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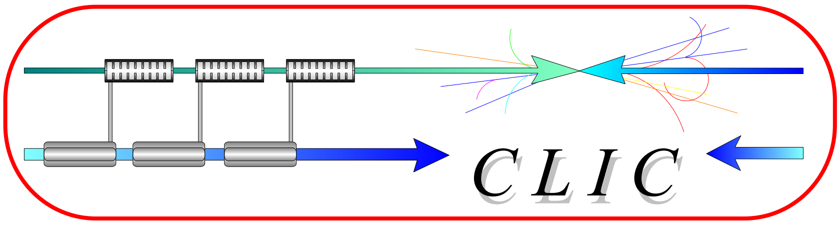

CLIC Note 357

High Performance Electronics for Alignment Regulation on the CLIC 30GHz modules

D . Carrica, R. Pittin

Abstract

The general outline of the High Performance Electronics for the Alignment System of the linear collider CLIC is presented. What is also shown are its most important characteristics. The main objective is to have a global view of the problems and the solutions found. The details of each of the subsystems and boards that compose the electronics will be published later.

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The general outline of the High Performance Electronics for the Alignment System of the linear collider CLIC is presented. What is also shown are its most important characteristics. The main objective is to have a global view of the problems and the solutions found. The details of each of the subsystems and boards that compose the electronics will be published later [6].

1. Introduction

CERN is studying a linear collider (CLIC) to obtain electron-positron collisions with centre-of-mass energies in the TeV range. The CLIC scheme* is based on beam acceleration at high gradient (150 MV/m) and high frequency (30 GHz) with RF power beam generation by the Two Beam Acceleration (TBA) method. Pulsed microwave power is extracted from the drive linac (Drive Beam) by means of power generating transfer structures and fed into the main linac (Probe Beam) through waveguide feeders.

*(2x3,5km for 0,5TeV-2x7Km for 1TeV-2x13,75Km for 3TeV)

The main drawback of the high frequency option comes from the small accelerator iris aperture which leads to the generation of strong wakefields increasing with the third power of the frequency in the transverse plane. In order to prevent the beam emittance being diluted by the adverse effects of the wakefields, sophisticated methods of beam trajectory correction, and structure alignment with a high precision have to be applied all along the linac.

To demonstrate the feasibility of CLIC, a test facility (CTF2) is being constructed with a 30 GHz two-beam section consisting of four identical modules resembling as closely as possible the real CLIC design [1]. Each 1.4 m long module consists of two linacs with a girder and a doublet or a triplet quadrupole per module. The girders are elements that support mechanically the cavities of the accelerator while the main objective of the quadrupole is to focus the particle beams. Fig. 1 shows the distribution of the modules with their girders and quadrupoles.

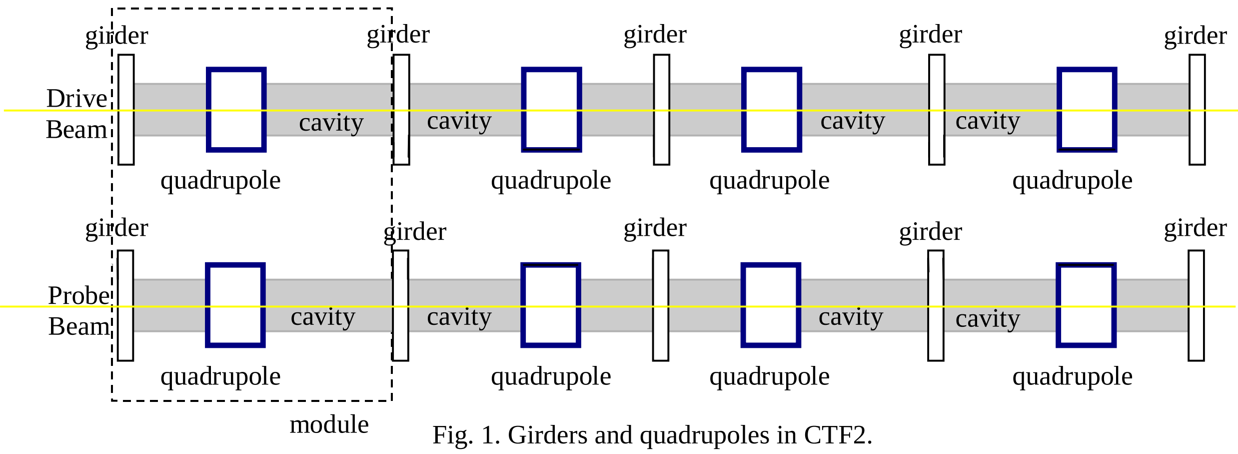

Fig. 1. Girders and quadrupoles in CTF2.

The alignment control system of CTF2[5], as in CLIC, must regulate the position of the girders and quadrupoles with a precision ⩽10μm, so that the beam stays done to the axis of the cavities and quadrupoles.

