

# APPLICATION NOTE

## Long Scan Autocorrelator

# 27

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# 1. Introduction

Direct measurements of laser pulses less than 20ps using photo detectors remain a challenge. The response time of high-speed photodiodes is currently limited to around 20 picoseconds; moreover, large bandwidth oscilloscopes (>60 GHz) required to accurately measure the output of these detectors are quite expensive.

Several indirect methods for measuring ultrashort pulses have been developed. Detailed reviews can be found in, "Frequency-Resolved Optical Gating: The Measurement of Ultrashort Laser Pulses," by Rick Trebino, Kluwer Academic Publishers, Boston, 2002, and "Ultrashort Laser Pulse Phenomena," by Jean Claude Diels and Wolfgang Rudolph, Academic Press, New York, 1995. When phase information of the pulse is not required, autocorrelation is the simplest and most affordable method for determining pulse width.

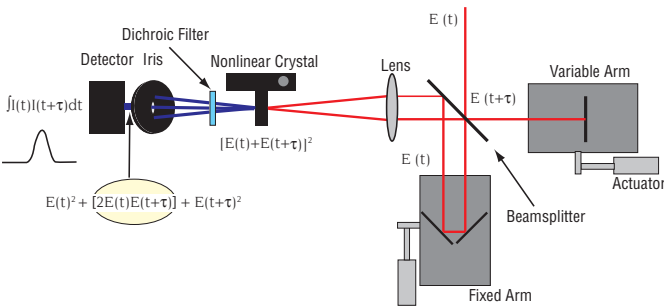


Figure 1.1 Schematic of the autocorrelator

Figure 1.1 illustrates a typical autocorrelator setup. The principle of operation is based on recording the second order correlation function using a Michelson Interferometer. An incoming pulse with electric field  $E(t)$ , is first split into two replicas by means of a beamsplitter. The two replicas are sent down two independent delay lines, one variable and one fixed, in order to generate a time delay,  $\tau$ , between the two replicas. The two replicas,  $E(t)$  and  $E(t+\tau)$ , are next recombined in a nonlinear crystal. Under proper phase matching conditions a second harmonic signal is generated in the crystal. The total intensity of the second harmonic signal  $I_{SH}$ , is proportional to,

$$I_{SH}(t+\tau) \sim [E(t) + E(t+\tau)]^2 \quad (1)$$

Unfolding the square of equation 1,

$$I_{SH}(t+\tau) \sim E(t)^2 + [2E(t)E(t+\tau)] + E(t+\tau)^2 \quad (2)$$

illustrates that there is a component of the second harmonic,  $[2E(t)E(t+\tau)]$ , that is due solely to the temporal overlap of the two pulses (i.e. this component of the signal will only be present when the two pulses are overlapping in time). In the case that the two beams enter the crystal in a noncollinear geometry as shown in Figure 1.1, and when the phase matching conditions are satisfied

only for the two beam contribution, equation (2) simplifies to,

$$I_{SH}(t+\tau) \sim [2E(t)E(t+\tau)] \quad (3)$$

The iris positioned after the doubling crystal blocks the two initial replica beams, and the middle second harmonic beam is sent to a detector. On top of converting the second harmonic to an electrical signal, the detector serves to square the incident field as well as integrate over the duration of the femtosecond pulse,  $t$ . Now, the amplitude of the photo detector signal,  $I_{AC}$ , is proportional to,

$$I_{AC}(\tau) \sim \int [2E(t)E(t+\tau)]^2 dt \quad (4)$$

which, by relating the square of the electric field to intensity can be expressed as,

$$I_{AC}(\tau) \sim \int I(t)I(t+\tau)dt \quad (5)$$

This represents the intensity autocorrelation of the laser pulse. It is proportional to the intensity of the two replicas. Equation 5 is formally a correlation integral and illustrates that the autocorrelation does not actually measure the pulse width directly, but a correlation function of pulse of the two replicas. If indeed the two replicas are identical, then equation 5 can be solved analytically and the pulse width can be determined simply by dividing the autocorrelation signal width by a constant factor that depends on the profile of the pulse (note that the autocorrelation width is always greater than the width of the actual pulse). Table 1.1 lists the parameters for two common pulse profiles, Gaussian and hyperbolic secant squared.

