Spatio-temporal pulse distortions

Ultrashort laser pulses lead difficult lives. They're routinely dispersed, stretched, amplified, and eventually compressed to, we hope, their shortest possible width. Whether from an oscillator, a regen, or a high-power amplifier, ultrashort pulses undergo massive manipulations to become so short. But at what price? *Spatio-temporal distortions*.

Unless all the above devices are precisely aligned, the pulse will suffer from spatio-temporal distortions. The two most important and common spatio-temporal pulse distortions are *spatial chirp* and *pulse-front tilt*. A beam with spatial chirp has color varying spatially across the beam. A simple plane-parallel window will introduce spatial chirp if tilted.

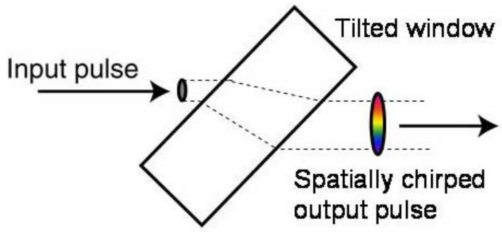

Fig. 1. Passage through a tilted window causes spatial chirp. This is simply due to Snell's law.

Pulse-front tilt is exactly what it sounds like. The very dispersion that is so useful for stretching and compressing pulses also causes pulse-front tilt (as well as spatial chirp) in the pulse if alignment of the stretcher or compressor is not perfect. In fact, pulse-front tilt can be shown to be equivalent to angular dispersion (a simple 2D Fourier transform shows this). The figures below show that dispersive elements, such as prisms and gratings, introduce these distortions.

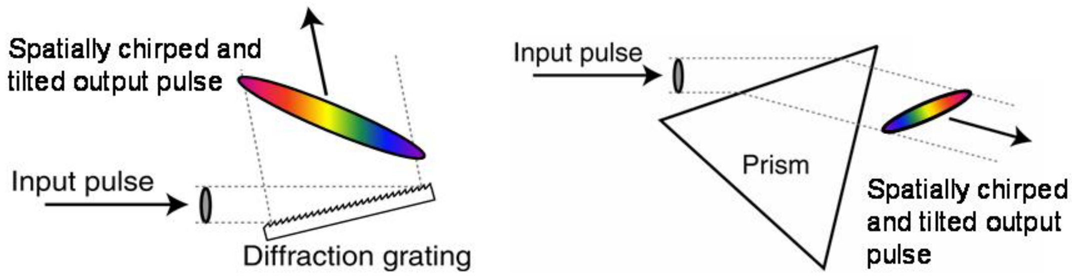

Fig. 2. Dispersive elements can yield both spatial chirp and pulse-front tilt. Pulse compressors, which are composed of as many as four dispersive elements, can yield both of these distortions unless aligned perfectly.

Slightly unequal prism or grating incidence angles in a compressor cause both spatial chirp and pulse-front tilt. A slightly diverging or converging beam entering the device will also. And a slightly wedged output mirror (required to avoid feedback into the laser) will also.

We have discovered that most ultrashort pulses are contaminated with both spatial chirp and pulse-front tilt. Amplified pulses are especially distorted. But no one ever looks for these distortions because, unfortunately, no quantitative diagnostic has been available for them. Research devices have been proposed, but they're so complex that they're more likely to *cause* these distortions than to measure them! One autocorrelator can tell if some of these distortions are present, but it can't tell what or how much.

Remarkably, GRENOUILLE measures both of these distortions quantitatively and very accurately. And it does so without additional components or cost. The GRENOUILLE trace actually contains all the required information!

Spatial chirp causes the GRENOUILLE trace (which is ordinarily symmetrical with respect to delay) to tilt by twice the spatial chirp (see Fig. 3).[1]

