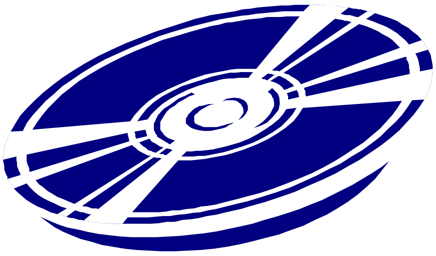
Tube Phono Preamps

Several topologies & tricks
Part 1 of 2



What I find amazing is not that vinyl persists, even twenty years after the introduction of the CD ("perfect sound forever"), but rather that it ever became popular in the first place.

Imagine that records were never made and that someone today broached the proposal that the delicate nuances of a musical performance could be reproduced by dragging a rock against a piece of plastic. Madness. If nothing else, rocks are hard and plastic is soft, so shouldn't it be plastic dragging against rock?

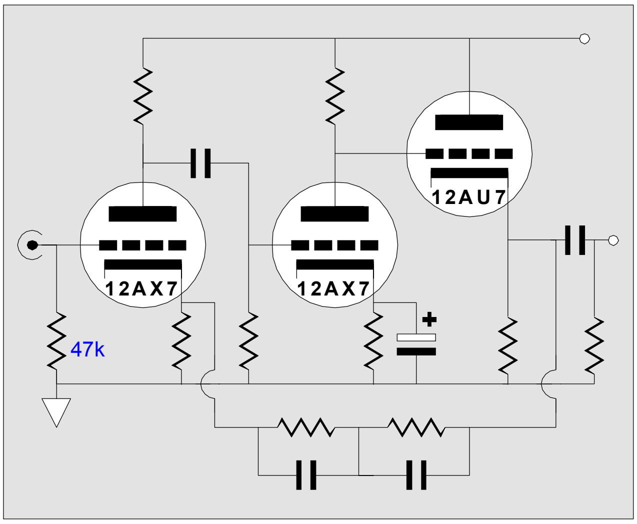
Of course, the same might be said if cars did not exist and someone proposes creating one-ton steel structures that could travel over one hundred miles-per-hour, controlled by anyone over the age of 16, no matter how aged, infirmed, drunk, high, or mentally unstable who could turn a key. What if he also proposes that they be placed on tracks of road 10 feet wide, what then would keep people from crashing into each other? "Painted lines on the road," he tells us. Absolute madness.

First, psychologists would explain that the stress resulting from the constant fear of dying from an accident would render any driver mentally crippled after only a few hours spent driving, as obviously driving a car would be a hundred times more difficult than flying an airplane because of the intimate contact with the ground. Second, complex computer simulations would show that if only one driver in a hundred were slow to react by more than a few milliseconds, the whole streaming mass of cars would collide, creating a vast sheet-metal graveyard. And last, the environmentalists would point out that 70% of all land animals would die within one year of the car's introduction.

Yet we drive. Yet records sound quite good. And records and tubes, V&V, "valves and vinyl" as the Brits say, go together well. Some have argued that the only reason tubes were resurrected was to hide or paint over the blemishes of CDs: had CDs sounded better, we would have been happy to continue down the solid-state path to perfect sound, forever. Maybe. We'll see if SACD (or DVD-A) buries the tube or (what is my guess) it only furthers bringing the tube's virtues to the forefront.

