Development of GRENOUILLE analysis tools

Contact *Mario.gall22@gmail.com*

Mario Galletti
INFN - LNF, Via Enrico Fermi 40, 00044 Frascati

Marco Galimberti, Alexis Boyle, Pedro Oliveira
Central Laser Facility, Science and Technology Facilities Council
Rutherford Appleton Laboratory, Harwell Science and Innovation Campus, Didcot OX11 0QX

Danilo Giulietti
Physics Department of the University and INFN, Pisa, Italy

Introduction

The characterization of the ultra-short high power laser pulses has always been a challenge [1]. It requires using the same pulse to measure itself, because it does not exist a shorter event to compare to. Moreover, there are many other difficulties to take into account, concerning the pulse itself (no-linear effects, distortions, etc.) and the complexity of the set-up required to perform the measurements.

Diagnostic tool: GRENOUILLE and developed algorithm

One of the most promising techniques is GRENOUILLE [2]. It is considerably more sensitive, extremely easy to set-up and to align. GRENOUILLE is based on a previous technique, FROG [1], with respect to which the experimental configuration provides simple changes (Fig.1): the simplification of the splitting and the recombination line of the pulse to be analyzed, obtained by replacing the beam-splitter, the delay line and the optical recombination of the two copies of the initial pulse with a Fresnel Bi-Prism; the substitution of the measuring tool, obtained by replacing the thin crystal for the generation of the laser second harmonic (SHG) and the related spectrometer with a thick crystal. This choice also offers the advantage of having a SHG signal more intense because it depends on the thickness of the crystal frequency doubler.

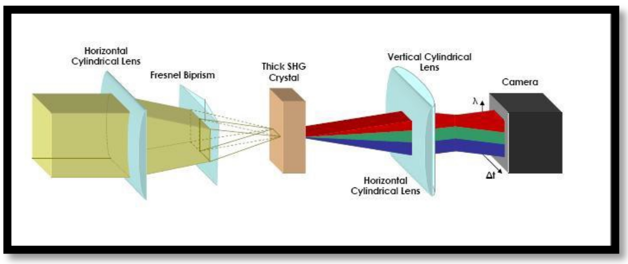

Fig. 1 GRENOUILLE set-up

In this communication we present the development of the analysis software [3, 4, 5] for FROG and GRENOUILLE data. This innovative laser-pulse diagnostics is based on the acquisition of an experimental image, which is subtracted from the background, calibrated and rescaled so it can be compared to the calculated image created starting from a reasonable arbitrary pulse guess. Immediately after being compared to the experimental one, by using a suitable algorithm that changes at each step the arbitrary pulse, we minimize the distance between the two images, finally obtaining the laser pulse shape of the investigated laser pulse. The software has been tested on experimental images acquired in the laser Vulcan Front End (Low Power). Afterward the same measurements have been performed in the Target Area PetaWatt (TAP), with the laser Vulcan at full power [3] at CLF (RAL).

TAP experimental Set-up

A single pulse Auto-Correlator was set up (Fig. 2).

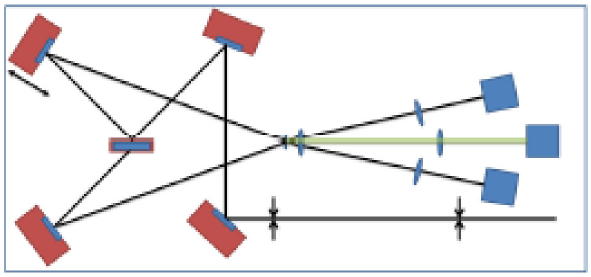

Fig. 2 Auto-Correlator set-up

It was used as a temporal reference tool respect to GRENOUILLE for the measurements of ultrashort laser pulses parameters of the Vulcan laser system. After the calibration of the Auto-Correlator and of the GRENOUILLE apparatus, the measurements were made in TAP. The Vulcan laser is equipped with a Front-End, operating at 2 Hz, giving about 8 mJ pulses, the energy is reduced at the end of the not activated amplifier chain to a few 10 μJ. For this reason the measurements in TAP have been achieved thanks to the bypass of the amplifier chain, so having pulses of a few mJ, while keeping the repetition frequency of 2 Hz (see Fig. 3).

