Photon counting detector for the personal radiography inspection system "SIBSCAN"

Babichev E.A., Baru S.E., Grigoriev D.N., Leonov V.V., Oleynikov V.P., Porosev V.V., Savinov G.A.
Budker Institute of Nuclear Physics, SB RAS Novosibirsk

Introduction

The current situation with international terrorism and drug smuggling generated a need for a mass screening of the peoples for a detection of the illegal items hidden in the clothes or inside of a human body. At present time, the single way to do it effectively is a radiographic inspection. Due to the need of examination a lot of healthy people the system should operate at the lowest possible dose defined by physical limits and the local regulations. Such systems have rather specific list of requirements: high contrast sensitivity and wide dynamic range to observe the objects as inside the clothes as behind of the most dense parts. It should provide big image size (more than human height and width) and short imaging cycle to provide necessary throughput. The application of the 1D detectors having high quantum efficiency with direct registration of X-ray photons increases the dynamic range of an X-ray image, significantly reduces background and considerably decreases irradiation dose. More than 10 years ago the digital scanning radiography system based on multistrip ionization chamber (MIC) was suggested in the Budker Institute of Nuclear Physics. In a last modification the system operates with the detector filled with pure Xe at 15 bar, having quantum efficiency ~70% and a pitch of channels 1.5 mm. Accordingly the regulation requirements: "..dose received by individuals from one non-medical facility shall not exceed 0,250 μSv (0.3 μSv). At given conditions a person can safely pass inspections at least 1000 times per year. This dose corresponds to a input flux ~7500 ph./mm^2 at detector plane and behind the most dense areas this value could be 100-300 times less. At such small signals an object detection capability of the system is seriously effected by any additional noise. The main purpose of the current research was a design of noise free detector that supersedes MIC one.

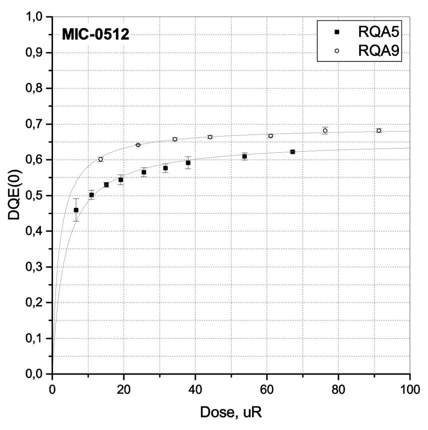
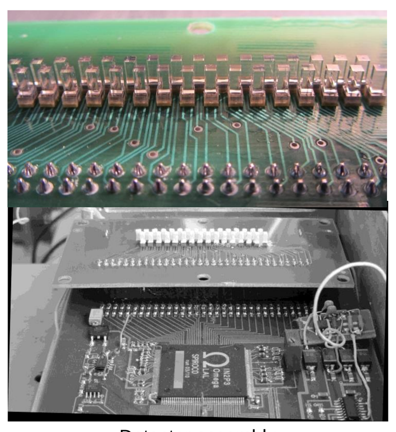
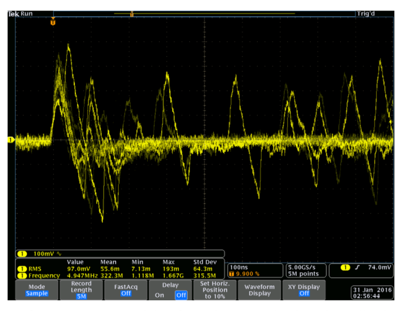


Fig.1 DQE of the MIC detector.



Detector assembly



Signals at a output bipolar shaper during irradiation

Scanning system with the detector

MIC Parameters

For multistrip ionization chamber the origins of extra noise are non-monochromatic x-ray spectrum, electronics noise and "microphone" effect induced my mechanical vibrations of a system during scanning. The most illustrative characteristic of the detector is Detective Quantum Efficiency (DQE). In Fig.1 the measured DQE value at different x-ray spectra (IEC RQA5 and RQA9 beam quality) are presented. The solid lines are calculated values . It is clearly seen that in spite of high quantum efficiency of the detector 73-76%, the maximal DQE value is ~10% less due to the signal fluctuations originated from different ways of x-ray interaction with material (photo effect, Compton scattering, emission of fluorescent photons). Moreover at dose less than 25 μR, it is dramatically effected by electronics noise. In our design it is compatible with a signal from 3 x-ray quanta.

