Aikido

Aikido Stereo Octal PCB
Revision C

USER GUIDE

05/30/2008

GlassWare
AUDIO DESIGN

☛ Warning! ☚

This PCB is for use with a high-voltage power supply; thus, a real shock hazard exists. Once the power supply is attached, be cautious at all times. In fact, always assume that capacitors will have retained their charge even after the power supply is disconnected or shut down. If you are not an experienced electrical practitioner, before applying the B-plus voltage have someone who is experienced review your work. There are too few tube-loving solder slingers left; we cannot afford to lose any more.

Rev. C Overview

Thank you for your purchase of the TCJ Aikido octal stereo Rev. C 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 made in the USA. 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. The boards are four inches by ten inches, with eight mounting holes, which help to prevent excessive PCB bending while inserting and pulling tubes from their sockets.

PCB Features

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 Coupling Capacitors The boards 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 C1 or C2 or both capacitors in parallel. Why again? One coupling capacitor can be Teflon and the other oil or polypropylene or bee's wax 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 capacitors for old Frank Sinatra recordings and the other for Beethoven string quartets.

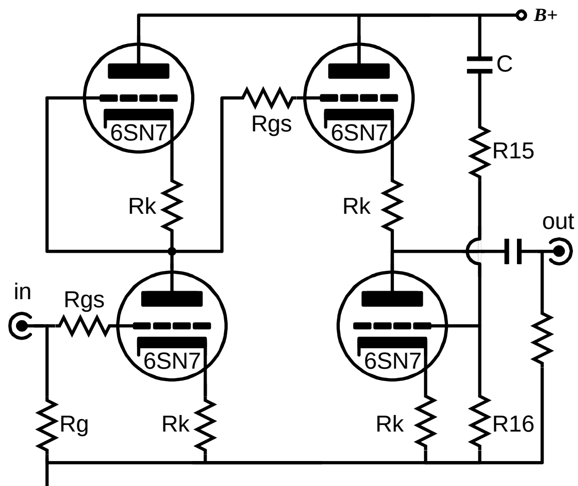
Or the same flavor capacitor can fill both spots: one lower-valued capacitor would set a low-frequency cutoff of 80Hz for background or late night listening; the other higher-valued capacitor, 5Hz for full range listening.

Or if you have found the perfect type of coupling capacitor, the two capacitors could be hardwired together on the PCBs via jumpers J8 and J9, one smaller one acting as a bypass capacitor for the larger coupling capacitor.

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— in spite of 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

In the schematic above, the 6SN7s 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. The circuit does not rely on 6SN7 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.)

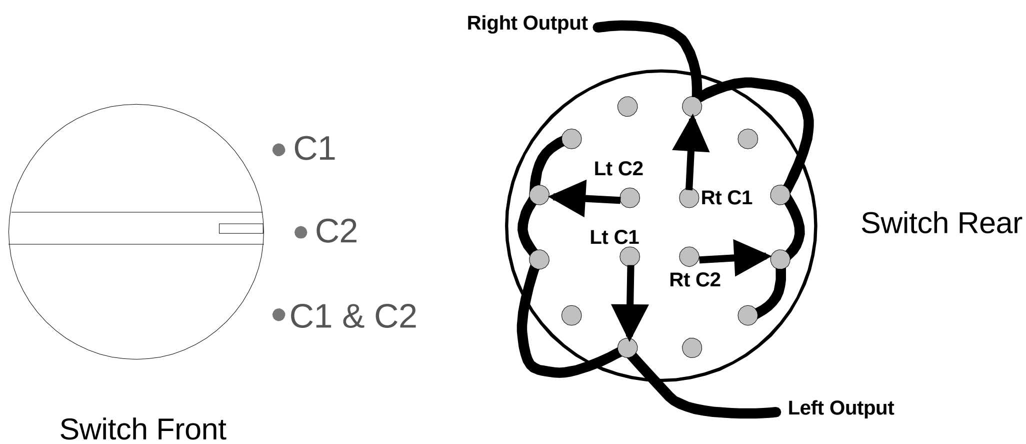
The Aikido circuit sidesteps power supply noise by incorporating the noise into its normal operation. The improved PSRR advantage is important, for it greatly unburdens the power-supply. With no tweaking or tube selecting, you should easily be able to get a -30dB PSRR figure (a conventional grounded-cathode amplifier with the same tubes and current draw yields only a -6dB PSRR); 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, 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 6SN7 is not the same as that same 6N7 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) define a voltage divider of 50%, so that 50% of the PS noise is presented to the CF's grid; at the same time the 100k 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).

