SAPIENZA
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Update on simulation for OF trigger

BULLKID analysis meeting
04/03/2026
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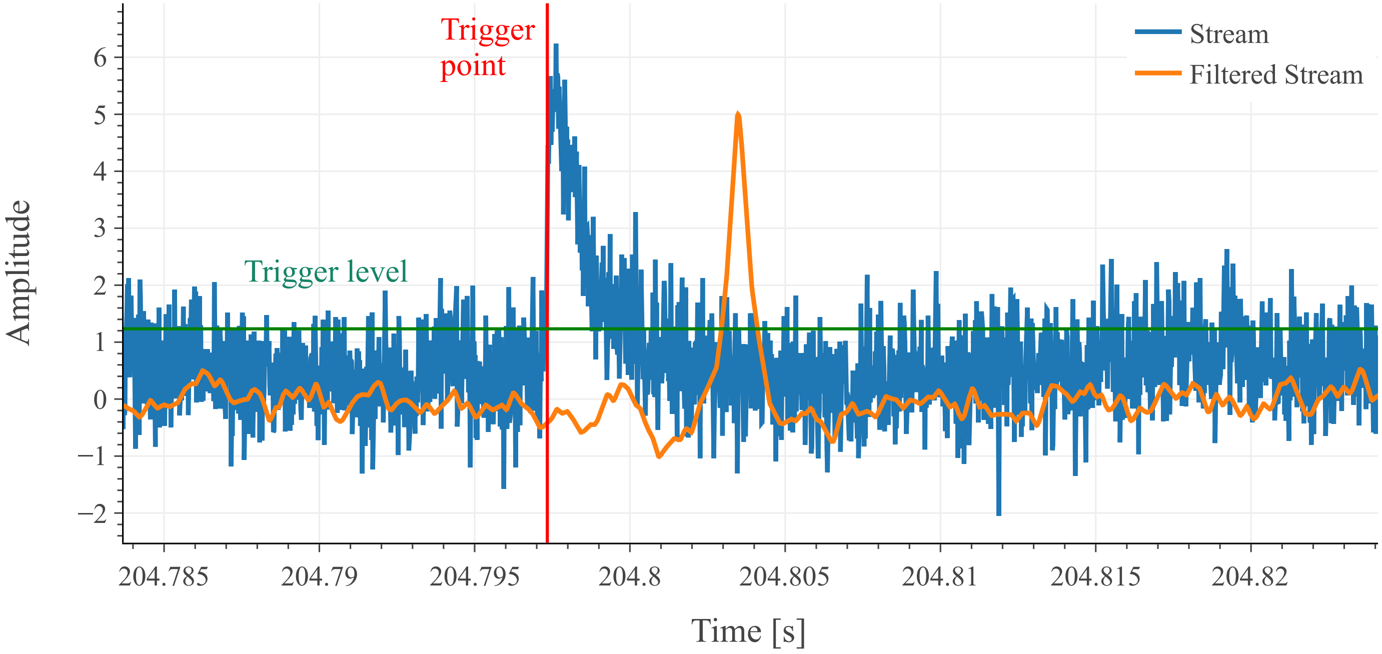
OF trigger

We use a trigger based on the Optimum Filter (OF) to lower the **trigger threshold**

- Filter the stream with the OF
- Trigger on the filtered stream



OF trigger

Filtering in the frequency domain

$$v_{\text{filt}}(t) = \int_{-\infty}^{\infty} df\, e^{i\omega t}\, \tilde{H}(f)\, \tilde{v}(f)$$

$$v_{\text{filt}}[k] = \sum_{j=0}^{N-1} e^{i2\pi \frac{k}{N} j}\, \tilde{H}[j]\, \tilde{v}[f]$$

Convolution in the time domain

$$v_{\text{filt}}(t) = \int_{-\infty}^{\infty} dt'\, H(t-t')\, v(t')$$

$$v_{\text{filt}}[k] = \sum_{j=0}^{N+1} H[(k-j+N)\%N]\, v[j]$$

Being H the filter and v the waveform to filter. The OF trigger in the new electronics will work on time domain data, we will need to do the **convolution** in the time domain.

