CLIC-ACM: ACQUISITON AND CONTROL SYSTEM

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Abstract

CLIC [1] (Compact Linear Collider) is a world-wide collaboration to study the next terascale lepton collider, relying upon a very innovative concept of two-beam-acceleration. In this scheme, the power is transported to the main accelerating structures by a primary electron beam. The Two Beam Module (TBM) is a compact integration with a high filling factor of all components: RF, Magnets, Instrumentation, Vacuum, Alignment and Stabilization. This paper describes the very challenging aspects of designing the compact system to serve as a dedicated Acquisition & Control Module (ACM) for all signals of the TBM. Very delicate conditions must be considered, in particular radiation doses that could reach several kGy in the tunnel. In such severe conditions shielding and hardened electronics will have to be taken into consideration. In addition, with more than 300 ADC&DAC channels per ACM and about 21000 ACMs in total, it appears clearly that power consumption will be an important issue. It is also obvious that digitalization of the signals acquisition will take place at the lowest possible hardware level and that neither the local processor, nor the operating system shall be used inside the ACM.

CLIC OVERVIEW

CLIC is designed to be a positon-negaton collider. Each of the two beams line, when built in full scale, will reach 1.5 TeV, giving a center-of-mass energy of 3 TeV. To achieve such high energy RF systems must generate a gradient of 100 $\frac{MV}{m}$ and even then each of two linacs will need to be 21 kilometers long.

Both linac will consist of 24 sectors, each 876 meters long. Each sector will house 440 Two Beam Modules (TBM) and a radiation free zone called “alcove” carved in the beam turnaround. Sectors will be decelerating the drive beam and feeding the extracted power from the drive beam to the main beam achieving its acceleration.

CLIC’s linac will be composed of over 21000 TBMs which are therefore considered their basic building blocks. However not all TBMs are identical; it is in fact possible to subdivide them within five different category depending on the number of Power Extraction and Transfer Structures (PETS) and quadrupoles. Each TBM will present the following subsystems:

- RF — beam acceleration and instrumentation;
- Quadrupoles driving;
- Vacuum and cooling;
- Prealignment and Stabilization.

PHYSICAL CONSTRAINS

The design of the ACM has two major physical constrains:

Power

The global requirements from tunnel cooling and ventilation systems limit the amount of power dissipated in the tunnel to 150 $\frac{W}{m}$. Due to the limited efficiency of power transfer between drive beam and main beam it is expected that about 250 W will be lost per module. This limits power budget available for the Acquisition and Control Module to 50 W.

Radiation

Radiation effects on electronics are clear to be a dominant constraints in the design of the ACM’s electronics. The particle shower generated by the main beam and the drive beam are known to be generating radiation, however a clear estimation of their level is not yet available. A model of the current situation is under design and will have to be kept up to date during design changes.

Current estimations show a possible Total Ionising Doses (TIDs) of 100–1000 Gy per year and a proportionate safety margin will have to be considered. Available solutions to counter effects of radiation of this magnitude will be described later.

REQUIREMENTS

The ACM is a device providing timing, data acquisition and control to the TBM module. It must embed redundant power supply units, optical communication interfaces to communicate with master side placed in alcoves and expandable system for hosting cards interfacing directly with TBM subsystems.

Channels

A survey has been conducted amongst groups responsible for different subsystems to gather precise requirements concerning number and types of channels. A summary of currently requested channels is available in Table 1.

The estimations have been made taking into account 50% extra spare channels and some supplementary channels for each acquisition/control card. As a result each ACM module will require around 500 channels.

