# ADVANCED X-BAND TEST ACCELERATOR FOR HIGH BRIGHTNESS ELECTRON AND GAMMA RAY BEAMS*

R. A. Marsh†,S. G. Anderson, T. S. Chu, C. A. Ebbers, D. J. Gibson, F. V. Hartemann, C. P. J. Barty, LLNL, Livermore, CA 94550, USA
C. Adolphsen, E. N. Jongewaard, S. G. Tantawi, A. E. Vlieks, J. W. Wang, T. Raubenheimer SLAC, Menlo Park, CA 94025, USA

*Abstract*

In support of Compton scattering gamma-ray source efforts at LLNL, a multi-bunch test stand is being developed to investigate accelerator optimization for future upgrades. This test stand will enable work to explore the science and technology paths required to boost the current 10 Hz monoenergetic gamma-ray (MEGa-Ray) technology to an effective repetition rate exceeding 1 kHz, potentially increasing the average gamma-ray brightness by two orders of magnitude. Multiple bunches must be of exceedingly high quality to produce narrow-bandwidth gamma-rays. Modeling efforts will be presented, along with plans for a multi-bunch test stand at LLNL. The test stand will consist of a 5.5 cell X-band rf photoinjector, single accelerator section, 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 quadrupole scanning techniques. Multi-bunch diagnostics will be developed so that the beam quality can be measured and compared with theory. Design will be presented with modeling simulations, and layout plans.

## INTRODUCTION

Extremely bright, narrow bandwidth gamma-ray sources are expanding the application of accelerator technology and light sources in new directions. Mono-energetic gamma-rays enable new features in nuclear applications by tapping into the very narrow unique nuclear resonances of various isotopes. Advancements in nuclear material detection, fuel rod assay, and waste management only begin to hint at the possibilities made possible by this transformational technology. Narrow bandwidth gamma-rays place very stringent demands on the laser and electron beams that interact to produce them. Next generation advancements in gamma-ray production require these demands be satisfied, while simultaneously increasing the average flux of gamma-rays at a specific energy (that is, N/eV/sec at the energy of interest). In order to increase the total flux, the machine currently being constructed at LLNL will operate at 120 Hz, while researching methods to raise the effective repetition rate of the machine to greater than kHz.

The effective repetition rate will be increased by operating the RF photoinjector in a multi-bunch mode, accelerating multiple electron bunches per RF pulse. This multi-bunch mode will require the same stringent requirements for the electron bunch properties including low emittance and energy spread, but across multiple bunches. The strategy for achieving multi-bunch operation at very low emittance and energy spread is as follows. 1) Redesign RF photoinjector for more robust high brightness operation, 2) Model effects that will degrade multi-bunch gamma-ray quality including: dark current, wakefields, and beam-loading, 3) Measure simulated effect in experiment, 4) Redesign RF photoinjector as necessary. An independent test stand has been planned and designed to carry out multi-bunch experiments to benchmark design performance and theoretical modeling. This paper will summarize the design for the test stand layout including beam dynamics, and the design of the RF photoinjector.

## TEST STAND LAYOUT

The advanced X-band test accelerator will be an independent beamline capable of performing experiments on future improvements to the LLNL center for gamma-ray applied science. The high power RF used for the main 250 MeV linac will also be used to power an RF photoinjector and single traveling wave accelerator section [3]. The same photocathode drive laser will also be used to generate multiple photoelectron bunches [2]. The test stand is shown in Fig. 1. Beam dynamics simulations predict less than 1 mm-mrad rms emittance, as shown in Fig. 2. The parameters for the test stand and the simulation are shown in Table 1. Beamline diagnostics will include pop-in screens, ICT, energy spectrometer, and a Faraday cup. In addition, a multi-bunch diagnostic beam deflector is planned so that the properties of multiple bunches can be distinguished independently.

