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Study of a solution with COTS for the LHCb calorimeter upgrade

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Abstract

We present a solution made out of Components Out of Shelf (COTS) for the analog processing of the signal of the LHCb calorimeters in the framework of the foreseen upgrade of the detector. The present proposal is based on the current functional solution, yet, to meet the stringent noise requirements, a number of modifications are proposed. Preliminary results on the prototype boards show promising results.

Keywords: Electronics, Low Noise, COTS, Calorimetry

1. Introduction

Since the end of the commissioning period in 2009 the LHCb detector has proven to work properly even in high pile-up conditions. By the end of 2010 nominal instantaneous luminosity was reached. Data taking is expected to continue for 5 more years, aiming to accumulate an integrated luminosity of 5fb^{-1}. Even if new physics is discovered at that time, it will be difficult to characterize it in the current scheme so an upgrade of the detector has been proposed [1] during the foreseen long shutdown to upgrade the LHC. As expressed in the Letter of Intent for the LHCb upgrade [1] the main objective of this enhancement is to have the full DAQ system working with a 40 MHz readout electronics to allow the use of a more flexible and efficient software-based triggering system. This will imply the replacement of a good part of the electronics of the detector. In particular, the Front End electronics of the calorimeters will have to be changed. This paper describes a proposed solution for the analogical part of the upgrade of LHCb's calorimeter readout, based on Commercial Off The Shelf (COTS) components.

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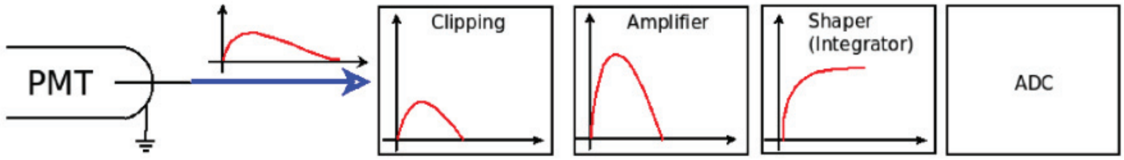

Figure 1 - Analog processing steps for both ECAL and HCAL.

2. The LHCb Calorimeter and its upgrade

The LHCb calorimeter is divided in four subdetectors: the Scintillator Pad Detector (SPD), the Preshower (PS), the Electromagnetic Calorimeter (ECAL) and the Hadronic Calorimeter (HCAL).

ECAL is a Shashlik calorimeter [2] while HCAL is a plane composed of sensing tiles; each made of a stack of scintillator and steel layers parallel to the beam axis. Wavelength shifting optical fibers collect the scintillation light and drive it to a Hamamatsu R7899-20 photomultiplier (PMT) [2]. Both the SPD and the PS are walls of scintillating tiles readout using multi-anode PMTs and currently providing information for the trigger system. The Front End electronics processes and digitizes the PMT signal: data are sent at a 1 MHz rate upon a trigger signal provided by the so called L0 trigger, a hardware base trigger system cutting down the data rate by a factor 40.

The main aim for the upgrade is to avoid the hardware trigger and send all captured data to a computer farm to select events by more flexible software means. Of course this requires the massive data transmission that the previous trigger was avoiding because of technological restrictions by the time it was designed.

For this reason the Front End boards will have to be replaced to update the digital part. Since the analog front end is located in the same printed circuit board as the digital part, analog electronics will also have to be substituted.

Besides, one needs to consider the increase in a factor of 5 the beam luminosity because of the accelerator upgrade. This would sensibly reduce life expectancy for the PMT's used in both ECAL and HCAL. PMT replacement is not considered an option because of cost reasons so in order to palliate the aging effect, the gain of the PMTs will be reduced by the same factor 5.

The PMT is soldered to its base so no replacement of this board is foreseen since this would be very time expensive and would imply a danger of damaging the devices. These changes will bring new requirements to the analog processing in the front end boards.

At present, the analog processing electronics (see Figure 1) is made of a clipping filter and a shaper. The clipping is done in the same base of the PMT. The signal is then injected without any amplification into the cable connecting the PMT anode to the electronics racks housing the Front End boards in top of the detector structure. In the Front End boards, the signal is amplified and shaped with an integrator.

The clipping principle can be seen in Figure 2a. The original signal is the blue one. By subtracting the purple signal, which is a delayed and scaled version of the original one, we obtain the brown signal. If the delay and attenuation are correctly calculated one signal will completely cancel the other after a certain time lapse, correcting in this way the spill over of the original signal onto the next clock cycle. The procedure is linear and so the integral of the signal will only be altered by a constant known factor that can be calibrated with good accuracy.

