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Whitepaper:

The final truth about DSP Volume Control in Roon and XMOS

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https://rooExtend.com

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Introduction

In the net I found a lot of discussions regarding the quality of Roon DSP volume control. The discussions revolve around whether it is better to use the device volume, the DAC volume, or an analogue volume control, for example here: https://community.roonlabs.com/t/better-volume-control/126279/13

My concern was to find out the truth about DSP volume control in Roon by measurements just to know and to let you know.

I also took a measurement with a PCM from DIYINHK housing an XMOS processor which is used in most modern DACs. In this case the volume control is done digitally inside the XMOS processor but different.

Measurement setup

I took this setup for the measurements:

1. Playback of different Mono WAV test signals in Roon
2. As audio output device I use a Raspberry Pi3 with an attached HiFiBerry Digi+ Pro hat with Roon Bridge software.
3. The digital output of the HiFiBerry Digi+ Pro is connected to the digital input of a M-Audio 2496 soundcard by a 75Ohm S/PDIF coax cable. The soundcard runs in a standard Windows PC.
4. To record the 24-Bit input of the soundcard I use the CD Wave Editor software on this PC. It creates 24Bit WAV files.

To have a high-quality input signal I computed a synthetic test signal (44.1kHz) with 64Bit Floating-point values consisting of two added sinus signals. The two frequencies I use (88.133Hz and 1378.125Hz) are a bit odd. But I chose them because they perfectly fit into a multiple of a 64k blocks I use for FFT. This prevents overlap errors in the FFT calculation enabling me to deliver accurate results without any frequency smear. The FFT of the basic 64Bit test signal looks like this:

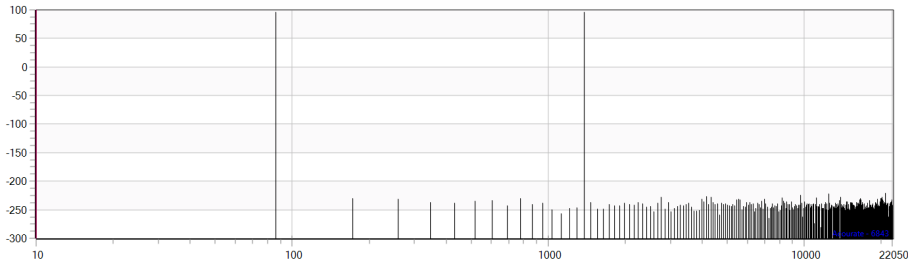


Fig.1: FFT of the computed two-tone test signal
(Double Precision Float)

As it is a full scale signal (-1 to +1) of 262.144 samples length, the FFT calculates quite a high amplitude (96,35dB). In all the measurements shown here I will normalize this to 0dB. Please keep in mind that the processed signals inside Roon are always full scale. Normalization is just a different scale for display. After normalization to 0dB, the synthetic test signal looks like this:

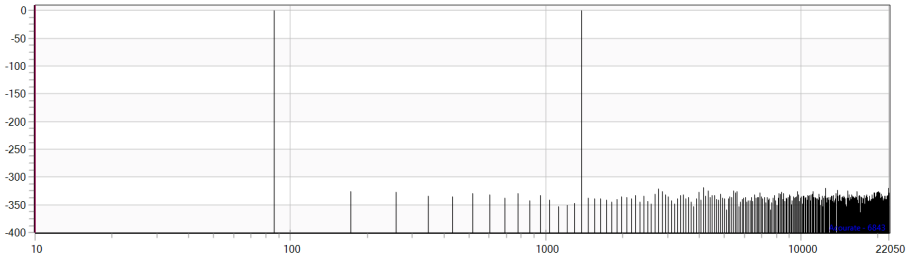


Fig.2: Normalized FFT of the computed test signal

As easily can be seem the digital noise floor is approx. at -320dB. This is the precision of 64Bit Floating-point math.

From this I created three Mono WAV test signals, one with 32Bit Floating-point one with 24Bit (normal) Integer and one with 16 Bit (normal) Integer format.

As expected, the noise floor for these three signals is significant higher. I deliberately did not include any dither when reducing the resolution, so I can see in what scenarios Roon works Bit Perfect or inserts dither.

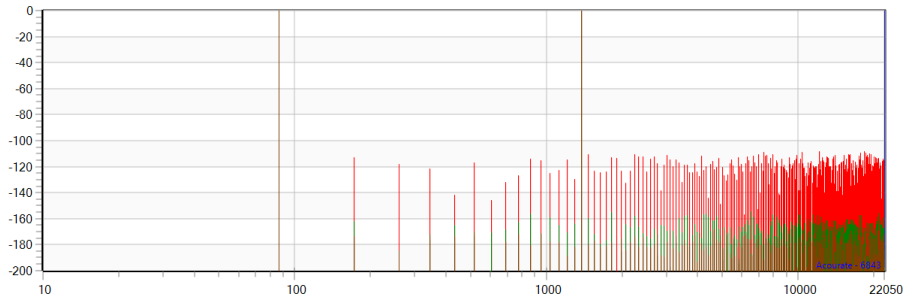


Fig.3: Normalized FFTs of the test signals

Here you see the FFT of the tree test signals. The red is 16Bit undithered, green is 24Bit undithered and the brown is the 32Bit undithered signal. The noise is now apx. -160dB for the 32Bit signal (half of 64Bit), the 24Bit signal is a bit higher and aprx. -110dB for the 16Bit test signal.

Let us remember that today's top DACs and amplifiers are no better than -125dB! So only the 16Bit input signal may be a real-world issue, if your DAC and power amplifier will be good enough.