Thus, the alignment system requires sensors that measure the position of the components with respect to the beam and also needs drives capable of shifting the girders and quadrupoles in order to maintain the system aligned.
Nevertheless, it is not possible to carry out the alignment using the beam as reference due to its much faster dynamics with respect to the alignment system (slow since it is a mechanical system). Thus, the alignment is made with reference to a catenary that is pre-aligned with the theoretical trajectory of the beam [2]. The catenary differs from a straight line, but the errors are well-known and so properly corrected. The terms of the correction only affect the vertical components of the measurements.

The position sensors of the catenary are known as WPS (Wire Position Sensor) and are attached to both girders and quadrupoles, as shown in fig. 2.

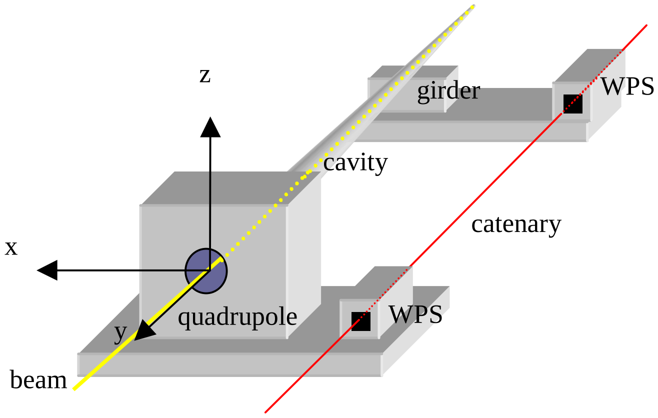

Fig. 2. WPS installation on girders and quadrupoles.

As regards the dynamic characteristics of the readings of WPS, these show significant damped sinusoidals between 30 and 50Hz. This is due to the mechanical resonance of the reference. For frequencies lower than 30Hz, there are no significant alterations in comparison with the required resolution. To filter these perturbations, Moving Average filters (MA) are implemented which are applied to each sensor output.

There are alignment errors with respect to the x and z axes, shown in fig. 2. The maximum alignment error allowed for girders and quadrupoles, in x or z directions, is $\leq 10\mu m$.

The displacement of girders and quadrupoles is done by stepping motors. The girders that support the cavities are moved by three motors, while the quadrupoles are moved by five motors, all coupled by ball and socket joints, as schematically shown in fig. 3.

The mechanisms illustrated in fig. 3 are associated with circular movements for which the non-linear equations are developed in [3]. These equations include the inclination of girders and quadrupoles. The inclination angles according to the three dimensions, α_x, α_y y α_z, are measured by inclination sensors TMS (Tilt Meter Sensor).

In fig. 4 the distribution of motors and sensors for the complete section of four modules of CFT2 is shown. The total quantity of resources to be controlled is: 70 motors, 26 WPS and 18 TMS. Since each WPS delivers two signals (one for x and one for z) and each TMS provides three (one for each dimension), 106 signals corresponding to WPS and TMS must be acquired. To this it must be added the temperature and hydrostatic level readings, present in the system, so there are 134 signals to be acquired for a section of four modules.

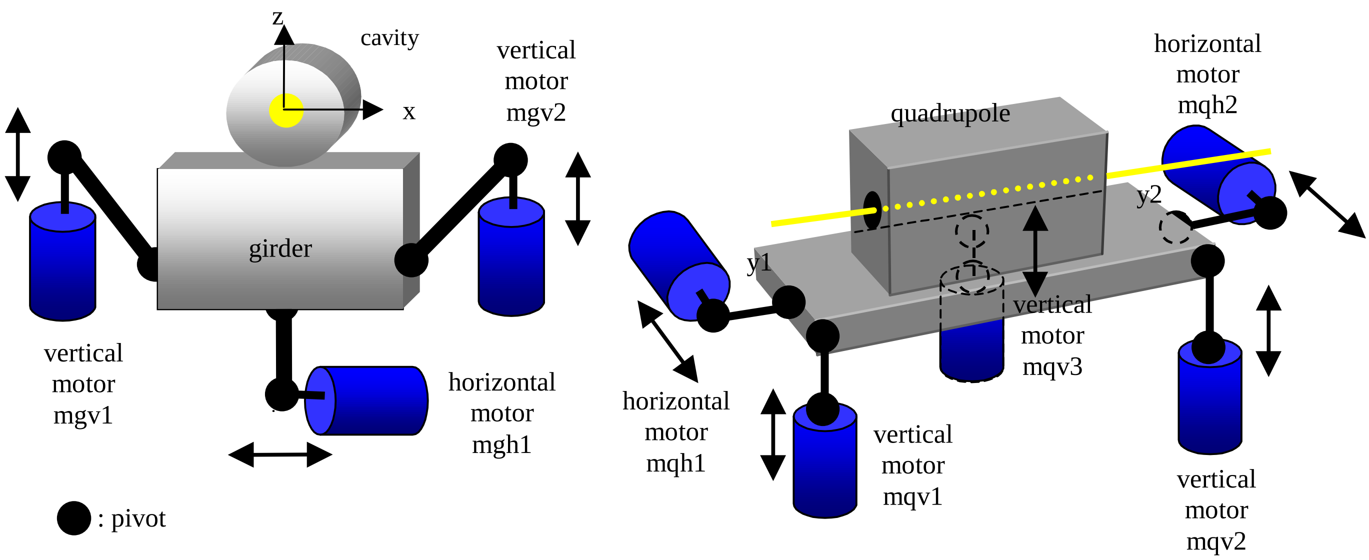

Fig. 3. Motors for girders and quadrupoles.

