

GLASSWARE
AUDIO DESIGN

BCF

Broskie Cathode Follower

USER GUIDE

Introduction
Overview
Schematics
Recommended Configurations
Assembly Instructions

07/27/2010

👉 **Warning!** 👈

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

BCF PCB Overview

Thank you for your purchase of the Aikido BCF 9-pin stereo PCB. This FR-4 PCB is extra thick, 0.094 inches; thus, inserting and pulling tubes from their sockets won't bend or break this board; it double-sided, with plated-through 2oz copper traces on both sides; and the PCB is expensively and lovingly made in the USA. Each PCB holds two Aikido BCF unity-gain buffers; thus, one board is all that is needed for stereo unbalanced use or one board for one channel of balanced buffering. The boards are four inches by six inches, with five mounting holes, which also helps to prevent excessive PCB bending while inserting and pulling tubes from their sockets.

PCB Features

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

Multiple Heater Arrangements The BCF PCB allows either 6.3V or 12.6V heater power supplies to be used; and two 6V tubes, such as the 6Q8, 6CG7, 6DJ8, and 6H30 can be used with a 12V heater power supply.

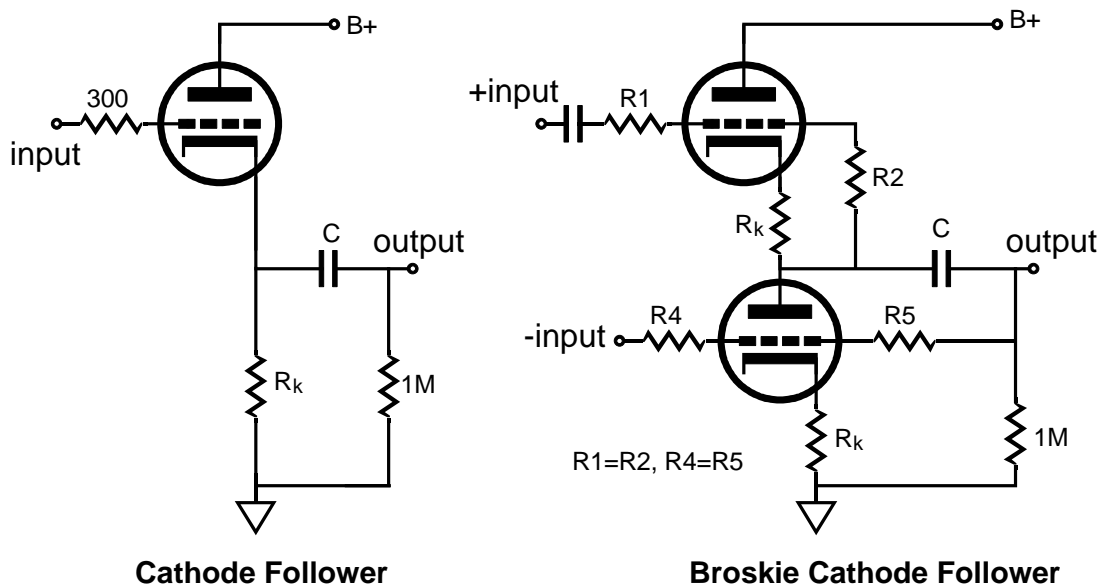
Balanced to Unbalanced

The Broskie cathode follower receives a balanced input signal and converts it to an unbalanced output. In addition, much like a signal transformer, the BCF offers common-mode signal rejection (CMRR); this means that BCF passes differential input signal, but largely ignores what is common to both input signals. Why is this a feature? Common-mode signals are extraneous to the actual input signal and usually consist of hum, power-supply noise, and RFI. The key advantage that a balanced signal offers is the chance to apply a high-CMRR transformer or circuit, which will then scrub away the added electrical contamination. The problem with using a high-quality signal transformer is cost. Good transformers are both rare and expensive.

The BCF consists of one vacuum tube per channel (two triode per tube envelope) and a handful of capacitors and resistors. It is a unity-gain buffer that offers a high input impedance, a low output impedance, low distortion, and great CMRR. In addition, because the BCF uses a push-pull topology, the BCF use is not limited to line-stages, as the BCF can be used as a headphone buffer-amplifier, if the headphone's impedance is high enough, say 300-ohms.

Introduction to the Broskie Cathode Follower

The Broskie cathode follower (BCF) was created to level the playing field. Designers of solid-state audio gear have held an advantage over their tube-audio competitors in that they can use a simple, inexpensive OpAmp-based circuit to convert a balanced input signal into an unbalanced (single-ended) signal. This solid-state differential circuit requires only one OpAmp and four resistors. Of course, a tube-based OpAmp could also be designed that used the same topology, but this would be quite an undertaking, requiring many tubes and, most probably, a negative power supply rail. The BCF, on the other hand, is a simple affair that uses just two triodes and six resistors and two coupling capacitors.