Problems:

- Resources: for each channel, O(2000) in the final experiment, we need **N weights** for the convolution, being N the **window length**
- Time: the filtered sample k needs $N/2$ points in the past and $N/2$ points in the future (or N points in the future) to be computed

Solution investigated:

- **Downsample** the stream to reduce N

New simulation

The simulation to see how much we can downsample the stream has been modified
Simulate pulses over a noise stream and then trigger with the OF trigger implemented in Diana

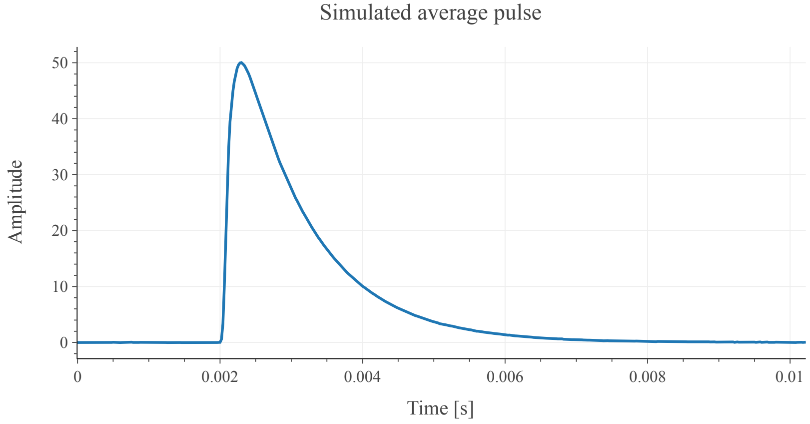
Simulation parameters:
Stream time: 6656 s
Sampling frequency: 50 kHz
τ_r = 100 μs (rise time)
τ_d = 1 ms (decay time)
Window length = 512 points (10.24 ms)
Noise contributions: flat + 1/f + $1/f^2$
σ noise (non filtered) = 1

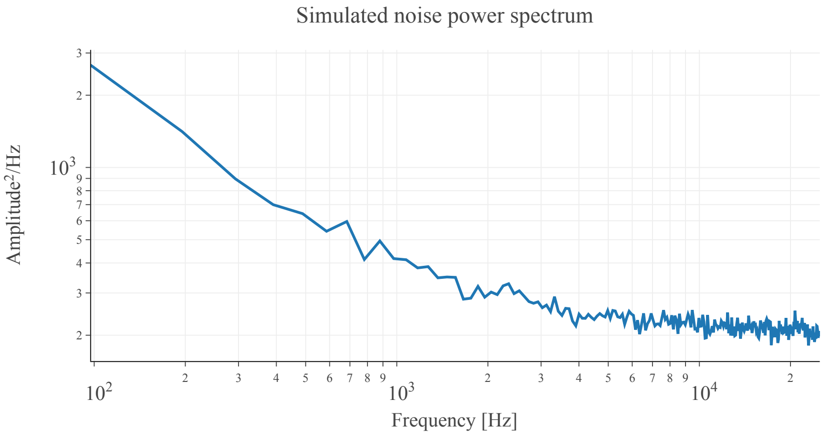
Pulse generated with the following amplitudes:
[0.3, 0.6, 0.8, 1, 1.1, 1.2, 1.25, 1.5, 1.7, 1.9, 2, 2.5, 5]

Downsample the stream at factors: [2,4,8,16,32,64]

Pulse model:

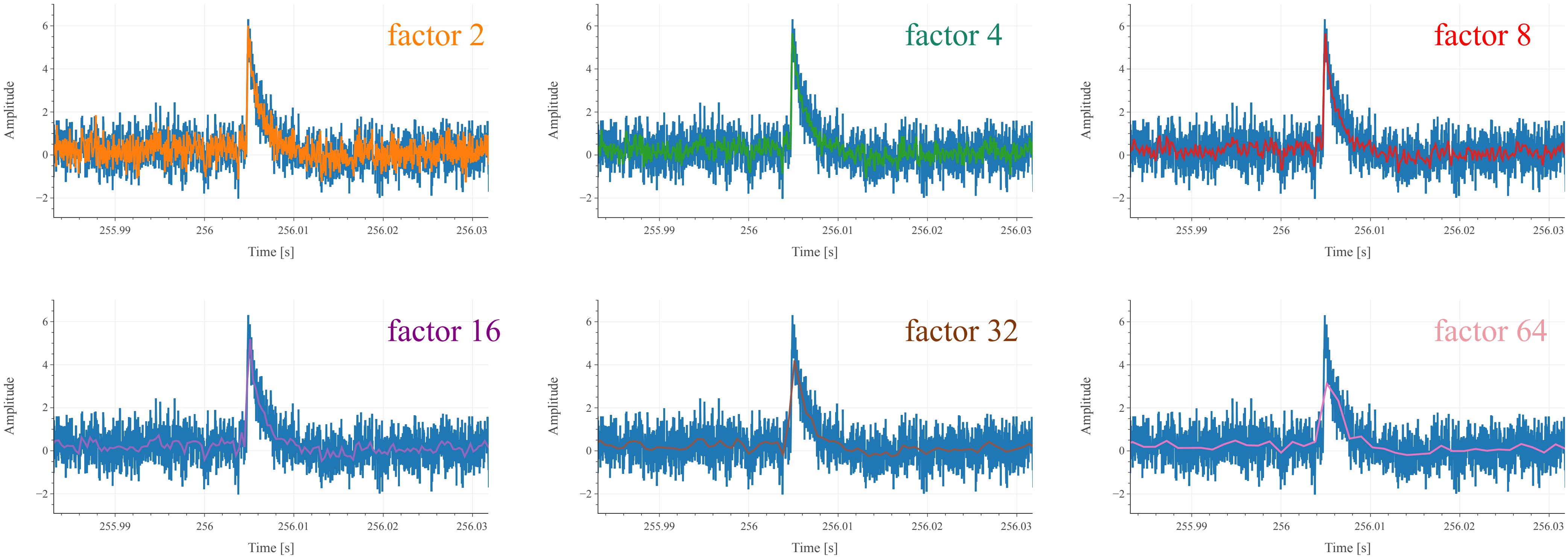
$$f(t) = \Theta(t - t_0)\left[e^{-\frac{t-t_0}{\tau_r}} + e^{-\frac{t-t_0}{\tau_d}}\right]$$





