

**The key to success is tailoring the FROG Scan specifications to the pulse measurements you wish to make, and FROG Scan is field changeable so its specifications can change with your needs.**

### **How do I determine the FROG Scan Specifications I need?**

With the servo on the delay stage of FROG Scan, we can easily achieve any pulse length you need—from 12 fs to nearly 30 ps. However, there are other specifications that are important for accurately measuring ultrashort laser pulses. What are these considerations?

- 1) What is the shortest pulse I want to measure?
- 2) What is the maximum bandwidth I need to consider?
- 3) What is the longest transform limited pulse/feature I need to measure?
- 4) Will I be doing pulse shaping?
- 5) What wavelength ranges am I interested in?
- 6) What is the minimum intensity I need to detect?

### ***Bandwidth***

The answers to the first two questions go hand in hand. A rough idea of the bandwidth needed can be determined by the time-bandwidth calculation  $\Delta\tau_{FWHM}\Delta f_{FWHM}\sim 0.44$ . Thus, if you want to measure a transform-limited 30 fs laser pulse, the widest spectral width is 14.7 THz, or  $489\text{ cm}^{-1}$ . From this, we can determine the crystal thickness appropriate for your needs by determining the group delay in the SHG crystal between the fundamental and the second harmonic. A 30  $\mu\text{m}$  thick BBO crystal can be used to measure pulses as short as 12 fs at 800 nm. A 100  $\mu\text{m}$  thick BBO crystal can be used to measure a transform-limited pulse slightly less than 40 fs in duration at 800 nm. If your pulse is chirped, then you will need a thinner crystal.

### ***Spectral Resolution***

Good spectral resolution is needed for two situations—measuring long pulses and pulse shaping. The first is for measuring long, transform-limited pulses. In this case, we use the time-bandwidth formula to determine the bandwidth of the longest transform limited pulse. For a 1 ps pulse, its bandwidth is only  $15\text{ cm}^{-1}$ . However, the bandwidth of the pulse increases by roughly a factor of  $\sqrt{2}$  when frequency doubled, increasing the bandwidth to  $21\text{ cm}^{-1}$  at the second harmonic. For an 800 nm 1 ps laser pulse, we would need a resolution of 0.34 nm at 400 nm.

For pulse shaping, you also need good spectral resolution because of the spectral filtering and the higher order phase distortions that can create structure in the FROG trace that requires spectral resolution to resolve and provide good contrast.

### ***Sensitivity***

We determine the sensitivity by specifying the peak power multiplied by the average power. This allows us to compare lasers with different pulse widths and repetition rates. Thus, for an oscillator outputting 100 fs pulses at an 88 MHz repetition rate, with an average power of 100 mW, we have a peak power of about  $100\text{mW}/(100\text{fs} * 88\text{MHz}) = 11.4\text{ kW}$ , which gives an average power times the peak power of  $1140\text{ W}^2$ . This is much greater than the sensitivity rating of  $4\text{ W}^2$  for FROG Scan fitted with a 30  $\mu\text{m}$  thick crystal so FROG Scan can easily detect pulses from a laser with these specifications. The SHG signal is proportional to the thickness of the crystal squared so a 100  $\mu\text{m}$  thick crystal provides about 10 times the signal and, consequently, 10 times the sensitivity.

### ***Wavelength Considerations***

As the wavelength decreases, the required crystal thickness decreases for a given pulse width. Therefore, measurement of a 500 nm 30 fs pulse requires a 20  $\mu\text{m}$  thick BBO crystal. Just the opposite is true for the IR.