Scintillating Fibre Tracker Front-End Electronics for LHCb upgrade

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Abstract—The LHCb detectors will be upgraded during the next LHC shutdown in 2018/19. The tracker system will undergo major changes. Its components will be replaced by new technologies in order to cope with the increased hit occupancy and the higher radiation dose.
A detector made of scintillating fibres read out by silicon photomultipliers (SiPM) is envisaged for this upgrade. Even if this technology has proven to achieve high efficiency and spatial resolution, its integration within a LHC experiment bears new challenges. The detector will consist of 12 planes of 5 to 6 layers of 250\( \mu \)m fibres stacked covering a total area of 5x6m\(^2\). The desired spatial resolution on the reconstructed hit is 100\( \mu \)m. SiPMs have been adapted to the detector geometry reducing the dead area between channels. A total of 64 channels are arranged in a single die with common cathode connection and channel size of 0.23x1.32mm\(^2\). Two dies are packaged together with only 0.25mm of dead area between them. Radiation tolerance of such devices is an important challenge. Operation at low temperatures will be crucial to achieve the desired performance. Several manufacturers have produced prototypes for testing with different characteristics but same form factor. This size leads to a total of over 500k channels which need to be read out at 40MHz.
The PACIFIC ASIC will readout of SiPMs with no interface components between devices and ASIC. It will handle 64 channels with analog signal processing and digitization. Last prototype comprises 8 channels. The first stage is a current conveyor followed by a fast shaper (\( \approx \)10ns to cope with signal arrival times) and a gated integrator. The digitization is done using a 2 bits non-linear flash ADC operating at 40MHz. The power consumption has been kept bellow 8mW per channel.

I. INTRODUCTION

Large Hadron Collider beauty (LHCb) experiment is one of the ongoing experiments running at the Large Hadron Collider at CERN in Geneva. Its main aim is to make precise measurements of CP violation and rare decays of beauty and charm hadrons.

LHCb is a forward spectrometer motivated by the fact that \( bb \) pairs produced at the LHC are generated in a large portion in the same direction (either forward or backward).

Starting from the interation point at the left of figure 1, the tracking system consists of a silicon strip device surrounding the interaction region (the Vertex Locator), a large area silicon strips detector (trigger tracker TT) and a combination of silicon strip detectors and straw drift-tubes (tracking stations T1, T2 and T3). Charged hadron identification is provided by two Ring Imaging Cherenkov (RICH) detectors. A calorimeter system is used for the detection of neutral particles and identification of electrons and protons formed by an electromagnetic (ECAL) and an hadronic (HCAL) calorimeter. Finally, muons are identified and measured by means of muon chambers separated by iron absorbers (M1 to M5). It’s planar structure permits easy access to it’s different detectors for maintenance.

The LHCb detectors will be upgraded during the next LHC shutdown in 2018/19. The tracker system will be replaced by new technologies in order to cope with the increased hit occupancy and the higher radiation dose: A detector made of scintillating fibres read out by silicon photomultipliers (SiPM) is envisaged\[1\]. The detector will consist of 12 planes of 5 layers of 250\( \mu \)m fibres stacked (see figure 2), covering a total area of 5x6m\(^2\) and leading to a total of over 500k SiPM channels which need to be read out at 40MHz.

The desired spatial resolution on the reconstructed hit is 100\( \mu \)m. The scintillating fibres will act as a light generator.
and signal transmission medium to guide the scintillation light to the SiPMs sitting at the outer boundaries of the detector.

Even if this technology has proven to achieve high efficiency and spatial resolution, its integration within a LHC experiment bears new challenges. Several SiPMs from different manufacturers and with different signal properties are currently discussed for the readout.

The low Power ASIC for the SCIllintating FIltres Tracker (PACIFIC) is developed to readout the SiPMs with no interface components between devices and ASIC. The ASIC will handle 64 channels with analog signal processing and digitization. Last prototype includes 8 channels.

II. SILICON PHOTO MULTIPLIERS

The multi-channel SiPM arrays have been adapted to the detector geometry reducing the dead area between channels. A total of 64 channels are arranged in a single die with common cathode connection and channel size of 0.23x1.32mm². With a total number of 96 micro-cells. Two dies are packaged together with only 0.25mm of dead area between them (see figure 3).

Two different manufacturers (Ketek and Hamamatsu) have provided samples for characterization. The pixel size is 57.5x62.5µm for the 2014 trenched detectors from Hamamatsu. Ketek provided two different versions with 82.5x62.5µm and 60x62.6µm pixel size.

To maximize the photon detection efficiency (PDE), the detectors with trenches are typically operated with a high over-voltage (3.5V) which is significantly higher than that used in earlier experiments[2]. This results in better channel-to-channel gain uniformity.