Table 1 Parameters for Two Common Pulse Profiles

	$I_{AC}(\tau)=$	$I(t)=$	$\Delta\tau / \Delta t$
Gaussian Pulse	$\exp[-\ln(2) * (2\tau / \Delta\tau)^2]$	$\exp[-\ln(2) * (2 t / \Delta t)^2]$	1.41
Hyperbolic Secant Squared Pulse <sup>1</sup>	$3[(c\tau/\Delta\tau) * \coth(c\tau/\Delta\tau) - 1] / [\sinh^2(c\tau/\Delta\tau)]$ $c=2.7196$	$\text{sech}^2(1.76275t/\Delta t)$	1.54

There are several commercially available autocorrelators on the market, including Newport's PulseScout™ (www.newport.com/pulsescout). They are usually designed to measure pulses from a few femtoseconds to several picoseconds in duration within a limited wavelength range. Very often, however, there is a need in research labs to combine the capabilities of measuring very short pulses in the range of tens of femtoseconds with the capability of measuring long pulses on the order of tens of picoseconds with femtosecond resolutions. A typical example is the stretching of a femtosecond pulse to many picoseconds for experiments where large bandwidths are required. In many cases these

<sup>1</sup>Rick Trebino, *Frequency-Resolved Optical Gating: The Measurement of Ultrashort Laser Pulses* (Boston: Kluwer Academic Publishers, 2002)

measurements are performed within a broad range of wavelengths covering tuning curves of lasers, OPAs and OPOs. More than just measuring ultrashort pulses, autocorrelators can also be used to detect signals in time regions relatively inaccessible by most detectors.

The autocorrelator kit described in this note provides a simple and cost effective solution for measuring pulse widths of various ultrafast lasers with wavelength in the 480 nm-2000 nm spectral range. It has 25 mm of travel corresponding to a total time delay of greater than 160 ps with 25 fs resolution. This makes it a valuable tool for investigating sidebands and satellites of laser pulses, which may contain significant amounts of the total pulse energy and interfere with complex time-domain signals associated with pump-probe experiments. In contrast to the commercially available autocorrelators, which have clear apertures of a few millimeters, the long scan autocorrelator described in this note is suitable for beam sizes of up to 10mm. The dynamic range of the detection system allows contrast measurements up to 7000:1.

## 2. Building the Assemblies

**WARNING-Radiation emitted by laser devices can be dangerous to the eyes and appropriate precautions must be taken when they are in use. Only individuals who are adequately trained in proper laser use and safety procedures should operate the laser devices described herein.**

Detailed diagrams for building subassemblies of the long scan autocorrelator are presented in the Appendix. When building Delay Line 1 (Assembly 1), the silver mirrors should be glued to the mirror mounts using epoxy glue (not included). Make sure that the two mirrors are positioned at a 90° angle with respect to each other and at a 45° angle with respect to the plane of the optical table. This is the correct orientation for the mirrors if the laser beam is horizontally polarized. (If the laser is polarized in the vertical direction, a  $\lambda/2$  wave-plate should be used to rotate the polarization). This assembly is meant to provide a vertical displacement to the incoming beam. When aligned correctly, the direction of the outgoing beam will be independent of stage position.

When short pulses are measured and the typical delay times are within a few hundred femtoseconds, then rapid scanning and quick updates of the autocorrelation trace can be achieved. In that case the computer controlled motorized actuator should be installed on the Delay Line 2 (see Appendix, Assembly 2; Fig. 1. 1, variable arm). When tens of picoseconds of delays are required, the actuator should be installed on the Delay Line 1 (see Appendix, Assembly 1; Fig. 1. 1, fixed arm).

As an option, the kit can be made portable, by assembling it on a base plate.

## 3. Routing the Beam

Prior to building the autocorrelator, the beam must be routed from the laser to the location of the autocorrelator. This should be done through the use of two routing mirrors. Figure 3.1 provides an illustrative example of a typical amplified femtosecond setup for experiments in nonlinear spectroscopy. A possible layout for placing the autocorrelator (AC) and routing the beam of a Ti:Sapphire laser or OPA into the AC, is shown.

