 | 29 | 31 | 34 | 36 | 38 | 41 | 43 | 46 | 48 |
| 1295 | 13 | 16 | 18 | 21 | 23 | 26 | 28 | 31 | 34 | 36 | 39 | 41 | 44 | 47 | 49 | 52 |
| 1322 | 13 | 16 | 19 | 21 | 24 | 26 | 29 | 32 | 34 | 37 | 40 | 42 | 45 | 48 | 50 | 53 |
| 1379 | 14 | 17 | 19 | 22 | 25 | 28 | 30 | 33 | 36 | 39 | 41 | 44 | 47 | 50 | 52 | 55 |
| 1545 | 15 | 19 | 22 | 25 | 28 | 31 | 34 | 37 | 40 | 43 | 46 | 49 | 53 | 56 | 59 | 62 |
| 1600 | 16 | 19 | 22 | 26 | 29 | 32 | 35 | 38 | 42 | 45 | 48 | 51 | 54 | 58 | 61 | 64 |
| 1667 | 17 | 20 | 23 | 27 | 30 | 33 | 37 | 40 | 43 | 47 | 50 | 53 | 57 | 60 | 63 | 67 |
| 1696 | 17 | 20 | 24 | 27 | 31 | 34 | 37 | 41 | 44 | 47 | 51 | 54 | 58 | 61 | 64 | 68 |
| 2000 | 20 | 24 | 28 | 32 | 36 | 40 | 44 | 48 | 52 | 56 | 60 | 64 | 68 | 72 | 76 | x |
| 2082 | 21 | 25 | 29 | 33 | 37 | 42 | 46 | 50 | 54 | 58 | 62 | 67 | 71 | 75 | 79 | 83 |
| 2308 | 23 | 28 | 32 | 37 | 42 | 46 | 51 | 55 | 60 | 65 | 69 | 74 | 78 | 83 | 88 | 92 |
| 2479 | 25 | 30 | 35 | 40 | 45 | 50 | 55 | 59 | 64 | 69 | 74 | 79 | 84 | 89 | 94 | 99 |
| 2806 | 28 | 34 | 39 | 45 | 51 | 56 | 62 | 67 | 73 | 79 | 84 | 90 | 95 | 101 | 107 | x |
| 3000 | 30 | 36 | 42 | 48 | 54 | 60 | 66 | 72 | 78 | 84 | 90 | x | x | x | x | x |
| 3900 | 39 | 47 | 55 | 62 | 70 | 78 | 86 | 94 | 101 | x | x | x | x | x | x | x |
| 4048 | 40 | 49 | 57 | 65 | 73 | 81 | 89 | 97 | 105 | 113 | 121 | 130 | 138 | x | x | x |
| 6800 | 68 | 82 | 95 | 109 | 122 | 136 | x | x | x | x | x | x | x | x | x | x |
| 10000 | 100 | 120 | 140 | x | x | x | x | x | x | x | x | x | x | x | x | x |
| mA | 10 | 12 | 14 | 16 | 18 | 20 | 22 | 24 | 26 | 28 | 30 | 32 | 34 | 36 | 38 | 40 |

x denotes that either the voltage or the current exceeds the resistor(s) limit

Age Tolerant Remember, tubes are not yardsticks, being more like car tires—they wear out. Just as a tire’s weight and diameter decrease over time, so does a tube’s conductance. In other words, a fresh 6SN7 is not the same as that same 6SN7 after 2,000 hours of use. But as long as the two triodes within the 6SN7 age in the same way—which they are inclined to do—the Aikido amplifier will always bias up correctly, splitting the B+ voltage between the triodes.

No Negative Feedback Loop The Aikido topology does not use any negative feedback, other than the local degenerative feedback because of the unbypassed cathode resistors in the input stage and the active load presented by the bottom triode of the output stage. In fact, the Aikido topology makes use of feedforward noise canceling at the output. Unlike negative feedback that has to wait until something goes wrong before it can work to undo the damage, feedforward feedback anticipates what will go wrong before it does. It is proactive, not reactive, to borrow the terms of pop-psychology.

The Aikido circuit eliminates power-supply noise from its output, by injecting the same amount of PS noise at the inputs of the top and bottom tubes in the two-tube cathode-follower circuit. Since both of these signals are equal in amplitude and phase, they cancel each other out, as each triode sees an identical increase in plate current—imagine two equally strong men in a tug of war contest. So, shouldn’t resistors R1 and R2 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 R1 and R2 is given by the following formula:

$$R1 = R2[(\mu - 2)/(\mu + 2)]$$

Low Output Impedance The Aikido topology uses a modified cathode follower circuit as the output stage. Cathode followers are famous for providing low distortion and low output impedances, but no voltage gain. This modified cathode follower scrubs away the power-supply noise from its output and provides a complementarily non-linear load for the top triode’s cathode. The top triode’s capacitor resistor is in series with the output, so its resistance must be added to the cathode follower output impedance. Had the output connection been taken from the top triode’s cathode, then the output impedance would be slightly lower, but the symmetry would be broken and the PSRR enhancement would be lost.

