Adaptive IIR-notch filter for RFI suppression in a radio detection of cosmic rays

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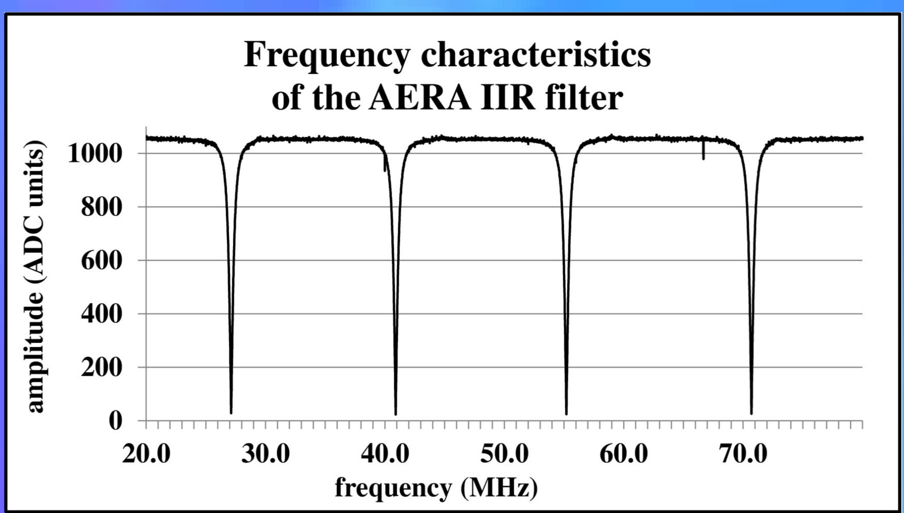
ABSTRACT

Radio stations can observe radio signals caused by coherent emissions due to a geomagnetic radiation and charge excess processes. The Auger Engineering Radio Array (AERA) observes the frequency band from 30 to 80 MHz. This range is highly contaminated by human-made RFI. In order to improve the signal to noise ratio, AERA uses RFI filters to suppress this contamination. IIR notch filters, used by AERA, operate with fixed parameters and suppress four narrow bands. They are not sensitive to new sources of RFI as walkie-talkies, mobile communicators and other human-made RFI. IIR filters are generally potentially unstable due to feedbacks, however they are much shorter and power efficient than FIR filters.

We implemented a NIOS® virtual processor calculating new set of IIR filter coefficients, which are reloaded dynamically on the fly. The spectrum analysis of 30-80 MHz band can also be supported by the Altera® FFT IP Core. The NIOS® adjusts the new coefficients of the filter checking whether the poles are inside the unique complex radius (a condition of stability) as well as it tunes a width of the notch filter. Practical implementation was tested in the laboratory with signal and pattern generators. Laboratory results are very promising. The IIR-filter follows the drifting frequencies in very wide ranges, keeping a suppression factor on a very high level.



