An Optimization of the FPGA/NIOS Adaptive FIR Filter Using Linear Prediction to Reduce Narrow Band RFI for the Next Generation Ground-Based Ultra-High Energy Cosmic-Ray Experiment

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ABSTRACT

The electromagnetic part of an extensive air shower developing in the atmosphere provides significant information complementary to that obtained by water Cherenkov detectors which are predominantly sensitive to the muonic content of an air shower at ground. The emissions can be observed in the frequency band between 10 - 100 MHz. However, this frequency range is significantly contaminated by narrow-band RFI and other human-made distortions. Auger Engineering Radio Array suppresses an RFI by multiple time-to-frequency domain conversions using an FFT procedure. An alternative approach developed in this paper is an adaptive FIR filter based on a linear prediction (LP). The coefficients for the linear predictor are dynamically refreshed and calculated in the virtual NIOS® processor. The Levinson recursion, used to obtain the filter coefficients is also supported by a direct multiplication in the DSP blocks of the logic FPGA segment. The radio detector is an autonomous system installed on the Argentinean pampas and supplied from a solar panel. A power consumption vs. a powerful calculation capacity inside the FPGA is a factor. Results show that a LP approach is very efficient and it does not introduce the distortion of signal, which may affect a trigger. The power consumption can be dynamically optimized as the function of the RFI contamination. The LP filter is being developed for the next generation of cosmic rays detector and it is supported by the ASPERA-2 consortium.

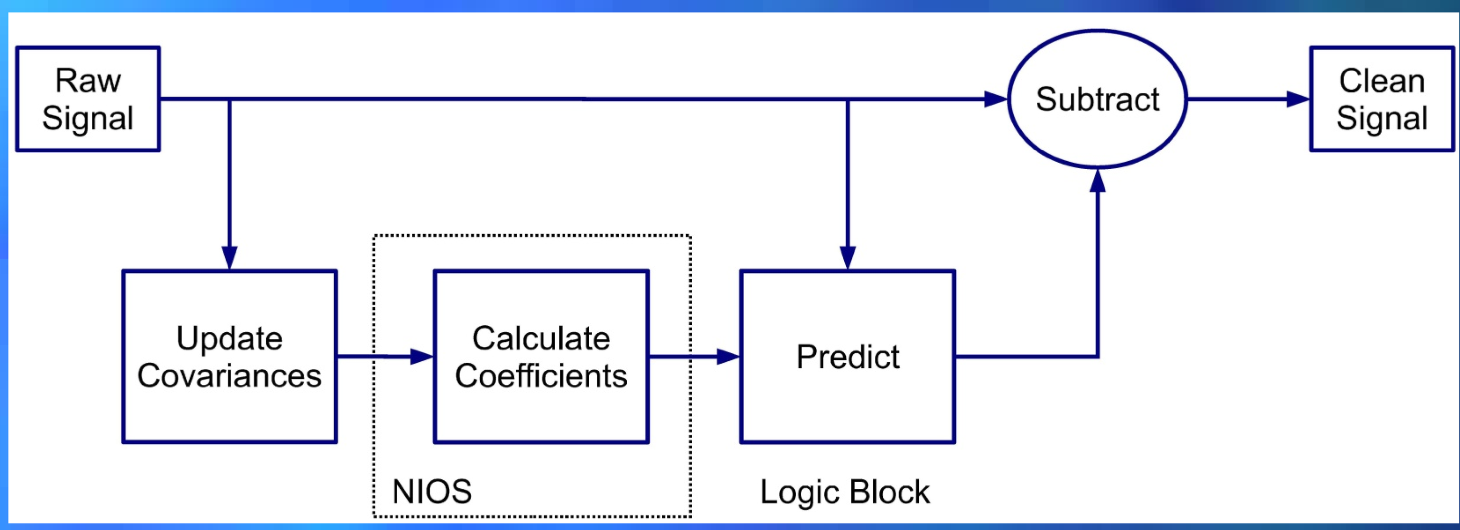


Fig. 1 – The data flow of the FIR filter based on linear prediction. Covariances are calculated in the FPGA fast logic block. The NIOS® processor solves a set of 32-64 linear equations and provides the coefficients needed for the FIR filter. The coefficients are next transferred from the NIOS® to the fast logic block to be used as the FIR coefficients in the ADC data filtering. The predicted data is next subtracted from the ADC input signal to give cleaned output data.

