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THz RADIATION GENERATION IN A MULTIMODE WAKEFIELD STRUCTURE*

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Abstract

A number of methods for producing sub-picosecond beam microbunching have been developed in recent years. A train of these bunches is capable of generating THz radiation via multiple mechanisms like transition, Cherenkov and undulator radiation. We utilize a bunch train with tunable spacing to selectively excite high order $TM_{0,n}$ modes in a multimode structure. In this paper we present experimental results obtained at the Accelerator Test Facility of Brookhaven National Laboratory.

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. This paper is a continuation and improvement of our work reported earlier [9].

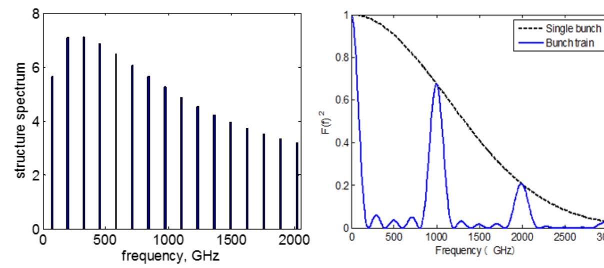

Figure 1: Left: Cherenkov spectrum of the multi-mode wakefield structure. Right: Formfactor of single bunch and bunch train.

EXPERIMENT

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

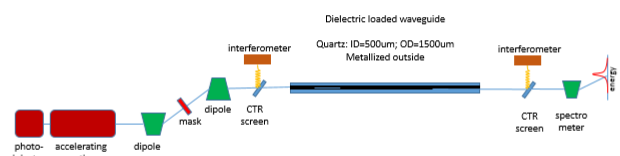

Figure 2: Experiment setup at ATF beamline.

For this experiment, the electron bunch was accelerated off-crest in the linac (to introduce an energy chirp, linear correlation between energy and longitudinal position of the particle) 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 chirp 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 coherent transition radiation (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

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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.

The calibrated bunch train had been transported through a dielectric loaded structure made out of 2 inch quartz tube (ε=3.8; ID=1.2mm; OD=1.8mm) metallized on the outside.

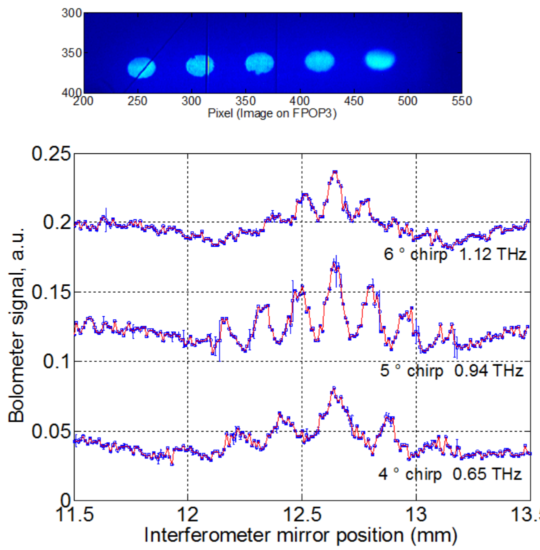

Figure 3: Measurement data of the coherent transition radiation of bunch train under different chirp phase of the linac.

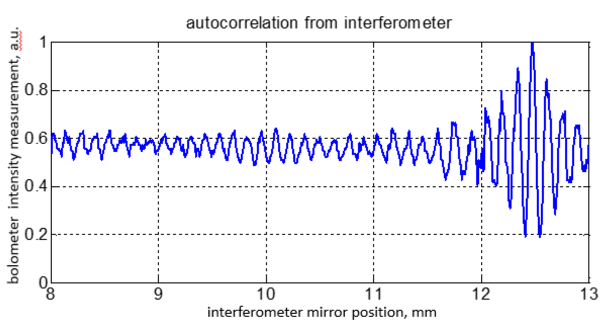

Figure 4: Interferometer measurement of the Cherenkov radiation mixed with coherent transition radiation: bolometer signal intensity as a function of interferometer mirror position.

The autocorrelation function is symmetrical around the maximal intensity measurement at ~12.5 mm mirror coordinate (Figure 4). This point represents the mirror position when optical path in both legs of the interferometer is identical. This measurement has two features: CTR portion of the analyzed signal in the vicinity of maxima (12-13 mm) and the long range ripples corresponding to Cherenkov radiation generated in the wakefield structure. At this moment CTR signal dominates the measurement because collection efficiency for Cherenkov radiation is not optimized. However CTR signal replicates the bunch train timing and is short in time, hence dies off quick. Cherenkov radiation is narrowband: has many oscillations that is why we can characterize Cherenkov radiation by analysing autocorrelation function past the CTR region in the middle.

