Design and Performance of a Circuit for the Analogue Optical Transmission in the CMS Inner Tracker

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Abstract

A new circuit for the conversion of analogue electrical signals into the corresponding optical ones has been built and tested by the CMS group of Perugia. This analogue opto-hybrid circuit will be assembled in the readout electronic chain of the CMS tracker inner barrel. The analogue opto-hybrid is a FR4 (vetronite) substrate equipped with one programmable laser driver chip and 2 or 3 laser diodes, all being radiation tolerant. The description of the circuit, production flow and qualification tests with results are reported and discussed.

I. Circuit Layout

The analogue opto-hybrid circuit designed and built by the Perugia CMS group [1] will be employed in the analogue optical link of the TIB (Tracker Inner Barrel) and TID (Tracker Inner Disks) parts of the CMS tracker [2]. A similar circuit has been prototyped for the TOB (Tracker Outer Barrel) and TEC (Tracker End Caps) at CERN. The schematic of the analogue optical link is reported in Figure 1.

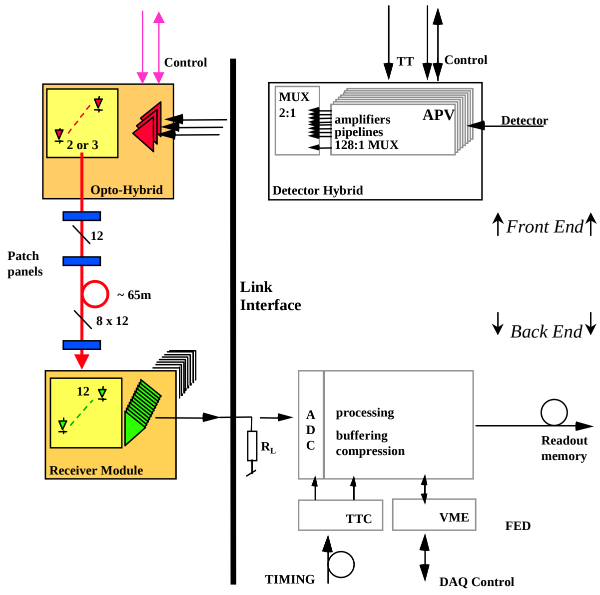

Figure 1: The tracker analogue optical link.

The analogue opto-hybrid converts the differential input voltage, coming from silicon microstrip detectors and sampled by the APV chips, into analogue optical signals transmitted via optical fibres to the back-end electronics. Each fibre will carry the multiplexed signals of 256 silicon detector microstrips. A total of 4000 analogue opto-hybrids for the TIB/TID system is required.

The dimensions of the PCB are 30 x 22 mm^2 and 0.5 mm in thickness. Figure 2 shows the upper side of the opto-hybrid circuit housing the connector, the un-packaged laser driver chip [3,4] and passive components.

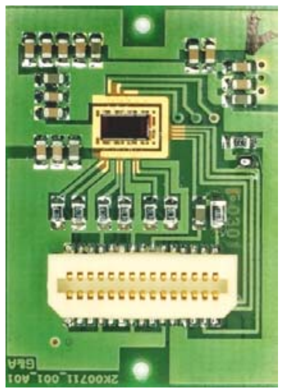

Figure 2: Connector side view of the analogue opto-hybrid.

COTS (Commercial Off-The-Shelf) components are used extensively in the opto-hybrid circuit for cost saving strategy. Laser diodes and the coupled optical fibres are located in the backside respect to the Figure 2. The laser driver chip is programmable via the I^{2}C interface and biases the laser diodes in their linear operational region. Input signals from the front-end amplifier directly modulate the bias current and are converted into optical signals (wavelength 1310 nm) by commercially available InGaAsP edge-emitting laser diodes. They are then transmitted to InGaAs photodiodes located at the receiver side for optical to electrical conversion. The number of laser diodes (fibres) is 2 or 3 depending on the opto-hybrid position in the detector. Both laser driver and laser diodes are glued to the substrate with a thermally conductive resin (Epo-Tek T7110) and the electrical contact is made through ultrasonic wedge-to-wedge aluminium wire bonds. Actually, PCB has to be redesigned to house next version of laser driver that will be packaged.

II. PRODUCTION FLOW

In the production phase (2002-2004), the analogue opto-hybrid circuit will be assembled by following the scheme reported in Figure 3.

