

# SCRF Low-Level RF(LLRF) Development for ILC-SMTF

## Classification (Cryomodule LLRF)

## Personnel and Institution(s) requesting funding

N. S. Lockyer  
University of Pennsylvania

## Collaborators

There are several groups interested in working on the project and others that are willing to consult based on their significant experience. Those presently interested in working on the project include a group from Fermilab (Helen Edwards, Philippe Piot, Ralph Pasquinelli, Brian Chase, Bill Foster), the Pisa group led by Giorgio Bellettini, and the University of Pennsylvania. Experts being consulted include Stefan Simrock from DESY, Larry Doolittle from LBNL, Mark Champion from Oak Ridge, Matthias Liepe Cornell, and Marc Ross from SLAC.

## Project Leader

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## Project Overview

We are planning to participate in a new national initiative in Superconducting Radio Frequency (SCRF) research. A Expression of Interest (EOI) or pre-proposal has been submitted to Fermilab outlining the ambitious plan. The proposal is entitled “Superconducting Module Test Facility” or SMTF. The proponents (except Penn) are all accelerator physicists. This proposal is intended to help establish a new direction of research in the particle physics group in the Physics Department, SCRF research in accelerator physics. We propose to collaborate on instrumentation for the LLRF and controls for the “capture cavity” and future energy upgrades planned for the electron beam test facility at Fermilab called the A0 photoinjector and SMTF in general. The photo injector will be the injector for the SMTF in Meson East at Fermilab. Several upgrades to the injector are planned. The purpose of the instrumentation is to control the frequency, phase, and amplitude of the RF electric field in the superconducting cavity, commonly referred to as the RF Control System or Low Level RF (LLRF). A new “capture cavity” will be commissioned beginning this summer at the meson lab at Fermilab as “Phase Zero” of the SMTF program. The Penn instrumentation group has extensive expertise in instrumentation, especially FPGAs (Field Programmable Arrays) as well as analog and digital electronics and this allows us to contribute uniquely to the hardware and firmware aspects of the project, while at the same time allowing the physicists an opportunity to learn the essential physics of the impact of SCRF cavities on low emittance electron beams. This project is intended to help begin to establish the researcher at Penn in accelerator physics instrumentation and educate a number of students and postdocs in the accelerator physics and prepare them for participation in future accelerator projects, hopefully the ILC. The two students, entering graduate school fall 05 at Penn, have been identified and they explicitly asked to work on an ILC based project for summer 05.

## **Prior Support**

There is no prior support for this activity. Thus far, the preparation for making this transition from particle physics to accelerator physics has really just begun. I am co-editing the SMTF proposal, have sent Penn post-doc Chris Neu to the accelerator school at Berkeley last month (EPICS controls course), organized a video meeting with the world LLRF experts, and interacted mostly with Philippe Piot and to a lesser extent Helen Edwards on the subject. Penn instrumentation engineer Mitch Newcomer has started to read documentation and spent two days at Fermilab understanding the needs of the A0 injector. The instrumentation at A0 would benefit from Penn's involvement. I created a WEB page with much of the documentation available on the TTF LLRF. The URL is

<http://rutherford.hep.upenn.edu/~lockyer/llrf.html>

## **Broader Impact**

This proposal will train accelerator physicists. In particular, it is my intention to co-supervise a Ph.D student with my colleagues at Fermilab, hopefully Helen Edwards or Shekhar Mishra. In addition, I plan to train students during the summer, both undergraduates and graduate students.

## **Facilities, Equipment and other resources**

The Penn High Energy Physics group is well supported by DOE HEP. We have one of the best instrumentation groups at a university in the country. The group provides integrated circuits as a by product of our own program, custom designed at Penn, to other groups around the world, at cost, as a service to the community. The ASDQ chip, used for drift chamber readout, is one example. It is the frontend readout chip for the CDF Central Outer Tracker (30,240 channels), that was my main responsibility to CDF. We design and build circuit boards (Cadence), program FPGAs, and design numerous electronic systems. Penn has excellent computing available and substantial lab space for the HEP group.

## **FY2005 Project Activities and Deliverables**

Since 1992, Fermilab has been engaged in the production of high-brightness electron beams. In conjunction with the TESLA collaboration, it has constructed and operated an L-band (1.3 GHz) photo injector, a copy of which was installed at the TESLA test facility in DESY Hamburg, for various tests, especially for the proof-of-principle UV SASE free-electron laser experiment. The Fermilab/NICADD photo injector laboratory (FNPL) is used as a test facility for beam dynamics studies associated to high brightness beam and its associated diagnosis, along with application to advanced accelerator physics.

We plan to start by preparing the LLRF for the SCRF 1.3 GHz "capture cavity" this summer. We will also begin evaluation the LLRF system used by DESY and design by Stefan Simrock and collaborators. We may use this system for SMTF but we do not yet have enough knowledge of that system to understand whether it meets the needs of SMTF.

