SLAC–PUB–7530R
May 12, 1997

Low-Level RF Signal Processing for the Next Linear Collider Test Accelerator*

S. Holmes, C. Ziomek, C. Adolphsen,. Akre, S. Allison, S. Clark, T. Dean, R. W. Fuller, S. Gold, R.K. Jobe, R. Koontz, T.L. Lavine, C. Nantista, Z. Wilson, A. Young,
Stanford Linear Accelerator Center, Stanford CA 94309

Abstract

In the X-band accelerator system for the Next Linear Collider Test Accelerator (NLCTA), the Low Level RF (LLRF) drive system must be very phase stable, but concurrently, be very phase agile. Phase agility is needed to make the Stanford Linear Doubler (SLED) power multiplier systems Energy work and to shape the RF waveforms to compensate beam loading in the accelerator sections. Similarly, precision fast phase and amplitude monitors are required to view, track, and feed back on RF signals at various locations throughout the system. The LLRF is composed of several subsystems: the RF Reference System generates and distributes a reference 11.424GHz signal to all of the RF stations, the Signal Processing Chassis creates the RF waveforms with the appropriate phase modulation, and the Phase Detector Assembly measures the amplitude and phase of monitored RF signals. The LLRF is run via VXI instrumentation. These instruments are controlled using HP VEE graphical programming software. Programs have been developed to shape the RF waveform, calibrate the phase modulators and demodulators, and display the measured waveforms. This paper describes these and other components of the LLRF system.

Invited talk presented at the Particle Accelerator Conference
Vancouver, B.C., Canada
May 12-16, 1997

* Work supported by Department of Energy contract DE–AC03–76SF00515.

Low-Level RF Signal Processing for the Next Linear Collider Test Accelerator

S. Holmes, C. Ziomek, C. Adolphsen, R. Akre, S. Allison, S. Clark, T. Dean, R. W. Fuller, S. Gold, R.K. Jobe, R. Koontz, T.L. Lavine, C. Nantista, Z. Wilson, A. Young,
Stanford Linear Accelerator Center, CA 94309

Abstract

In the X-band accelerator system for the Next Linear Collider Test Accelerator (NLCTA), the Low Level RF (LLRF) drive system must be very phase stable, but concurrently, be very phase agile. Phase agility is needed to make the Stanford Linear Energy Doubler (SLED) power multiplier systems work and to shape the RF waveforms to compensate beam loading in the accelerator sections. Similarly, precision fast phase and amplitude monitors are required to view, track, and feed back on RF signals at various locations throughout the system. The LLRF is composed of several subsystems: the RF Reference System generates and distributes a reference 11.424GHz signal to all of the RF stations, the Signal Processing Chassis creates the RF waveforms with the appropriate phase modulation, and the Phase Detector Assembly measures the amplitude and phase of monitored RF signals. The LLRF is run via VXI instrumentation. These instruments are controlled using HP VEE graphical programming software. Programs have been developed to shape the RF waveform, calibrate the phase modulators and demodulators, and display the measured waveforms. This paper describes these and other components of the LLRF system.

1 INTRODUCTION

The Next Linear Collider Test Accelerator (NLCTA) is an experimental high-gradient X-band linac at SLAC designed to integrate the technologies of X-band accelerators, klystrons, and RF pulse compression systems. The NLCTA will serve as a test bed as the design of the Next Linear Collider (NLC) evolves. The Low-Level RF (LLRF) Signal Processing System was designed to produce and monitor the highly phase agile RF drive to achieve the small ($\cong$ .1%) bunch-to-bunch energy spread required for the NLC [1].

2 11.424GHz RF REFERENCE SYSTEM

A single RF Drive System supplies RF to all of the NLCTA high-power RF stations [2]. This RF drive system derived from a 476MHz drive-line signal. The 476MHz CW signal is processed through a train of preamps, level-set attenuators, and mixers to produce signals at 2856MHz and 11.424GHz, in the power range of 10 to 20dBm. The 2856MHz signal is used for phase-reference purposes. The 11.424GHz signal is transmitted to each Signal Processing Chassis where it is phase modulated, and to each Phase Detector Assembly where it is a reference signal that is used to precisely measure the amplitude and phase of several RF monitoring points in the RF system. After further amplification, the modulated 11.424GHz signal is transmitted to the klystrons.

3 SIGNAL PROCESSING CHASSIS

RF phase and amplitude are coded as two orthogonal components: I (in phase) and Q (in quadrature), where phase is arctan(Q/I) and amplitude is $(I^2 + Q^2)^{1/2}$. A signal processing chassis for each NLCTA RF Station contains the low-level microwave electronics needed to create an RF output with arbitrary phase modulation. An I/Q modulator in the signal processing chassis up-converts baseband I and Q signals into an appropriately phase modulated, 10mW RF signal for driving the TWT that drives a 50MW klystron at X-band. Because the klystron is operated in saturation, the I/Q modulator is used as a fast phase shifter only, with its RF output kept at is a constant power level [3]. Figure 1 shows the HP VEE graphical interface used to calibrate the phase modulators.