Balanced-to-Unbalanced As a balanced-to-unbalanced converter, the [BCF] Broskie cathode follower's function is to subtract signal B from signal A; in other words, $output = A - B$, which makes the BCF a differential amplifier, an amplifier that accepts differences and ignores what is common. Because balanced audio signals consist of two phases, with signal B being equal to $-A$, the function effectively becomes $output = A - (-A)$, or $output = 2A$. A signal common to both A and B, let us call it C, is canceled, as the function, $C - C = 0$, obtains. Noise is usually equally shared between two balanced signals and is thus eliminated in the unbalanced, single-ended output signal.

So far, the circuit mimics an audio-signal transformer in function, which was one goal. But the BCF circuit differs from a transformer in that it does not reflect impedances, but rather provides a low output impedance and, unlike a generic cathode follower a symmetrical push-pull current swing, i.e. it can aggressively pull up or down like a White Cathode Follower. In other words, the BCF is like a cathode follower wedded to a plate follower (AKA anode follower)—but not quite, as a typical cathode follower does not hold a pair of resistors wrapped around its input and output. (Resistors R3, R4 were added to better balance the circuit's output swing and output impedance.)

The BCF differs from the classic OpAmp-based differential amplifier and 1:1 isolation transformer in that the BCF's output does not equal $2A$, but A . For example, if a balanced pair of input signals that consist of 1kHz at 1Vpk is presented to the BCF, the BCF output will be 1Vpk, not 2Vpk. This can be seen either as a -6dB insertion loss or as preserving unity-gain signal transference, depending on your perspective.

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Output Impedance What is the output impedance of this circuit, considering the two resistor networks wrapped about the circuit? Unity is the answer. Unity? By this we mean that the two triodes yield an output impedance equal to the same triode configured as a cathode follower. To understand how this result may occur, imagine a positive voltage pulse being fed into the output of our circuit. This pulse would provoke a change in current flow through the circuit that would work to eliminate the pulse. Since the tubes only see half of the pulse at their grids, because of the two two-resistor voltage dividers at each input, only half of the potential change in current occurs per tube. Two times one half equals unity and the magnitude of voltage pulse divided by the change in current equals the output impedance.

Once again, but in greater detail. We assume that the inputs are effectively grounded by the preceding stage's low output impedance. We also assume the cathode resistors are bypassed to make the circuit analyses simpler. Let's say a 1 volt pulse is forced into the output by a very buffed, ultra-low-output-impedance solid-state amplifier. The BCF's output is now forced 1 volt higher. This 1 volt increase is relayed through the top resistor network (R1 & R2) to the top tube's grid. Since the two resistors are wired in series, not all the voltage can present itself to the grid; in fact, as the two resistors are equal in value, only half of the 1 volt increase reaches the top grid. Effectively, this is equivalent to the grid having been driven $\frac{1}{2}$ volt negative relative to the cathode, as the cathode has moved up 1 volt and the grid has only moved up $\frac{1}{2}$ volt. The top triode will conduct less as a result of the negative voltage on its grid. How much? The transconductance of the triode times $\frac{1}{2}$ volt is basically the amount of decreased current. In the case of a 6922 with a Gm of 10 mA per volt, the current will decrease by 5 mA.

On the bottom triode, the positive pulse is also relayed to its grid via a two-resistor voltage divider. Once again only half of the pulse makes it to the grid. But this time the current increases by the Gm times the $\frac{1}{2}$ volt positive pulse. In the case of a 6922, the current will increase by 5 mA. The sum of the positive increase in current flow by the bottom tube and the negative decrease in current flow by the top tube is what the solid-state power amplifier must be able to source to maintain the pulse in the face of the change in current flowing through the tubes. Assume that at idle our balanced converter draws 10 mA. But in the presence of the 1 volt pulse, the top tube draws 5 mA less, which leaves it with 5 mA of current flow; the bottom tube's current draw increases by 5 mA, which leaves it with 15 mA of current flow. Thus net change in current is the absolute difference in each tube's change in current, as the top tube is now only conducting 5 mA and the bottom tube is conducting 10 mA more current than the top tube this extra current must flow into the amplifier causing the pulse. Consequently, the solid-state power amplifier must be able to source 10 mA of current or the pulse will not be sustainable. Now we can figure out the output impedance:

$$V / I = R$$

Thus, 1 volt / 0.01 amps = 100 ohms. Had the circuit consisted of one triode configured as a simple cathode follower, the output impedance would have also been 100 ohms. Besides from converting a balanced input signal into an unbalanced output, the BCF offers lower distortion than the conventional cathode follower and it offers a symmetrical pulling up and down, whereas the simple cathode follower can only aggressively pull up.

To bypass or not to bypass? In our analyses of the circuit's output impedance, the cathode resistors were assumed to be bypassed, but in actual use, the BCF's cathode resistors should be left unbypassed. What happens to the output impedance if the resistors are unbypassed? Normally, an unbypassed cathode resistor will greatly increase the output impedance. In a Grounded Cathode amplifier the effective increase in the value of r_p is equal to the $(\mu + 1)$ times the value of the cathode resistor. Here the value one cathode resistor is simply added to what the output impedance would be with bypassed cathode resistors. The formula for the output impedance with bypassed cathode resistors is given by:

$$Z_o = (r_p / [\mu + 1]) \parallel R_5 \parallel R_7.$$

And with unbypassed cathode resistors:

$$Z_o = (r_p / [\mu + 1] + R_k) \parallel R_5 \parallel R_7,$$

or roughly

$$Z_o = 1 / G_m + R_k.$$

In the case of a 6922 with a G_m of 10mA per volt and a cathode resistor of 200, the Z_o will equal 100 ohms with bypassed cathode resistors and 300 ohms with unbypassed cathode resistors. The result is basically the same as a single cathode follower that used the same tube. In many ways, what we have created here is one super triode out of two triodes.

