Selective Mode Excitation in a Multimode THz Slow-Wave Structure by a Relativistic Bunch Train

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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 TM0n - like modes in a multimode structure. In this paper we present experimental results obtained at the Accelerator Test Facility of Brookhaven National Laboratory.**

I. INTRODUCTION

THz radiation production is of great interest in science and industry. There are many approaches to the development of THz sources, for example laser driven THz emitters, solid state oscillators (high frequency diodes), quantum cascade lasers and electron beam driven. The beam driven sources of radiation can be separated into non-relativistic vacuum electronics devices and ultra-relativistic accelerator based radiators. The latter are the focus of the paper.

Similarly to vacuum electronics devices the electron beam has to be bunched (modulated) first and then it can effectively radiate at the frequency of its modulation. In recent years a number of methods to produce such microbunching had been demonstrated [1-6]. Such modulated beam can produce THz radiation via a number of mechanisms: transition, Cherenkov, diffraction, Smith-Purcell and undulator radiation. In this paper we present experimental results of selective excitation of high order modes in slow-wave structure by a tunable bunch train.

This experiment had been conducted at the Accelerator Test Facility of Brookhaven National Laboratory. A 57 MeV electron beam with a linear energy chirp (a correlation of particle energy and its position along the beam) was sent through a dipole magnet which worked as a spectrometer introducing a correlation between longitudinal (z) and transverse (x) coordinate (in a dipole bending plane. A hole array mask had been inserted right after the dipole which allowed only particles with certain energies to pass through. The second dipole was placed to cancel the effects of the first one, forming a so-called dog leg. After the second dipole the beam is restored except it is missing particles with certain energies which were blocked by the mask. This results in a mask shape being imprinted on a longitudinal charge distribution due to the initial energy – z correlation. A hole - array mask creates a bunch train. By changing the energy chirp (energy – z correlation) the bunch train periodicity can be adjusted [2]. In the experiment we could adjust the periodicity of the bunch train from about 0.4 to 1.6 THz. This was directly measured by characterizing a coherent transition radiation produced by the bunch train with interferometer using liquid helium bolometer as a detector.

This bunch train was later sent through a dielectric loaded waveguide, ID=0.5mm, OD=1.5mm, 1 inch long quartz tube metallized on the outside. Such structure supports modes with phase velocity equal to the speed of light (bunch train velocity). Because the thickness of the dielectric tube is compared to the inner diameter TM0n modes are rather close to each other and a single electron bunch is capable of exciting high order modes. By tuning the periodicity of the bunch train we can selectively excite $TM_{0,n}$ modes, when the frequency spectrum of the bunch train is overlapped with a certain mode causing electrons to excite this mode almost exclusively.

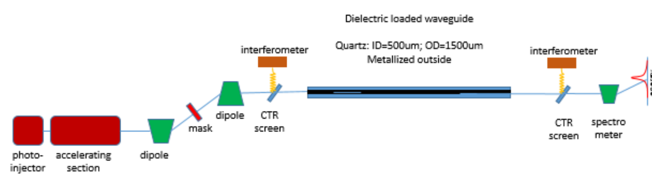

Fig. 1. Experimental layout.

II. RESULTS

In the experiment we used the interferometer to characterize Cherenkov radiation (waveguide modes) excited by the bunch train. Specifically we could selectively generate $TM_{03} - TM_{06}$ modes (0.67, 0.82, 1.2, 1.58 THz) in the same structure with the same setup by only changing the energy chirp of the initial beam. While the bunch train consist of about 5 beamlets and rather broadband in frequency, the modes generated in the waveguide a narrowband (>1% bandwidth) because of a relatively low group velocity on the order of 20% of speed of light for modes of interest.

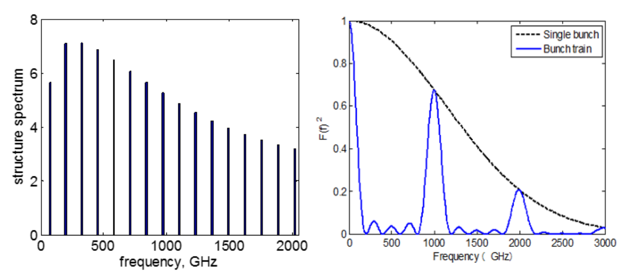

Fig. 2. Left: Cherenkov spectrum of the multi-mode wakefield structure. Right: Form factor of a single bunch and a bunch train.

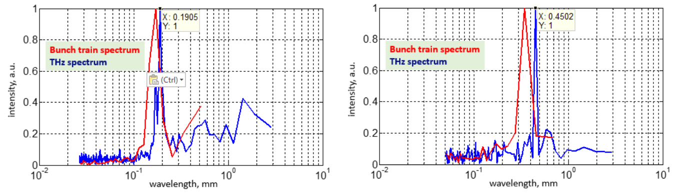

Fig. 3. On both plots: red – normalized spectrum of the bunch train, blue - spectrum of the Cherenkov radiation. Left: bunch train is tuned for larger spacing (about 400 microns); it excites a narrowband signal with 450 micron wavelength (0.67 THz). Right: bunch train is tuned to a small spacing (about 150 microns) it excites a narrowband signal at 190 micron wavelength (1.58 THz).

III. SUMMARY AND FUTURE WORK

In the experiment reported here we used a tunable bunch train with relatively wide bandwidth to excite selectively modes in a multi-mode wakefield structure. In the same setup we were able to generate a number of discrete frequencies from about 0.5 – 1.5 THz by changing the input beam parameters. The generated signals are narrowband, with about 1% bandwidth and can be adjusted by structure design (group velocity) in combination with its length. The frequency of generated radiation can be controlled by the structure dimensions and bunch train spacing, i. e. high order mode selection. While there was no effort made to couple out excited modes from the structure to the free space we were able to detect these signals with a Golay cell. This suggests that few micro Joules of energy per pulse was extracted, which corresponds to about ten kW of peak power.

REFERENCES

[1] J. Power and C. Jing, AIP Conf. Proc. 1086, 689 (2009).
[2] P. Muggli, et. al. Phys. Rev. Lett. 101, 054801 (2008).
[3] Y. C. Du, W. H. Huang, and C. X. Tang, Chinese Phys. C 36, 151 (2012).
[4] P. Piot, et. al, Appl. Phys. Lett. 98, 261501 (2011).
[5] D. Xiang and G. Stupakov, PRSTaB 12, 080701 (2009)
[6]. S. Antipov, et. al., Phys. Rev. Lett. **111**, 134802 (2013)