# LANSCE-R LOW LEVEL RF CONTROL SYSTEM

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## *Abstract*[1]

The Los Alamos Neutron Science Center (LANSCE) proton accelerator is scheduled for refurbishment. A new low level radio frequency (LLRF) system is part of the refurbishment plan since the existing LLRF system is analog-based and requires significant setup and maintenance time. Both field and resonance control aspects of the current system do not have the flexibility to meet future performance requirements. The LANSCE accelerator provides both $H^+$ and $H^-$ beams and due to the various user requirements there are a number of different beam pulse types varying in timing and current. In order to meet user needs, LANSCE must simultaneously transport both $H^+$ and $H^-$ in the accelerator. These requirements have motivated the development of a new LLRF system based on software defined radio technology. The new system will include field control using feedback and adaptive feed forward techniques, an upgraded resonance controller with frequency agility to improve startup and fault recovery times and a high power amplifier pre-compensation controller for improved cavity fill times and amplifier efficiency. Among the challenges with implementing the new system are interfacing with existing subsystems of the accelerator.

## LANSCE FACILITY REQUIREMENTS

The LANSCE accelerator facility provides a variety of different beams to its various user facilities as shown in Table 1. These beams vary in particle polarity, duration, repetition rate and current. These different beam types provide a challenge to the radio frequency (RF) systems and in particular the control system as it has to operate over a significant dynamic range of beam loading levels that change on a pulse-to-pulse basis. In addition to field control the LLRF is responsible for maintaining the cavity frequency, establishing the field in the cavity and minimizing the system errors due to time/temperature variation in RF chain components. Special requirements are imposed upon the LLRF systems during the beam tuning of the accelerator. These requirements break down into the following general categories: (1) Field control; (2) Frequency control; (3) Dynamic operations; and (4) System monitoring and control.

## LLRF SYSTEM FEATURES

The LLRF system implements a variety of control techniques to meet the requirements of the accelerator as shown in Table 2. The basis for the LLRF system is a software defined radio based upon an Altera field programmable gate array (FPGA) that allows flexibility in both the data processing and control functions. The system will be based upon a standard VME form factor and co-resides with accelerator controls modules in common crate. This provides for standardized equipment and simplified communications. The LLRF module consists of an FPGA carrier board and frequency specific mezzanine board. Included on the carrier board is a floating point digital signal processor (DSP).

## FIELD CONTROL

Field control is one of the two primary responsibilities of the LLRF control system (the other being frequency control) and it consists of two primary functions: the establishment of the field in the cavity in the minimum amount of time and the maintenance of the field during transient events. To accomplish these tasks under the dynamic beam conditions at LANSCE required the use of both classical and modern theory. The control system consists of a proportional-integral (PI) feedback controller, a set-point trajectory controller and an adaptive feed-forward control system. The set-point trajectory controller optimizes the establishment of the field in the cavity in minimum time by providing a time-varying set-point controlling the behavior of the feedback system during cavity fill time. The PI controller is utilized to maintain the field and to compensate for the slower transients of the field. The adaptive feed-forward controller mitigates the deterministic transients associated with the beam within the cavity. This particular controller has the ability to adaptively compensate the feed-forward control signal to minimize the error for different beam types on a pulse-to-pulse basis. Because of the large variations in beam current on a pulse-to-pulse time frame the ability to switch the feed forward control signal for each pulse. Figures 1 and 2 show the performance of the control system as a function of different LANSCE beam currents.

The tuning of the feedback control system is done using a neural network algorithm to optimize the gain settings of the PI controller.

## FREQUENCY CONTROL

Frequency control is of primary importance as it is a major factor in determining the efficiency of RF system.

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The 201.25 MHz portion is drift-tube linac (DTL) composed of 4 tank cavities with a loaded Q of approximately 30k. Maintaining the resonant character is important for operations and power efficiency but recovery of the system after an RF power loss and subsequent restart is of particular importance to maintain beam delivery. The DTL frequency control system consists of water controls and adjustable slug tuners. The recovery time is of particular importance for the 805 MHz coupled cavity linac (CCL) where the frequency control relies entirely on the water controls and can currently result in downtimes of up to an hour if the RF is lost and the water cools down the tank. To provide an effective means of bringing the system up for a cold condition the LLRF system includes a frequency agility capability so that the RF can be matched to the cavity resonance and effectively apply power to the cavity in order bring the cavity resonance frequency to its nominal operating frequency in a matter of minutes following turn-on. The LLRF system calculates the resonant frequency of the cavity and then generates the appropriate RF signal to match the cavity. The frequency of the cavity changes as it heats up and the RF signal tracks this frequency to maintain maximum efficiency. When the cavity reaches the operating frequency then the RF drive is once again locked to the master reference system. The on board DSP provides the processing for this function.

