# Radio Signals from Very Large Showers

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ABSTRACT

Radio signals from air showers with electron sizes in the range $1\times10^7$ to $2\times10^9$ have been detected at 50kHz, 170kHz and 1,647kHz at large core distances in the Akeno 20km$^2$ air-shower array. The field strength is higher than that expected from any mechanisms hitherto proposed.

**1. Introduction.** An experiment is being made to detect low-frequency radio signals from air showers observed in the Akeno 20km$^2$ air-shower array at large core distances. The motivation is a discussion on the possibility made by one of the present authors(K.S) at the Bangalore Conference in 1983(1) to observe giant air showers by detecting the low-frequency radio signal radiated from the electric current of air-shower particles due to the negative excess during the longitudinal development. And the experiment is an effort in seeking a method to detect air showers at a great core distance, which provides a huge effective area suitable to observe super giant air showers of very low flux beyond the 2.7K Greisen-Zatsepin cut-off, even if exists(2).

**2. Experimental.** Antennas are located in the yard of a closed primary school at a distance of about 2km from the center of the Akeno 20km$^2$ air-shower array(3), and the receivers and recording apparatus are set in the classroom. The recording of radio signals is made by a master pulse from the array sent through an optical-fiber cable.

Following two kinds of antennas are operated simultaneously:

(a) Ball antenna(4). A inverted metal cup, whose capacity to the ground is about 10pF, is fixed to the top of vertical glass-fiber pole of 10m and the potential difference of radio signal between the cup and the ground is measured. The preamplifier is enclosed in the metal cup, and the frequency response is flat from several Hz up to 10MHz with a gain of unity.

(b) Vertical wire antenna. A thin wire is stretched vertically along a glass-fiber pole of 10m. The preamplifier is set just above the ground, and the input stage consists of a capacity of 100pF parallel to a resistor of 20MΩ to the ground. The frequency response is flat from a few kHz up to 10MHz with a gain of 2.5.

The output of the preamplifier is sent through a co-axial cable(3C2W) to a receiver in the classroom. Following three kinds of receivers are operated alternately:

(i) Sony CRF1 commercial radio receiver(10kHz-30MHz). The output signal

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from the AM detection circuit is recorded at frequencies of 50kHz, 170kHz and 1,647kHz. The bandwidth is ±7kHz at -50dB.
(ii) Sony ICF2001 commercial radio receiver(150kHz-30MHz). The output signal from the AM detection circuit is recorded at frequencies of 170kHz and 1,647kHz. The bandwidth is almost same as the above receiver(i).
Following three kinds of recorders are operated alternately:
(I) Storage oscilloscope (Tektronix 7834, 400MHz).
(II) Storage oscilloscope (Tektronix 466, 100MHz).
(III) 1-100kHz passive band pass filter(BPF), low noise amplifier(×100, NF circuit LI75A), 17.4kHz active band elimination filter(BEF) and FFT (fast Fourier transform) signal analyser(100kHz, 12bit, Iwatsu SM-2100C). The display on CRT is made by a master pulse from the air-shower array and, then, the photograph is taken. The sensitivities of all combinations of the antennas and the commercial receivers are confirmed to be almost same at frequencies from 10kHz to 2MHz.

3. Recorded radio signals. Air showers accompanying radio signals observed well beyond the background noise at the output of commercial radio receiver are plotted with large open circles and those unaccompanying radio signals are plotted with small full circles in figure 1(170kHz) and figure 2(50kHz) for air showers with sec$\theta$($\theta$) smaller than 1.30(40°).