Re-Balancing the Input Impedances The BCF presents mismatch input impedances, with the positive (the top) input being much higher than the negative (the bottom) input. Because the top two-resistor voltage divider terminates into the output, the resistor string's effective impedance is magnified, as the output is in phase with the positive input signal. The top resistor string's effective impedance is increased by $1/(1 - \text{gain})$; for example, if the BCF output gain is 0.9, then the resistor string's effective impedance will be $1/(1 - 0.9)$ or 10 times greater than its nominal resistor values would indicate.

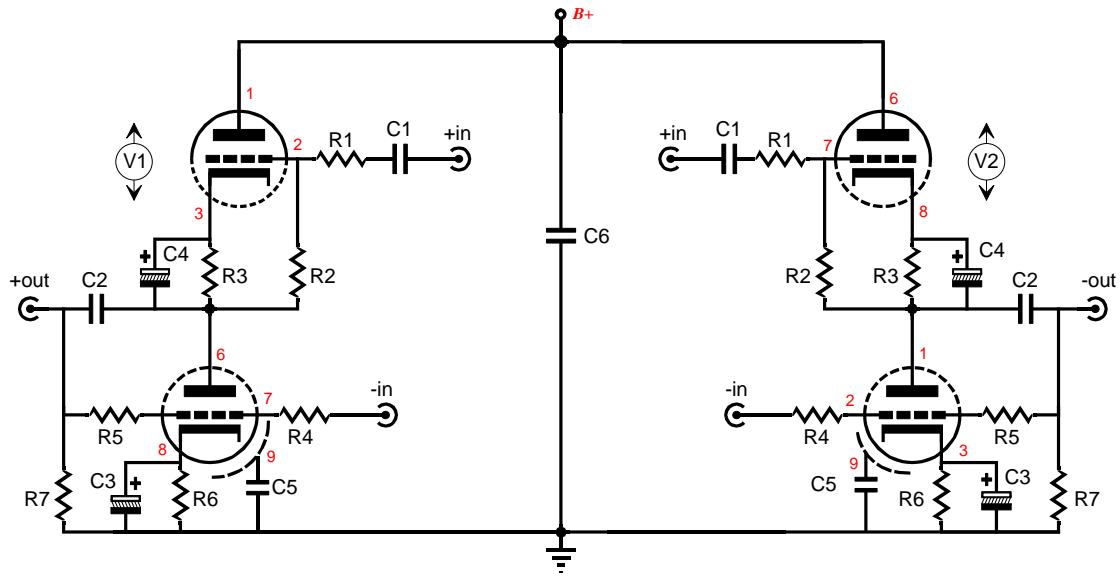
Is this important? For most applications, no. Most modern balanced input signal sources offer a relatively low output impedance. But certain old balanced gear and some audio matching transformers do not. In fact, an audio transformer works best when it is loaded by an optimal impedance. For example, say the transformer expects to see 600 ohms across its secondary, we should give 600 ohms then. We can place two 300-ohm resistors at each BCF input and to ground, which will then present 600 ohms to the secondary.

Output Coupling Capacitor This coupling capacitor is primarily responsible for restricting the BCF's low frequency extension. The larger the capacitor, the lower the low-frequency cutoff frequency. The formula is an easy one:

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

Where C is in μF and frequency is in Hertz and R equals resistors R_5 & R_7 in parallel with the external load impedance. For example, if $R_5 = 47\text{k}$ and $R_7 = 1\text{M}$ and the load = 20k , the resulting resistance will equal 13.8k , which with a $1\mu\text{F}$ coupling capacitor will give a -3dB frequency of 11.5Hz . If the BCF is used to drive 300-ohm headphones, a job that the BCF is amazingly good at, at least a $30\mu\text{F}$ coupling capacitor is needed.

