

STANDARDIZING MicroTCA INTEGRATION INTO THE TANGO CONTROL SYSTEM VIA ChimeraTK AND OPC UA AT SOLEIL

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Abstract

Twenty years ago, standard electronic systems such as cPCI, motion controllers, and the S7300 PLC were chosen to build the SOLEIL control system. Although fully operational since 2006, many of these technologies are now obsolete. As SOLEIL undergoes a major upgrade with the SOLEIL II project—aimed at constructing a 4th-generation synchrotron light source—modernizing the control system with state-of-the-art technologies has become essential. SOLEIL has adopted the MicroTCA (MTCA) platform as one of the new standard baselines for applications requiring high-speed control and data acquisition.

This poster presents ongoing efforts to standardize the integration of MicroTCA systems and applications into the TANGO control system. It outlines SOLEIL's MTCA integration strategy, including the development of a connector bridging TANGO to the ChimeraTK and FPGA framework (FWK) developed at DESY via OPC UA. This communication layer facilitates interoperability and modular integration within the SOLEIL control architecture. The approach is illustrated through two current MTCA-based projects—low-level Radio Frequency (LLRF) and fast orbit feedback (FOFB)—highlighting technology choices, system development, installation, and preliminary results.

INTRODUCTION

The SOLEIL [1] facility is currently upgrading its accelerators to the fourth generation of synchrotron light sources. As part of this transition, existing beamlines will be adapted or relocated to align with the new accelerator lattice. This ambitious project, known as SOLEIL II, aims to deliver exceptional performance through a redesigned beam lattice, renewed systems, and state-of-the-art technologies.

SOLEIL II [2] will enable experiments that are up to 10,000 times faster, 1,000 times more sensitive, and capable of achieving nanometer-scale resolution. These enhanced capabilities will make a significant contribution to tackling major societal challenges in areas such as advanced materials research, energy and sustainable development, health and well-being, and environmental protection.

To achieve the precise timing, low latency, and robust architecture required for such a high-performance system, SOLEIL II demands a new generation of electronics. These systems must support complex instrumentation, including beam diagnostics, feedback mechanisms, and experiment control. As part of its control and data acquisition strategy [3], SOLEIL has decided to transition from the legacy cPCI

system to FPGA-based solutions, selecting the appropriate approach based on the required processing resources.

The two main hardware platforms selected for this transition are MicroTCA and PandABox, as illustrated in Fig. 1.

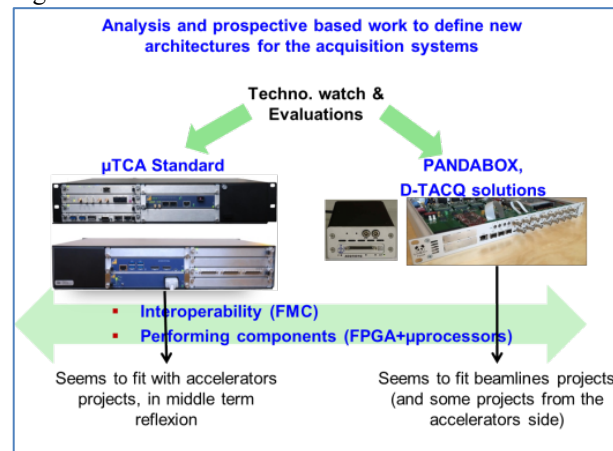


Figure 1: The two main hardware platforms evaluated for replacing the cPCI system.

MTCA is well-suited for synchrotron applications due to its high reliability, modularity, and support for high-speed data acquisition and control. The MTCA chassis accommodates a range of specialized modules, including:

- CPU/controller boards running real-time control software
- FPGA carrier boards for low-latency signal processing
- High-resolution ADC/DAC cards for precise analog-to-digital conversion and actuator control
- Timing and synchronization modules for accurate signal distribution across the accelerator
- Trigger and event receiver cards for coordinated data acquisition

This ecosystem offers a scalable and interoperable solution that meets the demanding requirements of SOLEIL II.