Topologies

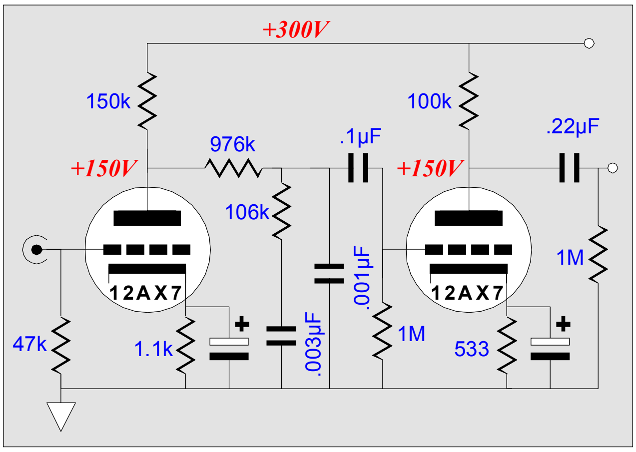
Not too long ago, all tube phono preamps looked (topologically) the pretty much the same. Usually they held two cascading gain stages that were often followed by a unity-gain buffer (a cathode follower), which always ended in a feedback loop that actively realized the inverse RIAA equalization curve. This is the topology found in the Audible Illusion *Mini-Mite*, the Berning *P-1*, most Conrad Johnson's early preamps, Dynaco *PAS-3*, Lux *3300*, Marantz *7* and *C-22*, all of the MFA preamps, the Precision Fidelity *C-4*, and numerous Audio Research preamps, *SP-6*, etc. (One notable exception to this scheme was the Leak *Point One* preamp, which used one pentode-based gain stage and wrapped the equalizing feedback loop around this gain stage in a plate-follower arrangement!)



Conventional active equalization preamp

This basic topology offered a simple way to achieve feedback and equalization in one step. The topology's limitation was that the feedback network itself constituted a severe load at high frequencies and that the maximum gain that was realizable from any two cascaded triodes limited the amount of available feedback. (The equalization capacitors decrease in impedance with increasing frequency and thus they load down the output; more gain stages endanger the fragile feedback stability.) Was this topology the end of the line for tube phono stages?

Back in the 70s, I remember the parade of boring schematics, the same conventional two-gain stage active equalization topology, differing only in component values, a relentless striving to squeeze greater performance from basically the same circuit. Then in the late 70s, the great French audiophile and tube fancier Jean Hiraga designed a preamp with zero global feedback loops and with a passively equalized output signal. H.L. Eisenenson and friends at *Audio Directions* in San Diego, California then mirrored his efforts. But passive equalization was not anything new, as anyone who had read a RCA tube manual had seen the RCA-recommended circuit that used a passive equalization in between two 7025-based-ground-cathode amplifiers. And many cheap tube-based stereo consoles used passive equalization. But it did seem fresh to those who had painted themselves in the old topological corner.



Passive equalization preamp

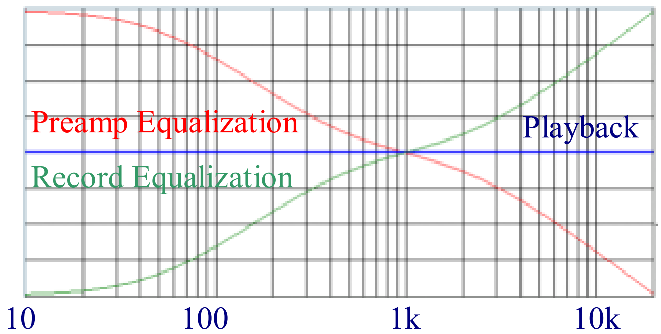
Starting in the late 70s and early 80s, several commercial preamps appeared that used the passive equalization approach: the Counterpoint *5.1*, the NYAL *NCP-1*, and several very high-end Conrad Johnson preamps.

Then the CD came out and the need for a better tube phono preamp topology seemed to disappear. (Yet in the 80s and the 90s we saw some of the best tube phono preamps being made: the MFA *MC Reference* and the Audio research *SP-11*, for example.)

Why Equalize?

If implementing an RIAA equalization curve is such a hassle, why not just record and playback a flat signal free of equalization? It could be done, but the LP would have to be renamed the VSP for “very short play.” To allow greater playback times (bass signals must be attenuated to conserve groove width) and to improve the high-frequency signal-to-noise ratio (high frequency signals must be accentuated to overwhelm the ticks and pops of a record’s surface), the sound recorded onto a phono album must follow a special equalization curve. The lows are greatly attenuated and the highs are greatly boosted. At playback the inverse of the recording EQ curve must be employed to return the signal to flat by boosting the lows and cutting the highs.

Since the need for equalization is not going to go away, we must decide how to implement it: actively or passively or a blend of both. Each approach has its adherents and distracters.