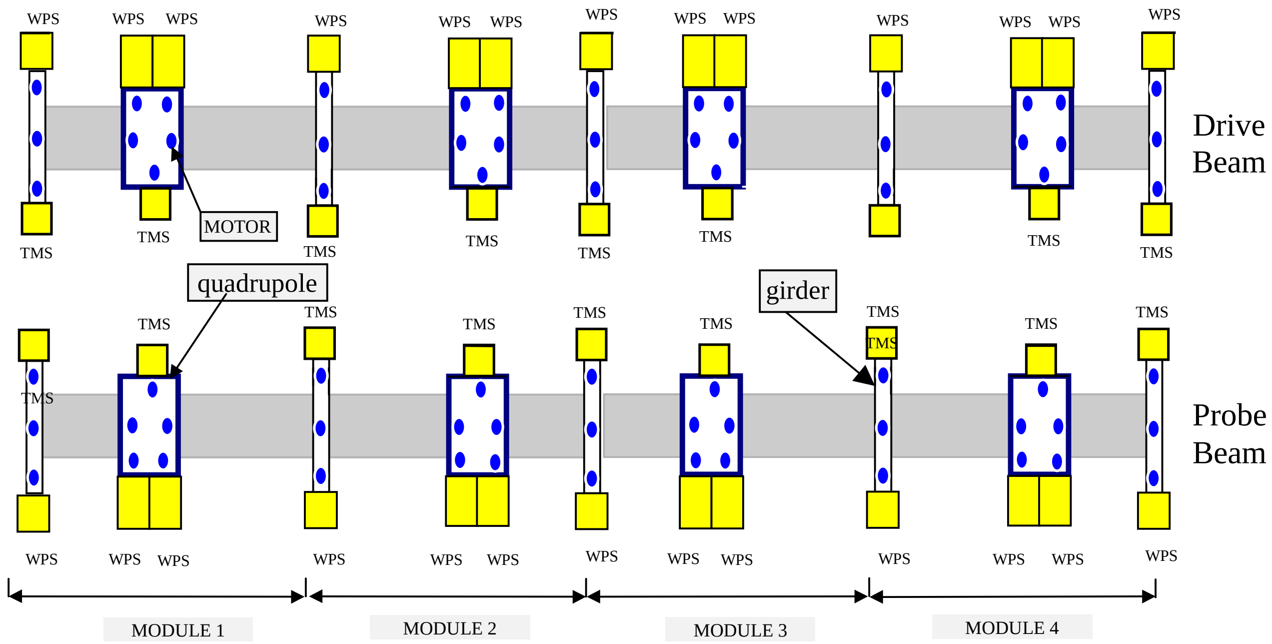

Fig. 4. Motors and sensors in CTF2.

The displacements must respect the mechanical laws in order to avoid the “lost step” errors. Due to mechanic inertia, friction and load torque to overcome, it is necessary to limit the acceleration. So for displacements of low quantity of steps (<100) low and constant speeds are preferred, using speed profiles for movements with a higher quantity of steps. The speed profiles imply a variation of speed that is trapezoidal in the case presented.

From the above mentioned development, it can be concluded that the electronics of the alignment system must fulfil the following specifications:

a) A high quantity of signals to read, filter and process (134).
b) A high quantity of motors to drive following speed profiles.
c) High accuracy (10µm.)

d) Processing speed: due to the dynamic of the system, the reading of the 134 signals, their processing, the execution of the corresponding control algorithms and the execution of algorithms of movement of motors (speed profiles) must be accomplished in less than 3 ms. This imposes demands in the processing time.
e) Communication capacity with more hierarchic systems: the system must communicate with other ones through a VME bus. The amount of data and parameters to exchange demand a flow of information specified in 512 words of 16 bits.
f) Low cost: the perspective to apply the electronics of CTF2 (4 x 1.4 m.) to CLIC 0.5Tev (2x3500 m.), that is about 1400 times CTF2, imposes cost conditions and small packaging.
g) Reduction of the wiring volume: the quantity of motors and sensors justify the search for wiring alternatives that allow significant reduction.
h) Immunity to electric and radiation noises: the demand of a high accuracy and the presence of strong radioactive environment generate restrictions as regards the conditions of the EMC (Electromagnetic Compatibility).
i) Flexibility: necessary to allow the typical changes of a development like CTF2 and then to be able to extend it to CLIC.
j) Modularity: allow adding modules with the same technology to versions each time more elaborate.

This work presents an electronic system that is able to fulfil the demands of CTF2 and that is also applicable to CLIC.

2. General Architecture of the system

In order to fulfil the specifications, the electronic proposal is based on the following principles:
a) Generalised utilisation of Field Programmable Gate Arrays (FPGA).
b) Utilisation of intelligent systems with high-speed and high-processing capacity.
c) Division of the system in modules of similar characteristics.
d) Galvanic isolation between boards and modules.

