Some Feedback about Electrolytic Capacitors...

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This note is about an engineering fix for a problem that may not exist – like many other problems that 'audiophile' circuit designers lose sleep over. But it costs almost nothing to use this technique and my view is: why not? If it pleases both the objectivists and the subjectivists, then that's a "result".

Now, I've always had to steer a careful course in the world of audio engineering. Customers and colleagues have relied on the objectivity and accuracy of the theoretical and practical guidance I've provided. There's no room for emotional and mystical attachments to belief systems that don't deliver falsifiable predictions. In audio engineering terms, it's just as important, and relevant, to apply quantitative judgments to circuit performance as it is to judge the profitability of your company using numbers.

A lifetime of listening to music replayed through countless good – and bad – reproduction systems has, however, continued to challenge the rational, objective, reductionist side of my character. So when people say that they can make changes to a piece of audio equipment that change the way it sounds without changing the way it measures, I'm quite happy with that, because I feel that my personal subjective experience has sometimes corroborated it. We're continually getting better at measuring tiny artefacts and imperfections, and at understanding how they can effect brain-level *perception* when older models of ear-level *detection* seem to imply a null result. Anyway, enough of my uncomfortable position on the spiky fence between objectivity and subjectivity.

Consider the moving magnet preamp circuit shown in figure 1. The passive component values are taken from Doug Self's book on small signal audio design (ref.1, p170). This configuration is widely used, though rarely engineered with the thoroughness that is Doug's trademark. The single-stage RIAA pre-amp is perhaps seen as a bit "old hat" in the audiophile community, where multistage designs are common. These rarely match the technical performance of a single stage design built with good active components, but they have their adherents. When I was selling op-amps, of course I was never upset that a customer would decide to use two or three to do the job of one. The component we're going to talk about here is C9, a large electrolytic capacitor whose job is to force the DC gain back down to unity to prevent the sizeable DC offset voltage that would otherwise result from the DC gain of 313x without it.

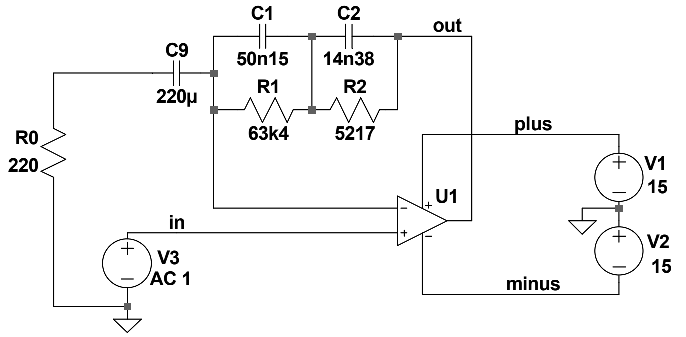

Figure 1: a moving-magnet input stage (after Self)

Many years ago, when I had to build my hifi because I couldn't afford to buy it – and when vinyl was my primary source – I built many RIAA preamps. I admit that I got a little bit concerned about the "mysterious capacitor shortcomings" that were muttered about, especially in connection with the use of electrolytic capacitors in the signal path and in feedback networks.

In my day job as a designer of filters and other industrial signal conditioning products, the imperfections of passive components could prevent gain and frequency response accuracy specifications from being achieved, and I had an adversarial relationship with these damaging parasitics and imperfections. I'd already experienced the effect of the high ESR of small electrolytic capacitors on gain accuracy in preamplifiers I'd designed for non-audio work. You can see why I might have been prone to fret about the use of chemical capacitors in supposedly ultra-high-fi circuitry, where every other component was of impeccable performance and pedigree.

Well, if such capacitors are the source of a somehow undetectable sonic error, then why not try putting the capacitors inside the feedback loop that's defining the amplifier's gain? Under the right conditions, negative feedback can reduce measurable errors, so presumably it can

