

Diagnostics of the Muon System Front-end Electronics during the LHCb Experiment

Bocci, V¹; Kashchuk, A²; Massafferri³, A; Nobrega¹, R; Schmidt, B²

INFN-Roma1¹, Rome, Italy; CERN², Geneva, Switzerland; INFN-Roma2³, Rome, Italy
 Valerio.Bocci@roma1.infn.it, Anatoli.Kashchuk@cern.ch, Andre.Massafferri@roma2.infn.it, Rafael.Nobrega@roma1.infn.it,
 Burkhardt.Schmidt@cern.ch

Abstract

This document describes a method to diagnose the Muon on-detector Front-End Electronics (FEE) during the LHCb experiment by means of threshold scan and noise rate analysis. The method does not make use of charge injection and it shows correct operation even with high voltage applied to chambers. The proposed technique can be used by the LHCb Muon Control System to provide alarm signals when parameters are out of specifications. Results and statistics obtained at CERN and INFN laboratories will be presented later on.

I. INTRODUCTION

The LHCb Muon Detector [1, 2] will consist of about 125 thousands physical channels whose signals will be processed by the front-end readout system, resulting in 26,000 logical channels used for triggering purposes and offline muon identification. Each physical channel will be read by a single Amplifier-Shaper-Discriminator (ASD) circuit. A single FE board consists of two 8-channel ASICs called CARIOCA [3] and one mainly digital ASIC called DIALOG, both have been implemented in an IBM 0,25um radiation-hard CMOS process. In front of each channel connected to the chamber (strip or pad) there are spark protection components.

A method to monitor physical channels operation is important to avoid inefficiencies due to failures on some detector subsystems such as chambers output lines, spark-protection equipment and physical connections between chambers and front-end boards.

A. Principle

The method [4] assumes a Gaussian amplitude distribution of the noise, which is in a first approximation a reasonable assumption. The noise rate versus threshold level can be represented as follows.

$$f_n = f_{n0} e^{-\frac{V_{Th}^2}{2V_n^2}} = f_{n0} e^{-\frac{Q_{Th}^2}{2Q_n^2}} \quad (1)$$

where V_n is the equivalent noise voltage on the input of discriminator, V_{Th} is the voltage threshold level, Q_n is the Equivalent Noise Charge (ENC), Q_{Th} is the charge threshold level, f_n is the noise rate at V_{Th} or Q_{Th} and f_{n0} is the noise rate at zero threshold.

The noise rate f_{n0} at zero-threshold is half of the frequency of zero-crossing f_0 (discriminator detects only one transition).

the expected number of zero-crossings per second for random noise is given by Rice's formula [5]

$$f_{n0} = \frac{1}{2} f_0 = \sqrt{\frac{\int_0^\infty f^2 w(f) df}{\int_0^\infty w(f) df}} \quad (2)$$

where $w(f)$ is the power spectrum function of the noise.

If $w(f)=const$ (white noise), and an ideal band-pass filter is used, whose bandwidth extends from f_a to f_b , eq.(2) is reduced to:

$$f_{n0} = \sqrt{\frac{1/3(f_b^3 - f_a^3)}{f_b - f_a}} \quad (3)$$

f_{n0} (here called 'vertex' frequency) and it can be experimentally found by identifying the crossing point between curves measured with different ASD input capacitance values. Fig. 1 shows noise measurements for a specific channel of a CARDIAC making use of different input capacitances.

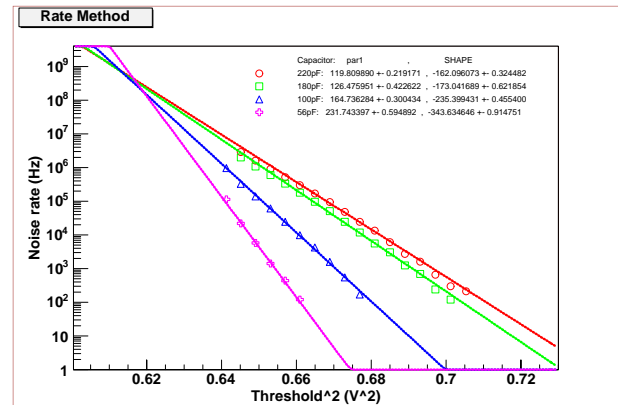


Figure 1 – ENC method curve.

