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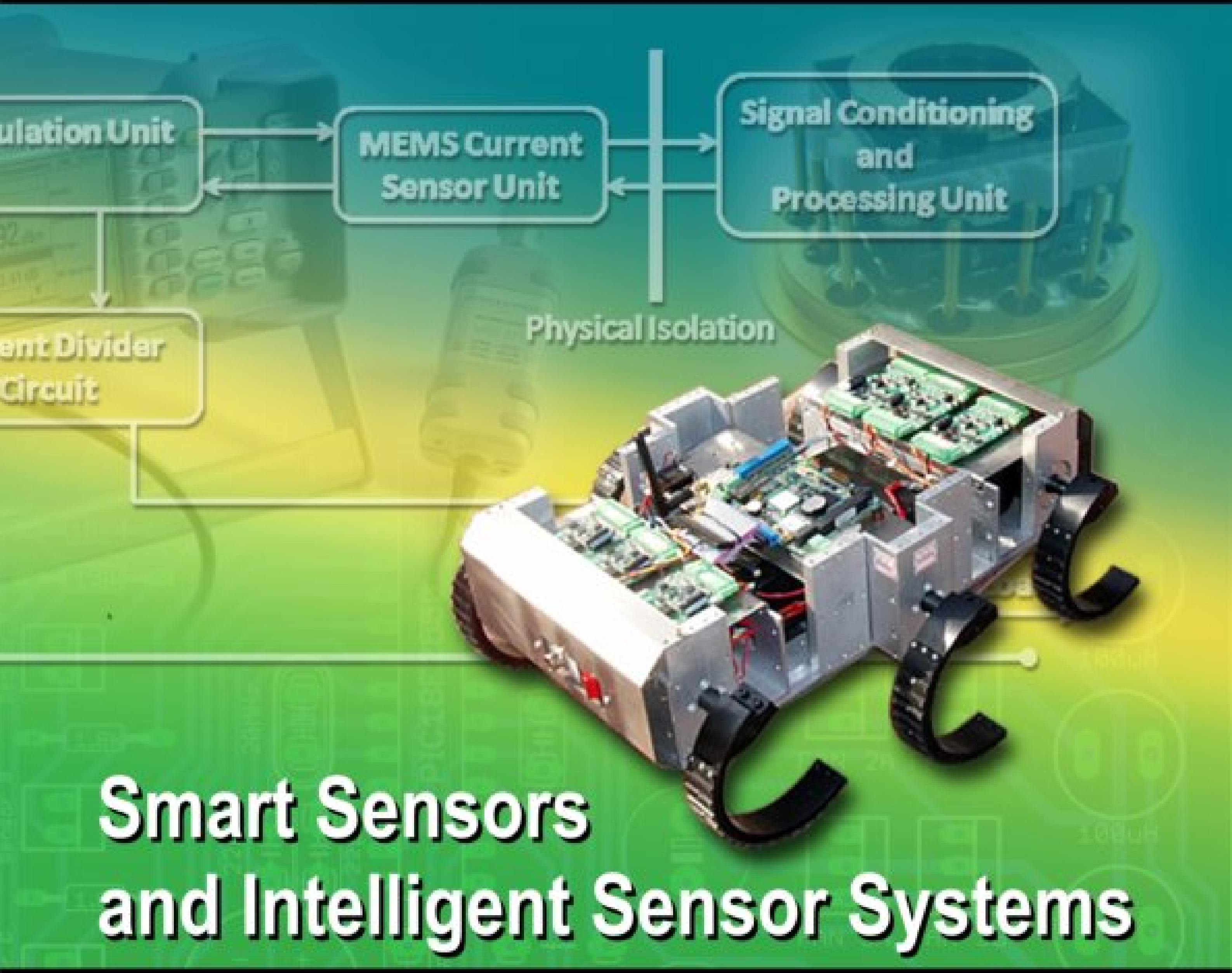

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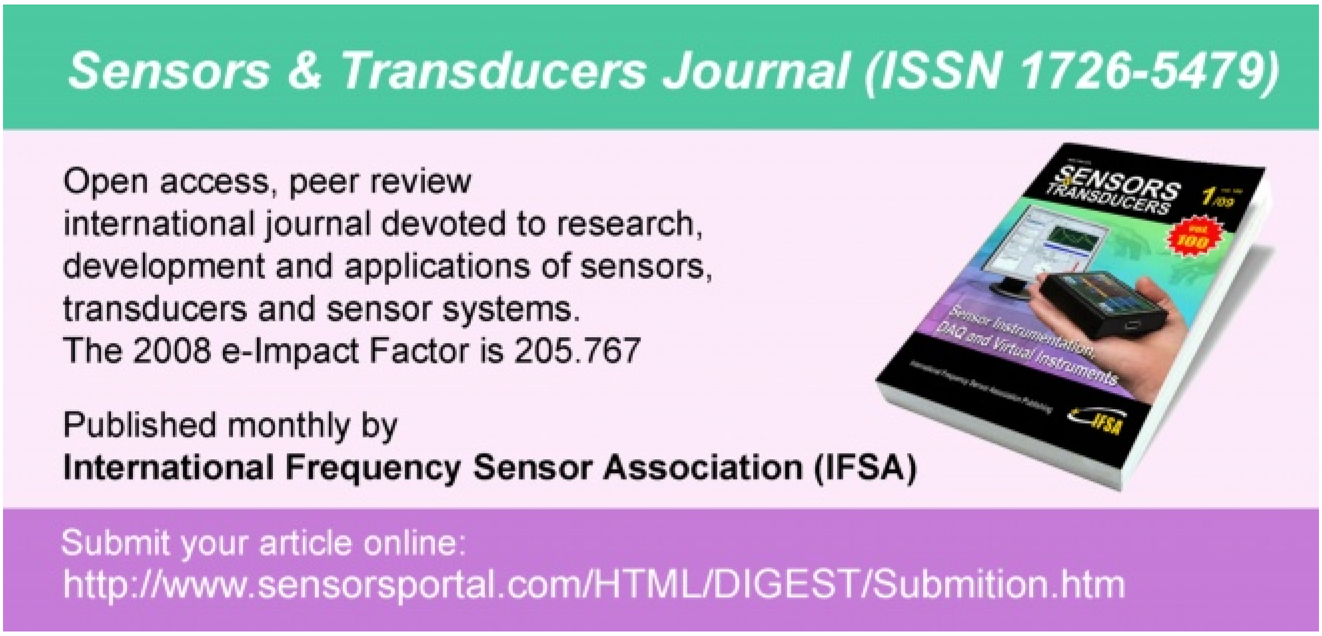