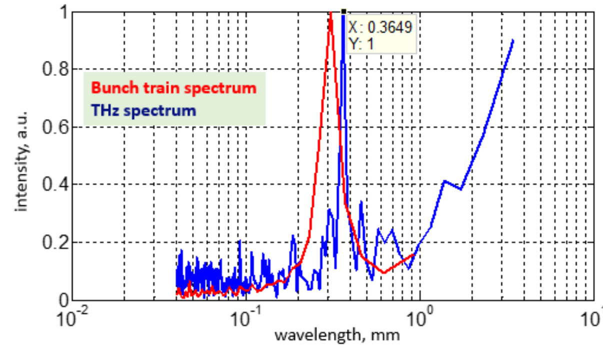

Figure 5: Spectrum from interferometer measurement. Wide-band bunch train spectrum and narrowband spectrum of the generated THz (0.82 THz ~ 365 um).

We got the following results in the experiment. By tuning a bunch train spacing via initial beam chirp we were able to excite individually TM_{03}, TM_{04}, TM_{05} and TM_{06} mode at 0.67, 0.82, 1.2 and 1.58 THz respectively (Figures 5 and 6). Slight difference with theoretical spectrum of the tube comes from the fact that quartz tube dimensions are nominal and actual dimensions may be off as well as vary over the length of the tube. THz signal obtained is a narrowband unlike the wide band bunch train frequency content. The THz signal is much more narrowband (less than 1 % - more than 100 oscillations) than it was possible to measure due to beam stability and signal to noise ratio issues in the measurement system.

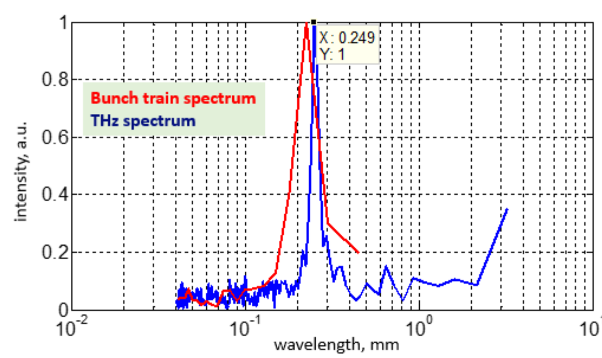

Figure 6: Spectrum from interferometer measurement. Wide-band bunch train spectrum and narrowband spectrum of the generated THz (1.2 THz ~ 250 um).

SUMMARY AND PLANS

In conclusion, we have measured narrowband THz generation by a bunch train in a multimode dielectric loaded wakefield structure. In the past [9] the structure we used had a dense spectrum of $TM_{0,n}$ modes and we were limited by a number of beamlets in a bunch train to be

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able to select a single mode without exciting neighboring modes. The new structure has a wider spacing between the modes in frequency domain. This time a number of different frequencies were individually excited by a tunable bunch train in the same structure. Produced signals are narrowband and the choice of frequency (mode) is controlled by the tuning of the bunch train passing through the structure. Ability to excite high order modes in the structure allows as to work with large aperture dielectric loaded waveguides. This method can be used as a quick tuning over discrete set of frequencies in a wakefield based methods of THz generation [8].

REFERENCES

[1] G.P. Gallerano et al., FRBIS02, Proc. of FEL2004, Trieste, Italy (2004); http://www.JACoW.org

[2] R. Bossart et al., CTF3 Design Report, CERN/PS 2002-008 (RF), March 2003; http://www.slac.stanford.edu/cgi-wrap/getdoc/slac-pub-9672.pdf

[3] Y. C. Huang, Appl. Phys. Lett. **96**, 231503 (2010).

[4] Z. Wu, et. al, Rev. Sci. Instrum. **84**, 022701 (2013).

[5] J. Rozenzweig, E-201 SAREC review, 2012; S. Antipov, E-205 SAREC review, 2012.

[6] F. Gao et al., Phys. Rev. ST Accel. Beams **11**, 041301 (2008).

[7] S. Antipov, C. Jing et al., Phys. Rev. Lett. **108**, 144801 (2012).

[8] S. Antipov et al., Phys. Rev. Lett. **111**, 134802 (2013).

[9] S.P. Antipov et al., WEPRO118 , Proc. of IPAC'14, Dresden, Germany (2014); http://www.JACoW.org 2248-2250.