

A Digital Front-end and Readout Microsystem for Calorimetry at LHC

The FERMI project

C. Alippi^d, G. Appelquist,^h S. Berglund^h, C. Bohm^h, L. Breveglieri^d, S. Brigati^f, P. Carlson^g, P. Cattaneo^e, L. Dadda^d, A. Dell'Acqua^a, C. Fuglesang^g, G. Fumagalli^e, U. Gatti^f, V. G. Goggi^e, M. Hansen^a, H. Hentzell^c, A. Kerek^g, B. Lofstedt^a, F. Malobertif^f, V. Piuri^d, F. Salice^d, M. Sami^d, R. Stefanelli^d, R. Sundbladⁱ, C. Svensson^h, G. Torellif^f, J.P. Vanuxem^a, N. Yamdagni^h, J. Yuan^b

^a CERN, CH-1211 Geneva 23, Switzerland

^b Department of Physics and Measurement Technology, University of Linköping, S-581 83 Linköping, Sweden

^c Center for Industrial Microelectronics and Materials Technology, University of Linköping, S-583 390 Linköping, Sweden

^d Dipartimento di Elettronica, Politecnico di Milano, Sezione INFN, Pavia, I-20133 Milano, Italy

^e Dipartimento di Fisica Nucleare e Teorica dell' Università e Sezione INFN, Pavia, I-27100 Pavia, Italy

^f Dipartimento di Elettronica dell' Università e Sezione INFN, Pavia, I-27100 Pavia, Italy

^g Manne Siegbahn Institute of Physics, S-104 05 Stockholm, Sweden

^h Fysikum, University of Stockholm, S-113 46 Stockholm, Sweden

ⁱ SiCon AB, S-583 30 Linköping, Sweden

Abstract

We present a digital solution to the front-end electronics for calorimetric detectors at future supercolliders based on high speed A/D converters, a fully programmable pipeline/digital filter chain and local intelligence. Questions of error correction, fault-tolerance and system redundancy are also considered.

A system integration of a multichannel device in a multichip, Silicon-on-Silicon Microsystem hybrid will be used. This solution allows a new level of integration of complex analog and digital functions, with an excellent flexibility in mixing technologies for the different functional blocks.

This type of VLSI multichip integration allows a high degree of programmability at both the function and the system level, and offers the possibility of customizing the microsystem with detector-specific functions.

INTRODUCTION

The electronics for signal detection and triggering for experiments at future proton supercolliders will be some of the most complex systems conceived so far for high energy physics. For calorimeters in particular, complexity, speed and decision (trigger) power requirements call for an unprecedented level of data identification, compaction and processing already at detector level. That, and the requirements of massive trigger processing early in the acquisition chain, require the front-end stage of these detectors to include a major portion of the total electronics system.

Front-end signal processing for calorimetric detectors is essential in order to achieve adequate selectivity in the trigger functions, with data identification and compaction before read

out being required in the high rate environment of a high luminosity hadron machine. Other crucial considerations are the extremely wide dynamic range and bandwidth requirements for the front-end electronics, as well as the volume of data to be transferred to the following stages of the trigger and readout system [1]. These requirements are best met by an early digitalization of the detector information, followed by on-chip digital signal processing and buffering functions at both the first-level and second-level decision latencies.

In the following we will present FERMI [2], a dedicated R&D project for digital readout and processing of calorimeter signals.

PHYSICS REQUIREMENTS AND GLOBAL PARAMETERS

The dynamic range required for calorimetry in the multi-TeV region is in the order of 15 to 16 bits

It is not feasible, with today's technology, to implement A/D converters with more than 10 bit resolution at a sampling speed of 60 to 70 MHz as required by the bunch frequency of the proposed supercolliders. Therefore, a compression of the dynamic range from 16 to 10 bits must be done before applying the analog signal to the converter. This compression has to obey the criteria outlined below.

The energy resolution $\sigma_d(E)$ of the detector is usually parametrized as a function of energy [3] as:

$$\frac{\sigma_d(E)}{E} = \frac{a}{E} \oplus \frac{b}{\sqrt{E}} + c \quad (1)$$

where a is the noise term, b a scaling term and c a constant. A quantization process matched to the detector resolution implies:

$$\text{LSB}(E) \leq \frac{\sigma_d(E)}{k} \quad (2)$$

If $n(E)$ is the (nonlinear) transfer function of the circuit,

$$\frac{dn(E)}{dE} = \frac{1}{\text{LSB}(E)} \quad (3a)$$

then eq.(2) translates into a bound on the derivative of the transfer function,

$$\frac{dn(E)}{dE} \geq \frac{k}{\sigma_d(E)} \quad (3b)$$

The value of k is set by the allowed contribution of the quantization noise σ_n to the overall resolution:

$$\sigma_n(E) = \frac{\sigma_d(E)}{k\sqrt{12}} \quad \sigma_{\text{tot}}(E) = \sigma_d(E) \oplus \sigma_n(E) \quad (4)$$

The combined effects of all noise sources (including conversion) on the theoretical calorimeter performance can then be described by the fractional increase of the detector resolution:

$$R(E) = \frac{\sigma_{\text{tot}}(E)}{\sigma_d(E)} - 1 \quad (5)$$

Any practical implementation of a compression-converter system should produce a function $R(E)$ bounded from above at all values of E .

The normalized integral of expression (3b) can be used to define the minimal transfer function $n_{\text{min}}(E)$ which provides the relevant bounds on a wide family of possible transfer functions. The detailed functional form of any transfer function fulfilling these bounds is largely irrelevant. This holds true provided it obeys the following general requirements at all energies: of being above the minimal transfer function, both in value and first derivative, and of having a monotonic behavior.

