An Integrated Laser Driver Array for Analogue Data Transmission in the LHC Experiments

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ABSTRACT

An ASIC consisting of an array of four Linear Laser-Drivers has been designed, fabricated and tested. The IC is dedicated to the transmission of analogue data from the CMS gas and silicon microstrip central tracker detectors to the front-end digitizer cards.
The IC drives four laser-diodes converting the analogue data produced by the front-end ICs into amplitude modulated optical signals. Each driver in the IC contains a programmable current source allowing independent biasing of any of the four laser-diodes in its linear region of operation. The ASIC was designed in a 0.8µm BiCMOS process and it was successfully tested both electrically and in combination with a laser-diode. The measured integral nonlinearity of the transfer characteristic is better than 0.42% for input voltages less than ±400 mV – the specified operating range. Pulse response tests show that the crosstalk between two channels is less than 0.27% for input signals with transition times up to 5 ns. The measured equivalent input noise is 1.8 mV and 4.4 mV for minimum and maximum laser-diode bias current respectively.

1 INTRODUCTION

The CMS tracker consists of two detectors: an inner cylinder of silicon microstrip (Si-strips) detectors and outer layers of microstrip gas chambers (MSGCs) [1, 2]. Figure 1 represents the general read-out architecture that will serve both types of detectors. On the occurrence of a first level trigger, the analogue signals that have been previously processed and pipelined by the eight APV front-end ICs [3,4] of the detector hybrid, are sent to the transmitter hybrid by the APV-Mux ASIC (Mux/Driver in Figure 1). This IC time division multiplexes the analogue data from the eight APVs into four 40 Ms/s communication channels. The data are sent to the transmitter hybrids using short lengths of twisted pair copper cables (0-30 cm) of 100 Ω characteristic impedance. In the transmitter hybrids, the electrical signals are converted into optical signals by the Linear Laser-Driver IC and the laser-diodes. The analogue data is transmitted as a direct amplitude modulated optical signal. Optical fibres are used to send the data to the Front End Digitiser (FED) modules situated outside the detector. Since each APV IC serves 128 detector channels, each optical fibre link transmits data from 256 channels. In the system there will be approximately 12 million detector channels (Si-strips and MSGCs) corresponding to 50 thousand optical read-out links [5].

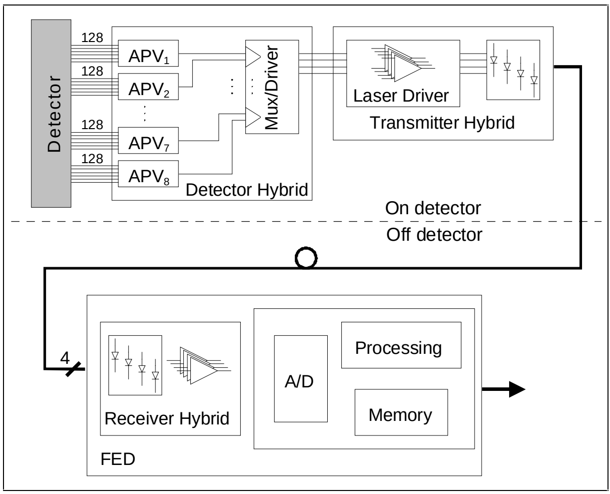

Figure 1 Tracker data path read-out architecture

In order for the communication channels to achieve a signal-to-noise ratio compatible with the transmission of amplitude modulated signals, the electrical-to-optical conversion has to be made with minimum noise and distortion. An objective for the whole communication channel – from the APVs outputs to the digitising modules – is to achieve a performance equivalent to that of a 7-bit digital system. Each link element should thus exceed this performance. The goal fixed for the Linear Laser-Driver IC was to attain an 8-bit equivalent dynamic range performance. Taking into account this requirement and the modularity of the data path, the following major specifications were set:

- Modularity: four channels per IC
- Dynamic range: 8 bits
- Integral nonlinearity< 1%

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- Equivalent input noise: < 1 mV (LSB/3)
- Settling time: <10 ns to within 1% of the final value
- Crosstalk: <0.3%

