DANGER!

This PCB holds a high-voltage power supply; thus, a real—and possibly—lethal shock hazard exists.

Ideally, a variac should be used to slowly power up the regulator, as it is better to have a mis-oriented electrolytic capacitor or a mis-located resistor blow at low voltages, rather than at high voltages. Remember that the danger increases by the square of the voltage; for example, 200 volts is four times more dangerous than 100 volts and 400 volts is sixteen times more dangerous.

Once the power supply is powered up, be cautious at all times. In fact, even when the power supply is disconnected or shut down, assume that power-supply capacitors will have retained their charge and, thus, can still shock. If you are not an experienced electrical practitioner, before attaching the transformer windings to the board, have someone who is well-experienced in electronics review your work.

There are too few tube-loving solder slingers left; we cannot afford to lose any more.

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AUDIO DESIGN
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www.tubecad.com

sales@glass-ware.com

Warning!

This PCB contains a high-voltage power supply; thus, a real and lethal shock hazard exists. Once the power transformer is attached, be cautious at all times. In fact, always assume that the high voltage capacitors will have retained their charge even after the power supply has been disconnected or shut down. If you are not an experienced electrical practitioner, before applying the AC 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.

Overview

Thank you for your purchase of the TCJ Aikido octal *All-in-One* 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 7 by 6 inches, with five 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). By including the necessary components for the heater and high voltage B+ power supplies on the PCB, the *All in One* board makes building a standard-setting line stage amplifier a breeze. This assembled board with a chassis, volume control, selector switch, power transformer, and a fistful of RCA jacks is all that is needed.

PCB Features

B+ and Heater Power Supplies On the *All in One* board, two power supplies reside, one for the high-voltage B+ for the tubes and a low-voltage power supply for the heaters. The high-voltage power supply uses an RC filter to smooth away ripple, while the low-voltage power supply uses a voltage regulator to provide a stable and noise-free voltage output. The power supplies require an external power transformer(s) with two secondary windings.

Aikido PP The Rev. B octal *All-in-One* 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 C1 or C2 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.

Aikido All In One

Aikido Stereo Octal PCB

Rev. B

USER GUIDE

- Introduction
- Overview
- Schematics
- Recommended Configurations
- Tube Lists
- Assembly Instructions

Apr 24 2012

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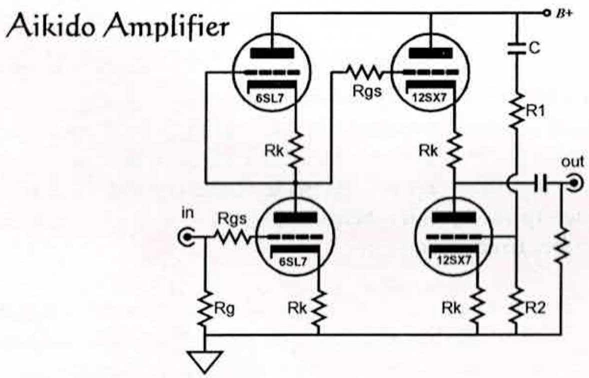
Introduction to the Aikido

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.

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

$$Gain = muRa/[Ra + (mu + 1)Rk + rp]$$

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

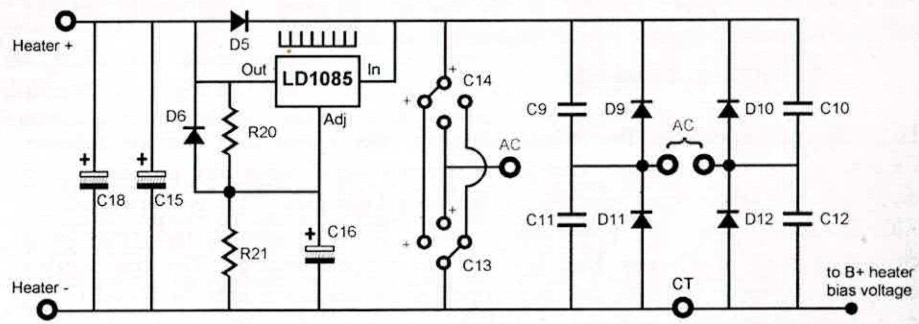
$$Gain = mu[(mu + 1)Rk + rp] / [(mu + 1)Rk + rp + (mu + 1)Rk + rp] = mu/2$$

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.

