TECHNOTE 004
POWER SUPPLY NOISE EVALUATION IN THE PWR002 7 OUTPUT SUPPLY

An investigation in to the performance of switching noise in the Clockworks supplies

Rev 1.0

10-May-2019

Signal Processing

http://clk.works/

Products referenced:

- PWR001 triple output supply module
- PWR002 seven output supply module

1. TABLE OF CONTENTS

1 INTRODUCTION

This report continues an investigation started in TN003 of the effect of supply design on the performance of a typical analog circuit. In this note a more detailed look at the 4 types of switcher modules used in the 7 output design is undertaken.

TN0003 established that a small LC filter on the supply outputs can make a measurable difference in circuit noise performance.

Some of the observations made during that process may help other system designers so Clockworks has put together this Technote to aid with system design.

In addition to TN0003 there are two related Technotes for the PWR001 triple output module that also apply to users of the PWR0002 seven output module.:

- TN001: Power supply noise sensitivity
- TN002: Power supply sequencing

1.1 SUMMARY

During initial testing of the PWR002 module supply frequency domain noise spikes in the audio band were observed. An effort was made to determine if these were from a single supply or the effects of intermodulation between the multiple supplies switching frequencies.

To help isolate things additional boards were built up with just a single supply.

For the regulators used for the digital 3.3V and 5V supplies, the noise is mostly broadband with tones well out of the audio band.

In an ideal world the switching regulators could be treated as a black box with a fixed, load independent output noise. In real life switching regulators are complex beasties with a feedback loop, and adding a reactive load (i.e. an LC filter) to reduce noise can have unintended consequences. The job is further complicated by the Clockworks supply being used in different applications with differing load requirements. One simplifying factor for the analog supplies is they will generally not have any large load transients like the digital supplies might experience.

A measurement on two different op-amp circuits was performed using the same process as TN003. No meaningful degradation of op-amp performance was noted with the PWR001 module compared to using batteries, though this test used the quieter +/-15V supplies.

1.1.1 SPECIFIC RECOMMENDATIONS

- LC filter is suggested for all supply outputs to minimize potential noise sources.
- Input (12V) supply must be verified to not enter burst mode under minimum expected load where audio is being processed. The amount depends on the supply design.

- The 3.3V and 5V digital supplies (Murata switching module) can be used without a load without creating excess noise
- Standby 3.3V (CUI switching module) must have a minimum 10 mA or 20mA load when audio is active
- The +/-15V Meanwell supply is well behaved in terms of noise.
- The +/-5V Meanwell supply is not well behaved, with significant noise across a range of load currents. More aggressive post filtering is suggested for this, as well as a separate analysis on its noise effect on actual circuits. For now the rev 2 design will add a 470 uH choke and a 100 uF cap to the PWR002 board.[1]

1.1.2 LEVELS

The prior Technotes have discussed target noise levels and the motivations behind them. As supplies only indirectly affect the circuit noise level (in any reasonable circuit) direct measurement of broadband and specific tones in the supply output does not necessarily mean that the supply will achieve the best system performance.

Generally in this Technote we would be concerned about total noise > -60 dBV RMS (1 mV) and noise tones > -100 dBV (10 uV).

Most of the measurements here are without the LC filter; that will further reduce supply noise, as well as the distributed decoupling capacitance in the SignalBlox system.

1.2 METHODOLOGY

A Rev 1 PCB for the PWR002 was used, along with a number of power resistors to act as loads for testing for supply noise under different loading.

For testing single supplies blank PCBs were populated with the minimal components needed to support the switching module to be evaluated, see the schematics for more details.

The power boards, when evaluating a single switched module, were powered with a CUI SW125-12-N wall wart supply (for standalone supply testing) previously evaluated (see TN001-TN003)

For the full PWR0002 module the 60W brick, Meanwell GST61A12, was used. The two large 10,000uF caps used in the PWR0002 to provide output holdup with loss of primary power present a rather large inrush current and the larger wattage supply is needed to ensure correct startup.

Unlike some of the earlier tests where a bench supply was used, sample supplies for providing the 12 VDC input were used to look for interaction issues, which were found when the input supply is lightly loaded and running in burst mode. There is also some dependency on input voltage shifting the frequencies of the spectral spikes. Therefor getting an exact replication of results would be difficult due

[1] It's a cost and PCB area tradeoff.

to normal component variances. For example two different supplies powering the Meanwell +/-5V supply produce the plot in Figure 1 had a 0.22V difference.

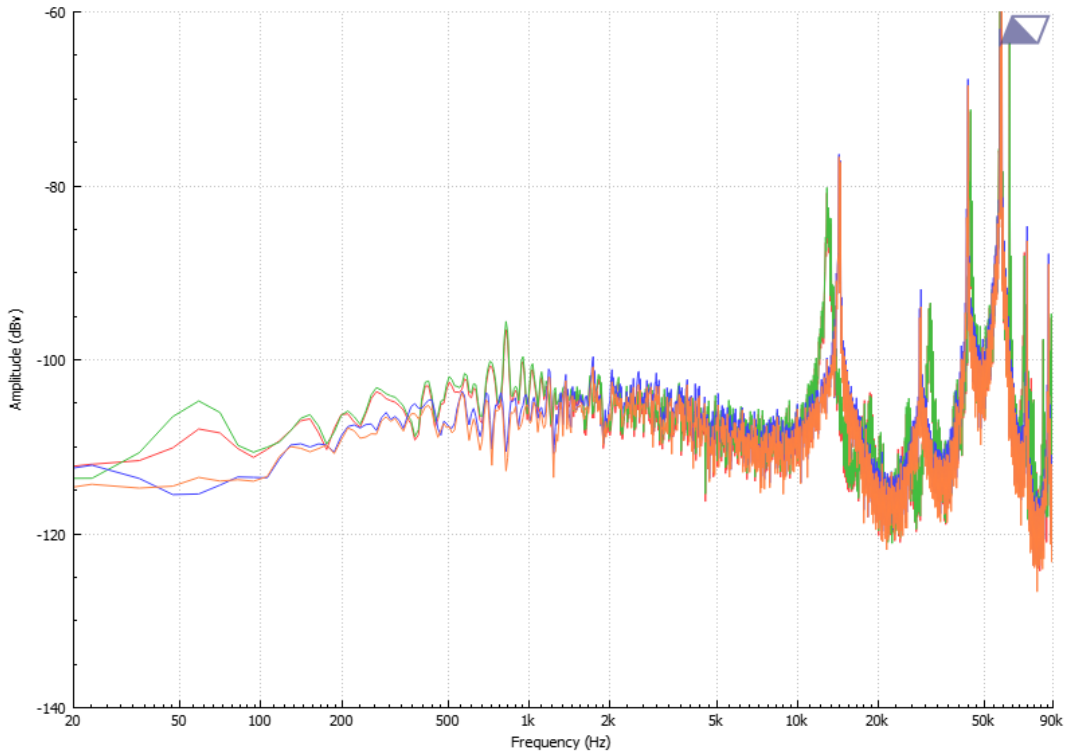

Figure 1 Supply noise variation example with input voltage (see text)

1.2.1 IT'S EASY TO MAKE AN OOPS

When looking for tones in the noise some "new" spikes appeared in the FFT that were not observed previously. After some serious cursing and redoing tests, it was realized that the larger 60W supply was being used for the standalone (single switcher) testing, and the current draw was too low, causing extra input noise to work its way through the test setup.[2]

[2] The test setup itself is pretty ugly; the noise concerns are really in the audio band but we captured with a 88 kHz bandwidth to see what we might find. Given the -100 dBV target it doesn't take much wire to cause problems. OTOH real systems can sometimes be far from perfect so if we can get good results from a bad test setup then we should get better results from an actual system. At higher frequencies that statement is probably less than true.

To illustrate this point, Figure 2 shows the Murata 3 amp module using the 60W brick to power it. There's a large spike around 1 kHz, and some related harmonics. In Figure 3 we don't see those, they were due to the input supply running in a burst mode at lower current.

Unfortunately we failed to notice this and quite a bit of the initial data has this extra noise that is not from the switching modules being evaluated, particularly under lower current draw.

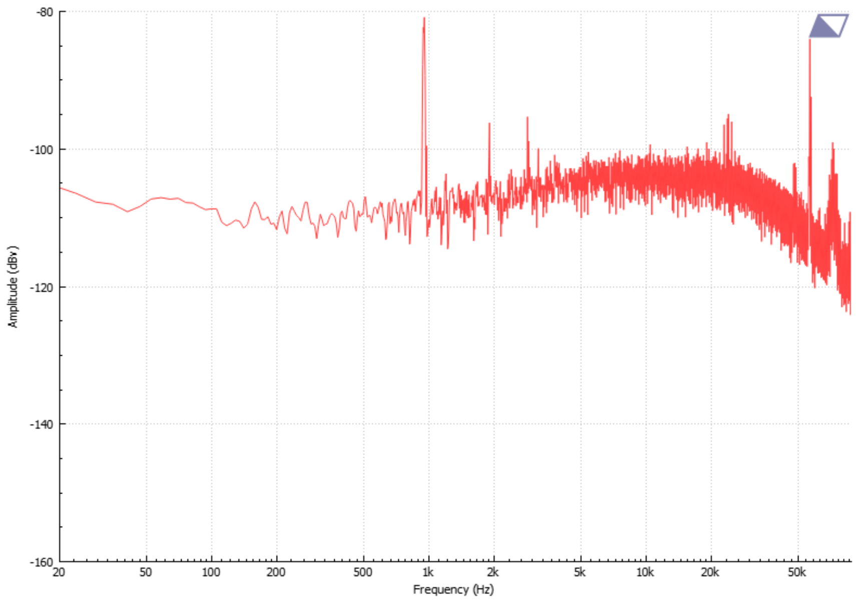

Figure 2 Noise spectrum of Murata 3 amp module (3.3v), with 1.2 amp load and 60 W (12V) input supply

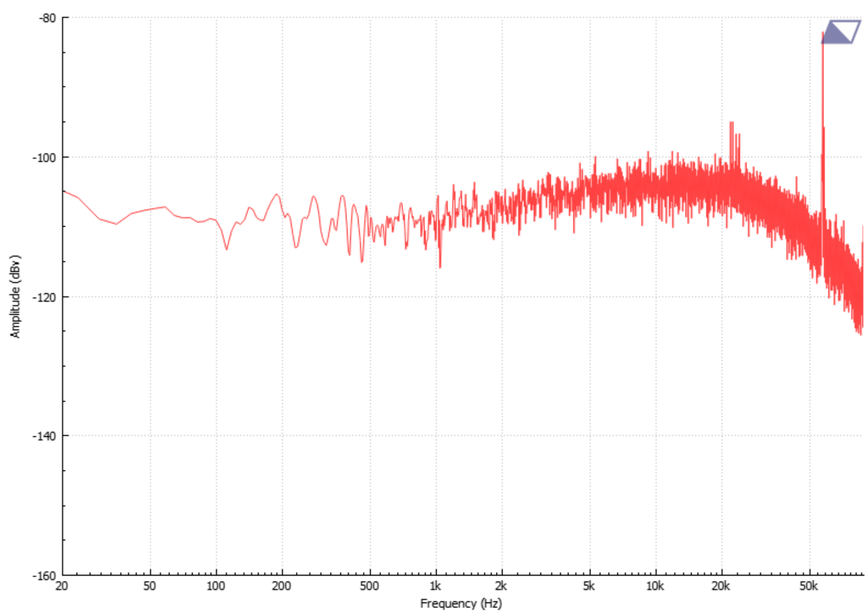

Figure 3 Noise spectrum of Murata 3 amp module (3.3v), with 1.2 amp load and 25 W (12V) input supply

The total RMS noise isn't all that affected by the specific spikes in the FFT; the total noise difference between above example is only about 0.5 dB.

Even with the lower power 25W input supply it to can enter burst mode and cause system noise, as seen in Figure 4. In Figure 5 an additional current drain of 400 mA was placed on the input supply, we can see that the noise peak around 1.8 kHz has gone away, though a new one has appeared out past 20 kHz. That higher frequency one will be attenuated a bit by the LC filter, and at some point it all becomes a game of whack a mole without driving up costs.