If the output connection is taken from the output cathode follower's cathode, then the balance will be broken. 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 higher output impedance. Unfortunately, it should be removed and the bypass capacitor C3 should be used when driving low-impedance headphones, 32-ohms for example. When used as a line stage amplifier, no cathode resistor bypass capacitors should be used, as these capacitors are very much in the signal path and very few do not damage the sound, unless high quality capacitors are used.)

How do I wire up a rotary switch for switching between the two coupling capacitors? We need a four-pole, three-position switch and some hookup wire. All four coupling capacitors attach to the input contacts and the two channels of output can receive either coupling capacitors C1's or C2's or both capacitors' outputs. The drawing below shows the knob on the faceplate and the rotary switch from behind. (The switch is shown on the "C1 + C2" position.)



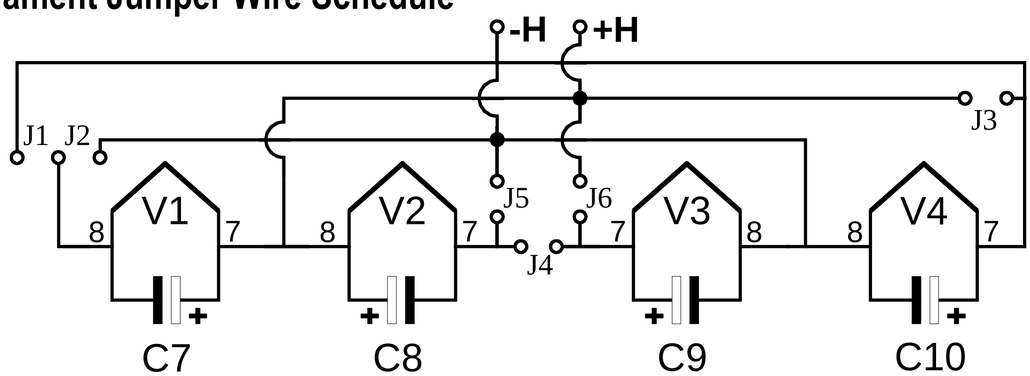
Heater Issues

The board assumes that a DC 12V power supply will be used for the heaters, so that 6.3V heater tubes (like the 6BX7 and 6SN7) or 12.6V tubes (like the 12SL7 or 12SX7) can be used. Both types can be used exclusively, or simultaneously; for example 12SN7 for the input tube and a 6BL7 for the output tube. For example, if the input tube (V2 and V3) is a 12SL7 and the output tube is a 6SN7 (V1 and V4), then use jumpers J1, J5 and J6.

6V Heater Power Supply Although designed for a 12V power supply, a 6V heater power supply can be used with the PCB, as long as all the tubes used have 6.3V heaters (or 5V or 8V or 18V power supply can be used, if all the tubes share the same 5V or 8V or 18V heater voltage). Just use jumpers J1 and J4 only. 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. (A 25V heater power supply can be used, if only 12.6V tubes are used. Just use the jumper settings that are listed on the PCB for series use. For example, if the input tube [V2 and V3] is a 12SN7 and the output tube is a 12SX7 [V1 and V4], then use jumpers J1 and J4.)

AC Heaters An AC heater power supply (6.3V or 12.6V) can be used, if the heater shunting capacitors C7, C8, C9, C10 are left off the board, or are replaced by 0.01µF ceramic capacitors.

Filament Jumper Wire Schedule



With a 6.3V heater PS

Use J2, J3, J5, and J6 only.

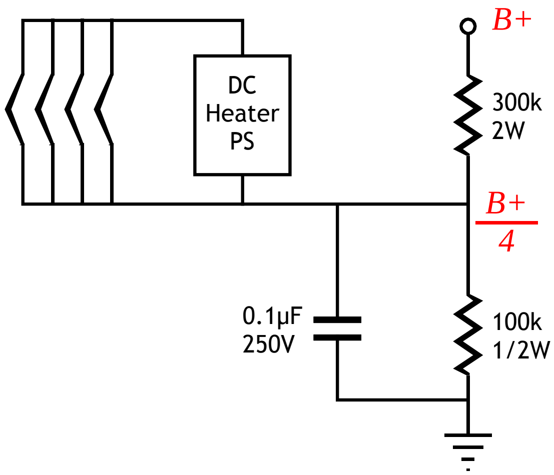
All tubes must be 6.3V heater types, such as 6BL7, 6SL7, and 6SN7.

