High resolution solar soft X-ray spectrometer

ZHANG Fei(张飞)[1,2] WANG Huan-Yu(王焕玉)[2] PENG Wen-Xi(彭文溪)[2]
LIANG Xiao-Hua(梁晓华)[2] ZHANG Chun-Lei(张春雷)[2] CAO Xue-Lei(曹学蕾)[2]
JIANG Wei-Chun(姜维春)[2] ZHANG Jia-Yu(张家宇)[2] CUI Xing-Zhu(崔兴柱)[2]

[1] Department of Modern Physics, University of Science and Technology of China, Hefei 230026, China
[2] Institute of High Energy Physics, Chinese Academy of Sciences, Beijing 100049, China

Abstract: A high resolution solar soft X-ray spectrometer (SOX) payload onboard a satellite is developed. A silicon drift detector (SDD) is adopted as the detector of the SOX spectrometer. The spectrometer consists of the detectors and their readout electronics, a data acquisition unit and a payload data handling unit. A ground test system is also developed to test SOX. The test results show that the design goals of the spectrometer system have been achieved.

Key words: solar X-ray, DAQ, PDHU, LVDS, 1553B

PACS: 07.05.Hd **DOI:** 10.1088/1674-1137/36/2/008

1 Introduction

A high resolution solar soft X-ray spectrometer (SOX) is being developed as a scientific payload onboard a solar exploration satellite. Its mission is to measure the solar X-ray 1–30 keV energy spectrum; study the evolution of thermal plasma and the characteristics of the X-ray radiation of solar flares; get the continuous spectrum and lines (mainly the Fe XXV line near 6.7 keV and the Fe/Ni line near 8 keV) of solar flare thermal radiation and the change in the thermal plasma temperature; and measure radiation emission and coronal abundances [1, 2].

2 The overall structure of the SOX spectrometer

The overall structure of the SOX spectrometer system is shown in Fig. 1. It consists of two-channel X-ray detectors (XD1/XD2), a data acquisition unit (DAQ), a payload data handling unit (PDHU) and a power supply system. The SOX spectrometer is powered by the +29 V primary power supply aboard the satellite. The regulators and DC/DC modules are used in the power supply system to generate +12 V, −12 V, +5 V and −5 V and −130 V. The LVDS bus is adopted to transfer data between the DAQ and the PDHU inside the SOX spectrometer. The 1553B bus with 1 Mbps bandwidth and the LVDS bus with 10 Mbps are used to transfer bidirectional telemeter/telecontrol messages and scientific data between the SOX and the satellite On-Board Data Handling (OBDH), respectively.

Two silicon drift detectors (SDDs) are used to measure the solar X-ray spectra in the energy range of 1–15 keV and 4–30 keV, respectively. The silicon

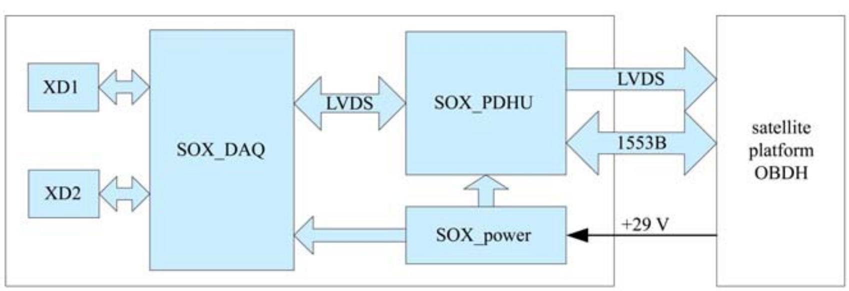

Fig. 1. The overall structure block diagram of SOX.

Received 7 May 2011, Revised 24 May 2011

drift detector with features of high resolution, small size, high count rate, internal integration of refrigeration [3], can precisely measure the solar soft X-ray.