Active Equalization

Active RIAA equalization means feedback equalization: the frequency response is tailored to fit that of the RIAA curve by varying the amounts of feedback returned to the input. The advantage of using feedback is consistency. Each channel will track the other to a very great degree in spite of aging parts or circuit wiring dissimilarities, as the feedback tends to iron everything out. The disadvantage is that, because it is active, the circuit can more readily suffer from input voltage overloads and the preamp must have voltage gain far in excess of nominal +40 dB usually specified, as the feedback uses the excess gain to force the output to conform to the desired curve. Another problem is potential instability, as each coupling capacitor and gain stage add some phase shift.

Since the bass frequencies must be amplified +20 dB higher than the 1-kHz center frequency, the +20 dB must be added to the +40 dB of gain, yielding +60 dB of total gain. On top of this +60 dB an additional 20 to 30 dB of gain might be added to feed the feedback mechanism. Thus, we need more gain, but we cannot risk adding more gain stages, as each coupling capacitor and Miller effect capacitance adds some phase shift, which can reverse the phase of the fed back signal, creating an oscillator, not an amplifier.

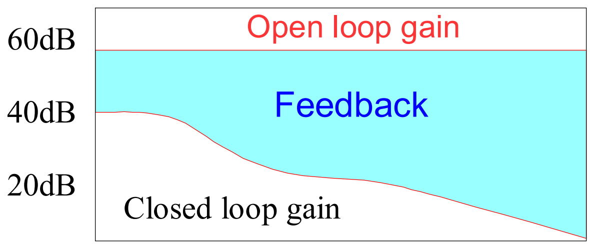
In the absence of this extra gain, the varying amount of frequency dependent feedback can result in looser bass reproduction because of smaller amount of feedback at low frequencies and possibly a pinched, compressed high frequency playback due to excessive feedback ratios at high frequencies since a 20-kHz signal is attenuated by -40 dB relative to a 20-Hz signal. In other words, a preamp with only +60 dB of open-loop gain will have zero feedback at 20-Hz and 40 dB of feedback at 20-kHz.

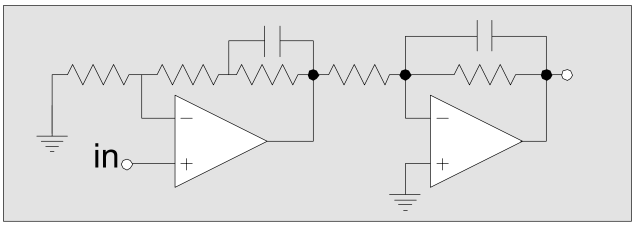
Now +60 dB equals a gain of 1000. This amount of gain could be had from cascading two +30 dB (gain of 31.6) grounded-cathode stages, which is easily achieved with two 12AX7s or even two 12AT7 triodes, but not by two 12AU7s or two 6DJ8s, as their amplification factors are too low.

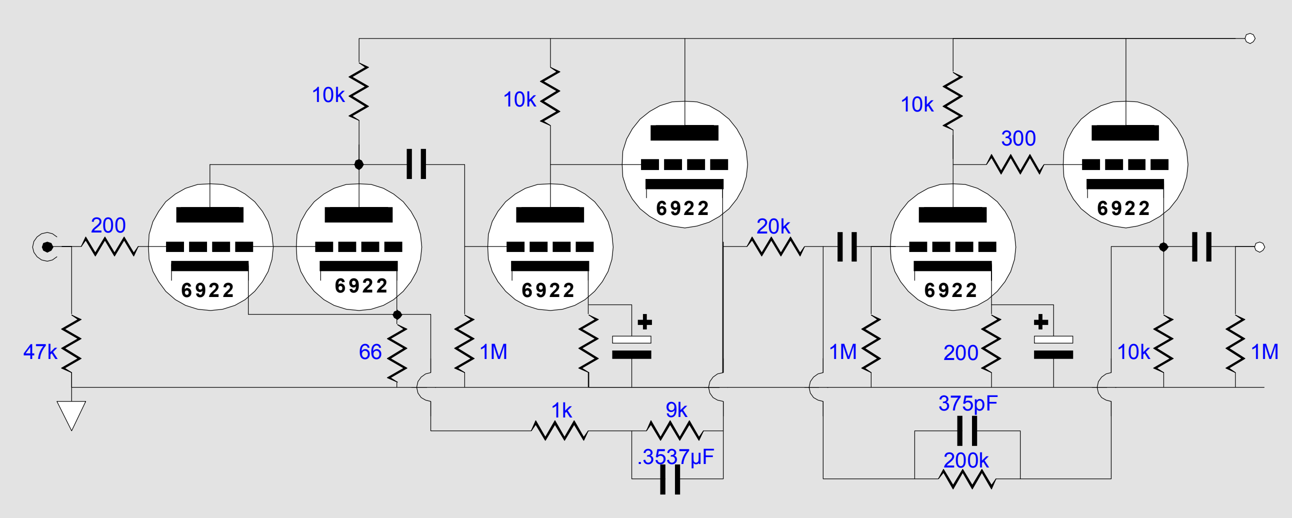
If we increase the desired gain to +80 dB (a gain of 10,000), then even two 12AX7s will not do, as we never realize the full potential gain implied by a triode's mu in a grounded-cathode amplifier, except when it is loaded by a constant current source and works into no other load impedance. One work-around is to use a cathode follower after each grounded-cathode amplifier, but this approach was seldom if ever taken.

