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Design and performance of a fully autonomous antenna for radio detection of extensive air showers

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Abstract: The use of the radio-detection technique in a wide area cosmic-ray detector requires autonomous antenna stations, in terms of power feeding, triggering and data transmission. A prototype has been tested at the Nançay Radio Observatory (France). It uses the broadband (1-200 MHz) active dipoles already in operation in the CODALEMA experiment (see other contributions in this conference), together with a solar power supply, an independent trigger electronics and a dedicated communication system. We present here the first sketch and the performances of this new kind of detector.

Introduction

The study of the high energy cosmic rays is still of prime interest even after 40 years of experimental studies. At the highest energies (above 10^{19} eV), the mechanisms responsible for the cosmic rays are not fully undestood and their sources not identified. Highest energy cosmic rays are usually studied through the Extensive Air Shower (EAS) they produce entering the atmosphere. Work in the 60's indicated that the shower could be a source of a coherent radioelectric field (see [1], [2]): Cerenkov radiation of the charge excess, the geosynchrotron emission and a dipolar emission coming from stationnary macroscopic current in the shower plane. The emission is observed at frequencies between 1 and 200 MHz. Radiodetection is a very promising field because it could give access to the primary cosmic ray characteristics with a 100 % duty cycle and a reduced cost. The CODALEMA experiment gave a firm evidence of radiosignal associated to EAS at energies of the order of 10^{17} eV (see [3] and [4]). The current setup covers 0.04 km^2 and the radio detector (16 antennas) is triggered by an array of 13 scintillators. In order to study cosmic rays at higher energies with sufficient statistics, we have to cover a wider area (tenths of square kilometers) with hundreds of antennas making mandatory the usage of fully autonomous antennas (independent trigger, power, wireless data transfer). We present here the first prototype of such autonomous radio station, based on the dipoles used in CODALEMA. We first describe the active antenna and its performances. Then we present its integration in an autonomous radio detector.

The active antenna

In order to collect the best possible physical information included in the transient electrical field, we use a wide band active antenna made of a dipolar receiver coupled with a front-end amplifier. This active antenna has an almost constant gain in our frequency domain. The dipole is composed of two aluminium slats of 0.6 m length and 0.1 m width, installed horizontally 1 m above ground. The frequency and directivity response are still under study but well understood at first order. Figure 1 presents the directivity diagram of the whole active dipole in operating conditions and for different frequencies. The Half Power Beam Width

(HPBW) is 90° in the H-plane and 60° in the E-plane and varies slowly with frequency.

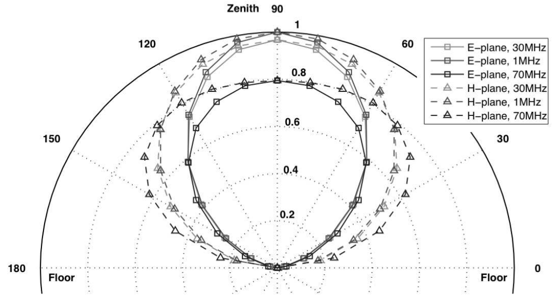

Figure 1: EZNEC simulation of the dipolar antenna normalized gain. The HPBW is 90° in the H-plane and 60° in the E-plane.

The amplifier is a low-noise, high input impedance, dedicated ASIC with a remarkably constant gain of 34 dB over the frequency range; the -3 dB limit corresponds to the 80 kHz-230 MHz band. Additionnal informations can be found in [5].

Performances achieved at Nançay

A network of active dipolar antennas is installed at the radio observatory in Nançay since June 2005. We have now 16 of these in addition to 13 scintillators; the setup and the results concerning cosmic rays studies are presented in other contributions to this conference (see [6], [7] and [8]). The energy threshold is above 5×10^{16} eV and the spacing between two antennas is of the order of 80 m. The radio data and power feed are sent by cables and the antennas are triggered by scintillators. We do not have independent radio trigger.

The sensitivity is mainly limited by the sky background temperature (see the spectrum obtained in Figure 2). Contribution of the FM emission (above 80 MHz) and other radio broadcasting signals below 25 MHz are also clearly seen.

Moreover, we have observed the transit of CasA using the decametric array in Nançay in interferometric mode with our antenna. The global system is phased to the local meridian and we used the data at 35 MHz with a 10 MHz bandwidth. In the time-frequency representation, we clearly see the interference fringes spread over the whole duration of the transit of CasA (see Figure 3).

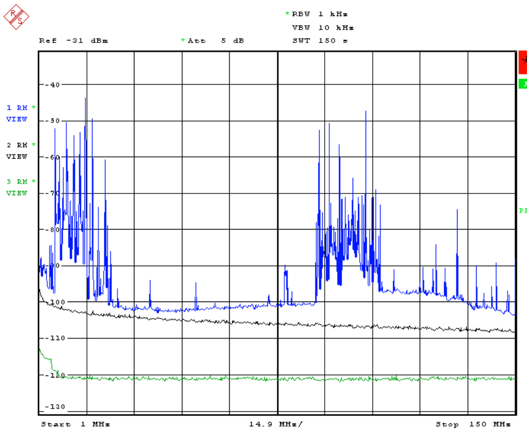

Figure 2: Frequency spectra of the antenna (top), amplifier noise (middle) and spectrum analyzer noise (bottom).

