Simulation of THz Spectra

Bolko Beutner, DESY

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THz spectra and their dependence on ACC1 phase were measured

- Strong changes of power for less than a degree phase change
- Patterns in the spectra for high off crest phases
- Structures in the range of a few ten micron
Introduction

- To understand the features of the spectra start-to-end simulations (thanks to M. Dohlus) for FLASH are used
- Spectra are generated from the longitudinal charge profiles for different ACC1 phases
- THz spectrometer response is generated from these spectra
Procedure Overview

• From the Fourier transform of the longitudinal charge profile one calculates the Form factor, the wavelength spectrum, and the spectrometer response

\[ \frac{dU_N}{d\omega} \propto |F(\omega)|^2 \]

\[ \frac{dU_N}{d\lambda} \propto \frac{1}{\lambda^2} |F(\lambda)|^2 \]
Simulated Form factors

ACC1 Phase

[Graph showing simulated form factors with intensity on the y-axis and frequency on the x-axis, and wavelength on the x-axis with intensity on the y-axis for different samples labeled from 6 to 15.]
ACC1 Phase scan

- Steep changes of spectra with ACC1 phase (only 1 deg steps in simulations)
- Substructure for off crest phases higher than about 10 deg
- Noise below about 20 micron
Comparison with measurements

- Phase shift between simulations and measurements of about 2deg or additional features at ~7deg in measurements
- simulations were not set up to match measurements (ACC1 gradient and BC bending angles might be slightly different)
Double spike structure

- Double spike structures after about 9 deg off crest
- Double Gaussian is fitted to charge profile and used for spectra generation
Comparison with double Gaussian I

- No proper fit at 8 deg (no double spike)
- Double Gaussian is not the best choice at 10 deg
Comparison with double Gaussian II

- Agreement of coarse structure between double Gaussian and Simulations
- For Phases higher than 12 deg the spike in the spectrum is reduced for real data (effects of third spike?)
Correlations with bunch dimensions

- Spike separation is compared with the wavelength spectrum
- Some correlations are visible
Toy model

- Simple structures build from Gaussians are used for qualitative understanding.
- Small scale modulations lead to a sharp signal at the wavelength.
- Two Gaussians gives rise to substructure in the spectrum.

Gaussian (sigma = 0.5ps)
Gaussian with sine (lambda = 1ps/300um)
two half Gaussians (Delta s = 8ps)
Substructure

- Minima are caused by destructive interference between the radiation of the two spikes

\[ \varphi(\Delta t) = 2\pi \frac{\Delta t}{T} \]

\[ \varphi \equiv (2n - 1)\pi \]

\[ \nu_n = \frac{1}{T} = \frac{2n - 1}{2\Delta t} \]

\[ \lambda_n = \frac{\Delta tc}{n - 1/2} \]
Comparison with Spectra

- Spike separation from the double Gaussian fit is used to estimate minima position
For ACC1 phase offsets higher than ~8deg minima patterns exist in measured spectra
=> indications for double spike structure

Qualitative correspondence to estimated pattern

H. Delsim-Hashemi

Bolko Beutner, DESY
• Minima structure in the phase range from 9 to 10 deg are determined and used for an estimation of spike separation $\Delta t$ using a linear fit to $\lambda_n = \frac{\Delta tc}{n - 1/2}$.
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$$\lambda_n = \frac{\Delta t c}{n - 1/2}$$
Comparison with Simulations

- Estimated spike separation from ~150 to ~300 micron
- Simulations go from ~100 to ~150 micron
- Simulations are not specifically set up to match measurements (RF and BC settings)

**Simulations vs Measurements**

![Graph comparing simulations and measurements](image)
Summary

• Steep increase of THz signal for small phase changes is reproduced in simulations
• Phase shift or additional feature at ~7 deg in measurements
• Qualitative understanding of substructure induced by double spikes
• Estimation of double spike structure from spectra is possible (no detailed error analysis yet)
• Simulations give no reliable information on micro bunching (<20 micron)
Next Steps

- Detailed analysis of measured double spike spectra
- Complete analysis of old and recent measured phase scan data

- more detailed start to end simulations
  - finer phase steps
  - Setup of simulations to match measurements
- Extract spike separation from simulated spectra to crosscheck the analysis procedures
- Comparison with micro bunching simulation models (<20 micron)

- Decomposition of charge profiles in more than two Gaussians (Delsim-Hashemi)