STATUS OF THE SARAF-PHASE2 CONTROL SYSTEM

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Abstract

SNRC and CEA collaborate to the upgrade of the SARAF accelerator [1] to 5 mA CW 40 Mev deuteron and proton beams and also closely to the control system. CEA is in charge of the Control System (including cabinets) design and implementation for the Injector (upgrade), MEBT and Super Conducting Linac made up of 4 cryomodules hosting HWR cavities and solenoid packages.

This paper gives a detailed presentation of the control system architecture from hardware and EPICS software points of view. The hardware standardization relies on MTCA.4 that is used for LLRF, BPM, BLM and FC controls and on Siemens PLC 1500 series for vacuum, cryogenics and interlock.

CEA IRFU EPICS Environment (IEE) platform is used for the whole accelerator. IEE is based on virtual machines and our MTCA.4 solutions and enables us to have homogenous EPICS modules. It also provides a development and production workflow. SNRC has integrated IEE into a new IT network based on advanced technology.
The commissioning is planned to start late summer 2021.

CONTEXT OF THE PANDEMIC

Because of the pandemic, the CEA team hadn't been able to go to the SNRC Lab since March 2020. The first impact was for the Injector. The CEA is in charge of the EPICS update of the Injector Control System. Four cabinets were delivered to SNRC in February 2020 as planned but the CEA could no longer go there and install software. Therefore, SNRC installed the four new cabinets and integrated the Injector control software by itself. At that time a remote connection between the 2 labs was not allowed. The CEA support was only by videoconferences and emails. Finally, there was a first beam on the Source on September 2nd 2021.

GENERAL ARCHITECTURE

In summer 2018, our partner SNRC accepted CEA's recommendation to migrate to the CEA MTCA.4 platform for the SARAF control system. This platform was presented at ICALEPCS19 [2] and is based on the very compact NATIVE-R2 crate with this common core on each crate: the NAT-MCH-PHYS80 board offers an 80-port PCIe Gen3 switch and can be combined with the Rear Transition Module CPU NAT-MCH-RTM-COMex-E3.

For semi-fast and fast acquisition, a set of IOxOS boards was also added to this common platform. See Figure 1. The intelligent FMC carrier IFC1410 (AMC form factor featuring an NXP QorIQ T series Power PC processor and one Xilinx Kintex UltraScale FPGA accessible by the user) is used with ADC-3117 and ADC-3111 FMC boards. The fast acquisition board ADC-3111 includes 8 channels with 16-bit/250Msps ADCs. The semi-fast acquisition board ADC-3117, whose sampling frequency is comprised between 1 and 5 Msps, has 20 channels and 2 channels DAC.

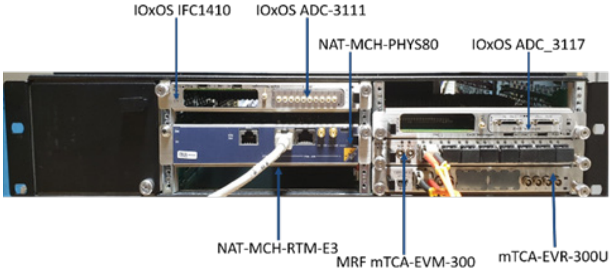

Figure 1: MTCA.4 NATIVE-R2 standardized platform.

The CEA team updated and standardized the IRFU EPICS Environment with MTCA.4 solutions based on IOxOS, MRFand NAT boards.

For the PLC domain essentially used for vacuum, cryogenics, tuning motorizations, current leads and interlocks, Siemens PLC 1500 series (CPU 1516) was selected with TIA Portal by CEA team.

Kontron Industrial PCs are also used in order to run EPICS IOCs for the communication with PLCs. This communication is based on Modbus/Tcp and S7plc.

FARADAY CUPS, ACCTS AND NBLMS

On LEBT and MEBT, this common platform including IOxOS boards is used for Faraday Cups and ACCTs intensity measurement with the IOxOS ADC-3117 board.

An acquisition based on IOxOS ADC-3111 is used for the Neutron sensitive Beam Loss Monitors (gaseous detectors) designed by CEA for SARAF. This CEA design is already used for ESS and gives entire satisfaction.

TIMING SYSTEM

The Timing System distributes trigger signals including the information for each RF pulse and manages timestamping mechanism that allows to date all the actions and events precisely. This timestamping is internally incremented and is periodically resynchronized with the Meridian II GPS by

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the PPS (Pulse Per Second) clock to avoid drifts. The Timing System also distributes the 176 MHz reference frequency coming from the Master Oscillator.

