Designer's Notebook: Power Supply Noise

The best hifi design can still be improved by optimizing the power supply components and layout.

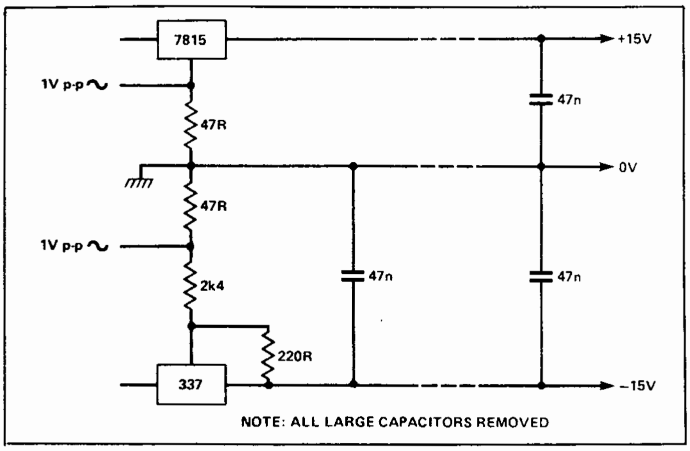
By Neil Munro

I HAD ALWAYS thought that the only real differences in pre-amps came down to hiss and the facilities offered, once adequate specifications had been achieved. But then, in between repairing and designing various small bits of hi-fi, studio and PA equipment for others, I knocked together a turntable pre-amp for myself. I brought it to the shop where I was working at the time and one of the sales staff set it up for a comparison with a newly introduced, expensive commercial design. I sat down, closed my eyes and listened. To my amazement, my pre-amp gave a noticeably clearer and less cluttered performance. I could hear the difference.

Since both pre-amps used broadly similar circuitry (based on the NE5534 and TL072 op-amp chips), both had less than 0.01% distortion at normal levels and both had similarly accurate EQ, I had no idea as to why they should sound so different. I set about developing the design, replacing the moving magnet input with one for a moving coil cartridge. After playing with several ideas, I found the familiar LM394/NE5534 hybrid configuration worked well. I filtered the supply to the LM394 input pair and was rewarded with perfect stability and a sensible slewrate. This MC circuit was predictably noisier than my original pre-amp but it sounded even clearer; the difference between hearing three voices or four voices was more distinguishable.

This didn't seem to be entirely due to cartridge variations, since a very expensive commercial MM pre-amp was just as clear. I was puzzled. What was behind all these evident differences?

I checked the marginal stability of the NE5534 circuit, but it was fine. I considered power supply rejection in the 5534 stage. The MC circuit used a 5534 stage and it performed very well. In fact, the 5534 has a stated power supply rejection ratio (PSSR) of 100uV/V and a stated common mode rejection ratio (CMMR) of 100dB. But this started me thinking. The figures are referred to input and should be reduced by whatever gain follows. They're also quoted at DC. Then there was the fact that the MC circuit's gain comes mostly from the LM394 input pair while the 5534's inverting and non-inverting inputs are fed from equal impedances.



NOTE: ALL LARGE CAPACITORS REMOVED

Fig. 1. Injecting modulation into the power supply.

I felt that I needed to check the real wideband PSSR referred to output, in order to get a true idea of what would happen when you actually listened to some of the music. I rigged up a power supply with a modulating input (Fig. 1), injected 1V p-p on both the positive and negative supply rails and checked the output of the MM circuit. The modulation appeared at -30dB to -40dB. Taking into account an assumed figure, -70dB for main supply noise, the modulation noise would drop to -100dB to -110dB when referred to a nominal 1V output from the pre-amp.

This was good news. But when I came to replace the 330 ohm dummy load at the input to the pre-amp with a real MM cartridge (typically 500R + 1200uH), I was surprised. In the 5-20KHz region, the modulated supply noise increased to -10dB. With the power supply back to normal and the cartridge still in place, I found that high frequency input signals gave up to 3mV or -50dBV of noise, which could appear at the output at an alarming -60dB. On the other hand, when I came to test the MC circuit I found that it fared well with a real cartridge in place. These are predominantly resistive at between 3R5 and 30R. It was even acceptable open circuited: -30dB to -40dB except at 20KHz; this was cured by enlarging the input coupling capacitor and using an active filter for the LM394 stage. The trouble with the capacitor was that low frequency reactance caused an impedance mismatch which reduced CMMR. And on reflection, I realized that it was the inductance of the MM cartridge that caused a mismatch on the inverting and non-inverting inputs to the 5534 op-amp, which ruined the PSSR and CMMR figures for the MM circuit (Fig. 2).

