Aikido All In One

Aikido Stereo 5687 PCB

USER GUIDE

Dec 16 2011

GlassWare
AUDIO DESIGN

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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☛ Warning! ☚

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Overview

Thank you for your purchase of the GlassWare Aikido 5687 *All in One* 9-pin 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 board is 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, the5687 *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 5687 *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 an LDO voltage regulator to provide a stable and noise-free voltage output. The power supplies require an external power transformer(s) with two secondary windings, one for the B+ voltage and one for the heater power supply.

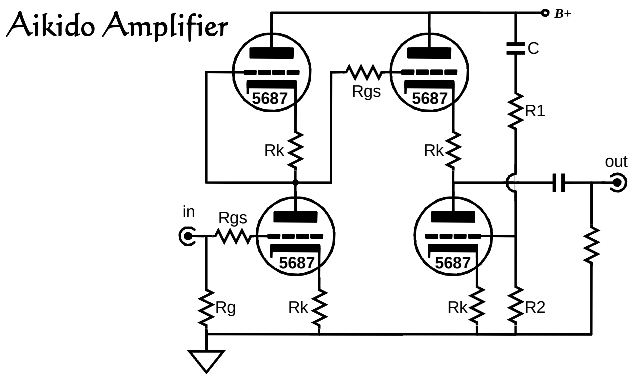
Redundant Solder Pads This board holds two sets of differently-spaced solder pads for each critical resistor, so that radial and axial resistors can easily be used (radial bulk-foil resistors and axial film resistors, for example). In addition, most capacitor locations find many redundant solder pads,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

Two Output-Stage Topologies The output stage can be configured either as the classic Aikido line amplifier or as an Aikido headphone amplifier. The 5687 is a robust triode that can deliver a lot of current at relatively low voltages, making it ideal for driving headphones or other low-impedance loads.

Power-Supply-Decoupling Capacitors The 5687 *All in One* 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.

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 5687 triodes are specified as an example only, as 300B 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 5687 is not the same as that same 5687 after 2,000 hours of use. But as long as the two triodes within the 5687 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

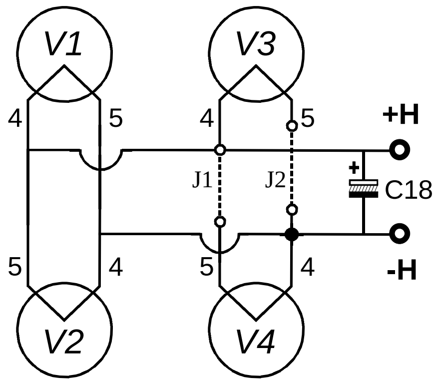
$$Gain = mu[(mu + 1)Rk + rp] / [(mu + 1)Rk + rp + (mu + 1)Rk + rp] = mu/2$$

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.

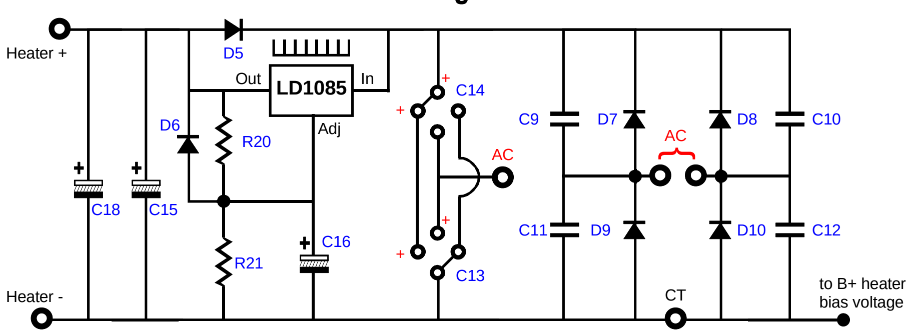
Heater Issues

The 5687 *All in One* PCB holds the heater's raw power supply and its DC voltage regulator. The regulator is an LD1085 low-dropout adjustable voltage regulator. The regulator can be set to an output voltage of 12V or 12.6V. The advantage of running a slightly low heater voltage (12Vdc) is that it extends tube life and can lower distortion a tad. All the 5687 tube's heaters are placed in parallel, so a 6.3V or 25.2V heater voltage cannot be used. Be sure use jumpers J1 and J2.