The slope of noise versus threshold curve allows an estimation of the equivalent noise charge and consequently the evaluation of capacitance at the FEB inputs (chamber capacitance). Vertex frequency can provide, as indicated before, information about FE circuit bandwidth.

B. MWP Chamber and Read-out Overview

LHCb Muon System has foreseen 20 geometrically different MWPCs. Depending on its type, chamber

capacitance can vary from roughly 40pF to 250pF and signal can be read from anode and/or cathode connections. Due to the later requirement, CARIOCA has been developed to process both polarities by implementing 2 different pre-amplifiers at the very ASD input stage. They show slightly different signal responses depending on the chosen polarity operation. The on-detector circuitry is composed of three boards: OR-PAD, Spark-Protection (SPB) and CARDIAC. The first two boards make use of passive components while the third board processes and digitalizes chamber signals.

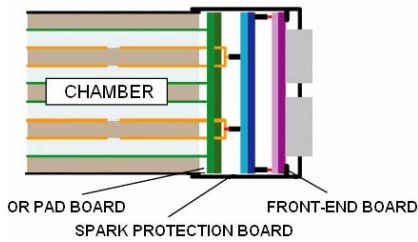


Figure 2 - Chamber readout boards.

CARDIAC is composed of 2 CARIOCAs and a DIALOG. CARIOCA functionalities include signal amplification, tail cancellation, base line restoration and signal digitalization into LVDS lines. DIALOG can read up to 16 CARIOCA outputs and has 16 8-bits DACs which provide a threshold voltage to each ASD channel on board. Furthermore it can perform signal width and delay adjustment and provides masking facility as well as a 24-bits scaler to each input channel for monitoring proposes. It can also generate auto-injected signals for remote testing. DIALOG control is performed via an LVDS-based I²C protocol which during the experiment will be accessed only by the Experiment Control System (ECS).

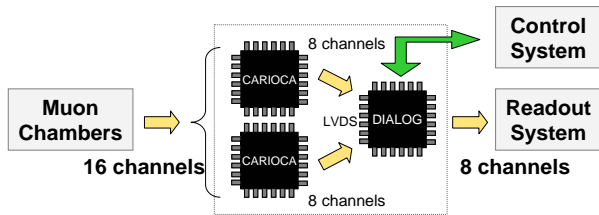


Figure 3 - CARDIAC block diagram.

CARIOCA discriminator makes use of a Differential Threshold Voltage (DTV) circuit (8 in total). It is able to provide a differential threshold ($V_{refA} - V_{refB}$) from an unipolar reference voltage (V_{ref}).

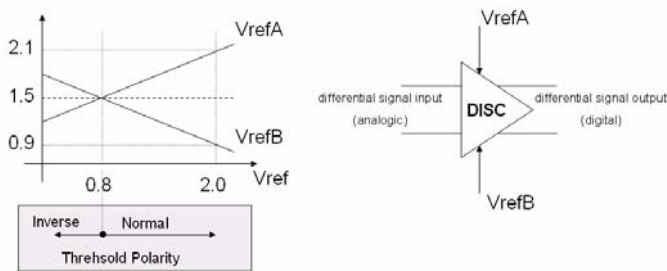


Figure 4 - Differential Threshold Voltage (DTV)

Assuming DTV usage for the CARIOCA discriminator one can expect a mirrored noise rate behaviour according to threshold variations as shown in Fig. 5. This noise measurement procedure has been implemented to provide and accumulate data for further analysis.

