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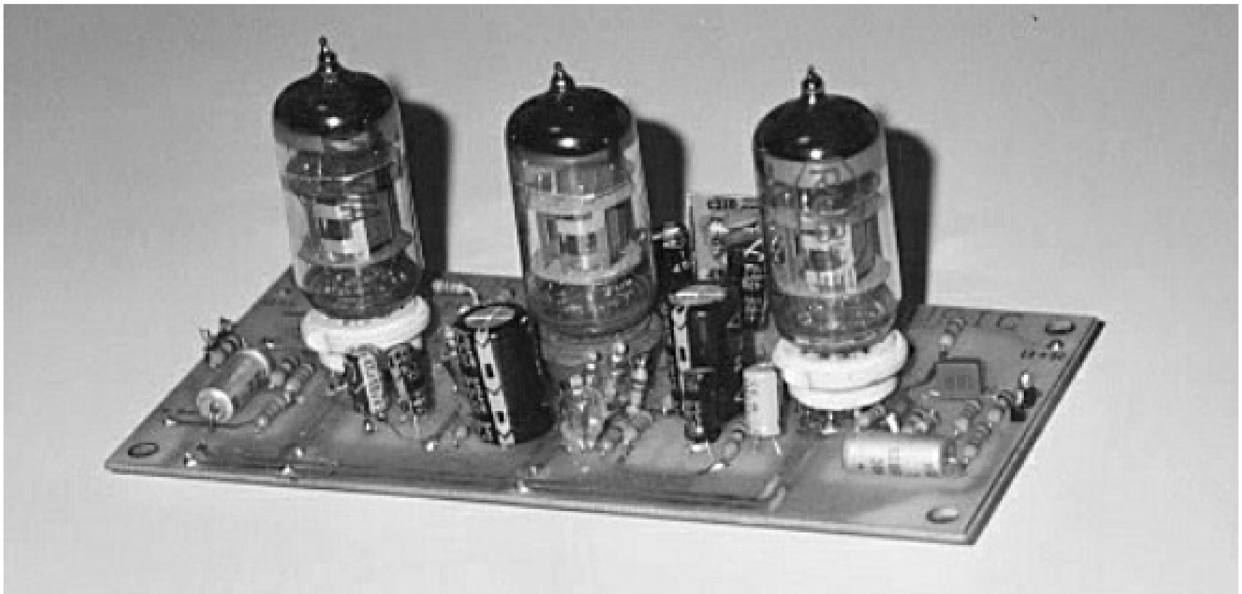
A HI-FI VACUUM TUBE PHONO PREAMP



The tube preamp, PCB style; right channel is configured as a phono preamp, via the small vertical “outrigger” board

1: DESIGN PHILOSOPHY

There has been much press lately about the merits (and drawbacks) of the venerable vacuum tube. How much of this retro movement is based in demonstrable principles, and how much is rooted in nostalgia or subjectivity is a debate that could fill volumes.

What *is* clear is that there is considerable renewed interest in vacuum tubes, a technology that even two decades ago was considered as obsolete as spats and top hats. Now the trend is reversing, and a number of manufacturers are again supplying tube gear for audiophiles, musicians and hobbyists. In many cases, these are simply old (or should we say "vintage") circuits masquerading as new creations. Other products offer new approaches to vacuum tube technology, adding what we've learned in the meantime to come up with some truly noteworty designs.

The central argument for the pro-tube movement is that specs can be almost meaningless, and that what counts is how it sounds to the individual listener. Highly subjective descriptions are therefore used, instead of the techno-babble we've more-or-less gotten used to in recent times. The opposite camp claims that numbers don't lie, and that you can't improve something by adding distortion of any kind.

Both camps have valid points. Most of us have heard expensive gear with spectacular specifications, but were left cold by the"too good to be true," almost clinical sound of such equipment. Similarly, most people will agree that just because something has tubes in it doesn't make it worth listening to. Turn on one of those old "All-American Five" table-top AM radios if you want a striking demonstration of just how *bad* vacuum tube equipment can sound.

Perhaps a way of reconciling the two viewpoints is to consider the distinction between musical equipment, and reproduction equipment. For musical gear, the individual frequency, waveform and phase distortions are part of what defines the sound of, say, a Fender tube amp. Just as no-one would try to define a fine Stradivarius violin with specs and distortion figures, so also it would be specious to argue that a certain tube amp has over 12% THD (total harmonic distortion) at 35 watts.

Reproduction equipment, on the other hand, has always been expected to give a perfect rendition of the signal applied to it. Sounds good in principle; if such a thing existed, we should be able to exactly and perfectly reproduce everything from a grundge band to the New York Philharmonic, making the reproductions indistinguishable from the original performances.

But therein lies the rub. The overall sound of a stereo system depends so heavily on the room it's in, the speakers, volume level, personal preference, and a host of other fuzzy variables that a perfect reproduction system cannot be said to exist even in this day and age, and probably never will. Add the fact that most if not all recordings are electronically sweetened to some degree to make them "sound good" (as opposed to being an exact copy of the performance), and arguments for the clinical reproduction approach lose credibility. If you think about it, personal preference is the only reason why stereos have volume controls, equalizers, and other adjustments to let us customize the sound to suit our very individual ears and brains.

It might be best to view the reproduction gear as a continuation of the same process that started with the construction of the instruments used in the performance. What we ultimately hear is the sum total effect of everything from that original instrument design, to the way it is played by the artist, through the entire recording, mixing and distribution process, to the gear we use to play it, and how we've set its controls.