9-Pin BCF Schematic



Typical Part Values () Parentheses denote recommended values

	6CG7	6DJ8	12AU7	6GM8 Low-Voltage Operation	6H30 High Current Operation
B+ Voltage =	240V	200V	250V	24V	120V
Heater Voltage =	6.3V @ 1.2A 12.6V @ 0.6A	6.3V @ 0.7A 12.6V @ 0.35A	12.6V @ 0.3mA	6.3V @ 0.7A 12.6 @ 0.35A	6.3 @ 1.65A 12.6V @ 0.825A
R1, 2, 4, 5 =	10k - 100k(47k)*	Same	Same	Same	Same
R3, 6 =	200 - 1k (470)*	100 - 1k (200)*	200 - 1k (340)*	300 - 680 (180)*	100 - 470 (150)*
R7 =	1M	1M	1M	1M	1M
*High-quality resistors essential in this position. All resistors 1/2W or higher					
V1, V2 =	6CG7, 6FQ7, 8CG8 (Subs) 12FQ7	6922, 7308, E88CC	6AU7, 5814, 5963, 6189, ECC82	ECC86, 6N27P	None
	6N1P	12BH7	12AT7	12AX7	5965
B+ Voltage =	240V	300V	200V	300V	240V
Heater Voltage =	6.3V @ 1.2A 12.6V @ 0.6A	12.6V @ 0.6A	12.6V @ 0.3mA	12.6 @ 0.3A	12.6 @ 0.225A
R1, 2, 4, 5 =	10k - 100k (47k)*	Same	Same	Same	Same
R3, 6 =	200 - 1k (300)*	100 - 1k (470)*	200 - 1k (340)*	300 - 680 (1.1k)*	100 - 470 (240)*
R7 =	1M	1M	1M	1M	1M
*High-quality resistors essential in this position. All resistors 1/2W or higher					
V1, V2 =	6BQ7, 6BS8, 6BZ7 (Subs)	12BH7A-EH	6201, CV4024, ECC81	12AX7A, 12AD7, 6681, 7025, 7729, B339, B759, CV492, CV4004, CV8156, CV8222, ECC83, ECC803, ECC803S, E2164	12AV7
C1 =	0.01 - 0.1µF* Film or PIO	Same	Same	Same	Same
C2 =	0.1 - 4µF* Film or PIO	"	"	"	"
C3, 4' =	1µK/16V (optional)	"	"	"	"
C5² =	0.01 - 0.1µF (optional)	"	"	"	"
C6 =	0.1 - 1µF* Film or PIO	"	"	"	"

*Voltage rating must equal or exceed B+ voltage

1. Use capacitor C3 & C4 only when lowest output impedance is required; must be high-quality.

2. Capacitors C5 used only with tubes that hold an internal shield at pin 9, such as the 6DJ8 and some 6CG7s.

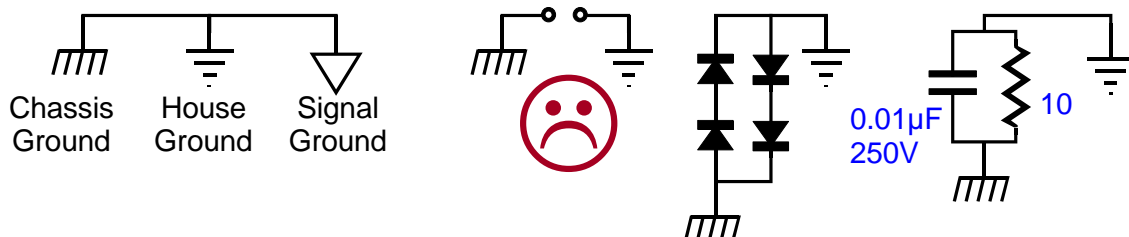
Grounding

The BCF PCB holds a star ground at its center. Ideally, this will be the only central ground used. A ground-loop is created when a device finds more than one connection to ground. Ground loops, unfortunately, are extremely easy to introduce. For example, if the output RCA jacks are grounded at the chassis, then the twisted pair of wires that connect the PCB to the jacks will each define a ground loop, as the chassis will attach to the PCB's central ground through at least four wires. The solution is either to isolate the jacks or use only a single hot wire from each 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 balanced-to-unbalanced converter, 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 Spur-Star ground method uses several ground "stars," which then terminate in a single star ground point, often a screw on the chassis. This system can work beautifully, if carefully executed. Unfortunately, often too much is included in each spur connection. For example, all the input and output RCA jacks share ground connection to a long run of bare wire, which more closely resembles a snake than a spur ground. In other words, the spurs should not be defined just physical proximity, but signal transference. Great care must be exercised not to double ground any spur point. For example, the volume control potentiometer can create a ground loop problem, if both of its ground tabs are soldered together at the potentiometer and twisted pairs, of hot and cold wires, arrive at and leave the potentiometer, as the two cold wires attaching to the PCB will define a ground loop. The Absolute-Star grounding scheme uses a lot of wire and is the most time consuming to lay out, but it does yield the best sonic rewards. Here each input signal source and each output lead gets its own ground wire that attaches, ultimately, at one star ground point; each input and output jack is isolated from the chassis. The BCF 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 at the service panel and usually the cold water pipe. The line-stage buffer can also attach to this ground connection, which is certainly the safest approach, as it provides a discharge path should the high voltage short to the chassis. Unfortunately, this setup often produces a hum problem. Some simply float the chassis (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 power 10-ohm resistor shunted by a small capacitor, say $0.001\mu\text{F}$ to $0.1\mu\text{F}/250\text{V}$.