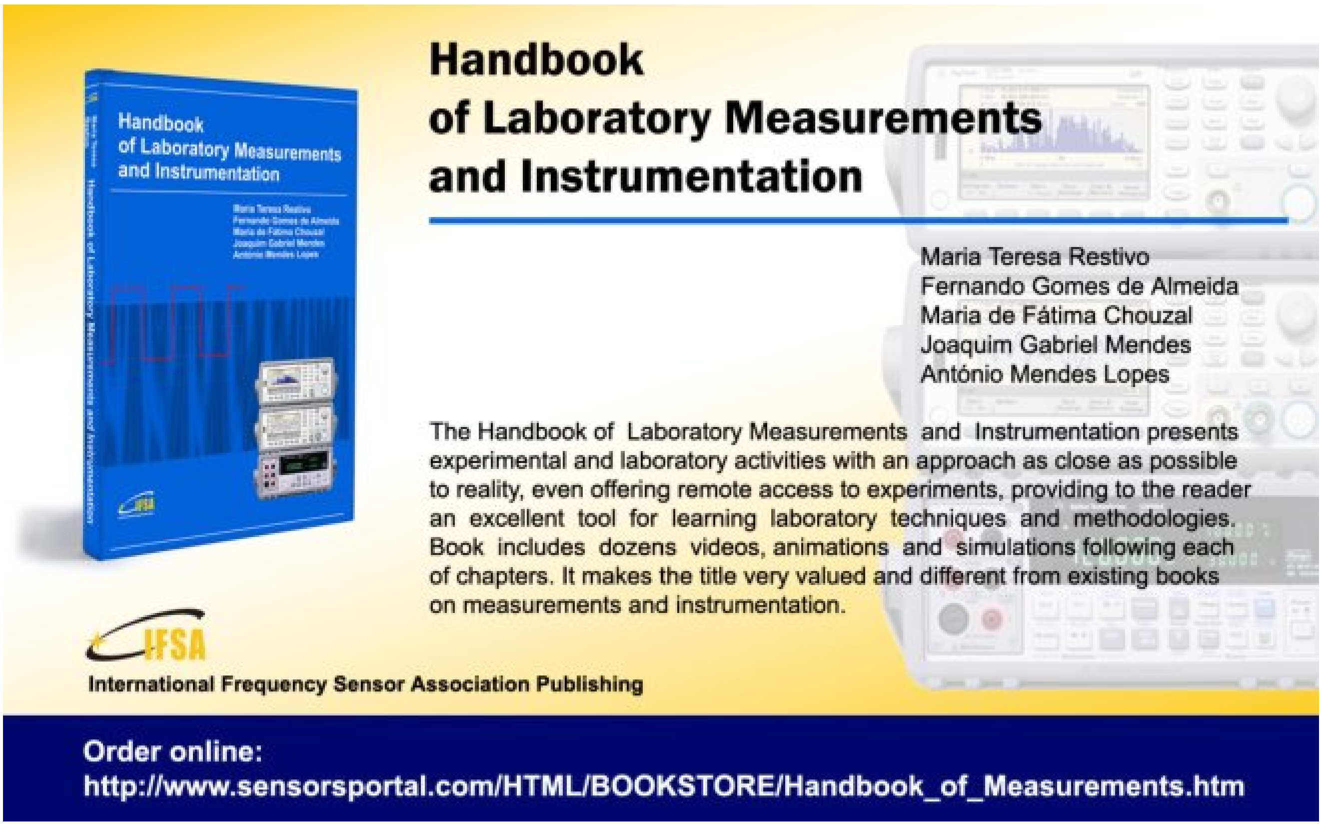

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A Compact X-ray Spectrometer Using Silicon Drift Detector

[1] M. Shanmugam, [1] Y. B. ACHARYA, [2] V. MISHRA, [2] P. N. PATEL,
[1] S. K. GOYAL
[1] Physical Research Laboratory, Ahmedabad, India
[2] Sardar Vallabhbhai National Institute of Technology, Surat, India
E-mail: shansm@prl.res.in

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Abstract: A compact, low power and low mass Silicon Drift Detector (SDD) based X-ray spectrometer has been developed for obtaining the elemental composition of unknown samples in the X-ray energy region 1 to 25 keV by non-destructive process. Elemental composition of the samples can be obtained by detecting the fluorescent X-rays from the unknown sample. The X-ray fluorescence from unknown sample could be due irradiation of the sample surface with artificial radioactive sources or by means of natural source like sun. The use of new technology X-ray detector such as SDD will provide good energy resolution for detecting the elements which are closely spaced ~150 eV. The developed X-ray spectrometer provides energy resolution (Full Width Half Maximum-FWHM) of about 150 eV at 5.9 keV with low energy threshold of <1 keV. Such instrument has a potential use in scientific analysis of unknown samples such as meteorites, rocks and soils etc. for obtaining their elemental composition. The design of X-ray spectrometer with various subsystems and performance results are discussed in the paper. *Copyright © 2012 IFSA.*

Keywords: Silicon drift detector (SDD), X-ray spectrometer, CSPA, Shaping amplifier.

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1. Introduction

Measurement of elemental composition of samples refers to identifying quantitative measurement of various elements in the sample such as Mg, Al, Si, K, Ca, Ti, Fe and other elements within the given energy range. Precise elemental composition of an unknown sample will give information on type of the sample composition which can be correlated to the origin of the sample. It could be a source asteroid planet in case of meteorite samples or it could give information related to evolution process and recent surface alteration processes from where the sample has been collected. While dealing with extraterrestrial samples, which are precious and sparse, it is often required to get the composition information without destructing and/or contaminating the sample, calling for special techniques.

The idea is to develop a laboratory X-ray spectrometer with low mass, low power and compact instrument for such measurements. Though Si PIN and SDD based X-ray spectrometer instruments are available off-the-shelf from AMPTEK, USA and KETEK, GmbH, the developed instrument uses components which are available in space qualified package by keeping in mind that the instrument can be suitably modified to use in any upcoming planetary missions. Towards this direction, an X-ray spectrometer has been developed to identify the elements in the energy region 1 to 25 keV (which covers K X-rays of most major elements of interest). In recent years missions such as Mars Exploration Rover (MER) [1], Selene [2] and Chandrayaan-1 [3] have carried X-ray spectrometers for obtaining the elemental composition of the planetary bodies through insitu and remote sensing techniques.

2. Detector Selection and its Properties

We have considered various available semi-conductor X-ray detectors suitable for the X-ray spectrometer development. Use of thin Cadmiun Telluride (CdTe) or Cadmiun Zinc Telluride (CdZnTe) compound semiconductor crystals would meet the requirement but the energy required to create an e-h pair is large (~5 eV) [4] and hence the signal amplitude is very small for the given X-ray photon which will eventually decide the low energy cut-off of the instrument. On the other hand thin crystals of Ge, which require ~2.8 eV per e-h pair, would give better energy resolution but requires cryogenic cooling for its operation with increasing the complexities of the experiment.

Thus only practical option is Si crystal which requires ~3.6 eV per e-h pair. Thin Si detectors can be used in two different configurations, Si-PIN and Silicon Drift Detector (SDD) for the X-ray spectrometer instrument. Si-PIN detector has larger detector capacitance due to its area type electrodes, which results in higher noise with energy resolution of ~300 eV @ 5.9 keV. SDD is functionally similar to a Si-PIN photodiode but has different electrode structure resulting in very low detector capacitance and therefore, under similar operating conditions, the SDD gives better energy resolution than a Si-PIN of same size.

