Model 409

Autocorrelator

User's Manual

Spectra-Physics
The Solid-State Laser Company

1335 Terra Bella Avenue
Mountain View, CA 94043

Part Number 0000-231A, Rev. B
April 2002

Preface

This manual contains the information necessary to safely install, align, operate, maintain, and service your *Model 409* autocorrelator.

The *Model 409* is designed for use with the Spectra-Physics *Tsunami* laser and *OPAL*® optical parametric oscillator (OPO), which are Class IV laser devices. These units emit laser radiation that can permanently damage eyes and skin. The "Laser Safety" section contains information about these hazards and offers suggestions on how to safeguard against them. To minimize the risk of injury or expensive repairs, be sure to read this chapter and carefully follow these instructions.

The introductory chapter contains a brief description of the *Model 409* and how it compliments the *Tsunami*® family of products. The middle chapters describe the *Model 409* controls and guide you through its installation, alignment and operation. The last part of the manual covers maintenance and service, and includes a replacement parts list and a list of world-wide Spectra-Physics service centers you can call if you need help. Appendices are included for those who wish more information on how autocorrelation works.

The "Maintenance" section contains information you need to keep your *Model 409* clean and operational on a day-to-day basis, whereas "Service and Repair" is intended to help you guide your Spectra-Physics field service engineer to the source of any problems. *Do not attempt repairs yourself while the unit is still under warranty.* Instead, report all problems to Spectra-Physics for warranty repair.

Every effort has been made to ensure that the information in this manual is accurate. All information in this document is subject to change without notice. Spectra-Physics makes no representation or warranty, either express or implied, with respect to this document. In no event will Spectra-Physics be liable for any direct, indirect, special, incidental or consequential damages resulting from any defects in this documentation.

Finally, if you encounter any difficulty with the content or style of this manual, please let us know. The last page is a form to aid in bringing such problems to our attention.

Thank you for your purchase of Spectra-Physics instruments.

CE Environmental Specifications

CE Electrical Equipment Requirements

For information regarding the equipment needed to provide the electrical service listed under “Service Requirements” at the end of Chapter 3, please refer to specification EN-309, “Plug, Outlet and Socket Couplers for Industrial Uses,” listed in the official *Journal of the European Communities.*

Environmental Specifications

The environmental conditions under which the laser system will function are listed below:

Indoor use

Altitude:	up to 2000 m
Temperatures:	10° C to 40° C
Maximum relative humidity:	80% non-condensing for temperatures up to 31° C.
Mains supply voltage:	do not exceed ±10% of the nominal voltage
Insulation category:	II
Pollution degree:	2

FCC Regulations

This equipment has been tested and found to comply with the limits for a Class A digital device pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference when the equipment is operated in a commercial environment. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instruction manual, may cause harmful interference to radio communications. Operation of this equipment in a residential area is likely to cause harmful interference in which case the user will be required to correct the interference at his own expense.

Modifications to the laser system not expressly approved by Spectra-Physics could void your right to operate the equipment.

Table of Contents

List of Figures

List of Tables

Warning Conventions

The following warnings are used throughout this manual to draw your attention to situations or procedures that require extra attention. They warn of hazards to your health, damage to equipment, sensitive procedures, and exceptional circumstances. All messages are set apart by a thin line above and below the text as shown here.

Danger! Laser Radiation	Laser radiation is present.
Danger!	Condition or action may present a hazard to personal safety.
Danger!	Condition or action may present an electrical hazard to personal safety.
Warning!	Condition or action may cause damage to equipment.
Warning! ESD	Action may cause electrostatic discharge and cause damage to equipment.
Caution!	Condition or action may cause poor performance or error.
Note	Text describes exceptional circumstances or makes a special reference.
Don't Touch!	Do not touch.
Eyewear Required	Appropriate laser safety eyewear should be worn during this operation.
	Refer to the manual before operating or using this device.

Standard Units

The following units, abbreviations, and prefixes are used in this Spectra-Physics manual:

Quantity	Unit	Abbreviation
mass	kilogram	kg
length	meter	m
time	second	s
frequency	hertz	Hz
force	newton	N
energy	joule	J
power	watt	W
electric current	ampere	A
electric charge	coulomb	C
electric potential	volt	V
resistance	ohm	Ω
inductance	henry	H
magnetic flux	weber	Wb
magnetic flux density	tesla	T
luminous intensity	candela	cd
temperature	celcius	C
pressure	pascal	Pa
capacitance	farad	F
angle	radian	rad

Prefixes								
tera	(10^{12})	T	deci	(10^{-1})	d	nano	(10^{-9})	n
giga	(10^{9})	G	centi	(10^{-2})	c	pico	(10^{-12})	p
mega	(10^{6})	M	mill	(10^{-3})	m	femto	(10^{-15})	f
kilo	(10^{3})	k	micro	(10^{-6})	μ	atto	(10^{-18})	a

Unpacking and Inspection

Unpacking Your Autocorrelator

Your *Model 409* autocorrelator was packed with great care, and its container was inspected prior to shipment–it left Spectra-Physics in good condition. Upon receiving your autocorrelator, immediately inspect the outside of the shipping container. If there is any major damage (holes in the container, crushing, etc.), insist that a representative of the carrier be present when you unpack the contents.

Carefully inspect your autocorrelator as you unpack it. If any damage is evident, such as dents or scratches on the cover or broken knobs, immediately notify the carrier and your Spectra-Physics sales representative.

Keep the shipping container. If you file a damage claim, you may need it to demonstrate that the damage occurred as a result of shipping. If you need to return the autocorrelator for service, the specially designed container assures adequate protection.

Accessory Kit

Included with the autocorrelator is this manual, a packing slip listing all the parts shipped, and an accessory kit containing the following items:

- Medium and thin blocks
- Medium and thin etalons
- One or two optional uv filters (if ordered) in a wooden optics kit. Opal (light blue) 1080 – 1600 nm, optional
  Dye laser (black) 550 – 680 nm, optional
  Tsunami (green) 680 – 1080 nm, standard (installed)
- 2 Table clamps
- 2 BNC cables, 1.2 m
- 1 US power cord, 2 m
- 1 European (German) power cord, 2m

You will need to supply:

- A high-impedance (1 MΩ) input oscilloscope

Chapter 1 Introduction

Introduction

The Spectra-Physics *Model 409* scanning autocorrelator is a device for measuring the duration of ultrashort pulses from mode-locked femtosecond (fs) and picosecond (ps) laser systems. The measured pulse is displayed on a standard high impedance oscilloscope for real-time viewing. This compact unit contains only three moving parts: a rotating block of fused silica for changing the relative optical path length of the two internal beam paths, an etalon that can be moved in and out of one of these beam paths to provide a known delay for calibration, and a doubling crystal that is rotated to phase match the two beams and create the auto correlation signal.

The *Model 409* is capable of operating over several wavelength ranges and, by changing rotating blocks and the calibration etalon, can be used to measure pulse widths from 60 ps to < 40 fs. In short, it provides you with instantaneous feedback of your laser performance and allows you to make meaningful adjustments of your operational parameters.

Features of the Model 409 Autocorrelator

Some of the features of the *Model 409* autocorrelator are:

- Easy to use
- Instant feedback of pulsed performance
- Picosecond and femtosecond resolution (depending on which rotating block is installed)
- Measures pulse widths from 60 ps to < 40 fs
- High sensitivity
- Broadband optical components:

  690–1080 nm for *Tsunami*

  1.1–2.6 mm for *OPAL*
- Hollow retro prisms and ultra thin optics incorporated where possible to minimize the effects of GVD pulse broadening.
- Compact size
- Durability

Accessory Kit

Included with the autocorrelator is this manual, a packing slip listing all the parts shipped, and an accessory kit containing the following items:

- Medium and thin blocks
- Medium and thin etalons
- One or two optional uv filters (if ordered) in a wooden optics kit.

  Opal (light blue) 1080–1600 nm, optional

  Dye laser (black) 550–680 nm, optional

  Tsunami (green) 680–1080 nm, standard (installed)
- 2 Table clamps
- 2 BNC cables, 1.2 m
- 1 US power cord, 2 m
- 1 European (German) power cord, 2 m

You will need to supply:

- A high-impedance (1 MΩ) input oscilloscope

Patent

4,406,542

Chapter 2 Laser Safety

For your safety, please read this section of the manual carefully before installing or operating your laser accessory.

Danger! Laser Radiation

The Spectra-Physics *Model 409* autocorrelator may be used with Class III and IV-High Power Lasers whose beams are, by definition, safety and fire hazards. Take precautions to prevent accidental exposure to both direct and reflected beams. Diffuse as well as specular beam reflections can cause severe eye or skin damage.

Danger! Laser Radiation

The protective housing of this product should always be in place during normal operation. Removal of the protective housing may expose the user to unnecessary radiation and should be done only in accordance with specific instructions given in this manual.

Precautions for the Safe Operation of Class III and IV High Power Lasers and Accessories

Danger! Laser Radiation

Spectra-Physics manufactures many different lasers and laser accessories. The maximum radiant input powers of these devices vary from a few microwatts to tens of watts. Units utilizing higher output powers normally have the potential for a greater safety hazard–especially those products that utilize pulsed or invisible output. The following general laser safety precautions are especially important for users of high-power laser products

- Use protective eyewear at all times; selection depends on the wave length and intensity of the radiation, the conditions of use, and the visual function required. Protective eyewear is available from vendors listed in the *Laser Focus World, Lasers and Optronics, and Photonics Spectra* buyer's guides. Consult the ANSI and ACGIH standards listed at the end of this section for guidance.
- Maintain a high ambient light level in the laser operation area. This keeps the eye's pupil constricted, thus reducing the possibility of eye damage.
- Keep the protective covers on the laser and its accessories at all times.

- Avoid looking at the laser beam; even diffuse reflections are hazardous.
- Avoid wearing jewelry or other objects that may reflect or scatter the beam while using the laser.
- Use an infrared detector or energy detector to verify that the laser beam is off before working in front of the laser.
- Operate the laser at the lowest beam intensity possible, given the requirements of the application, and especially during alignment.
- Expand the beam whenever possible to reduce beam intensity.
- Avoid blocking the output beam or its reflection with any part of your body.
- Establish a controlled-access area for laser operation. Limit access to those trained in laser safety principles.
- Maintain a high ambient light level in the laser operation area so the eye's pupil remains constricted, reducing the possibility of damage.
- Post prominent warning signs near the laser operation area (Figure 2-1).
- Set up experiments so the laser beam is either above or below eye level.
- Provide enclosures for beam paths whenever possible.
- Set up shields to prevent unnecessary specular reflections.
- Set up an energy absorbing target to capture the laser beam, preventing unnecessary reflections or scattering (Figure 2-2).

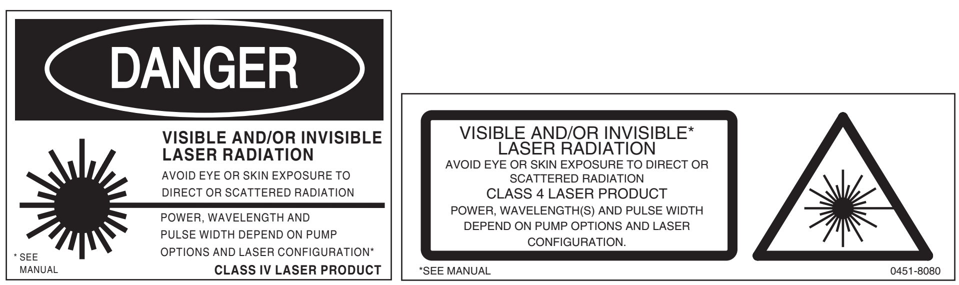

Figure 2-1: These standard safety warning labels would be appropriate for use as entry warning signs (EN 60825-1, ANSI 4.3.10.1).

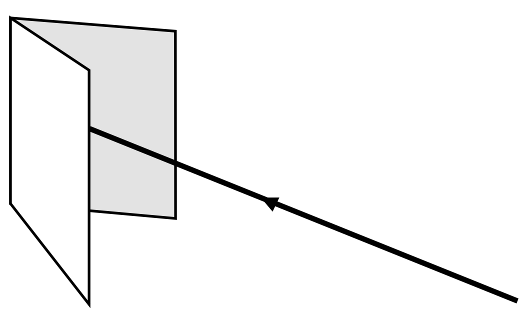

Figure 2-2: Folded Metal Beam Target

Label Translations

For safety, the following translations are provided regarding the labels shown in Figure 2-1 for non-English speaking personnel.

Table 2-1: Label Translations

Label	French	German	Spanish	Dutch
Left	Attention–Rayonnement Laser Visible et Invisible en Cas D'Ouverture et lorsque la securite est neutralisee; exposition dangereuse de l'oeil ou de la peau au rayonnement direct ou diffus. Puissance et longueurs D'onde dependant de la configuration et de la puissance de pompe. Laser de Classe 4.	Vorsicht; Austritt von sichtbarer un unsichtbarer Laserstrahlung wenn Abdeckung geoffnet und Sicherhetisschalter uberbruckt; Bestrahlung von Auge oder Haute durch direkte oder Streustrahlung vermeiden. Leistung, Wellenlange und Pulsbreite sind abhangig von Pumpquelle und Laserkonfiguration. Laserklasse 4.	Peligro, al abrir y retiar el dispositivo de seguridad exist radiacion laser visible e invisible; evite que los ohos o la piel queden expuestos tanto a la radiacion directa como a la dispersa. Potencia, Longitud de onda y anchura de pulso dependen de las opciones de bombeo y de la configuracion del laser. Producto laser clase 4.	Gevarr, zichtbare en neit zichtbare laserstraling wanneer geopend en bij uitgeschakelde interlock; Vermijd blootstelling van oog of huid aan directe straling of weerkaatsingen daarvan. Vermogen golfleugten en pulsduur afhankelijk van pomp optics en laser configuratie. Klasse 4 Laser Produkt.
Right	Rayonnement Laser Visible et Invisible en Cas D'Ouverture et lorsque la securite est neutralisee; exposition dangereuse de l'oeil ou de la peau au rayonnement direct ou diffus. Puissance et longueurs D'onde dependant de la configuration et de la puissance de pompe. Laser de Classe 4.	Austritt von sichtbarer un unsichtbarer Laserstrahlung wenn Abdeckung geoffnet und Sicherhetisschalter uberbruckt; Bestrahlung von Auge oder Haute durch direkte oder Streustrahlung vermeiden. Leistung, Wellenlange und Pulsbreite sind abhangig von Pumpquelle und Laserkonfiguration. Laserklasse 4.	Al abrir y retiar el dispositivo de seguridad exist radiacion laser visible e invisible; evite que los ohos o la piel queden expuestos tanto a la radiacion directa como a la dispersa. Potencia, Longitud de onda y anchura de pulso dependen de las opciones de bombeo y de la configuracion del laser. Producto laser clase 4.	Zichtbare en neit zichtbare laserstraling wanneer geopend en bij uitgeschakelde interlock; Vermijd blootstelling van oog of huid aan directe straling of weerkaatsingen daarvan. Vermogen golfleugten en pulsduur afhankelijk van pomp optics en laser configuratie. Klasse 4 Laser Produkt.

Caution!

The use of controls or adjustments, or the performance of procedures other than those specified herein may result in hazardous radiation exposure.

Follow the instructions contained in this manual for safe operation of your autocorrelator. At all times during installation, operation, maintenance or service of this laser accessory, avoid all unnecessary exposure to laser or collateral radiation[*] that exceeds the accessible emission limits listed in "Performance Standards for Laser Products," *United States Code of Federal Regulations*, 21CFR1040 10 (d).

Danger!

The *Model 409* autocorrelator contains electrical circuits operating at lethal voltage and current levels. Be extremely careful whenever the cover is removed. Avoid contact with high voltage terminals and components.

Danger! Laser Radiation

While the *Model 409* autocorrelator cover is removed, be extremely careful to avoid exposure to laser or collateral radiation.

[*] *Any electronic product radiation, except laser radiation, emitted by a laser product as a result of, or necessary for, the operation of a laser incorporated into that product.*

Sources for Additional Information

The following are some sources for additional information on laser safety standards, safety equipment, and training.

Laser Safety Standards

Safe Use of Lasers (Z136.1: 1993)
American National Standards Institute (ANSI)
11 West 42nd Street
New York, NY 10036
Tel: (212) 642-4900

Occupational Safety and Health Administration (Publication 8.1-7)
U. S. Department of Labor
200 Constitution Avenue N. W., Room N3647
Washington, DC 20210
Tel: (202) 693-1999

A Guide for Control of Laser Hazards, 4th Edition, Publication #0165
American Conference of Governmental and
Industrial Hygienists (ACGIH)
1330 Kemper Meadow Drive
Cincinnati, OH 45240
Tel: (513) 742-2020
Internet: www.acgih.org/home.htm

Laser Institute of America
13501 Ingenuity Drive, Suite 128
Orlando, FL 32826
Tel: (800) 345-2737
Internet: www.laserinstitute.org

Compliance Engineering
70 Codman Hill Road
Boxborough, MA 01719
Tel: (978) 635-8580

International Electrotechnical Commission
Journal of the European Communities
EN60825-1 TR3 Ed.1.0—Laser Safety Measurement and Instrumentation
IEC-309—Plug, Outlet and Socket Coupler for Industrial Uses
Tel: +41 22-919-0211
Fax: +41 22-919-0300
Internet: http://ftp.iec.c.h/

Cenelec
European Committee for Electrotechnical Standardization
Central Secretariat
rue de Stassart 35
B-1050 Brussels

Document Center
1504 Industrial Way, Unit 9
Belmont, CA 94002-4044
Tel: (415) 591-7600

Equipment and Training

Laser Safety Guide
Laser Institute of America
12424 Research Parkway, Suite 125
Orlando, FL 32826
Tel: (407) 380-1553

Laser Focus World Buyer's Guide
Laser Focus World
Penwell Publishing
10 Tara Blvd., 5th Floor
Nashua, NH 03062
Tel: (603) 891-0123

Lasers and Optronics Buyer's Guide
Lasers and Optronics
Gordon Publications
301 Gibraltar Drive
P.O. Box 650
Morris Plains, NJ 07950-0650
Tel: (973) 292-5100

Photonics Spectra Buyer's Guide
Photonics Spectra
Laurin Publications
Berkshire Common
PO Box 4949
Pittsfield, MA 01202-4949
Tel: (413) 499-0514

Chapter 3 Autocorrelator Description

The Autocorrelation Technique

Measurement of Ultrashort Pulses

The autocorrelation technique is the most common method used for deter mining pulse width characteristics for fs and ps pulsed laser systems. Using the principle that the speed of light within a given medium is constant, the autocorrelator translates differences in optical path length into time for use as an oscilloscope scanning time base.

The basic optical configuration is similar to that of a Michelson interferometer. An incoming pulse train is split into two beams of equal intensity, and an adjustable optical delay is imparted to one or both beams. The two beams are then recombined within a nonlinear crystal for second harmonic generation (SHG). The efficiency of the second harmonic generation resulting from the interaction of the two beams is proportional to the degree of pulse overlap within the crystal. Monitoring the intensity of this second harmonic uv generation as a function of relative delay between the recombining (overlapping) pulses produces a correlation function directly related to pulse width.

Two types of autocorrelation configurations are possible. In the first type, an interferometric autocorrelation (Figure 3-1), the two beams are recombined in a collinear fashion (one on top of the other). This configuration results in an autocorrelation signal sitting on top of a constant dc back ground. The background is produced by uv generation resulting from the portions of the scan during which the pulses are not overlapped. In the second scheme, a background-free autocorrelation (Figure 3-2), the two beams are displaced from a common optical axis and recombined in a noncollinear fashion. In this configuration, the background is eliminated because uv is generated only at the point where the two beams intersect, i.e., the phase matching conditions are correct.

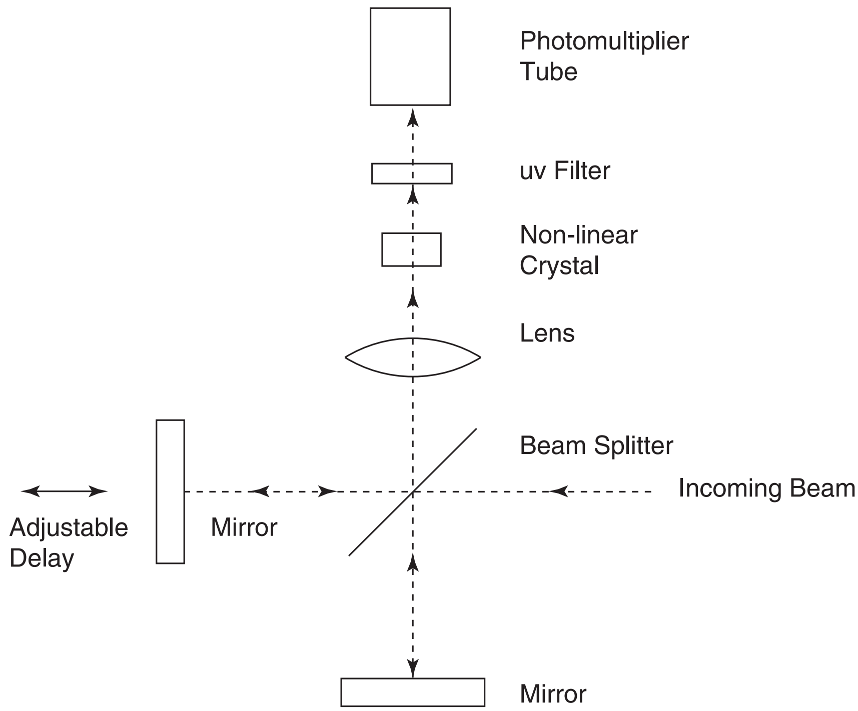

Figure 3-1: Interferometric (Collinear) Autocorrelation

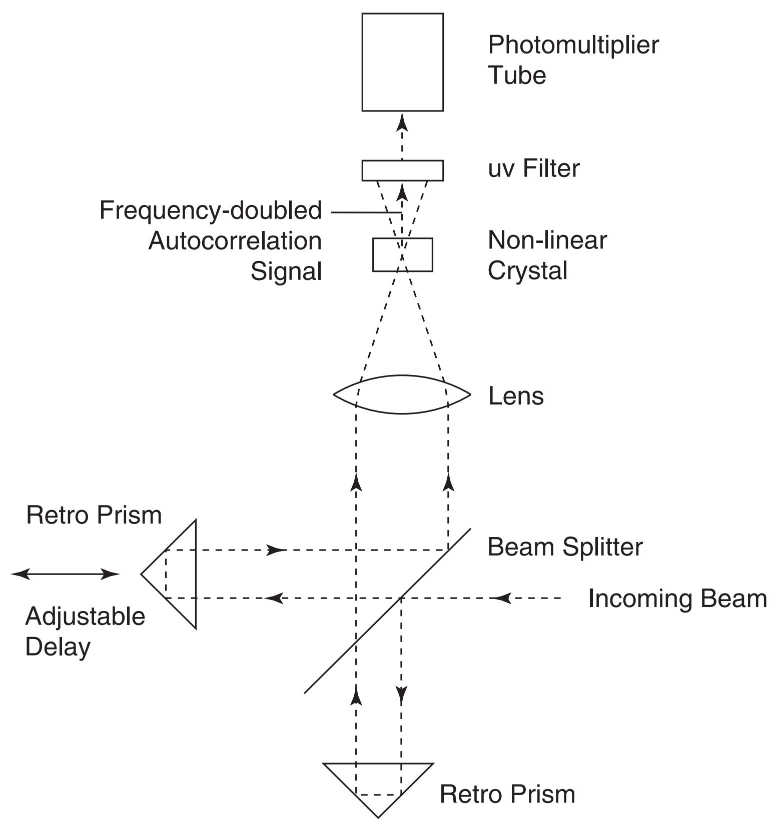

Figure 3-2: Background-free (Non-collinear) Autocorrelation

The Spectra-Physics Model 409 Autocorrelator

The Spectra-Physics *Model 409* scanning autocorrelator operates in a background-free configuration according to the principles of noncollinear autocorrelation described above.

The Scanning Mechanism

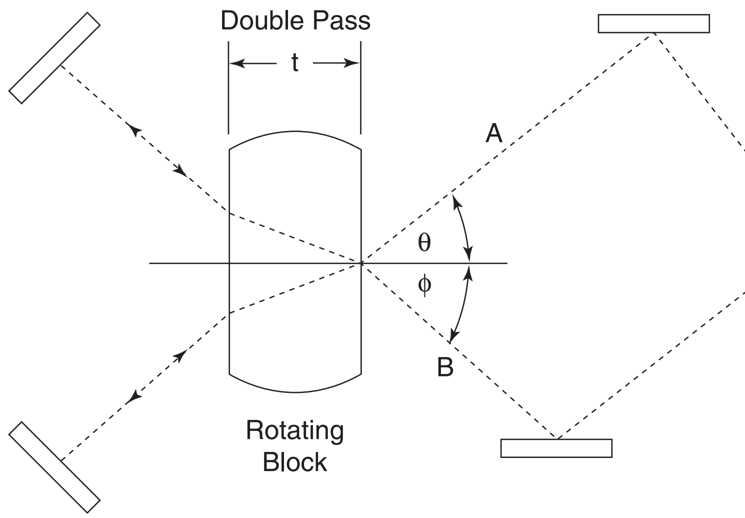

Figure 3-3: Scanning Mechanism, *Model 409*

The scanning mechanism of the *Model 409* is shown in Figure 3-3. The length of the two beam paths are changed by passing both of them through a rotating block of fused silica. The two beams enter the block at complementary angles with respect to the normal of the block surface, and as the block rotates, the angle of incidence that each arm makes with the surface of the block is varied and a change in optical path lengths results.

By passing both beams through the quartz block, the variation in path length of one beam relative to the other becomes nearly linear over an angle of rotation of approximately 72 degrees.

Figure 3-4 shows the sequence of pulse positions and overlap for each beam path as the block rotates. At the beginning of the scan, path A is at a minimum and path B is at a maximum. As the block rotates, the pulses move together at a constant relative rate. At the point where the angle of incidence for path A and B is the same, the pulses overlap. As the block continues to rotate, the pulses move apart, completing the scan.