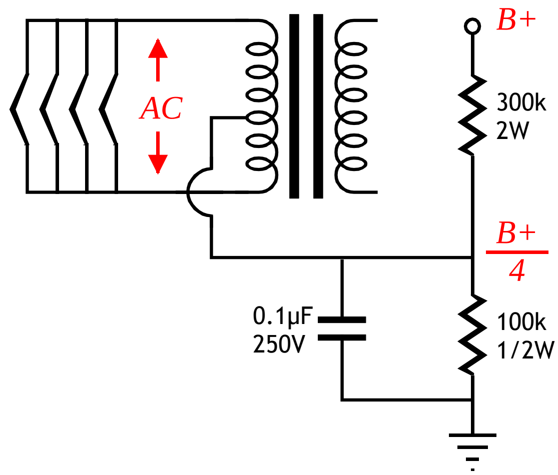
With a 12.6V heater PS

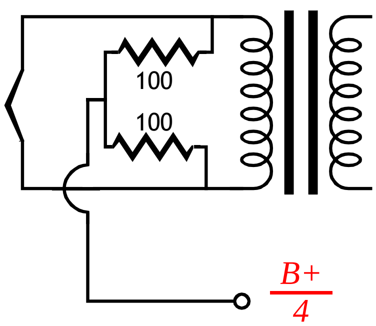
Output Tubes V1 and V4:
If tubes are 6.3V, use J1 only.
If tubes are 12.6V, use J2 and J3 only.

Input Tubes V2 and V3:
If tubes are 6.3V, use J4 only.
If tubes are 12.6V, use J5 and J6 only.

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 ¼ 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 following circuit:





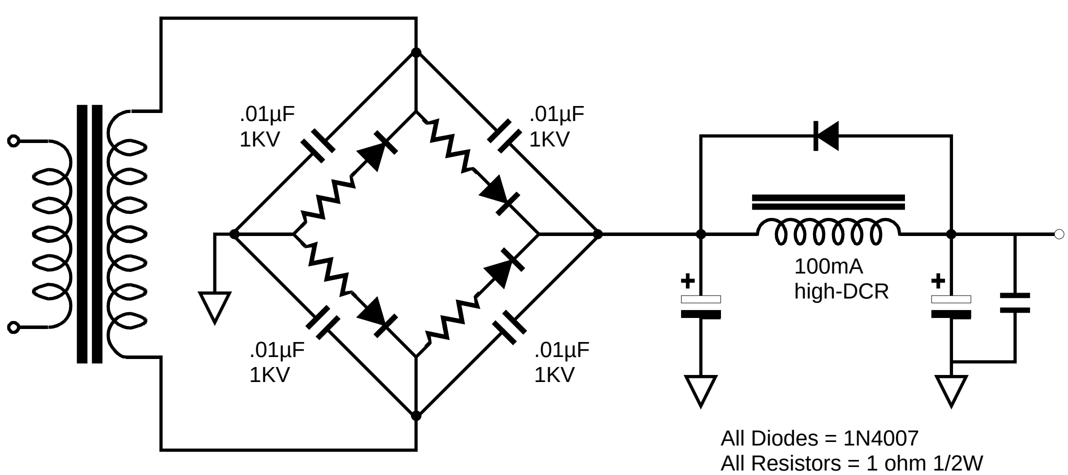


Alternatively, you might experiment with floating the heater power supply, by "grounding" the heater power supply via only a 0.1µF film or ceramic capacitor. The capacitor will charge up through the leakage current between heater and cathodes. Not only is this method cheap, it is often quite effective in reducing hum.

Power Supply

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. For example, 12SX7 can be used with a low 100-volt power supply, while 6SN7s work better with a 250-300V B-plus voltage. The sky is <u>not</u> the limit here, as the heater-to-cathode voltage sets an upward limit of about 400V.

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 1N4007.



Jumper J7 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 J7 out or replace it with a small-valued capacitor (0.01 to 0.1µF).

Tube Selection

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 (V2 & V3) will yield a gain close to 35 (mu/2), which would be suitable for a phono preamp or a SE 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 or 6BX7 in the output stage (V1 & 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 tube 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 sets the idle current for the triode: the larger the value of the resistor, the less current. In general, high-mu triodes require high-value cathode resistors (1-2K) and low-mu triodes require low-valued cathode resistors (100-1k). I recommend running the output tubes hotter than the input tubes. For example, 1k cathode resistors for the input tube (V2 and V3) and 300 or 470-ohm cathode resistors for the output tubes (V1 and V4), when using 6SN7s throughout. Thus, as the output tubes will age more quickly than the input tubes, rotating output for input tubes can extend the useful life of the tubes.