Filament Jumper Wire Schedule

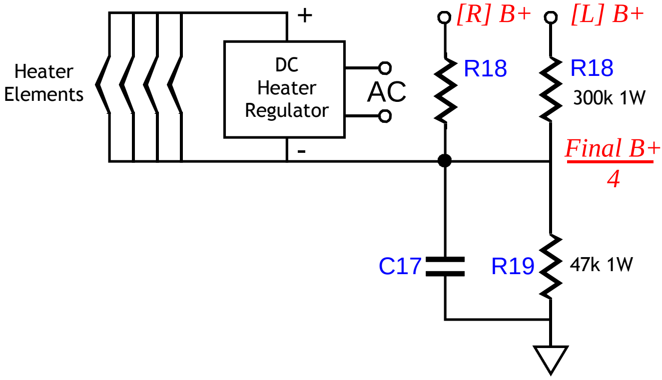


Filament Regulator



As can be seen, the power supply can accept either a 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 ("CT") pad at the bottom of the PCB; the secondary attaches to single "AC" pad in between capacitors C13 and C14 and AC pad number 2 that feeds rectifier D7 and D9; and D8, D10, 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 (1 & 2) and the secondary center-tap attaches to the CT pad and C11, C12, D9, and D10 removed. See the inside back cover for more information.

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. 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.

Typical Part Values

Heater Voltage =	12V	12.6V
R21 =	1.07k	1.13k
R20 =	124	124
D7 - D10 =	MUR410G	"
D5, D6 =	1N4007	"
C9, 10, 11, 12 =	0.1µF / 50V	"
C13, C14 =	10kµF*	"
C15, C16 =	1kµF / 16V	"
C18 =	1k-3900µF*	"
Regulator =	LD1085, LT1085	
Vac Input =	12Vac or 12.6Vac @ 3.5A for or 12Vdc or 12.6Vdc	

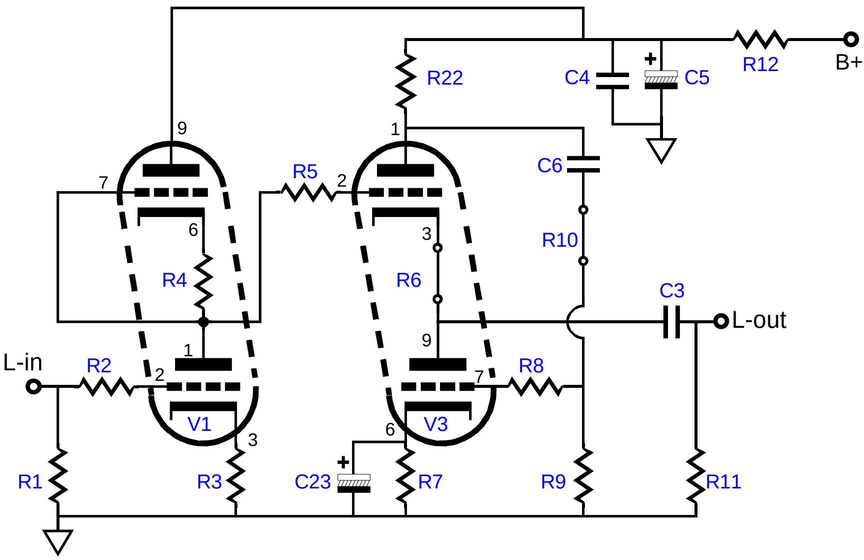
*Capacitor voltage must exceed 1.414 x Vac input voltage

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

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

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 stages can only deliver up to the idle current into a load, whereas class-A push-pull stages can deliver up to twice the idle current into the load. For a line stage, such big voltage and current swings are seldom required; headphones, on the other hand, do demand a lot more power; really, a 32-ohm load is brutally low impedance for any tube to drive. Fortunately, the PCB can be configured with an optimal White cathode-follower stage, which will both retain much of the Aikido's great PSRR and allow up to twice the idle current to be delivered into low-impedance loads. All that is required is to include resistor R22 and capacitor C23 and replace resistors R6 & R10 with jumper wires.