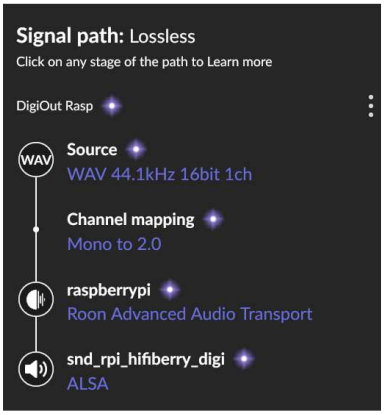
These three test signals were used as input for the upcoming measurements.

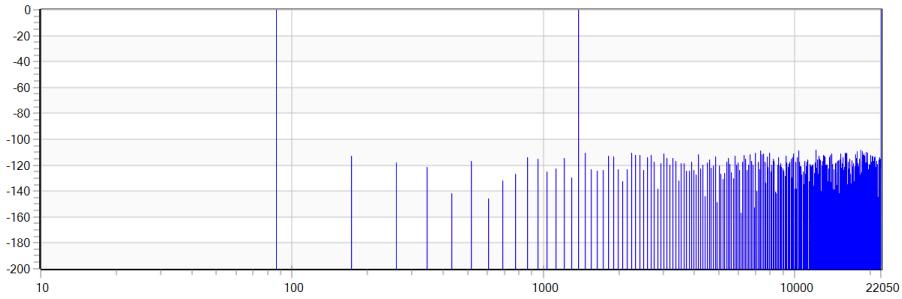
Measurements

Pure playback

As reference I first did a measurement playing the test signals and recording the output. Just to let you know jitter is not an issue in my setup because there is no conversion from digital to analogue.

16Bit Integer test signal



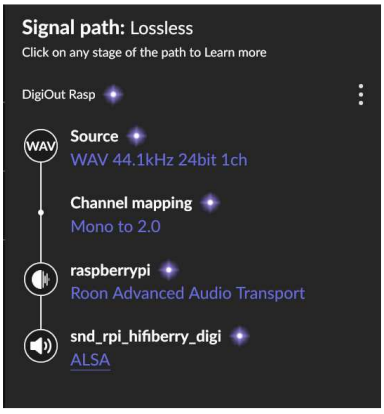


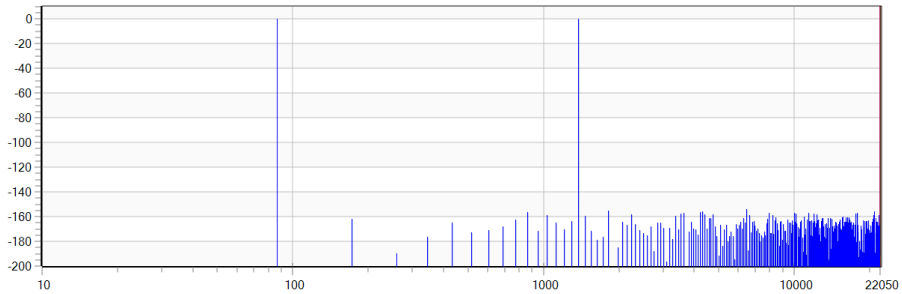
Looking at the signal path in Roon we see that the mono test signal is mapped to two stereo channels, transported to the Pi and then to the HiFiBerry Digi+ Pro. There is no signal processing involved.

This was proofed by the measurement. The blue FFT is the measured signal at the digital output of the Digi+ Pro. It perfectly fits the red test signal lying invisible below it. The match is so perfect that nothing can be seen of the red test signal.

Bit Perfect Playback!

24Bit Integer test signal

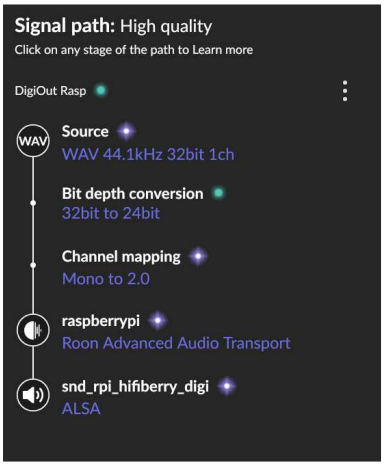


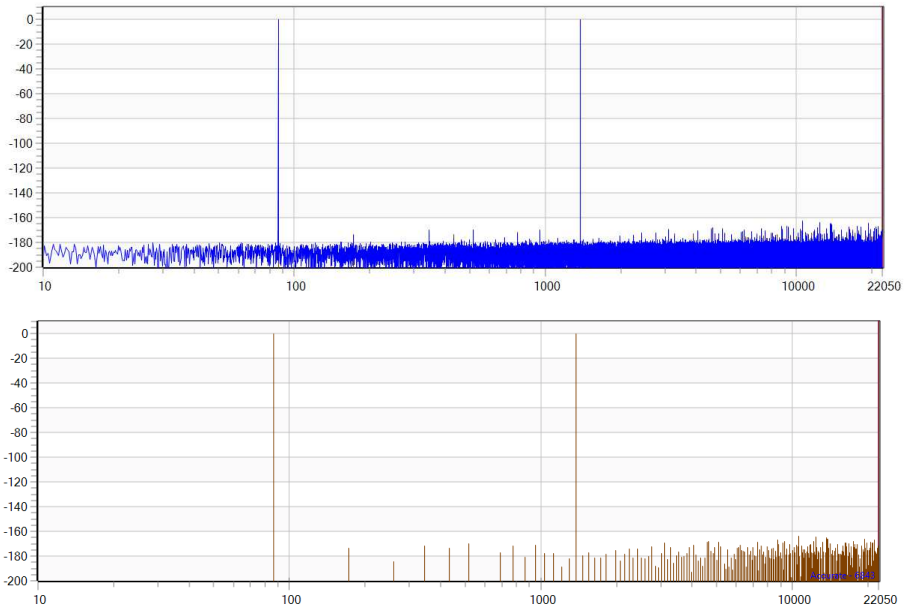


Same behaviour as with the 16Bit test signal.