When the pulses from the two beams overlap and are focused into the nonlinear crystal (which is set to the correct angle of incidence), autocorrelation occurs. The resulting emission from the crystal is filtered by the uv filter and then directed into the photomultiplier (PMT) tube. It is the output from this PMT circuit, together with a sync pulse generated by the rotating block motor, that creates the display on the oscilloscope.

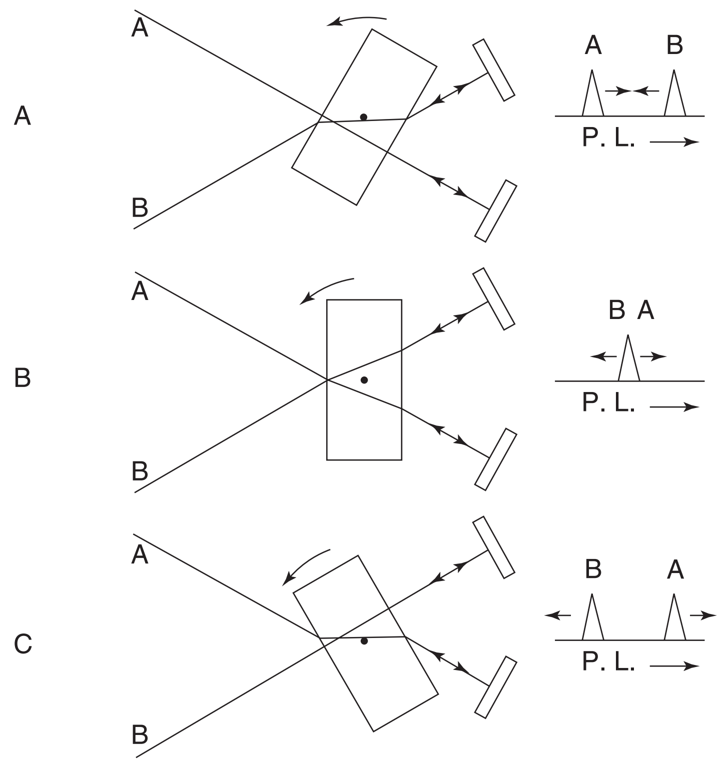

Figure 3-4: Pulse Position and Overlap as the Block Rotates

Signal Interpretation

Accurate interpretations of autocorrelation measurements, i.e., actual pulse width determinations, are complicated by two factors:

- The ratio of the actual pulse width to the width of the autocorrelation trace is a function of the pulse shape.
- The pulse shape can vary between two extremes, dependent upon the operating parameters of the laser system.

Fortunately, we can dismiss the second factor for, unlike a dye laser, the Tsunami laser outputs an easily measured $sech^2$ pulse, as does the OPAL system.* Figure 3-5 illustrates the relationship of pulse width to the autocorrelated pulse shape for a Tsunami or OPAL-generated $sech^2$ pulse. It is transform-limited and generally exhibits the shortest possible pulse width. The peak of the measured autocorrelation trace is the true peak of the actual pulse. The full-width half maximum (FWHM) point is measured at one half its full height as shown, and the width of the actual pulse is 0.65 of the measured (displayed) autocorrelation pulse width.

Note that the autocorrelation function must always be symmetric. If the output signal is asymmetric, the autocorrelator is either misaligned relative to the input beam or its internal optics are misaligned.

* *If you are measuring the output of an older dye laser, please refer to Appendix B for information specific to pulses generated by these systems.*

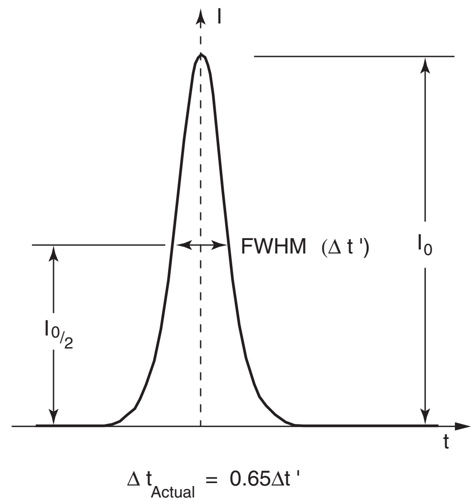

Figure 3-5: Transform-limited Sech^2 Pulse

The information offered here and in Chapter 5, "Setup and Operation," is meant for day-to-day use of the autocorrelator. Appendix A contains mathematical models to explain the scan mechanism of the *Model 409*. For even more detailed information on autocorrelation, refer to A.J. De Maria et al "Picosecond Laser Pulses," IEEE, Vol. 57 No. 1, p. 2, Jan. 1969.

Oscilloscope Display

Rotation of the quartz block is accomplished by means of an ac synchronous motor which spins the block at a rate of 30 rotations per second (RPS) for a 60 Hz source or 25 RPS for a 50 Hz source. At 60 Hz, each path length scan delay is equivalent to approximately:

Table 3-1: Scan Time

Block	Delay
Large	80 ps
Medium	15 ps
Thin	3 ps

$$\frac{72^\circ}{\text{scan}} \times \frac{1\ \text{revolution}}{360^\circ} \times \frac{1\ \text{s}}{30\ \text{revolutions}} = \frac{6.67\ \text{ms}}{\text{scan}}$$

$$\frac{\frac{100\ \text{ps delay}}{\text{scan}}}{\frac{6.67\ \text{ms}}{\text{scan}}} = \frac{15\ \text{ps delay}}{\text{ms of sweep time}}$$

The scan completes within a 72° window of rotation. An approximate calibration of the oscilloscope can be determined by calculating the time required for each scan to be completed. The equations above show how to calculate for pulse width using a 60 Hz motor. Substitute "25" in the place of "30" for revolutions if you are using a 50 Hz system.

Selecting the appropriate oscilloscope sweep time allows you to display all or part of the autocorrelation signal. A variable delay trigger operating at a repetition rate synchronized to the rotation of the quartz block provides accurate triggering of the oscilloscope time base relative to the arrival of the autocorrelation signal. This allows you to position the output trace on the oscilloscope.

Time Calibration

Calibrating the oscilloscope time base in terms of delay per sweep length is accomplished using either the method described above, provided the correct rotating quartz block is mounted, or by using the calibration etalon and the procedure described in Chapter 5, "Operation."

The calibration etalon is a piece of fused silica of known optical delay that is inserted into one or both beams of the M_2/HRR_2 beam path. When insert ed into both beams, the delay is doubled. For a quick estimate of the delay, use the delay times shown in Table 3-2 below. However, because the delay is also affected by the wavelength being measured, if you need to be more precise, use the calibration correction factor listed in Figure 3-6 to determine the exact delay for calibrating the oscilloscope for the wavelength in use.

Table 3-2: Etalon Delay Time

Etalon	Delay Time Single/Double-Pass
Large	20/40 ps
Medium	1.5/3 ps
Thin	300/600 fs

Note: insertion of the etalon into the optical path of the autocorrelator also allows you to examine an additional 40 ps or 600 fs into the wings of the pulse. Additional information about alignment and use of the calibration etalon is provided in Chapter 5.

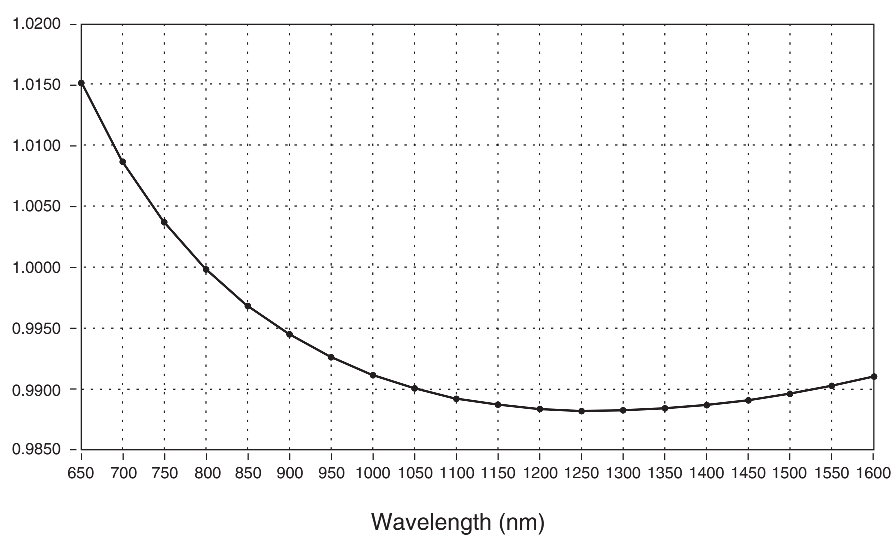

Figure 3-6: Correction Factor of Calibration Etalons Relative to Delay at 800 nm.

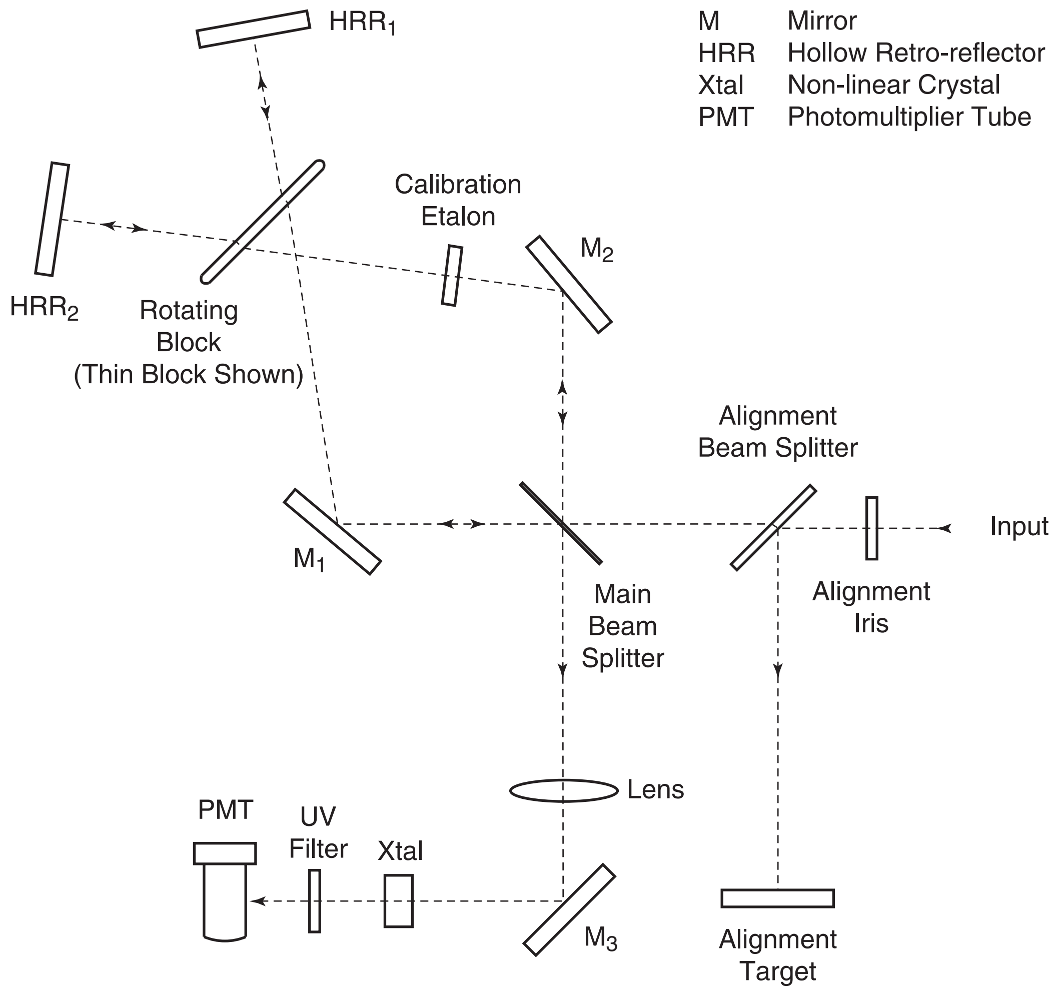

Figure 3-7: The *Model 409* Autocorrelator Schematic

Specifications

Table 3-3: ***Model 409*** **Specifications**

Optical	**Scan Range[1]**		
	3 ps	**15 ps**	**75 ps**
Pulse Width Resolution	<60 fs[2]–1 ps	200 fs–5 ps	1–25 ps
Scan Rate		25/30 Hz	
Scan Linearity[3]		± 2%	
Wavelength Coverage[4]	690 nm–1.1 µm, or 550 nm to 1.6 µm by changing uv filters		
Minimum Input Pulse Repetition Rate Required		10 kHz	
Input Polarization		Vertical	
Input Power		4 mW to 40 mW (30 mW typ.)	
Electrical			
Voltage		220/110 Vac, 50/60 Hz ±10%	
Current		0.250 A	
Mechanical			
Weight		7.4 kg (16.25 lbs)	

[1] *The different rotating blocks provide three different scan ranges.*
[2] *Represents the lower limit to resolution based upon pulse broadening caused by group velocity dispersion effects (at 800 nm). With external dispersion compensation, the lower limit is < 30 fs.*
[3] *Over the central 50% of scan range.*
[4] *Can be external from 1.1 to 1.6 µm by changing filter and beam splitter.*

Outline Drawing

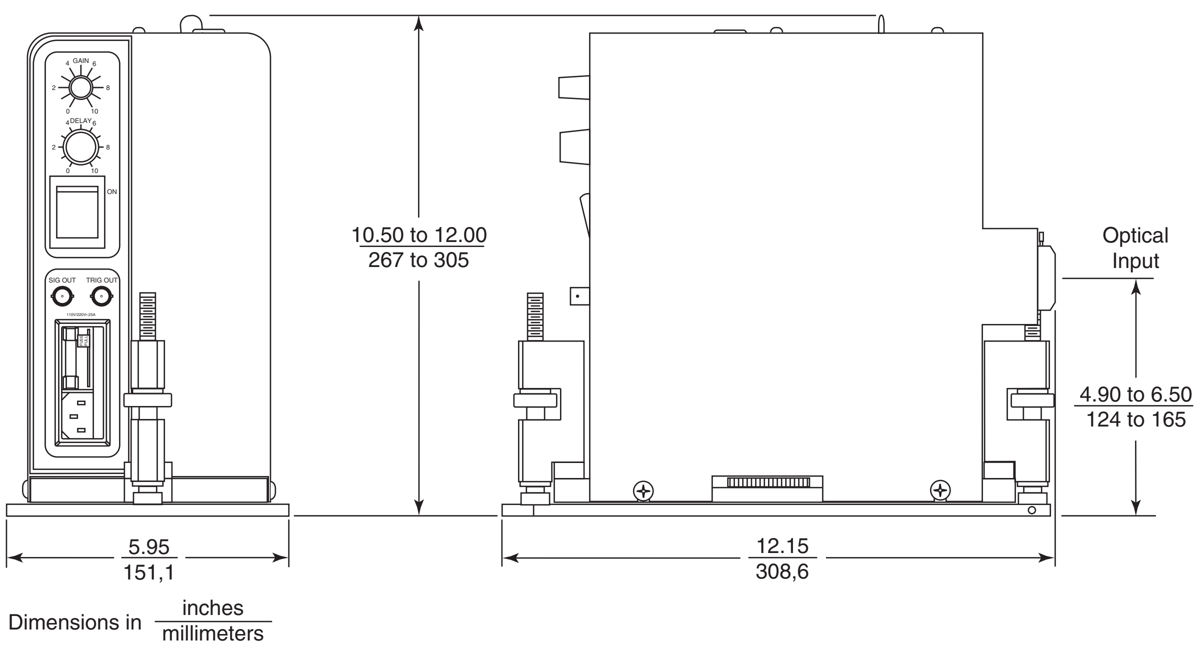

Figure 3-8: Outline Drawing

Chapter 4 Controls, Indicators and Connectors

This section illustrates show the external and internal components of the *Model 409* autocorrelator and explains their functions and use.

Danger!

The autocorrelator has no cover interlock and will continue to operate when the cover is removed. Be extremely careful whenever the cover is removed and avoid contact with high voltage terminals and components. Its electrical circuits operate at lethal voltage and current levels. Only properly trained individuals should be allowed to install and align the autocorrelator

---

Danger!
Laser Radiation

The cover of the *Model 409* blocks a path of laser radiation in a plane parallel to the center mounting plate. Exercise extreme caution when the cover is removed and while moving about this plane. Always use eye protection appropriate for the laser wavelength being measured.

Components

The *Model 409* scanning autocorrelator consists of the following components (refer to Figure 4-1). They are listed in each section in the order in which they encounter the input beam.

Alignment iris—provides a simple mechanism for aligning the autocorrelator to the input beam. It also provides a quick means to attenuate the input beam to acceptable power levels (<50 mW) as a short-term fix. For long-term we recommend using a beam pick-off or a neutral density filter instead. The single lever adjusts the iris size.

Alignment beam splitter—picks off a few percent of the input beam and directs it toward the alignment target in the base (see “Alignment target”). The beam splitter is covered and should never require alignment or cleaning. However, if it ever does, it is aligned by adjusting the three spring-loaded screws around the circumference. Remove the two screws below the input aperture to take the cover off. Align this component only when following the procedure outlined in Appendix C.

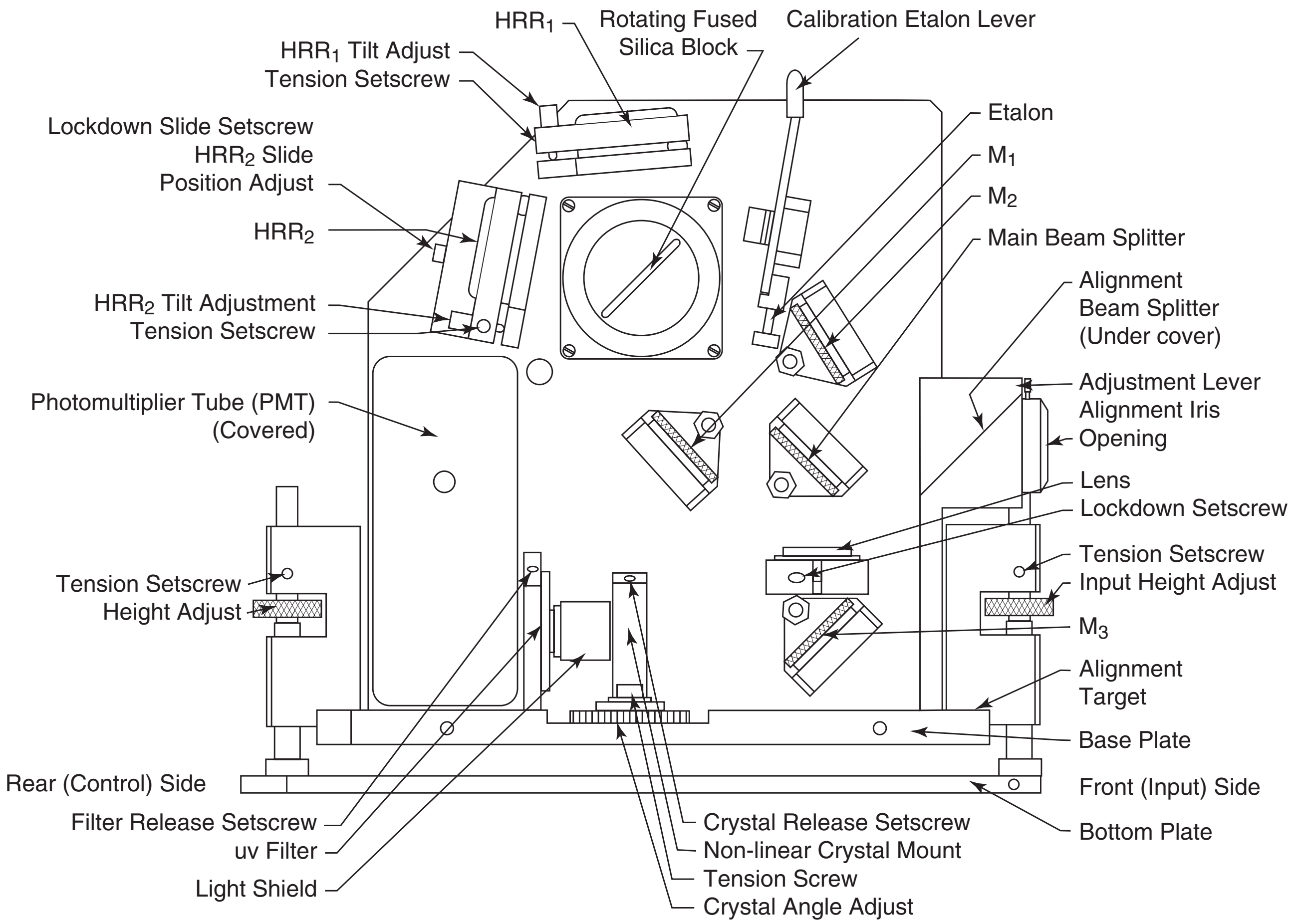

Figure 4-1: ***Model 409*** **Components, Controls, Indicators, and Connectors**

Alignment target—a reflective target in the top of the base plate on the input side. It is used as a guide to align the autocorrelator to the input beam. When properly aligned, the input beam is centered on the input iris and the alignment beam is centered on the target.

Main beam splitter—splits the input beam 50/50 and routes the two beams onto separate, equal length paths to and from hollow retro-reflectors HRR_1 and HRR_2 (Figure 4-2). The retro-reflectors offset each beam and return them to the beam splitter. Here they are placed in a single plane in line with the incoming beam and directed down to the lens.

The beam splitter is very thin to minimize the pulse broadening effects of group velocity dispersion (GVD). However, because it is thin, it is also very fragile and care must be taken when handling or cleaning it. It is designed for broadband operation from 550 to 1600 nm.

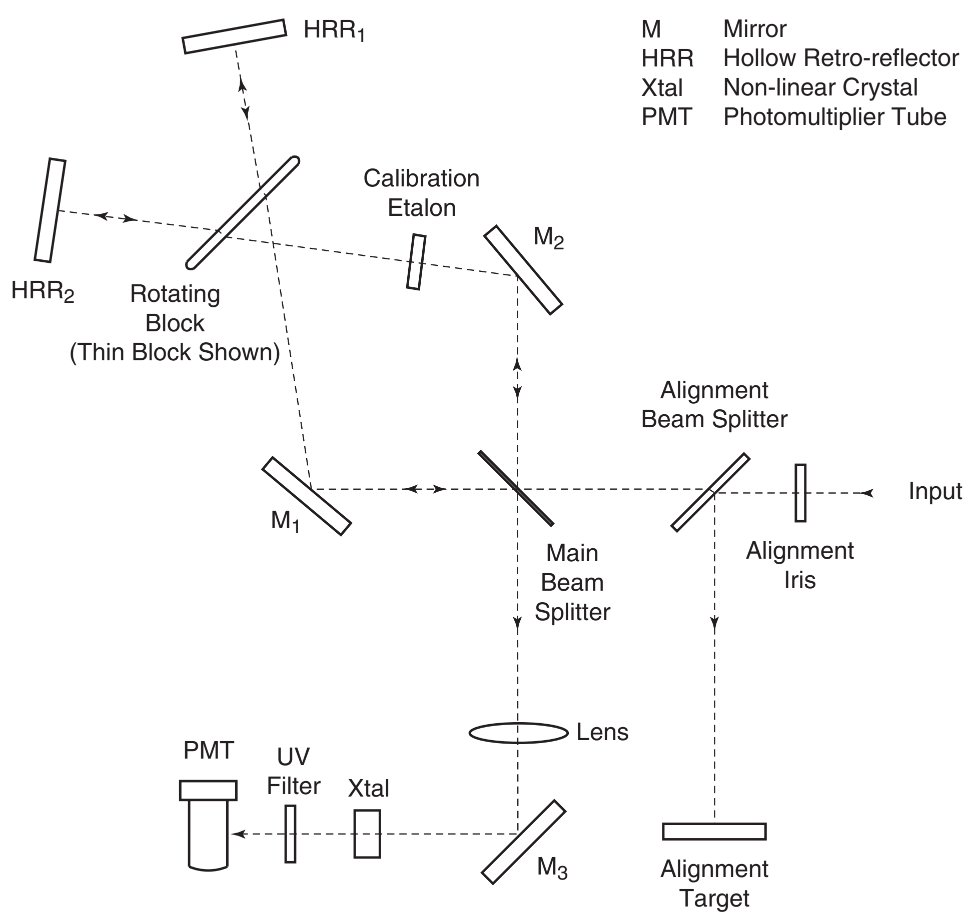

Figure 4-2: The *Model 409* Components and Optical Path

M_1, M_2 and M_3 routing mirrors—route beams along the beam path. M_1 and M_2 route beams 1 and 2, respectively, from the main beam splitter to HRR_1 and HRR_2, respectively, and the retro-reflected beams back to the beam splitter. M_3 routes the two beams from the lens to the nonlinear crystal.

Each mirror has a mount that can be rotated in a plane parallel to the center plate when the mounting bolt on the opposite side of the plate is loosened (Figure 4-4). Each also has a tilt control that permits a slight tilt of the mirror head when a jam nut at the base of the mount is loosened and the setscrew adjusted. Do not loosen this mount unless specifically told to do so in the "System Alignment" section of Appendix C.

Calibration etalon—a thin crystal that, when inserted into beam 2, provides a fixed optical delay of the autocorrelation signal for calibrating the oscilloscope time base. There are three etalons, each used with a corresponding rotating block. Use the large etalon with the large block, etc. The single-pass delay times for the etalons are shown in Table 4-1.

Please note that the etalon can be moved into both the input and return paths of beam 2 at the same time and, thus, double the above delay times. This will impact your time base calibration.

Table 4-1: Calibration Etalons

Etalon	Delay Time Single Pass
Large	20 ps
Medium	1.5 ps
Thin	300 fs

The arm supporting the etalon extends through the top of the autocorrelator cover for easy adjustment (see Figure 4-1). Position the arm toward the outside of the unit when the etalon is not in use. The etalon is changed by removing the etalon arm (the shoulder mounting screw), then removing the etalon holder (two Allen cap screws). Always block the input beam and turn off the autocorrelator to stop the spinning block when changing etalons.

