The Least Mean Squares Adaptive FIR Filter for Narrow Band RFI Suppression In Radio Detection of Cosmic Rays

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ABSTRACT

The radio emission from the Extensive Air Showers (EAS), initiated by ultra-high energy cosmic rays, was theoretically suggested over 50 years ago, however, due to technical limitations, successful detection can be taken for several years. Nowadays, this detection technique is used in many experiments consisting on detecting EAS. One of them is Auger Engineering Radio Array (AERA), located within the Pierre Auger Observatory. AERA focus on the radio emission, generated by electromagnetic part of the shower, mainly in geomagnetic and charge excess processes. Frequency band observed by AERA radio stations is 30 - 80 MHz. Chosen frequency range is contaminated by human-made and narrow-band radio frequency interferences (RFI). Suppression of these contaminations is very important to lower the rate of false triggers.

There are two kind of digital filters used in AERA radio stations to suppress these contaminations: the FFT median filter and four narrow-band IIR-notch filters. Both filters have successfully work in field for many years. Adaptive filter based on a Least Mean Squares (LMS) algorithm is very simple FIR filter, which can be an alternative for currently used filters. Simulations in MATLAB are very promising and shows, that LMS filter can be very efficient in suppressing RFI and only slightly distorts radio signals. LMS algorithm was implemented into Cyclone® V FPGA for testing of the stability, efficiency and adaptation time to new conditions. First results show that FIR filter based on the LMS algorithm can be successfully implemented and used in real AERA radio stations.

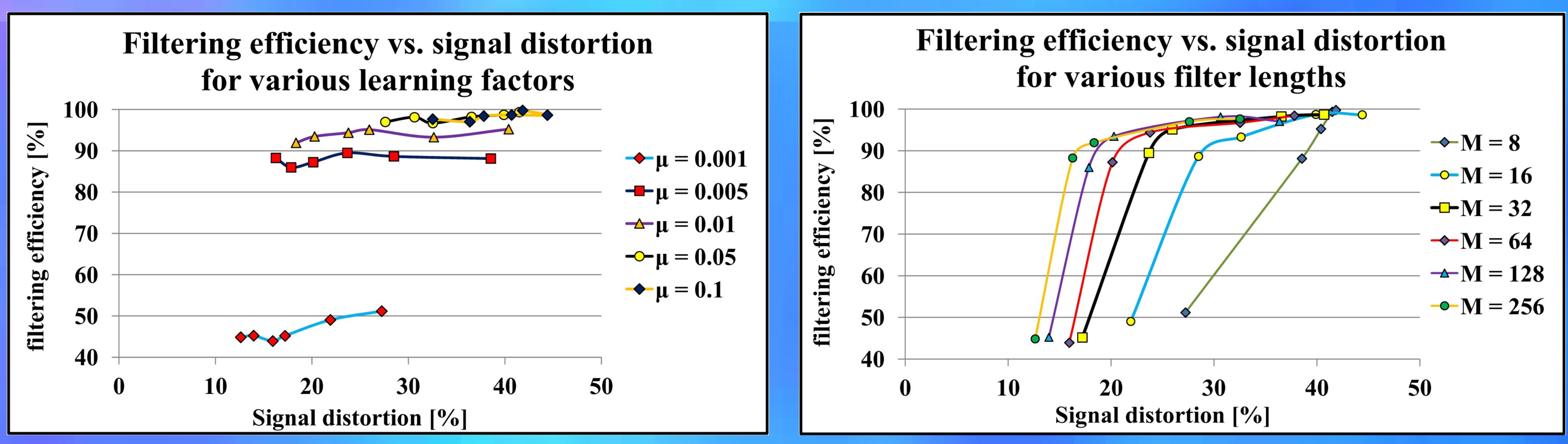

Fig. 1 – MATLAB filtering efficiency as a function of signal distortion for various learning factors (left) and filter lengths (right). Increasing filter length results in decreasing signal distortion, but does not influence on filtering efficiency. Learning factors can increase efficiency, however use too big values of this parameter may result in big distortion.

