Temporal and spectral characterization of Ultra-Short High Power Laser Pulses

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Within a collaboration with SPARC_LAB
Summary

- Measurements’ Importance
- Laser Diagnostic: **GRENOUILLE**
- Previous Algorithm: **BASIC FROG, GP, COMPOSITE.**
- The **DEVELOPED ALGORITHM**
- Characterization of **VULCAN DATA**
- Characterization of **FULL POWER GEMINI DATA**
- Conclusions
Measurements’ Importance

The characterization of the laser pulse is essential for studying many physical process:

- **The Photo-dissociation** is more efficient in the case of using a chirped pulse;
- The **Non-linear phenomena** like self-focusing, self-phase modulation, etc. which modify the laser beam;
- The **Test of theoretical models** about the laser physics and the **Production of shorter pulses**;
- The detection of the laser parameter, after passing a material, for understanding its **Structural characteristics**;
- The **Valuation of the pulse temporal shape** (pedestal, pre-pulses, etc.) for the employment of this type of pulses in plasma physics (laser-plasma interaction, fusion, etc.).
GRating-Eliminated No-nonsense Observation of Ultrafast Incident Laser Light E-fields

GRENOCILLE is a SPECTRALLY RESOLVED AUTOCORRELATION.

Patrick O'Shea, Mark Kimmel, Xun Gu, and Rick Trebino,
Highly simplified device for ultrashort-pulse measurement,
OPTICS LETTERS / Vol. 26, No. 12 / June 15, 2001
Previous algorithm

In order to characterize a pulse one must use a pulse retrieval algorithm, in which the GRENOUILLE TRACE serves as an input data.

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Previous algorithm

- **BASIC FROG** based on an iterative loop, where after calculating $I_{GREN}$ from an initial guess of $E(t)$, it substitutes the magnitude $I_{GREN}$ with the magnitude $I_{EXP}$ and makes the inverse-FT to conclude the loop;


- **GENERAL PROJECTION** based on a 1-D minimization algorithm;

- **COMPOSITE ALGORITHM** based on the mix of the previous two algorithm with other minimization algorithms.

Ultra-Short Pulse Reconstruction Software

The algorithm is based on the 1-D "CONIUGATE GRADIENT" MINIMIZATION METHOD. It consists of 2 main parts:

1. EXPERIMENTAL IMAGE CAPTURE, image that will be compared with (involves determining the $\chi^2$ "distance") a calculated one

$$I_{GRENOUILLE}^{SHG} = \left| \int_{-\infty}^{\infty} E(t)E(t-\tau)e^{-i\omega t} dt \right|^2,$$

the latter produced by a reasonable initial pulse guess;

2. AN ITERATIVE LOOP (includes a minimization algorithm) that proposes to vary the arbitrary initial pulse for decreasing of the $\chi^2$, succeeding so to obtain a reconstructed pulse as similar as possible to the real one.
Ultra-Short Pulse Reconstruction Software

The experimental image is not ready to be processed, so before processing in the first part of the algorithm, the images have been:

1.1 **SUBTRACTED** from the background;

1.2 **RE-SCALED** to have the needed dimension to be reconstructed;

1.3 **CENTERED** in the maximum of I(t).
Ultra-Short Pulse Reconstruction Software

GRENouille Trace of a **DOUBLE PULSE** made using a Michelson interferometer with a **100 FS Ti:Sa laser, 80 MHZ, 1053 NM.**

**Experimental Grenouille Trace**

**Modified Experimental Trace**

526 nm
Ultra-Short Pulse Reconstruction Software

The first part ends with:

1.4 **CHOICE OF THE FIELD** $E(t)$, in this case:

1.5 **SAMPLING** of the field, $E_j$;
The second part starts with the iterative loop that consists in:

2.1 **CALCULATION** of the GRENouille signal, of the "distance" $\chi^2$, of the $\chi^2$ gradient with respect to $E_j$ and of $\chi^2$ minimum in the gradient direction.

The "distance" $\chi^2$ is made up by 2 parts: one is **the "real distance"** between the sperimental and the analytical image, and the other was added to maintain the **temporal barycenter** in the middle of the analytical one so as to permit a better reconstruction of the GRENouille trace.

2.2 **UPDATING** of the new $E_j$ with the minimum position.

The steps are repeated until reaching conditions for which the reconstructed pulse does not vary significantly.

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Ultra-Short Pulse Reconstruction
Software

- The choice of the *initial field was a double pulse* with the parameters different from the real one.

The phase is reported even where the intensity is zero and it doesn't have a real physical sense and it is not treated with the unwrapping technique;

→ The **CONVERGENCE IS REACHED IN A REALLY FAST WAY** (60 iterations).
The choice of the initial field was a Gaussian pulse with FWHM larger than the temporal length of the real double pulse.

The Gaussian pulse is the most general one. It can be applied to most of the pulses deriving its parameters from the experimental traces.

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→ The phase is reported even where the intensity is zero and it doesn’t have a real physical sense and it is not treated with the unwrapping technique;

→ The **CONVERGENCE IS REACHED IN A FAST WAY** (300 iterations), moreover we reach a lower "distance" value than before.
Vulcan Measurements

In this experimental research was analyzed for the first time, in Target Area Petawatt of Vulcan ($GW$), the laser pulse ($MJ, 2\ Hz, 1053\ nm$) with a DIFFERENT TECHNIQUE from the AC.

The results show an excellent agreement between the two type of measurements.
The **RETRIEVED TEMPORAL SHAPE** are as expected.

M. Galletti, M. Galimberti, D. Giulietti,
*Ultra-Short Pulse Reconstruction Software in High Power Laser System, NIMB May 2015*
Gemini Full Power Measurements

This is a GRENUILLE trace of a GEMINI pulse.

Each beam will deliver **15 JOULES** to target in a pulse of **61 FEMTOSECONDS** (i.e. a peak power of about **PW**), with a shot rate of **ONE SHOT PER 20 SECONDS**.
The GEMINI temporal length is 61 fs while the RECONSTRUCTED TEMPORAL LENGTH IS 64.29 FS.
Gemini Full Power Measurements

The GEMINI spectral length is 29.5 nm while the reconstructed spectral length is 29.7 nm.
Conclusions 1/2

- The algorithm will be improved with functions analyzing information derived by other diagnostic tool (like *SPIDER*) so as to obtain more precise pulse characterization.

- The improved algorithm can be made faster and it could be used to make *ON-LINE MEASUREMENTS*. 
Our purpose is to make temporal and spectral characterization of **FLAME PULSES**.

**FLAME LASER** is based upon Ti:Sa, CPA system that will deliver **30 FS, 800 NM (BW 60 NM), 200 TW**, laser pulses with a **10 HZ** repetition rate.

The system has a **CONTRAST RATIO > 10^8.**
Thank you for your attention!!