## RF GUN DESIGN

The RF photoinjector is based on a high gradient 7 MeV 5.5 cell X-band RF gun [4, 5, 6]. Improvements specific to our application have been implemented and will be described in this paper. *PARMELA* simulations revealed that

* This 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 the Department of Homeland Security Domestic Nuclear Detection Office

† marsh19@llnl.gov

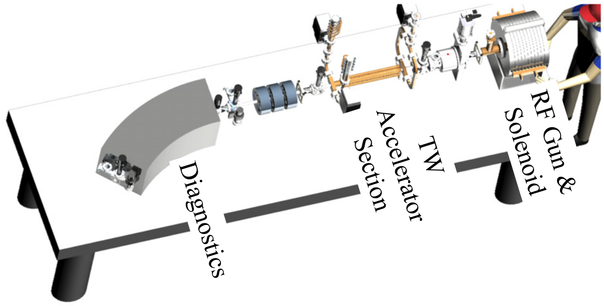


Figure 1: Layout of X-Band Test Stand including RF photoinjector and emittance compensation solenoid, single traveling wave accelerator section, and diagnostics.

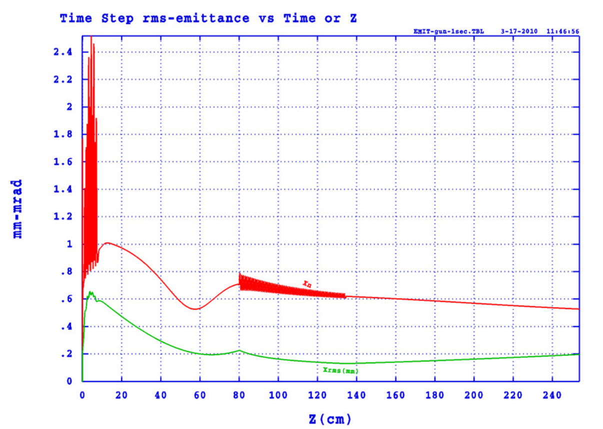


Figure 2: *PARMELA* simulation of test stand beam dynamics. Normalized rms emittance of 0.6 mm-mrad, including thermal effects.

a longer first half cell, as simulated with *SUPERFISH* resulted in a lower final emittance for the setup planned at LLNL. As a result a full redesign of the RF gun has been performed, using a longer first half cell, lengthened from a 0.49 cell to a 0.59 cell. A schematic for the RF gun is shown in Fig. 3.

The RF gun properties required for complete design are: field balanced across all cells, mode frequency of 11.424 GHz, and a coupling $\beta$ of $\sim$1.8. The circular iris profile, cell lengths (except for the first half cell), and coupler geometry are all adapted from the design of the new X-band RF gun [6]. This new RF gun boasts an improved mode separation of $>$10 MHz, which decreases mode beating of the electric field on the cathode. The improved mode

Table 1: Test Stand Parameters

| | |
|---|---|
| Charge | 250 pC |
| Emittance | $<$1 mm-mrad |
| Energy | 50 MeV |
| Cathode Field | 200 MV/m |
| Section Gradient | 75 MV/m |

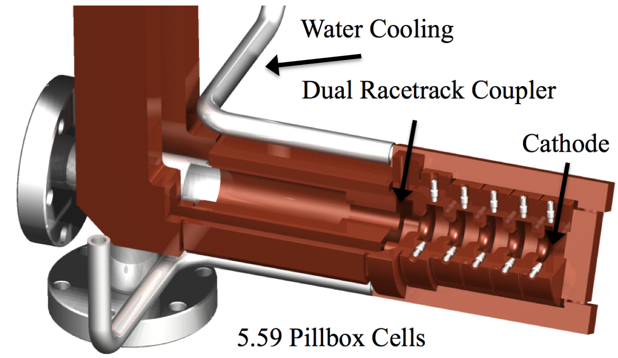


Figure 3: Drawing of RF photoinjector with cutaway, showing 5.59 tunable pillbox cells, dual feed racetrack coupler, and vacuum and cooling fixturing.

separation is demonstrated in Fig. 4. The new RF gun also employs a racetrack coupler to reduce the RF quadrupole field experienced by the electron beam. These improvements were incorporated into the design of a modified RF gun for LLNL.

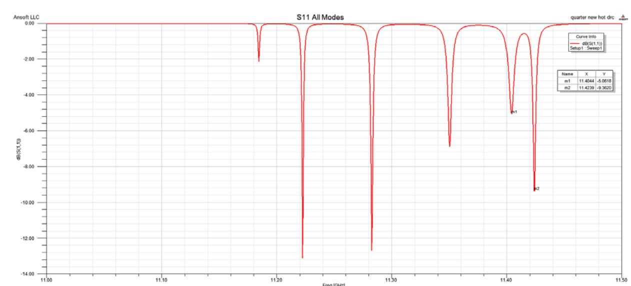


Figure 4: *HFSS* simulation $S_{11}$ result showing $>$10 MHz mode separation.