The electronics of the alignment system in the CTF2 is composed of two almost identical systems that operate independently except that both are slaves to a more hierarchic control. One is dedicated to the control of the Drive Beam and the other to the Probe Beam.

Each of these systems includes three subsystems: the Control Subsystem, the Acquisition Subsystem and the Driver Subsystem, as shown in fig. 5.

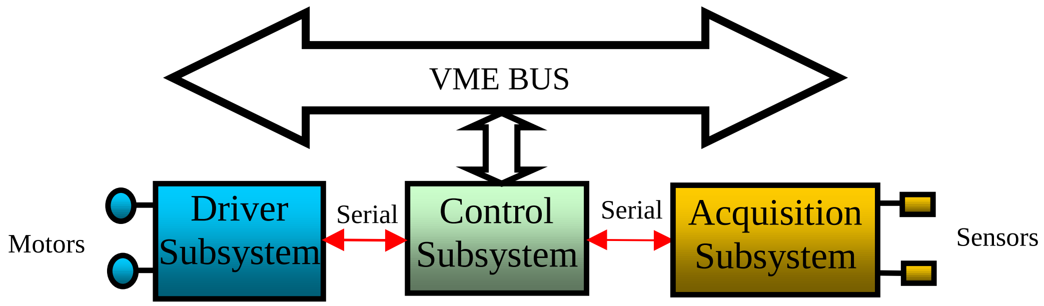

Fig. 5. General architecture of the electronics in CTF2.

2.1 The Control Subsystem

The Control Subsystem cyclically performs the functions that are shown in the flow diagram of fig. 6.

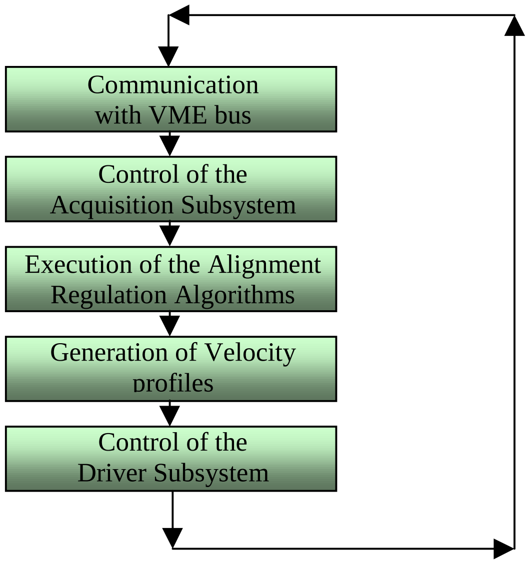

Fig. 6. Flowchart of Control Subsystem.

The Control Subsystem communicates with a system of higher hierarchy through a standard VME bus [4]. The communication is bi-directional, that is the alignment system receives and sends information to the more hierarchical system. The type of information received and transmitted is detailed below.

- Information received: offsets for the correction of the catenary, individual adjustments of sensors, MA filter parameters, velocity profile parameters, characteristics of each motor (μ/step ratio, currents), the desired shifting of each motor, characteristics of the counters of the μm accumulated in each motor.
- Information transmitted: TMS and WPS acquisitions, MA outputs for TMS and WPS, state of each motor (failure, position), state of the counters of μm accumulated in each motor.

The Control Subsystem is implemented trough a 5U board (Alignment Main Control Card, AMCC), that is plugged in the VME bus. The communication with the VME bus is of a parallel type.

After communicating with the VME bus, the AMCC initiates a process of acquisition of all the sensors. It sends to the Acquisition Subsystem the start conversion command and it immediately starts to receive the readings corresponding to the previous cycle, which are transmitted by the Acquisition Subsystem.

Once the parameters via bus VME are obtained, and after fulfilling the acquisitions, the Control Subsystem is in a condition to execute the regulation algorithms of alignment. The results of this process are useful to obtain the movements that each motor must perform. These are previously processed to fulfil the movements within the framework of speed profiles. Finally, the sequences to be executed by each motor are sent to the Driver Subsystem, where the power stages are found.

The architecture of the AMCC is given in fig. 7. The AMCC has a “dual port” interface memory, half of it stores the data coming from the VME bus and the other half to the transmission. This board utilises two DSPs. One is dedicated to the control of all the communications of the alignment system and the execution of the regulation algorithms. The other DSP is in charge of the generation of speed profiles and the control of the movement of all of the stepper motors.