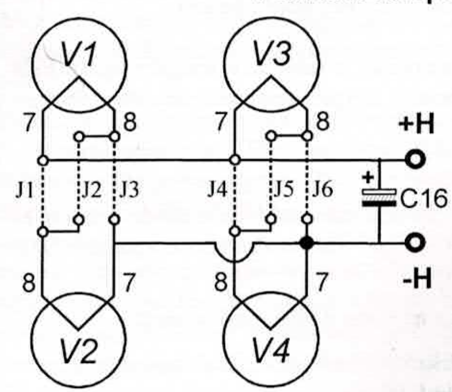
Heater Issues

The octal *All-in-One* PCB holds the heater raw power supply and voltage regulator. The heater power-supply uses an LD1085 low-dropout adjustable voltage regulator. The regulator can be set to an output voltage between 6V to 25V, but 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. Thus, for example if the input tubes (V1 and V2) are 6SN7s and the output tubes (V3 and V4) are 12SN7s and the heater regulator output voltage is 12Vdc, then use jumpers J2, J4, and J5. The preferred heater regulator voltage is 12V, even with four 6SN7s, as it greatly unburdens the regulator. Simply use jumpers J2 & J5 with four 6SN7s. Nonetheless, a 6Vdc (or 6.3Vdc) heater power supply can be used with the PCB, as long as all the tubes used have 6.3V heaters (or a 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, J3, J4, and J6 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.

AC Heaters An AC heater power supply (6.3V or 12.6V) can be used, if the heater rectifiers, power supply capacitors, and regulator are all 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.



Filament Jumper Wire Schedule



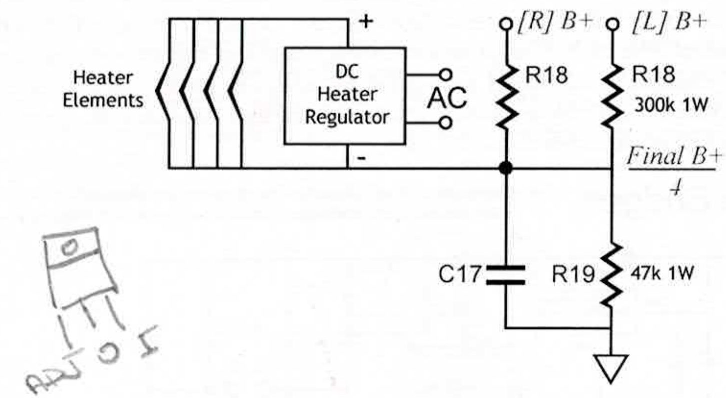
With a 12.6V PS

Tubes	V1 & V2	V3 & V4
If tubes are 6.3V:	J2 only	J5 only
If 12.6V:	J1 & J3	J4 & J6

With a 6.3V PS

Tubes	V1 & V2	V3 & V4
All tubes = 6.3V:	J1 & J3	J4 & J6
If 12.6V:	Cannot be used with 6.3V PS	

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:



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. This means that resistors R18 and R19 values must be follow a 6:1 ratio. 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 R18 and R19 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.

Typical Part Values

Heater Voltage =	6V	6.3V	8V	12V	12.6V
R21 =	470	499	670	1.07k	1.13k
R20 =	124	same	same	same	same
D7 - D10 =	MUR410G	"	"	"	"
D5, D6 =	1N4007	"	"	"	"
C9, 10, 11, 12 =	0.01µF / 50V	"	"	"	"
C13, C14 =	10kµF*	"	"	"	"
C15, C16 =	1kµF*	"	"	"	"
C18 =	1k-3900µF*	"	"	"	"

Regulator = LD1085, LM317, LM350, LT1085
Vac Input = 7-8Vac @ 5A for 6.3Vdc
12-12.6Vac @ 2.5A for 8Vdc or 12Vdc or 12.6Vdc
*Capacitor voltage must exceed 1.414 x Vac input voltage

Resistors R20 and R21 set the voltage regulator's output voltage. The formula is

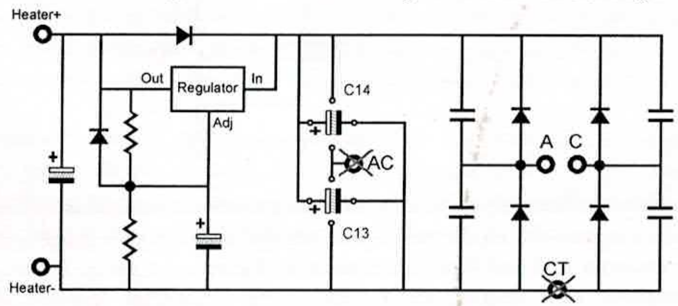
$$V_0 = 1.25(1 + R_{21} / R_{20})$$

Thus, using a 124-ohm resistor for R20 and a 2.4k resistor in R21 position, the output will climb to 25.2Vdc. See the values table above.

The heater power supply can accept either full-wave bridge rectifier circuit or a full-wave voltage doubler rectifier configuration. When used as a full-wave bridge rectifier circuit, the two power supply filtering capacitors are placed in parallel by orienting their positive leads to where the heatsink sits; and the secondary attaches to the two encircled AC pads. Configured as a voltage doubler, these capacitors placed in series by being rotated 90 degrees clockwise, so the positive leads point to the center-tap pad at the bottom of the PCB; the secondary attaches to single AC pad in between capacitors C13 and C14 and AC pad that feeds rectifier D9 and D11; and D10, D12, C10, C12 are left off the PCB. If used as a full-wave center-tap circuit, the two power supply filtering capacitors are placed in parallel by orienting their positive leads to where the heatsink sits; and the secondary attaches to the two encircled AC pads and the secondary center-tap attaches to the CT pad.

