New Radiation Sensor Embedded in a Metal Detection Unit

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***Abstract*— This work introduces the embedment of a radiation detection unit within a metal detector. The radiation sensor, based on the Silicon Photomultiplier coupled to a scintillation crystal, was successfully incorporated into a common metal detection unit. The results for sensitivity are presented. Background threshold adjustment and various application notes are discussed.**

***Index Terms*—handheld radiation detector, scintillators, silicon photomultipliers.**

I. Introduction

THE growing need for radiation detectors aimed for security applications is driving the technology to find new solutions. Several of the commonly used industrial isotopes which are in concern to be used as a Radiological Disperse Device (RDD) can be easily shielded with metal, e.g., attenuation of ^{241}Am by 3 mm of stainless steel is over 90%. Whereas, the pedestrian Radiation Portal Monitors (RPM) provide fine sensitivity for groups of isotopes, they hardly tackle the problem of shielding.

A handheld detection device, combining both metal detector and radiation sensor, can overcome a concealed RDD, by detecting the presence of the metal shielding.

The traditional sensitive radiation detection methods, which are based on the PMT technology as a light sensing device, carries two main reciprocate drawbacks, which make the proposed implementation almost impossible: on one hand the magnetic field which is produced by the metal detector affects the functionality of the PMT, and on the other hand the metallic magnificence of the PMT affects the sensitivity of the metal detector.

A solid-state solution based on PIN can overcome the PMT drawbacks and provide miniaturization of the sensor; however the photodiode has a major drawback caused by the microphonics of the device. This phenomenon prevents the implementation of the PIN sensor within handheld equipment for security applications where robustness and stability in responsiveness are among the main requirements.

A new approach based on the rapidly developing technology of Silicon Photomultiplier (SiPM) [1] was evaluated and determined to be the most suitable for the utilization in the addressed application. A detection method which combines the SiPM as the light sensor provides a solution that benefits from the best of both worlds. This work describes the specially designed radiation sensor and the way it was embedded into a commonly used metal detector. The results from sensitivity measurements and the alarm unit adjustments at differentiating background are reported.

II. Hardware Design

A. Metal Detector

A commonly used handheld metal detector Model 302F (Fig. 1a), produced by Elpam Electronics Ltd. was selected for the utilization of the newly designed radiation sensor. This metal detector has external dimensions of 467 mm × 101 mm × 40 mm, and weighs 590 gr. (including batteries).

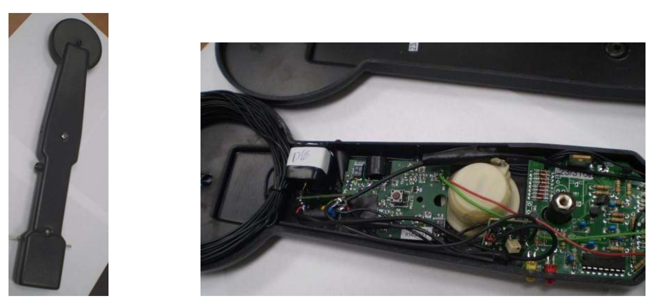

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Fig. 1. a – the metal detector Model 302F. b – the embedded radiation sensor.

B. Radiation Sensor

Based on previous studies [2], the CsI scintillation crystal with a doping of Tl was selected for the radiation sensor. The

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TABLE 1
CHARACTERISTICS OF SENSL SPMMICRO6035

Diode surface area	6 mm x 6 mm
Number of pixels	14560
Pixel size	35 µm x35 µm
Operating Voltage	29.5 V
Gain	$1x10^6$
PDE	13-30%

The fill factor of the device is, therefore, calculated to be 49.5%.

crystal, with the dimensions of 15 mm × 15 mm × 15 mm, is relatively large to have an intrinsic sensitive volume to comply with the ANSI N42.32 Performance Criteria for Alarming Personal Radiation Detectors for Homeland Security requirements to response within 2 s to ambient radiation level of 50 µR/h above background [3].

The SensL[1] SPMmicro series is a SiPM device with the detailed specifications described in Table 1. Due to its spectral response range of 400-800 nm with a peak sensitivity at 520 nm, this optical sensor has sufficient suitability for a light read-out from CsI(Tl) crystal with maximal emission at 550 nm.

The SiPM was attached to the CsI(Tl) crystal, and then the created photo-coupling was optically processed and covered with distinctive reflectors and opaque black tape for optimized scintillation light collection (Fig. 1b).

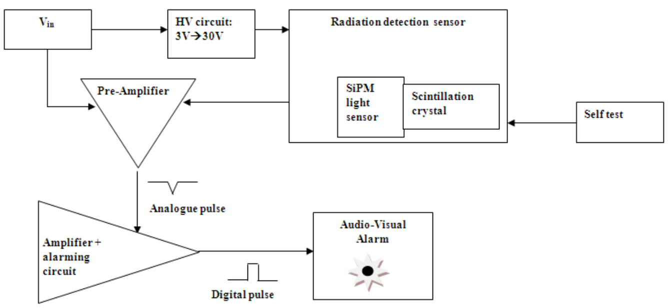

Fig. 2. Block scheme diagram of the radiation sensor and the electronic compounds of the detection unit.

C. Electronics and Alarm Unit

The readout from the radiation sensor was performed by an electronic unit which included a common HV bias voltage supply circuit for the SiPM and a fast, external pre-amplifier to integrate the output signal from the SiPM. The acquired analogue pulse is amplified and passed on, through amplitude discrimination, into the alarming circuit, where amplitude discrimination determines the triggering of the visual (LED) and audible (beeper) alarm, as shown in Fig. 2.