Downsample streams

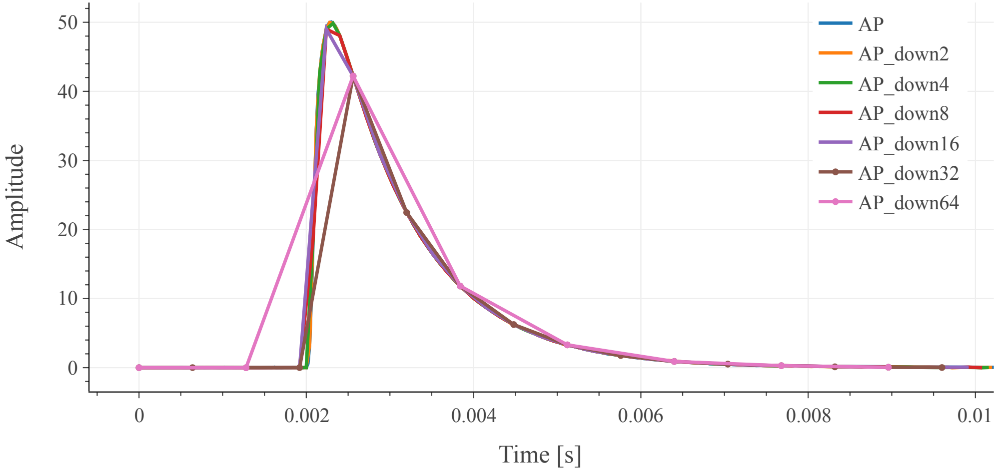
Downsampling the stream using scipy.signal.decimate, that includes an antialiasing filter.



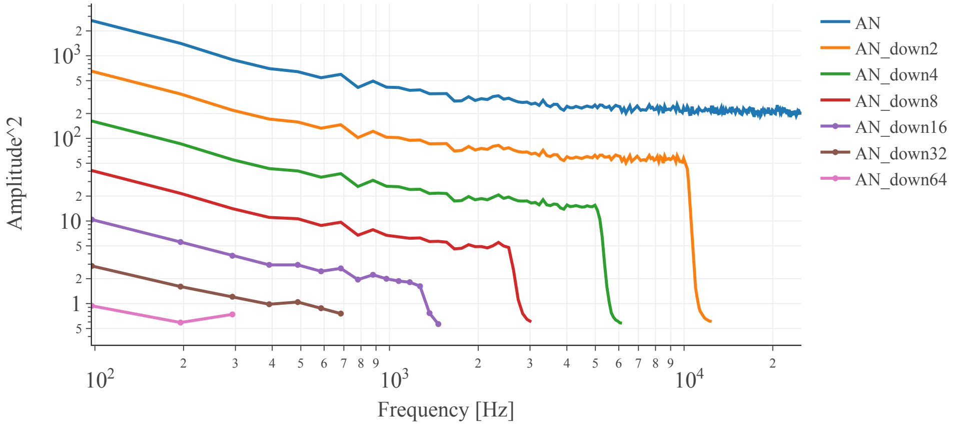
Filters

For each downsampling factor, we build a different optimum filter used for triggering, with the template pulse and the noise power spectrum (NPS)

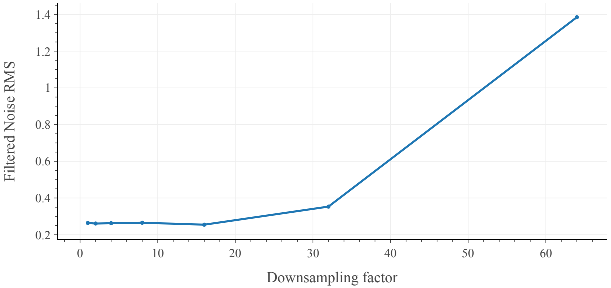
The template pulses are downsampled taking less points on the original template pulse, without antialiasing