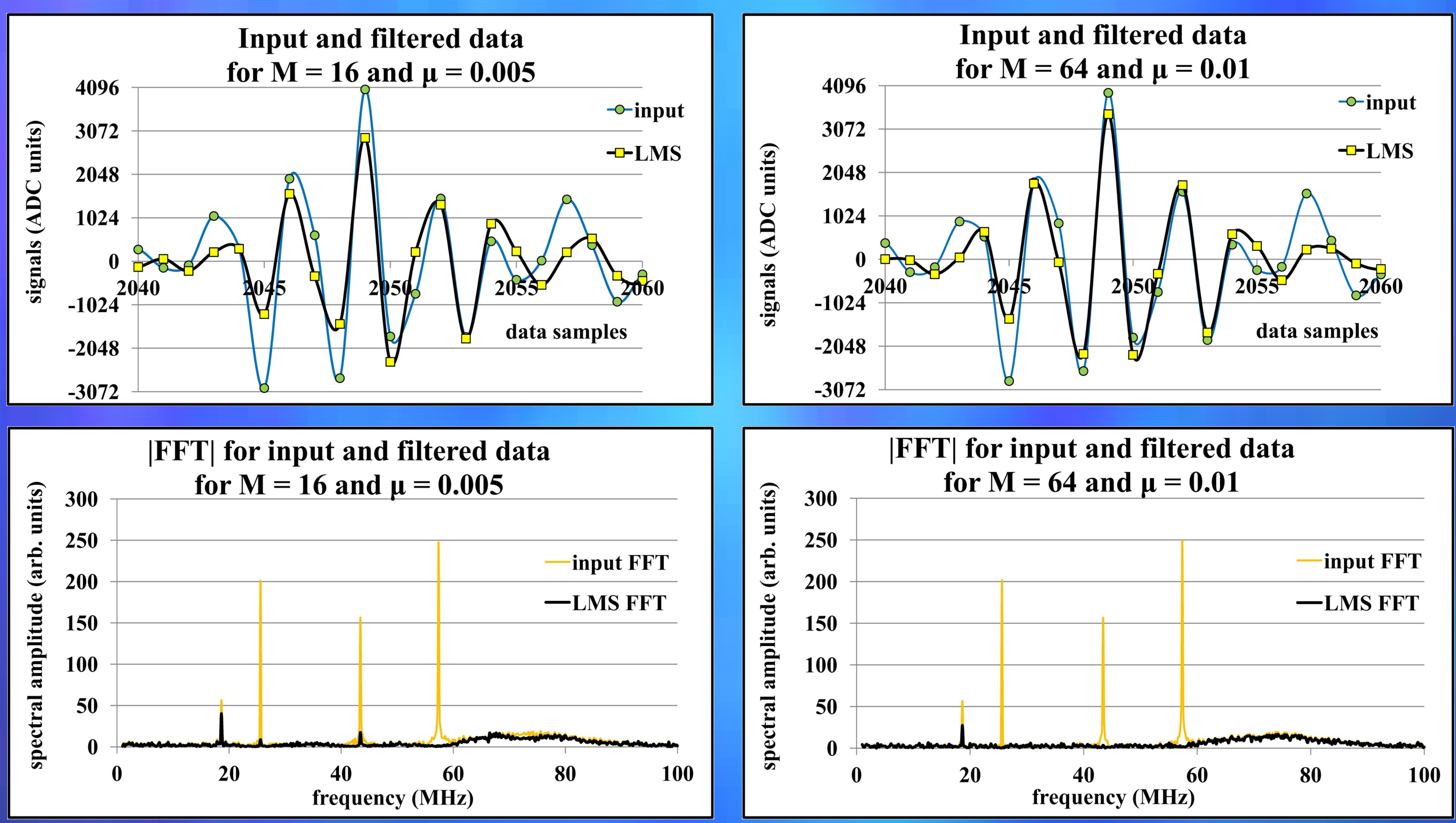

Fig. 2 – Results of MATLAB filtering for relatively short filter (left graphs) and longer one with greater learning factor. Both filters have very high efficiency in suppressing sine contaminations, however signal distortion made by shorter filter in trigger region is too big and cannot be accepted.