Still, there is a considerable difference in design approach between the "instrument" and "reproduction" categories. An earlier design ("The Real McTube". *Electronics Now* [date]) documented a vacuum tube preamplifier for use as an adjunct to electric instruments. The design approach was largely empirical, and the emphasis was on highlighting the unique distortion characteristics of the vacuum tube. This article explores the reproduction aspect; the design approach was quite mathematical and precise, and the emphasis is on *controlling* the characteristics of the vacuum tube.

Similar arguments are ongoing regarding vinyl records vs. compact discs. The CD camp points at the CD's accuracy, definition, and clarity, while vinyl lovers bemoan the CD's lack of warmth and claim that conventional records sound more "natural."

This project gives you the opportunity to explore these subjective and controversial debates, letting your own ears be the judge. You may find, as we did, that there is some program material that sounds better through the tube preamp, and others that benefit from the improved definition (whatever *that* is, technically speaking) that good solid-state preamps can offer.

The design philosophy was to improve on "vintage" tube designs by incorporating refinements normally only associated with solid-state gear. Prime among these is the use of a differential input stage, in which the inverting input is used strictly for feedback. Another is the use of direct coupling between stages, a technique once quite common in oscilloscopes, but rare in audio gear. The resulting circuit is thus closely related to the operational amplifier, and is used in a similar fashion.

Considerable effort was taken to design a preamp that is as clean as possible to satisfy discerning audiophiles, while maintaining a relatively low parts count to satisfy limited budgets.

The main circuit board was designed to be virtually universal in applicability. Small outrigger "feedback cards" are used to customize the response to almost anything you might need. As detailed here, the preamp is switchable between magnetic phono (RIAA equalization, high gain) and CD or ceramic phono (flat response, low gain) modes. See Figure 1, which graphs open-loop response and the two closed-loop curves. However, there is no reason why you couldn't adapt it for any other gain/equalization combinations, simply by modifying the feedback cards. Some examples are given at the end of this article (see Fig. 9).

In magnetic phono mode, the RIAA curve is achieved by using negative feedback to decrease the gain at higher frequencies, according to the RIAA specification. The result is that the amplifier runs almost open-loop (about 60 dB gain) at 40 Hz, and rolls off smoothly to a gain of less than 20 dB at 20 kHz. This means that the "tube sound" caused by even-order distortion will be most pronounced in the bass region, giving it that warmth that is so highly prized by vacuum tube aficionados. At higher frequencies, this distortion is increasingly cancelled out by the negative feedback that sets the gain, keeping the mids from sounding "brassy," and the highs from sounding "splashy" (two common complaints about open-loop tube amplifiers).

In CD (or ceramic cartridge) mode, response is flat within 0.5 dB over the audio range, and voltage gain is set at 5 (about 14 dB). At this relatively low gain, the circuit is very clean and distortion-free. However, discerning ears will hear a subtle quality of warmth not present in solid-state gear. A 3:1 voltage divider at the input results in an overall system gain of 5 dB. The output level of CD players varies widely among various models, so you can trim this input gain to suit your machine by changing a single input resistor per channel. Similarly, total circuit gain can be changed with a single resistor on the feedback cards.

The tube types and their operating points were carefully chosen to minimize power supply requirements, and to maximize tube life. Both channels together draw only about 7 mA from a 400 volt supply. This voltage can be derived from a stand-alone unit as documented in this article, or from a larger supply used to drive a vacuum tube power amp.

2: HOW IT WORKS

A: POWER SUPPLY

Figure 2 is a schematic diagram of the Hi-Fi Tube Stereo Preamp. Since both channels are identical, only one is shown. Please note that part numbers 100-199 refer to the left channel, and 200-299 refer to the right channel. We'll be assuming the left channel in this discussion.

Both channels share a single power supply, shown at the bottom of Figure 2. Transformer T1 steps the 120 volts AC from the power line down to 12.6 volts, to supply the heaters of the three tubes. The center-tapped configuration is used to help reduce hum induced by the heater circuits.

Transformer T2 steps the 12.6 volts AC back up to about 110 volts AC for our high-voltage plate supply. Diodes D1-D3 and capacitors C4-C6 are a voltage tripler circuit, providing about 450 volts DC open circuit, or around 380 volts under load. Note that D1, D2, C4 and C5 form the classic positive voltage doubler circuit. On negative half-cycles, C4 is charged through D1. On positive half-cycles, C4 is effectively placed in series with the transformer, and diode D2 transfers this doubled voltage to C5. D3 and C6 are a negative half-wave rectifier/ filter, so the total voltage across C5 and C6 is about three times what would be obtained from a half-wave rectifier. This configuration is used instead of the more common "cascade" tripler circuit because of its slightly better regulation.

The tripled voltage is filtered by the low-pass network formed by R1 and C7. It is further filtered and decoupled by R2/C9 and R3/C8 to form the main supply for each channel. This eliminates any cross-talk between channels due to power supply coupling.

Additional decoupling is provided for the critical first stage of each amplifier by onboard filters R117/C103 (left channel) and R217/C203 (right channel), reducing power supply hum injected into these high gain circuits.

B: DIFFERENTIAL INPUT STAGE

The appropriate input signal is coupled from the input jacks, through switch SW2, to the grid of the first section of V1 (a 12AX7A vacuum tube) via coupling capacitor C101. Since this grid is at a substantial DC voltage above ground, resistor R101 is used to insure that the input is always at DC ground potential.

