One-chip Wave-Particle Interaction Analyzer for Space Plasma Observations

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The Wave-Particle Interaction Analyzer (WPIA) is one of the methods to perform the quantitative research of wave-particle interaction in space plasmas. In the present paper, we demonstrate the principle and significance of the WPIA which has the advantages over the conventional method applied to earlier studies. In the conventional way, we have examined the correlation between plasma wave data of frequency spectra and plasma particle data reduced velocity distributions to study wave-particle interactions. In this method, qualitative discussions are unavoidable and we frequently face the lack of the time resolution. In wave-particle interactions such as beam instabilities, energies of particles fluctuate at a characteristic time scale. Therefore, the time resolution of data should be high enough to trace the phenomena. The direction of the energy exchange between particles and plasma waves is defined by the phase relation of the particles and the plasma waves. The processes result in the appearance of fluctuations in the velocity distribution, which is calculated by integrating the data for more than a few seconds. This integration makes the fluctuation averaged and results in the disappearance of the valuable variation of the velocity distributions. Further, despite the importance of the phase relation of plasma waves and particles, the velocity distribution has already lost the information on the phase relation. Thus, there is much difficulty in the study of wave-particle interactions. To resolve these problems, data accumulation in the WPIA is conducted after considering the phase relation of Ew and v, where Ew is an instantaneous electric field vector and v is the velocity vector of a plasma particle. The WPIA measures an important physical quantity, $Ew*v$, which quantitatively represents the wave-particle interaction. As known in generally, $E*v$ is equivalent to the time variation of the kinetic energy of a single particle. The WPIA accumulates $Ew*v$ for a period longer than a few times of characteristic time scales in the target phenomenon. To calculate accurate values, the WPIA needs extra calculations such as calibration of waveforms of Ew and transformations of coordinate. In addition, synchronous control between data of Ew and v is necessary. Since the load of the WPIA processing is very heavy, it is very difficult to share the onboard CPU with other instruments on the real time basis. Therefore, we propose the one-chip WPIA, which is realized using the Field Programmable Gate Array (FPGA). The one-chip WPIA system can realize real-time processing with lower power consumption. We will show that our WPIA system properly operates on the FPGA, that the errors in the calibration of Ew is negligible with good Signal-to-Noise Ratio, and that the total power of our one-chip WPIA system is adequate to be an on-board instrument.