The Heart of Noise

These things were all curable, but they didn't reach to the heart of the problem – the power supply noise in an actual circuit. Clearly, the first place to look for noise in a regulated power supply is the regulation itself. I was using 78/79 types and, as luck would have it, their quiescent noise (20-20z hum and hiss) was -70 to -80dBV. Later, I bought a batch for evaluation and found that some showed as much as -40dBV and often came complete with nasty splutterings.

But that's only part of the story. In operation, active circuitry tends to draw varying current. In Class A amplifiers, this is in step with the signal, but in Class B it becomes half-wave rectified as the positive and negative sections of the audio signal are driven into low impedance

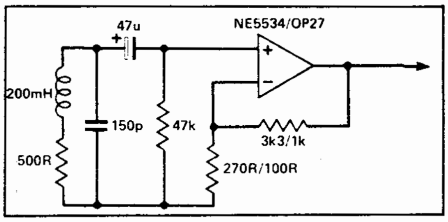


Fig. 2. PSSR test circuit with MM cartridge.

loads. The output impedance of the supply and the impedance of intervening wires and connectors become important, introducing modulation on the IC terminals. From this point-of-view, the quality of the power supply is irrelevant. What matters is the modulation.

The all-too-common practice of decoupling with a filter (typically, composed of a 10R resistor and 10uF capacitor) can actually make things worse because it assumes that the local signal common is 0V. But conventionally, the 0V rail is also signal common and should be treated as a signal path. You wouldn't connect capacitors from the supplies to the actual signal path because they will inject noise and modulation rubbish into it, producing a potential that adds to the signal output. This is because of the practical finite impedance of the signal path.

A 10uF capacitor also has an impedance of 8 ohms at 20 KHz, so signal modulation will be worse. Using a larger capacitor, say 470uF, will help, but at the cost of injecting noise more efficiently (Fig. 3). The only really effective approach (expensive) to ensuring stability on the signal common is to use local active regulation. Even here, care must be taken to avoid injecting DC or other noise into signal common.

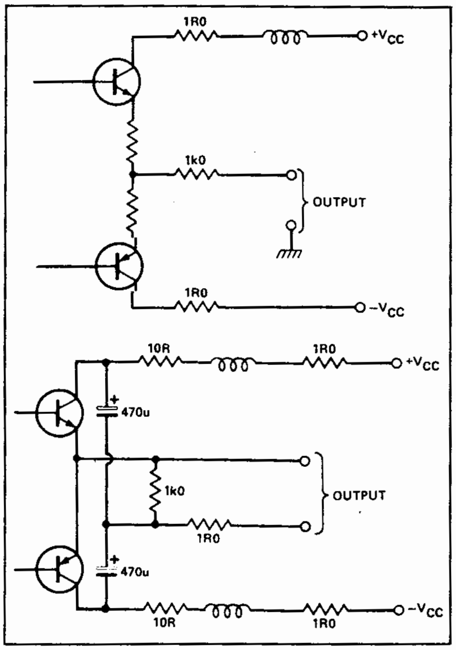


Fig. 3. PSU noise resulting from impedance of leads and signal common corruption in Class A and B output stages.

Another problem resulting from the finite impedance of signal common is that heavy load currents will generate errors. This is usually not offensive from an acoustic point-of-view, but with turntable input stages the feedback current is the pre-emphasized version of the signal with high frequencies boosted. The result can be nasty harsh noise when added to the equalized output. There are several methods for avoiding this: the use of true independent supplies in different stages, differential sensing of output, and shunt feedback or 0V regulation. I chose the last of these as it kills two birds with one stone (Fig.4). The feedback is handled by a local op-amp that transfers it to the opposite supply line instead of signal common, effectively reducing signal common impedance to the output impedance of the op-amp (for 1/2x5532 in unity gain configuration this is 10 milliohms, rising to 30 milliohms at 20 KHz). Also, the increase of current in the output stage is complemented by a reduction in the 0V regulator, which means that while the amplifier is operating in Class A mode (about 99% of the time), the overall current is constant.

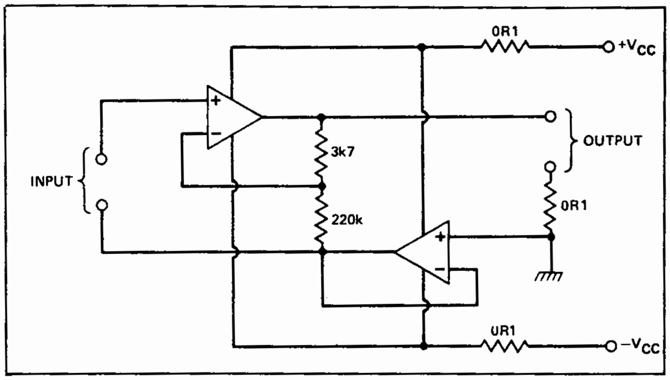


Fig. 4. Constant current series feedback giving OV regulation.