2 THE LINEAR LASER DRIVER IC

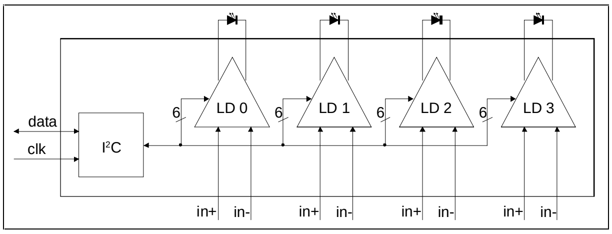

Figure 2 Linear Laser-Driver IC block diagram

The block diagram of the Linear Laser-Driver IC is presented in Figure 2. The IC is made of four Laser-Drivers (LD) and of an I^2C [6] interface. Each driver takes as input a differential voltage and converts it into an unipolar current that is used to modulate an external laser-diode. Besides signal modulation, each driver also generates a *dc* current that is used to bias the external laser-diode. This current allows the laser-diode to be operated above threshold in the linear region of its characteristics. As illustrated in Figure 3, the modulation current and the bias current are independently processed and summed in the output node.

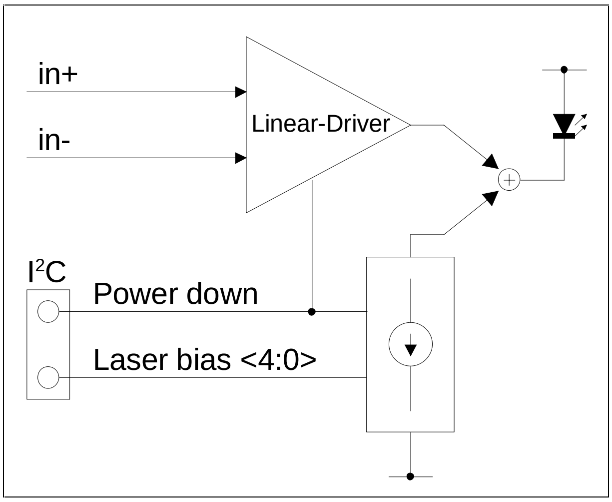

Figure 3 Single channel block diagram

Device ageing and performance degradation due to radiation causes the laser-diodes threshold currents to change with time. To compensate for these variations the laser-diode bias current was made programmable through the I^2C interface. Since each device in the array will have a different threshold and may age differently, the bias current produced by each driver was made individually programmable. Additionally, a "power-down" function is implemented for each channel allowing to reduce the power consumption of non-used or defective channels.

2.1 LINEAR-DRIVER

The Linear-Driver is the part of the Laser-Driver that is responsible for signal modulation of the laser-diode. This is the only part of the circuit with currents actually switching during data acquisition. Since one of the goals of the design was to include four drivers in the same IC, each Linear-Driver was designed as a full differential circuit. In this way, the sensitivity to power supply noise is minimised and the amount of power supply noise generated by each driver is reduced.

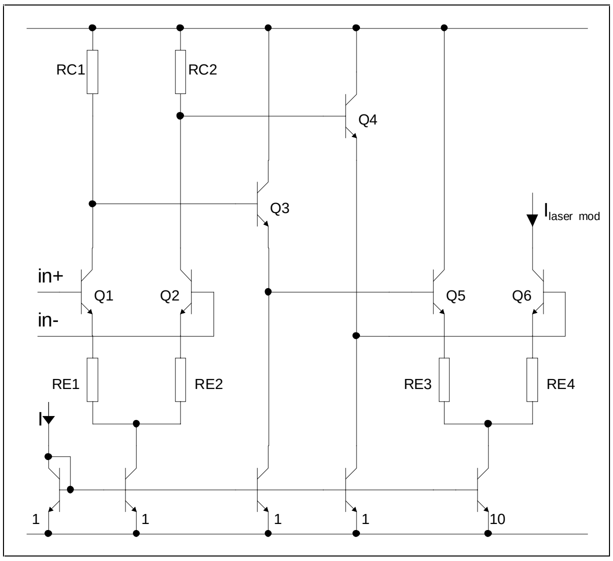

Figure 4 Linear-Driver

As shown in Figure 4 the Linear-Driver contains two differential pairs and a Common-Collector (CC) stage. The first differential pair provides signal gain "adapting" the input signal range to the linear operation range of the output stage. The emitter follower transistors (Q3 and Q4) provide level shifting for correct biasing of the output stage/laser-diode combination. Since all stages – including the CC stages – are biased by constant current sources, the power supply currents are – in first order – constant. However, to take advantage of the differential circuit topology to minimise power supply noise coupling a careful layout and power supply strategy for the output stage/laser-diode combination is required.

