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Dependence of normalized phase angle of cosmic ray radio signals on core location of an extensive air shower

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Abstract
High energy cosmic rays hitting the earth atmosphere induce extensive air showers propagating downward with a high gamma factor. Determining the core location of such air shower is a necessary step to measure other important characteristics of a cosmic ray such as the lateral distribution function. In this study and based on computer simulations and radio signal analyses we investigate the relation between normalized radio signal phase angle emitted from particles in an air shower to the position of a shower core. We perform a series of simulations based on CORSIKA and COREAS code for cosmic rays with different types of primary particles with an energy range from 0.1 to 1 EeV. The results show a direct relationship between the average slope of normalized radio signal phase angle as a function of frequency to the absolute distance from extensive air shower core location. We have calculated the normalized radio signal phase angle to have the absolute minimum value at close distances to a shower core location. We discuss a possible approach to estimate core location with different types of virtual radio arrays.

Keywords: Semnan University Radio Array (SURA), Cosmic Rays, Radio Detection

1. Introduction

There are different approaches to detect cosmic rays and to determine their key properties either by direct measurements or by investigating air showers created as a result of a primary particle interacting with the earth atmosphere [1]. These researches are carried out to answer unsolved question about cosmic rays and their possible sources [2]. Other cosmic ray characteristics including mass composition has also been investigated to provide a better understanding of the cosmic ray spectrum [3].

Over the past decade, the radio detection of cosmic ray air showers with its advantages including a nearly 100 percent duty cycle, an inexpensive setup and the complementary features has been used in many different experiments to determine key parameters of cosmic rays either in a self-trigger setup or as a complementary element with other detection techniques such as particle detectors and fluorescence light detectors [4], [5]. These techniques have been used in different experiments to determine a cosmic ray property such as energy, type and mass determination [6], [7] through an investigation on the properties of an extensive air shower.

Early measurements showed possibility of detecting radio signals from cosmic rays to be coherent in the frequencies below 100 MHz [8], [9]. Because of the progress made in this field, it is now possible to determine some of the most important characteristics of a cosmic ray like energy, direction and type of primary particle from radio measurements only [10], [11]. Previous studies have also shown the possibility of determining an air shower propagation direction based on the lateral distribution analyses [12]. The other important parameter is a place where the extensive air shower axis hits the ground, the shower core. Determining the position of this point may lead to specifying other important properties of a cosmic ray.

Radio signals can be interpreted in different ways in order to obtain various types of information. The phase value of radio signals in one of such elements which we investigate in this paper. Based on previous studies we know that the shower front of a cosmic ray extensive air shower is not a totally flat surface and even the radio signals propagating toward the ground forms a hyperbolical shape [13]. As a result of that, a study on the phase of radio signals and more specifically on the “Slope of the Normalized Phase Angle (which we call