This is especially important in a modular design like ours, using stage connectors, since the power supply modulation is negligible.

My comments on the 5534 op-amp and 78/79 series regulators are not intended to be derogatory. I'm sure the original designers would fall down laughing if they saw some of the uses these devices are put to. The 78/79s are perfectly good general purpose regulators, but they're not intended for precision supplies. The computer-optimized LM340 series (eg. LM340T-15) are consistently better, though the complementary LM320 series is rather expensive for negative supply regulation. The LM337 series are a better value, especially if TL072s are used, since their negative supply input is very noise sensitive. The 5534 is an excellent line processing block when driven from low kilohms with clean supplies. The power supply circuit shown in Fig. 5 has noise in the 20-20KHz range better than -80dBV with 100mA drawn and an output impedance of around 0R3 at 100KHz thanks to the 470uF output capacitors.

On the general topic of power supply decoupling, the use of separate filters for each channel is not recommended. It would be rather like isolating two people with the same contagious disease; it doesn't cure either of them. It's actually useful to have two channels sharing the same supply at each stage, since one can be driven with a signal and the other used to detect any noise generated in the process. And now to capacitors.

A Couple of Points

A 1958 *Radio and Electronics* handbook that I unearthed has an excellent section on power supply topography and mentions that paralleling a 220uF electrolytic with a 100nF film type overcomes some the problems connected with the equivalent series resistance (ESR) and leakage of the electrolytic. That was some time ago and it still applies if you're talking about the stability of wideband amplifiers, as long as the bypass capacitor is placed close to the circuitry, not the amplifiers. But anyone who believes that such bypassing has a significant effect in the audio band either hasn't bothered to look into the characteristics of modern electrolytics or is still using 27 year-old ones.

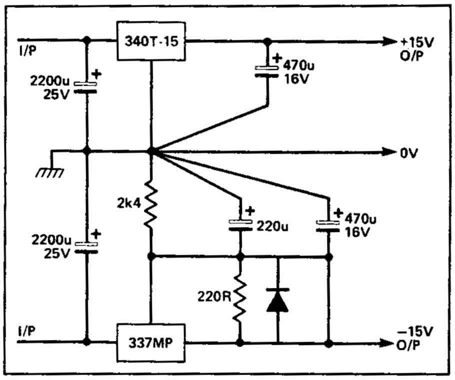


Fig. 5. Suggested PSU regulation circuit.

For example, the 220uF-16V cap used in my power amp feedback decoupling has an ESR of 0.3 to 0.4 ohms at 20KHz and 15 degrees C. A 470nF polyprop has an impedance of 17 ohms under the same conditions. So what's bypassing what? It's only when you get above the 500KHz range that inductive reactance starts taking over and the impedance of electrolytic and film caps begin to match. Bypassing at ICs can be important because inductive supplies in the MHz region can easily cause instability, but 10–47nF is quite adequate, cheaper and lessens noise injection into signal common.

And then you should be asking yourselves, why the pursuit of pure capacitance in coupling components? Ideally, a coupling component should block DC and have zero or constant impedance from at least 20Hz up to 20KHz. A perfect capacitor would do the former but would have a 1000:1 variation in impedance over the audio band. Admittedly, in dB terms this variation is miniscule, but the point still stands. Now, a large electrolytic can approach the second requirement for a coupling component. The variation of impedance with frequency in an electrolytic is not simple and there is a "break' frequency at which the slope flattens out. The electrolytic can be chosen so that this frequency is very low and in the critical mid to high frequency area ESR is practically constant. Inductive reactance is negligible below about 500KHz in any reputable make of capacitor in the sub 1000uF range.

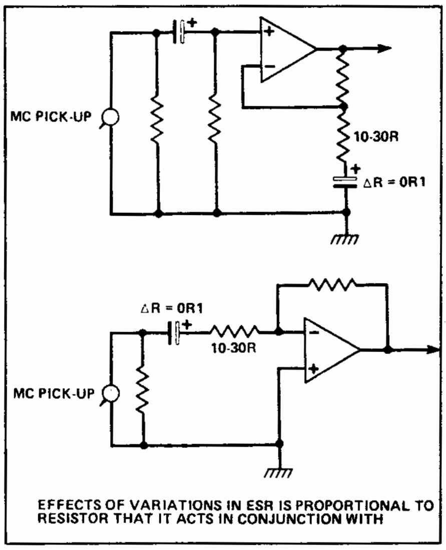


Fig. 6. ESR variation in electrolytics – some typical configurations.