2.1. Silicon Drift Detector (SDD)

The SDD concept was first introduced in 1984 by Gatti and Rehak [5]. The first circular SDD, optimized for energy was described in 1985 by Rehak and Gatti [6]. The early drift detectors used drift rings on both sides to produce the radial field. In 1987, Kemmer [7] introduced a design using a planar contact on one side with drift rings on the opposite side. SDD detectors with such contacts are commercially available for various applications and the research still continues for further improvements [8].

The primary innovation of SDD devices with the implementation of concentric rings in the detector surface which are applied with progressively higher reverse bias voltage. The applied bias voltage creates electric field line, which guides the photo-electrons generated on X-ray interaction in the detector volume to a "point" anode. The artistic representation of SDD cross section is shown in Fig. 1.

The detector capacitance between point anode and cathode has been minimized with such electrode configuration, and hence the low leakage current that allows the SDDs to operate at around -35^{o}C. Such operating temperature can be achieved by simple Peltier coolers provided with the detectors. In recent years, SDDs are also available with Field Effect Transistor built lithographically during the semiconductor process [9]. Such technology further improves the energy resolution by reducing the noise induced between the SDD and the preamplifier by eliminating the interconnection wires.

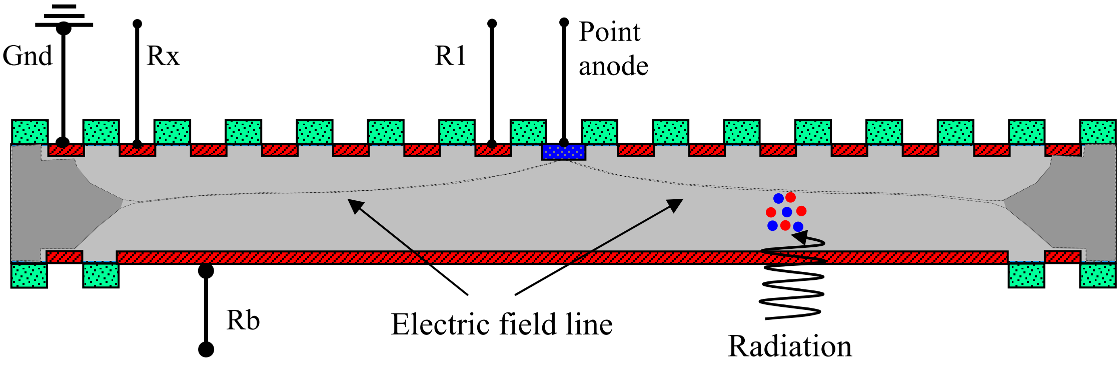


Fig. 1. Artistic representation of SDD cross sectional view, (Rx, R1 and Rb indicates bias voltage applied to outer ring, inner ring and back contact respectively, Courtesy KETEK, GmbH).

2.2. SDD Module and its Properties

The SDD used in the experiment has the detector active area 30mm^2 with detector thickness of 450 micron procured from KETEK, GmbH. These SDDs are available in the form of modules, which contain SDD, FET, charge integration capacitor, reset diode, temperature diode sensor and Peltier cooler. The point anode of the SDD is connected with gate terminal of the FET, charge integrating capacitor and the reset diode. The other terminals of the FET (Drain, Source and Substrate) are available externally for biasing and charge collection through an external charge to voltage amplifier. Another terminal of the charge integration capacitor is connected to output of the charge to voltage conversion amplifier and the reset diode is connected with the circuit which automatically generates the reset pulse based on the signal level at the output of the charge to voltage conversion amplifier.

The front face of the detector is protected with 8 micron thick Beryllium (Be) window which allows the electromagnetic radiation >1 keV to penetrate and interact with the detector. The low energy cut-off of the instrument is limited by the 8 micron thick Be window which is about 1 keV. The detector module has 12 pins for electrical interface arranged in four sides with three pins in each side. The detector also has heat sink for heat dissipation which is due to Peltier cooler. One such detector module from KETEK, GmbH is shown in Fig. 2.

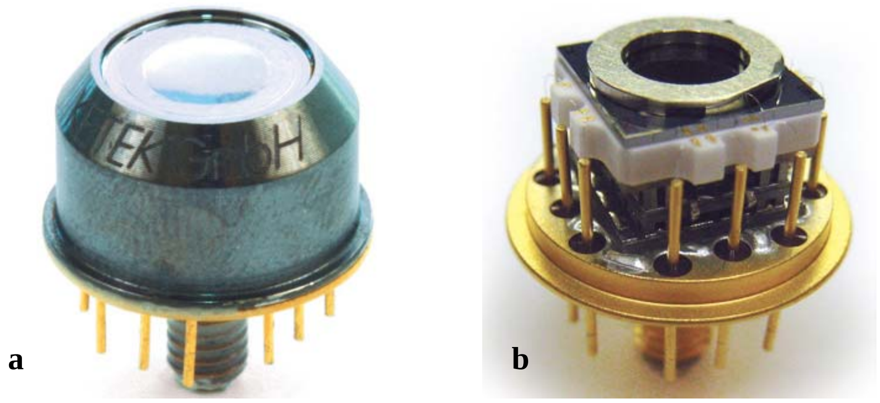


Fig. 2. View of a SDD module: a) SDD module enclosure; b) Internal view. (Courtesy KETEK, GmbH).

3. Design of SDD Based X-ray Spectrometer

The block schematic of the developed SDD based spectrometer is shown in Fig. 3. It consists of SDD module coupled with heat sink mechanism for dissipating the heat generated by the inbuilt Peltier cooler followed by Charge Sensitive Pre-Amplifier (CSPA) for charge to voltage conversion. The induced charge carriers due to X-ray interaction is collected by applying high voltage biases of about -130 V, -60 V and -20 V on Rx (Outer ring), Rback (Back contact) and R1 (Inner ring) of the SDD module (see Fig. 1). The output of CSPA is ramp signal with steps in the ramp indicating energy of X-rays interacting with the detector. These step pulses are converted into near Gaussian pulses using Shaping amplifier.

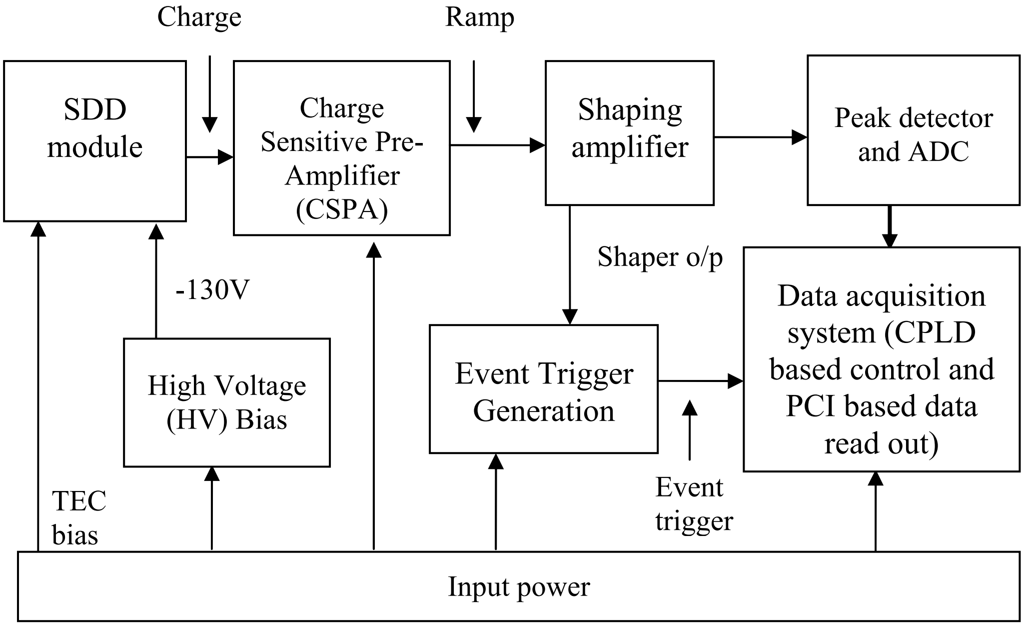


Fig. 3. Block schematic of SDD based X-ray spectrometer.

