DETECTION OF THE RF PULSE ASSOCIATED WITH COSMIC RAY AIR SHOWERS

Jonathan L. Rosner
Institute for Nuclear Theory
University of Washington, Seattle, WA 98195

and

Enrico Fermi Institute and Department of Physics
University of Chicago, Chicago, IL 60637

ABSTRACT

A project to detect the radio-frequency pulse associated with extensive air showers of cosmic rays is described briefly. Prototype work is being performed at the CASA/MIA array in Utah, with the intention of designing equipment that can be used in conjunction with the Auger Giant Array proposal.

1 Motivation

As a result of work in the 1960’s and 1970’s, some of which has continued beyond then, it is recognized that air showers of energy $10^{17}$ eV are accompanied by radio-frequency pulses, whose polarization and frequency spectrum suggest that they are due mainly to the separation of positive and negative charges of the shower in the Earth’s magnetic field. The most convincing data have been accumulated in the 50–100 MHz frequency range. However, opinions have differed regarding the strength of the pulses, and atmospheric and ionospheric effects have led to irreproducibility of results. In particular, there may also be pulses associated with cosmic-ray-induced atmospheric discharges.

A study is being undertaken of the feasibility of equipping the Auger array with the ability to detect such pulses. It is possible that the higher energy of the showers

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1 Appendix to proposal for the Auger Air Shower Array
2 Permanent address.
to which the array would be sensitive would change the parameters of detection. Before a design for large-scale RF pulse detection can be produced, it is necessary to retrace some of the steps of the past 30 years by conclusively demonstrating the existence of the pulses for $10^{17}$ eV showers, and by controlling or monitoring some of the factors which led to their irreproducibility in the past.

In this note we describe the prototype activity at the CASA/MIA site, mention related activities, and set forth some considerations regarding plans for the Auger project. More concrete plans for RF detection must await the outcome of protoyping work at the CASA/MIA site.

## 2 CASA/MIA Prototype setup

In order to verify the claim \[1\] that $10^{17}$ eV showers are accompanied by RF pulses with significant energy in the 50–100 MHz range, a prototype detector is being set up at the CASA/MIA site in Dugway, Utah. This section describes the status of that effort.

### 2.1 Large-event trigger

A trigger based on the coincidence of several muon “patches” was set to select “large” showers with a rate of several per hour. The MIA Patch-Sum trigger was sent into a fan-in/fan-out. From this, the signal was put into a LeCroy 821 Discriminator. This produced a pulse of height $-0.8$ V (on 50 Ohm output). The width of the output pulse was set to 200 nsec. The frequency of the output could be varied by adjusting the threshold on the discriminator. The observed rates as a function of this threshold were as follows:

| Threshold | Patches | Rate              |
|-----------|---------|-------------------|
| $-350$ mV | 6       | $45$ Hz (highly variable) |
| $-400$ mV | 7       | $3.7 \pm 0.25$ Hz  |
| $-450$ mV | 8       | $2.21 \pm 0.19$ Hz |
| $-500$ mV | 9       | $1.23 \pm 0.10$ Hz |
| $-560$ mV | 10      | $1.00 \pm 0.07$ Hz |
| $-690$ mV | 12      | $0.52 \pm 0.03$ Hz |
| $-750$ mV | 13      | $5.8 \pm 0.8$ min$^{-1}$ |
| $-810$ mV | 14      | $0.65 \pm 0.18$ min$^{-1}$ |
| $-870$ mV | 15      | $2.0 \pm 0.8$ hr$^{-1}$ |

The rate varied somewhat depending on how noisy any particular patch is. In particular, below 6 patches, the rate was not observed to be very stable. The electronics was initially set up at the 15 patch level. This was estimated to be $5 \times 10^{16}$ eV to $10^{17}$ eV, based on the rate at $10^{18}$ eV of $1$/km$^2$/day/sr.
The performance of this trigger was monitored during two runs (17985 and 17987) on June 30, 1995. During a period in which 26 million CASA triggers had been registered (estimated to be about 16 days assuming a 20 Hz rate), 240 “large-event triggers” had been registered, or about 15 per day. The counters were reset on the evening of 6/29/95. During the subsequent 12.5 hours, 7 counts were registered between 7:12 pm MDT 6/29 and 7:47 am MDT 6/30, consistent with the above rate. This is considerably less than the hoped-for several per hour or the 2 per hour noted in the table above.

On the morning of 6/30/95, the large-event trigger level was reset from −869 mV to −822 mV. At this level, it was checked that several counts per hour would be registered. The large-event trigger was used to key a transceiver which then broadcast a digitally recorded voice message which was picked up remotely.

Times of receipt of the trigger message were measured to an accuracy of about 5 seconds. During remote receipt of trigger notifications, other tasks were being performed, such as setting up of antenna, monitoring of RF backgrounds, and testing of preamplifier. Thus it is possible that some notifications were missed. For future studies it would be very helpful to record “large-event triggers” with a time stamp and, if possible, a pulse voltage level to determine by what amount a given threshold was exceeded.

A file of events with at least 15 muon patches was generated after the day’s runs:

| Run   | Events | Live time (minutes) | Events/minute |
|-------|--------|---------------------|---------------|
| 17985 | 446    | 354                 | 1.26 ± 0.06   |
| 17987 | 495    | 354                 | 1.40 ± 0.06   |
| Both  | 941    | 708                 | 1.33 ± 0.04   |

The times of events in this file which matched within 5 seconds of those found using the remote-monitoring system mentioned were recorded. Of 58 potential matches between large-event triggers and events in the above file, only 27 actual matches were found. Although this correlation appears higher than accidental, it is clear that many large-event triggers failed to match with events in the actual data record. Consequently, more effort is being devoted to construction of an efficient large-event trigger. It is notable that in measuring HiRes - MIA coincidences for events of $10^{17}$ eV, a rate of somewhat less than 1 per hour was achieved.