The NPS are re-computed from the downsampled noise traces



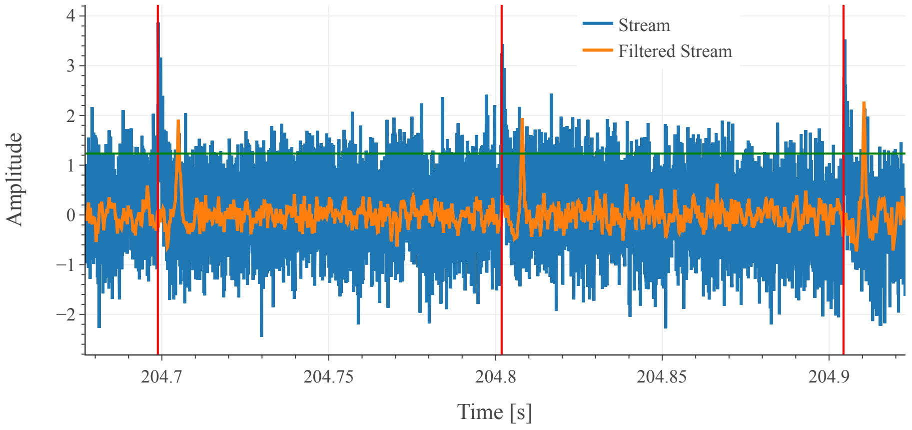
The RMS of the filtered noise changes appreciably only from downsampling = 32

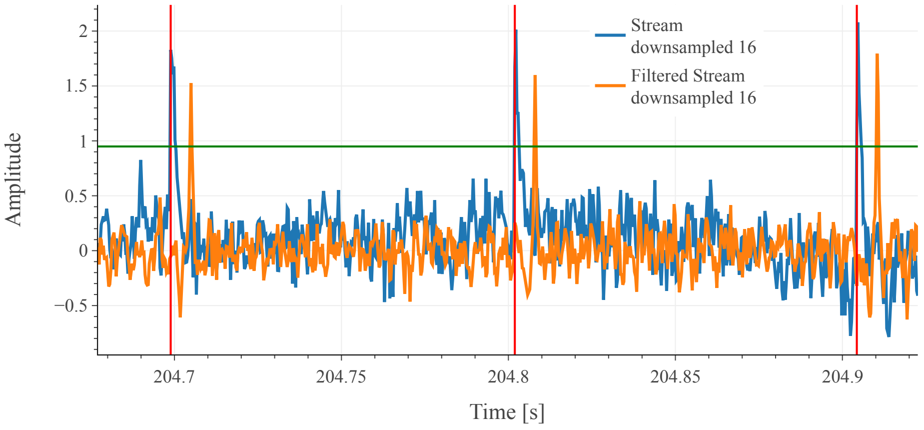


Filter and trigger streams

For each downsampling factor, filter and trigger the streams with the corresponding filter.

Trigger points and trigger level.