The survey also covered additional requirements such as maximum length of cables, sampling window, the need for post processing, and supplied timing precision. Using this information and assuming a 50 Hz repetition rate it was

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Table 1: Summary of Requested Channels

Type of channel	Number of channels
Fast ADC (200 MS/s, 14 b)	28
Slow ADC (10 kS/s+, 16 b)	55
Raw DIO	110
Serial IO (RS232/485)	18
Slow DAC (10 kS/s+, 16 b)	24
Total	301

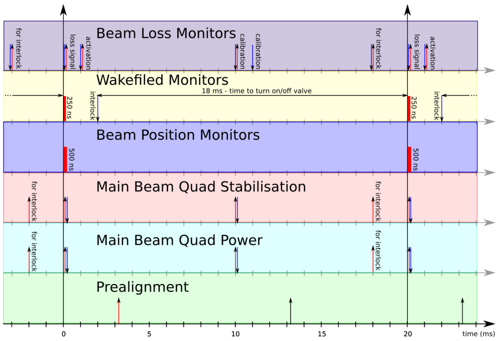

Figure 1: Timing diagram for acquisition channels.

possible to estimate the bandwidth required to upload measurements to the control center: 2500 kb/s. This requirement could be fulfilled even with standard copper cabling however this value could linearly increase with the repetition rate and the interlock system which may require a lower latency.

Power Consumption

To decrease the power consumed by ACM, several techniques will have to be employed. During channel survey information about timing patters was gathered to discover which channels could be turned off for some time. A timing diagram for most important acquisition channels has been included in Fig. 1. Channels with sample rate of 200 MS/s (Beam Position Monitors, Wakefield Monitors) are expected to consume most of the power and according to Fig. 1 it should be possible to stop sampling between pulses. Other channels could be acquired using multiplexing ADCs distributing power consumed over a longer period of time.

The prealignment system does only a few checks during accelerator operation. Movers used to align the linac will be used only when there's no beam so they don't have to be included in 50 W power budget.

Timing

Providing precise timing information to all front ends scattered all over CLIC complex is a challenging task. Currently at CERN a dedicated optical fibre network is used to provide timing and commands. This approach allows to precisely deliver signals to all stations, however this solution does not scale well as the connection to each node has to be manually adjusted using an atomic clock.

In the case of CLIC, providing a separate optic fibre or RF cable with precise clock to each of ACMs is not possible. A precise timing will probably be distributed to each of the alcoves. The original idea was to adopt White Rabbit [2] (WR) to provide data transmission and timing distribution, but since a rad-hard WR device is not likely to be designed and manufactured we assume to be only able to adopt this technology in radiation-free zones such as the alcoves.

According to the previously mentioned survey the most demanding subsystem with respect to timing is Beam Position Monitors. This system requires to sample data synchronously with the machine clock tolerating an absolute start of acquisition time difference between ACMs below one sampling period.

Machine Protection

The beams present in CLIC carry enough energy to damage the machine in case of a failure. The machine protection has the mission to ensure no harm is done to any machine components from miscontrolled beams. Data from all ACMs are sent to a local supervisor which forwards them to a master supervisor responsible for granting permission for the next cycle.

The control system plays a crucial role in making the machine protection system work by delivering measurements reliably and on time. There are two possible kind of failures [3]: data corruption (may lead to structure damage if false permit has been issued); no data received (next pulse is inhibited, machine availability loss).

Amongst the 300 channels present in each ACM about 10 (mostly responsible for powering quadrupoles) have been marked critical. Not receiving results from these channels will cause immediate machine stop.

There are also signals which are vital to keep CLIC efficient in terms of beam intensity but losing one of them will not cause instant shut down. It is anyway important to make sure that some of those channels are not simultaneously lost in adjacent ACMs to prevent permanent damages.

False permit may cause permanent damage and huge system downtime; false vetos cause short system downtime needing to restart the machine with probe beams and ramp the energy up to the nominal value. Even though the later is less critical it can be tolerated on average maximum 3 times a day.

SOLUTIONS

The proposed solution for the ACM has been split into several parts that will be presented in the following subsections.

Crate System

After examining several modern crate systems, including μTCA, CompactPCI-Serial, VXS and VPX it was concluded that no standard fits all of CLIC ACM needs. Crates that are convenient to be used in a server room or in a

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laboratory do not seem to be a good solution for such an extreme environment as the CLIC tunnel. All the crates need a processor unit to control buses available on the backplanes and the usage of any standard processor is not possible due to the expected radiation level.