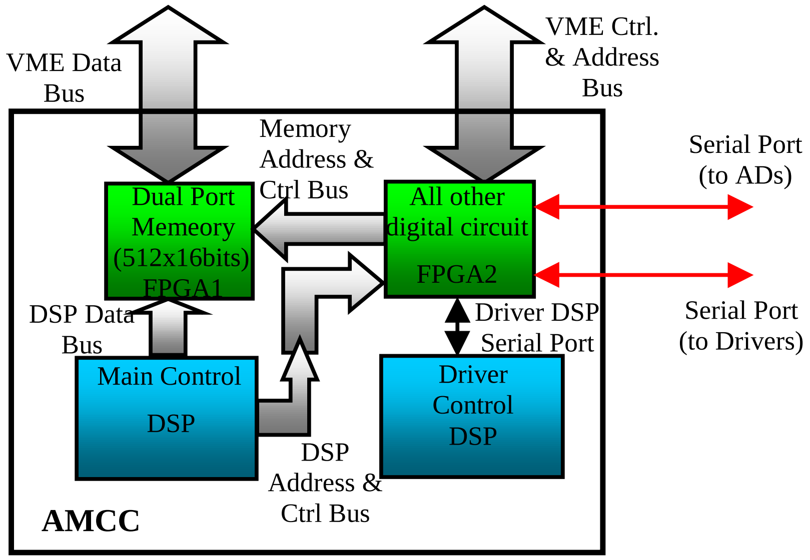

Fig. 7. AMCC Architecture.

The AMCC also uses FPGA technology. All the logic and all the interface “dual port” memory are implemented trough the FPGA. The utilisation of the DSP and the FPGA technologies allow the execution of all the activities on one board. Besides, since the whole thing is programmable, a greater flexibility in its development is achieved. This is important considering the experimental stage of the CTF2.

2.2 Acquisition Subsystem

The Acquisition Subsystem performs the following functions:
- Acquisition of sensor signals (67 signals) with a 16 bit resolution.
- Communication with the Control Subsystem.

The architecture of the Acquisition Subsystem consists of a set of chassis that are intercommunicated in a daisy-chain way (fig. 8). Every chassis includes boards where the electronic conditioning of the sensor signals is accomplished. Furthermore, each chassis has an acquisition board.

The acquisition boards are of 14 channels each, with a 16 bit resolution and a maximum sampling rate of 500 Hz. This board possesses a digital electronics that performs the channel selection and the AD series communication. The acquisition board also includes the serial communication logic of the chassis and the corresponding decoding circuit. All the digital devices mentioned are implemented in FPGA, that allow to achieve a board of reduced dimensions (3U: 100x160mm), whose distribution is observed in fig. 9.

The serial daisy-chain communication allows high flexibility since it permits to add as many chassis as necessary. This is only limited by the capacity to be addressed of each acquisition board. Since they possess five address bits, the maximum capacity is of 32 acquisition boards, that is to say, 32 chassis. Expressed in quantity of signals, 14 channels per board result in 448 signals. This is the maximum number of channels that each AMCC can handle. In the CTF2 application only 67 channels are to be handled.