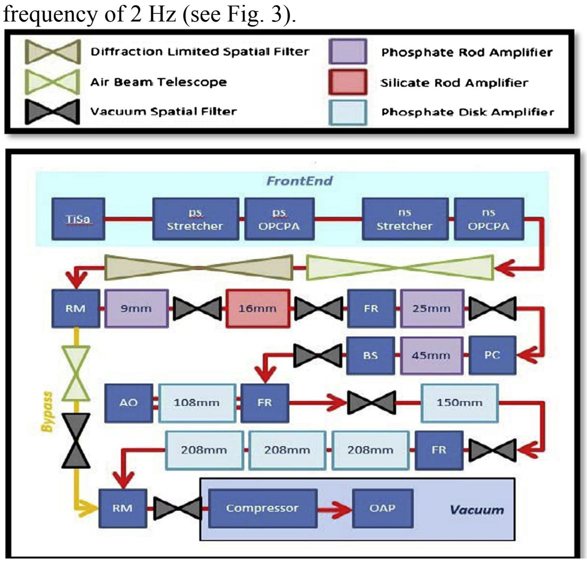

Fig. 3 TAP experimental set-up.

The laser beam after the optical compressor, before the final focusing optics, has a diameter of 60 cm and it propagates in vacuum. Later on the beam is focused by an off-axis parabola with a focal length of 180 cm. The measurements require beam collimation after the parabola, performed by using a lens with a focal length of about 34 mm. In this way the beam is also reduced in diameter to about 1 cm. Through a pair of lenses, assembled in telescope configuration, the beam is propagated outside the vacuum chamber. The use of fully and partially reflecting mirrors allows to direct the beam (3 mm x 1 cm) towards the various diagnostic, in our case the Auto-Correlator and the GRENOUILLE set-up. The experimental set-up in TAP is reported in Fig. 4.

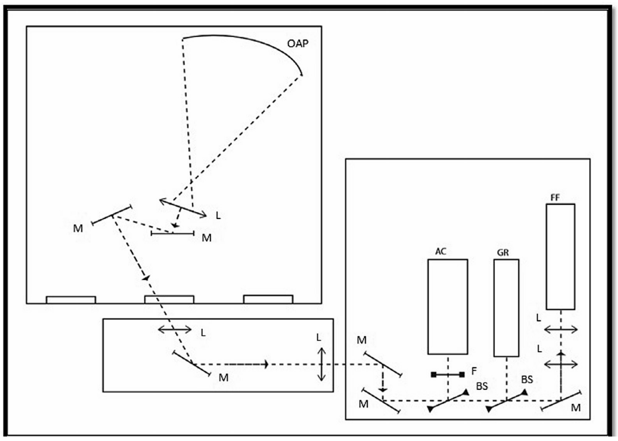

Fig. 4 Diagnostic experimental set-up in TAP.

TAP experimental Data

Fig. 5 reports the images taken with the Auto-Correlator and the GRENOUILLE apparatus, corresponding to the same laser pulse. These are the images that will be considered for the complete reconstruction of the laser pulse and to compare the above mentioned diagnostics techniques.

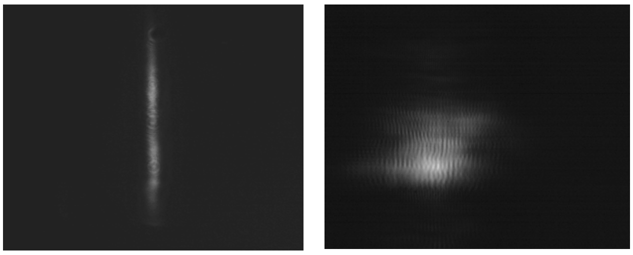

Fig. 5 Autocorrelation trace (LT) and GRENOUILLE trace (RT).

TAP Data processing

The Auto-Correlation image analysis is relatively simple. In order to get the only information available concerning the duration of the pulse, we simply did the horizontal lineout of the image so obtaining, after time scale calibration, the FWHM of the laser pulse (Fig. 7 LT). The analysis carried out on the GRENOUILLE trace by our algorithm allows to obtain the temporal and spectral intensity and phase of the pulse and χ^2that indicates the difference between the input experimental image and the analytical one. The GRENOUILLE images were analyzed taking as the initial reasonable guess for $E(t)$:

$$E(t) = e^{-(\frac{t}{B})^2} e^{-iat^2}$$

with the parameters a (Gaussian second order temporal phase) and B (Gaussian FWHM) in the Table 1.

