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Radio detection of cosmic ray air showers by the CODALEMA experiment

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Abstract

The possibilities of measuring Extremely High Energy Cosmic Rays by radio detection of electromagnetic pulses radiated during the development of extensive air showers in the atmosphere are investigated. We present the demonstrative CODALEMA experiment, set up at Nançay Radio-Observatory (France). The radio-decametric array has been adapted to measure radio transients in time coincidence between antennas.

Keywords: Cosmic ray; Radio detection; Air shower; Astroparticle

1. Motivation

Radio emission from cosmic ray air showers has been predicted in the 1960s [1]. In the subsequent decade, several experiments have asserted the observation of such emission [2,3]. For this period, following the review of Allan [4], different mechanisms of electromagnetic pulse generation have been identified, such as negative charge excess (10–25%) in the shower. For our purpose, calculations of the electromagnetic pulse were performed within a simple model considering only this negative charge excess contribution. The resulting electric field can be expressed as

$$\vec{E}(t) = \frac{1}{4\pi\varepsilon}\sum_{t'}\frac{e(t')(1-\beta^2)(\vec{n}-\vec{\beta})}{R^2|1-\vec{n}\vec{\beta}|^3} + \frac{1}{4\pi\varepsilon c}\sum_{t'}\frac{e'(t')(\vec{n}-\vec{\beta})}{R(1-\vec{n}\vec{\beta})|1-\vec{n}\cdot\vec{\beta}|}$$

with $\vec{\beta}=\vec{v}/c$, $\vec{n}=\vec{R}/R$, and $c(t-t')=R$ the distance between the moving charges of the shower and the observation point. For the numerical simulation, we have assumed a charge excess distribution $e(t')$ along the shower axis with 7×10^9 charges at the maximum for a 100 EeV Extremely High Energy Cosmic Rays (EHECR) and no spatial shower extension. The corresponding electric fields for three different impact

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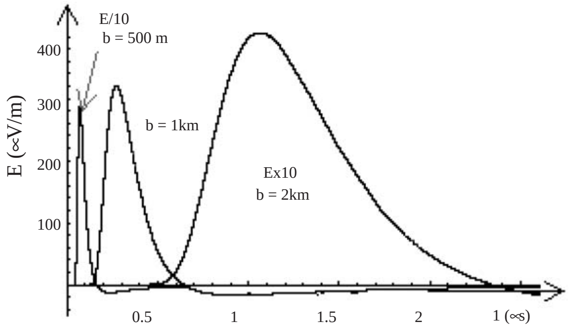

Fig. 1. Simulated electric field as a function of time for impact parameter $b = 0.5$, 1 and 2 km.

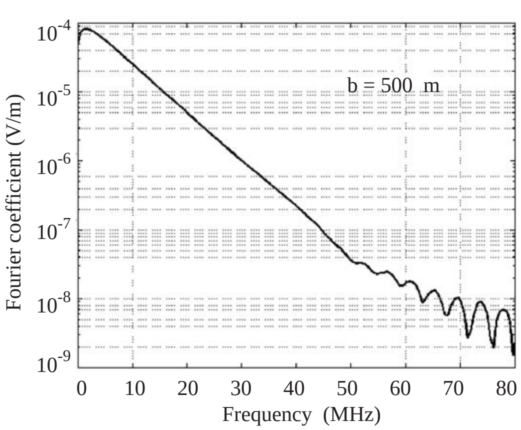

Fig. 2. Fourier spectrum of a simulated pulse at $b = 500$ m.

parameters b in a vertical shower configuration are shown in Fig. 1.

These electric fields are strong enough to be measured. It is worth noting that the pulse width increases with the impact parameter. Thus, a complete knowledge of the pulse waveform enables to determine the charge profile of the shower and consequently the energy of the primary EHECR. Due to the large frequency content of the Fourier spectrum (see Fig. 2), broadband antennas are requested for accurate pulse shape determination. It is also possible, by an appropriate narrow-band frequency filter, to use stand-alone triggered antennas. Moreover, using at least three antennas in time coincidence enables to reconstruct the shower direction.