As shown in Fig. 2, a SDD consists of a volume of fully depleted high-resistivity silicon, in which an electric field parallel to the surface, created by properly biased contiguous field strips, drives signal charges towards a collecting anode. A front-end n-channel Junction Gate Field-Effect transistor (JFET) is integrated on the detector chip close to the n+ implanted anode [4]. The extremely small value of the anode capacitance enables higher resolution at a short shaping time. Fig. 3 shows the detector efficiency curve of the 450 μm SDD with a 25 μm thick beryllium window. The detector efficiency for X-ray is about 100% at 10 keV and 15% at 30 keV.

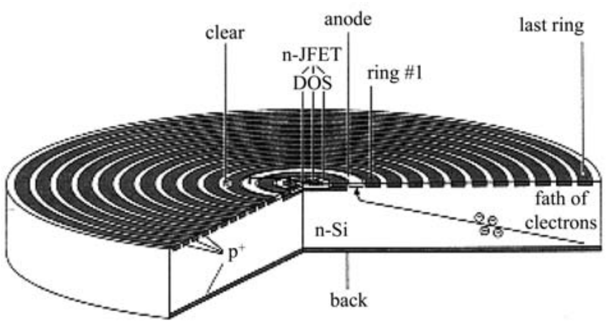

Fig. 2. The cross section of a cylindrical SDD with integrated n-channel JFET.

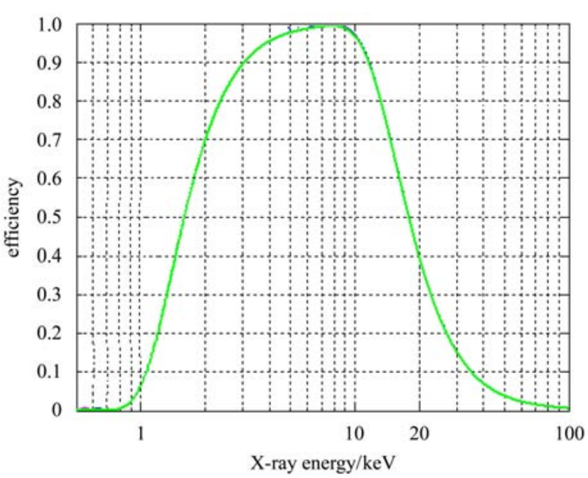

Fig. 3. The SDD efficiency curve (450 μm SDD with a 25 μm thick beryllium window).

3 Electronics for the SOX spectrometer

3.1 Readout electronics of the front detector

The readout electronics block diagram of the front SDD detector is shown in Fig. 4. The SDD is powered by the bias voltage (+12 V, −12 V and −130 V). The charge signal generated from the SDD detector (XD1/XD2) goes through the charge sensitive amplifier (CSA), the filter & shaper circuit, the pole-zero cancellation, the main amplifier and the baseline restorer. Finally the signal becomes a near gaussian shape and feeds to a DAQ unit. The detector also provides the temperature signal from the integrated temperature sensitive diode indicating the SDD working temperature.

3.2 SOX data acquisition unit

The data acquisition unit (DAQ) is responsible for the data acquisition of two detectors, housekeeping data monitoring (voltage, temperature, etc.) and data transfer through the LVDS bus between the DAQ and PDHU. Fig. 5 is the electronics block diagram of the SOX spectrometer DAQ unit. There are two identical data acquisition circuit modules for processing detector signals, housekeeping data monitoring, control chip FPGA, configuration PROM, LVDS transceivers and several other components.

The FPGA is the main logic control chip to realize all kinds of DAQ unit software functions. The induced signal of each channel detector (XD1/XD2) will be fed to discriminator and peak holder circuit simultaneously. If the signal amplitude is higher than the threshold of the discriminator where it passes through, a trigger event happens and the FPGA will start ADC to sample the peak holder signal. An external DAC controlled by FPGA is also adopted in the discriminator to generate different discriminating thresholds.

The DAQ unit has two operating modes: the normal mode and the burst mode. The FPGA will accumulate a block of energy spectrum per 5 seconds in normal mode and per 0.2 seconds in burst mode. When the event rate is higher than the threshold, it will automatically switch to burst mode from normal mode.

