Harmonics in the cosmic ray solar diurnal anisotropy up to third have been experimentally observed. Very high statistics is required to investigate higher harmonics because of exceedingly small amplitudes. The GRAPE3-3 experiment located in Ooty, India contains a large area (560 m$^2$) tracking muon telescope that provides a high statistical record of muon flux ($\sim 4 \times 10^7$ per day). This allows measurement of tiny variations in cosmic ray intensity ($\pm 0.01\%$) caused by various solar phenomena. After making appropriate corrections for the efficiency of the detector and atmospheric pressure variations, a continuous stream of one year data was used to investigate the diurnal anisotropy. A fast Fourier transform based analysis revealed clear presence of the first three harmonics as well as the fourth harmonic for the first time. Further, a clear rigidity dependence of each of the four harmonics was also obtained.

Prior to obtaining the rigidity spectra of harmonic amplitudes, the median rigidity of the primary cosmic rays responsible for the production of muons detected in each direction of the GRAPE-3 muon telescope were calculated taking into account the effect of geomagnetic bending using a trajectory program and the standard geomagnetic field model called International Geomagnetic Reference Field 11th generation (IGRF-11) [6]. Atmospheric simulation of primary protons were performed using air shower simulation code CORSIKA [7]. An in-house developed program was used to simulate the muon detector response taking into the geometrical factors and various experimental conditions. The calculated median rigidity values varied from 64 GV to 141 GV across the 169 directional bins.

Data of 169 directional bins were combined into appropriate rigidity bins after correcting for the time offsets related to the Earth’s rotation and subjected to FFT analysis. Figure 5 shows the rigidity spectra for the four harmonics. The rigidity dependence of the amplitudes were derived by fitting a power law of the form $K \propto R^\gamma$, where $R$ was the median rigidity and $\gamma$ the spectral index. The spectral indices obtained from the fits for the first, second, third, and fourth harmonics were derived ($0.53 \pm 0.06$, $0.45 \pm 0.02$, and $1.81 \pm 0.04$, respectively).

The mean and the root mean square (rms) values of the phases obtained for various rigidity bins for the first, second, third, and fourth harmonics were derivded ($12.4 \pm 0.3h$, $47.4 \pm 0.2h$, and $90 \pm 0.2h$ local time, respectively. It is interesting to note that the phases of the four harmonics became nearly same if integral multiples of periods, namely, 12h, 8h and 2h are added to the second, third, and fourth harmonics. The phase values became $12.4 \pm 0.3h$, $12.7 \pm 0.2h$ and $12.9 \pm 0.2h$ in close phase agreement with the phase of first harmonic.

A comparison of the amplitudes of the first three harmonics from our observations provided good agreement with the results reported by others in the past. Further, the unambiguous observation of a fourth harmonic is new. The rigidity spectrum of harmonics over a wide range of rigidities with extremely high significance was measured using a single detector, namely, GRAPE3-3. The observation of similar phase for all the four harmonics show that these features could not be due to different physical processes. Our results support the unified model proposed by Bieber & Pomerantz [8] that allow generation of harmonics beyond second and the higher harmonics are believed to be manifestation of a common physical process.