CCA

Cathode Coupled Amplifier

9-Pin PCB

USER GUIDE

Dec 11 2010

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.

GlassWare
AUDIO DESIGN
www.glass-ware.com
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 Cathode-Coupled Amplifier [CCA] 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 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 cathode-coupled amplifier line-stage amplifiers and two Aikido cathode follower output stages; 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 Cathode-Coupled Amplifier (CCA) 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

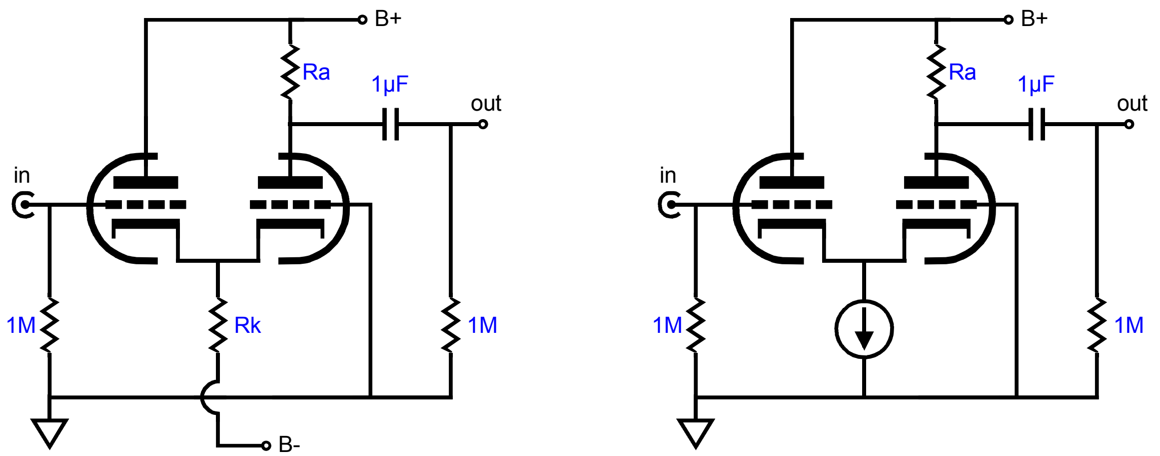
B+ and Heater Power Supplies On the CCA board, two power supplies reside, one for the high-voltage B+ for the tubes and a low-voltage power supply for the heaters. The high-voltage power supply uses two RC filters to smooth away ripple, while the low-voltage power supply uses an LDO voltage regulator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

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.

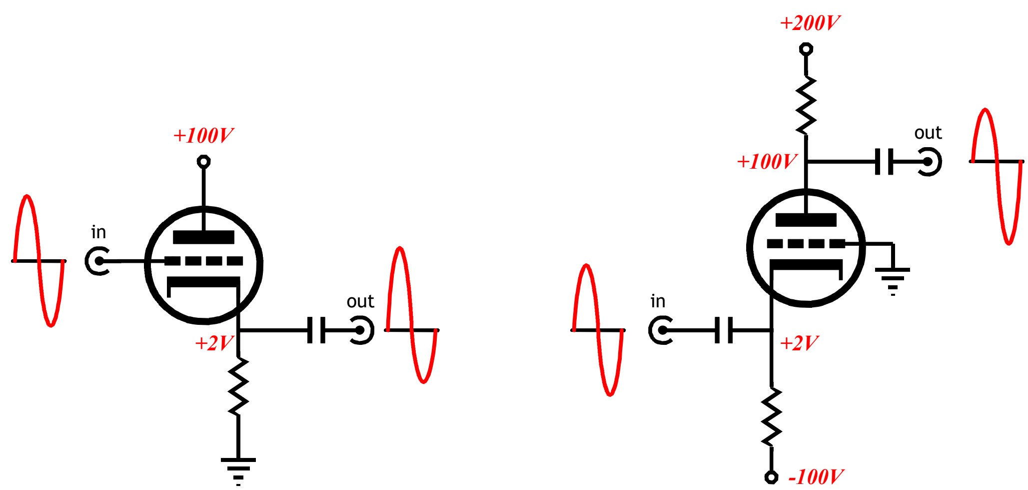
Multiple Heater Arrangements The CCA PCB allows either 6.3V or 12.6V heater power supplies to be used; and 6V tubes, such as the 6CG7, can be used with 12V tubes, such as the 12BH7 (if a 12V heater voltage is used).

Power-Supply-Decoupling Capacitors The CCA PCB provides cascading RC high voltage power supply filters to decouple both gain stages from the B+ connection and each other. This arrangement uses large-valued electrolytic capacitors and small-valued film capacitor in parallel, while a series voltage-dropping resistor completes the RC filter. In place of the first RC series resistors off-board chokes can be used and resistors R12 can be replaced with off-board chokes as well.

Introduction to the Cathode-Coupled Amplifier



Cathode-Coupled Amplifier Topology The cathode-coupled amplifier is well named, as its primary topological attribute lies in its having a shared cathode connection between the input triode (on the left) and the output triode (on the right), which works into a single plate resistor. In other words, it deconstructs into a cathode follower directly coupled to a grounded-grid amplifier.

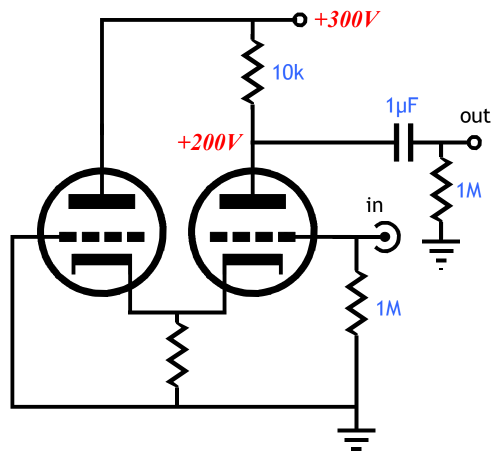


Cathode Follower

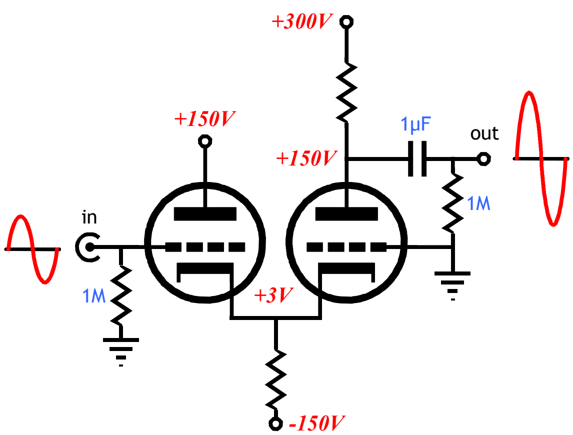
Grounded-Grid Amplifier

No doubt, at the mention of "cathode follower," a few have already grown nervous. "All cathode followers are sonically bad, aren't they?" they ask. "Bad in what sense?" I answer. If any amplifier sounds bad, it must be distorting the signal in some way. Now, let's say that the cathode follower is bending the signal in the wrong direction, the question is: What happens when its bent signal then drives a grounded-grid amplifier's cathode input? If the grounded-grid amplifier were a perfect amplifier, a bent signal would be amplified bent. However, the grounded-grid amplifier, like all amplifiers, is not perfect; it bends just as much as the cathode follower does. Now, do the two circuits bend in the same direction or opposite directions? Since the common-cathode produces such a clean output, the answer can only be that they bend in opposite directions; in other words, the grounded-grid amplifier undoes the cathode follower's twist of the signal by twisting in the other direction, resulting in a more linear output signal.

In fact, if the cathode-coupled amplifier is driven from the "wrong" input, the right triode's grid, while the left triode's grid is grounded, the distortion produced is lower than obtains with a comparable grounded-cathode amplifier. How's that possible? The left triode effectively becomes a cathode resistor, but not so nearly a linear a resistor as the worse-made resistor sold today. But since the amplifying (right) triode is not perfectly linear, the triode as resistor counter balances the triode as amplifier to straighten the transfer curve. This configuration, however, does not shield the input from the Miller-effect capacitance.



