Development of linear array X-ray detectors and electronics for dual energy X-ray baggage scanning systems

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Introduction

Dual energy X-ray based baggage inspection systems (XBIS) are widely used for security applications for the detection of threat objects in passenger baggage. In these systems, two sets of detector arrays are used for the measurement of transmitted X-rays through the objects to generate line scan images. Electronics Division, BARC has carried out the indigenous development of X-ray detectors and readout/data acquisition electronics for dual energy XBIS. Since silicon sensors allow realization of systems with higher spatial resolution and sensitivity, compactness and lower voltage of operation, the indigenous X-ray detectors comprising scintillator-coupled PIN photodiode arrays are used for the generation of line scan images. A 64-channel low noise readout electronics has been developed for detector signal processing. The detectors and electronics are qualified for desired imaging performance by integrating in a XBIS. An overview of this development is presented in the subsequent sections.

Dual energy X-ray detectors

Typical dual energy XBIS incorporates two sets of detectors referred as Low Energy (LE) and High Energy (HE), each comprising 640 pixels. The design of detectors was optimized using GEANT4 Monte Carlo simulations. A detailed theoretical modelling of the generation of X-rays, their interaction with the scintillator materials, the light production, and effect of reflector/separator on light collection, etc., was carried out. The photodiode technology was developed at a silicon foundry. To achieve very low dark currents, the P-I-N device structure was employed. The diodes were fabricated with high purity silicon wafers. The linear photodiode arrays (PDA) were designed as linear arrays of sixteen pixels. These diodes were coupled to CsI scintillators of two different thicknesses for developing LE and HE detectors. Fig. 1 shows the indigenous PIN photodiodes and, HE and LE X-ray detectors.

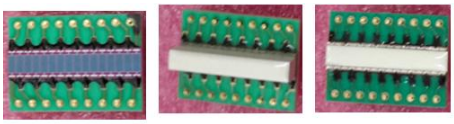

Fig. 1 PIN photodiode linear array, CsI-photodiode coupled HE and LE detectors.

Front-end and data acquisition electronics

The detector system for XBIS was designed in a modular fashion to cater to a wide range of applications comprising various detector geometries and spatial coverage requirements for XBIS. For a 60x40 tunnel dual energy XBIS, the Detector System incorporated 1280 pixels and corresponding 1280-chanel front-end readout electronics. This was achieved with ten detector cards each incorporating 128 detector pixels and 128 channel readout (64 low energy (LE) and 64 high energy (HE) pixels). The basic readout amplifier was a charge integrator with a programmable gain and maximum range of 52 pC. The digitization of analog signals of all channels was performed using 16-bit ADCs. The detector cards were daisy chained and data was ported serially from one card to the next card. The data acquisition (DAQ) electronics was used to generate various signals for timing, configuration and control. These signals were generated with a FPGA. For interfacing with a PC, USB 2.0 and Ethernet interfaces were provided in the DAQ card. A GUI was developed for setting various parameters and for displaying real time images on the PC monitor. The software also implemented functions for movement of conveyer and control of X-ray source, and various image corrections such as offset subtraction, gain normalization, etc. The fabricated detector cards and data acquisition card for XBIS are shown in Fig. 2.

Fig. 2 Detector cards and DAQ electronics for dual energy XBIS.

Performance validation of detector and electronics

The performance testing of the detectors and electronics was initially carried out using a setup comprising a constant potential high flux 450 kV X-ray source at ITIS, BARC. The exposures were made at X-ray source settings of different voltages (80-140 kV step) and tube currents (0.5-1.0 mA) with a source-to-detector distance of about one meter and focal spot size of 0.4 mm. A backscatter shielding (10 mm thick lead sheet) was placed between the detector and base to improve Contrast-to-Noise Ratio (CNR). Further, the data acquisition board was covered with lead shielding to avoid scattering artifacts which leads to better signal-to-noise ratio (SNR). The data was acquired on an Ethernet interface from DAQ card with a PC.

The standard deviation of measured counts for 250 scans was about 0.5-0.6%. The linearity of the response of the pixels was measured by varying the beam current from 0.1-0.7 mA. The coefficient of determination (R^2) of the linear line fitting was close to 1 indicating that the detector response along with frond-end electronics is very linear. The typical digitized signals as measured by the electronics after 16-bit A/D conversion are shown in Fig. 3. The raw data shows variation from pixel to pixel. To take care of this variation, the signals from all channels are normalized for every pixels while taking images.

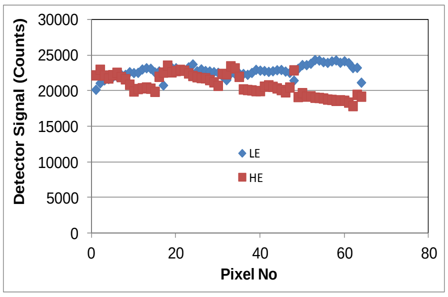

Fig. 3 Raw data acquired from LE and HE pixels at 140 keV, 0. 6 mA X-ray tube settings.

Subsequent to functional testing of detectors and electronics, the detector and DAQ cards (Fig. 2) were integrated in an XBIS. The typical HE image obtained with a variety of objects are shown in Fig. 4. As can be seen, various objects are clearly visible in the images.

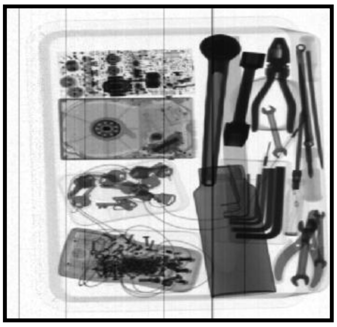

Fig. 4 Sample HE image obtained with detectors and electronics after integration with XBIS.

The imaging performance was further qualified used a Comprehensive Test Piece (CTP). The developed detectors and electronics were qualified for a spatial resolution of 1 mm, penetration of 30 mm steel, discrimination between salt and sugar, visibility of SWG 42 diameter wire, etc. As the indigenous detectors and electronics meet the desired imaging criteria, the knowhow will be utilized for industrial production of such machines.

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