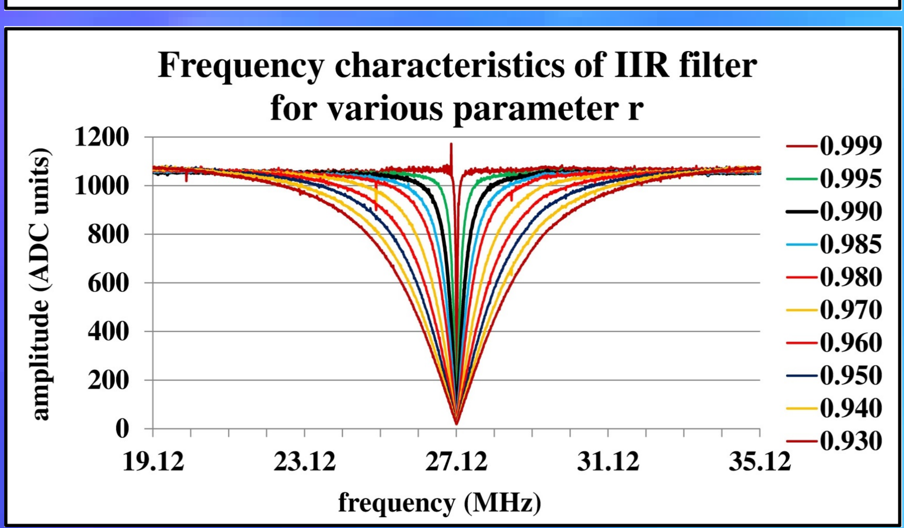
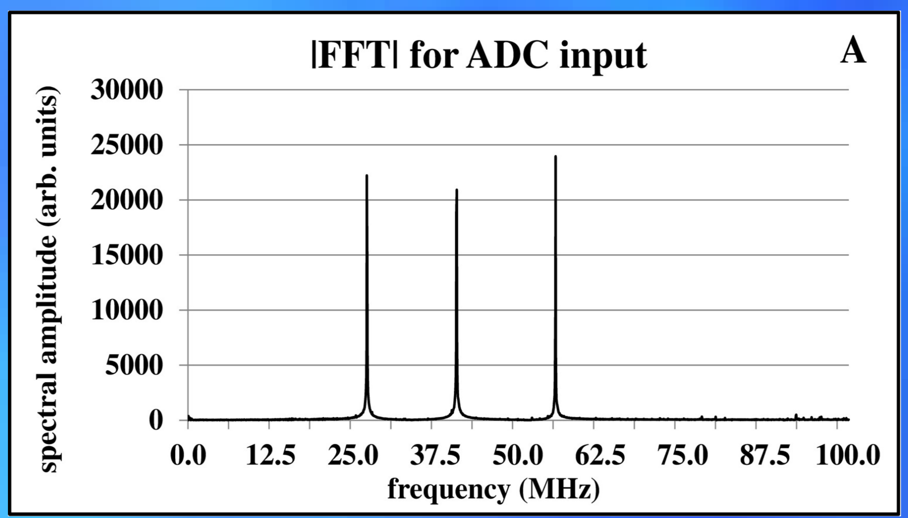
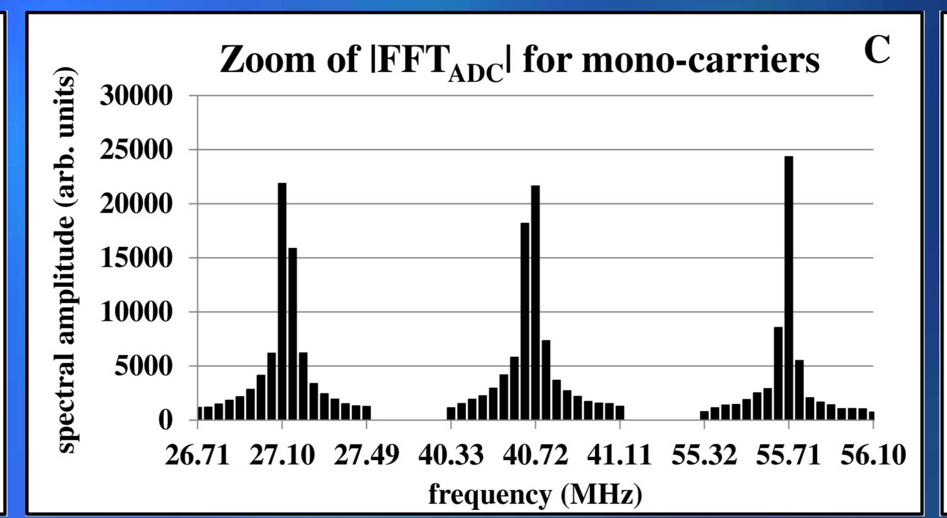
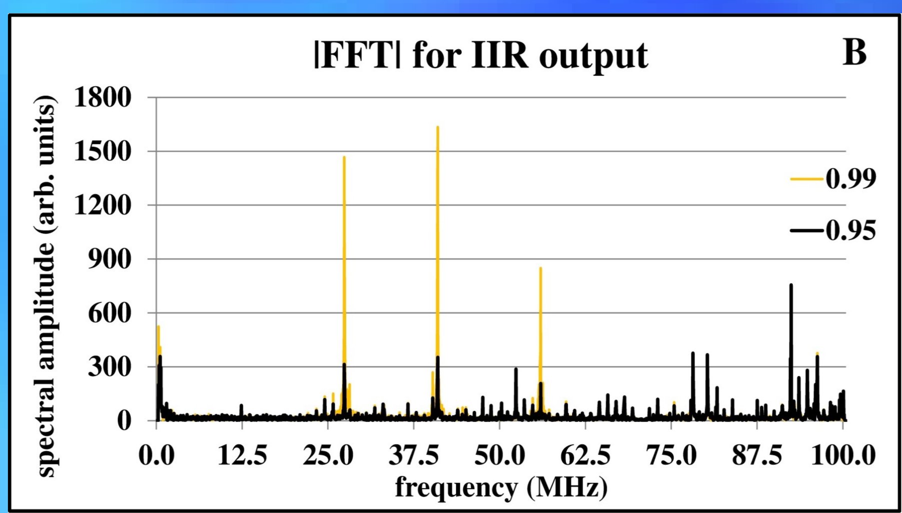


Fig. 1 − Frequency characteristics of the AERA IIR notch filter (upper graph) and frequency characteristics of the single IIR notch filter for various parameter r.