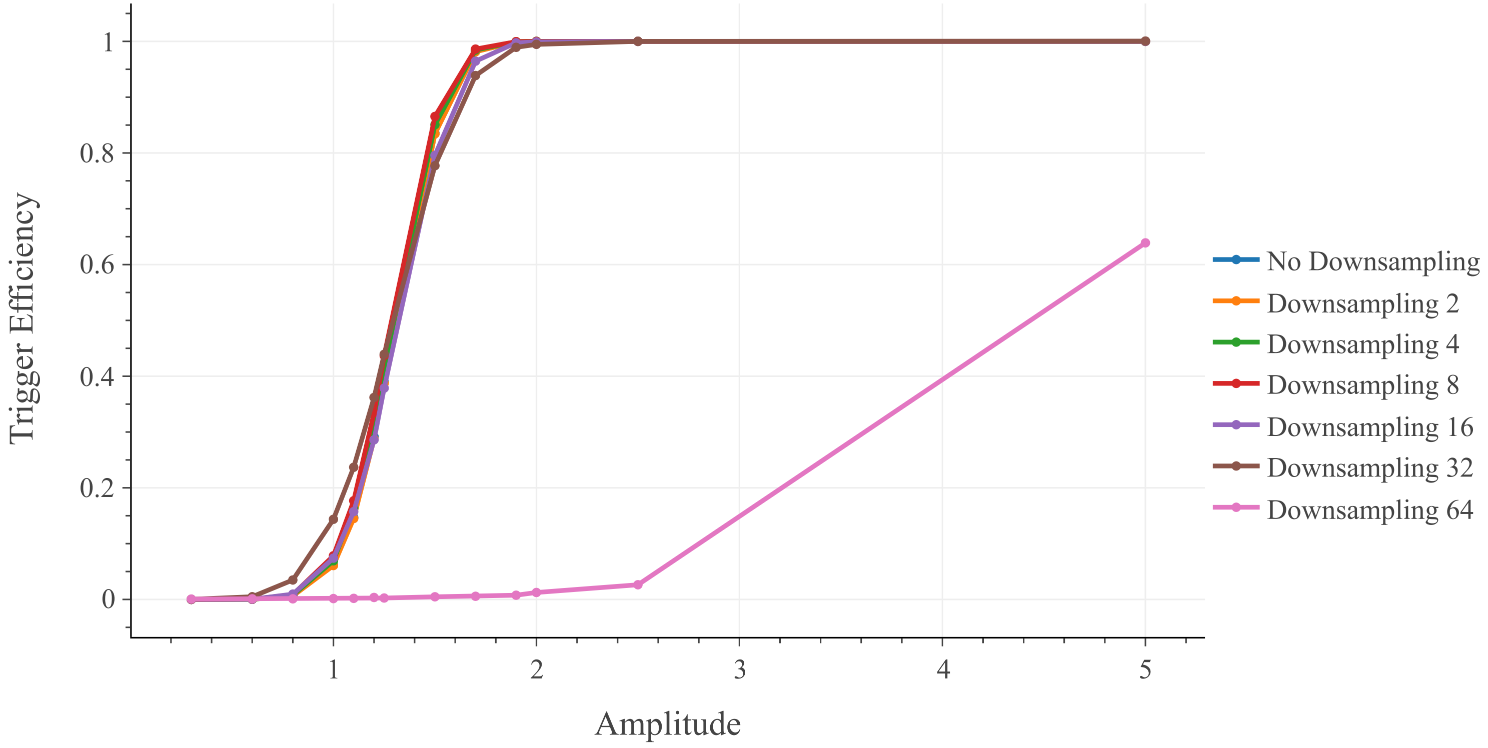


Downsampling factor	Threshold [σ]
1	5
2	5
4	4.9
8	4.7
16	4
32	2.9
64	2.5

In order not to loose events, we need to decrease the **trigger threshold** the more we downsample.

Trigger efficiency

The efficiency curves are now aligned to have the **same trigger efficiency** for every downsampling factor (except for the last one).
What about false positives? (they could increase due to the low threshold)