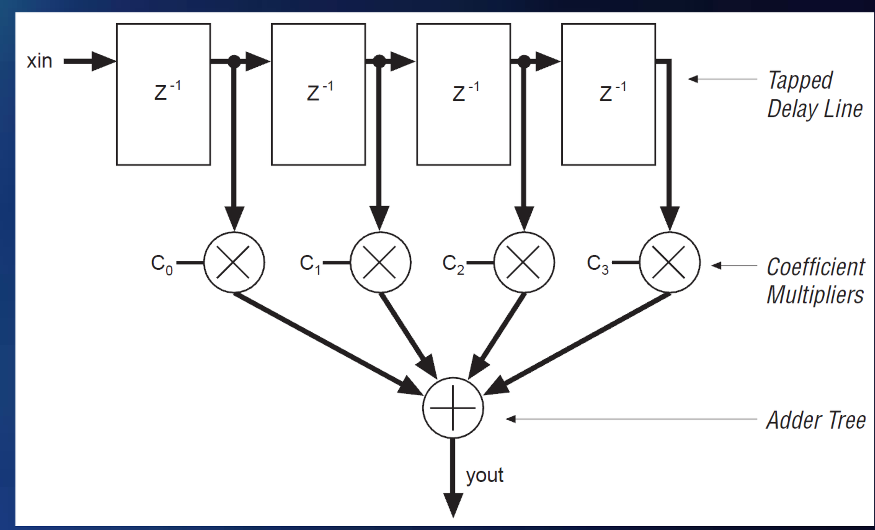


Fig. 2 - A schematic of the FIR filter. The ADC data delayed in the 12-bit register chain are multiplied by the 18(14)-bit coefficients in the embedded DSP multipliers and summed in 30-bit routine. Finally the processed signal is subtracted from the original one from the ADC.