This unit, with extremely low current consumption (~20 µA) was powered from the same battery cluster which powered the metal detector.

The whole detection unit weighs 670 gr, thus the radiation sensor by itself adds a negligible weight of less than 100 gr.

[1] SensL (www.sensl.com) provides low light sensing solutions to the market and specializes in the development of Silicon Photomultipliers and Photon Counting and Timing detectors.

III. SENSITIVITY MEASUREMENTS

Activity and Shielding Dependency

The intrinsic efficiency of the CsI(Tl) crystals is a well known value for various energies, which correlates with the crystal's density and the atomic number. Whereas, the sensitivity of the whole detector assembly is determined by alternating, non-intrinsic factors, such as different light transition effects within the crystal and in the intermediate environment between the crystal and the optical sensor; electronic amplifying characteristics; mechanical structure of the detector. The radiation sensitivity of this new detector was measured in different experimental setups.

A set of measurements were performed using the ^{241}Am, ^{137}Cs and ^{57}Co radioactive sources, separately. At this stage the background level adjustment was not performed, i.e. the alarm threshold was not yet assessed. Each set was carried out with the source covered by different type of shielding:

0 – no shield
1 – metal box, 8 mm
2 – lead shield 8 mm
3 – lead shield 14 mm

The average count rate was calculated for each set.
The results are presented in Table 2.

TABLE 2
DETECTORS SENSITIVITY PER SOURCE ACTIVITY AS THE FUNCTION OF THE SHIELDING

	Shielding type			
	0	**1**	**2**	**3**
Isotope	sensitivity [cps per µCi]			
^{137}Cs	31	30	13	5
^{57}Co	69	48	2	<2
^{241}Am	3	<1	~0	~0

All the isotopes were measured in a constant distance of 20 cm from the detectors surface.

This kind of measurement provides an assessment of the detectors sensitivity per source activity and the type of shielding, at a distance simulating a metal detector inspection.

Alarm Threshold Adjustment

After the sensitivity of the detector had been determined, the alarm threshold could be set considering the local background level.

The alarm indicators (beeper, LED) were adjusted to actuate once in about 2 minutes, as a prescribed indication for a normative local background level of ~5 µR/h. Than the sources, listed in the previous setup, were placed in varying ranges from the detector in order to obtain a constant radiation field. The number of alarm actuations (beeps) were, than, measured and the sensitivity of the alarming mechanism was determined per each source.

The results shown in Table 3 represent the sensitivity of the detector with adjusted alarm threshold.

TABLE 3

DETECTORS SENSITIVITY AFTER THE ADJUSTMENT OF THE ALARM THRESHOLD

Isotope	Energy	Sensitivity [Beeps per minute]
^{137}Cs	662keV	**169**
^{60}Co	1173kev ; 1332keV	**115.2**
^{241}Am	60keV	**191.6**

The sensitivity was obtained for a constant dose rate of 40 µR/h.

IV. COMPARATIVE STUDY

Other inductive measurements have been carried out for emphasizing the beneficial characteristics of the use of SiPM based radiation detector.

The response to microphonic noise is a prominent problem of the traditional semiconductor photo-detectors (Fig. 3a). This phenomenon would prevent the use of the radiation detector in the proposed application. However, the SiPM is not affected by the vibrations (Fig. 3b).

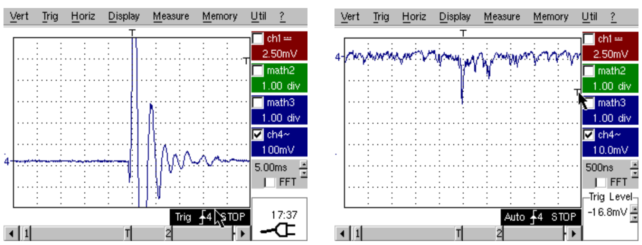

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Fig. 3. Comparison of the response to vibrations: a - PIN diode. b – SiPM.

Another satisfactory advantage of the SiPM was revealed when the type of operational (bias) voltage supply for the device was considered. As it is shown on Fig. 4, the SiPM performances are not affected by the alternating type of the voltage supply. The ripple caused by regulated voltage that was supplied to the SiPM did not affect the noise level. This condition provides a potential contingency to use the device either in portable applications – to be operated on batteries, or in the stationary, indoor applications.

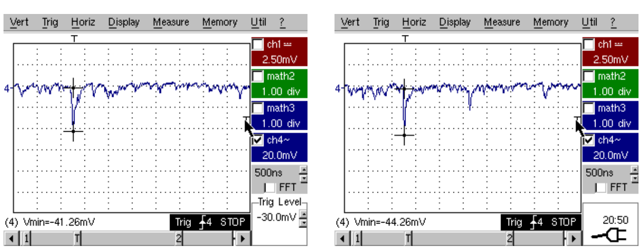

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Fig. 4. Different types of operational voltage supply to the SiPM: a –voltage regulator ; b – batteries.

V. CONCLUSION

The traditional sensitive radiation detection methods, which are based on the PMT technology as a photon sensing device carries two main reciprocative drawbacks, which make the proposed implementation almost impossible:

1. The magnetic field which is produced by the metal detector affects the functionality of the PMT.
2. The metallic magnificence of the PMT affects the sensitivity of the metal detector.

A solid-state solution based on PIN has a major drawback caused by the sensitivity of the device to microphonic noise.

A novel method based on silicon photomultiplier as the photon sensor of the radiation detector is presented, emphasizing the following parameters and comparisons:

1. The detector's low noise.
2. The physical characteristics and the dimensions of the detector.
3. A comparison of the response to vibrations between the SiPM and the PIN diode
4. The noise level of the detector vs. the supplied regulated voltage.

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