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THz RADIATION GENERATION IN MULTIMODE WAKEFIELD STRUCTURES*

S. Antipov#, C. Jing, S. Baryshev, and A. Kanareykin, Euclid Techlabs LLC, Solon, OH-44139, USA
D. Wang, W. Gai, A. Zholents, Argonne National Laboratory, Argonne, IL-60439, USA
M. Fedurin, Brookhaven National Accelerator Laboratory, Upton, NY-11973, USA

Abstract

A number of methods for producing sub-picosecond electron bunches have been demonstrated in recent years. A train of these bunches is capable of generating THz radiation via multiple mechanisms like transition, Cherenkov and undulator radiation. We propose to use a bunch train like this to selectively excite a high order mode in a dielectric wakefield structure. This allows us to use wakefield structures that are geometrically larger and easier to fabricate for beam-based THz generation. In this paper we present a THz source design based on this concept and experimental progress to date.

INTRODUCTION

THz radiation production is of great interest in science and industry. There are many approaches to the development of THz sources [1], for example laser driven THz emitters, solid state oscillators (high frequency diodes), quantum cascade laser-based and electron beam driven. In this paper we present a THz source based on wakefield excitation by an electron beam. When electron beam passes through a slow-wave structure (power extractor) it decelerates due to emitting Cherenkov radiation (wakefield). The power extractor can be designed to be tunable and operate at THz frequencies. In this case the beam will generate THz radiation. It is important, however, that the beam spectrum has THz frequency content; a DC current will not be able to excite THz radiation.

In the past decade, many approaches have been investigated to generate THz micro bunches that include: bunch generation from a photoinjector with micro laser pulses produced by birefringent crystals [2]; bunch train with a picosecond separation using an emittance exchanger combined with transverse beam masking and other similar techniques [3, 4]; some bunch compression techniques [5, 6] and a two-step approach based on beam self-wake energy modulation followed by a compression in chicane [7, 8].

Once the bunch train with sub-picosecond spacing (and hence a THz frequency content) had been generated it can be used to generate THz radiation by various mechanisms: transition, Cherenkov, undulator and Smith Purcell radiation. In this paper we report on experimental results of high order mode generation in a multimode dielectric loaded wakefield structure by a sub-picosecond bunch train. In Figure 1 a spectrum of TM_{0n} modes is presented on the left. On the right a spectrum of the bunch train is shown in blue. In a multimode structure bunch train will excite modes that belong to its spectrum hence selecting only one or two modes.

EXPERIMENT

The experiment using a tunable dechirper was performed at the Accelerator Test Facility at Brookhaven National Laboratory. Figure 2 shows the general experimental layout.

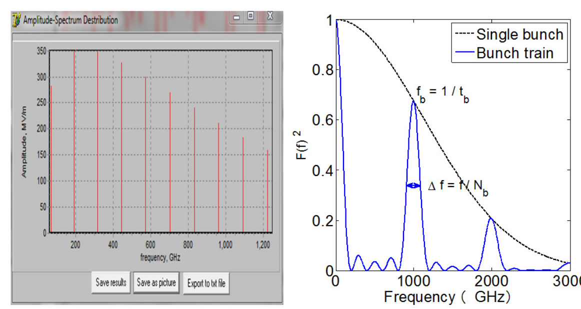

Figure 1: Left : Cherenkov spectrum of the multi-mode wakefield structure. Right : Formfactor of single bunch and bunch train.

