

9-22-2019

Creation of integrated system for registration radio emissions from high-energy extensive air showers at an altitude 3340 meters above sea level

M. Nassurlla
Satbayev University, Kazakhstan

T. Kh. Sadykov
Satbayev University, Kazakhstan

B. A. Iskakov
Satbayev University, Kazakhstan

Y. M. Tautayev
Satbayev University, Kazakhstan

K. Tastanova
Al-Farabi Kazakh National University, Kazakhstan

Follow this and additional works at: <https://www.ephys.kz/journal>

See next page for additional authors

 Part of the [Materials Science and Engineering Commons](#), and the [Physics Commons](#)

Recommended Citation

Nassurlla, M.; Sadykov, T. Kh.; Iskakov, B. A.; Tautayev, Y. M.; Tastanova, K.; Khabargeldina, M. B.; Zhumabayev, A. I.; Beisenova, A. D.; Haungs, A.; Novolodskaya, O. A.; Idrisova, T.; and Salikhov, N. M. (2019) "Creation of integrated system for registration radio emissions from high-energy extensive air showers at an altitude 3340 meters above sea level," *Eurasian Journal of Physics and Functional Materials*: Vol. 3: No. 3, Article 4.

DOI: <https://doi.org/10.29317/ejpfm.2019030304>

This Original Study is brought to you for free and open access by Eurasian Journal of Physics and Functional Materials. It has been accepted for inclusion in Eurasian Journal of Physics and Functional Materials by an authorized editor of Eurasian Journal of Physics and Functional Materials.

Creation of integrated system for registration radio emissions from high-energy extensive air showers at an altitude 3340 meters above sea level

Authors

M. Nassurlla, T. Kh. Sadykov, B. A. Iskakov, Y. M. Tautayev, K. Tastanova, M. B. Khabargeldina, A. I. Zhumabayev, A. D. Beisenova, A. Haungs, O. A. Novolodskaya, T. Idrisova, and N. M. Salikhov

Creation of integrated system for registration radio emissions from high-energy extensive air showers at an altitude 3340 meters above sea level

M. Nassurlla¹, T.Kh. Sadykov¹, B.A. Iskakov^{1,2},
Y.M. Tautayev^{*,1,2}, K. Tastanova², M.B. Khabargeldina²,
A.I. Zhumabayev², A.D. Beisenova¹, A. Haungs⁴,
O.A. Novolodskaya¹, T. Idrisova¹, N.M. Salikhov³

¹Satbayev University, Almaty, Kazakhstan

²Al-Farabi Kazakh National University, Almaty, Kazakhstan

³Institute of Ionosphere, Almaty, Kazakhstan

⁴Karlsruhe Institute of Technology, Karlsruhe, Germany

E-mail: tautayev@mail.ru

DOI: 10.29317/ejpfm.2019030304

Received: 19.07.2019 - after revision

At the High mountain station of cosmic rays at an altitude of 3340 meters above sea level in 2018, work on modernization of registration of radio emission from extensive air showers was carried out. To date, 4 radio antennas have been installed in the direction of north, south, west, east at a distance of 30 meters from the registration center. Registration is carried out in the frequency range 30 - 80 MHz. As a result of the preliminary experiment, some event candidates were selected that demonstrate the presence of a noticeable radio signal pulse in the vicinity of the nearest EAS arrival time 1 - 3 μ s. The features of the particle density distribution in these events suggest that most of them have a fairly high primary energy $E_0 > (2 - 5) 10^{16}$ eV and the shower center is close to the radio antenna, therefore the coincidence time of the observed radio pulse with the arrival time of the shower front in these events can not be completely random. Consequently, the radio antenna system installed on the Tien Shan, together with the developed software for recording the signal, really provides an effective choice of radio emission from EAS particles, and further work in this direction should be seriously considered.

Keywords: radio emission, radio antenna, pulse, shower.

Introduction

The study of the sources and mechanisms of the formation of cosmic rays of high and ultrahigh energies is a fundamental problem of astrophysics [1]. To solve this problem, particular interest is study of primary cosmic rays at energy range (10^{16} - 10^{19}) eV, where, as it is assumed, there is a transition from galactic (supernova explosions, pulsars, close binary systems, etc.) to extragalactic (active galactic nuclei), quasars, sources of gamma-ray bursts, etc.) to sources [2]. This energy region attracts special attention due to its importance for understanding the nature of sources and mechanisms of acceleration of ultrahigh-energy particles; moreover, the results of measurements at different facilities are very different in the region of limiting energies [3]. At energies $E_0 = 10^{15}$ eV, the possibility of direct measurements is already excluded, therefore, cosmic rays of high energies are studied, registering the products of their interaction with the atmosphere. As a result of the interaction so-called extensive air showers (EAS) are develop. Significant distances traveled by the shower during development allow many components to be born, among which were hadron, electron-photon, muon, neutrino, as well as Cherenkov and radio emission. At high energies, almost all elementary particles can be present in EASs, but mainly electrons, muons, γ quanta, neutrinos, Cherenkov radiation, fluorescence radiation and radio emission reach the Earth's surface (Figure 1).