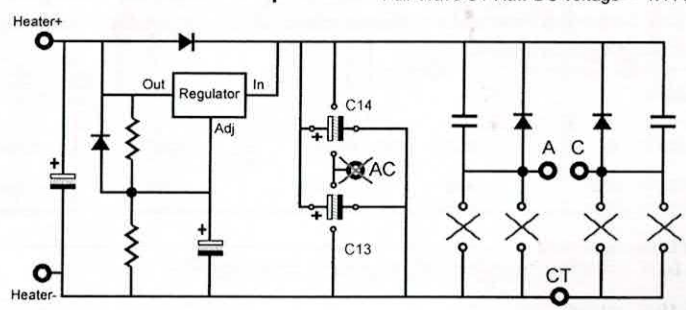
Full-Wave Bridge

Capacitor C13 & C14 positive leads pointing to heatsink
Fullwave-Bridge Rectification. Raw DC voltage = 1.414Vac - 2V



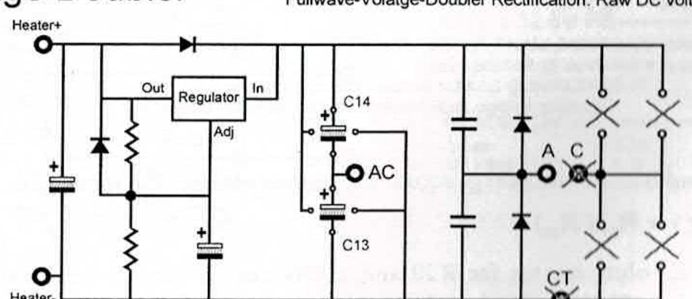
Full-Wave Center-Tap

Capacitor C13 & C14 positive leads pointing to heatsink
Full-Wave CT Raw DC voltage = 1.414Vac - 1V



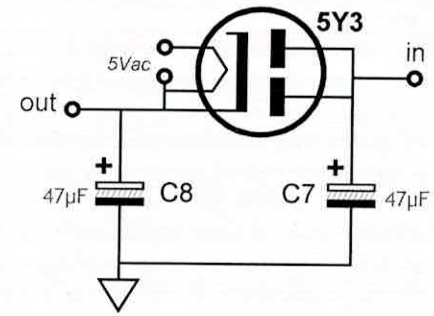
Voltage Doubler

Capacitor C13 & C14 positive leads pointing to the right
Fullwave-Volatge-Doubler Rectification. Raw DC voltage = 2.828Vac - 2V



Power Transformer(s)

The Aikido octal *All-in-One* PCB requires a power transformer(s) to energize its two power supplies. Either a single power transformer or two separate transformers can be used. The advantage that two transformers offer is that the heater transformer can be turned on first, allowing the heaters to warm, before applying the high-voltage to the plates. In addition, the supremely high and brief charging current that must flow into the heater rectifier circuit will not magnetically couple to the high-voltage secondary, as they must in a single power transformer. Power transformer made for tube amplifiers often hold a 5Vac heater winding. This winding can either be taped up (and not used) or can be used heat a tube rectifier, even with the solid-state rectifiers. Just replace resistor R17 with rectifier, such as the 5Y3 (or 5AR4). The 5Y3 is thus used as slow-turn-on resistor, not a rectifier. The tube rectifier comes in between two high-voltage, power-supply 47µF/450V capacitors C7 & C8, in place of resistor R17. I like this setup a great deal, as the slow turn-on results in a smoother start up.



The heater power-supply secondary must offer at least 1.8 times more AC current than the heaters will draw with a DC voltage. For example, four 6SN7s will draw 1.2A @12.6v, so the heater power transformer must be able to sustain an AC 2.16A current draw. In addition, with sine waves, the AC voltage equals the peak voltage divided by the square root of 2, i.e. 1.414. Thus, a 10Vac sine wave peaks at 14.14V; a 6.3Vac, 8.9V. In other words, a sine wave that peaks at 14.14V will produce the same amount of heat in a resistance as a 10Vdc voltage source would produce in the same resistance; so, we label the 14.14Vpk sine wave as being 10Vac. Thus, in order to get the 16Vdc a 12.6V heater voltage regulator requires an input voltage equal to sum of 16V and the rectifier loss (about 1.4V) divided by 1.414, which is roughly 12Vac to 12.6Vac. in this example, a 30VA single heater transformer could be used.

The high voltage power transformer must also follow the same rules. Thus, to achieve 300V of raw DC voltage, the transformer primary must deliver (300V + 1.4V) / 1.414, or about 214Vac. And if 50mA is required, the power transformer must be rated for 50mA x 1.8, or about 90mA. Such a transformer VA rating would equal 33VA.

A power transformer with a center-tapped secondary can be used; just leave D7, D8, R15, and R16 off the board, then attach the secondary center-tap to the "CT" pad. For example, a 500Vac CT secondary is the equal to a 250Vac non-CT secondary. Be aware of the poor regulation figure for most high-voltage power transformers, as the 400V power-supply capacitors might see to high an initial B+ voltage at start up, when the tubes are cold and not conducting. In other words, when not fully loaded, the transformer delivers a higher secondary voltage.

