Cross-correlation system for femtosecond pulses

Summer student work report

Vlasov Alexander
Moscow State University

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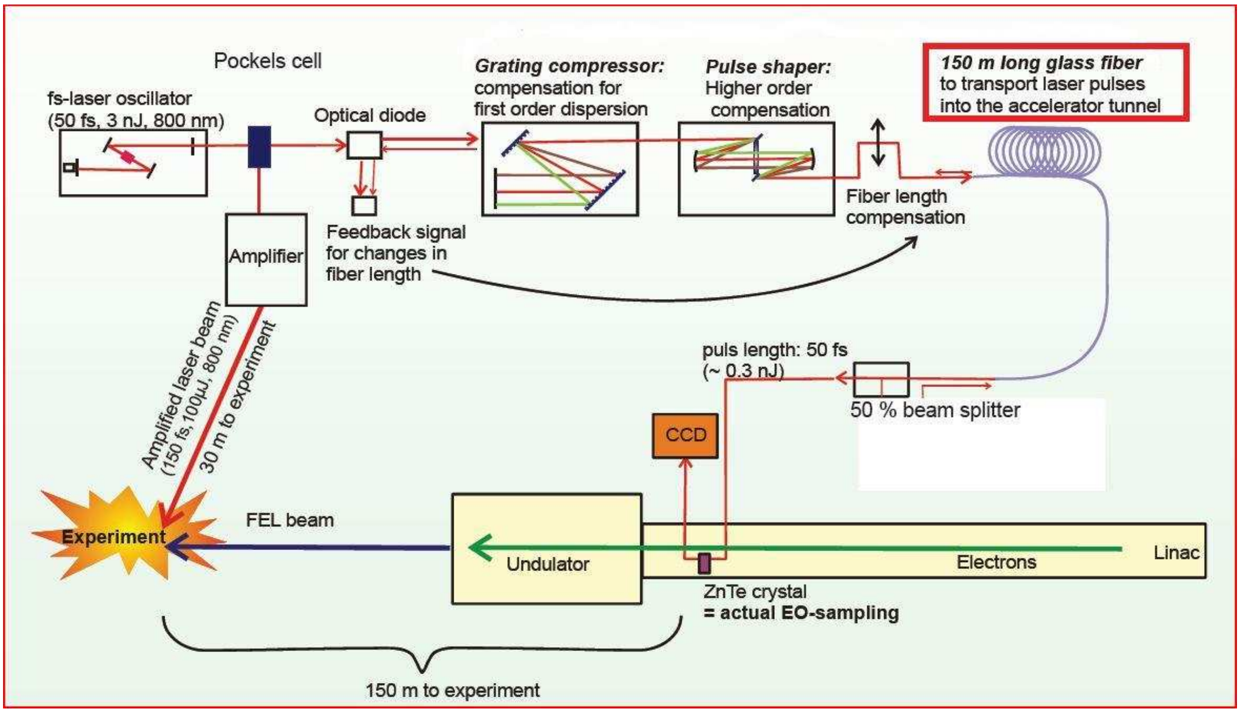
Introduction

FLASH experiment system includes free electron laser and pump-and-probe infrared laser for user experiments. Both lasers deliver short pulses, so such system is used for experiments with time resolution. In that case synchronization is a big issue. There are sources for time drift as in FEL, so in optical laser system.



Jitter measurement by electro-optical sampling VUV-FEL at DESY, 2005-05-02 A.Azima
http://flash.desy.de/meetings/

TEO system (showed as ZnTe crystal with a beam transport on a picture) is used to measure timing between both laser pulses on shot to shot basis. This data can be used to correct user experimental data afterwards.

This TEO system is not effective to measure drifts that are produced in HIDRA amplifier. HIDRA amplifier drifts reason will be explained later.

The principal solution is to use a cross-correlator between HIDRA and oscillator to measure that drift and immediately correct it.

The aim of my small project is to build such a drift-measurement system for pump-and-probe laser system for FLASH users.

At the beginning of the report I will describe basics of non-linear optics. Afterwards principal drift reasons will be described. Last part is system setup overview and results.

Non-linear optics

Non-linear optics describes the behavior of light in non-linear media, that is, media in which the dielectric polarization vector ***P*** responds non-linearly to the electric field ***E*** of the light. Non-linear effects are usually observed at high light intensities such as provided by pulsed lasers, for example.

Non-linear optical processes include many effects, such as:

-Second harmonic generation (SHG), or frequency doubling
-Third harmonic generation (THG)
-High harmonic generation (HHG)
-Sum and Difference frequency generation (SFG and DFG respectively)
-Optical parametric amplification (OPA), amplification of a signal input in the presence of a higher-frequency pump wave (and at the same time generation an *idler* wave (can be considered as DFG))

And many other effects.