Bit Perfect Playback!

32Bit Floating-point test signal





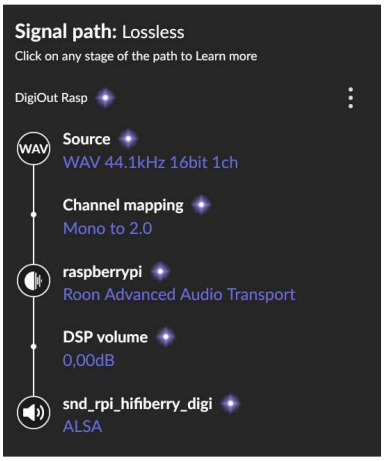
What we see here in the signal path is that Roon performs a Bit depth conversion from 32Bit to 24Bit before processing the rest of the signal path. In the image above I inserted the measured signal (blue) and the original signal (brown) below to clearly show the difference. Roon inserts a dither at Bit depth conversion. This is what must be done to get best audible results. This inserts a neglectable noise floor at approx. -178dB.

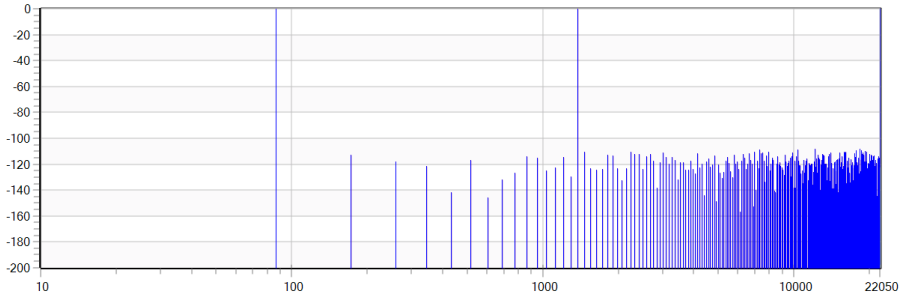
In this case, the output is no more Bit perfect. Is it audible? A clear NO! The dither noise floor is approx. -40dB below noise floor of the DAC or the amplifier so it is a non brainer at all.

DSP Volume 0dB

Next, I wanted to know whether the insertion of the DSP volume at 0dB has any influence on the output signal.

16Bit Integer test signal

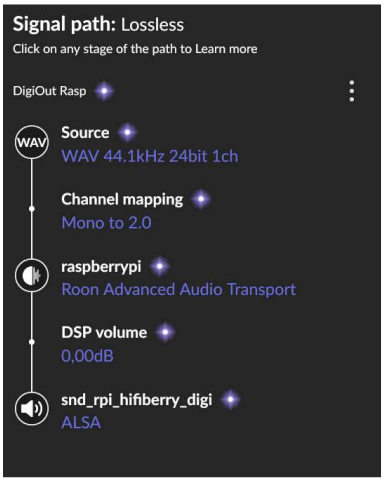


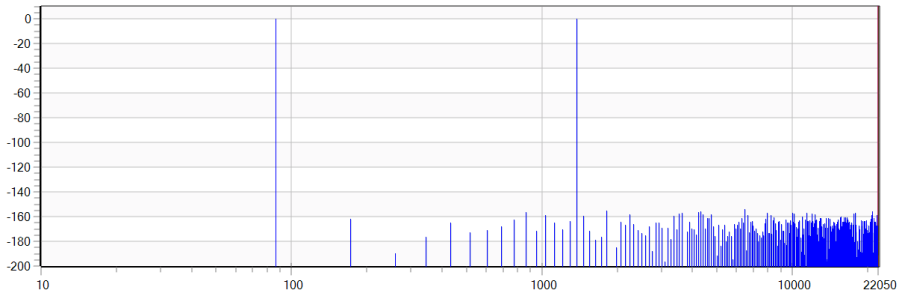


No influence at all, as perfect as without DSP volume control.

Bit Perfect Playback!

