

# TIMING OF ULTRAFAST ELECTRON AND LASER PULSES WITH NARROWBAND THz INTERFEROMETRY FOR ULTRAFAST ELECTRON DIFFRACTION\*

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## Abstract

Ultimately, accurate time of arrival determination of laser pump and electron beam probe will determine the temporal resolution of the SLAC MeV-Ultrafast Electron Diffraction\* (MeV-UED) instrument, and therefore methods to achieve this at femto-second scales is an ultrafast science enabler. Interferometry of THz based e-beam and pump laser THz signals is a natural path towards this goal. As a first step, a detection scheme will be developed in a lab using laser pulses. The second step involves extracting the electron beam signal from a 100 GHz accelerating structure. Subsequently, both pump and electron beam signals are combined, filtered, amplified, and a temporal analysis can be performed. This proposal is for experimental detection and characterization of such signals, which arises from electron beam wakefield excitation of electromagnetic fields in a 100/200 GHz accelerating structure combined with a laser pump derived signal.

## INTRODUCTION

The MeV-UED facility at SLAC provides short (100 fs), low charge (5-20 fC) bunches of 4 MeV electrons for pump probe experiments on a wide variety of material samples [1]. The pump is often a short (60 fs) laser pulse of predetermined wavelength prescribed to excite particular photo-dynamics in the sample of interest. The pump laser is temporally delayed with respect to the electron bunch by a controlled path length, and delay-correlated electron probe diffraction images are captured to infer atomic dynamics. These events occur at fs-ps time scales. The progress towards characterization of this temporal resolution is the subject of this study. Measurements based on known dynamics, ie thin films of Bismuth, indicate instrument resolution at 150 fs rms [2]. Other well known methods can be used to derive e-beam and pump laser pulse length separately, but require lengthy and invasive set-up.

## MOTIVATION

Temporal resolution places important limits on the understanding of photo-excited states of matter. Leveraging both optical and rf characterization, laser and electron beam signals can be distilled to electronic pulses and mixed, the mixed

product signal containing the temporal resolution information. This is performed in the millimeter-wavelength range, where THz optical techniques and w-band rf electronics can be leveraged simultaneously. Fig. 2 shows a schematic description of a potential setup. The MeV-UED laser source is 12 mJ of 800 nm from a commercial chirped pulse amplified Ti:Sapphire system. Compressed 800 nm is split to drive the UV rf photo-electron gun and the sample optical pump. Pump laser can be split or temporarily diverted to the setup. The laser pulse is rectified using non-linear optical rectification. Periodically poled Lithium-Niobate (PPLN) [5] is available to enhance 100 GHz spectral components of the laser pulse. The rectified laser pulse is captured by a w-band mm-wave horn antenna and directed into a band-pass filter, centered at 100 GHz with 4 GHz of bandwidth. This filtered signal is incident in one arm of a w-band magic tee, to be combined with an electron beam signal incident in another arm. The electron beam signal results from electromagnetic modes (wakefields) excited in a metal 100 GHz resonant traveling wave rf structure by the electron beam [4]. The structure is depicted in a test setup in Fig. 1.

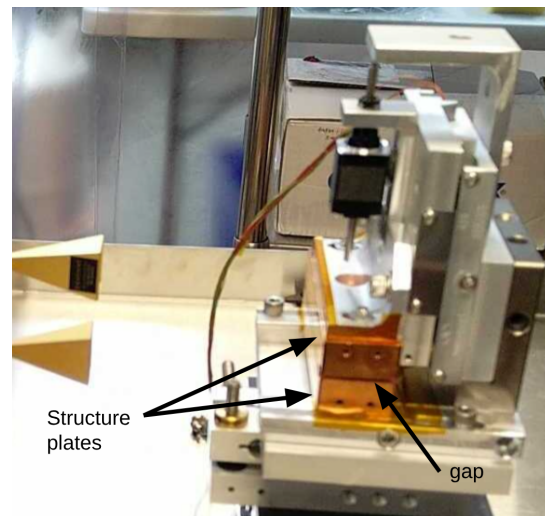


Figure 1: Copper rf structures in a test setup.

## SIGNAL TO NOISE

The 100 GHz signals levels are expected to be low, 30 uW peak power for the 5 fC electrons. Depending on the details of the pump laser rectification, only a small fraction of the spectrum falls into the 100 GHz domain.