Many non-linear effects can be described as frequency-mixing processes. Dielectric polarization ***P*** in media can be written as a power series in the electrical field ***E***

$$P(t) \propto \chi^1 E(t) + \chi^2 E^2(t) + \chi^3 E^3(t) + \cdots$$

Coefficients $\chi^{(n)}$ are the *n*-th order of susceptibilities of the medium.

If we consider an electric field as

$$E(t) \propto E_1 e^{i\omega_1 t} + E_2 e^{i\omega_2 t} + c.c.$$

Where E_1 and E_2 are incident beams, the second order term will be

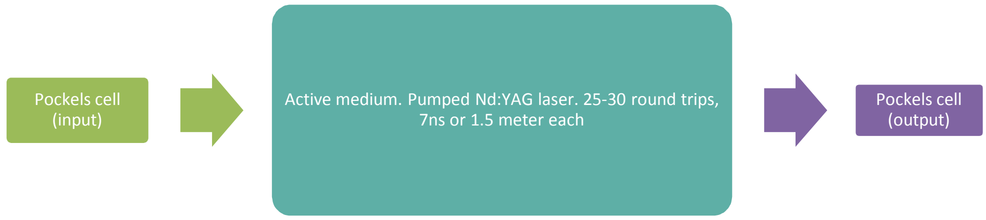
$$P^{(2)}(t) \propto \sum \chi^{(2)} n_0 E^{n_1} E^{n_2} e^{i(m_1\omega_1 + m_2\omega_2)t}$$

Sum goes through different possible coefficients $(n_0, n_1, n_2, m_1, m_2)$. So, with a combination (2,1,1,1,1) sum frequency term can be generated. Also, in our assumption $\chi^{(2)}$ is a scalar. Really, it's a tensor.

Same way as frequency summing, *k*-vectors of the incident beams can be summed too. It will be used in this work later.

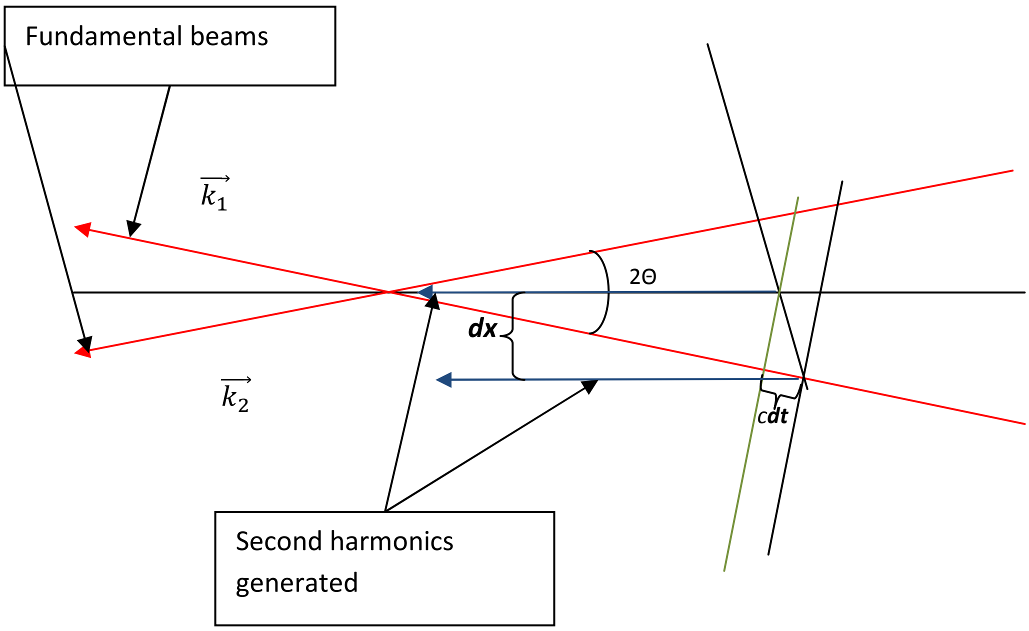
Current system setup and work's purpose

HIDRA amplifier is uses a Nd:YAG pump laser (1064 nm) and used for amplification of Ti:Sapphire (800 nm, around 100fs) laser pulses, which are later used for pump-and-probe experiments. Each pulse goes into active medium though the Pockels cell (fast optical shutter). After about 25-30 round trips (each about 7ns or 1.5 meter) nanojoule pulse is amplified to millijoules, and goes out through another Pockels cell.



Temperature changes for about 1 degree of Celsius over few hours. For steel thermal expansion coefficient is about $12 * 10^{-6} * K^{-1}$, so for 25 round trips of 1.5 meter each, 1 degree temperature increase it is $4.5 * 10^{-4}$ meters, or about 1.5 picoseconds in term of travel time duration (order of magnitude more than pulse duration). Due to so small time intervals, they can't be measured by electronic devices. The only exit is optics.