Frequency domain analysis

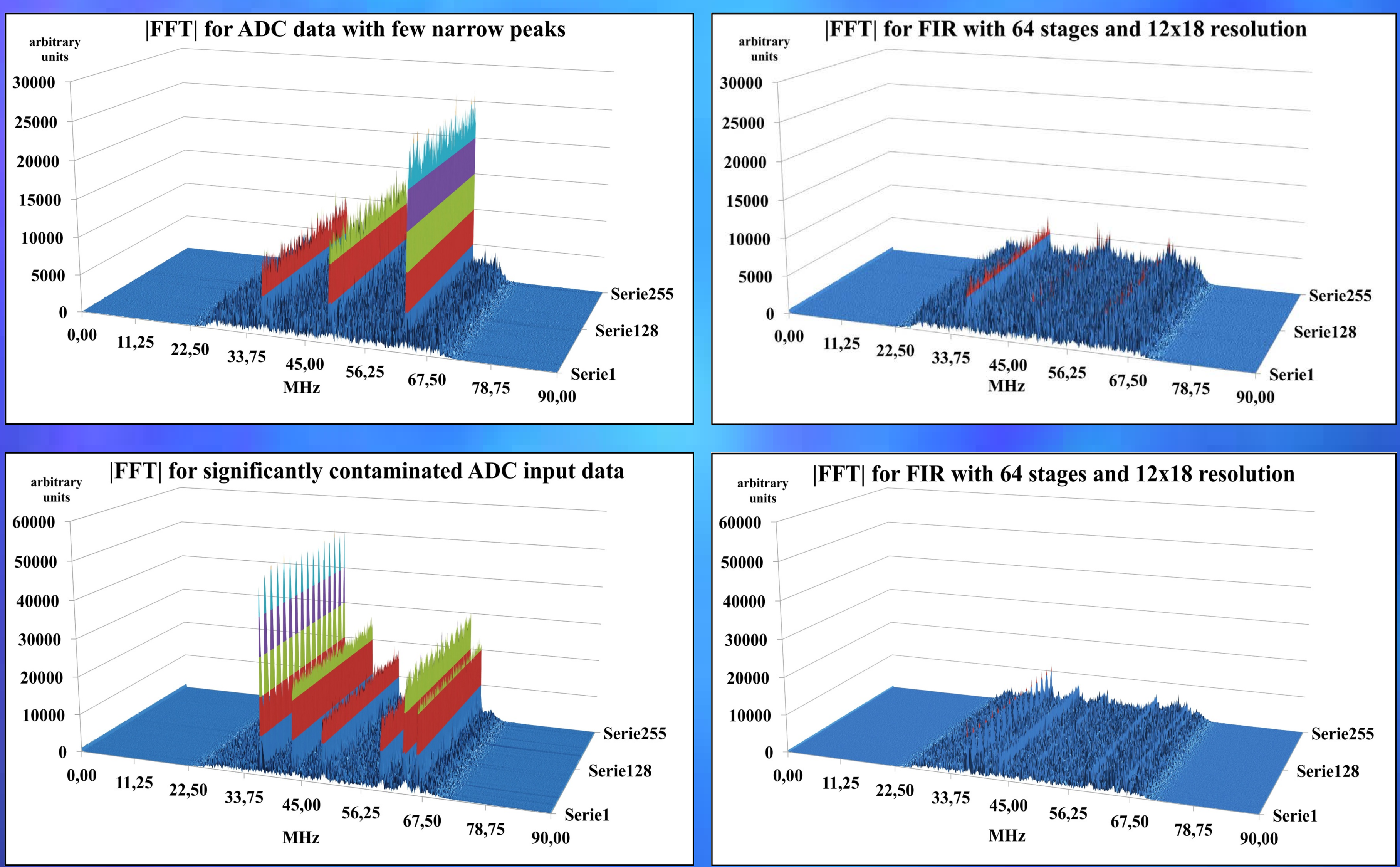
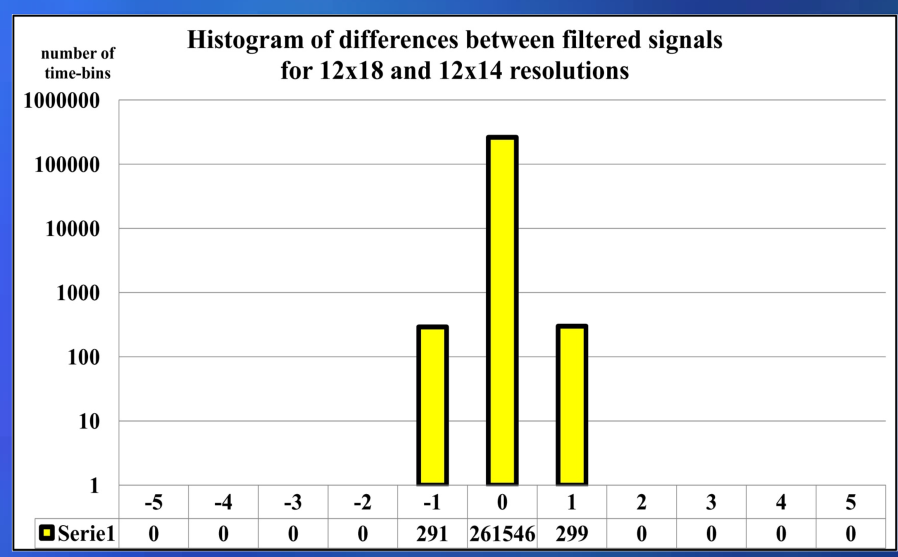


Fig. 3 – Spectrograms for artificially generated input data (left) with at the top only three single frequency peaks and at the bottom significantly contaminated input data with both an amplitude modulated and a frequency modulated peak. The filtered signals (right) show considerable RFI suppression.

Optimization of the FPGA implementation



FIR	Cfg more	Pwr mW	FIR	Cfg few	Pwr mW
64	12x18	587	64	12x18	595
64	12x14	558	64	12x14	573
48	12x18	492	48	12x14	447
32	12x18	328	32	12x14	333

Table 1– Power consumptions for EP3C120F780C7 with 180 MHz sampling, for more contaminated signal (left) and for few peaks in the frequency domain (right). 12x14 configuration reduces the power of ~25mW only.