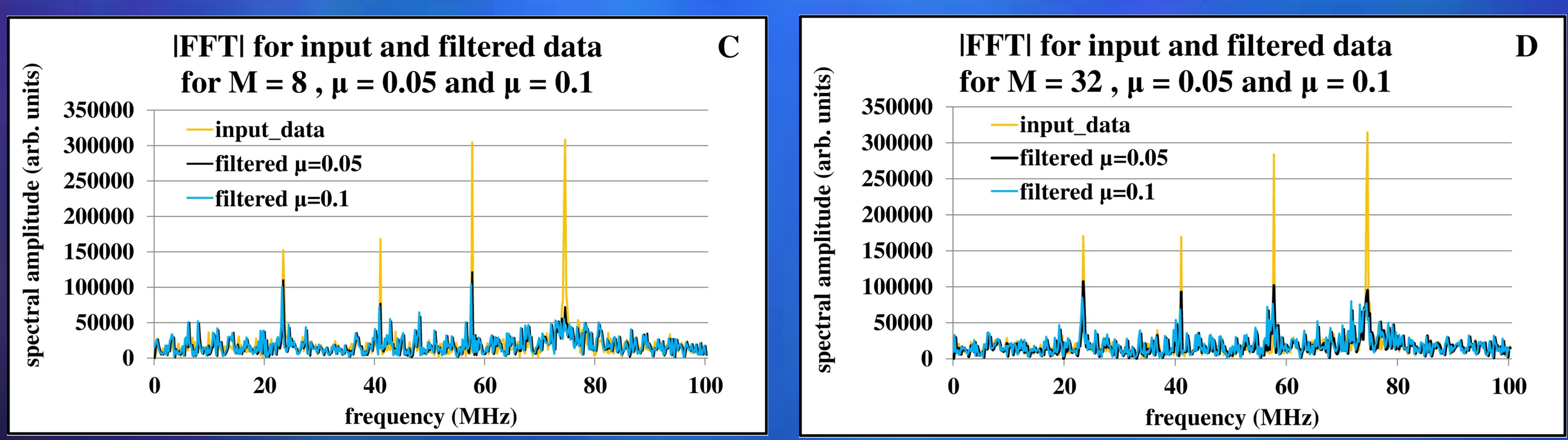

Fig. 3 – FPGA filtering results for very short (M=8) and longer (M=32) filters for learning factor μ= 0.05 and 0.1. Filtering efficiency is similar and confirm MATLAB results, that filter length does not influence on efficiency.