MRF solution was decided early in the project. The timing system modules used are the MRF mTCA-EVM-300 used as Event Master and the MRF mTCA-EVR-300U as Event Receiver. In addition, mTCA-EVM-300 modules are used as fan-outs and concentrators. There is one EVR in each MTCA crate and one fan-out/concentrator almost in each one.

MTCA.4 backplane lines and Timing System signals have been standardized for all the MTCA EVRs, it means LLRF, BPMs, nBLMs and ACCT/Faraday Cup acquisitions as indicated in table 1.

The SARAF timing system is detailed in [3].

Table 1: MTCA.4 Backplane Lines and Timing Signals

Backplane standardization		
Crate bus line	Trigger code	Trigger nick-name
17_1	TS1	Trigger user buffer (TUB)
17_2	TS2	Beam presence or Acquisition (RoI)
18_1	TS3_m	Signals dedicated to the protection (m = instance of LLRF, BPM …)
18_2	TS3_m	
19_1	TS3_m	
19_2	TS3_m	
20_1	TS4	RF gate
20_2	TS6	General post mortem (GPM)

LLRF SYSTEMS

LLRFs have been outsourced to Seven Solutions [4] with the duty to use the common core (NATIVE-R2, COMex-E3, PHYS80 and MRF EVR) in the purpose of homogeneity of the control architecture. Seven Solutions has designed an AMC board running 2 LLRFs and the standardized NATIVE-R2 can only include 2 LLRF AMC boards. Seven Solutions has designed, developed, manufactured and tested the system based on CEA technical specifications. The final version of this digital LLRF will be installed in the SARAF accelerator in Israel at the end of 2021.

RFQ and MEBT sections need four LLRFs, one for the RFQ and three for the 3 rebuncher cavities. In the Super Conducting Linac, there are 4 cryomodules including 6 and 7 cavities respectively for CryoModule 1 and CryoModules 2, 3 and 4. Therefore, there are 2 NATIVE-R2 crates for each cryomodule and one for the set RFQ and MEBT. Globally 31 LLRFs are needed for the SARAF Linac.

Currently, the LLRF tests give satisfaction and the MEBT RF cabinet (Figure 2) is ready for the shipment to SNRC.

Figure 2: RF cabinet with MTCA LLRF crate.

BEAM POSITION MONITORS

The beam position measurement function is spread over the linac with 24 BPMs and it is performed by analysing signals of the 4 buttons of each BPM, a total of 96 signals. The layout strategy is to group the BPMs operating at room temperature and those operating at temperatures close to 4 K degrees, respectively 4 in the MEBT and 20 in the 4 cryomodules of the superconducting linac (6 for CM1 and CM2, 4 for CM3 and CM4).

For BPMs, some requirements are very close to LLRF issues and finally the BPM control has also been outsourced to Seven Solutions.

BPM systems are included in MTCA NATIVE-R2 crate. Each one can include up to 3 BPM boards, each board handling signal analysis of 2 BPMs. Overall, the linac BPM function is ensured by 5 MTCA crates: one BPM crate for the MEBT and one crate for each cryomodule. The BPM control development is in progress.

HARPS

There are 5 Harps in the MEBT and SCL.The Harps and their electronics are outsourced to the Proactive company. They don't have an MTCA solution but only a VME solution. The VME will house 16 digitizer cards that will communicate with an EPICS standardized Kontron IPC through a USB hub. This IPC will include a PCIe-EVR 300DC for integration in the MRF Timing System network. This EVR300 is connected through a microSPCI card to an IFB300 box that delivers up to 16 TTL signals. See Figure 3.

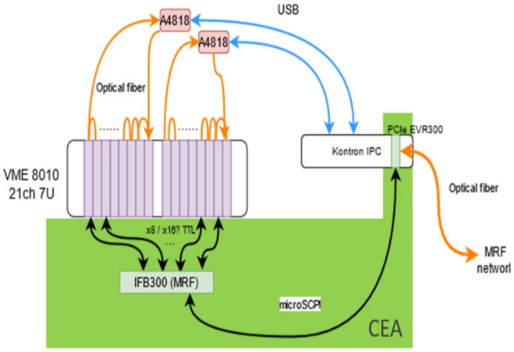

Figure 3: Harps control based on VME, Kontron IPC and MRF.

MEBT QUADRUPOLES, STEERERS AND SCL SUPERCONDUCTING MAGNETS

Different CAENels power supplies were chosen for all these magnets. There are 8 quadrupoles and steerers in the MEBT and 20 superconducting solenoid in the SCL. For the CAENels power supplies, the EPICS control is based on streamdevice and TCP/IP communication. Interlocks are managed by PLC. This control was installed at SNRC in 2020 for the MEBT.