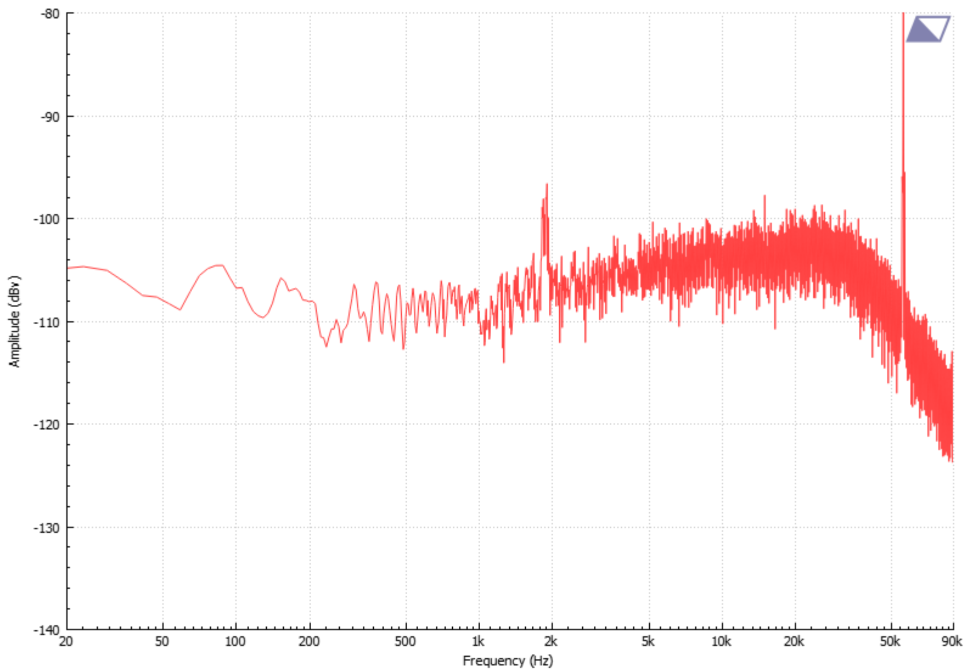

Figure 4 Noise spectrum of Murata 3 amp module (3.3v), with 40 mA load and 25 W (12V) input supply

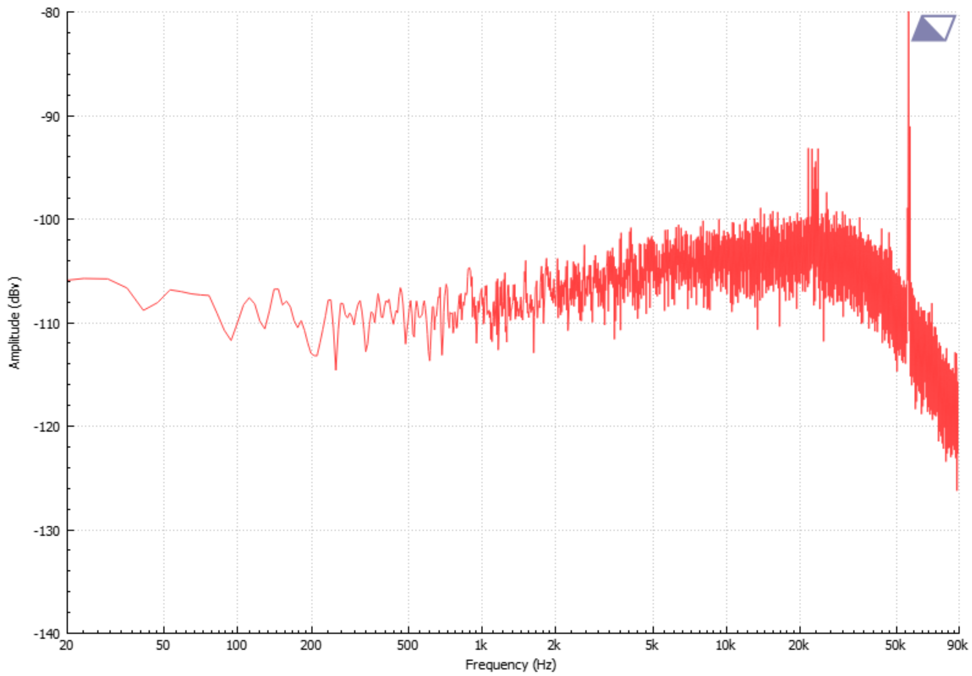

Figure 5 Noise spectrum of Murata 3 amp module (3.3v), with 40 mA load and 25 W (12V) input supply with additional 400 mA load on the input supply

We can isolate input supply created noise by using different input load currents, peaks that move would be associated with the input. We do see the Murata module enter a burst mode at 10 mA.

1.3 TEST EQUIPMENT

Avermetrics Averlab generator/analyzer Version 3.0.0 B12-CL1391

2 MEASURED RESULTS – INDIVIDUAL SUPPLIES - MURATA

The Murata OKR-T/3-W12-C module is used for 3.3V and 5V supplies, providing up to 3 amps. While not used for powering analog circuits noise from this supply could work its way in to other parts of the system and therefor knowing that it won't provide a potential source of noise – particularly discrete tones that might be heard – is a consideration in system design.

Total noise[3] from the supply is around -66 dBV from 50% load down to 40 mA, where it increases to about – 60 dBV. The FFT plots show that at light loads the supply starts producing switching

[3] Unless noted otherwise this is noise in the audio band, which is filtered by the measurement setup as 20 Hz to 22 kHz. This is an unweighted measurement.

components that can fall in the audio range. Figure 6 shows the noise for three different loads, the total noise is roughly the same, just the spectral shape changes. The green and blue spikes are on top of each other. The noise around 20 kHz is not totally isolated as to cause.

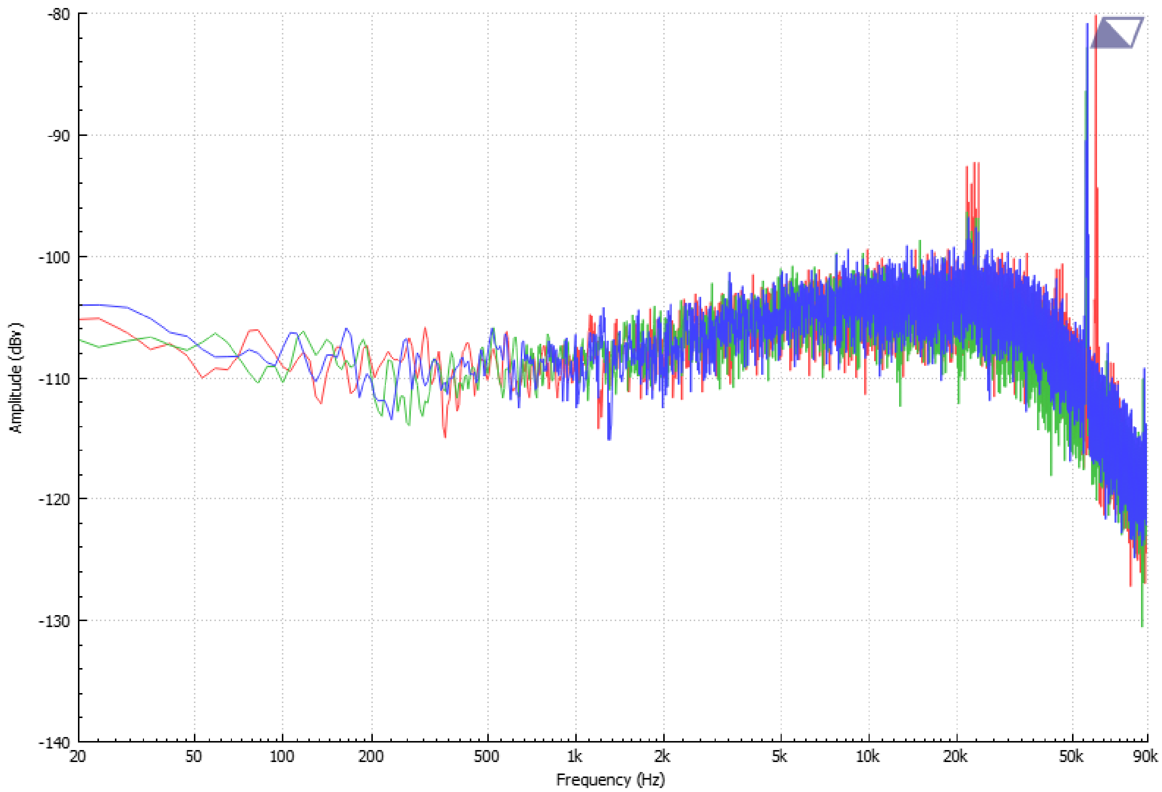

Figure 6 Murata module, 3.3V, 32K pt FFT, 1.6 amp (Red), 0.8 amps (Green), 0.33 amps (Blue)

Of more interest is what happens under lightly loaded conditions, Figure 7 shows the results for the no load case but the plot is the same even at 40 mA.

These measurements are without the LC filter that has already been identified (in TN003).

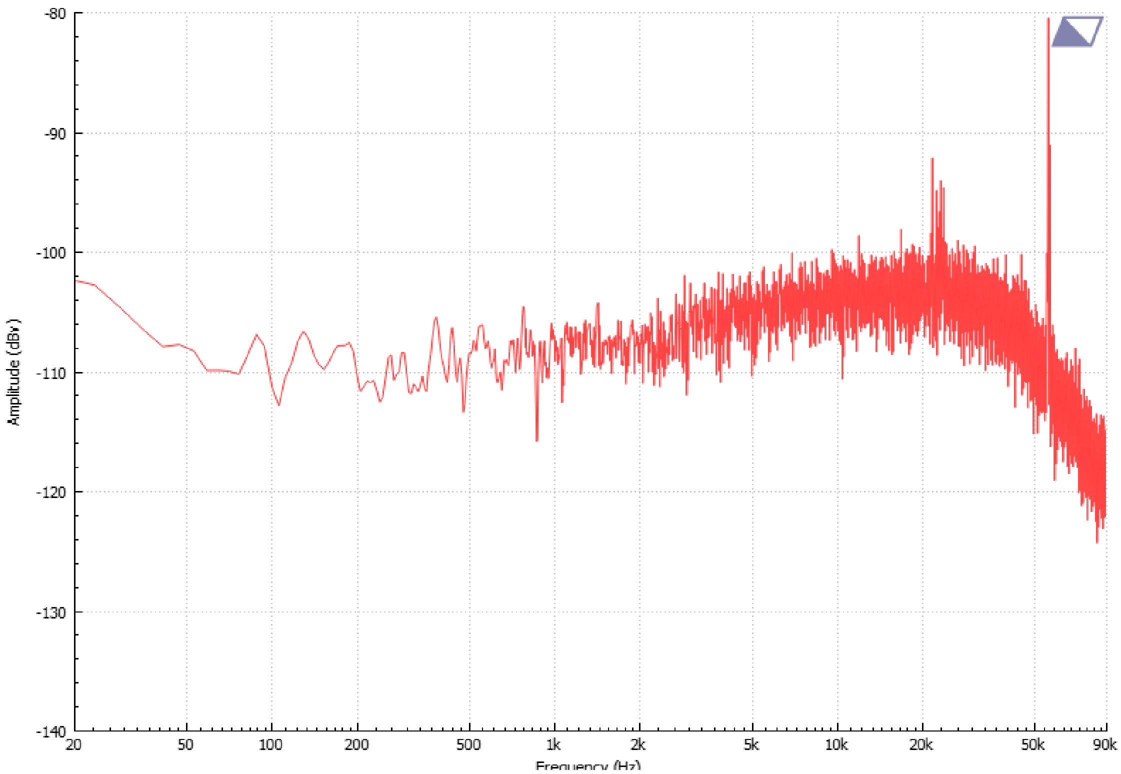

Figure 7 Murata 3.3V, 32K FFT, no load (input supply loaded)

In Figure 8 the 10 uH/100 uF filter is added and its effect on the 10 mA load case is shown; the large peak near 50 kHz is reduced from -80 dB to a little more than -100 dB. Additional capacitance at the loads would further reduce the levels.

