# DEVICE CONTROL AT CEBAF*

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CEBAF has undergone a major conversion of its accelerator control system from TACL to EPICS, affecting device control for the RF system, magnets, the machine protection system, the vacuum and valves, and the diagnostic systems including beam position monitors (BPMs), harps, and the camera and solenoid devices (beam viewers, faraday cups, optical transition radiation viewers, synchrotron radiation monitor, etc.). Altogether these devices require approximately 125,000 EPICS database records. The majority of these devices are controlled through CAMAC; some use embedded microprocessors (RF and magnets), and newer interfaces are in VME. The standard EPICS toolkit was extended to include a driver for CAMAC which supports dual processors on one serial highway, custom database records for magnets and BPMs, and custom data acquisition tasks for the BPMs.

## I. Differences Between TACL and EPICS

The systematic differences between TACL and EPICS have been well-documented, see [1 & 2]. From the standpoint of the low-level application developers at CEBAF involved in the conversion of the control system, a few key differences stand out.

### *A. Hardware Control*

In TACL, control algorithms were stored as elements in a logic grid where different subsystems were distinguished by location in the grid. This inhibited independent development because only one subsystem at a time could access the grid to work on its control algorithm. In EPICS, the control algorithms are stored in independent databases which are not combined until the system is loaded onto the input-output controller (ioc).

Another difference is the frequency with which logic elements or database records are processed. Because TACL ran on UNIX machines, processing frequency was non-deterministic. EPICS runs on processors which use a real-time kernel, therefore the rate at which EPICS database records are processed is deterministic.

In TACL the logic grid was processed sequentially from left-to-right and cycled at a rate determined by the size of the logic grid and the speed of the processor. EPICS has a greater variety of execution options including differential scan rates, passive processing (records process only when triggered by another record), and software and hardware event-triggered processing. EPICS also provides a tool which makes it easy to set up finite state machines (sequencers) which give a finer degree of control over how database records are processed.

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In TACL, predefined defaults could be set for signals coming from a remote computer when communication between two computers was lost. In EPICS, signals retain the last known value before communication was lost.

TACL provided predefined logical operators like OR, AND, NAND, and inverter as well mathematical operators including transcendental functions. TACL also provided digital logic elements such as Flip Flops, multiplexers/demultiplexers, comparators, and words-to-bits, bits-to-words convertors. The number of inputs and outputs for these elements could be easily set by the application developer. EPICS does not provide these operators in a pre-defined manner. It is not easy in EPICS to expand the number of inputs and outputs to a database record.

### *B. Operator Interface*

The operator interface (OPI) portion of the control system in EPICS is fully integrated into the XWindows system while the TACL OPI was built using a proprietary graphics system that ran only on HP workstations. One impact is that in TACL, the OPI was limited to a single window per workstation while in EPICS the OPI can display multiple windows. In TACL, display screens tended to contain a lot of information and became very crowded. In EPICS, it is possible to modularize the information presented to operators which makes it easier to focus on a specific task.

The EPICS OPI does not have the same concept of a push-button as did TACL. In TACL it was possible to tie two signals to a single push-button so that the operator could set one signal and read back the results on a separate signal. In EPICS, push-buttons are tied to a single signal only. Also, the TACL OPI had a predefined symbol that interacted with the word-to-bits and bits-to-words logic element which would allow an operator to set and/or monitor individual bits. A pair of word-to-bits and bits-to-words records were added to EPICS at CEBAF early in the conversion process but a matching symbol was not added to the OPI until much later. Even now, it is not easy to set individual bits from the OPI in EPICS.

## II. Conversion From TACL to EPICS

### *C. RF Prototype and CAMAC Driver*

The first system to be converted was the RF system which supplies the power needed to accelerate the beam. The RF system is distributed across 350 modules and each module is controlled by a microprocessor. The microprocessors communicate to the control system via CAMAC buffer cards. Some additional control and monitoring functions are provided by CAMAC cards which are not integrated into the microprocessor system.