In a normal X-ray spectrometer, the shaper output is given to a standard Multi Channel Analyzer (MCA) to obtain the spectral information of the sample. Since this effort is in the direction to make a compact spectrometer, shaper output is further processed such that it can be suitably adapted for space use without much design changes. Therefore the shaped output pulses are passed through peak detector to hold the peak signal amplitude for analog to digital conversion. 12 bit serial ADC has been used in the experiment which has the conversion time of 8.5μs. The output of the shaping amplifier is also fed to event reference generation circuit, which is used to initiate the digital signal processing. The digital system is designed using Complex Programmable Logic Device (CPLD) for controlling the peak detector and ADC. CPLD based system also has interface with PCI based PC interface with LABVIEW software. Each block is described in detail in the following sub topics.

3.1. SDD Detector with Cooling Mechanism

SDDs are provided with two stage inbuilt Peltier cooler to achieve the desirable detector operating temperature. The cold side of the Peltier is coupled with SDD and the hot side of the Peltier is coupled to kovar base plate and then to a M4 screw made of copper for effective heat conduction. This metallic portion of the detector needs to be coupled with an additional heat dissipation mechanism to drain out the heat produced by the Peltier in order to maintain the detector operating temperature ≤ -35°C. The desired detector operating temperature has been obtained by mounting the detector on a 1mm thick Aluminum (Al) structure by allowing maximum possible mechanical contact between them. This Al structure is then coupled with the instrument body which is also made of Al as shown in Fig. 4.

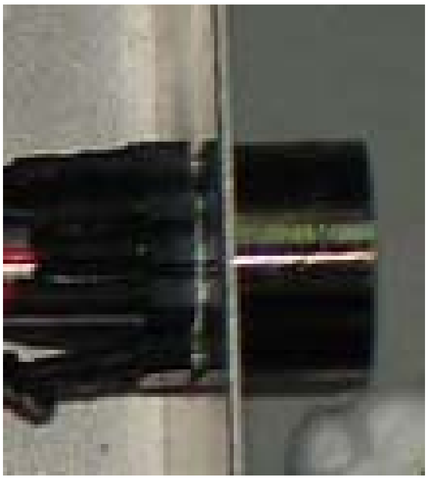


Fig. 4. Photographic view of SDD module coupled with 1mm thick Aluminum heat sink.

With this cooling mechanism, the desirable detector operating temperature of -35 °C has been achieved for the input power of about 1.25 W when the ambient temperature is at 25 °C (ΔT of 60 °C). The plot shown in Fig. 5 has the measured performance of the heat dissipation mechanism compared with the manufacturer data.

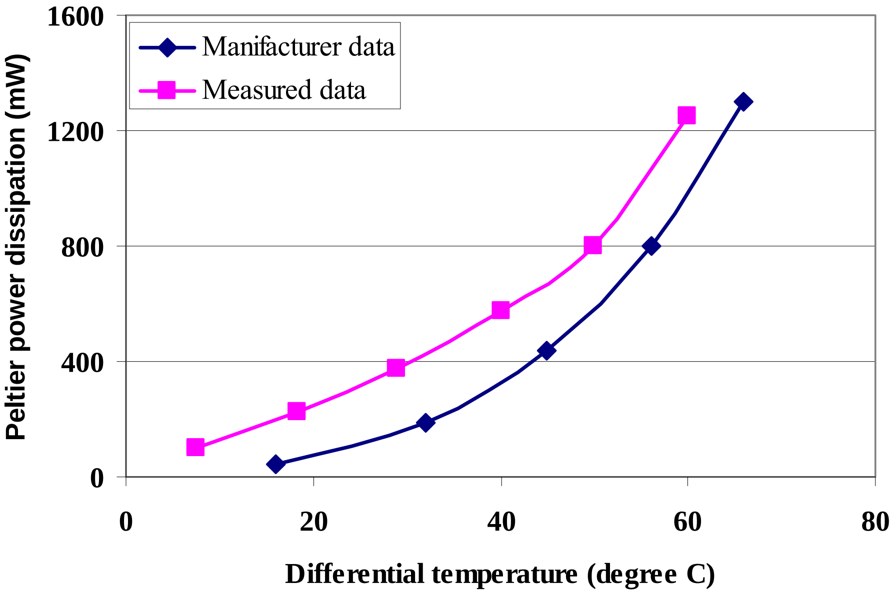


Fig. 5. Performance of heat dissipation mechanism when the ambient temperature is at 25°C.

Though the desirable detector operating temperature has been obtained for performance evaluation, the difference in cooling performance shown in the plot could be due to different ambient conditions and the detector to metallic plate coupling efficiency.

3.2. High Voltage Requirement for SDD

The induced charge carriers in the active volume of the SDD are collected to a point anode by applying suitable High Voltage (HV) bias. SDD requires three different HV biases namely RX (outer ring), R1 (inner ring) and RB (back contact) with voltage levels -130 V, -20 V and -60 V respectively. These voltage levels have been generated using 12 voltage multipliers with oscillator frequency of about 500 kHz. The main output voltage (-130V) is divided using voltage divider network to produce the other required voltage levels. The total load current requirement on these voltage levels is about ~20 μA.

