CONTROLS INTERFACE INTO THE LOW-LEVEL RF SYSTEM IN THE ARIEL e-LINAC AT TRIUMF

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Abstract

Phase I of TRIUMF Advanced Rare Isotope Laboratory (ARIEL) was completed in September 2014. At phase I, the Low-Level RF (LLRF) system of ARIEL's electron linear accelerator (e-Linac) consists of a buncher and a deflector, one single-cavity injector cryomodule and the first cavity of two dual-cavity accelerating cryomodules. The model for the e-Linac LLRF system is largely based on the experience gained from the fully-commissioned TRIUMF ISAC-II linear accelerator (linac). Similarly, the EPICS-based Controls for the e-Linac LLRF builds on the lessons learned with the linac LLRF Controls. This paper describes the interface between the ARIEL Control System (ACS) and the e-Linac LLRF using EPICS ASYN/StreamDevice and a SCPI-like protocol. Also discussed are the ACS EDM displays and future plans for LLRF Controls.

INTRODUCTION

The Advanced Rare Isotope Laboratory (ARIEL) is the latest project in the Rare Isotope Beam (RIB) program at TRIUMF. In conjunction with ISAC and ISAC-II, ARIEL is designed to triple RIB production and expand the range of exotic isotopes "for Nuclear Physics and Astrophysics, Nuclear Medicine and Materials Science" [1].

In September 2014, phase I of ARIEL was completed with the delivery of a 300KeV DC thermionic gun, a buncher and a deflector, a single-cavity injector cryomodule (ICM), and the first cavity of a dual-cavity accelerating cryomodule (ACM). These components constitute the first half of ARIEL's superconducting electron linear accelerator (e-Linac). The second half of the e-Linac is presently under way and comprises the second cavity of the first ACM, and a second dual-cavity ACM, for a total of five cavities in three superconducting cryomodules.

The design of the Low-Level RF (LLRF) system for ARIEL's e-Linac borrowed extensively from the model used in ISAC-II superconducting linear accelerator (linac) [2] – TRIUMF's first fully-commissioned linac. It was natural then, that the new ARIEL Control System (ACS) interface into the e-Linac LLRF also followed the model used in ISAC-II linac Controls. However, as in any new project, LLRF Controls of ARIEL's e-Linac presented an opportunity to improve on some of the unexpected drawbacks encountered in ISAC-II Controls.

INTERFACE

LLRF-ACS Interface

The overall framework used in ISAC-II LLRF Controls has been carried over into the LLRF-ACS interface. At one end, the LLRF system exchanges information with Controls via an EPICS IOC. At the other end, the IOC makes LLRF data available to EPICS clients in the form of process variables (PV). While this model has worked well at TRIUMF, the way it was implemented in ISAC-II LLRF Controls uncovered some drawbacks that were addressed in the LLRF-ACS interface.

In ISAC-II, the LLRF system interfaced with the Controls EPICS IOC using a shared memory model [3]. The implementation of this method brought in a number of firm constraints. First, inter-process communication via shared memory implies a high degree of coupling. The LLRF system and ISAC-II Controls had to adhere to a strict memory mapping scheme, was not very portable, and carried a moderate amount of complexity to maintain.

Another implication on the use of shared memory is that the IOC needs to run in the same LLRF system computer. The host machine is owned and maintained by the LLRF group. For simplicity and security reasons, LLRF computers are stand-alone machines and are not connected to the site's network. If Controls wanted to perform diagnosis or maintenance of the IOC it was necessary to inconvenience the LLRF group for physical access to the host computer. Even simple actions like viewing IOC log messages or machine crash dumps required local access to the machine.

Furthermore, the IOC had to be built to run on Microsoft Windows. But Controls have had limited experience developing for the Windows environment. Only one Controls programmer gained enough knowledge to build a heavily-customized Windows IOC based on the EPICS Portable Channel Access Server framework and make available to LLRF engineers a C++ API to read/write the shared memory. Plus, the programming was done in Visual Studio and involved the use of WIN32 DLLs [4], these development tools were also unfamiliar to Controls.

During the early stages of ARIEL phase I an alternative implementation for the LLRF-ACS interface was put forward. After some consultation with the relevant groups one of the main conclusions was to not proceed with the shared memory model. Instead, the ACS would use the EPICS ASYN/StreamDevice method of communication with LLRF. The Controls group is familiar with

ISBN 978-3-95450-148-9

ASYN/StreamDevice. It has been used in previous occasions to interface with various kinds of peripheral equipment at TRIUMF so the knowledge and experience is well spread among Controls personnel.

In addition, the decision to not use shared memory gave Controls more freedom to choose where to run the EPICS IOC. Whereas in ISAC-II the Controls IOC was required to be hosted in the LLRF system computer, in ARIEL the IOC moved into a computer in the ACS domain. This setup gives Controls personnel freer access, without unnecessary inconvenience to LLRF staff, to peruse the logs and system messages for diagnosis, maintenance, and updates. Not to mention that there is a clearer separation of responsibilities. For example, in ISAC-II, the LLRF group was responsible for updating the Controls IOC database. Not so in ARIEL where the IOC database is out of the hands of LLRF and into ACS.

Another benefit of hosting on an ACS computer is that the EPICS IOC runs on a Linux machine. Controls have ample expertise on Linux - the standard operating system in the group [5]. And Controls is also very familiar with building, maintaining, and debugging EPICS IOCs on Linux. The additional knowledge in Windows shared memory, Visual Studio, or WIN32 DLLs is no longer required.

