Tsunami

Mode-locked Ti:sapphire Laser

User's Manual

Spectra-Physics
The Solid-State Laser Company

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Preface

This manual contains information you need in order to safely install, align, operate, maintain, and service your *Model 3950* picosecond (ps) *Tsunami*® laser, *Model 3960* femtosecond (fs) *Tsunami* laser, or *Model 3941* femtosecond-only *Tsunami Lite* laser.

The "Unpacking and Inspection" section contains information on how to unpack your *Tsunami* system and lists the items you should have received. It also lists any options you may have purchased. Please read this short, but important, section before you begin to unpack your unit.

The "Introduction" contains a brief description of the various *Tsunami* laser configurations and conversions from fs to ps operation (if your system is reconfigurable) and vice versa, and how to adapt the *Tsunami* for *Lok-to-Clock*® operation.

Following that section is an important chapter on safety. The *Tsunami* is a Class IV laser and, as such, emits laser radiation which can permanently damage eyes and skin. This section contains information about these hazards and offers suggestions on how to safeguard against them. It also suggests installation procedures and maintenance you must perform in order to keep your system in compliance with CDRH regulations. To ensure your system is installed according to these regulations and to minimize the risk of injury or expensive repairs, be sure to read this chapter—then follow these instructions.

"Laser Description" contains a brief exposition on Titanium:sapphire laser theory, which is followed by a more detailed description of the *Tsunami* laser system. The chapter concludes with system specifications and outline drawings.

The middle chapters describe the *Tsunami* controls, then guide you through its installation, alignment and operation. A separate chapter introduces the *Model 3930 Lok-to-Clock* electronics module and covers its installation and usage. The last part of the manual covers options, maintenance and service. The latter includes a replacement parts list. "Customer Service" contains a list of world-wide Spectra-Physics Service Centers you can call if you need help.

Whereas the "Maintenance" section contains information you need to keep your laser clean and operational on a day-to-day basis, "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.

Should you experience any problems with any equipment purchased from Spectra-Physics, or you are in need of technical information or support, please contact Spectra-Physics as described in "Customer Service." This chapter contains a list of world-wide Spectra-Physics Service Centers you can call if you need help.

Appendix A provides information on short pulse formation in the mode-locked *Tsunami* laser while Appendix B provides general information on pulse width measurement. Appendix C provides direction on setting line voltage. Appendix D provides general information on the *Lok-to-Clock* LabView Interface. Appendix E contains Material Safety Data Sheets for products used with this unit.

The *Tsunami* laser is designed to be pumped by a Spectra-Physics *Millennia*® series diode-pumped solid-state laser. The specifications listed in this manual are only for units pumped by these lasers.

This product has been tested and found to conform to "Directive 89/336/EEC for Electromagnetic Compatibility." Class A compliance was demonstrated for "EN 50081-2:1993 Emissions" and "EN 50082-1:1992 Immunity" as listed in the official *Journal of the European Communities*. It also meets the intent of "Directive 73/23/EEC for Low Voltage." Class A compliance was demonstrated for "EN 61010-1:1993 Safety Requirements for Electrical Equipment for Measurement, Control and Laboratory use" and "EN 60825-1:1992 Radiation Safety for Laser Products." Refer to the "CE Declaration of Conformity" in Chapter 2, "Laser Safety."

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.

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

Preface . . . iii

Environmental Specifications. . . . v

CE Electrical Equipment Requirements . . . v
Environmental Specifications . . . v
FCC Regulations . . . v

Table of Contents. . . . vii

Warning Conventions . . . xv

Standard Units . . . xvii

Abbreviations. . . . xix

Unpacking and Inspection . . . xxi

Chapter 1: Introduction . . . 1-1

The Tsunami System . . . 1-1
System Configurations . . . 1-2
Conversions . . . 1-2
Upgradeability . . . 1-3
Patents . . . 1-3