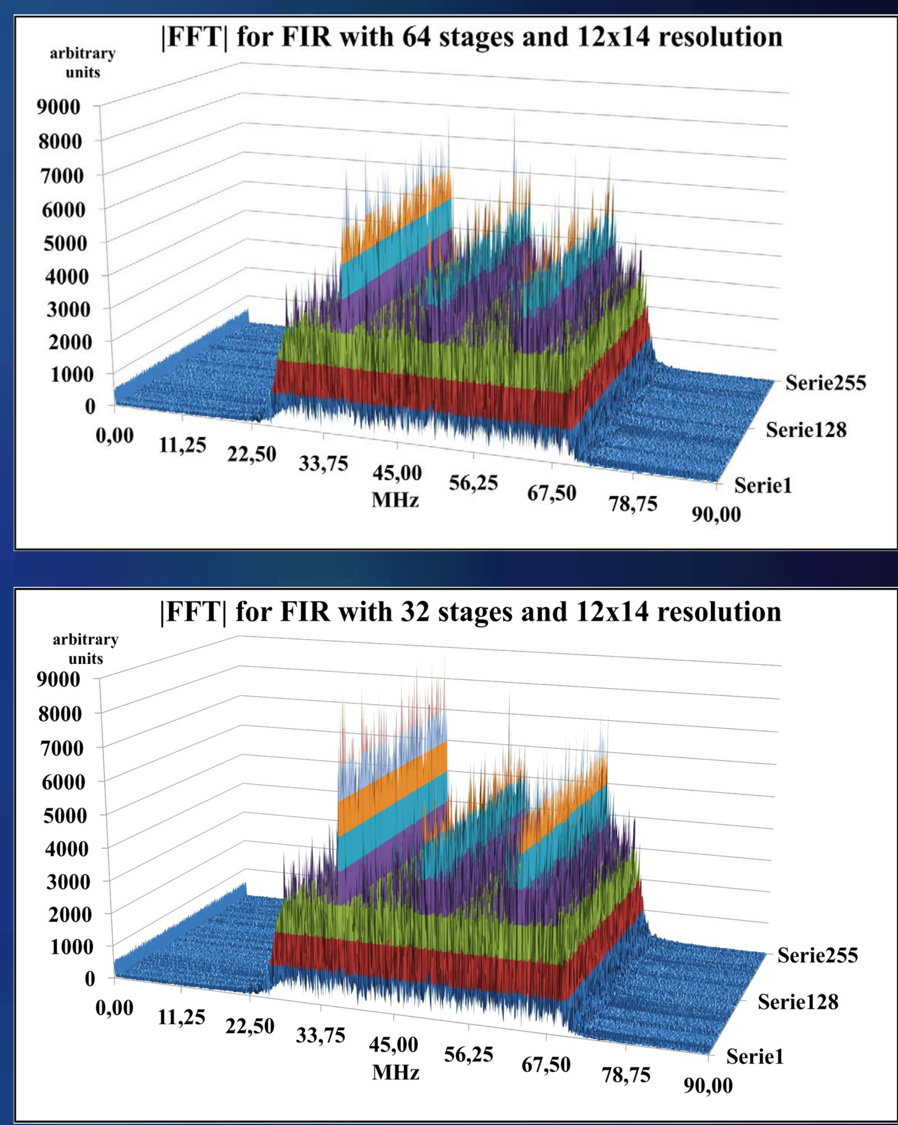


Fig. 4 – Comparison of Fourier spectra for 64 and 32 stages of the filter, respectively. For few narrow peaks 32-stage FIR filter is efficient enough. A longer filter is not necessary.