This research is currently evaluating the possibility of adopting a simpler crate system that would provide a mechanical form factor without any additional logic. A possible alternative would be Eurocard, DIN 41612 and simple μTCA. Special attention would be given to the last mentioned solution.

Electronic Components

Assuming 800 Gy is the target radiation level to be withstood by the electronic that shall be installed in the accelerators' tunnel most of COTS (Commercial Off The Shelf) can not be adopted.

There are therefore two main solutions which seem suitable and are left to investigate. The first is the creation of a custom ASIC (Application Specific Integrated Circuits) adopting a radiation hard technology library. This system shall be responsible of the low level data acquisition, the signal preconditioning, the triggering, the data buffering and up-streaming. Designing such a system on ASICs technology would provide a good tolerance to radiation and a very power efficient solution. Despite the mentioned advantages the ASICs solution does not provide us enough flexibility.

At the state of the art the best solution in term of reprogrammability and radiation resistance is provided by SRAM (Static Random Access Memory) based FPGAs (Field Programmable Gate Arrays) for space application. The problem of this solution is that the price for these components makes them unreachable for project to be deployed on a large scale. A good tread-off is provided by flash FPGAs; flash FPGAs that are capable to withstand total ionising doses up to 800 Gy and are economically affordable. Their maximum operating speed is however much lower than the speed achievable by ASICs or SRAM FPGAs.

Communication and Timing

White Rabbit could not be selected as last mile solution for data and timing transfer therefore other solution are currently under evaluation. GBT [4], a CERN project aiming at delivering reliable rad-hard devices and protocol for timing and data acquisition, seems to be the best candidate. GBTX (the GBT ASIC implementation) main specification are:

- 4.8 Gb/s line rate (3.2 Gb/s for users);
- Reed-Solomon encoding;
- radiation resistant 130 nm technology (up to 3 kGy);
- build-in e-link switch;
- guaranteed fixed latency;
- guaranteed bandwidth per endpoint;
- low power consumption — 2 W;
- clock recovery.

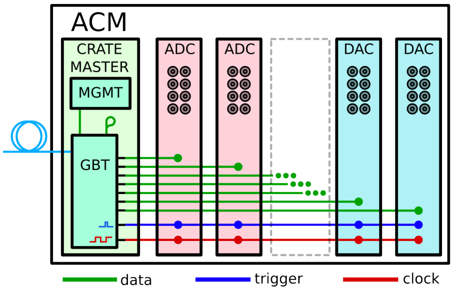

Figure 2: Concept of ACM using GBT.

The radiation is considered to be the main constrain of our system. Nominal GBTX radiation resistance should provide our system with a higher reliability. The total bandwidth given by the device is much higher than our current requirements so there is a good safety margin in case of specification changes.

GBTX has also built-in ”switch” which multiplexes/demultiplexes data stream into up to 40 independent e-link channels. For each of the channels a slot of the GBT protocol frame is reserved so each link is guaranteed to get 80 Mb/s in both directions. Two or four channels can be combined together forming even faster interface (up to 320 Mb/s).

As shown by the simple diagram presented in Fig. 2, each card will be connected by a dedicated e-links connection. Spare links could be used to:

- connect a dedicated ACM manager;
- test link latency by performing remote loop back;
- trigger all cards in the crate.

A first batch of GBT chips straight from a manufacturer is expected at the end of 2013. CERN's PH-ESE group has also plans to design a new version of GBT chip with some improvements including further reduction of consumed power.

Critical Channel Acquisition

As previously mentioned some channels are critical for the machine's operation and their loss will cause immediate stop. In order to minimize the downtime critical channels shall be sampled simultaneously by multiple ACMs. The availability of this scenario can be further improved adopting interleaving schemas while distributing data and power to the different modules. Adjacent ACMs shall be connected to separate power circuits and have separate data transmission paths — e.g. optical fibres terminated in separate patch panels, serviced by separate FECs (Front End Computers).

Visualisation of this idea with measurements being done in two adjacent ACMs is shown in Fig. 3. Please note separate data connections for every third ACM.