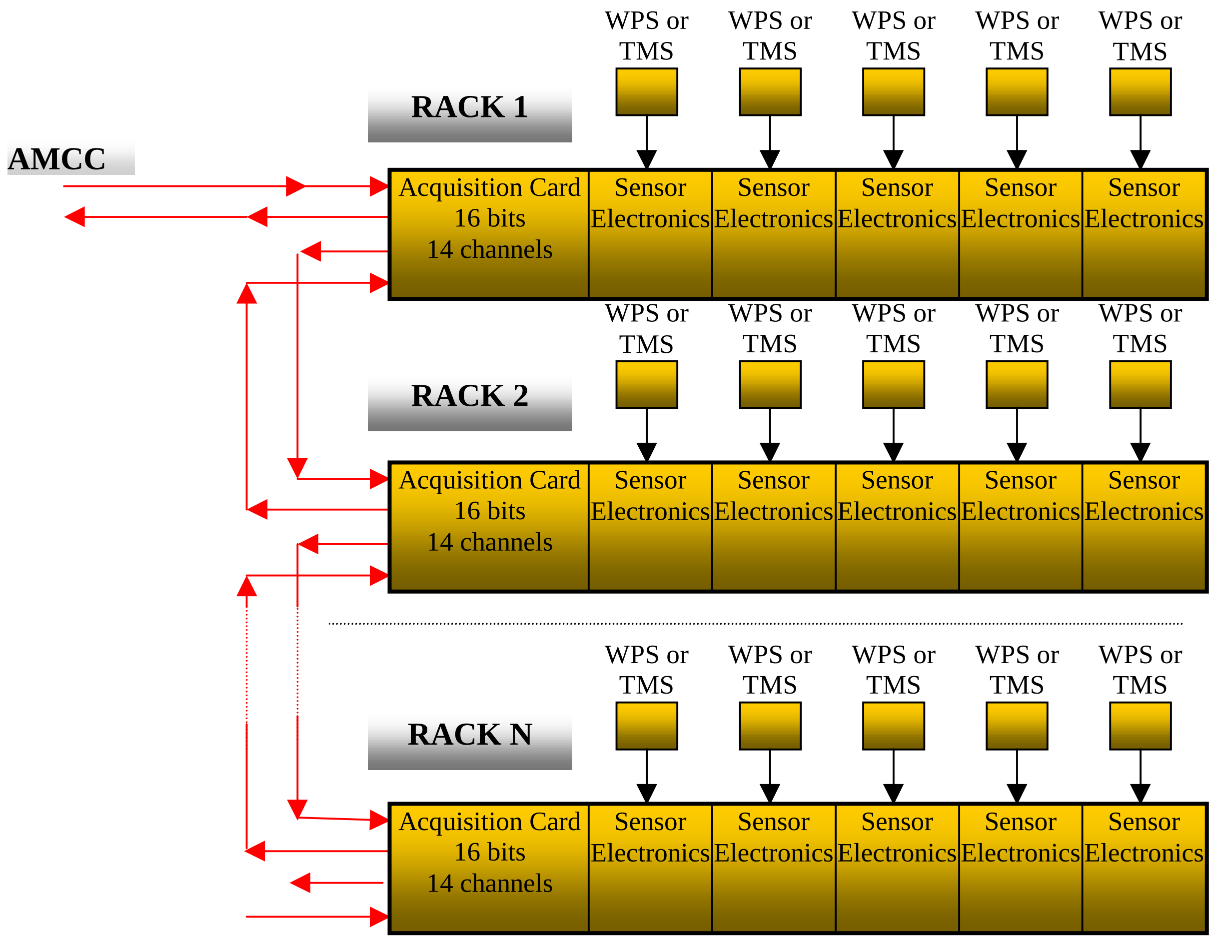

Fig. 8. Acquisition Subsystem.

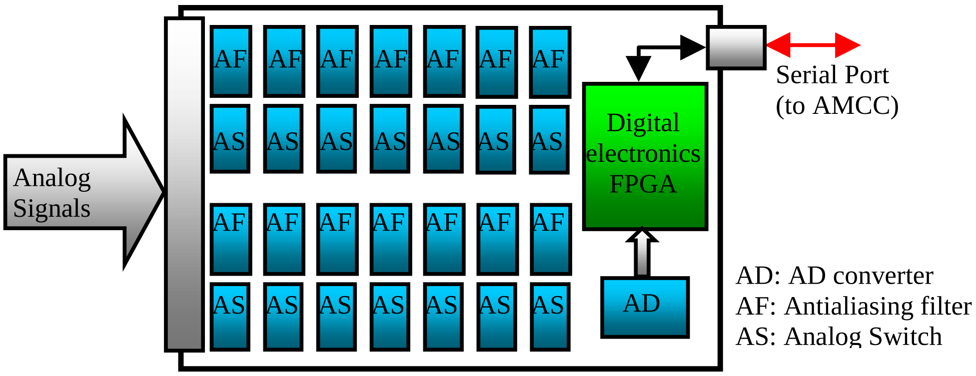

Fig. 9. Acquisition Card.

The serial communication between the Control and the Acquisition Subsystems is asynchronous, with a 5 Mbit/s speed. Optical fiber is used in order to galvanic isolation and to eliminate the electromagnetic perturbations produced in the tunnel.

2.3 Drive Subsystem

The Drive Subsystem is structured round a set of racks, intercommunicated in a daisy-chain way, fig. 10. Each rack includes up to five boards (Driver Cards) that possess the electronic drive for 6 motors each. Thus, each rack can drive up to 30 motors. The internal communication of the rack is performed through a bus plane.