3.3 SOX payload data handling unit

The payload data handling unit (PDHU) is used to process telecommands, control DAQ system operation and communicate between SOX and the satellite OBDH. The electronics block diagram of the SOX PDHU is shown in Fig. 6. It contains the main control chip FPGA, the configuration chip PROM, the LVDS transceiver, the 1553B protocol chip BU-61580, the oscillator and voltage regulator chips. The FPGA loads configuration logic data automatically from the external PROM and starts to work as long as the power is on.

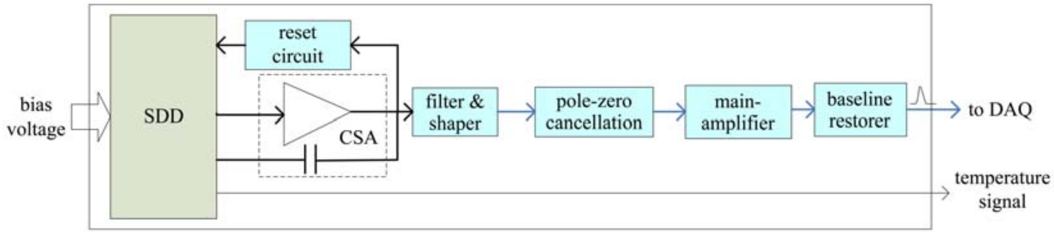

Fig. 4. The readout electronics block diagram of the front detector.

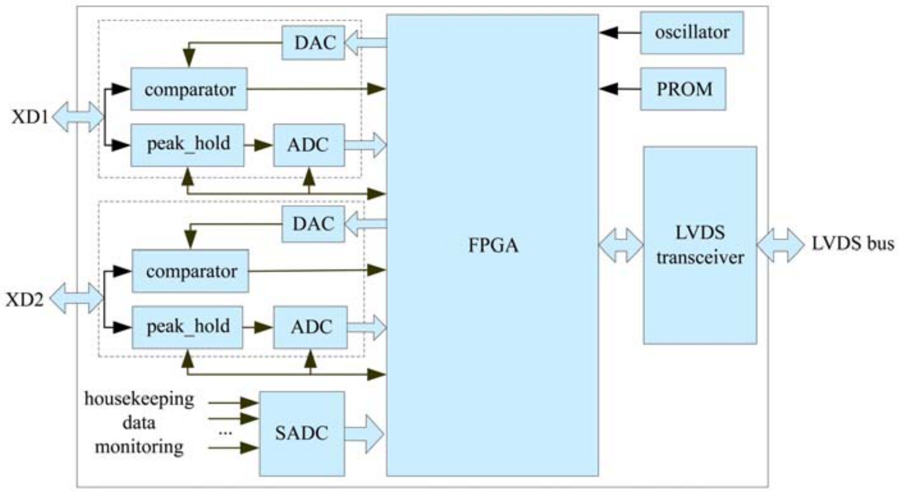

Fig. 5. The electronics block diagram of SOX DAQ.

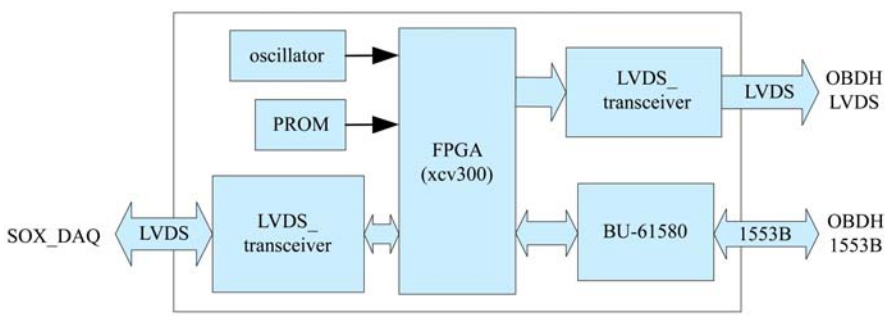

Fig. 6. The electronics block diagram of SOX PDHU.

