Development of Self-Trigger Algorithms for Radio Detection of Air-Showers*

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Abstract. The detection of extensive air-showers with radio method is a relatively young. But promising branch in experimental astrophysics of ultrahigh energies. This method allows one to carry out observations regardless of weather conditions and time of day, and the precision of reconstruction of the properties of primary particles is comparable to the classical methods. The main disadvantage of this method is the complexity of the trigger implementation. Radio signals from extensive air-showers have a duration of few tens nanoseconds and amplitudes comparable to the surrounding background. Moreover, industrial noise, tele- and radio broadcasting signals, as well as noise from the electronic equipment of the experiment, often interfere with measurements. Most of the setups for detecting radio emission from extensive air-showers use an external trigger from optical or particle detectors. Despite numerous attempts to develop autonomous (operating with an internal trigger) cosmic ray radio detectors, there is still no established cost-effective technology for the sparse radio arrays. In the present work, we give an overview of our progress in this direction, particularly, we describe a noise generator and simulation study using data from the Tunka-Rex Virtual Observatory.

Keywords: Trigger detectors, Antennas, Instrumental noise, Instrument optimization, Real-time monitoring

1 Introduction

The technology of radio detection of ultra-high energy cosmic-ray extensive air-showers (EAS) is under active development. This method is cost-effective in comparison with other methods and provides high duty-cycle and reconstruction accuracy. The critical disadvantage of this method is trigger implementation

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complexity. Most of the ground-based EAS radio arrays perform measurements jointly with master detectors (particle or optical ones). The difficulty of trigger implementation is a low signal-to-noise ratio (SNR) and a lot of non-EAS radio frequency interference (RFI), which distorts the EAS signal. Due to these difficulties, simple threshold trigger for radio measurements becomes not effective (except in experimental works in radio-quiet conditions, like in Antarctica).

For implementation of efficient independent trigger for EAS radio array, one has to develop complex multi-layer procedure of rejecting noise pulses and searching for EAS pulses in high background conditions. Currently, research in this direction is carried out in several experiments (e.g. OVRO-LWA [1] and LOFAR [2]).

Due to a huge volume of input data, the first step of trigger implementation is reducing input flow by rejecting data contaminated with noise. To implement this step, we performed a study of noise pulses in Tunka-Rex conditions.

2 Tunka-Rex and TRVO

The Tunka Radio Extension (Tunka-Rex) [3] is a digital antenna array located in Eastern Siberia which measures the EAS radio emission in the energy range of primary particle of 10^{17} - 10^{18} eV and frequency band of 30-80 MHz. The Tunka-Rex setup was operated from 2012 to 2019. Array consists of 63 antenna stations based on SALLA (Short Aperiodic Loaded Loop Antenna) [4]. Tunka-Rex received a trigger from the Tunka-133 and Tunka-Grande installations.

During the lifetime of the experiment, we collected a large set of data which is loaded into the Tunka-Rex Virtual Observatory (TRVO) [5], the open database containing raw and preprocessed data. Now TRVO contains 100 M traces. The database is currently undergoing a beta test.

3 Trigger architecture

Experience with Tunka-Rex shows the efficiency of placing antenna stations in compact clusters. This allows one to achieve high EAS detection efficiency. Also, this approach enables easy connection of all stations to one joint DAQ with a minimal length of signal lines and provides performance of simple real-time calculations on the cluster level.

However, due to the limited speed of data transfer and computing power of hardware, one has to reduce the input flow of raw data by rejecting noise pulses and, afterwards, search for EAS pulses in data at station, cluster and multi-cluster levels.