Chapter 2: Laser Safety. . . . 2-1

Precautions for the Safe Operation of
Class IV-High Power Lasers . . . 2-1
Interlocks . . . 2-3
Maintenance Required to Keep this Laser Product in Compliance with Center for Devices
and Radio logical Health (CDRH) Regulations . . . 2-4
CD/CDRH Radiation Control Drawing . . . 2-5
CE/CDRH Warning Labels . . . 2-6
Label Translations . . . 2-7
CE Declaration of Conformity . . . 2-8
CE Declaration of Conformity . . . 2-9
Sources for Additional Information . . . 2-10
Laser Safety Standards . . . 2-10
Equipment and Training . . . 2-11

Chapter 3: Laser Description 3-1

General Overview 3-1
Ti:sapphire Laser Theory 3-2
Pumping Optimization 3-3
Tsunami Laser Description 3-4
Pump Laser 3-4
The Folded Cavity 3-4
A/O Modulator (AOM) 3-5
Wavelength Tuning Characteristics 3-5
Wavelength Selection 3-9
Pulse Width Selection 3-10
Purging the Tsunami 3-10
Specifications 3-12
Outline Dimensions for Models 3941, 3950 and 3960 3-18

Chapter 4: Controls, Indicators and Connections 4-1

Introduction 4-1
Laser Head Controls 4-1
Input Bezel Connections 4-2
Control Panel 4-2
Mechanical Controls 4-3
Opto-Mechanical Controls: All systems 4-4
Opto-Mechanical Controls: fs Configuration 4-7
Opto-Mechanical Controls: ps Configuration 4-8
Model 3955 Electronics Module Controls 4-8
Front Panel 4-8
Rear Panel 4-9
Model 3910 Purge Unit Controls 4-11

Chapter 5: Installation. 5-1

Laser Installation 5-1
Installing the Pump Laser 5-1
Initial Placement of the Tsunami Laser Head 5-2
Aligning the Tsunami Laser Head to the Pump Beam 5-2
Installing the Chiller 5-3
Removing the Chiller Hoses from the Laser Head and Chiller 5-5
Installing the Model 3910 Regulator/Filter Purge Unit 5-5
Removing the Purge Line from the Laser Head and Model 3910 5-6
Installing the Tsunami Model 3955 Electronics Module 5-6
Installing the GTI (ps configuration) 5-7
Verifying Cable Connections 5-9

Chapter 6: Alignment 6-1

Equipment Required: 6-2
Front-End Alignment 6-2
Cavity Alignment for a FS System 6-7
Aligning the A/O Modulator (AOM) 6-12
Establish Modelocking 6-13
Optimizing Modelocking 6-13
Cavity Alignment for a PS System 6-14
Aligning the A/O Modulator (AOM) 6-16
Establish Modelocking 6-17

Optimize Modelocking 6-19
Selecting, Installing and Aligning the Birefringent Filter 6-20
Aligning the Photodiode PC Board 6-22
Test for Proper Modelocking 6-23
Converting Between Non-overlapping Optics Sets 6-25
Changing the Prism Setting (fs Systems Only) 6-30
Converting Between Overlapping Optics Sets 6-33
Converting Between fs and ps Configurations 6-34
Requirements for Conversion 6-34
Fs to ps Conversion 6-35
Ps to fs Conversion 6-37
Coarse Phase Adjustment and Changing the RF and Photodiode Cables 6-40

Chapter 7: Operation 7-1

System Start-up 7-1
Optimizing Laser Output 7-3
Modelocking the Laser 7-4
Selecting Wavelength, fs Configuration (Using the Slit) 7-5
Selecting Wavelength, ps Configuration (Using the Birefringent Filter) 7-6
Operating in the Broad fs Regime (150 fs – 1 ps) 7-7
Tsunami System Verification 7-7
Conversion for Broad Femtosecond Operation 7-7
Operating in the Broad Picosecond Regime 7-8
Tsunami System Verification 7-8
Conversion for Long Picosecond Operation 7-9
Operating with the Ultrashort Pulse Option (USP) 7-10
Operating in the Sub-35 fs Regime 7-10
Troubleshooting in the Sub-35 fs Regime 7-13
Operating with Lok-to-Clock 7-14
System Shut-down 7-15