In line with its standardization strategy, SOLEIL has chosen MTCA as the main hardware platform for control and data acquisition. A critical aspect of this effort is integrating MTCA into the Tango Control System (CS) in a standardized and sustainable manner.

This standardization effort considers the scalability, flexibility, and reliability of the platform in terms of Gateway, Firmware, and Software. As illustrated in Fig. 2, SOLEIL has selected the FWK and ChimeraTK frameworks, developed at DESY [3], as flexible architectural solutions for

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embedded processing and connectivity in control and acquisition systems using the MicroTCA platform.

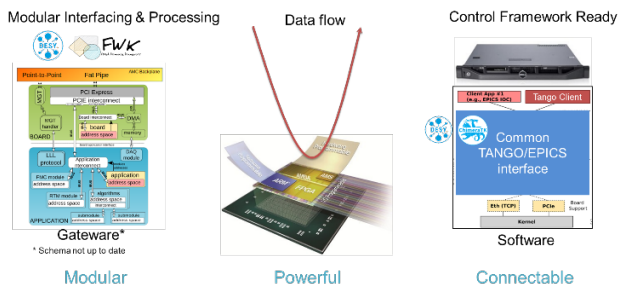


Figure 2 : Generic framework approach.

TANGO CS INTEGRATION

SOLEIL is standardizing its FPGA framework to provide a unified software base to all FPGA developers and facilitate the integration of diverse applications into the TANGO control system. To achieve this, SOLEIL has selected FWK, an open-source FPGA firmware framework developed by DESY, which is used not only for machine control but also for other applications.

FWK significantly simplifies the FPGA development process by providing:

- A standardized project structure
- Automated build flows
- A unified build environment compatible with synthesis tools from different FPGA vendors
- Board Support Packages (BSPs)
- A library of reusable IP blocks

In addition, the framework automatically generates a detailed register map file, including register names, addresses, and descriptions of the data transported through those registers. This greatly aids in firmware/software integration and system documentation.

Also developed by DESY, ChimeraTK is a software framework designed to facilitate the development of control applications. It offers a unified interface to access FPGA and MTCA hardware via the FWK-generated register map. With robust hardware abstraction capabilities and support for standard communication protocols, ChimeraTK can be easily integrated into various control system architectures.

In collaboration with DESY, SOLEIL has developed a new ChimeraTK adapter to support user applications within the TANGO control system. This adapter allows automatic generation of Tango device classes and enables real-time updates of process variables (register values) as Tango attributes. The resulting Tango device can run either:

- Directly on the embedded Linux OS of the MTCA system, or
- On an external server connected to the MTCA via PCIe Endpoint

ChimeraTK's generic device interface supports not only the Tango control adapter but also other adapters, enabling integration with various control systems. Among these, the

OPC UA adapter is also being evaluated as a candidate for communication between MTCA and Tango.

In summary, SOLEIL has identified three main configurations for integrating MTCA-based systems into the Tango control system:

1. Tango device running directly on MTCA embedded Linux
2. Tango device hosted on an external server via PCIe connection
3. Integration via OPC UA control adapter

Onboard Tango Device

A Tango device with its application can be created and run onboard. The Tango control system can connect to onboard device by ethernet. Developer can create a Yocto layer to compile and run this device on embedded linux of MTCA. In this configuration, developers need to maintain the ChimeraTK and Tango layer.

Tango Device on Control System Network

A Tango device built with ChimeraTK Tango controller adapter uses PCIe backend to read and write register on the FPGA. This configuration requires managing the version of register map used for embedded linux and for the control system server. A limitation had not been solved while using an PCIe-over-cable to connect to PCI endpoint, once the FPGA is reprogrammed, it is necessary to reboot the CPU AMC to recognize the FPGA card as an endpoint device.

Onboard OPCUA Server

The OPCUA server automatically maps the hardware register map to OPCUA nodes. It uses the register map file for the specific configuration of the FPGA and UIO backend to read/write registers on the FPGA.