Time domain analysis

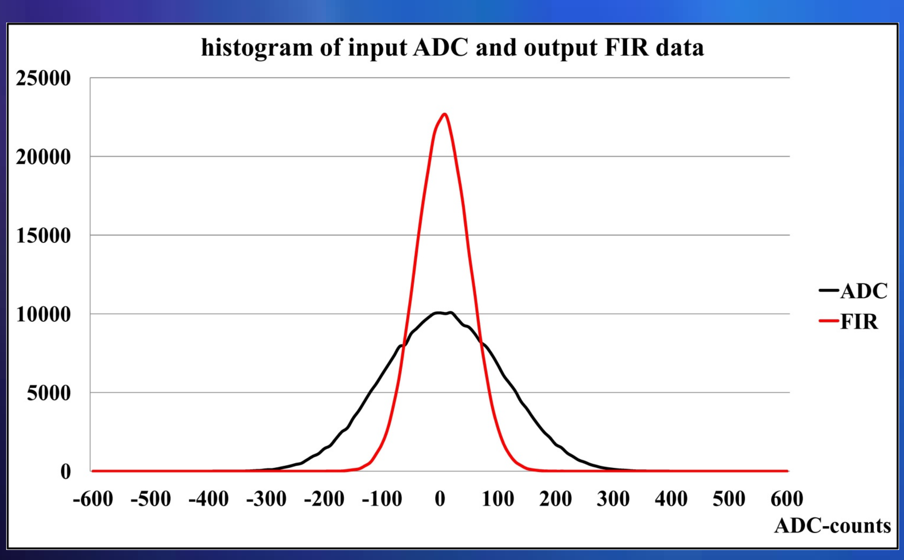


Fig. 5– Distribution of filtered signals is much narrower

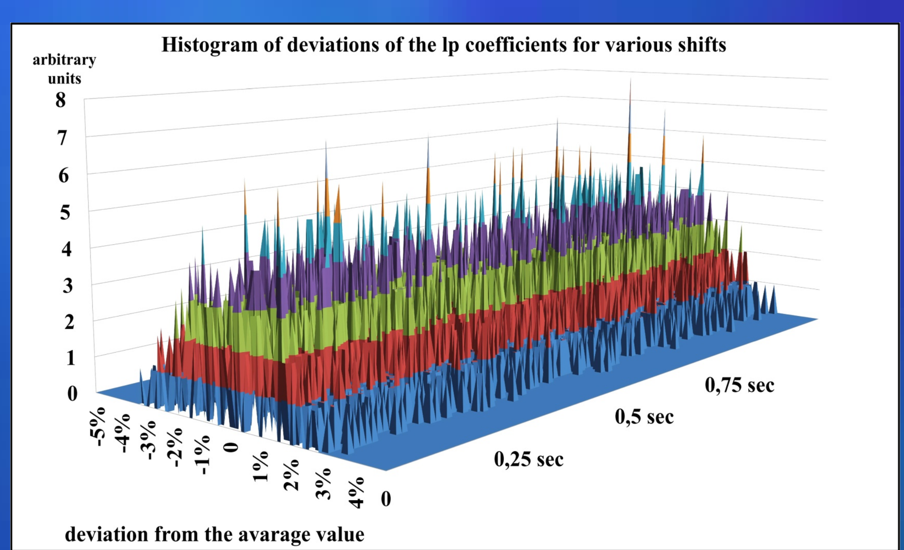
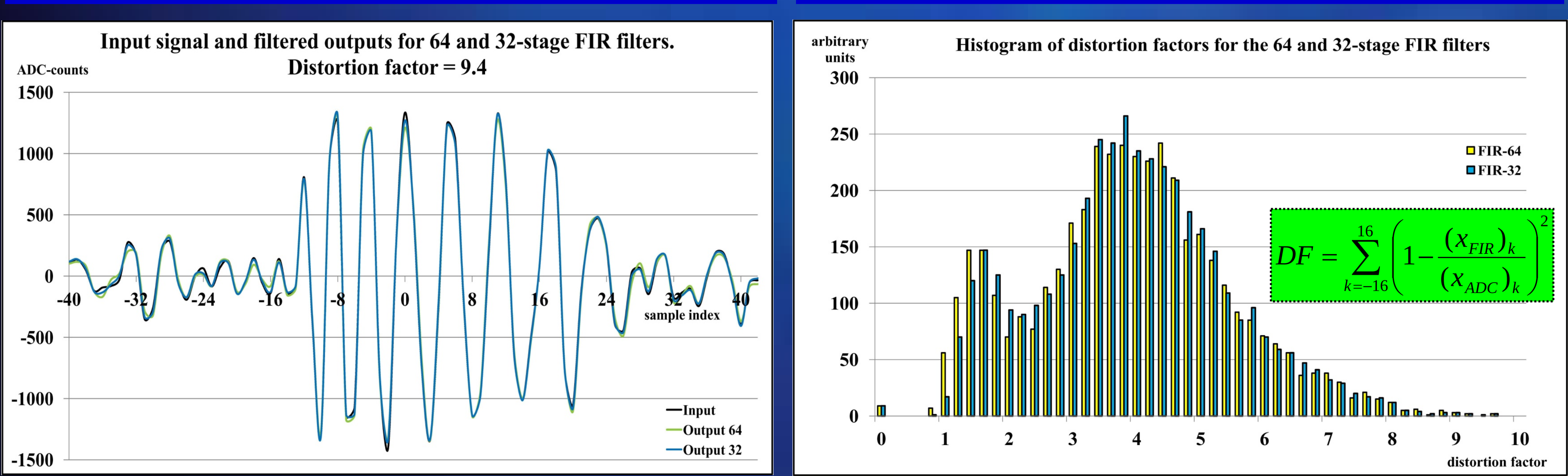