Modified Grounded-Cathode Amplifier

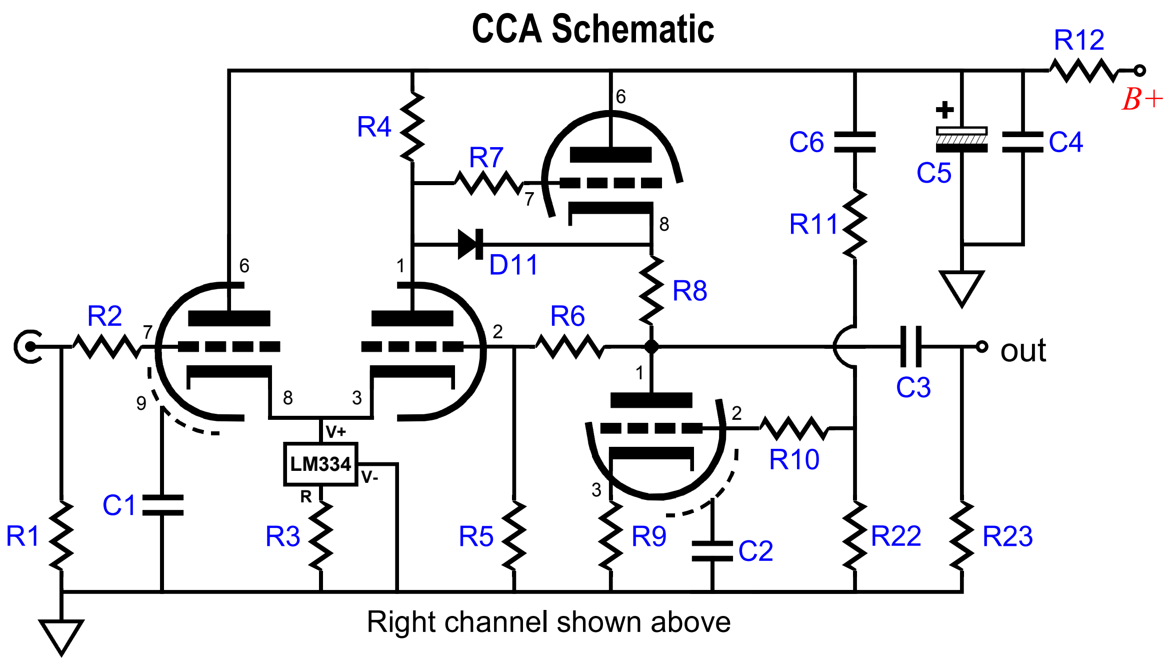


Cathode-Coupled Amplifier

In the cathode-coupled amplifier, the input triode's plate is, in AC terms, terminated into the B+ connection and its grid receives the input signal, while its cathode is connected to the right triode's cathode and to a shared resistor that usually terminates into a negative power supply. As the input signal swings positive, the left triode's cathode follows, forcing the right triode's cathode more positive; thus making the grid voltage of the right triode even more negative relative to its cathode.

This negative change in cathode-to-grid voltage forces a decrease the current flowing through the right triode and, because they are in series with each other, through its plate load resistor, which in turn results in a smaller voltage drop across the plate resistor, causing a positive voltage swing at the output; thus no phase inversion. A positive signal voltage applied to the right triode's grid will cause the cathode-coupled amplifier output to swing negatively, not positively, which allows us to use this second input as a negative feedback input. And unlike a grounded-cathode amplifier's cathode, offers a supremely high input impedance, making the cathode-coupled amplifier a closer approximation to an ideal OpAmp.

The cleanliness of this picture is dirtied by the problem of providing the correct DC biasing for the two grids. Remember, the current flowing through a triode is defined by the cathode-to-plate voltage and the cathode-to-grid voltage. If the first triode has a cathode to plate voltage of 300 volts and the second triode, 150 volts because of the voltage drop across the plate resistor, then the left tube's cathode to grid voltage must be even more negative to match that of the left triode. One solution, although not a desirable one, is to provide two power supplies: a 150 VDC for the first triode and a 300 VDC for the second triode. The solution used on the CCA PCB is to give the right triode's grid a more positive grid voltage than the left triode's grid.



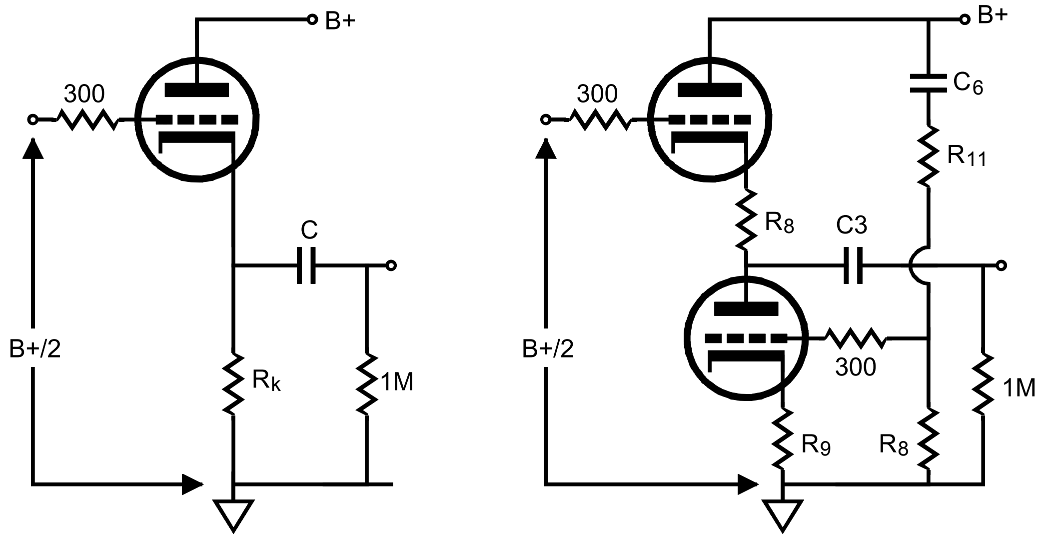
In fact, if the using CCA circuit didn't entail dealing with dissimilar cathode-to-plate voltages, this topology would be much more popular, as it has so much to offer, such as low distortion, low input capacitance, no phase inversion, and a high-impedance feedback port. The cathode-coupled amplifier, however, needs a bit more help to become a first-rate line-stage amplifier, as its output impedance is too high and PSRR is weak (almost nonexistent). Adding an Aikido cathode follower to the CCA input stage makes a complete, high-quality line-stage amplifier that offers low distortion, low input capacitance, low output impedance, wide bandwidth, no phase inversion, and a stellar PSRR figure.

In the schematic above, on the leftside, we see two CCA triodes that share a common constant-current source, the LM334, and same B+ voltage, but with differing DC grid voltages The goal here is to ensure that the two CCA triodes share identical current draws, as the identical idle currents helps linearize the combined tube's transfer function. Keeping the idle currents equal while using the single B+ voltage, however, entails giving the CCA triodes differing DC grid-bias voltages.

Finding the right values for resistors R5 & R6 is easy enough. As we all know, a triode's amplification factor is simply a measure of the relative effectiveness of the grid over the plate in controlling the current flow through the triode. Thus, a triode with a mu of 10 holds a grid that is 10 times more efficient than its plate. So an increase in plate voltage of 10 volts can be countered by a decrease of 1V on the grid. In other words, we can maintain a fixed idle current in spite of a 10V increase in plate voltage by moving the grid 1V more negative. Thus, we need a voltage that yield a 1/mu voltage division; so R6 should be (mu – 1) times bigger than R5. This wonderful trick works because the voltage from ground to the Aikido cathode follower's out is equal to the voltage across the plate resistor, R4, which is also the difference in plate voltages.

The LM334 constant-current source is optional, as resistor R3 can be used by itself. On the other hand, the LM334 constant-current source does reduce the distortion substantially and increases the gain a tad, but it does make the CCA a more sensitive to changes in the B+ voltage and will require more circuitry tweaking to obtain as low a noise figure as the simple common-cathode resistor achieves.