Chapter 8: Lok-to-Clock Electronics 8-1

Functional Overview 8-1
System Controls 8-2
Front Panel 8-2
Rear Panel 8-3
Installing the Model 3930 8-7
Operation Notes 8-8
Start-up 8-9
Shut Down 8-9
Typical Set-ups 8-9
Example 1: Synchronizing Pulses from Two LTC Tsunami Lasers 8-9
Example 2: Synchronizing Pulses from a mode-locked laser with an LTC Tsunami 8-12
Operating a Model 3941D/3950D/3960D Without the Model 3930 8-14
Lok-to-Clock Computer Interface 8-16
The Model 3930 Command Set 8-16
General comments on the SCPI Standard Protocol 8-17
Differences between the Lok-to-Clock implementation and the SCPI standard 8-21

Chapter 9: Maintenance 9-1

Notes on the Cleaning of Laser Optics 9-1
Equipment Required: 9-2
Standard Cleaning Procedures 9-2

General Procedures for Cleaning Optics 9-3
Removing and Cleaning Tsunami Optics 9-5
Brewster Windows 9-6
Prisms (fs Configuration) 9-6
Ti:sapphire Rod 9-6
Birefringent Filter (ps configuration) 9-7
Pump Mirrors P1 and P2 9-8
Focus Mirror M3 and Output Coupler M10 9-9
High Reflector M1, Focus Mirror M2, Fold Mirrors M4 and M5, and Prism Mirrors M6 to M9 9-9
GTI (ps configuration) 9-10
A/O Modulator (AOM) 9-10
Beam Splitter 9-12
Routing Mirrors 9-12
Replacing Filters in the Model 3910 Purge Unit 9-12

Chapter 10: Options and Accessories 10-1

Options 10-1
Ultrashort (< 50 fs) Pulse Option 10-1
Ultrashort (< 35 fs) Pulse Option 10-1
Broad Femtosecond Pulse Option 10-1
Broad Picosecond Pulse Option 10-1
76 MHz Option 10-1
Lok-to-Clock® System 10-2
Accessories 10-2
Model 409-08 Scanning Autocorrelator 10-2
Model 3980 Frequency Doubler/Pulse Selector 10-2
Model 3931 10-2
GWU Harmonic Generator System 10-2
Opal® System 10-2
GWU-OPO-PS 10-3
Regenerative Amplifier Systems 10-3
Accessory and Conversion Optics Sets 10-4

Chapter 11: Service and Repair 11-1

Troubleshooting Guide 11-1
Generic Troubleshooting (Non-Lok-to-Clock Systems) 11-2
Troubleshooting LTC Systems 11-8

Chapter 12: Customer Service 12-1

Warranty 12-1
Return of the Instrument for Repair 12-2
Service Centers 12-3

Appendix A: Modelocking A-1

General A-1
Modelocking Techniques A-2
Regenerative Modelocking in the Tsunami A-4
Group Velocity Dispersion (GVD) A-5
Nonlinear Effects A-6
GVD Compensation A-7

Appendix B: Pulse Width Measurement B-1

Introduction B-1
The Autocorrelation Technique B-1
Measurement of Ultrashort Pulses B-1
Signal Interpretation B-4
GVD Compensation in Measurement
of Ultrashort Pulses B-5
Calculating Pulse Broadening B-7
CW Breakthrough B-9