Be careful when removing and replacing the autocorrelator cover. The etalon lever can be easily bumped and the etalon moved into one or both beam paths by accident. This can impact your calibration or pulse measurement. Always reposition the etalon lever toward the outside of the unit when you are done removing or installing the cover.

The three etalons are made of fused-silica. By their thin nature, the medium and thin etalons are very fragile and care must be taken when handling or cleaning them, or when moving about the cavity at any time.

Rotating block—spins in the paths of the split beams to create an optomechanical change in path length for each beam with respect to one another: as one path becomes longer, the other becomes shorter. Thus, pulses in one beam are swept past the pulses in the other. When these pulses overlap in the nonlinear crystal, a time-related autocorrelation signal is created.

The autocorrelation signal is sent to the vertical channel of the oscilloscope, while a sync signal (provided by the motor driver) is sent to the oscilloscope EXT time base input. Together they produce a real-time, viewable, measurable output pulse.

One of three different sized blocks is installed to optimize pulse width resolution for pulses from 30 fs to 65 ps (see Table 4-2). A single setscrew holds the block to the motor shaft, and the shoulder stop on the block assembly places the block at the correct position on the shaft relative to the beams when it is pushed all the way onto the shaft.

All three blocks are made of fused-silica. By their thin nature, the medium and thin blocks are very fragile and care must be taken when handling or cleaning them, or when moving about the cavity at any time.

Always block the incoming beam and turn off the autocorrelator when changing blocks.

Table 4-2: Block Sizes

Pulse Width	Block Size
1 ps < x < 65 ps	Large
0.2 ps < x < 5 ps	Medium
80 fs < x < 500 ps	Thin
30 fs < x < 80 ps	Thin (with prism compensation)

Hollow retro—reflectors HRR_1 and HRR_2 reflect the split beams back through the rotating block to the main beam splitter and provide an offset that prevents reverse coupling into the input beam. In lieu of prisms, the hollow retro-reflectors eliminate glass from the beam paths, and, thus, minimize the pulse broadening effects of group velocity dispersion (GVD).

Lens—focuses reflected beams 1 and 2 from the main beam splitter into the nonlinear crystal for efficient autocorrelation signal generation. The lens can be moved up and down in the holder to compensate for change in beam waist position due to change in wavelength. Made from thin, 1 mm thick BBO crystal, it allows transmission of wavelengths up to 1.6 mm and minimizes the pulse broadening effects of GVD. A single lockdown setscrew holds the lens in place (Figure 4-1).

Nonlinear crystal—frequency-doubles the two reflected beams and generates an autocorrelation signal when (i) it is set to the proper angle for the laser wavelength used, (ii) the pulses in the two beams overlap, and (iii) the overlapped pulses are properly focused within the crystal.

A thumb wheel protruding from the optics side of the autocorrelator near the base plate sets the phase-matching angle of the crystal. The tension mounting screw and spring washer provide enough friction to maintain the crystal at the angle set by the operator, yet allows the operator to move it at will. This screw is removed in order to remove the crystal assembly from the unit. Do not overtighten this screw.

The crystal is polarization sensitive and the SP label on the front of it should appear upright for sampling vertically polarized light. The crystal is mounted in a sealed housing filled with a phase-matching liquid—*never open the sealed unit*. When properly installed in its mount, the crystal is flush with the input side of the mount. A single setscrew on the top exposed corner of the mount holds the crystal in place (Figure 4-1).

UV Filter—absorbs all but the frequency-doubled UV light from the nonlinear crystal. This UV light then passes on to the photomultiplier tube (PMT) for detection and amplification. A single setscrew on the top exposed corner of the mount holds the filter in place. A light shield (shroud) slides onto the input snout of the filter and minimizes the amount of ambient light that reaches the filter.

Three filters are used to cover the entire wavelength range, and each is identified by a different color (refer to Table 4-3). The green filter is provided as standard for use with the Tsunami laser. The other two are optional.

Table 4-3: UV Filters

Filter Color	For Input Wavelength Regions
Black	550 to 680 nm (Opt.)
Green	680 to 1080 nm (Std.)
Light Blue	1080 to 1600 nm (Opt.)

Photomultiplier case—encloses the photomultiplier tube (PMT) which has a high spectral sensitivity in the UV range from 550 nm to 1.6 mm. A small aperture in the case allows only the filtered, UV light to enter the PMT. *Do not open the case*.

Power supply—(located on the side opposite the optics) provides dc power to the *Model 409* from standard line voltages. It also contains the GAIN amplifier, the variable DELAY control circuit, and provides a sync signal from the ac synchronous motor drive circuit.

Controls

The following controls are located on the rear panel of the autocorrelator (Figure 4-3).

GAIN control—used to control the gain of the photomultiplier tube (PMT). Saturation of the PMT output may occur if input beam power is
<50 mW or the GAIN control setting is too high. Normal GAIN setting is between “0” and “2.” The values silkscreened around the control knob are for uncalibrated reference only.

DELAY control—determines the time interval between the trigger pulse output and the autocorrelation signal. Use it to center the autocorrelation trace displayed on the oscilloscope. It is a 10-turn knob for fine position control.

Power switch–turns power on and off to the autocorrelator. It is lit when placed in the ON position and ac line power is available, thus indicating the autocorrelator is operational.

Connectors

The following connectors are located on the rear panel of the autocorrelator (Figure 4-3).

SIGnal OUT connector (BNC)—provides attachment for a BNC cable between the autocorrelator and the high impedance vertical amplifier of an oscilloscope. It sends the output signal from the photomultiplier tube to the oscilloscope.

TRIGger OUT connector (BNC)—provides attachment for a BNC cable between the autocorrelator and the external trigger of an oscilloscope. It sends the DELAY trigger pulse signal to the oscilloscope.

Power connector—provides attachment for the power cord and contains the fuse as well as the voltage-select pc board that is used for setting the system for 100, 120, 220, or 240 Vac.

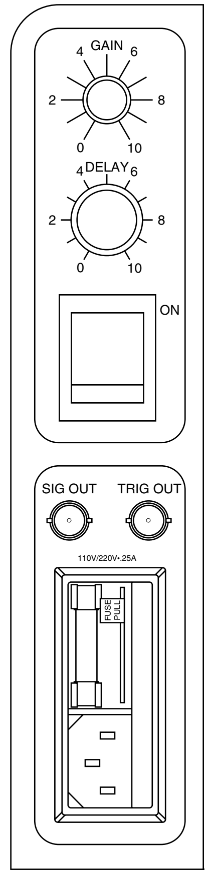

Figure 4-3: ***Model 409*** **Rear Control Panel**

Adjustments

Caution!

With the exception of the crystal angle adjust, do not realign the internal components of the autocorrelator unless you are certain the system has been tampered with or dropped. All day-to-day alignment adjustments, including changing the rotating block, etalon and UV filter are covered in Chapter 5, "Setup and Operation."

Crystal angle adjust—is a thumb wheel that protrudes from the optics side of the autocorrelator just above the base plate and is used to rotate the nonlinear crystal. This rotation sets the crystal to the phase-matching angle for the wavelength used and produces the autocorrelation signal when the pulses in both beams are overlapped and properly focused in the crystal. The tension screw applies just enough friction to keep the wheel from turning accidentally, yet allows it to be rotated when intended.

HRR_1 tilt adjust—used to align reflected beam 1 parallel to the center plate. When properly adjusted, beams 1 and 2 spatially overlap in the nonlinear crystal. The adjustment is accessed through the top of the cover via an access hole covered by a plastic plug. This adjustment is used to optimize the autocorrelation signal. A tension setscrew on the side of the mount (Figure 4-1) supplies friction to hold this adjustment in place; loosen it only if the tilt adjust is too tight to turn. Changing the tension on the tilt adjust can affect the autocorrelator alignment slightly.

HRR_2 tilt adjust—used to align reflected beam 2 parallel to the center plate. When properly adjusted, beams 1 and 2 spatially overlap in the nonlinear crystal. This adjustment is accessed only by removing the cover and should be used only when the position of beam 2 is adjusted during a system alignment. A tension setscrew on the side of the mount (Figure 3-1) supplies friction to hold this adjustment in place; loosen it if the tilt adjust is too tight to turn. Changing the tension on the tilt adjust can affect the autocorrelator alignment slightly.

HRR_2 position adjust—used to set the path length of beam 2 equal to that of beam 1, thus enabling the two separate pulses to temporally overlap in the nonlinear crystal for proper autocorrelation. The position adjustment moves HRR_2 on a dovetail slide, and it is secured via a lockdown setscrew to prevent accidental movement (Figure 4-1). The adjustment and set screw are accessible only when the cover is removed. Adjust this control only when specifically told to do so in the alignment procedure in Appendix C. The position adjust is set at the factory and should not be readjusted.

Mirror and main beam splitter mount clamping screws (4)—used to secure the three mirrors and the main beam splitter to the center plate once they have been aligned at the factory (Figure 4-4). Do not loosen these nuts unless advised to do so elsewhere in this manual.

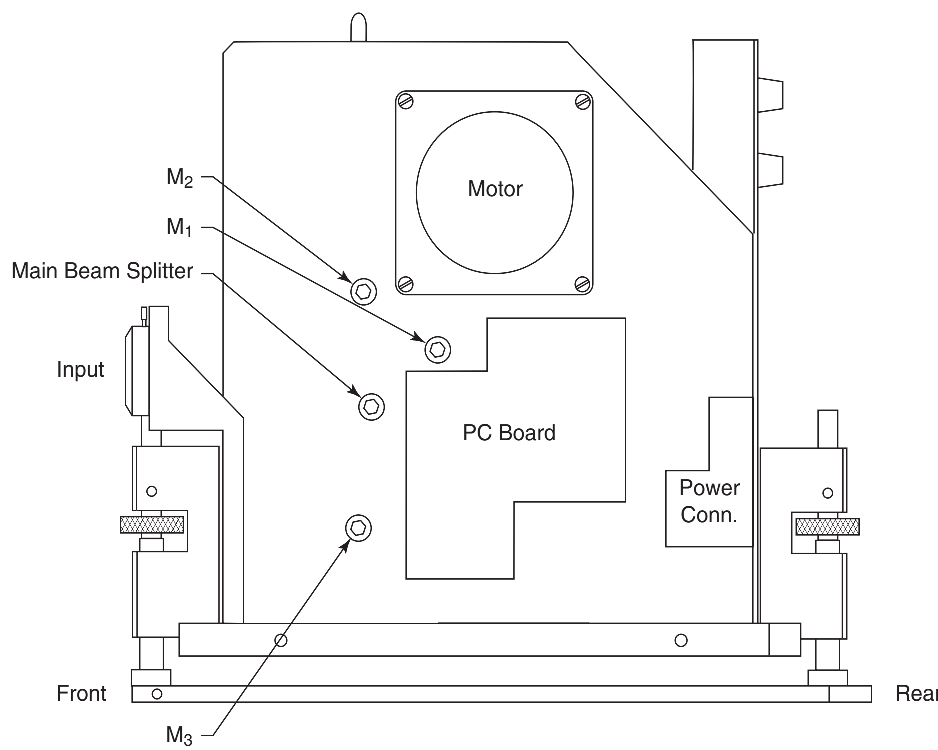

Figure 4-4: The Four Clamping Screws for the Mirrors and Main Beam Splitter

Chapter 5 Setup and Operation

Setup

The *Model 409* autocorrelator is easy to set up. The summary below is a check list for setting up the autocorrelator quickly. Following the list is a detailed step by step setup procedure for first time users and for those using the autocorrelator only occasionally. As you continue to use your unit, you will find its setup becoming second-nature and the summary list will serve as a quick reference.

Note

The *Model 409* is designed to measure vertically polarized light. For horizontally polarized light measurements, use a polar rotator external to the unit to rotate the light vertically—do not rotate the nonlinear crystal to compensate. The label on the crystal should always be upright and the long axis of the crystal should be horizontal.

Setup summary

- Place the autocorrelator on the table near the laser beam pick-off point.
- Connect the autocorrelator to an oscilloscope and set the oscilloscope for 200 mV/div. and 5 ms/div. sweep and external trigger.
- Turn on the autocorrelator and oscilloscope and verify the connections are correct and the unit is working properly by adjusting the GAIN and DELAY controls.
- If required, set up a beam splitter to pick off less than 50 mW of the sampled beam and direct it parallel to the table toward the autocorrelator.
- Align the autocorrelator to the laser beam using the alignment iris and alignment beam and target, and clamp the autocorrelator to the table.

Setup Procedure

Set up the autocorrelator so it is convenient to use.

Caution!

The autocorrelator can be misaligned by sharp shocks or impacts. *DO NOT* drop the unit or jar it while placing it upon a surface. When moving the *Model 409*, support it by holding onto its base.

Input power greater than 50 mW to the *Model 409* will saturate the photomultiplier tube, causing the output signal to be limited or unusable. If high laser power is required, use a beam splitter to pick off a sample of the beam for measurement, or use an attenuator.

In the procedure below we refer to the beam input side as the “front” of the autocorrelator and the control panel side as the “rear.”

Place Unit on the Table and Hook Up the Cables

1. Place the autocorrelator on the table near the point you plan to pick off a sample of the laser beam. Allow room for any collimating lens or prism-pair compensation* you wish to use. Place an oscilloscope close by.

   The autocorrelator controls should be accessible to you, and the inter connecting BNC cables should be able to reach between the control panel and the oscilloscope. The power cord for the autocorrelator is about 2 m long.

2. Plug the autocorrelator power cord to line power.
   a. Verify that the voltage-select pc board is properly installed before plugging in the power cord.

      The voltage-select pc board is located inside the power receptacle on the rear control panel, and the voltage setting is visible through the small sliding window (Figure 4-3). Before operating the unit the first time, verify this voltage setting matches your facility voltage. Also verify a fuse is installed. The fuse is rated at 0.25 A.

      To check the fuse or change the voltage setting, slide the window to the side. Pull out on the FUSE PULL lever to remove the fuse. To change the board setting, use needle-nose pliers to grasp the board and remove it from its seat, rotate it and/or flip it over so your voltage is selected for view in the window, and reinsert it.

   b. Plug the power cord into the unit's power receptacle, then plug the cord into your facility power source.

3. Attach a BNC cable between the SIG OUT connector on the control panel and the high-impedance (1 MΩ) vertical channel on an oscilloscope. Attach another cable between the TRIG OUT connector on the control panel and the external trigger input on the oscilloscope.

4. Turn on the autocorrelator and oscilloscope and set the oscilloscope to 200 mV/div. for the vertical amplifier and 5 ms/div. for the time base. Also set the time base to EXTernal trigger.

5. Verify the autocorrelator amplifier is operating correctly by varying the GAIN control.

   As gain is increased, the trace on the oscilloscope forms a sawtooth wave form. This is normal. If this does not happen, check that the cable is correctly connected to the oscilloscope and that the oscilloscope setting is correct (Step 4 above).

* *A discussion of prism-pair compensation for group velocity dispersion, or GVD, is found in Appendix D.*

6. Verify the autocorrelator DELAY control works properly by turning this knob.

   Does the trace on the oscilloscope move from side to side when the DELAY knob is adjusted? If this does not happen, check that the cable is correctly connected to the oscilloscope and that the oscilloscope setting is correct (Step 4 above).

7. Close the alignment iris by pushing the lever to one side.

8. If the power of the laser beam to be measured is greater than 50 mw, use an uncoated beam splitter to pick off part of it and direct it toward the autocorrelator. A retro-reflection from any beam in the setup can also be used as an input to reduce the amount of glass in the measurement. Make sure the picked-off beam is parallel to the table. Note: it is not advisable to use the alignment iris as a beam attenuator if exact pulse width measurement is desired. If the beam profile is not symmetrical, the measurement can vary depending on the part of the beam measured.

   If power greater than 50 mW is measured, the photomultiplier tube (PMT) will saturate and the signal output will become distorted. The pulse will widen and "wings" will appear. Figure 5-1 shows a normal pulse and a typical saturated signal.

9. Reposition the autocorrelator on the table to horizontally align its alignment iris to the picked-off beam.

10. Adjust the height of the autocorrelator so the input beam is centered on the input alignment iris.

    Adjust the height by turning the knurled wheel on the front leg. If the wheel is too tight to turn, loosen the tension setscrew on the side of the mount (Figure 5-2) just enough so the wheel can turn, yet you can still feel a drag on it.

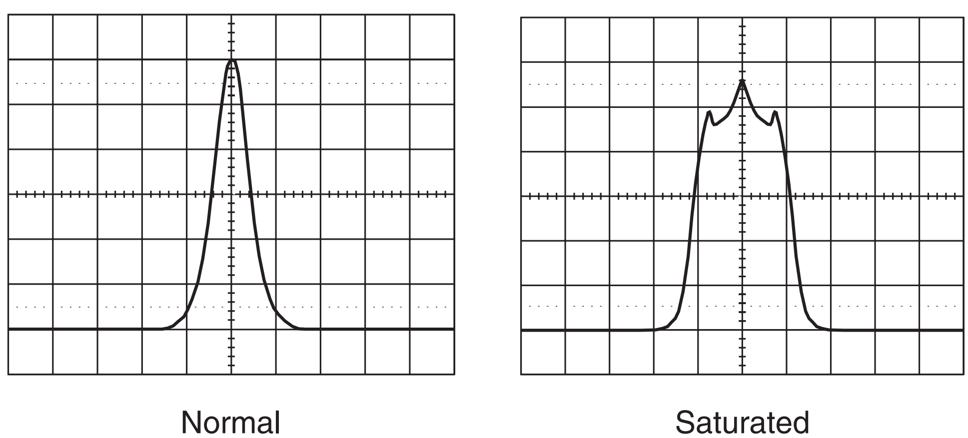

Figure 5-1: Normal pulse vs. a PMT-saturated Pulse with Wings.

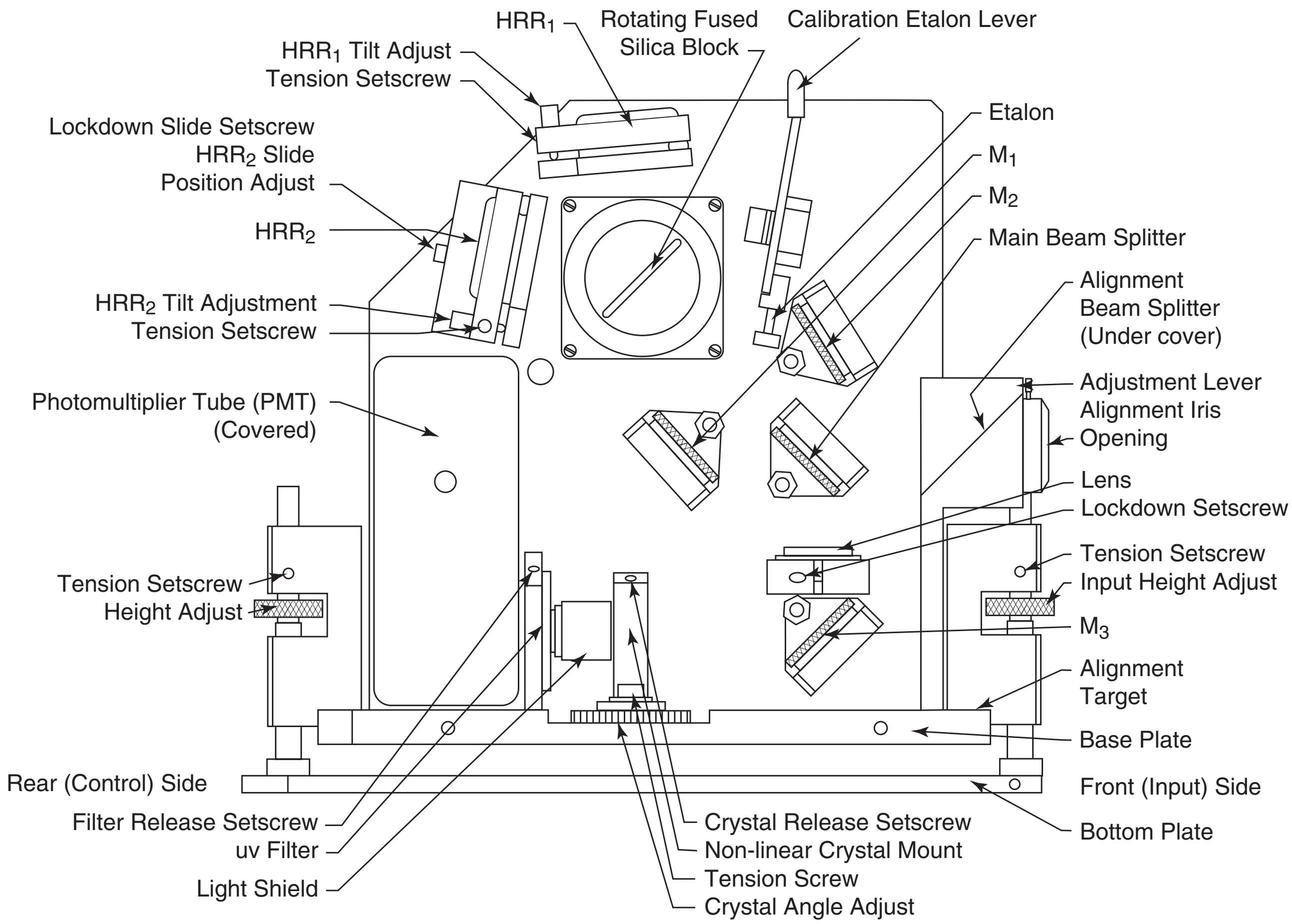

Figure 5-2: ***Model 409*** **Controls, Indicators, and Connectors**

11. Open the iris to the size of the beam diameter, and repeat Steps 9 and 10, if necessary, if the beam moved off the center of the opening.

Aligning on the Alignment Target

12. Using one of the two table clamps provided in the accessory kit, clamp one of the input-side corners of the bottom plate to the table.

    This provides a swivel point and prevents the front of the unit from moving laterally, yet allows lateral movement of the rear during the next few steps.

For the following steps, use a white business card, transparent tape, an IR viewer, or fluorescent card to help you see the alignment beam spot.

13. Adjust the autocorrelator yaw alignment.

    While viewing the alignment target (Figure 5-2) from directly overhead (if possible), move the back of the autocorrelator from side-to-side to place the alignment beam spot in line with the center of the target. Note: the beam exits below and behind the alignment iris. When done, the input beam should still be centered on the input iris.

14. Adjust the autocorrelator pitch alignment.

Again, view the alignment target from above and adjust the height of the back leg to center the alignment beam on the target. If the wheel is too tight to turn, loosen the tension setscrew on the side of the mount (Figure 4-2) just enough so the wheel can turn, yet you can still feel a drag on it.

15. Clamp the rear of the bottom plate to the table using the second table clamp. Verify the input beam is still centered on the input iris. If it has moved, loosen the front table clamp and repeat Steps 9 through 14.

This completes the autocorrelator setup. Continue with “Operation” for instructions on using your unit.

Operation

The summary below is a check list to allow you to use the autocorrelator quickly on a day-to-day basis. Following the list are step by step start-up and shut down procedures for first time users and for those using the autocorrelator only occasionally. As you continue to use your unit, you will find many of these procedures becoming second-nature and the summary list will serve as a quick reference.

When the pulse width to be measured is changed considerably, the rotating block and etalon might need to be changed in order to maintain optimum measurable resolution. When there are large changes in laser input wave length, the UV filter might need to be changed to accommodate the new wavelength, and when and if the UV filter is changed, the lens might need readjustment to refocus the beams in the nonlinear crystal. The sections, “Changing the Block and Etalon” and “Changing the UV Filter” at the end of this chapter explain how to make these changes and readjustments.

Operation Summary

- Verify the autocorrelator is setup and aligned to the picked-off input beam according to the setup instructions above.
- Verify the laser is pulsing and mode locked, and, if you have a dye laser, that the output beam is collimated.
- Change the block, etalon, and UV filter, if necessary, for the pulse width being measured and laser wavelength used.
- Adjust the nonlinear crystal until the autocorrelator signal is found midway between the two square-shaped beam signals.
- Use the calibration etalon to verify the signal is a true autocorrelation pulse (the signal shifts once the etalon is “in/out”).
- Readjust the GAIN control on the autocorrelator and the vertical and horizontal controls on the oscilloscope to display a good pulse. The time base should be set between 0.1 and 5 ms.
- If you are measuring pulses less than 100 fs, use a prism-pair to compensate for group velocity dispersion (GVD). Refer to Appendix D.

Start-up Procedure

Once the autocorrelator is set up, each time it is used during that setup, simply confirm its alignment to the input beam by verifying the input beam is centered on the input iris and the alignment beam is centered on the alignment target. If either is not the case, refer to the setup section again to realign the autocorrelator to the input beam. Once aligned, proceed as follows for day-to-day operation:

1. Verify the laser is pulsing and mode locked. An ultrafast photodiode such as the ET2000 can be used, or, if you have a fs system, a grating can be used instead to spread the 1^{st} order spectrum. (If no pulses are present, no spreading will result.) If you are using a dye laser, verify the input beam is collimated and that its mode is TEM_{00}.
2. If you are not changing pulse width or laser wavelength from that used last time, skip to Step 3. If you are changing pulse width, you might need to change the block and etalon. Refer to “Changing the Block and Etalon” at the end of this chapter. If you are changing wavelengths, refer to “Changing the UV Filter” also at the end of this chapter.

Finding a Pulse

3. While watching the oscilloscope, adjust the nonlinear crystal to get an autocorrelation signal. If an autocorrelator signal is observed, skip to “Testing for Autocorrelation” later in this chapter and continue from that point.

Note

The autocorrelation phase-matching angle of the nonlinear crystal also changes with a change in laser wavelength. Therefore, the crystal angle should be adjusted every time you change laser wavelengths.

If you cannot find the signal after following the rest of this step, and Steps 4 through 8 if you have a Tsunami laser, continue with the next section, “Cannot Find an Autocorrelation Trace.”

Rotate the crystal and look for any gain response on the oscilloscope. Any increase in gain means pulses are present. If no gain increase is observed and you are positive pulses are present, refer to the trouble shooting guide in Chapter 6 to determine the cause.

