

# Prototype Analogue Optohybrids for the CMS Outer Barrel and Endcap Tracker

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## Abstract

Prototype analogue optohybrids have been designed and built for the CMS Tracker Outer Barrel and End Cap detectors. The total requirement for both types in CMS is 12900 that will be assembled between 2002 and 2004. Using very close to final optoelectronic and electronic components several optohybrids have been assembled and tested using standardised procedures very similar to those to be implemented during production. Analogue performance has met the specifications in all cases when operated in isolation and when inserted into the full prototype optical readout system.

## I. INTRODUCTION

The CMS Tracker readout system consists of  $\sim 10$  million individual detector channels that are time-multiplexed onto  $\sim 40000$  uni-directional optical links for transmission between the detector and  $\sim 65\text{m}$  distant counting room[1]. Data are transmitted in analogue fashion for digitisation at the Front-End Driver (FED) Boards located in the shielded counting room. Thus only the transmitting elements of the analogue optical links are located in the radiation area of the experiment. All electro-optical components of the optical transmission system have been proven to function within specifications after exposure to radiation levels beyond those expected in the CMS Tracker[2,3]. A system-level diagram of the CMS Tracker readout system is shown in Figure 1.

Hybrid circuits are required to carry the electro-optical components (linear laser driver and 2 or 3 laser diodes) to be situated in close proximity to the detector hybrids distributed throughout the CMS Tracker. A block diagram highlighting the required interfaces of the analogue optohybrid is shown in Figure 2. The requirement for such *Optohybrids* matches the number of detector hybrids one-to-one, yielding a total number for the whole Tracker of approximately 17000. Responsibility for the design and procurement of optohybrids has been split according to the destination of the optohybrids within the Tracker: HEPHY Wien (Austria) has the responsibility to supply the 12900 optohybrids for Tracker Outer Barrel (TOB) and Tracker EndCap (TEC); while INFN Perugia (Italy) will supply the remaining fraction for Tracker Inner Barrel (TIB) and Tracker Inner Disks (TID).

The Tracker Optical Links group at CERN has developed several prototype optohybrids suitable for use by TOB and TEC. The prototype development was carried out by CERN

as the responsibility for the final supply was only recently apportioned. This paper will describe the prototype circuit, the test methods used to characterise its performance and the results obtained from this characterisation.

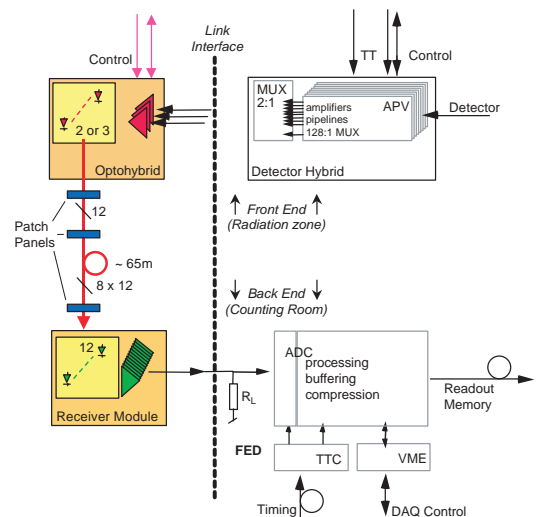


Figure 1: CMS Tracker Readout System, with Analogue Optical Link highlighted on left-hand side.

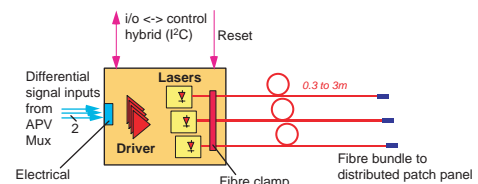


Figure 2: Analogue optohybrid block diagram.

## II. ANALOGUE OPTOHYBRID DESIGN

The major design-driver of the optohybrid substrate layout was the physical size of the final object, as the optohybrid must integrate into the mechanical structure of the Tracker system where space is at a premium. Effort was placed in achieving a design which meets both TOB and TEC requirements and a solution was found which is adapted to both sub-systems by simple differential assembly – the electrical interface connector is mounted on the component-side for the TOB and the reverse-side for the TEC. In all other respects the two optohybrid types are identical.