Gain Calculating the gain from an Aikido amplifier is easy, as it roughly equals half the mu of the input triode used. The gain from a simple grounded-cathode amplifier (with an un-bypassed cathode resistor) is

$$\text{Gain} = \mu R_a / [R_a + (\mu + 1)R_k + r_p]$$

In the Aikido, the resistance presented by the top tube and its cathode resistor is R' = (mu + 1)Rk + rp. So if you substitute R' for Ra in the above equation and simplify you get

$$\text{Gain} = \mu [(\mu + 1)R_k + r_p] / [(\mu + 1)R_k + r_p + (\mu + 1)R_k + r_p] = \mu / 2$$

Of course there is a slight loss though the Aikido’s modified-cathode-follower output stage, whose gain usually falls between 0.93 to 0.98.

Assembly & Testing

Assembly Cleanliness is essential. Before soldering, be sure to clean both sides the PCB with 90% to 99% isopropyl alcohol. Do not use dull-looking solder; solder should shine. If it doesn't, first clean away the outer oxidation with some steel wool or a copper scouring pad. If the resistor leads look in the least gray, clean away the oxidation with either steel wool or a wire sniper's sharp edges. Admittedly, with new resistors and a fresh PCB, such metal dulling is rare; but if the parts have sat in your closet for a year or two, then expect a good amount of oxidation to have developed.

First, solder all the small resistors, then the small capacitors, and, finally the large capacitors and sockets. Be consistent in orienting the resistors; keep all the tolerance bands on the resistor's body at the right side as you face the resistor straight on. This will pay dividends later, if you need to locate a soldered a resistor in the wrong location. Because the board is double sided, with traces and pads on each side, it is easier to solder the resistors from their top side. As the PCB is so overbuilt, it is extremely difficult to remove an incorrectly placed part. Be sure to confirm all the electrolytic capacitor orientations, as a reversed polarized capacitor can easily vent (or even explode) when presented with high-voltage. Confirm twice, solder once. NOTE: unlike all the other resistors, resistors R5 & R6 are not symmetrically arranged on the PCB; in other words, they do not mirror each other.

Testing Before testing, visually inspect the PCB for breaks in symmetry between left and right sides. Wear safety eye goggles, which is not as pantywaist a counsel as it sounds, as a venting power-supply capacitor will spray hot caustic chemicals. Make a habit of using only one hand, with the other hand behind your back, while attaching probes or handling high-voltage gear, as a current flow across your chest can result in death. In addition, wear rubber-soled shoes and work in dry environment. Remember, safety first, second, and last.

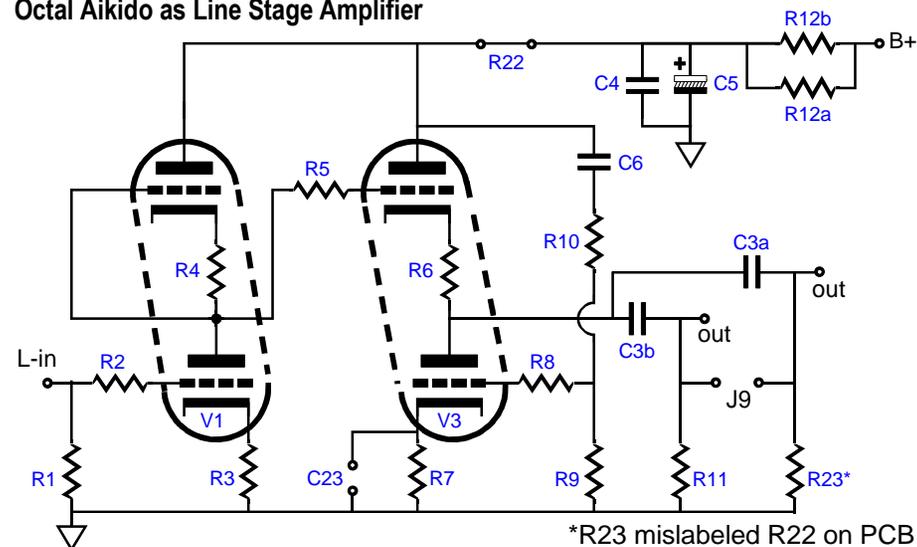
1. Attach only the heater power supply, leaving the high-voltage power-supply leads unattached and electrical tape shrouded, with no tubes in their sockets.
2. Use a variac and slowly bring up the AC voltage, while looking for smoke or part discoloration or bulging.
3. Measure the heater voltage without and with a load. If the heater regulator fails to regulate, try either lowering the heater voltage a tad, for example 12V instead of 12.6V, as the 0.6V difference might be enough to bring the regulator back into regulation.
4. Next, power down the heater power supply and attach the high-voltage power supply and insert the tubes in their sockets.
5. Attach the high-voltage power supply to a variac and slowly bring up the AC voltage.
6. Measure the voltage across ground and B-plus pads in the center of the PCB; then measure the voltage across capacitors, C4 & C5. If the two channels differ by more than 10Vdc, try switching tubes from one channel to the other. If the imbalance does not follow the tubes, there is a problem, probably a misplaced part.

Only after you are sure that both heater and B-plus power supplies are working well, should you attach the line-stage amplifier to a power amplifier.

Configuring the PCB as 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. In general, the 6SN7 will be the first choice for most builders—with good cause, as the 6SN7 makes an excellent sounding line-stage amplifier. But do not paint yourself into the 6.3V heater corner, as perfectly good, NOS 6SN7-like tubes, such as the 8SN7, 12SN7, 12SX7, 18SN7, can be bought for a fraction of the cost of the same tube with a 6.3V heater. In fact, I have seen what would have been a \$75 NOS 6SN7 sell for \$8 because it was an 8SN7. The two tubes were exactly the same, except for the heater voltage. The 8SN7 requires 8.4 volts at 450 mA to run its heater. The 12SX7 is a wonderful sounding tube that can be used in an Aikido line-stage amplifier with a B+ voltage of only 120Vdc (150 to 170Vdc before the RC filter).