Two large squarish pulses should appear on the oscilloscope, one for each of the frequency-doubled beams, and, midway between, the $sech^2$ autocorrelation pulse (Figure 5-3). The autocorrelation pulse is often very small and you might have to change the gain of the autocorrelator in order to see it. It is also possible you might have to reduce the gain if the signal appears saturated, i.e., the top is flattened and the pulse appears to have wings (Figure 5-1)

If you can see squarish pulses but cannot find the autocorrelation pulse, there might be too much light noise in the room. Reduce the ambient light as much as possible. (Note that too much input beam power, the GAIN set too high, the wrong UV filter installed, or a poorly focused lens will also cause this problem.)

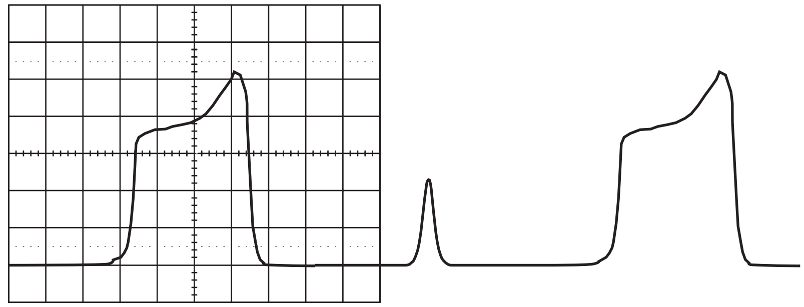

Figure 5-3: Autocorrelation pulse bounded by the squarish frequency-doubled beam pulses. The pulses shown are typical, but sizes and shape can vary widely.

The following Steps, 4 through 7, applies to fs and ps Tsunami systems. The precursor indication shown in Figure 5-4, a - e, however, does not exist for fs systems.

4. Increase the gain on the autocorrelator so a trace is seen on the oscilloscope (noise on the baseline, Figure 5-4a).
5. Adjust the fine PHASE control on the Tsunami Model 3955 to maximize the amplitude of the pulse Figure 5-4, b - d).

   Small adjustments to the bi-fi (ps) or prism pair (fs) may also be necessary. Turn the appropriate micrometer control $^1/_4$ turn at a time.
6. Adjust the prism dispersion compensation control (fs) until a pulse occurs (Figure 5-4f) or the GTI POSITION control (ps) until a pulse begins to appear (Figure 5-4, e - f).
7. Slightly adjust the angular adjustment knobs on the AOM mount to maximize the amplitude of the autocorrelator trace.

Repeat Steps 5, 6, and 7 until the pulse locks. The amplitude will drastically increase and the pulse will be well defined at this point. If the autocorrelator gain is too high and the signal is saturated (Figure 5-4g), lower the gain on the autocorrelator until a clean pulse is present, and increase the oscilloscope sweep speed to broaden the pulse for viewing (Figure 5-4h).

8. Optimize Tsunami output power, then skip to “Testing for a True Autocorrelation.”

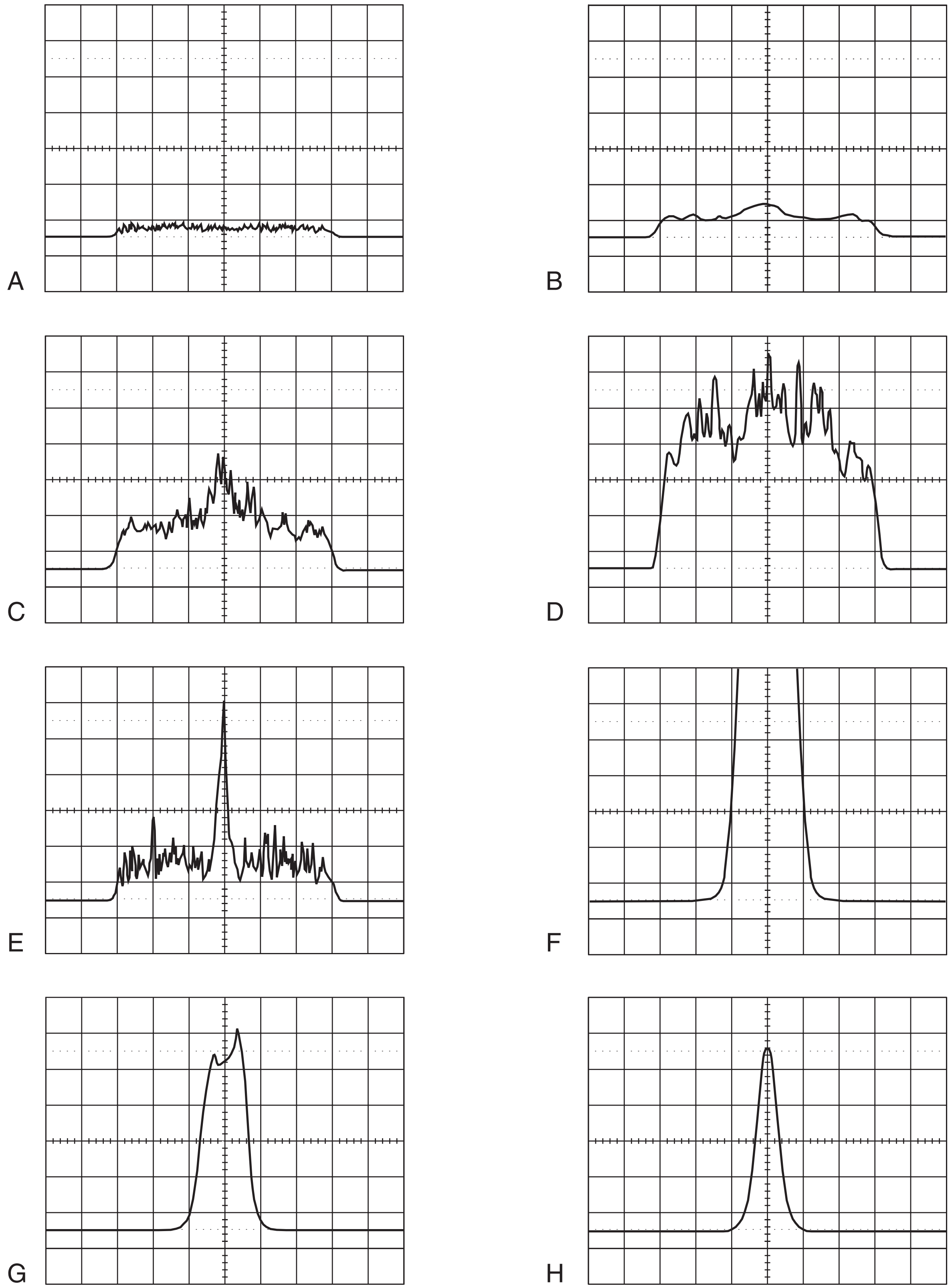

Figure 5-4: Precursor to mode locking a pulse (ps) as seen through an autocorrelator on an oscilloscope.

Cannot Find an Autocorrelation Trace

If the autocorrelation trace cannot be found, *do not try to align the autocorrelator optics yet.* If the unit worked the last time it was used, it should work this time—even if you changed the block and etalon and/or UV filter. It is more likely that the laser is either not emitting pulses or the autocorrelator is not set up properly for the pulse width or wavelength being measured.

Verifying the Laser is Emitting Pulses

1. Verify the laser is emitting pulses.
   a. Connect an oscilloscope to the MONITOR and SYNC outputs on the Tsunami electronics module, or, if you are using a different laser, use a fast photodiode (such as the ET2000) and a fast oscilloscope to sample the output.
   b. If mode-locked pulses are evident, continue with "Verifying the Correct Block is Installed."
   c. If no pulses are evident, refer to your laser manual for instructions on how to coax pulses from your laser and on how to mode lock it. When mode-locked pulses are evident, return to Step 3 under "Start-up Procedure." If, after following those instructions for setting the crystal angle, you still cannot find an autocorrelation trace, continue with "Verifying the Correct Block is Installed."

Verifying the Correct Block is Installed

The *Model 409* system comes with three sizes of rotating blocks with matching etalons to cover the 65 ps to 30 fs range. Using the correct block ensures the highest pulse width resolution display possible.

2. Refer to Table 5-1 and verify the correct block is installed.

Table 5-1: Block Sizes

Pulse Width	Block Size
1 ps < x < 65 ps	Large
0.2 ps < x < 5 ps	Medium
80 fs < x < 500 ps	Thin
30 fs < x < 80 ps	Thin (with prism compensation)

If you need to change the block and etalon, refer to "Changing the Block and Etalon" at the end of this chapter for instructions then return here. Always change the etalon when you change the block.

If pulses are evident once the correct block and etalon are installed, replace the cover (make sure the etalon is not bumped into the beam path), and return to Step 3 in the "Start-up Procedure."

If no pulses are evident, continue with "Verifying the Correct Filter is Installed."

Verifying the Correct Filter is Installed

Three UV filters are supplied to cover the 550 to 1600 nm range of measurable input wavelengths. Each filter is color-coded and covers a wavelength region that ensures the best autocorrelation signal possible for amplification by the photomultiplier.

3. Refer to Table Table 5-2 and verify the correct UV filter is installed for the laser wavelength used.

Table 5-2: UV Filters

Filter Color	For Input Wavelength Regions
Black	550 to 680 nm (Opt.)
Green	680 to 1080 nm (Std.)
Light Blue	1080 to 1600 nm (Opt.)

If you do not need to change the filter, skip to “Adjusting the Focus of the Lens” below.

If the UV filter needs to be changed, refer to “Changing the UV Filter” at the end of this chapter for instructions, then return here.

At this point, the filter should be changed and the lens refocused. Return to Step 3 in the “Start-up Procedure” to adjust the crystal angle for the new wavelength and to find the autocorrelation trace.

Adjusting the Focus of the Lens

If the wavelength being measured is quite different from that measured last time, the focal point for beams 1 and 2 might be shifted enough to position it outside the nonlinear crystal. Adjust the position of the lens to return the focal point to a place inside the crystal.

4. Remove the nonlinear crystal assembly by removing the single tension mounting screw and, grasping the crystal mount, lift the whole assembly off the pivot pin.
5. Loosen the lens clamping screw with a $^7/_{64}$ in. driver just enough so that the lens can be moved up and down by hand but does not fall out.
6. Hold a white card directly over the crystal assembly pivot pin and move the lens up and down until beams 1 and 2 merge into a single spot on the card. A small tilt correction of HRR_2 might be necessary to place one beam on top of the other. If you cannot focus the two spots on the card, a realignment of the autocorrelator might be required. Refer to Appendix C, “System Alignment: Internal Optical Alignment.”
7. Once the two beams are focused on the card, remove the card and replace the crystal assembly.

   Do not tighten the crystal assembly tension mounting screw too much–it applies friction to the wheel keep the crystal from moving on its own, yet allows the wheel to be moved manually for angle adjustment.

8. Repeat Step 3 under "Start-up Procedure" to obtain an autocorrelation trace.
   a. If you still cannot find a pulse, place a white card in front of the UV filter (Figure 5-5) and adjust the crystal angle until one of the two frequency-doubled, bright blue beam spots appears on the card. Note the position of the crystal angle adjustment wheel. Then continue to rotate the crystal until the second bright blue spot appears and again note the position of the wheel. Set the wheel midway between these two positions and dither it around this point. A faint fluorescent autocorrelation spot the size of a pencil dot should appear (it will blink). *It will be hard to see* and you may have to darken the room in order to see it (Figure 5-6). When you find the autocorrelation dot, remove the card and the pulse should be visible on the oscilloscope.
   b. If the autocorrelation trace is evident on the oscilloscope, replace the cover, but do not bump the adjustment wheel or the etalon lever! Then skip to "Testing for Autocorrelation."

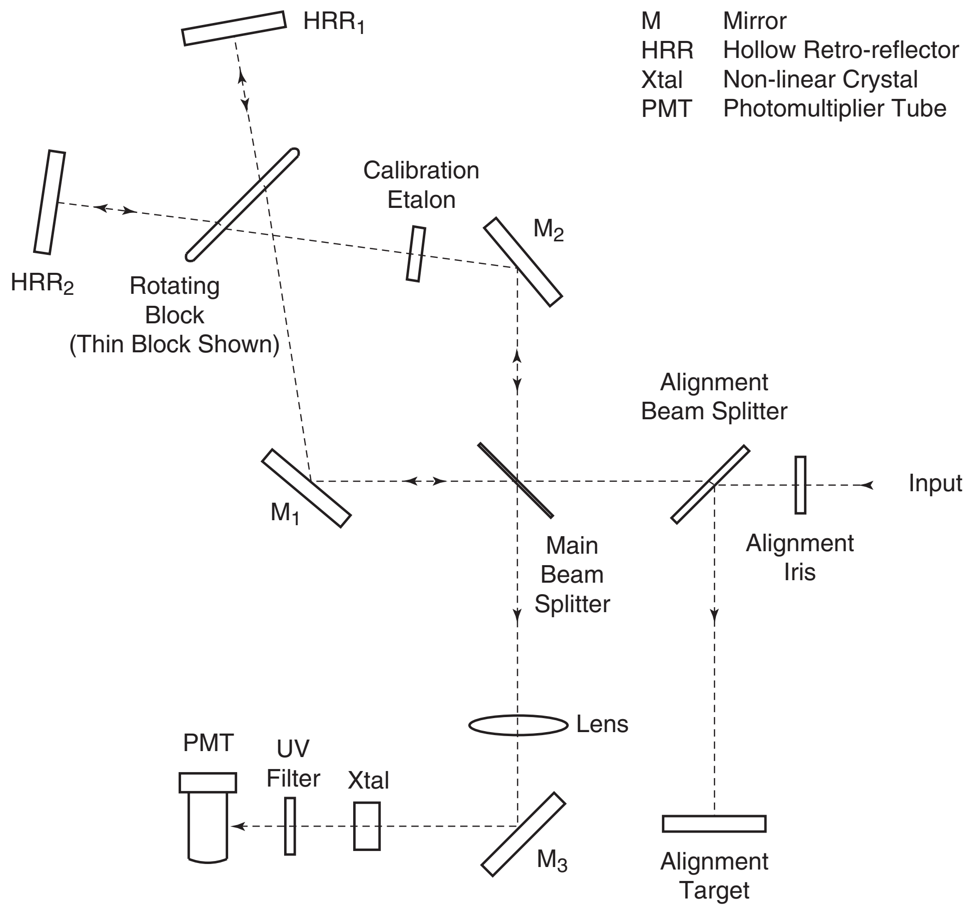

Figure 5-5: The *Model 409* Components and Optical Path

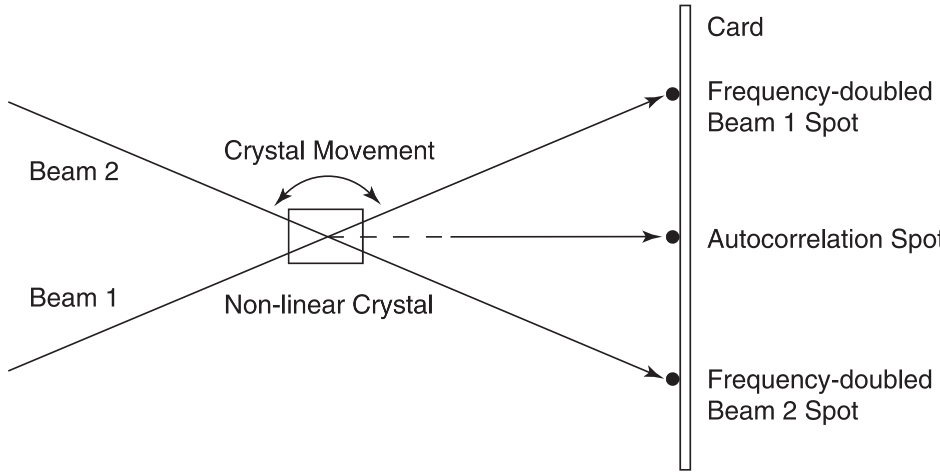

Figure 5-6: The frequency-doubled retro-reflected beams and autocorrelation spots on a white card.

c. If the autocorrelation trace is not evident on the oscilloscope, there might be a problem with the PMT. Refer to the trouble-shooting guide in Chapter 6 for information on replacing the PMT. When this is fixed, return to the very beginning of the "Start-up Procedure." If you still fail to obtain an autocorrelation pulse and you have performed all the steps in this procedure you might need to realign the autocorrelator. Refer to Appendix C, "System Alignment."

Testing for Autocorrelation

The following procedure is a simple test to verify the pulse shown on the oscilloscope is a true autocorrelation trace. It is also a quick test to see if an optical alignment is warranted.

1. Lower room lighting (especially if you are using fluorescent lighting) to minimize possible background noise.

The Test

2. Move the etalon into the beam(s) by pushing the lever toward the center of the autocorrelator. If the pulse shown on the oscilloscope is a true autocorrelation pulse, it will shift when the etalon delays the pulse. If it shifts, continue with "Calibrating the Oscilloscope." If it does not shift, repeat Step 3 of the "Start-up Procedure" at the beginning of this chapter, then repeat this test.

Calibrating the Oscilloscope

When the calibration etalon is moved into the beam path, the etalon delays the pulse according to Table 5-3 and shifts the pulse on the oscilloscope screen. The amount of shift permits us to calibrate the oscilloscope for this amount of ps or fs of delay per ms of sweep time. Be sure to note the sweep time of the oscilloscope. It should be set to 5 ms/div.

Table 5-3: Etalon Delay Time

Etalon	Delay Time for a Single Pass/ms
Large	20 ps
Medium	1.5 ps
Thin	300 fs

Determining the Delay

The following formula is used to determine the delay Δt:

$$\Delta t = \frac{(n-1) \times D}{C}$$

Where n = defraction index of fused silica taken from Figure 5-7

D = the thickness of the calibration etalon from Table 5-4, and

C = the speed of light.

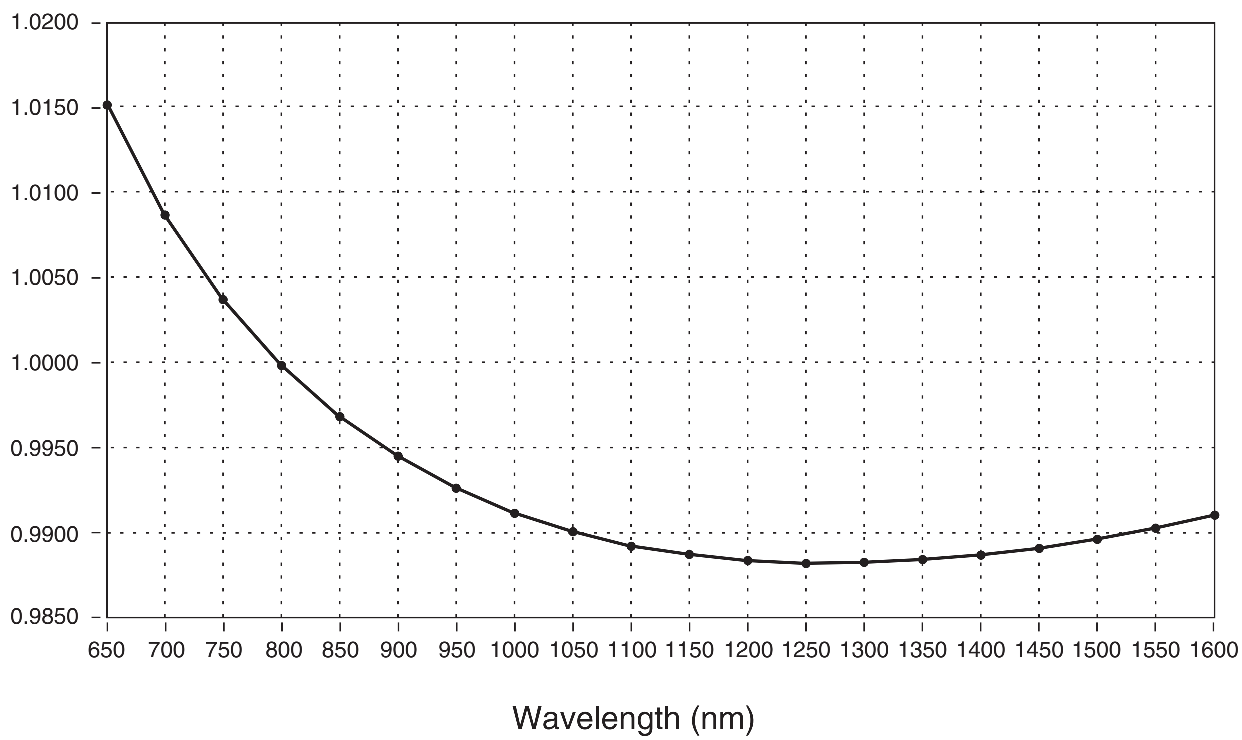

Figure 5-7: Calibration Etalon Correction Factor Relative to Delay at 800 nm.

Table 5-4: Etalon Thickness

Etalon	Thickness
Large	13.15 mm (0.52 in.)
Medium	5.0 mm (0.20 in.)
Thin	1.0 mm (0.04 in.)

If the etalon is positioned so it intercepts both the input and return beam paths, in addition to doubling the pulse delay time, it allows observation of pulse artifacts that are off to the side and normally out of view.

Interpreting the Signal

Unlike a dye laser, the Tsunami laser outputs an easily measured $sech^2$ pulse, as does the Opal system.* Figure 5-8 illustrates the relationship of pulse width to the autocorrelated pulse shape for a Tsunami or Opal $sech^2$ pulse. It is transform-limited and generally exhibits the shortest possible pulse width. In addition, the peak of the measured autocorrelation trace is the true peak of the actual pulse, unlike that for a dye laser. The full-width half maximum (FWHM) point is measured at one half its full height as shown, and the width of the actual pulse at that point is 0.65 of the measured (displayed) autocorrelation pulse width.

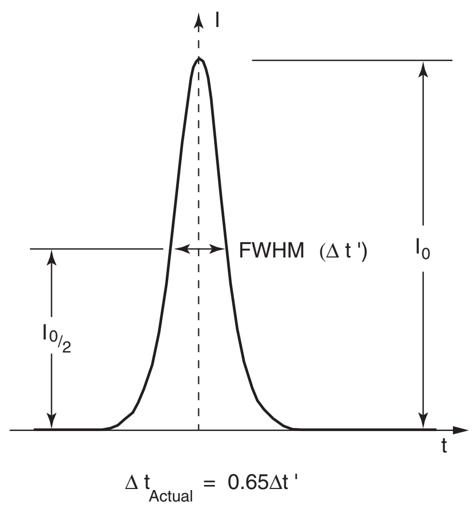

Figure 5-8: Transform-limited $sech^2$ Pulse

Note that the autocorrelation function must always be symmetric. If the output signal is asymmetric, the autocorrelator is either misaligned relative to the input beam or its internal optics are misaligned. Refer to the beginning of this chapter for information on aligning the autocorrelator to the input beam; refer to Appendix C, "System Alignment," for information on aligning the autocorrelator.

The pulse measured by the *Model 409* at the experimental point is very likely not the same as that produced by the laser, i.e., it is usually broadened due to group velocity dispersion (GVD). Appendix D, "Prism-pair Compensation," covers compensation for GVD and shows how to ensure the shortest possible pulse arrives at the experiment and how to measure it.

* *If you are measuring the output of an older dye laser, please refer to Appendix B for information specific to pulses generated by these systems.*

Shut down Procedure

The *Model 409* autocorrelator is simple to shut down:

1. Block the input beam.
2. Turn off the autocorrelator.

Changing the Block and Etalon

Table 5-5 lists the three available block sizes and the pulse widths for which they are designed. Select the appropriate block size for the pulse width you will be measuring, then select the corresponding etalon. Always change the rotating block and calibration etalon at the same time. Remember to place the optics that were removed in the optics kit to prevent damage. The optics are both fragile and expensive. *Always wear clean, powderless latex gloves when handling optics.*

Table 5-5: Block Sizes

Pulse Width	Block Size
1 ps < x < 65 ps	Large
0.2 ps < x < 5 ps	Medium
80 fs < x < 500 ps	Thin
30 fs < x < 80 ps	Thin (with prism compensation)

1. Turn off the autocorrelator.
2. Loosen the four Phillips screws around the bottom of the unit and remove the two screws on top of the unit. Then move the etalon lever toward the center of the unit and carefully lift the cover off (it can be a tight fit).

   Note: remove the cover only after the autocorrelator has been aligned to the incoming beam, and the base plate has been clamped to the table. This will prevent the alignment from getting jarred when the cover is removed or replaced.

Caution!

The cover of the *Model 409* blocks a path of laser radiation in a plane parallel to the center mounting plate. Exercise extreme caution when the cover is off and when moving about this plane, and always use eye protection appropriate for the laser wavelength being measured.

3. Rotate the block by hand until the mounting setscrew in the base is exposed. Use an $^{1}/_{16}$ in. Allen wrench or hex driver to loosen the screw, then, holding onto the assembly base, slide the block assembly off the motor shaft and place it in the optics kit.

Caution!

Be very careful when you are near the block. The blocks are fragile optics, but the medium and thin blocks are extremely fragile because of their thin nature—it doesn't take much pressure to chip or crack them. *Always hold the block by the assembly base.*

4. Replace the etalon while the block assembly is out of the way.

   Extend the etalon holder out as far as possible and remove the two $^{3}/_{32}$ in. Allen cap head screws holding the etalon assembly to the lever. Carefully remove the assembly.

Caution!

Again, be very careful when removing and replacing the etalon, especially the medium and thin etalons. These are extremely fragile optics because of their thin nature—it doesn't take much pressure to chip or crack them. *Always hold the etalon by the metal holder.*

5. Install the new etalon from the optics kit and replace the two screws. Do not overtighten. Place the etalon just removed into the optics kit.
6. Note the orientation of the flat side of the motor shaft and, again holding onto the assembly base, slide the new block from the optics kit onto the shaft so the clamping setscrew will press against the flat surface. The setscrew should be tight, but not too tight.
7. Replace the cover and turn on the autocorrelator.
8. Verify the *Model 409* is still properly aligned to the incoming laser beam. When properly adjusted, the input beam is centered on the input iris and the alignment beam is centered on the alignment target. If this is not the case, refer to the “Setup Procedure” at the beginning of this chapter for instructions.