The electrical design and layout of the prototype TOB/TEC optohybrid was done at CERN and the PCBs were subsequently produced in Taiwanese industry. The board layout is shown in Figure 3, which also shows the dimensions

of the PCB:  $23 \times 30$  mm. The PCB thickness is 0.5mm, leading to an overall thickness of a populated TOB optohybrid of 3mm and of a populated TEC optohybrid of 6mm. The prototype optohybrid design is specific to the first version of linear laser driver ASIC realised in  $0.25\mu\text{m}$  technology, but can host two types of laser diode from candidate manufacturers. Attachment points have been added to meet the requirements of TOB and TEC in terms of cooling as well as mechanical restraint.

Of the 30 optohybrid substrate PCBs produced, 10 were populated with passive components in Taiwan, while the remaining 20 of the prototype batch were fully assembled at CERN. In all cases the ASIC and laser diodes were glued and wire-bonded at CERN. Examples of fully populated TOB and TEC optohybrids are shown in Figure 4.

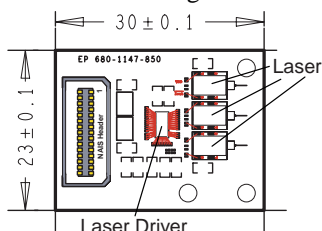


Figure 3: Layout of CERN-design Analogue Optohybrid, showing connector header on left-hand side, driver ASIC in the center and lasers on right-hand side.

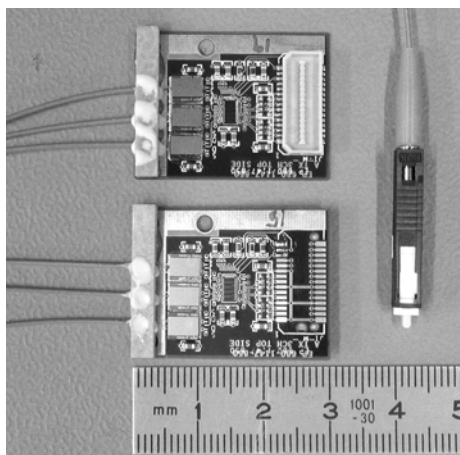


Figure 4: TOB (top) and TEC (bottom) optohybrids with MU optical connector.

Half of the total prototype run of 30 optohybrid substrates have been assembled with connector sockets for use as TEC-type optohybrids, with the other half having been assembled with connector headers for use as TOB-type optohybrids. Eleven TEC-type optohybrids have been assembled with a full complement of three laser diodes using four different prototype configurations of laser diode- and optical connector type. The remaining four TEC-type optohybrids were used as mechanical samples. Eight TOB-type optohybrids have to date been assembled with three laser diodes of the latest generation of close-to-final laser packaging configuration and MU-type optical connectors as shown in Figure 4.

It should be noted that the optohybrids produced could be used in CMS but for the fact that the ASIC design has changed sufficiently to require a PCB layout change. This is

partly due to the fact that the laser driver will be placed in a  $5 \times 5$  mm LPCC package, which will simplify the assembly of the optohybrid by reducing the number of wire-bonds required during assembly and allow pre-testing of the ASIC.

### III. TEST METHODS

Testing of the prototype optohybrids has been carried out *in-system* by measuring the performance via pre-prototype optical receivers. The test methods used have previously been described in detail[4], but will be outlined here.

Static characterisation of optical links containing optohybrids is carried out as follows: (Refer to Figure 5)

1. A fast ramp (staircase) is injected at the optohybrid input
2. This ramp is measured at the output of the optical receiver using a 12-bit ADC to obtain the transfer characteristic
3. A slow ramp (staircase) is injected at the optohybrid input
4. At each DC level of the ramp the AC-coupled output is sampled with an oscilloscope to obtain the noise

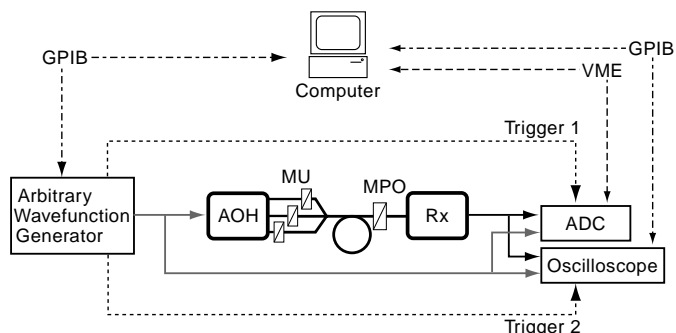


Figure 5: Analogue OptoHybrid (AOH) Static Characterisation set-up.