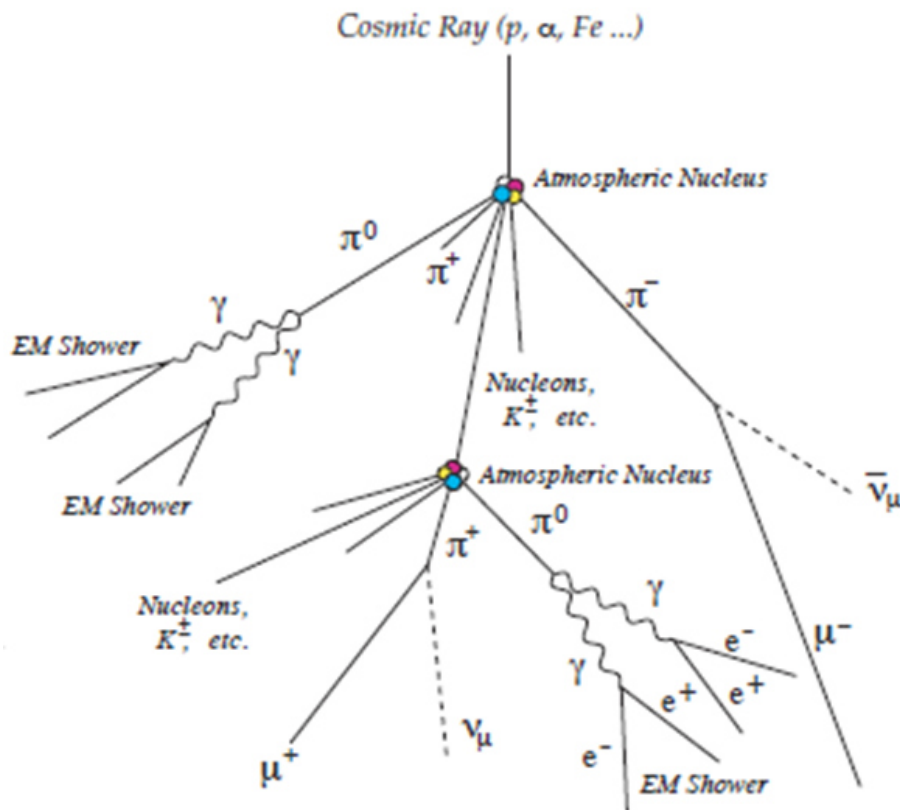


Figure 1. Generation of extension air shower.

In most existing facilities for studying high-energy cosmic rays, the charged component of EAS is detected. At the same time, significant differences still remain

in the results of measurements at different facilities. The latter is a consequence of both methodological and technical problems in the calibration of installations and significant fluctuations of the charged component of EAS, which ultimately leads to large statistical and systematic errors in the measurement results [4]. Significantly more accurate data on cosmic rays can be obtained using the method of observing EAS radio emission. The advantage of this method is due to the fact that the atmosphere plays the role of a giant calorimeter during the generation of radio emission, while the fluctuations characteristic of the charged EAS component are substantially smoothed out.

EAS radio emission generation mechanisms.

EAS radio emission is a complex phenomenon. In theoretical models, several types of radio emission generation contribute to the total radio emission, such as the Cherenkov radiation, the Askarian effect, the geo-electric mechanism, the geomagnetic mechanism, radio emission caused by ionization electrons in the field of atmospheric electricity, transition radiation from excess shower electrons, transition radiation from an EAS quasi static dipole, etc. To date, it has been found that the main mechanism for generating radio emission is the geomagnetic mechanism, which contributes the most contribution to the radio emission ($\approx 90\%$). Below are descriptions of the main mechanisms for generating EAS radio emission. Let's consider them in more detail.