As mentioned above, the transmission of amplitude modulated analogue signals requires low distortion electrical-to-optical conversion. Since, when biased well above threshold, the output optical power emitted by a laser-diode is proportional to the input current, it is thus sufficient to ensure that the modulation current through the laser-diode is a linearly scaled replica of the input signal. That is, it is enough to linearise the Laser-Driver

transconductance and to ensure that the laser-diode is biased in its linear region of operation. As shown in Figure 4, linearisation of the overall circuit transconductance is made on each differential pair by means of local feedback – emitter degeneration resistors (RE1 to RE4) are used in the differential pairs to linearise their transconductance. Since the common-collector stages are biased by a constant current they are intrinsically linear and no special linearisation technique is required in these stages. Although global feedback can be a more efficient means of linearisation of the overall transconductance it is also potentially more susceptible to produce stability problems due to output loading effects. For this reason, local linearisation of the transconductance of each amplifying stage in the Linear-Driver was preferred.
Each Laser-Driver in the IC typically works with an input differential voltage between ±400 mV. Within this range, the integral nonlinearity of the output current is guaranteed to be better than 1%. Each driver can however accept differential input voltages up to ±800 mV. Above this limit, the output current saturates. The driver transconductance is approximately 6.3 mS. This results in an output current change of 5 mA when the input differential voltage changes from -400 mV to +400 mV.
In the read-out system, the analogue input signal will be transmitted to the IC using a 100 Ω twisted pair cable. To avoid reflections of the signal it is important to terminate the cable with its characteristic impedance. In the IC technology used, there were no precision resistors available, making it is necessary to terminate the cable with an external 100 Ω resistor.

2.2 *LASER-DIODE BIAS*

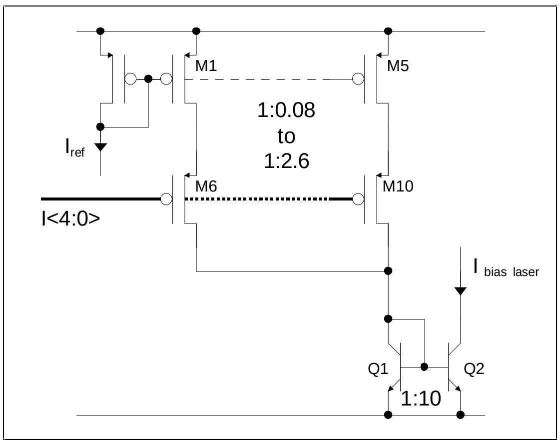

Figure 5 Laser-diode bias circuit

The laser-diode bias circuit, which is basically a programmable current mirror, is schematically represented in Figure 5. In this circuit, the MOS transistors M1 to M5 make binary weighted copies of the reference current I_{ref}. These current copies are then summed in the base node of the current mirror Q1-Q2. The resulting current is then multiplied by a factor of ten and made available to bias the external laser-diode. To program the current mirror, transistors M6 to M10 act as current switches that are controlled by the I^2C interface.

3 MEASUREMENTS

Several tests were made on the IC. These included purely electrical (*e*) and electrical-optical-electrical (*e/o/e*) measurements. The e/o/e measurements were done using the IC, a laser-diode(s) and an optical receiver. Consequently, the results reported here for the *e/o/e* measurements represent the performance of the whole chain and not only that of the Linear Laser-Driver IC.
All the measurements reported here were done with a ±2 V power supply. The power consumption depends on the programmed laser-diode bias current. Per channel, it is between 50 mW and 150 mW for minimum and maximum laser-diode bias current respectively.

3.1 *LASER-DIODE BIAS CURRENT*

The laser-diode bias currents are programmed through the I^2C interface by writing in one of four internal read/write registers. The complete range of laser-diode bias currents were measured and are shown in Figure 6