24Bit Integer test signal

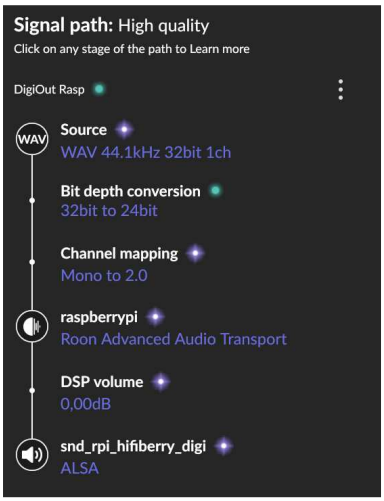


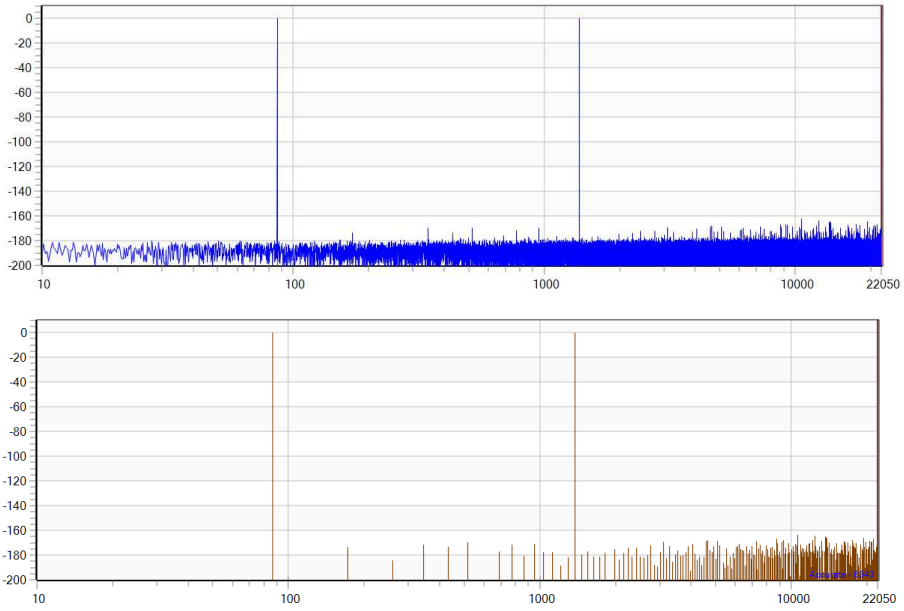


No influence at all, as perfect as without DSP volume control.

Bit Perfect Playback!

32Bit Floating-point test signal





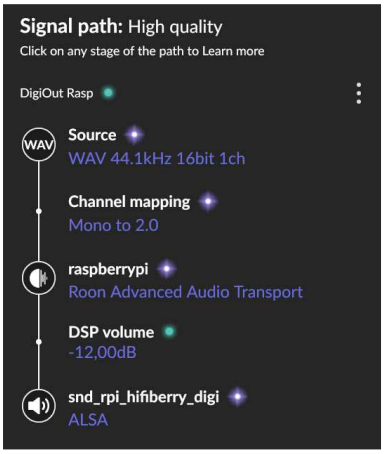
Also, no influence of the DSP volume at 0dB on the result.

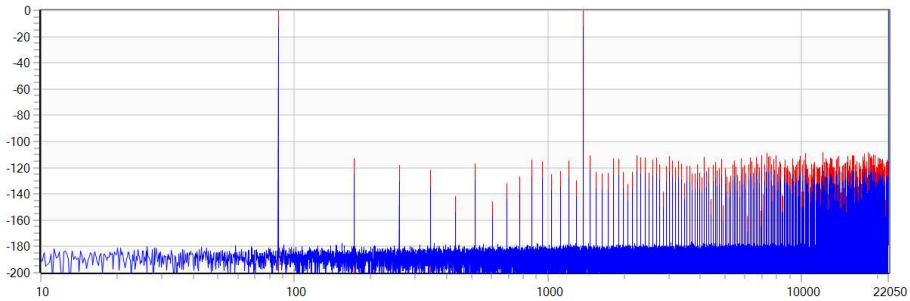
Well done!

DSP Volume -12dB

In this measurement I reduced the volume by 12dB, to one fourth of the perceived volume.

16Bit Integer test signal

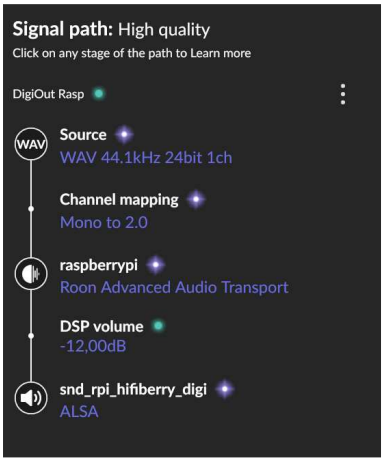


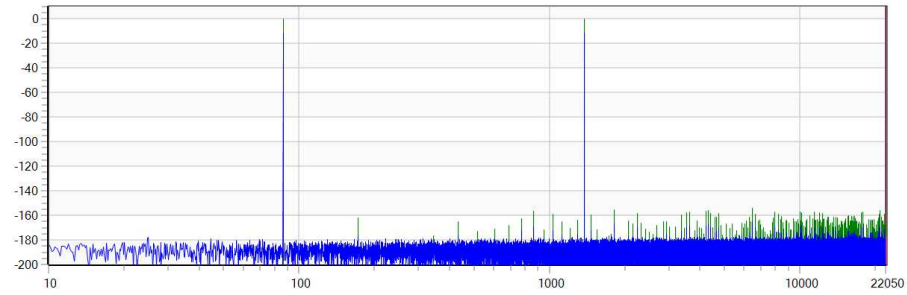


What we see here is that the two peaks of the measurement (blue) are 12dB below the red test signal. Both signals are overlayed in the graph to show the difference. As easily can be seen with DSP volume also dither is inserted at a level of approx. -178dB. Also, the noise of the test signal (red) reaching up to -110dB got attenuated. At the end there is a noise level at approx. -125dB. If you have a good DAC and amplifier, it also may be in this region.

This means DSP volume at -12dB does not introduce any loss of resolution.