Octal Aikido as Line Stage Amplifier



Typical Part Values

() Parentheses denote recommended values

| Input Tubes = 6SN7 | 6SN7 | 6SL7 | 6SN7 | 6SN7 | 6H30Pi | 12SN7 | 12SX7 |
|--------------------------|-----------------|-----------------|------------------|-----------------|-----------------|-----------------|-----------------|
| Output Tubes = 6SN7 | 6SN7 | 6SN7 | 6SN7 | 6SN7 | 6H30Pi | 12SN7 | 12SX7 |
| Raw B+ Voltage = 280V | 170V | 300V | 300V | 300V | 300V | 120V | 115V - 120V |
| B+ at Tubes = 250V | 150V | Same | Same | Same | Same | Same | Same |
| R1,11, 23 = 1M | Same | Same | Same | Same | Same | Same | Same |
| R3,4 = 680* [Iq = 6mA] | 470* [Iq = 3mA] | 1k* [1mA] | 680* [Iq = 6mA] | 330* [Iq = 3mA] |
| R2,5,8 = 100 - 1k (300)* | Same | Same | Same | Same | Same | Same | Same |
| R6,7 = 300* [Iq = 9mA] | 300* [Iq = 4mA] | 300* [Iq = 9mA] | 470* [Iq = 17mA] | 330* [Iq = 3mA] |
| R12a = 2k | 3.9k | 3k | 2k | 2k | 2k | 2k | 2k |
| R12b = None | 10k | None | 3.9k | None | 3.9k | None | None |
| R10 = 82.5k | 82.5k | 82.5k | 82.5k | 82.5k | 82.5k | 82.5k | 82.5k |
| R9 = 100k | 100k | Same | Same | Same | Same | Same | Same |
| R18 = 300k | Same | Same | Same | Same | Same | Same | Same |
| R19 = 47k | Same | Same | Same | Same | Same | Same | Same |

*High-quality resistors essential in this position
All resistors 1/2W or higher

| | | | | | | | |
|--------------------|--------|--------|--------|--------|--------|--------|--------|
| C3 = 0.1µ to 10µF* | Same |
| C4 = 0.1µ to 10µF* | Same |
| C5 = 150µF* | 390µF* | 150µF* | 150µF* | 150µF* | 150µF* | 390µF* | 390µF* |
| C6 = 0.1µF* | Same |

*Voltage rating must comfortably exceed raw B+ voltage

Grounding

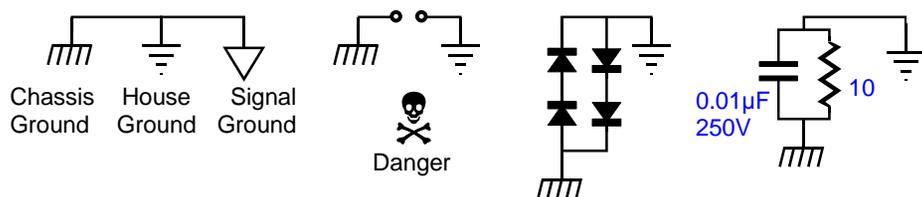
The Aikido Octal PCB holds a star ground at its center. Ideally, this will be the only central ground in the line-stage amplifier. Ground loops, however, are extremely easy to introduce. For example, if the RCA jacks are not isolated from the chassis, then the twisted pair of wires that connect the PCB to the jacks will each define a ground loop. The solution is either to isolate the jacks or use only a single hot wire from 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 Semi-Star ground method uses several ground “stars” that are often called spurs, 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 Aikido Octal 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, usually the cold water pipe. The line-stage amplifier can also attach to this ground connection, which is certainly the safest approach, as it provides a discharge path should the B+ short to the chassis. Unfortunately, this setup often produces a hum problem. Some simply float the ground, 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 10-ohm resistor shunted by a small capacitor, say 0.001μF to 0.1μF/250V.



Headphones require big current swings and little voltage swings. Thus, a high idle current and a low B+ voltage are best for driving headphones, say 150Vdc and 25mA, as are high transconductance output tubes, for example, the 6DJ8, 6H30, 12BH7, and ECC99. An output coupling capacitor of at least 30μF is required when driving 300-ohm headphones; 330μF for 32-ohm headphones. Capacitor C3a can be bypassed by using a small film or PIO capacitor for C3b.

Okay, how do we design an Aikido Push-Pull amplifier based on this topology? The first step is setting the two-resistor voltage divider values, which will null the power-supply noise from the output. Pick a value for resistor R9, say 100k. Next, use the classic Aikido formula:

$$R10 = R9(\mu - 2) / (\mu + 2)$$

where μ is the amplification factor of the output triode. For example, the 6DJ8 holds a μ of 33, so $R10 = R9(33 - 2) / (\mu + 2)$, which with R9 equal to 100k makes R10 equal to 88.6k. Since 1% resistor values don't offer 88.6 k resistors, we use an 88.7k resistor instead.