Appendix C: Setting the Line Voltage Switch C-1

Appendix D: Lok-to-Clock LabView Interface D-1

Overview D-1
Setup D-1
Controls Description D-2

Appendix E: Material Safety Data Sheets E-1

Notes

Report Form for Problems and Solutions

List of Figures

Figure 1-1: The Tsunami Laser System (chiller not shown) 1-1
Figure 2-1: These CDRH and CE standard safety warning labels would be appropriate
for use as entry warning signs (ANSI 4.3.10.1, EN 60825-1). 2-2
Figure 2-2: Folded Metal Beam Target 2-2
Figure 2-3: Laser Head Shutter Interlock 2-3
Figure 2-4: Tsunami Radiation Control Drawing (refer to labels on next page) 2-5
Figure 2-5: CE/CDRH Warning Labels 2-6
Figure 3-1: Absorption and emission spectra of Ti:sapphire 3-2
Figure 3-2: Energy level structure of Ti3+ in sapphire 3-3
Figure 3-3: Beam Path for Tsunami Models 3960 and 3941 Femtosecond Configurations 3-4
Figure 3-4: Beam Path for Tsunami Model 3950 Picosecond Configuration 3-5
Figure 3-5: Tsunami femtosecond tuning curves for broadband optics when pumped by
the various Millennia diode-pumped cw lasers shown. 3-6
Figure 3-6: Tsunami picosecond tuning curves for broadband optics when pumped by
the various Millennia diode-pumped CW lasers shown. 3-7
Figure 3-7: Tsunami femtosecond tuning curves for the optics sets shown when pumped by
a 10 W Millennia Xs diode-pumped CW laser. 3-7
Figure 3-8: Tsunami femtosecond tuning curves for the optics sets shown when pumped by
a 5 W Millennia Vs diode-pumped CW laser. 3-8
Figure 3-9: Tsunami picosecond tuning curves for the optics sets shown when pumped by
a 10 W Millennia Xs diode-pumped CW laser. 3-8
Figure 3-10: Tsunami picosecond tuning curves for the optics sets shown when pumped by
a 5 W Millennia Vs diode-pumped CW laser. 3-9
Figure 3-11: Transmittance vs. Wavelength for Oxygen and Water Vapor. 3-11
Figure 3-12: Outline Drawing 3-18
Figure 4-1: Tsunami external laser head controls. Not all controls are present on some models. . . . 4-1
Figure 4-2: Tsunami Laser Head Control Panel 4-3
Figure 4-3: Laser Head, Rod Side View 4-5