Geomagnetic effect

The geomagnetic effect occurs when ultrahigh-energy particles pass through the atmosphere, at which a cascade of secondary high-energy particles is born. Due to high velocities, most of the particles are concentrated in a relatively thin front of the shower, which is called the disk [5]. The disk, which is supposed to be electrically neutral, contains a large number of electrons and positrons. Close to the shower core, the disk has a typical thickness of the order of a meter and moves to the Earth's surface at a speed close to the speed of light. Relativistic electrons and positrons in the disk under the influence of the Lorentz force are separated from each other due to the magnetic field of the Earth. This imposes a directional motion, independent of the charge, of the lateral movement of particles perpendicular to both the shower axis and the magnetic field, with the electrons and positrons moving in mutually opposite directions. Such a phenomenon has a formal similarity with the behavior of free electrons in a conductor when a constant potential difference is created in it. In both cases, such directed motion of the particles is an electric current, the value of which is determined by the magnitude of the charge passing through the conditional cross-sectional area. Such a transverse current in the shower can be considered as the cause of the polarization of the disk, which is neutral in general. When moving in a magnetic field, the positron disk and the electron disk move apart in opposite directions, forming an electric dipole, the direction of which coincides with the direction of

the transverse current. In that part of the shower movement, where the number of particles is close to the maximum, we can assume that in the transverse direction there is a dynamic quasi equilibrium, in which the number of particles born in the barrel is equal to the number of particles that leave the shower. Therefore, extensive air shower can be likened to a moving quasi static dipole, in which the transverse current supports the dipole moment. The polarization of geomagnetic radio emission is perpendicular to the Earth's magnetic field, therefore, radiation is observed mainly in the east-west direction.

Askaryan effect

The excess of electrons is a consequence of the annihilation of the positrons of the shower and the involvement of Compton and Delta electrons in the avalanche. During the development of EAS, the absolute amount of excess electrons changes, which leads to radio emission with radial polarization. An excess of electrons with an average energy can reach 10% of the total number of particles in the shower. With a large number of them, coherent radiation of an excess negative charge can reach high intensity. In the radio frequency wavelength range, an uncompensated charge in a shower can increase the intensity of Cherenkov, bremsstrahlung, or other types of radiation by orders of magnitude. This is due to the fact that in this region of electromagnetic waves the radiation intensity is proportional to the square of the frequency and the number of particles in the shower.

Installation for registration EAS radio emission

A convenient place for the development of the radio method for detecting EAS particles is the high-altitude cosmic ray station on the Tien Shan ($43^{\circ} 15' \text{ N}$, $76^{\circ} 57' \text{ E}$, 3340 m above sea level), where the facilities for a comprehensive study of EAS in primary energy range ($10^{14} - 10^{18}$) eV. It is possible to conduct experiments both on the direct detection of charged shower particles at the station level, and on recording Cherenkov light emitted above in the atmosphere. The inclusion of a system for recording EAS of electromagnetic radiation in the range of radio frequencies in this complex makes it possible to calibrate all three EAS research methods and allows you to set the accuracy limits for determining EAS parameters based on their simultaneous operation. In the future, with the development of experimental technology and the expansion of the detector system, the study of EASs with primary energy up to 10^{19} eV should be possible. This opens up the possibility of studying many still unclear problems, such as the primary composition, the anisotropy of the sources of cosmic-ray particles of ultrahigh energies, the features of their interaction with matter, etc., which remain until modern cosmic-ray physics.

As a detecting element, 2 loop antennas of the SALLA type (Short Aperiodic Loaded Loop Antenna) [6], oriented to the northwest and northeast direction, are used. This type of antenna, developed by German engineer Oliver Kroemer, has two main advantages: firstly, these antennas are inexpensive and easy to

manufacture, and secondly, their directivity pattern does not depend much on the underlying surface (Figure 2).