Overview of Part Values

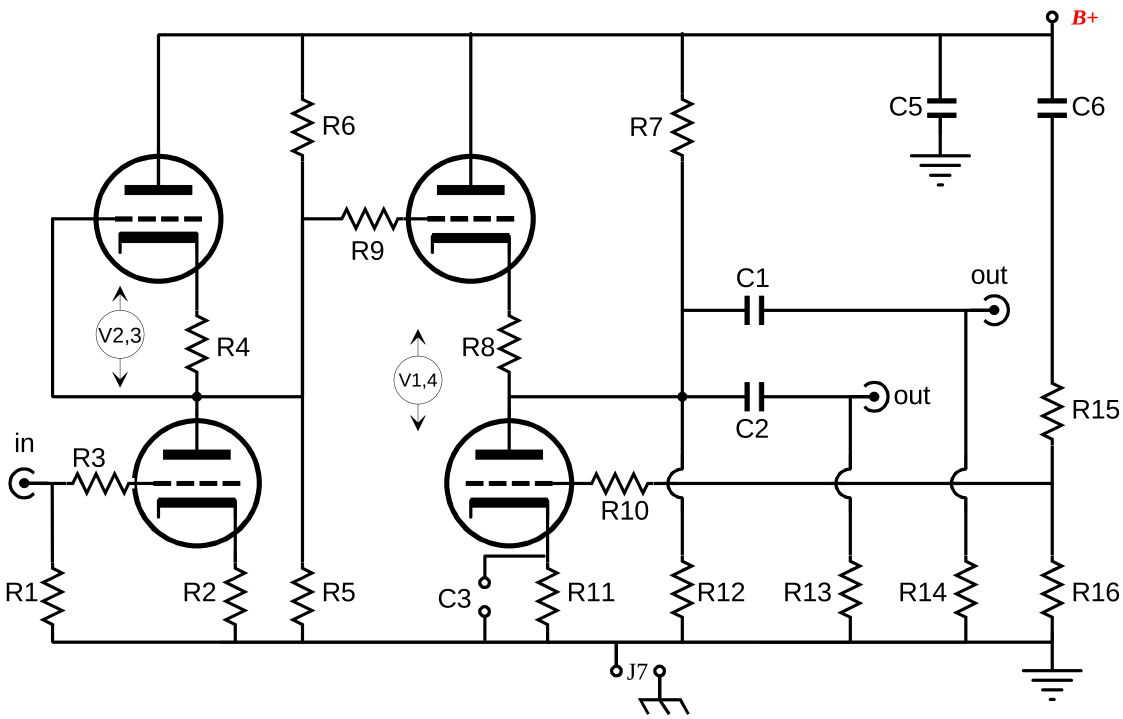
R1, R6, R5, R7, R12, R13, R14 =	1M
R3, R9, R10 =	100 - 470 ohm*
R2, R4 =	200 - 2k (depends on tube)*
R8,R11 =	100 - 1k (depends on tube)*
R15 =	R16 x (mu - 2) / (mu + 2) eg 82k for 6SN7
R16 =	100k

*High-quality resistors. All resistors 1/2W or higher

C1 =	0.1 - 4µF (voltage rating must exceed B+ voltage)
C2 =	0.1 - 4µF (voltage rating must exceed B+ voltage)
C3 =	at least 1kµF 16V (use only when driving headphones)
C5 =	1 - 10µF (voltage rating must exceed B+ voltage)
C6 =	0.1µF (voltage rating must exceed B+ voltage)
C7, C8, C9, C10 =	10-100µF (Use only with DC power supply; heater-shunting capacitors, from pins 7 to 8; voltage rating must exceed heater power-supply voltage)
(inputs) V2, V3 =	6SL7, 6SN7, 12SL7, 12SN7, 12SX7, 5691, 5692, B65, ECC32, ECC33
(outputs) V1, V4 =	6AS7, 6BL7, 6BX7, 6H30Pi, 6SN7, 8SN7, 12SN7, 12SX7, 5692, 6080, B65, ECC32, ECC33

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. The key points are not to use capacitor C3. For guidance on part values, look at the page 12, which lists several line-amplifier design examples. Calculating R15's value is easy; it equals R16 against [(mu -2)/(mu + 2)]. For example, a triode with a mu of 20 results in R15 = 100k x (20 – 2)/(20 + 2) = 81.8k (82k)