In the frame of this project, we propose a common scheme of multi-level trigger generation as follow:

1. Channel level
   - Digital bandpass and median filters
2. Station level (L0 trigger)

   - Threshold trigger
   - Pairwise channel analysis
   - False triggers suppression
3. Cluster level (L1 trigger)
   - Match pattern
   - Suppression of known RFI
   - Restriction on direction
   - EAS signal search

The main idea is to reduce the count rate of the trigger without decreasing efficiency of the EAS detection. The multi-layer system reduces data flow from layer to layer simultaneously increasing complexity of analysis. The first layer (channel level) performs improvement of signal quality by digital filtering. The second layer (station level) performs suppressing of the known RFI sources and generates an L0 trigger. The third layer (cluster level) includes the scheme of coincidences between stations, suppressing RFI by templates and arrival direction. the trigger at this level can be implemented by an amplitude cut in the coherent sum and a convolution with a signal template.

4 RFI searching method

One of the main problems of the trigger implementation is a lot of RFI. The proposed method of searching for RFI in data is the analysis of the root-mean-square (RMS) distribution. RFI candidates are selected by exceeding the value of RMS above the background in a sliding window. We produce a channel-to-channel histogram of RMS for the found RFI from the given station and time interval and look for cores (areas with a concentration of the given RMS values). Figure 1 shows examples of RMS distributions and average RFI templates. In the red circle, one can see the RFI candidates from stable sources. After that, by averaging of pulses corresponding to each core we take a set of the RFI templates (Fig. 1, bottom row). For testing this approach we use the TRVO data. This approach enables one to detect the stable RFI sources by the data from a single antenna station.

5 Noise generator

To test the trigger generation algorithms by the fully-described initial conditions, we propose a noise generator based on the real noise samples from Tunka Valley. The algorithm is defined as follows (see Fig. 2):

1. Take a set of noise traces from TRVO (specific for the station and/or time interval).
2. Make an averaged spectrum of these traces and calculate the standard deviation for each amplitude of the spectrum.
3. Randomize amplitudes of this spectrum with the Gauss statistics corresponding to the defined standard deviation.

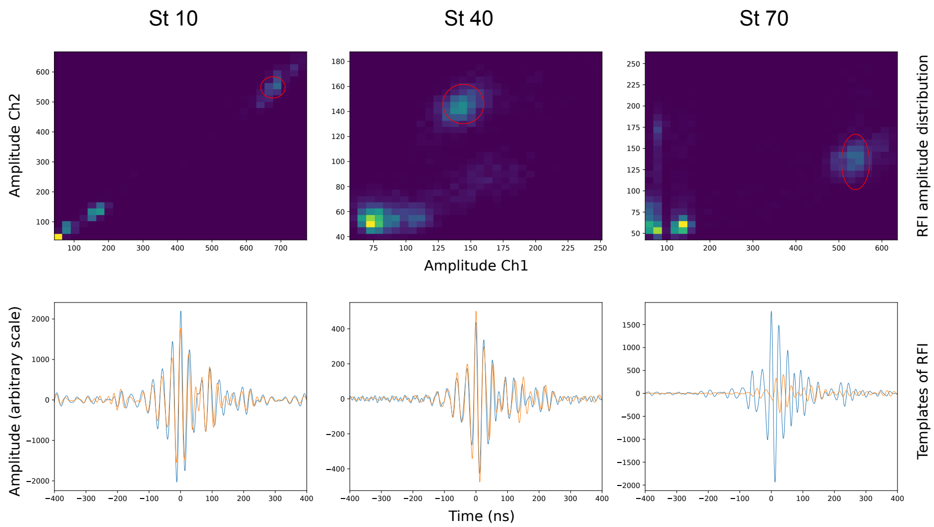

Fig. 1. Top: channel-to-channel RMS distributions of the found RFI. the red circle is the distribution core. Bottom: templates of RFI.

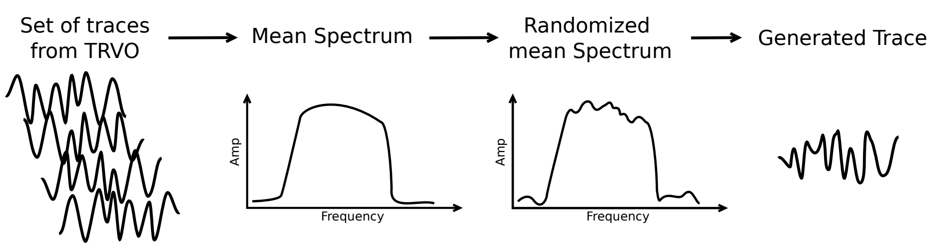

Fig. 2. Schematic representation of noise generation from the TRVO data.