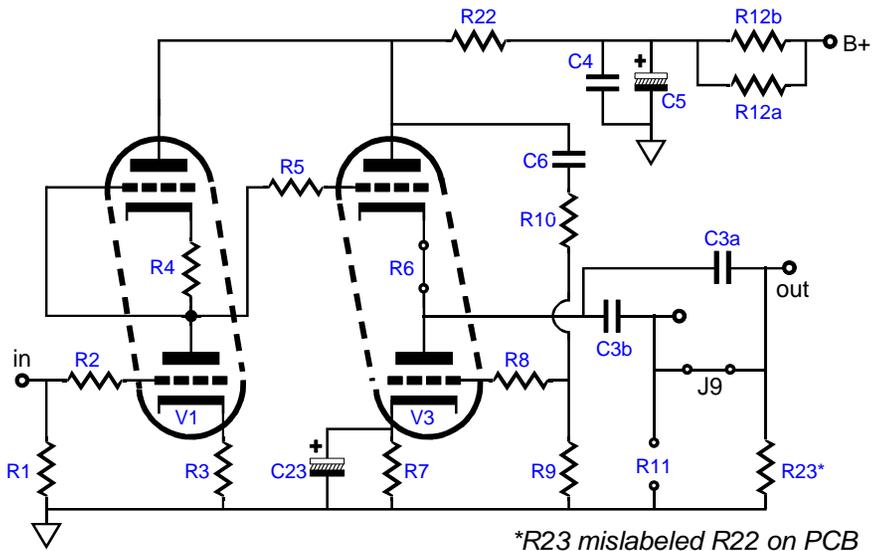
This formula works regardless of the value of the series sense resistor (R22) and regardless whether or not we use bypassed cathode resistors. The next step is to work out the sense resistor value. If the top cathode resistor is replaced by a shunting piece of wire and the bottom cathode resistor is bypassed (or is also omitted and a negative grid-bias voltage used), the following formula is used:

$$R22 = R_s = (R9 + R10)(r_p + 2R_{load}) / \mu \cdot R10,$$

where R_{load} equals the load impedance. On the other hand, if unbypassed top and bottom cathode resistors are used, as shown in the schematic below, then the following formula is needed:

$$R22 = R_s = (R9 + R10)(r_p + (\mu + 1)R_k + 2R_{load}) / \mu \cdot R10$$

The big problem we face in making a good headphone amplifier based on the 6SN7 is that the triode is quite weak in terms of transconductance. In order to a decently high idle current, we must employ a relatively high B+ voltage, say 250Vdc, whereas a 6922 could get away with half that amount. In addition, the 6SN7's weak transconductance results in a higher Z_o than we would like. The following headphone amplifier squeezes the most performance possible from the 6SN7, but requires the use of a bypass capacitor across resistor R7, which means that this capacitor will be very much in the signal path. Nonetheless, this arrangement yields the lowest output impedance and distortion and highest PSRR from the 6SN7. The assumption is that a 300-ohm headphone is driven; 32-ohm headphones will require a step-down transformer (3:1).



*R23 mislabeled R22 on PCB

| Input Tubes = | 6SN7 | 6SN7 | 6SN7 |
|------------------|-----------------|-----------------|-----------------|
| Output Tubes = | 6SN7 | 6SN7 | 6BX7 |
| Raw B+ Voltage = | 300Vdc - 350Vdc | 300Vdc - 350Vdc | 160Vdc - 180Vdc |
| B+ at Tubes = | 250Vdc | 250Vdc | 150Vdc |
| Iq per Channel = | 16mA | 15.7mA | 23.5mA |

| | | | |
|----------------|--------|------|--------|
| R1, R11, R23 = | 1M | 1M | 1M |
| R3, R4 = | 470* | 470* | 470* |
| R2, R5, R8 = | 300* | 300* | 300* |
| R6 = | Jumper | 100* | Jumper |
| R7 = | 100* | 100* | 150 |
| R9 = | 100k | 100K | 100k |
| R10 = | 82k | 82k | 68k |
| R22 = | 665* | 910* | 357 |

*High-quality resistors essential in this position. All resistors 1/2W or higher

| | | | |
|-------|-------------|------------|------------|
| C3a = | 30µF 250V | Same | Same |
| C3b = | 0.1µF - 3µF | Same | Same |
| C4 = | 1µF - 4.7µF | Same | Same |
| C5 = | 150µF 400V | 150µF 400V | 390µF 250V |
| C6 = | 0.1µF - 1µF | Same | Same |
| C23 = | 1kµF 16V | None | 1kµF 16V |

Headphone/Line-Stage Amplifier

What happens when we use an Aikido push-pull headphone amplifier not to drive headphones, but a power amplifier with a 20k to 100k input impedance? The excellent PSRR and low Output impedance remain unchanged and the distortion drops substantially, as the circuit slides back into quasi single-ended operation, with the top output triode doing most the work. Here is where the dual output coupling capacitors comes in handy, as we can use a 30µF good-quality capacitor for the headphones and a 0.33µF high-quality capacitor as both a bypass capacitor for the 30µF capacitor and as the line-stage amplifier output capacitor. This will require a switch such as the GlassWare Select-C switch.