Network Topology

Network connection is another important part of control system. To ensure high reliability all our considerations

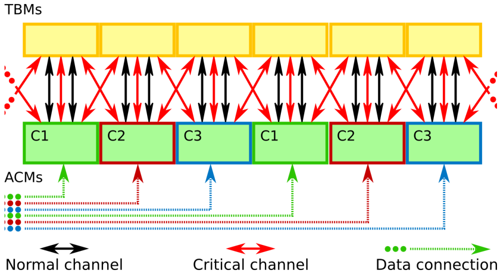

Figure 3: Redundant critical channel acquisition.

include redundancy. Three different topologies have been investigated: a star, a ring with 8 devices and a ring with 16 devices.

The installation of a star topology network seemed to be much more complex and expensive than that of a ring because all the ACMs would need to have a point-to-point connection with the closest alcove. Furthermore the number of interfaces in FEC's side would have to match the number of ACMs. In the ring topology only some ACMs require direct connection to the alcove; all the other nodes are connected to adjacent ACMs using short patch cables. The number of FECs required is reduced by a factor equal to the number of devices in a chain and so is the bandwidth available for each of ACMs. First estimations of the implementation's cost for the mentioned topologies were surprising: a ring with 16 devices per chain is only 25% cheaper than a star. Decreasing the number of devices per ring to 8 causes the costs to rise sharply and reach almost twofold of ring 16 set-up.

Table 2: Comparison of Network Topologies

	Cost	FECs	Timing	Bandwidth
Star	Medium	N	Easy	B
Ring 8	High	N/8	Medium	B/8
Ring 16	Low	N/16	Hard	B/16

Other benefits of using dual star are possibility of using GBT chip and increased reliability. Currently dual star is considered to be the best solution for CLIC.

Placement

There is currently no place for the ACM reserved in the tunnel. There are four placement possibilities (see Fig. 4 for reference): on the left wall, on the right wall, in the middle, under the drive beam. A recent discussion about the placement has shown that the middle position seems to be the best solution despite the risk of mechanical damages. This in fact benefits from easy maintenance access and miminises the cable length between the sensor and the ACM.

Another considered place is the left wall although it is difficult to reach and cable trays would need to cross the water draining trench. The other two options (placing the ACM under the drive beam or on the right wall) have too many disadvantages to be taken into account.

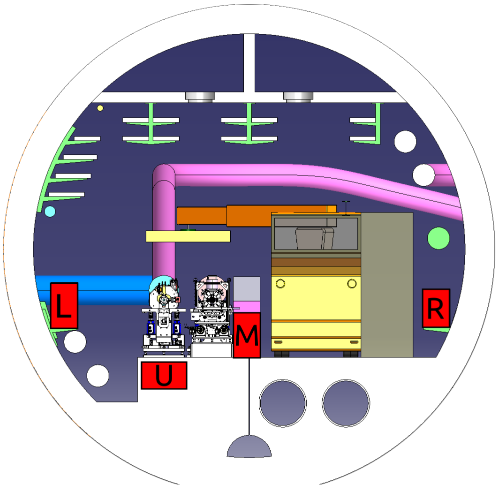

Figure 4: CLIC tunnel cross section[1].

CONCLUSIONS AND PLANS

Gathering requirements and designing the ACM for CLIC is a long term and challenging project that would require multiple iterations. As different groups refine their specifications, requirements change and the design of the ACM has to adapt accordingly.

Recently we started another round of meetings to update the channel requirements and refine the gathered information. A series of radiation measurements has been done in CLIC Test Facility 3 to be able to calibrate available FLUKA models to get better idea of expected conditions. The conducted survey for possible placement of the ACM also plays a role in estimating which technology can be used with available shielding.

In the near future, the possibility of using GBT and flash based FPGAs (Actel's ProASICs 3 for acquisition cards) will be investigated. Further steps include specifications of interfaces between ACM and cards as well as a mechanical format of the crate.

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[1] Figure courtesy of A. Samochkine, CERN, Geneva, Switzerland