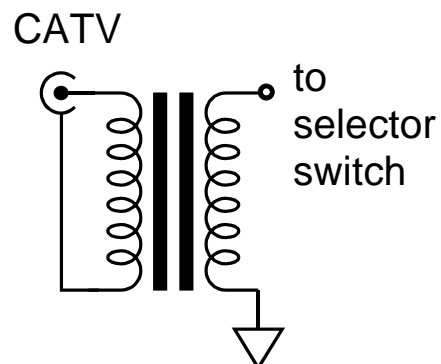
Never use a "cheater" plug to fix a hum problem; these plugs were design to promote safety, not to create a danger. Before trying any fix, make sure that all the wall sockets are wired correctly. For less than \$10 you can buy an AC socket checker, which although not capable of revealing all miswires, can expose many wiring problems. A good second test procedure is to detach all the signal inputs and all the output connections from the line-stage buffer. Then measure the AC voltage between the line-stage amplifier's chassis and the house's ground. Then measure the chassis ground to the first signal source's ground on its output RCA jack (while the signal source is turned on). If it reads more than a few volts, try reversing the signal source's plug orientation as it plugs into the wall socket. Use which ever orientation that results in the lowest AC voltage reading. Then do the rest with the rest of the signal sources. 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. The air is filled with RFI from light dimmers, switching power supplies, cordless phone cradles, computers... First make sure that all contacts are clean. Second, 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 input RCA jack and then again at the selector switch. Increasing the grid-stopper resistor's (R1) value, say to 1k or 10k, can also work wonders (use a carbon-composition or bulk-foil resistor or some other non-inductive resistor type).

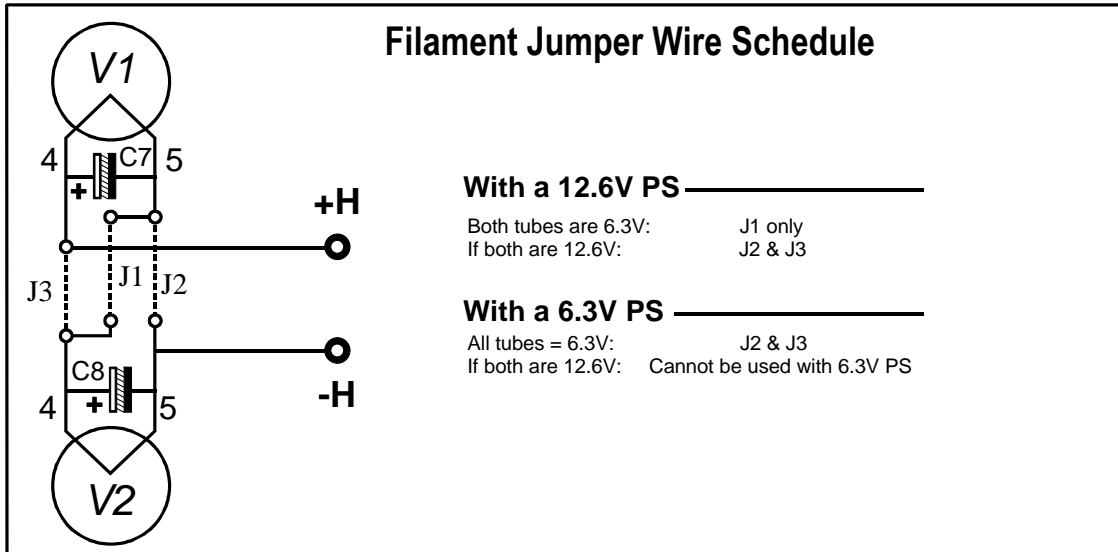
Terminating Resistors Here's a cheap trick to try: at each input RCA jack, place a 100k to 1M resistor, bridging input hot and jack ground; and on an XLR jack, bridging pins 2 & 3. Why? The resistor provides a path for the AC signal present at the jack, so given a choice between radiating into the chassis or going through the relatively low-impedance resistor, the AC signal chooses the latter path, reducing crosstalk.

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

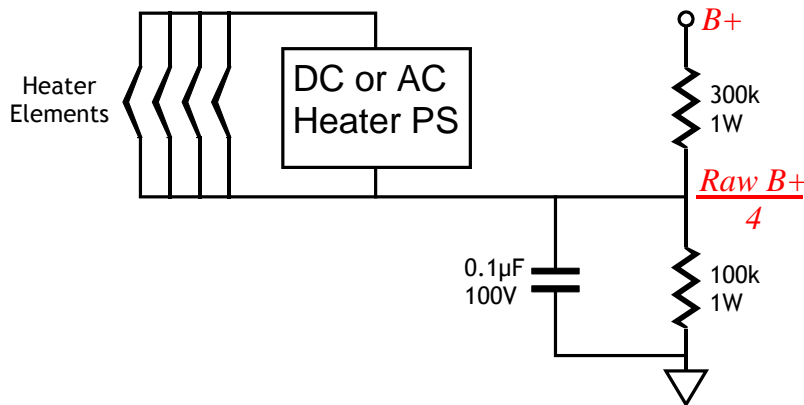


Heater Issues

The external heater power supply voltage can be either a 12V or a 6Vdc. Using a 12V heater power supply is more flexible, as both 12V and 6V tubes can be used, with the correct jumper settings. If an AC heater voltage is applied, be sure to remove capacitors, C7 & C8. Note: Perfectly good tubes with uncommon heater voltages, such as the 8CG7, can often be found at swap meets, eBay, and surplus stores for a few dollars each. Think outside 6.3V box.