Headphones require big current swings and little voltage swings, so we should lower the B+ voltage and raise the idle current, say 160Vdc and 24mA for the output tubes (Rk = 47 ohms). A coupling capacitor of at least 30µF is required when driving 300-ohm headphones; 330µF for 32-ohm headphones. Capacitor C3 can be bypassed by using a small film or PIO capacitor on bottom of the PCB.

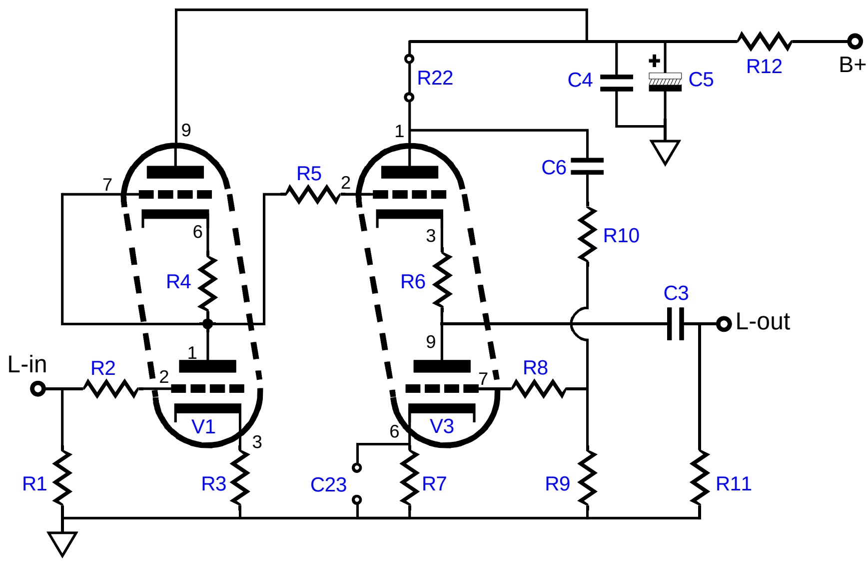
In the optimal White cathode follower, the critical resistor is R22. This resistor is used to sense current flow variations through the top triode and to create an anti-phase signal that is relayed to the bottom triode's grid. In other words, it sets the dynamic current balance between top and bottom tubes. A value that is too high or too low will compromise performance. Finding the correct value for resistor R22 is easy:

$$\mathbf{R22 = (rp + 2R_{load})/mu,}$$

where rp equals the plate resistance and R_{load} equals the load impedance. From a quick inspection, we see that the lower the load impedance, the closer the formula comes to: Ra = rp/mu. On the other hand, when the load impedance is as much as 600 ohms and the rp as low as the 5687's 1600 ohms, then the difference is fairly large.

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 to replace resistor R22 with a jumper wire and leave capacitor C23 off the PCB. The following table list four recommended configurations, but actually there are in infinite number of possible setups.



Typical Part Values

() Parentheses denote recommended values

Tubes =	**5687 & 5687**	**5687 & 5687**	**5687 & 5687**	**5687 & 5687**
B+ Voltage =	100V	150V	200V	250V
AC Secondary =	150 - 170Vac	230 - 250Vac	200 - 250Vac	115 - 120Vac
AC Current =	50mA	60mA	80mA	60mA
Heater Voltage =	6.3V or 12.6V	6.3V or 12.6V	12.6V	6.3V or 12.6V
Heater Current =	2A or 1A	2.5A or 1.25A	0.75A	1.5A or 0.75A
R1,11 =	1M	1M	1M	1M
R2,5,8* =	100 - 1k (300)	Same	Same	Same
R3,4* =	100 - 470 (300, 5.5mA)	300 - 1k (390, 7mA)	300 - 1k (390, 10mA)	300 - 1k (845, 7mA)
R6,7* =	200 - 340 (150, 8mA)	200 - 470 (240, 10mA)	200 - 470 (300, 12mA)	300 - 1k (680, 10mA)
R9 =	100k	Same	Same	Same
R10 =	78.7k	78.7k	78.7k	78.7k
R22 =	Jumper	Same	Same	Same

