VXI Based Low Level RF System for Fermilab Linac Upgrade

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Abstract

A VXI-based Low Level RF (LLRF) system has been designed for the Linac Upgrade project at Fermilab.[1] The design includes not only amplitude and phase feedback around the 805 MHz Klystron and side coupled cavities, but also an adaptive feedforward circuit to compensate for beam loading. In this paper, we will concentrate on the advantages of the VXI environment as well as actual system performance.

I. INTRODUCTION

Accelerator RF systems have had higher demands placed on them in the last decade, both in performance and flexibility. This has led to the use of embedded micro-computers, which in turn creates the new problems of mixing computer and RF environments. Needs in the military and industry for high performance, compact Automated Test Equipment (ATE) drove the development of the VME Extensions for Instrumentation (VXI) standard in July 1987.[2] This standard addresses the issues of integrating a flexible instrumentation system. VXI has matured in the last 6 years to become a very "friendly" architecture for accelerator instrumentation.

We now have an operational RF system that is ready for commissioning later this year. The VXI based LLRF has proven to be flexible and reliable. VXI has also provided a smooth path for system evolution.

II. LLRF DESCRIPTION

The LLRF provides the necessary amplitude and phase feedback control for the 12 megawatt and 200 kilowatt linac stations. All operational levels are at the 100 milliwatt level or below. In addition, a feedforward loop has been added with the use of local VXI based computing power. Feedforward provides the extra level of amplitude and phase control that is required due to beam loading.

The LLRF also provides the capability of electronically adjusting the phase of each individual station for the proper phase advance of the beam. Waveguide to cavity phase is measured for the temperature regulation of the cavities. Figure 1 is a block diagram of the RF system.

The need for feedforward is most critical in the debuncher section. The debuncher is located after the beam chopper, so all beam that passes through it is injected into the Booster accelerator. In order to limit momentum spread, the beam-induced current vector in the cavity must be countered by RF power with exact timing, amplitude and phase.

The correct amplitude of the feedforward waveform is computed from the digitized error signals of the magnitude and phase loops. The average error during beam loading is subtracted from the average error before beam loading. This difference is multiplied by a gain factor and then filtered over many RF cycles to produce the amplitude of the pulse. The pulse timing is selected with 100ns resolution from the control system.

III. PLATFORM CONSIDERATIONS

One of our goals is to have a clean topology both in functionality and in physical hardware. Experience with trouble-shooting broken accelerators at all hours of the day and night defines the need for straight-forward signal flow, limited cabling and as many monitor points as possible. Other considerations are data way bandwidth, triggering, power supply, module size, cooling, electrical shielding, and integration into the accelerator control system. The two solutions proposed are a VME/NIM combination and VXI.

In the VME/NIM system, both the computation of the feedforward correction and data acquisition are done in VME. The RF circuitry resides in a NIM crate. This traditional solution is very workable, however, it requires large numbers of interconnections between the two crates of high-speed analog and digital signals.

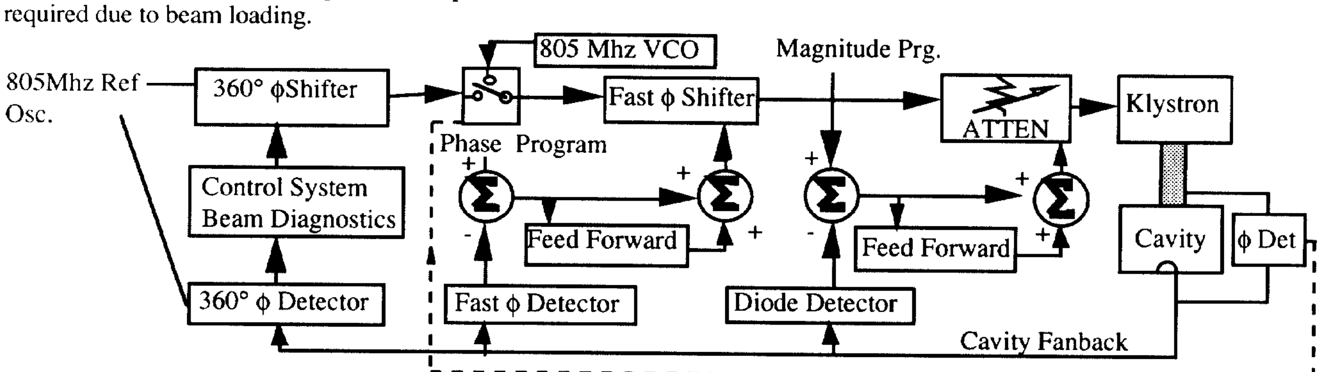

Figure 1. LLRF System Block Diagram

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With the VXI platform, all system functions are provided in one crate, with a minimum of front panel connections. Much of the VXI backplane capabilities are utilized. The VME bus is used for high speed communication between the CPU and the RF modules. The 10 MHz ECL clock is locked between all stations in the linac. RF events are timed from the trigger bus. Software tasks are called by the interrupt bus. The Local Bus is used for both analog and digital signals between modules. The mod ID line is used by the resource manager to determine hardware configuration. By knowing the crate configuration, the CPU knows if it is controlling one or two RF stations. For two stations the first four modules are shared. A VXI crate has a total of thirteen slots, of which one station uses seven .

