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HIGH FREQUENCY RADIO PULSES FROM EAS

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ABSTRACT

Two radio receivers centered at 30 and 408 MHz, each with a bandwidth of 2 MHz have been simultaneously triggered by three plastic scintillators. Pulses from showers of energy $\geq 5.10^{15}$ eV have been observed. While no single well-defined pulses above noise have been seen at 408 MHz statistical analysis of all traces shows a positive significant increase at the expected position.

The 30 MHz system data show that about $\frac{2}{3}$ of the traces carry a radio pulse suggesting that most showers are accompanied by radio emission.

INTRODUCTION

The existence of coherent radio emission from extensive air showers (EAS) has been well established in the past four years by different groups (1,2,3,4,5).
The production mechanism of such pulses, although not definitely clarified, seems to favour the Earth magnetic field separation theory (6) against the charge excess (7).
The frequency range for coherent radio pulses goes from a few MHz to about 75 MHz (1,7,8).
Although coherent radio emission has been studied fairly intensively, it did not look very promising, since the very beginning, in a search for extremely energetic showers, because the counting rate of radio pulses per number of showers appeared to be about 1:100. Many authors (5,8) have noticed, in their analysis, a great number of small pulses at noise level, which suggested an emission from most showers, but below detectability which seemed to be bound to the antenna array and the restrictive coherence conditions. An incoherent radio emission at higher frequencies has been suggested by Rosenthal & Filchenkov (9).
In this line some preliminary experimental checks have been performed (11,12) with moderate success.
Radio pulses in the U.H.F. region would be of very high interest mainly because at high frequencies the noise temperature of the sky, as well as man-made interference, are much lower

than at meter wavelengths.

In this paper an experiment to investigate high frequency and low frequency radio pulses from EAS and their correlation will be described. The present observations were performed at Medicina, 50 m a.s.l. 25 Km East of Bologna, using the "Northern Cross" Italian Radio Telescope facilities. Showers were triggered by three plastic scintillators in coincidence.

To search for high frequency radio pulses an antenna was built at 408 MHz, a radio astronomy band and, therefore, interference-free. Simultaneously an array of four 30 MHz antennae was operated.

Pulses from both radio systems were observed and recorded on a dual beam oscilloscope when a shower was triggered by the scintillators.

1.-Description of the apparatus

The three scintillation counters were placed at the vertices of an equilateral triangle of about 40 m per side. The aerials were placed at one vertex of the triangle.

1.1.-Shower triggering system

Two of the plastic scintillation counters had an area of 0.7x0.7 m^2 and the third 1x1 m^2. The coincidence gate had a resolving time of 120 ns.

The pulse-height spectra of the three scintillators were taken with a pulse-analyser.

The discrimination levels were set up in such a way that the most probable energy of the triggering showers was $\sim 5.10^{15}$ eV. The shower counting rate was 3.2 showers/hour.
Such showers triggered a two-beam oscilloscope displaying both the 30 and 408 MHz signals on a 10 μs time base, and pictures of the events were taken.

1.2.-<u>408 MHz System</u>

The experiment was performed in two parts.
In the first part a 3 elements Yagi type antenna was used. The area of such antenna was 0.1 m^2 with a beam of 60° (at 3 db points).
In the second part of the experiment a new antenna was built, always centered at the frequency of 408 MHz but with 11 elements and a gain of 12 db. The area increased to 0.5 m^2 and the beam-width became 30°.
The antennae were E-W polarized and pointed to the zenith. The output signals of the antennae were mixed with a local oscillator, used by the radio telescope, at 378 MHz, then were amplified by a pre-amplifier and an IF amplifier, and finally detected. The detecting system was not changed during the course of the experiment.
The detected signals passed through a suitable delay line and were displayed on one trace of the oscilloscope.
The radio pulses were expected to appear after 6.3 μs on the trace. The overall recording system had a bandwidth of 2 MHz.

The whole receiving system was regularly checked sending a standard signal from a signal generator. In order to check against the possibility of spurious pulses from the electronics ,dummy loads were placed in place of the aerials and random triggering both from a pulse generator and feeding the output of one single scintillator into the discriminators were taken throughout the whole experiment.
No pulses were seen at the expected position during those checks.

