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RADIO DETECTION OF COSMIC RAY EXTENSIVE AIR SHOWERS: PRESENT STATUS OF THE CODALEMA EXPERIMENT

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Abstract. In operation for more than one year, data acquisition and analysis on the CODALEMA experiment has allowed to improve the knowledge with this new device. At the same time, an important effort has been made to develop signal processes able to extract transient signal from interferences.

1 Motivation

First experimented in the 60's (Linsley 1963, Jelley 1966, Weekes 2001), radiodetection of ultra high energy cosmic ray (UHECR) was set aside until a recent revival of interest due to the evolution of electronic devices. Two experimental systems, namely CASA-MIA (Green et al. 2003) and KASKADE (Falcke and Gorham 2003), have aimed to show radio-frequencies transients associated with extensive air showers (EAS) using antennas triggered with particle detector array. Until now, no EAS candidate has been published.

Along the development of the EAS in the atmosphere, several mechanisms of electromagnetic emission contribute to generate an electric pulse (Allan 1971). Considering only one of those mechanisms (Ravel et al. 2003), the resulting signal of a vertical shower with a primary particle energy of 10^{20} eV should reach 40 to 300 $\mu\text{V}\times\text{m}^{-1}$ with a 10 ns to more than 1 μs duration depending on the impact parameter. This is large enough to be measurable. Using pulse arrival times on at least 3 antennas, the incidence of the transient wavefront could be determined. Besides this, it should be possible to extract primary particle related informations such as energy, impact parameter or nature directly from the shape of the electric signal as a function of time.

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2 The CODALEMA setup

Started by march 2003, the CODALEMA (COsmic ray Detection Array with Logarithmic ElectroMagnetic Antennas) experiment has been set up at the Radio Observatory of Nançay where suitable antennas (used in the 1-100 MHz frequency band for CODALEMA) were available on the DecAMetric array (DAM), an instrument dedicated to the sun and Jupiter observations. CODALEMA is using 6 out of the 144 log-periodic antennas constituting the DAM with the arrangement shown on the figure below.

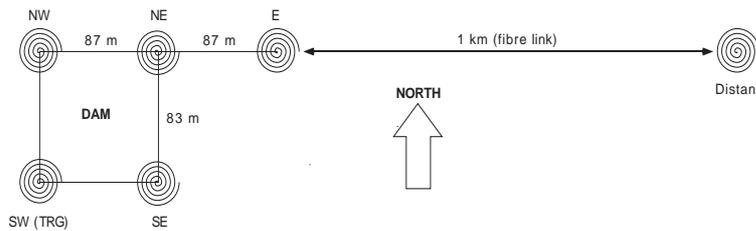


Fig. 1. Current CODALEMA setup. The trigger is the SW antenna.

The 5 nearest antennas are linked, after signal amplification (gain 37 dB), via 150 m long wires to digital oscilloscopes that numerize signals (8 bits ADC, 500 MS/s, 10 μ s recording time). Then data are stored on disk for off-line analysis. The 6th antenna presents a quite different signal transmission (1 km optical fibre link), due to its location 1 km eastbound from the rest of the antennas. This particular location may allow to see the effect of the impact parameter on the signal (near and far electromagnetic field). The originality of CODALEMA rests on the fact that the system is self-triggered using a devoted antenna filtered in an appropriate, interferences free frequency band (33-65 MHz). Indeed, no particle detector is used to acquire data contrary to the above mentioned experiments. Signals from the whole set of antennas are acquired when a voltage threshold is reached on the trigger antenna (Dallier et al. 2003).

3 Source localization

Due to the presence of radio transmitters in the full frequency band, an off-line numerical passband 33-65 MHz (trigger frequency band) is needed to make the transient come into sight. Provided that a physical transient signal is present in the data, this process allows to put in evidence coincidences on several antennas. Assuming that the source of this signal is far enough from the detector, the propagating wavefront can be considered as a plane. Thus, using time delays between each antenna, the location of the emission source is reconstructed.