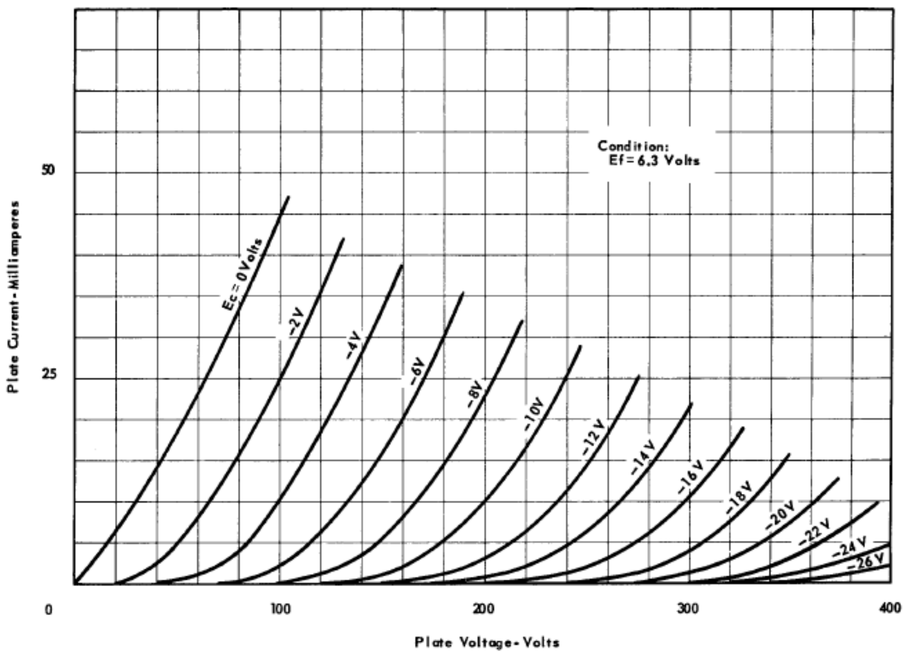
*High-quality resistors essential in this position. All resistors 1/2W or higher

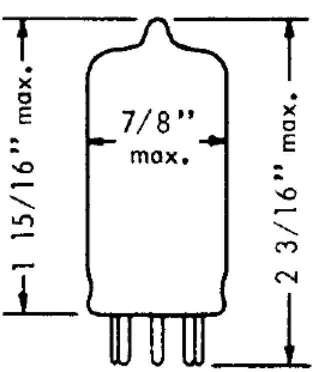
C1, C2 =	0.01-0.33µF (optional)	Same	Same	Same
C3* =	0.1 - 4µF Film or PIO	"	"	"
C4* =	0.01 - 1µF Film or PIO	"	"	"
C5 =	270µF 200V	270µF 200V	150µF 400V	150µF 400V
C6* =	0.1 - 1µF Film or PIO	Same	Same	Same
C7, C8 =	220µF 200V	220µF 200V	47µF 450V	47µF 450V
C23 =	None	None	None	None

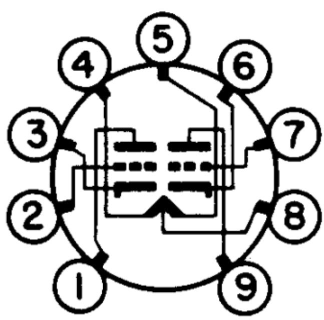
*Voltage rating must equal or exceed B+ voltage

5687 Specifications

Heater Voltage	6.3V & 12.6V
Heater Current	900mA & 450mA
Maximum Plate Voltage	330V
Maximum Plate Dissipation	4.2W
Maximum Cathode Current	65mA
Maximum Cathode-to-heater Voltage	100V
Amplification Factor	18.5
Transconductance	11.5mA/V
Plate Resistance	1600 Ohms
Grid-to-Plate Capacitance	0.75pF







RETMA 9H
Bottom View

Pin 1: Plate, triode 2
Pin 2: Grid, triode 2
Pin 3: Cathode, triode 2
Pin 4: Heater
Pin 5: Heater
Pin 6: Cathode, triode 1
Pin 7: Grid, triode 1
Pin 8: Heater center-tap
Pin 9: Plate, Triode 1

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 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.