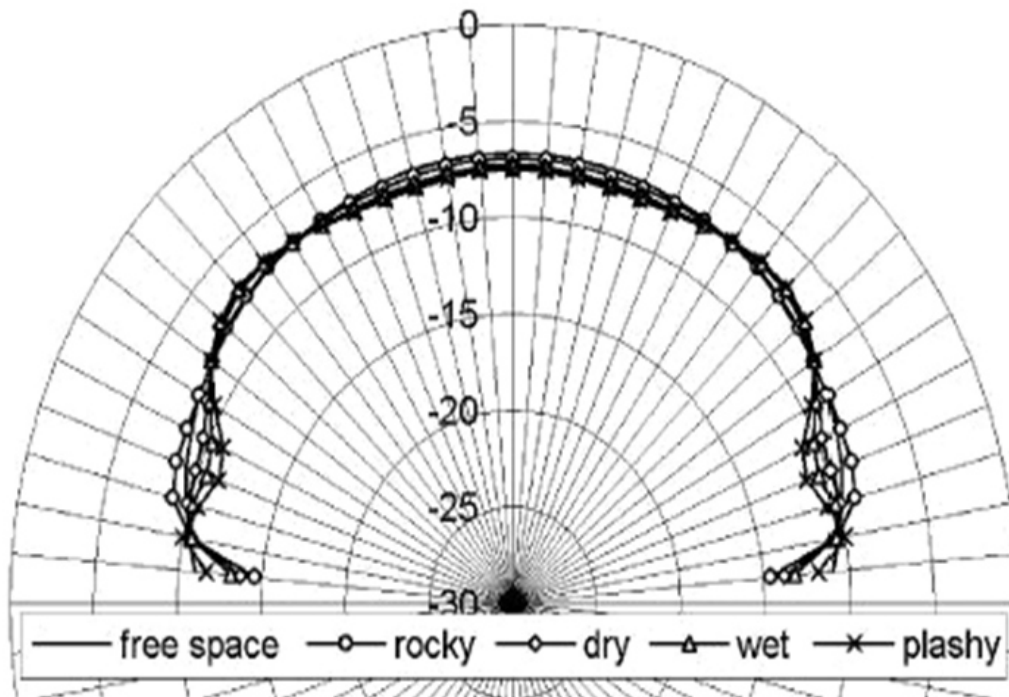


Figure 2. SALLA radiation pattern in the vertical plane for a frequency of 50 MHz. Different lines correspond to different types of surface: rocky, dry, marshy, wet.

Each antenna station is located 30 m from the registration point in the north, south, west, east direction and has two perpendicular antennas, which allows you to restore the polarization of the electromagnetic wave (Figure 3).

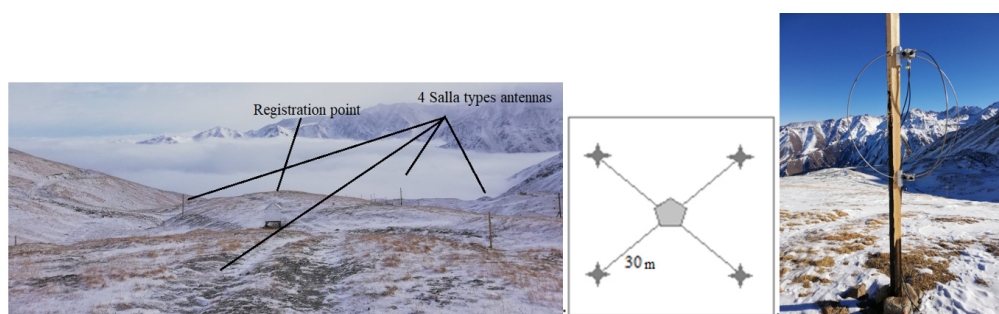


Figure 3. Location of antennas at an altitude of 3340 m above sea level. a) the location of the antennas, b) the schematic arrangement of the antennas at a distance of 30 m from the registration point, c) the radio antenna SALLA.

The antennas in the lower part are shorted to the load, and in the upper part they are connected via a matching impedance transformer to the broadband LNA preamplifier (Low Noise Amplifier - amplifier with a transmission coefficient of 24 dB, developed on the basis of the MGA-62563 chip). Further, the signal passes through a 30 meter cable RG213, which was dug to a depth of 40 cm of soil, to the center of the installation cluster on the filter amplifier (Figure 4). The filter amplifier has the following characteristics: a filter passband of (30-80) MHz, a gain of 32 dB,

a suppression of side frequencies of 46 over 90 dB. The signal amplified by the filter-amplifier is fed to the input of the ADC board of the Tunka-133 installation data acquisition system, where it is digitized with a sampling frequency of 200 MHz and a resolution of 12 bits.