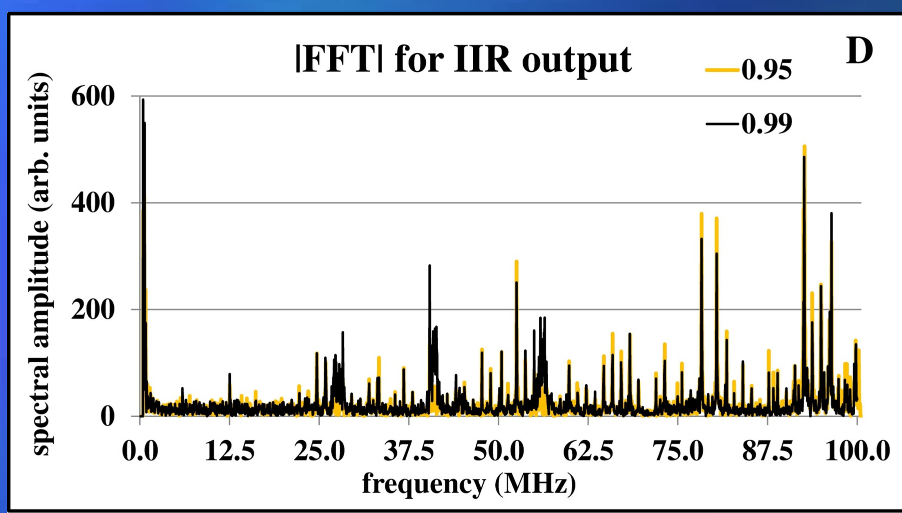
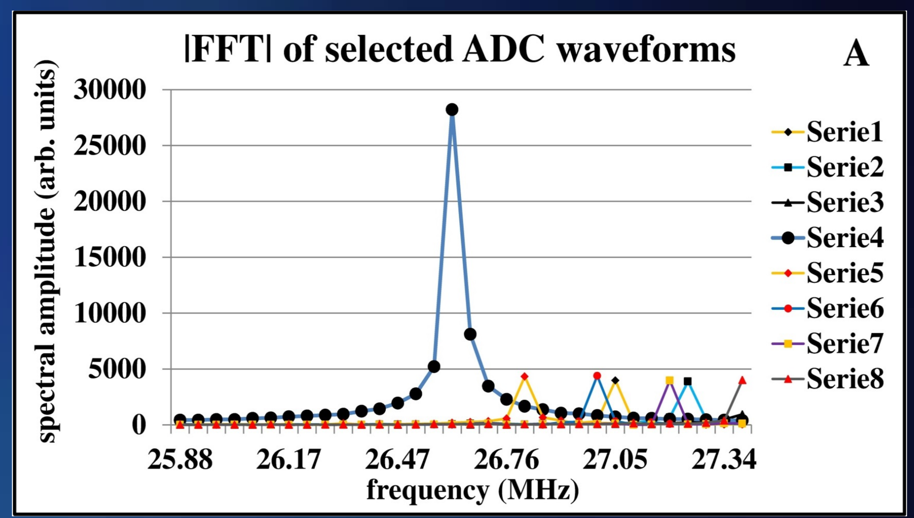


Fig. 4 − Frequency characteristics for ADC signal (A) and for filtered by the IIR with a simple calculation of IIR coefficients for found maximum peaks (B). If a distribution of ||FFT|| (C) is taken into account the suppression is much stronger (D).



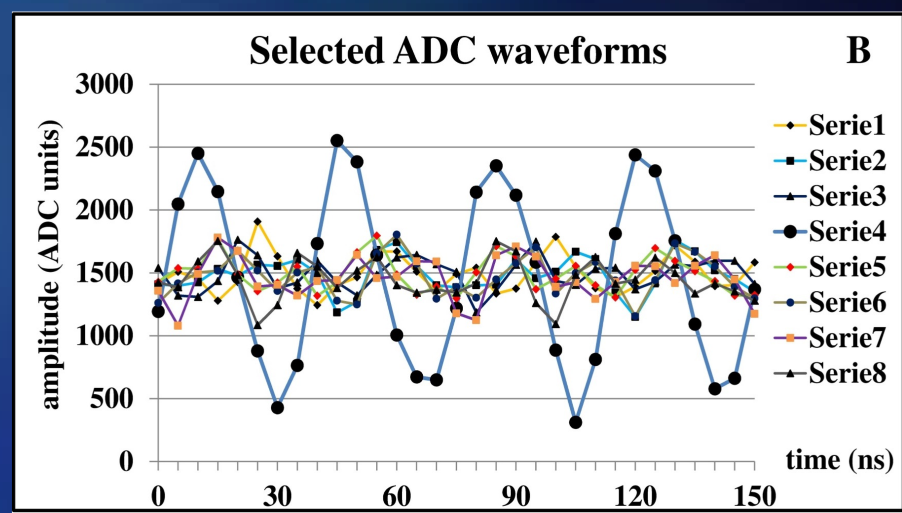


Fig. 6 − A selected spike in a frequency domain and corresponding ADC waveforms.