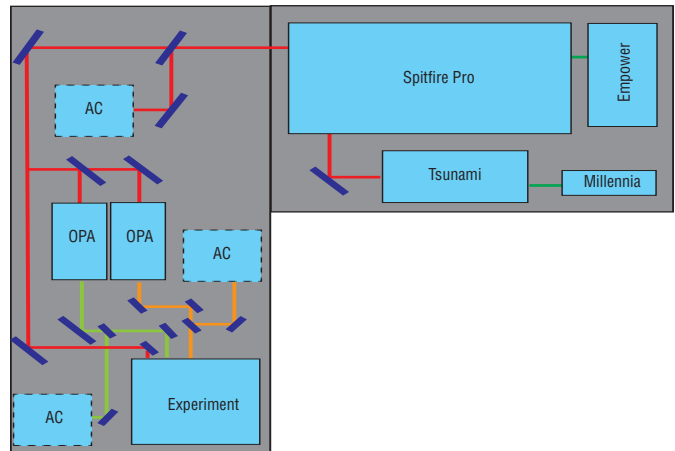


Figure. 3.1 Typical experimental setup for ultrafast nonlinear spectroscopy

The first mirror/beam sampler should be positioned such that the beam exiting the laser is centered on it. This mirror should then be adjusted such that the reflected beam is centered on the second mirror. The height of the second mirror should be chosen carefully since it defines the height of the beam throughout the autocorrelator.

## 4. Assembling the Autocorrelator

At this point, it is useful to construct an alignment tool using the parts from the Iris Assembly. The Iris Assembly should be aligned such that the beam is centered in the middle of the iris immediately after the second routing mirror as illustrated in Figure 4.1.

Using the hole pattern on the optical table as a guide, the iris should be moved in a straight line far from the 2nd routing mirror as shown in Figure 4.2. Using the tip/tilt adjustment on the 2nd routing mirror, center the beam on the iris.

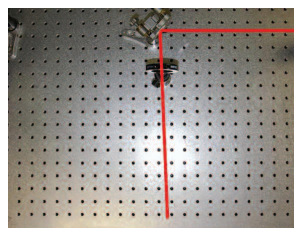


Figure 4.1 The laser beam should be centered in the middle of the iris

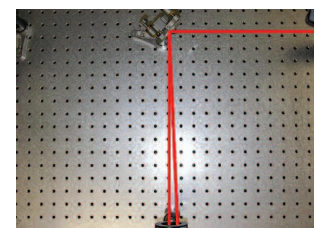


Figure 4.2 The iris should then be moved away from the 2nd routing mirror

Repeat this procedure iteratively until the beam travels parallel to the hole pattern of the table.

Position the Delay Line 1 Assembly at least 200 mm behind routing mirror 2 such that the beam is centered on both mirrors (see Figure 4.3). Using the two routing mirrors, ensure that the beam is traveling at a constant height and parallel to the axis of motion of the stage. The beam should hit the center of the top mirror and be reflected from the center of the bottom mirror. The beam exiting the delay line should travel parallel to the incoming beam with a vertical displacement of approximately 25 mm as show in Figure 4.4. The exiting beam should not translate with position of the stage.

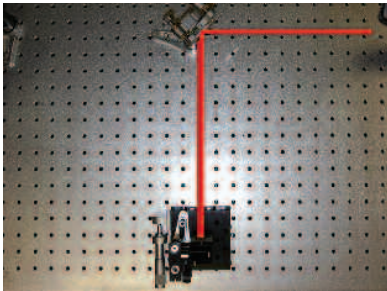


Figure 4.3 Center the beam on both mirrors



Figure 4.4 The beam exiting the delay line should travel parallel to the incoming beam

**WARNING**-Power densities greater than  $1\text{W}/\text{cm}^2$  will result in catastrophic damage to the beamsplitter. Care must be taken to attenuate the beam if necessary.

Insert the Beamsplitter Assembly between routing mirror 2 and Delay Line 1 as shown in Figure 4.5. The center of the beamsplitter should be approximately 100 mm from the edge of the stage and the beam should be centered vertically on the beamsplitter approximately 1 cm from the top. Using the tip/tilt adjustments on the Beamsplitter Assembly, ensure that the reflected beam travels at constant height and is completely perpendicular to the axis of motion of Delay Line 1 as shown in Figure 4.6. Use the procedure described above utilizing the Iris Assembly as a target.

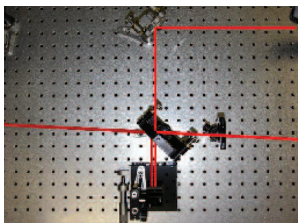


Figure 4.5 The beamsplitter is inserted between the 2nd routing mirror and the 1st delay line

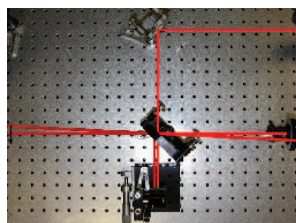


Figure 4.6 The reflected beam should travel at a constant height and be perpendicular to the axis of motion of the 1st delay line

Insert Delay Line 2 approximately 115 mm behind the Beamsplitter Assembly. Using the tip/tilt adjustments on the mirror mount, ensure that this beam travels back on itself. After the beamsplitter, verify that the two beams corresponding to the two arms of the autocorrelator are displaced vertically by approximately 25 mm and are traveling parallel to each other as well as to the table.