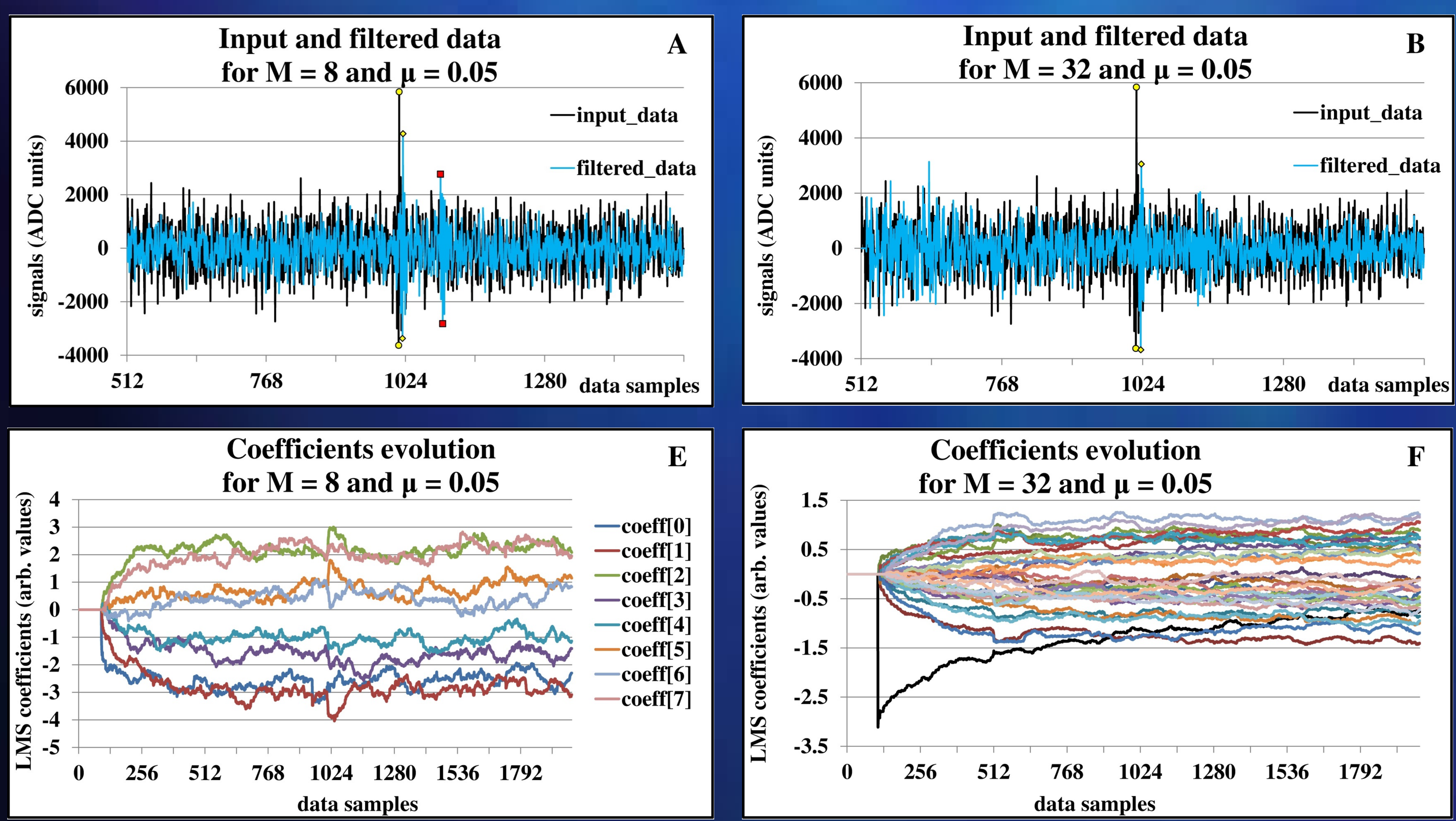

Fig. 4 – Results of filtering by very short (M = 8 - left column) and longer (M = 32 - right column) filters. Short filter introduces additional distortions in filtered signal in trigger window (graph A - additional spikes with red squares). Probable cause is too big coefficients values (graph E). For longer filter coefficients are much more stable (jumps in trigger region is not observed as for the M = 8). Artificial spikes are also not visible (graph B).

