Swamp Optics

GMP
GENERAL MICROTECHNOLOGY & PHOTONICS

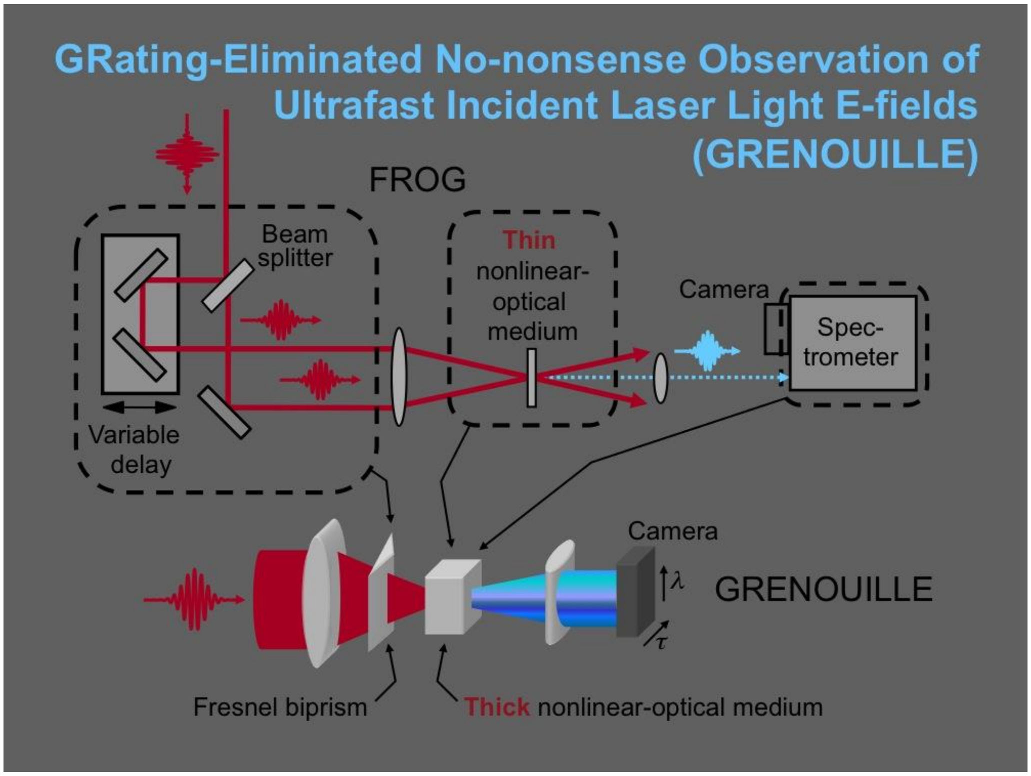
Why GRENOUILLE over a scanning FROG?

Introduction

At Swamp Optics, we are often asked why we don't offer a scanning FROG, in which the delay is scanned over many laser shots and a trace is generated over many laser pulses. This was the original FROG, invented way back in 1991 by Prof. Trebino and his post-docs. And Prof. Trebino, the founder of Swamp Optics, holds essentially all the patents on it. Why does his company not sell the device that he himself invented? Indeed, scanning FROGs are often claimed to be much more versatile than GRENOUILLEs.

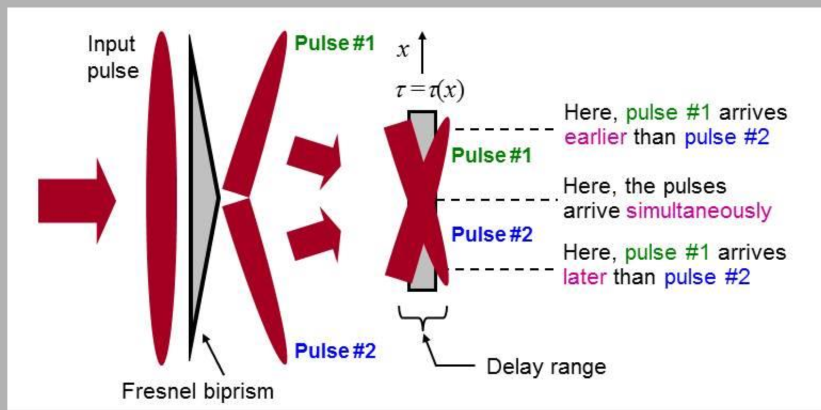
There are many very good reasons why GRENOUILLE is far superior to a scanning FROG, the first of which is that the previous statement is simply not true!