For this experiment, the electron bunch was accelerated off-crest in the linac (to introduce a positive 0.33-MeV/mm energy chirp) to 60 MeV and sent through a “dogleg” type magnetic achromat with two identical dipole magnets. A beam collimator mask was placed at the high dispersion point between the dipoles where the beam transverse size was dominated by the correlated energy spread induced in the linac. Therefore the transverse pattern introduced by the mask appeared in the longitudinal charge density distribution after the achromat. The image of the beam taken directly after the mask and shown in Figure 3 (top) represents the longitudinal beam distribution after the dog leg. The actual distance between these beamlets appearing in the longitudinal direction after the dogleg was measured by the interferometer equipped with a helium-cooled bolometer that received the CTR signal emitted by the beamlets passing through a thin foil. From these measurements the distance between beamlets was determined and the phosphor screen image after the mask was calibrated. This measurement is presented on Figure 3 (bottom). The distance between beamlets depends on the initial beam chirp. Changing chirp from 4 degree to 6 degree changes separation significantly: from about 460 microns to about 265 microns.

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#s.antipov@euclidtechlabs.com

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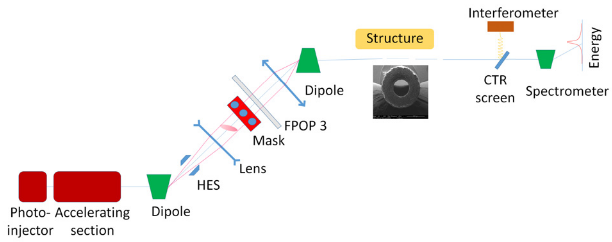

Figure 2: Experiment setup at ATF beamline. HES is used to cut the head and tail of the beam, also reduce the jitter. FPOP3 is a YAG in F-beamline which is quite close to the mask.

The calibrated bunch train had been transported through a dielectric loaded structure made out of 2 inch alumina tube (ε=9.8; ID=0.51mm; OD=1.27mm) metallized on the outside.

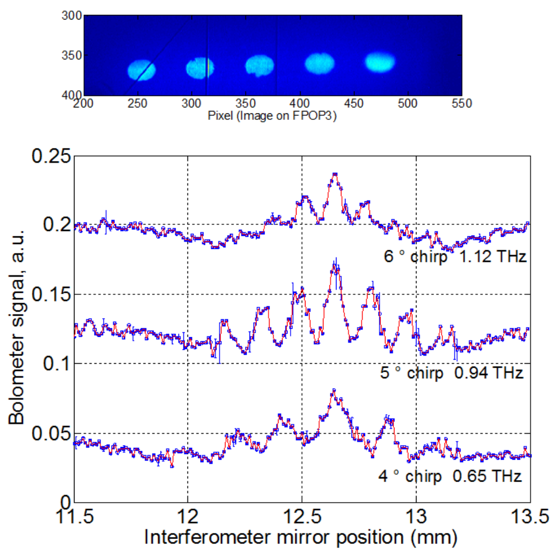

Figure 3: Measurement data of the coherent transition radiation of bunch train under different chirp phase of the linac.

Cherenkov radiation (wakefield) generated by a bunch train had been delivered to the interferometer with bolometer as a detector. The autocorrelation function had been recorded (Figure 4). Besides the Cherenkov signal there is a strong CTR signal produced by the beam as it passes through the hole in a copper mirror which used to direct THz radiation towards the interferometer. The CTR portion of a signal is similar to Figure 3 and quite strong compared to the wakefield signal because the extraction and transmission of the latter one is not optimized. That's why we measure autocorrelation function for mirror locations away from the interferometer mid-point where longer Cherenkov signal is present, while short CTR signal is not.

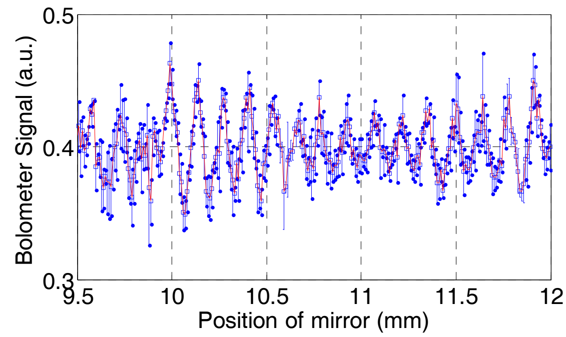

Figure 4: Upper: Bunch train image on FPOP3 with linac phase is about 6° chirp, calibration on FPOP3 is 4.78 um per pixel. Lower: Cherenkov radiation signal excited by a single bunch and bunch train with spacing of 263 um.