Introduction to Power Supplies

For most modern electronic products—printers, alarm clocks, LCD photo frames—the power supply is the least important portion of the package. Which helps explain why cheap, small, switching, universal, wall-wart power supplies fill every available outlet in most houses. All proficient tube-circuit designers, on the other hand, must master the subtleties of creating a clean DC voltage. Although a heater may be powered by either an AC or DC power supply, a DC power supply is always necessary, as the remaining portion of the tube circuit requires solely DC voltage. With audio circuits, the cleaner, the steadier, the lower and the flatter in output impedance across the audio band of frequencies, the better suited that power supply is for audio use. A good metaphor is that the audio gear is the film in a movie projector and the high-intensity light source is the power supply; the whiter and steadier the light, the better the picture.

Paradoxically enough, high-voltage power supplies are at once both the easiest and the most challenging element of tube electronics. Requiring as little as one transformer, diode, and capacitor, what could be simpler? Or utilizing as much as a several power transformers, many precision voltage references, twelve rectifier bridges, a score of high-voltage MOSFETs, a fistful of OpAmps, dozens of capacitors, a cup of individual diodes, and several hundred resistors, what could be more complex?

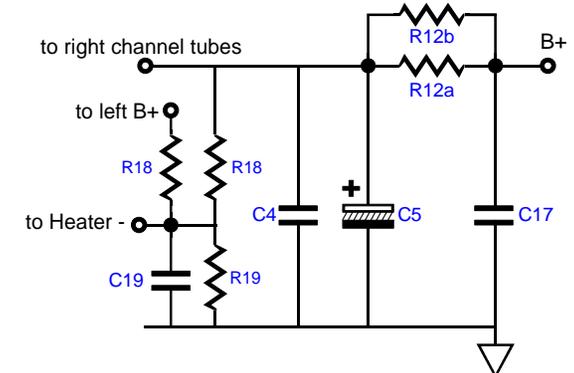
While the Aikido circuit greatly overcomes the failings of a power supply, nonetheless there are limits to what an Aikido can undo. In other words, the raw power-supply noise should only measure in millivolts, not volts.

B-plus Power Supply

The Aikido Octal PCB must be attached to a high-voltage power supply; the PCB holds an input B+ capacitor, C17, which is then followed by an RC-smoothing filter in each channel. The optimal B-plus voltage depends on the tubes used. For example, 12SX7s can be used with a low 48V power supply, while 6SN7s work better with a 150V to 240V B-plus voltage. The sky is not the limit here, as the power supply capacitors and the heater-to-cathode voltage set an upward limit of about 350V for the raw power supply voltage (after the rectifiers and RC power supply filter) and about 300V at the tubes. Resistors R12a and R12b are in parallel, so that greater dissipation and value selection are possible; for example, treat two 10k/3W resistors as one 5k/6W resistor. Resistor heat equals $I^2 \times R$ (and V^2/R); for example, 20mA and 5k will dissipate 2W. See page 14 for more information.

Typical Part Values

| | |
|--------------|--------------------------|
| C4 = | 0.1µF to 4.7µF |
| C5 = | 150µF 400V or 270µF 200V |
| C17 = | 0.68µF 400V |
| C19 = | 0.01µF to 0.47µF >= 100V |
| R12(a & b) = | 100 to 20k |
| R18 = | 300k 1W |
| R19 = | 100k 1W |

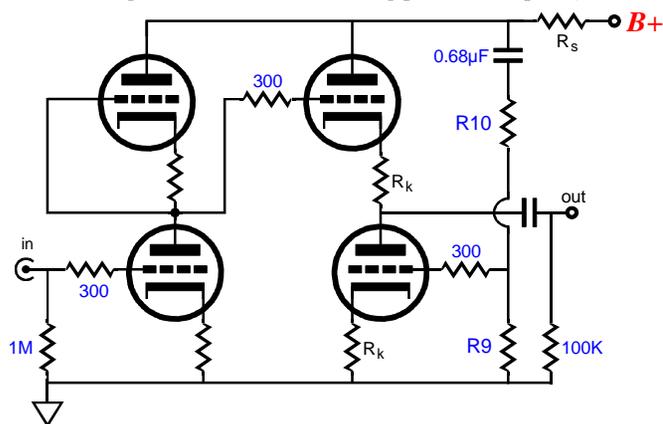


Configuring the PCB as a Headphone Amplifier

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 output stages can only deliver up to the idle current into a load, whereas class-A push-pull output 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, big voltage and current swings are seldom required; headphones, on the other hand, do demand a lot more power; in truth, a 300-ohm load is brutally low impedance for any tube to drive. Fortunately, the Aikido Octal PCB can be configured with an Aikido push-pull output stage, a modification and improvement on the optimal-White-cathode-follower output stage, which both retains much of the Aikido's great PSRR and allows twice the idle current to be delivered into low-impedance loads.

Aikido Push-Pull Topology

"Aikido" is a fairly recently coined word, which I use to label the technique of eliminating power-supply noise from the output by anticipating its presence and countering it simultaneously. Where the traditional method of applying as much negative feedback as possible *after the fact* is the brute-force, reactive technique, the Aikido method is subtle, clever, and proactive, much like the martial art. Thus, while the name Aikido may be a bit whimsical, it is also apt. Since I already have indulged whimsy with the Aikido name and since this circuit is a variation on the Aikido topology, the best name is probably the accurate, but somewhat stodgy "Aikido Push-Pull." Indeed, the original Aikido topology could more accurately be labeled the "Aikido Single-Ended." By the way, push-pull here refers to the output stage, not the input stage, which is still a purely single-ended affair. (It drives me crazy when I see the original Aikido being described as two SRPP stages in cascade, for nothing pushes and pulls.)



