The Los Alamos VXI-Based Modular RF Control System*

S. P. Jachim, C. Ziomek, E. F. Natter, A. H. Regan, J. Hill, L. Eaton, W. D. Gutscher, M. Curtin, P. Denney, E. Hansberry, T. Brooks
MS-H827, Los Alamos National Laboratory, Los Alamos, NM 87545

Abstract

This paper describes the design and implementation of the Los Alamos modular RF control system, which provides highperformance feedback and/or feedforward control of RF accelerator cavities. This is a flexible, modular control system that has been realized in the industry-standard VXI cardmodular format. A wide spectrum of system functionality can be accommodated simply by incorporating only those modules and features required for a particular application. The fundamental principles of the design approach are discussed. Details of the VXI implementation are given, including the system architecture and interfaces, performance capabilities, and available features.

Introduction

The AT-5 group at Los Alamos National Laboratory (LANL) is developing the RF system for the Ground Test Accelerator (GTA), including the RF control system, which is the topic of this paper. The GTA Program is a development vehicle for Neutral Particle Beam (NPB) physics and technology.

Because GTA operates at several different harmonicallyrelated frequencies using various power amplifier technologies, a decision was made early on to pursue a modular RF control-system architecture. This architecture is designed to be independent of RF frequency, power level, and type of accelerating structure. This approach has proven successful on GTA and has allowed the same hardware to be used in a wide variety of other accelerator applications worldwide.

The first LANL VME Extensions for Instrumentation (VXI) module was designed and built in 1989, and the fourth complete control system began operating for GTA in 1992. Additionally, four other systems have been installed and are operating at various other institutions. In all, more than 200 C-size VXI modules have been built to date.

System Requirements

The primary purpose of an RF control system is to tightly regulate the RF field in an accelerator cavity [1]. This regulation must be maintained in the presence of variations in the accelerator system parameters, such as cavity resonant frequency, beam current, and power-amplifier performance. The design objective for field regulation tolerance in the GTA RF control system is $\pm 0.5\%$ in amplitude and $\pm 0.5^{\circ}$ in phase. This applies for beam loading conditions up to 80%.

To achieve this level of regulation and to ensure efficient RF power transfer to the cavity, the resonant frequency of the accelerator cavity must be maintained within prescribed limits. A regulation tolerance of $\pm 2^{\circ}$ was chosen as an objective for the cavity reflection coefficient phase on GTA.

System Architecture

Figure 1 illustrates the essential aspects of the LANL RF control-system architecture as applied to a particular accelerating cavity [2,3]. A sample of the cavity field is downconverted to a 20 MHz IF signal and synchronously detected against the RF reference signal. The in-phase (I) and quadrature-phase (Q) components of this detected signal are compared to their respective commanded values, or setpoints.



Figure 1. LANL RF control system architecture.

The difference between the detected components and their setpoints produces an error vector. Proportional, integral, and differential (PID) closed-loop control actions are then derived from this error vector, producing a control vector. An openloop control vector can optionally be generated at the beginning of the acceleration cycle to fill the cavity in a programmed manner.

A vector modulator translates the control vector to a 20 MHz IF carrier, which is subsequently upconverted back to the original RF frequency. This RF control vector is applied to a high-power amplifier (HPA) whose output is an RF cavity drive vector, thus closing the feedback loop.

The RF control system is partitioned into several functional VXI modules as shown in Figure 2. The modules with solid outlines constitute the basic RF control system. The modules with dashed outlines are optional system components and can be incorporated as desired to enhance the performance of the basic control system. The Beam Feedforward Module estimates the beam loading disturbance and applies appropriate feedforward signals to minimize field perturbations. The Control Predistorter Module provides dynamic decoupling of the I and Q control rails, which are cross-coupled by the cavity. The Adaptive Feedforward Module measures, integrates, and corrects repetitive loop disturbances in a pulsed RF system. Details of these optional modules can be found elsewhere [2-6].

^{*}Work supported and funded by the US Department of Defense, Army Space and Strategic Defense Command, under the auspices of the US Department of Energy.



Figure 2. VXI modular implementation.

Feedback control is also employed to regulate the resonant frequency of the cavity [7,8]. As shown in Figure 3, this is achieved by detecting the forward- and reverse-traveling waves in the cavity drive line, computing the complex reflection coefficient of the cavity, and taking corrective feedback action by applying a control signal to a mechanical cavity tuner. Accuracy is assured by calibration and vector error correction [9]. All computations for this process are performed in software, and the feedback loop is closed through a virtual network connection to the tuner actuator.