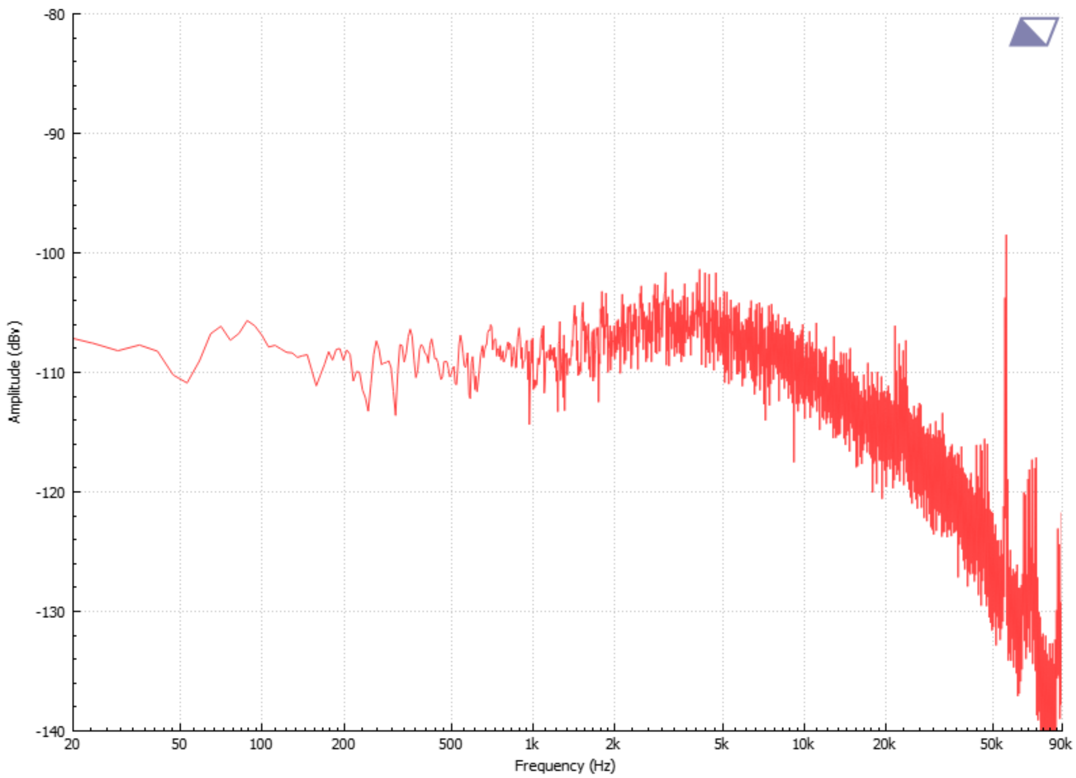

Figure 8 Effect of adding LC filter with 10 mA load

3 MEASURED RESULTS – INDIVIDUAL SUPPLIES - CUI

A CUI VX7803-1000 is used to provide the standby (always on) 3.3V supply at up to 1 amp. While designed as a drop in replacement for 78xx linear regulators it's low level current performance is noisy in a way a linear regulator wouldn't be.[4]

As with the Murata module, this part is only supplying power to digital circuits but coupling of noise into analog circuits would be concern.

Overall noise performance is similar to that of the Murata module, -65 dBV at typical loads and increasing to -55 dBV under low (< 10 mA) load. Noise with loads from 800 mA to 40 mA, Figure 9, doesn't indicate any concerns, particularly if the LC filter is added. See section 5.1.1 for the effect of the LC filter.

[4] An actual linear regulator in this application would require a heat sink as well as lack the efficiency to meet CE standby power limits.

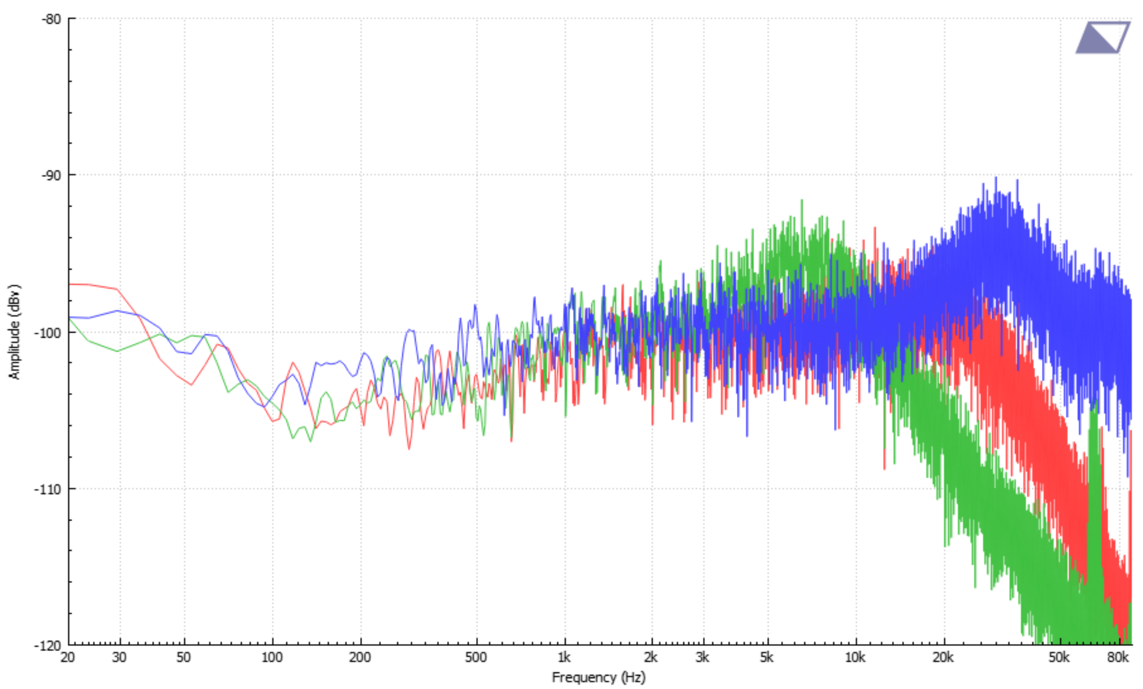

Figure 9 CUI noise spectrum 32K pt FFT. 800 mA (Red), 100 mA (Blue), 40 mA (Green)

At the low currents analyzed in Figure 10 the peaks in noise might be a concern if the LC filter was not going to be present. The no load state though clearly presents a problem; OTOH in that state the system presumably isn't on and we wouldn't care about audio noise.

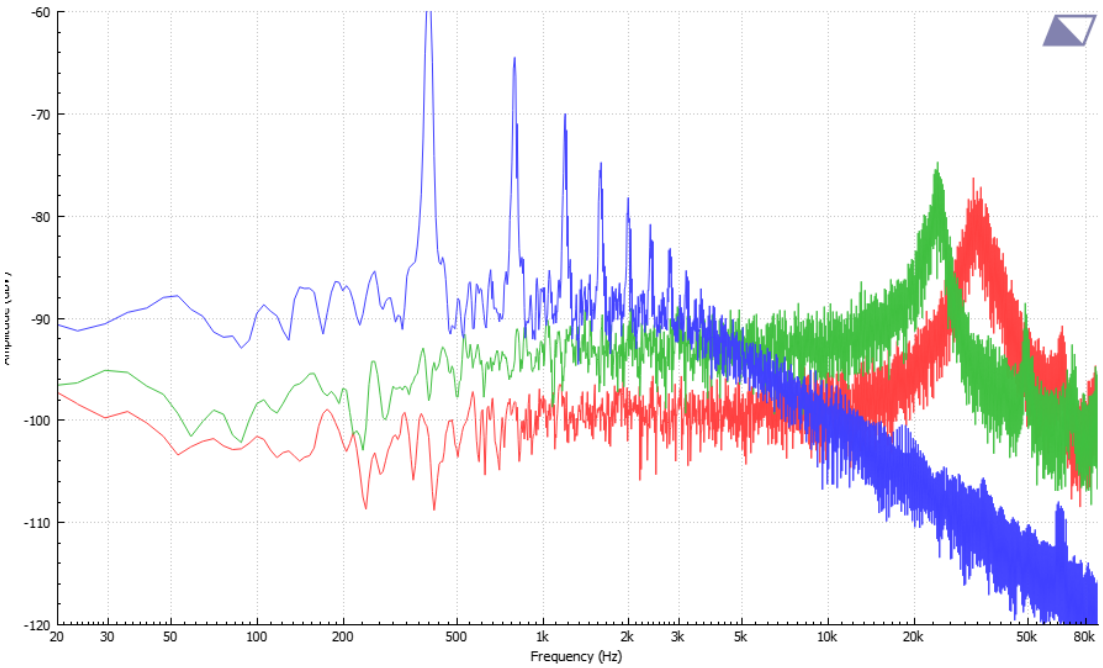

Figure 10 CUI noise spectrum 32K pt FFT. 20 mA (Red), 10 mA (Green), no load (Blue)

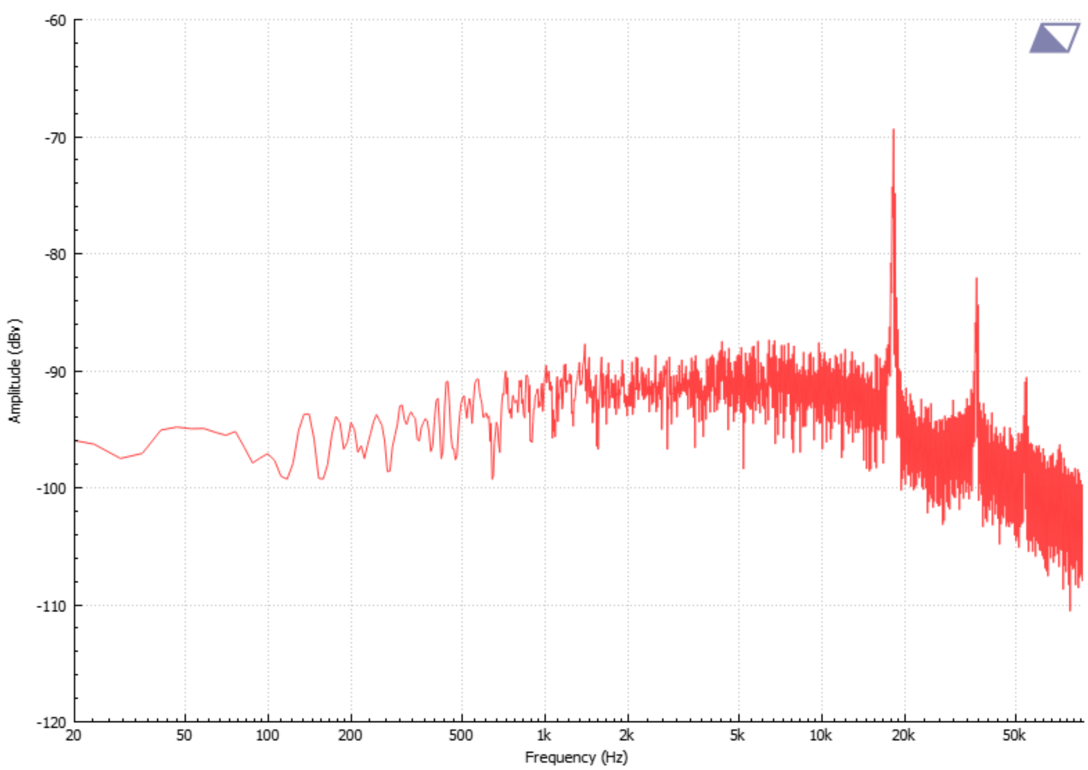

Figure 11 CUI noise with 3 mA load

4 MEASURED RESULTS – INDIVIDUAL SUPPLIES – MEANWELL +/-5V

There are two Meanwell modules used in the system, both are from the NSD10-12D family of modules.