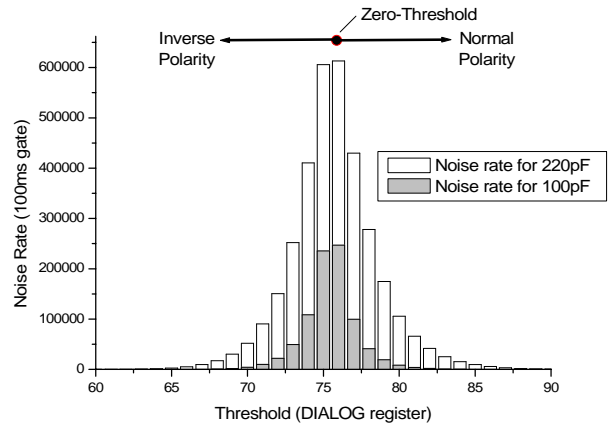


Figure 5 – CARIOCA threshold scan and noise rate response using DIALOG chip.

It will be shown how threshold versus noise rate behaves according to ASD input capacitance and how it can be used to test and monitor chamber and FEE operation.

II. SET-UP AND APPARATUS DESCRIPTION

To study such a method for the LHCb Muon System two set-ups have been employed: one simulating chamber capacitance by means of 16-channels capacitor boards, each fitted with a different value (47pF, 56pF, 100pF, 180pF and 220pF) connected between ASD input lines and ground, and the other using equipped MWPC chambers (M2R3, M3R1 and M3R3 with gas end high-voltage systems).

The FEB used has been the CARDIAC board, version 2.3. The main features of such a circuit which have been used were the individual thresholds lines and internal scalers (one per channel) which have permitted threshold scanning and noise rate acquisition. The procedure is performed channel-by-channel and in the meantime all the other channels are kept quiet (high level threshold) in order to avoid interference between channels during measurements.

To control such a system a Service Board (SB) [6], a C++ and a Root program have been used, resulting in a fixture permitting DIALOG access, control and data analysis. Test procedure implementation [7] allows to study noise behaviour by means of threshold scan, DIALOG internal scalers readout and creation of local a database. During the FEB test procedure information about noise behaviour versus threshold variation for all 16 channels is acquired. Such information is then read by a Root-based program which processes, analyses and displays data.

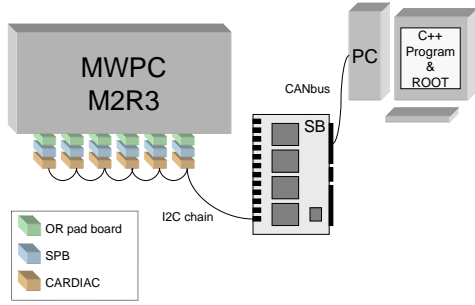


Figure 6 - Setup illustration of M2R3 equipped chamber and control fixture.

III. EXPERIMENTAL RESULTS

Results presented here were based on noise versus threshold measurements using the two set-ups mentioned before. The first set-up has been used to identify and obtain calibration curves and study method for the LHCb Muon Electronics while chamber measurements illustrate experimental results for the LHCb Muon Detector.

A. ENC Method Evaluation

Method efficiency has been studied throughout two different cases:

- Individual: Evaluation of single channels where results distribution is considered only for the same channel.
- General: Several FE channels analyzed collectively. Analysis of data from multiple channels by means of statistical examination.

Results will show method limitations in both cases and will indicate where and how they can be used.

ENC method results are given mostly in fC. Conversion, from Volts to Coulombs, has been made by a function which computes CARIOCA ASD sensitivity according to input capacitance (C_{in}):

$$senf\left(\frac{mV}{fC}\right) = 15.57 - 0.0543C_{in} + 0.00008413C_{in}^2$$

Estimation of chamber capacitance is carried out first utilizing Volts unit and thereafter values are transformed into Coulombs. This *senf* function represents the last official result which can describe sensitivity versus CARIOCA input capacitance (function parameters might be replaced by future results for CARIOCA 10).

1) Individual Case (per channel):

For an initial evaluation of the ENC method procedure it has been assumed that each channel presents variations on parameters as offset and sensitivity. This affects noise versus threshold curves: for diagnostic purposes, results achieved on chambers must be compared channel by channel. Calibration curves for all channels tested must be considered. Alternatively, parameters of the curves can be monitored for variations with time.