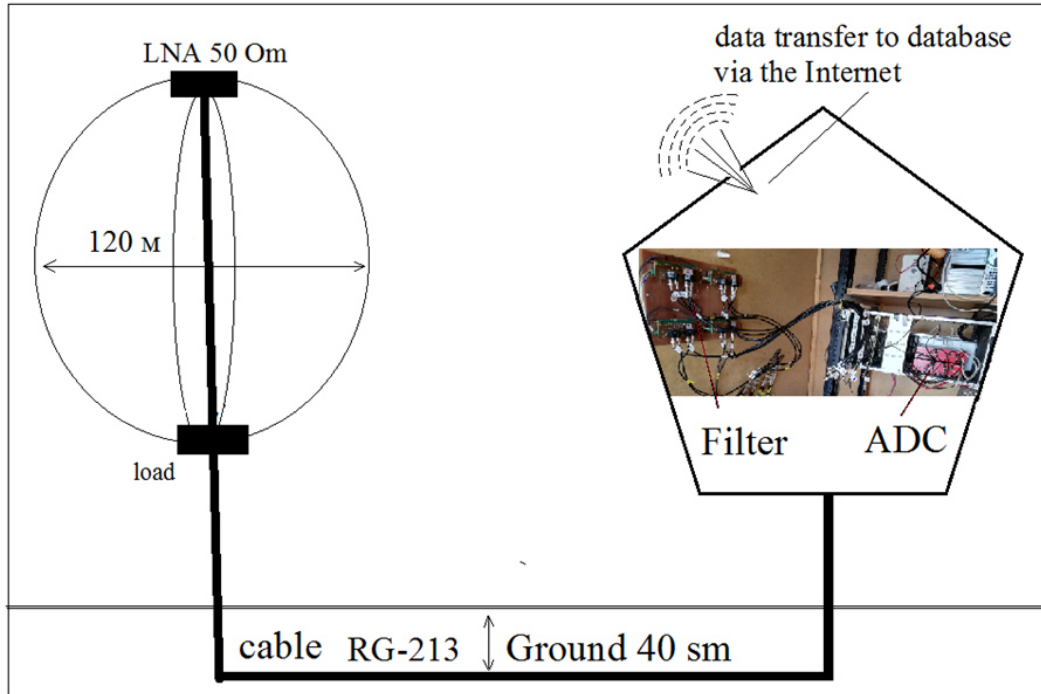


Figure 4. Connection diagram of the SALLA antenna.

A fast ADC system consisting of a pair of Italian-made CAEN DT5720 4-channel electronic modules was used to register the detected signal from the radio antenna installed in the experiment.

This system digitizes an analog input signal with a time resolution of 4 ns and stores in its internal memory a continuous record of the input signal history time, stored for at least several tens of microseconds. Currently, the outputs of all three antenna dipoles of point A1, and two horizontal dipoles at point A2 are connected to these ADC modules.

When registering a shower, the trigger signal generated by the shower system and the entire data set is stored in the internal memory of the ADC and transferred to a special program in the main control computer, and the latter, in turn, transfers this information to a common database. At the same time, the spatial distribution of particle density of EAS measured with a central carpet detector system is also loaded into the same database; these distributions can be used in the future to determine the parameters of the corresponding shower: the position of the center of the shower in the plane of the installation for the shower, the zenith and azimuth directions of the angles of the shower axis, the parameters of the age and size of the shower (the size has the physical meaning of the total number of particles in the shower. It is proportional to the primary energy of the particle E_0 , which generates the event, and can be used under some assumptions, for a direct estimate). All entries in the database are recorded with a time stamp at the time of registration of EAS with an accuracy of 1 second (in time zone, UT); The clock of the local data

recording system is checked continuously over the Internet and the time of GPS servers.

Conclusion

Customizable radio signal registration systems are mostly sensitive in the 30 - 80 MHz band. This system is designed to simultaneously work with the density of EAS particles and Cherenkov radiation detectors that are present at the station and allow mutual calibration of all these independent EAS research methods. In the future, using the EAS radio emission registration method, research is expected to increase the energy range of primary cosmic rays up to $E_0 \approx 10^{19}$ eV.

It is assumed that in the future, events with a noticeable EAS signal will serve as a prototype for developing an automatic algorithm for recognizing EAS radio emission events, which is necessary for the final version of the corresponding software package and any rigorous statistical studies.

Acknowledgments

The work was supported by the project No. BR05236291 of Ministry of Education and Science of the Republic of Kazakhstan.

References

- [1] E. Fermi, Physical Review **75**(8) (1949) 1169.
- [2] J. Abraham et al., Astroparticle Physics **27** (2007) 244.
- [3] V.A. Bednyakov, Physics of elementary particles and the atomic nucleus of JINR **33**(5) (2002) 1146.
- [4] A.P. Garyaka et al., Bulletin of the National Academy of Sciences of Armenia, Physics **48**(2) (2013) 79.
- [5] T. Huege, Proceedings of the 33rd international cosmic ray conference, Rio de Janeiro (2013).
- [6] O. Kroemer, Proceedings of the 31st ICRC, Lodz (2009) 25.