An illustrative example of this is given in Fig. 2, where a series of successive trigger actions occurred in a limited time range on CODALEMA. For each event, directions of wavefronts were determined in terms of azimuth and elevation angles. Then

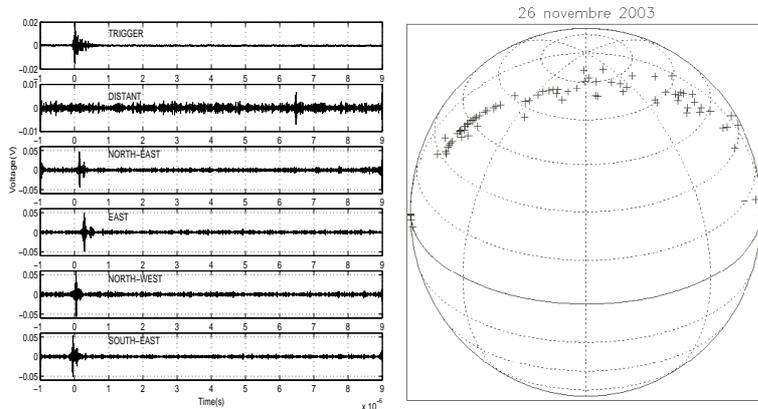


Fig. 2. Left : Coincidence transients detected with CODALEMA after 33-65 MHz numerical filtering. From Top to Bottom : trigger, distant (1 km), NE, E, NW and SW antennas respectively. Right : Location in the sky of sources of successive events.

they were plotted on a 3D graphic representing the sky over the Radio Observatory of Nançay. This series of trigger actions lasted 2 minutes, so the assumption was made that it was actually the same source moving from north to south and passing straight up from the detectors array as an air plane could have done. Identifying such anthropic interferences allows to reduce the counting rate. The one obtained after removing such contributions is compatible with expectations for EAS rates.

4 Pulse extraction

Although numerical filtering is useful for time tagging and source localization, it is irrelevant to bring any information about the shape of the original electric pulse. Therefore a signal processing tool able to extract the pulse waveform from the background radio noise is under development. In order to evaluate the efficiency of such a process, simulated signals have been generated by adding a pulse to a typical background noise recorded on CODALEMA, then the process has been applied on it.

The method, based on the Discret Fourier Transform (DFT), performs a cut off of the strongest radio transmitter lines in the frequency domain (1-20 & 80-100 MHz). Then an appropriate spectrum model is fitted to the resulting spectrum in the 20-80 MHz frequency band. Finally, the whole-band fitted spectrum (1-100 MHz) associated with its phase is brought back in the time domain to get the pulse waveform. An example of this process is given Fig. 3 : the pulse (Fig. 3a), hidden into radio interferences (Fig. 3b), is extracted (Fig. 3c) with an unoscillating structure. Notice, however, that the peak voltage is significantly reduced.

The assumption made when the spectrum is fitted puts limits on the interest of the method. Another approach, based on Linear Predictive Coding (LPC) filtering, is

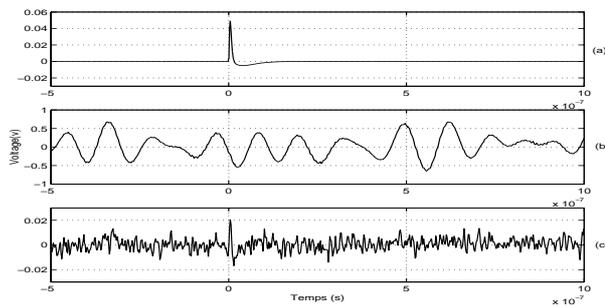


Fig. 3. Process applied to a simulated signal. (a) Original generated pulse (50 mV peak, i.e. about $200 \mu\text{V} \times \text{m}^{-1}$ electric field strength, 20 ns duration). (b) Simulated signal made up of the pulse and a background radio noise waveform recorded on CODALEMA. (c) Recovered pulse after signal processing (20 mV peak, 18 ns duration).

currently under investigation. An advantage of this method is that no hypothesis is made on the detected transient. About 200000 recorded events, covering 18 months of activity, are currently under analysis.

5 Latest developments

The CODALEMA set up will know a couple of upgrades during September 2004. First, 7 extra antennas are going to be added to the existing array. They will be arranged on a East-West 600 m line just beside the original array. This should allow to study the influence of the impact parameter. Then, the antenna array is going to be coupled with 4 double scintillators of 2.25 m^2 each, arranged on a 100 m side square. Still triggered with the dedicated antenna, this new set up is expected to bring an unambiguous EAS radio signal.

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