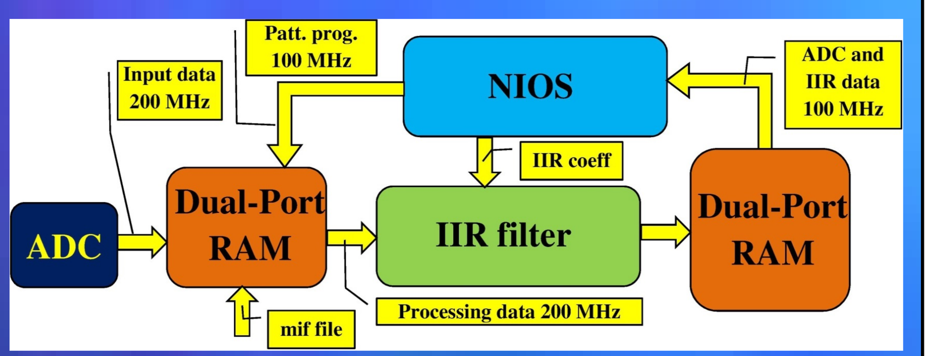
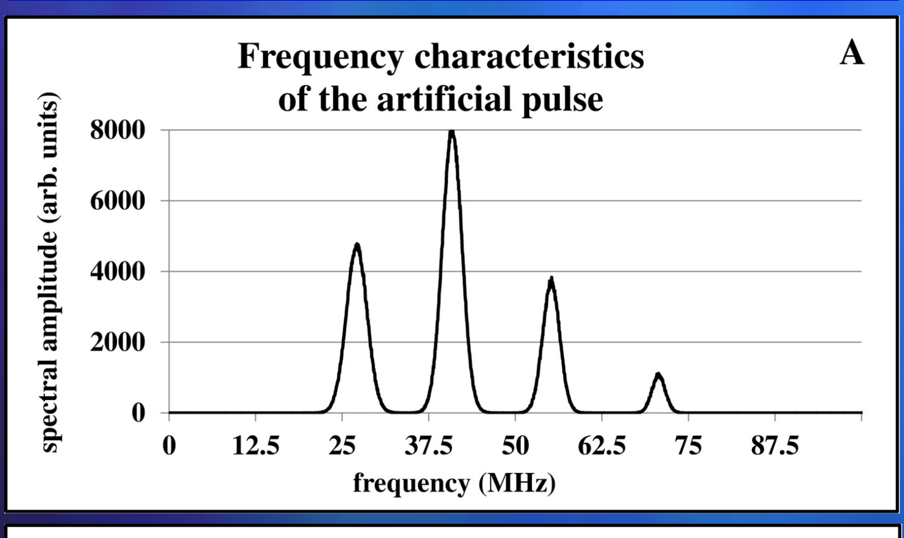


Fig. 2 − Laboratory test setup. For Cyclone® V E 5CEFA9F31I7 Clk_{ADC} = 200 