- HP1404A slot 0 crate controller
- Motorola MVME133 CPU
- 1MB Battery Backed RAM
- Vertical Interconnect: a fast link to the Linac Control System.
- 360 degree Phase Shifter/Detector
- LLRF Module (Shown in figure 2)
- Cavity Temperature Control Loop Phase detector and Startup VCXO

IV. MEASURED SYSTEM PERFORMANCE

Testing of the low level system with real beam loading can not be done until the system is commissioned later this year. For this reason, we built a test box to introduce an amplitude and phase step in the RF drive to the Klystron. While this cannot simulate effects such as cavity fill time or Q shift, it does give us a good measurement of system loop gain and settling time.

Figure 3 shows the open loop response of the system to simulated beam loading. The dominant pole in the loop comes from the loaded Q of the cavity. The measured unloaded Q of the cavity is 20,000. If the waveguide was back-terminated into its characteristic impedance, the loaded Q would drop to 10,000. In this case, there is no circulator in the waveguide, hence much of the return energy from the cavity is reflected off of the Klystron to add in phase with the cavity voltage.

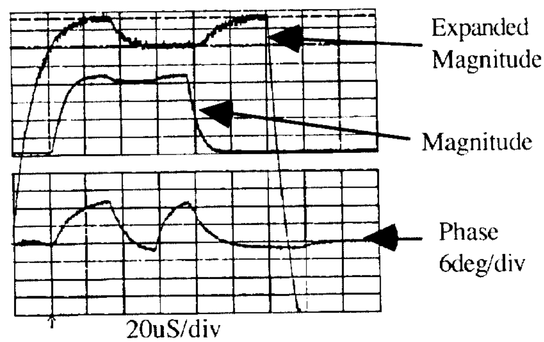

Figure 3. System open loop response to simulated 7.5% beam loading and 18 deg. phase shift. Klystron operating at 7.5 Mwatts,

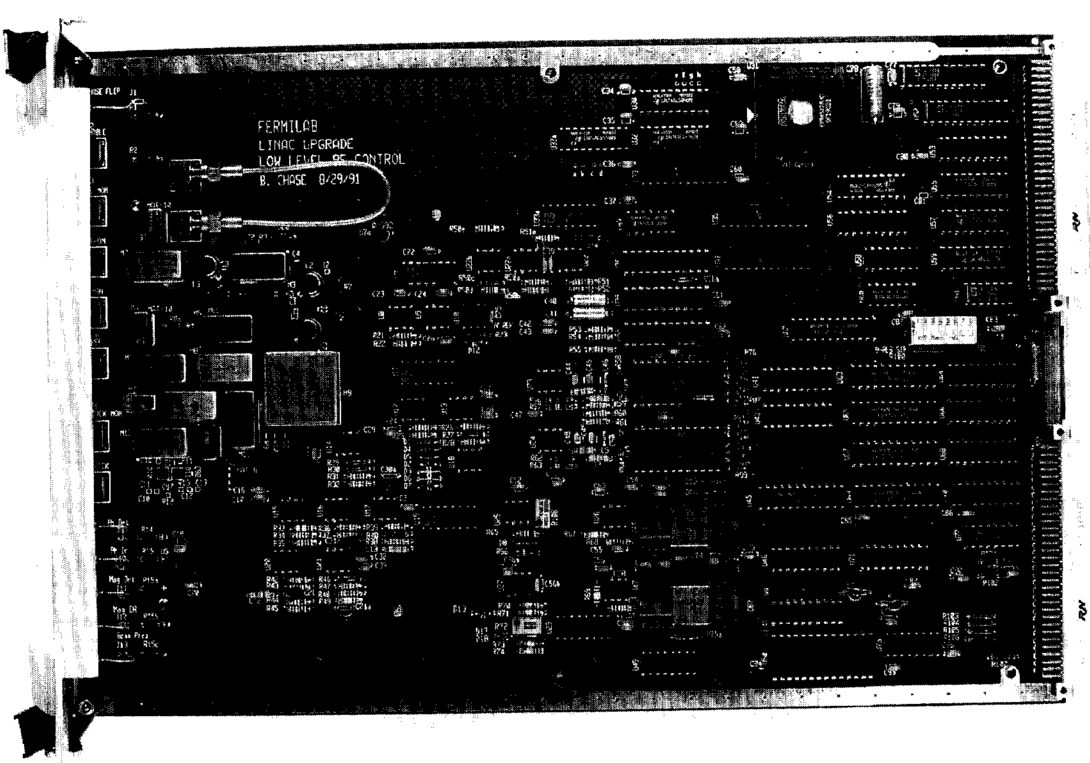

Figure 2. Linac Upgrade Low Level RF Module.