Fig. 6 – Evolution of the LP coefficients in 1 second



$$DF = \sum_{k=-16}^{16}\left(1-\frac{(x_{FIR})_k}{(x_{ADC})_k}\right)^2$$

Fig. 7 – Sample of simulated events with a very big distortion factors with the histogram of distortion factors for 64 and 32-stage FIR filters. Shape differences between the filtered and original signals are almost negligible for both filters

Improvement of the Signal to Noise ratio

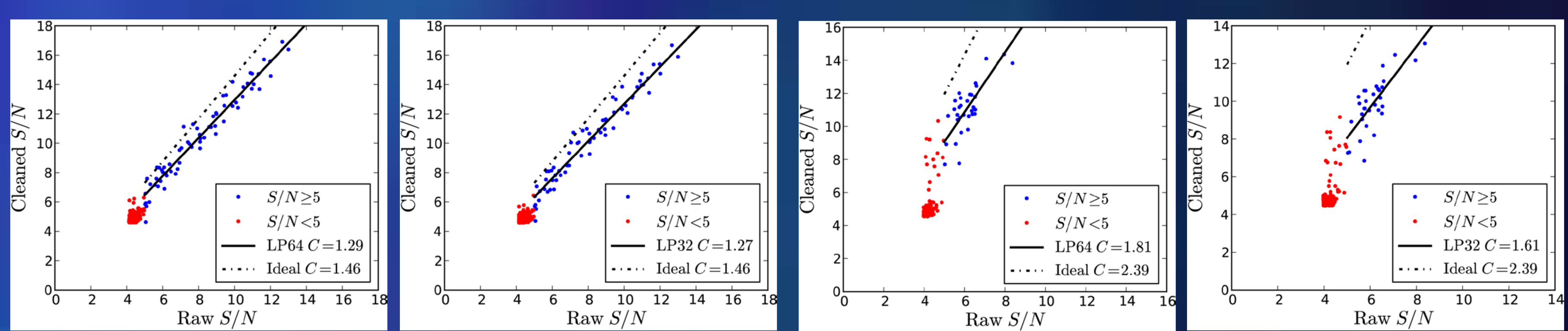


Fig. 8 – Analysis in the time domain for data with few peaks (2 graphs left) and with a significant contamination (2 graphs right). The S/N ratio is similar for 64 and 32 stages for data with few peaks. For significantly contaminated data 64-stage FIR filter is recommended. Online analysis and the optimization of the FIR length is the task of the virtual NIOS® processor