Figure 4-4: Laser Head, Output Coupler Side View 4-6
Figure 4-5: Model 3955 Electronics Module Front Panel Controls and Indicators 4-8
Figure 4-6: Model 3955 Electronics Module Rear Panel Controls and Connections 4-9
Figure 4-7: Typical MONITOR signal 4-10
Figure 4-8: Typical SYNC signal 4-10
Figure 4-9: Model 3910 Regulator/Filter Purge Unit 4-11
Figure 5-1: Typical Tsunami Head and Pump Laser Head Layout 5-1
Figure 5-2: Typical System Interconnect Diagram 5-4
Figure 5-3: The Gires-Tournois Interferometer (GTI). 5-8
Figure 5-4: Tsunami Laser Head PC Board Connections 5-9
Figure 5-5: Photodiode PC Board 5-10
Figure 6-1: Tsunami fs Configuration. 6-3
Figure 6-2: Tsunami ps Configuration. 6-3
Figure 6-3: The M3 Translation Stage 6-4
Figure 6-4: Cavity Focus Mirrors M2 and M3 and the Laser Rod 6-5
Figure 6-5: Pump Mirrors P1 and P2 6-6
Figure 6-6: M1 and M3 Images Focused on the White Card 6-7
Figure 6-7: Locations of M4 and M5 for fs operation. 6-8
Figure 6-8: The Slit Control 6-9
Figure 6-9: Four Prism/Four Mirror Section of fs Laser Cavity 6-10
Figure 6-10: AOM, Output Coupler, Photodiode PC Board, and Beam Splitter 6-12
Figure 6-11: Bandwidth vs. Pulse Width for a Transform-limited sech2 Pulse Shape. 6-14
Figure 6-12: Locations of M4 and M5 for ps operation. 6-15
Figure 6-13: AOM, Output Coupler, Photodiode PC Board, and Beam Splitter 6-17
Figure 6-14: Precursor to modelocking a ps pulse as seen using an autocorrelator and oscilloscope. 6-18
Figure 6-15: The Birefringent Filter 6-20
Figure 6-16: Photodiode PC board 6-22
Figure 6-17: Tsunami fs Configuration. 6-25
Figure 6-18: Tsunami ps Configuration. 6-26
Figure 6-19: Pr1 Prism Translation Adjust and Setscrew 6-28
Figure 6-20: Tsunami Laser Head PC Board Connections 6-28
Figure 6-21: The Gires-Tournois Interferometer (GTI). 6-29
Figure 6-22: Pr1/Pr4 prisms showing placement of beam. Refer to Table 6-6 for the value of x. 6-31
Figure 7-1: Transmittance vs. Wavelength for Oxygen and Water Vapor. 7-2
Figure 7-2: Tsunami External Laser Head Controls 7-3
Figure 7-3: Bandwidth vs Pulse Width for a Transform-limited sech2 Pulse Shape. 7-6
Figure 7-4: Placement of Pr1 and Pr4 in beam 7-7
Figure 8-1: The Lok-to-Clock Phase-locked Loop. 8-1
Figure 8-2: Model 3930 Electronics Module Front Panel Controls and Indicators 8-2
Figure 8-3: Model 3930 Electronics Module Rear Panel Controls and Connections 8-4
Figure 8-4: Lok-to-Clock fs System Block Diagram 8-5
Figure 8-5: Lok-to-Clock ps System Block Diagram 8-6
Figure 8-6: Synchronization of two Lok-to-Clock Tsunami Lasers 8-10
Figure 8-7: Typical cross-correlation signal for two LTC Tsunami lasers.. 8-11
Figure 8-8: Synchronization of a Standard Tsunami Laser to a Lok-to-Clock Tsunami Laser. 8-12
Figure 8-9: Typical Cross-correlation Signal for an LTC Tsunami Laser and Mode-locked Laser. 8-14
Figure 8-10: The TO 3930 Connector 8-14
Figure 8-11: A suggested schematic for driving the coarse position M1 motor. 8-15
Figure 9-1: Drop and Drag Method. 9-4
Figure 9-2: Lens Tissue Folded for Cleaning 9-4
Figure 9-3: Birefringent Filter 9-8
Figure 9-4: AOM, Output Coupler M10, and Beam Splitter 9-11
Figure 9-5: Underside of Model 3910 showing filter assembly placement and orientation. 9-13
Figure A-1: Typical output of a mode-locked laser, where L is the cavity length and c is the

velocity of light. A-2
Figure A-2: Active modelocking using an AOM. Modulation sidebands are produced when a wave passes through an amplitude modulator. A-3
Figure A-3: Amplitude and frequency of longitudinal modes in a mode-locked laser. A-3
Figure A-4: Configuration of the electronics for a regenerative mode-locked laser. A-5
Figure A-5: Typical wavelength dependence of the refractive index of a material A-6
Figure A-6: The four prism sequence used for dispersion compensation in the Tsunami laser. An input pulse with a positive chirp (red frequencies at the leading edge of the pulse) experiences negative GVD (red frequencies have longer group delay time) in the prism sequence. The net effect is that the prism sequence compensates for the positive GVD and produces a pulse which has no chirp. A-8
Figure A-7: Group delay time as a function of wavelength for a GTI with a 40 µm spacing and a 4% reflector. A-9
Figure B-1: Interferometric (Collinear) Autocorrelation B-2
Figure B-2: Background-free (Non-collinear) Autocorrelation B-2
Figure B-3: The Model 409-08 Autocorrelator Optical Path. The beam paths are displaced by HRR1 and HRR2 in and out of the plane of the paper, so the configuration corresponds to the background-free method shown in Figure B-2. . . . . B-3
Figure B-4: Using two prisms to compensate for positive GVD. B-6
Figure B-5: Broadening Curve B-8
Figure B-6: A Typical Monochromator/CCD Setup B-10
Figure B-7: Output spectrum of the Tsunami monitored with an external monochromator/CCD system. (a) shows a CW component of 1%, (b) shows a CW component of less than 0.1%. B-10
Figure C-1: Power Switch, Line Cord, and Voltage Selector Module C-1
Figure D-1: The Lok-to-Clock LabView Control Panel D-1