Insert the Focusing Assembly approximately 50 mm after the beamsplitter. Adjust the position of the lens such that the two beams are centered vertically and balanced horizontally. The two beams should overlap in tight focus approximately 200 mm behind the lens. If the two beams do not overlap in tight focus, use the tip/tilt adjustment on the Delay Line 2 mirror to overlap them.

Insert the Crystal Assembly approximately 200 mm after the lens at the intersection of the two beams. Make sure that the principle plane of the crystal is oriented at 90 degrees with respect to the polarization plane of the incoming beam. Place the dichroic filter immediately after the crystal. Using a sheet of white paper, rotate the crystal until the second harmonic of one of the two beams becomes visible on the paper (note the angle). Continue rotating the crystal until the second harmonic of the second beam becomes visible (note the angle). The phase-matching angle for two beam second harmonic is the half point between these two angles. Set the crystal angle to this half point.

Scan the two delay lines until a time dependent second harmonic signal can be observed between the two beams. This is a delicate procedure, which may involve several iterations of overlapping the two beams spatially in the crystal followed by scanning the two delay lines. Once the two beam second harmonic is found, aperture it with the Iris Assembly such that no additional contribution from the single beam second harmonic is passing through the iris. Place the detector head as close to the iris as possible. Center the second harmonic on the detector head. When completed, the autocorrelator should resemble that shown in Figure 4.7.

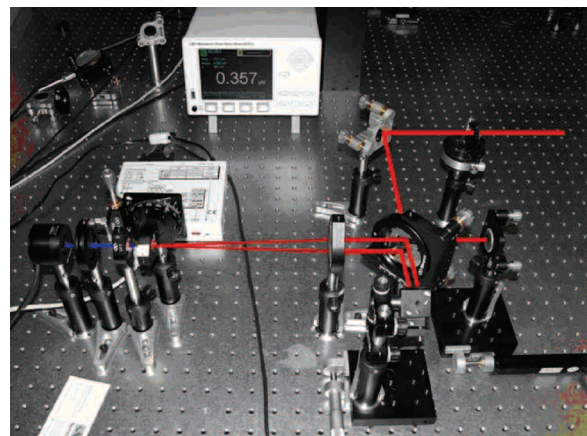


Figure 4.7 Fully configured long scan autocorrelator

## 5. Detection and Data Acquisition

Detection is based on Newport's 1935-C series power meter with 918D-UV-OD3 photodiode head. The data acquisition and analysis is accomplished through LabView based software provided with this kit. You can also request a copy by e-mailing [techsupport@newport.com](mailto:techsupport@newport.com); please reference Application Note 27.

Make sure the detector head is attached to the power meter and turn the power meter on. Block the beam and zero the power meter. Unblock the beam and optimize the power of the second harmonic using the micrometer on Delay Line 1 and the tip/tilt adjustment on the mirror mount of Delay Line 2. The minimum SH power requirement for the autocorrelator to operate is 1 nanowatt. If the average power of the second harmonic is less than 1 nanowatt, a photomultiplier will be required.

Once the two beam signal is aligned on the detector and the power is optimized, set the range to manual and connect the power meter to the computer through the USB port. If faster data acquisition rates are required, the analog output of the power meter along with a fast D/A converter should be utilized. Provided software will work for data transfer through USB only. Connect the motorized actuator on Delay Line 2 to the SMC100CC Controller shown in Figure 4.7 immediately above the crystal assembly. Connect the SMC100CC Controller to the computer using the RS232 cable provided. Install the SMC100CC software that comes with the controller and the SMC Autocorrelation Software included in the kit, and reboot the computer. Run the SMC program from the Programs folder under the Start Menu. Make sure the actuator is properly configured and then send the actuator to the home position. The home position corresponds to the actuator fully retracted. Now command the actuator back to its original position such that the second harmonic signal is again optimized on the detector; note this offset value. Close the SMC200 program.

Open the SMC Autocorrelation Software (Figure 5.1) and set the home to the offset value determined above. Set the acceleration and velocity using the sidebars and enter a desired delay. Press the start switch. Congratulations, you are now autocorrelating!