In the Aikido Push-Pull topology, the two key resistors are R9, R10 and Rs (R22). If their values conform to a set of relationships defined by a few formulas, the circuit exhibits four wonderful attributes:

1. Wonderfully high PSRR
2. Low output impedance
3. Low-distortion gain
4. Push-pull class-A output (that can deliver twice the output tube's idle current into the load)

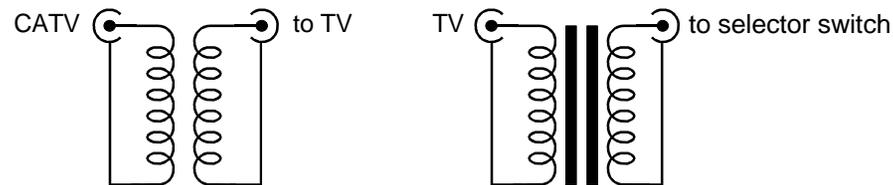
A good test procedure is to detach all the signal inputs and all the output connection from the line-stage amplifier. Then measure the AC voltage between the line-stage amplifier's chassis and the house's ground. If it reads more than a few volts, try reversing the line-stage amplifier's plug as it plugs into the wall socket. Use whichever orientation that results in the lowest AC voltage reading. Then measure the chassis ground to the first signal source's ground (while the signal source is turned on). Once again flip the signal source's plug until the lowest AC voltage setting is found. Then do the rest with the rest of the system. The results can prove far more satisfying than what would be yielded by buying thousand-dollar cables.

RFI Radio frequency interference can be a hassle to track down and eliminate. First 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 RCA jack and then again at the selector switch. Increasing the grid-stopper resistor's (R2) value, say to 1k, can also work wonders (use a carbon-composition or bulk-foil resistor or some other non-inductive resistor type).

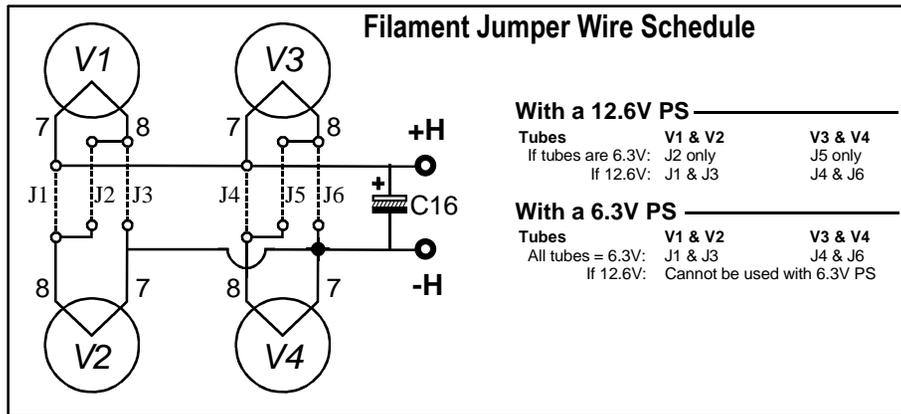
Terminating Resistors Here's a cheap trick to try: at each input RCA jack, place a 100k to 1M resistor, bridging input hot and jack ground. Why? The resistor provides a path for the AC signal present at the jack, so given a choice between radiating into the chassis or going through the relatively low-impedance resistor, the AC signal chooses the latter path, reducing crosstalk.

CATV Ground Attaching a line-stage amplifier to TV or VCR can cause huge hum problems, as the "ground" used by the connection CATV connection may introduce hum. Isolation transformers work supremely well in this application. In fact, an isolation transformer can be used on all the input signals only (one transformer per channel is required, if it is located after, rather than before the selector switch.) Look on the Web for more complicated solutions to the CATV hum problem.



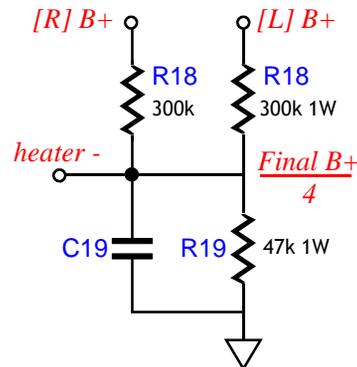
Heater Issues

The Aikido Octal PCB must be attached to a heater power supply, preferably a voltage regulated supply, with an output voltage between 6Vdc to 25Vdc. The assumption is that a 12Vdc or 12.6Vdc output voltage will be used for the heaters, so that 6.3V heater tubes (like the 6BX7 and 6SN7) or 12.6V tubes (like the 12SN7 or 12SX7) can be used. Both voltage types can be used exclusively, or simultaneously; for example two 12SN7s for the input tubes and two 6H30pi for the output tubes. Note: Perfectly good tubes with uncommon heater voltages can often be found at swap meets, eBay, and surplus stores for a few dollars each. Think outside 6.3V box. An AC heater power supply (6.3V or 12.6V) can be used, if capacitor C18, is left off the board. This is not in the least recommended, as the high-current AC voltage will introduce hum (many 6SN7s are hum magnets) and compromise the bass reproduction.



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 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 PCB's R18 & R19.

