LABORATORY DIRECTED RESEARCH AND DEVELOPMENT
X-BAND GUN EVALUATION

<table>
<thead>
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<th>C.LIMBORG-DEPREY</th>
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<td>8685</td>
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<td><a href="mailto:Limborg@slac.stanford.edu">Limborg@slac.stanford.edu</a></td>
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<tr>
<td>Date:</td>
<td>April 16th, 2012</td>
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<td>RFARED</td>
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<td>Directorate:</td>
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<td>C.Adolphsen, F.Wang, M.Dunning, A.Miahnahri</td>
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<tr>
<td>Proposal Term</td>
<td>From: 10/2012</td>
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<td>Through: 09/2013</td>
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Abstract

We propose to conduct an experimental evaluation of the X-Band photo-injector that has been designed and fabricated using previous LDRD funding. Peak brightness will be measured for a variety of charge and power levels.

Summary of Proposal

Description of Project

The design and fabrication of the X-band RF electron gun and ancillary components has been completed using LDRD funding. A first phase of the installation of RF components for the X-band Test Area (XTA) in the NLCTA tunnel was completed in March 2012. The gun and accelerating section have been processed since then with high power. The second phase of installation is scheduled for late April 2012. We expect to produce photo-electron beams in the early summer of 2012 if not earlier. The beam quality of the 5.5 cell X-Band gun will be measured for the pulse charges typically used for LCLS operation (250 pC, 150 pC, 20 pC). Simulations show that our 5.5 cell X-Band gun has similar or better transverse emittance and lower longitudinal emittance than the LCLS S-band gun, making it potentially unique driver for (1) compact Free Electron Lasers (FELs), (2) Ultra-fast Electron Diffraction (UED) experiments, and (3) Inverse Compton Scattering (ICS) facilities. Our program aims at demonstrating that our X-Band injector gun is indeed an excellent driver for the sources listed above.

Beam properties, including transverse emittance, bunch length and energy spread, will be measured at low charges of 10 pC, 5 pC, and as low as 1 pC, in order to establish a baseline. Higher charge operation and a 2-bunch configuration will be explored to determine how beam quality changes from the baseline. Beam properties will be measured for a variety of power levels in the gun - our X-Band gun offers a unique possibility to study photo-emission properties, namely quantum efficiency and thermal emittance, in the presence of extremely high peak field on the cathode (>200MV/m). We will also measure beam performances as a function of laser pulse shape and for different photoemission modes, including blow-out emission and multiphoton emission with IR illumination. Finally, a design for a version of the gun having a removable cathode will be finalized if budget allows.

Expected Results
The X-Band gun evaluation program will help answering fundamental questions for high brightness electron guns used for FEL and ICS sources:

1. Is the X-Band gun an appropriate driver for a compact FEL? Results from simulations show that the X-Band gun is a very good driver for a compact FEL as it produces very short bunches (120 fs rms for 10-pC charges, with normalized emittance $\varepsilon_{95} = 0.12$ mm-mrad). Start-to-end simulations have demonstrated that a 200-m long machine with an X-Band linac, two compressors (and no linearizer), a 20-m undulator can deliver ~2-fs pulses and 20 GW for 1.5-Angstrom photons. Again we would like to verify experimentally the numbers obtained in simulation for our X-Band gun run at 10 pC and possibly for charges smaller than 5 pC.

2. How does the X-Band gun perform for high repetition rate and/or with multiple bunches? This question is raised by both the FEL and Compton source communities. In our present gun design, the pulse heating is already at the limit of acceptable operation with $\Delta T = 50$ degC for 200MV/m and a 180-ns long RF pulse (cavity fill time is 80 ns). This suggests that the design could be improved and that operation at lower peak field should be investigated.

Simulations have shown that good emittances, namely $\varepsilon_{95} = 0.63$ mm-mrad for 100 pC, could be obtained for a 120MV/m accelerating voltage in our gun. If demonstrated experimentally, this would support greatly the idea that X-Band technology is appropriate for multi-kHz operation. We would like to verify the numbers obtained from simulations (0.63mm-mrad/100pC/120MV/m).

3. What are the thermal emittance and quantum efficiency (QE) values of the cathode in the presence of high fields? The discrepancy between theory and measurements for the thermal emittance of copper cathodes still remains to be understood. Systematic measurements of both QE and thermal emittance for a wide range of electric fields at the cathode, i.e. 10MV/m to 200 MV/m, should help answer the haunting inconsistency of a factor of 2 higher thermal emittance found in measurements compared with predictions from theory. The efforts to design a new gun with a removable cathode will allow, in the future, a systematic study of other cathode materials such as Mg, sputtered Mg on Cu, Cu with CsBr coating and others. We will also measure thermal emittance and QE for multi-photon emission with IR.
Our X-Band evaluation program will also demonstrate that the X-Band Test Area is the appropriate place for performing unique UltraFast Electron Diffraction experiments.

(1) The small divergence of (0.1 mrad) a low energy beam (5MeV) produced from our gun will be measured.