Temporal Scale	*Spectral Scale*
$B = 0.00861 * \Delta pix$	$beta = \frac{\sqrt{[(\Delta pix * B)^2 0.0165 - 1]}}{B^2}$
$\Delta pix = 107\ pixel$ $B = 0.92142$	$\Delta pix = 105\ pixel$ $beta = 14.589$

TAB. 1 Gaussian initial parameters.

In Fig. 6 is reported the reconstructed image corresponding to the experimental GRENOUILLE one (Fig. 5 RT).

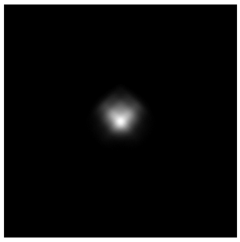

Fig. 6 Reconstructed GRENOUILLE trace.

We can see that the reconstruction do not reproduces faithfully the structures appearing in the corresponding experimental image. However one has to note that the experimental image does not appear to be symmetrical, as it should be for the GRENOUILLE images. This discrepancy may be due to the presence of chromatic aberrations of the beam and/or to the problem connected to the optical system between the crystal and the camera in the GRENOUILLE set-up. However, the analysis program can extract the useful signal component from the experimental image, thanks to research of maximum similarity between the experimental and the simulated image.
On the down side of Fig. 7 the temporal intensity and phase of the analyzed laser pulse obtained as final result of the software is reported.

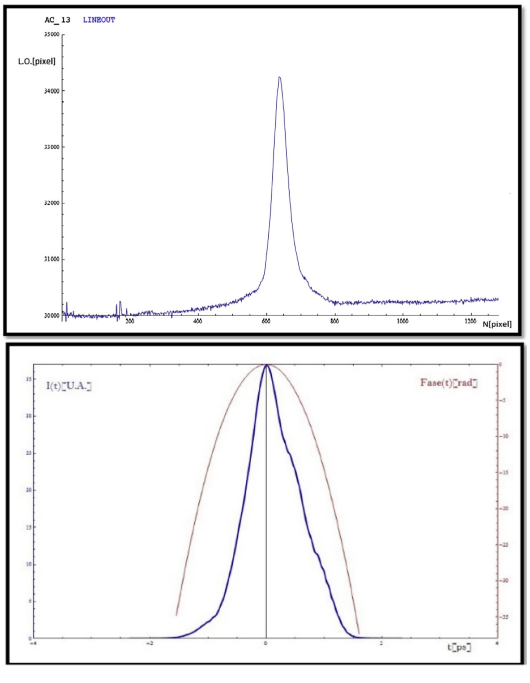

Fig. 7 Horizontal lineout of the auto-correlator image [pixel] vs N[pixel]. De-convolution from auto-correlation to pulse: $1.41\ \Delta_{t[pulse]} = \Delta_{t[AC]}$ (up). Retrieved temporal shape of the analysed pulse (down).

As we can see the values of the FWHM of the laser pulse intensity analysed by the two diagnostics techniques are in great agreement:

$$\Delta_t = 1.0071\, ps\ from\ Auto - Correlator\ trace$$
$$\Delta_t = 1.0038\, ps\ from\ GRENOUILLE\ trace$$

Conclusions

From the analysis of the Front End experimental GRENOUILLE traces, it was verified that the software program is reliable and it is able to completely reconstruct the ultra-short pulse in a very accurate way. Analyzing the results of the AC and those of GRENOUILLE, through the reconstruction software, we note the obtained temporal lengths are comparable, so confirming the accuracy of the characterization of ultra-short pulses by the software developed.

References

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[2] P. O'Shea, M. Kimmel, X. Gu and R. Trebino, Highly simplified device for ultrashort-pulse measurement, OPTICS LETTERS/ Vol. 26, No. 12/ June 15, 2001

[3] M.Galletti, M.Galimberti, D.Giulietti, Ultra-Short Pulse Reconstruction Software in High Power Laser System, NIMB 355, 232-236, 20152015

[4] Article name, Article relative to the PPLA 2015 Conference, in preparation.

[5] Ultra-short pulse reconstruction software applied on the GEMINI high power laser system at CLS facility, RAL, Article relative to the EAAC 2015 Conference, in preparation.