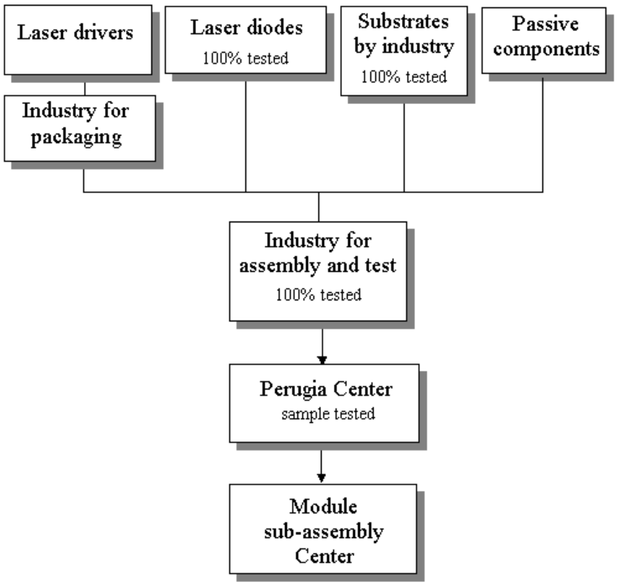

Figure 3: Production flow of the analogue opto-hybrid.

The opto-hybrid substrate is produced in industry, while the active devices (laser driver and laser diodes) are procured by CERN. All these subcomponents are 100% tested. The assembly of the circuit using COTS and active devices is done by the manufacturing industry that will take care of the test on 100% of the production. Perugia will receive the opto-hybrids and will test a sample (see the following paragraph). The circuits will then be sent to CMS tracker sub-assembly centers in order to be mounted in the front-end modules. At present, about 30 opto-hybrid circuits have been produced by the manufacturing industry and delivered to the CMS group of Perugia.

III. CHARACTERISATION

A series of tests to characterise the opto-hybrid circuit have been defined in the specifications for the CMS tracker optical link [5]. Electrical tests, thermal cycles and irradiation tests are some of those required for the circuit qualification. Table 1 reports the complete list of the tests to be done both by the manufacturer (i.e. the manufacturing industry) and the Perugia CMS group for TIB/TID. The main effort in the test activity is foreseen before production during product qualification when extensive measurements are required. In the subsequent production phase, the industry will be provided with an ATE (Automatic Test Equipment) by CERN for the lot validation tests. Test centres are charged with the lot acceptance tests on a sample of the production.

Table 1:

Specification to be tested	Manufacturer		CMS Institute in charge	
	Product qualification	Lot validation (before delivery	Product qualification	Lot acceptance
Number of channels	♦	♦	♦	♦
Gain		♦	♦	♦
Peak signal to noise ratio		♦	♦	♦
Integral linearity deviation		♦	♦	♦
Bandwidth		♦[1]	♦[1]	♦[1]
Settling time to ±1%			♦	
Skew			♦	
Jitter			♦	
Crosstalk			♦	
Max. operating input voltage range		♦	♦	♦
Input voltage range		♦	♦	♦
Input impedance			♦	
Quiescent operating point		♦	♦	♦
Quiescent operating point after reset		♦	♦	♦
Hardware Reset		♦	♦	♦
Power supply			♦	
Power supply rejection ratio			♦	
Power dissipation			♦	
Wavelength				
Output power range		♦	♦	♦
Pre-bias output resolution		♦	♦	♦
Magnetic field			♦	
Hadronic fluence			♦	
Gamma radiation dose			♦	
Temperature			♦	
Operating humidity	♦			

* rise time and fall time measurements

A. Electrical Tests

Some of the electrical tests reported in Table 1 have been done on 5 out of 30 analogue opto-hybrids already delivered to Perugia. Before starting the tests, each laser diode has to be biased at its working point, i.e. the current value corresponding to the linear response region (typically a few mA). This is achieved through the programmable laser driver that permits also to set the gain of the signal between 5 mS and 12.5 mS. These features are used to compensate changes in laser characteristics caused by the tracker radiation environment. Since the bias current depends on the temperature, the electrical specifications are referred to 25 °C. The electrical tests reported in this paper are the link gain measurements, the noise, the deviation from linearity and the bandwidth. The set-up is shown in Figure 4, except for the bandwidth measurement, where a network analyzer is employed. The input signal is generated by an AWG (Arbitrary Waveform Generator) and is converted into a differential signal for input to the analogue opto-hybrid. The test card is connected to the opto-hybrid by a kapton cable and provides the power supply and the inputs (data and clock lines) to the circuit. The opto-hybrid output signal carried by the optical fibres is converted into an analogue electrical signal by a prototype of the optical link receiver [6]. The output is digitized by the 16 bit ADC and data are stored in the computer which runs Labview.