Grounding

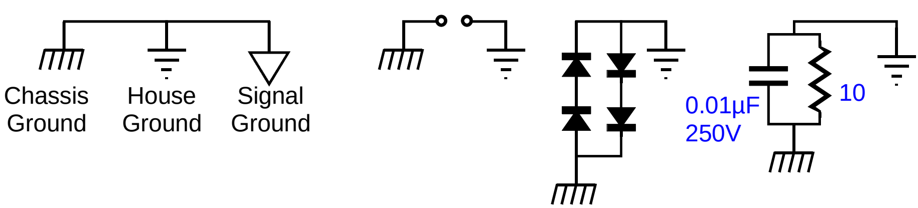
The 5687 *All-in-One* PCB holds a star ground at its center. Ideally, this will be the only central ground in the line-stage amplifier. Ground loops, however, are extremely easy to introduce. For example, if the RCA jacks are not isolated from the chassis, then the twisted pair of wires that connect the PCB to the jacks will each define a ground loop (as will jumper J3, 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 time consuming to layout, 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 5687 *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 (**NOT NEUTRAL**) via the third prong, and others still use a 10-ohm resistor shunted by a small capacitor, say 0.001 µF to 0.1 µF/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.

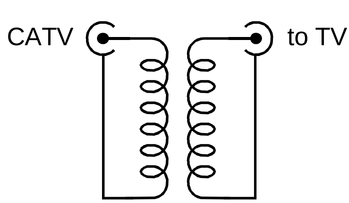
RFI Radio frequency interference can be a hassle to track down and eliminate. First make sure that the source of the problem actually resides in the line-stage amplifier. For example, if only one signal source suffers from RFI noise, make sure that it is normally RFI free. In other words, attach it to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

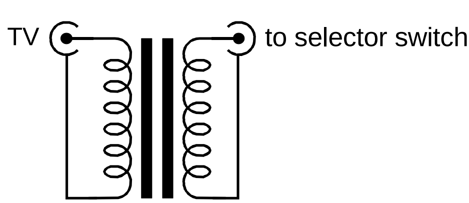
Ferrite beads can also help; try using beads on the hot lead as it leaves the RCA jack and then again at the selector switch. Increasing the grid-stopper resistor's (R2) value, say to 1k, can also work wonders (use a carbon-composition or bulk-foil resistor or some other non-inductive resistor type).

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 J7 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 J7 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.

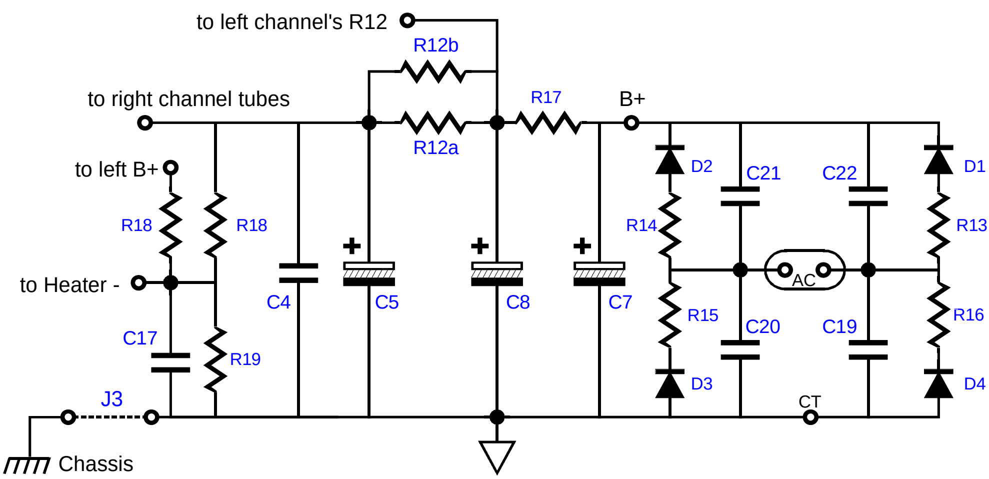




B-plus Power Supply

The high voltage B-plus power supply resides on the Aikido 5687 *All in One* PCB. It contains a full-wave bridge rectifier circuit and reservoir capacitor, which is then followed by an RC, ripple-smoothing filter. 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 your strategy. 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. In addition, a typical 200V 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. Normally, a higher B+ voltage is better, as it allows the tubes to draw more current, but the 5687 can draw an amazing amount of current at low plate voltages. In other words, we can get away with a lower B+ voltage, because the 5687 is so well suited to low-voltage use. Configured as a headphone amplifier, the lower B+ voltage, say 150Vdc, is the only way to go.