MHz, but Clk_{NIOS} = 100 MHz only.



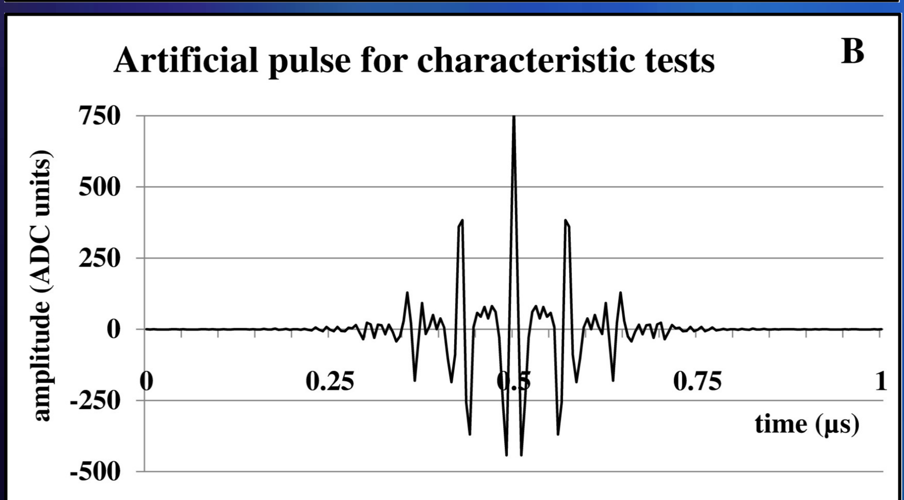
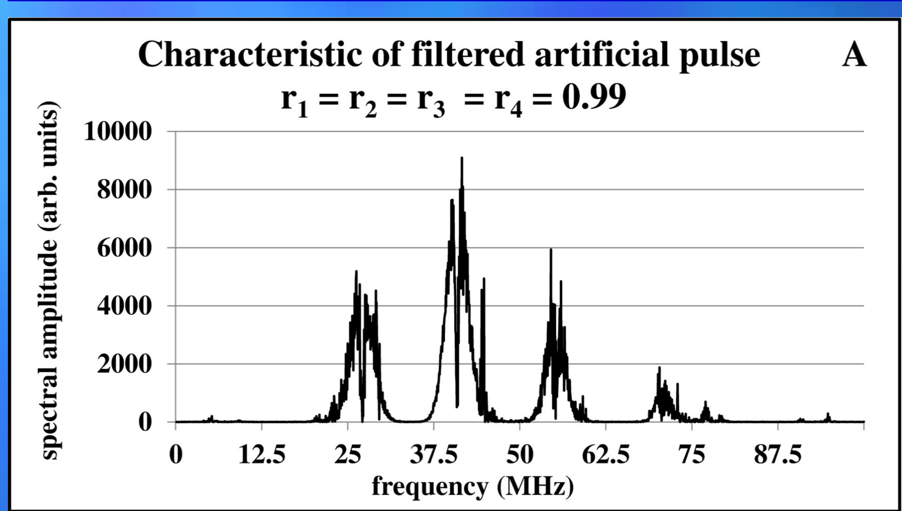
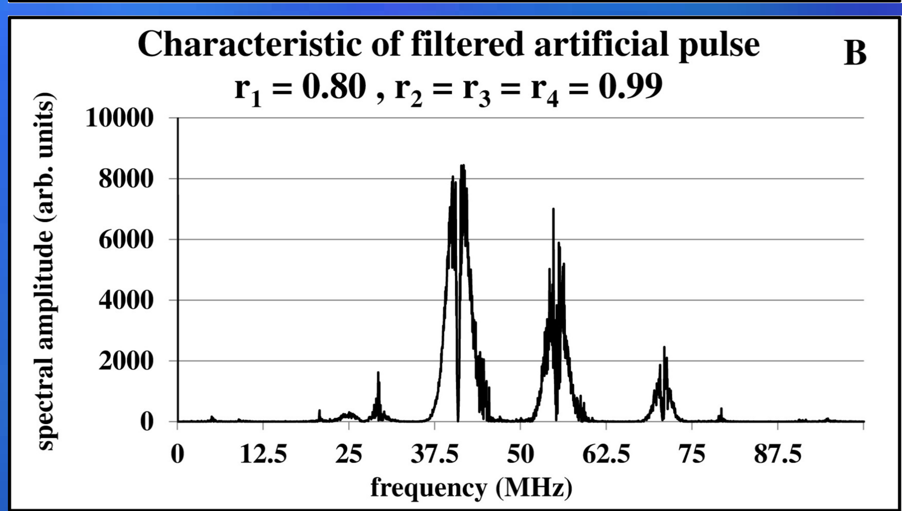