The lower power loss results in a Q of about 1300 and a baseband dominant pole of 32KHz for the magnitude and phase detector signals. This pole combined with the system group delay determine the maximum gain and bandwidth of the feedback loops.

Figure 4 shows the corrected cavity voltage waveform with feedback and feedforward on. Feedback loop gains are typically 15 dB while feedforward is unconditionally stable with loop gains of 46 dB.

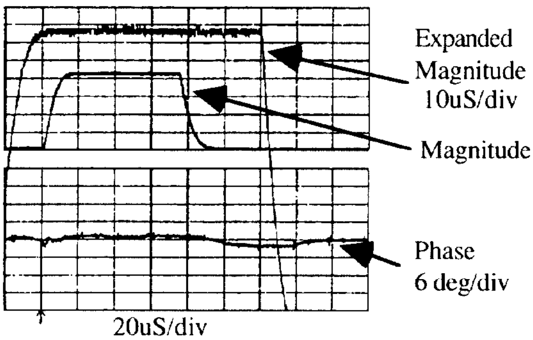

Figure 4. System response to simulated 7.5% beam loading and 18 deg. phase shift with feedforward on. Klystron is operating at 7.5 Mwatts.

The response of the IIR filter is shown in figure 5.

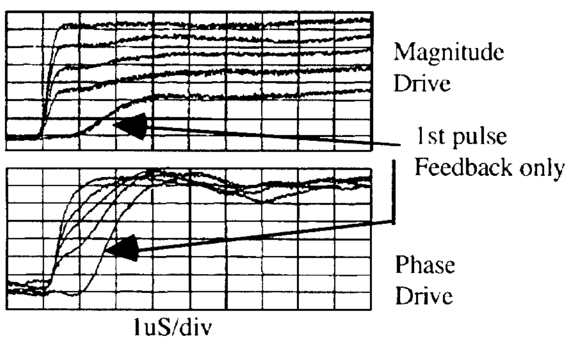

Figure 5. Phase Shifter and Mixer Drive Signals Feedforward "Learning" response to a 10% amplitude and 18% phase step.

V. SYSTEM EVOLUTION WITH VXI

When we started testing the RF system with a real Klystron and cavity, all the custom circuitry resided on one VXI module. We have since added two more custom modules. Most accelerator electronics are by nature development projects. Changes to the original concepts and the evolution of hardware are a natural part of good engineering practice. Therefore, it is important that the original design does not limit growth. VXI, by design, is very general in its architecture and has provided us with a seamless path for upgrades.

We designed much flexibility into the LLRF module. By having a high speed computer bus directly connected to the board, it is easy to put almost any parameter of interest under computer control. By building in a 16 channel ADC, we are able to monitor all signals of interest at any time during the RF cycle. Many variables in the feedforward program are parameters in the control system. Operation of the system relies on the easy access to control and monitor points.

During early running at the test station, a large shift in the resonant frequency of the cavities was found when the RF pulsed drive is turned off for even a few seconds. This is caused by the RF heating of the cavity nose cones and their short thermal time constant. With the cavity off resonance from the reference oscillator, there is a large amount of reflected power back to the klystron. This power is detected and trips the klystron protection system so that the cavities will never warm up. A local VCO was added to track the cavity resonant frequency until the nose cones were at operating temperature. At this point the reference oscillator is switched back in. The Cavity Temperature Control Loop Phase-detector and Startup VCXO module is fairly simple, requiring only a few channels of analog and digital I/O. To take advantage of existing hardware, the VXI local bus was used to route the needed signals to and from the LLRF Module.

Late last year there was a request from Beam diagnostics for a 360 degree Phase Shifter and Detector. For this module we took advantage of a commercial VXI interface daughter card.[4] The daughter card provides the VME bus interface as well as the VXI defined registers. This interface saved us much time in the design, layout, and trouble shooting of this card.

VI. CONCLUSIONS

A low level RF system is installed and tested for the Fermilab Linac Upgrade. The control of the LLRF has taken advantage of the VXI architecture. VXI provides both the analog/RF and control system interface environment in one packaging scheme. The response of the feedback loops to beam loading has been greatly improved by a learning feed forward algorithm. Two years of experience with the VXI platform has proven it to be well suited to accelerator instrumentation.

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