The way I see it….

Supply Decoupling – finesse before brute force

Stan Curtis

Few designers develop an audio circuit these days without giving a lot of thought to the power supply. Indeed some are driven to go to quite extreme levels in creating supplies that have almost unmeasurable levels of output noise and near absolute voltage stability. Yet my conversations with many such enthusiasts suggest that sometimes they are going to such extremes without having a clear understanding of what they are trying to do. Often this is displayed when we get onto the topic of the once humble supply decoupling capacitor. So again I will write down some of my own experiences in the belief that readers might be stimulated into thinking some fresh thoughts.

My own attitude to power supplies was greatly influenced by the trials and tribulations I experienced when I first started to design transistor audio amplifiers at a time when all my colleagues were busy soldering components into their latest tube amplifiers. Back then in the early 1960s I was a student-apprentice working at Smiths Aerospace in Cheltenham; a town famous for housing the UK's spy centre, GCHQ. I quickly became known to senior management as the lad who could build good audio amplifiers and to help me fulfil my increasing order book (all supplied free-of-charge but all representing favours done in the positive column of life) I was given total access to the redundant stores; a stockpile of unwanted, but high quality components mostly paid for by the taxpayer via the Ministry of Defence. My prototypes had used 10% tolerance carbon resistors, as commonly found in commercial products of that era, together with whatever other components I could find in the various junk boxes but now I was able to build "production" units with 0.1% tolerance (yes that is 0.1%) metal oxide resistors; high quality Painton potentiometers (each of which cost more than my weekly salary); a selection of very high quality capacitors and, best of all, some newly developed pure silver wire with PTFE insulation. Yes nothing was too expensive for the government. One slight limitation was that I was restricted to whatever I could find so maybe in retrospect there was some puzzlement over my use of, for example, 102.1 kohm resistors instead of the more common 100kohm and my use of such odd-ball capacitor values as 0.2276mfd; but it all added to the mystique of being a future hi-fi guru. These were true "audiophile" amplifiers before the genre had been invented. They were full of the best military spec components the MOD could afford to throw away and they seemed to work extremely well. In fact compared to my prototypes the sound was "brighter" and "louder", my pre-stereo; pre-hi-fi vocabulary being limited to the more obvious aspects of the sound. What was more, the difference between the commercial component versions and the new versions was so obvious to everyone that a couple of the early adopters promptly demanded that I exchange their inferior amplifiers.

I then came across a hoard of beautiful C-core transformers and some examples of the then new toroidal type of transformer. The only problem was that they were designed for the 400Hz supplies used on aircraft and when plugged into the 50Hz mains they did nothing more than fry the fuses. A friendly old-timer suggested I borrowed one of the lab's power-supply units which was little more than a 400 Hz oscillator and a powerful valve amplifier. I was very surprised to find that with my new mains supply my amplifiers sounded still "louder" (I desperately needed some more descriptive terms at that stage but years were to pass before they came to me) and had less background hum and noise. And what's more the toroids sounded even better than the C-cores. So again the experimental facts stared me in the face; clean power supplies improved the sound and better regulated power supplies also affected the sound. But did I make the right connections for my future thinking? Well partly and I've specified toroid transformers in my designs from that day to this.

By now I was beginning to understand transistors and after learning a load more theory and finally overcoming the smell of burning resistors I was able to develop some better designs. However when constructed as prototypes they all oscillated creating the once very familiar "motor-boating" sound. I had no idea what was going on until the same old timer asked me where I'd located the decoupling capacitors. The what? I had a couple of capacitors in the power supply; why would I need any more? With admirable patience he explained to me everything I needed to know about capacitors and how to use them for supply decoupling. When I returned to university I was taught no end of theory and maths yet to this day that first lesson remains my dominant guide.