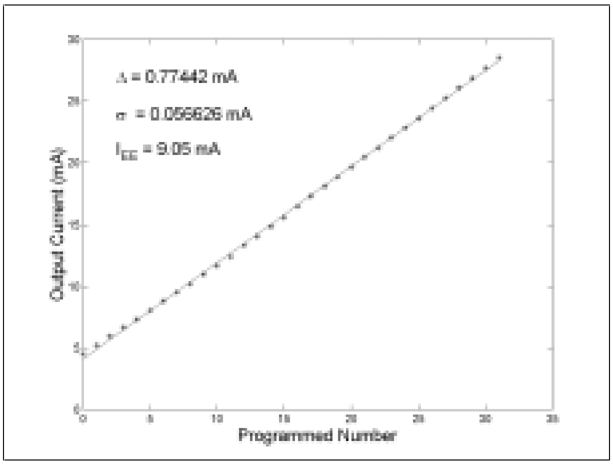

Figure 6 Measured laser-diode bias current

3.2 *TRANSFER CHARACTERISTICS*

Electrical and *e/o/e* measurements were made of the *dc* transfer characteristics. The integral nonlinearity was measured to be better that 0.14% for differential input voltages less than ±400 mV – the specified operating range. The *e/o/e* measurements are represented in Figure 7 and Figure 8. The IC was connected to a laser-diode and the emitted optical power was detected by a pin-diode. The transfer function (input-differential-voltage/pin-diode-current) is shown in Figure 7. The corresponding integral nonlinearity, shown in Figure 8, is less than 0.42% for input voltages within the operation range.

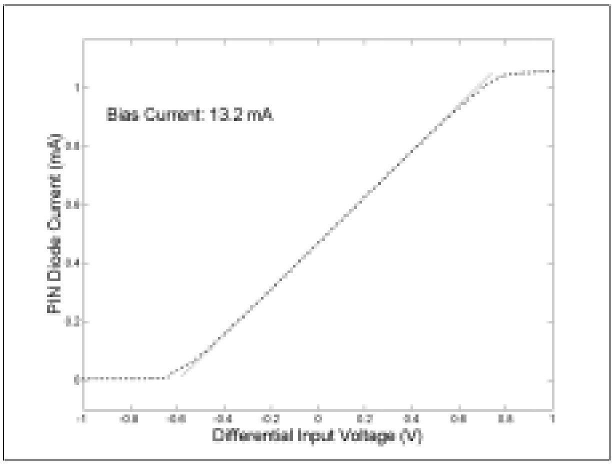

Figure 7 Measured *dc* transfer function (*e/o/e*)

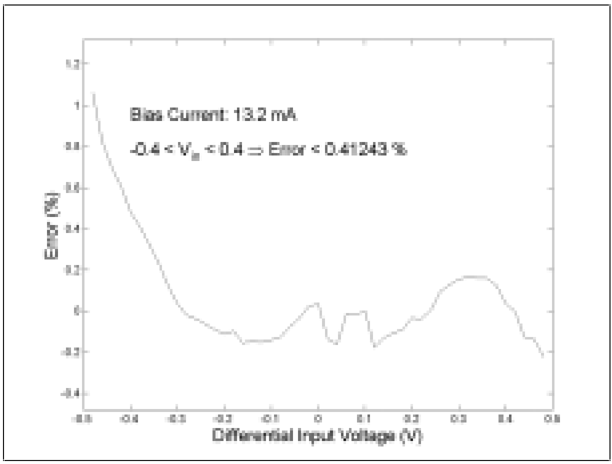

Figure 8 Measured integral nonlinearity (*e/o/e*)

3.3 COMMON MODE RANGE

The IC operates between ±2 V. For this power supply the common mode input range was specified as ±250 mV around 0 V. Here, the following definition for the common mode range was used: it is the set of common mode voltages that result in an output current deviation smaller than 1% relative to the output current with 0 V common mode. Figure 9 shows the output current error as function of the input common mode voltage. From this figure the common mode range is found to be $-0.6\ V \leq V_{cm} \leq 0.9\ V$. Over this range the measured ratio of the differential to common mode transconductance is $G_m(cm)/G_m(diff) = -62.4$ dB.

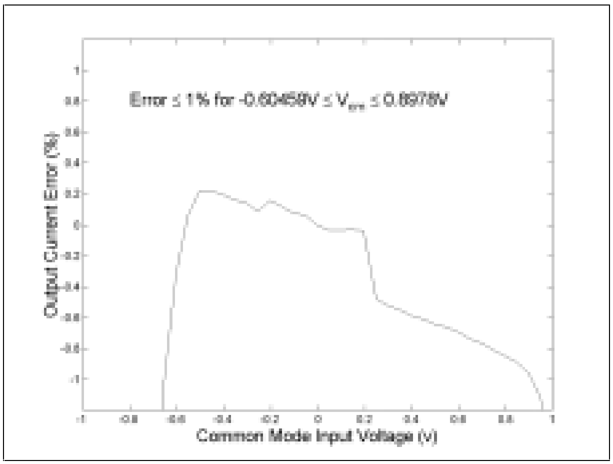

Figure 9 Common mode – *e* measurement

3.4 PULSE RESPONSE

The signals out of the APV-Mux ASICs are expected to have rise and fall times close to 5 ns. The IC pulse response was tested with Piecewise Linear (PL) pulses. Figure 10 shows the IC pulse response (bottom) to an input signal with 5 ns rise and fall times (top).