SiPM based scintillation detector

To evaluate possibilities of the technology we build 32 channel detector prototype using LFS-3 scintillator and KETEK 1.2 mm square SiPMs (PM1125NS-SB0). The scintillators have a dimensions 1.5 x 1.5 x 3.5 mm and a pitch of detector channels is 1.6 mm. All scintillator crystals were painted with EJ-510. Detector electronics was based on a 32-channel Omega EASIROC front-end chip. Each ASICs channel incorporates a 15 ns peaking time fast shaper followed by a discriminator, the threshold of which is set by an integrated 10-bit DAC. The cathodes of SiPM are connected to a common high-voltage power supply, whereas anodes are loaded by resistor (30 Ohm typically). Each input channel has an integrated front-end DAC for SiPM operation voltage adjustment in the range from 0 to 4.5 V. The trigger outputs come to the PLC that counts number of the events in each channel when outputs of the fast shapers exceed the threshold. In Fig.2 the trigger efficiency versus "DAC-threshold" value is shown. It's clearly seen that we can reliably define a threshold to separate a SiPM thermal noise from x-ray signals. In Fig.3 the trigger efficiency at different SiPM offset voltage is presented. The operational voltage range when intrinsic SiPM noise not influences on detector operation ~1V. The minimal signal value is defined by natural radioactivity of Lu-based scintillators and the intensity is ~0.25 Hz per channel.

Count rate capability and DQE

Another issue that is important for a photon counting detector is count rate capability. For current scanning system design, the expected input flux is ~4.5 MHz per a channel. To estimate a system dead time we measured a distribution of intervals between trigger events in a channel during detector exposure at different intensity. The trigger output of EASIROC channel was recorded with Tektronics DPO4104B oscilloscope and transferred to PC for off-line processing. In Fig.4 the measured distributions are presented. The solid lines are the results of fits with Poisson distribution. The systems demonstrate paralyzable behavior with a dead time in the range 43-54 ns that grows with intensity. In Fig.5 the DQE of SiPM based detector at IEC RQA5 beam quality is show. The solid line is a calculated DQE value for non-paralyzable counter with dead time 50 ns and quantum efficiency 65%. The detector demonstrates rather complex behavior. Generally, the DQE is lower than it is defined from geometrical factors. The main reason of that is influence of the discriminator threshold. Due to stochastical nature of light emission by scintillator, the signals at a bipolar shaper output could have an amplitude lower than the discriminator threshold. Additionally high-Z scintillator has a significant probability of the fluorescent photons emission that create low amplitude signals too. At higher over-voltage (large signal amplitude) and intensity the detector demonstrate deviation from pure Poisson statistics due to interference of the bipolar pulses in EASIROC chip. Anyway DQE of photon counting detector is higher than the multistrip ionization chamber one and grows with intensity due to miscounts.

Image quality.

To illustrate difference between a energy integrating detector and photon counting one we produce the images of a test object that is used to measure penetration capabilities of the system. On back side of steel stepwedge there is a lead strip with a width 1 cm and a thickness 1 mm. In Fig.6 the sample images of the test object made with MIC and SiPM based detectors are presented. It is clearly seen that photon counting system demonstrates better an object detectability at low intensity.

Sample image of a real drug trafficker

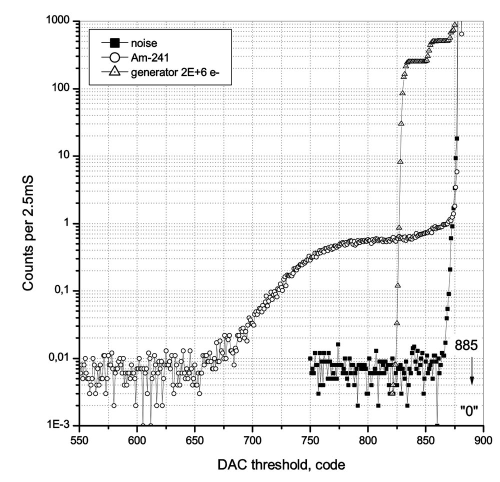


Fig.2 Detector count versus threshold value (DACs code). For comparison the data for Am-241, intrinsic SiPM noise and charge injection 2E+6 e- from generator are presented.