While previous testing and a quick recheck performed here did not spot any issues with the +/-15V version, the +/-5V version was seen to be very noisy under some conditions. Under low load conditions it does produce more broadband noise, see Figure 12

Specifically, 155 mA or less resulted in mostly flat noise in the audio band and the peaks well out of the audio band, see Figure 14. Higher than that and things turn ugly, see Figure 15, up until about 240 mA, when the peaks move out of the audio band (see Figure 16).

Note that the left axis is shifted on some of the plots, though they all cover an 80 dB range.

As the +/-5V supplies are intended for use by ADCs and DACs this noise should be considered during system noise budget design.

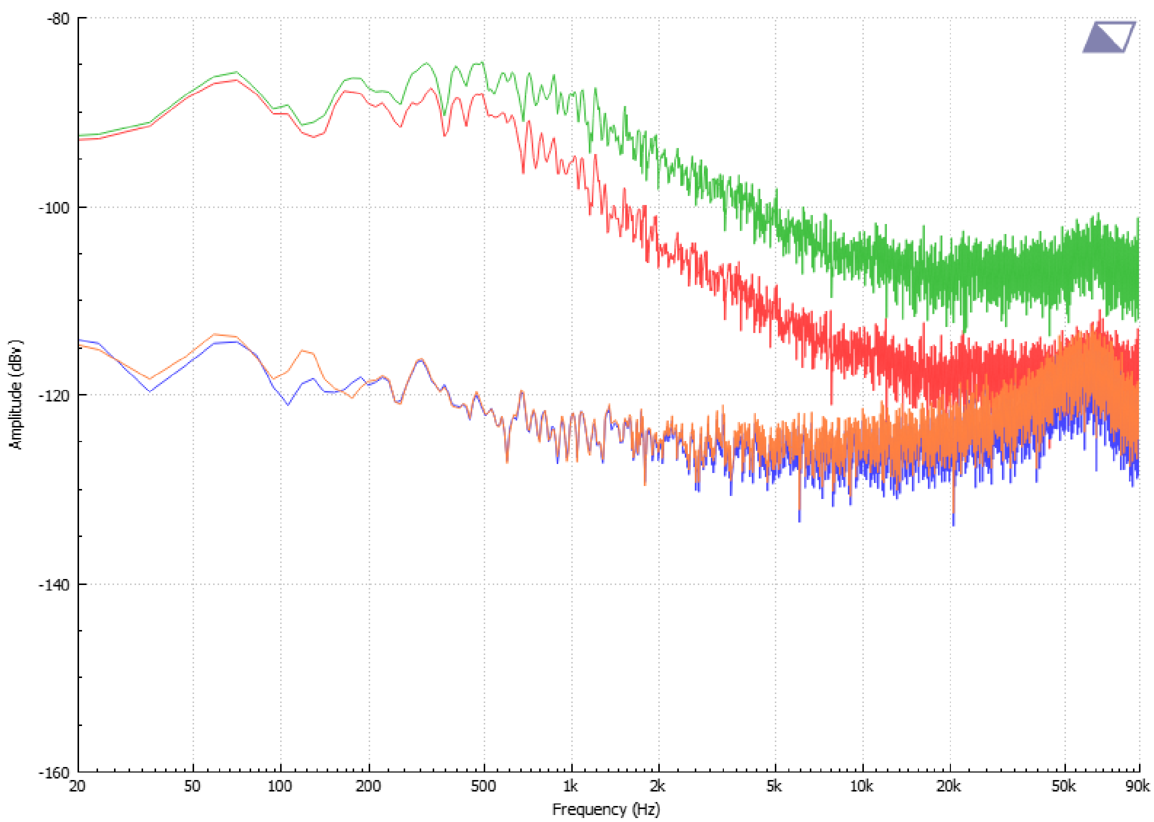

Figure 12 MW +/-5V no load (+5, red, -5, green) and 30 mA load (+5 orange, -5 blue)

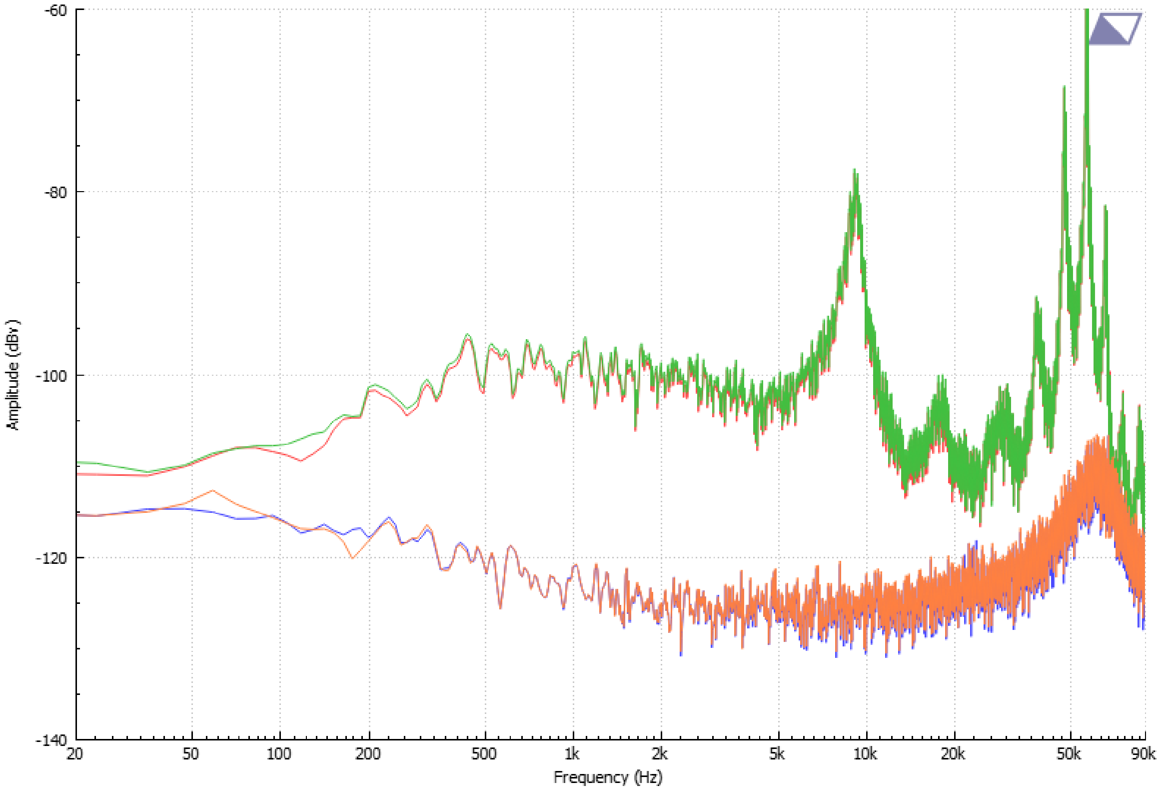

Figure 13 MW +/-5V 133 mA load (+5, red, -5, green) and 66 mA load (+5 orange, -5 blue)