Figure 3. Resonance control system.

Several ancillary functions are assigned to the RF control system as well. Measurements of various RF signal amplitudes in the system, such as the cavity field amplitude and drive, are supported with Envelope Detector Modules. These modules sample and quantize each of eight RF input signals once per RF pulse.

The RF system associated with each cavity is sequenced and timed by the RF control system. This function is performed in the Upconverter Module, which sends two independent optical timing signals to the HPA.

The RF system, like the rest of the accelerator, is required to operate remotely under complete automation. Thus, supervisory computer control, data acquisition, and remote signal monitoring are implemented in the GTA RF control system. All relevant RF control system parameters are writeable and readable through the GTA database, and all control functions are integrated and operated through Experimental Physics and Industrial Control System (EPICS) control screens [10].

Hardware Realization

The VXI standard [11], which emerged in the 1988-89 time frame, was developed by a consortium of leading instrument manufacturers. This standard builds on, and is compatible with, the ubiquitous and powerful VME standard, producing a robust card-modular medium capable of supporting high-performance analog, digital, and microwave instruments. The design of the RF control system commenced in this time period, and VXI was chosen as the packaging medium. VXI held the promise of not only supporting the needs of the RF control hardware, but also of fitting seamlessly into the GTA computer control system, it being of a VME-based distributed architecture.

The promise of VXI has held true in practice. Most of the RF control modules have been, of necessity, designed inhouse. In all cases, adherence to the VXI standard has been maintained. Several commercial VME cards, such as a 68020-based processor and an Ethernet[™] interface card, had already been integrated into the computer control system. These VME modules were directly embedded in the VXI RF control system and integrated together without significant difficulty.

Figure 4 shows a conceptual layout of a typical LANL VXI module. Details of the register-based VXI interface can be found elsewhere [12]. All timing and signal conversion functions are distributed down to the module level. A 10 MHz clock and a synchronizing trigger are broadcast to all modules on the VXI backplane. Counters on each module's interface circuit count down from preloaded register values and provide on-board timing signals. As needed, A/D and D/A converters are provided on each module. Signal sampling is triggered by the on-board timing signals, which are under software control. This approach greatly simplifies system integration and configuration management. Because the number of connectors and cables in the system has been minimized, reliability is improved.



Figure 4. Conceptual VXI module layout.

Analog, digital, and mixed-signal circuits are judiciously combined on the LANL VXI printed circuit (PC) boards. The structure of these PC boards ranges from 2 to 10 layers, depending on the complexity of the application. Sensitive RF and microwave circuits are housed in traditional-style metal enclosures and mounted on their respective VXI motherboards. Figure 5 shows a typical design, in this case an 8-channel RF Envelope Detector Module. Pulsed RF signals are applied to the front-panel connectors, and digitized samples are readable in the module's VXI registers.



Figure 5. LANL 8-channel envelope detector module.

Remote monitoring of analog signals is provided, if needed, by an insertable monitor multiplexer daughter board. This circuitry selectively accesses, under software control, any two of eight designated analog signals on its associated motherboard. Each module in a crate, again under software control, places its selected signals on the VXI backplane. These signals are sensed by another module, which in turn transmits them to a remotely located receiver. Through this multiplexing technique, a large number of real-time analog signals is efficiently accessed remotely for tune-up, monitoring, and troubleshooting of the RF control system.

The measured performance of the LANL RF control system meets or exceeds all performance requirements [13]. After the integration and shakedown periods typical of all new designs, remote operation of the control system has been highly reliable.

Other Applications

The success of the generic, modular design approach described in the introduction is proven by its successful application to machines other than GTA. LANL control systems have been applied to the FEL accelerators at both the Boeing and the University of Twente FELs with good results. In the latter case, the operating environment is an embedded MacintoshTM controller running LabVIEWTM, illustrating the general utility of the VXI format. The SSC Laboratory has applied a LANL control system to their RFQ, and is evaluating applications to other machines. The APS linac at Argonne National Laboratory is incorporating the front-end

LANL modules, with upgraded signal acquisition speeds, for machine control and diagnostics.

Summary

The LANL VXI RF control system has been successfully applied not only to its original target, GTA, but also to various other machines. This validates the original design goals of a high-performance, modular, generic control system.

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