

Design of a Virtual Nuclear Pulse Signal Generator Based on Direct Sampling Method

Radioactive sources are essential in nuclear applications such as calibration of nuclear spectrometer and nuclear physics experiment. However, nuclear radiation brings security risks at the same time. If there is a pulse signal generator capable of outputting the same signal as the true nuclear pulse, the radioactive sources and the detectors can be replaced, and therefore radiation safety problems can be avoided.

The nuclear pulse signal meets the Poisson distribution in time and conforms to a specific probability distribution (energy spectrum) in pulse amplitude. The direct sampling method can obtain random numbers of arbitrary known distributions using uniformly distributed random numbers. Based on this idea, we developed a virtual nuclear pulse signal generator based on direct sampling technique.

The core of this design is the accurate calculation and generation of the randomness of the nuclear pulse signal. The workflow of the whole system is as follows: (1) The reference amplitude spectrum of the nuclear pulse signal is generated by the Monte Carlo simulation results of the interaction between the radioactive sources and the detectors. (2) The probability distribution of the pulse time interval is calculated from the intensity of nuclear radiation and the Poisson distribution of the nuclear pulse signal. (3) The amplitude and time interval random numbers of the pulse signal are generated from the uniformly distributed random numbers through direct sampling method. (4) The digital pulse signal is synthesized in the Field Programmable Gate Array (FPGA) according to these random numbers combined with the waveform characteristics of nuclear pulse signal. (5) The virtual nuclear pulse signal is output by a Digital-Analog Converter (DAC).

Experimental results show that the generator has a count rate of 2 MHz and a pulse interval accuracy of 10 ns. The normalized variance between the simulated pulse spectrum and reference spectrum is less than 10⁻³ for Cs137 gamma spectrum detected by NaI scintillator. Therefore, it can well satisfy the requirements for calibration and testing of nuclear spectrometer and nuclear physics experiment simulation.

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