So why do electrolytics sometimes sound so odd? I've found that ESR can vary, particularly with temperature, by up to 0.1 ohms. In conjunction with a 10R resistor, as in all too many MC circuits (Fig. 6), the variation can amount to -40dB. With considerably higher resistances (above 1 kilohm), this figure drops to -80dB or so.

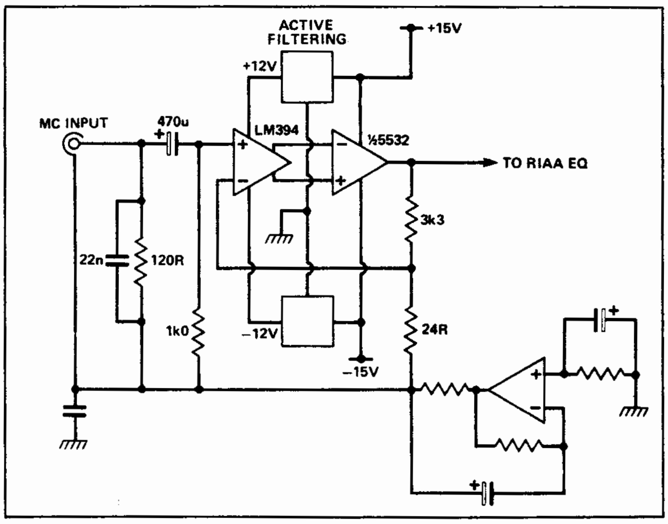


Fig. 7. Basic configuration of MC pre-amp input stage.

Voltage modulation can also affect the performance of coupling electrolytics. In a competently designed circuit an electrolytic is operated well above its break frequency so that the voltage drop across it is a small fraction of the applied voltage – at most, hundreds of millivolts. I have found no evidence of acoustic effects at this level. Even these slight reverse voltages can be eliminated by using predictable offsets to polarize the electrolytics to the peak expected reverse voltage. We have done this with our design, and while I'm not convinced that it has any significant impact, it certainly does no harm (Fig. 7 and 8).

Electrolytics may also suffer from microphonics, a feature used to positive advantage in capacitor microphones. At 200uV sensitivity, microphonics in input and feedback capacitors in an MC input stage is hardly surprising, although it varies with the type and make. Generally, tantalums produce a "boing" while aluminum electrolytics give more of a 'dumph' – which may explain why tantalums are out of favour. In both cases, mounting in a glob of silicon rubber helps enormously, damping the resonance due to vibration of the body relative to the leads. Incidentally, other components can suffer from microphonics, particularly FETs. It can be helpful to gently tap all components with a plastic pen to test them.

When it comes to power amp main capacitors, bypassing becomes even more ridiculous. To achieve 100 milliohms at 20KHz would require 80uF of pure (expensive) capacitance. There is no substitute for low ESR electrolytics, now widely available thanks to their development for switch-mode power supplies. Phillips manufactures 10000uF–63V types with low ESR values and they are available from Electro Sonic in Willowdale, Ontario, (416) 494–1555.

Stiff and Nonsense

Before getting obsessed with basic power supply impedance, it's useful to stop and ask, "why does it matter?". In a sense, the only power supply to an amplifier is usually the 120V AC line, conditioned as required for the sake of convenience so that an input voltage can control this power source to produce an analogous output. All too often, designers become obsessed with the intermediate energy store and do not view the systems as a whole. So we get stories of "stiff" supplies using massive transformers and capacitors with the idea that this will achieve quality, not just (overkilled) quantity. Once you realize the irrelevance of this, you can start investigating what it is about the intermediate store that corrupts the controlling process.

There are many more complicated factors than the ones I've been able to deal with here: induced coupling from supply and load cables to the input stage,

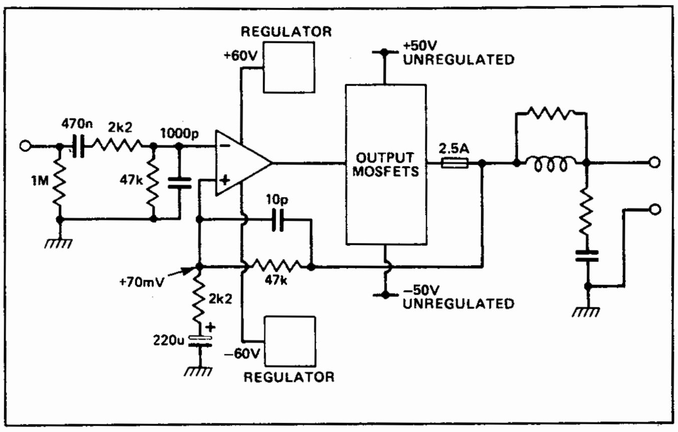


Fig. 8. Basic configuration of power amp module.

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