So here is the dilemma: we do not want to exceed two gain stages and yet we want more gain. One solution has been to use at least one cascode stage in the mix. The cascode circuit has the very desirable attribute of realizing a gain in excess of the mu of the triode used. (This plan was beautifully implemented in Audio Research's *SP-10* and MFA's *MC Reference* preamp.) Pentode-based circuits and hybrid circuits can also realize a much larger gain than can be developed by the triodes alone.

Still another solution can be gleaned from some solid-state phono preamps: forgo the single-all-encompassing-equalizing feedback loop around the entire preamp stage. In other words, split the equalization curve into its sub-curves and use two gain stages, each with its own equalizing feedback loop. For example, the fist stage can produce the 50-Hz to 500-Hz part of the RIAA equalization curve, while the second stage can yield the 2122-Hz low-pass function of the curve. This arrangement greatly unburdens each amplifier stage and allows for the realization of a much greater total gain.





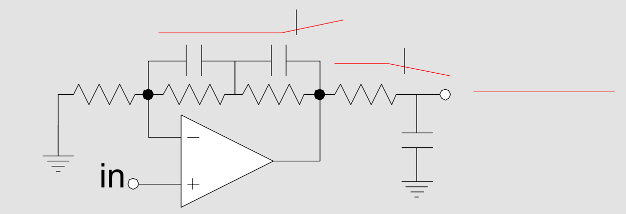


One possible implementation of the this two section approach is shown above. Here the first stage is a fairly straightforward two triode cascaded amplifier. The first triode(s) inverts the input at its plate, which in turn is inverted again by the second triode back to normal phase. The non-inverted signal is then given to a cathode follower which buffers the second triode from the added load imposed by the following stage and the feedback loop. The output from the cathode follower is then returned to the first triode's cathode via the two resistor feedback loop.

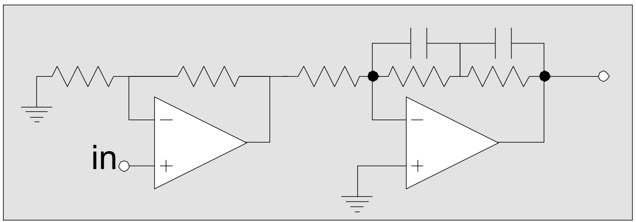
At low frequencies, all of the resistance within the feedback loop is used to voltage divide the output signal deeply as it returns to the first triode's cathode. Thus the gain at these low frequencies is great, as a positive signal applied to the first tube's cathode subtracts from the total gain of the amplifier; thus the less signal returned, the greater the gain. But at higher frequencies, the feedback loop capacitor shunts away one of the feedback resistor's resistance and now the voltage division only partially voltage divides the output signal, thus greatly reducing the output at these frequencies, as more positive signal is given to the first stages cathode. This creates two gain plateaus: one below 50-Hz and one above 500-Hz, the latter being down –20 decibels relative to the former. This is the first half of the inverse RIAA equalization curve.