Wakefield signal generated by a 1.12 THz bunch train is virtually a sine wave indicating selection of just one or two modes and FFT of it confirms it (Figure 5). In this experiment the mode spacing in the structure is about 100 GHz (Figure 1). We were able to produce a 5 beamlet bunch train centered at 1.12 THz for 6 degree chirp. Such bunch train has a 20% bandwidth (1/5) or ~225GHz. That's why it effectively excited more than one mode (Figure 5).

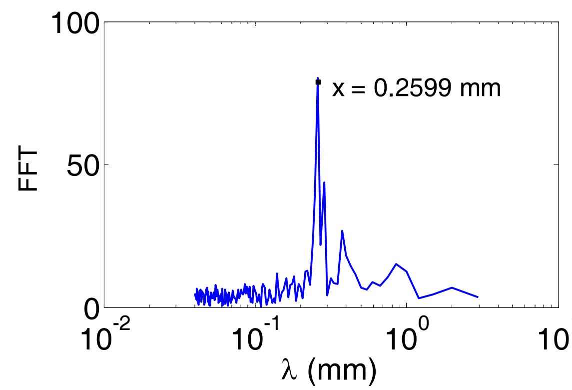

Figure 5: FFT of Cherenkov radiation from multi-mode structure. Left: Spectrum of signal excited by a single bunch; Right: Spectrum of signal excited by bunch train in Fig. 4.

Besides the multimode structure we used a single mode dielectric wakefield structure made out of quartz (ε=3.8; ID=0.4mm; OD=0.55mm). In this structure mode spacing is significant (~1THz) and it is virtually a single mode structure with the TM_{01} mode at ~ 0.5 THz. The autocorrelation measurement shows virtually a sine wave, experimentally demonstrating 2.5% bandwidth (40 oscillations), limited by the travel range of the mirror in the interferometer (Figure 6). Based on transmitted charge and its measured (by CTR interferometry) time structure we calculated that wakefield gradient of 40 MV/m had been generated, peak power in a pulse is 350 kW and energy in a pulse is 58 uJ.

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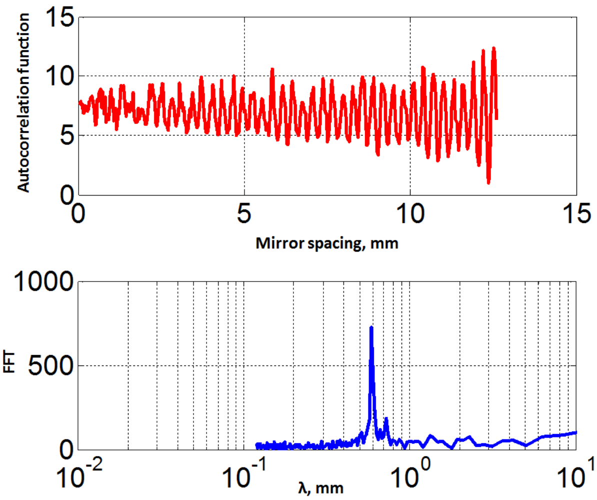

Figure 6: FFT of Cherenkov radiation from multi-mode structure. Left: Spectrum of signal excited by a single bunch; Right: Spectrum of signal excited by bunch train in Fig. 4.

SUMMARY AND PLANS

In conclusion, we have measured narrowband THz generation by a bunch train in a multimode dielectric loaded wakefield structure. We were limited by a number of beamlets in a bunch train. Because of that single mode selection was not possible. In a single mode structure, where mode spacing was significant we were able to generate and measure 2.5% bandwidth 0.5 THz signal. This measurement was limited by interferometer scan range with actual theoretical bandwidth being better than 1%. We estimated that about 58 micro Joule of energy had been generated in a pulse.

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