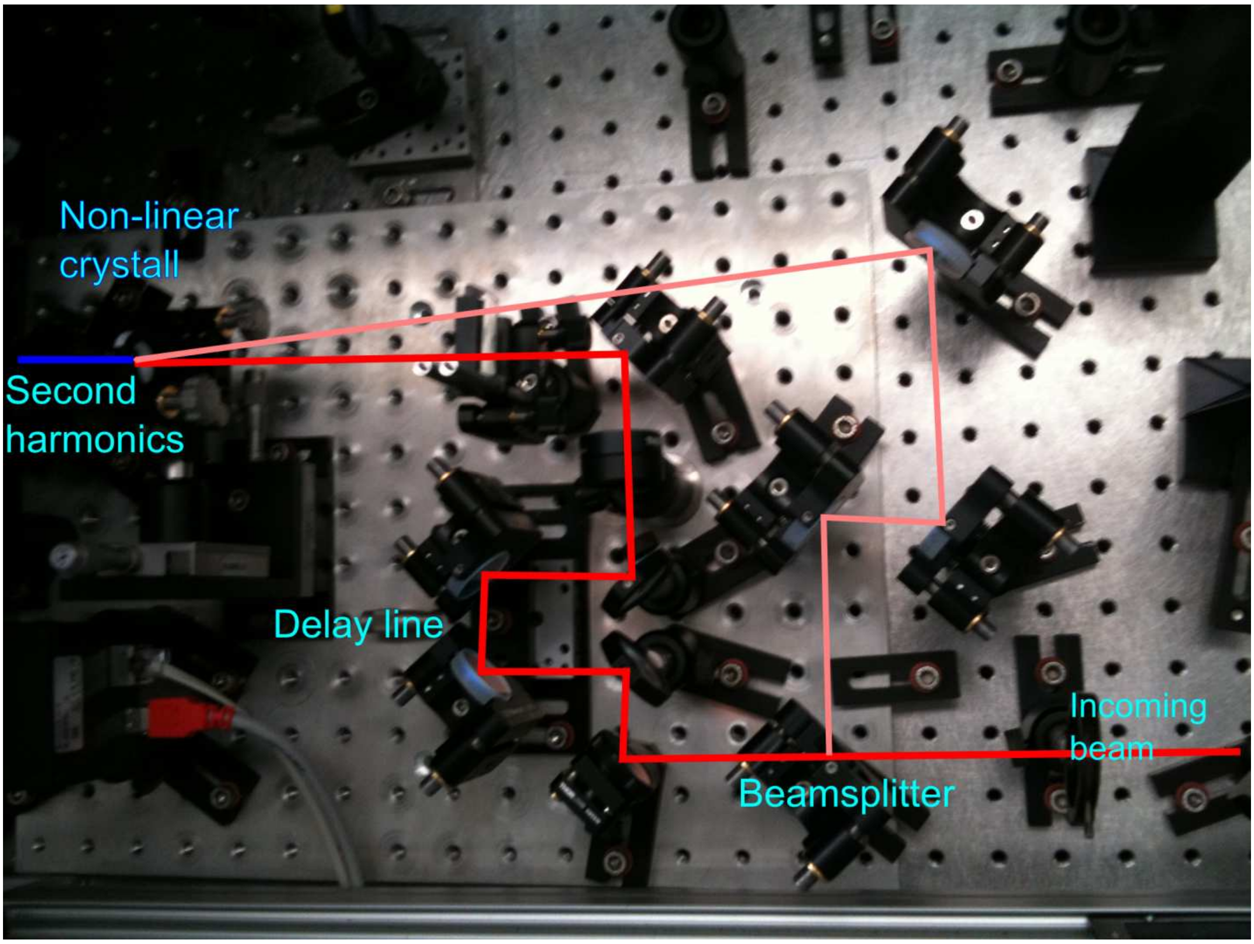
In our setup two beams (one from Ti:Sapphire oscillator, and one from HIDRA) are crossed in non-linear crystal (in our case – 2nd order non-linear BBO crystal). Effects of frequency and *k*-vector summing are used to measure delay ***dt*** in time domain though measuring signal center shift ***dx*** in spatial domain. On the picture below you can see 2 beams with vectors $\boldsymbol{k_1}$ and $\boldsymbol{k_2}$ propagating in non-linear media. From a simple geometry you can calculate spatial shift to time delay ratio (green wave of beam 1 has delay 0, black wave has delay ***dt)***



$$\boldsymbol{dx} = \frac{c * \boldsymbol{dt}}{n * \sin(\Theta)}$$

where 2Θ is an angle between 2 beams.