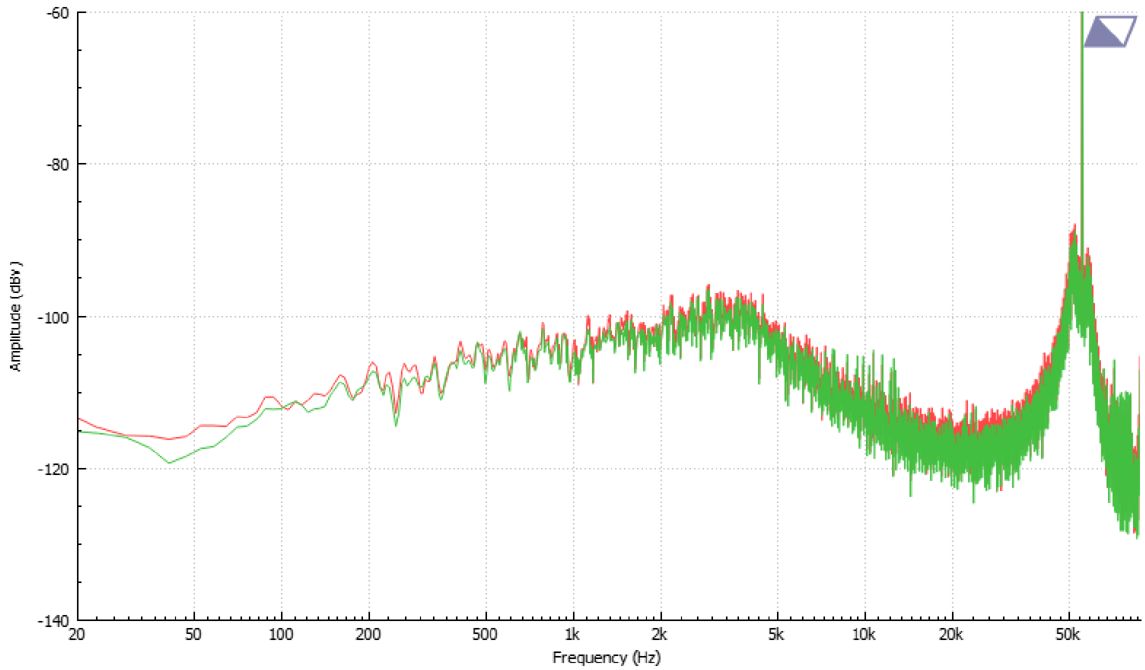

Figure 14 Meanwell +/-5V 155 mA load

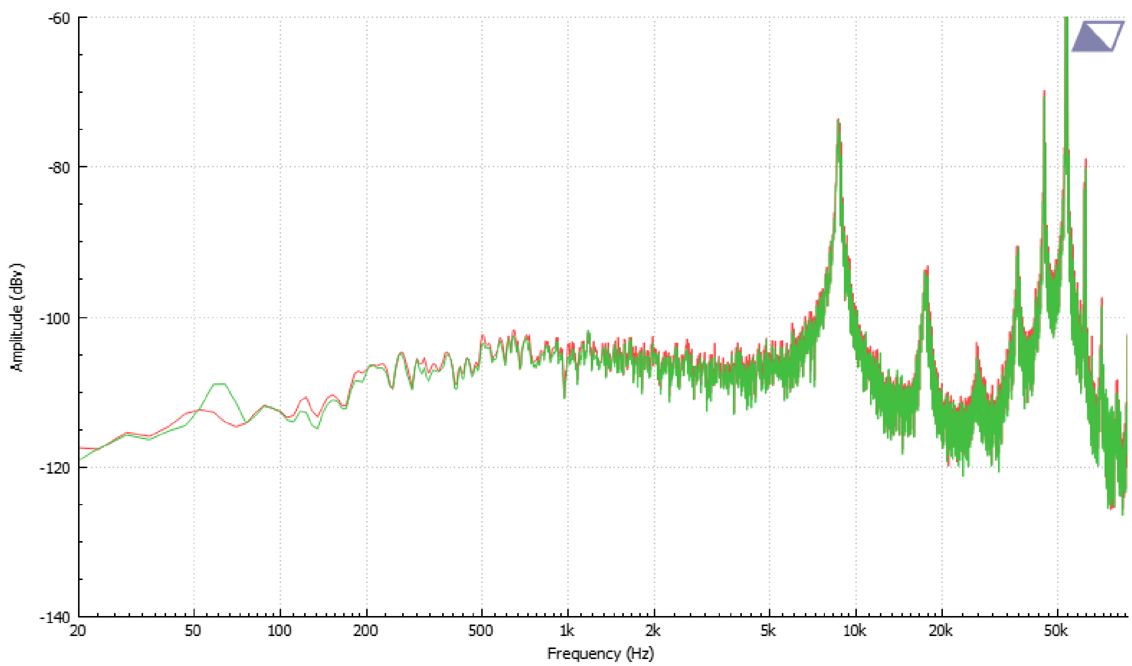

Figure 15 Meanwell +/-5V 166 mA load

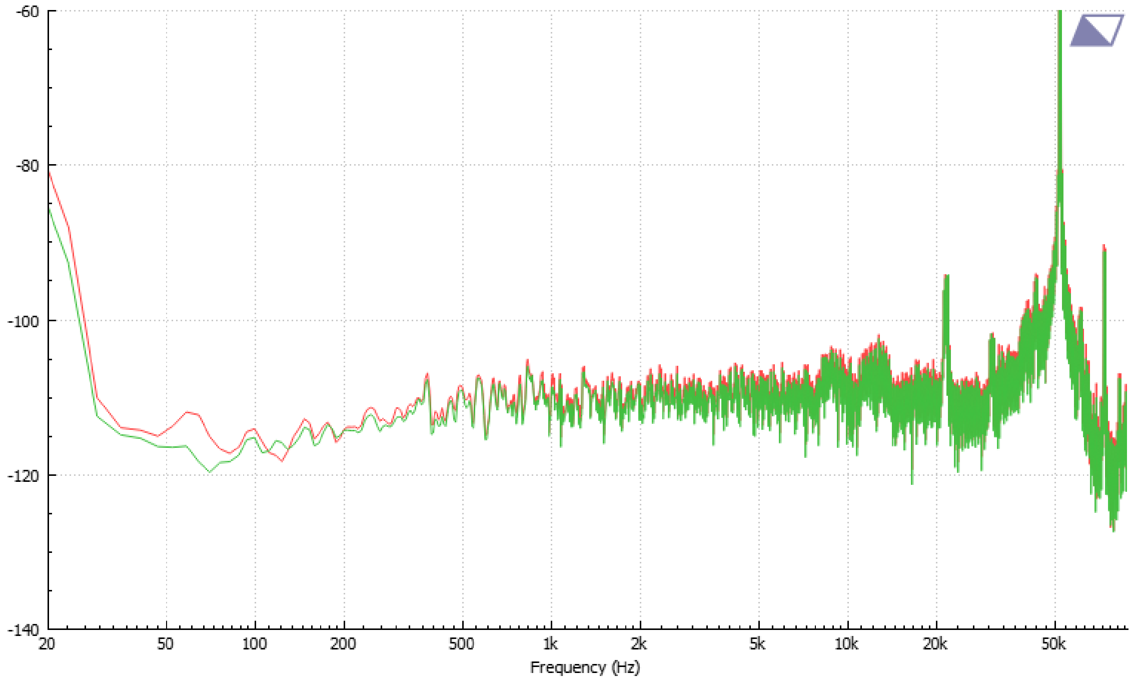

Figure 16 Meanwell +/-5V 250 mA load

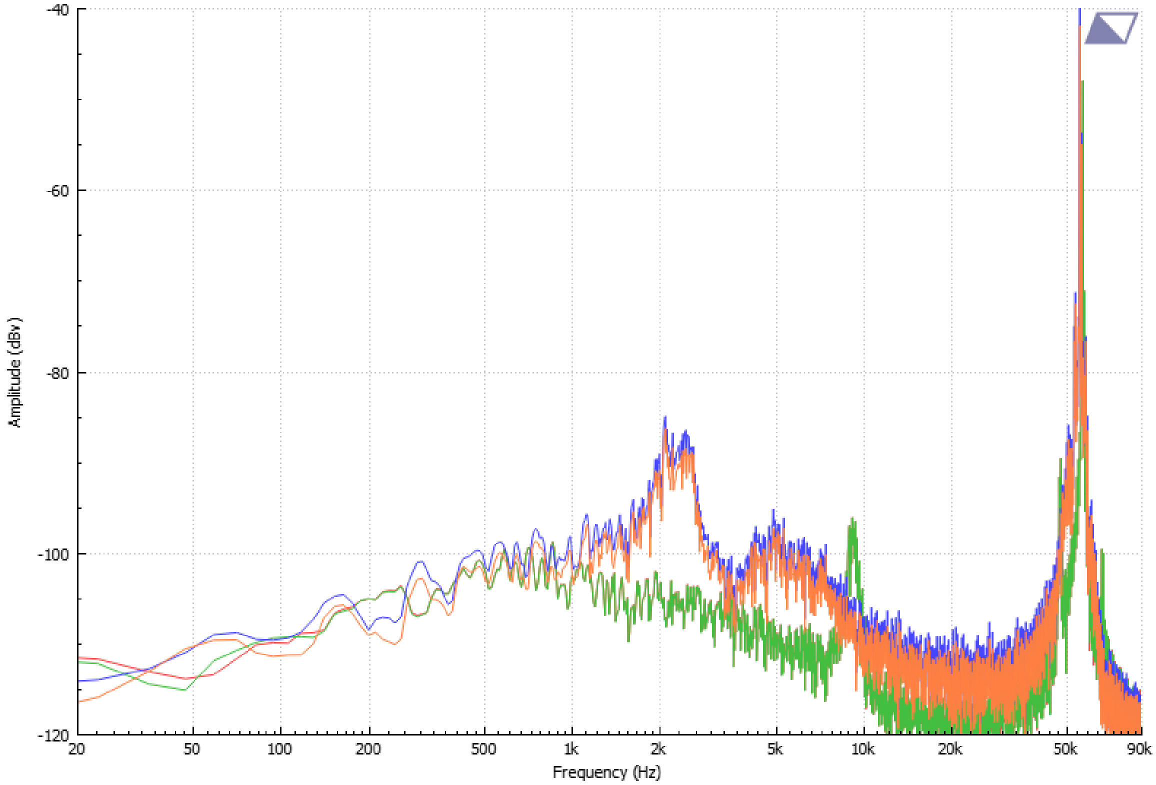

Figure 17 Meanwell +/-5V with 500 mA (green, red) and 640 mA (orange blue) loads

4.1 FILTER EFFECT

To deal with the noise peaks in the audio band across the range of currents it is proposed to use a LC filter with 100 uH or 470 uHinductor on the +/- 5V instead of the 10 uH used in the other parts of the design.

Adding the 100 uH filter we see a 20 dB reduction in the lowest frequency peak in Figure 18 and Figure 19. Interestingly the addition of the filter also changed the supply's switching frequency. When connected to a SignalBlox carrier there will be additional capacitance on the supply lines, as shown in Figure 20 this will further reduce the noise, with the peak of concern (at 5 kHz) now at -100 dBV.

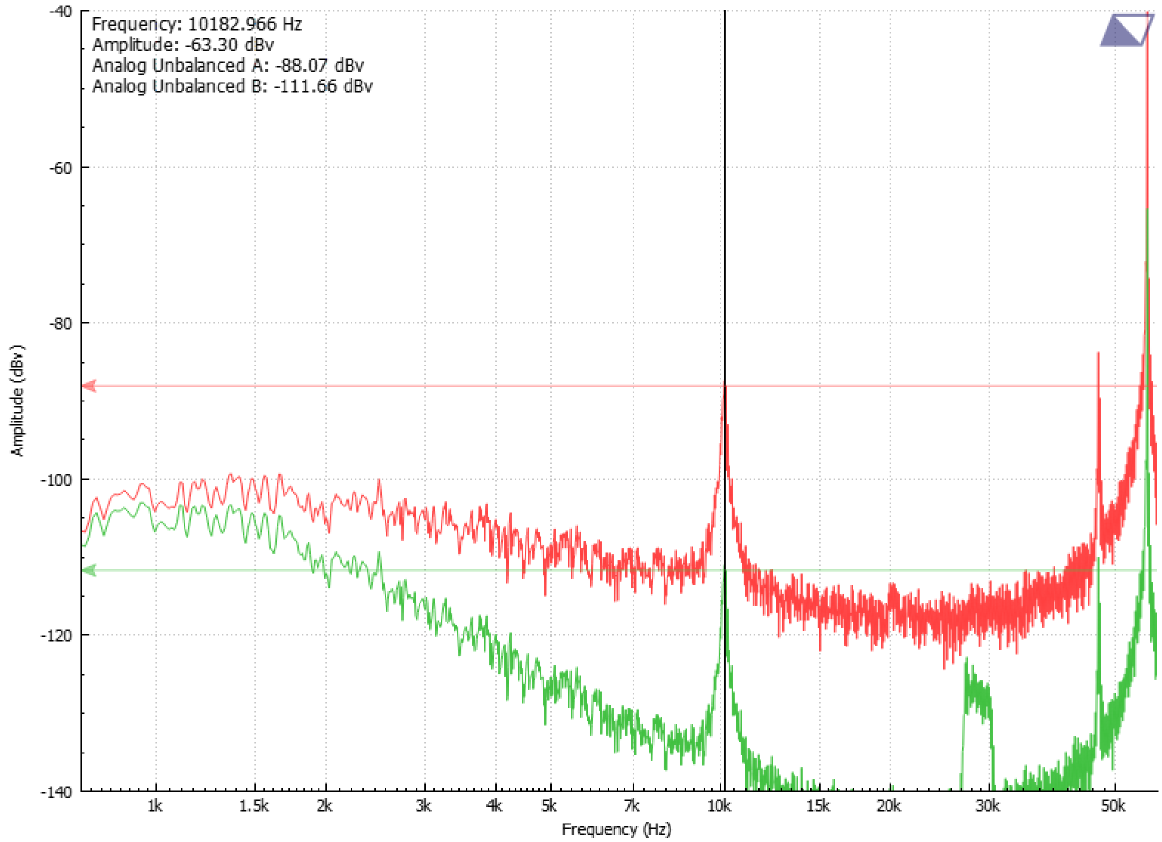

Figure 18 Meanwell +5V output with no filter (Green) and 100 uH + 100 uF (Red) 640 mA load , zoomed view

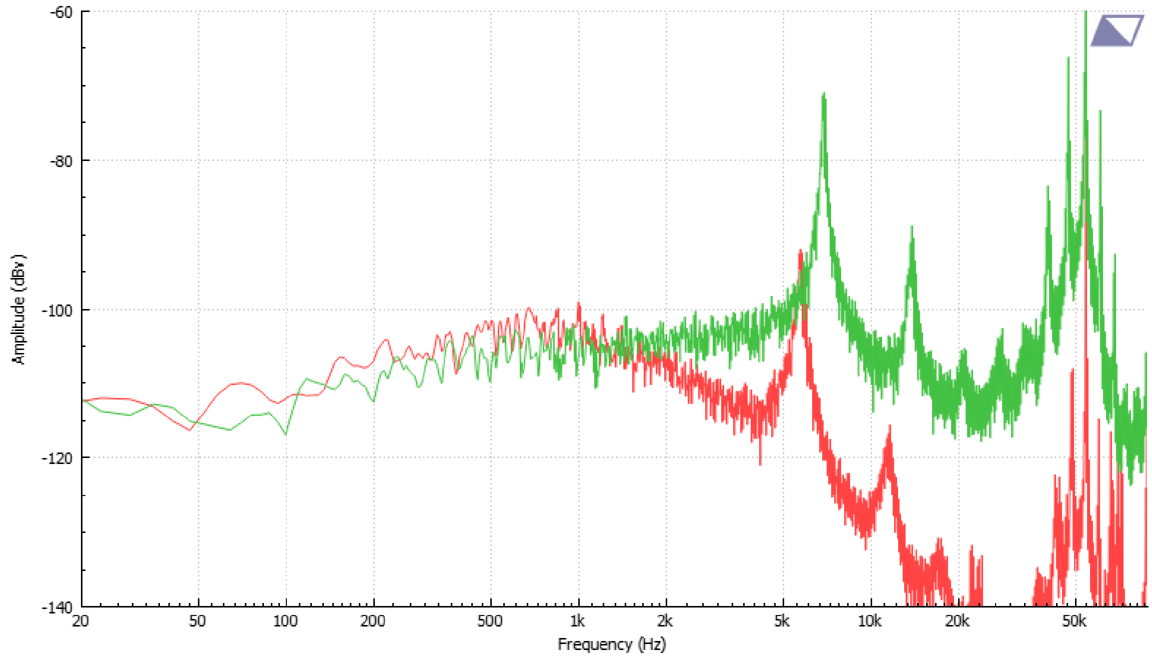

Figure 19 Meanwell +5V output with no filter (Green) and 100 uH + 100 uF (Red) 166 mA load