This method is implemented with no active component, just using the cable transmission line properties like, for instance, reflection. As shown on Figure 2b, the PMT is connected both to the cable and to a miss-adapted transmission line. The miss-adaptation is intentional and calculated to reflect a negative scaled version of the input pulse so that, when both the original and reflected signals meet, the resulting signal will be desired one, mainly contained in the current clock cycle with a tail decaying much faster than the PMT or the clipping signal.

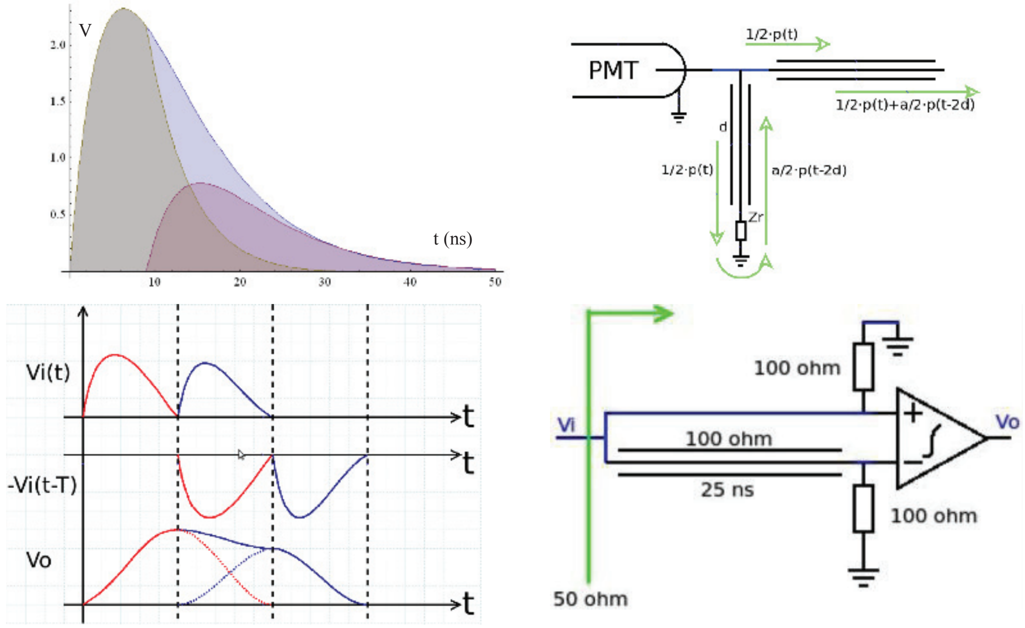

Figure 2.- Details of the clipping and integrating the PMT signals. Top left (a) the signal shapes, top right (b) the clipping scheme, bottom left (c) combining the signal clipping and integration, bottom right (d) the integrator scheme.

The second important processing block is the integrator. Integrators are usually implemented as operational amplifiers with capacitive feedback network. The capacitive feedback network is used as a charge to voltage converter. After each measurement the charge must be pumped out of the capacitor to be able to convert the next measurement without any offset from the previous one. In order to meet specification, the integrator must avoid any dead time.

The scheme in Figure 2d is used to avoid any dead time while satisfying the need of discharging the capacitor after each measurement, this diagram illustrates the concept of an integrator capable of integrating and disintegrating signals coming from two sources at the same time, although the way this is implemented (shown later in Figure 4) is not the one this figure may suggest. It takes advantage of the linearity of integration to charge the capacitor with the current measurement and meanwhile it discharges the exact same signal of the previous measurement. The neat result (see Figure 2c) is that at the end of the cycle the integration of the current signal is done and any contribution from the previous measurement is completely cancelled. Figure 2c exemplifies the case of two consecutive pulses arriving, the blue and the red one in top axis (Vi). Negative delayed versions are produced by the delay line as shown in middle axis (-Vi(t-T)), and the result of integrating both things together (Vo) is shown together with some help to visualize what happens during the second integration.

The objective for the analog processing electronics upgrade is producing an equivalent acquisition system with compensated gain for the 1/5 loss caused by PMT gain reduction. This implies that the signal processing chain must have at least 12 bits of dynamic range, the linearity must be better than 1% to have precise measurements, and the total noise at the output of the system must be less than 1 Least Significant Bit (LSB). This translates into 1nV/√Hz equivalent noise at the input of the system.

It is highly desirable to avoid major modifications in the PMT bases. The cabling and the electronics racks will not be modified so the system must fit in the same space and use the same connectors to interface with the channels. The current electronics also uses specifically made radiation hard power regulators. These regulators are being discontinued and shall be replaced with a new model which is switched, not linear as the current ones.