(2) The high resolution of our bunch length measurement station (fs-level for few MeV beams) will be verified

(3) The possibility of producing extremely short pulses from ballistic compression by means of a linac used as a compressor will be demonstrated

This project is an ideal match with the technical capabilities and science directives at SLAC. It uses the X-Band technology developed over the last two decades at SLAC with its mission to develop forefront accelerator and light sources.

Proposal Narrative

Purpose/Goals

The main purpose of our project is to evaluate the transverse and longitudinal emittances of the electron bunches produced from an X-Band RF gun for a variety of charges, RF fields and laser pulse shapes. We intend to demonstrate that our X-Band photoinjector is the ideal candidate for (1) Compact FELs, (2) Ultra-fast Electron Diffraction (UED) and (3) Inverse Compton Scattering (ICS) facilities.

A new solenoid will also have to be fabricated as our present solenoid is on a 2-year loan expiring by the end of 2012 from UC Davies. If budget allows, the design of a new version of the gun with removable cathode will also be completed.

Approach/Methods

The XTA is equipped with diagnostics which enable measurements of transverse slice and projected emittances, bunch length and energy spread. Measurements and systematic comparisons to calculations made with space charge simulation codes will be performed. Accelerator physicists will support this effort. The quality of measurements will depend on the reliability of the laser system and
on the flexibility of our newly commissioned XTA control system. Adequate support in those two fields is required. Diagnostics improvements will be needed for low charges such as new cameras and optics. Various electronic devices (EPICS scopes, delay box, etc.) will also be acquired for efficiency of the operation of the XTA.

**Specific Location of Work**

The measurements will be done on the XTA beamline, which is located in the NLCTA alcove as illustrated in figure 1. It is equipped with all the diagnostics necessary to characterize fully the photo-electron beam, and an EPICS LCLS style control system.

Station 2 provides 180-ns X-Band pulses of 200 MW peak. This power is distributed for $\frac{1}{4}$ to the gun which requires only 17 MW and for $\frac{3}{4}$ to the T105 accelerating structure. A series of quadrupoles is used to measure the emittance at 2 different screens. Station 3 will provide the power required to operate the transverse deflector. Station 3 is also used for the main transverse deflectors of the main NLCTA beamline (for ECHO seeding experiments).
Figure 1- XTA Beamline in the NLCTA alcove
Figure 2- RF components at the XTA after phase I installation: (a) 5.5cell X-Band RF gun, (b) X-Band Phase Shifters, (c) T105 accelerating structure

Figure 3- Dark Current from X-Band gun at XTA for ~ 7 MW, gun RF waveforms (magenta is forward power, blue is reflected power) measured in March 2012
Anticipated Outcomes/Results

Based on simulations, we expect the transverse emittance from the X-Band gun to be comparable or better than that of the LCLS for the 250-pC nominal operating charge, but the bunch length is expected to be 2-3 times smaller than that from the LCLS S-band gun. XTA tuning for operating charges of 100 pC, 20 pC, 10 pC will be optimized and measured emittance numbers compared to those calculated in simulations and presented in table 1. The 10-pC tuning is particularly interesting for a compact X-FEL design as stated earlier. Tuning of the gun with lower peak voltages will also be studied, in a view to promote the X-Band gun for high repetition rate machines. Multibunch operation studies will be performed. A summary of some of the early simulations results is given in figure 2.

<table>
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<th>Q [pC]</th>
<th>$\varepsilon_x, 100%$, $\varepsilon_x, 95%$ [mm-mrad]</th>
<th>$\sigma_t$ [mm]</th>
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<tr>
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Table 1 –Results from optimizations of XTA beamline
Figure 2 - Simulations for 100pC for reduced peak voltage

- a) Transverse emittance for reduced peak voltage
- b) Peak current for reduced peak voltage

VITA (Lead Scientist)

This information is required for the lead scientist on the proposal. Provide concise vitae, listing professional and academic essentials and complete contact information.

C. Limborg-Deprey, RFARED Accelerator Physicist

2010-2012: XTA physicist

2009-2010: On leave from SLAC, working in a privately owned company producing accelerator based Compton X-Ray sources

2001-2008: LCLS injector Liaison Physicist: simulation, design, tolerances and specifications of the LCLS injector components; commissioning of LCLS

1998-2003: SPEAR 3 Collective effects physicist

1997-1998: SPEAR Collective effects and diagnostics

1996: PhD ESRF, “Brightness in 3rd generation storage ring”

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Limborg@slac.stanford.edu
Budget

FY13:

Scientific labor:  1.25 FTE, 319.3 K
Support labor:  0.61 FTE, 206 K
Travel:  0 K
M&S:  75 K
Total:  600.3 K
Approvals

X-Band Gun Evaluation – Limborg-Deprey

NA
Department/Division Administrator

Robert Hettel,
Department Chair/Division Manager
[Signature]

Norbert Holtkamp,
Associate Laboratory Director
[Signature] 30 April 2012