Simple experimental technique for analytically characterizing ultrashort laser pulses

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In this paper we will describe general methodology that allows the phase an unknown pulse to be analytically obtained. This technique brings together time-frequency and interferometric techniques while at the same time it maintains robust error checking capabilities. Besides, it does not rely on the use of iterative retrieval algorithms. Our methodology only requires a simple collinear autocorrelator whose output is spectrally resolved as a function of delay. We call this technique Measurement of Electric Field by Interferometric Spectral Trace Observation (MEFISTO). Mathematically, it can be described as:

$$I^{SHG}(f,\tau) = \left| F_t\left\{ \left(E(t)\exp[i2\pi f_0 t] + E(t-\tau)\exp[i2\pi f_0(t-\tau)] \right)^2 \right\} \right|^2 \quad (1)$$

where $E(t)$ is the slowly varying amplitude of the complex electric field centred at the frequency f_0 and F_t is the Fourier transform with respect to the variable t. To obtain the phase from equation (1), we first calculate its Fourier transform in the τ axis, i.e., $Y^{SHG}(f,\kappa) = F_\tau\{I^{SHG}(f,\tau)\}$. The resulting expression consist of 5 main spectral components at frequencies DC, $\pm f_0$ and $\pm 2f_0$ [1]. Here we focus on the spectral components of $Y^{SHG}(f,\kappa)$ near $\kappa \approx f_0$, which can be written as,

$$Y^{SHG}_{\kappa\approx f_0}(f,\kappa) = 4U_{SHG}(f)U(f+f_0-\kappa)U(\kappa-f_0)\ \cos[\phi_{SHG}(f) - \phi(f+f_0-\kappa) - \phi(\kappa-f_0)] \quad (2)$$

where we write the complex electric field amplitude in polar form, i.e. $E(f) = U(f)\exp(i\phi(f))$ and the second harmonic field is defined as U_{SHG}. Under typical lab conditions, the amplitude of the fundamental pulses, $U(f)$, and the corresponding second harmonic, $U_{SHG}(f)$, are known. Therefore, the only unknowns in equation (2) are the phases of the fundamental and second harmonic pulses, i.e. $\phi(f)$ and $\phi_{SHG}(f)$. To find these, we first take two different slices in the transformed space of the interferometric trace, e.g., at $\kappa = f_0$ and $\kappa = f_0 - \Delta f$ and then we subtract them. This results in:

$$\Delta\phi(f) = \phi(f+\Delta f) - \phi(f) = \cos^{-1}[\Omega(f,\kappa = f_0)] - \cos^{-1}[\Omega(f,\kappa = f_0 - \Delta f)] + \phi(0) - \phi(-\Delta f) \quad (3)$$

where we have defined, $\Omega(f,\kappa) = Y^{SHG}(f,\kappa)\cdot\left(4U_{SHG}(f)U(f+f_0-\kappa)U(\kappa-f_0)\right)^{-1}$. Note that all the functions in the parameter $\Omega(f,\kappa)$ can be experimentally obtained. Equation (3) will be used to obtain the phase of $E(f)$, taking an arbitrary origin $\phi(0)$ and varying f.

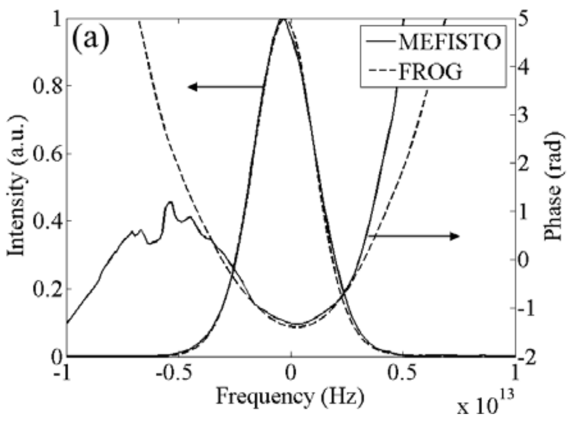

Fig. 1. Spectra and phases of the pulse obtained using MEFISTO (lines) and SHG-FROG (dashed lines).

To show the validity of the MEFISTO methodology, we experimentally obtain the spectral phase of pulses originating from a Kerr-lens mode-locked Ti:Sapphire laser and the results were compared with standard SHG-FROG technique. The obtained results are outlined in Fig. 1, where the spectral intensity and phase are compared. We can see that although the methodologies used were completely different, the intensity and phase of the pulses show very good agreement

In conclusion, we have outlined a new procedure that allows the complex amplitude of ultrashort pulses to be analytically deduced (no iterative retrieval algorithm needed). This technique is based on a simple collinear autocorrelator and it relies on Fourier analysis after obtaining a spectrally resolved interferometric autocorrelation trace.

References

1. I. Amat-Roldán, *et. al*, Opt. Express, **12,** 1169 (2004).