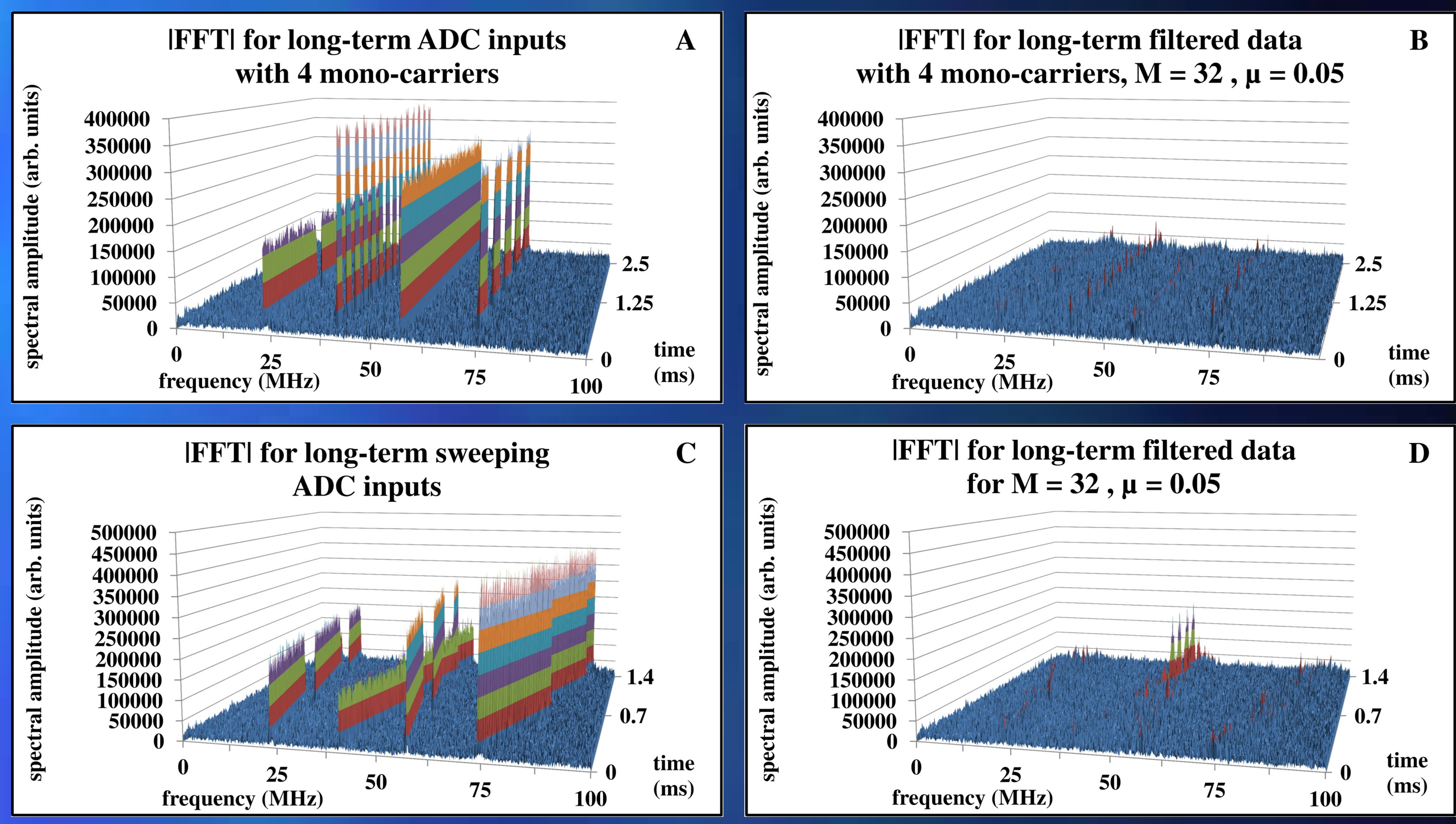

Fig. 5 – Spectral characteristics for input and filtered data for 4 mono-carriers (A,B) and for drifting frequencies (C,D). In both cases the efficiency of RFI suppression is very high. Some remaining RFI visible on graph D comes from very artificial and aggressive RFI signals driven the filter.