CONTROL OF THE 4 CRYOMODULES

The SARAF Super Conducting Linac offers four CryoModules (CM) including 6 cavities for CM1 and 7 cavities for CM2, CM3 and CM4 and 20 superconducting solenoids (6 solenoids for CM1 and CM2 and 4 for CM3 and CM4). Each cryomodule can be divided into four control type applications: cryogenics, vacuum, solenoid current lead and LLRF cold tuning system.

One PLC CPU manages every sensor, actuator and automatic processes through the remote input-output cards and also the communication protocols (TCP-IP or Modbus) and fieldbuses like Profinet and Profibus DP.

The field network Profinet is essentially used to control cryogenic temperatures, remote input-output channels, motorizations based on Phymotions [5] and Festo devices for pneumatic valves. Profibus DP is mainly used for vacuum controls (turbopump controllers and total pressure gauges TPG300 controllers).

This control architecture based on only one PLC CPU per cryomodule is duplicated for each one of the four cryomodules for homogeneity purpose but also to simplify the communication with the SOREQ helium liquefier.

Each cryomodule PLC will have to deal with data of the SNRC local liquefier and this will be done via one PLC interface that will be the unique communication partner of the Air Liquide liquefier PLC.

For each cryomodule, a Kontron Industrial PC is running an EPICS IOC that enables the communication between the PLC CPU with any other EPICS IOC of the architecture (Figure 4).

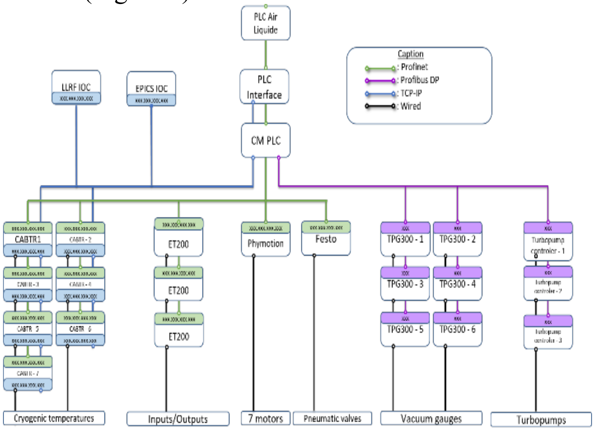

Figure 4: Architecture template for 1 of the 4 CryoModules.

SARAF EPICS ENVIRONMENT

Irfu EPICS Environment

The SARAF project uses the Irfu EPICS Environment (IEE) to deploy a homogenous and versioned EPICS environment. As detailed in a previous publication [6] the IEE relies mainly on the following aspects: a centralized EPICS installation is available from an NFS server; CPU devices use stateless network boot to load the same generic root file system; virtual machines (VM) are used for robustness and eased sharing; Ansible scripts under continuous integration enable to provision and update the IEE server and client machines. See Figure 5.

IEE Ansible Scripts

IEE Ansible scripts were delivered in December 2020 and used successfully on premises at SNRC to provision the current production IEE server. The main difficulty has been that the accelerator network is not connected to the Internet, this was solved by provisioning the IEE server on another network before moving it to the production network through a cybersecurity check. This could be improved in the future by deploying a Yum repository server on the premises. Similarly, this lack of internet made the delivery of git packages more complicated, but also because the CEA Gitlab instance is not open to non-CEA users, this has been solved by setting up a continuous delivery pipeline to duplicate and keep updated the appropriate repositories on a shared Bitbucket-cloud instance. This bitbucket instance is then copied locally at SNRC onto the secured network.

Running Ansible

Running Ansible scripts is not the only way used to distribute the IEE environment. To sum up, in practice only system administrators use the scripts: either to provision the production environment within virtual containers (CT) in Proxmox or Nutanix clusters, and also to provision “ready-to-use” VM for use with VirtualBox. These VMs are for instance shared with subcontractors to ensure the compatibility of their developments to the IEE, or by developers that need to have a working environment disconnected from the IEE server. VMs are also provided for acceptance tests, this way new hardware and software can be validated before being fully integrated into the production network. All these VMs provide the feature of an IEE server (local EPICS environment and if needed boot server) as well as an IEE DevEnv machine (users, CSS, VSCode [7]…). They are produced by running the same Ansible playbook that can configure either IEE servers or IEE DevEnv.

Unlike CTs running on a cluster, which are provisioned using an orchestration machine to run the Ansible playbook, on VM this playbook is executed locally (after installing Ansible on the VM later on). Therefore, the scripts are still available to update the VM easily. This is particularly useful when the VM is also used as a boot server.