Aikido Cathode Follower



Cathode Follower **Aikido Cathode Follower**

Here is a new circuit born from the rib of the two-stage Aikido amplifier topology. In other words, it is basically the last half of the Aikido amplifier, which uses a modified cathode follower circuit as the output stage. 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, thereby lowering its distortion. The Aikido cathode follower gives the GlassWare CCA its low output impedance and great PSRR.

Why is the Aikido cathode follower needed? The cathode-coupled amplifier, by itself, is not a good line-stage amplifier, as its output impedance and power-supply noise are too high.

The obvious solution to the problem of too high a Zo is to add a cathode follower to the cathode-coupled amplifier's output. This solution makes a lot of sense, as the cathode follower offers a gain close to unity and both a low output impedance and distortion figure. A cathode follower, however, isn't the only circuit that will work as a buffer. For example, the plate-follower and White cathode follower also provide unity-gain, a low output impedance and distortion figure. The cathode follower, however is the most popular buffer, as it is the simplest. So simple in fact that a cathode follower can be made from just three resistors and one coupling capacitor as supporting parts. Several modifications to this simple circuit are possible. For example, the cathode resistor can be replaced by a choke, which will function as a constant-current source in AC terms. Another possibility is to replace the cathode resistor with a high voltage constant-current-source circuit.

Unlike the grounded-cathode amplifier, whose PSRR improves by the replacement of the plate resistor with a constant-current source, the cathode follower's PSRR worsens with the replacement of its cathode resistor by a constant-current source. Why? In the grounded-cathode amplifier circuit, the constant-current source shields the plate from the noise source; but in the cathode follower circuit, the triode shields the constant-current source from the power-supply noise. With no external load impedance and a true constant-current source, the cathode follower's PSRR falls to 1/mu; thus the higher the mu, the smaller the percentage of power-supply noise making to the output.

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. Since the cathode follower already enjoys 100% degeneration at its cathode, the slight reduction in distortion by using the triode-based load is not as marked as in is in a grounded-cathode amplifier, but it is a worthwhile modification. I addition, the active load allows us to anticipate the power-supply noise that would normally appear at the output and counter this noise before it can appear.

Imagine that the output coupling capacitor is infinitely large in value and that the load impedance is zero ohms and that the input is grounded. No power-supply noise could make it to the follower's output. Now imagine no power-supply noise at the output, but with no coupling capacitor or external load, with only the bottom triode providing a current path into the top triode and the B+ connection. In both scenarios, only the top triode sees the power-supply noise at its plate. Thus, any signal (power-supply noise) on the top triode's plate will impose a current conduction variation in the top triode equal to Vnoise / (rp + [mu + 1]Rk). Since the both tubes are in series, the bottom triode must match this current variation to null the noise at the follower's output. So, in the ideal setup, the top triode sees a fixed cathode and grid voltage, while its plate varies with the power-supply noise; and the bottom triode sees a fixed plate voltage, while its grid's voltage is varied to provoke a matching variation in current conduction.

A triode's a grid is—by definition—mu times more effective than the plate in controlling triode's current conduction; thus, the bottom triode's grid must see the power supply noise dived by the mu of the triode used. For example, a 6GC7 (with a mu of 20) will need to see 1/20th of the power supply noise at its grid; a 12AX7 (with a mu of 100), 1/100th of the power supply noise at its grid. Therefore, the voltage divider resistors must conform to the following ratios:

R11/R22 = mu-1 and **R11 = R22(mu-1)** and **R22 = R11/(mu-1)**

For example, with a 12AU7 (with a mu of 17), R11 would equal 17 x R22; with a 12AX7 (with a mu of 100), R11 equals 99 x R22. The coupling capacitor feeds the two-resistor voltage divider needs to big enough in value to ensure enough low-frequency bandwidth to prevent excessive phase shifts at 50 or 60Hz. Thus,

C6 = 318310/(R11 + R22)/F,

where F = frequency and the result is in µF; typical values fall between 0.047 to 1µF. Is the Aikido cathode follower worth the extra triode and the slightly higher output impedance? Yes, for several reasons. The first is simply that it offers an improved PSRR figure. Second, its distortion is slightly lower due to the extra signal degeneration at the output because of the top cathode resistor being in series with the output and because the bottom triode and its cathode resistor define a nicely complementary non-linearity to the top triode, balancing the curvatures into a straighter transfer function.

The Aikido cathode follower DC couples with the CCA stage, and the two-resistor voltage divider defined by resistors R5 & R6 provides the DC feedback loop to keep the Aikido cathode follower output centered at half the B+ voltage. The second voltage divider resistor string, R11 & R22, injects the required sampling of power-supply noise into the Aikido cathode follower's bottom triode's grid to null the power-supply noise at the Aikido cathode follower's output. The diode D11 is a safety device that protects the Aikido cathode follower top triode at start up, when the tubes are cold and not conducting; once the tubes are hot, the diode falls out of the circuit, as it will no longer be forward biased.

Finding R11's value takes a bit more work, as the previously given Aikido formula does not apply here, as it assumed a noise-free input signal for the Aikido cathode follower. The cathode-coupled amplifier is not power-supply noise free. If a constant-current source is used to load its coupled cathodes, then the cathode-coupled amplifier presents almost zero power supply rejection, requiring that 100% of the power-supply noise must be fed to the Aikido cathode follower's bottom triode's grid (in other words, replace R11 with a jumper). On the other hand, with a common-cathode resistor in place of the constant-current source and with a 6CG7 cathode-coupled amplifier tube, there is a 17% reduction in power-supply noise at the cathode-coupled amplifier's output, requiring an R11 value of 15.6k (R22 = 100k) to scrub the power-supply noise from the CCA's output. Different tubes will require different resistor values. For example, if a 12AU7 is used as the input tube, use a 931-ohm common-cathode resistor (R3) and set R11 to 15k and R6 to 175k. Wait a minute! Don't you first need to know what the B+ voltage is? No. That's the amazing thing about this topology—these values work perfectly with a B+ voltage that spans 100V to 400V.

On the other hand, if the LM334 CCS is used in place of the simple common-cathode resistor, R3, then the CCA's plate resistor's value must equal B+/Iccs and R11 must be replaced by a jumper wire and R8's value must be slightly greater than R9's value to null the power-supply noise from the CCA's output. How much greater? It depends on the triode's mu and rp. The following formula establishes the correct ratio between resistors R8 & R9, when a constant-current source is used.

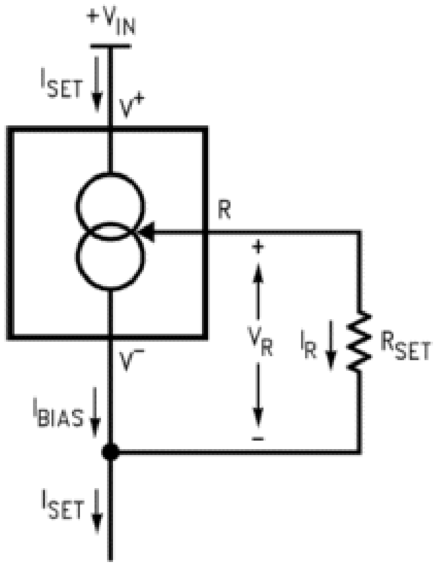
$$R9 = \frac{rp + (\mu + 1)R8}{\mu} - \frac{rp}{\mu - 1}$$

If using the LM334 constant-current source, then resistor R4's value must be selected to provide a voltage drop across this resistor equal to the B+ available to the tubes dived by two. For example, with an LM334 current draw of 10mA and B+ voltage of 200Vdc, resistor R4's value would equal 20k, as 5mA against 20k of resistance equals a voltage of 100Vdc. Although this resistor will only dissipate 1/2W of heat, a wattage rating of 1W (or 2W) would prove safer.