List of Tables

Table 2-1 : Label Translations. 2-7
Table 3-1 : Tsunami Femtosecond Broadband Performance when Pumped by a Millennia laser 3-12
Table 3-2 : Tsunami Picosecond Broadband Performance when Pumped by a Millennia laser. 3-13
Table 3-3 : Tsunami Femtosecond Performance when Pumped by a Millennia laser 3-14
Table 3-4 : Tsunami Picosecond Performance when Pumped by a Millennia Laser 3-15
Table 3-5 : Electrical, Mechanical and Physical Specifications. 3-16
Table 3-6: Environmental Specifications 3-16
Table 3-7: Lok-to-Clock Tsunami Specifications 3-17
Table 6-1: Pump Power Requirements 6-4
Table 6-2: Pump Power Requirements 6-7
Table 6-3 : Bi-Fi Alignment for Picosecond Operation 6-21
Table 6-4: Photodiode part Numbers 6-23
Table 6-5 : Vertical Mirror Adjustment (Turns) for Changing Wavelengths. 6-31
Table 6-6: Nominal Distance from Beam to Apex (see Figure 6-22) 6-31
Table 7-1: Bi-fi Selection for Broad Picosecond Operation 7-9
Table 8-1: The SCPI Command Set 8-16
Table 10-1 : Standard fs Tsunami Mirrors—Millennia Xs Pump Laser 10-4
Table 10-2 : Standard fs Tsunami Mirrors—Millennia Vs Pump Laser 10-4
Table 10-3 : Standard ps Tsunami Mirrors—Millennia Xs Pump Laser 10-4
Table 10-4 : Standard ps Tsunami Mirrors—Millennia Vs Pump Laser 10-4
Table 10-5 : Broadband fs Tsunami Mirrors—Millennia Xs Pump Laser 10-5
Table 10-6 : Broadband fs Tsunami Mirrors—Millennia VIIIs Pump Laser 10-5
Table 10-7 : Broadband fs Tsunami Mirrors—Millennia Vs Pump Laser 10-5
Table 10-8 : Broadband ps Tsunami Mirrors—Millennia Xs Pump Laser 10-5
Table 10-9 : Broadband ps Tsunami Mirrors—Millennia VIIIs Pump Laser 10-5
Table 10-10 : Broadband ps Tsunami Mirrors—Millennia Vs Pump Laser 10-5

Table 10-11 : fs Tsunami—Wavelength Conversion Sets 10-6
Table 10-12 : fs Tsunami—Wavelength Conversion Sets 10-6
Table 10-13 : ps Tsunami—Wavelength Conversion Sets 10-7
Table 10-14 : ps Tsunami—Wavelength Conversion Sets 10-7
Table 10-15 : fs to ps Tsunami–Wavelength Conversion Sets 10-8
Table 10-16 : ps to fs Tsunami–Wavelength Conversion Sets 10-8
Table 10-17 : GTI and Bi-Fi for Broad Pulse Operation 10-9
Table 10-18: Photodiode PC Board 10-9
Table 11-1 : Optics 11-9
Table 11-2 : Hardware 11-9
Table 11-3 : Model 3910 Purge Unit Filter Hardware 11-9
Table B-1 : Second-order Autocorrelation functions and Time-Bandwidth Products for Various Pulse Shape Models B-4
Table B-3: Positive Dispersion Values @ 800 nm B-7
Table B-4: Negative Dispersion Values @ 800 nm B-7
Table B-5: Recommended Monochromator/CCD Components B-11