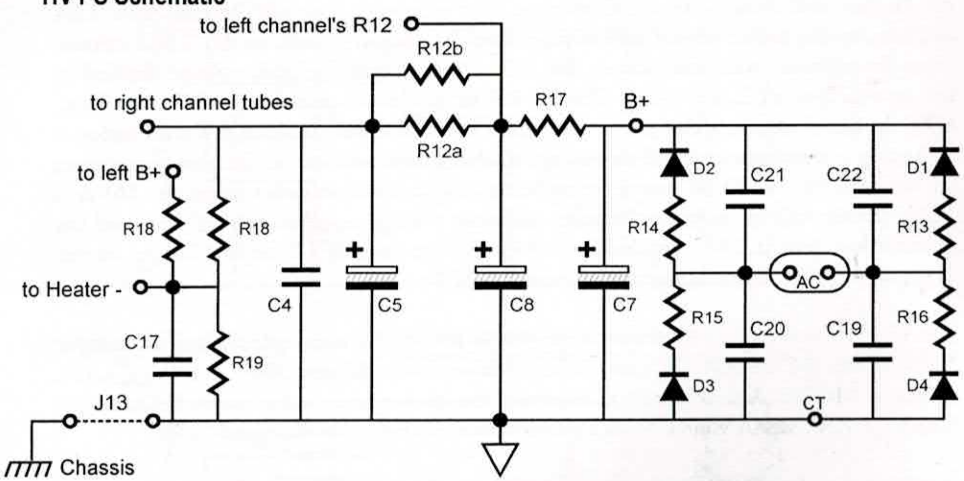
B-plus Power Supply

The high voltage B-plus power supply resides on the Aikido *All in One* PCB. It contains a full-wave bridge rectifier circuit and reservoir capacitor, which is then followed by an RC-smoothing filter common to both channels, then a second RC filter for each channel. The high voltage power transformer is external to the PCB and can be mounted in, or outside, the chassis that houses the PCB.

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 pages 13 and 14 for more information.

Bear in mind, there is a practical limit to how large a power-supply noise signal can be nulled at the Aikido's output. So there are several goals that work against each other: we want the largest voltage-dropping resistor value possible, as it reduces the ripple appearing at the tubes' power supply connection; we want the lowest raw B-plus voltage possible, as it will allow a larger-valued reservoir capacitor and limit the heater-to-cathode voltage; and we want the highest plate voltage possible for the tubes, as it makes for better sound. We cannot have it all. A typical 250V capacitor is much more volumetrically efficient than a 400V capacitor. Thus, running a lower B-plus voltage allows us to increase greatly the capacitance in the power supply. Running lighter current allows us to maximize resistor R12's (combined) value.

HV PS Schematic



Typical Part Values () Parentheses denote recommended values

C4 = 0.1µf to 1µF* (0.68µF 400V)
C5 = 47µF to 470µF* (150µF 400V or 270µF 200V)
C7, C8 = 47µF to 300µF* (47µF 450V or 220µF 200V)
C17 = 0.01µF to 0.47µF >= 100V
C19-22 = 1000pF to 0.01µF 1kV

D1-4 = HER108, 1N4007, UF4007

R12(a & b) = 100 to 20k
R13-16 = 10-ohm 1W
R17 = 100-1K
R18 = 300k 1W
R19 = 100k 1W

*Voltage depends on transformer used.
All must exceed the B+ voltage.

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 it own pair of R12 resistors. The resulting parallel resistance is shown in the chart at the top of page 13. 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 delivers 250Vdc to the tubes.

R	R12a	R12b	Imax mA	Vmax	Wattage	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

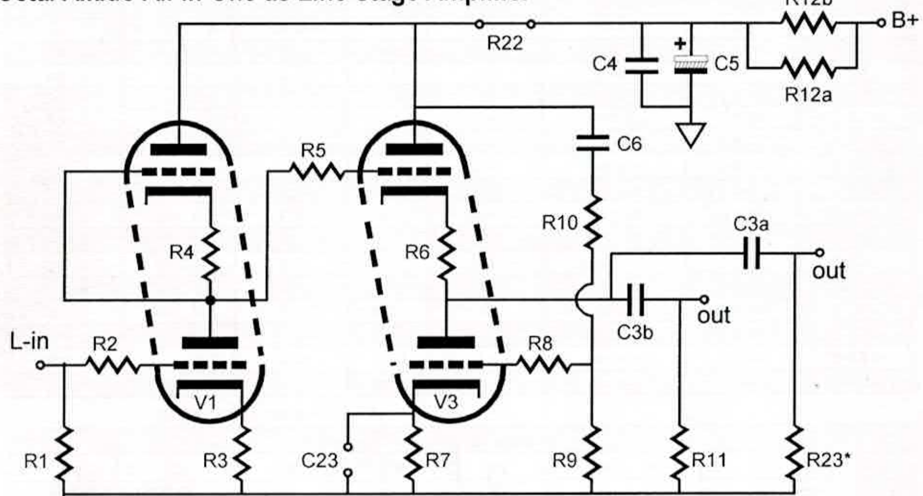
R	Voltage Drop Against Current															
889	9	11	12	14	16	18	20	21	23	25	27	28	30	32	34	36
1043	10	13	15	17	19	21	23	25	27	29	31	33	35	38	40	42
1135	11	14	16	18	20	23	25	27	29	32	34	36	39	41	43	45
1200	12	14	17	19	22	24	26	29	31	34	36	38	41	43	46	48
1295	13	16	18	21	23	26	28	31	34	36	39	41	44	47	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

