50 MW X-BAND RF SYSTEM FOR A PHOTOINJECTOR TEST STATION AT LLNL *

R.A. Marsh, S.G. Anderson, G.K. Beer, R.R. Cross, G.A. Deis, C.A. Ebbers, D.J. Gibson,
F. V. Hartemann, T.L. Houck, C.P.J. Barty, LLNL, Livermore, CA 94550, USA
C. Adolphsen, A. Candel, T.S. Chu, E. N. Jongewaard, Z. Li, S.G. Tantawi, A. Vlieks, F. Wang,
J.W. Wang, F. Zhou, T. Raubenheimer, SLAC, Menlo Park, CA 94025, USA

Abstract

In support of X-band photoinjector development efforts at LLNL, a 50 MW test station is being constructed to investigate structure and photocathode optimization for future upgrades. A SLAC XL-4 klystron capable of generating 50 MW, 1.5 microsecond pulses will be the high power RF source for the system. Timing of the laser pulse on the photocathode with the applied RF field places very stringent requirements on phase jitter and drift. To achieve these requirements, the klystron will be powered by a state of the art, solid-state, high voltage modulator. The 50 MW will be divided between the photoinjector and a traveling wave accelerator section. A high power phase shifter is located between the photoinjector and accelerator section to adjust the phasing of the electron bunches with respect to the accelerating field. A variable attenuator is included on the input of the photoinjector. The distribution system including the various x-band components is being designed and constructed. In this paper, we will present the design, layout, and status of the RF system.

INTRODUCTION

Compton scattering gamma-ray source efforts, such as the LLNL MEGa-Ray [1], place very stringent demands on the laser and electron beams that interact to produce them. We are constructing a test station to develop and optimize a X-band (11.424 GHz) photoinjector as the electron beam source for Compton scattering applications. The test station will consist of a 5.5 cell X-band RFphotoinjector, single accelerator section (T53VG3), and beam diagnostics. The photoinjector will be a high gradient standing wave structure, featuring a dual feed racetrack coupler. The accelerator will increase the electron energy so that the emittance can be measured using standard quadrupole scanning techniques. The beam emittance we want to achieve in our test station is less than 2 mm mrad. SLAC has pursued X-band LINAC research and development for many years as part of the Next Linear Collider project (NLC 1991-2004). In fact, high gradient testing of X-band accelerator structures is continuing today at SLAC. The collaboration with our SLAC colleagues has enabled us to effectively select, design, and proceed with our photoinjector layout. This paper will describe the 50 MW RF system including the major components and general RF power distribution.

HIGH POWER RF SOURCE

The high power RF system is required to provide variable power to the photoinjector with adequate power to the T53VG3 to achieve the nominal beam end energy of 30 MeV. This beam energy will permit accurate emittance measurements. The X-band photoinjector is a modified version of the 5.49 cells RF gun tested at SLAC in 2002 [2]. The RF budget for the gun is 20 MW and the fill time of the structure is 65 ns. The T53VG3 type travelling wave structure was extensively tested for high gradient operation and has operated at high gradient with low breakdown rates [3]. This structure is suitable for our LINAC because our planned electron bunch separation is sufficiently large (~10 ns) that wake-fields are not likely to degrade the electron beam quality from bunch to bunch. The T series structures are essentially the low group velocity (downstream) portion of the original 1.8 m NLCTAstructures. This structure can be operated with acceptable trip rate at gradients up to 90 MV/m. The fill time of this structure is 74.3 ns. 20 MW is budgeted for the structure in the initial, single klystron test station configuration.

Klystron

The high power RF source is a X-band klystron (XL-4) developed by SLAC in the mid 90's for the high power testing of X-band structures [4]. The XL-4 is a solenoid focused klystron that requires a 0.47 Tesla field. An Applied System Engineering TWT amplifier provides the low level RF signal. The key characteristics of the klystron are summarized in Table 1. A photograph of our klystron prior to HV testing is shown in Figure 1.

Table 1: Klystron Specifications

Parameter	XL-4 Value	Units
Frequency	11.424	GHz
Peak Power	50	MW
Pulse Width	1.5	µsec
PRF	120	Hz
Beam Voltage	430-450	kV
Perveance	1.2	$10^{-6}A/V^{1.5}$
Efficiency	40	%
Bandwidth	50	MHz

---

* Work performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract DE-AC52-07NA27344, and funded by DHS Domestic Nuclear Detection Office.

Figure 1. An XL-4 Klstron without solenoid.

High Voltage Modulator

The high voltage pulse required by the klystron is provided by a state of the art, solid-state high voltage modulator. We have chosen the K2-3X modulator built by ScandiNova for its pulse flattop, pulse to pulse stability, and solid-state modular design. To achieve the emittance goal, a RF phase stability of 1 degree is required. This requirement leads to a voltage ripple of only +/-0.25% on the voltage flattop. Specifications of the high voltage modulator are summarized in Table 2.