Fig. 3 − Artificial pulse for characteristic tests (B) generated by iFFT from arbitrarily assumed frequency characteristics (A). Similar pulses were used for tests with narrower „Gauss bells".





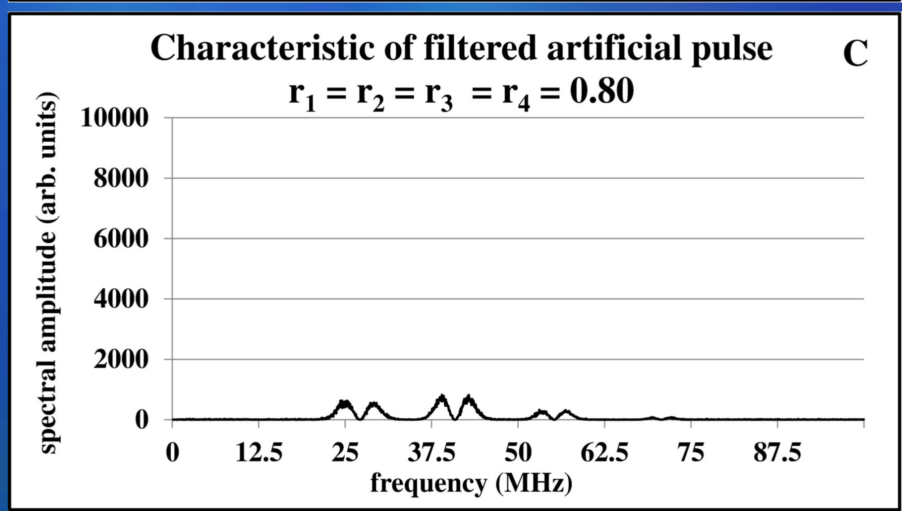
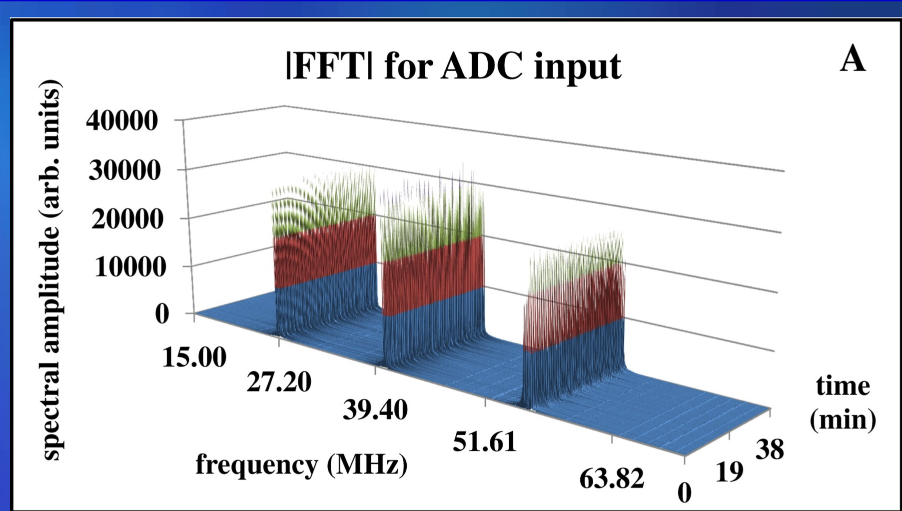
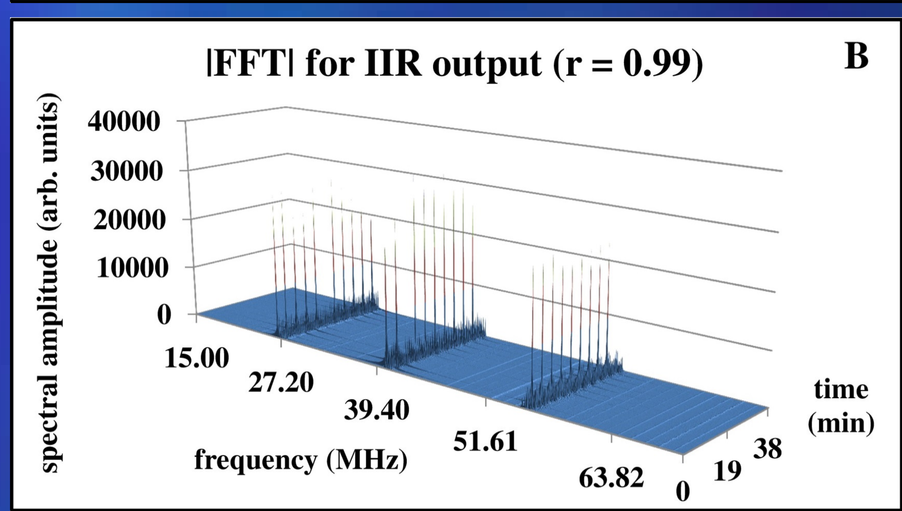
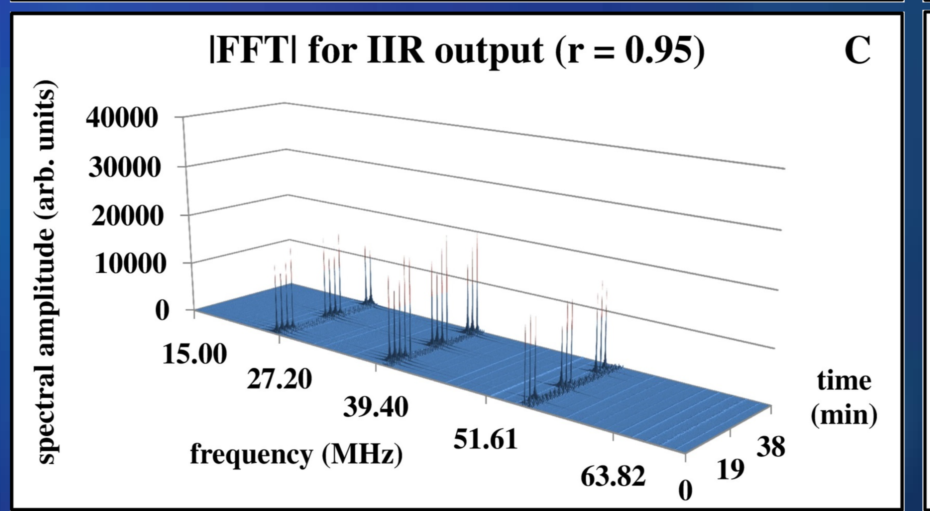


Fig. 5 − Frequency characteristics of filtered pulses with r_1 = 0.99 and r_1 = 0.80 for the 1st stage, respectively for A and B graphs. The parameters of the 2nd, 3rd and 4th stages are $r_2 = r_3 = r_4 = 0.99$. Graph C corresponds to $r_1 = r_2 = r_3 = r_4 = 0.80$