Practical implementations of nonlinear transfer functions satisfying the bounds given by $n_{\text{min}}(E)$ can be obtained with piecewise approximations having linear and/or logarithmic segments. A practical compressor circuit using a 4-fold piecewise linear transfer function has been implemented.

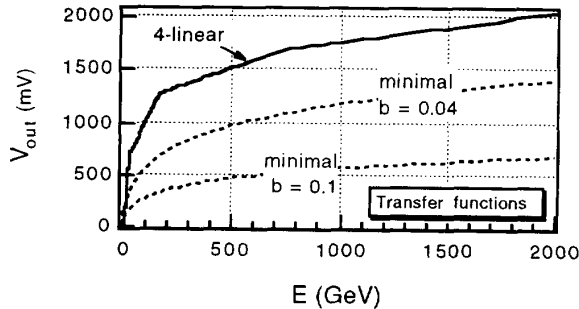


Fig. 1 Actual and minimal transfer functions

Fig. 1 shows this transfer function, together with the "minimal" ones for two detector families:

A : $a=0.05$ GeV, $b=0.10$, $c=0.01$, representative of scintillating fibre or liquid argon calorimeters;

B: $a=0.02$ GeV, $b=0.04$, $c=0.005$, representative of high performance scintillating crystal calorimeters.

The "minimal" functions result from integrating expression (3b) in the energy range between 0.1 GeV and 2 TeV, with $k=1/\sqrt{2}$ (corresponding to an upper limit of $R(E)=0.08$). All transfer curves are normalized to two counts at $E=0.1$ GeV.

The relative effect of the composite transfer function-digitalization described above on detector resolution for a type A calorimeter is shown in fig.2.

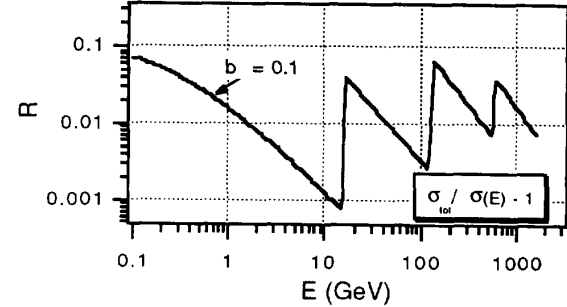


Fig. 2 Relative error contribution from the compressor/converter

On the average, above 1 GeV the intrinsic resolution of the calorimeter increases by a *relative* factor in the order of a few percent. With the appropriate choice of compressor parameters, similar results can be obtained for practically all calorimeter families.

It can be concluded from the above discussion that the combination of a suitable compression scheme and a practical 10 bit A/D converter (i.e. with 9 - 9.5 effective bits) can be an adequate solution for early digitization of the data from most types of calorimetric detectors in the LHC/SSC energy range.

DESCRIPTION OF THE FERMI STRUCTURE

The FERMI microsystem is designed to perform dynamic range compression, 67 MHz digitalization, DSP and buffering of the data up to and including second-level trigger latency. It is intended to be mounted directly on the detector, along with a multi-FERMI controller performing control, calibration and other system functions. Due to the harsh environment and limited accessibility, the design will incorporate a high degree of redundancy, fault- and radiation- tolerance.

Fig. 3 contains all major FERMI components in the form of a simplified block diagram. It is divided into two main parts: an acquisition part and a common service part. The former consists of twelve identical channels in three groups of four channels, while the latter is unique. Only nine channels are used for data acquisition, the others serving as a redundant elements. To achieve a matching reliability in the service part, it is designed with a high degree of fault tolerance.

The acquisition channel begins with a non-linear amplifier to achieve signal compression. The compressed signal is applied to the A/D converter where it is sampled at the rising edge of the internal 67 MHz clock. This event also starts the

or it may require controller intervention. In the latter case, on-line error checking will alarm the controller, which will respond with a hardware reconfiguration, thus eliminating the source of error.

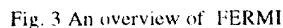
STATUS OF THE PROJECT

The digital part is modeled using the VHDL language and is being verified using XILINX programmable arrays as test media.

A floor-plan for a complete microsystem is under design.

In this paper we have demonstrated the feasibility of producing calorimeter readout electronics, based on early digitalization, for the next generation of hadron colliders. The digital representation of the data allows the generation of very sharp thresholds for the trigger processes. The problems of handling signals with very high dynamic range has been solved by the use of a non-linear transfer function matched to the resolution of the particular detector. A/D converters fulfilling the requirements specially those which concern speed, size and power consumption are being developed. Digital circuits providing the necessary storage, processing and communication functions are described. The questions of fault tolerance and reconfigurability have been addressed at each stage of the design. A Silicon-on-Silicon microsystem packaging technology [4] is used to achieve a compact, yet flexible, readout system.

- [1] V.G. Goggi and B. Lofstedt: "Digital Front-end Electronics for Calorimetry at LHC", *Proc. ECFA Large Hadron Collider Workshop, CERN 90-10, ECFA 90-133*, vol. 3, pp. 190-200, December 1990.
- [2] The FERMI collaboration : "Status Report on the FERMI Project", *CERN/DRDC/92-26*, May 1992.
- [3] For a review see: R. Wigmans: *Ann. Rev. of Nucl. and Part. Sci.*, vol 41 (1991) p. 33
- [4] A. Novak *et al.*, "A Standard Microsystem Module", *Presented at the ISHIM Meeting, Nordic Chapter, Åland, Finland, September 1990.*



External circuitry keeps track of where all samples are stored until the first level trigger has made its decision. If a sample point is accepted as a valid event, a predefined temporal environment (a time frame) is kept in the memory while locations that do not belong to such intervals are released. Released locations are recycled to be used for new input storage.

FAULT TOLERANCE

426