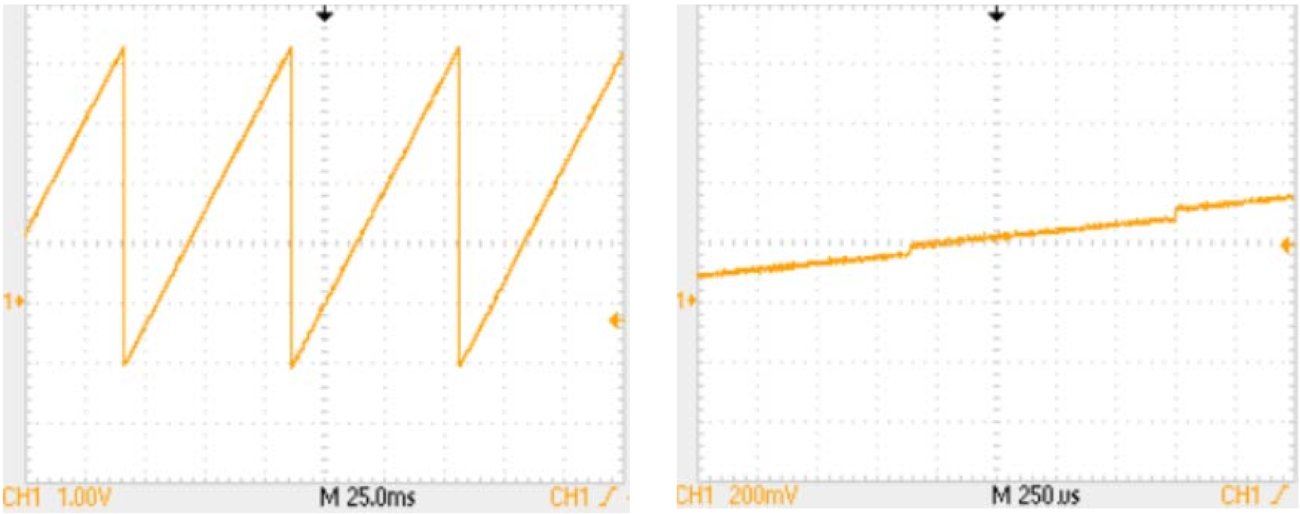
3.3. Charge Sensitive Pre-Amplifier (CSPA)

The charge carriers induced in the active volume of the detector due to photo electric effect is collected by applying suitable high voltage bias to the electrodes of the detector. These charge clouds are then converted in to voltage by using Charge Sensitive Pre-Amplifier (CSPA). It is well known that CSPAs are widely used in radiation spectroscopy as its output voltage is proportional to only feedback capacitor on which charge carriers are integrated. There are two types of CSPAs, one is “RC feedback type” and another is “Reset type”. The internal configuration of the SDD module used in the experiment is designed such that only “Reset type” preamplifier can be used to convert the charge into voltage. The output of reset type CSPA will be in the form of ramp signal made of small steps and each step in the ramp indicates photon interaction with the detector and height of the step gives energy of the incident photon.

The CSPA has been developed for converting the induced charge in the detector to voltage using high frequency, wide bandwidth and high slew rate video amplifier ICs with first stage containing charge to voltage conversion followed by a gain amplifier. The sensitivity of the CSPA is about 7.5 mV / 10 keV for the given feedback capacitor inside the SDD module. The ramp signal is further amplified with an amplifier having gain of about 5. This amplified signal is fed to comparator based Schmitt trigger circuit to create a reset pulse of 1μs to discharge the ramp stored in the feedback capacitor as and when it reaches certain amplitude level. The ramp signal frequency depends on the detector leakage current in the absence of X-ray interaction on the detector and varies with energy and rate of X-ray interaction with the detector. The outputs of CSPA with and without X-ray interaction is shown in Fig. 6a and 6b respectively.

3.4. Shaping Amplifier

The step pulses from the CSPA needs to be amplified with suitable pulse shaping time for the improved energy resolution. The energy resolution improves with higher pulse shaping time. The shaping amplifier has been designed using hybrid amplifier modules procured from AMPTEK, which are available with optimal power and packaging requirements. These hybrid components are available in Single Inline Package (SIP) form which consumes about 15 mW while operating on ±6 V. Input to the shaping amplifier is a series of step signals whose amplitude depends on the energy of the X-rays interact with the SDD detector. These step signals are passed through a three stage CR-$(RC)^2$ type shaping amplifier with peaking time of 3 μs. The three stage shaping amplifier has been designed to provide the total gain of about 125 such that the pulse signal amplitudes are maintained within 4 V range for the maximum X-ray energy of about 25 keV.



(a) (b)

Fig. 6. (a) CRO screen shot of ramp signal output from CSPA; (b) CRO screen shot of step on the ramp signal indicating X-ray interaction with the SDD detector.

3.5. Event Trigger Generator

Event trigger signal is required to initiate the digital system for controlling the digital logics associated with the peak detector and analog to digital converter to acquire pulse height information related to X-ray interactions on the detector. This is carried out by providing the first stage of the shaping amplifier output to a hybrid module which has gain amplifier (X10) followed by a discriminator. The discriminator provides pulse output when the input signal amplitude is crosses the set threshold. The first stage output of the shaping amplifier has used because the discriminator output should be available before the pulse rising edge of the third stage output of the shaping amplifier in order to initiate the digital signal processing.

3.6. Peak Detector

Peak detector is used in the experiment to hold the signal amplitude for the duration of analog to digital conversion. The AMPTEK make peak detector PH300 has been used to hold the peak signal amplitude for the duration of ~15 µs which includes time for A/D conversion and signal processing. PH300 is available in hybrid form with low droop rate and less power consumption. On occurrence of event pulse, event trigger signal is generated. At the positive edge of the event trigger signal, GATE input of the peak detector is activated and RAMP & DUMP digital inputs are inactivated so that the peak detector will go to charging mode. RAMP & DUMP digital inputs are used for discharging the peak detector. Once the peak detector reaches the peak signal amplitude, PKDT digital output of the peak detector goes low indicating the peak detector has stored the maximum pulse amplitude. The GATE input is made inactive on occurrence of PKDT and hence the peak detector goes to hold mode. During hold mode no other pulse is allowed to reach the peak detector until the event processing is completed. RAMP and DUMP signals are activated for the duration of 1 µs on completion of the digital signal processing to discharge the stored pulse and then to initiate the subsequent pulse detection.

3.7. Analog to Digital Conversion

The analog to digital converter with 12 bit resolution is required to resolve the closely spaced X-ray line energies of about 150 eV. We have used 12 bit serial analog to digital converter in this experiment which has throughput rate of 5 MHz. The A/D converter is successive approximation type with conversion time of 8.5 μs and also provides reference voltage of 4 V for its conversion.

3.8. Data Acquisition System

Data acquisition system consists of Complex Programmable Logic Device (CPLD) based control system and PCI based PC interface for data readout. The CPLD is used to generate control signals for peak detector & ADC and acquiring the serial digital data. On occurrence of event trigger pulse, CPLD provides necessary control signals for peak detector to hold the signal amplitude and also for analog to digital conversion. CPLD reads the serial data by providing serial clock to the ADC and converts serial data into parallel data which is then fed to PCI based parallel interface though PCI bus in the personal computer. The PCI bus interface has been established using NI PC-5364 32 bit PCI card. The data acquisition software is developed using LABVIEW. CPLD sends a reference signal to PCI port with 12 bit data which is available on the falling edge of the reference signal. LABVIEW based software reads the 12 bit data on sensing the falling edge of the reference signal and then stores event data in to a file.

4. System Operation

The spectrometer system is designed such that any X-ray photon interacting with the detector will not be detected for the duration of about 16 μs from the occurrence of first pulse. Event trigger pulse is generated when X-ray interacts with the detector whose amplitude is greater than set threshold voltage. Peak detector starts charging on the positive edge of the event trigger pulse and holds the peak signal amplitude for the duration of about 15 μs. Once peak detector goes to hold mode, analog to digital converter starts conversion and the digital data is available after 8.5 μs. The serial data from the ADC is readout using 2 MHz serial clock frequency generated from the CPLD. It requires 13 clock cycles to readout the 12 bit serial data. The data at the serial data output of ADC is available at the positive edge of the serial clock and the readout system will read the data at the negative edge of the serial clock. The overall timing diagram of the system operation is shown in Fig. 7.