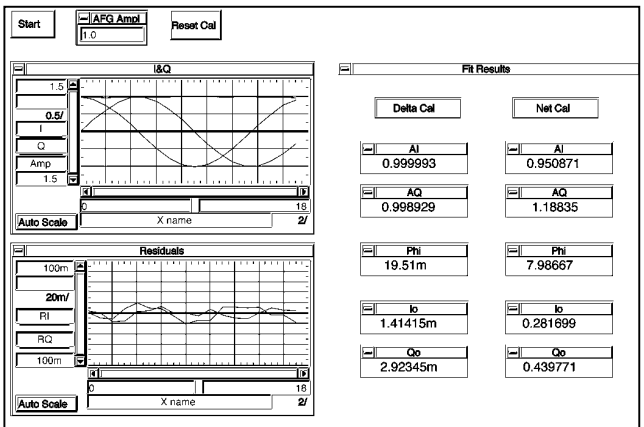

Figure 1. Phase Modulator Calibration Software

Calibrations are done to characterize the I/Q modulator accurately at a single RF output level. On-line calibrations (using a designated detector in the Phase Detector Chassis) must be done everyday to correct for changes in the modulator characteristics.

3.1 Phase Profiles

Two programmable Arbitrary Function Generators (AFG's) produce the I and Q waveforms that are used by the Signal Processing Chassis to modulate the phase of the RF that drives a saturated TWT (and klystron) [4]. The phase modulation is eventually converted, by a high-power pulse compression system (SLED-II, described by Tantawi et al., in these proceedings [5]) to amplitude modulation which compensates for transient beam loading in the accelerator (see Adolphsen et al., in these proceedings [6]). Figure 2 shows an example of a phase profile and the predicted RF amplitude waveform that results after high-power RF pulse compression.

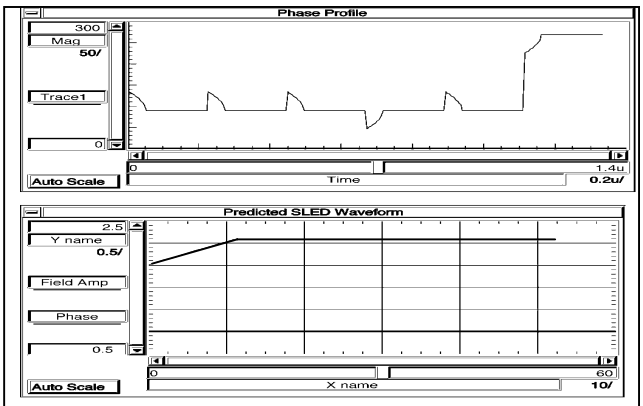

Figure 2. Example of a Phase Profile produced with the AFG's and the SLED Waveform it is predicted to generate.

3.2 Station Phase

Real-time adjustments of the station phase is provided to compensate for phase drifts and drifts caused by thermal expansion. In order to accomplish this, the station phase adjustment has been divided into two hardware devices: a fixed phase setpoint incorporated in the AFG waveform and an analog phase shifter that allows +/-180 degrees of phase adjustments to be performed in real time. The fixed phase setpoint incorporated into the AFG is accomplished through software during initial turn-on and remains fixed thereafter. Real-time adjustments of +/-180 degrees around the station phase setpoints are accomplished with an analog phase shifter that is driven by a VXI module. This analog phase shifter allows an operator to adjust a knob and see phase changes occur in real-time.

4 PHASE DETECTOR ASSEMBLY

There is one Phase Detector Assembly per NLCTA RF Station, consisting of eight I/Q demodulators. These I/Q demodulators are used to downconvert RF signals for precision amplitude and phase measurements. The RF signals that are measured are from various monitor points in the RF system. (e.g., Vector Modulator Output, TWT Output, Klystron Output, Accelerator Input). The pairs of downconverted I/Q signals from one Phase Detector Chassis Assembly are multiplexed into two digitizer channels and simultaneously sampled at 1GHz.

4.1 Software Calibrations

The Calibrations of both the Modulator and Demodulators are done through HP VEE software. The software operations performed upon the I/Q data include data correction, data conversion, and data display. Figure 3 shows the software algorithm for the I/Q demodulator. The data correction step consists of four multiply and two add operations. The six constants used in this correction (II, QI, IQ, QQ, Ioffset, and Qoffset) are determined by a calibration algorithm that is described below. The data conversion step performs the non-linear operations that convert I/Q to amplitude/phase. The algorithm in Figure 3 is performed upon each measured I and Q in the data sample.

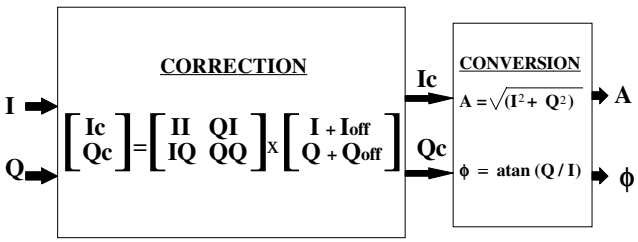

Figure 3. Software algorithm for the I/Q Demodulators

To measure the six calibration constants of a demodulator an 11.414GHz source switched into the RF input of the demodulator. The calibration signal is offset by 10MHz from the RF center frequency, resulting in 10MHz sinusoids on the output I and Q signals from the I/Q demodulator. The calibration signal is digitized over three complete cycles of the 10MHz sinusoids. This data is then analyzed to find the six constants in Figure 3 that make Ic

and Qc orthoginal sinusoids of equal amplitude and zero offset.