1.3.-MHz system

Parallel to the small 408 MHz antenna a 30 MHz three-elements Yagi type antenna was operated with an area of $\sim 10\ m^2$ and a beamwidth of 60°. An array of four antennae was successively put in place of the single antenna. The antennae were located at each corner of a square of $\frac{3}{4}\lambda$ m in side and $\frac{3\lambda}{4}$ m above ground. The output signals were added by three hybrid rings and sent via a band-pass filter to a pre-amplifier, an IF amplifier and detector (10). The beam of the array was 30°, pointed to the zenith. The antennae were E-W polarized. The area of the array was 200 m^2 and the signals, suitably delayed, were displayed and photographed with the 408 MHz signals. The system was regularly checked as described for the 408 MHz.

2.-Results from the 408 MHz system

During the operation time with the three-elements antenna, about 1000 showers were recorded; no single pulse at the expected delay was seen,and from a statistical treatment, of the data no significant increase in the expected position was noticed. With the new 11-elements antenna 723 traces were analysed; only two pulses at the right position well above noise were observed, one of which appeared in coincidence with a pulse in the 30 MHz trace.

The vertical deflections of the traces were read at each microsecond for the first four microseconds, and every half microsecond from the fourth to the eighth, plus an extra reading at 6.3 μs.

The result is shown in fig.1; clearly the maximum at 6.3 μs is significant.

3.-Results from the 30 MHz System

While only one antenna was operated out of about 1000 showers triggered only 7 pulses could be considered as possible shower pulses. However no statistically significant information could be inferred also because,since no band-pass filter was used in this part of the experiment a large amount of interference appeared in the records. With the new aerial array using the band-pass filter as described above, 513 traces were recorded,and analysed.

Readings for each trace of the vertical deflections were taken at each microsecond from one to eight microseconds; intermediate readings at one half of a microsecond from four to eight plus an extra reading at 6.3 µs. as described for the 408 MHz were taken.

The total number of traces was devided, in a random way, into two halves. For each of the two samples the average deflection was found.

Results are shown in fig.2

From the similarity of the curves, taking into account the statistical fluctuations of the noise, the average pulse shape is identical. One can notice that from the two curves of fig.2 the rise time of the pulse appears to be smaller than 0.8 µs. Because of the high signal-to-noise ratio as shown in fig.2, it seemed reasonable to analyse the presence of the radio pulse in the single traces.

Table I shows the results of the analysis. In 2/3 of all traces the pulse is visible; as the vertical deflection increases the certainty of identification of a pulse rapidly increases.

Conclusions

Statistical treatment of the 408 MHz data suggests the presence of radio emission from EAS at high frequency, the enhancement at the expected position being statistically significant. In the present work no attempt has been made to investigate the nature of the emission mechanism at 408 MHz.

The estimated power for the average pulse-height amounts to $(1.7 \pm 0.3) \times 10^{-20}$ W,m^{-1} Hz^{-1} which corresponds to a field strength of $\sim$1.8 uV m^{-1} MHz^{-1}. These values are obtained taking an average of all the events recorded and analyzed. In this way a signal-to-noise ratio of $\sim$0.26 was obtained.

The 30 MHz results seem to confirm previous findings (5-8) that most showers are accompanied by a radio signal. In the present experiment no attempt was made to estimate the size of each single shower giving a certain radio pulse. The estimated power for the average pulse-height, obtained, considering all the events analyzed, turns out to be

$(2.5 \pm 0.1) \times 10^{-22}$ W m^{-1} Hz^{-1}, which corresponds to a field strength of $\sim$0.2 uV m^{-1} MHz^{-1}. The average signal-to-noise ratio is $\sim$2.8. From the results it also appears that the pulse shape, regardless of its height, remains fairly constant. This seems to suggest that the pulse shape does not vary much with the shower parameters' fluctuations.

However this effect could just be due to the narrow bandwidth of the recording system. Signal to noise ratio is, on the average, quite large. This seems to look promising for a highly efficient method of detecting EAS with $E > 10^{15} - 10^{16}$ eV.