With these specifications in mind the group proposed two possible solutions, either to design an ASIC to perform the task or to design a suitable system with commercial components. Both solutions are currently under study (see reference [3] for the ASIC solution), yet this paper describes the solution with Components Out of the Shelf (COTS) whose implementation would require a lower budget.

3. Commercial components proposal

The main concern about the design of a suitable solution is noise since the specifications are 1nV/√Hz. In order to illustrate how low this is, it can be compared to the noise produced by a 50Ω terminating resistor, about 0.9nV/√Hz, or the noise produced by the resistor in the clipping line, about 0.6nV/√Hz. Since the order in which the operations over the signal are performed is important in terms of noise, the analysis of the current scheme shows not to be done in the optimal way. In effect, according to Friis' equation [4] the gain of the first stage of an analogical system strongly determines the noise performance of the whole system, and there is no possible way to palliate it. The higher the initial gain is, the better noise performance the system will have. In the original design the first stage (clipping) not only produces no gain but it introduces attenuation. The signal is then injected to a cable that further attenuates it and introduces induced noise in addition to the thermal one it could naturally produce. It is not possible to design a suitable system with commercial components in this scenario. The only possibility in order to make the problem solvable is to relax noise specifications.

The COTS proposal is to remove the clipping system from the PMT base. The procedure is achievable with a reasonable difficulty because it would only imply the cut of a relatively isolated PCB track in the PMT bases as shown in figure 3 on the left.

The main principle of the COTS scheme is working with a relaxed noise requirements produced by the removal of the clipping in the PMT base. Working without the clipping line produces several benefits. The first one is that a signal without clipping has more area, so the signal to noise ratio is better for the same amount of noise. The second one is that the clipping resistance was introducing noise in the first stage where the system is more sensitive; by removing it there is some gain. The third one is that the clipping introduced a low impedance path to the signal, making it easier for interfering signals to couple the signal of interest (common mode noise).

The second principle is processing data in the optimal way from the noise reduction point of view, which is first amplifying, and then clipping and integrating in order to produce a gain in signal to noise ratio (see for instance [5]).

The COTS approach is linear and time invariant, keeping the main principles of the current calorimeter solutions but the order changes previously mentioned. Figure 4 shows a simplified schematic of the proposal: the PMT signal inputs in unipolar mode the amplifier. Then, the delay line performs the clipping of the signal, which goes to an impedance adapting block. A second delay line inverts the clipped signals and sums it to the original one coming from the amplifier. Finally, the signal is integrated in the last block. One of the differences that can be appreciated respect to the one in Figure 2b is that the driver of the clipping system is a low impedance amplifier. For this reason the original clipping system cannot be used and an alternative implementation is used (Figure 3b).

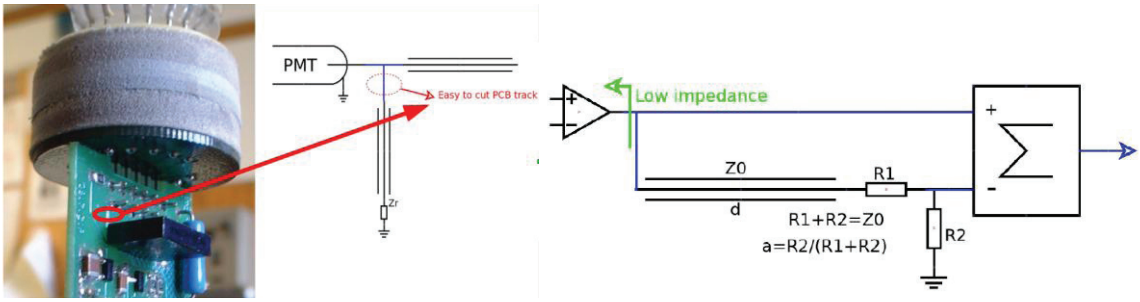

Figure 3.- Left (a), PMT base intervention. Right (b), new proposed clipping scheme.

