Yet More On Decoupling, Part 5 – When Harry Regulator Met Sally Op-Amp
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After the first four parts of “Yet more...” you are, I hope, curious about what happens when everything is connected together. We’ve seen that some fearsome ringing can appear on our simulated supply if we chose the values of the decoupling capacitance and the ESR of the regulator’s output capacitor poorly. We’ve seen that it’s inevitable that high frequency variations of the power supply line will punch through to the amplifier’s output pin, where they will at the very least add on top of what is supposed to be there anyway.

So, without further ado, let’s get started on Part 5. The test fixture we’re using is the same as shown in figure 3.10 of part 3. We’re running the amplifier at a closed-loop gain of -1; the output of the amplifier is loaded so that later, when we drive it, we’ll take the right amount of current from the rails (that’s the theory, anyway).

We can now plot the *rejection transresistance* of the system. It’s the output voltage of the op-amp divided by the input test current injected into our composite power supply. It’s basically the resultant voltage on the power supply multiplied by the power supply rejection of the amplifier at the gain used, which as you’ll remember just looks like a line which slopes down at 6dB per falling-frequency octave from some frequency. So all the real action is up at high frequencies, giving a rich tapestry of interaction between our supply impedance resonances and the high frequency behaviour of the amplifier. Figures 5.1 and 5.2 show, on the red traces, the rejection transimpedance of the 200MHz LT1723 and the 30MHz LT1630. The latter has so little high frequency rejection that it faithfully follows the supply peaking above about 4MHz. You can see that it has aspirations to be more of a ‘precision’ amplifier, though, and its greater low frequency gain pushes the low frequency power supply gain down, giving improved rejection transimpedance below 1kHz.

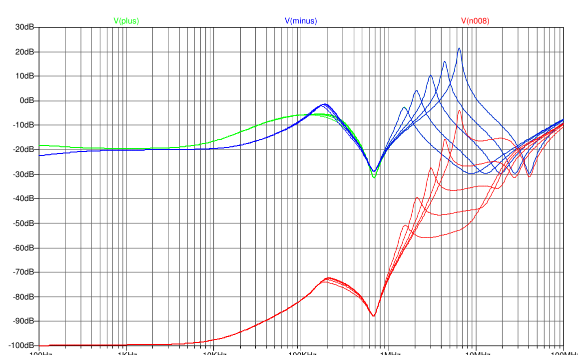

Figure 5.1(L): rejection transimpedance of the LT1723 model. Basically, Vout versus excitation current

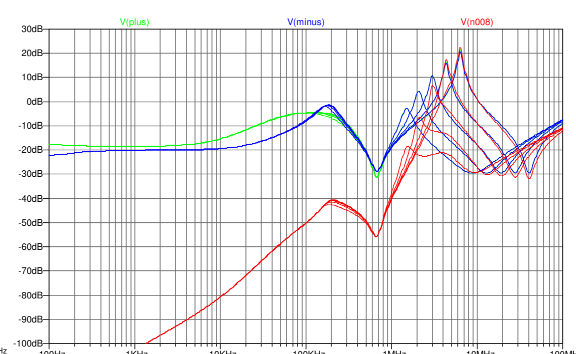

Figure 5.2(R):rejection transimpedance of the much lower bandwidth LT LT1630 model (better below 1kHz though)

Let’s analyse the result in the time domain. Using the same, appropriately phased 10mA, 100kHz test currents as deployed in part 2, we see the expected signals on the supply lines and a smaller signal on the output pin of the op-amp. Figures 5.3 and 5.4

show the results, with the worst-case 22nF capacitor, for the high and low GBW amplifiers; the advantages of a high GBW are quite obvious.

Now, by the way, in case you think these traces are plotted with 22nF just for effect because the give the most dramatic demonstration, remember back to the very first part, and the voltage-dependency discussion. If you were remiss enough to use a 100nF 16V Z5U capacitor for decoupling your 5V rails, the actual value of that capacitor under bias would be close to 22nF. So this isn't just whacky wrong-value simulation, it shows what could really happen if you take your eye off the component ball!

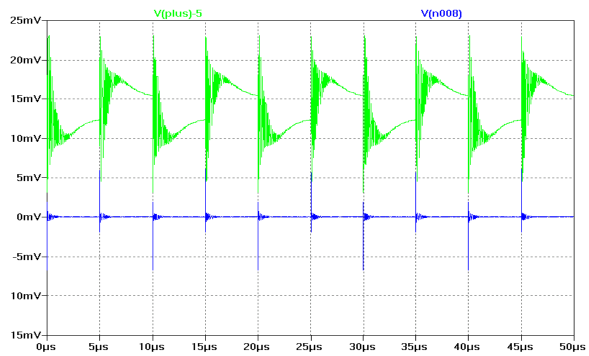

Figure 5.3(L): the positive supply and the output of the LT LT1723 model (lower, blue, with 22nF decoupler)

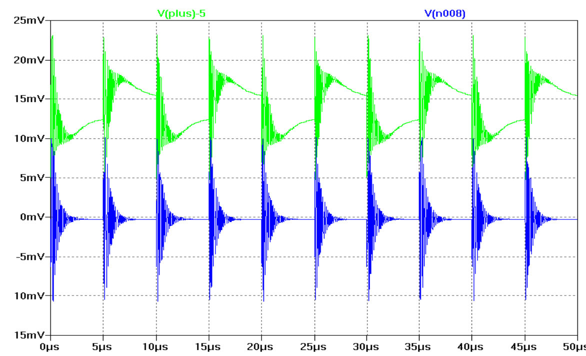

Figure 5.4(R): the positive supply and the output of the LT LT1630 model (lower, blue, with 22nF decoupler)

When we zoom into the output signal in the time domain (figures 5.5 and 5.6, with the traces for 22nF to 470nF decoupling capacitors now spread apart for clarity) we indeed see a high-pass filtered version of this ringing there on the output pin. The fundamental frequency of our excitation doesn't show up visibly. This points to the *high* frequency behaviours of the decoupling network being most important when we consider the op-amp output – no surprises there, say all you analog guys out there.