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T A B L E I

<u>All traces</u>	
"Flat" Traces	7%
Traces with abs. max. in the interval 6–7 μs	66%
Traces without abs. max. in the interval 6–7 μs	27%
TRACES WITH VERTICAL DEFLECTION 7 ARBITRARY UNITS	
Traces with abs. max. in the interval 6–7 μs	86%
Traces without abs. max. in the interval 6–7 μs	14%
TRACES WITH VERTICAL DEFLECTION 12 ARBITRARY UNITS	
Traces with abs. max. in the interval 6–7 μs	93%
Traces without abs. max. in the interval 6–7 μs	7%

It can be seen that only a small proportion of traces had vertical deflections so small ("Flat" traces) that no pulses could be identified.

FIGURE CAPTION

Fig.1 Results obtained from statistical analysis of the 723 traces at 408 MHz.
The arrow shows the expected position of the pulse.

Fig.2 Results obtained from the 30 MHz system

———————— statistical analysis of 255 traces randomly chosen

- - - - - - - - - - statistical analysis of the remaining 256 traces.

The arrow shows the expected position of the pulse.

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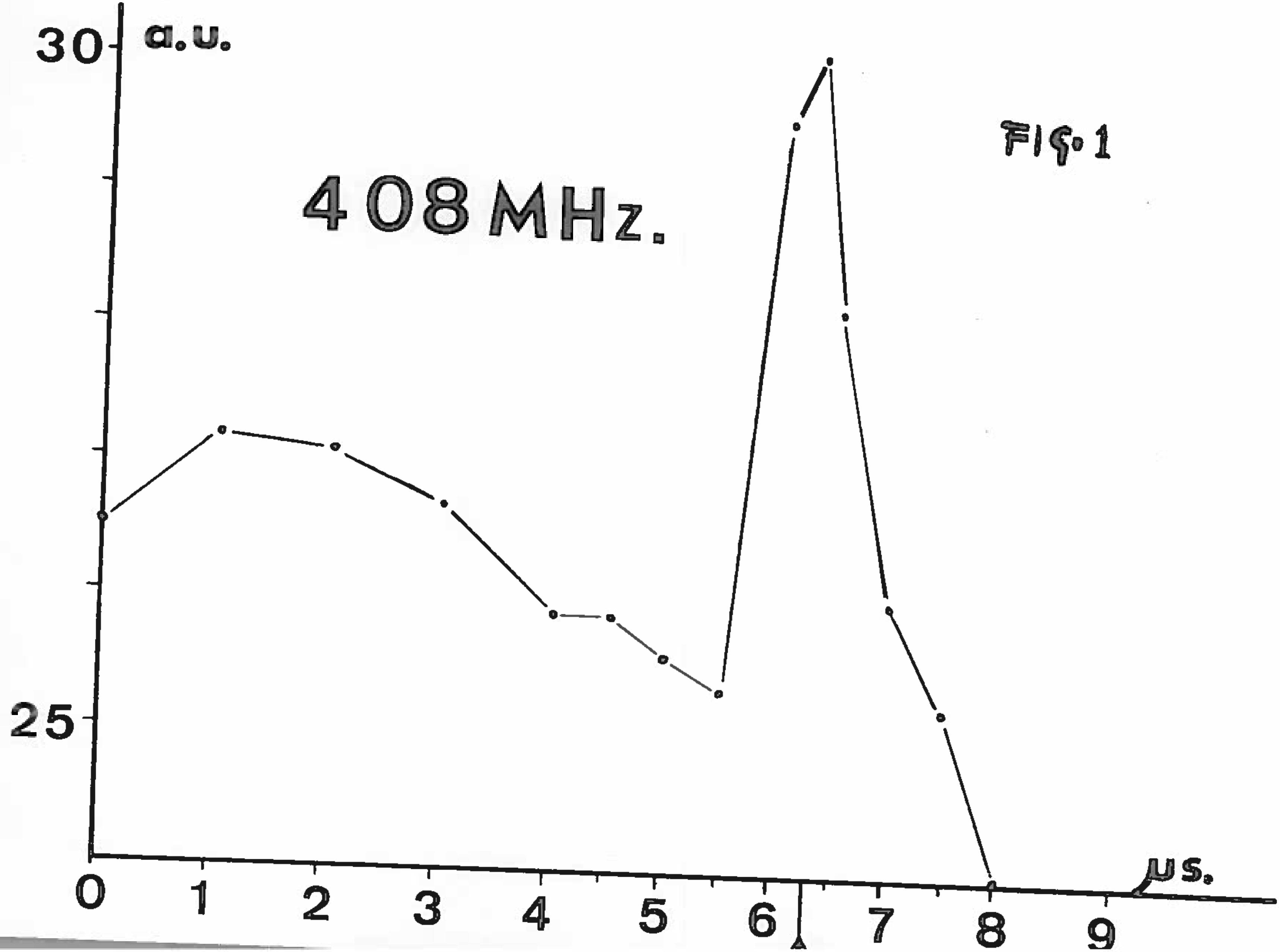