At that time in my innocence I'd assumed a capacitor was a capacitor with but one characteristic; namely capacitance but soon I learned about the equivalent circuit being composed of the equivalent series resistance (ESR), the equivalent series inductance (ESL), the capacitive reactance (XC) and the inductive reactance (XL); this latter value being largely ignored as being insignificant at audio frequencies. The ESR was a value which I initially assumed to be constant because at the time manufacturers rarely quoted a figure and certainly no indication of the equivalent impedance at different frequencies so again I was shown how to get an approximate measure of impedance using a few resistors, an oscillator and a meter. And so I learned that XC is at a maximum at DC, and then decreases as the frequency increases until a resonance is reached when XC equals XL which is when the impedance equals the ESR. My boss told me to measure many of the capacitors we used so I spent a restful week in front of a meter. Although I'd been told to measure everything at 400 Hz I soon expanded my brief to also measure at 50 Hz and 100 Hz and then to measure the aforementioned resonance frequencies; finally moving on to combinations of large and small values in parallel. Yes my little audio amplifier department was equipping itself for the next generation.

With my discovery of decoupling capacitors I assumed bigger would be better and so put a big cap in the power supply and a capacitor of equal size hung across the input transistor stage. The result was hum and distortion so back I went to my mentor for another dose of knowledge. And so I learned that the big reservoir capacitor provides the bulk capacitance and that the time required to transfer the charge of this reservoir capacitor to the load is determined by a time constant created between the capacitance; the equivalent resistance of the wiring, the ESR and load. This time delay is enough to be significant and so can degrade the output signal of the stage and cause distortion. One solution is to provide local capacitance with a small capacitor wired directly to the amplifier stage. If that capacitor is very small then the time constant will be small so the available charge will be small and be quickly depleted by a large current transient. Increasing the size of the capacitor holds up the supply for longer but the time constant is increased. Eureka ! It all came down to a mix of time constants so my new amplifiers appeared with networks of decoupling capacitors. The instability disappeared but at the time changing the mix of capacitors didn't seem to make much difference. However this knowledge paid dividends in the 1980s when I designed several generations of Rotel amplifiers all praised for their "bouncy" sound; a characteristic which was all down to an unusual mix of time constants in the power supply.

It was in the late 1970s that the craze for multiple coupling capacitors first started in hi-fi following its popularisation by Jean Hiraga describing some tube amplifier designs for L'Audiophile magazine. I remember thinking at the time that this was hardly new. Wasn't this something all apprentices were taught? Apparently not! Of course audiophiles went over the top and started to bypass large electrolytics with smaller electrolytics in turn bypassed by polystyrenes and then polypropylenes and finally small silver mica capacitors. Such was the belief in this new panacea that I was able to demonstrate the addition of yet another "super capacitor" comprised of two insulated wires twisted together and adding maybe 4 pF of extra capacitance. You may not be surprised when I tell you there were some who claimed to hear the difference. But by the 1980s some designers, myself included, were trying to bring some consistency to the selection of the right combination by measuring the impedance of the resulting network at different frequencies. If only I had kept my voluminous table of results from my student days.

This interest in power supply lines fed through into improved supply isolation and regulator design and eventually to the modern mania of having separate regulator stages for every portion of the amplifier. Thus a two stage phono amplifer will have two sets of regulators; the volume control stage will have more regulators and then still more for the output stage. Add a digital stage or two and pretty soon the bulk of the circuitry will be for power supply functions. Certainly this can make a difference and I've used this arrangement myself but it is very wasteful and thus bad engineering. Some may disagree but I now find that thoughtful use of star grounding and simple isolation through a single transistor before the decoupling can give equally good results for far less money. And thinking is what you need to do if you want to design good sounding but low-cost products such as the Cambridge Audios and Rotels of my past. Let me just give you one example to ponder upon. Figure 1