We propose to implement the RF control system for the 3rd harmonic accelerating structure after the capture cavity and evaluation is complete. The 3rd harmonic 3.9 GHz accelerating structure planned for the photo injector is necessary to linearize the energy of the electron bunch after acceleration in the preceding RF cavity and is this important for optimal bunch

compression.

The RF control system fulfills several functions. It stabilizes the frequency, amplitude, and phase variations induced by sources such as the RF drive, beam current variations, Lorentz force detuning, and microphonics. The typical loaded  $Q$  of superconducting cavities is chosen to be a few  $10^6$ . The resulting narrow bandwidth makes superconducting cavities much more sensitive to mechanical vibrations (microphonics). The RF field in a cavity also interacts with the RF wall current resulting in a Lorentz force which causes a deformation of the cavity shape which results in a change in the cavity resonant frequency.

The precision and stability of the combined resonant frequency, amplitude, and phase control determines the energy spread in the beam of the linear accelerator. The energy spread is critical to measuring the mass of new elementary particles as well as the top quark. These precision mass measurements are essential to the understanding of dark matter candidates. The high  $Q$  value of these cavities makes the LLRF system crucial for the success of the program. Interestingly, the criteria are not as stringent as needed at the X-FEL at DESY. Their experience will be important for us to monitor. (private communication Hasan Padamsee)

Deliverables: Commissioning of the LLRF and controls for the new “capture captivity” by the end of summer 05. Evaluate the DESY LLRF system and recommend whether it should be used for the 3rd Harmonic accelerating cavity and SMTF cryomodules.

### **FY2006 Project Activities and Deliverables**

The activities in year two will be to complete and expand the plans for year one. A “Chechia” horizontal test facility is planned for the Meson East area. We will need to install the controls and LLRF for that facility. This will be a prototype SMTF cryomodule system, but it will work for only one 9-cell cavity.

We will be working toward preparing the controls and LLRF for the first US-ILC 8-cavity 1.3 GHz cryomodule that we expect to arrive during FY07.

Deliverable: LLRF for “Chechia” horizontal test facility at Fermilab. Install and commission the controls and LLRF for the first full cryomodule at SMTF.

### **FY2007 Project Activities and Deliverables**

The following section is from the SMTF plan.

Electron Beam Tests:

We outline below possible studies with an electron beam. First, the RF performance of the cavities can be measured directly with beam and secondly, the impact of the cavity on the beam can be assessed. Note that item three below is primarily the responsibility of Penn and the control system performance. However, we plan to be involved with many measurements with the facility. An initial set of measurements would include:

Beam energy: a spectrometer would provide an independent and accurate measurement of the accelerating gradient (RF based techniques are not as accurate). Long Range wake-field

characterization: Measure frequency spectra of bunch positions downstream of cryomodule to search for high Q cavity dipole modes that could cause beam break-up in the ILC. Correlate these data with HOM power measurements. Tests of low-level RF system: demonstrate that a  $< 0.1\%$  bunch-to-bunch energy spread can be achieved in a 1 msec bunch train. (Penn proposed responsibility) Impact of the SCRF cavity on transverse beam dynamics: measure the beam kicks caused by the fundamental mode fields. Study beam centering based on HOM (higher order modes) dipole signals.

To study basic cavity performance during beam operation, the photo injector should provide bunch trains comparable to those envisioned for the linear collider. The main requirements include:

bunch charge: up to  $2e10$  electrons bunch length: as low as 300 microns rms bunch spacing: nominally 337 ns with option of halving this. bunch energy stability  $< 1\%$  rms average (Penn) current stability  $< 1\%$  rms (preferably  $< 0.1\%$  rms) number of bunches: up to 2820 pulse rep rate = up to 5 Hz.

This broad range of measurements will present several technical challenges, the details of which have to be worked out.

Deliverables:

Operate the full LLRF system with a cryomodule and begin to understand the beam and cryomodule performance. We expect to make many measurements on the cryomodule with and without beam.

(Budget justification)

The first year budget is for two incoming graduate students for one summer. Travel and subsistence is included.

The second and third year we request additional funds for a postdoc as well as continued summer support for the students.

(Three-year budget)

Year 1: \$21,794

Year 2: \$95,232

Year 3: \$98,089

Total: \$215,115

Item	FY2005	FY2006	FY2007	Total
Other Professionals	0	43000	44290	87290
Graduate Students	8750	9012	9282	27046
Undergraduate Students	0	0	0	0
Total Salaries and Wages	8750	52012	53572	114334
Fringe Benefits	0	4171	4296	8467
Total Salaries, Wages and Fringe Benefits	8750	56184	57869	122803
Equipment	0	0	0	0
Travel	5000			5000
Materials and Supplies	0	0	0	0
Other direct costs	0	3900	4017	7917
Institution 2 subcontract	0	0	0	0
Total direct costs	13750	60084	61886	135720
Indirect costs(1)	8044	35149	36203	79396
Total direct and indirect costs	21794	95232	98089	215115