24Bit Integer test signal

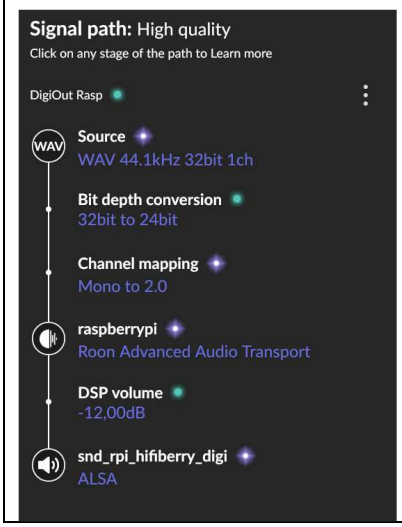


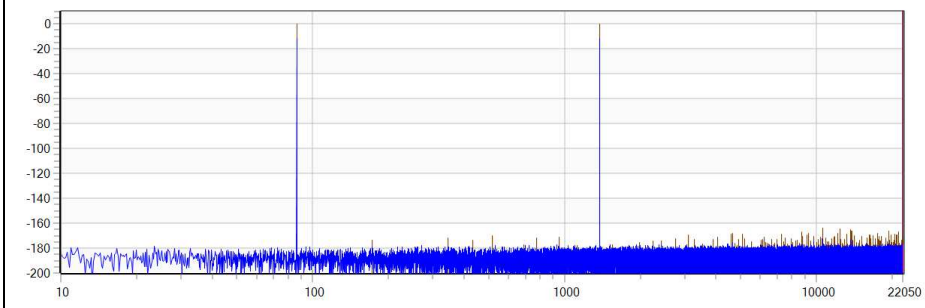


Same behavior as above. The peaks of the measurement (blue) are 12dB below the green test signal. Also, dither is inserted at a level of approx. -178dB. The noise of the test signal (green) originally reaching up to -160dB got attenuated. At the end there is a noise level at approx. -175db.

This is far beyond the noise level of the DAC or amplifier so no audible issue at all.

32Bit Floating-point test signal





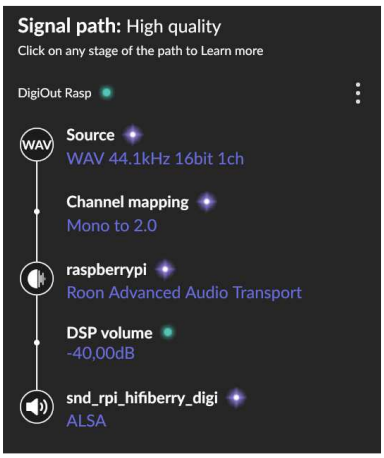
Nearly the same result here. As the 32Bit test signal has a lower noise floor as the 24Bit signal it is attenuated nearly completely below the -178db dither amplitude.

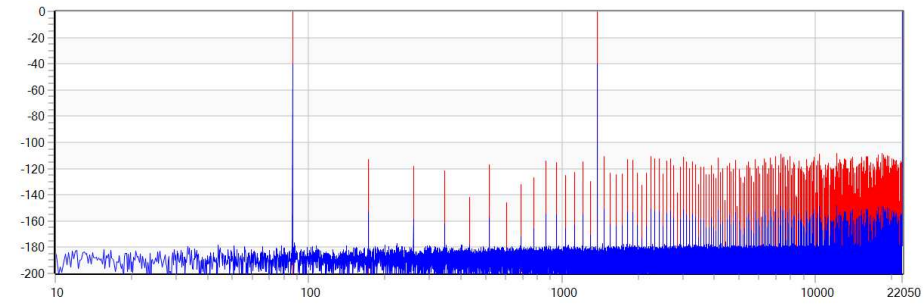
I would like to point out that despite a double dither in the signal path (Bit depth conversion and DSP volume) the noise would not rise above -178db!

DSP Volume -40dB

In this measurement I reduced the volume by the huge amount of 40dB!

16Bit Integer test signal

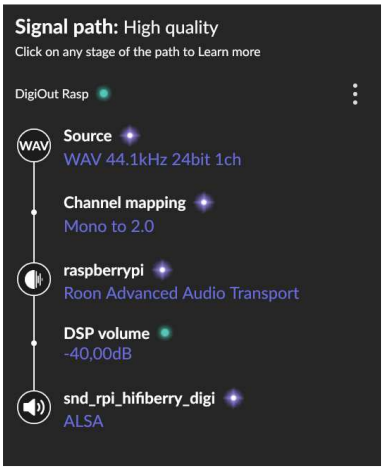


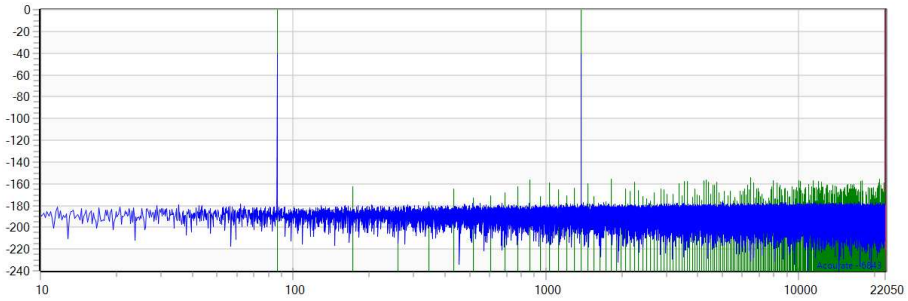


At an attenuation of -40dB it can be clearly seen that the two peaks of the blue FFT drop down to -40dB. The dither noise floor stays at -178db. Not all the noise of the red signal had disappeared in the dither noise floor, but it got perfectly attenuated.

Even at the attenuation of -40db the signal to noise ratio of the attenuated red signal stays intact there is no loss of resolution.