The two triode sections of V1 are used as a differential amplifier. Note that the cathodes are tied together, and go to ground via a relatively large shared cathode resistance consisting of R104 and R105. This acts as a rudimentary constant-current source. If the current in either triode increases, a comparable amount of current will be robbed from the other triode. Therefore, if the voltage on the signal input increases (goes more positive), plate current increases and the plate voltage of that triode will drop. However, if the voltage on the feedback input increases, causing an increase in current in that triode, the voltage on the plate of the first triode section will *increase*.

A portion of the cathode resistor voltage drop is sampled by R104, low-pass filtered by R103 and C102, and provides the grid bias for the first section of V1 via R102. An interesting feature of this circuit is that this also sets the bias and operating points for the entire amplifier, as we'll see as we progress through the analysis.

Experienced electronicists will be quick to point out that a simple cathode resistor is not an ideal current source. As a result, the "common-mode rejection ratio" (that is, the gain matching of the two inputs) of this circuit is quite low. A great improvement would result by using a pentode as a current source in the differential amplifier cathode circuit, at a considerable increase in cost and complexity.

What we do instead is "cheat the system" and carefully choose the operating points of the two triodes to be different, to help offset the error. Note that, even though there is approximately the same current flowing in the plate circuit of each triode section (about 500 microamperes), the plate voltage on the second section is considerably higher (by about 90 volts) than the plate voltage of the first section. This is because of the lower value of plate resistor R107, as compared to R106. This "trick" assumes that the two sections of the tube are reasonably well-matched, and will furthermore track as the tube ages. Tests with different tubes of varying manufacture and condition have verified that this assumption is indeed valid.

C: OUTPUT STAGE

The output of our differential amplifier is direct-coupled to the grid of the second stage, V2, a 12AT7 dual triode. This tube was chosen over the more common (and cheaper) 12AU7 because it sports about three times the gain (transconductance), yet is capable of almost the same output drive.

The difficulty with direct-coupled vacuum tubes is that the grid of the second stage sits at a substantial voltage above ground (about 200 volts in our circuit). This is why we need such a high B+ voltage, since we have to insure that the plate circuit of the second stage has enough headroom. So why bother at all? After all, tube amps have been made for over half a century with good old RC interstage coupling. The answer has to do with dynamic stability as the tubes age. Unlike conventional multi-stage tube amplifiers, our circuit is self-levelling because its DC biasing is in a closed feedback loop.

R115 in series with the grid of V2 introduces a high-frequency pole with V2's grid-to-plate capacitance, effectively limiting high-frequency response. This allows us to run the preamp with relatively heavy negative feedback (low gain) without worrying about oscillations caused by phase shifts.

In order to bias V2's grid at the proper voltage (about -1 volts with respect to cathode), we need a humungous cathode resistor R108. To avoid losing all our AC gain, this resistor is bypassed for AC by capacitor C106.

C: DC FEEDBACK

The rest of our circuitry completes the DC feedback loop. In case you're wondering about the presence of the three NE-2 neon bulbs in series (collectively called V3), let's analyze the circuit without them. The plate of V2 will be sitting at about 315 volts, whereas the grids of V1 are at about 27 volts, or a factor of about 12:1. We could use a 12-to-1 voltage divider, which would give us a DC closed-loop gain of about 13. That is, it would require a 13 volt change at the output to compensate for a 1 volt change at the input.

We can easily improve on this considerably. The lowly neon bulb can be viewed as the tube-technology equivalent of the zener diode. That is, the voltage drop across the bulb (typically about 65 volts) is reasonably independent of the current passing through it. The three NE-2's can therefore be viewed as a 200 volt "level shifter," allowing us to use a much lower voltage division ratio (about 4:1) in our DC feedback loop. The result is an almost 3 times improvement in DC operating point stability. (Besides, those six neon lamps just *look* really cool!)

The level-shifted and divided output voltage goes through a two-stage low-pass filter consisting of R111, C105, R112 and C104. This strips AC signals from our DC feedback loop, to insure that the amplifier will still have full open-loop AC gain. The resulting DC feedback voltage is applied to the inverting input of our differential amplifier via R113. The junction of R113 and C104 also forms a convenient "AC Ground" point for our signal feedback networks.

Let's step through what happens if some change occurs in DC operating point. This change could be caused by tubes and other components aging, power supply voltage fluctuations, or input overdrive conditions. Let's assume that the change causes the output voltage to rise, as would be the case as V2's emission decreases. This would cause an increase of bias voltage on the grid of V1B (the feedback input), causing that stage to draw more current and increase the voltage on the common cathode. V1A (our input stage) would therefore draw *less* current, causing the voltage on its plate (and therefore the grid of V2) to increase. This would cause an increased V2 plate current, resulting in a *decrease* in plate voltage, tending to buck the original change. See how the overall circuit is self-regulating?

Resistor R114 forms the plate load for V2, and C107 couples the output to our output jack J103. Capacitor C108 provides another pole of high-frequency attenuation (compensation) to prevent oscillation at low gain. (Before I added this additional compensation, the first prototype became a dandy 11 megahertz transmitter at gains lower than about 3!)

D: AC FEEDBACK

So far we have an amplifier with an open-loop passband gain of about 60 dB, with 3-dB corners at about 40 Hz and 2 kHz. (See Fig. 1.) While the low-frequency end isn't bad, the high-frequency end is pretty awful. This is because of the compensation intentionally introduced by R115 and C108. Not to worry, our bandwidth automatically increases again when we apply negative feedback.