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 All-in-One as Line Stage Amplifier



*R23 mislabeled R22 on PCB

Typical Part Values

() Parentheses denote recommended values

	6SN7 & 6SN7 (12SX7 & 12SX7)	6SL7 & 6SN7 (12SL7 & 12SN7/12SX7)	6SN7 & 6H30Pi (12SN7/12SX7 & 6H30pi)	12SX7 & 12SX7 (Low-Voltage Setup)
B+ Voltage =	300V	300V	300V	120V
Vac to Rectifiers =	240V	Same	Same	115V - 120V
R1,11, 23 =	1M	Same	Same	Same
R3,4 =	680* [Iq = 6mA]	1k* [1mA]	680* [Iq = 6mA]	330* [Iq = 3mA]
R2,5,8 =	100 - 1k (300)*	Same	Same	Same
R6,7 =	300* [Iq = 9mA]	300* [Iq = 9mA]	470* [Iq = 17mA]	330* [Iq = 3mA]
R12a =	2K	3k	2k	6.8k
R12b =	None	None	3.9k	None
R10 =	82.5k	82.5k	78k	82.5k
R9 =	100k	Same	Same	Same
R17 =	300K	Same	Same	Same
R18 =	82k	82k	82k	75k

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

C3 =	0.1 - 4µF* Film or Oil	"	"	"
C4 =	0.01 - 1µF* Film or Oil	"	"	"
C5 =	150µF*	"	"	"
C6 =	0.1 - 1µF* Film or Oil	"	"	"
C7 =	47µF 450V	"	"	220µF 200V
C8 =	0.1µF 160V	"	"	"

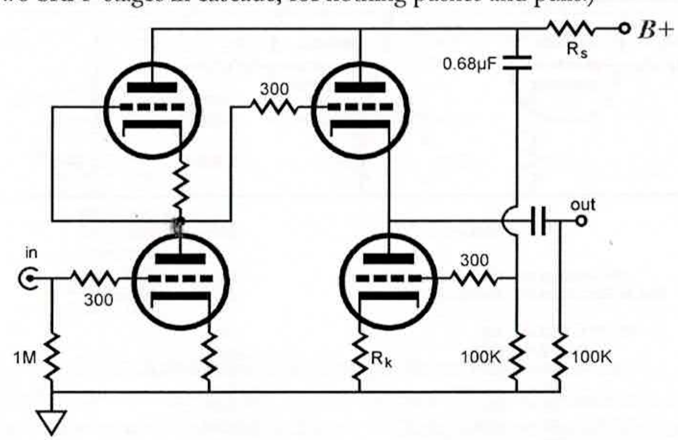
*Voltage rating must equal or exceed B+ voltage

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 octal *All-in-One* 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 Rk and Rs. 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)

If these resistors are not carefully chosen, then much of the magic disappears. I do not like to repeat myself, but the following two-step design procedure is worth repeating. The first step is to find the cathode resistor's value for the output stage, which will ensure the deepest null in power-supply noise at the output:

$$Rk = rp(mu - 2) / (mu^2 + 3mu + 2)$$

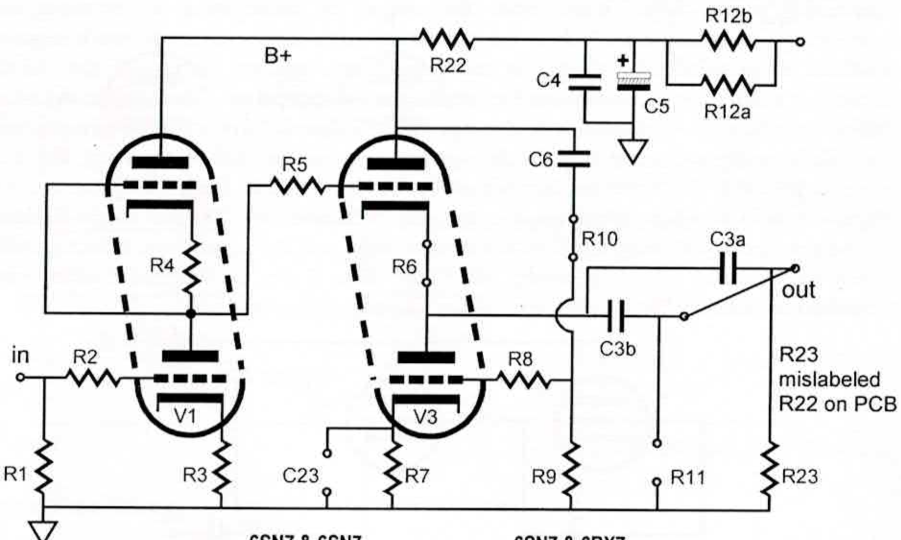
The second step is to find the resistance R, which is the effective resistance of one of the input stage's triodes and its unbypassed cathode resistor, not the output stage cathode resistor:

