Characterization of laser diodes for analog parallel optical links

Fredrik B. H. Jensen, Christina Aguilar, Vincent Arbet-Engels, Carlos Simoes Azevedo, Giovanni Cervelli, Karl A. Gill, Robert Grabit, Chantal Mommaert and Francois Vasey

CERN, EP-CME, CERN, CH-1211, Geneva 23, Switzerland

ABSTRACT

Optical links are being developed for the Large Hadron Collider experiments at CERN. For the tracker of the Compact Muon Solenoid (CMS) experiment, over 50000, 100m long, analog links are required to read out data. The front-end lasers will be subjected to both nuclear radiation and magnetic fields up to 4 Tesla and intervention will be costly due to the complexity of the detector and considerable induced radiation levels. Proper choice of laser diodes with sufficient analog performance and lifetime is therefore critical to the success of the experiment. It is thus imperative to use well-defined evaluation criteria and efficient measurement procedures to enable optimal component selection.

In this paper results from the evaluation and comparison of the analog performance of laser transmitters from several different manufacturers will be reported. The bulk of the tested devices were commercially available InGaAsP edge-emitters (1- and 4-way packages). The evaluation of the lasers is based on a semiautomatic setup that characterizes static properties such as slope efficiency, noise and linearity. The measured data is visualized in a compact way with system pass/fail criteria that enables easy comparison and selection of different laser diodes with respect to system noise, deviation from linearity and operating range.

Keywords: Semiconductor laser, performance testing, analog, optical links

1. INTRODUCTION

Optical links are being developed for the Large Hadron Collider experiments at CERN. For the central tracker of the Compact Muon Solenoid (CMS) experiment over 50000, 100m long, analog links are required to read out data. The front-end lasers will be subjected to a harsh operating environment including both nuclear radiation and magnetic fields up to 4 Tesla. In addition any intervention during the experiment lifetime of 10 years or more will be costly due to the complexity of the detector and considerable induced radiation levels. It is thus necessary to carefully evaluate all components of the link for analog performance and reliability to enable optimal component selection.

The full link baseline consists of a monolithic quad laser driver ASIC followed by a hybrid assembly of InGaAsP/InP edge-emitting laser diodes transmitting at ~1310nm over a distance of approximately 110m of single-mode fiber through 3 patch panels based on angle-polished MT-connectors. The receivers are InGaAs/InP pin photodiodes followed by 2-stage transimpedance amplifiers (Ref. 3). The basic building blocks of the optical link transmitters and receivers are assemblies of edge-emitting lasers, pin photodiodes and optical fibers on silicon submounts. These assemblies can be tested individually for performance and radiation hardness (Ref. 2). The packaging envisaged could be 1-way or multi-way or the components could be assembled directly onto hybrids or printed circuit boards. This flexible scheme allows validation of the opto-electronic components before the full details of the system architecture are known and before a final package or hybrid has been selected. The laser transmitters will be distributed over the volume of the tracker (a cylinder-type structure of length ~3m and diameter ~1.7m) and therefore the ideal transmitter modularity varies as a function of the position in the tracker. A compromise has been found in custom-developed 4-way packages that are also low mass and non-magnetic to suit the environmental constraints. This 4-way solution is the present baseline choice for the tracker optical link (Fig. 1). As a first step toward selection of suitable laser diodes the analog performance of 1-way lasers from a number of commercial sources have been evaluated. In addition lasers from one manufacturer have also been tested packaged in a 4-way hybrid DIL-