The circuit behaves very much like an operational amplifier (op-amp). But before we get on with designing feedback networks, we'll point out the ways in which it is *not* like an op-amp:

a) Open loop gain, although quite high, cannot be considered infinite as in many op-amp applications.

b) The circuit exhibits a large output-to-input voltage offset (on the order of 290 volts). Any AC feedback elements between output and input therefore have to include DC blocking capacitors.

c) The DC voltage at the feedback input is non-zero (about 27 volts in practise), so again there is a need for DC blocking. The point marked "ACG" (AC Ground) is provided for convenience, acting as a virtual ground for AC.

Keeping these restrictions in mind, we can use the formula for the classic non-inverting op-amp to determine our gain with feedback. Note that the inverting input (-IN) has a 47K resistor (R113) to "AC Ground". This is our "default" value for input resistance to the feedback input. Let's call that resistance R_i . The bare-minimum feedback network would consist of just a single resistance (we'll call it R_f) in series with a DC blocking capacitor between output and -IN. The theoretical gain with feedback would then be:

$$A_v = (R_f / R_i) + 1$$

For instance, let's compute our gain if we connect a "bare bones" feedback network consisting of a 430K resistor in series with a DC blocking capacitor between "OUT" and "-IN". That is, $R_f / R_i = 9.15$, so our gain would be 10.15, or about 20 dB.

The feedback elements do not have to be pure resistances; the above formula could be generalized to include complex impedances.

$$A_v = (Z_f / Z_i) + 1$$

The circuit's actual performance follows this predicted formula very closely, verifying that our gain-matching shortcut described earlier works just fine. See Figure 3 for an actual plot of the prototype. The slight curve at the low end is caused by that "+1" factor in the equation; as R_f / R_i increases, that factor becomes less significant, and the graph approaches a straight-line relationship. However, at gain settings above about 200 (46 dB), the relationship begins to fall apart as we approach the amplifier's open-loop gain.

E: CD/CERAMIC FEEDBACK NETWORK

The feedback network for the CD/Ceramic phono input is little more than our "bare bones" network described above. R118 in series with C109 forms our Z_f . R119 is added as a refinement to insure that the negative end of C109 is always held at the DC potential of our feedback input, eliminating the massive pop that would otherwise result when switching modes. Note, however, that it is effectively in parallel with R113, lowering our R_i value to 38.7K. You can verify that our closed-loop gain would therefore be (150/38.7)+1, or about 5.

Input resistor R123 attenuates our input signal by a factor of about 3:1, so the overall system gain is a little less than 2 (5 dB).

The final element is C110, which introduces a 3 dB corner at about 20 kHz, rolling off ultrasonics that we aren't interested in. (Without this capacitor, the gain is actually flat to well beyond 100 kilohertz! See how feedback got rid of that open-loop corner at 2 kHz?)

F: MAGNETIC PHONO FEEDBACK

The magnetic phono feedback is only a little more involved. The straight thin lines in Figure 1 show the theoretical RIAA specification (asymptotes), and the curve shows the actual response of our preamp in this mode.

Note that, in the bass region, our preamp has to run open-loop in order to get the required 60 dB gain. Our feedback network therefore doesn't even have to bother with the poles in this region. Instead, R120 was chosen to present an appropriately low value for R_i . The effect is to further "swamp" any low frequencies that manage to make it through the DC feedback filter consisting of R111, C105, R112 and C104. This pushes our low-frequency "hump" to exactly where we want it.

As frequency increases, at about 50 Hz., C111 comes into play and acts as an integrator to roll off our response. At about 530 Hz., the pole consisting of C111 and R122 tries to level the response, and at about 1600 Hz. C112 and R122 introduce the second roll-off section. The net result is a gradual rolloff over the audio range at a somewhat gentler average slope (about 4.5 dB per octave) than would be achieved with a single-pole integrator (6 dB per octave). Finally, R121 limits minimum gain to about 6 dB at ultrasonic frequencies, helping to insure stability.

Other feedback options are briefly discussed at the end of this article.

3: HUM REDUCTION IN TUBE CIRCUITS

Before we get on with building the hi-fi tube preamp, a few notes are in order regarding that bane of vacuum-tube circuitry -- power line hum at 60 Hz (and its harmonics).

A: Filament supplies in preamplifiers using dual triodes should be center-tapped, with the center-tap connected to pin 9 and grounded. The reason is that contemporary designs of such small-signal tubes have an internal shield connected to pin 9. This obviates the need for an external tube shield in most situations. If you're using the older designs without internal shields, an outside shield might be of significant help.

B: The main filament lines should be twisted together, and routed away from signal points (especially inputs). If using a printed circuit board, ground-planing on the opposite side of the board can help.

C: The B+ supply should be filtered and decoupled to within an inch of its life. This is especially important in pre-amplifier stages. In power amplifiers, a considerable hum reduction can be achieved using choke-input filters. This also tends to improve voltage regulation.

D: All grounds should be tied together to the chassis at a single point. Avoid the temptation of running grounds willy-nilly to the nearest convenient point on the chassis. You'd be amazed at how much of a hum component can be picked up over a seemingly zero resistance stretch of steel chassis.

E: Grounds to low-level input jacks (e.g. phono, tape head, microphone) should be isolated from chassis ground. The shield on the cable running to the jack should be terminated at both ends. In all other cases (high-level inputs, outputs, lines to volume controls, etc.) the shield should be terminated at one end only.

F: The power supply should be placed as far as practical from the low-level portion of the circuitry. Transformers can be a source of both electrostatic and magnetic induction. Physically orienting transformers for minimum hum can be of significant help. Transformers can also be wrapped with conductive shielding material to good avail. Mu-metal shielding is best, as it reduces magnetic induction as well as electrostatic fields.