On the other hand, the 5687 can be used with higher voltages, as its maximum plate voltage is 330V. The sky is not the limit here, however, as the 400V power supply capacitors and the 100V maximum heater-to-cathode voltage set an upward limit of about 350V for the raw power supply voltage just after the rectifiers and about 300V at the tubes after the RC filter.



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

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

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

RC Power-Supply Filter

Resistors R12a and R12b are in parallel. The 5687 *All in One* resistor power supply kit supplies six 3W resistors for R12 use: 1.6k, 2k, 3k, 3.9k, 6.8k, and 10k. Each resistor can be used in isolation or in parallel with one other resistor. Many possible combinations are possible; the resulting parallel resistance is shown in the following chart, which show the voltage drop across the R12 versus the current flow. Remember each channel gets it own pair of R12 resistors. For example, a 5687 *All in One* line-stage amplifier might run each tube with 10mA of idle current, for a total of 20mA per channel. So by looking up the 20mA column, we can see the resulting voltage drops. Thus, one 1.6k resistor will drop 32V, so a 170Vdc raw DC power supply will deliver 148Vdc to the tubes. An * denotes excessive current or voltage, so that combination cannot be used without risking damaging the at least one of the resistors.

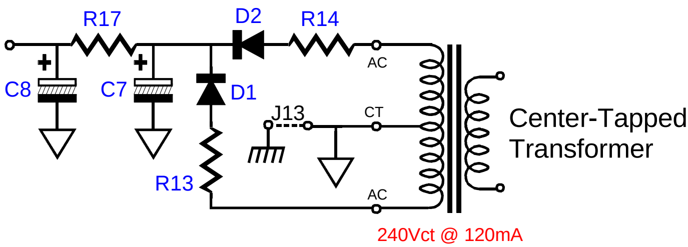
R	Voltage Drop Against Current															
889	9	11	12	14	16	18	20	21	23	25	27	28	30	32	34	36
1043	10	13	15	17	19	21	23	25	27	29	31	33	35	38	40	42
1135	11	14	16	18	20	23	25	27	29	32	34	36	39	41	43	45
1200	12	14	17	19	22	24	26	29	31	34	36	38	41	43	46	48
1295	13	16	18	21	23	26	28	31	34	36	39	41	44	47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

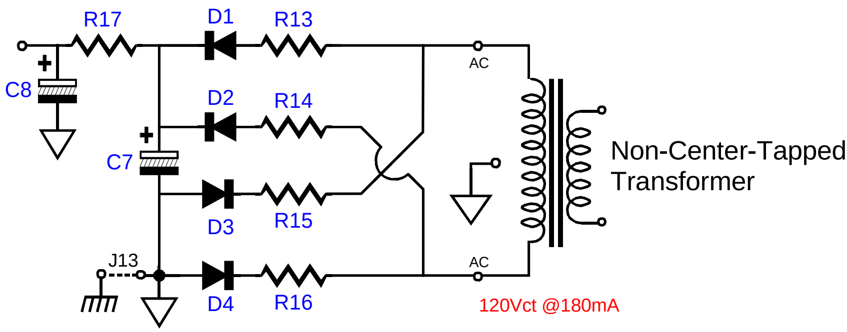
x denotes that either the voltage or the current exceeds the resistor(s) limit

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

Transformer-Rectifier Configurations

Transformers As shown below, the 5687 *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.





An isolation or step-up or step-down power transformers (115V or 230V), either standard EI or toroidal core, are excellent choices for the B+ transformer, as 120Vac becomes about 170Vdc rectified, depending on the transformer's regulation, the current drawn by the load, and the wall voltage. One great advantage that the 5687 tube offers is ability to draw a heavy current in spite of a low plate voltage. For example, a 12AU7 working in an Aikido line-stage amplifier with a final B+ voltage of 150Vdc can draw only about 5mA, whereas a 5687 in the same Aikido line-stage amplifier can draw 10mA to 20mA. Thus, although a 5687 can withstand a cathode-to-plate voltage of 330V, it can work beautifully with only 75Vdc of plate voltage in an Aikido line-stage amplifier with a B+ voltage of 150Vdc.

One danger is over voltage, as the power supply capacitors are only rated 200Vdc (or 400V) 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.