The main functions of this FPGA are as follows:

(1) It controls the BU-61580 to act as a remote terminal (RT) and perform the 1553B bus communication between SOX and satellite OBDH.

(2) It transfers the 1553B telecommands to DAQ and receives kinds of data packets from DAQ.

(3) It transfers scientific data buffered in FPGA to satellite OBDH through LVDS bus.

4 SOX spectrometer test

A ground test system is developed to test the SOX spectrometer before the entire satellite joint test. It consists of a LVDS-to-USB converter board, a 1553B-to-PCMCIA converter card and application software on a PC. As shown in Fig. 7, the software on the PC provides a graphical user interface from which we can control the SOX spectrometer through the 1553B bus, get scientific data from the LVDS bus, process the data and display the results on-line.

The SOX spectrometer system can work stably in a 24 hour test. The basic electronics function has been realized. In normal work, the total power dissipation of the SOX system is lower than 10 watts.

In order to measure the electronics linearity, a series of gaussian pulses with increasing amplitude

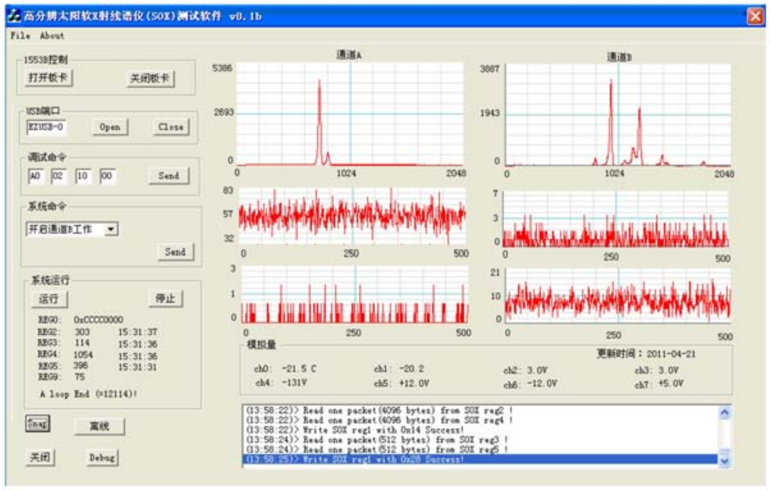

Fig. 7. The graphical user interface of the SOX ground test system.

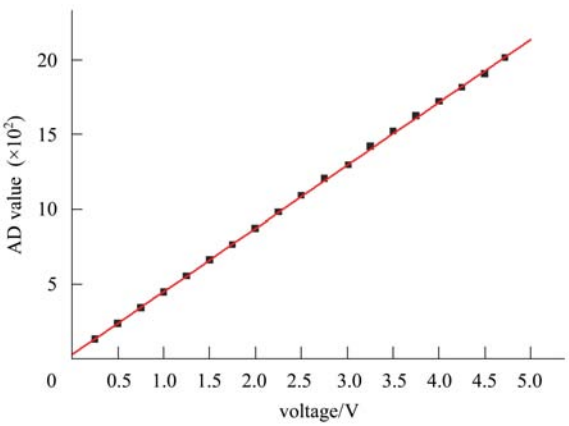

Fig. 8. The SOX DAQ electronics linear curve.

generated from a signal generator are measured by the DAQ unit of the SOX. A linear curve is shown in Fig. 8 with an integral non-linearity (INL) of less than 1.2%.

The energy calibration experiments were made to get the conversion relationship between channel and energy. The calibration data is mainly from the characteristic lines of different types of material (Mg, Al, Si, Fe/Ti, Cu, Zn) bombarded by X-rays generated from an X-ray tube. The energy spectrum lines of ^{55}Fe and ^{241}Am radioactive sources measured by SOX are also used as a supplement to calibration data. The calibration linear fit curves are shown in Fig. 9. The SOX spectrometer has a nice channel-to-energy linear relationship with a correlation coefficient of better than 0.99. The linear formulas are E=0.00766C+0.1446 for XD1 and E=0.01487C+0.1968 for XD2, where C is the channel value and E is the corresponding energy (keV).

