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Analog Optohybrids for the Readout of the CMS Silicon Tracker

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Abstract

The Compact Muon Solenoid experiment (CMS) at the Large Hadron Collider (LHC) at CERN will include a Silicon Strip Tracker covering a sensitive area of $206 \, \text{m}^2$ with about 9.3 million channels. The particle signals are read out by APV25 front-end chips and transferred to the processing units using approximately 37,000 optical links over a distance of about 100 m.

In order to convert the electrical signals to intensity-modulated light, roughly 15,000 optohybrids with 2 or 3 channels each will be distributed in the Tracker volume. These devices are designed to operate at $-10^9 \, \text{C}$ in a magnetic field of 4 T and the harsh radiation environment of CMS with good linearity and low noise. Single-mode optical fibers will guide the light to 12-way pin diode arrays converting it back to electrical signals for digitization and processing. Custom-specific optoelectronics and ASICs are involved on both ends of the optical links.

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1 Introduction

The Compact Muon Solenoid (CMS) will be one of the four experiments at the Large Hadron Collider (LHC) at CERN. Its tracking capabilities rely on a powerful Silicon Strip Tracker [1, 2] which covers a sensitive area of 206 $m^2$. The high granularity of the strip detectors result in about 9.3 million readout channels.

2 Readout System

Optical data transmission has been chosen for the CMS Tracker because of its high speed, low mass, low power, immunity against electromagnetic interference and galvanic isolation.

The optical analog readout chain of the CMS Tracker [3] is shown in fig. 1. A CMS Silicon Detector module consists of one or two daisy-chained sensors with 512 or 768 strips each, which are read out by four or six APV25 [4] front-end chips, respectively. After 2:1 multiplexing by the APVMUX chip, the analog strip signals are presented to the Analog Optohybrid [5] at a rate of 40 MS/s, which converts them to intensity-modulated infrared light at $\lambda = 1310 \text{ nm}$ using a Linear Laser Driver ASIC (LLD) [6] to drive edge-emitting Fabry-Perot laser diodes. Both APV25 and LLD are manufactured in radiation-tolerant 0.25 $\mu m$ CMOS technology. Groups of 12 and then 96 commercial step-index single-mode fibers are bundled in multi-ribbon cables which are guided to the counting room over a distance of up to 100 m. At the receiver side, pin photo-diode arrays in the Analog Rx Modules convert the light of 12 fibers back to electrical signals for subsequent digitization and processing in the Front End Driver (FED) modules [7].

The analog optical link system comprises a total of about 15,000 optohybrids, 37,000 fiber channels and 3,100 receiver modules. In similar fashion, but smaller quantities, a bi-directional digital optical link system [8] is used to control the CMS Tracker front-end electronics.

3 Performance

The principal device of the analog optical link is the front-end optohybrid, since it is located in the radiation environment at a magnetic field of 4 T and has to fulfill stringent optical and electronical requirements. The analog optohybrid (fig. 2) contains the Linear Laser Driver, which converts the differential input voltage to a current suitable to drive two or three laser diodes. One of four different gains of the Laser Driver can be selected by its I2C interface to account for various laser efficiencies. Similarly, the pre-bias current can be adjusted to compensate the increase of the laser transmitter threshold current with irradiation.

Fig. 3 shows typical input-output characteristics of an optohybrid with the four different gains of the Laser Driver measured at room temperature and without a magnetic field. There is no relevant difference to the operating conditions because the principal effect of both environmental conditions, a shift of the laser threshold current, is compensated by a different pre-bias setting of the Linear Laser Driver.

The specifications of the Analog Optohybrid define a limit for the Integral Linearity Deviation of 1.5 % in the operating input range, which is typically measured to be below 0.5 %. The input referred RMS noise of the optohybrid...
Figure 2: Photograph of the Analog Optohybrid (size: $30 \times 23 \text{ mm}^2$).

Figure 3: Measured input-output characteristics of the Analog Optohybrid. Typically, the Linear Laser Driver gain=1 is closest to the target gain.
has to reside within 3 mV, while typical measurement results show a value of about 1.25 mV, corresponding to a dynamic range of 9 bits. Yet, the minimum bandwidth specification of 90 MHz is by far exceeded while the crosstalk limit between adjacent channels of −54 dB is well observed.

Moreover, parts of the Analog Optohybrid and the laser diodes in particular were tested in CMS-like environmental conditions. It was found that the laser operation does not suffer the high magnetic field of CMS. Fig. 4 shows that the laser threshold current decreases by about 0.5% in the presence of a 4 T field.

![Laser threshold shift with magnetic field](image)

**Figure 4:** Measured laser threshold current shift in the presence of a magnetic field.

Laser diodes and other parts to be used in the front-end optohybrids (e.g. capacitors and glues) were irradiated with protons, neutrons and photons. The lasers showed an increase of the threshold current with proton irradiation as expected, while the other components were found to be radiation tolerant within the levels expected at CMS. Consistent results were obtained with proton irradiation of Analog Optohybrid prototypes [9]. The first few meters of the optical fiber are located in the radiation area as well. However, since optical fiber is highly radiation tolerant, the maximum light power loss in the CMS Tracker scenario will only be about 0.1 dB and thus negligible.

## 4 Production

The research and development phase has been completed, feasibility and readiness for operation in CMS have been demonstrated on prototypes and thus the project has now entered the phase of mass production.

Including spares, about 17,000 Analog Optohybrids will be manufactured by Austrian [10] and Italian [11] companies. Large efforts have been made to ensure the best possible production quality, including testing of all devices at several stages of the assembly procedure using an automated test setup developed at HEPHY Vienna, which is used in both industries and the institutes in charge (HEPHY Vienna and INFN Perugia). The results of the pre-production batches are very encouraging and reveal bright prospects for the series production.

In parallel, the mass production of optical fibers and Analog Rx Modules is about to start under the responsibility of CERN. Due to the high radiation tolerance of fibers and the less demanding requirements outside of the radiation area, those items are closer to industry-standard and thus can be produced faster than the Analog Optohybrids.

## References

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