Typical Part Values

() Parentheses denote recommended values

	[6/12]SN7 & [6/12]SN7	[6/12]SL7 & [6/12]SN7	6SN7 & 6H30Pi
B+ Voltage =	170V - 300V (300V)	200V - 300V (300V)	200V - 300V (300V)
Heater Voltage =	6.3V/12.6V	6.3V/12.6V	6.3V
R1,5,6,7,12,13 =	1M	Same	Same
R2,4 =	270 - 1k (470)*	470 - 2k (1k)*	270 - 1k (330)*
R3,9,10 =	100 - 1k (300)*	Same	Same
R8, R11 =	240* [Iq = 10mA]	390* [Iq = 17mA]	270* [Iq = 20mA]
R15 =	83.3k	Same	78k
R16 =	100k	100k	100k

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

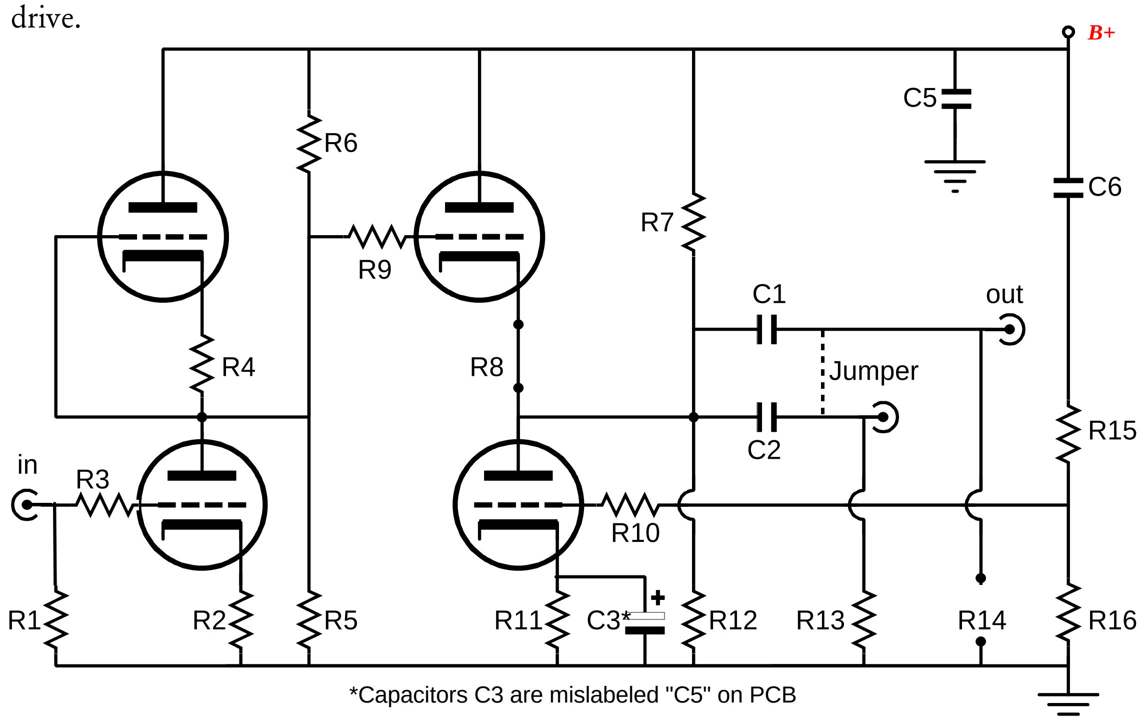
C1 =	0.1 - 10µF* Film or oil	Same	Same
C2 =	0.1 - 10µF* Film or oil	"	"
C3 =	Do not use	"	"
C5 =	0.1 - 10µF*	"	"
C6 =	0.047µF - 0.22µF* Film or oil	"	"

*voltage rating must equal or exceed B+ voltage
2. Capacitors C3 are below resistors R11 and are mislabeled "C5" on the PCB

(input) V1 =	6SN7, 12SN7, 12SX7, 5692, B65, ECC32, ECC33	6SL7, 6SU7, 12SL7, 5691	6SN7, 12SN7, 12SX7, 5692, B65, ECC32, ECC33
(output) V2=	6SN7, 12SN7, 12SX7, 5692, B65, ECC32, ECC33	Same	6BL7, 6H30Pi

Configuring the PCB as a Headphone Amplifier

The Aikido topology 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 deliver. Single-ended stages can only transfer up to the idle current into a load, whereas class-AB output stages can provide many times the idle current. Unfortunately, a heavy idle current is needed to ensure large voltage swings into low-impedance loads. Headphones require a lot of power; really, a 32-ohm load is brutally low impedance for any tube to drive.