The linearity performance of the optohybrid under test can be calculated as the deviation from a straight-line fit to the static transfer characteristic. To assess the performance the deviation from linearity is referred to the input of the optical link to yield the Equivalent Input Non-Linearity (EINL). The system specification for EINL is better than 12mV, which corresponds to 2% integral non-linearity over the input operating range of 600mV.

In order to assess the noise performance of the optohybrid under test the measured raw noise is also referred to the input to yield the Equivalent Input Noise (EIN). System specification for EIN is better than 2.4mV over the optical link input range 600mV, to allow for a system peak Signal to Noise Ratio  $>256:1$ .

Dynamic characterisation of the prototype optohybrids was carried out by measuring the pulse response of the optical link system. A periodic input pulse train of  $\pm 400\text{mV}$  at 10MHz was used for this test. The rise time of the input signal was below 1ns. The rise time of the output signal as well as the output pulse shape was used to infer the dynamic response of the optohybrid.

Crosstalk between channels on the prototype optohybrid was measured by injecting the same signal used for dynamic characterisation into one of the three channels on the optohybrid under test and measuring the output of the other channels using a separate receiver. In this way any receiver crosstalk effects are removed from the measurement results.

All measurements (unless otherwise stated) were carried out with the optohybrid under test located in a temperature controlled chamber at 25°C.

The experience gained from optohybrid testing has been used to define the test sequences for use during final production and to provide a basis for the implementation of an automated production test station for optohybrids.

#### IV. RESULTS

Of the 20 optohybrids fully populated with laser diodes to date, 11 have been characterised using the methodology described above. The same receiver channel has been used throughout the characterisation series to facilitate comparison between optohybrids without possible variations due to the receiver. It should be noted that the receiver used for this characterisation was a previous prototype design based on discrete components[5] whereas the amplifier array foreseen for use within CMS is a 12-channel ASIC. The gain of the receiver used for these comparative tests is higher than that of the final one, so that comparisons of the gain values obtained here with the nominal optical link system gain of 0.8V/V must be undertaken with caution. A further minor point is that the voltage output of the prototype can be both positive and negative and has a widely variable offset. In contrast the final receiving amplifier has more limited offset adjustment and only outputs positive signals.

The static characteristics of each optohybrid were measured for all four possible gain settings (5.0mS, 7.5mS, 10.0mS & 12.5mS) of the laser driver. These measurements yield a results-set such as the one shown in Figure 6 for each optohybrid measured. The transfer curve Figure 6 (top) is fitted with a straight line over the operating input range ( $\pm 300\text{mV}$ ) and the resulting deviation of the data from the fit computed to yield the non-linearity plotted in Figure 6 (middle), referred to the input by division by the measured gain. The input referred noise (Figure 6 – bottom) completes the basic results-set. The shaded areas in Figure 6 represent the operating range ( $\pm 300\text{mV}$ ) and maximum input range ( $\pm 400\text{mV}$ ) of the optical link, thus showing that the measurements are carried out over a wider input range. The nominal input to the optical link is 100mV per Minimum Ionising Particle and the APV operating range is 600mV.

Figure 6 (bottom) shows the effect of gain on this computed measurement: the measured raw noise being very similar in magnitude for all gain settings. It is therefore advantageous in terms of noise to operate the laser driver at higher gain settings.