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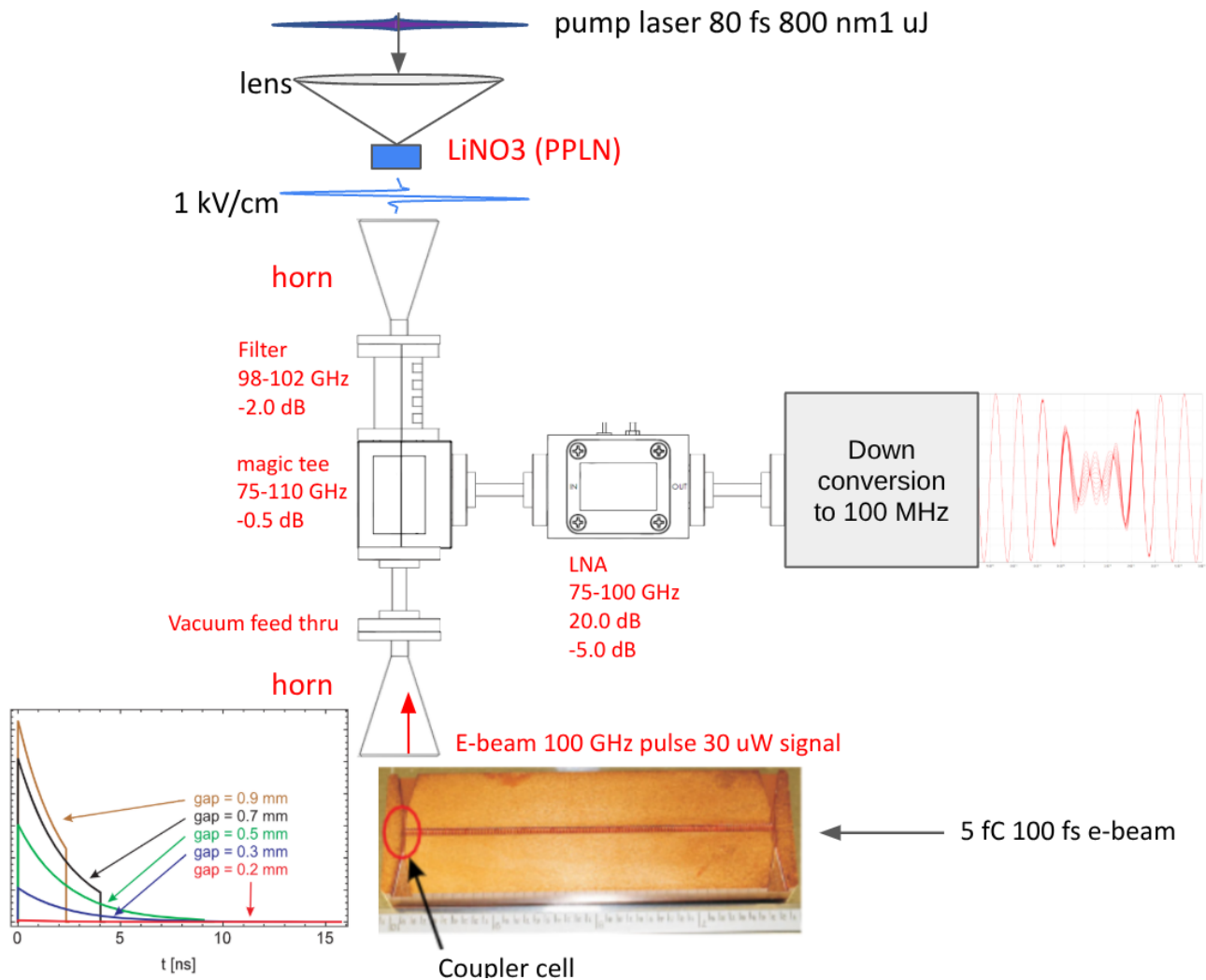


Figure 2: Schematic for capturing pump laser and electron beam signals. Laser is optically rectified in the LiNO<sub>3</sub> PPL to produce few cycles of THz radiation, then filtered at 100 GHz. A passive rf structure extracts 100 GHz radiation from the electron beam. 100 GHz signals are combined in a w-band magic tee, then amplified in a w-band low noise amplifier (LNA).

### Electron Beam Signals

The passive rf structure comprises two metal plates, each with 112 cavities milled into the surface. Each cavity is 1.7 mm wide x 0.6 mm long. Total length of the structure is 10 cm. One of the plates can be seen in Fig. 2. The opposing milled surfaces are arranged to form an adjustable gap as shown in the test setup Fig. 1. The radiation exits through coupler cells at the ends of the structure. The calculated pulse power profiles are shown in the graph of Fig. 2 as a function of the gap between the plates [4]. The structure is well characterized in experiments performed at FACET (Facility for Advanced Accelerator Experimental Tests) at SLAC National Laboratory with 2-3 nC charge, 25 μm bunch length at 20 GeV, achieving peak pulse power of up to 1 MW [3]. Since the power is proportional to the square of the charge, the expected peak power for a 5 fC MeV-UED beam is in the uW range, which can be amplified to around 1 mW. Assuming a signal bandwidth of 1 GHz

and thermal noise of  $-174$  dBm/Hz, a GHz system would see a timing noise of around 30 fs, assuming a electronics noise figure of 10 dBm. Signal to noise is 74 dB in this case.

### Pump Laser Signals

A common technique for generation of few-cycle THz radiation from femtosecond 800 nm pulses is employed [5]. A w-band horn antenna passes 75-110 GHz of this radiation into WR-10 waveguide to be filtered in a 4 GHz bandwidth around 100 GHz. An experiment is currently underway to generate and characterize this signal.

### Combined Signals

The Laser and electron 100 GHz signals are incident in the co-linear ports of a magic Tee and summed at the H-port with preserved phase relationships. The E-port is terminated with a matched load. Reflections are minimized for equal-amplitude input signals. This is a simpler alternative

to optically combining the signals. A low-noise w-band amplifier (LNA) provides 20-30 dB of gain. One or more rf down-conversion stages are required to see the interferometry.

## CONCLUSION

The MeV-UED repetition rate is 1080 Hz providing statistics for a realtime average of instrument time resolution to be used as a tuning signal and monitor of timing drift or jumps during experiments. Ultimately if measurements can be obtained on each shot, sub-100 fs timing may be possible.

## ACKNOWLEDGEMENTS

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