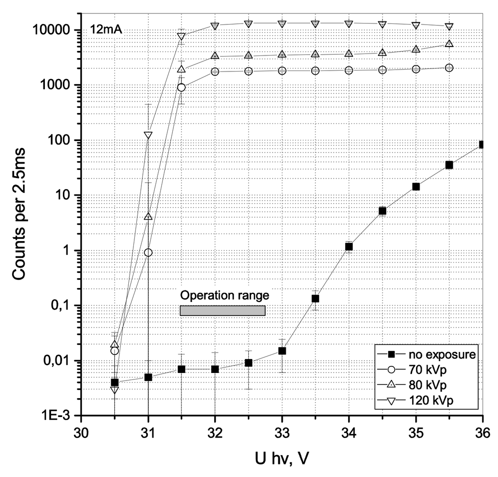


Fig.3 Count versus offset voltage at fixed threshold value. The data at different x-ray tube intensity (different kVp) and without irradiation are presented.

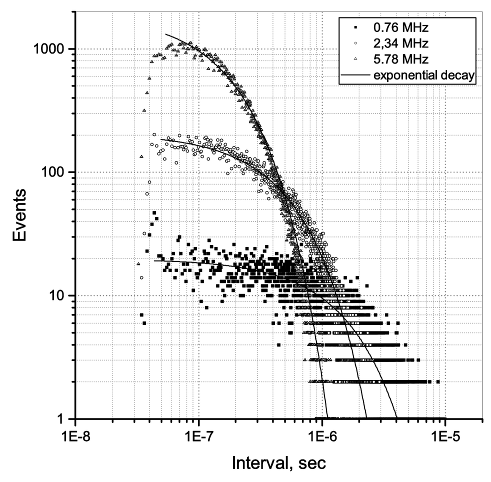


Fig.4 Distribution of the intervals between trigger events at different x-ray intensity

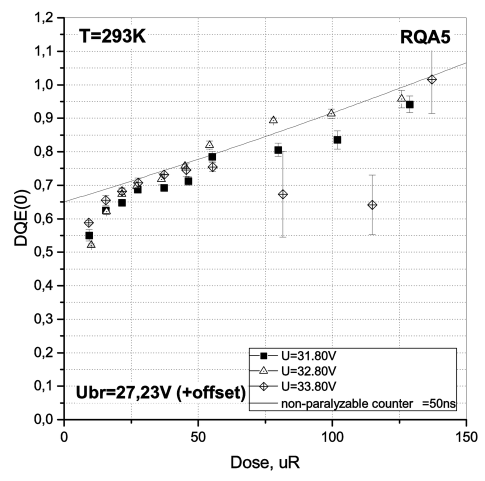


Fig.5 DQE of SiPM based scintillation detector at different operation voltages

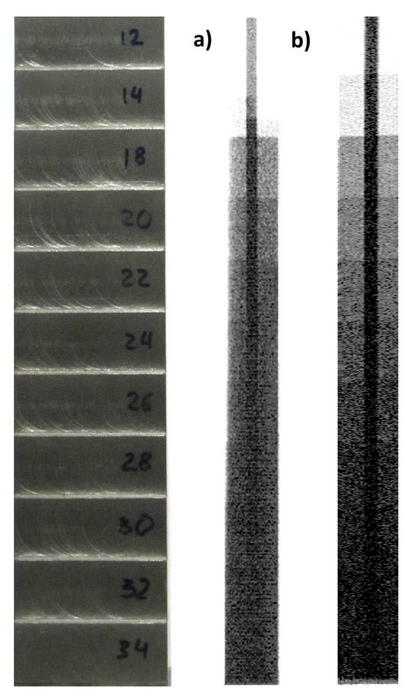


Fig. 6 The images of a test object to measure penetration capabilities made with MIC (a) and SiPM based detector (b) at 120 kVp.

Conclusion

The results of evaluation of the detector parameters confirms the fact that a photon counting detector provides a better image quality than energy integrating one. Because SiPM is more technological device it's becomes possible to realize multi-line detector with improved spatial resolution. Application good scintillators opens possibility to realize an energy dispersion imaging. Such detectors could be useful not only for security inspection purposes but for medical diagnostics too. In near future we plan to assemble full scale detector for real tests.

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