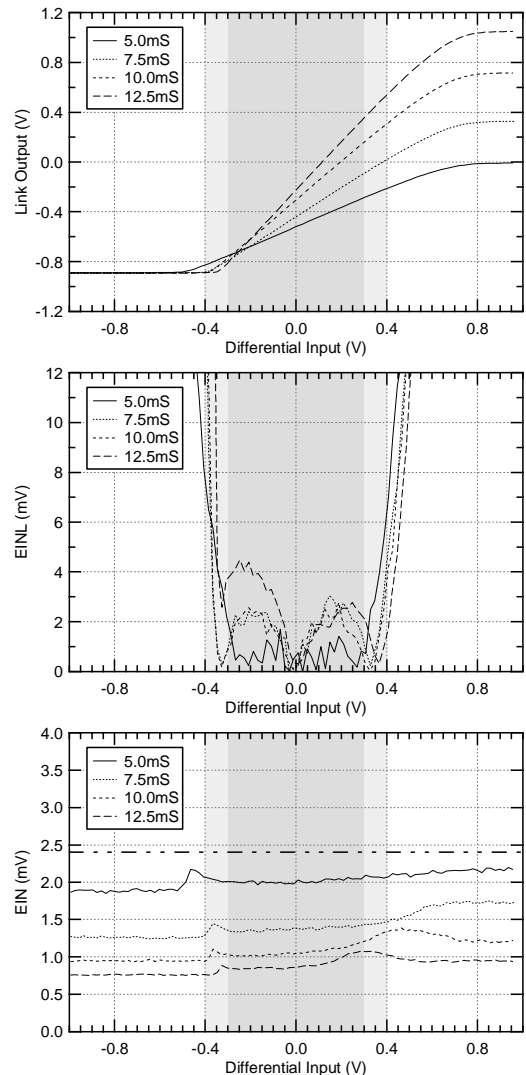


Figure 6: Typical results-set for static characterisation of an analogue optohybrid: (top) transfer curve; (middle) Equivalent Input Non-linearity; and (bottom) Equivalent Input Noise.

In order to more easily represent and compare the performance of many optohybrids the static characteristics are used to compute four *figures of merit*:

1. *Link Gain*: the slope of the straight line fit to the data within the operating range.
2. *Link linear range*: the input range over which the EINL is below the specified value of 12mV.
3. *Average EIN*: the mean value of EIN over the operating range.
4. *Input range within noise spec*: the input range starting at  $V_{in} = -300\text{mV}$  before EIN exceeds the specified value of 2.4mV

The last figure of merit picks out channels which show spikes in the noise characteristic (e.g. Figure 9) even where the average EIN is below the specified value of 2.4mV.

Figure 7 shows the four figures of merit for the complete results-set for eleven optohybrids at the four different gain settings. Also marked on the figures are the relevant specification levels for linear range, average EIN and input

range within noise spec. It is clear that the majority of the channels and gain settings measured meet the specified target levels of performance and that good performance has thus been achieved for this first prototype analogue optohybrid design.

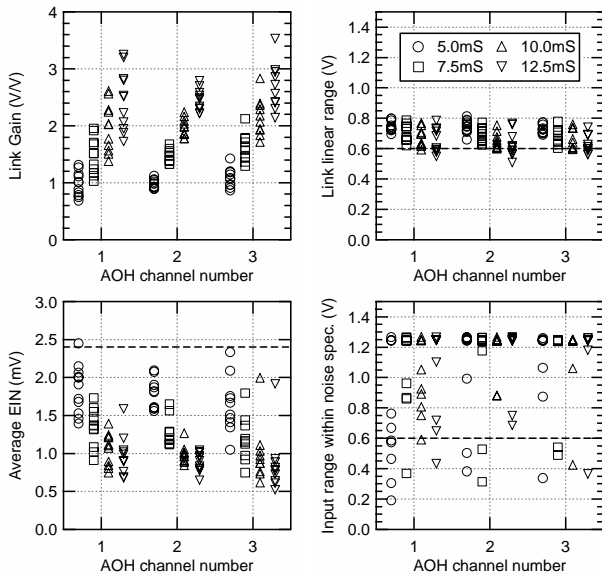


Figure 7: Figures of Merit for eleven prototype analogue optohybrids measured using standardised test procedures.

Dynamic measurements carried out on the prototype analogue optohybrids show that the pulse response of the laser driver ASIC is not degraded by its placement on the optohybrid. Rise times in the range 3.8 – 4.2 ns were obtained from pulse response measurements carried out. These values translate to slightly lower bandwidth values than the target of 90MHz, but are consistent with those carried out on the laser driver ASIC itself. The speed of the laser driver which will be used to equip future versions of the optohybrid will be increased.