The heater power supply power transformer winding must offer at least 1.8 times more current than the heaters will draw. The four 5687s will draw 1.8A @12.6v, so the heater power transformer must be able to sustain an AC 3.3A current draw, when used in a full-wave bridge rectifier circuit. In addition, with sine waves, the AC voltage equals the AC peak voltage divided by the square root of 2, i.e. 1.414. Thus, a 10Vac sine wave peaks at 14.14Vpk. 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; thus, we label the 14.14Vpk sine wave as being 10Vac. Therefore, in order to get the raw 16Vdc a 12.6V regulated heater voltage power supply requires, a secondary voltage equal to sum of 16V and the rectifier loss (about 1.1V with the MUR410G rectifiers) divided by 1.414, which is roughly 12Vac.

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 + 2V) / 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 center-tapped, high voltage primary can be used; just leave C19, C20, D3, D4, R15, and R16 off the board, then attach the center-tap to CT PCB pad. In the full-wave, center-tap rectifier configuration, the DC current is multiplied against 1.2 to find the AC current rating. (Most high voltage, center-tap power transformer already include this current conversion ratio in their specifications. For example, such a transformer with a 100mA rating can deliver 100mA DC after rectification.)

Tube Selection

Although intended to be used with four 5687 tubes, other tubes can be used, as as they share the 5687 tube's 9H pinout, such as the 6900, 7044, 7119, 7370, 7892, and E182CC. Tubes that share the 5687's electrical characteristics but not the 9H pinout, such as the ECC99, cannot be used.