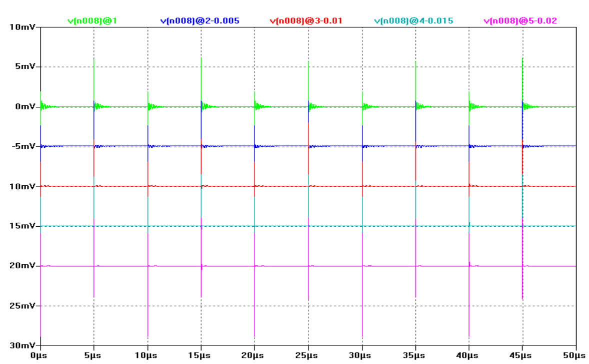

Figure 5.5(L): LT LT1723 model output ringing changing as the decoupler is stepped from 22nF to 470nF

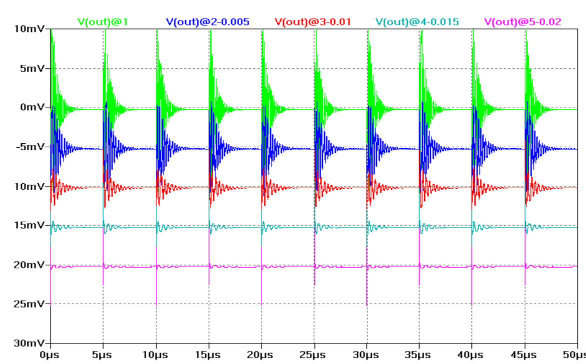

Figure 5.6(R): same as figure 5.3 but with the LT1630, showing how low GBW makes it worse

Since we saw that the supply ringing was much reduced by using a tantalum capacitor on the regulator, we shouldn't be surprised if the output voltage of the op-amp is also much cleaner if we try that. Figure 5.7 shows what happens to the output of our lower-bandwidth LT1630 if we just change over to our standard tantalum output caps on the regulators. The high frequency thrashing is almost eliminated, and what's more, there's not a lot of difference in the peak-to-peak value of what's left when we change the decoupling capacitor value.

The output of the LT1723 on the same scale now shows so little detail that we need to zoom much further in. Figure 5.8 is starting to look interesting! Here we at last start to see the detail changes to the dynamics of the amplifier which might occur with changes in decoupling capacitor value. Who was that guy who said they couldn't make any difference to the performance?

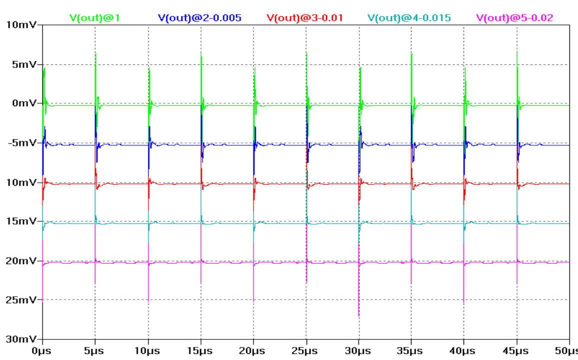

Figure 5.7(L): LT LT1630 model's output, just changing the regulator capacitors to tantalum

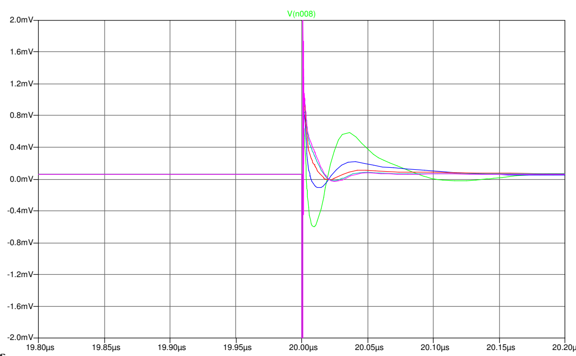

Figure 5.8(R): zooming in on the LT1723 output with tantalum output caps on the regulators

We are almost there. At the moment we are still applying an external excitation stimulus to the supply rails. What would be really interesting is to see how the amplifier might interfere with its own performance, by making demands on the supply rails which turn into accuracy-robbing output effects.

To do this we'll feed a signal directly into the amplifier. And sadly the disappointment with the results of the manufacturers' models is not over yet. To be continued...

Take-aways from this part:

- The choice of decoupling and regulator output capacitors *will* affect the accuracy of your op-amp circuits, and you *can* model these effects.
- Transient signals on the supply pins of an op-amp *will* find their way to the output, in amounts which might be critical in a high accuracy system