This completes the installation of the block and etalon. *You should not have to realign anything when you replace these components.*

Changing the UV Filter

To span the 550 to 1600 nm wavelength range of the *Model 409*, three UV filters are used.Table 5-6 lists the wavelength range for each optic with its color-code for easy identification. The green filter for the 680 to 1080 nm Tsunami range is shipped standard with the autocorrelator. The other two are optional: black is for use with a dye laser, and light blue-green for use with the Opal laser. Select the filter for the laser wavelength range being measured.

Table 5-6: UV Filters

Filter Color	For Input Wavelength Regions
Black	550 to 680 nm (Opt.)
Green	680 to 1080 nm (Std.)
Light Blue-green	1080 to 1600 nm (Opt.)

To change filters:

1. Turn off the autocorrelator.
2. Loosen the four Phillips screws around the bottom of the unit and remove the two screws on top of the unit, then carefully lift the cover off (it can be a tight fit).

   Note: remove the cover only after the autocorrelator has been aligned to the incoming beam, and the base plate has been clamped to the table. This will prevent the alignment from getting jarred when the cover is removed or replaced.

Danger! Laser Radiation

The cover of the *Model 409* blocks a path of laser radiation in a plane parallel to the center mounting plate. Exercise extreme caution when the cover is off and when moving about this plane, and always use eye protection appropriate for the laser wavelength being measured.

---

3. Slide the light shield off the filter and set it aside.
4. Shine a light on the filter element to see which one is installed.
5. Loosen the filter release setscrew on top exposed corner of the holder (Figure 3-1) and pull the filter out.
6. Replace the filter with the correct one from the optics kit (refer to Table 4-6). Push the filter all the way in, then tighten the release setscrew. Place the filter just removed into the optics kit.
7. Replace the light shield.
8. Readjust the lens to properly focus the two beams in the crystal. The lens should not have to move more than 3 mm to focus the beams.

   Refer to "Adjusting the Focus of the Lens" earlier in this chapter.
9. Replace the cover.
10. Verify the *Model 409* is still properly aligned with the incoming laser beam. When properly adjusted, the input beam is centered on the input iris and the alignment beam is centered on the alignment target. If this is not the case, refer to "Setup Procedure" at the beginning of this chapter for instructions.
11. Turn on the autocorrelator.

This completes the installation of the UV filter.

Chapter 6 Maintenance

The condition of the laboratory environment, the amount of time you use the autocorrelator, and the amount of time the cover is off affects your periodic maintenance schedule.

Do not allow smoking in the laboratory: the optics stay clean longer. Condensation due to excessive humidity can also contaminate optical surfaces. The cleaner the environment, the slower the rate of contamination.

If the cover is left in place, there is little you must do day-to-day to maintain the autocorrelator. All controls required for day-to-day operation, except when you need to exchange the rotating block and calibration etalon, are accessible from the outside.

When you finally do need to clean the optics, follow the procedures below.

Notes on the Cleaning of Laser Optics

Laser optics are made by vacuum-depositing microthin layers of materials of varying indices of refraction onto glass or quartz substrates. If the surface is scratched to a depth as shallow as 0.01 mm (0.0004 in.), the operating efficiency of the optical coating can be reduced significantly and the coating can degrade.

Because the optics in the autocorrelator are outside the laser cavity, the performance of the unit does not degrade when they get dirty anywhere near what happens when laser intracavity optics get dirty. However, dust on these optical surfaces can still cause damage to the optics when the dust is hit with a laser beam and burned into the surface. Therefore, cleanliness is still essential, and you must apply the same laser optics maintenance techniques to the autocorrelator optics with extreme care and with attention to detail.

"Clean" is a relative description; nothing is ever perfectly clean and no cleaning operation can ever completely remove contaminants. Cleaning is a process of reducing objectionable materials to acceptable levels.

Equipment Required

- dry, filtered nitrogen, canned air, or rubber squeeze bulb
- hemostats
- optical-grade lens tissue
- clean, lint-free finger cots or powderless latex gloves

Cleaning Solutions Required

- spectroscopic-grade acetone and/or methanol

Methanol tends to clean better but may deposit a water-based film on the surface being cleaned if not fresh. If this occurs, follow the methanol wipe with an acetone wipe to remove the film. As always, use fresh solvent from a bottle with little air in it.

Standard Cleaning Procedures

Follow the principles below whenever you clean any optical surface.

- Clean only one element at a time.
- Work in a clean environment and, whenever possible, over a soft, lint-free cloth or pad if you have to remove an optic.
- Wash your hands thoroughly with liquid detergent.

  Body oils and contaminants can render otherwise fastidious cleaning practices useless.
- Always use clean, powderless and lint-free latex finger cots or gloves when handling optics.

  Remember not to touch any contaminating surface while wearing gloves; if you scratch that itch, you will transfer oils and acids onto the optics.
- Use filtered dry nitrogen, canned air, or a rubber squeeze bulb to blow dust or lint from the optic surface before cleaning it with solvent; permanent damage can occur if dust scratches the glass or mirror coating.
- Use spectroscopic-grade solvents.

  Since cleaning simply dilutes contamination to the limit set by solvent impurities, solvents must be pure as possible. Use solvents sparingly and leave as little on the surface as possible. As any solvent evaporates, it leaves impurities behind in proportion to its volume.
- Store methanol and acetone in small glass bottles.

  These solvents collect moisture during prolonged exposure to air. Avoid storing methanol and acetone in bottles where a large volume of air is trapped above the solvent.
- Use Kodak Lens Cleaning Paper™ (or equivalent photographic cleaning tissue) to clean optics.
- Use each piece of lens tissue only once; dirty tissue merely redistributes contamination–it does not remove it.

Caution!

Do not use lens tissue designated for cleaning eye glasses. Such tissue contains silicones. These molecules bind themselves to the optic coatings and can cause permanent damage. Also, do not use cotton swabs, e.g., Q-Tips™. Solvents dissolve the glue used to fasten the cotton to the stick, resulting in contaminated coatings. Only use photographic lens tissue to clean optical components.

General Procedures for Cleaning Optics

Caution!

With the exception of the doubling crystal, *DO NOT* remove the optics from their mounts for cleaning; doing so will require a complete realignment of the system. Optics can and should be cleaned in place. If the cover is kept on the unit, little, if any, cleaning is required. *Only clean optics when you need to.*

Clean only the optics that need to be cleaned. If you bump, or otherwise jar an optic, or drip acetone on an optic, you can cause more harm than good. In addition, the medium and thin blocks and the beam splitter are very thin and *are easily broken.* Also note that, because these optics are not inside the laser cavity, they are much less susceptible to signal loss than those in the laser. The autocorrelator is quite well sealed if the cover is kept on the unit; there should be little chance of dirt and dust getting inside.

When you do feel you need to clean the optics, you will probably only have to clean those optics that have a surface facing upward: the main beam splitter, the lens, mirrors M_1 and M_3, and perhaps the rotating block. Clean the top surface of these optics first, then test the results. This will usually prove satisfactory. None of the optics need to be removed for cleaning: clean them in place.

Caution!

Several optics, notably the beam splitters and the medium and thin blocks and etalons, are extremely fragile because of their thin nature. It doesn't take much pressure to chip or crack them. *Always hold the block by the assembly base.* Accidental damage is not covered by your warranty.

1. Block the incoming laser beam.
2. Use a squeeze bulb, dry nitrogen, or canned air to clean away any dust or grit before cleaning optics with solvent.

Stop at this point if the optic looks clean enough.

3. Use a tissue in a hemostat to clean the optic.
   a. Fold a piece of tissue in half repeatedly until you have a pad about 1 cm (0.5 in.) square, and clamp it in a plastic hemostat (Figure 6-1).

Caution!

While folding, *do not touch* the surface of the tissue that will contact the optic, or you will contaminate the solvent.

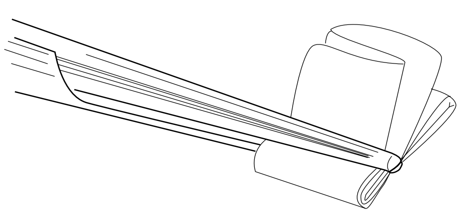

Figure 6-1: Lens Tissue Folded for Cleaning

b. If required, cut the paper with a solvent-cleaned tool to allow access to the optic.

c. Saturate the tissue with acetone or methanol, shake off the excess, resaturate, and shake again.

   Do not allow the tissue to remain saturated; excess acetone or methanol can run down the sides of optics, such as a beam splitter, and dissolve the cement holding it in its holder. This cement can later migrate onto the surface of the optic, making it even harder to clean, or ruin it.

d. Wipe the surface in a single motion.

   Be careful that the hemostat does not touch the optic surface or the coating may be scratched.

4. Repeat the cleaning with a fresh swab if necessary: never reuse a tissue.

When you need to clean the crystal, remove the single shoulder screw and lift the assembly off the pivot pin. *Do not disassemble the unit; only clean the windows.*

This completes the cleaning procedure.

Chapter 7 Service and Repair

This chapter contains a general troubleshooting guide for use by you, the user. It is provided to assist you in isolating some of the problems that might arise while using the autocorrelator. A complete repair procedure is beyond the scope of this manual. For information concerning repair by Spectra-Physics, see Chapter 8, "Customer Service."

At the end of this chapter is a replacements parts table listing components that can be replaced by you.

Troubleshooting Guide

Use this guide if the performance of the *Model 409* drops unexpectedly. If you try the following suggestions and are unable to bring your autocorrelator up to specification, call your Spectra-Physics service representative for help.

Danger!
Laser Radiation

Many of these procedures require you to adjust or replace optics with the cover off and the laser at high power. For safety, block the input beam every time you change an optic or interfere with the beam path in any way, and only unblock it during alignment. Protect yourself with appropriate eyewear at all times.

First, verify the autocorrelator voltage and fuse setting matches that of your facility voltage (see Chapter 4, "Installation and Alignment: Setting up the Autocorrelator"). Confirm all connectors for continuity. When the autocorrelator is turned on, the power switch glows.

Symptom: No autocorrelator signal

Possible Causes	Corrective Action
Crystal is not set to the correct phase-matching angle for the wavelength in use.	Place a white card in front of the uv filter, then rotate the crystal assembly until one of the two frequency-doubled, bright blue beam spots appears on the card. Note the position of the crystal adjustment wheel. Continue to rotate the crystal until the second bright blue spot appears and again note the position of the knob. By setting the control wheel midway between these two positions and dithering the wheel around this point, a faint fluorescent autocorrelated spot the size of a pencil dot should appear (blink). It will be hard to see; you may have to darken the room in order to see it. Once you see it, remove the card and try to find the pulse on the oscilloscope. Figure 7-1 illustrates the idea.

Symptom: No autocorrelator signal

Possible Causes	Corrective Action
Laser is not emitting pulses or is not mode locked.	Using a high-speed photodiode, verify the laser is emitting pulses and is mode locked.
Misaligned lens.	Maximize the uv output from the crystal by moving the lens up and down slightly in its mount. Place a white card in front of the photomultiplier tube case to observe the uv spot. If a large change in wavelength is made, the lens might need adjustment to refocus it in the crystal. Refer to subsections "Aligning M_3" and "Focusing the Lens" in Appendix C.
Poor input beam quality.	Check the power, collimation, and mode quality of the input beam. Improve if necessary.
Retro-reflector HRR1 tilt is out of adjustment.	Slowly swivel the crystal mount through its range. At each step, rotate HRR_1 tilt adjustment through a ¼ turn range about its original position while watching for a signal on the oscilloscope. For gross maladjustment, remove the cover and use a business card to stop beam 1 and 2 as they approach the crystal. Tilt HRR_1 to position the beams in the same horizontal plane, then repeat the procedure listed above.
One beam path is longer than the other (fs systems).	Adjust the HRR_2 slide position. Refer to Step 42 under subheading "Optimizing the Pulse" in Appendix C for instructions on aligning HRR_2 for equal beam path length with fs pulses present.
The wrong uv filter is installed for the wavelength used.	Loosen the filter release setscrew on top corner of the filter holder (Figure 4-1) and push the filter out. Replace the filter with the appropriate one from the optics kit (refer to Table 4-3) and set its holder flush with the input side of the holder, then tighten the release setscrew to hold it in place.
Faulty electronics	+12 Vdc should be found at pin E_4 (measure with respect to chassis ground or pins E_2, E_5, or E_{15} of the printed circuit board). With the autocorrelator off, remove the uv filter assembly. Turn the unit on and observe the response to room light. If there is still no signal proceed. With the autocorrelator off, open the PMT case (1 screw) and remove the tube. Clean and inspect the pins and socket contacts. Replace the tube in its socket. Turn the unit on and check for a signal. If there is still no signal, proceed. With the unit off, remove the PMT. Turn the unit back on and, using a DVM, carefully measure the high voltage from contact 11 of the socket to chassis ground (see Figure 6-1). It should be about –200 to –1200 Vdc (it varies with the setting of the GAIN control on the panel). +2 to +9 Vdc should be found at pin E_7 (when measured with respect to chassis ground or pin E_5. Verify oscilloscope trigger is working properly. Use clip leads to display the signal across the PMT load resistor (located on the PMT base mount) on the oscilloscope. If there is no PMT response at a full GAIN setting, the PMT may be bad.

Symptom: Signal evident but faulty	
Possible Causes	**Corrective Action**
Signal evident but no correlation trace.	Possible optical misalignment. Refer to appendix C, “System Alignment.” Gain is set too low or too high. Check for stray light getting into the PMT (especially fluorescent light).
No sweep trace on the oscilloscope.	check for tight connections between the oscilloscope trigger input and the autocorrelator TRIG OUT connector.
Less than full scan range can be seen.	Possible optical misalignment. Refer to appendix C, “System Alignment.” Check for possible damage to the rotating block.
Weak signal.	Possible optical misalignment of HRR_1 tilt adjust. Refer to appendix C, “SystemAlignment.” Possible optical misalignment of the lens. Refer to Steps 4 through 7 under “Adjusting the Focus of the Lens” in Chapter 5. Insufficient laser input power. Increase laser output power. Dirty optics. Clean the optics. Refer to Chapter 6, “Maintenance.”
Signal is too strong.	GAIN control is set too high; reduce gain. Laser input power is set too high; close down the input iris to attenuate the beam.
Signal-to-noise ratio is too low.	Possible optical misalignment. Refer to Appendix C, “System Alignment.” Not enough power; verify beam is collimated (beam width < 3 mm), mode is TEM00, and ambient light entering the *Model 409* is minimized (especially fluorescent light).

Symptom: Pulses are too wide (fs systems only)	
Possible Causes	**Corrective Action**
Dispersion of the input beam is too great.	Provide GVD compensation using prisms or gratings. The autocorrelator is ok. Refer to Appendix D for information regarding GVD compensation and on using prism-pairs.
The amount of GVD from the source to the autocorrelator is different than that from the source to the experiment.	Verify the GVD is the same in both legs. The *Model 409* contains about 3.8 mm of fused silica. Refer to Appendix D for information regarding GVD compensation and on using prism-pairs.

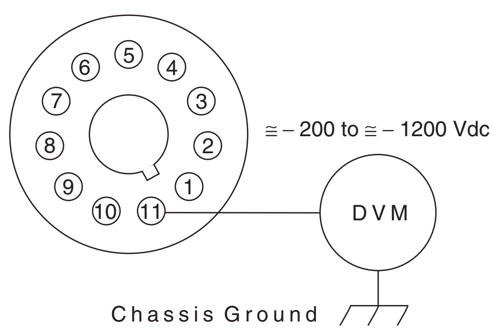

Figure 7-1: Position of Pin 11 on PMT Socket

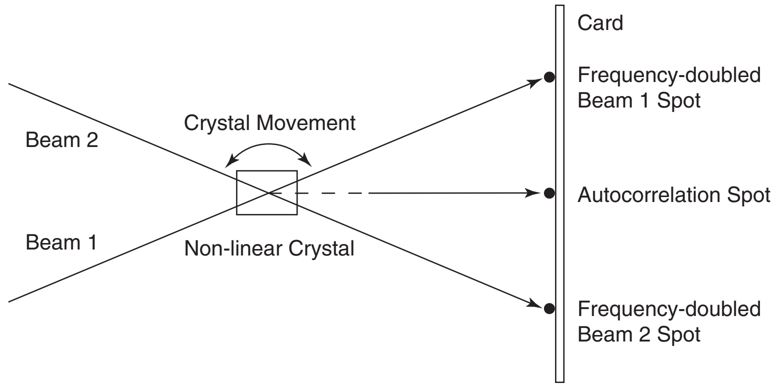

Figure 7-2: The frequency-doubled retro-reflected beams and autocorrelation spots on a white card.

Replacement Parts

Table 7-1: Replacement Parts

Description	Part Number
Beam splitter, broadband	G0020-001
Beam splitter, 25.4 fs substrate	G0020-000
Routing mirrors	
Thick Block	G0149-000
Medium Block	0449-5680
Thin Block	
Thick Etalon	G0151-000
Medium Etalon	
Thin Etalon	G0377-000
uv Filter, 280−320 nm (*Model 409-01*)	0424-2401
uv Filter, 345−405 nm (*Model 409-06*)	0424-2402
uv Filter, assembly	0424-2521S
Filter assembly, 1000−1600 nm	0451-0960
Mounted Filter, 345−405 nm	0424-2522S
Crystal assembly, KDP, 540−640 nm	0424-6631
Crystal assembly, Li Iodate, 700−800 nm	0424-6632
Crystal assembly, BBO, 700−1100 nm	0445-6430
Mirror, 430−810 nm	G0050-010
Prism, retro-reflecting	G0150-000
Optic, 15 mm, 560−640 nm	G0072-009
Optic, 15 mm, 690−810 nm	G0072-010
Photomultiplier tube, Hamamatsu R928-HA	5708-0091
PCB assembly	0448-4310
Model 409 Autocorrelator User's Manual	0000-231A

Chapter 8 Customer Service

At Spectra-Physics, we take pride in the durability of our products. We place considerable emphasis on controlled manufacturing methods and quality control throughout the manufacturing process; nevertheless, even the finest precision instruments will need occasional service. We feel our instruments have excellent service records compared to competitive products, and we hope to demonstrate, in the long run, that we provide above-average service to our customers–not only in providing the best equipment for the money, but in addition, service facilities that get your instrument repaired and back to you as soon as possible.

Spectra-Physics maintains major service centers in the United States, Europe, and Japan. Additionally, there are field service offices in major United States cities. When calling for service inside the United States, dial our toll-free number: **1 (800) 456-2552**. To phone for service in other countries, refer to the Service Centers listing located at the end of this section.

Order replacement parts directly from Spectra-Physics. For ordering or shipping instructions, or for assistance of any kind, contact your nearest sales office or service center. You will need your instrument model and serial number available when you call. Service data or shipping instructions will be promptly supplied.

Warranty

This warranty supplements the warranty contained in the specific sales order. In the event of a conflict between documents, the terms and conditions of the sales order shall prevail.

The *Model 409* is protected by a 12-month warranty. All mechanical and optical parts and assemblies are unconditionally warranted to be free of defects in workmanship and material for one (1) year following delivery of the equipment to the F.O.B. point.

Liability under this warranty is limited to repairing, replacing, or giving credit for the purchase price of any part of the equipment that proves defective during the warranty period, provided prior authorization for such return has been given by an authorized representative of Spectra-Physics. Warranty repairs or a replacement unit is warranted only for the remaining unexpired portion of the original warranty period applicable to the repaired or replaced equipment.

This warranty does not apply to any component not manufactured by Spectra-Physics. When products manufactured by others are included in Spectra-Physics equipment, the original manufacturer's warranty is extended to

Spectra-Physics customers. When products manufactured by others are used in conjunction with Spectra-Physics equipment, this warranty is extended only to the equipment manufactured by Spectra-Physics.

Spectra-Physics will provide at its expense all parts and labor and one-way return shipping of the defective part or instrument (if required).

This warranty does not apply to equipment or components that, upon inspection by Spectra-Physics, discloses to be defective or unworkable due to abuse, mishandling, misuse, alteration, negligence, improper installation, unauthorized modification, damage in transit, or other causes beyond Spectra-Physics ' control.

The above warranty is valid for units purchased and used in the United States only. Products with foreign destinations are subject to a warranty surcharge.

Return of the Instrument for Repair

Contact your nearest Spectra-Physics field sales office, service center, or local distributor for shipping instructions or an on-site service appointment. You are responsible for one-way shipment of the defective part or instrument to Spectra-Physics.

We encourage you to use the original packing box to secure the *Model 409* during shipment. If the shipping box has been lost or destroyed, we recommend you order a new one. Spectra-Physics will only return instruments in Spectra-Physics containers.

Service Centers

Benelux

Telephone: (31) 40 265 99 59

France

Telephone: (33) 1-69 18 63 10

Germany and Export Countries*

Spectra-Physics GmbH
Guerickeweg 7
D-64291 Darmstadt
Telephone: (49) 06151 708-0
Fax: (49) 06151 79102

Japan (East)

Spectra-Physics KK
East Regional Office
Daiwa-Nakameguro Building
4-6-1 Nakameguro
Meguro-ku, Tokyo 153
Telephone: (81) 3-3794-5511
Fax: (81) 3-3794-5510

Japan (West)

Spectra-Physics KK
West Regional Office
Nishi-honmachi Solar Building
3-1-43 Nishi-honmachi
Nishi-ku, Osaka 550-0005
Telephone: (81) 6-4390-6770
Fax: (81) 6-4390-2760
e-mail: niwamuro@splasers.co.jp

United Kingdom

Telephone: (44) 1442-258100

United States and Export Countries**

Spectra-Physics
1330 Terra Bella Avenue
Mountain View, CA 94043
Telephone: (800) 456-2552 (Service) or
(800) SPL-LASER (Sales) or
(800) 775-5273 (Sales) or
(650) 961-2550 (Operator)
Fax: (650) 964-3584
e-mail: service@splasers.com
sales@splasers.com
Internet: www.spectra-physics.com

**And all European and Middle Eastern countries not included on this list.*
***And all non-European or Middle Eastern countries not included on this list.*

Appendix A The Scanning Mechanism

The scanning mechanism of the *Model 409* is shown in Figure A-1. The length of the two beam paths are changed by passing both of them through a rotating block of fused silica. The two beams enter the block at complementary angles with respect to the normal of the block surface. As the block rotates, the angle of incidence that each arm makes with the surface of the block is varied and, due to the effects of Snell's law, a change in optical path lengths results.

The well known expression of Snell's law is:

$$n \sin \theta = n' \sin \phi$$

Where θ = the angle of incidence,

ϕ = the angle of refraction, and

n and n' are the refractive indices of the first and second medium.

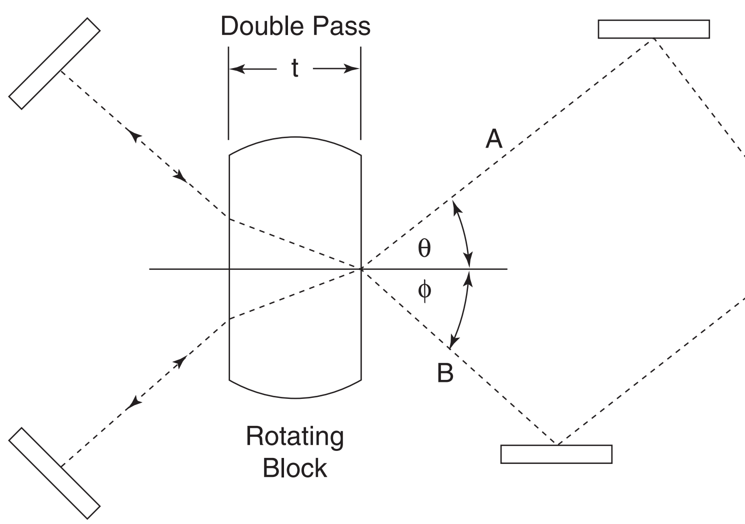

Figure A-1: Scanning Mechanism, *Model 409*

The actual variation in effective optical path length of a single beam as a function of the normal incident angle (to the block) is given by the expression:

$$\Delta L_{(\theta)} = 2t(\sqrt{n^2 - sin^2\theta} - \cos\theta + 1 - n)$$

Where L = the path length variation relative to normal incidence for a single beam,

n = the block index of refraction, and

t = the thickness of the block.

Since the angles at which the two beams enter the block are complimentary (i.e., as one angle is increasing, the other is decreasing), the expression for the relative change in optical path length between the two arms of the autocorrelator is given by the difference between the expressions for each one individually:

$$\Delta L_{A(\theta)} - \Delta L_{B(\phi)} = 2t\left\{[\sqrt{n^2 - sin^2\theta} - \cos\theta] - [\sqrt{n^2 - sin^2\phi} - \cos\phi]\right\}$$

Where L= the path length variation relative to normal incidence for a single beam,

t = the thickness of the block,

n = the block index of refraction,

q = the angle of incidence for beam path 1, and

f = the angle of incidence for beam path 2.

The factor of 2 is due to each beam path making two passes through the quartz block. A graph of the change in path length as a function of incident angle is shown in Figure A-2 where each beam path is taken separately and their respective difference is shown. As you can see, when both beams pass through the quartz block, the variation in path length of one beam relative to the other is nearly linear over an angle of rotation of approximately 72 degrees.

The sequence of pulse position and overlap for each beam path is illustrated in Figure A-3. At the beginning of the scan, path A is at a minimum and path B is at a maximum. As the block rotates, the pulses move together at a constant relative rate. At the point where the angle of incidence for path A and B is the same, the pulses overlap. As the block continues to rotate, the pulses move apart, completing the scan.