*Capacitors C3 are mislabeled "C5" on PCB

The best output tubes for driving low-impedance headphones are the 6BL7, 6BX7, and 6H30Pi; for high-impedance headphones, the 6SN7/12SN7 works well. What about the 6AS7 or 6080? Unfortunately, this dual power triode is less suited than it first appears. Asides from the 2.5A heater requirement, the triode must be run at a fairly high idle current to move into its more linear range, say 40-60mA. Second, its low mu of only 2 means that it require a huge cathode bias resistor and plate resistor; in other words, it should be used with fixed negative-bias voltage instead in a different topology.

A coupling capacitor of at least 30µF is required when driving 300-ohm headphones; 300µF for 32-ohm headphones, which means electrolytic capacitor, as nothing else will fit on the PCB. If an electrolytic capacitor is used, try to find a photo-flash capacitor or a high-frequency or low-impedance electrolytic. A small-valued coupling capacitor (0.1 to 0.47µF) should be used in capacitor C2 position and should be soldered in place before coupling capacitor C1. Space is tight, which can be increased by using several layers of adhesive foam below capacitor C1. Capacitor C3 (mislabeled "C5" on PCB) should be at least 470µF. On the other hand, if only 300-ohm headphones are going to be driven, then the best choice might be to use a 6SN7/12SN7 and both cathode resistors, R8 and R11, leaving both resistors unbypassed. The output impedance will be higher, but the distortion will be lower.

Typical Part Values

() Parentheses denote recommended values

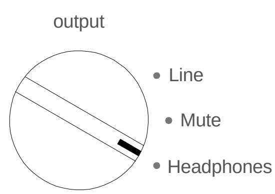
	[6/12]SN7 & [6/12]SN7	[6/12]SN7 & 6H30Pi	[6/12]SN7 & 6BX7
B+ Voltage =	170V - 300V (250V)	170V - 240V (200V)	200V - 300V (300V)
Heater Voltage =	6.3V/12.6V	6.3V/12.6V	6.3V/12.6V
R1,5,6,7,12,13 =	1M	Same	Same
R2,4 =	270 - 1k (470)*	Same	Same
R3,9,10 =	100 - 1k (300)*	Same	Same
R8 =	0, Jumper	Same	Same
(300-ohm HP) R11 =	100* [Iq = 14mA]	220* [Iq = 20mA]	470* [Iq = 21mA]
(32-ohm HP) R11 =	Not recommended	120* [Iq = 30mA]	290* [Iq = 32mA]
R15 =	82.6k	78k	65k
R16 =	100k	100k	100k

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

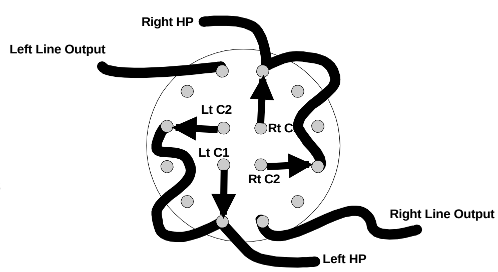
(300-ohm HP) C1 =	27 - 47µF* Film	Same	Same
(32-ohm HP) C1 =	Not recommended	300 - 470µF* Electrolytic	"
C2 =	0.47µF* Film or oil	Same	"
C3 =	=> 1kµF, 16V Electrolytic[2]	"	"
C5 =	0.1 - 10µF* Flim	"	"
C6 =	0.047µF - 1µF* Film or PIO	"	"

*voltage rating must equal or exceed B+ voltage
2. Electrolytic capacitors C3 are marked C5 on PCB

(input tube) V1 =	6SN7, 12SN7, 12SX7, 5692, B65, ECC32, ECC33	Same	Same
(output tube) V2=	6SN7, 12SN7, 12SX7, 5692, B65, ECC32, ECC33	6H30Pi, 6BL7	6BL7, 6BX7