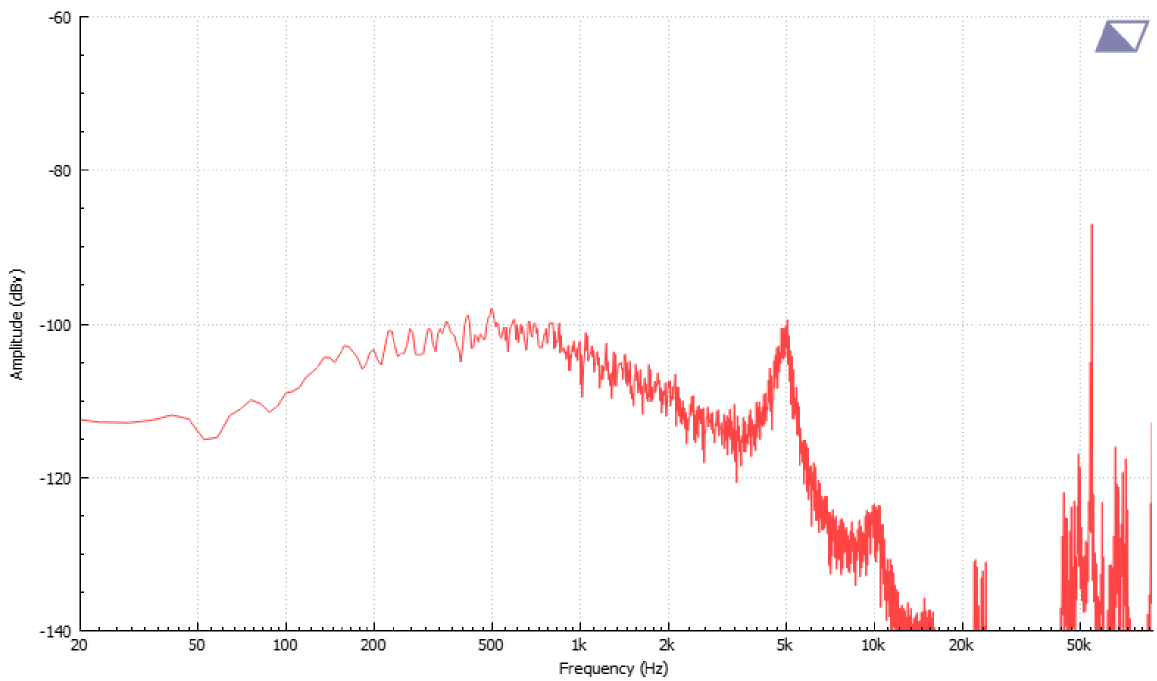

Figure 20 As above but with 200 uF

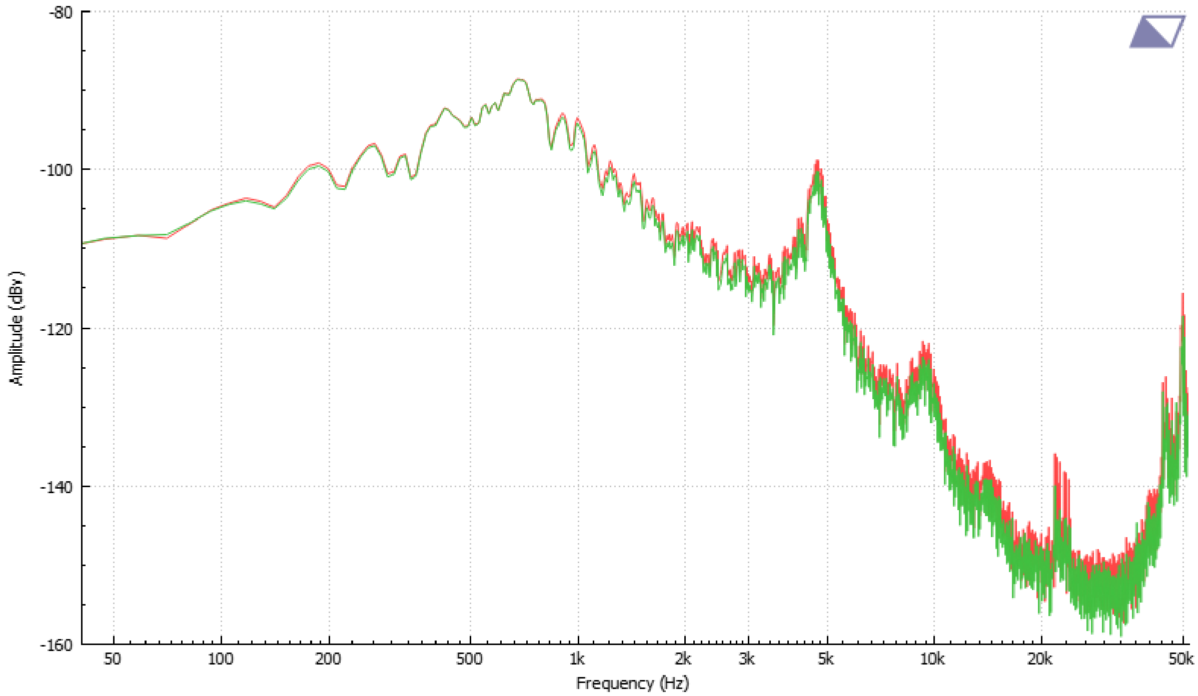

Figure 21 With 470uH/100uF filter (for 166 mA load)

5 MEASURED RESULTS – INDIVIDUAL SUPPLIES – MEANWELL +/- 15V

Original testing of the Meanwell supplies was done on the +/- 15V version and it is pretty well behaved compared to the +/-5V one. Despite being from the same family of parts the switching controller appears to act much differently between the two versions.

In Figure 21 the noise spikes around multiples of 22 kHz were identified with the input power supply.

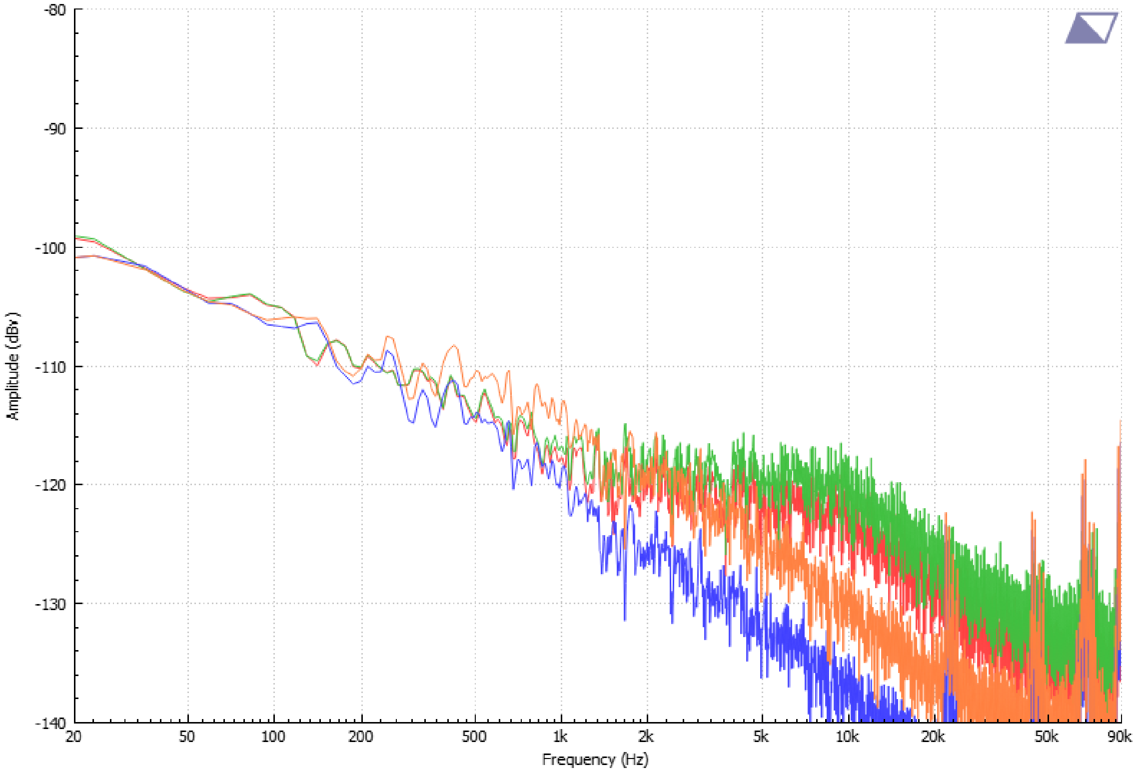

Figure 22 MW +/-15V no load (blue orange) and 14 mA load (red green)

With higher currents there is some increase in the broadband noise around 15 kHz but no spikes are observed, see Figure 22.

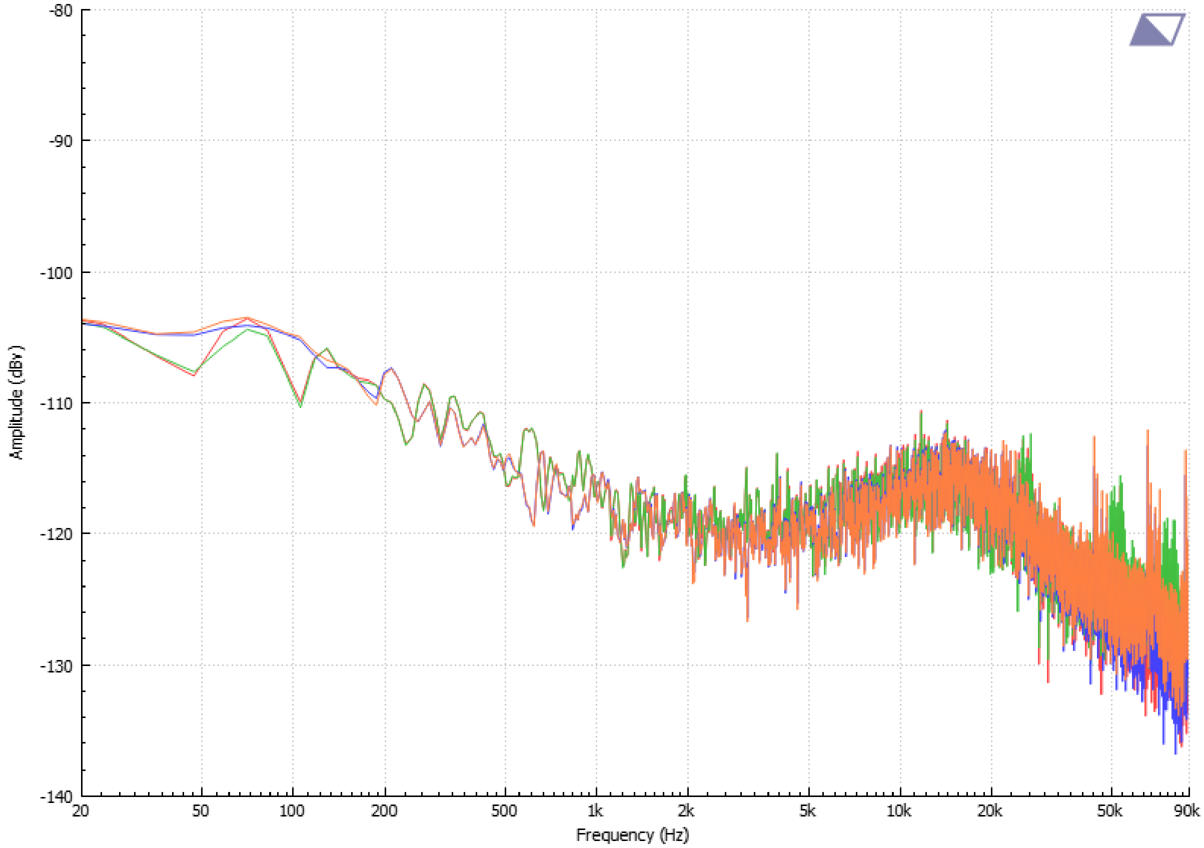

Figure 23 Meanwell +/- 15V with 100 mA and 200 mA loads, 270 mA was also the same

5.1 REV 2 PWR001 MODULE COMPARISON

The Rev 2 PWR001 module includes the LC filters, Figure 23 illustrates the noise reduction. Measured audio band noise is around -86 dBV.