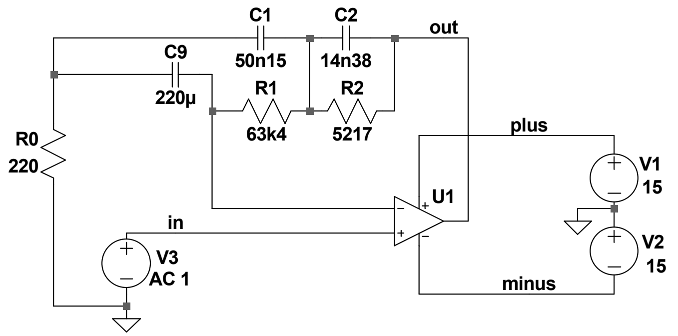

Figure 2: move just one connection, now C9 is inside a feedback loop

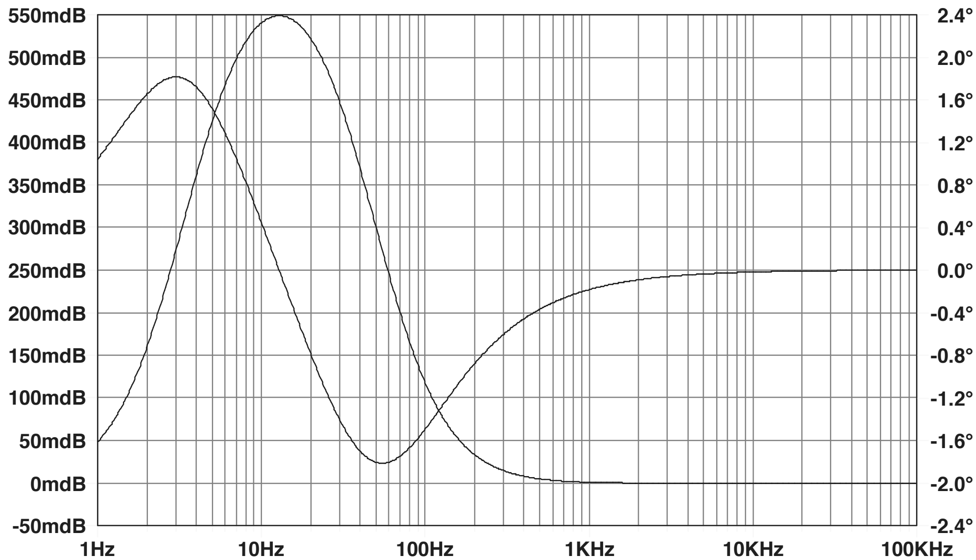

Figure 3: Deviation in response when we move that connection

reduce unmeasurable ones as well. In other words, why not wire your RIAA preamplifier up as in figure 2 – spot the small difference.

The configuration has two advantages. Firstly, at mid and treble frequencies, any parasitic additional impedance caused by the capacitor is irrelevant, as the gain of the preamp is dominated by the outer feedback loop of C1, C2 and R0. Secondly, the significant amount of high frequency current that could flow through these components to ground under extreme input conditions no longer flows through C9, so the attendant voltage drop can't possibly cause some kind of "sonic signature". Seems like this tiny rearrangement has a lot going for it.

Except there was a problem. Measurement (remember that? it's what engineers used to do in the days before simulation) quickly showed that something had gone wrong with the low frequency response of the circuit. Figure 3 shows the (simulated) deviation in response between the old and the new circuits, and it's not acceptable, over 0.5dB out at 20Hz. So, is this another part-good idea that falls at a later fence?

Actually, no, we can fix it – but it'll cost ya! An extra resistor, to be precise. Resistor Rx in series with the capacitor C9 eliminates the error when it has the correct value. But what is this value? It's the resistance that forms a 50Hz rolloff with capacitor C9 – 50Hz being the frequency at which the main feedback network begins to roll off the basic stage gain. The correction would be exact if the feedback

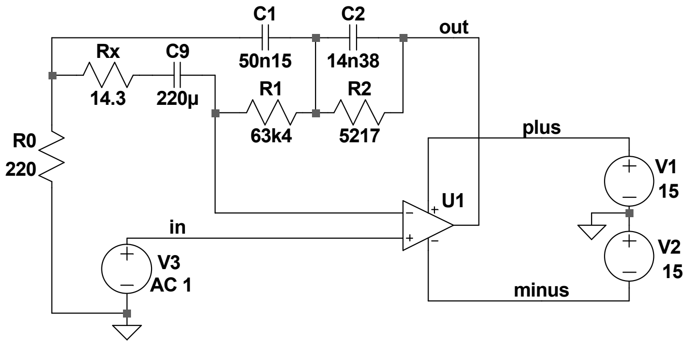

Figure 4: that's better: add Rx to eliminate the discrepancy in figure 3

network contained a single RC network with this time constant, but the residual discrepancy with a 'real' RIAA network is <0.004dB with the nearest preferred value of 14.3 ohms (of course, you can adjust that if C9 really does have significant ESR).