4. Produce noise trace from the inverse Fourier transform.

This approach enables one to vary features of noise by taking different sets of input traces and increase the length of the resulted noise trace by interpolating the spectrum. The properties of the generated noise depend on the selected trace. Fig. 3 shows an example of the generated noise. The length of the generated trace is eight times longer than that of the original.

6 Preliminary evaluation of the L0 trigger

The evaluation of the algorithms was carried out on the TRVO data. To estimate the detection threshold, the simulated data was summed with real noise from TRVO. After that, we performed convolution with the averaged EAS pulse template and generated a trigger by the amplitude threshold of 4 sigma above

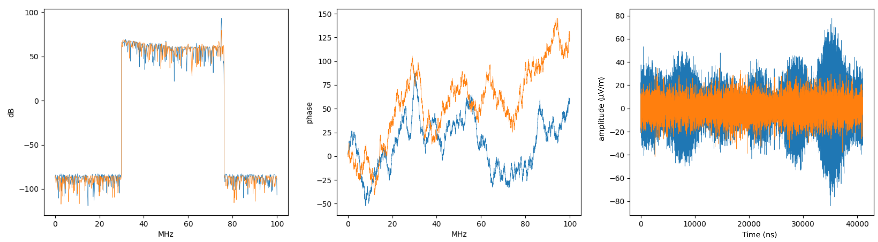

Fig. 3. Example of generated noise. From left to right: spectra, phases, resulting traces.

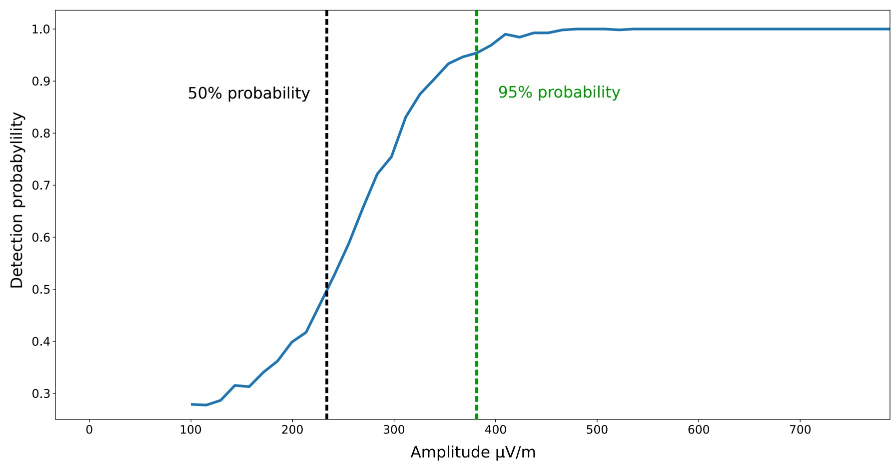

Fig. 4. Dependence of detection probability on signal amplitude.

the mean value. The resulted count rate of the trigger is 250 kHz. the probability of 50% for the EAS detection was achieved for 230 μV/m amplitude.

Figure 4 shows an example of the dependence of the detection probability on the signal amplitude.

These counting rates are very high for the last level trigger, however, they can be further reduced by fine-tuning the algorithm, implementation of the RFI suppression algorithms, and a new trigger layer.

7 Discussion and conclusion

We developed a common multi-layer scheme of the trigger generation, a method for searching a stable RFI and a noise generator. After that, we performed a test of the L0 trigger based on the template convolution of the EAS pulse detector on the raw Tunka-Rex data from TRVO and obtained preliminary results of this system. The count rate of the trigger is 250 kHz with 50% detection probability at the amplitude level of 230 μV/m. To increase the efficiency and reduce the count rate of the trigger, to it is needed to combine the trigger with advanced noise suppression and improve the methods of trigger generation.

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