Optik 149 (2017) 430–438

Contents lists available at ScienceDirect

Optik

journal homepage: www.elsevier.de/ijleo

Original research article

Detector random time delay compensation method for X-ray pulsar observation

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ARTICLE INFO

Article history:
Received 6 June 2017
Accepted 18 September 2017

Keywords:
X-ray pulsar observation
X-ray detector
Delay compensation
Deconvolution

ABSTRACT

For recent few decades, the observation for X-ray emission of pulsar is very popular. Among the multiple experiments, to construct the signal profile of X-ray pulsar is a significant one. During the observation, the X-ray signal photons of pulsars need to be collected by sensors in space. At present, the applied silicon-based X-ray sensors include Silicon Drift Detector (SDD), Swept Charge Device (SCD) and so on. Owing to the X-ray photons reach different places on the sensor at a time, the photon arrival time these detectors record always includes random time delay. This kind of delay will decrease the accuracy of detected signal profile. Therefore, studying how to compensate this delay is very necessary. In this paper, the principle how sensor time delay affects the signal profile is presented. Furthermore, based on the deconvolution calculation, a time delay compensation method is proposed. According to simulation and the hardware-in-loop experiments, it can be proven that the method can eliminate the effects of profile time delay and profile distortion. The method can support astro observation in space and X-ray pulsar-based navigation.

1. Introduction

Pulsar is a kind of neutron star which rotates very fast [1]. Its rotation axis and magnetic axis are not coincident and its two magnetic poles emit rays. Therefore when the rays sweep onto the sensors, the signal with time and energy information can be detected. The rotation periods of some pulsars possess high long term stability. It can compare with favorably with most excellent atom clocks [2]. Since 1993, a series of pulsar observation schemes are carried out. A large number of achievements are obtained. At present, X-ray pulsar observation springs up in domestic. The remarkable astronomical satellite of China, Hard X-ray Modulation Telescope (HXMT) [3], will be launched in 2017. There are three main payloads onboard HXMT, the high energy X-ray telescope, the medium energy X-ray telescope and low energy X-ray telescope. It plans to scan the Galactic Plane to find new transient sources, monitor the known variable sources, observe X-ray binaries and find and study Gamma Ray Burst (GRB) by Csl detector [4]. Furthermore, the first special pulsar-based navigation test satellite XPNAV-1 [5] was launched in 2016. Therefore, the pulsar signal processing based on the measured data will be a significant work in China in the future.

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http://dx.doi.org/10.1016/j.ijleo.2017.09.069
0030-4026/

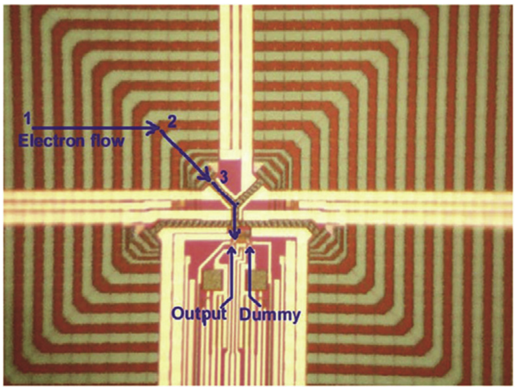

Fig. 1. Structure of LE sensing element [9].

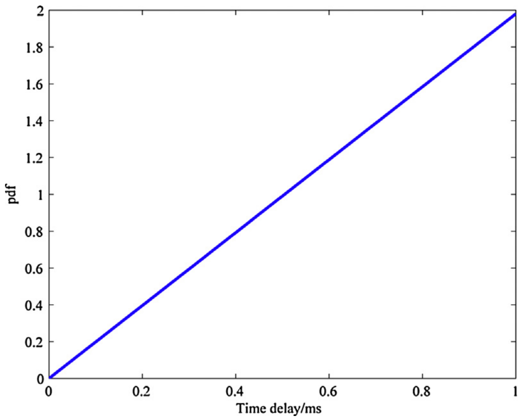

Fig. 2. The time delay distribution of LE.

One of important contents in measured data processing is profile construction of pulsar signal. In order to obtain high precious signal profile, it will take a long time for the spacecraft in orbit to collect X-ray photon's arrival time (Photon TOAs) in the direction of the pulsar. And then the method we usually use to construct the profile is epoch folding. The method includes three steps [6]. 1) Barycenter correction. 2) Uniform the collected TOA photon series to a single pulse period. 3) Divide the period into some equal Bins, and put the uniformed photons into their Bins. 4) Compute the number of the photons in every Bin, and plot the profile of the pulse. From here we can see that the precision of profile is limited by the precision of Photon TOAs.

To the silicon based sensors, a time delay response will affect the measurement precision of Photon TOAs. That is because the electron cloud excited by the X-ray photon need move to the electron readout terminal along a path. However, the position a photon arrives is random, so the length of the path that an electron cloud should move is also different. Therefore the time delay of Photon TOAs exist random characteristic [7]. The random characteristic is closely related with the design of a sensor [8]. In other words, the Photon TOAs collected by the sensor directly contain random error. So the profile constructed by these directly measured Photon TOAs will be distorted.

The low energy X-ray telescope (LE) is developed by Institute of High Energy Physics Chinese Academy of Sciences and e2 v cooperation of United Kingdom. It is specially used for the project of HXMT LE. LE is one of the main payloads on HXMT satellite, the range of energy detection is 1–15keV. The sensors in LE are called Swept Charge Device (SCD), and a single piece of SCD is shown in Fig. 1. SCD is a kind of special CCD (Charge Coupled Device). It is removed the position information of photons and the readout speed is faster. A special double output technology is used to decrease the common-mode noise. The area of every piece of the sensing element can reach up to 4 cm^2 [9].

The time resolution of LE is about 1 ms. According to the structure of LE's readout circuit, the delay distribution of the photon arrival time is triangular distribution which is shown in Fig. 2. The mean value of the time delay is about 500 μs [9].

Silicon Drift Detector (SDD) is another kind of silicon based X-ray sensor. At present, it has the best energy resolution in normal temperature environment. This kind of sensor is used for Mars rover, Moon rover and some novel spectrograph in USA. By the design of two-sided PN junctions, the collection electrodes are arranged in a very small area. Therefore, the energy resolution is very high. It can reach up to 150eV@5.9 keV for a 1 cm^2 SDD. In addition the time resolution is about 1–10 μs [10].