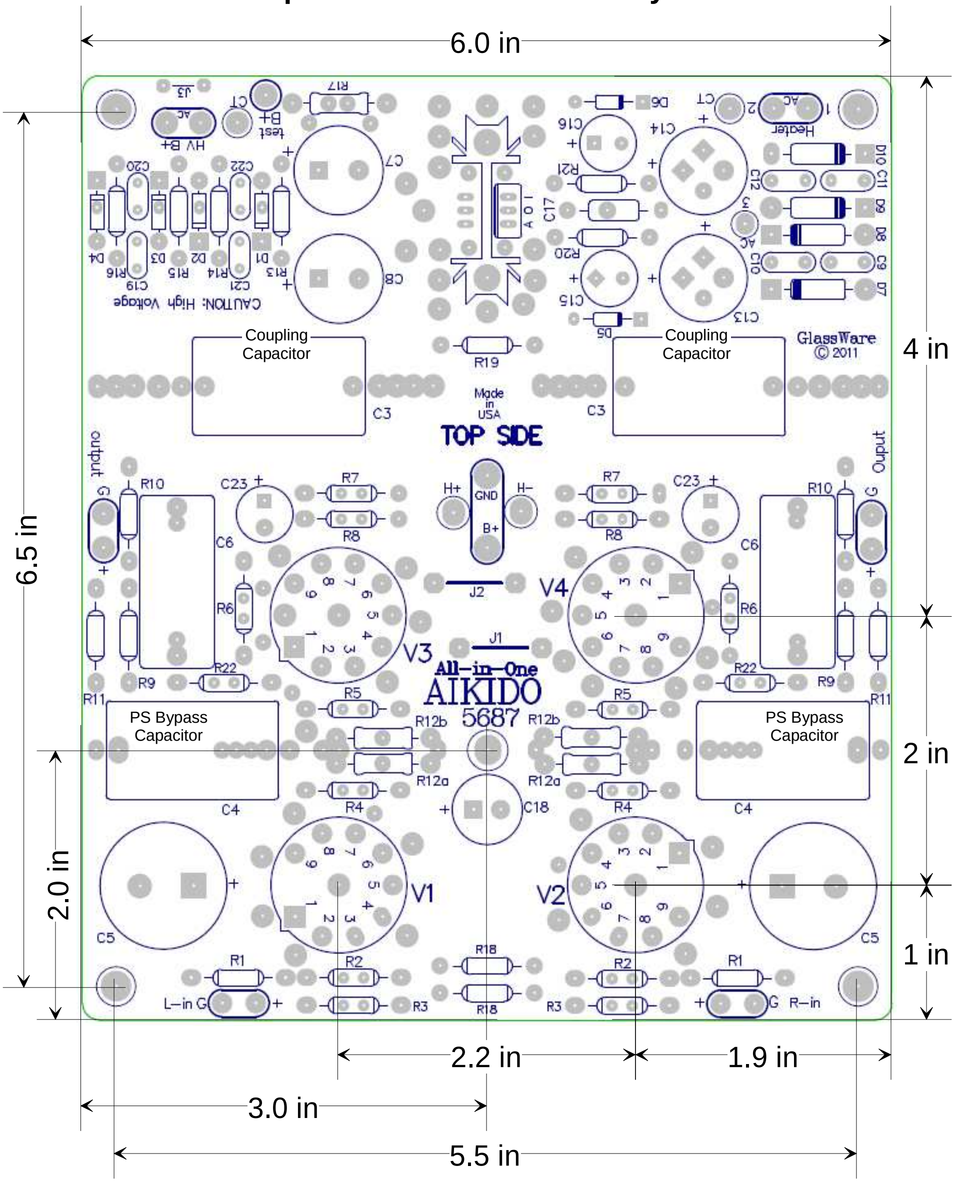
Cathode Resistor Values

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 Iq is an easy one:

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

So, for example, a 5687 in an Aikido circuit with a B+ voltage of +160V and 430-ohm cathode resistors will draw 160/2(2.73k + [16.5 + 1]430) amperes of current, or 7.8mA. I recommend a cathode resistor value between 300 to 680 ohms for the input tubes; between 200 to 470 ohms for output tubes. Of course, the other big variable is the B+ voltage. Because the cathode resistors see so little voltage differential, 1/2W resistors can readily be used.

Top Side PCB Mechanical Layout



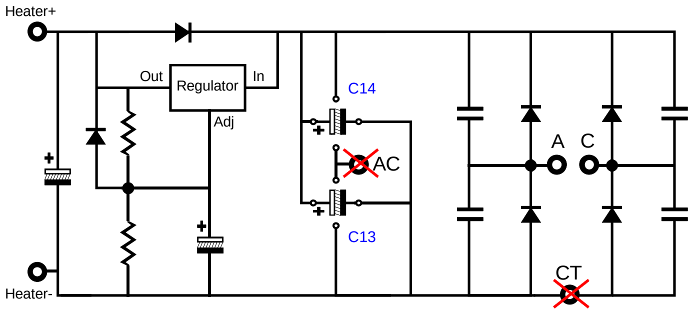
Let me know what you think

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 coupling capacitor value or cathode resistor values, drop me a line by e-mail to the address on the back cover (begin the subject line with either "Aikido" or "tube" or the spam filters are sure to eat your message).

Heater PS Configurations

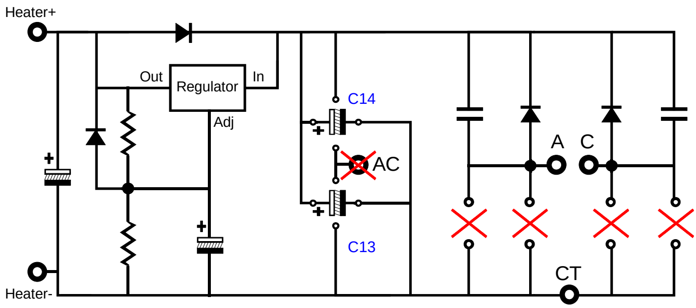
Full-Wave Bridge

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



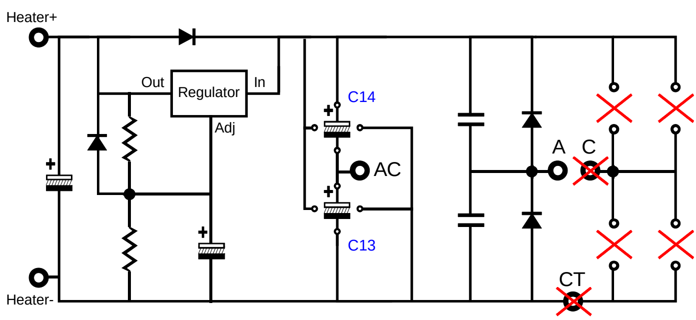
Full-Wave Center-Tap

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 "CT" pad at bottom of PCB.
Fullwave-Volatge-Doubler Rectification. Raw DC voltage = 2.828Vac - 1.4V



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