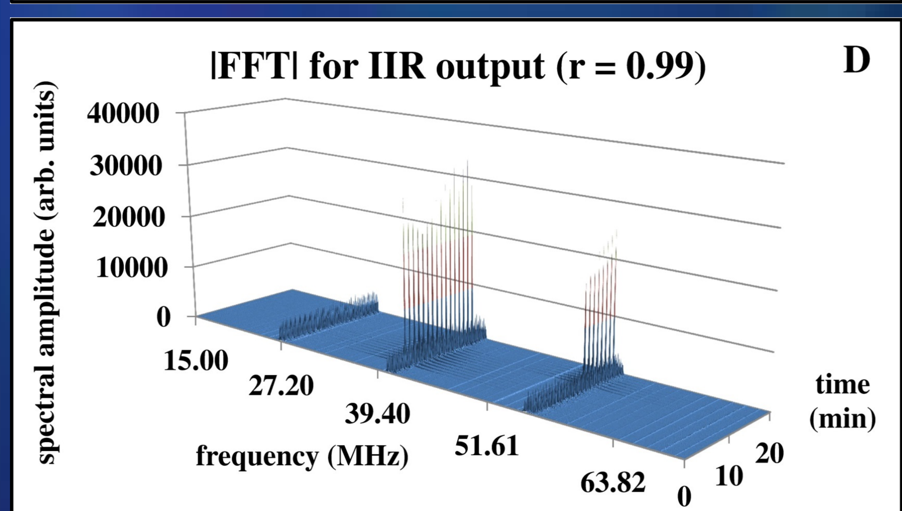
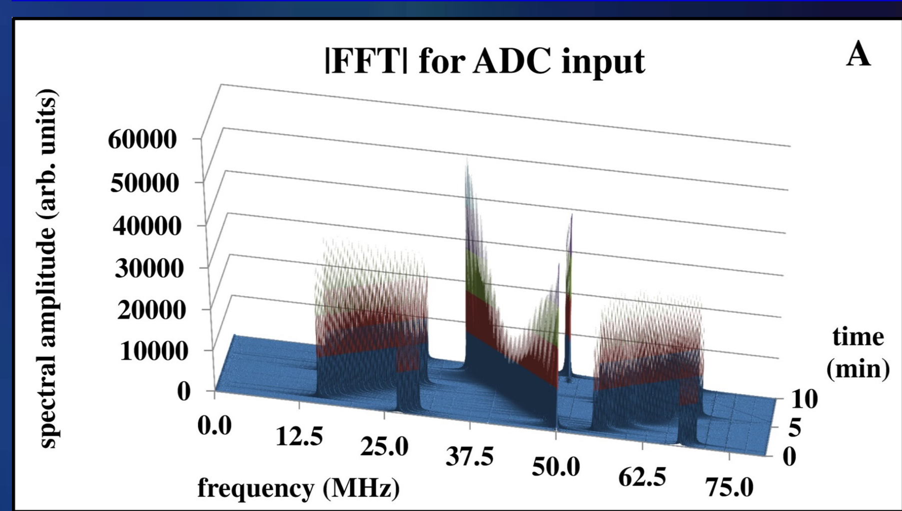
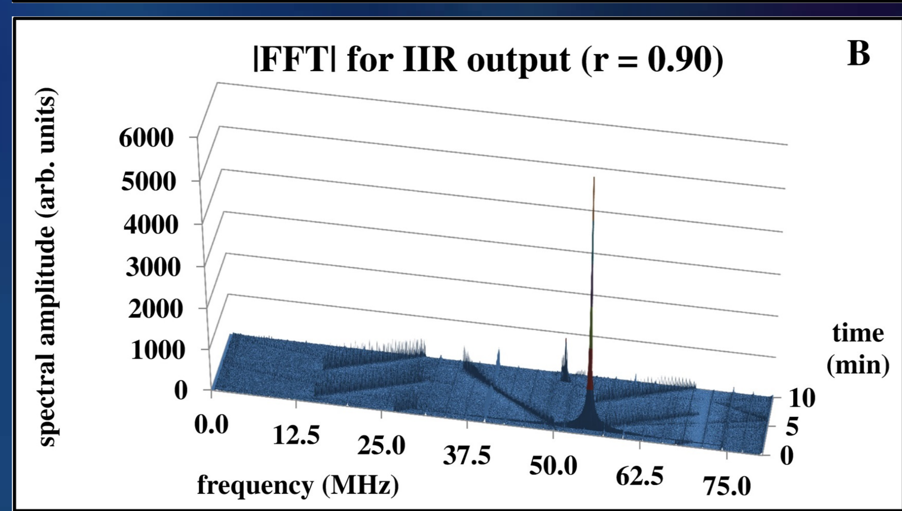
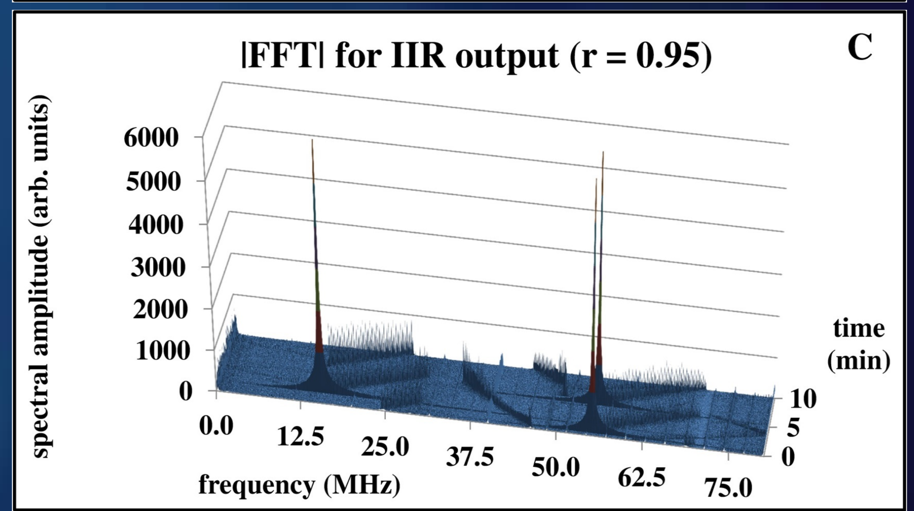


Fig. 7 − Freq. characteristics for ADC signal (A) and for filtered by the IIR coefficients taking into with ||FFT|| peaks (B,C,D).