$$R = rp + (mu + 1)Rk$$

The third step is to plug R into Chris Paul's formula:

$$Rs = \frac{2 \cdot R \cdot mu[Rload(mu + 2) + mu \cdot rp]}{R \cdot mu^2(mu + 2) - mu \cdot rp(3mu + 4) - 2Rload(mu + 2)(mu + 1)^2}$$

Bear in mind that the resistor Rs (R22) is in parallel with the bottom triode's grid resistor (R9). If the ratio of Rg/Rs is more than 100, we can pretty much ignore Rg, as most resistors seldom are better than 1% accurate.



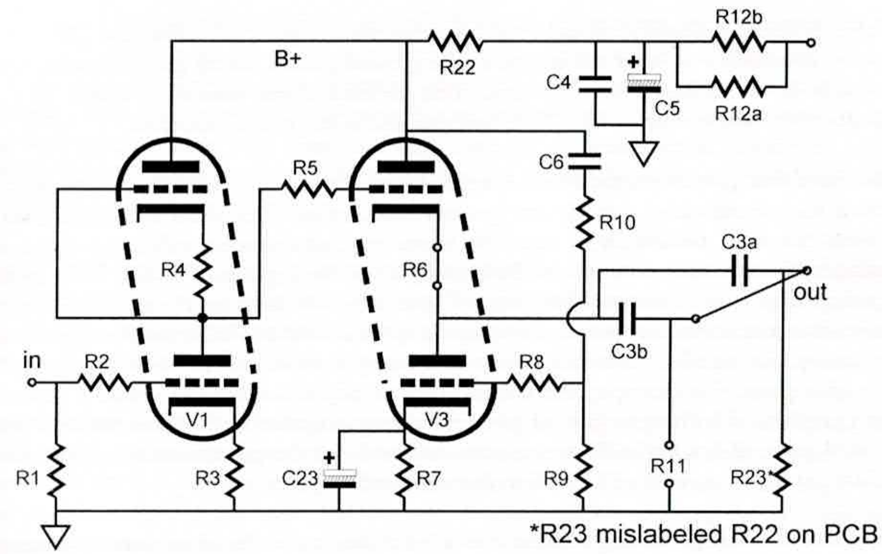
	6SN7 & 6SN7	6SN7 & 6BX7
B+ Voltage =	250Vdc - 280Vdc	150Vdc - 180Vdc
Vac to Rectifiers =	110Vac - 125Vac	220Vac - 250Vac
R1, R11, R23 =	1M	1M
R3, R4 =	470*	470*
R2, R5, R8 =	300*	300*
R6 =	Jumper	43*
R7 =	300*	150*
R9 =	100k	100K
R10 =	Jumper	Jumper
R22 =	680*	390*

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

	6SN7 & 6SN7	6SN7 & 6BX7
C3a =	30µF 250V Film	30µF 250V Flim
C3b =	0.1µF - 1µF 400V	0.1µF - 1µF 250V
C4 =	0.1µF - 10µF 400V	0.1µF - 10µF 250V
C5 =	150µF 400V	270µF 200V
C6 =	0.1 - 1µF* 400V	0.1 - 1µF* 250V
C23 =	None	None

*Voltage rating must equal or exceed B+ voltage

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 Zo 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

B+ Voltage =	250Vdc - 280Vdc
Vac =	220Vac - 250Vac or 440Vac CT to 500Vac CT
R1, R11 =	1M
R3, R4 =	470
R2, R5, R8 =	300
R6 =	Jumper
R7 =	100
R9 =	100k
R10 =	80.6k
R22 =	620
C23 =	1kµF

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.

Grounding

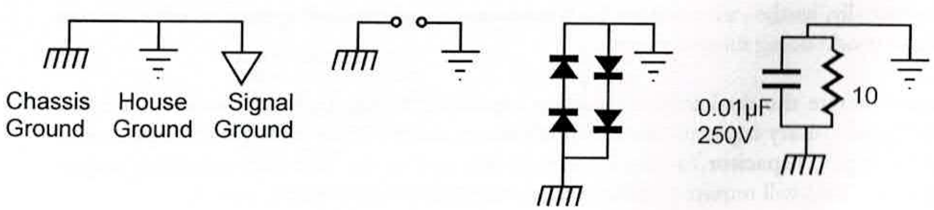
The *All-in-One* PCB holds a star ground at its center. Ideally, this will be the only central ground in the line-stage amplifier. Ground loops, however, are extremely easy to introduce. For example, if the RCA jacks are not isolated from the chassis, then the twisted pair of wires that connect the PCB to the jacks will each define a ground loop (as will jumper J13, which bridges the PCB's ground to the chassis). 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 *All in One* 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 (**<u>NOT NEUTRAL</u>**) via the third prong, and others still use a 10-ohm resistor shunted by a small capacitor, say 0.001µF to 0.1µF/250V.