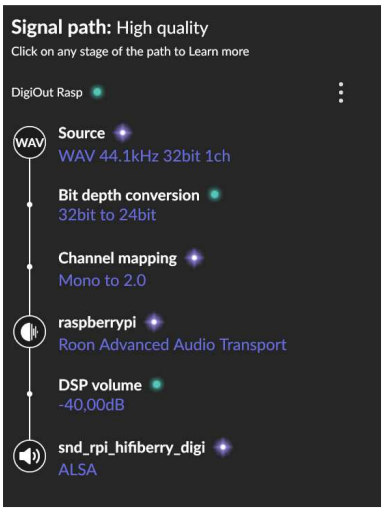
24Bit Integer test signal

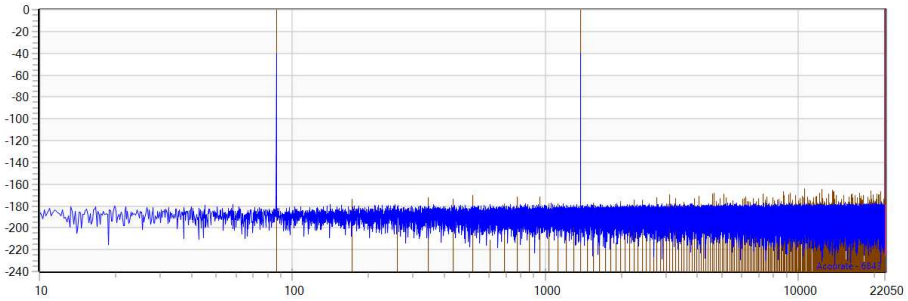




At an attenuation of -40dB the peaks of the blue FFT drop down to -40dB. The dither noise floor stays at -178db all noise above that in the green signal is completely attenuated now. Even with this high attenuation there is still a signal noise ratio of 138dB much more than a real word DAC or amplifier can deliver.

32Bit Floating-point test signal

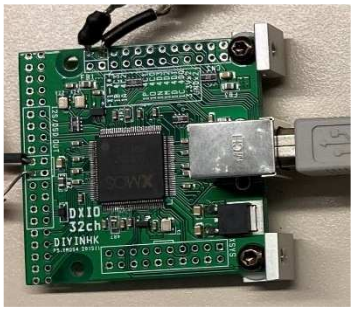


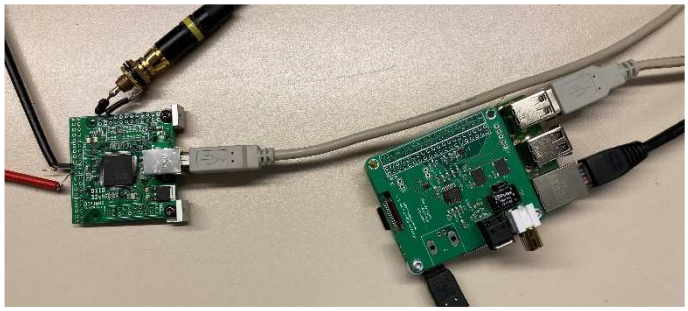


Same result as with the 24Bit input signal.

HIYINHK XMOS 384kHz Device Volume 0dB

In my home I found this small PCB from HIYINHK that I bought some time ago (https://www.diyinhk.com/shop/audio-kits/113-xmos-384khz-dxd-dsd256-high-quality-usb-to-i2sdsdspdif-pcb.html). This PCB (on the left side) has a USB input so I could connect it to my Raspberry Pi running Roon Bridge. Luckily, it has a 3.3V S/PDIF output, so I soldered a 75Ohm resistor to a Cinch connector to get the digital signal for recording.

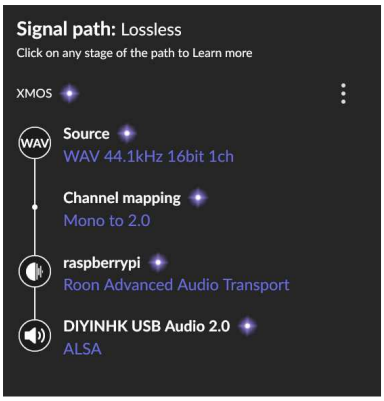


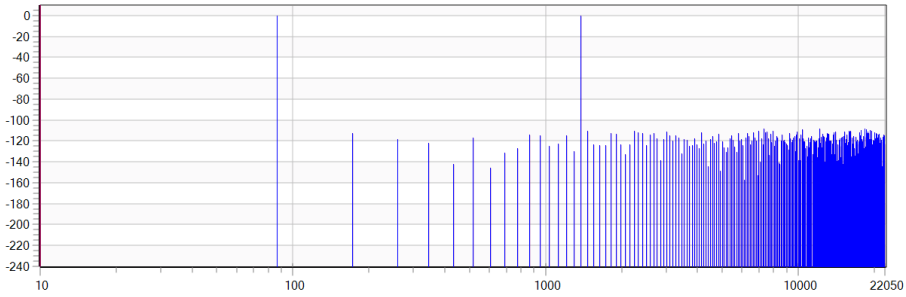


The idea behind this experiment was to evaluate the XMOS DSP volume built into the firmware running on the XMOS chip. This is a kind of standard firmware that XMOS ships to the DAC manufacturers using their processor. I have no knowledge if the manufacturers use exactly this firmware or modify it. So, the measurements presented here are only valid for this PCB from DIYINHK.

On the Roon side there is no DSP volume involved. Therefore, Roon always shows us a “Lossless” signal path. This makes us believe that XMOS DSP volume control is better that DSP volume in Roon, but we will see it is not.