The Fig. 7 (top plot) shows statistical behaviour of one single channel tested for 5 different capacitances (100 measurements per capacitance value). Such Gaussians permit to evaluate chamber channel capacitance with precision given by their sigma values. The bottom plot shows linearity behaviour of equivalent noise charge versus ASD input capacitance. It must be noted that for the bottom graph (the same applies to Figs. 8, 9, 10, 12), horizontal error bars represent 5% capacitance tolerance while vertical error bars represent Gaussian standard deviation.

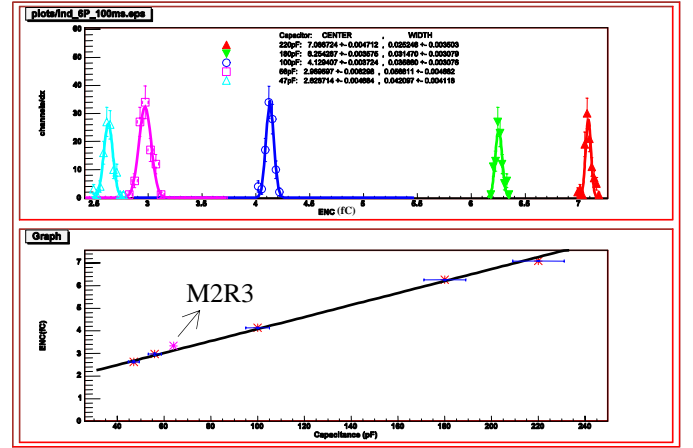


Figure 7 - Study of ENC method for single channels.

2) General Case:

FE and chamber connections can be tested without the need of an individual calibration database. Such a method requires a single and general calibration curve for the ENC (slope) parameter.

Fig. 8 shows Gaussian distribution of ENC values for the following cases: 47pF, 100pF, 180pF, 220pF and M2R3 MWP chamber. The main reason for such a large Gaussian spread is the channel-to-channel variation of CARIOCA characteristics. It does not give high precision for chamber capacitance evaluation but it can still be useful to estimate the average chamber capacitance and to identify open/broken channels.

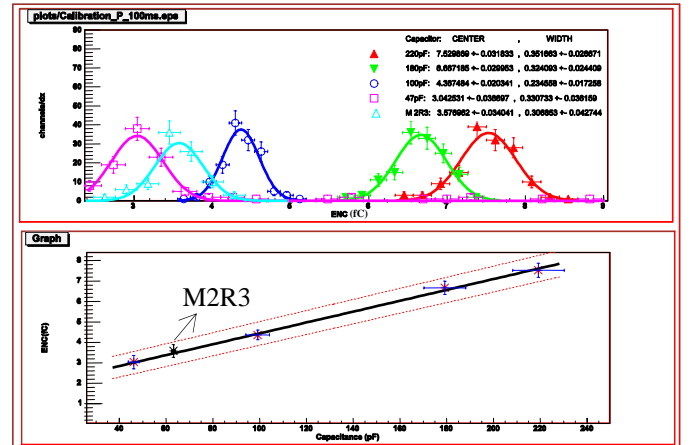


Figure 8 - Study of ENC method including many FE channels on statistics.

Fig. 9 shows equivalent noise in Volts and experimental results for the following MWPCs: M2R3, M3R1 and M3R3.

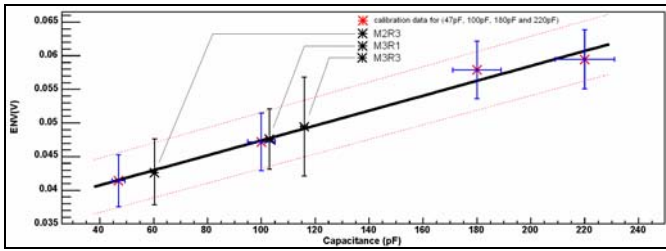


Figure 9 - Test of MWPCs using equivalent noise voltage.

B. Maximum and Integral Noise Rate

As DIALOG DAC (threshold) resolution does not allow use of the ENC method for low capacitances, other methods have been introduced to investigate cases where input capacitance also can be in the region of few pF. Two methods based on noise rate counting are described. The first method is based on the evaluation of maximum noise rate and the second is given by the sum of noise rate. It has been studied their correlation with CARIOCA input capacitance and results have shown that it is possible to identify such capacitances with both methods.