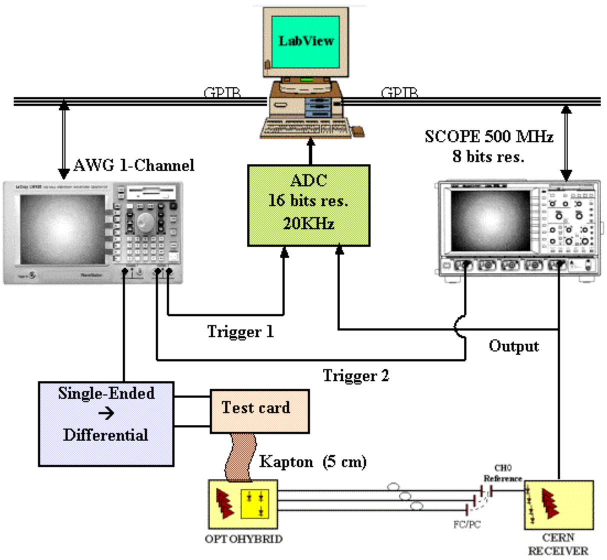

Figure 4: Set-up for electrical tests of the analogue opto-hybrid.

1)Link Gain

The gain of the laser driver chip is configurable via the I^2C interface. The nominal values are 5, 7.5, 10 and 12.5 mS. The link gain, G, is estimated by measuring the link transfer characteristic. A 100 step input voltage ramp (stair-case) between –500 mV and 500 mV is generated by the AWG and the output is acquired by the 16-bit resolution ADC. Figure 5 reports the link transfer characteristic of a 3-channel opto-hybrid at the lowest laser driver gain value.

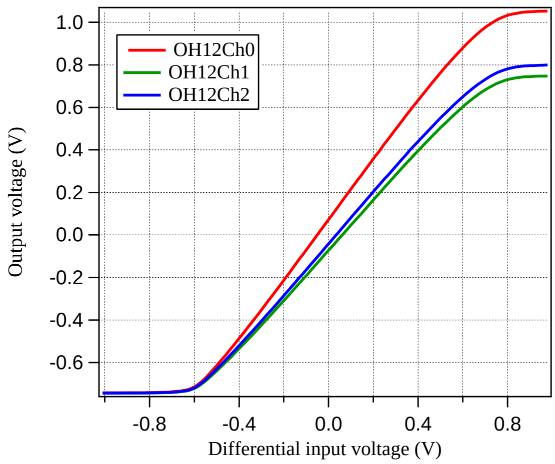

Figure 5: Output voltage as a function of the differential input voltage for a typical 3-channel opto-hybrid.

The link gain G is then calculated from a linear regression fit over a range extending from –300 up to 300 mV. Values between 0.9 and 1.2 have been found for tested opto-hybrids. These values are higher than the specifications, but the receiver used has a greater gain respect to its final version.

2)RMS-Noise

The RMS-noise dY(X) has been measured with the oscilloscope for each level of the voltage ramp generated by the AWG. For ease of comparison the measured RMS noise is referred to the link input to obtain the Equivalent Input Noise (EIN):

$$EIN = \frac{dY(X)}{G}$$

Specifications on the optical link require 2.4 mV as the maximum value for EIN in the interval between –300 and 300 mV. Figure 6 reports the EIN for the 5 tested opto-hybrids.

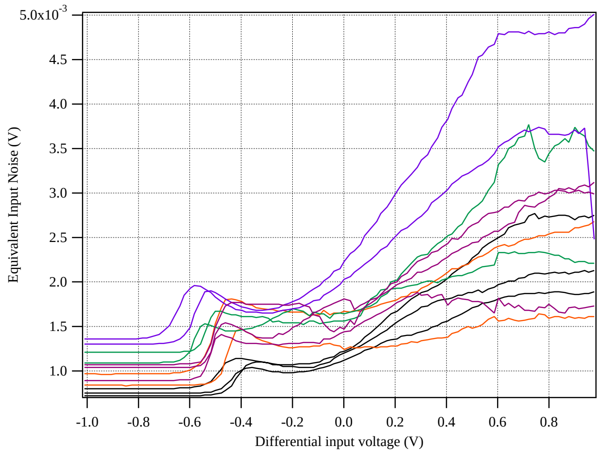

Figure 6: Equivalent Input Noise for the measured opto-hybrid channels.