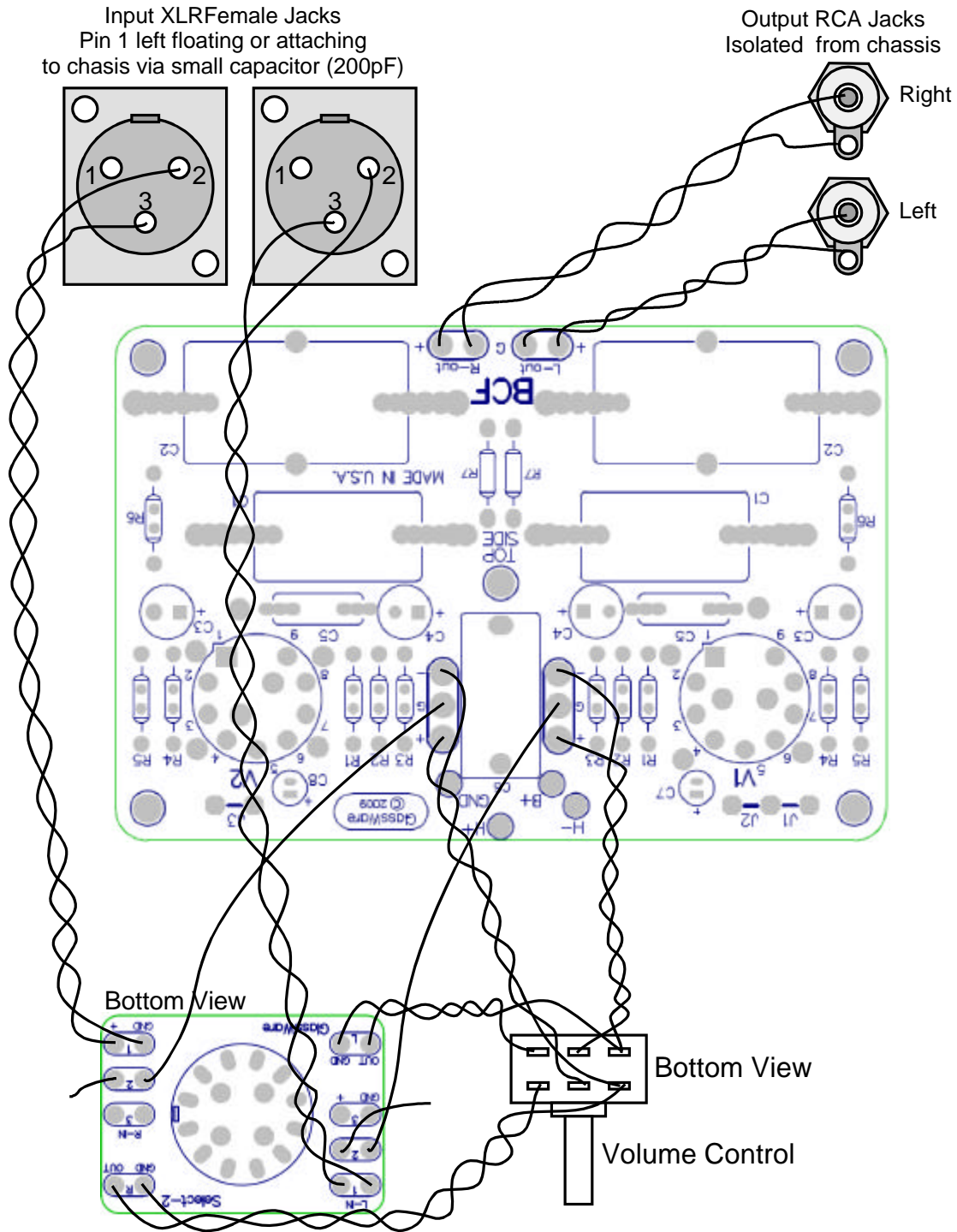


Since one triode stands atop another, the heater-to-cathode voltage experienced differs between triodes. The safest path is to reference the heater power supply to a voltage equal to one fourth the B+ voltage; for example, 75V, when using a 300V power supply. This $\frac{1}{4}$ B+ voltage ensures that both top and bottom triodes see the same magnitude of heater-to-cathode voltage. The easiest way to set this voltage relationship up is the following circuit external to the PCB:



Alternatively, you might experiment with floating the heater power supply, by “grounding” the heater power supply via only a $0.1\mu\text{F}$ film or ceramic capacitor. The capacitor will charge up through the leakage current between heater and cathodes. Not only is this method inexpensive, it is often quite effective in reducing hum with certain tubes.

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In this preferred physical setup, the XLR jacks have their pin 1 left floating or attached to a small-valued ceramic capacitor (100pF to 0.01 μ F) that ground at the jack's entrance to the chassis and each output RCA jack gets its own pair of hot and ground wires and are isolated from the chassis with non-conducting shoulder washers; and the same holds true for the input RCA jacks if they are used. On the XLR jack, pin 2 is the hot and pin 3 is the cold; attach the hot signal lead to the + input on the BCF PCB. The input RCA jacks' hots attaches +inputs on the GlassWare Select-2 selector switch PCB and the selector switch's -input attaches to ground; thus when a RCA jack input is selected, the bottom section of the BCF has its input grounded.