This configuration is not a panacea for all the problems that C9 could introduce. The tolerance of C9 will still have an effect; the accuracy of the correction at 20Hz is about 0.08dB for a 20% variation in C9's value (increasing the loss when the capacitor value rises), if the correction resistor doesn't change. Dielectric absorption time-constants and signal-dependent value will presumably affect the circuit in the same way as before, at very low frequencies. So if you believe that all your capacitor 'sonic' problems are at these low frequencies, this configuration may not do so much for you. But if you're a bit concerned about letting the impedance characteristics of a chunky electrolytic influence the audible midrange and treble character of your RIAA stage in some hard-to-define way, why not try this approach. It might at least allow you to use a physically smaller, cheaper capacitor with poorer published ESR characteristics, without concern that these might mess something up.

Incidentally, the basic approach of achieving DC rolloff through the use of small capacitors in split feedback networks while not compromising mid-band impedance levels has found use in lower-fi portable applications. Figure 5 shows two gain block circuits with equivalent low frequency behaviour, showing a significant (~50x) reduction in capacitor value in (b).

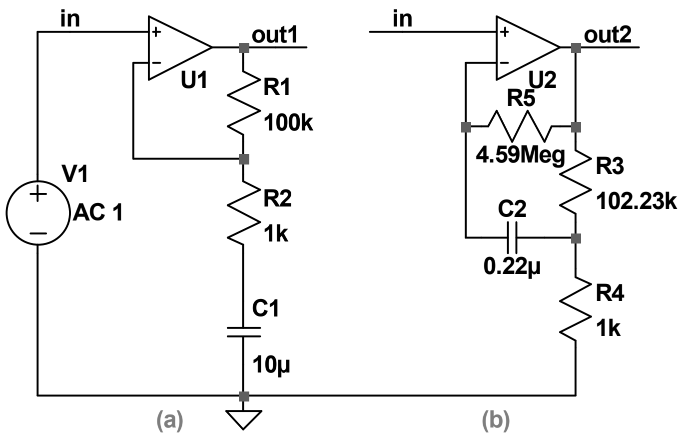

Figure 5: reducing capacitor sizes in miniature portable audio circuitry

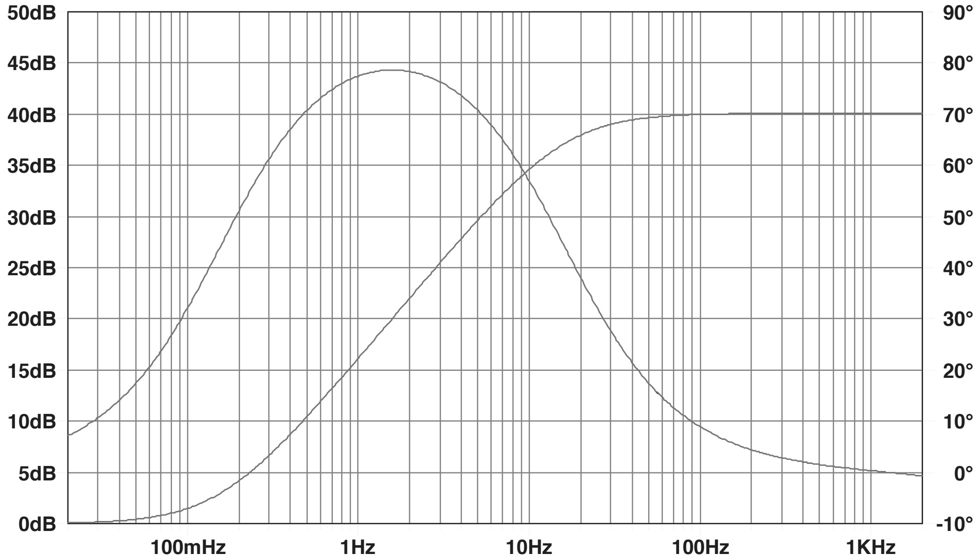

Figure 6: overlaid amplitude and phase responses of figure 5 a&b.

This configuration takes advantage of the very low leakage current at the typically-used CMOS amplifiers' input stage (whose low frequency noise will almost always dominate the noise contribution from the feedback network). Eliminating large capacitors is of great interest to miniature audio equipment designers, and I've recommended this approach to several customers in the past.

There are also benefits to be had from including output coupling capacitors in a feedback loop, as long as a proper analysis is done to understand the effect on frequency response. That'll have to be left to a future note!

Reference

[1] Small Signal Audio Design - Douglas Self. Focal Press (Oxford, England, UK, www.elsvier.com), 2010. Paperback, 556 pages, ISBN 978-0240521170. $ 62.95