Readout electronics for an HAPD detector

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Readout electronics for an HAPD detector

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ABSTRACT: We describe the design, construction and performance of electronics for the readout of a hybrid avalanche photodiode (HAPD). The HAPDs are being studied as possible candidates for the detection of Cherenkov rings in a proximity focusing ring imaging Cherenkov (RICH) detector, which is foreseen for the upgrade of the Belle spectrometer at the KEKB collider.

KEYWORDS: Front-end electronics for detector readout; Cherenkov detectors; Particle identification methods

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1 Introduction

The forthcoming upgrade of the Belle spectrometer [1] includes an improvement of the particle identification system. The threshold Cherenkov counter in the endcap will be replaced by a proximity focusing ring imaging detector, with aerogel as radiator. The main requirements for the detector are: it must fit into the limited available space, it must allow a 4σ separation of pions from kaons up to 4 GeV/c, it must operate reliably in a strong magnetic field and it should not deteriorate appreciably under the elevated radiation levels. The total 1 MeV equivalent neutron fluence expected during the operation in the area of the ring imaging Cherenkov detector amounts to 10^{12} cm^{-2}.

In search for an optimal detector, investigations have included aerogel layers forming a "focusing configuration" [2] and different position sensitive photon detectors [3–5]. One of the candidates for photon detection is the HAPD (figure 1) [6]. The HAPD is a position sensitive detector of single photoelectrons ejected from a bialkali photocatode and accelerated in vacuum over several kilovolts of potential difference. The accelerated photoelectron penetrates in a silicon photodiode, producing

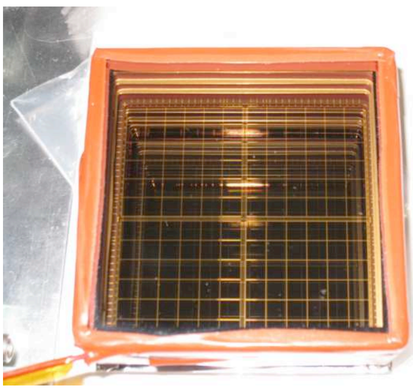

Figure 1. Photograph of the Hamamatsu 144 channel Hybrid Avalanche Photodiode.

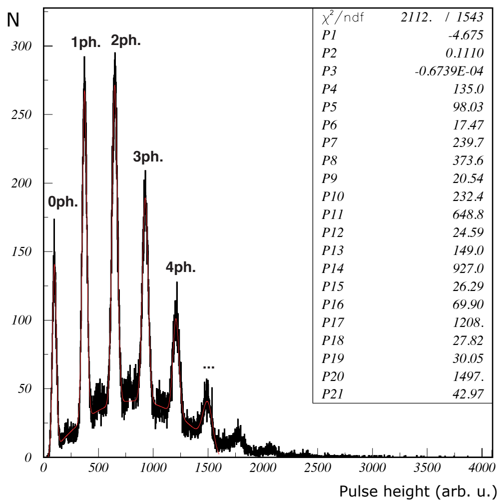

Figure 2. Pulse height distribution of the HAPD.

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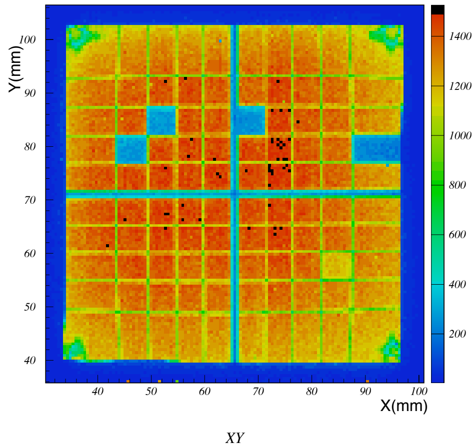

Figure 3. Two dimensional scan across the surface of the Hybrid Avalanche Photodiode. Scale is in mm.

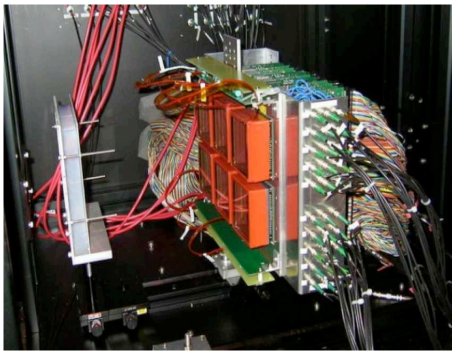

Figure 4. Experimental setup with aerogel radiator and an array of 6 HAPDs.