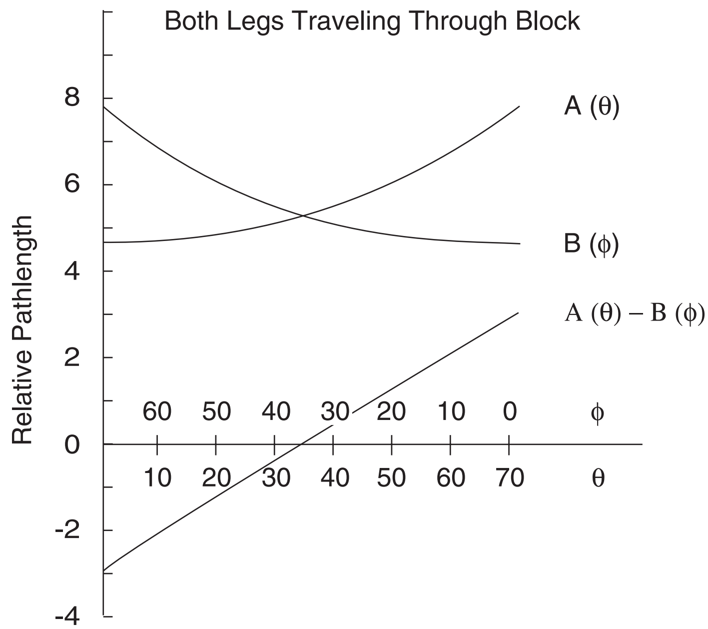

Figure A-2: Variation in Path Length as a Function of Angle

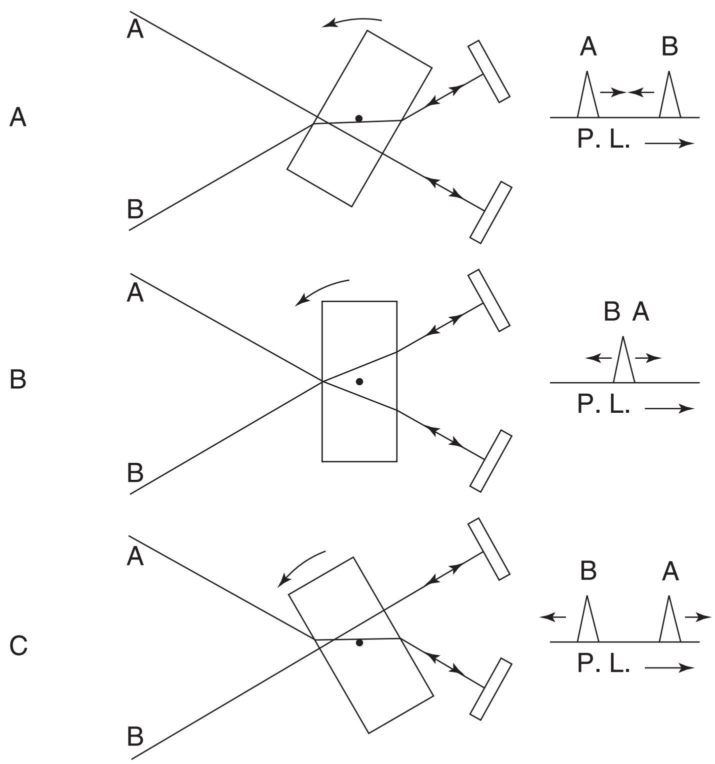

Figure A-3: Pulse Position and Overlap as the Block Rotates

At 60 Hz, each path length scan delay is equivalent to approximately:

Table A-1: Scan Time

Block	Delay
Large	80 ps
Medium	15 ps
Thin	3 ps

$$\frac{72^\circ}{\text{scan}} \times \frac{1 \text{ revolution}}{360^\circ} \times \frac{1 \text{ s}}{30 \text{ revolutions}} = \frac{6.67 \text{ ms}}{\text{scan}}$$

$$\frac{\dfrac{100 \text{ ps delay}}{\text{scan}}}{\dfrac{6.67 \text{ ms}}{\text{scan}}} = \frac{15 \text{ ps delay}}{\text{ms of sweep time}}$$

The scan completes within a 72° window of rotation. An approximate calibration of the oscilloscope can be determined by calculating the time required for each scan to be completed. The equations above show how to calculate for pulse width using a 60 Hz motor. Substitute "25" in the place of "30" for revolutions if you are using a 50 Hz system.

Selecting the appropriate oscilloscope sweep time allows you to display all or part of the autocorrelation signal. A variable delay trigger, operating at a repetition rate synchronized to the rotation of the quartz block, provides accurate triggering of the oscilloscope time base relative to the arrival of the autocorrelation signal. This allows you to position the output trace on the oscilloscope.

Time Calibration

Calibrating the oscilloscope time base in terms of delay per sweep length can be accomplished using either the method described above, provided the correct rotating quartz block is mounted, or by using the calibration etalon and the procedure described in Chapter 5, "Operation."

The calibration etalon is a piece of fused silica of known optical delay that can be inserted into one or both beams of the M_2/HRR_2 beam path. When inserted into both beams, the delay is doubled. For a quick delay estimate you can use delay times from Table A-2 below. However, because the actual delay is affected by the wavelength being measured, use the calibration correction factor listed in Figure A-4 to determine the exact delay for calibrating the oscilloscope.

Note: insertion of the etalon into the optical path of the autocorrelator also allows you to examine an additional 40 ps or 600 fs into the wings of the pulse. Additional information about alignment and use of the calibration etalon is provided in Chapter 3.

Table A-2: Etalon Delay Time

Etalon	Delay Time Single/Double-Pass
Large	20 / 40 ps
Medium	1.5 / 3 ps
Thin	300 / 600 fs

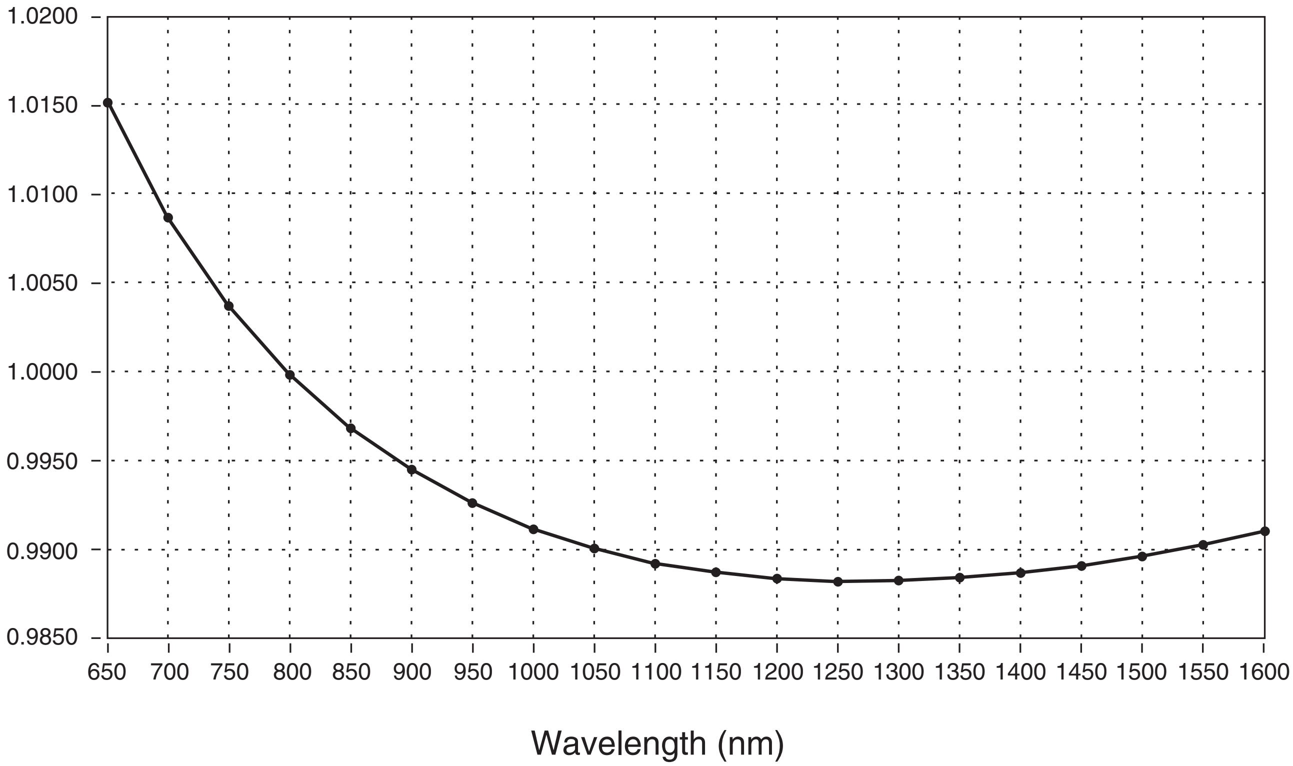

Figure A-4: Calibration Etalon Correction Factor Relative to Delay at 800 nm.

For more information on autocorrelation, refer to A.J. De Maria et al "Picosecond Laser Pulses," IEEE, Vol. 57 No. 1, p. 2, Jan. 1969.

Appendix B Signal Interpretation, Dye Lasers

Accurate interpretations of autocorrelation measurements, i.e., actual pulse width determinations, are complicated by two factors:

- The ratio of the actual pulse width to the width of the autocorrelation trace is a function of the pulse shape.
- The pulse shape can vary between two extremes, dependent upon the operating parameters of the laser system.

For the Tsunami and Opal systems, we can dismiss the second factor, for unlike dye laser systems, these systems output an easily measured $sech^2$ pulse (Figure B-1).

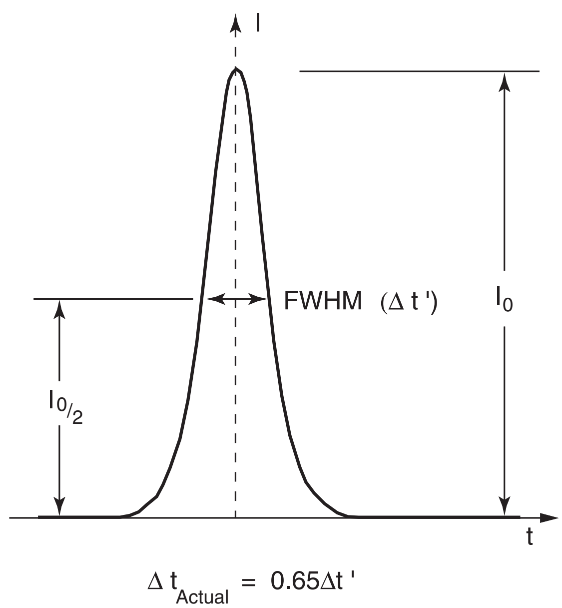

Figure B-1: Transform-limited $sech^2$ Pulse from a Tsunami Laser.

However, for users of dyes systems, it is not quite this simple. Figure B-2 and Figure B-3 illustrate the relationship of pulse width to pulse shape. Figure B-2 illustrates an autocorrelation trace corresponding to a Gaussian-shaped input pulse. Gaussian pulses are generally observed when the laser is operating in a nontransform-limited mode and the pulses are no longer than the optimum width achievable. These longer, nontransform-limited pulses exhibit the characteristic coherence spike which is a result of E fields adding coherently, and not a result of autocorrelation of the intensity envelope. Consequently, the peak corresponding to the coherence spike cannot be taken as the true peak, and the pulse height is deter mined from the plateau beneath the coherence spike (I_0). The full-width half maximum (FWHM) point is thus measured as shown, and the ratio of actual pulse width to autocorrelation width for a Gaussian-shaped pulse is 0.7.

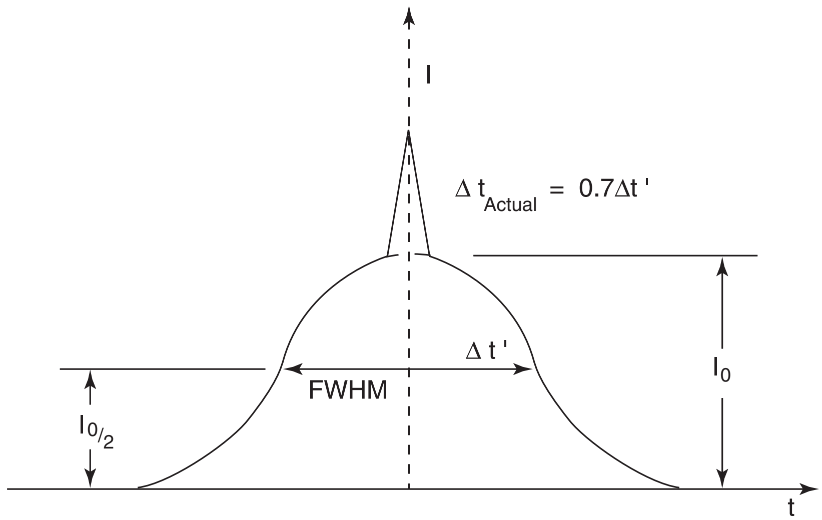

Figure B-2: Nontransform-limited Gaussian Pulse.

The other pulse shape extreme is the single-sided exponential pulse shown in Figure B-3. Single-sided exponential pulses are observed during trans form-limited operation and generally exhibit the shortest possible pulse width. In the case of a transform-limited pulse, the peak of the autocorrelation trace is the peak of the pulse. Consequently, the FWHM point is measured from its full height as shown. In the case of a single-sided exponential pulse, the ratio of actual pulse width to autocorrelation width is 0.5.

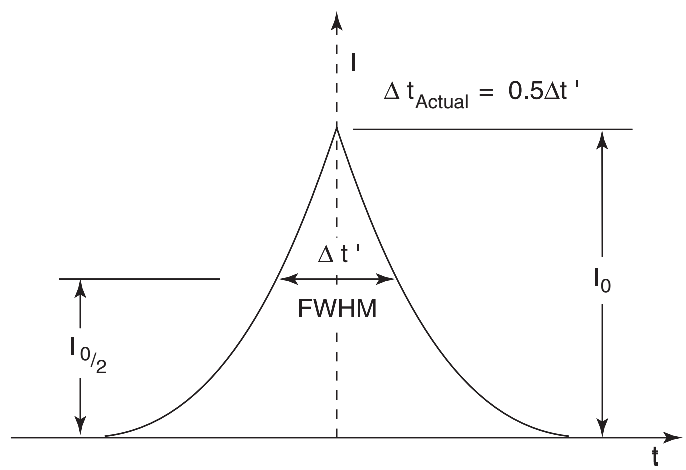

Figure B-3: Transform-limited, Single-sided Exponential Pulse.

Interpretation of the autocorrelation trace FWHM is fairly clear in the two extreme cases–pulses that are far from transformed limited (Gaussian), and pulses that are exactly transform limited (no coherence spike). The ambiguities in interpretation can result, however, from the presence of a coherence spike when the pulses are almost transform limited. The difficulty lies in deciding where the actual peak of an almost transform-limited pulse is, so that a measurement of the FWHM point can be made. Figure B-4 illustrates an intermediate case for which pulse shape and pulse width determination become a matter of individual judgement.

Note that the autocorrelation function must always be symmetric. If the output signal is asymmetric, the autocorrelator is either misaligned relative to the input beam or its internal optics are misaligned.

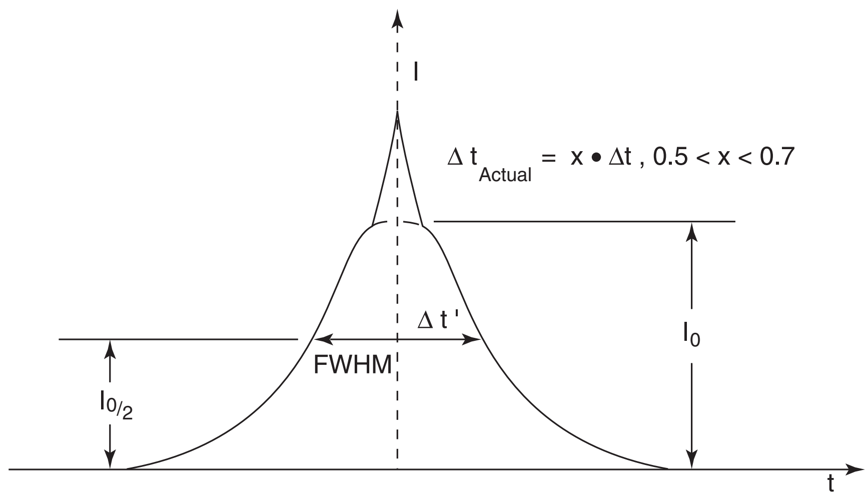

Figure B-4: Nearly transform-limited pulse. Shape is uncertain.

Appendix C System Alignment

Danger!

The autocorrelator has no cover interlock and will continue to operate when the cover is removed. Be extremely careful whenever the cover is removed and avoid contact with high voltage terminals and components. Its electrical circuits operate at lethal voltage and current levels. Only properly trained individuals should be allowed to align the autocorrelator.

Danger!
Laser Radiation

The cover of the *Model 409* blocks a path of laser radiation in a plane parallel to the center mounting plate. Exercise extreme caution when the cover is removed and while moving about this plane. Always use eye protection appropriate for the laser wavelength being measured.

In all but exceptional cases, the following alignment procedure is not necessary; the unit was properly aligned at the factory and the optics securely mounted. Unless you are sure the system was dropped or misaligned, use the procedures in Chapter 5, "Setup and Operation," to set up the autocorrelator for normal operation. Normal operation includes placing the autocorrelator on the table, hooking up cables to the oscilloscope, setting up a beam pick-off, adjusting the nonlinear crystal, changing the rotating block, etalon, and UV filter when necessary, testing for a true autocorrelation signal and measuring the pulse.

Note

99% of the time, it is because the nonlinear crystal is set to an incorrect angle that an autocorrelation trace cannot be found. Also, if there was a large change in wavelength since the autocorrelator was last used, the lens might require slight readjustment to refocus $Beam_1$ and $Beam_2$ into the thin nonlinear crystal. The lack of an autocorrelator signal is rarely due to a misaligned autocorrelator.

Caution!

Do not attempt to realign the internal components of the autocorrelator unless (i) you cannot get an autocorrelation trace, even after following the instructions in Chapter 5, (ii) you are certain the system has been tampered with, or (iii) the unit has been dropped.

Alignment Procedure Cautions

Danger! Laser Radiation

These procedures may require you to change the rotating block, etalon, and/or UV filter while using the laser at high power. For safety, block the input beam every time you interfere with the internal beam paths in any way, and unblock it only during alignment. Protect your self with appropriate eyewear at all times.

Prior to aligning the *Model 409*, please heed the following:

- Verify the *Model 409* is properly set up and aligned to the input beam and that beam power has been reduced to <50 mW as outlined in the "Setup" section of Chapter 5. A low power HeNe laser can also be used to perform the beam alignment portion of the alignment.
- Use a high-speed photodiode such as the ET2000 to verify the laser is emitting pulses.
- Verify the correct block, etalon, and UV filter are installed.
- Optimize both pump and pulse laser outputs. If measuring fs pulses, compensate for GVD pulse broadening by using prism-pair compensation (see Appendix D). Then perform the "Test for Autocorrelation" found in Chapter 4. If it is a true autocorrelation trace, the unit does not require realignment.
- *Do not clean the optics of the Model 409 unless they appear truly dirty.* If you find you need to clean the optics, refer to Chapter 6, "Maintenance," for cleaning procedures. Heed the warnings to prevent accidental damage to your unit.
- During the alignment procedure, loosen the mounting screws for the three mirrors and beam splitter *only if you are absolutely sure alignment of these optics is needed*, and then loosen only one mount at a time; loosening more than one at a time often results in a poorly aligned system when the mounting screws are tightened again.

Verifying the Correct Components are Installed

1. Turn off power to the autocorrelator.
2. Remove the autocorrelator cover.

   Note: remove the cover only after the autocorrelator has been aligned to the incoming beam and the base plate has been clamped to the table as outlined in the "Setup" section of Chapter 5.

   Loosen the 4 Phillips screws around the bottom of the autocorrelator and remove the 2 screws on top of the unit, then carefully lift the cover off (it can be a tight fit).

Danger! Laser Radiation

The cover of the *Model 409* blocks a path of laser radiation in a plane parallel to the center mounting plate. Reduce laser power and exercise extreme caution when the cover is off and when moving about this plane, and always use eye protection appropriate for the wavelength being measured.

3. Verify the correct block and etalon are installed for the pulse width being measured (see Table C-1).

   If the wrong set is installed, refer to Chapter 5, "Setup and Operation: Changing the Block and Etalon," for instructions on changing these two items.

Table C-1: Block Sizes

Pulse Width	Block Size
1 ps < x < 65 ps	Large
0.2 ps < x < 5 ps	Medium
80 fs < x < 500 ps	Thin
30 fs < x < 80 ps	Thin (with prism compensation)

4. Verify the correct UV filter is installed for the measured wavelength.

   To span the 550 to 1600 nm wavelength range, three UV filters are used and they are listed in Table C-2. Each filter has a unique color and is easily identified. The 680 to 1080 nm green filter is shipped standard with the autocorrelator. The other two are optional: black for use with a dye laser, and light blue-green for use with the Opal laser. Select the filter that is appropriate for the input wavelength being measured.

Table C-2: UV Filters

Filter Color	For Input Wavelength Regions
Black	550 to 680 nm (Opt.)
Green	680 to 1080 nm (Std.)
Light Blue-green	1080 to 1600 nm (Opt.)

   a. Slide the light shield off the filter snout and set it aside for now.
   b. Note the color of the filter. If the wrong UV filter is installed, loosen the filter release setscrew on the top corner of the holder (Figure C-1) and pull the filter out.
   c. Replace the filter with the correct one from the optics kit (refer to Table C-2). Push the filter all the way in, then tighten the release setscrew. Place the filter just removed into the optics kit.

Verifying Beam Alignment

1. Verify the autocorrelator is still aligned to the incoming beam (the beam is centered on the alignment iris and the alignment beam is centered on the alignment target). Make sure you are viewing the target from directly overhead.
2. Rotate the block by hand so the normal of the block faces the main beam splitter (Figure C-2).

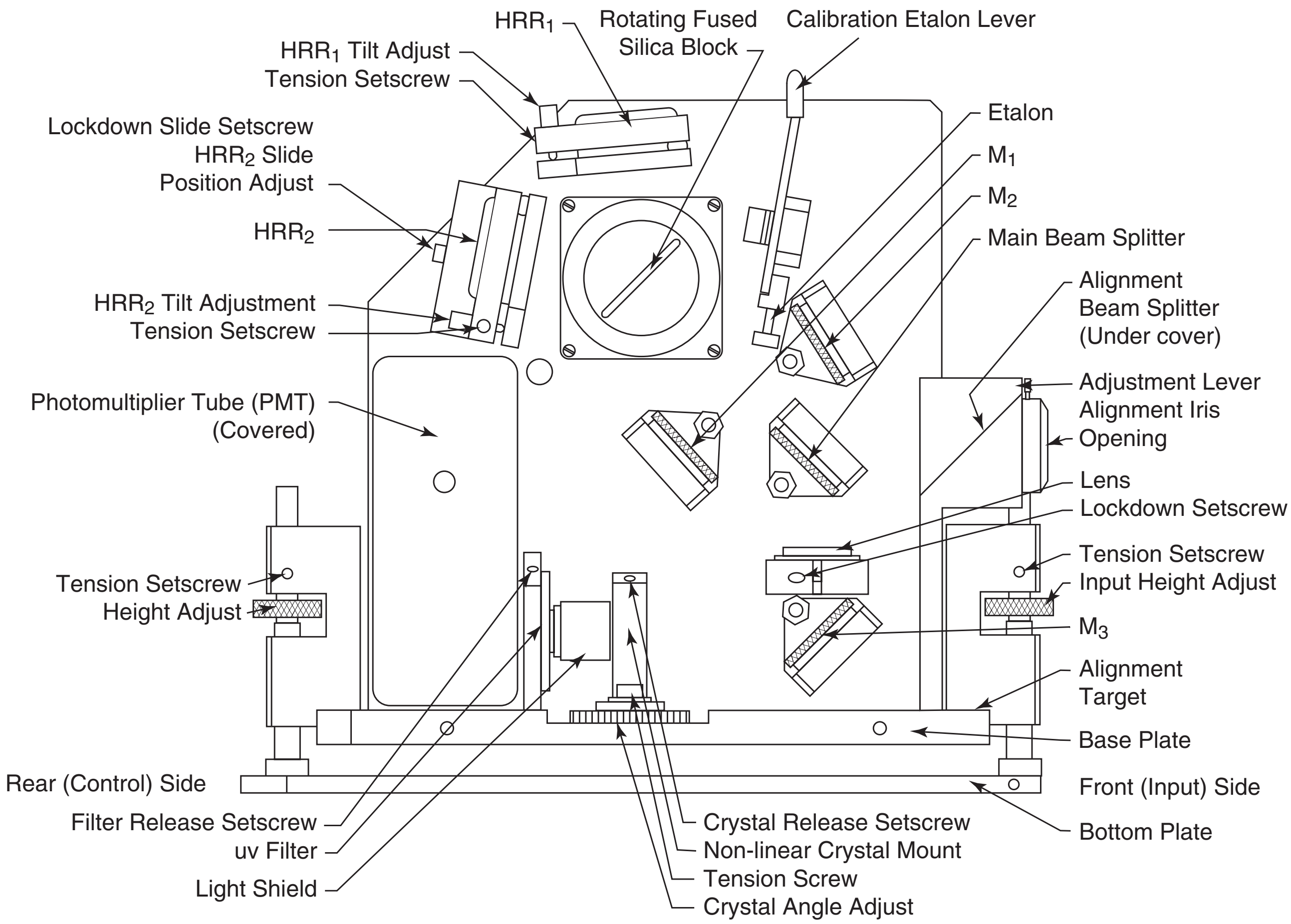

Figure C-1: *Model 409* Controls, Indicators, and Connectors

3. Using an IR viewer if necessary, check the alignment of the internal beams. In a well aligned system the beam spots should fall on the beam splitter, block, and lens as shown in Figure C-3, Figure C-4, and Figure C-5. If the spots are properly positioned on these optics, skip to Step 7. If they are not, continue with Step 4.
4. The retro-reflected beams should be parallel to the center mounting plate and should appear on the beam splitter on either side of the input beam spot as shown in Figure C-3. If *both* of the reflected beam spots are in line with each other but are offset from the input beam, adjust the rear height of the autocorrelator to move them in line with the input beam. If only one beam is offset, adjust the tilt of the HRR associated with that beam to bring it in line with the other two. You may have to use a combination of these two procedures.

   If you can get the spots aligned in this manner, refer to the Note below, then continue with Step 5.

   If you cannot position the spots properly on the three optics, the auto correlator needs alignment. Proceed to “Alignment” below.