In order to test the performance of the SOX spectrometer, we measured the ^{55}Fe and ^{241}Am source

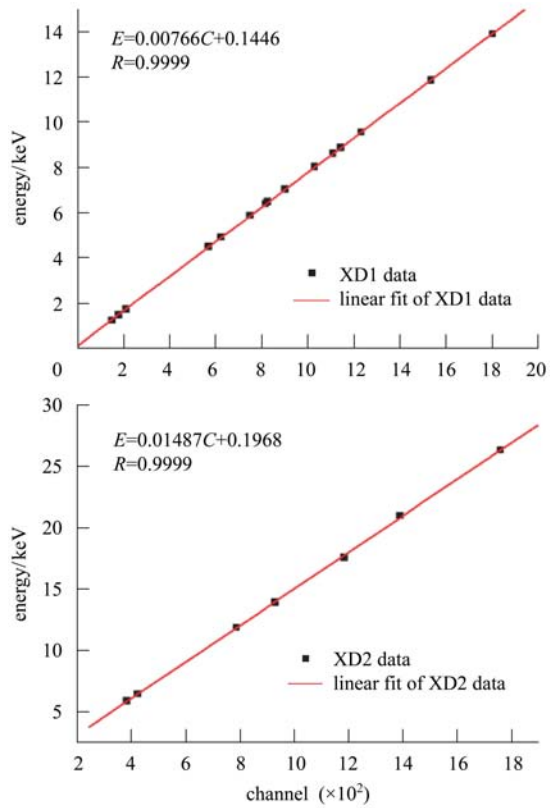

Fig. 9. The calibration linear fit curves of channel-to-energy conversion for SOX XD1 (left figure) and XD2 (right figure).

energy spectra using the SOX front detectors XD1 and XD2, respectively. The results presented in Fig. 10 show that the energy resolution (FWHM) is around 150 eV@ 5.90 keV and 165 eV@ 6.49 keV for XD1, 220 eV@ 11.87 keV, 250 eV@ 13.93 keV, 265 eV@ 17.61 keV, 270 eV@ 21.00 keV and 280 eV@ 26.35 keV for XD2.

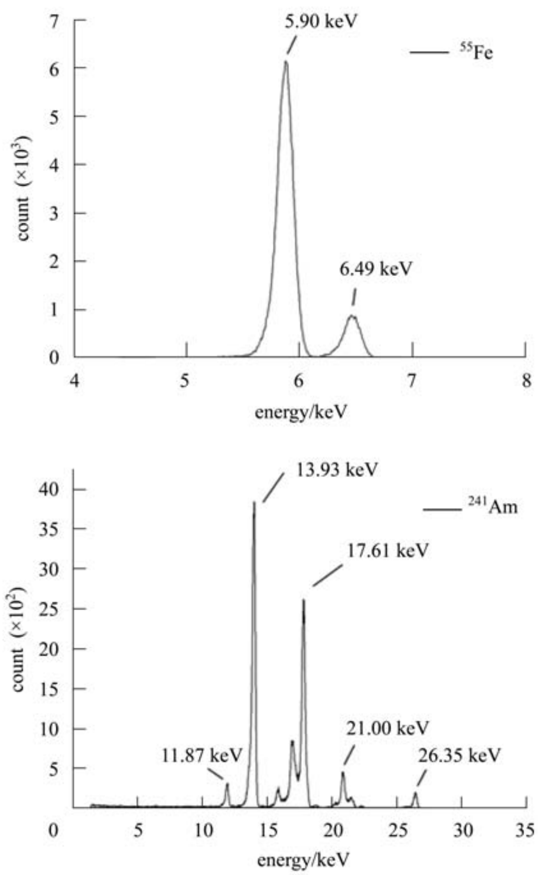

Fig. 10. The test spectrum of the SOX spectrometer at SDD temperature −25 ℃. The left figure is the ^{55}Fe spectrum measured by the SOX XD1 and the right figure is the ^{241}Am spectrum measured by the SOX XD2.