$\approx 10^3$ e-h pairs, which in turn get an additional amplification of about 40 in the avalanche of the p-n junction. The capability of separating events according to the number of detected photons is impressive (figure 2).

In the present paper we report on the design and construction of readout electronics, especially manufactured for this type of position sensitive, single photon detector.

2 The beam-test and the bench test results

We have investigated a Hamamatsu HAPD detector shown in figure 1. The detector with outer dimensions 76×76 mm^2, consists of 144 pads (4 chips $\times$ 6 rows $\times$ 6 columns) of 5×5 mm^2 each. Thus, the geometrical acceptance of the detector is 67%. A scan with a laser light beam, with 5 μm diameter across the surface of the detector, reveals some non working channels, but otherwise the variation of sensitivity is small (figure 3).

The apparatus used in figure 4 was tesed in the KEKB test beam of 2GeV/c electrons. For detection of Cherenkov rings we have used an array of 6 HAPD photon detectors. The events have been triggered by scintillation counters and the beam particles straight trajectories have been recorded with multiwire proportional chambers. For each track-photon hit pair a Cherenkov angle was calculated. The accumulated distribution of photons is shown in figure 5 as a function of the corresponding Cherenkov angle. The measured performance would enable a 6 σ separation of kaons and pions [4].

3 The read out electronics

The requirements for the readout electronics of around 500 HAPDs in the Belle II RICH are the following:

- operation in high magnetic field of 1.5T,

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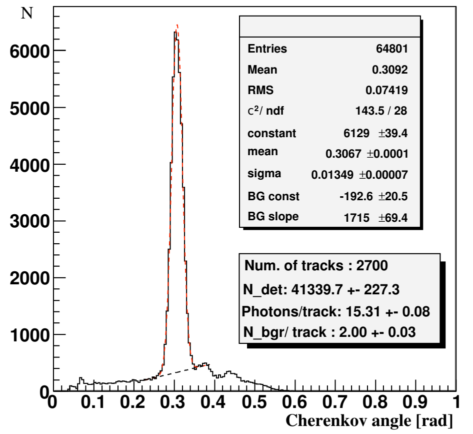

Figure 5. Number of photons as function of the Cherenkov angle.

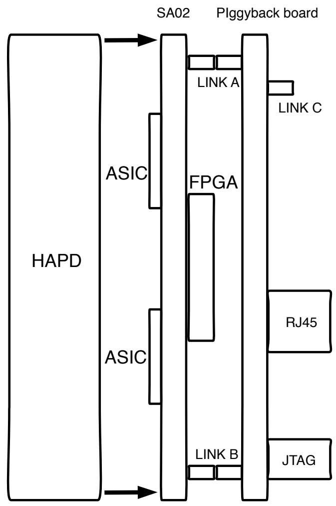

Figure 6. Two readout boards attached onto the HAPD.

- the electronics boards should fit behind the HAPD detector occupying a relatively small overall volume (50 mm × 76 mm × 76 mm),
- in-situ, periodic testing and diagnosis of individual channels and status of the device should be possible,
- remote adjustments of most parameters should be possible (e.g. gain, peaking times, offset and treshold) allowing compensation of expected decline of detector performance due to e.g. radiation damage (increase of noise and leakage current),
- monitoring of health parameters, such as the temperatures on both sides of the electronics boards and power supply voltages, should be provided by remote system diagnostic tools.

We are developing a modular readout system composed of two boards, which are connected behind the HAPD detector (figure 6), and occupy a volume less than 76×76×50 mm^3. Both sides of the two boards with respective block diagrams are shown in figure 7, and figure 8. The proposed readout system fits behind one HAPD and could readout all 144 channels.

The ASIC chip SA02, packed in LTCC (Low Temperature Co-fired Ceramic) BGA package, can digitize analog signals from 36 channels [7]. The analog electronic front-end chain for each channel consists of a charge sensitive preamplifier, a shaper and a threshold comparator (figure 9). Gain values, peaking times and offsets may be set for individual channels remotely, while the threshold level is equal for all channels. The amplification factor of the charge sensitive preamplifier can be set from 2 to 7.25V/pC and the shaping time is variable between 250ns to 1 μs. These two parameters allow to optimize the signal to noise ratio due to the declined detector performance. We expect to achieve the noise level of 1200 e^- at HAPD sensor capacitance of 80 pF.