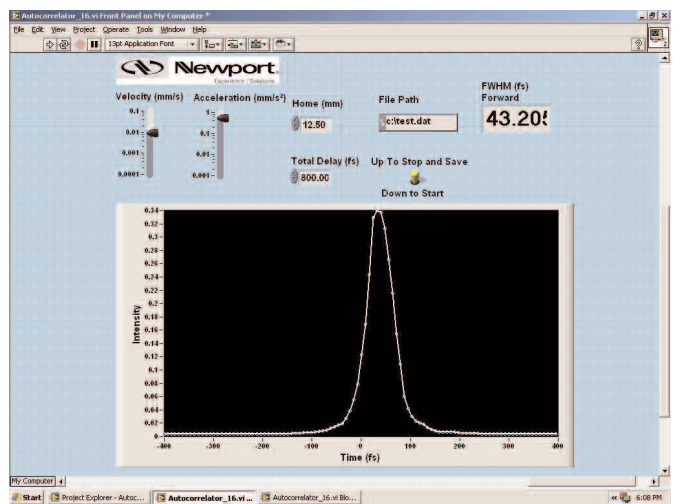


Figure 5.1 GUI of the long scan autocorrelator

After the measurement is complete, click the STOP switch and save the data into a file. The data is saved in ASCII format and can be imported into any data analysis software. As an example, Figure 5.2 shows the result of a long scan autocorrelation measurement performed on a Spectra-Physics Spitfire® Pro Ti: Sapphire amplifier at Newport's Technology and Applications Center. Contrast ratio of 7000:1 is demonstrated throughout the entire scanning range of the autocorrelator.

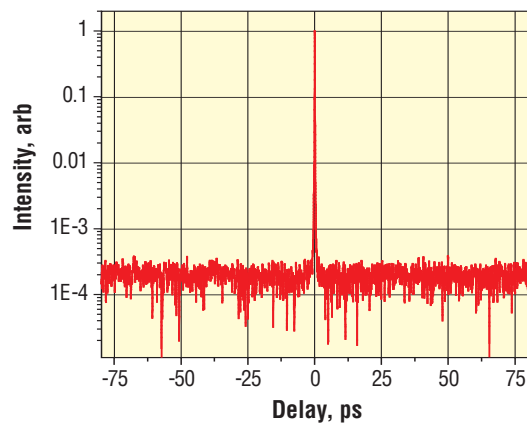


Figure 5.2 Long scan autocorrelation data collected on the Spitfire® Pro amplifier. A contrast ratio better than 7000:1 is demonstrated.

## Appendix: Diagrams of Assemblies and Parts List

### Assembly 1

#### Delay Line 1

1. Translation Stage: 1 x 426
2. Micrometer: 1 x SM-25
3. Mirror: 2 x 10SD520ER.2
4. Mirror Mount: 2 x P100-P
5. Mounting Post: 2 x SP-1
6. Bracket: 2 x CA-1
7. Post: 1 x SP-4
8. Post Holder: 2 x VPH-X-P
9. Clamp: 2 x PS-F



### Assembly 4

#### Focusing Lens

1. Lens: 1 x KPX199
2. Mount: 1 x LH-2
3. Post: 1 x SP-X
4. Post Holder: 1 x VPH-X-P
5. Clamp: 1 x PS-F (not shown)



### Assembly 2

#### Delay Line 2

1. Translation Stage: 1 x 426
2. Micrometer: 1 x CMA-25CCCL
3. Motion Controller: 1 x SMC100CC (not shown)
4. Mirror: 1 x 10D10ER.2
5. Mirror Mount: 1 x P100A-A
6. Post: 1 x SP-X
7. Post Holder: 1 x VPH-X-P
8. Clamp: 1 x PS-F
9. Misc: 1 x RS232 Cable



### Assembly 5

#### Nonlinear Crystal

1. Crystal: 1 x 5mm x 5mm x 0.2mm BBO,  
Type 1,  $\theta = 48^\circ$  for  
480nm-700nm,  
or  $\theta = 29^\circ$  for 700nm-2000nm
2. Crystal Mount: 1 inch diameter
3. Mount: 1 x LH-1
4. Rotation Stage: 1 x RS65
5. Actuator 1x SM13
6. Post: 1 x SP-X
7. Post Holder: 1 x VPH-X-P
8. Clamp: 1 x PS-F (not shown)



### Assembly 3

#### Beamsplitter

1. Beamsplitter: 1 x PBS-2C
2. Mount: 1 x U300-A2K
3. Post: 1 x SP-X
4. Post Holder: 1 x VPH-X-P
5. Clamp: 1 x PS-F (not shown)



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