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 the smallest components in place, and then solder the next larger, then the largest last. 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 solder one tube socket pin from the top first and then to solder the rest of the socket's pin from the bottom side of PCB. As the PCB is so overbuilt, it is extremely difficult to remove an incorrectly placed part. Be especially sure to confirm all the electrolytic capacitor and power supply connections are orientated correctly, as a reversed polarized capacitor can easily vent (or even explode) when presented with high-voltage. Confirm twice, solder once.

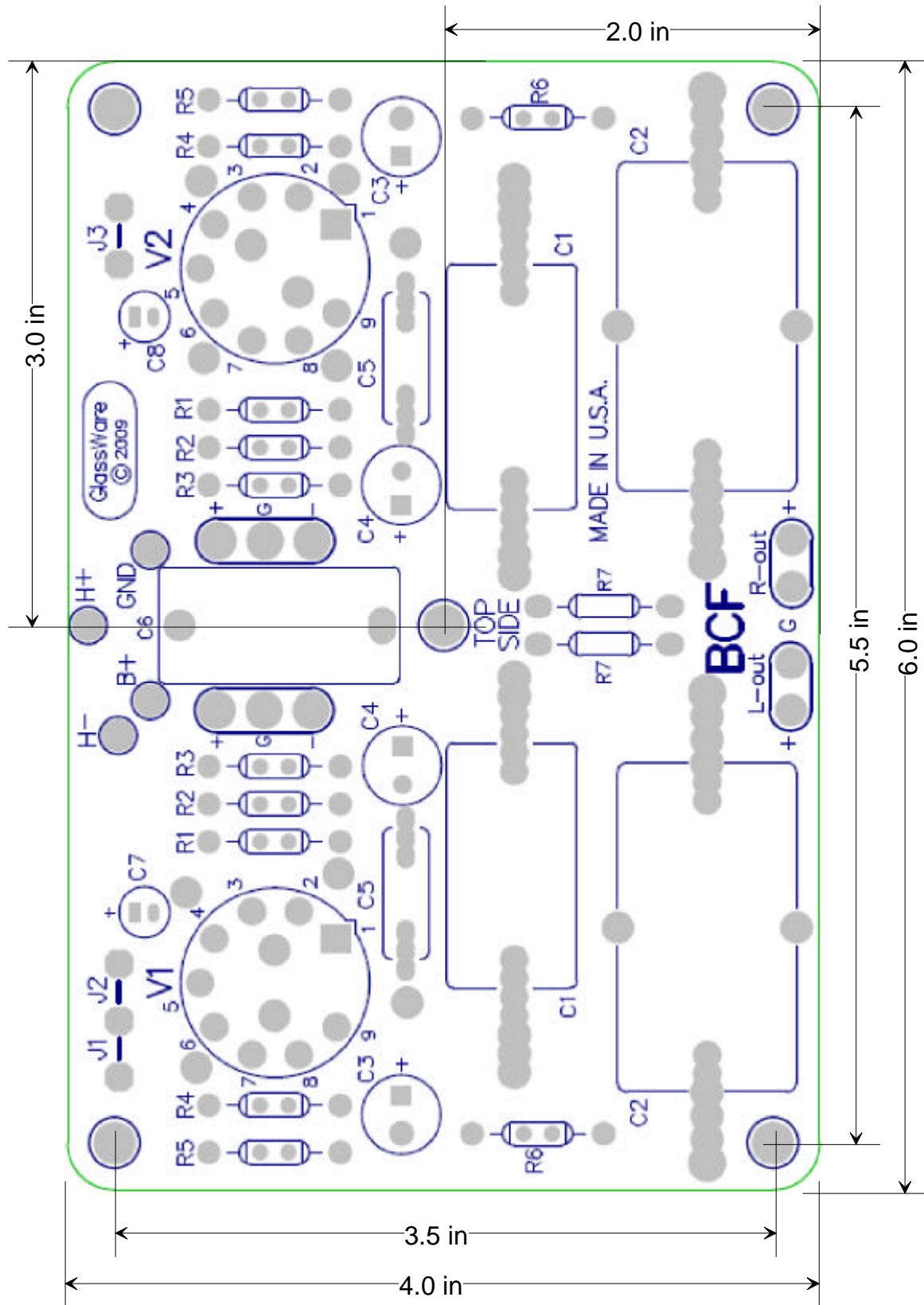
By the way, the tube sockets must be soldered to the PCB's topside, but all the remaining parts can be soldered to the bottom side. Thus, the BCF PCB can be used with the tubes protruding from holes in the chassis top plate, with the all the other tall parts not interfering; be sure to use all five standoffs.

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 electrolytic capacitor will spray hot caustic chemicals. Make a habit of using only one hand, with the other hand behind your back, while attaching probes or handling high-voltage gear, as a current flow across your chest can result in death. In addition, wear rubber-soled shoes and work in dry environment.

Remember, safety first, second, and last.