G: Silicon rectifier diodes should be bypassed with small capacitors (.002 to .02 uF) to reduce the transients that occur when the diodes commutate off. See the power supply schematic for an example of this. Further improvement can be obtained in many cases by adding small resistors (about 100 ohms for low-current supplies as for our preamp) in series with each diode to limit the inrush current. If this is done, there is no significant advantage to using tube rectifiers (e.g. 5U4, 6X4).

H: Use good-quality shielded wire for all signal leads. RG174U is a good choice. If wires carrying AC power (120 volts or heater supply) must pass near signal areas, shield these also. In my layout, I used RG174 even for the power on/off switch, since for the sake of convenience it was mounted on the front apron, bringing it uncomfortably close to the preamp PCB.

I: You might have some residual hum even if all these precautions are observed. This is especially true if your cathode(s) are "hot" for signal, as in our case, and can be due to capacitive coupling between heater and cathode. This is often best handled with a "hum-bucker" circuit, such as is shown in dotted lines in the schematic of Figure 2. This injects a sample of the filament supply into a convenient input point, and allows nulling with a small trimpot. Depending on the design, the element feeding the input will be either a large resistor or a small capacitor, depending on whether the residual hum is in-phase (0 or 180 degrees) or shifted by 90 degrees (or 270 degrees) from the mains supply.

J: Don't set up your preamps for a lot more gain than you need, under the tenet that "more is better". Un-necessarily high gain only gives more opportunity for hum to creep in, and also worsens the thermal noise situation. (Thermionic tubes are substantially noisier than their solid-state counterparts, operating as they do at much higher temperatures.) This shows up as a hiss in "flat" preamps, or as a scratchy rumble in preamps with high-frequency de-emphasis (e.g. phono and tape head preamps). The exception, of course, is if you want massive gain for special effects like overdrive distortion, (e.g. "The Real McTube) in which case thermal noise will be a negligible noise component of your output signal.

4: BUILDING THE HI-FI PREAMP

A: MECHANICS AND POWER SUPPLY

Start by doing all the mechanical work. Lay out, drill and cut your enclosure for the power transformers, input and output jacks, power cord, switches, and standoffs for the PC board. In other words, do as I say, don't do as I do. When prototyping, the design and construction aspects often go hand in hand, leaving plenty of opportunity for a slip of the drill to send you crashing through some delicate part of the circuit. You, as the builder, have the luxury of being able to methodically start with the heavy stuff, and progress to the more delicate circuitry once all the grunt-work has been done.

Your enclosure should be metal (steel or aluminum). Plastic or other non-conductive enclosures are simply not appropriate for this design, mainly because they are a lot more prone to hum. The prototype shown in the photographs was built in an 8" x 6" x 2" steel chassis box (available from Radio Shack). However, this particular box is a rather tight fit, especially if using 2 amp transformers. A somewhat larger box will give you more elbow room, and allow you to place the transformers further away from the more sensitive circuitry.

Next wire up the power supply. This is best done using the point-to-point approach. Carefully follow the schematic diagram, being *very very* careful to observe polarity on diodes and capacitors. This is not just an idle warning; reverse polarity at these voltages can cause electrolytic capacitors to explode enthusiastically, making a heck of a mess at best and possibly injuring someone (e.g. you) at worst.

Incidentally, don't skimp on capacitor voltage ratings. A few of them are already "living on the edge," especially during warm-up when the power supply voltage is higher than normal. Higher voltage ratings are okay, but don't get too carried away (especially on the ones that will later go onto the PC board) or you might have trouble mechanically fitting the larger units into the layout.

The photos can be used as a guide in component layout. Don't ground the high voltage supply and heater grounds just yet; avoid the temptation of using the grounded lug of your terminal strips for either ground. Instead, leave them isolated from the case for now.

Make provision to connect the ground wire from your turntable to the chassis of the preamp. A bolt, lockwasher, and a couple nuts is all it takes for this. Or, make arrangements for a wing-nut, thumb-screw or wire clip arrangement if you prefer.

An important part of building the power supply is making an insulated "bleeder resistor." This consists of a 10K, 1 watt resistor soldered to insulated wire, with shrink-wrap or tape completely covering the connections. At the ends of the wires install insulated 'gator clips. This is to discharge the capacitors after testing or otherwise working on the power supply. Connect the clips between the positive end of C7, and "Pwr Ground" for *at least ten seconds* before touching anything in the power supply area. Getting sloppy with this can result in nasty (and potentially dangerous) surprises. However, don't forget to unclip the bleeder resistor before powering up; the resistor will heat up in a hurry if you do, letting you know in a startling (and smelly) way.

Check, double-check, and re-check your wiring before proceeding. Then do a preliminary test by turning the supply on very briefly (2 seconds or so). There should be no smoke. Use your VOM in 500 to 2000 volt range, and check the voltage at your B+ outputs; they should read several hundred volts. If ok so far, turn the unit on while monitoring the B+ voltage. After a few seconds it should stabilize at 450-470 volts. Power down, and *don't forget to bleed the capacitors!*

Optionally, you can check the supply under load by temporarily soldering 100K, 2 watt resistors between each B+ line and "power ground," and a 27 ohm, 5 watt resistor across the filament lines. Your B+ voltage should be around 390 volts DC, (no less than about 360), and filament voltage should be right about 12 volts AC (6 volts either side of "heater ground".) Don't leave the supply on for too long; the resistors will get quite hot after a while.