Table 1. The detailed peak energies.

	channel	energy/keV	characteristic lines/keV
P1	149	1.27	Mg-Kα (1.254), Mg-Kβ (1.297)
P2	183	1.55	Al-Kα (1.487), Al-Kβ (1.553)
P3	212	1.75	Si-Kα (1.740), Si-Kβ (1.832)
P4	368	2.96	Ar-Kα (2.957)
P5	397	3.19	Ar-Kβ (3.192)
P6	413	3.31	K-Kα (3.313)
P7	461	3.67	Ca-Kα (3.691)
P8	505	4.01	Ca-Kβ(4.012)
P9	569	4.50	Ti-Kα (4.510)
P10	625	4.93	Ti-Kβ (4.931)
P11	685	5.39	Cr-Kα (5.414)
P12	750	5.89	Mn-Kα (5.898)
P13	813	6.39	Fe-Kα (6.403)
P14	901	7.05	Fe-Kβ (7.057)

The X-ray generated by an X-ray tube is also adopted to bombard the plagioclase amphibolite. The fluorescence spectrum measured by the SOX spectrometer is shown in Fig. 11. The energy values of every peak in the fluorescence spectrum are calculated according to the above channel-to-energy linear calibration formulas. The detailed peak energies are shown in Table 1 from which we can distinguish the Mg, Al, Si, K, Ca, Ti, Cr, Mn and Fe characteristic lines.

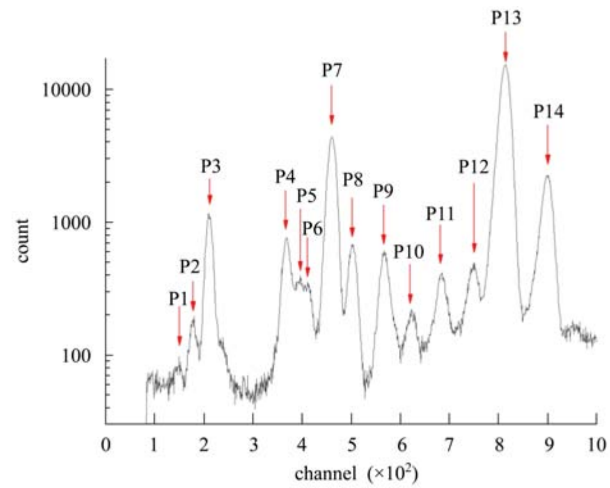

Fig. 11. The plagioclase amphibolite X-ray fluorescence spectrum obtained by the SOX spectrometer under the bombardment of X-rays from an X-ray tube.

5 Conclusions

The SOX spectrometer electronics is presented and the ground testing work is introduced in this article. The energy resolution of the SOX spectrometer is around 150 eV@ 5.9 keV (XD1) and 250 eV@ 13.93 keV (XD2) which satisfies the scientific requirements. The test results show that the SOX spectrometer can complete the solar soft X-ray spectrum measurement precisely in the range of 1–30 keV. To meet the reliability requirements of space mission payload, further efforts to improve the system design and perform several kinds of limit experiments will be made.

References

1 Jerry F. Drake. Solar Physics, 1971, **16**: 152–185

2 QIU Ke-Ping, TANG Yu-Hua, XU Ao-Ao. Process in Astronomy, 2004, **22**(3): 228–233 (in Chinese)

3 YANG Jin-Wei, ZHANG Wei et al. Nuclear Electronics & Detection Technology, 2004, **24**(4): 331–334 (in Chinese)

4 Peter Lechner, Stefan Eckbauer, Robert Hartmann et al. Nuclear Instruments and Methods in Physics Research A, 1996, **377**: 346–351