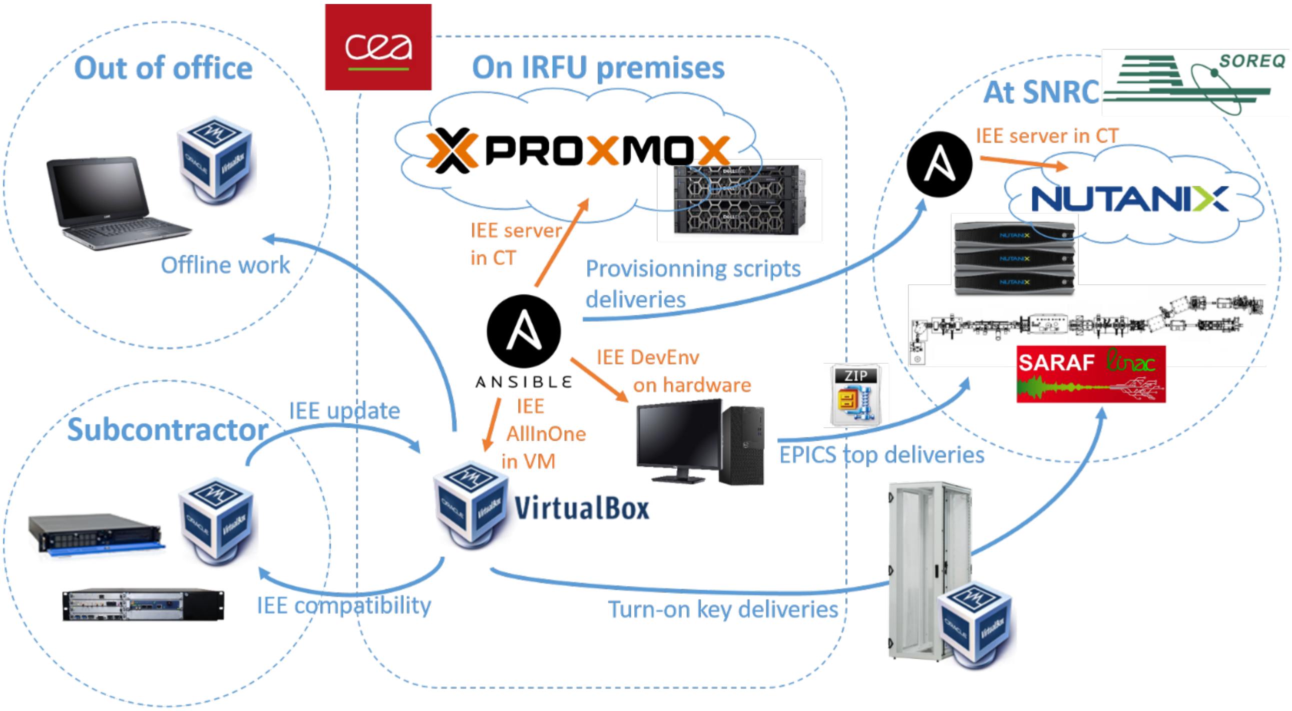

Figure 5: CEA and SARAF EPICS environment.

Improvements

However, the ability to use the Ansible scripts to update, rather than configure a machine from scratch, has only been improved recently. This combined with the need to provision the machine on a separate network before moving it to the secured network, has made it such that producing a new IEE Server, was not fast enough to follow the delivery rate of developers. Therefore, bug fixes and major feature request of EPICS development are delivered by sending a top composed of git submodules.

Prospects

Another drawback of Ansible scripts is that integrating new functionalities can be very time consuming, even if this change is anecdotal when performed manually. Automating is often costing when it must be done properly (researched, implemented, tested and CI maintenance). For this reason, outsourced developments have a pretty loose constraint on what it means to be compatible with the IEE environment. In the end it mainly involves using stateless network boot, and using a predefined NFS mount to export data. The EPICS version is fixed, and a naming must be followed. But cross-compilation tools and code source are not required to be integrated to the IEE Server unlike for CEA developments.

CONCLUSION

The SARAF Linac control includes many new technologies as described herein that are very motivating for SNRC and CEA control teams. Furthermore, the relationship is very good between the two teams. The Injector and MEBT are already located at SNRC and the control tests are in finalization or in progress depending on the devices.

During the coming months, the CryoModule 1 will be tested on the CryoModule Test Stand at Saclay. Then, the four Super Conducting Linac cryomodules including cavities and solenoids will be shipped from CEA Saclay to SNRC during 2022.

ISBN: 978-3-95450-221-9 ISSN: 2226-0358 doi:10.18429/JACoW-ICALEPCS2021-MOPV001

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