Table 2: HV Modulator Specifications

Parameter	K2-3X Value	Units
Peak Voltage	450	kV
Peak Current	350	A
Pulse Flattop	1.5	μsec
PRF	0-120	Hz
Inverse Voltage	10 (max)	kV
Voltage Ripple	+/- 0.25	%
P-P Stability	+/- 0.1	%
Bandwidth	50	MHz

Standard pulse forming lines and networks were considered for the modulator, but not chosen due to voltage flatness and amplitude stability specifications. The ScandiNova modulator uses a parallel, solid-state switching technology that has demonstrated our requirements. Other attractive features of this technology are the relatively low voltage outside of the insulating oil/transformer container (~1 kV) and robustness (no cascading switch failures). The switches are rated for 1.7 kV and we expect high reliability at the 1 kV operating value. The relatively low voltage allows for a compact grounding architecture that minimizes electrical noise. The solid state switches also provide greater time between replacements/failures than gas switch based systems.

RF DISTRIBUTION

The RF distribution system is based on components developed by SLAC in the Accelerator Structure Test Area (ASTA) for the Next Linear Collider Test Accelerator (NLCTA) [5]. The modulator and klystron are positioned within a few meters of the test station. This distance will be spanned with a single run of overmoded (TE01) circular waveguide to minimize losses. WR-90 rectangular waveguide will be used for shorter distances.

General Layout

A schematic block diagram of the layout showing major components is provided in Figure 2. The photogun can be isolated from the vacuum system through an inline gate valve in the low energy beam transport section. The CAD drawing in Figure 3 illustrates the numerous couplers, pumping ports, and RF power loads used in the distribution system.

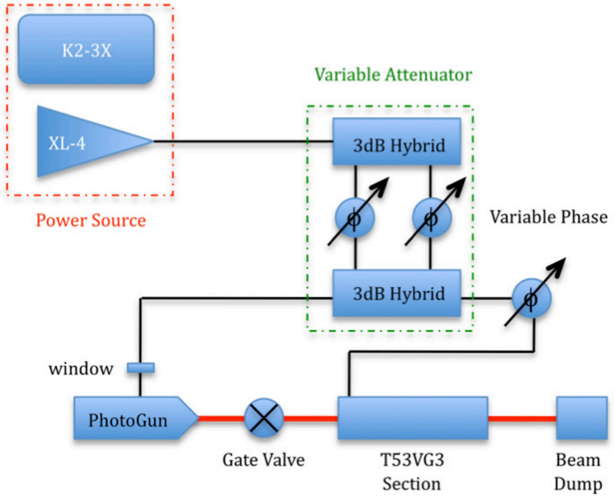

Figure 2. Block diagram of the RF distribution system.

Variable Attenuator

The most complex component in the distribution system is the variable attenuator. This SLAC concept uses two 3dB H-plane hybrid couplers and two variable phase shifters. The block diagram in Figure 2 indicates the major components of the attenuator. A microwave pulse entering Port 1 will be evenly split in power, but with a 90° phase difference, between two output ports as described in Eq. 1. As the pulses pass through the phase adjusters they will pick up a phase change, Δ, depending on how each adjuster is set (refer to Eq. 2). Finally, the two pulses enter the second hybrid and portions are combined at the output ports as indicated in Eq. 3 and Eq. 4. Note that ϕ represents a constant phase advance equal for both pulses and will vary depending on path lengths.

$$e^{i(\omega t+\phi)} \Rightarrow e^{i(\omega t+\phi)}\Big/\sqrt{2} \text{ and } e^{i(\omega t+\phi+\pi/2)}\Big/\sqrt{2} \qquad (1)$$

$$\Rightarrow e^{i(\omega t+\phi+\Delta_1)}\Big/\sqrt{2} \text{ and } e^{i(\omega t+\phi+\pi/2+\Delta_2)}\Big/\sqrt{2} \qquad (2)$$

$$\Rightarrow \cos\left(\frac{\Delta_1-\Delta_2}{2}\right)e^{i(\omega t+\phi+\Delta_1/2+\Delta_2/2)} \qquad (3)$$

$$\Rightarrow \sin\left(\frac{\Delta_1-\Delta_2}{2}\right)e^{i(\omega t+\phi+\Delta_1/2+\Delta_2/2)} \qquad (4)$$

The normalized power amplitude assuming no wall losses at the output ports of the second hybrid are: $\cos^2\left(\frac{\Delta_1-\Delta_2}{2}\right)$ and $\sin^2\left(\frac{\Delta_1-\Delta_2}{2}\right)$, respectively. Thus, by adjusting the phase, the amount of input power going to the photoinjector is changed with the difference going to the accelerator section.