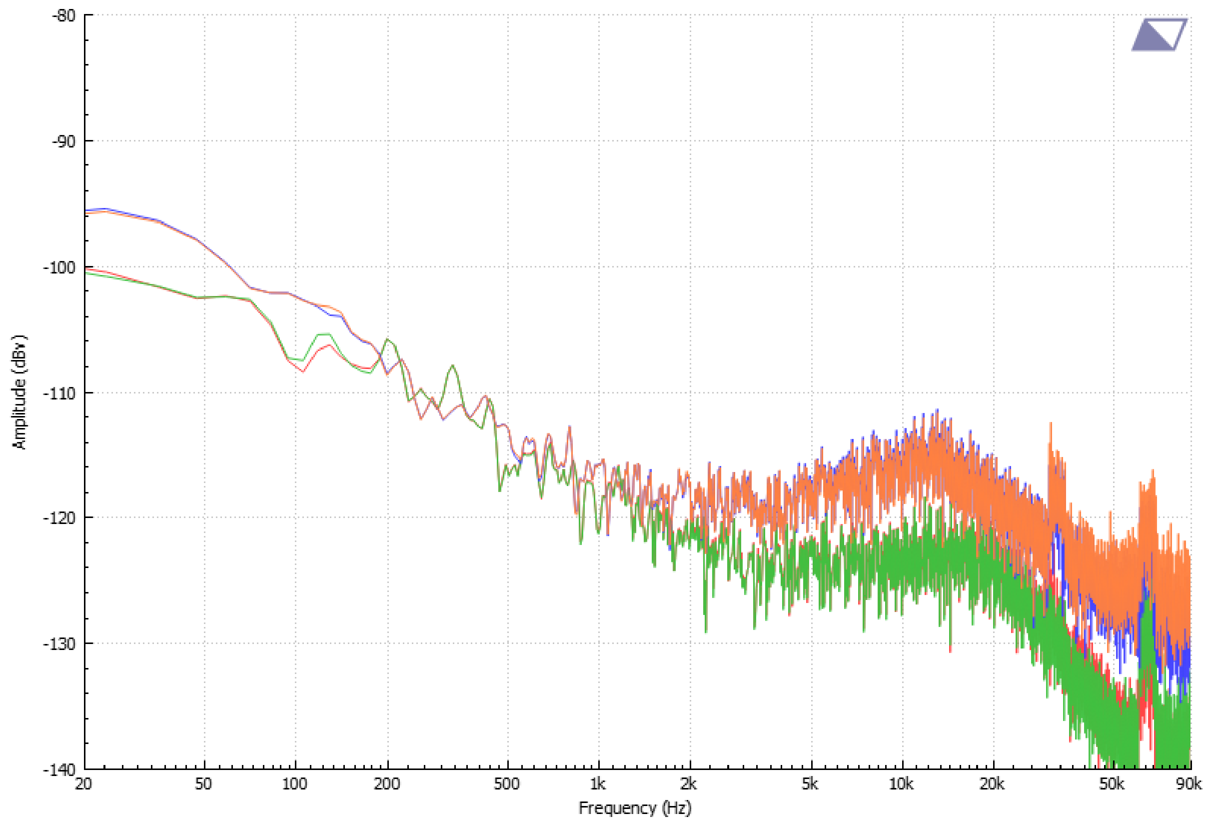

Figure 24 Comparison of +/-15V output of PWR001 (rev 2 PCB) with (red green) and without (blue orange) 10 uH/100 uF filter, 270 mA load

5.1.1 CUI 3.3 ON PWR001 (REV 2)

Figure 24 and Figure 25 show the CUI module noise spectrum on the rev 2 PWR001 module, which includes the 10 uH/100 uF filter. Compare these with the plots in section 3.

The PWR001 module includes a LED on the 3.3 line so the no load current isn't actually zero like previosuly measured. We can suggest that 20 mA should be the minimum current draw when the system is active, though the impact of noise from this supply is probably minimal.

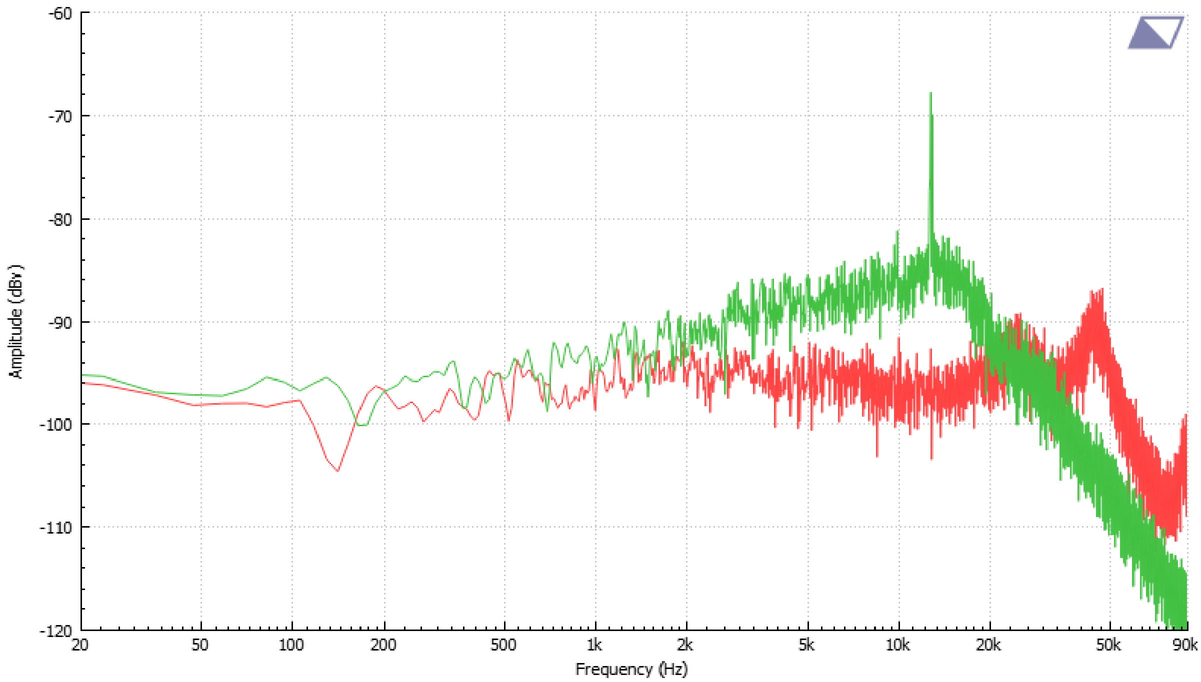

Figure 25 3.3V CUI module with LC filter (rev 2 PWR001) with no load (green) and 20 mA (red)

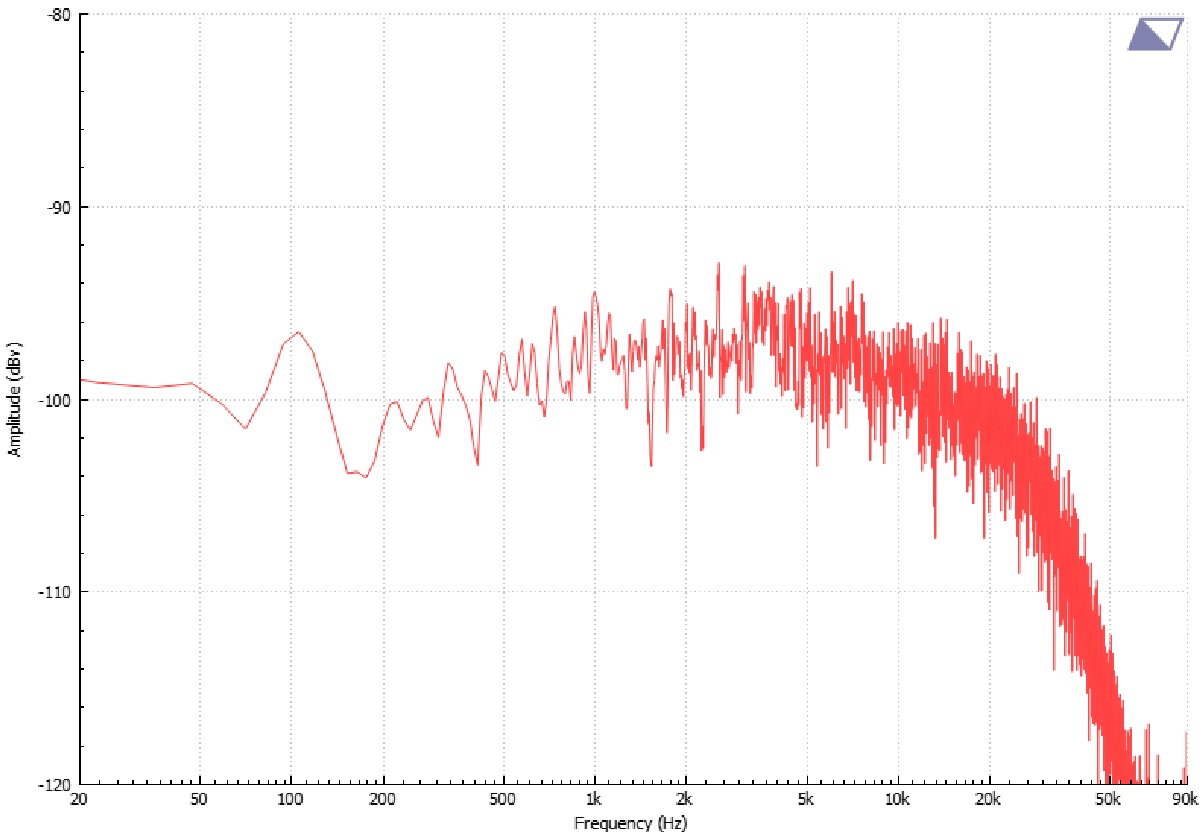

Figure 26 3.3V CUI module with LC filter (rev 2 PWR001) 330 mA load

6 OP-AMP MEASUREMENTS

For detailed background on this measurement please see TN003. These tests were performed with a test circuit built on the AA0106 prototyping board plugged in to a CC002 single module carrier.

6.1 SUMMARY

Two different circuits we used, a NE5532 inverting and AD797 non inverting configurations. The SPICE simulated noise was -107.5 and -127 dBV, respectively.

With the system connected but the muting relays shorted (i.e. off) residual system noise was -124 dBV in the channel used for the NE5532 and -126 dBV for the AD797. We would therefor expect instrument noise to dominate the Ad797 test, with the ideal measurement from those floor values being -123.5 dB.

Figure 26 shows the noise floor. The source of the two peaks[5] is not known as this was done with only the required equipment turned on around the setup.