B: MAIN PREAMP PC BOARD

We recommend making or buying pc boards for this project, mainly because the layout has been proven to work. If you do decide to use the point-to-point wiring approach, you can improve your odds by following the guidelines for hum reduction shown above, and by keeping all lines as short as possible. However, you're on your own if the circuit oscillates at low gain, or otherwise misbehaves.

Figure 4a shows the actual-size PC board artwork for the wiring side of the main pc board, and Fig. 4b is the component side. Fig. 4c is the artwork for the little "outrigger" boards. Note that the left and right channel outriggers are mirror-images of each other.

Also note that this project takes a departure from the usual convention in this magazine by printing the artwork "flipped" (i.e. mirror-imaged). This is mainly for the benefit of builders using the iron-on toner-transfer method of making PC boards. Simply photocopy the flipped images directly onto your toner-transfer sheet, and it will be automatically correct when you iron it on.

The "flipped image" approach also has an advantage if you use the conventional photographic approach. Photocopy it onto clear mylar as always, but note that the image will now be directly in contact with your pre-sensitized PC board when you go to expose it. You therefore won't have even the thickness of the mylar between the light source and your pc board to diffuse the circuit traces.

If, like me, you have trouble getting good registration on double-sided boards, consider making two single-sided boards, and then sandwiching them together. If you use this approach, we suggest using half-thickness boards to keep the resulting sandwich from being too thick for easy installation of the tube sockets (remembering that some of the pins have to be soldered on both sides).

Figure 5 shows silk-screen artwork for the main board and the outriggers. You can copy these onto toner-transfer sheets, and iron onto your etched PC board before drilling. Alternately, make a clear mylar copy and use it as an overlay.

Figure 6 shows the silk-screen, superimposed over the wiring side artwork, for use as reference during assembly. Again, be careful about capacitor polarities. As laid out, most electrolytic capacitors are the radial type (both leads coming out of one end). The exceptions are C102 and C202, which are axial (leads coming out of opposite ends). However, which style you use isn't critical; simply bend the leads as required to make the capacitor fit the PC board.

Note that any pads that appear on the component side must be soldered on both sides. This includes pins 4, 5 and 9 of the tube sockets; so don't seat the sockets all the way flush on the board. Instead, push the socket through the holes until the pins just barely protrude from the other side. Tack down one pin (e.g. pin 1), and adjust the socket so that it's level. Tack down another pin (e.g. pin 5) and verify that it's still level. Then solder the rest of the pins on the wiring side. Finally, solder pins 4, 5 and 9 on the component side.

Similarly, any components that have pads on the component side should be soldered on both sides, even if the wiring-side pad doesn't go anywhere. There are a few pads (e.g. on the heater supply lines, inputs and outputs) that don't have a component associated with them, but still need feedthroughs. Use bits of resistor-ends for these. The exceptions are the two pads marked "CD". In these, solder 2" lengths of bus wire (i.e. 22 gauge un-insulated wire) to the pad. These will connect to the top of our outrigger boards, to bring the CD feedback network output to the main board.

For any of the pads that go to flying leads off the board, leave the wire ends a bit longer (about 1/4") to give you more to solder the flying leads onto. I suggest running all flying leads from the wiring side, to give a neater appearance ("Look ma, no wires!")

All the resistors lie on the board horizontally, with the exception of R209. For this one, bend one of the leads over 180 degrees, and stand it up vertically.

You might consider buying, say, 10 or 12 of the little NE-2 neon bulbs, so that you can select them for the desired voltage. One by one, check the voltage drop across each, using your power supply. Connect a 330K, 1 watt resistor in series with the lamp under test, and connect the series combination across your B+ supply using test leads. Have a large sheet of paper available, and write down the measured voltage drop of each lamp. Power down, bleed your capacitors, and tape each lamp to the sheet of paper under the voltage you wrote down for it. They will normally be in the range of 60-70 volts; any that are way different from the rest should be rejected out of hand, as they might be leaky. The idea is to come up with two pairs of three lamps that add up to as close to 200 volts as is practical. This procedure is, admittedly, a bit fussy and not really necessary; however, if you have the time and the inclination, it will assure that your two preamp channels are matched for DC stability and operating point.

C: FEEDBACK OUTRIGGER BOARDS

Etch, drill, and stuff the outriggers as per usual. When installing the electrolytic DC blocking capacitors (C109/C209), bend the leads at right angles. This allows a better fit (more clearance from the tubes) than the more usual approach.

After thoroughly checking the outriggers for correct assembly, install them on the main board. (This is important, since it's hard to make corrections on them once installed.) Note that the project will only work if they are installed correctly; don't switch them! When installed properly, the components will be towards the front of the board (facing the tubes). The pads marked "OUT" will be towards the center of the board, and the bent-over electrolytic cap will be towards the outside of the board (near the tubes V1L and V1R).

Position the outrigger so that it lines up with the large rectangular pads on the main board, with about 1/8" of the pads sticking out beyond the edge of the outrigger. Holding it as vertically as possible, tack one of the pads into place. Verify that it's square and straight, re-tacking as needed. When satisfied, solder all three pads well. Don't skimp on the solder, but don't make huge blobs either.

Finally, cut the bus wire jumpers so that they extend about 1/8" beyond the top of the outriggers, and form the ends at right angles. Push them through the pad on the outrigger marked "CD", and solder into place. These help give the outriggers mechanical integrity. Insure that they don't short against anything.

Check your work so far, and verify continuity of all traces. Repair any dropouts you find. Be on the lookout for any solder bridges, verify all values and orientations, and take a break.