The SiPMs are placed in a region with a low level of ionising radiation. A moderate ionising dose of 40 to 80 Gy after 50fb⁻¹ is estimated to be present in the worst case region. The dominating radiation effect is produced by the neutron flux for which a fluence of 10¹² neutrons cm⁻² is expected (for an operation time equivalent to 50fb⁻¹).

The main effect of the neutron radiation is an increase of the dark count rate. For this reason it is planned to operate the SiPMs at a temperature of -40°C for which the device presents much smaller dark count rate and it’s increment with the neutron irradiation is kept to a reasonable level. Irradiation studies have been done in the LHCb cavern, in the neutron irradiation facility at Ljubljana and with a Pu-Be neutron source. The dark current is reduced by a factor of two when the temperature is reduced by 10 °C, as seen in figure 4.

The non-triggered full bunch crossing read-out scheme for the LHCb Upgrade requires data reduction by zero suppression. This will be done by searching and building clusters from hits of neighbouring channels. The clustering will be performed on 128 detector channels with clusters comprising at least two channels.
III. READOUT ASIC

The PACIFIC ASIC will readout the previously described SiPM sensors.

A. Signal timing

First measurements of the signal produced by the 2.5m scintillating fibres showed a large dispersion in the time of arrival of the light (see figure 5, depending on the impact point of the crossing particle. This effect is increased if a mirror is placed at the end of the fibres.

The ASIC must deal with this incoming signal delay. Moreover the time response of the two proposed sensors are completely different (see figure 6. This is a fundamental characteristic to achieve fast signal shaping and integration but with short recovery time. The recovery time constant for the pixel (20ns for Hamamatsu and 100ns for KETEK) was chosen such that no significant dead time occurs due to the signal and noise induced discharge rate of the pixel.

B. Architecture

For this previously discussed timing characteristics of the signal an interleaved gated integrator solution for the readout has been proposed.

The blocks diagram of the ASIC channel is shown in figure 7: The first stage is a current conveyor with low input impedance (≈34Ω) and high bandwidth[3]. It is followed by a fast shaper (≈10ns shaping time to cope with signal arrival times) and the gated integrator. This design generates an output integrating around 90% of the signal before the end of the current bunch crossing (25ns). The digitization is done using a 2 bits non-linear flash ADC operating at 40MHz (based on three hysteresis comparators). To account for the different signal time constants of the different SiPM types the shaping parameters can be configured. Digital slow control (based on standard I2C) and serialization of the digital output is also included (serialization takes 4 bits, from two channels at 160MHz). The power consumption has been kept bellow 8mW per channel. Several debug functions have been implemented in order to multiplex main analog signals in the processing chain.

During 2013 two prototypes where submitted including just the current conveyor in the first prototype (PACIFICr0), adding shaper and integrator in the second (PACIFICr1). A third prototype has been submitted in 2014 to provide usable electronics for a test system with the full processing chain with direct digital output (PACIFICr2) and comprising 8 channel with a total area of 2500 x 1200 µm (see figure 8).

Fig. 5. Signal arrival time

Fig. 6. SiPMs response

Fig. 7. PACIFIC channel blocs diagram

Fig. 8. PACIFICr2 layout
C. Measurements

For characterization of prototypes directly wire bond in an analog front end printed circuit board (PCB) has been used. This board includes all the analog power supply (using Low Drop Out regulators) and connectors for input/output signals. Using an external digital PCB the needed signals are generated for control and readout.

1) Input Impedance: According to simulations input impedance should be kept around 35Ω but prototype measurements showed an increased value. This could be explained by some parasitic elements added on the PCB. As can be seen in figure 9 the montecarlo simulations show always better performance than measurement. Since the excess impedance is also present in low frequencies some trace resistance and series resistor process variation must be one of the causes. Correct input stage operation point is also under study.

As seen in figures 10 and 11 the single photons peaks can be clearly seen using the full analog chain.

2) Shaping output: Using PACIFICr1 prototype and shaper analog output a measurement using an LED pulsing in front of the detector has been performed. The signal is integrated during 25ns by an oscilloscope. This measurement has been performed using both sensors and matching configuration parameters.

3) Integrator: Using previous measurement an electrical signal equivalent to 10pe has been injected to PACIFICr1 and the total amount of signal present at the output of the interleaved integrators has been measured by function of delay between input signal and clock. The results can be seen in figure 12, showing an acceptable recollection of the charge for the following stage.

IV. Conclusions

A suitable solution for the readout of the envisaged tracker upgrade detector at LHCb has been presented with it’s latest test results. It’s functionality should be verified and extended in the testing of current prototype before going to a full size final prototype. It has been proved that the configurable shaping scheme prior to integration can fit the different sensor shapes and signal time of arrival.
REFERENCES