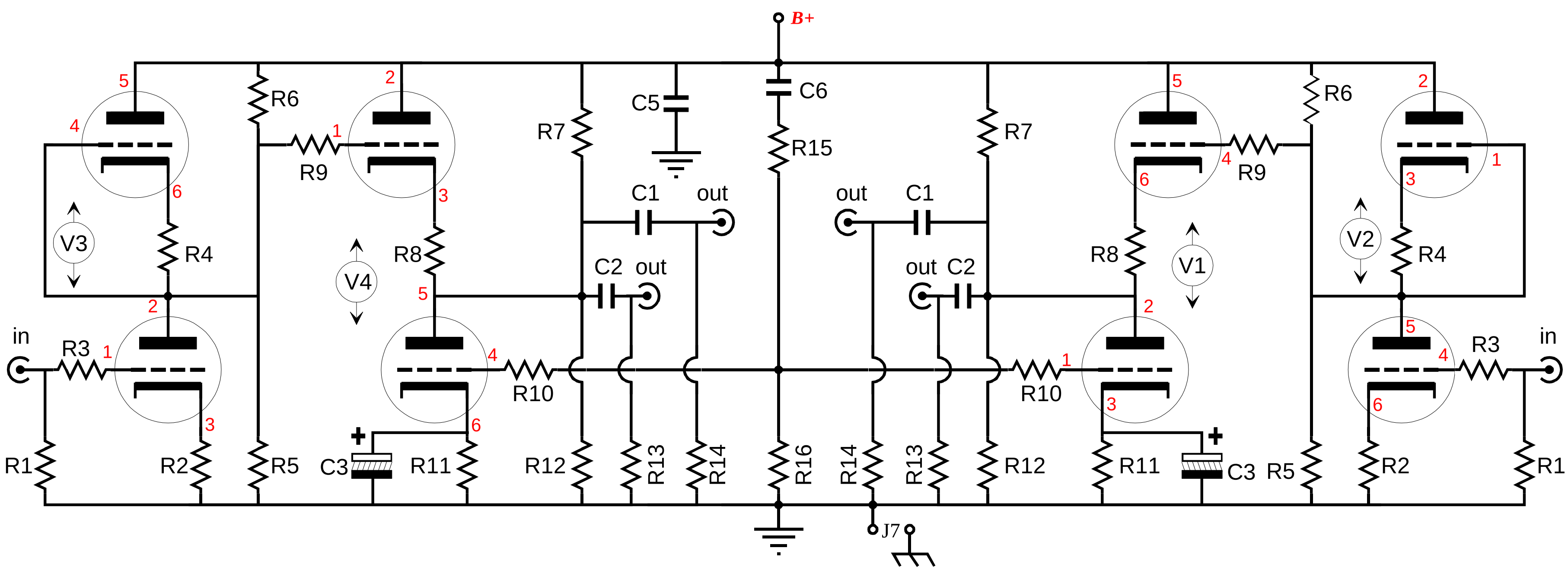
Switch Front



Switch Rear

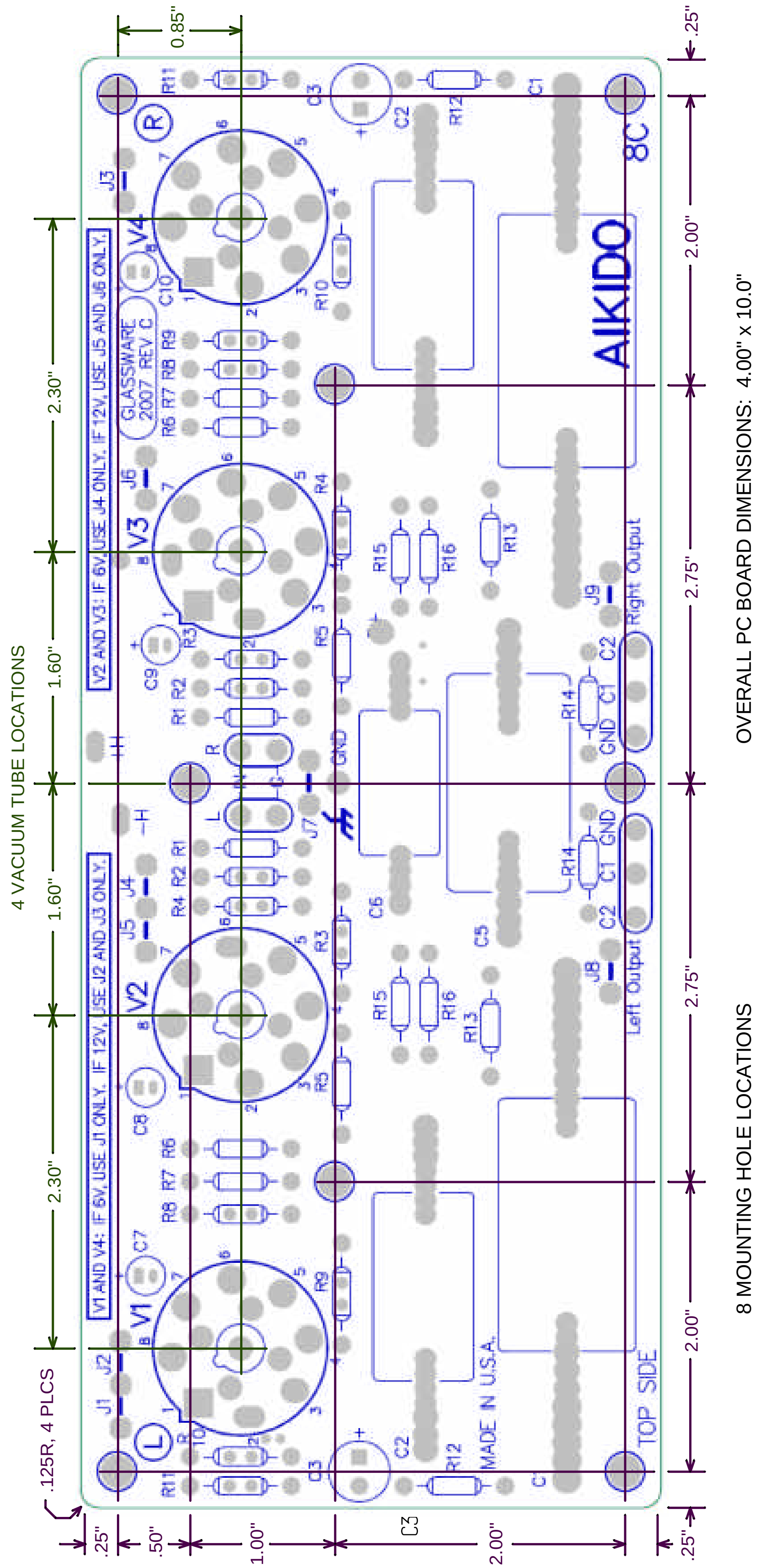
Assembly

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 a marketing gimmick.) Normally, such as when the PCB sits on the floor of its chassis, all the parts sit on the top side of the PCB (the top side is marked). If you wish to have the tubes protrude from holes on the top of the chassis (and to place the PCB within 1" of the top panel with the aid of standoffs), then all the other parts— *except* the tube sockets— can be placed on the PCB's backside; it is a double-sided board after all (be sure to observe the electrolytic capacitors' polarity and glue or tie-wrap heavy coupling capacitors to the PCB).



Octal Aikido Schematic (Rev. C)

Important. Capacitors C3 are mismarked C5 on the PCB. Only use these capacitors when driving headphones



Top Side PCB Mechanical Layout

Tube	mu	Rp Ohms	Rk Ohms	Ik (mA)	B+ Volts	R15 Ohms	R16 Ohms	Input Gain	Input Gain dBs	Output Gain	Output in dBs	Zo 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
6BL7	14.8	3140	196	10	150	76190	100k	7.4	17.3	0.91	-0.83	343
6BL7	15.4	2470	94	20	200	77011	100k	7.7	17.7	0.91	-0.86	219
6BL7	15.4	2540	165	20	250	77011	100k	7.7	17.7	0.91	-0.79	283