Fig. 10 and 12 show that both parameters (maximum and sum of noise rate) yields chamber capacitance with uncertainty given by Gaussian standard deviation. Its valuation has shown that such a method can also be considered to diagnostic proposes.

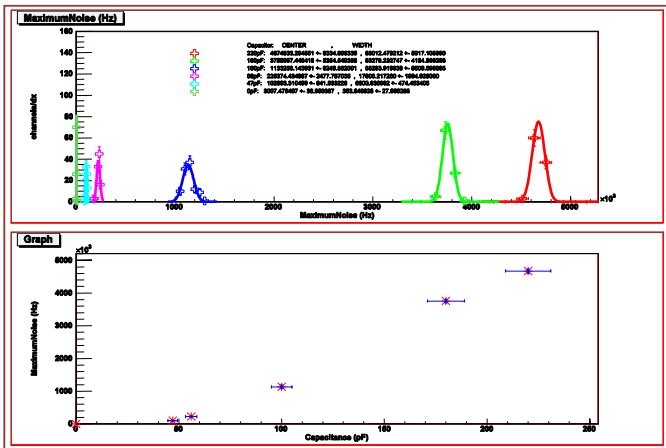


Figure 10 - Study of maximum noise rate for a single CARDIAC channel on threshold scan procedure.

Fig. 11 and 13 show that both parameters are sensitive to small variations of capacitance and therefore they can be used to single out broken channels and to estimate chamber capacitance with good accuracy in the low capacitance range.

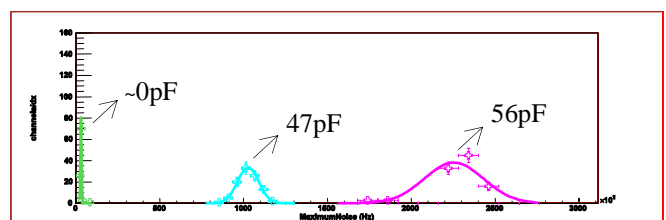


Figure 11 - Zoom of Fig. 10 for low capacitance region.

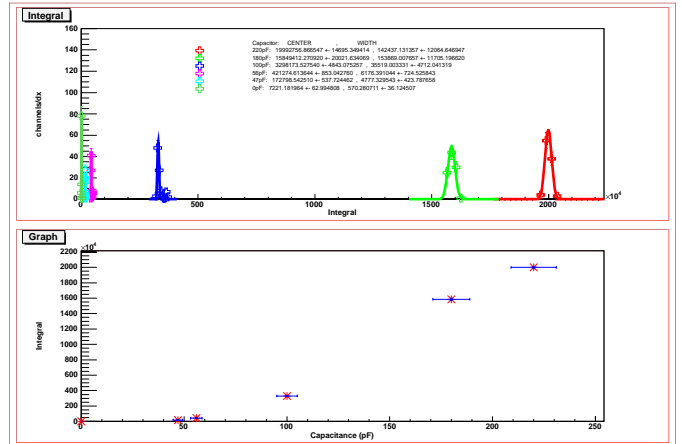


Figure 12 - Study of noise rate sum for a single CARDIAC channel on threshold scan procedure.

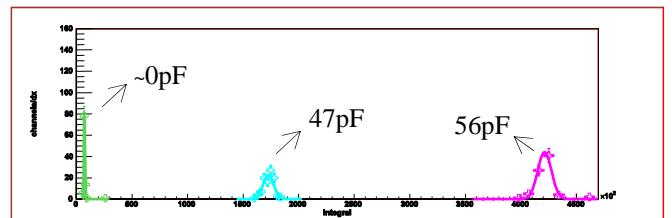


Figure 13 - Zoom of Fig. 12 for low capacitance region.

IV. CONCLUSION

Rate-Method individual and general cases present consistent results for analysis of chambers and front-end circuitry functionalities. It has been shown that maximum and integral noise rate can be used as a complementary and redundant procedure to the ENC method to facility the chamber and FEE test and diagnostics. Such procedures can be used to evaluate ASD input capacitance (chamber capacitance) and to detect broken/open channels for the LHCb Muon System.

V. REFERENCES

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