The OPCUA client or a Tango device named OPCUA Proxy can subscribe to data change on server side and show them as attributes. IHM or Tango device server can connect on the top of this device. OPCUAProxy has been used at SOLEIL in communication with PLC.

The advantage of this configuration is that OPCUA server is already included on ChimeraTK layer of Yocto [4–6]. OPCUA server will be compiled, installed automatically and ready to use so this significantly reduces development time and complexity. The limit is that there is no application except the data reading/writing.

Among these three configurations, up to now, SOLEIL decided to use the OPCUA standard for control of FOFB system and therefore LLRF system.

FOFB APPLICATION

The FOFB is at the interconnection with the storage ring Beam Position Monitors Electronic and Power Supply units of the Correctors, all scattered around the synchrotron building. FOFB system strongly depends on the machine layout, stabilization strategy and boundary system.

For SOLEIL, the main part of the FOFB system had been embedded in the FPGA located inside Beam Position Monitor Electronic (eBPM). For SOLEIL II, a new architecture

has been designed to be more modular, scalable and compatible with the legacy system.

The SOLEIL circular topology has been replaced by a star topology [7]: each eBPMs module sends beam position data to its dedicated cellnode (Fig. 3). Each cellnode aggregates the beam position data of a set of eBPM and sends it to the central node. The central node collects the beam position data from the cellnode, computes the corrector setpoints for correction magnet power supplies, and sends these setpoint to the cellnodes. The cellnode distributes the setpoints to a set of Magnet Power Supply units.

The cellnode and centralnode are based on the same Micro TCA hardware platform: a mother board CaenELS DAMC-FMC2ZUP equipped with up to 2 CaenELS 4SFP+ FMC boards. The cellnode are also equipped with in-house designed RTM board for serial communication with the Power Supply units.

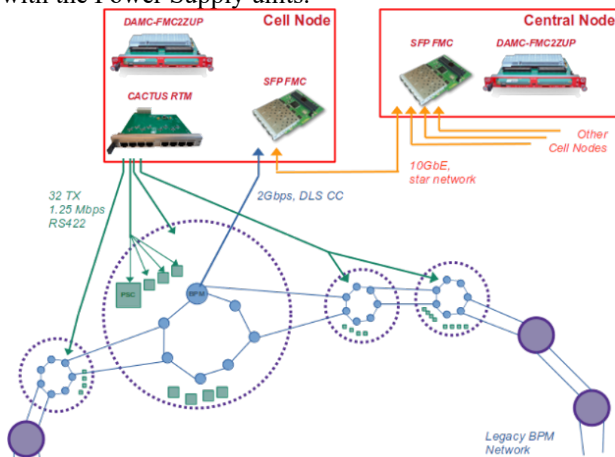


Figure 3: FOFB network topology.

The FPGA is based on the FWK firmware framework. The ZynqUltraScale+ provides a CPU which is running a Linux distribution built by Yocto. Regular operation can be performed: SSH connection, NFS mount, configuration scripting, logging, etc.

Control command interface between the FPGA registers and the Tango world is done via OPCUA as communication standard (Fig. 4).

ChimeraTK generic device built with OPCUA Control adapter works as a server and push event to an OPCUA client which is a Tango Device. Two other devices on the top of OPCUA client are used for control and data viewing: FOFBCommand and FOFBWatcher.

The new FOFB platform based on MTCA was installed at SOLEIL and has reached the actual performances.

LLRF

SOLEIL II aims at designing and operating a machine whose main organ will be a new Storage Ring (SR) based on a Multi-Bend Achromat lattice to achieve much higher average spectral brilliance, coherent and nano-focused flux while maintaining the broad spectrum of photons ranging from the far infrared to hard X-rays.