False positives

Does the lower trigger threshold increase the number of false triggers?

```
######################################## Downsampling factor : 1  ########################################
Amplitude value : 0.3   Injected triggers : 10000                Found triggers : 0     False positives : 0)
Amplitude value : 0.6   Injected triggers : 10000                Found triggers : 2     False positives : 0)
Amplitude value : 0.8   Injected triggers : 10000                Found triggers : 65    False positives : 0)
Amplitude value : 1     Injected triggers : 10000                Found triggers : 621   False positives : 1)
Amplitude value : 1.1   Injected triggers : 10000                Found triggers : 1468  False positives : 0)
Amplitude value : 1.2   Injected triggers : 10000                Found triggers : 2917  False positives : 0)
Amplitude value : 1.25  Injected triggers : 10000                Found triggers : 3896  False positives : 0)
Amplitude value : 1.5   Injected triggers : 10000                Found triggers : 8352  False positives : 0)
Amplitude value : 1.7   Injected triggers : 10000                Found triggers : 9817  False positives : 0)
Amplitude value : 1.9   Injected triggers : 10000                Found triggers : 9992  False positives : 0)
Amplitude value : 2     Injected triggers : 10000                Found triggers : 9999  False positives : 0)
Amplitude value : 2.5   Injected triggers : 10000                Found triggers : 10000 False positives : 0)
Amplitude value : 5     Injected triggers : 10000                Found triggers : 10000 False positives : 0)
```

```
######################################## Downsampling factor : 2  ########################################
Amplitude value : 0.3   Injected triggers : 10000                Found triggers : 0     False positives : 0)
Amplitude value : 0.6   Injected triggers : 10000                Found triggers : 2     False positives : 0)
Amplitude value : 0.8   Injected triggers : 10000                Found triggers : 62    False positives : 0)
Amplitude value : 1     Injected triggers : 10000                Found triggers : 607   False positives : 0)
Amplitude value : 1.1   Injected triggers : 10000                Found triggers : 1450  False positives : 0)
Amplitude value : 1.2   Injected triggers : 10000                Found triggers : 2874  False positives : 0)
Amplitude value : 1.25  Injected triggers : 10000                Found triggers : 3873  False positives : 0)
Amplitude value : 1.5   Injected triggers : 10000                Found triggers : 8342  False positives : 0)
Amplitude value : 1.7   Injected triggers : 10000                Found triggers : 9814  False positives : 0)
Amplitude value : 1.9   Injected triggers : 10000                Found triggers : 9991  False positives : 0)
Amplitude value : 2     Injected triggers : 10000                Found triggers : 9999  False positives : 0)
Amplitude value : 2.5   Injected triggers : 10000                Found triggers : 10000 False positives : 0)
Amplitude value : 5     Injected triggers : 10000                Found triggers : 10000 False positives : 0)
```

```
######################################## Downsampling factor : 4  ########################################
Amplitude value : 0.3   Injected triggers : 10000                Found triggers : 0     False positives : 0)
Amplitude value : 0.6   Injected triggers : 10000                Found triggers : 2     False positives : 0)
Amplitude value : 0.8   Injected triggers : 10000                Found triggers : 76    False positives : 0)
Amplitude value : 1     Injected triggers : 10000                Found triggers : 692   False positives : 0)
Amplitude value : 1.1   Injected triggers : 10000                Found triggers : 1635  False positives : 0)
Amplitude value : 1.2   Injected triggers : 10000                Found triggers : 3118  False positives : 0)
Amplitude value : 1.25  Injected triggers : 10000                Found triggers : 4144  False positives : 0)
Amplitude value : 1.5   Injected triggers : 10000                Found triggers : 8506  False positives : 0)
Amplitude value : 1.7   Injected triggers : 10000                Found triggers : 9844  False positives : 0)
Amplitude value : 1.9   Injected triggers : 10000                Found triggers : 9993  False positives : 0)
Amplitude value : 2     Injected triggers : 10000                Found triggers : 9999  False positives : 0)
Amplitude value : 2.5   Injected triggers : 10000                Found triggers : 10000 False positives : 0)
Amplitude value : 5     Injected triggers : 10000                Found triggers : 10000 False positives : 0)
```

```
######################################## Downsampling factor : 8  ########################################
Amplitude value : 0.3   Injected triggers : 10000                Found triggers : 0     False positives : 0)
Amplitude value : 0.6   Injected triggers : 10000                Found triggers : 3     False positives : 0)
Amplitude value : 0.8   Injected triggers : 10000                Found triggers : 86    False positives : 0)
Amplitude value : 1     Injected triggers : 10000                Found triggers : 782   False positives : 0)
Amplitude value : 1.1   Injected triggers : 10000                Found triggers : 1768  False positives : 0)
Amplitude value : 1.2   Injected triggers : 10000                Found triggers : 3344  False positives : 0)
Amplitude value : 1.25  Injected triggers : 10000                Found triggers : 4369  False positives : 0)
Amplitude value : 1.5   Injected triggers : 10000                Found triggers : 8654  False positives : 0)
Amplitude value : 1.7   Injected triggers : 10000                Found triggers : 9861  False positives : 0)
Amplitude value : 1.9   Injected triggers : 10000                Found triggers : 9994  False positives : 0)
Amplitude value : 2     Injected triggers : 10000                Found triggers : 9998  False positives : 0)
Amplitude value : 2.5   Injected triggers : 10000                Found triggers : 10000 False positives : 0)
Amplitude value : 5     Injected triggers : 10000                Found triggers : 10000 False positives : 0)
```

```
######################################## Downsampling factor : 16  ########################################
Amplitude value : 0.3   Injected triggers : 10000                Found triggers : 0     False positives : 0)
Amplitude value : 0.6   Injected triggers : 10000                Found triggers : 4     False positives : 0)
Amplitude value : 0.8   Injected triggers : 10000                Found triggers : 95    False positives : 0)
Amplitude value : 1     Injected triggers : 10000                Found triggers : 739   False positives : 0)
Amplitude value : 1.1   Injected triggers : 10000                Found triggers : 1573  False positives : 0)
Amplitude value : 1.2   Injected triggers : 10000                Found triggers : 2859  False positives : 0)
Amplitude value : 1.25  Injected triggers : 10000                Found triggers : 3786  False positives : 0)
Amplitude value : 1.5   Injected triggers : 10000                Found triggers : 7957  False positives : 1)
Amplitude value : 1.7   Injected triggers : 10000                Found triggers : 9645  False positives : 0)
Amplitude value : 1.9   Injected triggers : 10000                Found triggers : 9973  False positives : 0)
Amplitude value : 2     Injected triggers : 10000                Found triggers : 9990  False positives : 0)
Amplitude value : 2.5   Injected triggers : 10000                Found triggers : 10000 False positives : 0)
Amplitude value : 5     Injected triggers : 10000                Found triggers : 10000 False positives : 0)
```

```
######################################## Downsampling factor : 32  ########################################
Amplitude value : 0.3   Injected triggers : 10000                Found triggers : 2     False positives : 1)
Amplitude value : 0.6   Injected triggers : 10000                Found triggers : 48    False positives : 0)
Amplitude value : 0.8   Injected triggers : 10000                Found triggers : 348   False positives : 0)
Amplitude value : 1     Injected triggers : 10000                Found triggers : 1436  False positives : 0)
Amplitude value : 1.1   Injected triggers : 10000                Found triggers : 2368  False positives : 0)
Amplitude value : 1.2   Injected triggers : 10000                Found triggers : 3619  False positives : 0)
Amplitude value : 1.25  Injected triggers : 10000                Found triggers : 4392  False positives : 0)
Amplitude value : 1.5   Injected triggers : 10000                Found triggers : 7771  False positives : 1)
Amplitude value : 1.7   Injected triggers : 10000                Found triggers : 9387  False positives : 0)
Amplitude value : 1.9   Injected triggers : 10000                Found triggers : 9892  False positives : 1)
Amplitude value : 2     Injected triggers : 10000                Found triggers : 9946  False positives : 0)
Amplitude value : 2.5   Injected triggers : 10000                Found triggers : 10000 False positives : 0)

Amplitude value : 5     Injected triggers : 10000                Found triggers : 10005 False positives : 2)
```