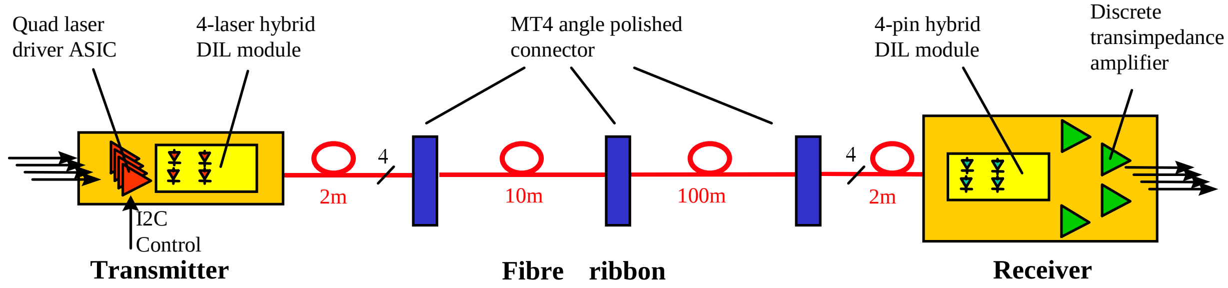

Figure 1. 4-channel optical link prototype

module in the baseline link configuration described above. This paper will present the evaluation procedure used and results from performance tests. The criteria for component selection will also be outlined.

2. DEVICE TESTS

2.1 DEVICES UNDER TEST

The comparative performance tests were carried out on nine different 1-way edge-emitting lasers all working at ~1310nm, and one 4-way device. The characteristics of the devices under test are described in table 1.

Table 1. Devices under test

Emitters	Ith (mA)	Slope Efficiency@25C (•W/mA)	Package
A	7	105	Coaxial
B	8	45	Coaxial
C	11	60	Mini-DIL
D	11	60	Mini-DIL
E	11	130	Mini-DIL
F	10	80	Mini-DIL
G	3	60	Coaxial
H (4-way)	10	60	ceramic DIL
I	8	40	Mini-DIL
J	10	8	Mini-DIL

2.2 EXPERIMENTAL SET-UP

The experimental setup used to evaluate the various laser transmitters is shown in Fig. 2. The objective is to measure the static and noise characteristics of the systems under test. A computer running labview software controls an arbitrary waveform generator (AWG) and an oscilloscope via GPIB.

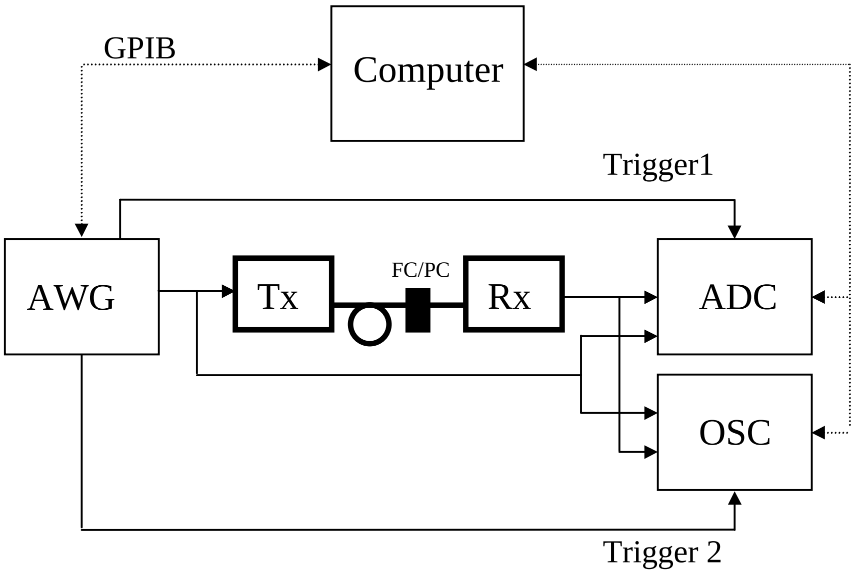

Fig. 2. Experimental setup for link and device performance tests

The laser pre-bias is selected manually or in the case of the 4-way system via an I2C bus. The optical links have one breakpoint with FC/PC connectors and single mode fiber pigtails approximately 2m long. On the receiver side the same type of pin-diodes are used for all measurements with an average responsivity of 0.93A/W and the amplifiers have a transimpedance of 10kΩ. A high resolution (12bit) analog to digital converter (ADC), housed in a VME-crate, is used to evaluate the deviation from linearity of the system to better than 1% and a large bandwidth (300MHz) oscilloscope is utilized to measure the noise into the system bandwidth (Ref. 4). In order to match the expected system input swing of ±400mV an input swing of at least ±500mV was used in all cases. All system outputs are terminated with 50•, however it has been demonstrated that this termination can be removed if the receiving amplifiers are positioned close to the ADC.