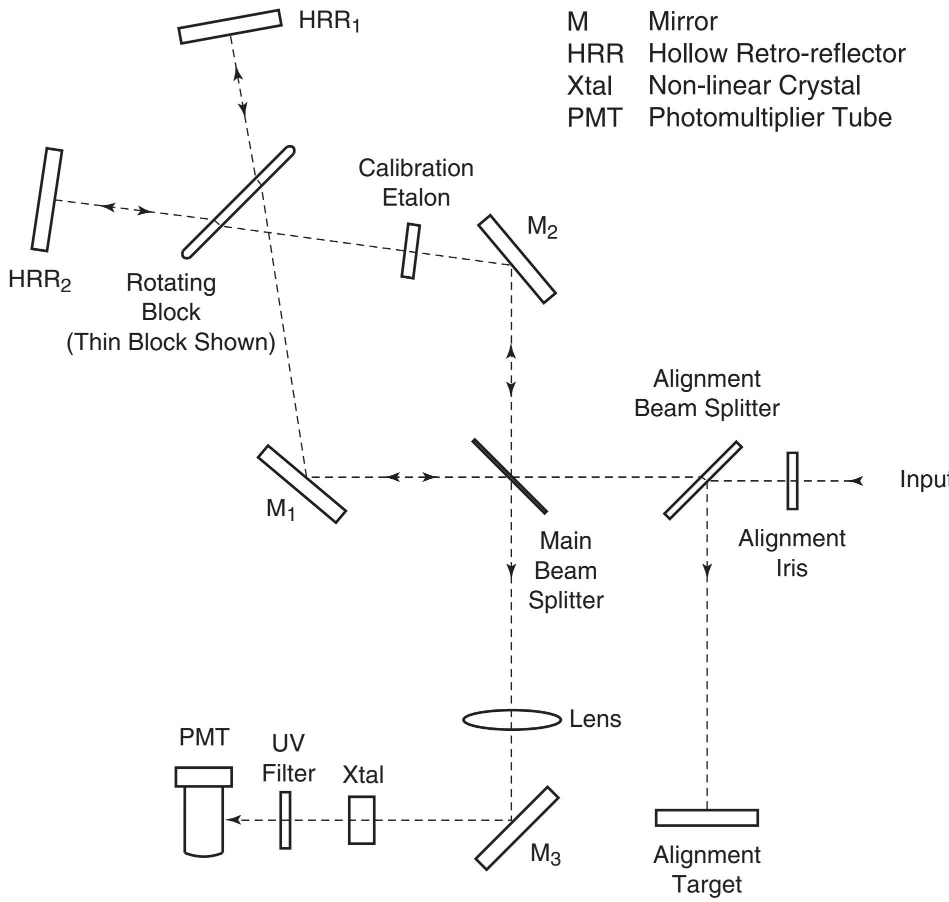

Figure C-2: The *Model 409* Components and Optical Path

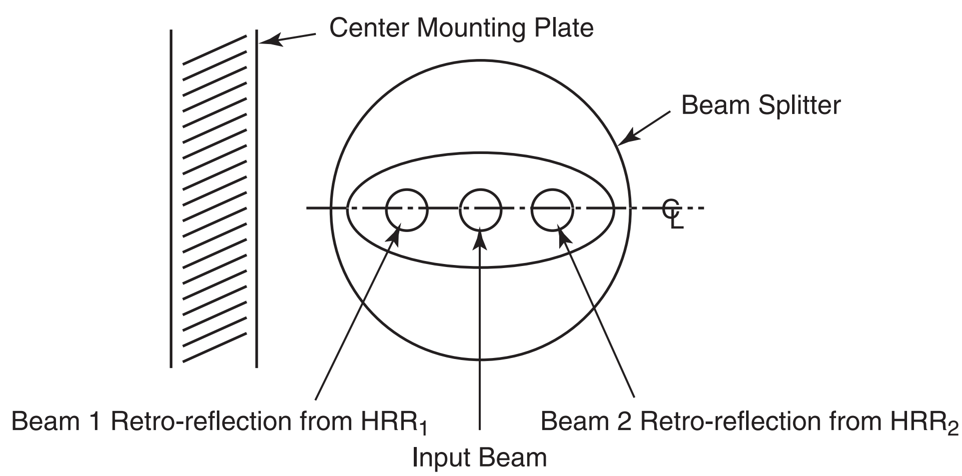

Figure C-3: Beam Splitter Showing Input and Retro-reflected Beam Spots

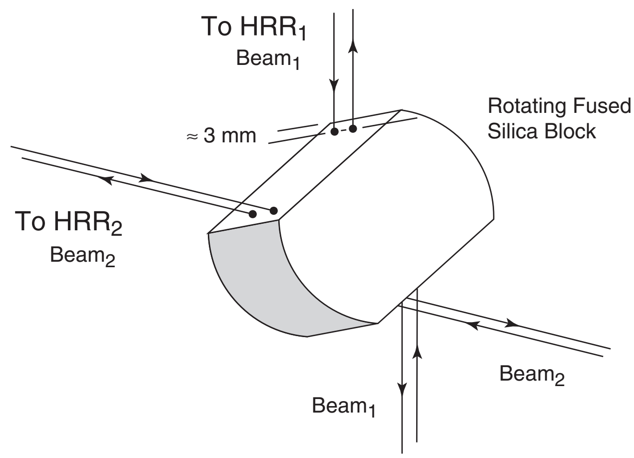

Figure C-4: Input and output beam position on the rotating block.

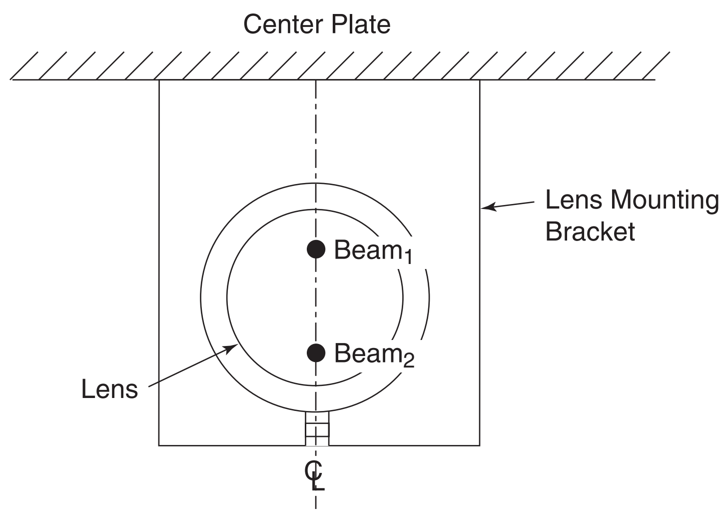

Figure C-5: Correct position of reflected beams on lens.

Note If, after performing Steps 5 through 8, you are able to find an autocorrelation pulse but the alignment beam is no longer centered on the alignment target, the alignment beam splitter must be realigned. Refer to "Adjusting the Alignment Beam Splitter" at the end of this chapter for instructions.

---

5. The exit beam spots on the large block should appear as shown in Figure C-4, i.e., they should be equally distanced from the corresponding input beam.

   As the block is rotated by hand, each beam should approach the edge, then stop about the same distance from the edge and return to its original position. If this is true, continue with Step 6. If this is not true, the autocorrelator needs realignment. Proceed to "Alignment" below.

6. The reflected beam spots should be centered on the lens as shown in Figure C-5. If this is true, continue with Step 7. If it is otherwise, the autocorrelator needs realignment. Proceed to “Alignment” below.
7. Place a piece of transparent tape across the front of the UV filter. If the two beam spots shown are not centered on the filter hole, adjust M_3 so that they are.
   a. If the beam spots are not vertically centered, loosen the clamping nut on the mount (Figure C-6) and swivel M_3 to properly position the beam spots on the filter. Tighten the nut.
   b. If the beam spots are not horizontally centered, loosen the jam nut at the base of the mount and adjust the tilt setscrew to properly position the beam spots on the filter. Tighten the nut.
   c. Remove the tape.
8. Adjust the crystal angle to try to find an autocorrelation pulse.

   Refer to Chapter 5, “Setup and Operation: Start-up Procedure,” for help on finding a pulse. If, after following those instructions, you cannot find a pulse, refer to the troubleshooting guide in Chapter 7, “Symptom: No Autocorrelation Signal—Faulty Electronics,” to try to find the problem. If this fails to solve the problem, call your Spectra-Physics representative.

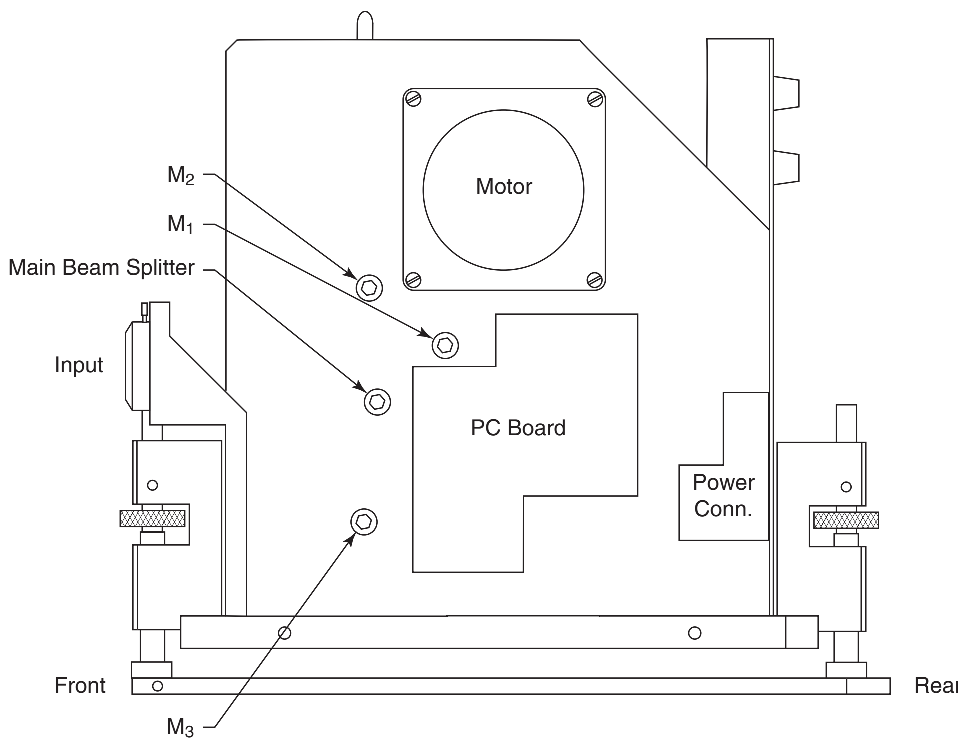

Figure C-6: The four clamping screws for the mirrors and Main Beam Splitter

Alignment

For the front-end beam alignment portion of this procedure, a non-pulsing, low power laser can be used (such as a HeNe laser). However, a pulsing ps laser will be required later in order to generate an autocorrelation signal. A fs laser can be used, but aligning the autocorrelator is more difficult.

This section assumes you have followed the instructions under “Verifying the Correct Components are Installed” and “Verifying Beam Alignment” above, that the unit is aligned to the input beam, and the measured input beam power is <50 mW.

1. Install the large block and etalon if they are not already resident.

   Refer to “Changing the Block and Etalon” at the end of Chapter 4 for instructions. With the large block installed, we can (i) verify the crystal is at the correct angle, (ii) verify the pulse displayed is a true autocorrelation pulse, and (iii) easily center the pulse in the scan range. The latter becomes increasingly difficult, if not impossible, with the medium or thin blocks.

Verifying the Main Beam Splitter is Installed Correctly

2. Verify the two pins on the main beam splitter are facing downward and that the oval window is oriented horizontally.

   If this is not the case:

   a. Block the incoming beam.
   b. Unscrew the knurled ring and remove the beam splitter.

Caution! The beam splitter is very thin and easy to break. Be very careful as you handle it.

   c. Turn the beam splitter over so the pins face downward.
   d. Hold onto the two small pins with your fingers and turn the optic so the oval window is horizontally oriented.
   e. While holding the pins to keep the oval window properly positioned, screw the ring back in place and tighten it.
   f. Unblock the incoming beam.

Aligning the Beam Paths

3. With the autocorrelator properly aligned to the input beam, the input beam spot should be centered horizontally and vertically on the main beam splitter and on mirror M_1. If this is true, skip to Step 4.

   If it is not true, the alignment beam splitter is not properly realigned. It will be realigned later. At this time:

   a. Unclamp the rear of the bottom plate and move the back of the autocorrelator so the input beam spot is horizontally centered on the main beam splitter. Then reclamp the bottom plate.
   b. If necessary, adjust the rear height of the autocorrelator to center the input beam spot vertically on the main beam splitter.

c. Verify the input beam is still centered on the alignment iris. If it is not centered, unclamp the front and recenter it, then repeat this entire step.

4. Position the block as shown in Figure C-2.

$Beam_1$ should now pass through the center of main beam splitter, reflect off M_1, then pass through the block, exiting it about 3 mm from the upper outer edge of the top surface as shown in Figure C-4.

5. Dither the block manually between 45 and 80 degrees. $Beam_1$ should move toward the upper outer edge, stop, and then return to its original position. If it does, skip to Step 6. If it does not move as described, use a $^3/_{16}$ in. Allen wrench to loosen the M_1 mounting bolt (Figure C-6) sufficiently so the mount can be rotated with moderate finger pressure. Then rotate M_1 so $Beam_1$ just grazes the outer edge of the block as the block is rotated. Leave the bolt loose and continue with Step 6.
6. Adjust the tilt of HRR_1 to reflect $Beam_1$ back along a path parallel to its incoming path so that the input beam spot and the reflected $Beam_1$ spot appear on the block as shown in Figure C-4 and on the main beam splitter as shown in Figure C-3.
7. Adjust the tilt of M_1 to place reflected $Beam_1$ about 8 mm to the inside (toward the center mounting plate) of the input beam, then continue to adjust it until the distance between the input and the reflected beam is the same on both the block and the main beam splitter.

   Adjust the tilt angle of M_1 by loosening the mounting bolt (if not already loose) then loosening the jam nut at the base of the mount and adjusting the setscrew. Retighten the jam nut when done.
8. Tighten the M_1 mounting bolt when the alignment is complete, then verify the alignment of Steps 5 through 7 was not disturbed when the bolt was tightened.

Retro-reflected $Beam_1$ is now reflected off the bottom of the main beam splitter and routed toward the lens where it should appear on the lens as shown in Figure C-5.

9. If necessary, adjust the main beam splitter by rotating it so that $Beam_1$ is positioned on the lens as shown in Figure C-5. The distance from the center mounting plate to the beam spot on the lens should be the same as it was from the center mounting plate to the spot on the main beam splitter. The beam splitter should not require a tilt adjustment.

   Release the beam splitter mounting bolt (Figure C-6) sufficiently so the mount can be rotated with moderate finger pressure.
10. Reposition the block as shown in Figure C-2.
11. Dither the block manually between 45 and 80 degrees. $Beam_2$ should move toward the lower outer edge, stop, and then return to its original position. If it does, skip to Step 12. If it does not move as described, use a $^3/_{16}$ in. Allen wrench to loosen the M_2 mounting bolt (Figure C-6) sufficiently so the mount can be rotated with moderate finger pressure. Then rotate M_2 so $Beam_2$ just grazes the outer edge of the block as the block is rotated. Leave the bolt loose and continue with Step 12.

12. Adjust the tilt of HRR_2 to reflect $Beam_2$ back along a path parallel to its incoming path so that the input beam spot and the reflected $Beam_2$ spot appear on the block as shown in Figure C-4 and on the main beam splitter as shown in Figure C-3.
13. Adjust the tilt of M_2 to place reflected $Beam_1$ about 8 mm to the outside (away from the center mounting plate) of the input beam, then continue to adjust it until the distance between the input and the two reflected beams are the same on both the block and the main beam splitter.

    Adjust the tilt angle of the M_2 by loosening the jam nut at its base and adjusting the setscrew. Retighten the jam nut when done.
14. Tighten the M_2 mounting bolt when the alignment is complete, then verify the alignment of Steps 11 through 13 was not disturbed when the bolt was tightened.
15. Before we move on, verify the input beam is still centered on the alignment iris as well as on the main beam splitter and M_1. The input and retro-reflections of both beams 1 and 2 as seen on the block should approach clipping the glass edge and then reverse direction as the block is rotated. The position of the beam spots should appear on the beam splitter, block, and lens as shown in Figure C-3, Figure C-4, and Figure C-5. If this is not the case, repeat this entire alignment procedure until they are. If you still cannot get the beam spots to align properly, call your Spectra-Physics representative.

Aligning M_3

16. Remove the nonlinear crystal assembly by unscrewing the tension mounting screw and lifting it off the pivot pin.
17. Remove the filter light shield and place a piece of transparent tape over the input to the UV filter.
18. Adjust mirror M_3 to center the two beams on the UV filter opening seen behind the tape.

    They may both fit inside the circle or they may not. The next few steps will place them where they should be. At this point, loosen the M_3 mounting bolt sufficiently so the mount can be rotated with moderate finger pressure, then rotate M_3 so the two beam spots are vertically centered on the filter opening. If necessary, adjust the tilt angle of M_3 by loosening the jam nut at its base and adjusting the setscrew. Retighten the jam nut and mounting bolt when done.

    This is a rough setting. The fine adjustments will be made when the autocorrelation adjustments are made.
19. Remove the tape and replace the light shield.

Focusing the Lens

20. Using a $^{7}/_{64}$ in. Allen driver, loosen the lens clamping screw just enough so the lens can be moved up and down by hand but does not fall out.

21. Hold a white card directly over the crystal pivot pin and move the lens up and down until the two beams merge into one spot on the card. You should not have to move the lens more than about 3 mm. A small tilt correction on HRR_2 might be necessary to place one beam on top of the other.
22. Remove the card and replace the crystal assembly.

    Do not tighten the tension mounting screw too much–it supplies friction to keep the crystal from moving on its own, yet allows it to be moved manually for angle adjustment.

Finding the Autocorrelation Pulse Using the Oscilloscope

A mode-locked, pulsing laser is required for the rest of this alignment.

Frequency-doubling occurs when the angle of the nonlinear crystal is properly set to match the phase of the beam wavelength. Autocorrelation occurs at an angle midway between the two frequency-doubling angles when a pulse from $Beam_1$ arrives coincidentally with a pulse from $Beam_2$ and the two beams are focused into the nonlinear crystal. The amplitude of the autocorrelation signal is maximized when the two beams have maximum overlap in the crystal.

It is difficult to observe the central UV spot since both the block and the crystal must be at the proper angular position simultaneously. The following procedures simplify this.

Because the PMT is more sensitive than the eye, we will first try finding the autocorrelation position in Steps 23 through 29 by observing the PMT output on the oscilloscope. If this fails to produce a visible pulse, we will try to find the three beam spots that correspond to $Beam_1$, $Beam_2$ and the autocorrelation pulse placing a card in front of the filter and looking for them as we rotate the crystal. In this manner, we can determine whether or not these signals are getting to the PMT.

23. As the crystal is rotated, a squarish pulse should appear on the oscilloscope for each of the frequency-doubled beams. Midway between these pulses is the $sech^2$ autocorrelation pulse (Figure C-7). If you find the pulse, skip to "Verifying Autocorrelation." Otherwise continue with Step 24.

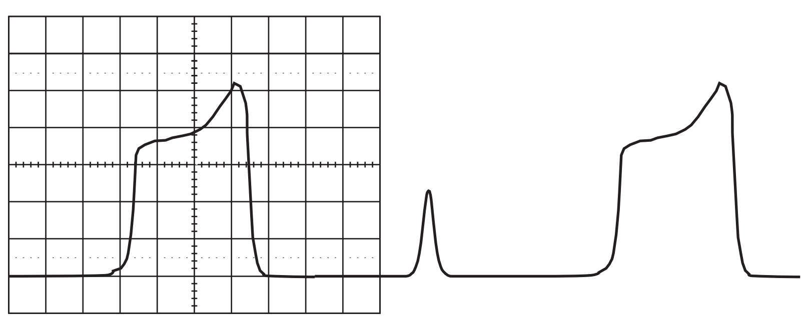

Figure C-7: $sech^2$ Autocorrelation pulse bounded by the squarish pulses from the frequency-doubled beams.

24. If you can see squarish pulses but cannot find the autocorrelation pulse, there might be too much light noise in the room. Reduce the ambient light as much as possible. (Note that too much input beam power, the GAIN set too high, the wrong UV filter installed, or a poorly focused lens will also cause this problem.)
25. If pulses are still not evident, adjust the position of HRR_2 using the slide position adjust screw until you see a nice large signal. Once a signal is obtained, iterate adjustments of the HRR_2 slide position and tilt controls to maintain and enhance the signal.

    If the slide is difficult to move, loosen the lockdown setscrew just enough to be able to adjust the slide position. If it is set too loose, the slide will also become loose and will be poorly positioned.

Steps 26 through 29 apply to fs and ps Tsunami systems in particular, but other systems will react similarly when similar controls are adjusted. The precursor indication shown in Figure C-8, a–e, does not exist for fs systems. Fs pulses either show up suddenly or they do not show up at all.

26. Increase the gain on the autocorrelator so a trace is seen on the oscilloscope (noise on the baseline, Figure C-8a).
27. Adjust the fine PHASE control on the Tsunami Model 3955 to maximize the amplitude of the pulse (Figure C-8, b - d).

    Small adjustments to the bi-fi (ps) or prism pair (fs) may also be necessary. Turn the appropriate micrometer control $^1/_4$ turn at a time.
28. Adjust the prism dispersion compensation control (fs) until a pulse occurs (Figure C-8f) or the GTI POSITION control (ps) until a pulse begins to appear (Figure C-8, e - f).
29. Slightly adjust the angular adjustment knobs on the AOM mount to maximize the amplitude of the autocorrelator trace.

Repeat Steps 27, 28, and 29 until the pulse locks. The amplitude will drastically increase and the pulse will be well defined at this point. If the autocorrelator gain is too high and the signal is saturated (Figure C-8g), lower the gain on the autocorrelator and/or lower the beam input power until a clean pulse is evident. Finally, increase the oscilloscope sweep speed to broaden the pulse for viewing and measuring (Figure C-8h). Note that a fs pulse displayed using the large block is asymmetrical as shown in Figure C-9.

If you have obtained a pulse, proceed to “Verifying Autocorrelation.” If you cannot find a pulse, proceed with Step 30.

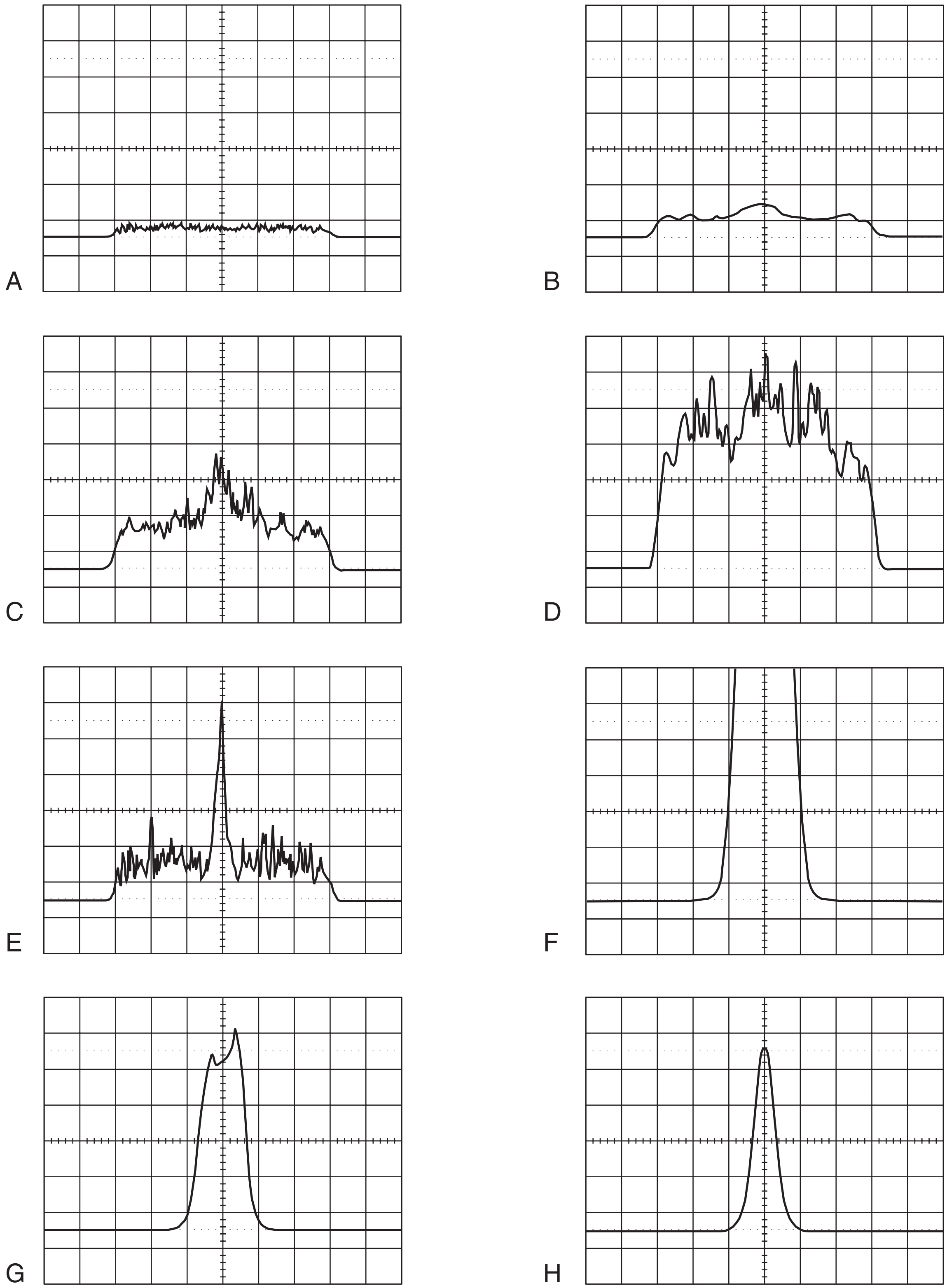

Figure C-8: Precursor to mode locking a pulse (ps) as seen through an autocorrelator on an oscilloscope.