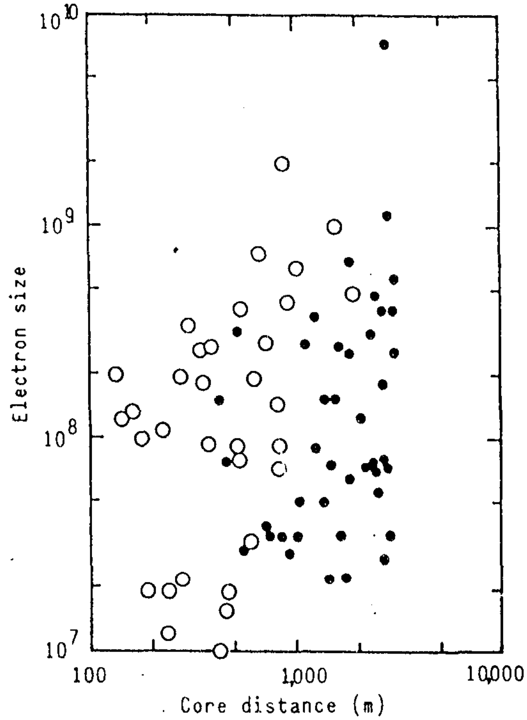

Fig. 1

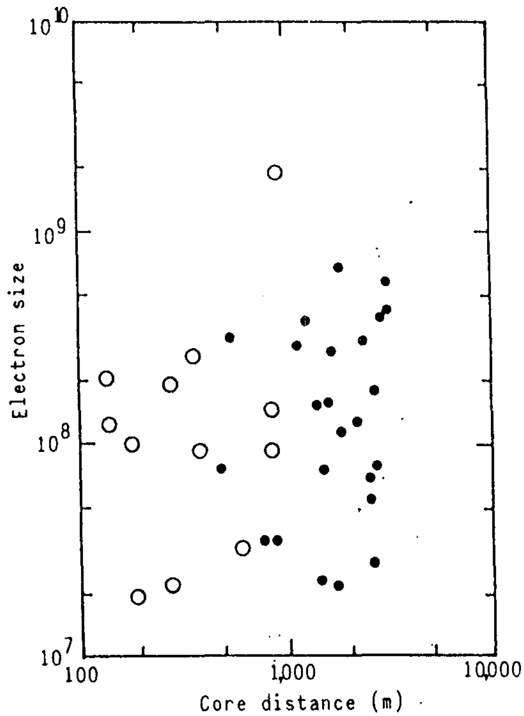

Fig. 2

The effective core distances for showers with zenith angles larger than 40° are somewhat longer. Radio signals were observed at 1,647kHz up to almost same core distances as at 50kHz. The effective core distances seem to be independent of the weather condition, such as clear sky, fog, cloud, rain, snow, humidity, temperature, and radio signals have been observed stabely during the intermittent operation in every months from December 1984 to May 1985.

The operation with the FFT signal analyser has been made in order to obtain information on the shape of radio pulse. The 1-100kHz BPF is used to cut intense local MF broadcasts and the 17.4kHz BEF an intense local VLF radio signal. A radio signal stored in the FFT signal analyser with a master pulse from the air-shower array undergoes the Fourier transform, and the real and imaginary parts at frequencies corresponding to man-made radio waves are erased. Then, after the inverse Fourier transform is applied, the reconstructed signal is displayed on CRT and is photographed. A wave packet was observed for a shower with the associated radio signal at the output of the commercial radio receiver. From these patterns of observed wave packets, the main component of frequencies of the radio signal associated with the air shower in the present experiment seems to be above 100kHz of the limit of the signal analyser, although the shape of the radio pulse is not known at present.

The field strength of the radio pulse observed in the present experiment can not be estimated accurately for lack of the knowledge of the pulse shape and due to an application of commercial radio receivers. However, the calibration of the radio receivers with pulses of various shapes and lengths seems to indicate that the field strength of the radio pulse peak may be higher than several mV/m at largest core distances where the radio signals were observed well beyond the background noise level as shown in figure 1 and figure 2.

4. Discussion. As is described in section 3, radio signals of 50kHz, 170kHz and 1,647kHz from the same air showers have been detected simultaneously at large core distances. The range of electron sizes is $1\times 10^7$ to $2\times10^9$ and the effective core distance extends to about 2km. The detection was stable and seems to be independent of the weather condition. Clay et al already reported the detection of radio signals from air showers with primary energies in the range $10^{15}$eV to $10^{16}$eV at a frequency of 100kHz (bandwidth 80 kHz)(5). However, the detection was unstable(5)(6).

The field strength of the radio pulse detected in the present experiment seems to be at least 100 times higher than that expected from the electric current of air-shower particles due to the negative excess during the longitudinal development. The field strength seems to be also at least 10 times higher than that expected from local reduction of the atmospheric electric field(A.E.F.) due to the acceleration of electrons produced by ionization of air-shower particles in A.E.F. discussed by Wilson(7). A plausible mechanism to produce radio signals detected in the present experiment seems to be radiation from electrons produced by ionization of air-shower particles in the atmosphere due to the acceleration in A.E.F.. The field

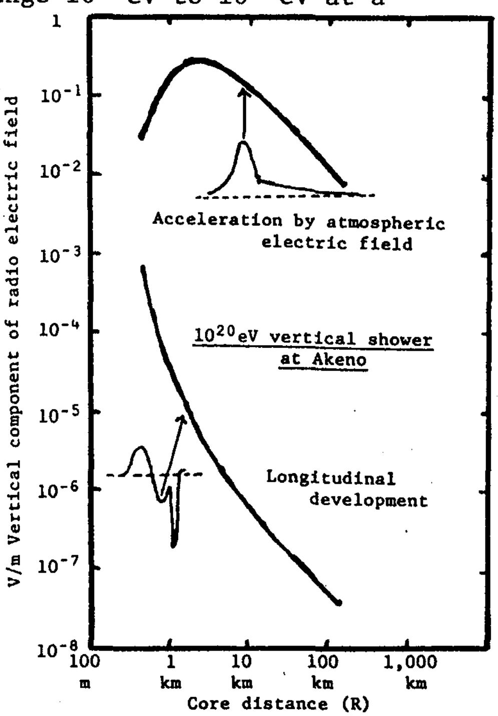

Fig. 3

strength of this radio pulse estimated for a vertical air shower with primary energy of $10^{20}$eV observed at Akeno is shown in figure 3, together with that of radio pulse expected from the net negative current of air-shower particles during the longitudinal development. The slow tail of the radio pulse also shown in the figure is due to the acceleration of ions produced by ionization of air shower particles in A.E.F. and contains a frequency component from several tens of Hz to 0.1Hz. This extremely low-frequency component is very important, since the frequencies of the Schumann resonance (earth-ionosphere cavity resonance) are 8Hz and 14Hz for the ground mode and the second mode, respectively. An experiment is undertaken with the ball antenna, a 20Hz passive low pass filter, the low noise amplifier, an active 5-20Hz BPF and the FFT signal analyser.

It is clear that further work to observe many air showers with electron sizes larger than $10^9$ is required to examine whether this low-frequency radio method is promising for providing a huge effective area of detection. It is also important to check whether the mechanism tentatively suggested above is accepted. For that purpose, the shape of radio pulse will be examined with a wave form recorder(20ns sampling, 10 bit) connected to the FFT signal analyser.

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