In TACL, the CAMAC interface to the control system was via GPIB into the HP computers. In EPICS the CAMAC interface goes through a HYTEC VSD 2992 Serial Highway Link Driver via the VME bus into the ioc. Initially EPICS did not possess drivers for CAMAC that were useful for CEBAF. Nor were drivers available to handle I/O to the RF microprocessors through the CAMAC buffer card. But due to the open architecture philosophy of EPICS it was possible to extend the EPICS toolkit to include drivers for standard CAMAC devices and a special driver to handle the buffered information to and from the RF microprocessors. The CAMAC driver also includes support for multiple processors on one serial highway, a feature which was not previously available in EPICS.

A parallel effort to the development of driver support was the conversion of the RF application from TACL to EPICS. The method used was to directly translate the TACL logic array, user processes and user functions, and state machine into EPICS database records, subroutine records and state machines. For the most part, the missing logic functions (logic gates, boolean operators, etc.) could be replaced with EPICS calculation and subroutine records. It was necessary to add two records to the standard EPICS library: bits-to-words and words-to-bits. TACL user functions and processes could be translated directly using standard EPICS records.

Translating the RF state machine proved to be slightly more difficult because the TACL version relied on the cyclical nature of execution of the logic grid and on the locations of some sets of logic elements relative to other sets in the logic grid, i.e., it was guaranteed that certain logic elements would process before other logic elements. In EPICS, the application developer has more flexibility to control the flow of processing but also more responsibility to make sure database records get processed in the correct order and at the correct time.

On the whole the conversion for the RF system went extremely well. It took the RF prototype team 3 months to produce a useable RF control system in EPICS. The major problems were the slow learning curve and the lack of novice oriented documentation for EPICS. Expert assistance from Los Alamos aided the prototype effort and allowed the CEBAF programmers on the prototype team to gain enough experience with the system to help others in the next phase of the conversion.

*D. Vacuum and Valves and Harps*

Once the CAMAC driver and device support were added to EPICS most low-level applications could be converted using only the available features of the standard EPICS toolkit. The simplest systems to convert were the beamline vacuum and valves and harps. The vacuum and valve system measures the vacuum in the beamline and provides control for valves which shut off sections of the beamline if contaminants are detected. The harps are diagnostic beam profile wire scanners. The conversion strategy for these systems was to take the existing TACL logic sets and find corresponding EPICS records. The vacuum and valve systems in TACL made heavy use of the JK Flip Flop logic element which has no matching record in EPICS. It turned out to be easy to model the behavior of this logic element with an EPICS subroutine record. The harps required the addition of a sequencer to replace a TACL user function used to control a stepper motor. The first operational tests for these applications were completed within 3 months of the initial testing of the RF prototype.

*E. Machine Protection System*

The machine protection system (MPS) is used to detect and prevent operating conditions which are potentially dangerous to the accelerator due to beam power and/or beam loss. The MPS control software allows operators to determine the status of all the MPS elements in the accelerator at a glance as well as the ability to enter high voltage set points and read back voltages and currents. The first conversion of this system was operational within two months of first operations with the RF prototype. Again the conversion strategy was a direct translation from TACL to EPICS. Later iterations of this system preserved the functionality but took advantage of EPICS features that did not exist in TACL (such as differential scan rates). Future releases of EPICS will also permit security so that only operators in the control room can change selected parameters.

*F. Solenoid and Camera Devices*

The solenoid and camera system consists of solenoid driven devices such as faraday cups and retractable slits, solenoid and camera devices, mainly beam viewers, and some remote video monitoring devices, like experimental hall target chamber video. A single button selection of any one of these devices performs all functions for that device. For example, beam viewers cannot sustain high average beam currents without shattering, so the viewer control system must make sure that the thermionic gun parameters are lowered prior to insertion of a viewer. Some viewers are positioned such that they share the same physical location in the beamline as other devices so the viewer control software must make sure that these devices are retracted before a viewer is inserted. Also, since several viewers are connected to a single camera via a switcher only one can be viewed at a time. The software must retract a viewer which is currently inserted if another viewer is requested.

These systems are fairly simple as far as the hardware interface is concerned. One device has at most two limit switch readbacks, one solenoid control, and one camera control. All of these control points can be manipulated using standard EPICS records. The complexity of this system comes from the single button interface and the interfaces between other systems. In particular, it was possible to implement the mutual exclusion requirement very easily in TACL using logic gates with expandable numbers of inputs and outputs and a very simple user function. In order to duplicate this functionality in EPICS a fairly complex sequencer program had to be written.