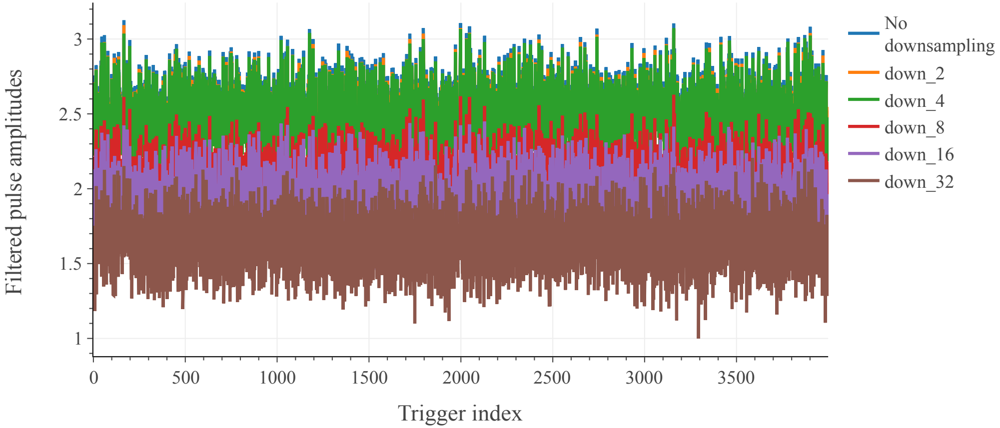
```
######################################## Downsampling factor : 64  ########################################
Amplitude value : 0.3   Injected triggers : 10000                Found triggers : 6     False positives : 0
Amplitude value : 0.6   Injected triggers : 10000                Found triggers : 11    False positives : 0
Amplitude value : 0.8   Injected triggers : 10000                Found triggers : 10    False positives : 0
Amplitude value : 1     Injected triggers : 10000                Found triggers : 15    False positives : 0
Amplitude value : 1.1   Injected triggers : 10000                Found triggers : 19    False positives : 0
Amplitude value : 1.2   Injected triggers : 10000                Found triggers : 35    False positives : 0
Amplitude value : 1.25  Injected triggers : 10000                Found triggers : 25    False positives : 0
Amplitude value : 1.5   Injected triggers : 10000                Found triggers : 47    False positives : 0
Amplitude value : 1.7   Injected triggers : 10000                Found triggers : 56    False positives : 0
Amplitude value : 1.9   Injected triggers : 10000                Found triggers : 75    False positives : 0
Amplitude value : 2     Injected triggers : 10000                Found triggers : 124   False positives : 0
Amplitude value : 2.5   Injected triggers : 10000                Found triggers : 263   False positives : 0
Amplitude value : 5     Injected triggers : 10000                Found triggers : 6389  False positives : 0
```

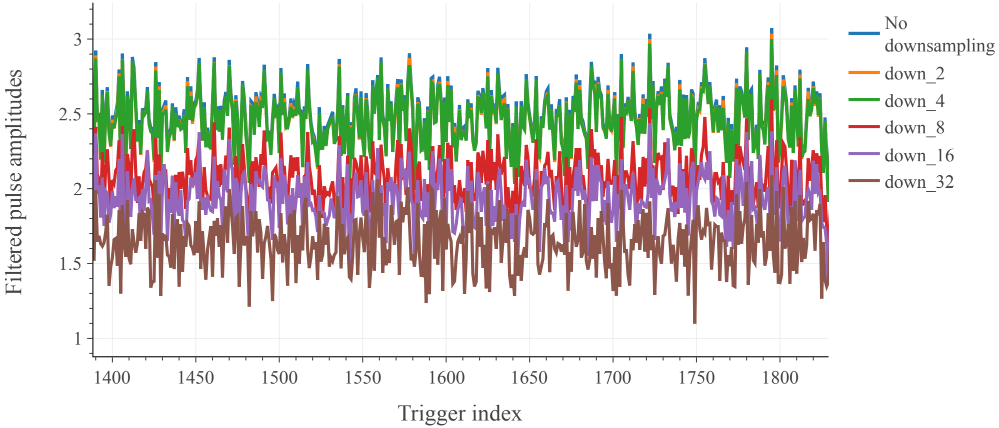
No, the rate of false positive (which is low in ~2h of data) does not increase so much

Rate of false positives

Why the rate of false positives does not increase when triggering at low threshold on the downsampled streams?