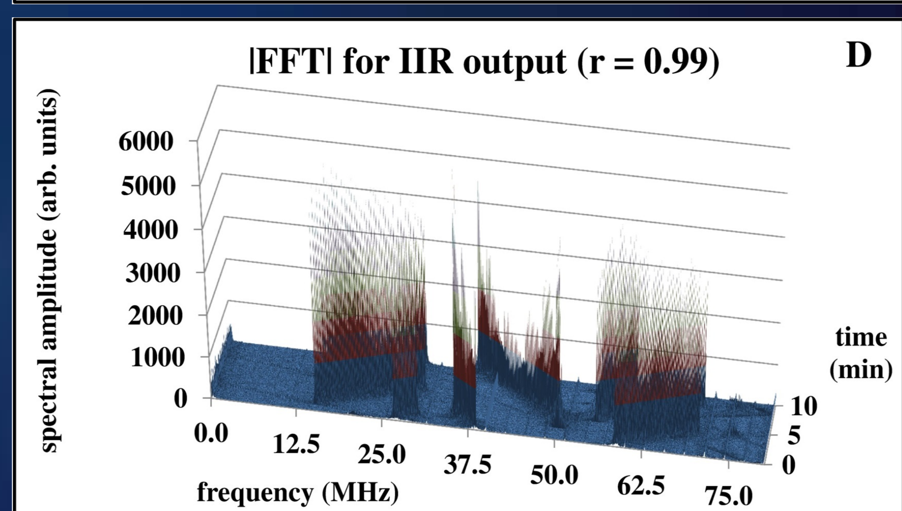


Fig. 8 − Frequency characteristics for ADC signal driven from wide-range sweeping generators

[1] Pierre Auger collaboration, A. Aab et al., *The Pierre Auger Cosmic Ray Observatory, Nucl. Instrum. Meth.*, **A 798** (2015) 172.

[2] Z. Szadkowski, *16-point discrete Fourier transform based on the Radix-2 FFT algorithm implemented into Cyclone FPGA as the UHECR trigger for horizontal air showers in the Pierre Auger Observatory, Nucl. Instrum. Meth.*, **A 560** (2006) 309.

[3] 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*, **A 58**, no 4 (2011) 1621.

[4] J. L. Kelley, *Data Acquisition, Triggering, and Filtering at the Auger Engineering Radio Array, Nucl. Instrum. Meth.*, **A 725** (2013) 133.

[5] Z. Szadkowski, E.D. Fraenkel, A. M. 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, IEEE Trans. on Nucl. Science*, **60** (2013) 3483.

[5] Z. Szadkowski, E.D. Fraenkel, A. M. 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, IEEE Trans. on Nucl. Science*, **60** (2013) 3483.

[6] Z. Szadkowski, E.D. Fraenkel, D. Głas, *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, Nucl. Instrum. Meth.*, **A 732** (2013) 535.

[7] Z. Szadkowski, D. Głas, C. Timmermans, T. Wijnen for the Pierre Auger Collaboration, *First results from the FPGA/NIOS Adaptive FIR Filter Using Linear Prediction Implemented in the AERA Radio Stations to Reduce Narrow Band RFI for Radio Detection of Cosmic Rays", IEEE Trans. on Nucl. Science*, **62**, Issue: 3 (2015) 977.

CONCLUSIONS

A dynamical refreshment of the IIR filter coefficients passed successfully all tests. A refreshment time is on a reasonable level (~700 ms - without a data transmission) for the new IIR coefficients calculated in the virtual NIOS® processor by the 4096-point Danielson-Lanczos procedure independently of the FPGA fabric (100 MHz internal NIOS ® clock was selected). For some specific correlations between the input carriers and the IIR notch filter characteristics oscillations may appear. However, a potential instability is a undesirable IIR filter feature. Instabilities are observed independently of the r factor, although it lies inside the unit radius on the complex plane, which theoretically should guaranteed a stable operation. A FFT calculation time can be significantly reduced by utilization of the Altera® internal IP FFT routine. However, it increases resources occupancy and power consumption. Such a solution can be considered for a necessity of a short-term contamination suppression. The IIR filter was tested on the new prototype Front-End Board designed for the Pierre Auger surface detector, but with two channels for e.g. a radio detection (sampling independent of the PMT channels).

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