First, the following few figures show how GRENOUILLE works in case you're new to GRENOUILLE. It is a significant simplification of the second-harmonic-generation (SHG) version of FROG. A single prism with a large apex angle, called a *Fresnel biprism*, replaces the beam-splitter, delay stage, and beam-recombining optics. And a *thick* SHG crystal replaces the seemingly essential very thin SHG crystal of a scanning FROG.



The Fresnel biprism

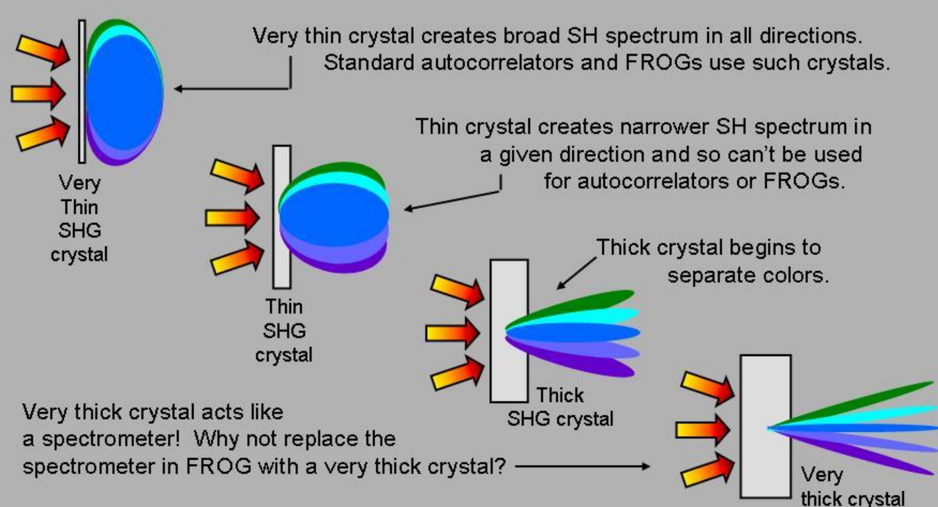
Crossing beams at a large angle maps delay onto transverse position.