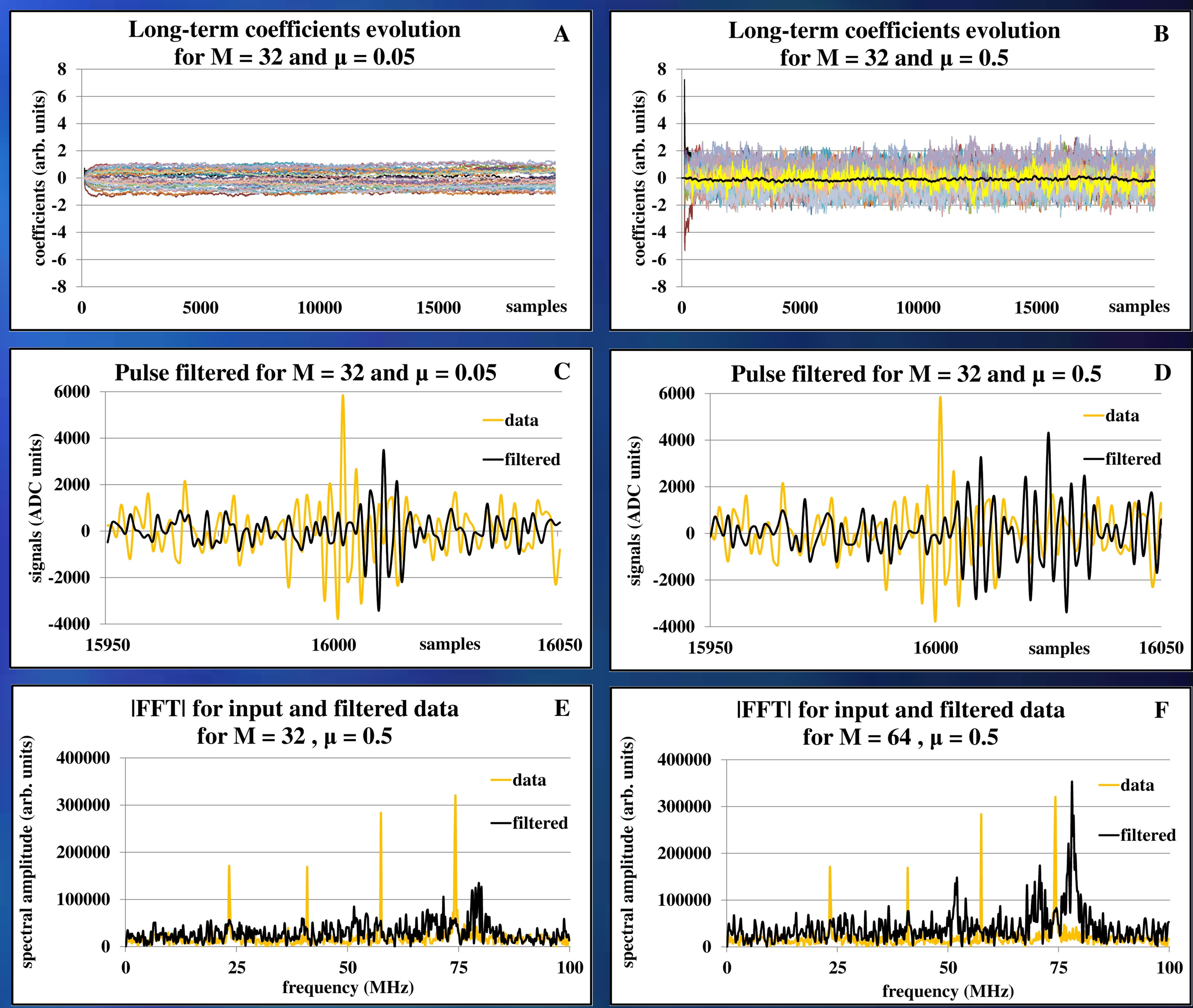

Fig. 6 – Instability of filtered data for filtering with learning factor μ = 0.5. This learning factor is too big and greatly increase initial coefficient value. Despite of fast stabilization of these coefficients, filtered data are strongly contaminated. This behavior can generate false triggers and should be avoided. Filter has big efficiency in filtering sine interferences, however coefficient instability introduce new ones. This effect is even bigger for LMS filter with 64 coefficients (graphs E and F).

CONCLUSIONS

Adaptive FIR filter based on LMS algorithm has been successfully tested in MATLAB and implemented in Cyclone ® V FPGA 5CEFA9F31I7. The stability and high efficiency in suppressing RFI with simultaneous small distortion of the radio pulse have been confirmed. Tests of power consumption and adaptation time vs. learning factors are planned soon with real antenna in contaminated environment of Łódź. Simplicity and short refreshment time of the coefficients shows that LMS filter can be good alternative for digital filters currently used in AERA.

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