The second stage is an inverting amplifier made up of a grounded-cathode amplifier cascading into a cathode follower. The feedback loop consists of only the 200k resistor and its shunting capacitor. At low frequencies, the input resistor (20k) and feedback resistor define the gain of the stage based on the ratio of their values. At high frequencies, the shunting capacitor's declining impedance shortens that ratio, which decreases the gain. At an infinitely high frequency, the capacitor's impedance becomes effectively zero and the gain falls to zero, not unity (1), but zero output. This is an improvement over the conventional single equalization feedback loop applied across a non-inverting amplifier, as the output should continue to fall with increase frequency, not go flat once unity gain is reached, which effectively results in a high-frequency boost.

(To overcome this departure from the RIAA curve two approaches have found favor: do nothing, as the record itself has its own high frequency limitation, its own falling off with ever higher frequency function, which even if it did once have infinite frequency response, playing it once would scrape the highs off its surface; and add a fourth pole to the equalization network to help the output follow the RIAA curve beyond the unity gain point, usually this takes the form of a simple passive-RC-low-pass filter added to the preamp's output.)



Other topological variations are certainly possible. An input amplifier with no equalization could feed an inverting plate-follower amplifier with all of the equalization, which would accurately follow the RIAA beyond unity gain.



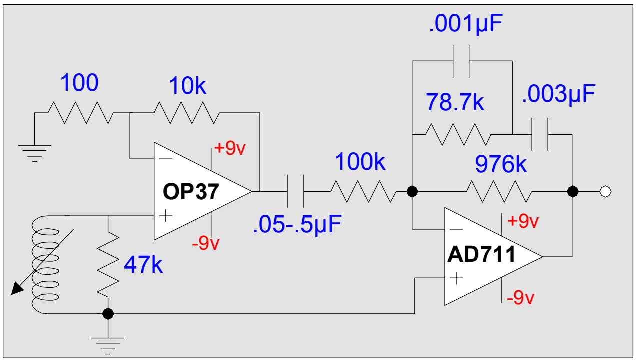
An inverting plate-follower amplifier with only the 2122 Hz part of the equalization might make a good first stage of a two stage MC phono preamp, as moving coils cartridges work well with low impedance shunting impedances, which this first stage could easily present. The second stage would actively finish implementing the 50 to 500 Hz part of the equalization curve.

One complaint might be that any inverting plate-follower amplifier will invert the phase at its output, which if it does cascade into another inverting stage, will result in phase inversion at the output. This is a non-issue, as the leads to the phono cartridge only need to be reversed in phasing to set the output straight. The cartridge does not know how it is being hooked up to a preamp; its coils do not "know" what phase configuration is "correct."

In fact, there is one distinct advantage to having the preamp invert the phase at its output: it lessens the chance of the output signal re-circulating back into the input and causing oscillation. The danger any high gain non-inverting amplifier faces is that its output signal is so much greater than its input signal that only a small fraction of its output being fed back to its positive input can lead to wild oscillation. On the other hand, an inverting amplifier cannot oscillate under the same conditions

Reality Check Preamp

Before moving on, I recommend building a reality check preamp. If several hundred dollars worth of expensive parts and ten hours of frustration and work cannot beat the sonics from a twenty dollar IC-based preamp, then we need to go no further. The schematic below shows a preamp I built back in the 80s. It offers 40 dB of gain and is very quiet. I was able to stuff all of the parts and four 9-volt batteries (dual mono power supplies) in a small aluminum box that sat underneath my turntable. The input leads were hard wired in place and only a foot in length. I used a four-pole rotary switch to turn on the unit. Battery life was easily 20-50 hours, which meant weeks of listening; Costco sold a brick of batteries (25) for under $10 back then, which would last many years. (Yet friends who owned $1000 phono cartridges that were only good for 700 hours of use looked troubled by the expense of replacing the batteries!)



The circuit can be improved by adding negative pull-down resistors to the IC outputs, but at the cost of less battery life or by using a pair of batteries per Op-Amp, thereby doubling the battery life. Now, do not get me wrong; this circuit is not the best phono preamp in the world, far from it. However, whatever tube-based preamp we do build must decisively beat it or we are wasting our money and time.

Next Time

The second half of this article will cover my preferred equalization method: passive equalization and a few hybrid topologies.

//JRB