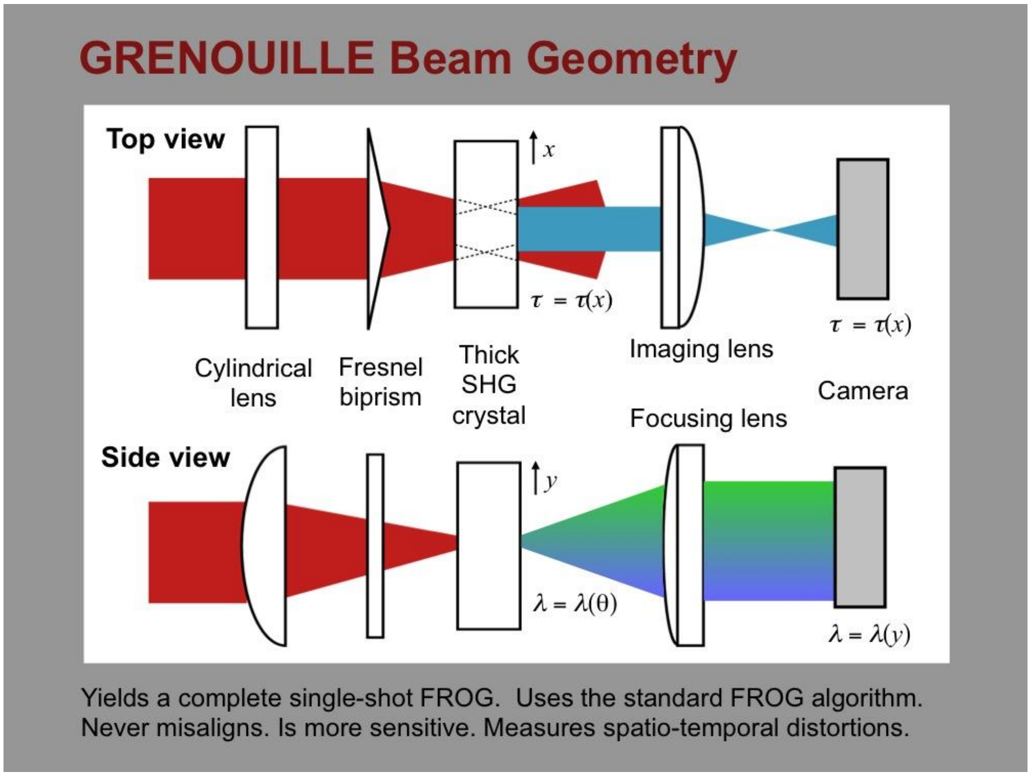


This achieves the entire range of delays for a single pulse and so yields an **alignment-free single-shot** measurement of a pulse.

The thick crystal

Suppose **broadband** light with a large **convergence** angle impinges on an SHG crystal. The SH generated depends on the angle. And the angular width of the SH beam created varies inversely with the crystal thickness.





Versatility

First, suppose that a scanning FROG claims that it can measure pulses from, say, 10fs to 10ps (which is a larger pulse-length range than that of a typical GRENOUILLE).

In order for the scanning FROG to be able to measure the shortest pulse length (10fs), it must then have a very very thin (~10 microns!) crystal; otherwise measurement errors will occur due to the well-known effect of insufficient phase-matching bandwidth in the crystal. In other words, it would only measure a fraction of the pulse spectrum, almost always leading to a shorter pulse than is in fact present. Okay, so it must use a very very thin SHG crystal. But, because the second-harmonic-generation (SHG) efficiency scales with the square of the thickness of the crystal, this means that the device will be very very insensitive and very unlikely to have the required sensitivity to measure longer pulses, which have less intensity for a given pulse energy. You can replace the crystal with a thicker one, but then it's not so versatile anymore, and this costs extra and is considerable extra work and alignment.

Second, for the scanning FROG to be able to measure the longest pulse in the above range (10ps), it must also have a high-resolution spectrometer to measure this longer pulse's much narrower spectral features. But such a spectrometer is also far less efficient and, worse, spreads your trace over many more pixels reducing the device's sensitivity further. You can replace the grating with the correct one for your pulses, but, again, it's not so versatile anymore, and this also costs extra and is extra work and alignment.

The result is that the scanning FROG must be designed for long and short pulses simultaneously, and the compromises are rather severe. In the end it doesn't work that well for any pulse length.

GRENOUILLE, on the other hand, is specifically designed for a much smaller pulse length range and spectral width range, and you choose the perfect range for your particular laser pulse, which is extremely unlikely to range over a factor of 1000 in length. Even better, due to its unique (patented) operating principle, GRENOUILLE does *not* require a very thin crystal; indeed, it *must* use a SHG crystal that is approximately 30 times thicker for a given pulse length than that of a scanning FROG or autocorrelator, yielding much greater sensitivity.

Scanning FROGs also claim that they can measure a wide range of wavelengths. But to do so, you need to buy a different crystal and different optics (and perhaps even a different camera) for the new wavelength range, and you must replace them yourself. So you're really spending about as much money as you'd spend for two GRENOUILLEs, but you'd only have one device, and you'd be doing a lot of modifications and re-alignment yourself. Not so useful.

On the other hand, if you purchase two GRENOUILLEs at the same time, there is significant discount on the second one. So instead of one-size-fits-none device that doesn't work well for any pulse, you could have two devices, each of which perfectly fits your two needs.

The Need for Speed and Accuracy

Worse, scanning FROGs are slow, requiring a few seconds to record a trace due to the need to scan the delay over many pulses, making alignment using them quite irritating. GRENOUILLE yields a FROG trace immediately, with no delay.