3. EVALUATION CRITERIA

3.1 MEASUREMENT SEQUENCE

The evaluation of the different lasers is based on the measurement of the system static transfer characteristic. The lasers under test are measured in an otherwise fixed system configuration that resembles the final link system. The AWG generates about 100 static levels that are fed sequentially to the system input as a ramp, plus synchronization signals for the measuring instruments. For each static measurement point the average and standard deviation of the link output voltage is measured.

3.2 EQUIVALENT INPUT NOISE

The link gains are calculated from the slope of a regression line fit to the transfer characteristics above the laser threshold and below any receiver saturation. To have a signal independent measure of the transmitter noise performance the measured standard deviation, or *rms-noise*, is divided by the link gain, g, to give the gain-normalized noise, or *equivalent input noise*. To have a simple measure of the noise characteristics of transmitters that does not represent a worst case (as opposed to maximum gain normalized noise) the average gain normalized noise is also calculated.

3.3 DIFFERENTIAL NON-LINEARITY

The linearity of the tested devices was evaluated using the *differential non-linearity*, ε_{dnl}, of the transfer characteristics defined as:

$$\varepsilon_{dnl} = \frac{g - df/dy}{df/dy} \qquad (1)$$

The absolute value of ε_{dnl} is then calculated and, as in the case of the equivalent input noise, the max and average over the input range derived. The maximum and average equivalent input noise and differential non-linearity is then graphed in a simple 2D-plot to enable easy comparison of the analog performance of tested laser transmitters.

4. PERFORMANCE TEST RESULTS

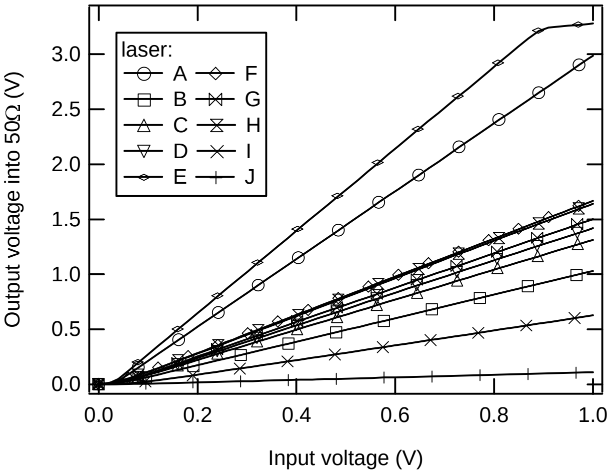

Fig. 3. Static transfer characteristics for tested laser transmitters

The static transfer characteristics of the ten tested lasers are shown in Fig. 3 for an input voltage swing of ~1V. At low voltages, a kink can be seen that is due to laser threshold. At high voltages the receiver saturation point is reached already at an input voltage of ~0.9V for laser E due to the high slope efficiency of this device. The gain of the measured links varied between 3.73 and 0.12V/V (into 50 •••mainly due to the large differences in laser efficiencies (table 1). For every measurement point the output voltage is measured with an oscilloscope featuring a bandwidth that largely exceeds the bandwidth of the optical link (typically 120 MHz), therefore the values obtained represent the real link rms noise. In Fig. 4(a), (b) the equivalent input noise is displayed as a function of the input voltage. In Fig. 4(a) the full set of measurements for the 10 devices are shown and in Fig. 4(b) the same data are shown with lasers I and J excluded. In the following, only links with lasers A-H will be considered.