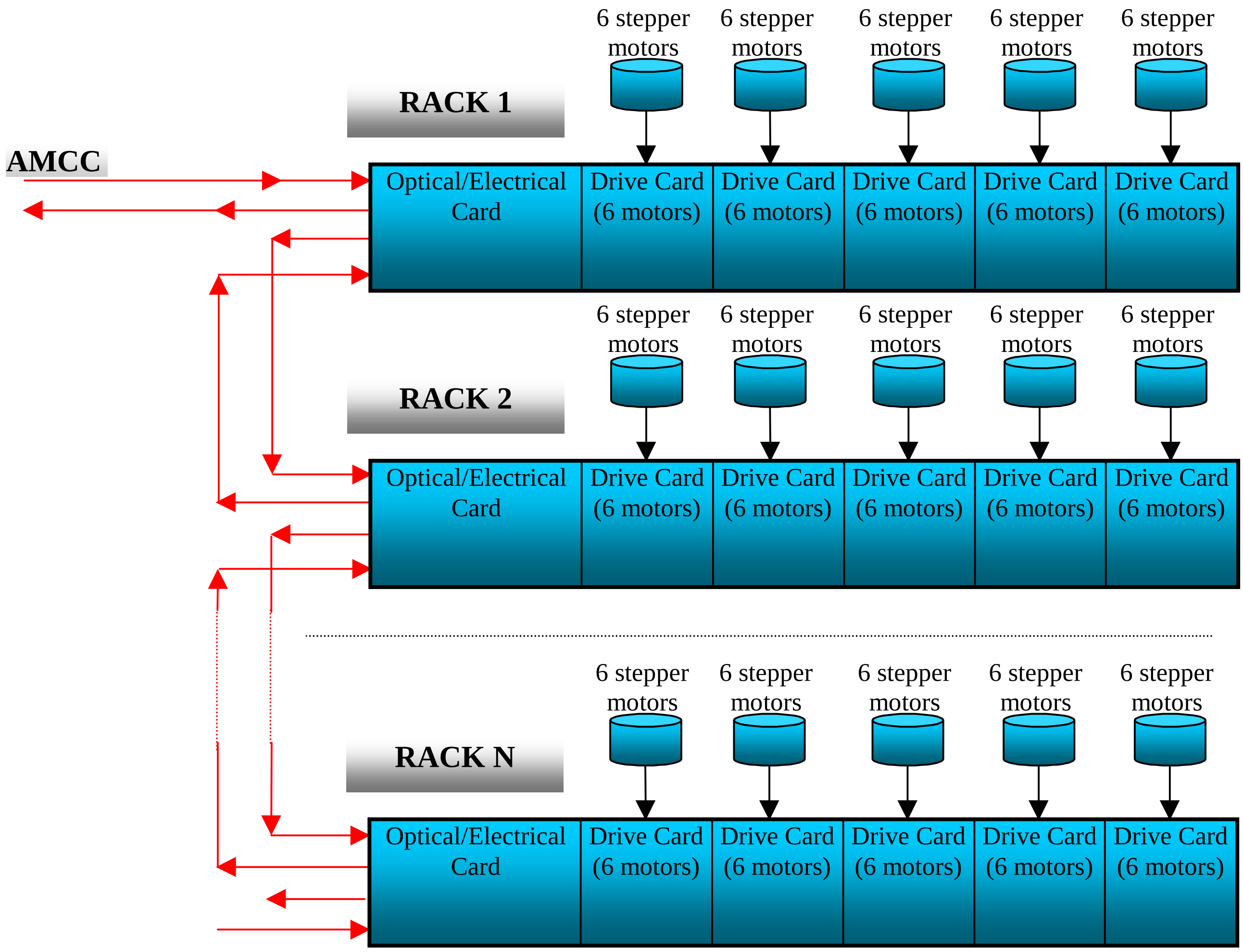

Fig. 10. Driver Subsystem.

The inter-racks communication and the communication with the respective AMCC is performed through optical fiber for isolation purposes and due to noise problems. In each rack, it exists a board that changes optical signals in electrical ones. The communication between the Control Sub-system and each Driver Card (through the rack) is serial asynchronous, with a 5 Mbit/s speed.

The power electronics needed to drive the six motors, with a maximum current of 2 A per phase, is fulfilled in the Driver Card. Each motor is driven with current pulses (imposed currents), which are generated in a PWM form. It is here included a failure monitoring system (open circuit failures) and the corresponding protection.

In the Driver Card, apart from the control logic associated with the generation of PWM and the protection of faults, there exist additional circuits for the maximum current per motor programming, the management of the information of the state of each motor (failure and position of each motor), the asynchronous communication and the address decoding. This is all implemented through a FPGA with a capacity of 6000 logic gates. In this way, a 3U board is obtained (100x160mm), addressable, capable of driving six motors with protections included, very flexible, that allows the programming of the currents of each motor (fig.11).

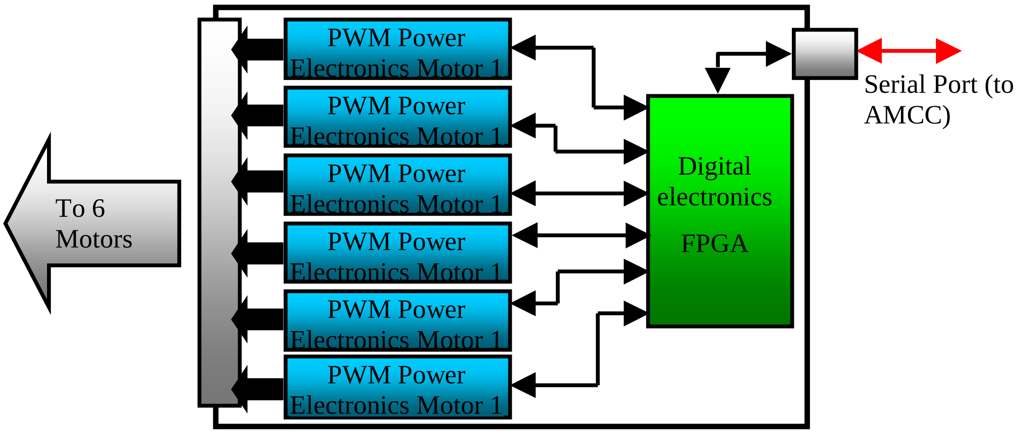

Fig. 11. Driver Card.

The address of each driver consists of a 5-bit word, so that the AMCC can control up to 32 Driver Cards, that is up to 192 motors. In the CTF2 application, each AMCC drives only 35 motors.

Anyway, the amount of motors that can be controlled is limited by the processing speed of the AMCC. With the motion algorithms developed for this application, moving the six motors one step takes 30µs. In terms of the speed of movement, this means that the maximum speed that a motor can be moved is 1/(N. 30µs), being N the quantity of groups of six motors that is desired to move simultaneously. Thus, maximum possible speed vary between 1040 steps/s and 33333 steps/s if one group is driven simultaneously or 32 respectively.