For its part, the ARIEL LLRF group committed to building a server application to respond to commands and queries from the ACS over a network connection. To preserve the security of LLRF computers, the ACS connection is done over a private network, shielded from the outside world. The LLRF system and ACS agreed to follow the guidelines for Standard Commands for Programmable Instruments (SCPI) for the structure of commands and queries [6]. However, our model does not fully adhere to the complete SCPI (pronounced "skippy") specification. The intention was not to degrade the standard but to make it as simple as possible to meet our needs at the time. For example, the SCPI specification for command concatenation was deemed unnecessary and thus, not implemented. Similarly, command abbreviation was also not implemented. The set of allowed SCPI-like commands and queries was documented in a table on an internal TRIUMF web page [7] to facilitate separate implementations in both groups. Figure 1 shows the various protocols used and the separation of responsibilities in the model for the LLRF-ACS interface.

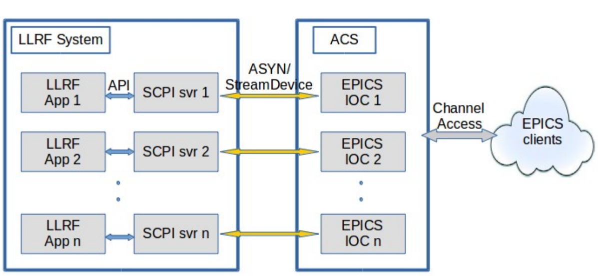

Figure 1: LLRF-ACS Interface.

Controls GUI

The ACS graphical displays did not see any major changes from those used in ISAC-I and ISAC-II Controls. In fact, the idea was to borrow or re-use as much as possible from earlier projects [5]. Development of the displays was done using the EPICS Extensible Display Manager (EDM). Colour schemes, size of objects, fonts, etc. followed the same established site guidelines. To preserve the same look-and-feel of ISAC-I and ISAC-II displays the placement of buttons, sliders, labels, etc. was also emulated in the ACS. Figure 2 shows a screenshot of the display for the e-Linac ICM LLRF Controls. Figure 3 shows the expert display, which is used mainly by the LLRF group for more detailed diagnostics.

Figure 2: ACS Display of the ICM LLRF.

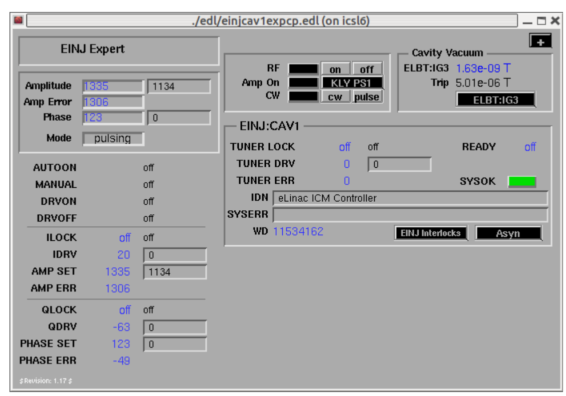

Figure 3: ACS Expert Display of the ICM LLRF.

One notable feature is the addition of a delay on fast, successive commands. In ISAC-II, there were cases when operating on an EDM slider object made the LLRF system unresponsive to remote commands and only a reboot of the LLRF computer would fix it. So far, this issue has not been resolved but we speculate that the fast storm of setpoint commands from the slider overwhelmed the LLRF system and sent it into a funny state. In the ACS, the IOC communicates changes in setpoint values to the LLRF SCPI server at 500ms intervals. Changes in setpoints in between this period are discarded. In other words, the IOC throttles the number of commands to

ISBN 978-3-95450-148-9

change setpoints to avoid overwhelming the SCPI server. Granted, this feature is implemented at the IOC level but it directly addresses a potential issue with the setpoint objects of the ACS displays.

FUTURE PLANS

After the implementation of the LLRF-ACS interface was completed in ARIEL phase I, the Operations group anticipated that the improvements would be backfitted to earlier projects. As of this writing, a retrofit of ISAC-II LLRF Controls is being commissioned. The changes have been transparent to Operations because the bulk of the modifications is at the IOC-LLRF interface level, whereas EPICS displays remain largely unchanged. It is hoped that issues like the slider control problem will not re-appear. There are also plans to apply these improvements to ISAC-I LLRF Controls.

It is also worth noting that the shared memory model was applied, to a minor degree, in specific sub-systems in the Laser Control System and Beam Diagnostics System [3]. There are plans to retrofit these sub-systems too but due to constraints in time and resources this may not occur in the immediate future.

SUMMARY

The model for ARIEL's LLRF-ACS interface is heavily based on the design of ISAC-II LLRF Controls. Although the overall framework is maintained, there are notable improvements from an implementation point of view. The decision to replace the shared memory model with ASYN/StreamDevice interface reduced the number of restrictive implementation constraints and allowed for a clearer division of responsibilities. As for the ACS GUI displays, the same guidelines and same look-and-feel of earlier projects were closely followed. ISAC-II operators would be hard pressed to notice much difference in the ACS displays from what they are used to seeing.

In conclusion, the improvements to the LLRF-ACS interface described in this paper have been well received and so far there are no major issues to contend. In fact, there are plans to apply these changes to existing Controls-related projects where the shared memory model is still in use.

ACKNOWLEDGEMENT

The authors would like to acknowledge the contribution of time and expertise from the SRF/RF group: Ken Fong, Mike Laverty for unraveling the requirements for LLRF Controls. Philipp Kolb, Zhongyuan Yao, Qiwen Zheng for spending endless hours testing the Controls interface.

Also, many thanks to all members of the Controls group for their support and guidance. In particular, Shawn Rapaz for helping setup the Controls hardware and Evgeniy Tikhomolov for sharing his experience of ISAC-II LLRF Controls development.

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ISBN 978-3-95450-148-9