16Bit Integer test signal

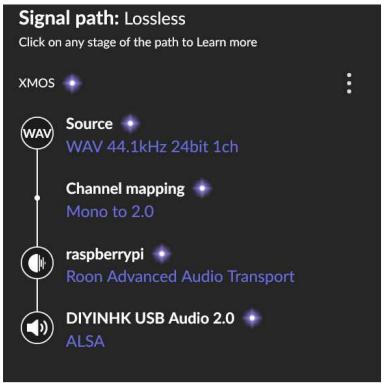


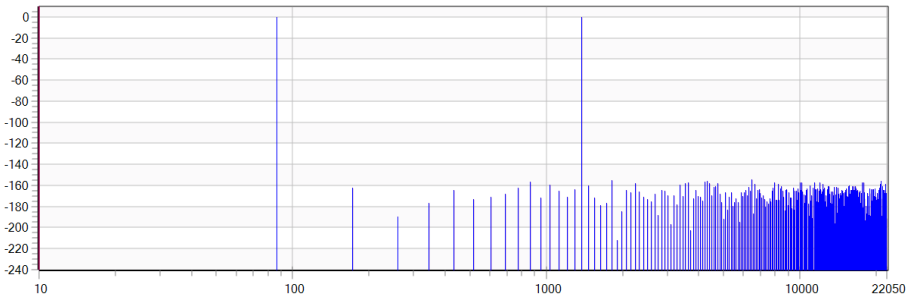


First, I again tested the 16Bit test signal with XMOS DSP volume set to 0dB.

Bit Perfect Playback!

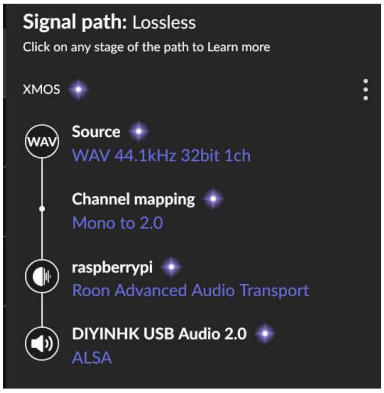
24Bit Integer test signal

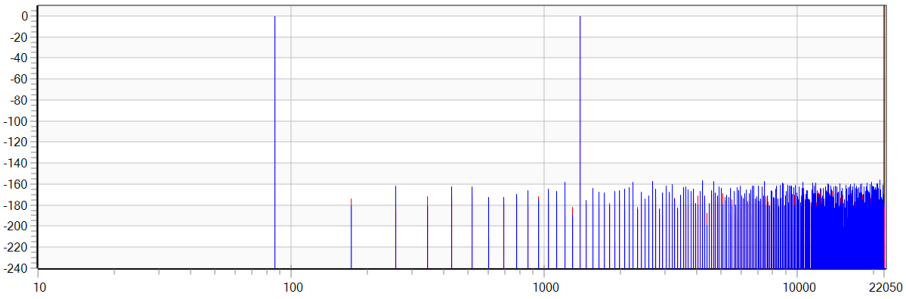




Same with the 24Bit Signal.

32Bit Floating-point test signal





Here we see some first little errors. I wonder why because 0dB should be a simple multiplication with one. But you can see the red spectrum showing up here and there below the blue one.

HIYINHK XMOS 384kHz Device Volume -40dB

Next, I reduced the volume by 40dB. This is not so easy using XMOS device volume because Roon has no more volume display in dB but shows numbers from 0 to 100.

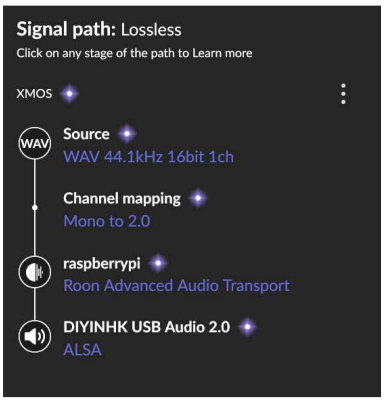
To set it up correctly I opened a bash in Linux and adjusted the ALSA volume to -40dB. Caused by this Roon immediately changed its volume display to 21 at the GUI. Great!

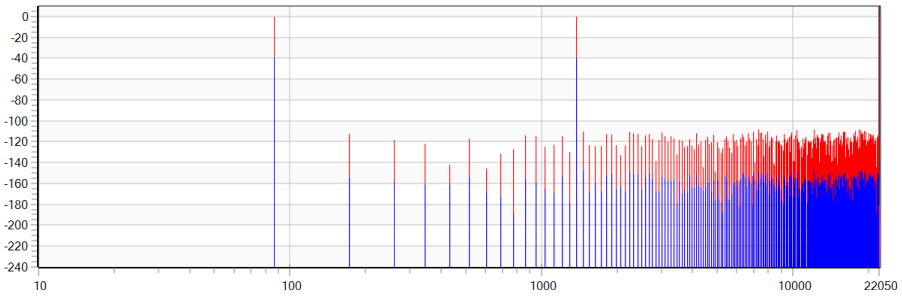
Below you see the statement I entered and the output below. The PCB has six digital outputs, so you see six values here. It is a bit odd because to get 0dB you must enter 127 and to get -127dB you must enter 0. This means for -40dB I had to enter 87.

```
pi@raspberrypi:~ $ amixer -c 2 cset numid=5 87
numid=5,iface=MIXER,name='DIYINHK USB Audio 2.0  Playback Volume'
  ; type=INTEGER,access=rw---R--,values=6,min=0,max=127,step=0
  : values=87,87,87,87,87,87
  | dBminmax-min=-127.00dB,max=0.00dB
```

With this setting I started my measurements.