1. Attach only the heater power supply, leaving the high-voltage leads unattached and electrical tape shrouded, with no tubes in their sockets.
2. Use a variac and slowly bring up the AC voltage feeding the power supply, while looking for smoke or part discoloration or bulging.
3. Measure the tube's heater voltage pins (4 & 5) without and with the tube.
4. Next, power down the heater power supply and attach the high-voltage windings and insert the tubes in their sockets.
5. Attach the power supply to a variac and slowly bring up the AC voltage.
6. Measure the voltage across ground and B-plus pads in the top of the PCB; then measure the voltage across coupling capacitor C2. 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.

Before testing the BCF's AC performance, short the balanced inputs to ground. The output should be noise free and stable. Then, attach a balanced input signal to the BCF and experiment with the grounding configuration to obtain the quietest out. Only after you are sure that the each channels triodes splitting the B+ voltage and that there is no oscillation at the output should you attach the BCF to a power amplifier.



Top Side BCF PCB Mechanical Layout

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Tube	Unbypassed R3 and R6							with C3 & C4
	mu	rp	R3 & R6	Ik(mA)	B+	Wp	Zo	Zo
6AQ8	57	9700	100	10.0	300	1.49	266	167
6BK7	43	4600	200	10.0	300	1.48	302	104
6BQ7	38	5900	191	10.0	300	1.48	340	151
6BS8	36	5000	220	10.0	300	1.48	352	135
6CG7	20.5	10200	583	3.0	150	0.22	1033	469
6CG7	21.1	8960	397	5.0	200	0.49	788	402
6CG7	21	9250	626	5.0	250	0.61	1023	417
6CG7	20.8	9840	1000	4.5	300	0.65	1406	447
6CG7	21.4	8370	470	7.3	300	1.07	828	371
6CG7	21.9	7530	243	10.0	300	1.48	565	326
6CG7	21.8	7680	352	10.0	350	1.71	678	334
6DJ8	30.2	3670	182	5.0	100	0.25	298	117
6DJ8	30.7	2870	124	10.0	150	0.74	214	90
6DJ8	30	2960	205	10.0	200	0.98	298	95
6DJ8	29.6	3060	291	10.0	250	1.22	388	100
6DJ8	28.6	3980	673	5.0	250	0.61	793	134
6DJ8	28.3	4080	845	5.0	300	0.73	963	139
6DJ8	28.9	3400	481	8.0	300	1.17	587	113
6FQ7	See 6CG7							
6GM8	14	3400	187	2.0	24	0.02	410	226
6H30	15.4	1140	69	20.0	100	0.97	138	69
6H30	15.9	1040	74	30.0	150	2.18	135	61
6H30	15.4	1310	221	20.0	200	1.91	299	80
6H30	15.4	1380	294	20.0	250	2.38	375	84
6H30	15	1670	530	15.0	300	2.13	626	104
6N1P	39.8	12200	328	3.0	200	0.30	618	297
6N1P	36	9480	221	5.0	250	0.62	472	255
6N1P	35	956	642	5.0	300	0.73	659	27
6N27P	See 6GM8							
9AQ8	See 6AQ8							
12AT7	60	15000	270	3.7	200	0.37	510	245
12AU7	17	9560	427	2.5	100	0.12	938	525
12AU7	16.6	9570	741	3.0	150	0.22	1249	537
12AU7	16.7	9130	768	4.0	200	0.39	1248	510
12AU7	17.9	7440	336	8.0	250	0.98	718	390
12AU7	18.1	7120	328	10.0	300	1.47	690	370
12AV7	37	6100	120	9.0	200	0.89	279	160
12AV7	41	4800	56	18.0	300	2.68	170	114
12AZ7	See 12AT7							
12AX7	100	80000	2000	0.5	200	0.05	2629	778
12AX7	100	62500	1100	1.0	300	0.15	1655	610
12BH7	16.1	5480	340	4.0	100	0.19	651	318
12BH7	15.7	6090	706	4.0	150	0.29	1046	362
12BH7	15.9	6140	787	5.0	200	0.48	1122	360
12BH7	17.4	4870	383	10.0	250	1.21	638	263
12BH7	18.4	4300	267	15.0	300	2.19	483	221
12BZ7	100.0	31800	560	2.0	300	0.30	858	313
12DJ8	See 6DJ8							
12FQ7	See 6CG7							
5751	70	58000	1250	0.8	200	0.08	1976	802
5963	21	6600	200	10.0	250	1.23	494	298
5965	47	7250	220	8.2	300	1.22	368	151
6072	44	25000	1250	2.0	300	0.30	1736	549
7119	21.7	2390	324	15.0	300	2.18	425	105
ECC81	See 12AT7							
ECC82	See 12AU7							
ECC83	See 12AX7							
ECC85	See 6AQ8							
ECC86	See 6GM8							
ECC88	See 6DJ8							

The above table lists many of triodes suitable for the 9-pin-based BCF PCB. This table lists the same tube under several different B+ voltages and with different cathode resistor values. Two output impedances are listed: the first is the output impedance the tube realizes with unbypassed cathode resistors; the second is the output impedance for the same tube, but with resistors R3 & R6 bypassed with 1µF capacitors (C4 & C5), which will result in the lowest output impedance, but at the expense of slightly increased distortion.