The CPLD converts the serial data into parallel data and the Labview based readout software reads event wise parallel data and then stores in to a file. Software also has the provision to store either event data or spectral data.

5. Experimental Setup

All the developed systems are mounted in an aluminium enclosure and interconnected them as per the requirement. All the systems were provided with necessary low voltage biases required for their operation. Photograph of the experimental set up is shown in Fig. 8. It consists of all the designs described in section 3. The digital interfaces are not shown in the photograph.

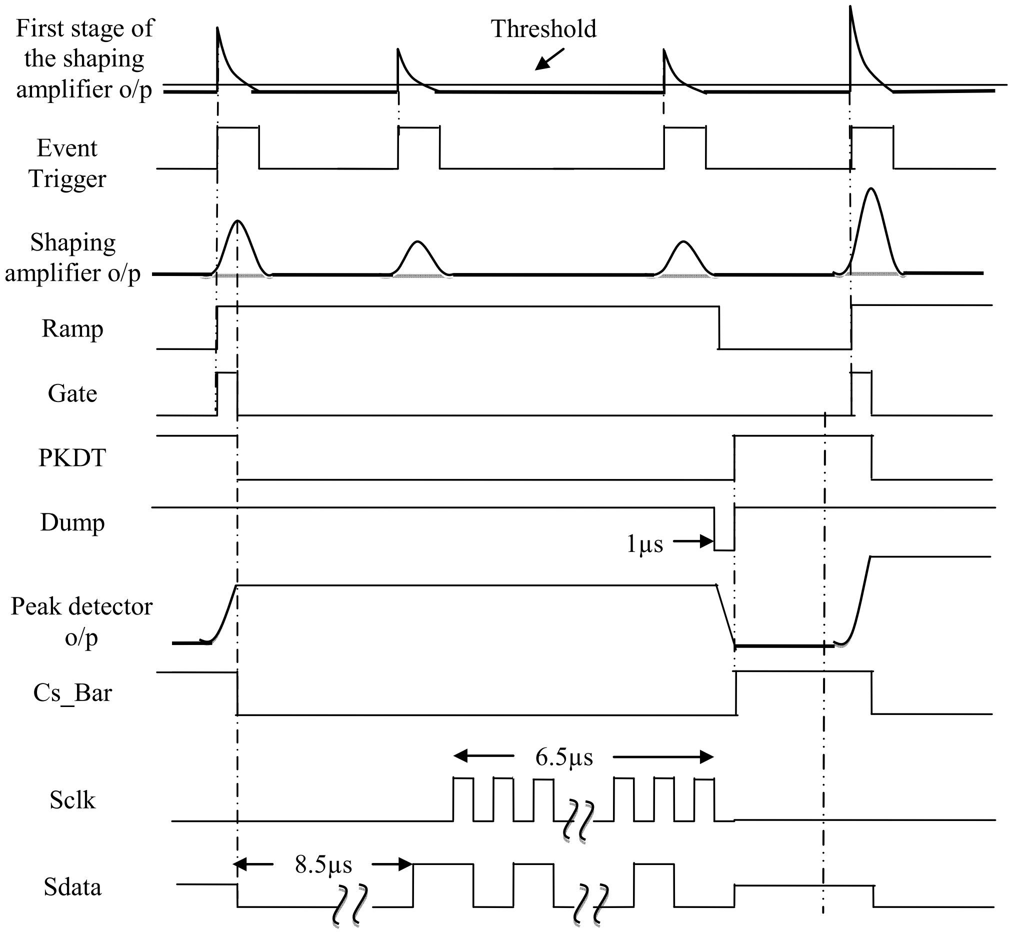


Fig. 7. Timing diagram of X-ray spectrometer operation.

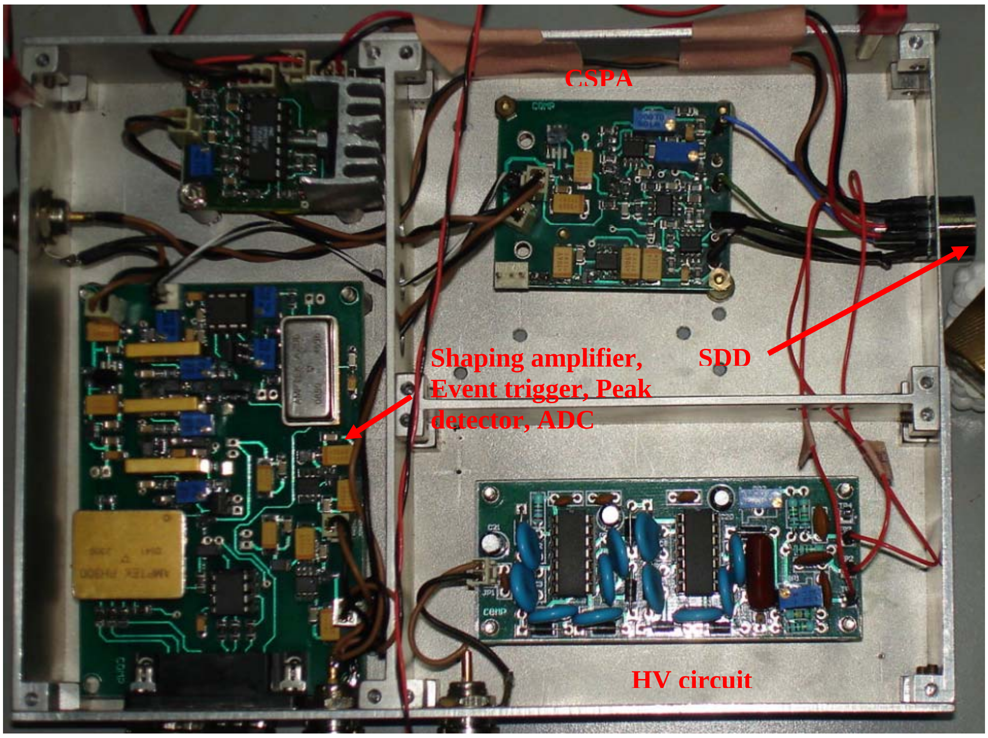


Fig. 8. Photograph of the SDD based X-ray spectrometer experimental setup.

6. Experimental Results

The developed X-ray spectrometer has been tested for various parameters such as spectral energy resolution, Linearity, Energy resolution variation with pulse peaking tine and X-ray fluorescence detection from different meteorite samples. Experimental results are described below.

6.1. Spectral Energy Resolution

The performance of the developed X-ray spectrometer has been evaluated using three X-ray radioactive sources with known energies. The X-ray sources used are Fe-55 (5.9 keV), Am-241 (14.1 keV and 17.9 keV) and Cd-109 (22.1 keV). These sources were placed one at a time in front of the detector and acquired the spectra. The combined spectral response for three sources is shown in Fig. 9 and the energy resolution of about 150 eV @ 5.9 keV has been achieved which is comparable to the commercially available SDD based spectrometer systems.