Almost all of tested opto-hybrids have the EIN value inside the specification. A 2-channel opto-hybrid shows a higher noise

3)Deviation from linearity

The link transfer characteristic measurement is also used to determine the deviation from linearity of the opto-hybrid response. The linear regression fit is used to calculate the Equivalent Input Non Linearity, EINL(X), defined as:

$$EINL(X) = \frac{|Y(X) - GX|}{G}$$

where Y(X) is the measured output voltage and GX is the linear fit. The specification limits to EINL are stated as follows: 9 mV in any 100 and 200 mV window within –300 and 300 mV, 18 mV in any 400 mV window within the same range. The equivalent input non linearity (EINL) for some of the tested opto-hybrid channels is reported in figure 7. Results are within the specifications given above.

4)Bandwidth

The bandwidth of the optical link has been measured by a network analyser. Values found for the tested opto-hybrids are around 90 MHz, slightly lower than specifications. These results are, nevertheless, in agreement with those found for the laser driver itself. Higher values of the bandwidth will be achieved in the future with a speeder laser driver.

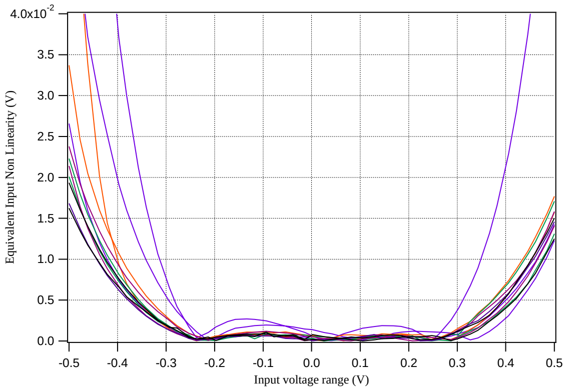

Figure 7: Equivalent Input Non Linearity for the measured opto-hybrid channels.

B. *Thermal qualification*

The nominal operating temperature of the CMS tracker is –10 °C. The thermal qualification of the opto-hybrid equipped with all its parts follows some preliminary validation tests on single components. As an example, the choice of the resin type for the gluing of the laser driver and laser diodes to the substrate is heavily affected by its thermal response. Outgassing during the resin cure time is strongly unwanted, since it likely damages optoelectronic components.

A total of 100 consecutive cycles has been currently used for a preliminary test on the CTE (Coefficient of Thermal Expansion) matching between the opto-hybrid substrate, the resin and the components. At this stage, only dummy optoelectronic components have been used. The temperature cycle generated by the climatic chamber used for the thermal qualification is reported in Figure 8. The thermal qualification of the fully populated opto-hybrid circuit will be the scope of future tests.

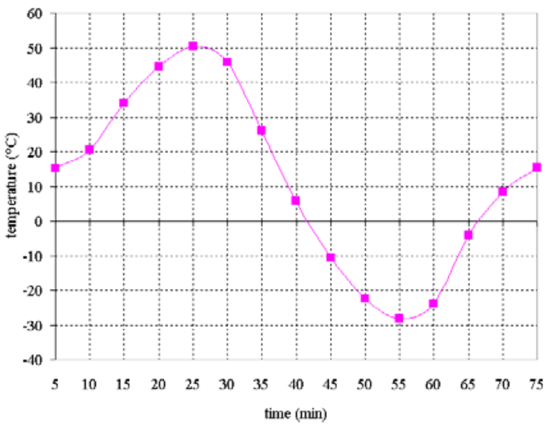

Figure 8: Temperature cycle generated by the climatic chamber.

C. *Irradiation qualification*

The radiation environment corresponding to 10 years of LHC life has to be reproduced in irradiation facilities with beams of nucleons and gammas in order to check the radiation hardness of the opto-hybrid circuit. A first survey was done by irradiating with low energy neutrons (<100 keV) the opto-hybrid substrate and the resistors and capacitors used in the design. Note, that the active devices, i.e. the laser driver and laser diodes have been found to be radiation tolerant [7]. This irradiation test was done in June 2000 at the ENEA Casaccia reactor located near Rome. The test has shown no relevant variations in the mechanical structure and in the measured resistance and capacitance values. Further tests are foreseen with gammas and neutrons and will involve the powered opto-hybrid circuit.

IV. Conclusions

The analogue opto-hybrid circuit developed by the CMS group of Perugia has been produced. About 30 circuits have been delivered and the electrical performances of 5 of them have been tested. The results have shown a good agreement with specifications. More qualification tests will define the final circuit in order to start the final production in 2002.

V. Acknowledgements

We gratefully acknowledge the CERN opto-hybrid team, F.Vasey, J. Troska and K. Gill, for their useful support in the definition of qualification tests for the circuit characterisation.

VI. References

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