The measurement of crosstalk on the prototype optohybrid yielded results comfortably within the specified value (adjacent channel) of -55dB. The values obtained were consistently below -60dB for the nearest neighbour channel and dropped to below -70dB for the furthest neighbour channel.

## V. REFERENCE CHAIN OPERATION

In addition to the standalone characterisation of the prototype analogue optohybrid described in the previous section, some examples were included in a test of the full optical link chain. In this investigation the prototype optohybrids were inserted into a reference chain that contained the final type- and number of optical connections and approximately the final fibre lengths as foreseen for the optical link system in CMS (Figure 1). Four TEC-type optohybrids were placed on a carrier board which was placed inside an environmental chamber so that the ambient temperature during operation could be varied (see Figure 8). The twelve optical channels (MU optical connectors) were connected to a single-fibre to ribbon fan-in (sMU to MPO connectors), then via ~100m ribbon fibre to a pre-final

prototype 12-way receiver module (MPO receptacle) housed on a VME card.

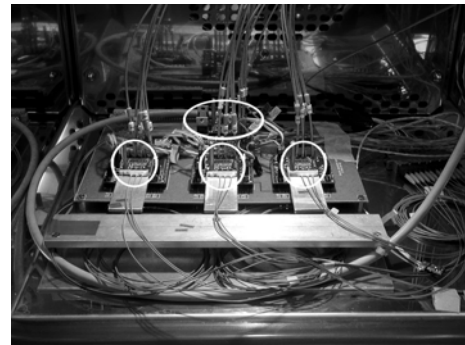


Figure 8: Four optohybrids (ringed) on test board during reference chain operation.

The static measurements described earlier were carried out for all channels at both room temperature (25°C) and the nominal optical link operating temperature when it is installed in the CMS Tracker (-10°C). The results-set is shown in Figure 9. For these measurements the gain setting at the laser driver was chosen to give an overall channel gain as close to the nominal value of 0.8 as possible, with the laser bias setting then chosen to match the gain setting. The laser bias setting is chosen so as to operate the optical link above the laser threshold while keeping the bias current as low as possible. Minimising the bias current ensures that the noise performance over the entire input range of the optical link ( $\pm 400\text{mV}$ ) is adequate – higher bias currents leading in general to higher laser noise. The bias setting was revised to take into account the lower laser threshold when operating at -10°C, although for ease of comparison the gain setting was not varied as the temperature changed.

Overall, the figures of merit obtained from the reference chain measurements (Figure 10) are very encouraging. The noise measured in the final-form optical link is lower than for the measurements presented in the previous section. Linearity remains good for all cases.

The figure of merit most systematically affected by the change in operating temperature is the gain, which increases for all channels at lower temperature. This is believed to be largely due to changes in the coupling efficiency between laser die and optical fibre within the small form-factor laser diode package. It is clear that very good noise performance is achieved especially at the lower temperature, while the gain spread is tolerable[6].

As well as obtaining the same typical values of risetime as for the measurements of the prototype optohybrids described in the previous section, the final system was exercised using a simulated APVMUX data-stream. An arbitrary waveform generator was used to mimic the data that will be transmitted through the final optical link in the CMS Tracker, where each optical channel will be used to transmit the output stream of one APVMUX channel. The data-stream as transmitted via a typical optical link channel of the reference optical link chain is shown in Figure 11. In the transition between temperatures the laser bias setting was changed as described above.