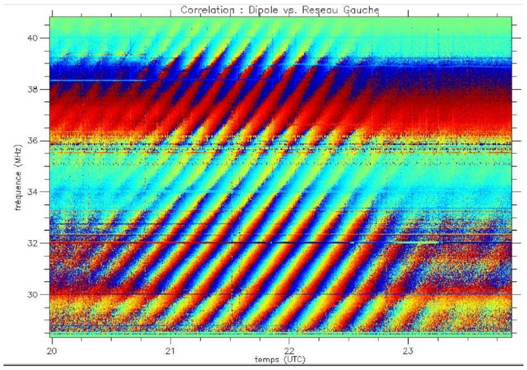

Figure 3: Time-frequency graph of the interference pattern obtained by combination of the decametric array in Nançay and one dipolar antenna used in CODALEMA, phased on the local meridian. The transit of the radio source CasA (23N5A) is clearly visible.

Autonomous antenna prototype

In order to detect higher energy cosmic rays with sufficient statistics, we have to cover a larger area and consequently (fixed cost!) to have larger spacing between antennas. For installation, cost reasons and especially for trigger simplicity consideration with no data exchange with other surrounding detectors acting as external trigger, we took the option to try to work with fully autonomous radio stations. In order to keep maximum of flexibility, the station is built as simple as possible using off-the-shelf equipments.

The complete setup of this pre-prototype is as follow:

- two dipolar active antennas presented previously, one in the North-South direction, the other in the East-West direction to study the polarization in the horizontal plane,
- a trigger board with a tunable radiofrequency filter to get rid of frequencies due to human activities,
- 8 bit Analog to Digital converter electronics adapted to large band wave form analysis, working at 250 MS/s for a 10 μs registered waveform; the ADC is a Tektro THS730A handheld scope, 1 GHz bandwidth,
- GPS receiver for event time tagging at the 10 nanoseconds level,
- 100 W solar panels and 100 A.h, 12 V batteries for power supply,
- the local acquisition system is the standard Unified Board developped for the Cerenkov tanks in Auger; it masters the local data streams and manages the communication with the distant Radio Central Data Acquisition System (RDAS),
- standard Wifi system (115 kb/s) to send antenna data to the RDAS.

The total power budget is 18 W. Figure 4 shows a view of our prototype.

We can see the Wifi antenna (top right), the electric box (with the door open) containing the oscilloscope, the trigger box (small grey box on top of the electrical box) and the mother board. The small white box at the bottom is the Wifi module. The solar panel is above and the blue box below contains 2 batteries in parallel.

The trigger works on the filtered signal in a narrow band which can be selected within the $24-82$ MHz range on one of both antennas. In the current setup, the trigger requires the filtered signal to be greater than an adjustable threshold in the chosen polarization.

Figure 4: View of the autonomous detector.

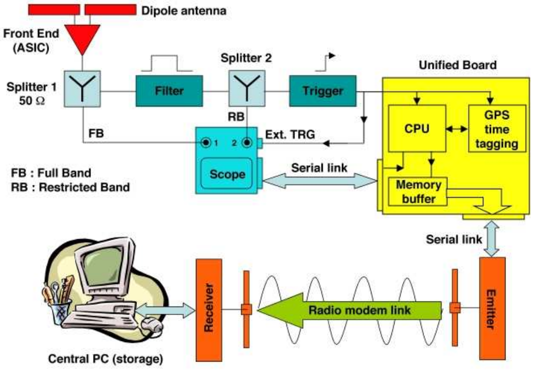

Figure 5: Electronic scheme. See text for details.

As shown in Figure 5, at the trigger level, a splitter divides the dipole signal into two parts: the full band (FB) is directly digitized and the $24-82$ MHz filtered band (RB for Restricted Band) goes to the threshold comparator which tells the UB whether to record the event or not. When an event is detected, the data is immediatly sent to the RDAS through the Wifi link. The dead time of the acquisition is 2.7 s. The second channel of the scope records the full band of the other dipolar antenna (in order to collect 2 polarizations).

Radio coincidences have been detected (storms, anthropic signals...). An example of such radio coincidences is shown in Figure 6.

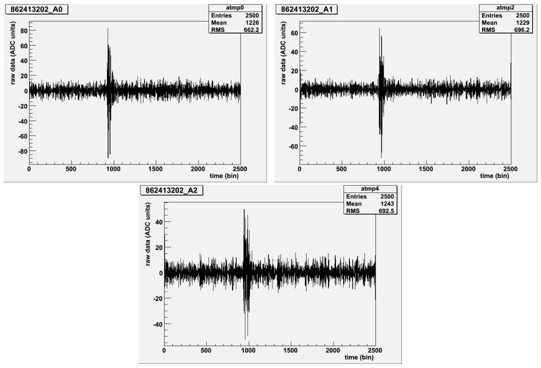

Figure 6: Example of a 3-fold coincidence between three prototypes. The signal presented is filtered in the $30 - 80$ MHz band for the 3 autonomous stations in the NS polarization.

Conclusion

We built a prototype of an autonomous radio station based on the dipolar active antenna used in the CODALEMA experiment. Three of these are currently taking data at the Pierre Auger Observatory and coincidences with the Auger surface detector are expected very soon. This first sketch of autonomous stations serves to test the faisability of the concept.

A second version of these stations will be tested at Nançay at the end of 2007. This version will present a full optimization: 14 bit ADC, nanosecond GPS, trigger, internal data exchange between components, communication technologies towards the external world with multiple standard like WiMax, GSM, etc; they will be powered in multiple ways (standard facility, solar, wind energy). The final apparatus will be very compact (less than 1 m^3) and have low power consumption (less than 25 W). Twenty of these stations will be installed among the already existing detector in CODALEMA.

Acknowledgments

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