### 2.2 Monitoring of RF noise environment

It was a concern that the RF noise of the local electronics and the presence of an extensive lightning-protection array might dictate the placement of one or more antennas outside the periphery of the array, or might make the site unsuitable altogether. The behavior of a single CASA board was investigated at the University
of Chicago. The various clock signals were detected at short distances (\(< 1 \text{ m}\)) from the board, but a much more intense set of harmonics of 78 kHz emanated from the switching power supplies. These harmonics persisted well above 100 MHz. At 144–148 MHz, they overlapped, leading to intense broad-band noise.

An initial survey of RF noise at the CASA site was performed. On the basis of the results, which indicated some RF noise within the array, it was decided to perform an initial follow-up survey sitting just outside the array. The original log-periodic antenna used to detect RF pulses at Chacaltaya in the 1960’s and 1970’s was obtained, tested for bandwidth, taken out to Utah, and used in a follow-up study of RF noise in the 60–85 MHz frequency range. Sources of most strong RF signals in this range appeared to be due to either the receiver itself or to local TV stations. Spectrum analysis techniques may be suitable for removing such monochromatic signals.

### 2.3 Near-term plans

It is proposed to monitor the RF noise and to detect pulses by mounting the log-periodic antenna near the CASA central trailer site, just above the lightning protection grid. A digital storage scope will be used to register several microseconds of RF data on a rolling basis. These data will then be captured and inspected visually upon receipt of a large-event trigger.

The experiment will be repeated using successively greater amounts of amplification and narrower band-pass filters once these become available. The filters are being developed at the University of Chicago. Once the large-event trigger has been demonstrated to select events of \(10^{17}\) eV and above, permanent digital recording of coincident pulses will be undertaken.

Still to be performed are experiments which seek to monitor RF pulses at lower frequencies and at greater distances from the array. For these pulses, whose strengths may be correlated with atmospheric electric fields, it is planned to monitor such fields with the help of a field mill.

A spectrum analyzer will be used to make a broader survey of the RF noise in various frequency ranges and may be of help in detecting potential sources of interference to RF communications in the Auger project.

### 3 Recent information on related activities

#### 3.1 FORTE, BLACKBEARD, SNO, and other projects requiring digitizers

Discussions with John Wilkerson at the University of Washington have been very productive. Wilkerson was engaged in projects at Los Alamos with the acronyms FORTE and BLACKBEARD whose aim was detection of electromagnetic pulses,
including those produced by cosmic-ray-induced electromagnetic discharges, with frequency ranges in the 30–100 MHz range. Many of the fast-digitization and memory problems appear to be identical to those in the proposal for a prototype pulse detector at CASA/MIA. Time-frequency plots have been obtained by the BLACKBEARD project which are exactly those one would hope to generate in a survey at CASA/MIA.

Wilkerson has also encountered requirements similar to ours for digitization of SNO data. His estimate is that one can use Maxim MAX 100 A/D chips for less than $1K per channel, but that feeding their output into memory may well amount to another $1K per channel. Other references on digitizers have been obtained [4, 5]. Discussions with Wilkerson will continue, and further discussions with Dan Holden at Los Alamos are envisioned.

3.2 Status of GHz detection

David Wilkinson, who visited the University of Chicago during the spring of 1995, has promised to look into the power radiated at frequencies of several GHz, where new opportunities exist associated with the availability of low-noise receivers. At latest report he had planned to complete the relevant calculations during the summer of 1995.

3.3 Other options

Dispersion between arrival times of GPS signals on two different frequencies may serve as a useful monitor of air shower activity. The possibility of correlation of large showers with such dispersion events will be investigated.

It may be possible at the CASA/MIA site to monitor commercial broadcast signals in the 55 - 88 MHz range to detect momentary enhancements associated with large showers, in the same sense that meteor showers produce such enhancements. Television Channels 3 and 6, for which no nearby stations exist, offer one possibility.

4 Considerations for Auger project

At present we can only present a rough sketch of criteria for detection in the 50–100 MHz range. Data would be digitized at a 500 MHz rate at each station and stored in a rolling manner, with at least 10 microseconds of data in the pipeline at any moment. Upon receipt of a trigger signaling the presence of a “large” shower ($> 10^{17}$ eV), these data would be merged into the rest of the data stream at each station.

Per station, we estimate the following additional costs, in US dollars, for RF pulse detection:
## Two antennas and impedance transformers: 200 (a)

Mounting hardware: 100 (b)

Cables and connectors: 200 (c)

Preamps and lightning protection: 100 (d)

Digitization and memory electronics: 2000 (e)

Total per station: 2600 (f)

(a) Two commercial log-periodic TV antennas with commercial 4:1 baluns; crossed polarizations. Difference signal to be detected.

(b) Highly dependent on other installations at site. Antennas are to be pointed vertically but optimum elevation not yet determined.

(c) Antennas are mounted near central data acquisition site of each station.

(d) Commercial GaAsFET preamps and gas discharge tubes.

(e) Subject to prototype development experience. Power requirements not yet known.

(f) The number of stations equipped with RF detection will not exceed 2000 per array, but could easily be fewer, depending on prototype experience.

The above estimate assumes that one can power the preamps and DAQ electronics from the supply at each station without substantial added cost. It also assumes that the “large-event trigger” will be available at each station. A further assumption is that the difference signal suffices to characterize the pulse. Additional preamplification and DAQ electronics may be required if this is not so. A major consideration may be the acquisition of antennas robust enough to withstand extreme weather (particularly wind) conditions.

For detection at frequencies above or below 50–100 MHz, the criteria are not yet well enough developed to permit any cost estimate.

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