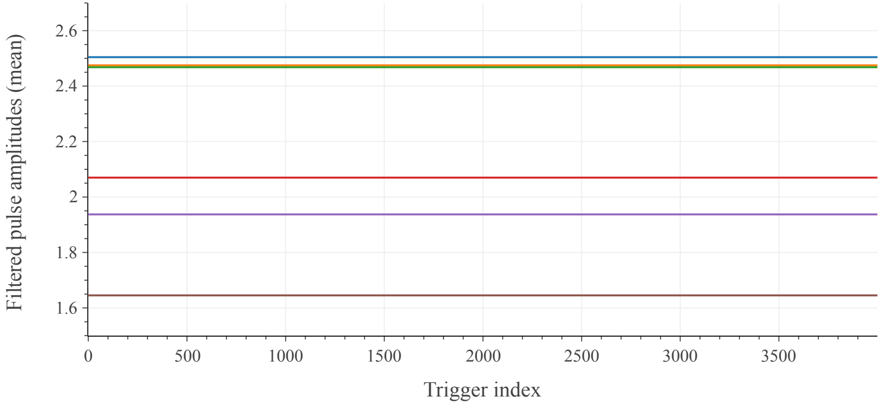
Reconstructed amplitudes (the injected one is 2.5):





The reconstructed amplitude of the filtered pulses decrease with the downsampling.

The noise RMS, on the other hand, does not change so much



Rate of false positives

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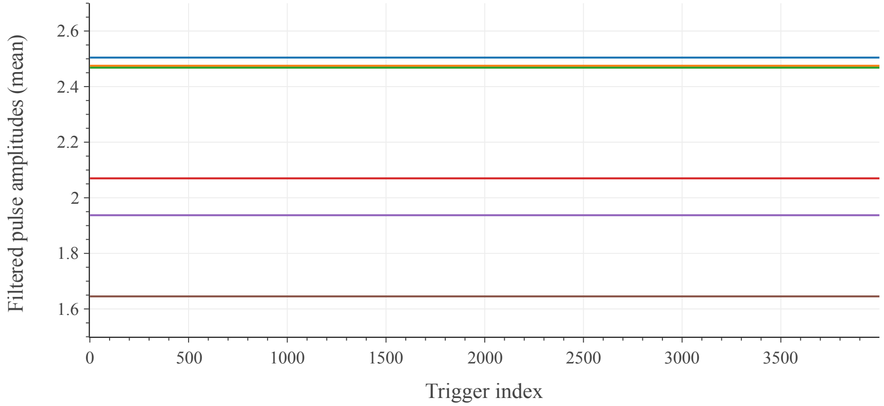

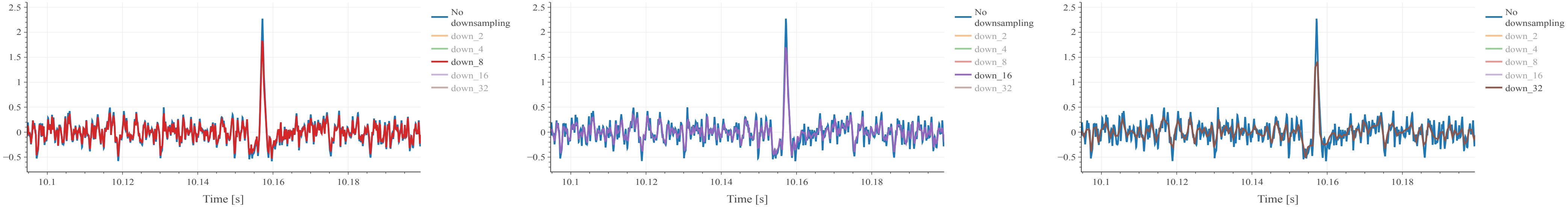

Conclusions

Results

- Window length was decreased to 512 points and downsampling extended to a factor 64
- We can **downsample up to a factor ~8-16** lowering the threshold and without losing efficiency and **without introducing false positives**
- We can work with window length of 512 at 50 kHz. With downsampling at factor 16 this means **just 32 points** on the window (and **32 filter coefficients**)
- To be implemented on FPGA as an hardware online trigger (with the help of Timo). Downsample + FIR filter (?)

To do:

- See if the antialising when downsampling the stream is needed.
- Think about ways to reduce computational costs (IIR, math)
- See if a single filter for every channel is sufficient

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thanks for the attention