Fig. 1

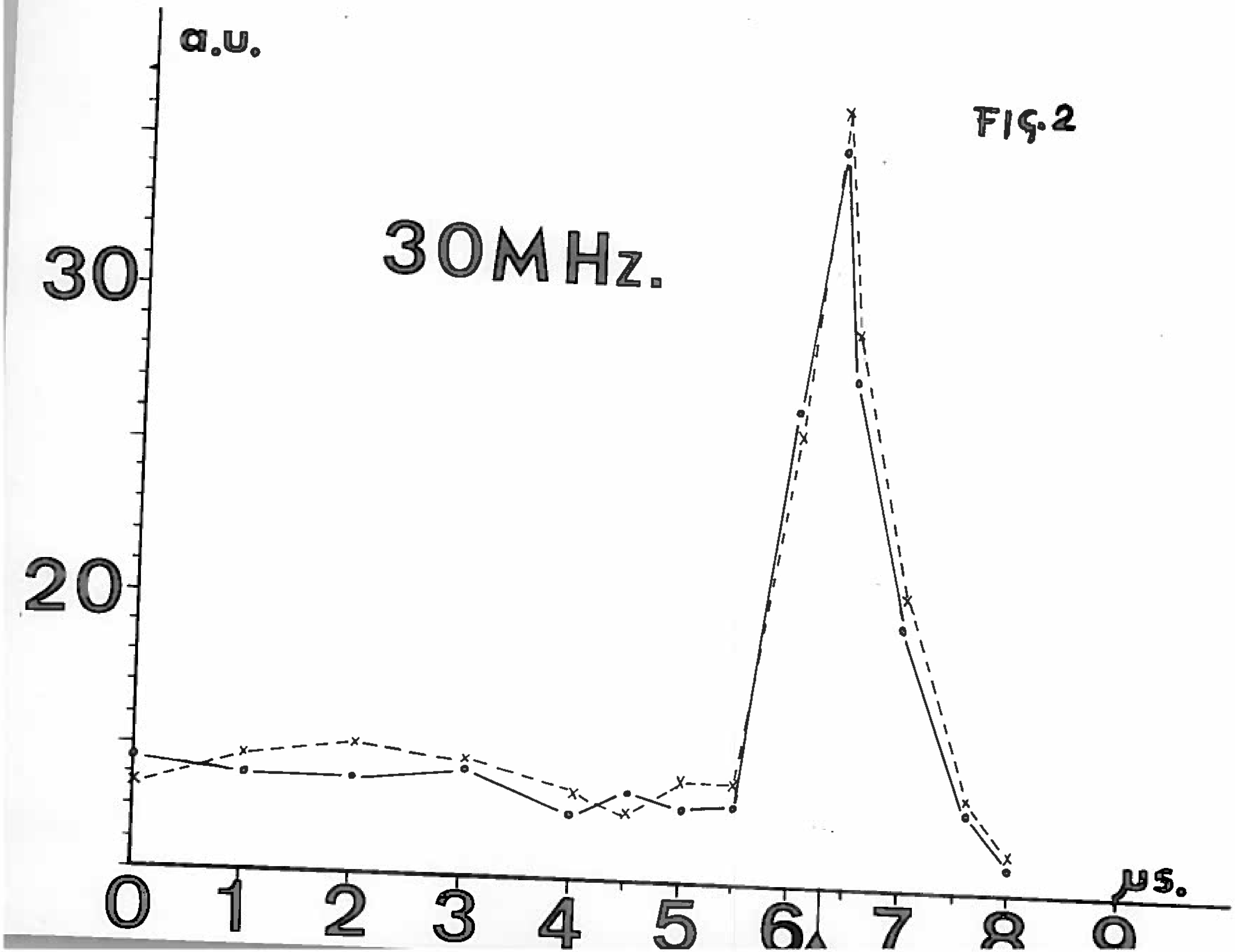

FIG. 2