Since the CTF2 requires a simultaneous movement of 7 groups of motors (N=7), the maximum speed that allows the system is of 4760 steps/s, that exceeds the needs of CTF2 when the system is closed-loop (in closed-loop the movements are small and the speeds are reduced).

When the system is open-loop, large movements could be necessary but driving one motor each time. In these case the speeds, that follow profiles, reach 33333 steps/s, that exceeds by far the maximum mechanical speed of motors that are used in this application.

4. Results

All the requirements of the CTF2 are accomplished:

a) 134 signals to be read and processed.
b) 70 motors to be driven, following the speed.
c) 3ms processing time to acquire 134 signals, to perform the control and motion algorithms of the motors (speed profiles).
d) Communication with a more hierarchic system via VME bus.

The magnitude of the resulting system is as follows.

- 2 AMCC
- 4 driver Racks that include 12 Driver Cards.
- 13 AD Racks that include 13 AD 16-bit cards.

The whole system is commanded through only 8 optical fibers. This is feasible since schemes of serial type are used in all communications.

It was experimentally tested the accuracy obtained by the system in open-loop mode. For tests in open–loop mode, the acquisition system inputs were set as highly-stable dc signals in place of sensor inputs. Rehearsals were performed to show the variations of the readings round the acquired value. The results obtained are shown in fig. 12(a). It is observed that in 100 acquisitions the maximum deviation was of 2 lsb (1 lsb corresponds to 0.3μ). The statistical values obtained are the following: Mean Value=4000.16 lsb, Standard Deviation=0.746 lsb.

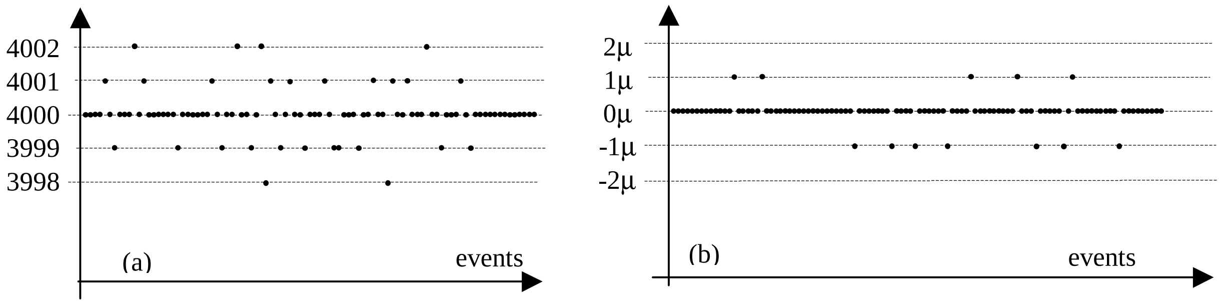

Fig. 12. (a) Acquisition Tests: 5.000 V input, 100 acquisitions. (b) Alignment errors, 100 acquisitions.

It was then verified the accuracy of the system alignment with the system in closed-loop mode. Readings of the WPS during the active alignment were performed. The readings showed a maximum deviation of 1μ as observed in fig. 12(b). The corresponding statistical values are the following: Mean Value=0.08 μ, Standard Deviation=0.493 μ.

5. Conclusions

In spite of the magnitude and the complexity of the system to be controlled, a modular and compact scheme was conceived, implemented in its different boards with FPGA technology and processors of high speed and high processing capacity (DSP).

The system is now mounted in CTF2 and possesses a high noise immunity because of galvanic isolation (optical fibers) among the different components of the system. Besides, there has been a high reduction of fibre optic cables thanks to the generalised use of series communication.

Extremely good performance indicators were obtained, particularly the low alignment error that, in the experiments performed, showed values of 1μ against the 10μ demanded.

Thanks to the flexibility, simplicity and reduction of components obtained, the system can be used in the CLIC development, even before subsequent quantity addition of modules to be controlled. In fact, the system would control modules that involve up to a maximum of 384 motors and 896 sensors without making substantial changes.

References

[1] R. Bossart, H. Braun, F. Chautard, M. Comunian, J.P. Delahaye, J.C.Godot, I. Kamber, J.H.B. Madsen,, L. Rinolfi, S. Schreiber, G. Suberlucq, I. Wilson, W. Wuensch, “Performances obtained with the CERN Linear Collider Test Facility”, European Particle Accelerator Conference, London, 1994, pp. 680-682
.
[2] W. Coosemans, H. Mainaud, “PRE-ALIGNMENT OF CLIC USING THE DOUBLE-WIRE METHOD”, CLIC-NOTE 343, 21/5/97, CERN.

[3] P. Poirier, “L’Alignement Dynamique submicrometrique de Sections Acceleratrices”, Memoire de soutenance du Diplome de Recherche Specialisee en Sciences, Universite Louis Pasteur de Strasbourg, 1991.

[4] “American National Standard for VME64”, VMEbus International Trade Association, 1995.\
[5] Jean-Marc Bouché, William Coosemans, Romain Pittin, “ Active Alignment for 30GHz Modules in CTF2 , CLIC-NOTE 350

[6] CTF Notes for Sub Systems of Electronic Active Alignment