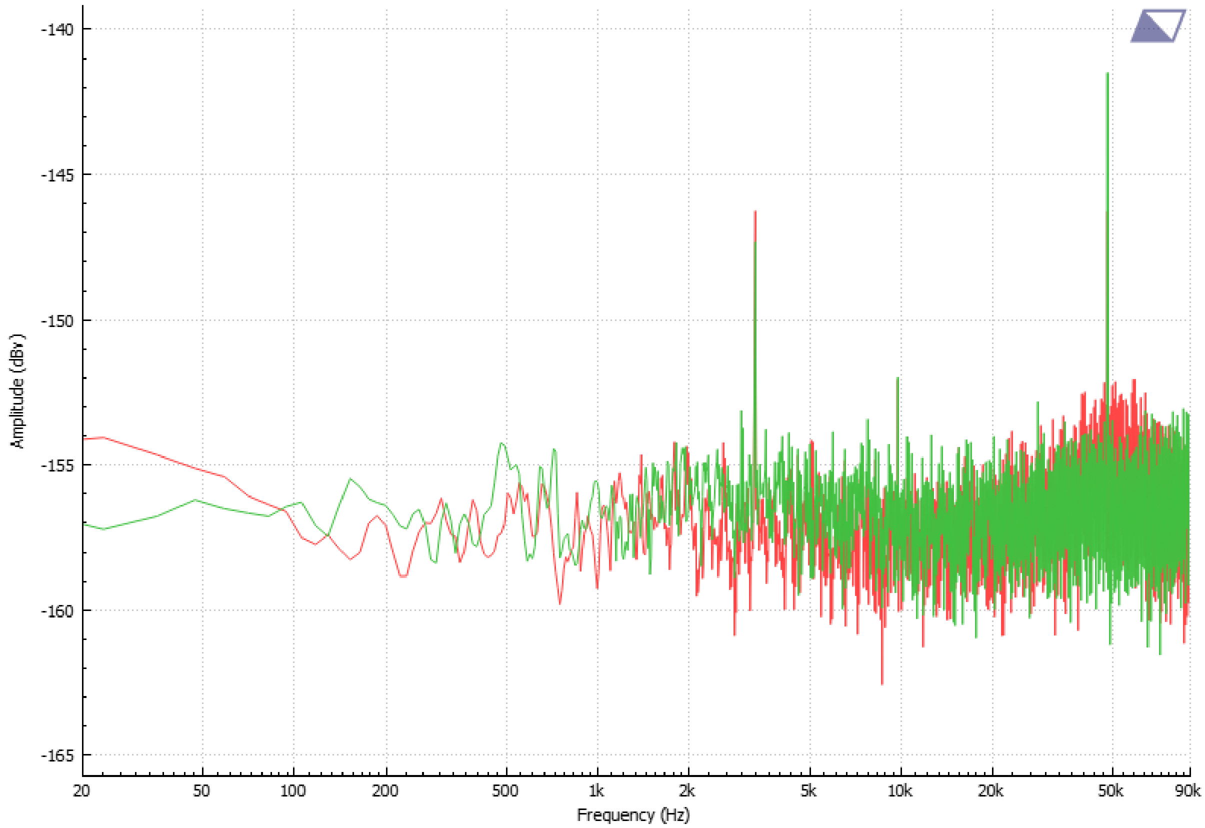

Figure 27 Op-amp test setup with measurement input shorted to measurement system on (AT0104) RCA output board.

To provide an ideal measurement with no chance of power supply contamination batteries were used to power the op-amps and the mute relays (which have NC contacts). The 5532 output noise was -107.8 dB, in good agreement with the simulated value. The AD797 however measured -120.3 dBV, about 3 dB worse than expected.

Figure 27 does show an unexpected peak in the noise in the 40 – 50 kHz area but the RMS noise emeasurement is only in the audio band. From the perspective of maintaining a SNR great enough for the bulk of intended applications, the noise floor being -123 dB below the peak signal (for unbalanced, 2V RMS peak output) would be fine.

[5] The big one is 80 nV, really not something to get excited about to answer the questions we want to answer.

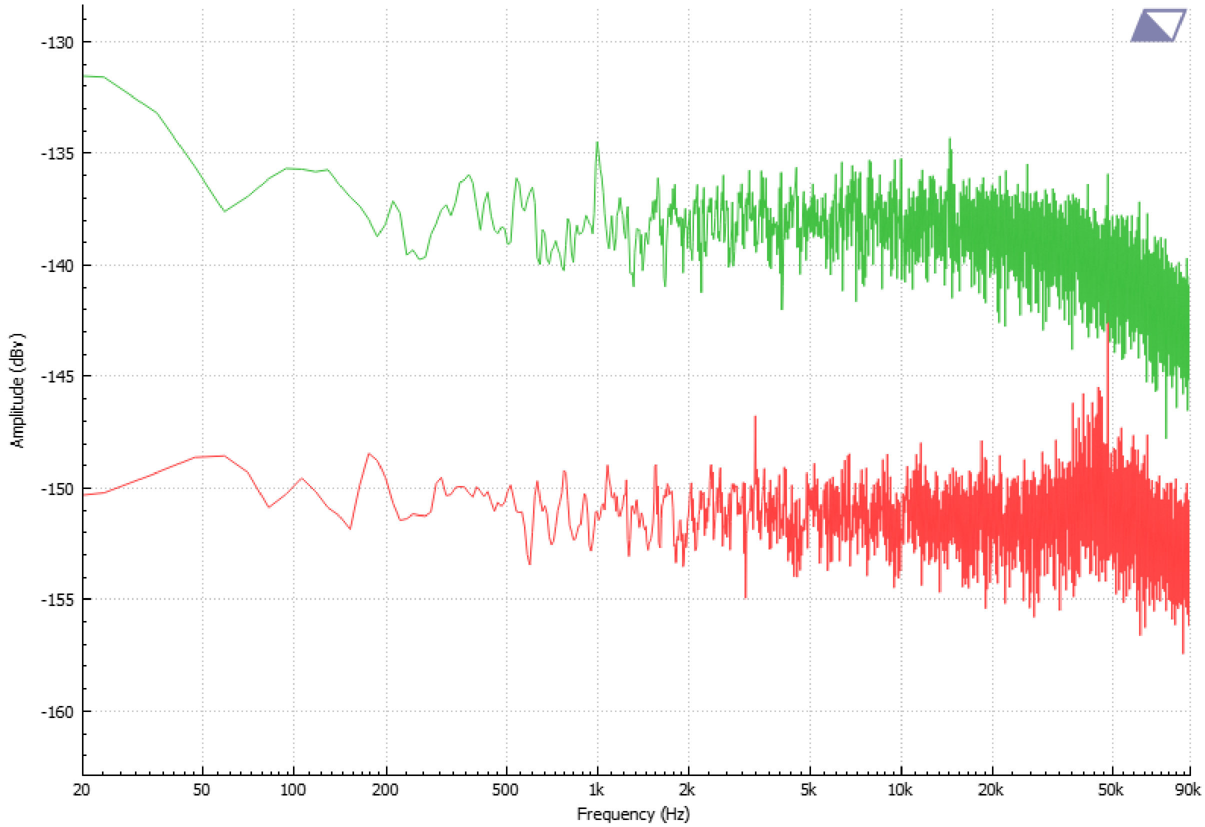

Figure 28 Op-amp input shorted noise floor with battery powered NE5532 (green) and AD797 (red) (16K FFT, 16 avgs)

When powered with the PWR001 (rev 2) module the NE5532 noise floor is unchanged but the Ad797 increases to -119.4 dBV, a decrease of about 0.9 dBV. From the spectrum in Figure 28 there's no specific degradation noted in the audio band. Ground loops between the power supply and measurement system could also easily explain the increase in noise.

Looking at the smoothed FFT in Figure 29 there's no obvious difference for the AD797 other than in the 8 kHz to 20 kHz region the PWR001 noise is a tad higher than the battery based measurement, which given it's 50% of the bandwidth would have significant weight in computing the overall RMS noise.

OTOH it's kind of tough to explain the battery results, though in this measurement the batteries were 9V and thus not a direct comparison to the +/-15V PWR001 supply. We'll have to re-run this when we can get a 15V battery.[6]

[6] Yes, they do exist.

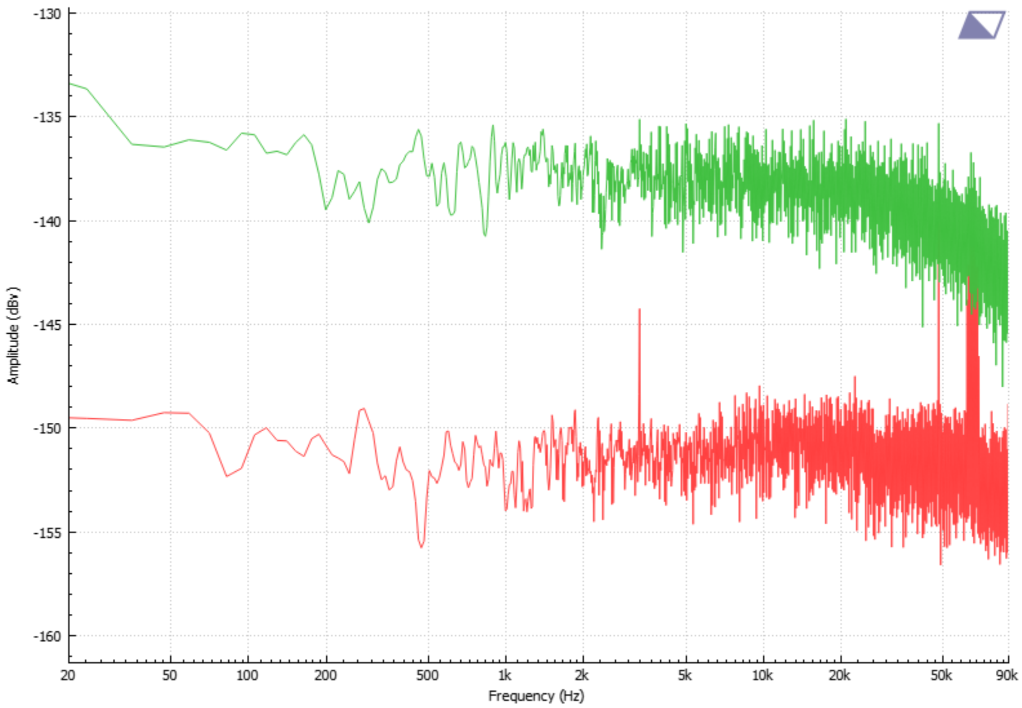

Figure 29 Op-amp input shorted noise floor with power from PWR001 module. NE5532 (green) and AD797 (red) (16K FFT, 16 avgs)

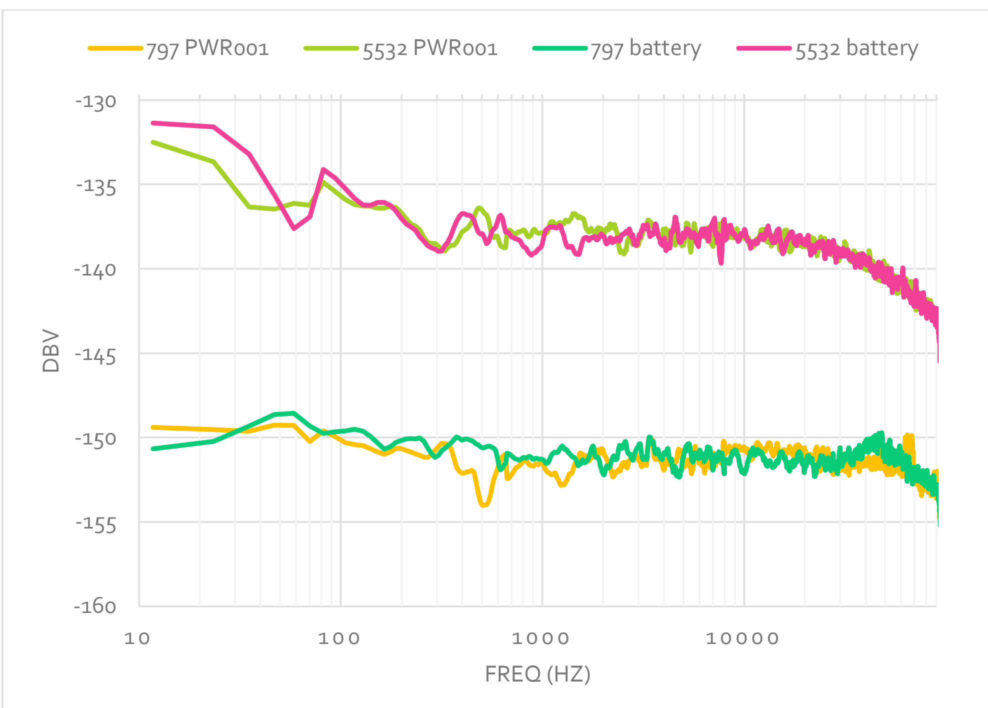

Figure 30 Smoothed FFT results comparing battery and PWR001 power sources on op-amp circuits

7 MEANWELL MODULES

From inspection (see Figure 26) the two Meanwell modules are the same circuit topology, with component value differences being the only observed changes between the +/-5 and +/-15 volt output versions. The controller is the 30 year old TI[7] TL3843.

Nothing obvious as to why the +/-5V one would be so noisy.

Figure 31 Meanwell modules, +/-15V on left, +/-5V on right.

[7] Maybe acquired from Unitrode.