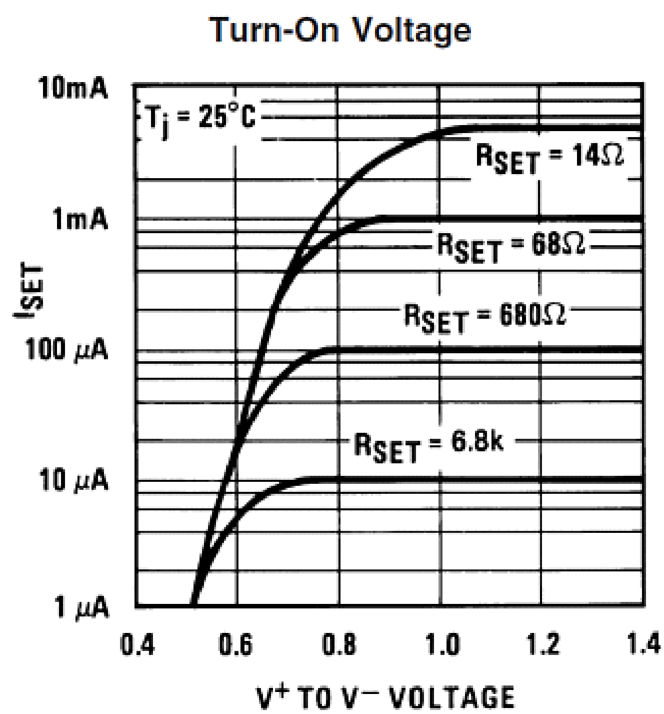
The LM334's idle current can be set to a lower value, but not a higher one, as 10mA is the limit for this solid-state device. Its voltage limit should never be encountered, as even a 6H30 input tube would only necessitate a 20V grid bias voltage with a B+ voltage of 300Vdc, well within the LM334's 40V maximum. At the other extreme, the LM334 needs at least 1.4Vdc to maintain steady current, which makes using high-mu tubes, such as the 12AX7 problematic, if not impossible with the constant-current source. The greater the B+ voltage and the lower the idle current, the higher the grid bias voltage needed. For example, a 6N1P could be used with a B+ voltage of 300 and an idle of 2.5mA per triode (5mA for the LM334).

LM334

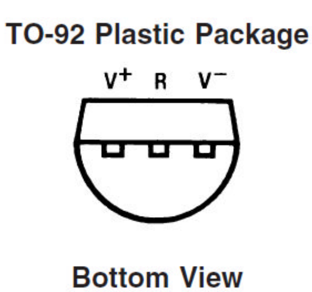
The National Semiconductor LM334 constant-current source is a well established device. It comes in four different packages, but the CCA PCB is configured for the TO-92, three-lead package. The LM334 offers excellent performance and requires only one resistor, Rset, to establish its idle current. The following graph shows the turn-on voltages and bias currents set by various Rset resistor values.



$$I_{SET} = I_R + I_{BIAS} = \frac{V_R}{R_{SET}} + I_{BIAS}$$



Note that 10mA, the optimal value for most CCA setups, does not receive a resistor value, but we can readily see that 6.8 ohms is the correct value. (The LM334 datasheet goes into much more detail, but for tube work, 6.8 ohms is close enough.) Although 10mA is the LM334's maximum current flow, the device sees less than 10V with most tubes, such as the 6CG7 and 12AU7, so the device's dissipation is usually less than 100mW, well below its 400mW limit. Nonetheless, it is a good idea to attach a small heatsink to the IC, as it better ensures an accurate idle current.



LM334 Specifications

V+ to V- Forward Voltage	
LM134/LM234/LM334	40V
V+ to V- Reverse Voltage	20V
R Pin to V- Voltage	5V
Set Current (max)	10mA
Power Dissipation	400mW
ESD Susceptibility	2000V
Operating Temperature Range	
LM334	0°C to +70°C
Soldering Information	
TO-92 Package (10 sec.)	260°C

R12	Imax mA	Vmax	Wattage	F3 150µF	F3 270µF
100	100mA	10V	1W	10.61Hz	5.89Hz
200	70mA	14V	1W	5.31Hz	2.95Hz
300	57mA	17V	1W	3.54Hz	1.96Hz
470	46mA	21V	1W	2.26Hz	1.25Hz
680	38mA	25V	1W	1.56Hz	0.87Hz
1000	31mA	31V	1W	1.06Hz	0.59Hz
1600	43mA	69V	3W	0.66Hz	0.37Hz
2000	39mA	77V	3W	0.53Hz	0.29Hz
3000	32mA	95V	3W	0.35Hz	0.2Hz
3900	28mA	108V	3W	0.27Hz	0.15Hz
6800	21mA	143V	3W	0.16Hz	0.09Hz
10000	14mA	170V	3W	0.11Hz	0.06Hz

Resistor	Voltage Drop Against Current									
100	0.10	0.20	0.30	0.40	0.50	0.60	0.70	0.80	0.90	1.00
200	0.20	0.40	0.60	0.80	1.00	1.20	1.40	1.60	1.80	2.00
300	0.30	0.60	0.90	1.20	1.50	1.80	2.10	2.40	2.70	3.00
470	0.47	0.94	1.41	1.88	2.35	2.82	3.29	3.76	4.23	4.70
680	0.68	1.36	2.04	2.72	3.40	4.08	4.76	5.44	6.12	6.80
1000	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00
1600	1.6	3.2	4.8	6.4	8.0	9.6	11.2	12.8	14.4	16.0
2000	2.0	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0
3000	3.0	6.0	9.0	12.0	15.0	18.0	21.0	24.0	27.0	30.0
3900	3.9	7.8	11.7	15.6	19.5	23.4	27.3	31.2	35.1	39.0
6800	6.8	13.6	20.4	27.2	34.0	40.8	47.6	54.4	61.2	68.0
10000	10.0	20.0	30.0	40.0	50.0	60.0	70.0	80.0	90.0	100.0
	1	2	3	4	5	6	7	8	9	10

Current in mA

Resistor	Voltage Drop Against Current									
100	1.10	1.20	1.30	1.40	1.50	1.60	1.70	1.80	1.90	2.00
200	2.20	2.40	2.60	2.80	3.00	3.20	3.40	3.60	3.80	4.00
300	3.30	3.60	3.90	4.20	4.50	4.80	5.10	5.40	5.70	6.00
470	5.17	5.64	6.11	6.58	7.05	7.52	7.99	8.46	8.93	9.40
680	7.48	8.16	8.84	9.52	10.20	10.88	11.56	12.24	12.92	13.60
1000	11.00	12.00	13.00	14.00	15.00	16.00	17.00	18.00	19.00	20.00
1600	17.60	19.20	20.80	22.40	24.00	25.60	27.20	28.80	30.40	32.00
2000	22.00	24.00	26.00	28.00	30.00	32.00	34.00	36.00	38.00	40.00
3000	33.00	36.00	39.00	42.00	45.00	48.00	51.00	54.00	57.00	60.00
3900	42.90	46.80	50.70	54.60	58.50	62.40	66.30	70.20	74.10	78.00
6800	74.80	81.60	88.40	95.20	102.00	108.80	115.60	122.40	129.20	136.00
10000	110.00	120.00	130.00	*	*	*	*	*	*	*
	11	12	13	14	15	16	17	18	19	20

Current in mA

Resistor	Voltage Drop Against Current									
100	2.10	2.20	2.30	2.40	2.50	2.60	2.70	2.80	2.90	3.00
200	4.20	4.40	4.60	4.80	5.00	5.20	5.40	5.60	5.80	6.00
300	6.30	6.60	6.90	7.20	7.50	7.80	8.10	8.40	8.70	9.00
470	9.87	10.34	10.81	11.28	11.75	12.22	12.69	13.16	13.63	14.10
680	14.28	14.96	15.64	16.32	17.00	17.68	18.36	19.04	19.72	20.40
1000	21.00	22.00	23.00	24.00	25.00	26.00	27.00	28.00	29.00	30.00
1600	33.60	35.20	36.80	38.40	40.00	41.60	43.20	44.80	46.40	48.00
2000	42.00	44.00	46.00	48.00	50.00	52.00	54.00	56.00	58.00	60.00
3000	63.00	66.00	69.00	72.00	75.00	78.00	81.00	84.00	87.00	90.00
3900	81.90	85.80	89.70	93.60	97.50	101.40	105.30	109.20	*	*
6800	142.80	*	*	*	*	*	*	*	*	*
10000	*	*	*	*	*	*	*	*	*	*
	21	22	23	24	25	26	27	28	29	30

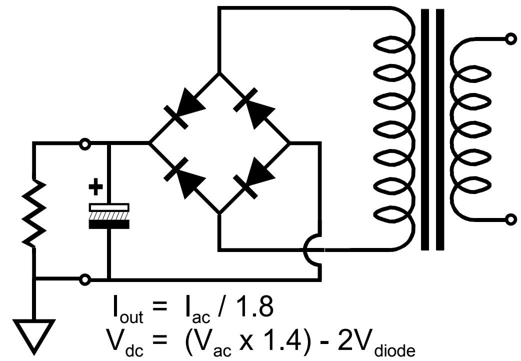
Current in mA

* Exceeds maximum Voltage/Current

Rectifier Circuits

Tube equipment was born to run on DC and everywhere it is chained to AC wall sockets. In other words, all power supplies that plug into wall sockets, must convert AC voltage to DC voltage. This conversion requires rectifiers and capacitors; and there are several ways that the rectifiers can be configured.