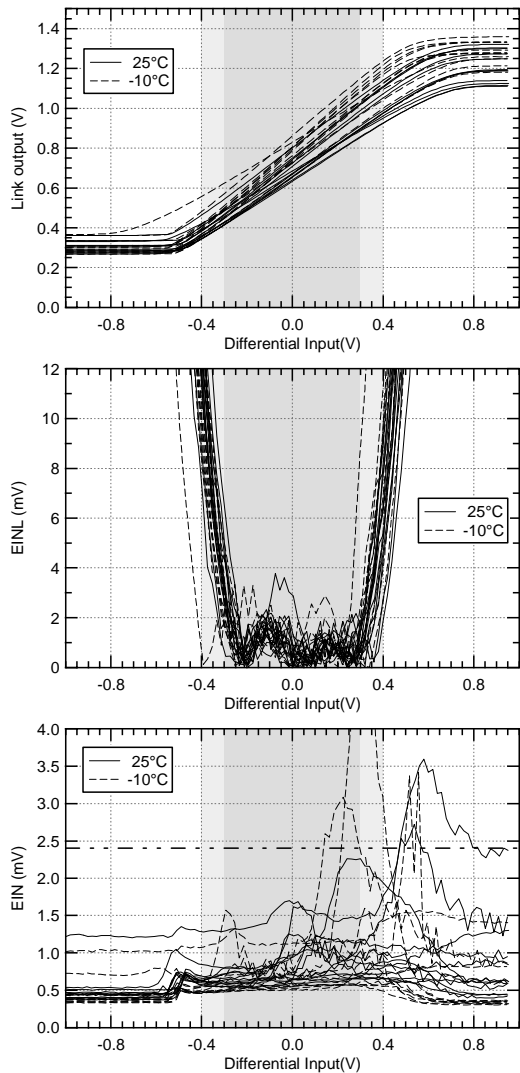


Figure 9: Static characteristics of all reference chain channels at room and operating temperatures: (top) transfer curve; (middle) Equiv. Input Non-Linearity; and (bottom) Equiv. Input Noise.

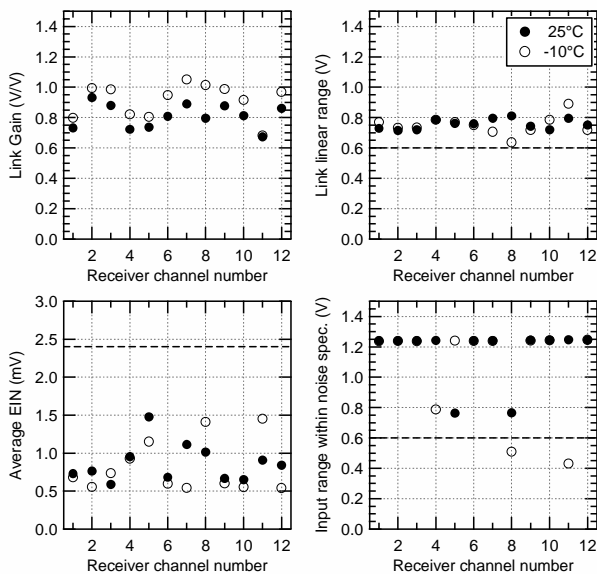


Figure 10: Figures of Merit for all reference chain channels.

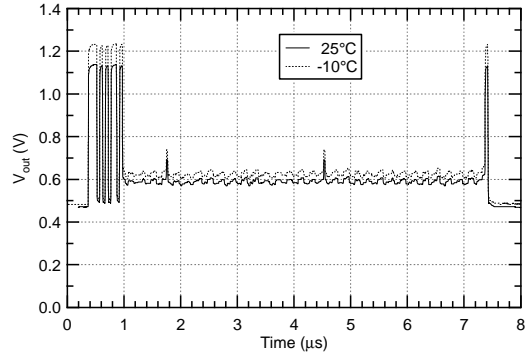


Figure 11: Simulated APVMUX data-stream at the output of the prototype optical link with very close to final components.

## VI. CONCLUSIONS

Approximately 20 prototype analogue optohybrids suitable for use in the Outer Barrel and Endcap of the CMS Tracker have been assembled from a common PCB design. They have been populated with close-to-final electronic and opto-electronic components and tested using standardised procedures which will form the basis of production testing of the final quantity of 12900.

The performance of the prototype optohybrids has been reported to be within specifications for the majority of cases, while the outliers of the distribution are not far from meeting the required criteria. Figures of merit have been used to reduce the large raw dataset to ease the comparison of many devices. These provide an immediate overview of the key analogue optohybrid performance parameters of gain, linearity and noise.

With the successful testing of the first prototype analogue optohybrids confidence has been gained that the transmitting components of the analogue optical link for the CMS Tracker can be successfully embedded into the overall system. Future testing will put the prototypes described here into a larger test of the full readout system including detector modules in their final mechanical structures.

## VII. REFERENCES

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