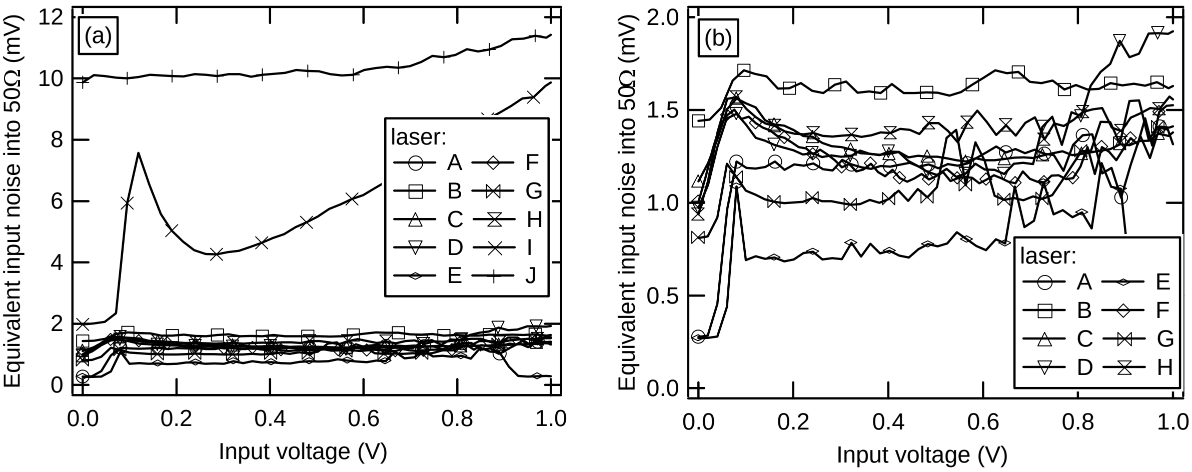

Fig. 4. Equivalent input noise for links with different laser transmitters (a) full set of 10 different lasers. (b) lasers I and J excluded.

The differential non-linearity, as defined in section 3, is shown in Fig. 5. To avoid excess influence of local noise variations on the analysis of the linearity characteristics the transfer characteristics for each laser was fit by a 4th or 5th order polynomial. This polynomial was then differentiated to get df/dx and the ε_{dnl} was calculated using eq. (1). The process was iterated over the polynomial order so that the final ε_{dnl} value was minimized. Using a polynomial fit might introduce artifacts when the maximum and minimum differential non-linearity is calculated and work is in progress to improve the analysis. However the average differential non-linearity can be expected to be less influenced by fitting artifacts and to form a good measure for comparing transmitters.

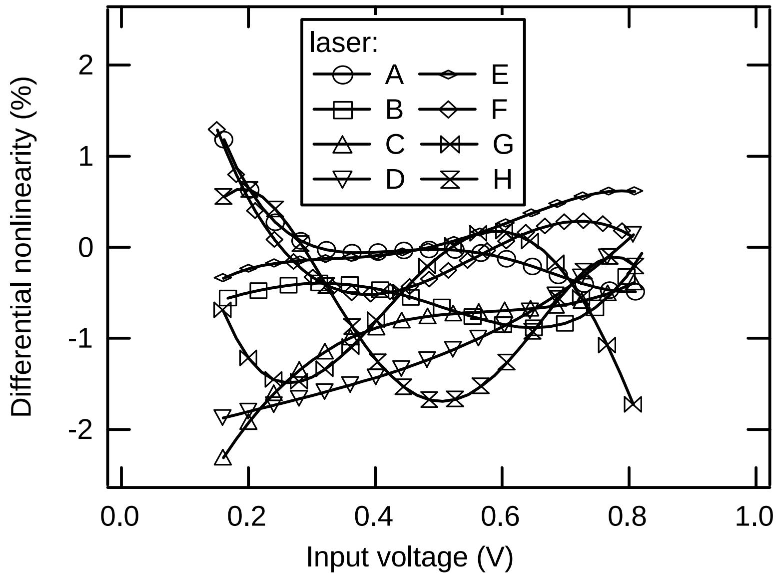

Fig. 5. Differential non-linearity of lasers A-H (laser I, J excluded) as a function of link input voltage. Non-linear regions close to laser threshold and receiver saturation have been excluded.