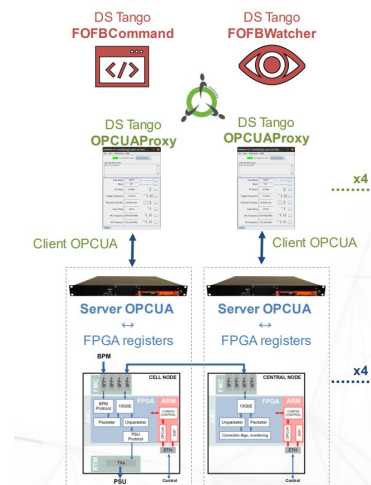


Figure 4: Integration of FOFB to Tango Control.

The new SR will essentially rely on two RF systems:

- A fundamental system at 352 MHz with four cavities, which will provide the RF voltage and power necessary for an adequate electron beam energy acceptance and compensation of its energy loss per turn.
- A harmonic system with three cavities, at 4 times 352 MHz, aimed at lengthening the bunches up to about 100 ps FWHM to preserve the low emittance and insure a suitable beam lifetime. One of the three cavities will be detuned to be spare.

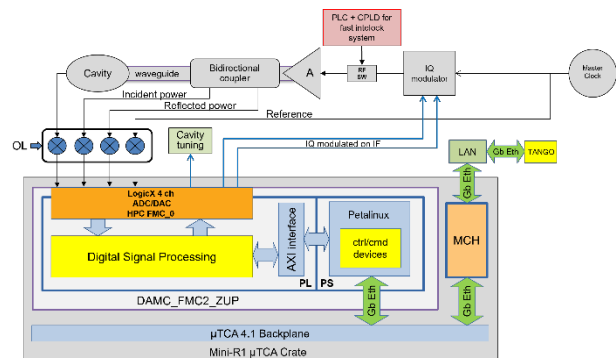


Figure 5: LLRF system architecture and interface.

A MTCA.4 system is used to control the LLRF at SOLEIL (Fig. 5). We use a Mini-R1 μ TCA platform, MCH-PHYS8 with DAMC-FMC2ZUP and one FMC LX31K4-DC 4 channel 16-bit ADC/DAC.

For one cavity, the DLLRF:

- Gets 4 analog input signals (incident power, reflected power, cavity signal, RF clock)
- Drives the cavity tuner
- Controls the "IQ" modulator through the RF amplifier in order to maintain constantly the RF accelerating field in the cavity

To ensure consistency, maintainability across applications, and efficient collaboration between developers, the RF group has adopted the framework (FWK) previously validated by the FOFB project. By aligning both projects around the same FWK framework, the Yocto project could

be reused, with only the FOFB-specific developments replaced by the new RF FPGA application.

In order to integrate the DLLRF application in the control system, a similar OPC UA communication like for the FOFB has been implemented including a Tango device, OPCUAProxy which communicates with the embedded OPC UA server (ChimeraTK generic device). A new RF Human-Machine Interface (HMI) for RF control will be developed to interface with the Tango device.

The gateway tests, performed using a dedicated Python-based software to configure it, were successfully validated on the SOLEIL cavity with stored beam. The results were highly successful: the closed-loop accuracy achieved was $3 \times 10^{-4} / 2.4 \times 10^{-20}$ RMS, with a loop gain of 18.

The phase noise of the cavity pickup signal was measured directly using a Rohde & Schwarz [8] FSUP analyzer equipped with the B60 option, yielding a result of 0.06 ps, which is comparable to the existing analog system. Additionally, the tuner was successfully tested on the beam.

CONCLUSION

The combined utilization of MTCA, FWK, and ChimeraTK, OPCUA offers a powerful, scalable, and maintainable infrastructure for control and data acquisition systems in synchrotron facilities. MTCA provides a robust hardware platform designed for high-performance and modular applications, ideal for the demanding requirements of accelerator environments. FWK complements this by streamlining FPGA development through standardized project structures, automated build processes, and reliable address space management. On the software side, ChimeraTK bridges the gap between firmware and control systems, enabling seamless integration with our Tango platform while offering flexible, high-level access to complex hardware. Together, these technologies support a cohesive workflow from low-level hardware design to high-

level control and monitoring, ensuring long-term maintainability, interoperability, and efficient operation of modern synchrotron systems.

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