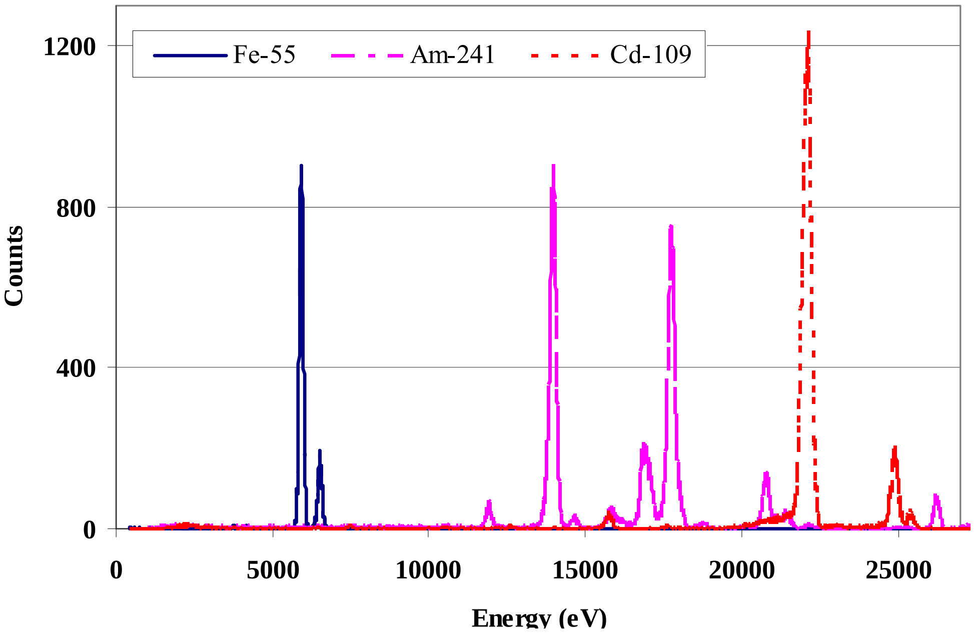


Fig. 9. Spectra obtained from the developed X-ray spectrometer using three different X-ray sources.

The energy resolutions (FWHM) at these energies are given in the Table 1.

Table 1. Energy resolution at different X-ray line energies.

X-ray energies (radioactive sources)	5.9 keV	14.1 keV	17.9 keV	22.1 keV
Resolution (FWHM)	149 eV	240 eV	269 eV	341 eV

6.2. System Linearity

The system linearity has been checked for four prominent X-ray energies using the above mentioned sources as shown in Fig. 10. Linearity is plotted between the ADC channel numbers (12 bit ADC output) versus X-ray energy. It is shown that the ADC output is linearly varying with X-ray energy interacting with the detector.

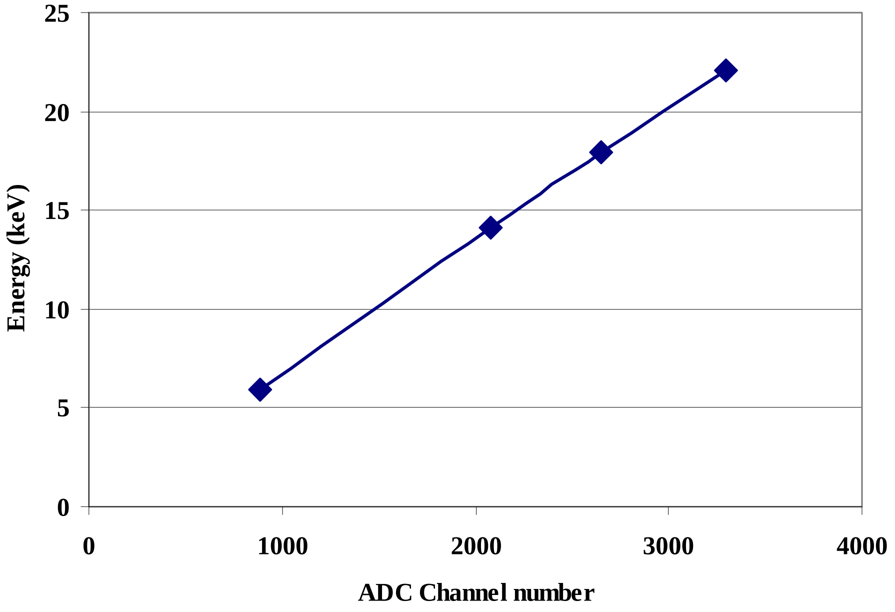


Fig. 10. Linearity plot of the X-ray spectrometer.

6.3. X-ray Fluorescence Measurement from Meteorite Samples

We also performed measurement of X-ray fluorescence as may be the real case by irradiating the meteorite samples “Allende-3882”, “Allende-4560”, “Kavarpura” and “Mahadevpura” with Am-241 X-ray source. The X-ray source – sample – detector is positioned such that X-rays from the sources is viewed by the sample and the fluorescent X-rays are viewed by the X-ray detector. The data acquisition was carried out for the duration of 30 minutes in each case and the spectral response for all the meteorites are shown in Fig. 11 (a, b, c and d).

Observation from such measurements is that the meteorite samples “Allende-3882” and “Allende-4560” are iron (Fe) rich and they are very similar in elemental composition though there could be difference in concentration. “Kavarpura” meteorite is also rich in iron concentration and “Mahadevpura” is rich in calcium (Ca) and they have similar elemental composition at the higher energy side (above 10 keV). Quantitative measurement of elemental composition of such samples is under progress and will be reported separately.

7. Conclusion

The development of a compact X-ray spectrometer with energy resolution of about 150 eV at 5.9 keV, which is comparable to off-the-shelf X-ray spectrometer systems by using the components which are available in space qualified version, is described. It was also shown that the spectrometer system is linear in the operating energy range. We also obtained the spectra for meteorite samples which are similar to the X-ray fluorescent measurement to be carried out in future. Total power consumption of the instrument is estimated to be about 2.5 W. By suitably designing the PCBs of appropriate size and accommodating the developed electronics circuits in it will provide a compact instrument with mass less than 1 kg as a stand alone system.