Parameter settings could be done during operation as data buses and control lines are separated. Moreover, each analog input pin is controlled by software, so that it may be set into different operation modes (normal, test or off mode). Built onto the board is also a pulse generator with

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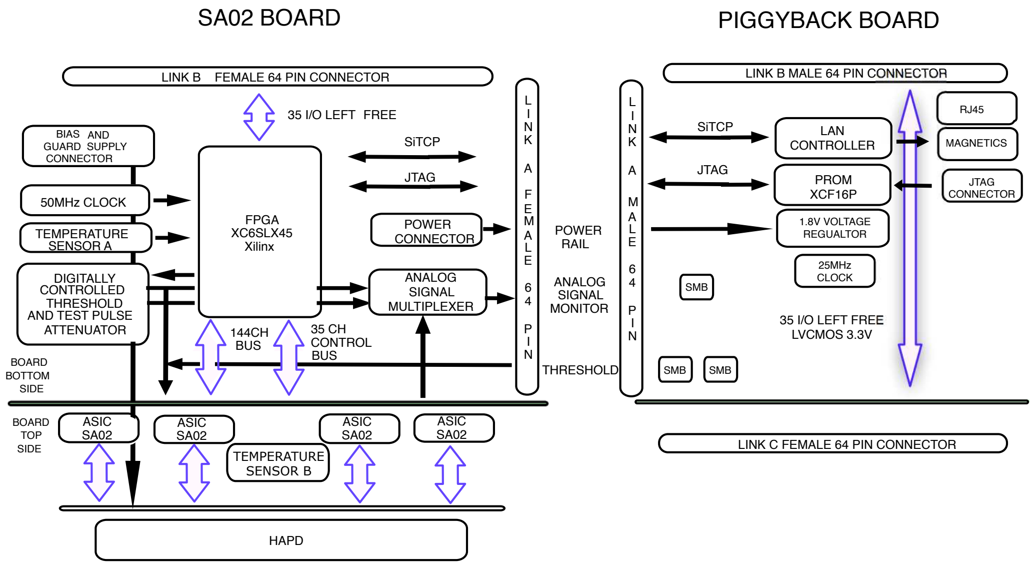

Figure 7. SA02 and Piggyback functional block diagram.