Complete 3D RF design for the photoinjector was accomplished using *HFSS* . Each modification affects the three design criteria: field balance is primarily a function of relative cell radii; coupling is primarily a function of the coupler cell radius and coupling aperture; the frequency is primarily changed by scaling all cell radii. Each adjustment changes the primary goal being modified, but also affects the other two. Final design is achieved by successive iteration, until all parameters are simultaneously met. The final field balance is quite excellent, as shown in Fig. 5. The final coupling was achieved at 11.424 GHz, with a $\beta$ of $\sim$2, as shown in Fig. 6.

Final modification of the design is necessary to converge on a set of dimensions for engineering drawings and actual copper fabrication. Machining will be done at 20 °C, while operation is planned for 45 °C. Scaling of the design dimensions was calculated and simulated. Design numbers were then truncated to acceptable fabrication tolerances, which required readjustment of the drawing numbers to conform with optimal field balance, coupling, and frequency at the operating temperature of 45 °C. Engineering drawings have

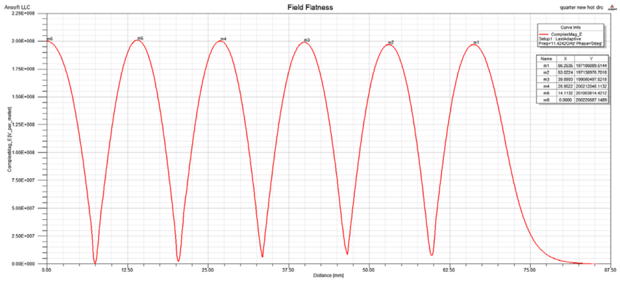


Figure 5: *HFSS* simulation result showing field flatness of ∼1% across all cells.

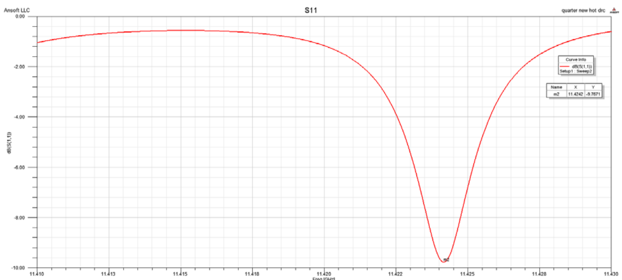


Figure 6: *HFSS* simulation $S_{11}$ result showing an operating mode coupling $\beta$ of ∼2 and a design frequency of 11.424 GHz.

been completed, and fabrication is planned in the near future.

## FUTURE WORK

Future modeling efforts will focus on the predicted performance of the new RF photoinjector, specifically on the multi-bunch performance of the RF gun. Simulation of beam loading will determine the predicted bunch to bunch energy spread, and drive compensation efforts. The test stand experimental program will focus on the fabrication and commissioning. Experiments will benchmark modeling results and focus future research and development on solving the technical challenges to increasing gamma-ray flux and repetition rates. The technology developed on the test stand will serve as the basis for future upgrades to LLNL's center for gamma-ray applied science to further increase the gamma-ray production.

## REFERENCES

[1] F. Hartemann, *et al.*, Phys. Rev. ST Accel. Beams **8**, 100702 (2005).

[2] M. Shverdin, *et al.*, *"Laser Technology for Precision Monoenergetic Gamma-ray Source R&D at LLNL"* **TUPD097**, *these proceedings*.

[3] T. S. Chu, *et al.*, *"500 MW X-band RF System of a 0.25 GeV Electron LINAC for Advanced Compton Scattering Source Application"* **THPEA055**, *these proceedings*.

[4] A. Vlieks, *et al.*, in *High Energy Density and High Power RF: 5th Workshop* AIP **CP625** p. 107 (2002).

[5] A. Vlieks, *et al.*, in *High Energy Density and High Power RF: 6th Workshop* AIP **CP691** p. 358 (2003).

[6] A. Vlieks, *et al.*, *"X-band RF Gun Development"* **THPEA063**, *these proceedings*.