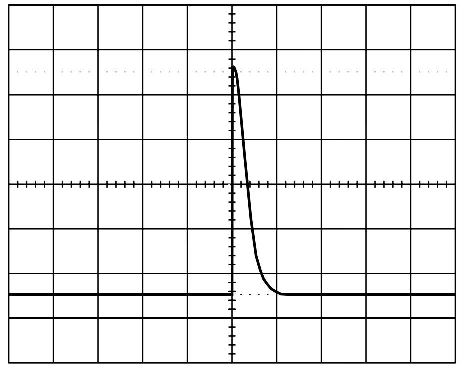

Figure C-9: An asymmetrical fs pulse is displayed when the large block is installed.

Finding the Autocorrelation Pulse Using a White Card

30. Remove the light shield from the UV filter and place a white card in front of the filter.
31. Find the autocorrelation spot between the frequency-doubled spots (Figure C-10 illustrates this step.).

    Rotate the crystal assembly until one of the two frequency-doubled, bright blue beam spots appears on the card. Note the position of the crystal angle adjustment wheel. Continue to rotate the crystal until the second bright blue spot appears and again note the position of the knob. Set the control wheel midway between these two positions and, very slightly, dither the wheel around this point. A faint fluorescent autocorrelated spot the size of a pencil dot should appear (it will blink as you pass through the autocorrelation position). *It will be hard to see–y*ou might have to darken the room in order to see it. Once you see it and it is stable, remove the card.

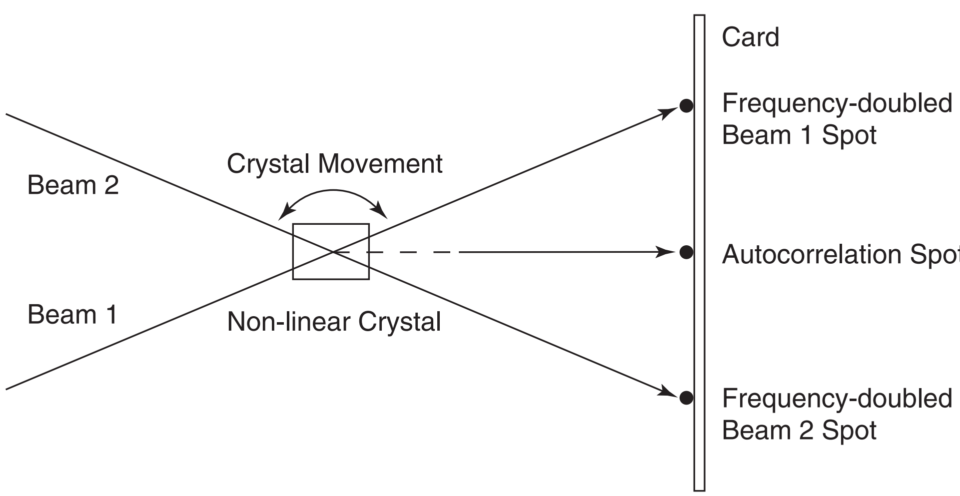

Figure C-10:The frequency-doubled retro-reflected beams and auto-correlation spots on a white card.

a. If no frequency-doubled spots are seen, the laser is not pulsing. Verify the laser is pulsing. An ultrafast photodiode such as the ET2000 can be used, or, if you have a fs system, a grating can be used to spread the 1st order spectrum. (If no pulses are present, no spreading will result.)

b. If the frequency-doubled spots are seen but the autocorrelation spot cannot be found, either the lens is improperly focused or the front-end beam alignment is not adjusted properly. Refer to the early part of this alignment procedure.

c. If all three spots are evident but you cannot get them to display on the oscilloscope, refer to the troubleshooting section in Chapter 7 to identify the problem. If, after following the instructions there, you still obtain pulses, call your Spectra-Physics representative.

Verifying Autocorrelation

32. While watching the oscilloscope, block beams 1 and 2 near HRR_1 and HRR_2 (Figure C-1), one at a time, to determine if you are viewing a true autocorrelation pulse, or ambient light, or just one of the two frequency-doubled beams from the crystal.

    If the signal disappears when only one of the two beams is blocked, the pulse on the screen is from the other frequency-doubled beam. If the signal does not disappear when either of the beams are blocked, there is ambient light getting into the PMT—reduce the light in the room. *If the signal disappears in both instances and the oscilloscope shows a flat trace, it is a true autocorrelated signal.*

    If you cannot verify an autocorrelation pulse, repeat this alignment procedure or refer to Chapter 7, "Service and Repair: Troubleshooting," if it appears there might be something else wrong with the unit. If you still cannot get a proper signal, call your Spectra-Physics service representative.

Centering the Pulse in the Scan

33. To center the pulse in the scan, equalize the lengths of the autocorrelator beam paths by adjusting the position of HRR_2.

    The location of the pulse can be determined by creating a very long input pulse (>100 ps FWHM), or by increasing the gain until a sharp drop-off on the edge of the signal is observed.

34. Minimize room lighting or turn it off, and set autocorrelator gain so that the pulse appears maximized, yet not saturated.

35. Set the oscilloscope time base to 1 ms, then widen the pulse by:

    a. Adjusting the GTI for a ps system, or

    b. Adjusting the prism compensation control for a fs system.

    For the large block, you should see a 80 to 100 ps squarish pulse with ripple on top. It will be similar to one of the pulses shown in Figure C-8c, d, or e. This is the large block scan range and the auto correlation pulse should still be visible.

36. Center the autocorrelation pulse (it will be the only one that moves) on the squarish pulse by iterating adjustments of the HRR_2 slide position and tilt controls. When it is centered, the beam path lengths are equal.
    a. Translate the HRR_2 assembly in its slide mount until the peak is centered.

       Slightly loosen the lockdown slide setscrew (Figure C-1) on the side of the HRR_2 mount if the slide position translation screw is difficult to rotate. A movement of 0.15 mm equals 1 ps shift. Movement to the rear shifts the trace in the same direction it would move if the calibration etalon was inserted in the beam.
    b. Optimize the signal on the oscilloscope by adjusting the tilt on HRR_2.
    c. Carefully tighten the lockdown slide setscrew.

Setting the System for the Pulses You are Measuring

If you have a ps-only system and have obtained a true autocorrelation signal, skip to "Optimizing the Pulse."

If you have a true autocorrelation signal and a fs system, or if you have a ps-configured fs/ps system that might be reconfigured later to measure fs pulses, perform this step.

37. Use the chart below to determine the block type for the pulses you ultimately intend to measure. If you need to change to the medium or thin block, refer to "Changing the Block and Etalon" at the end of Chapter 5 for instructions. However, do not replace the cover when told to do so. Instead, return here. Remember to always change the etalon when you change the block as outlined.

Table C-3: Block Sizes

Pulse Width	Block Size
1 ps < x < 65 ps	Large
0.2 ps < x < 5 ps	Medium
80 fs < x < 500 ps	Thin
30 fs < x < 80 ps	Thin (with prism compensation)

Note

If you are going to install the thin block, replace the large block with the medium block first before moving to the thin block. If you omit the extra steps, you may have difficulty finding the fs autocorrelation pulse using the thin block.

38. Install the medium block, then repeat the steps under "Finding the Autocorrelation Pulse Using the Oscilloscope" above to find the autocorrelation pulse, then refer to "Centering the Pulse in the Scan" above to adjust the position of HRR_2 to recenter the pulse in the scan range. Note that the pulses appear wider.

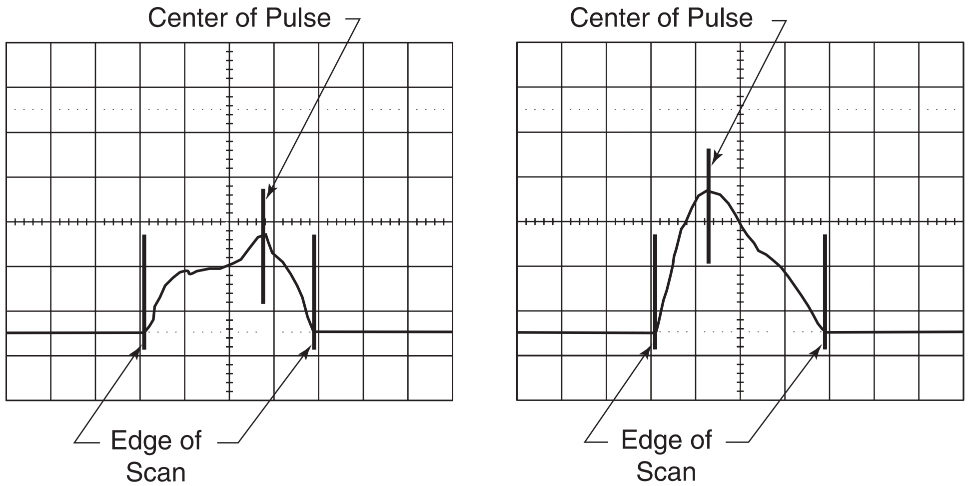

Figure C-11: Typical pulses using the medium block shown off-center.

If the thin block is not to be used, proceed to Step 40, otherwise, continue.

39. Install the thin block and repeat the procedures in Step 38 to find an autocorrelation pulse and to recenter the pulse in the scan range. Note that the pulses widen again. Adjust the time base on the oscilloscope to see the whole pulse if necessary.

Optimizing the Pulse

40. Once you have obtained the autocorrelation pulse for the proper block size, readjust the GTI or prism compensation control to generate a normal $sech^2$ pulse.
41. Then iterate between adjusting the tilt of HRR_1, adjusting the lens up and down slightly, and adjusting the rotation and tilt of M_3 to maximize the output signal.

If you have a ps system, proceed to "Adjusting the Alignment Beam Splitter."

42. Fs users must center the pulse in the scan one more time. Figure C-12 shows typical fs pulses in a single scan. The "good" pulses are at 0° and 180° and they appear a bit wider than those at 90° and 270°. The latter are created when the block is at an oblique angle to the beams and the beams become distorted. Do not use these pulses for measurement.
    a. Center the 0° and 180° pulses on the screen as shown in the graph in Figure C-12. The 90°/ 270° pulse may or may not be centered.

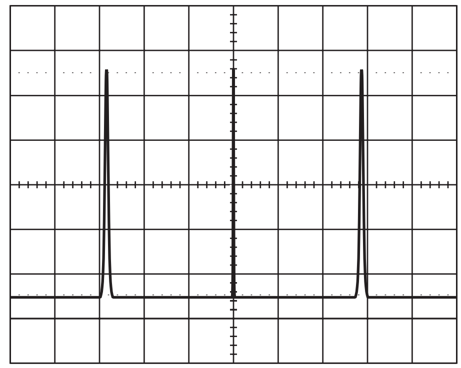

Figure C-12: 0°, 90°/270°, and 180° fs pulses as shown on the oscilloscope.

b. Iterate adjustments of the HRR_2 position and tilt controls to move the 90°/ 270° pulse with respect to the 0° and 180° pulses until the 90°/ 270° pulse is centered between the 0° and 180° pulses and all pulses are centered on the screen. Use the DELAY control to recenter the pulses on the graph if necessary.

c. Tighten the lockdown slide setscrew when you are done, then verify the pulses did not move or diminish when the screw was tightened.

Adjusting the Alignment Beam Splitter

If (i) the beam alignment is correct according to the instructions in "Verifying Beam Alignment" earlier in this chapter, and (ii) you are able to obtain an autocorrelation pulse, but (iii) the alignment beam is not centered on the alignment target, the alignment beam splitter must be realigned. If this is not the case and the beam is centered in the target, skip to Step 46.

The alignment beam splitter is aligned at the factory and should never require realignment, and this procedure is provided in the event the beam splitter is mistakenly adjusted.

Make the following adjustments only after verifying the autocorrelator is aligned and showing a true autocorrelation.

43. Remove the alignment beam splitter cover (2 screws).
44. While viewing the alignment target, adjust the three alignment screws around the beam splitter until the alignment beam is centered on the target.
45. Replace the beam splitter cover.
46. Replace the autocorrelator cover. Be careful not to bump the etalon lever and move it into the beam.

This completes the autocorrelator alignment procedure.

Appendix D Prism-Pair Compensation

Compensation Required to Properly Measure Ultrashort Pulses

Because the pulses produced by lasers such as the Tsunami can be extremely short (< 80 fs), the pulse broadening in optical materials from group velocity dispersion (GVD) makes measurement of its true pulse width difficult. Also, because the GVD of glass causes the pulse width to broaden, the pulse that reaches an experimental sample after traveling through beam splitters, lenses, etc., may not be the same pulse measured by the autocorrelator. It is, thus, important to ensure that the measurement technique and experimental setup incorporate the same amount of glass and some GVD compensation if the shortest pulses possible are to be measured and delivered to a sample.

Even before the pulse leaves the laser, it travels through extra glass. For example, if we assume the pulse in a Tsunami laser is at its shortest as it passes through the coating of the output coupler, it then travels through the output coupler substrate, the photodiode beam splitter and the output window. For the Tsunami laser, the total thickness of these optics is about 1.9 cm. Thus, using the formulas found in “Calculating Pulse Broadening” later in this chapter, a pulse that is 60 fs at the output coupler coating becomes 66 fs by the time it exits the laser. Include the glass of the autocorrelator and that in any experimental setup and the pulse can be broadened substantially.

Since the *Model 409* uses two beam splitters, a lens, and a spinning block, the pulse from a Tsunami laser is broadened before it is measured. This means the pulse out of the Tsunami may be actually shorter than that indicated by direct measurement. Consequently, GVD must be compensated for when using this or any autocorrelator if an exact measurement is required.

Since the GVD of optical material is generally positive for the wavelengths produced by the Tsunami laser, introducing negative GVD into the beam path compensates for the broadening effect produced by this material. By using prism pairs, grating pairs, or a Gires-Tournois Interferometer (GTI) negative GVD can be introduced into a system. The prism pair provides the easiest, lowest loss means for compensating for positive GVD.

A simple setup using two high index prisms made of SF-10 is all that is necessary. Figure D-1 shows the layout (top and side views) for an easily built pre-compensation unit. The laser pulse travels through the first prism where different frequency components are spread in space. Then the broadened pulse travels through the second prism, strikes a high reflector, and reflects back along its original path–with one exception. The high reflector is slightly tilted in the plane perpendicular to the spectral spreading and causes the pulse to travel back through the prisms at a slightly different vertical height. After the beam returns through the first prism it is picked off by a mirror and directed to the autocorrelator and/or the experiment.

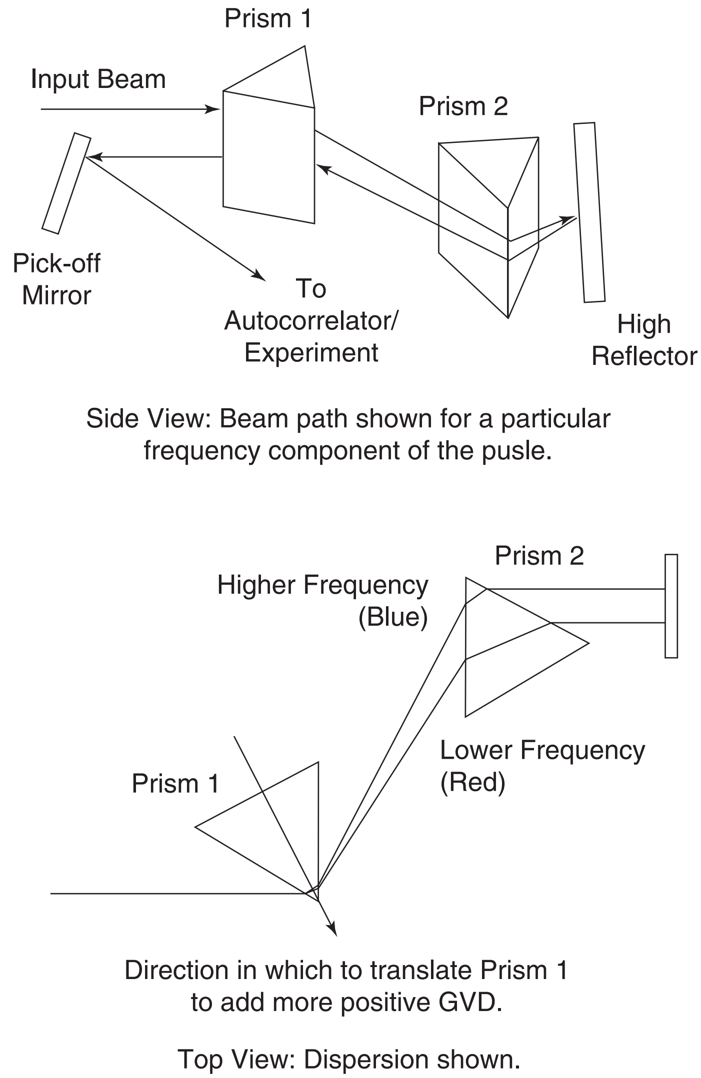

Figure D-1: Using two prisms to compensate for positive GVD.

This setup allows the higher frequencies (blue) to catch up with the lower frequencies (red). This is not intuitively obvious, since it appears that the higher frequencies actually travel a longer path length than the lower frequencies. However, it is the second derivative of the path with respect to wavelength, d^2P/dl^2, that determines the sign of the GVD. Table D-1 and Table D-2 provide dispersion values at 800 nm for optical material and grating prism pairs. The dispersion, D_ω, is expressed in units fs^2/cm of path length.

Table D-1: Positive Dispersion Values @ 800 nm

Material	D_ω(fs²/cm)
Fused Silica	300
BK-7	450
Ti:sapphire	580
SF-10	1590

Table D-2: Negative Dispersion Values @ 800 nm

System	D_ω(fs²/cm)
SF-10 Brewster Prism pair, double pass	–80.2
BK-7 Brewster Prism pair, double pass	–12.8
Grating pair, 400 lines/cm @ 30° incidence angle, double pass	–1500
Grating pair, 1000 lines/cm @ 30° incidence angle, double pass	–10,000

The reason for double passing the prisms is to maintain the spatial profile of the beam. If only one pass through the prism is used, the output is spatially chirped. While the spacing of the prisms provides negative dispersion, the prism material actually adds more positive dispersion to the system. This can be used to our advantage in the optimization of a prism pre-compensator.

For an initial setup based on a Tsunami laser and the *Model 409* autocorrelator, set the prisms approximately 30 cm apart and at Brewster's angle to the beam, with the high reflector a few cm from the second prism. With this spacing, the prism pair should start with excess negative GVD. By moving the prism tips into the beam (increasing the amount of optical material in the beam), we can balance the GVD for minimum pulse width.

To do this, place the first prism on a translation stage so the stage moves the prism in the direction of the bisector of the apex. This way, more glass can be pushed into the beam path without displacing the beam or changing its angular direction. By moving the prism into the beam path and monitoring the output from a *Model 409*, the pulse should get narrower as the dispersion is balanced. If a minimum cannot be found, adjust the prism spacing and search for the minimum again.

Calculating Pulse Broadening

Below are some simple formulae for calculating the effects of GVD and compensation. B (broadening), is defined as the ratio of the output pulse width to the input pulse width where $B = t_{out}/t_{in}$.

A simple formula for calculating the broadening of a transform-limited Gaussian pulse by dispersive elements is:

$$B = t_{out} / t_{in} = \left\{ 1 + \left[7.68 \cdot \left(D_{\omega} \cdot L / t_{in}^{2} \right)^{2} \right] \right\}^{\frac{1}{2}} \qquad [1]$$

where t_{in} is the input pulse width in femtoseconds, and D_{ω} is a dispersion value normalized for a given length and wavelength. Table D-1 gives values for different materials at 800 nm. Table D-2 gives values for some negative dispersion setups such as prisms and grating pairs for compensation at 800 nm. Using these values, B is calculated directly. Consequently, knowing the input pulse width and B, $t_{out} = B \cdot t_{in}$.

We define S as:

$$S = D_{\omega} \cdot \frac{L}{t_{in}^{2}} \qquad [2]$$

Using Figure D-2, you can relate the value of S to a value for B.

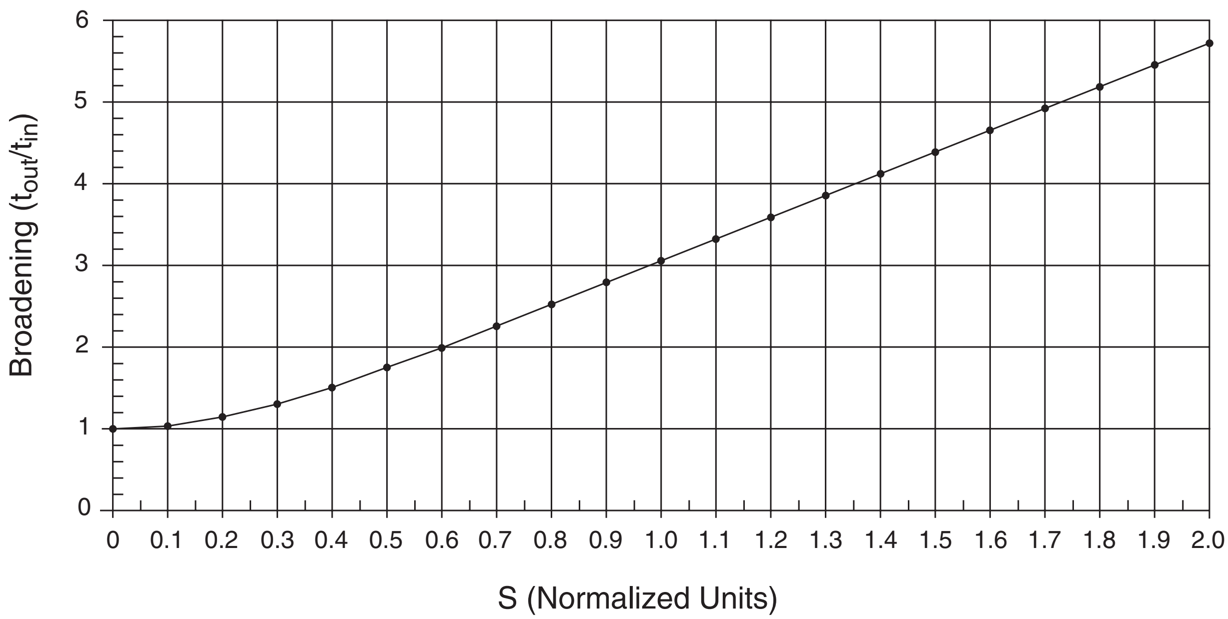

Figure D-2: Broadening Curve

When using this equation and graph, it is important to remember that the values of D_{ω} are wavelength sensitive. For example, for BK-7 material, the difference from 800 nm to 880 nm is 17%. Therefore, it is important to use the correct value of D_{ω} for the operational wavelength. Also, if there are several materials present, the values for dispersion must be added before calculating B. For example:

$$D_{\omega(tot)}L_{\omega(tot)} = D_{\omega(1)}L_{\omega(1)} + D_{\omega(2)}L_{\omega(2)} + ..D_{\omega(n)}L_{\omega(n)} \qquad [3]$$

This provides a simple means for calculating the spacing between prisms necessary for compensation.

Example 1: Calculating pulse width as measured by a *Model 409* without pre-compensation.

Assume the 800 nm pulse at the output coupler surface of a Tsunami laser is 55 fs long and transform limited. It passes through 1.9 cm of fused silica before exiting the Tsunami, and another 0.25 cm of BK-7 glass and 0.26 cm of fused silica in the *Model 409*.

$$D_{\omega(tot)}L_{\omega(tot)} = D_{\omega(1)}L_{\omega(1)} + D_{\omega(2)}L_{\omega(2)} \qquad [4]$$

$$= 300 \cdot 1.9 + 300 \cdot 0.26 + 450 \cdot 0.25 = 760\ \text{fs}^2$$

Therefore

$$S = 760(\text{fs}^2)/(55\ \text{fs})^2 = 0.251$$

Then, looking at our normalized curve (Figure D-2)

$S = 0.251$, and

$B = 1.22$, $t_{out} = 1.22 \cdot t_{in} = 67$ fs.

Example 2: Calculating the prism spacing necessary for pre-compensating the *Model 409*.

Since dispersion is additive, it is only necessary to make the total dispersion equal to zero to eliminate all broadening effects. This allows a direct calculation of the required prism spacing without finding the actual broadening.

Again, start with a 55 fs transform-limited, 800 nm pulse going through 2.16 cm of fused silica and 0.25 cm of BK-7. Also assume the use of an SF-10 prism-pair pre-compensator where the beam passes through a total of 2 mm of prism tip per pass, or 8 mm total. The GVD for all parts of the system and the length for everything but the prism spacing are known. The length can be calculated by setting total GVD = 0.

$$D_{\omega(tot)}L_{\omega(tot)} = D_{\omega(1)}L_{\omega(1)} + D_{\omega(2)}L_{\omega(2)} + D_{\omega(3)}L_{\omega(3)} + D_{\omega(4)}L_{\omega(4)} = 0 \qquad [5]$$

$$= 300 \cdot 2.16 + 450 \cdot 0.25 + 0.8 \cdot 1590 + L \cdot (-80.2) = 0$$

Therefore

$L = 25.3$ cm (10 in.).

Note: the spacing L is the distance between the two tips of a prism in a double-pass configuration, or the distance between the two tips in one leg of a four-prism sequence.

The calculated L is shorter than recommended above, but since the material dispersion value of SF-10 prisms is so high, sliding just a bit more glass in will add enough positive GVD to balance out the prism spacing.

Notes

Report Form for Problems and Solutions

We have provided this form to encourage you to tell us about any difficulties you have experienced in using your Spectra-Physics instrument or its manual—problems that did not require a formal call or letter to our service department, but that you feel should be remedied. We are always interested in improving our products and manuals, and we appreciate all suggestions.

Thank you.

From:

Name ______________________________

Company or Institution ______________________________

Department ______________________________

Address ______________________________

____

Instrument Model Number ______________ Serial Number ______________

Problem: ______________________________

____

____

____

____

Suggested Solution(s): ______________________________

____

____

Mail To:

Spectra-Physics, Inc.
ISL Quality Manager
1330 Terra Bella Avenue, M/S 15-50
Post Office Box 7013
Mountain View, CA 94039-7013
U.S.A.

E-mail: sales@splasers.com
www.spectra-physics.com

FAX to:

Attention: ISL Quality Manager
(650) 961-7101