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 which ever 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.

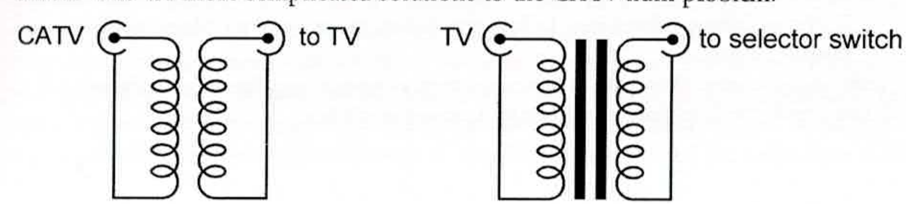
RFI Radio frequency interference can be a hassle to track down and eliminate. First make sure that the source of the problem actually resides in the line-stage amplifier. For example, if only one signal source suffers from RFI noise, make sure that it is normally RFI free. In other words, attach it to 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.

Chassis Ground Jumper J13 connects the PCB's ground to the chassis through the top leftmost mounting hole. If you wish to float the chassis or capacitor couple the chassis to ground, then either leave jumper J13 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; tubes, use metal washer in place of top O-ring.

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 my 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.



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 diodes in place, and then solder the resistors, rectifiers, capacitors, and heatsinks. Be consistent in orienting the resistors; keep all the tolerance bands on the resistor's body at the right side or top 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. It is often easier to attach the LD1085 (heater regulator) to its heatsink first (using the heatsink hardware kit) and then to solder both the heatsink and regulator to the PCB at once. 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.

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's transformer winding, leaving the high-voltage transformer 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 regulator's output 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 regulator and attach the high-voltage windings and insert the tubes in their sockets.
5. Attach the transformer 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.

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

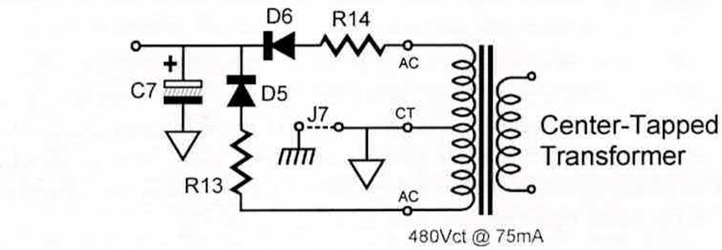
The bigger in value the coupling capacitor, the lower the -3dB high-pass corner frequency will be. The higher the load impedance, the lower the corner frequency. The formula is as follows:

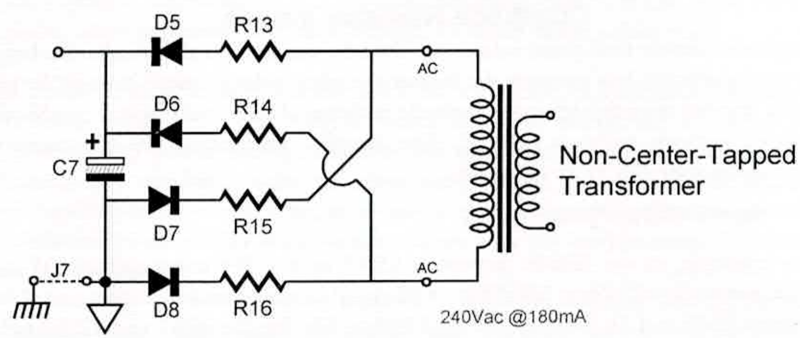
Frequency = 159155/C/R

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.

Transformers & Rectifiers

Transformers As shown below, the *All-in-One's* high-voltage regulator can use either a conventional tube-intended, high-voltage, center-tapped transformer or a non-center-tapped power transformer. The topmost transformer's current rating is in rectified DC yield, while the bottommost transformer, in AC current yield; nonetheless, both transformers deliver the same amount of power for the power supply. Never overlook that the rectifiers in the center-tap arrangement will see twice the peak reverse voltage that the rectifiers see in the full-wave bridge arrangement.





Step-up power transformers (115V to 230V), either standard EI or toroidal core, are excellent choices for the B+ transformer, as 230Vac becomes about 325Vdc to 340Vdc rectified, depending on the transformer's regulation, the current drawn by the load, and the wall voltage. (Of course, if you live in a country that uses 230V wall voltage, then the transformer will not be a step-up but a an isolation transformer.)