Only one variable phase shifter is needed. However, the phase shifters operate by mechanically changing the physical volume of the structure and have limited adjustment range. By using two adjusters the available range is doubled and the power variation can be maximized.

STATUS AND PLANS

We are in the process of preparing the facility, e.g. bringing in additional electrical power and cooling water. The K2-3X modulator is ready and will be installed/tested once the facility preparation is completed. Initial on site testing of the klystron will occur this summer. The RF distribution system will be installed and tested in sections over the next several months as components arrive. The test station is schedule to be completed this calendar year.

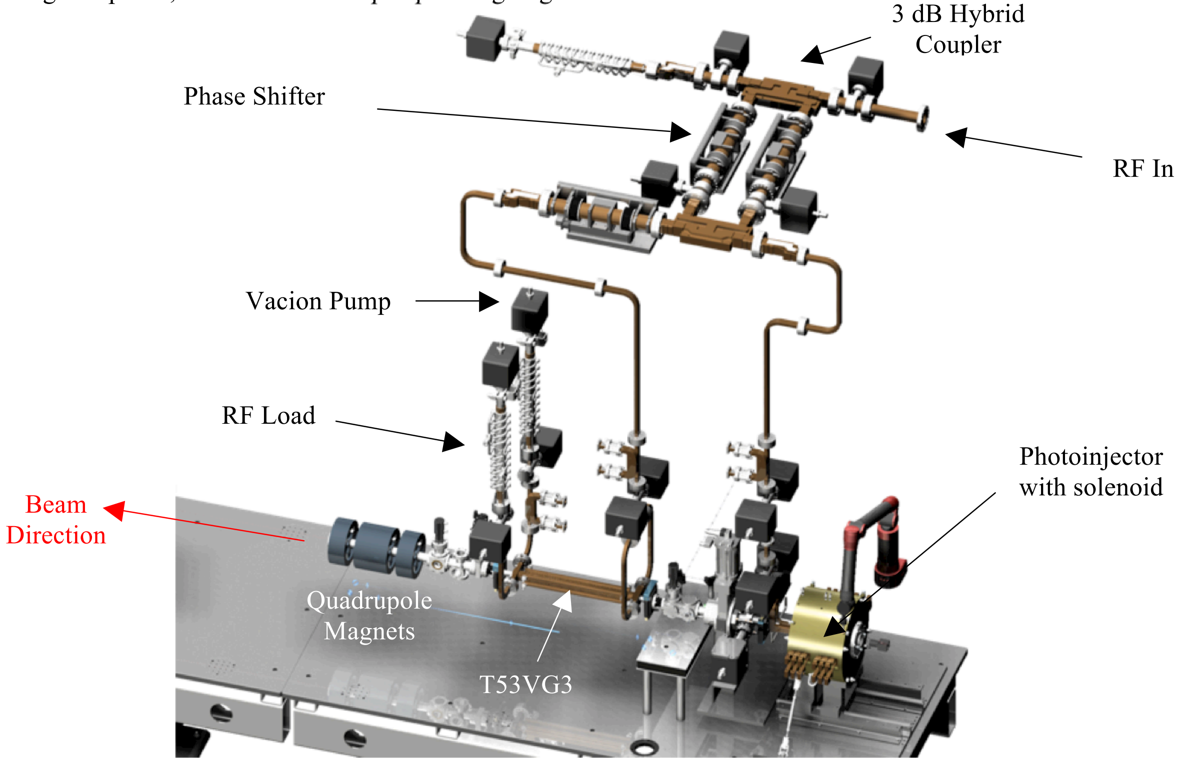

Figure 3. Illustration of RF distribution at photoinjector.

REFERENCES

[1] F.V. Hartemann, et al., “Development of a Precision Tunable Gamma-Ray Source Driven by a Compact X-Band LINAC,” Proc. PAC 2009, Vancouver, Canada.

[2] A. E. Vlieks, et al. “Development of an X-band photoinjector at SLAC,” Proc. LINAC 2002, Pohang Accelerator Laboratory, 164-166 (2002).

[3] C. Adolphsen, et al. “Normal-Conducting RF Structure Test Facilities and Results”, PAC2003, Portland USA.

[4] G. Caryotakis, “The X-Band Klystron Program at SLAC", SLAC-PUB- 7146, April, 1996.

[5] S.G. Tantawi and C.D. Nantista, “Multimoded RF Components and Their Application to High-Power RF Pulse Compression Systems,” presented at the XXI International LINAC Conference, Gyeongju, Korea, August 19-23, 2002; SLAC-PUB-9502.