The heater's PS reference bias voltage to target is one quarter of the B-plus voltage that the Aikido's tubes use, not the initial raw B-plus voltage at the high voltage rectifiers. Alternatively, you might experiment with floating the heater power supply, by "grounding" the heater power supply via only a 0.1µF film or ceramic capacitor, leaving resistors R19 and R18s off the board. The capacitor will charge up through the leakage current between heater and cathodes. Not only is this method cheap, it is often quite effective in reducing hum with certain tubes.



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. For example, a 6SL7 input tube (V1 & V2) will yield a gain close to 35 (mu/2), which would be suitable for a low-gain microphone preamp or a SE amplifier input stage; a 6SN7 (5692) or 12SN7 input tube will yield a gain near 10, which would be excellent for a line stage amplifier; the 6BL7, 6BX7, or 6H30Pi in the output stage (V3 & V4) would deliver a low output impedance that could drive capacitance-laden cables or even high-impedance headphones.

The list of possible tubes is not overly long: 2C50, 6BL7, 6BX7, 6H30Pi, 6SL7, 6SN7, 6SU7, 12SL7, 12SN7, 12SX7, 5691, 5692, 6080, ECC32. The only stipulations are that the two triodes within the envelope be similar and that the tube conforms to the 8BD base pin-out. Additionally, both input tubes must match each other as should both output tubes. In other words, don't use a 5691 as the input tube in one channel while using a 6SL7 in the other (their heaters draw differing currents).

Cathode Resistor Values

The cathode resistor and plate voltage set the idle current for the triode: the larger the value of the resistor, less current; the higher the plate voltage, more current. In general, high-mu triodes require high-value cathode resistors (1-2K) and low-mu triodes require low-valued cathode resistors (100-1k). The formula for setting the idle current in a single Aikido stage (Iq) is an easy one:

$$Iq = B+/2(rp + [mu + 1]Rk)$$

So, for example, in an Aikido circuit, a 6SN7 with a B+ voltage of +300V and 1k cathode resistors will draw 300/2(8k + [2 + 1]1k) amperes of current, or 2.6mA. I recommend 680 to 1.1k for the 6SL7 and 100 to 470 for the 6SN7 and 12SX7 tubes.

Because the cathode resistors see so little voltage differential, 1/2W resistors can readily be used. Be sure to see the tube chart on the last page for many design illustrations.

Coupling-Capacitor Values

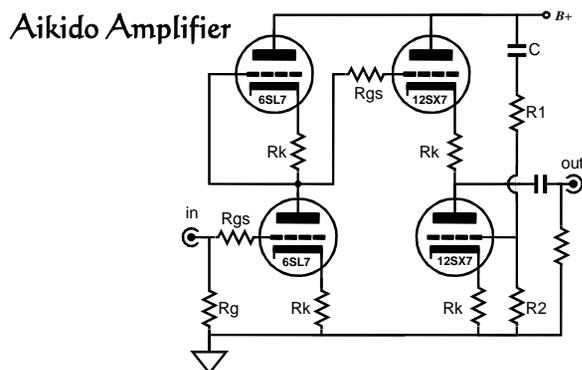
The bigger in value the coupling capacitor, the lower the -3dB high-pass corner frequency will be. The higher the load impedance, the lower the corner frequency. The formula is as follows:

$$\text{Frequency} = 159155/C/R$$

where C is in µF. For example, with a 1µF coupling capacitor and a power amplifier with an input impedance of 47k, the corner frequency would be 3.5Hz. If setup as a headphone amplifier, the coupling capacitor should be at least 30µF for 250 to 600 ohm headphones. (A 6SN7-based headphone amplifier cannot easily drive low-impedance headphones, such as 16 to 50 ohm headphones. The coupling capacitor voltage rating must at least equal the B+ voltage, for safety's sake. Although pads weren't provided for bypass capacitors for the coupling capacitors, a small bypass capacitor can be solder on the bottom of the PCB, using two of the redundant solder pads.

Introduction to the Aikido

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—despite 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.



Universal Topology In the schematic above, the triodes are specified as an example only. Although they would never fit on the printed circuit board (PCBs), 211 and 845 triodes could be used to make an Aikido amplifier. The circuit does not rely on these 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.)

Low Distortion 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 clearly. 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 that triode.

PSRR The Aikido circuit sidesteps power supply noise by incorporating the noise into its normal operation. The improved PSRR advantage is important, 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); and with some tweaking of resistor R1's value, -60dB—or more—is possible. Additionally, unless regulated power supplies are used for the plate and heater, these critical voltages will vary as the power line's voltage falls and climbs with your house's and neighbors' house's use, usually throwing the supposedly fixed wall-voltage askew. Nevertheless, the Aikido amplifier will still function flawlessly, as it tracks these voltage changes symmetrically.

Dual Coupling Capacitors The PCB can hold two coupling capacitors, each finding its own 1M resistor to ground. Why? The idea here is that you can select (via a rotary switch) between coupling capacitors C3a or C3b or both capacitors in parallel. Why again? One coupling capacitor can be Teflon and the other oil or polypropylene or beeswax or wet-slug tantalum.... As they used to sing in a candy bar commercial: "Sometimes you feel like a nut; sometimes you don't." Each type of capacitor has its virtues and failings. So use the one that best suits the music; for example, one type of coupling capacitor for old Frank Sinatra recordings and the other for late Beethoven string quartets. Alternatively, the same flavor capacitor can fill both spots: one lower-valued capacitor setting a low-frequency cutoff of 80Hz for background or late night listening; the other higher-valued capacitor, 5Hz for full range listening.