D: POWER SUPPLY WIRING

Figure 7 shows the power supply and output wiring. Note that so far only two things are connected to the chassis: the sleeves of the two output jacks. Choose the more accessible one, and make that your system ground. Route all power supply wires as far as practical from signal areas (especially the inputs and feedback networks). Leave wires long enough to allow you to tilt the board to gain access, but no longer than necessary.

Install the tubes. Note that the 12AT7 must be in the center socket. By the way, don't use old beaters from somebody's junk box; invest in new tubes, and save yourself a lot of potential grief. There are excellent tubes available under the "Ruby" trademark that are manufactured in China. The "Svetlana" brand (made in Russia) is also excellent, but a bit pricier. Unless you're a purist, there's no need to pay extra for matched pairs of 12AX7A's.

At this point you can do a DC operating point check on your preamplifier. Make sure that the PC board assembly is well insulated from the case, and anything else for that matter. Plug it in, and hook up your VOM to one of the B+ lines. Turn the power switch on, the six NE-2 neon lamps should light within about 1/2 second. Your B+ should read around 420 volts, and the tubes' heaters should start lighting up. After about ten seconds, the B+ should suddenly sag, stabilizing at about 380-390 volts. If it goes lower than about 360, panic.

Check the voltages at the following points. A deviation of about 10% is nothing to worry about, but larger differences should be investigated. Compare the readings for both channels; they should agree quite well.

Plate V1A (bottom of R106/R206)	190-210 V
Plate V1B (bottom of R107/R207)	270-290 V
Cathodes V1 (top of R104/R204)	26-32 V
Grid supply V1A (top of C102/C202)	1.5 V less than cathodes
Grid supply V1B (ACG)	2V less than cathodes
Grid V2 (R115/R215)	same as Plate V1A
Cathode V2 (top of R108/R208)	1.5V higher than Grid V2
Plate V2 (OUT)	290-310 V
+IN (top of R101/R201), Outputs	0V

OK so far? Congratulations! Your DC servo loops are working just great. If not, don't fret. Remember that any problem in the DC loop will probably cause *all* voltages to be wonky, so it may not be easy to troubleshoot. Take your time, go over all your connections, verify parts, etc. Still having trouble with one channel? Swap 12AX7A's. If the problem follows the tube, you've got a bad one. If the problem stays with the same channel, there's a problem on the board circuitry. There, you got it? Well done!

E: FINAL WIRING

The home stretch is always the most grueling, and this is where you're most prone to make mistakes. So far you've been careful, and have a tidy power supply unit and a clean, well-assembled PC board. Your DC loops work great, and you're excited to finally hear this thing in action. Don't blow it by rushing the final wiring; take your time, expend the additional effort to make your wiring professional-looking. You'll be rewarded with a completed project that looks and works great, and reflects the care and interest you took in it.

Figure 8 shows the recommended signal wiring (inputs and feedback). The feedback networks connect to the mode switch SW2 using short lengths of three-conductor cable with an overall shield. Ground the shields at the PC board only, by soldering to the large groundplane. A piece of spaghetti insulation over the ground wire forestalls the possibility of shorts when seating the board later.

That leaves six coax cables to connect to the switch: 2 phono input, 2 CD/Ceramic input, and 2 cables to +IN on the board. The shields of all six should be connected together near the switch end, but *should not* be grounded to chassis at this point. Again, take the time to do a clean job, and you'll greatly reduce the possibility of frustration later.

The phono inputs (J101/J201) should be isolated RCA jacks; that is, the sleeves should not connect with the chassis. On these, the shield of the cable must be connected to the jack's sleeve connection.

Similarly, the shields *are* connected at the input terminals of the PC board.

Since the CD/Ceramic input is at a much higher level, there is no need to isolate it from the chassis. In this case, *do not* connect the cable's shield to the jack's sleeve connection (i.e. the chassis). However, if you use isolated jacks for these inputs also, you *should* connect the shield to the jack's sleeve. Note that resistors R123 and R223 are wired between the cable end and the jack "pin" connection.

Again, make the cables only as long as necessary to allow the board to tilt out of the way for service. Route them in such a way as to keep them away from AC and output lines. Judicious use of "zap-straps" (nylon cable ties) can do wonders to keep your wiring securely out of harm's way.

5: USING THE PREAMP

Connecting and using the preamp is pretty straight-forward. The output jacks (J103/J203) connect via patch cords to your amplifier's CD, AUX, TUNER, or TAPE IN inputs. The CD/Ceramic (J102/J202) go to your CD player, or turntable with ceramic cartridge. The Mag Phono inputs (J101/J102) go to your magnetic phono. Don't forget to connect the ground wire from the turntable to the ground post on your preamp.

Plug it in, turn it on, and take it for a spin. You can get a neat demonstration of the effectiveness of the DC servo loop by letting the preamp warm up and stabilize, then turning it off while a record is playing. You might be surprised at how long it continues to operate properly, even as the filter capacitors are discharging and the heaters are cooling down.

6: OTHER APPLICATIONS

Figure 9 shows a few other options for the basic preamp circuit.

You might have an old reel-to-reel in a closet somewhere. If not, keep an eye out at the second-hand stores; these can often be picked up for a song. The biggest drawback with many of these is the early transistor playback preamps, especially the ones that use germanium transistors. Replace the playback amp with the variation shown in Fig. 9a. Note that for proper equalization at both speeds (3-3/4 and 7-1/2 ips) you'll need to switch between two different values for C_{NAB}.