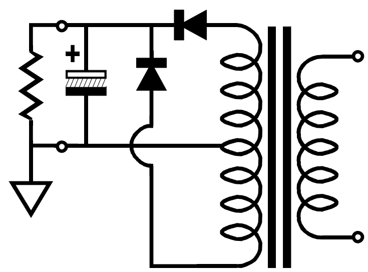
Full-Wave Bridge This is the most popular power supply configuration. The entire primary winding is used and four rectifiers are required. This configuration is seldom used with tube rectifiers, as the rectifier cathodes cannot be heated by just a single heater winding. The two diode voltage-drops mean little in a high-voltage power supply, but are a big liability in low-voltage power supplies.



$I_{out} = I_{ac} / 1.8$

$V_{dc} = (V_{ac} \times 1.4) - 2V_{diode}$

Full-Wave Center-Tap This is the classic tube amplifier power supply configuration. It uses only half of secondary winding at a time and requires a center-tapped winding and two rectifiers, saving two compared to the full-wave bridge configuration. On the other hand, the two rectifiers will see twice the peak reverse voltage that four rectifiers would see in a full-wave bridge configuration, which can greatly limit the use of solid-state rectifiers in high-voltage power supplies; in addition, the primary is only about 75% as effectively utilized in this configuration compared to the FW bridge circuit. Paradoxically enough for what many consider a purely high-voltage circuit, this rectifier circuit is often used in extremely low-voltage power supplies, as the single-diode voltage drop greatly increases this circuit's efficiency.

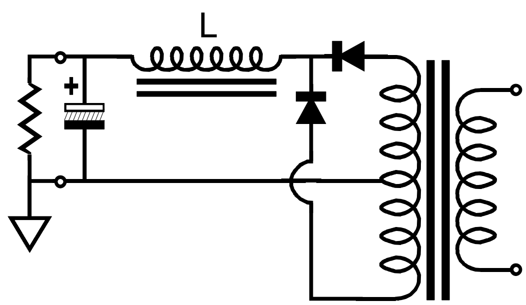


$I_{out} = I_{ac} / 1.27$

$V_{dc} = V_{ac}^{*} / 1.43 - V_{diode}$

*entire primary

Full-Wave Choke Input This power-supply configuration is often used with tube rectifiers and requires quite a bit of tuning. When designed correctly, this power supply topology yields the flattest output voltage over a wide range of current draw, as the power supply capacitor is charged by a near square waveform. On the other hand, the large choke will be expensive, heavy, and given to loud mechanical noise. This circuit requires a relatively low-valued bleeder resistor to keep the output voltage from peaking dangerously high at turn on.



(60Hz) $L \approx V_{out} / I_{out}$ (mA)

(50Hz) $L \approx 1.2 \times V_{out} / I_{out}$ (mA)

$I_{out} = I_{ac} / 0.707$

$V_{dc} = V_{ac}^{*} / 2.2 - V_{diode} - R_{inductor} \times I_{dc}$

*entire primary voltage

Tube Selection

A CCA line-stage amplifier can be built in a nearly infinite number of ways. For example, a 12AU7 input tube will yield a gain of +13dB (+16dB with LM334 constant-current source), which would be excellent for a line stage amplifier; the 6DJ8 or 6H30 or ECC99 as the output tube would deliver a low output impedance that could drive capacitance-laden cables. In other words, the list of useable tubes is a long one: 6AQ8, 6BC8, 6BK7, 6BQ7, 6BS8, 6DJ8, 6FQ7, 6GC7, 6H30, 6KN8, 6N1P, 12AU7, 12AX7, 12BH7, 12DJ8, 12FQ7, 5963, 5965, 6922, E188CC, ECC88, ECC99... In general, a low-mu tube works best as the input tube and a high-transconductance tube works best as an output tube. The only stipulations are that the two triodes within the envelope be similar and that the tube conforms to the 9A or 9AJ base pin-out. Sadly, the 12B4 and 5687 cannot be used with this PCB.

Internal Shields

If the triode's pin 9 attaches to an internal shield, as it does with the 6AQ8 and 6DJ8, then capacitors C1 and C2 can be replaced with a jumper, which will ground the shield. However, using the capacitors rather than jumpers will also ground the shield (in AC terms) and allow swapping in triodes whose pin-9 attaches to the center tap of its heater, such as the 12AU7.

Cathode Resistor Values

If the LM334 constant-current source is not used, then common cathode resistor R3's value should be gleaned from inspection of the tube's plate curves, although the following formula is a good starting point. The cathode resistors, R8 & R9, and B+ voltage set the idle current for the Aikido cathode follower output stage: 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 for either the CCA input stage or the Aikido cathode follower output stage is an easy one:

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

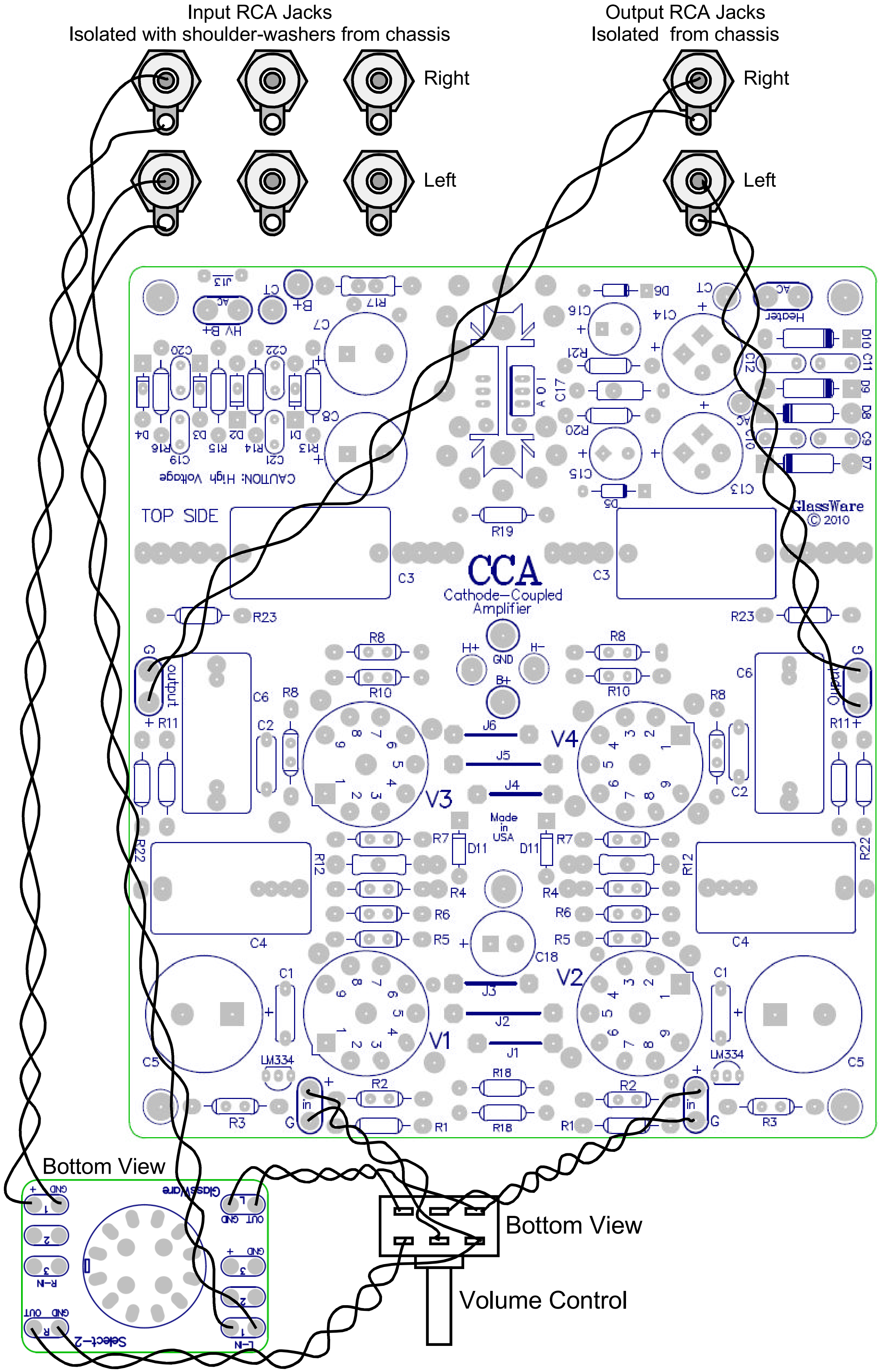
So, for example, a 6CG7 in the Aikido cathode follower, with a B+ voltage of +300V and 1k cathode resistors, will draw 300/2(8k + [2 + 1]1k) amperes of current, or 2.6mA. I recommend 100 to 330 for the 6DJ8 and 6N1P tubes. Other tubes, such as the 6CG7, 12AT7, 12AU7, 12BH7 work well with 470-ohm cathode resistors. Because the Aikido cathode follower's cathode resistors see so little voltage differential, 1/2W resistors can readily be used here.