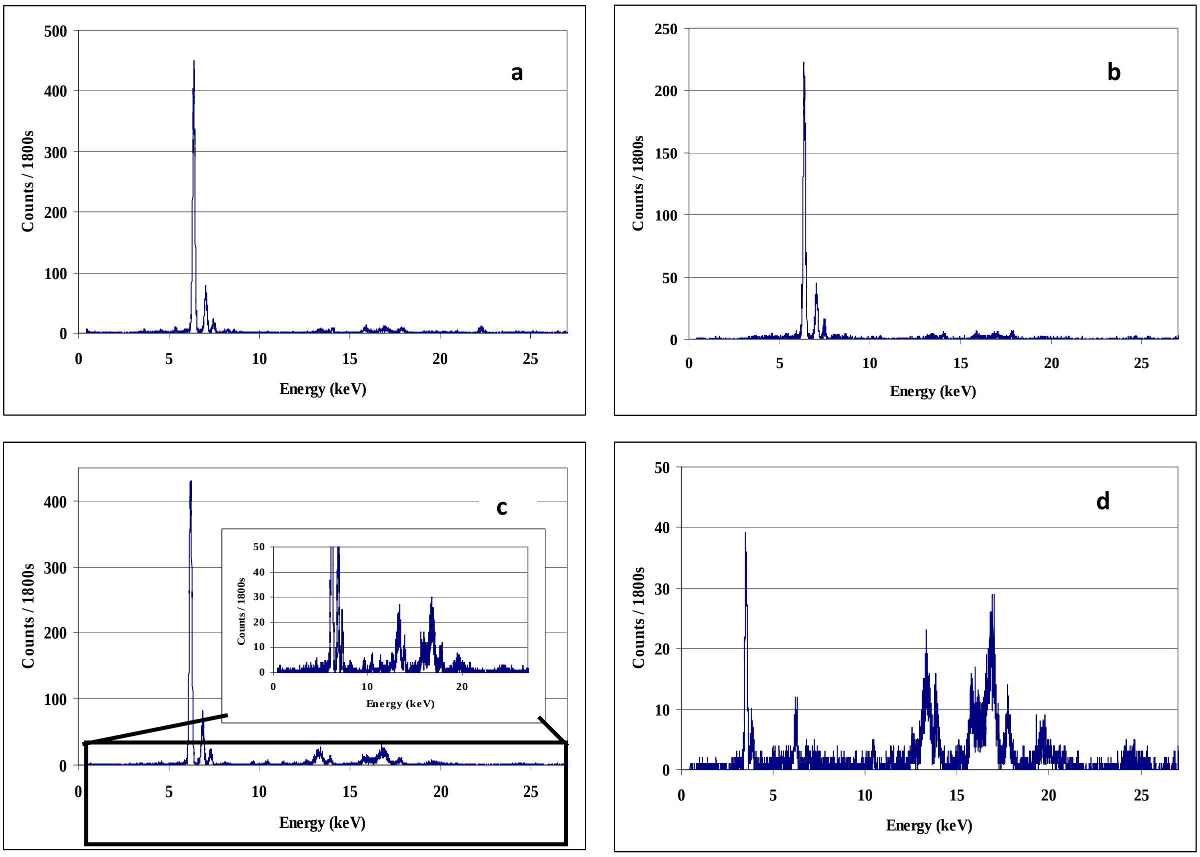


Fig. 11. Spectral response obtained from meteorite samples:
a) Allende-3882; b) Allende-4560; c) Kavarpura and d) Mahadevpura for the duration of 30 minutes by irradiating the samples with Am-241 X-ray source.

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References

[1]. R. Rieder, R. Gellert, J. Bruckner, G. Klingelhofer, G. Dreibus, A. Yen, and S. W. Squyres, The new Athena alpha particle X-ray spectrometer for the Mars Exploration Rovers, *Journal of Geophysical Research,* Vol. 108, No. E12, 2003.

[2]. T. Okada, M. Kato, Y. Yamashita, K. Shirai, Y. Yamamoto, T. Matsuda, H. Tsunemi and S. Kitamoto, Lunar X-ray spectrometer experiment on the Selene mission, *Adv. Space Res.* Vol. 30, No. 8, 2002, pp. 1909-1914.

[3]. Manuel Grande, Brian J. Maddison, P. Sreekumar, Johani Huovelin, Barry J. Kellett, Chris J. Howe, Ian A. Crawford and D. R. Smith, The Chandrayaan-1 X-ray Spectrometer, *Current Science,* Vol. 96, No. 4, 2009, pp. 517-519.

[4]. G. F. Knoll, Radiation Detection and Measurement, *John Wiley & Sons*, 3rd edition, 1999.

[5]. E. Gatti and P. Rehak, Semiconductor drift chamber - an application of a novel charge transport scheme, *Nucl. Instr. and Meth. A*, Vol. 225, 1984, pp. 608-614.

[6]. P. Rehak, E. Gatti, A. Longoni, J. Kemmer, P. Holl, R. Klanner, G. Lutz and W. Wylie, Semiconductor drift chambers for position and energy measurements, *Nucl. Instrum. Meth. A,* Vol. 235, 1985, pp. 224-234.

[7]. J. Kemmer, G. Lutz, E. Beleau, U. Prechtel and W. Welser, Low capacity drift diode, *Nucl. Instrum. Meth.*, A, Vol. 253, 1987, pp. 378-381.

[8]. G. A. Carini and W. Chen, Performance of a thin-window silicon drift detector X-ray fluorescence spectrometer, *IEEE. Trans. Nucl. Sci.,* Vol. 56, No. 2, 2009, pp. 2843-2849.

[9]. A. Niculae, P. Lechner, H. Soltau, G. Lutz, L. Struder, C. Fiorini, A. Longoni, Optimized readout methods of silicon drift detectors for high-resolution X-ray spectroscopy, *Nucl. Instr. and Meth.,* A, 568, 2006, pp. 336-342.

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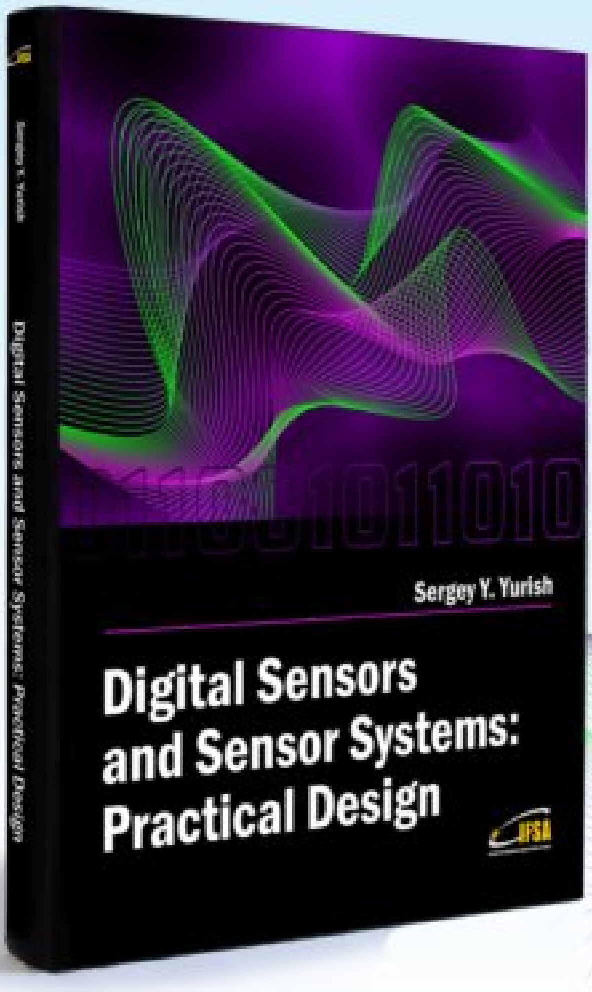
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