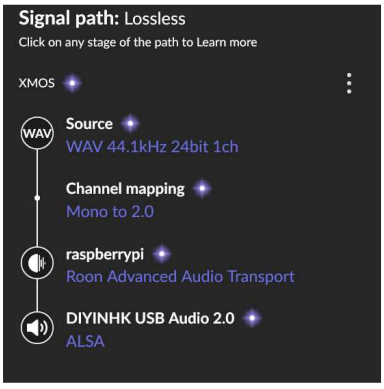
16Bit Integer test signal

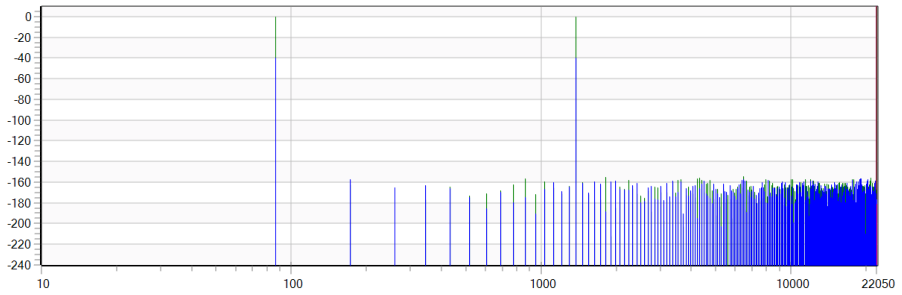




With the 16Bit test signal we clearly see the 40dB attenuation. What we also see is that there is no dither inserted at. For the 16Bit test signal this makes no big difference, the signal got properly damped down to approx. -160dB.

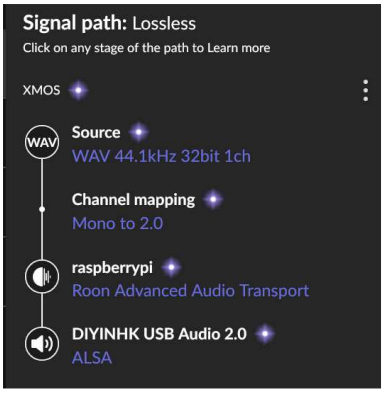
24Bit Integer test signal

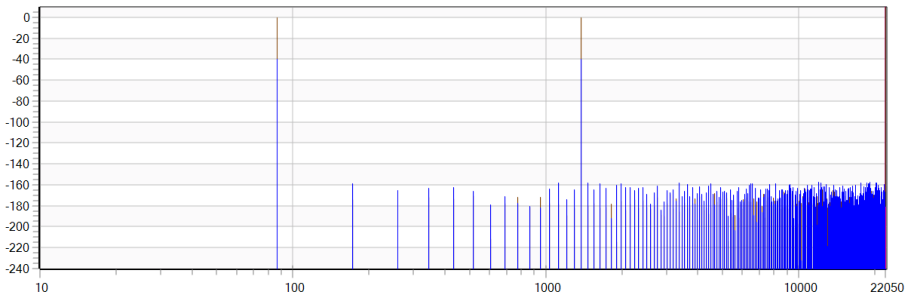




With the 24Bit test signal we see the difference. The signal should go down to nearly -178dB but the noise floor remains at -160dB. That's 20dB worse than what Roon's DSP volume delivers!

32Bit Floating-point test signal





The same we see with the 32bit test signal. The noise should be attenuated below -180dB but we also see the -160dB limitation here.

Conclusion

The DSP volume control inside the Roon Bridge is as perfect as can be.

The noise floor remains at -178dB, regardless of which attenuation is set for the DSP volume. This means that even at volumes down to -50dB the dynamic at the output is higher as the signal to noise ratio of the best DACs and power amplifiers. No other issues like intermodulation artefacts between the two frequencies or other distortions have been found. The dither is very well done with a completely flat response.

My conclusion is that there is nothing at all to worry about DSP volume in the Roon Bridge. No analogue volume control in the word can deliver these results. The thermal noise of a potentiometer or an analogue ladder attenuator will be much higher than the -178dB the DSP volume control of Roon delivers.

Using XMOS DSP volume in the DIYINHK PCB the noise floor is 20dB higher as with DSP volume from Roon. In this case Roon shows the purple dot making us believe the output quality is superior as with their own DSP volume. Fact is DSP volume in Roon is much better as XMOS DSP volume within the DIYINHK PCB.

Is it audible? My guess is no. If you feel better seeing a purple dot instead of a green one use XMOS DSP volume. My recommendation is: Use DSP Volume because I feel better to know the output is perfectly dithered.

Some final thoughts:

To keep resolution as good as possible there should be no volume attenuation in the signal path at all. Best results would be achieved in this respect if the volume control would be behind the power amplifier right before the speakers. But for sure there are a lot of reasons why such a solution is not really a good idea.

The next best place for a volume attenuator is before the power amplifier. Placing it there the final resolution at your ear will be the resolution of the power amplifier (let it be 100dB) reduced by the attenuation of your volume control no matter if it is digital or analogue. Reducing volume by 30dB in this scenario will result in a maximum resolution of 70dB at your ears!

To make this work you best connect your DAC directly to your power amplifier and use the DSP volume of Roon or if your DAC offers DAC-Volume use this. DACs normally outperform power amplifiers regarding the noise floor so there is no reason why they should not be directly connected to the power amplifier.

Another important point is that your power amplifier and your speakers should match. If the perceived volume is inacceptable high running the amplifier without volume attenuation either the amplifier is too strong for the speakers or the speakers are too sensitive for your amplifier.

Bearing this in mind the discussion of a “bad DSP volume” with a noise floor of -178dB is ridiculous.

If you like to get an impression of power amplifier noise figures please go here: https://www.audiosciencereview.com/forum/index.php?threads/review-and-measurements-of-benchmark-ahb2-amp.7628/

Here you find something similar for DACs:

https://www.audiosciencereview.com/forum/index.php?threads/okto-dac8-stereo-dac-review.14705/

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