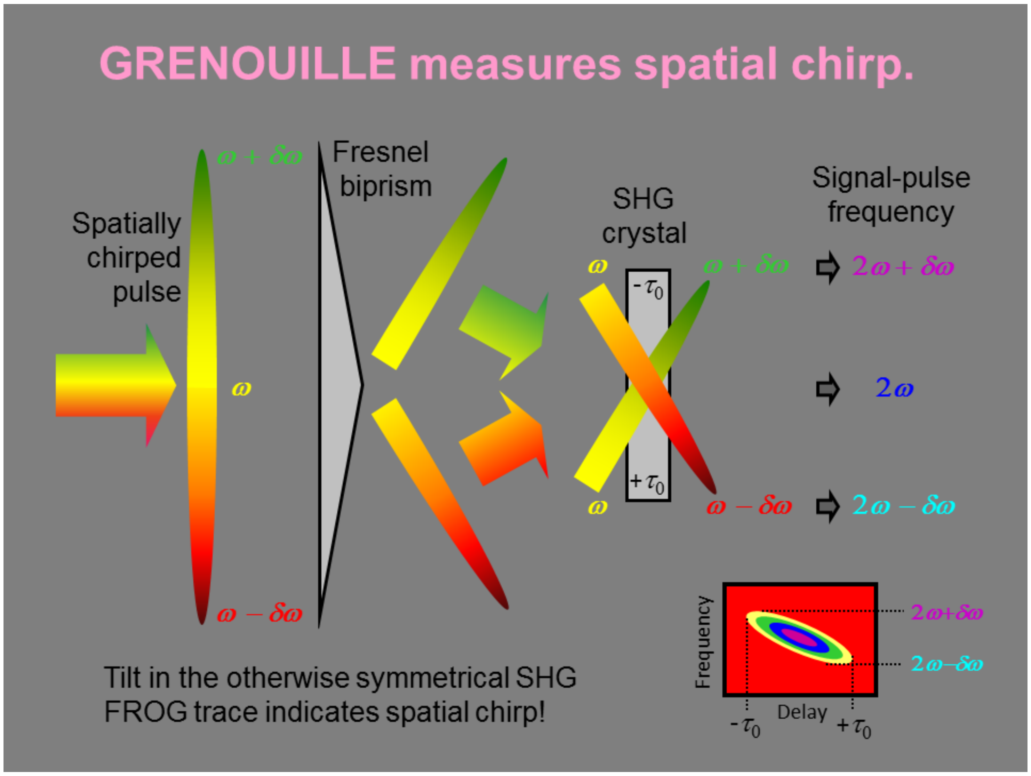
Another result is that you can't ever measure a single pulse with a scanning FROG. As a result, scanning FROGs are more subject to the coherent artifact, which can cause the measurement to be wrong and yield a pulse that is too short. In general, FROG is better at distinguishing this artifact than all other methods (especially SPIDER), but GRENOUILLE's single-shot measurement capability avoids it completely.