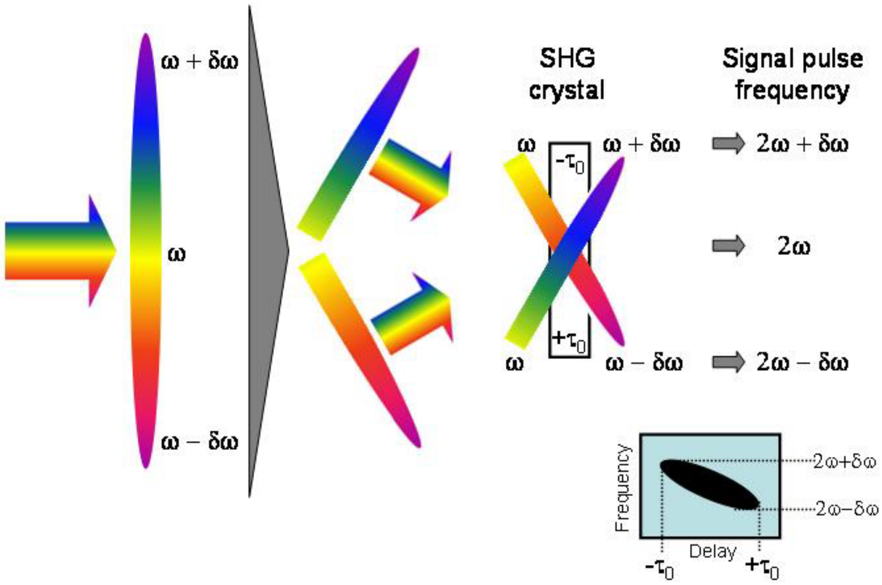

Fig. 3. A pulse with spatial chirp entering a GRENOUILLE. The Fresnel biprism separates the bluer and redder halves of the beam, which cross in the SHG crystal. Notice that the mean wavelength will vary across the trace, indicating the spatial chirp.

Pulse-front tilt displaces the trace along the delay axis in direct proportion to the pulse-front tilt (see Fig. 4).[2] Indeed, GRENOUILLE is the most accurate device ever developed for pulse-front tilt![2]

With GRENOUILLE, you can simply observe the measured trace to see these distortions, or, better, use the VideoFROG software, which, not only rapidly retrieves the pulse intensity and phase, but also determines both of these spatio-temporal distortions for all pulse measurements using GRENOUILLE.

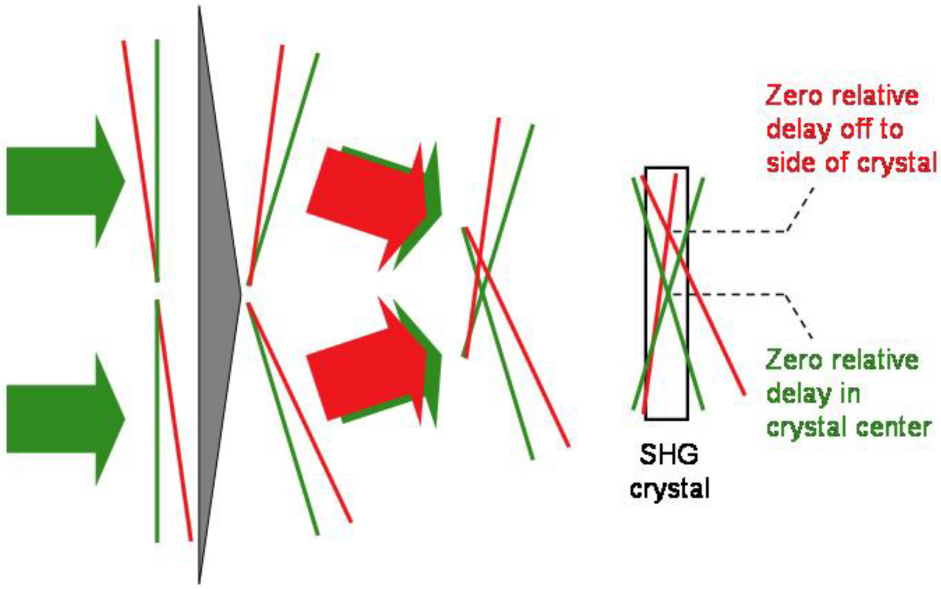

Fig. 4. Pulses with (red) and without (green) pulse-front tilt entering a GRENOUILLE. Notice that pulse-front tilt displaces the trace center by an amount directly proportional to the pulse-front tilt.

References

[1] S. Akturk, M. Kimmel, P. O'Shea, and R. Trebino, *Measuring spatial chirp in ultrashort pulses using single-shot Frequency-Resolved Optical Gating,* Opt. Expr., 11(1), p. 68-78, 2003.

[2] S. Akturk, M. Kimmel, P. O'Shea, and R. Trebino, *Measuring pulse-front tilt in ultrashort pulses using GRENOUILLE,* Opt. Expr., 11(5), p. 491 - 501, 2003.