## DYNAMIC OPERATIONS

The multiplicity of beam types at LANSCE provides a number of challenges unique to the facility. The beam loading varies on a pulse to pulse basis over 3 orders of magnitude and at a 120 Hz pulse rate. In order to maximize the performance of the accelerator for the different beam users it is necessary to tailor the control system on pulse to pulse time frame. This requires a close integration with the accelerator control system in order to receive the necessary information in a timely fashion.

## SYSTEM MONITORING

The various components within the RF system have time and temperature dependent parameters that impact the performance of the accelerator. The LLRF system monitors and provides correction to various components within the RF chain. Of particular importance are the high power amplifiers and their behavioral changes as a function of temperature, voltage and input signal level. A pre-distortion filter implemented to compensate for high power amplifier system non-linearities and through the use of a observer is able to monitor the amplifier system and adaptively modify the filter parameters. Results are shown in figure 3.

## STATUS OF LLRF SYSTEM

The LANSCE-R LLRF system is currently in prototype fabrication and expects fully operational prototype controller hardware by the end of summer 2007. Additional LLRF systems being replaced or refurbished during the LANSCE-R program include the RF reference source and source transmission system and resonance controls for all buncher and 201.25 MHz systems. Upgrades to the 805 MHz water controls are also planned.

Table 1 Beam Types at LANSCE

| Beam Type | Species | Peak Current (mA) | RF Gate (us) | Rep Rate (Hz) | Beam Loading 201.25 MHz DTL (kW) | Beam Loading 805 MHz CCL (kW) |
|---|---|---|---|---|---|---|
| IPF | $H^+$ | 10-16.5 | 625 | 10-40 | 25-360 | n/a |
| Lujan | $H^-$ | 11-12 | 625-775 | 20 | 50-450 | 130-180 |
| PRad | $H^-$ | 0.1 | 300 | 1 | 0.2-1.4 | 0.52-0.72 |
| WNR | $H^-$ | 0.1 | 625 | 100 | 0.4-2.8 | 1.04-1.44 |
| UCN | $H^-$ | 11-12 | 625 | 10 | 50-450 | 130-180 |
| MTS | $H^+$ | 16.5 | 625 | 60-90 | 71-600 | 184-297 |
| MTS-R | $H^+$ | 16.5 | 625 | 100 | 71-600 | 184-297 |
| MTS-R+ | $H^+$ | 21 | 625-1250 | 100 | 90-760 | 234-378 |
| PSR-WNR | $H^-$ | 3-4 | 625 | 40 | 13-144 | 34-72 |

Table 2 LLRF System at LANSCE

| LLRF Systems | Frequency MHz | #Systems | Dynamic Operations | Field Control | Frequency Control | System Monitoring |
|---|---|---|---|---|---|---|
| Low Frequency Buncher | 16.77 | 1 | No | Yes | Yes | Yes |
| Pre-Buncher | 201.25 | 2 | Yes | Yes | Yes | Yes |
| Main Buncher | 201.25 | 1 | Yes | Yes | Yes | Yes |
| DTL Systems | 201.25 | 4 | Yes | Yes | Yes | Yes |
| CCL Systems | 805 | 44 | Yes | Yes | Yes | Yes |
| Reference Source | 201.25/805 | 4 | No | Yes | No | Yes |

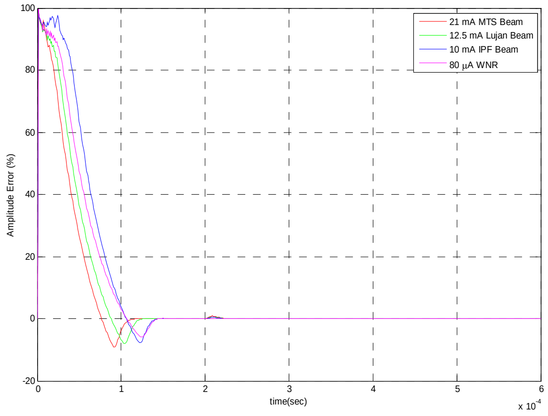


Figure 1a. Amplitude errors for different beam current levels. Beam at 200 usec.