The noise figures used for the performance comparison are the max and average of the equivalent input noise. The data from Fig. 4(b) and 5 was thus used to calculate max/average equivalent input noise and max/average differential non-linearity. The results of this calculation are shown in Fig. 6for lasers A-H. A typical value for the average equivalent input noise is 1.5mV for lasers A-H and the typical average differential non-linearity below 1.5%. The maximum equivalent input noise is below 2mV for lasers A-H. The maximum differential non-linearity is below 2% for all devices except laser C which has a maximum of ~2.3%.

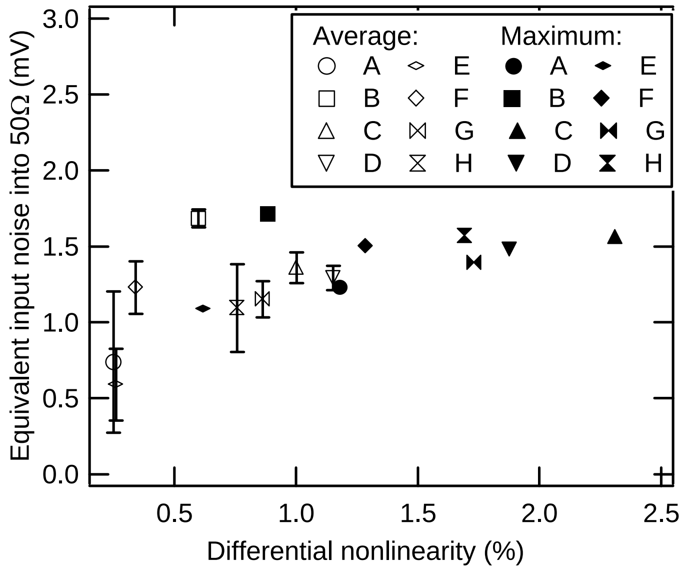

Fig. 6. Average and maximum of equivalent input noise and absolute differential non-linearity for lasers A-H. Error bars give standard deviation of equivalent input noise.

5. CONCLUSIONS

Edge-emitting semiconductor lasers of ten different types, all working at ~1310nm, have been evaluated for their analog performance in a configuration well matched to the final link application. A test-setup has been developed to enable simultaneous measurements of static transfer and noise characteristics of the lasers. Evaluation criteria used to compare individual components have been produced. The CMS tracker optical link system is specified to have a signal to noise ratio of 48dB for an input swing of ±400mV which gives a maximum allowed equivalent input noise of 3.1mV and the maximum allowed differential non-linearity should be below 2%. Out of the ten lasers measured eight met the noise specifications and in this group of eight seven of the lasers also met the requirements on linearity. It can be concluded that a wide range of lasers are available that meet the system specifications on analog laser performance required for the CMS tracker optical links.

6. REFERENCES

1. G. Hall, “Analogue optical data transfer for the CMS tracker”, Nuclear Instruments and Methods in Physics Research A, Vol. 386, pp. 138-142, 1997.
2. F. Vasey, V. Arbet-Engels, J. Batten, G. Cervelli, K. Gill, R. Grabit, C. Mommaert, G. Stefanini, J. Troska, "Development of radiation-hard optical links for the CMS tracker at CERN", IEEE Transactions on Nuclear Science, Vol. 45, No. 3, pp. 331-7, 1998.
3. F. Vasey, C. Aguilar, C. Azevedo, V. Arbet-Engels, G. Cervelli, K. Gill, R. Grabit, F. Jensen, C. Mommaert, P. Moreira and G. Stefanini, ‘A 4-channel analogue optical link for the CMS-Tracker”, Proceedings from the 4th Workshop on electronics for LHC Experiments, Rome, pp. 344-348, 1998.
4. G. Cervelli, V. Arbet-Engels, K. Gill, R. Grabit, C. Mommaert, G. Stefanini, F. Vasey, "A method for the static characterisation of the CMS tracker analogue optical links", Technical note, CMS Note 043, 1998. Available on: http://www.cern.ch/CERN/Divisions/ECP/CME/OpticalLinks/