*G. Magnets*

The CEBAF accelerator uses over 2000 magnets of various types. The use of EPICS allowed features to be incorporated in the control software that were not easily available under TACL. One of these features is the ability to write to hardware only on request, which limits the possibility of writing noise to magnets causing them to go off hysteresis. Other features are: selectable control modes to track setpoint commands and initiate hysteresis cycling in the event that a setpoint command would violate the hysteresis curve; ability to control magnets by current or by field; control of the rate at which the current is requested to change; ability to maintain a constant field in magnets while doing maintenance in local mode.

It was not pratical to implement all of these features using standard records from the EPICS toolkit; custom records were used instead. Since EPICS was designed as an open system that is easily extensible this did not present a real problem although, the effort was again hampered by the lack of good novice users documentation. But once the process was understood, extending EPICS to incorporate new record types was not a difficult task.

*H. Beam Position Monitors (BPMs)*

The CEBAF accelerator contains approximately 500 BPMs. Two different types of electronics are used to acquire data for these BPMs. In addition, some of the BPMs are multiplexed so that up to five BPMs share the same set of electronics. The most common type of BPM electronics are interfaced to CAMAC (the 4-channel BPMs); some of these BPMs are multiplexed and the multiplexer controller sits on the VME bus. The rest of the BPMs use switched electrode electronics (SEE) and are interfaced directly to the VME bus.

In theory, the 4-channel BPMs could have used the CAMAC driver support connected to the standard set of EPICS records. This proved not to be practical. The 4-channel BPMs need to acquire data at 60 Hz and the maximum cycling rate in EPICS is 10 Hz. This rate could be set higher, but some iocs control 40 BPMs and the overhead involved in database record processing made it impossible to acquire and process data for each BPM individually at a fast enough rate. The solution to this problem was to utilize the fact that EPICS allows an external process to event-trigger database processing. A data acquisition task was designed to acquire multiple data points for all the BPMs in a CAMAC crate, distribute the data to custom BPM records in the database and then trigger these records to process.

The data acquisition requirements for the SEE BPMs are even higher. These devices are controlled directly from VME and offer much greater performance and processing capabilities than the 4-channel BPMs. The same processing strategy was adopted for the SEE BPMs. This structure allows operators to control both types of BPMs electronics with the same set of global controls and presents a common interface to high level applications.

It was also necessary to write new EPICS VME driver support for the multiplexer controller since this board was developed in-house. It was possible to attach this driver to existing EPICS records.

## III. Advantages of EPICS as a Control System

EPICS is both an open system and a modular system. At the lowest level, the toolkit uses a real-time OS kernel and at the higher level, it uses X-Windows. It is easy to integrate new device support and to extend the system to include new record types. EPICS has very flexible control options such as settable, differential scan rates and event-triggered processing. Integrated tools are available to aid in development, database management, debugging, and operations. Since CEBAF began its conversion effort the novice documentation has been improved considerably and is available on the World Wide Web.

*I. Scale of CEBAF Control System*

Some idea of the size of the CEBAF accelerator control system can be summarized by the following table:

**Table 1: Size of CEBAF Control System**

| System | # EPICS Records | # Control Points |
|---|---|---|
| RF | 72034 | 28205 |
| Vacuum and Valves | 916 | 743 |
| Harps | 5281 | 3323 |
| Machine Protection | 3024 | 1773 |
| Magnets | 26849 | 8479 |
| Solenoid and Camera | 4336 | 419 |
| BPMs | 12625 | 4892 |
| Total | 125065 | 47834 |

The number of control points is defined to be the number of analog inputs and outputs plus the number of command bit inputs and outputs that communicate directly with the hardware.

The original TACL system controlled approximately 25% of the CEBAF accelerator. The current EPICS control system is operating the entire machine and is still growing. EPICS has proven to be a system which scales well and which provides good tools to aid application developers.

## IV. References

[1] William A. Watson III, et. al., "The CEBAF Accelerator Control System: Migrating from a TACL to an EPICS Based System", *International Conference on Accelerator and Large Experimental Physics Control Systems*, Oct., 1993.

[2] Karen S. White, et. al., "The Migration of the CEBAF Accelerator Control System from TACL to EPICS", *CEBAF Control System Review*, May, 1994.