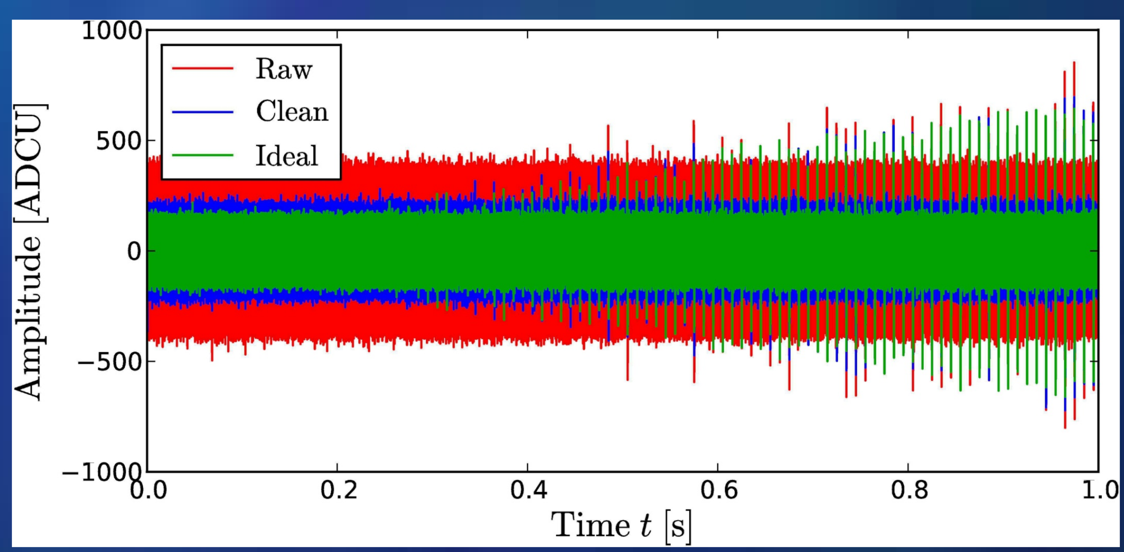


Fig. 9 – 1 second simulated trace with artificial signals cleaned by the LP FIR filter. Improvement of the S/N ratio is clearly visible. The efficiency of the filter depends on the length of the filter, the width of LP coefficients calculated in the NIOS® virtual processor inside the FPGA and next uploaded to the filter implemented in the FPGA fast logic block.

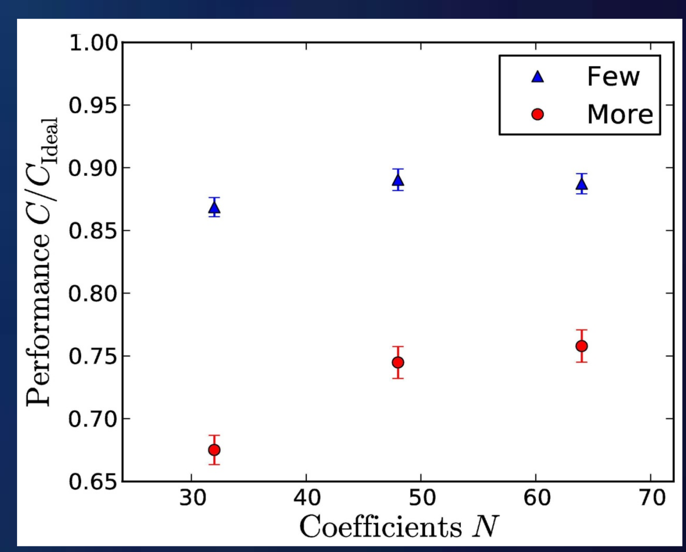


Fig. 10 – The efficency of the filtering for various FIR filter length and for a diffrent structure of the filtered signal. The efficiency of filteing of signals with few narrow peaks is close to the ideal case.

CONCLUSIONS

The RFI filter based on the liner prediction [1] is an alternative approach to the design based on the filtering by the median filter in the frequency domain with application of the FFT procedures [2].

We conclude that the LP FIR filter works well for removing narrow band RFI. In addition it is shown that the filter works well, even if the RFI is amplitude or frequency modulated. The efficiency increases with the number of coefficients but there is a limit which is mainly caused by numerical noise due to the fixed point, low resolution, calculations. The optimum number of coefficients depends on the amount of RFI that is present in the traces. For relatively low amounts of RFI it is better to choose a lower amount of coefficients. (Tests for floating point calculations also show a limit on the number of coefficients but in this case the limit is determined primarily by the amount samples that are used to determine the coefficients).

[1] Z. Szadkowski, E.D. Fraenkel, A. van den Berg, „FPGA/NIOS implementation of an adaptive FIR filter using linear prediction to reduce narrow-band RFI for radio detection of cosmic rays", Real Time Conference, Berkeley, June 2012.

[2] A. Schmidt, H. Gemmeke, A. Haungs, K-H. Kampert, C. Rühle, Z. Szadkowski, „FPGA Based Signal-Processing for Radio Detection of Cosmic Rays", IEEE Trans. on Nucl. Science, vol. **58**, pp. 1621-1627, Aug. 2011.

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