6BL7	15.9	2200	114	30	300	77654	100k	7.9	18	0.91	-0.79	219
6BX7	8.96	1760	267	10	100	63504	100k	4.5	13	0.87	-1.24	370
6BX7	9.44	1420	182	20	150	65035	100k	4.7	13.5	0.87	-1.21	273
6BX7	9.8	1270	158	30	200	66102	100k	4.9	13.8	0.87	-1.16	239
6BX7	10.1	1170	147	40	250	66942	100k	5	14	0.88	-1.13	220
6BX7	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 octal-based Aikido amplifier PCB. The table lists the same tube under different B+ voltages and with different cathode resistor values. Two gains are listed: the first is the gain the tube realizes in the input position in the Aikido; the second is the gain of the same tube in the output stage. To calculate the final gain multiply the two voltage gains together (or add the gain in dBs together). For example, given an Aikido line amplifier with a B+ voltage of 300V, and a 6SN7 input tube with cathode resistors of 680 ohms, and a 6BX7 output tube with cathode resistors of 542 ohms, the final voltage gain equals 10.3 from the 6SN7 against the 0.89 gain of the 6BX7, with a product of 9.17. or, working with dBs instead, 20.3dB plus -.1.04dB, for a total of 19.26dB. (Aren't decibels great?)

If you have additional data, send it in and I'll add to the list.

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").