Coupling-Capacitor Values

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


Input RCA Jacks
Isolated with shoulder-washers from chassis
Output RCA Jacks
Isolated from chassis
Right
Left
Right
Left
TOP SIDE
CAUTION: High Voltage
CCA
Cathode-Coupled
Amplifier
GlassWare
© 2010
Made in USA
V1
V2
V3
V4
output
input
in
Bottom View
Select-2
Bottom View
Volume Control

Configuring the PCB as a Line Amplifier

The CCA circuit makes a perfect line amplifier, as it offers low distortion and input capacitance, low output impedance, no phase inversion, and excellent power-supply noise rejection— all without a global feedback loop. The input and output tubes do not have to be the same type or even share the same heater voltage. the following design examples are not exhaustive by any means. For example, the 6H30 and ECC99 would make powerful output tubes and the 5693 might make a stellar input tube (followed by a 5695 in the Aikido cathode follower position would make an all-computer-tube line-stage amplifier).

Typical Part Values

() Parentheses denote recommended values

(input) V1, V2 =	6CG7/6FQ7	12AU7	12BH7	6DJ8[1] Low-Voltage Operation
B+ Voltage =	250V	250V	250V	150V
AC Secondary =	330Vac	330Vac	330Vac	120Vac
DC Heater Voltage =	6.3V or 12.6V	12.6V	12.6V	6.3V or 12.6V
R1,23 =	1M	1M	1M	1M
R2,7,10 =	100 - 1k (300)*	Same	Same	Same
(without CCS) R3 =	845*	931*	1.2k*	390*
(with CCS) R3 =	6.81	6.81	6.81	6.81
R4 =	24k/1W*	24k/1W*	24k/1W*	15k/1W*
R5 =	10k	Same	Same	Same
R6 =	200k	175k	175k	300k
(without CCS) R8,9 =	300 - 680 (470)*	300 - 680 (390)*	240 - 680 (470)*	200 - 470 (300)*
(with CCS) R9 =	Use formula below			
(with CCS) R11 =	Jumper	Same	Same	Same
(without CCS) R11 =	15.6k	15k	15k	13k
R22 =	100k	Same	Same	Same

*High-quality resistors essential in this position.

(output) V3, V4 =	6CG7/6FQ7	12AU7	12BH7	6DJ8 Low-Voltage Operation
(without CCS) R8, 9 =	200 - 680 (300)*	300 - 680 (390)*	240 - 680 (470)*	200 - 470 (300)*
(with CCS) R8 =	300*	300*	470*	300*
(with CCS) R9 =	270*	267*	430*	287*

(with CCS) R9 =

$$R9 = \frac{rp + (\mu + 1)R8}{\mu} - \frac{rp}{\mu - 1}$$

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 =	150µF* 400V	"	"	270µF 200V
C6 =	0.1 - 1µF* Film or PIO	"	"	Same
C7, C8 =	47µF 450V	"	"	220µF 200V

*Voltage rating must equal or exceed B+ voltage

1 The input triode in the CCA sees the biggest cathode-to-plate voltage differential, so care should be taken to not to exceed the triode's maximum cathode-to-plate voltage. This brings up the controversial issue of the 6DJ8's actual cathode-to-plate voltage limit. Most tube manuals state that the limit is 130Vdc, an amazingly low voltage for such a triode. I believe this voltage only refers to the 6DJ8 under cascode use, not in a grounded-cathode amplifier or cathode follower. For example, the JJ E88CC specifications sheet states that its maximum plate voltage is 220Vdc. So before proceeding, WARNING EXCEEDS PUBLISHED 6DJ8 PLATE VOLTAGE LIMIT. Nonetheless, I tried the 6DJ8 in the CCA, with a B+ voltage of only 150V. Nothing exploded or arced. Furthermore, the sound was surprisingly fine and the gain was close to +20dB. The lower B+ voltage allowed me to use much larger-valued capacitors in the high-voltage power supply (220µF/200V rather than 47µF/450V for C7 & C8 and 270µF/200V rather than 150µF/400V for C5), which greatly reduced the ripple the Aikido cathode follower had to whisk away. In other words, it was dead quiet.

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.

Double-Sided Board Because the board is double sided, with traces and plated-through pads on each side, it is often easier to solder the resistors from the top side. In addition, it is often easier to attach the LD1085 (heater regulator) to its heatsink first (using heatsink hardware kit) and then to solder both heatsink and device to the PCB at once. You may solder the tube sockets on the top of the PCB and solder all the remaining parts on the bottom, which allows attaching the PCB to the chassis's top panel, with the tubes protruding through holes, which can easily be done with the CCA PCB, as the solid-state regulator and LM334 can be soldered on the bottom without having to twist their leads to conform to the inverted pad positions, as the heater regulator gets a redundant set of solder pads on the PCB's bottom side. Just be sure to attach the regulator the other side of the heatsink.

Capacitors Because the PCB is so overbuilt, it is extremely difficult to remove an incorrectly placed part. Thus, 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. In addition, large coupling and bypass capacitors should be adhered to the PCB with double-sided foam tape or hot glue.

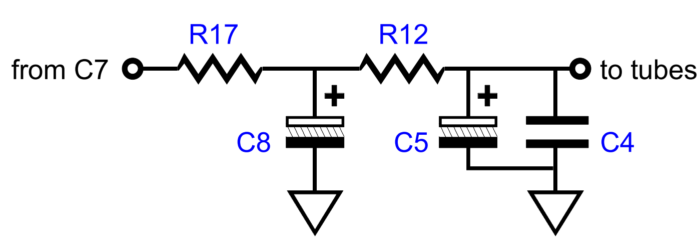
Fusing Usually a fuse is placed in series with the power transformer's primary, but both the high voltage and the heater secondaries can receive fuses as well. Use a slow blow fuse for the heater and quick blow fuse with the B+ output.

Standoffs Tubes are microphonic by nature, being mechanical structures. Thus, it pays to prevent vibrations from reaching the tubes. One easy technique is to use small rubber O-rings below and above the PCB where the screws enter the PCB's mounting holes. The screws should be just tightened enough to keep the PCB from ringing or rattling when tapped.

RC Power-Supply Filter

Resistors R17 and R12 are the voltage-dropping resistors in the two RC power supply filters used in the CCA. Resistor R17 is used in the first RC filter. Its value can be anything between 1 to 1kohms. This resistor will see the entire high voltage current draw of the CCA line-stage amplifier. This resistor can be replaced by a low-DCR choke that mounts on the chassis.