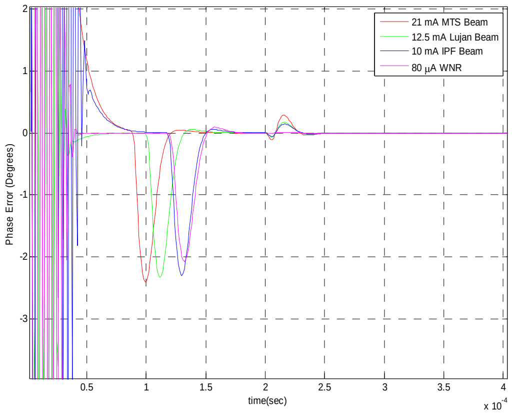
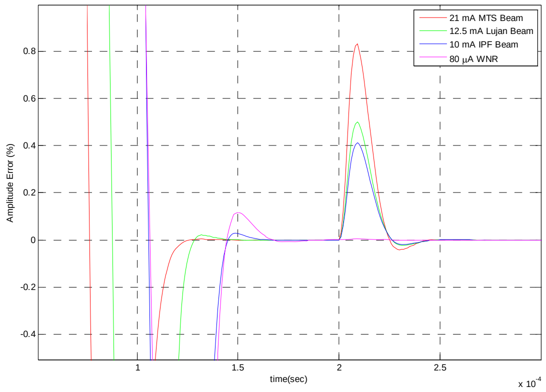


Figure 2b. Magnified Phase Error. Beam at 200 usec.



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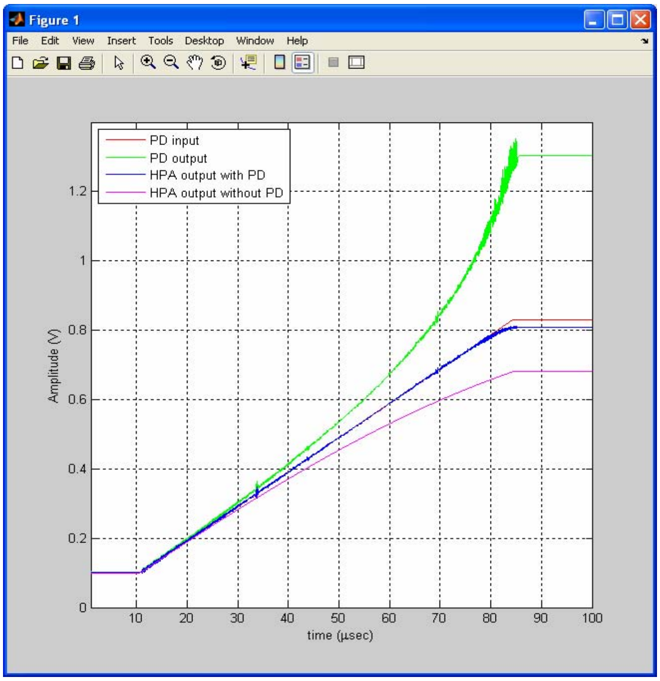
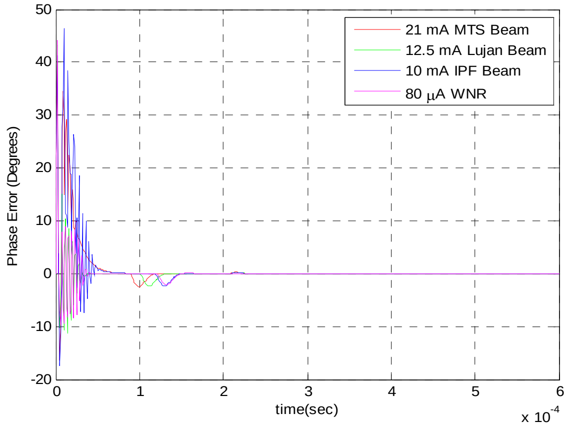


Figure 3. Simulation of the predistortion filter performance.



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