One danger is over voltage, as the power supply capacitors are only rated 400Vdc (or 200V) and the solid-state rectifiers do not drop the 10V to 40V that a tube rectifier would. In other words, be careful not to fry the capacitors with too much voltage. Furthermore, many high voltage power transformers suffer from poor regulation, which is the measure of the transformer's secondary voltage with no load over the secondary voltage with a load. For example, a 100Vac power transformer with a regulator figure of 10% will put out 110Vac with no load and 100Vac with its rated load. By the way, a regulation figure of 10% is fairly impressive in a high-voltage transformer, as many present 20% or 30% figures. Unfortunately for the power supply capacitors, tubes are slow to conduct, requiring time to warm up first. Thus during startup, the power transformer will effectively see no load, so its secondary voltage will equal its rated value plus its regulation figure against secondary voltage: Vpeak = 1.414 x (1 + Regulation) x Vsec. Be warned.

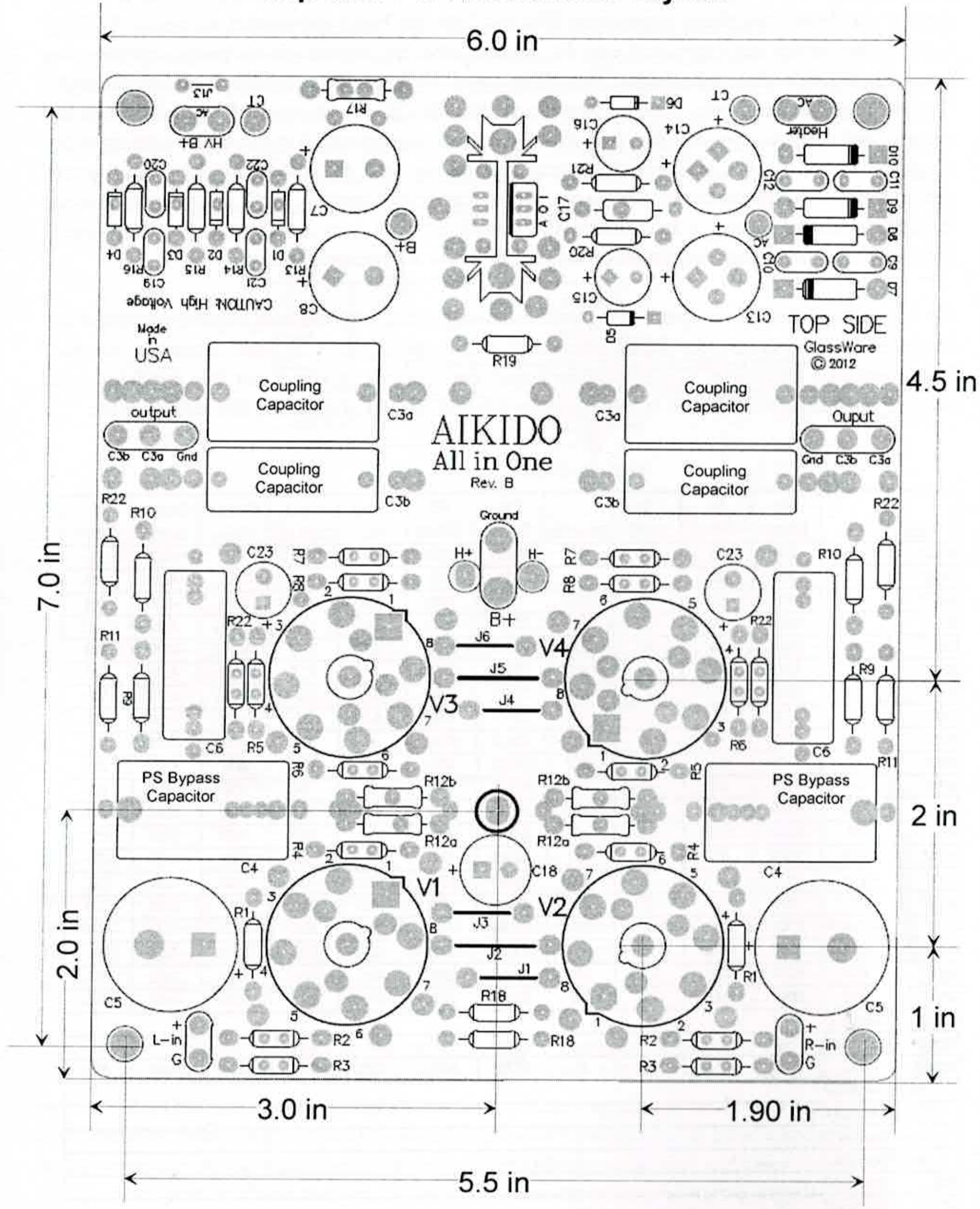
Dual Coupling Capacitors The PCB can hold two coupling capacitors, each finding its own 1M resistor to ground. Why? The idea here is that you can select (via a rotary switch) between coupling capacitors C3a or C3b or both capacitors in parallel. Why again? One coupling capacitor can be Teflon and the 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 lager 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.

Tube	mu	Rp Ohms	Rk Ohms	Ik (mA)	B+ Volts	R10 Ohms	R9 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
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
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 *All in One* 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).

Top Side PCB Mechanical Layout



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").