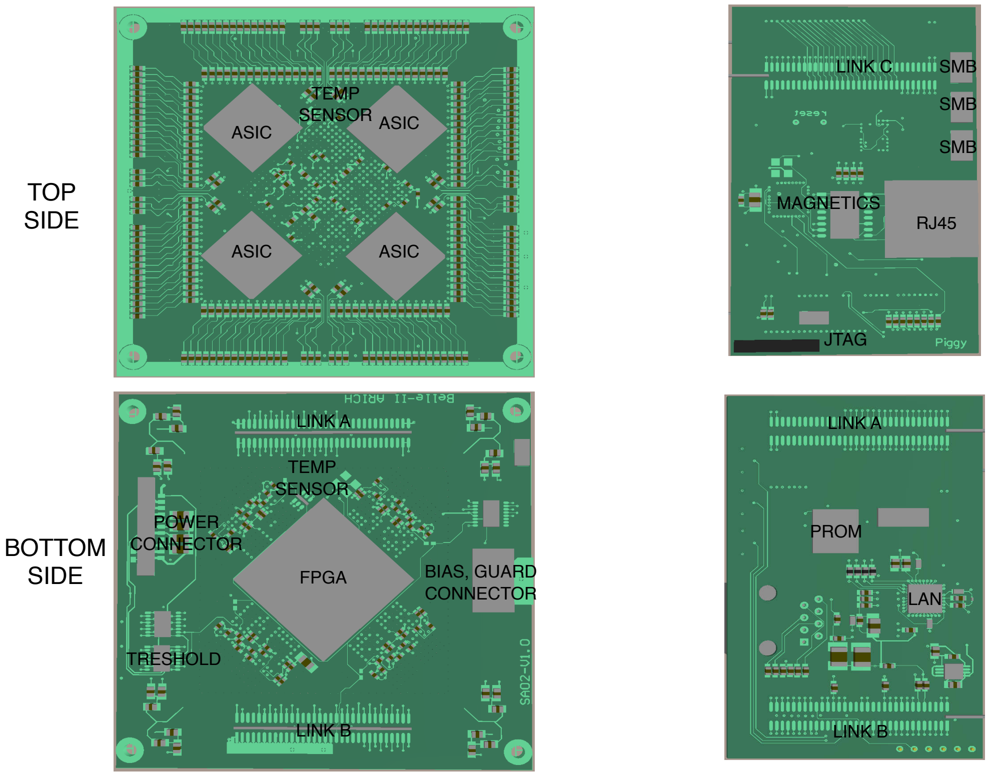

Figure 8. SA02 (left) and Piggyback (right) boards geometrical layouts.

variable attenuation for test pulse analysis. The ASIC allows monitoring of analog signal for the channel selected by software.

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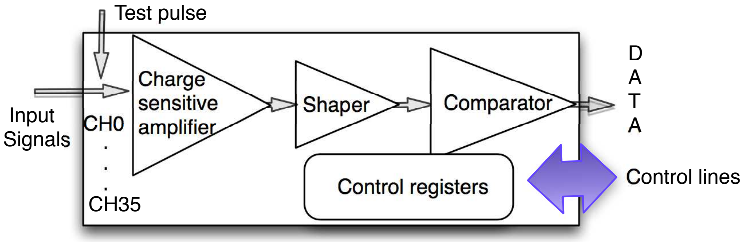

Figure 9. SA02 ASIC front end chains and logic.

The SA02 board has 4 ASIC chips facing the HAPD detector, and one FPGA (Xilinx Spartan 6 FPGA) for data processing on the other side of the board. Its readout core is composed of 16 bit shift registers for every channel. The shifting clock is designed as a divider of the storage ring clock from the accelerator (about 4 MHz). At a trigger event, the last four bits, stored in the shift registers, are shifted out toward the data acquisition system. The detectors read out time is about 2.8 μs. During read out time, four trigger events separated for more than 250 ns can be stored in the internal FPGA registers. The read out electronics should be able to work with a trigger of about 30 KHz, expected in the Belle II detector. The communication will be synchronized with the central data acquisition system [9]. The core features also control drivers for large bandwidth analog multiplexers, temperature sensors and attenuators. In this sense, the SA02 is a stand alone system almost ready for final implementation.

The piggyback board is connected to the SA02 board and provides bitstream boot from PROM or via JTAG. For laboratory test purposes the board integrates a LAN8700 controller with magnetic coupling for ethernet connection via an RJ45 connector using the SiTCP protocol [8]. In addition 35 I/O pins (LVCMOS 3.3V) are left free on the LINK C connector allowing the freedom to extend its functionality. The piggyback board is an intermediate stage of development and is designed to test the functionality of the SA02 board during the on-the-bench and beam test. In the Belle II detector, the piggyback board will be replaced with the board, that will collect the data from several SA02 board and will be responsible for communication and data transfer [9]. Both boards should be capable to work in a high magnetic field of 1.5T.

The selected FPGA has sufficient available gates to design a radiation tolerant firmware. In order to minimize data loss due to bit flipping in the digital part of the circuitry, we foresee a dynamic mode of operation. FPGAs of separate HAPD detectors will be randomly reloaded with bitstream code during run time operation. We plan to continuously verify ASIC control registers content in order to ensure the integrity of the register settings. By simulating randomly distributed events, the loss of the overall detector efficiency during firmware reloading, was found to be negligible.

4 Summary

We are developing a readout electronics for a ring imaging Cherenkov detector consisting of aerogel radiators and HAPD position sensitive single photon detectors. The novel electronics system will fit in to the small volume behind the HAPDs and will allow signal digitalization and acquisition, as well as adjustments of performance parameters. Its modular design gives freedom to evaluate the

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system in a variety of environments and bench setups. In addition to optimization of the efficiency of the detector, such a system also allows for compensation of slow parameter drifts due to radiation damage. We forsee to test the proposed read out electronics during a beam test in summer 2011.

Acknowledgments

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