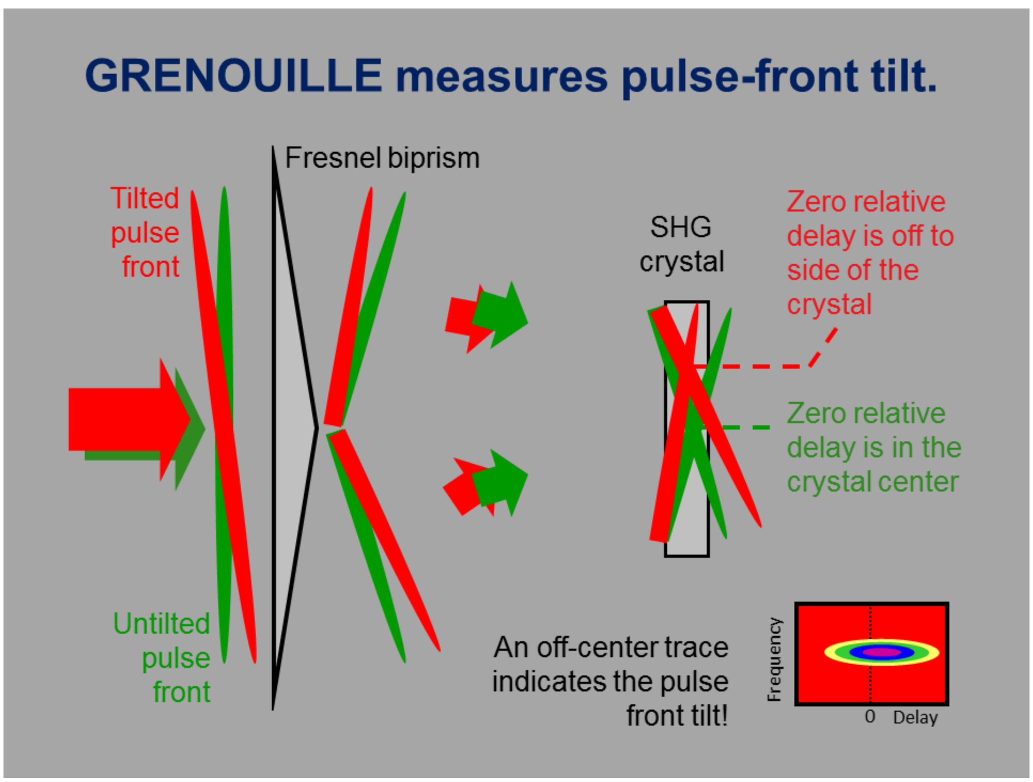
Spatial and Spatiotemporal Measurements

GRENOUILLE also measures the beam spatial profile, which scanning FROGs do *not* do. This saves you the thousands of dollars that beam profilometers cost.

In addition, GRENOUILLE can measure *all of the first-order spatio-temporal distortions*. There are eight of them in all, but once you know two of them, you can find them all. GRENOUILLE explicitly measures the spatial chirp and pulse-front tilt. With these two measurements, you can find all of them for your pulse. These distortions are important, especially if you plan to focus your pulse, as pulses with such distortions will not focus to a high intensity. They are also important if you plan to perform micromachining, where it has been shown that cutting depends sensitively on the pulse-front tilt. Scanning FROGs (or any other pulse-measurement devices for that matter) cannot make such measurements.

For more information, see the tutorial on spatiotemporal distortions.


GRENOUILLE measures spatial chirp.
Spatially chirped pulse
ω + δω
ω
ω – δω
Fresnel biprism
SHG crystal
-τ0
+τ0
Signal-pulse frequency
2ω + δω
2ω
2ω – δω
Frequency
Delay
2ω+δω
2ω–δω
Tilt in the otherwise symmetrical SHG FROG trace indicates spatial chirp!


GRENOUILLE measures pulse-front tilt.
Tilted pulse front
Untilted pulse front
Fresnel biprism
SHG crystal
Zero relative delay is off to side of the crystal
Zero relative delay is in the crystal center
An off-center trace indicates the pulse front tilt!
Frequency
0 Delay

Simplicity of Use

In addition, GRENOUILLE is very robust and never misaligns, and most of the GRENOUILLEs sold over a decade ago still work perfectly. Scanning FROGs have many moving parts and so require frequent re-alignment and component replacement.

Finally, you can waste a great deal of time trying to align your beam into a scanning FROG, for which no simple alignment process exists. But, using the spatial-profile beam measurement, GRENOUILLE has built into it a very easy process for aligning your beam into it. As a result, the average time to align your beam into a GRENOUILLE is less than five minutes. So it's easy to move a GRENOUILLE from one setup to another, eliminating the need for building it into a setup and reducing the effective cost further.

Other Issues

Some people claim that the single-shot beam geometry that GRENOUILLEs use, in which the beams cross at an angle, mapping the delay onto transverse crystal position and then imaging crystal transverse position onto the camera, can yield incorrect results if the beam spatial profile is poor. While this can be true for single-shot FROGs (although your beam profile would have to be very bad for this to occur), it is *not* true for GRENOUILLE, whose thick crystal smooths out any such effects [D. Lee, et al., "The effect—and removal—of an ultrashort pulse's spatial profile on the single-shot measurement of its temporal profile," J. Opt. Soc. Am. B **25**(6) (2008)].

Conclusions

In short, there is really no reason to use a scanning FROG when a GRENOUILLE is available. Scanning FROGs are a quarter-century old and are obsolete, time-consuming, non-robust, and less informative. While they're still a better choice than some very complex and ill-advised techniques that are available, they really offer no advantage over GRENOUILLEs and have numerous disadvantages.

About Swamp Optics

Founded in 2001, Swamp Optics, LLC., offers cost-effective quality devices to measure ultrashort laser pulses. The company specializes in frequency-resolved optical gating (FROG), a method for measuring the time-dependent (or, equivalently, frequency-dependent) intensity and phase of an ultrashort pulse. FROG is rigorous, general, and relatively simple to implement; it has become a very successful technique, with many accomplishments.

Swamp Optics' primary products are GRENOUILLEs and custom FROG devices, the most robust, compact, and simple units available to measure full laser pulse intensity and phase, including the beam spatial profile and spatial chirp.