5 VXI INSTRUMENTATION

Each NLCTA RF Station consists of a VXI Crate containing one GPIB controlled command module, two analog multiplexers (MUX's), one Digitizing Ocilloscope, and two Arbitrary Function Generator's (AFG's). An additional VXI Crate, which is used for other purposes, contains a HPUX processor that is used to control the RF VXI Crates via GPIB and HP's VEE graphical interface software. The AFG's are programmed to output user-defined arbitrary waveforms which go into the Signal Processing Chassis Phase Modulator. The I (in-phase) and Q (quadrature) waveforms from the Phase Detector Assembly are multiplexed using the MUX's. Figure 4 is the output display of the amplitude and phase for one of the demodulator channels. These waveforms were acquired with the digitizing scope.

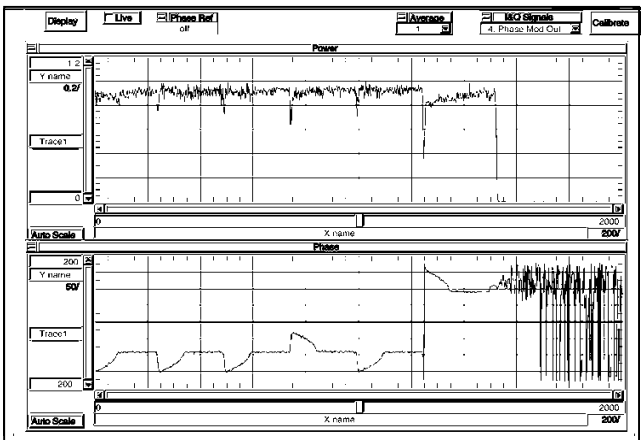

Figure 4. Output display of one I/Q Phase Demodulator

5.1 Timing

There is one Camac Simple Timing Buffer (STB) card per RF station that provides the NIM-level triggers used for synchronization of the LLRF system [7]. The VXI scope trigger starts the digitizer data acquisition cycle at the normal machine repetition rate. The Calibration trigger enables the on-line calibration of the I/Q demodulators by switching on a calibration source. The ARB Trigger initiates the AFG's waveform outputs. The LLRF Trigger is used by the RF Trigger Chassis to create the RF Gate pulse. This RF Gate is used by the RF Signal Processing Chassis to pulse modulate the LLRF output.

6 CONCLUSIONS

The design of the LLRF Signal Processing system for the Next Linear Collider will be based heavily on experience gained from existing systems developed for the NLCTA. The experimental program of the LLRF system for NLCTA has been successful in acheiving the ability to make RF phase and amplitude measurements with time resolutions comparable to the NLC bunch spacing (1.4ns). Upon completion of the NLCTA the design of the NLC will progress with a better understanding of X-band LLRF Signal Processing systems.

REFERENCES

[1] Physics and Technology of the Next Linear Collider: A Report Submitted to Snowmass '96. BNL 52-502, Fermilab-Pub-96/112, LBNL-Pub-5425, SLAC Report 485, UCRL-ID-124160

[2] NLC Test Accelerator Conceptual Design Report Stanford Linear Accelerator Center, Stanford, California, August 1993. SLAC-Report-411

[3] C. Ziomek "Low-Level RF Signal Processing Software", Stanford Linear Accelerator Center, March, 1996. NLCTA-Note-56.

[4] T. Lavine, "Preliminary Functional Specification for Klystron Phase Modulation Control," Stanford Linear Accelerator Center, July, 1994. NLCTA-Note-26.

[5] S. Tantawi et al., "The Next Linear Collider Test Accelerator's RF Pulse Compression and Transmission," these proceedings.

[6] C. Adolphsen et al., "Beam Loading Compensation in the NLCTA," these proceedings.

[7] S. Allison, S. Clark, T. Dean, C. Adolphsen, T. Lavine, C. Ziomek, "NLCTA RF High Level Controls Software", Stanford Linear Accelerator Center, October, 1996. NLCTA-Note-50.1.

Filename:	PAC97NLC.DOC
Directory:	C:\WINWORD
Template:	C:\WINWORD\NORMAL.DOT
Title:	Low-Level RF Signal Processing for the
Subject:	
Author:	ron akre
Keywords:	
Comments:	
Creation Date:	05/27/97 3:05 PM
Revision Number:	3
Last Saved On:	05/27/97 3:06 PM
Last Saved By:	ron akre
Total Editing Time:	4 Minutes
Last Printed On:	05/27/97 3:08 PM

As of Last Complete Printing

Number of Pages:	4
Number of Words:	1,469 (approx.)
Number of Characters:	8,376 (approx.)