The CCA kit supplies five pairs 3W resistors for R12 use: 1.6k, 2k, 3k, 3.9k, and 10k. Page 9 holds a chart that shows the voltage drop across the R12 versus the current flow. Remember each channel gets it own R12 resistor. For example, a CCA line-stage amplifier might run a total of 20mA of idle current per channel, for a total of 40mA for the entire line-stage amplifier. So by looking up the 20mA column, we can see the resulting voltage drops. Thus, a 2k resistor will drop 40V, so a 300Vdc raw DC power supply will deliver 260Vdc to the input and output tubes. An * denotes excessive current or voltage, so that resistor value cannot be used without risking damaging the at least one of the resistors.

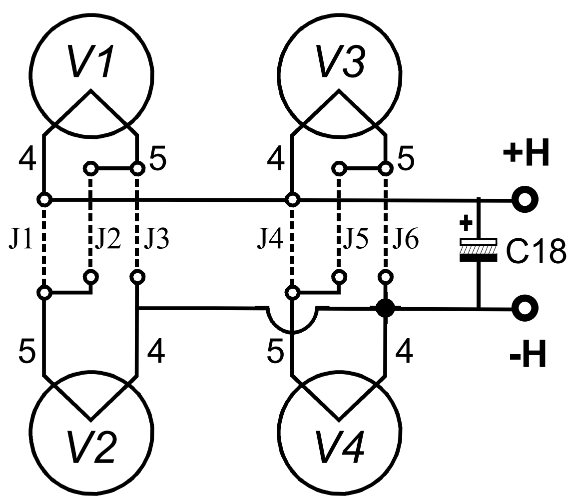


Heater Issues

The CCA PCB holds a heater power supply and low-voltage regulator. The regulator used is the LD1085 low-dropout adjustable voltage regulator, which can be set to any output voltage between 6V to 25V, but the assumption is that a 12Vdc output voltage will be used for the heaters, so that 6.3V heater tubes (like the 6FQ7 and 6DJ8) or 12.6V tubes (like the 12AU7 or 12AX7) can be used. Both voltage types can be used exclusively, or simultaneously; for example a 6GC7 for the input tube and a ECC99 for the output tube. Thus, if the input tubes (V1 and V2) are 6FQ7s and the output tubes (V3 and V4) are 12BH7s and the heater regulator output voltage is 12Vdc, then use jumpers J2, J4, and J5.

Although the preferred power supply voltage is 12V, 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.

Filament Jumper Wire Schedule

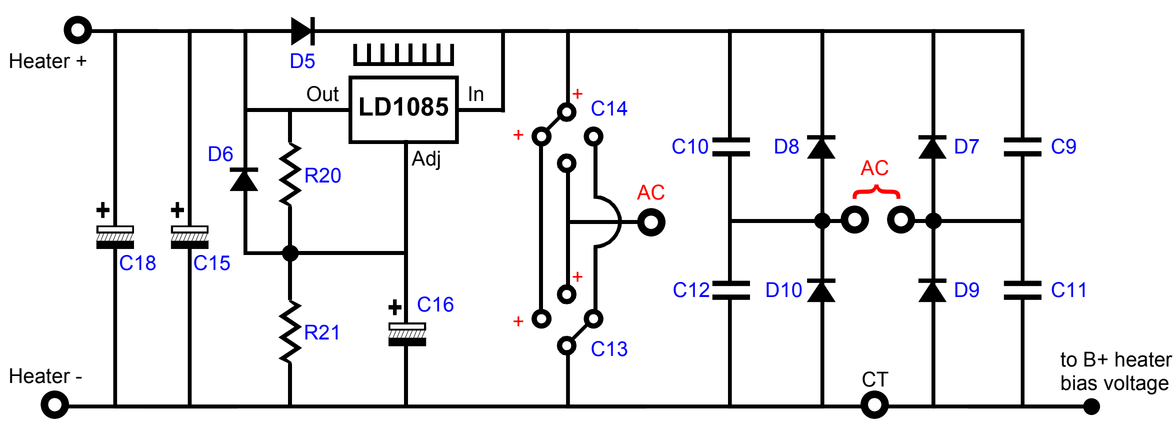


With a 12.6V PS

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

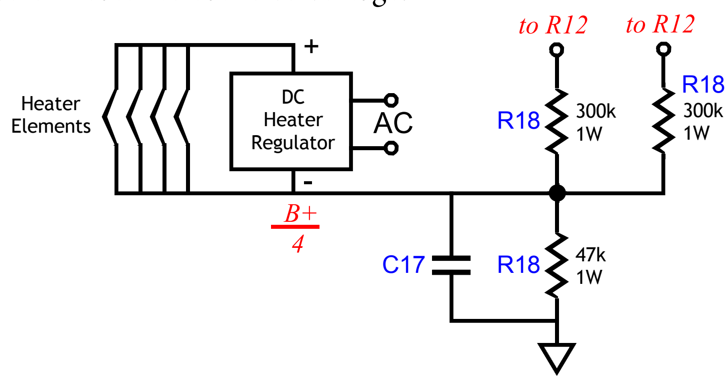
Tubes	V1 & V2	V3 & V4
All tubes = 6.3V:	J1 & J3	J4 & J6
If 12.6V:	Cannot be used with 6.3V PS	



As can be seen, the 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 (CT) pad at the bottom of the PCB; the transformer secondary attaches to both the single AC pad in between capacitors C13 and C14 and AC pad that feeds rectifier D10 and D8; and D7, D9, C9, C11 are left off the PCB. If used as a full-wave center-tap circuit, the two heater capacitors, C13 & C14, are placed in parallel by orienting their positive leads to where the heatsink sits; and the secondary attaches to the two encircled AC pads while the secondary center-tap attaches to the CT pad.

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, 50V, when using a 200V power supply. The ¼ B+ voltage ensures that both top and bottom triodes see the same magnitude of heater-to-cathode voltage.



The heater's PS reference bias voltage to target is one quarter of the B-plus voltage that the CCA'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, C17, leaving resistors R18(s) 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	8.4V	12V	12.6V
R21 =	470	499	715	1.07k	1.13k
R20 =	124	same	same	same	same
D9, 10, 11, 12 =	MUR410G	"	"	"	"
D1*, 2* =	1N4007	"	"	"	"
C9, 10, 11, 12 =	1000pF - 50V	"	"	"	"
C13, 14 =	10kµF*	"	"	"	"
C15, 16 =	1kµF*	"	"	"	"
C17 =	0.01µF*	"	"	"	"
C18 =	1kµf - 3300µF*	"	"	"	"

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

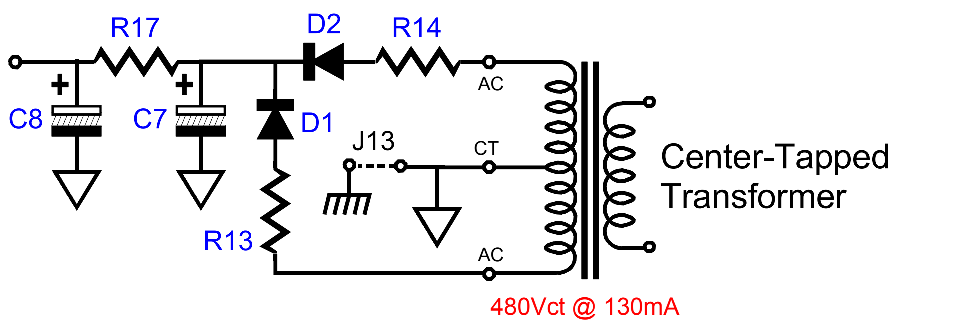
Resistors R20 and R21 set the heater voltage regulator's output voltage. The formula is