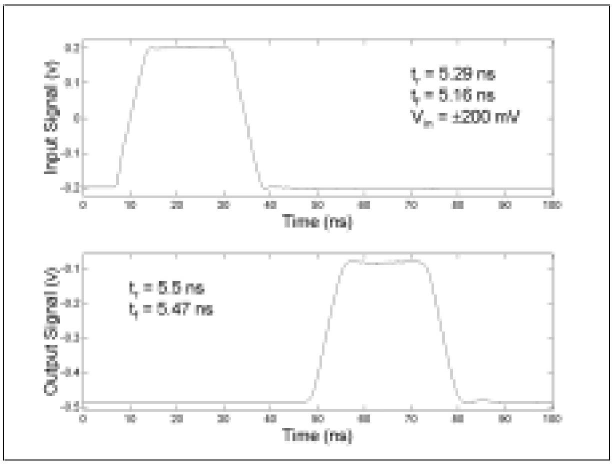

Figure 10 Pulse response (bottom) for a 5 ns rise/fall time input signal (top) – *e/o/e* measurement

Figure 11 shows the pulse response to an 1 ns rise/fall time PL signal. From the relative response error (Figure 11 bottom) it can be seen that the settling time is less than 11 ns. Additionally, from the pulse response measurements it was found that crosstalk among channels is less than 0.27%.

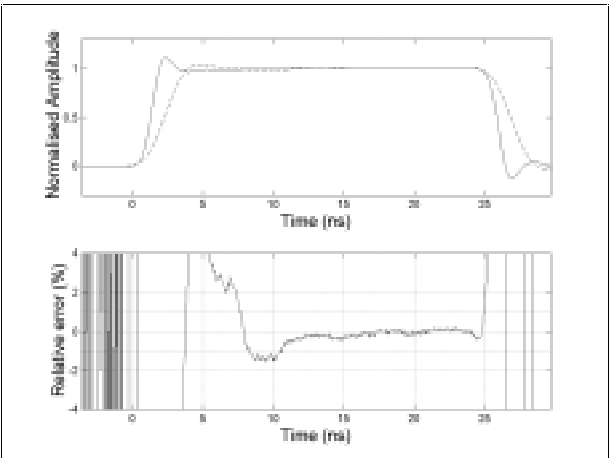

Figure 11 Top: Input (solid-line) and output (broken-line) signals. Bottom: relative response error – *e/o/e* measurement

3.5 Noise

The equivalent input noise voltage was measured to be 2.0 mV and 4.5 mV for minimum and maximum laser-diode bias current, respectively. These values are higher than the goal of 1 mV (for maximum bias) and considerably higher than the simulated values of 0.3 mV (minimum bias) and 1.1 mV (maximum bias). This discrepancy between simulations and measurement results is probably due to inaccurate noise modelling of the devices. Figure 12 summarises the Laser-Driver main noise contributions. It shows that 85% of the total noise contribution is due to the bias circuit. This happens because a large current gain exists between the bias circuit and the output of the driver: For the present circuit a current gain of 100 is necessary to generate the output stage tail current and current gains up to 260 are necessary to produce the laser-diode bias current.

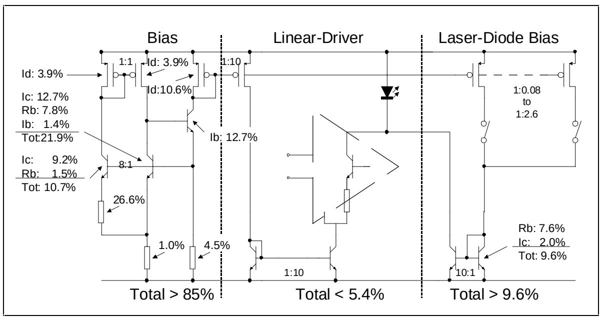

Figure 12 Summary of the main noise contributions

4 Conclusion

An ASIC consisting of an array of four Linear Laser-Drivers for analogue data transmission has been designed, fabricated and successfully tested. The IC meets all the specifications with the exception of the noise performance. Since the IC is to be operated under radiation, the development of a radiation-hard version of this ASIC is now being done. It is expected that in this new IC the noise will be reduced to the required levels by redesign of the bias circuit and improved low pass filtering in the current mirrors.

References

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