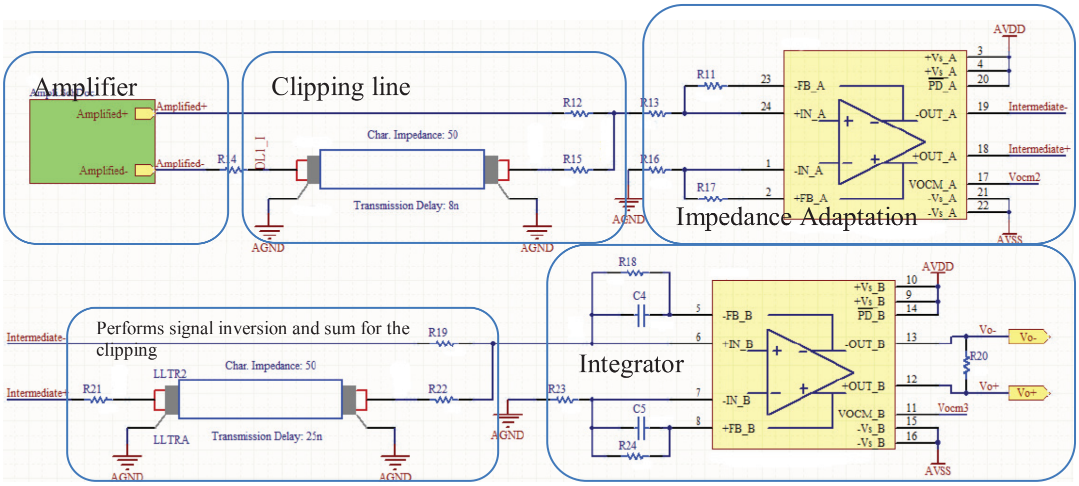

Figure 4.- Simplified Schematic.

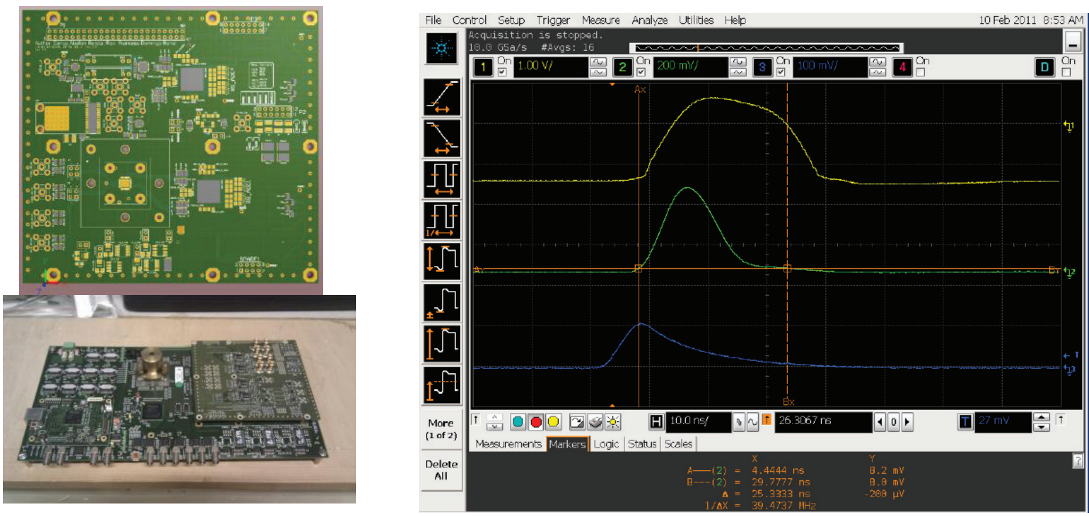

Figure 5.- PCB of the analog COTS mezzanine top left, the mezzanine connected to the first prototype of the Front End board. Right, oscilloscope image of the signals on the board

In order to simplify the design, differential operational amplifiers are used (ADA4930). However, the design cannot be considered fully differential, mainly because the inputs are unbalanced. To make the system fully differential, 4 delay lines would be needed instead of the actual 2, which would require more space than available.

The PCB design is shaped in the form of a mezzanine board adjusting to a prototype for the digital part of the Front End board as shown on the left of figure 5. The analog mezzanine ADCs are included to minimize noise and distortion due to track routing and to be able to test different grounding strategies that are mainly dependent on the analogical part. The version shown is the third one which is intended to measure both the COTS and the ASIC solution with the help of the definitive ADCs, and realistic grounding with switching noise induced by the digital electronics. Also it incorporates the SM01C switched regulator [6].

As for the measurements, a screen dump is shown in figure 5 on the right. The blue signal is the input from a PMT emulator, the green signal is the clipped one and the yellow signal is the integrated result. It can be seen that the integrated result decays in time. Another important parameter is the so called "plateau", that is the time range in which the signal variation is smaller than the 1% demanded resolution. In this case it is better than the ±1.5ns required by the specifications, but anyway the wider plateau the better immunity the system will have to phase shifts.

4. Conclusions

The analog electronics for the Front End boards of the upgrade of the LHCb calorimeters will have very tight requirements in terms of noise. A COTS solution preserving the principles of the actual solution can be foreseen provided we change the steps in which operations are performed. This requires a minimal manipulation on the current hardware of the PMT bases. Prototype boards have been designed and implemented and first measurements look promising enough to continue investigating the solution.

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