The NAB tape standard is even simpler than the RIAA phono spec, consisting essentially of a 6 dB per octave de-emphasis. Again, we use the preamp in open-loop mode at low bass frequencies, and again we use a low value of R_i to maximize our bass response.

Fig. 9b shows a preamp for high-impedance, single-ended dynamic microphones. It is similar to our CD/Ceramic mode, except for a substantially higher gain. Add an impedance-matching transformer, and the circuit is usable with low-impedance microphones.

Fig. 9c shows a application of the differential input capability of our preamp. This is for balanced, low impedance microphones. Note that this is a transformer-less circuit, and therefore offers a significant improvement over Fig. 9b. However, the circuit's shortcomings should be pointed out: First, as mentioned earlier, the common-mode rejection ratio of this circuit is nothing to write home about, and so it will not be suitable if your microphone is connected via a long cable run near stage lighting cables, etc. Secondly, the microphone element will be sitting at about 25 volts DC relative to system ground. Stay tuned for a dedicated balanced mic tube preamp from Dogstar Music, that avoids these shortcomings.

Finally, Fig. 9d shows a "spring reverb" driver. The transformer can be a small output transformer, such as might be salvaged from an old tube radio. A turns ratio of about 25:1 (corresponding to an impedance ratio of 5000 ohms to 8 ohms or thereabouts) would be fine. The first preamplifier (e.g. "left") amplifies your instrument's output with enough drive to run the reverb input transducer via the matching transformer. The second preamplifier (e.g. "right") amplifies the much lower voltage appearing at the reverb's output transducer. Separate gain controls allow you to mix "dry" and "reverb" signals to your heart's content. The resistor values are given as a starting point; depending on the instrument and your particular spring reverb assembly, you might have to trim values to suit. As shown, there should be enough gain to allow you to distort either signal by overdriving the preamp sections.

Incidentally, because of the unique DC feedback system, the clipping characteristics of this circuit are quite a bit different than what you might be used to, even compared to other tube circuits. The author has not experimented with the fine points of this, so the field is ripe for experimentation in this area.

Welcome to the *nouveau retro* world of tubular vinyl!

Fred Nachbaur

August, 1997

PARTS LIST

HI-FI STEREO TUBE PREAMP

POWER SUPPLY and MAIN CHASSIS:

C1-C3 - .005 to .02 uF, 600 V disc ceramic capacitors
C4, C6 - 47 uF, 250V electrolytic capacitor
C5 - 47 uF, 350V electrolytic capacitor
C7 - 100 uF, 450V electrolytic capacitor
C8, C9 - 10 uF, 450V electrolytic capacitors

D1-D3 - 1N4007 or equivalent, 1000V 1A rectifier diodes

F1 - 125VAC, 1/4A Slo-blo fuse (MDL 0.25)

J101, J201 - Female chassis-mount isolated RCA jacks
J102, J103, J202, J203 - Female chassis-mount RCA jacks (isolation not req'd)

P1 - AC power cord with plug

R1 - 470 ohm, 1/2W resistor
R2, R3 - 3.3K, 1/2W resistors

S1 - SPST 125VAC, 3A miniature toggle switch
S2 - 4PDT miniature toggle switch

T1, T2 - 12.6 VAC Center-tapped, 1.5A or 2A Filament transformers

Misc:
2 - 7-position phenolic terminal strips (for power supply wiring)
Standoffs for pc boards, hardware (bolts, nuts, washers, etc.)
Enclosure, fuse holder (optional), hook-up wire, insulating "spaghetti"
1 - 10K, 1W resistor with insulated leads and 'gator clips
(bleeder resistor for testing)
2 - 100K, 2W resistors (optional; for power supply load testing. See text.)
1 - 330K, 1W resistor (optional; for matching NE-2 lamps. See text.)

PC BOARD ASSEMBLY:

CAPACITORS: (Higher voltage ratings acceptable.)

C101, C201 - 0.1 uF, 50V mylar
C102, C202 - 2.2 uF, 50V electrolytic
C103, C203 - 10 uF, 450V electrolytic
C104, C204 - 47 uF, 50V electrolytic
C105, C205 - 10 uF, 50V electrolytic
C106, C206 - 20 uF, 250V electrolytic
C107, C109, C207, C209 - 1 uF, 450V electrolytic

C108, C208 - .001 uF, 100V disc ceramic
C110, C210 - 47 pF, 450V disc ceramic
C111, C211 - 6800 pF, 450V disc ceramic
C112, C212 - 2200 pF, 100V disc ceramic

RESISTORS: (1/4W 5% unless otherwise specified)

R101, R102, R112, R201, R202, R212 - 100K
R103, R113, R116, R203, R212, R216 - 47K
R104, R204 - 1.5K
R105, R114, R205, R214 - 27K
R106, R206 - 330K
R107, R207 - 180K
108, R208 - 91K, 1/2W
R109, R109 - 160K
R110, R210 - 51K
R111, R211 - 22K
R115, R215 - 4.7K
R117, R217 - 10K
R118, R218 - 150K
R119, R219 - 220K
R120, R220 - 1K
R121, R221 - 1.2K
R122, R222 - 43K

VACUUM TUBES:
V1L, V1R - 12AX7A dual triodes
V2 - 12AT7 dual triode
V3L, V3R - Three NE-2 lamps in series (total of six lamps). See text.

Misc: Main and Feedback card PC boards, hookup wire, shielded cable, 3-conductor shielded cable, 3 ea. PC-mount 9-pin miniature tube sockets

Optional: 2 - 50K trimpots, 4 - 100K resistors, 2 - 100 pF capacitors (for humbuckers; see text)

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