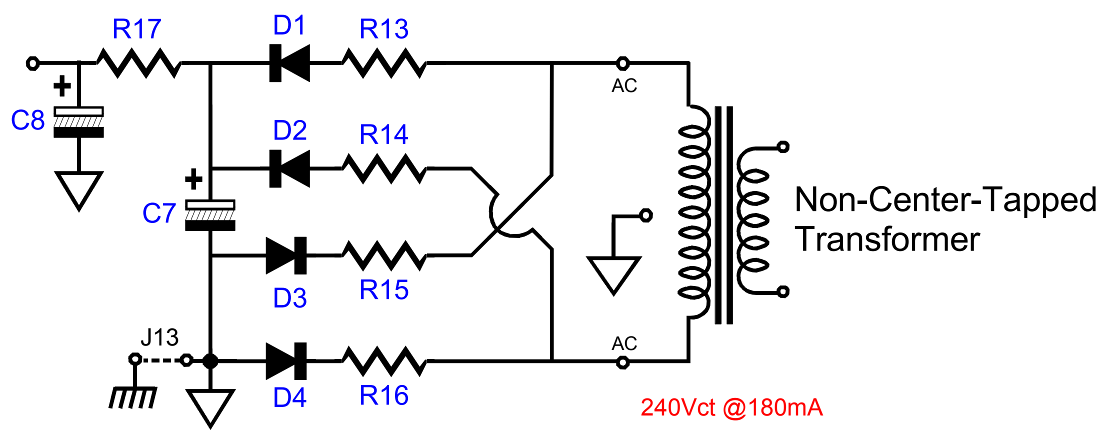
$$V_0 = 1.25(1 + R_{19} / R_{20})$$

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

Transformer-Rectifier Configurations

Transformers As shown below, the CCA high-voltage power supply 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.

Grounding

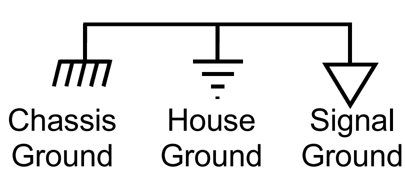
The CCA PCB holds a star ground at its center. Ideally, this will be the only central ground in the line-stage amplifier. Ground loops, however, are extremely easy to introduce. For example, if the RCA jacks are not isolated from the chassis, then the twisted pair of wires that connect the PCB to the 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 an input RCA 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.

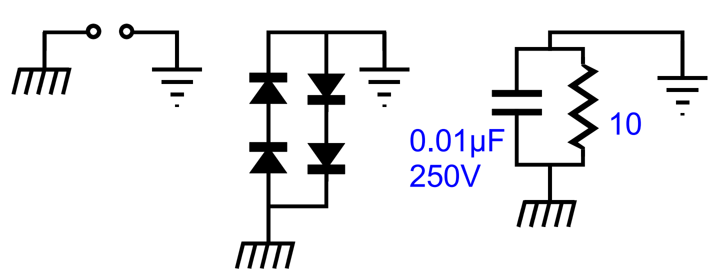
Three different schools of thought hold for grounding a piece of audio gear. The Old-School approach is to treat the chassis as the ground; period. Every ground connection is made at the closest screw and nut. This method is the easiest to follow and it produces the worst sonic results. Steel and aluminum 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 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 CCA 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 (not safe), others use several solid-state rectifiers in parallel to attach the chassis ground to the house ground (**NOT NEUTRAL**) via the third prong, and others still use a 10-ohm resistor shunted by a small capacitor, say 0.001µF to 0.1µF/250V. One last technique might prove the best solution: couple the power supply ground to the house ground via a choke. A low-DCR choke will provide a ready DC discharge path and if its inductance is high enough, it will isolate the audio ground from the AC noise present on the house ground.





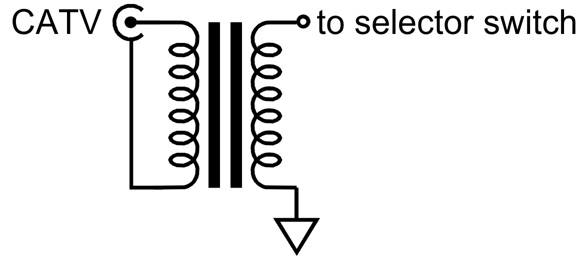
A good test procedure is to detach all the signal inputs and all the output connection from the line-stage amplifier. Then measure the AC voltage between the line-stage amplifier's chassis and the house's ground. If it reads more than a few volts, try reversing the line-stage amplifier's plug as it plugs 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).

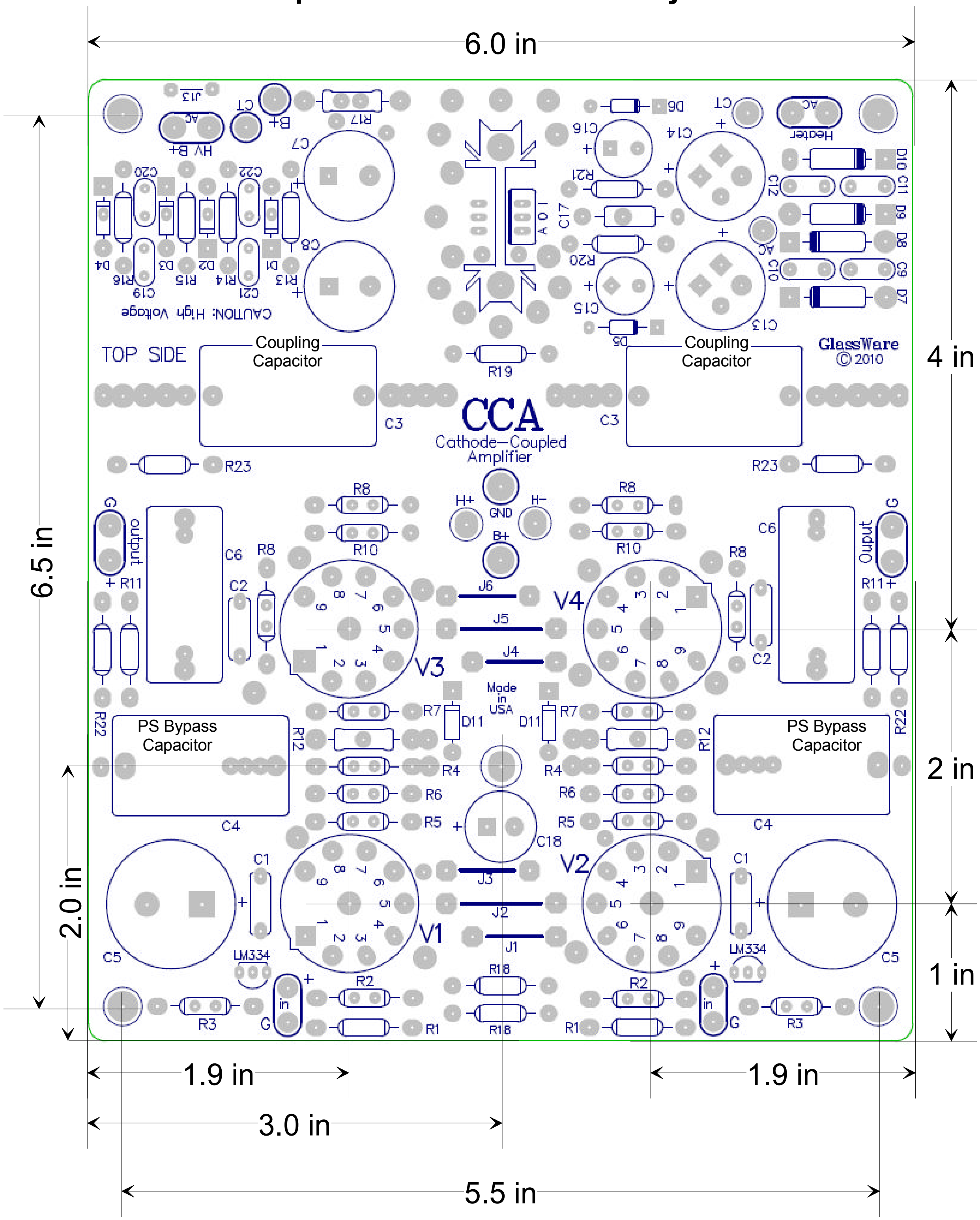
Terminating Resistors Here's a cheap trick to try: at each input RCA jack, place a 100k to 1M resistor, bridging input hot and jack ground. Why? The resistor provides a path for the AC signal present at the jack, so given a choice between radiating into the chassis or going through the relatively low-impedance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



Top Side PCB Mechanical Layout



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