The first step was to build auto-correlation system, that is similar to cross-correlation system, but uses two beams from the same source (and so they have zero time delay at the beginning) instead of 2 sources, for which we need to find time overlap first. Average scheme of autocorrelation system looks this way:

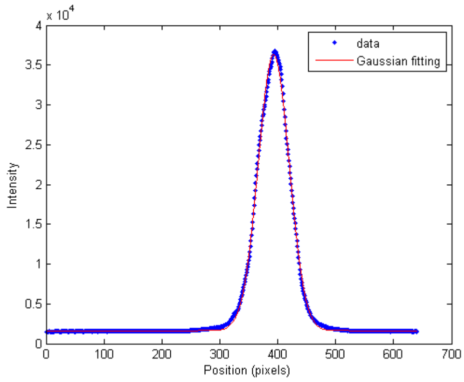


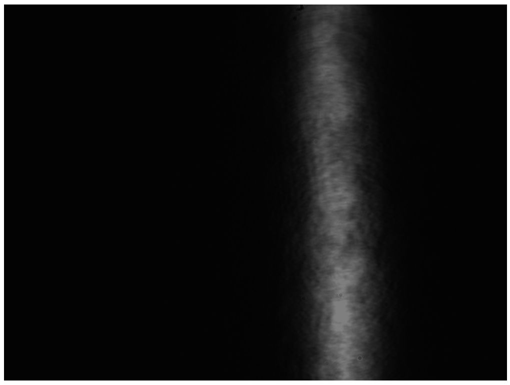
It's not shown on a picture, but both fundamental (primary) beams are still present, as well as seconds harmonics generated with $\boldsymbol{k_1}$ and $\boldsymbol{k_2}$ vectors respectively.

Results

By this time the auto-correlation system is finished and gave promising results:

1) 2nd harmonic generation was observed and shifts in time and linear domains corresponded to formula above

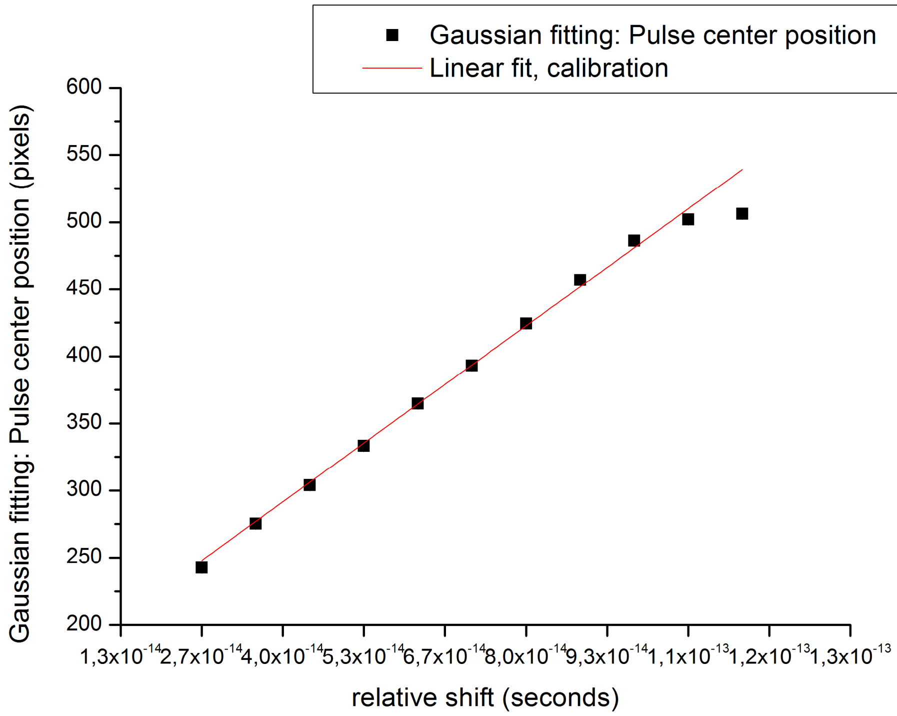




2) Using the micrometer screw of delay line system was calibrated to determine a constant

$$A = \frac{c}{n * \sin(\Theta)}$$

It's not possible to calculate this number because the angle between beams can't be measured precisely. Precision of the constant is about 3% with 10 calibration points



3) Beam profile from the camera was fitted with Gaussian to determine FWHM (full width half maximum), that corresponds to pulse width as

$$FWHM_{autocorrelation} = \sqrt{2}FWHM_{pulse}$$

result of 120fs fitted very well to what was expected during system build-up and measured with other auto-correlators.

4) Also, not as a main purpose, that system can be used as calibration for pulse-compression system, that was done, but not very precisely and only as a background task.