Or if you have found the perfect type of coupling capacitor, the two capacitors could be hardwired together on the PCB, one smaller one acting as a bypass capacitor for the larger coupling capacitor. On the other hand, each coupling capacitor can feed its own output, for example, one for low-frequency-limited satellites and one for subwoofers.

Tubes and Operating Points

| Tube | μ | R_p Ohms | R_k Ohms | I_k (mA) | B_+ Volts | R_{10} Ohms | R_9 Ohms | Input Gain | Input Gain dBs | Output Gain | Output in dBs | Z_o Ohms |
|--------|----------|---------------|---------------|---------------|-------------|------------------|---------------|---------------|-------------------|----------------|------------------|---------------|
| 6AS7 | 2.23 | 234 | 55 | 100 | 100 | 5437 | 100k | 1.1 | 0.9 | 0.6 | -4.47 | 95 |
| 6AS7 | 2 | 310 | 205 | 75 | 150 | 0 | 100k | 1 | 0 | 0.61 | -4.28 | 220 |
| 6AS7 | 1.87 | 441 | 530 | 50 | 200 | 0 | 100k | 0.9 | -0.6 | 0.61 | -4.24 | 456 |
| 6EL7 | 14.8 | 3140 | 196 | 10 | 150 | 76190 | 100k | 7.4 | 17.3 | 0.91 | -0.83 | 343 |
| 6EL7 | 15.4 | 2470 | 94 | 20 | 200 | 77011 | 100k | 7.7 | 17.7 | 0.91 | -0.86 | 219 |
| 6EL7 | 15.4 | 2540 | 165 | 20 | 250 | 77011 | 100k | 7.7 | 17.7 | 0.91 | -0.79 | 283 |
| 6EL7 | 15.9 | 2200 | 114 | 30 | 300 | 77654 | 100k | 7.9 | 18 | 0.91 | -0.79 | 219 |
| 6BK7 | 8.96 | 1760 | 267 | 10 | 100 | 63504 | 100k | 4.5 | 13 | 0.87 | -1.24 | 370 |
| 6BK7 | 9.44 | 1420 | 182 | 20 | 150 | 65035 | 100k | 4.7 | 13.5 | 0.87 | -1.21 | 273 |
| 6BK7 | 9.8 | 1270 | 158 | 30 | 200 | 66102 | 100k | 4.9 | 13.8 | 0.87 | -1.16 | 239 |
| 6BK7 | 10.1 | 1170 | 147 | 40 | 250 | 66942 | 100k | 5 | 14 | 0.88 | -1.13 | 220 |
| 6BK7 | 9.52 | 1730 | 542 | 20 | 300 | 65278 | 100k | 4.7 | 13.5 | 0.89 | -1.04 | 565 |
| 6SL7 | 70 | 43000 | 1000 | 1.3 | 300 | 94444 | 100k | 31.4 | 29.9 | 0.98 | -0.17 | 1174 |
| 6SN7 | 20.5 | 10200 | 583 | 3 | 150 | 82222 | 100k | 10 | 20 | 0.93 | -0.59 | 827 |
| 6SN7 | 21.1 | 8960 | 397 | 5 | 200 | 82684 | 100k | 10.4 | 20.3 | 0.93 | -0.59 | 657 |
| 6SN7 | 21 | 9250 | 626 | 5 | 250 | 82609 | 100k | 10.3 | 20.2 | 0.94 | -0.56 | 820 |
| 6SN7 | 21.9 | 7530 | 243 | 10 | 300 | 83264 | 100k | 10.8 | 20.7 | 0.93 | -0.6 | 489 |
| 6SN7 | 21.1 | 9000 | 680 | 5.8 | 300 | 82684 | 100k | 10.3 | 20.3 | 0.94 | -0.54 | 846 |
| 6SN7 | 21.4 | 8360 | 470 | 7.2 | 300 | 82906 | 100k | 10.5 | 20.4 | 0.94 | -0.56 | 685 |
| 6SN7 | 20.8 | 9840 | 1000 | 4.5 | 300 | 82456 | 100k | 10.1 | 20.1 | 0.94 | -0.53 | 1063 |
| 12SL7 | See 6SL7 | | | | | | | | | | | |
| 12SN7 | See 6SN7 | | | | | | | | | | | |
| 12SX7* | 21.2 | 8750 | 218 | 5 | 80 | 82759 | 100k | 10.5 | 20.4 | 0.93 | -0.64 | 519 |
| 5691 | See 6SL7 | | | | | | | | | | | |
| 5692 | See 6SN7 | | | | | | | | | | | |
| 6080 | See 6AS7 | | | | | | | | | | | |
| 6082 | See 6AS7 | | | | | | | | | | | |
| B65 | See 6SN7 | | | | | | | | | | | |
| ECC32 | See 6SN7 | | | | | | | | | | | |
| ECC33 | 35 | 9700 | | | | 89189 | 100k | 17.3 | 24.8 | 0.95 | -0.48 | 248 |

The table above lists many triodes suitable for the Aikido Octal PCB, listing the same tube under different B_+ voltages and with different cathode resistor values. Two gains are listed: the first is the gain realized in the input position in the Aikido; the second, the gain of the same tube in the output stage cathode follower position. To calculate the final gain multiply the two voltage gains together (or add the gain in dBs together).