2. The CODALEMA experiment

These considerations motivated us to implement a demonstrative experiment, named CODALEMA, at the Radio Observatory of Nançay [5] (France). CODALEMA uses six large frequency bandwidth antennas (1–100 MHz) in time coincidence. The experimental central array (83 m × 87 m) consists of the corner antennas of the Réseau Décamétrique de Nançay (RDN) and a narrow-filtered antenna (33–65 MHz) used as a trigger. One additional antenna linked by optical fiber is located 1 km East from the central array (see Fig. 3).

The data acquisition system is based on 3 LeCroy digital oscilloscopes (1 GS/s) which record the amplified antenna voltage signal. Our first task has been to identify the various sources of background, mainly the radio broadcasting stations. Bandpass filters (24–82 MHz) suppress the AM and FM bands. Additional anthropic noise comes from the acquisition room's air-conditioning and the computing network hub: these effects have been filtered out. Within these precautions we have reached a trigger rate of 12 events/h for a 40 μV triggering antenna signal; among them 85% have been already identified as noise pulses.

3. First results

A typical six antennas coincidence signal, triggered by the dedicated narrow filtered antenna of the central array is shown Fig. 4. After a preliminary analysis of time delays, we can assert that such an event is not compatible with identified sources of noise and can be considered as a possible candidate for cosmic ray air shower radio

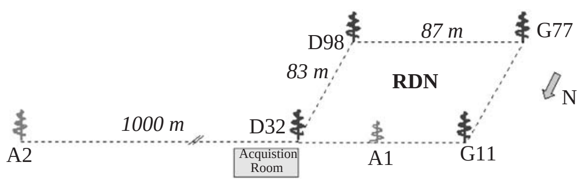

Fig. 3. CODALEMA setup.

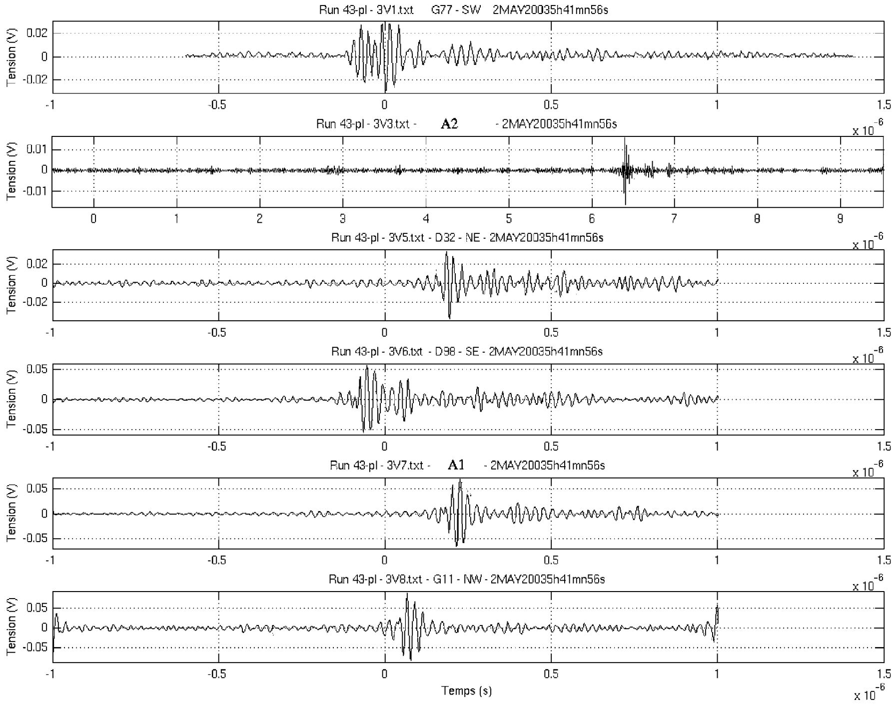

Fig. 4. Coincidence transients after numerical filtering (35–65 MHz) detected with CODALEMA.

emission. CODALEMA has been now recording data at a duty cycle of 100% since mid-march 2003, and until the end of 2003.

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