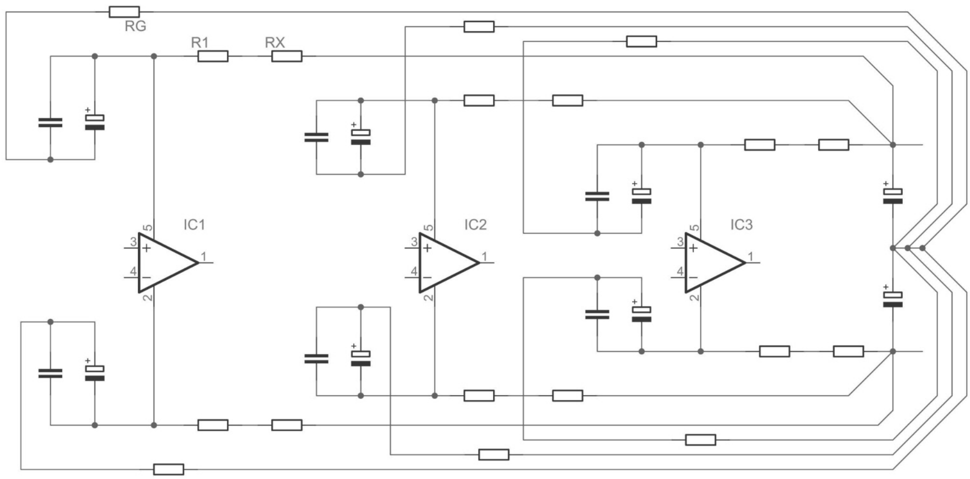

Figure 1

shows a notional 3-stage amplifier with a simplified equivalent diagram of the supply chain wired in a conventional fashion with star grounding and separate supply decoupling capacitor networks at each stage. R1 represents the series resistor (which could be zero) whilst RX represents the series loss (track or wiring resistance). So far so conventional.

Figure 2 shows the same amplifier with a small decoupling capacitor wired in the same fashion but with a localised larger capacitor shared between the three stages. The same arrangement could work over more stages and is perhaps to some minds not quite so conventional. Figure 2 is certainly

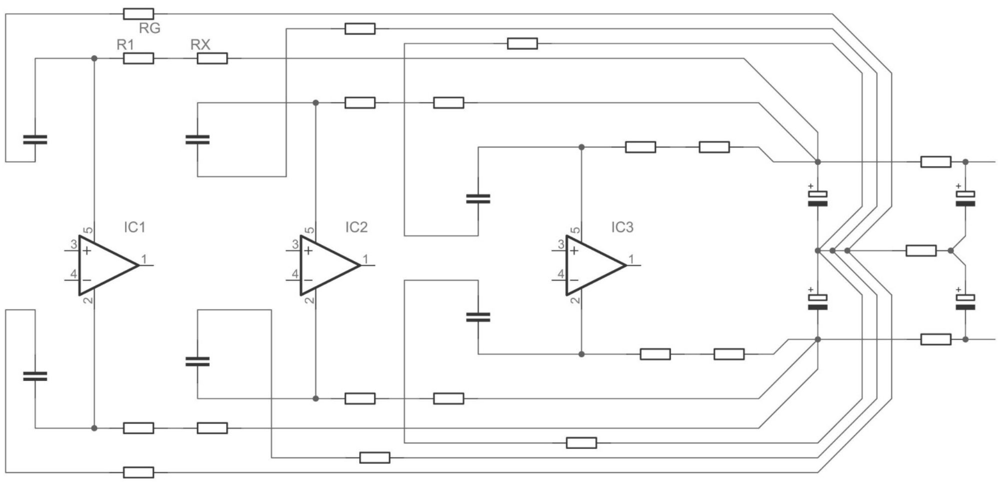

Figure 2

cheaper to manufacture but does it work as well? Well at first glance I think it would be criticised by a lot of armchair audiophiles but in my experience it does indeed work well providing you watch those impedances (and ground planes help) and think out the time constants. And it certainly saves on the pennies. It is all part of my prevailing engineering belief that any fool ought to be able to design a high-end amplifier given an open cheque book but it takes a rarer skill to design a good product when the manufacturer tells you that the build cost is 36 dollars maximum. Chinese factory or not suddenly every single component has to earn its keep.

So far we've been focused on simple analogue amplifiers which despite appearances haven't changed massively since the 1960s. But the importance of decoupling capacitors has been brought home to me in recent years when trying to design switching amplifiers (Class D in popular nomenclature) to true high-end standards. Focus as much as you like on potentially 1 MHz switching frequencies and clever output filters but for me such designs can be made or broken by the humble decoupling capacitors. Certainly the arrangement shown in Figure 2 performs well in such amplifiers but don't be in any doubt. Suddenly every supply wire; track and capacitor needs to be chosen with care. Spend some time thinking about where the energy needs to flow and how those time constants pan out and you can transform the performance of such amplifiers. Yes the humble decoupling capacitor is as important as ever.