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

Abbreviations

The following is a list of abbreviations used in this manual:

ac	alternating current
AOM	acousto-optic modulator
APM	active pulse mode locking
AR	antireflection
bi-fi	birefringent filter
CDRH	Center of Devices and Radiological Health
CPM	colliding pulse mode locking
CW	continous wave
dc	direct current
E/O	electro-optic
fs	femtosecond or 10^{-15} second
GTI	Gires-Toutnois Interferometer
GVD	group velocity dispersion
HR	high reflector
IR	infrared
LTC	Lok-to-Clock®
OC	output coupler
ps	picosecond or 10^{-12} second
PZT	piezo-elecric transducer
RF	radio frequency
SCFH	standard cubic feet per hour
SPM	self phase modulation
TEM	transverse electromagnetic mode
Ti:sapphire	Titanium-doped Sapphire
UV	ultraviolet
λ	wavelength

Unpacking and Inspection

Unpacking Your Laser

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

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

Keep the shipping containers. If you file a damage claim, you may need them to demonstrate that the damage occurred as a result of shipping. If you need to return the system for service at a later date, the specially designed container assures adequate protection.

Warning!

Spectra-Physics considers itself responsible for the safety, reliability, and performance of the *Tsunami* laser only under the following conditions:

- All field installable options, modifications, or repairs are performed by persons trained and authorized by Spectra-Physics.
- The equipment is used in accordance with the instructions provided in this manual.

System Components

- *Tsunami* laser head
- *Model 3955* electronic module
- *Model 3930 Lok-to-Clock*® option (if ordered)
- *Model 3910* purge regulator/filter Unit with gas tubing and connectors
- A chiller with tubing and fittings and its own user’s manual
- An accessory kit (see below)

Accessory Kit

Included with the laser system is this manual, a test summary, a packing slip listing all the components shipped with this order, and an accessory kit containing the following items:

- Two hoses (cooling system water supply and return lines)
- Three foot clamps with hardware for mounting the *Tsunami* laser head
- A tool kit containing:
  - Allen (hex) ball drivers for optimizing laser output
  - An IR card
  - a tweezer
  - A plastic hemostat
  - A packet of *Kodak Lens Cleaning Paper*
  - Any optional optics and optical assemblies that were ordered

You will need to supply several items, including:

- Spectrophotometric-grade (HPLC) acetone and methanol for optics cleaning
- Clean, lint-free finger cots or powder-less latex gloves for optics cleaning
- Ir viewer
- Optical spectrum analyzer (recommended)
- Fast photodiode (recommended)

Chapter 1 Introduction

The *Tsunami* System

Titanium-doped sapphire (Ti:sapphire) is a solid-state laser medium capable of tunable operation over a broad range of near infrared (IR) wavelengths. The mode locked *Tsunami*® laser uses this laser medium and, with properly chosen optics, delivers continuously tunable output over a broad range of near IR wavelengths: from 690 nm to 1080 nm. It also produces a range of pulse widths that are continuously variable from 80 ps to < 50 fs—all with solid state convenience. Energy for the lasing process (the "pump" energy) is supplied by a Millennia® series, continuous wave (CW), diode-pumped, solid-state laser.

A *Tsunami* laser comprises five main elements:

- Ti:sapphire laser head
- Electronics module
- Purge filter/regulator unit (depending on system configuration)
- Chiller

Figure 1-1: The *Tsunami* Laser System (chiller not shown)

The laser head contains the Ti:sapphire rod and the optics that form the resonator cavity. The *Model 3955* electronics module contains the heater and rf driver circuits for the mode locker, as well as circuits for the Gires-Tournois interferometer (GTI) which is required for picosecond operation. The optional *Model 3930 Lok-to-Clock*® electronics module can be added to any of the three systems to allow the output from the *Tsunami* to operate with low timing jitter and/or to be synchronized to another mode-locked source or to another *Tsunami* laser.

The *Model 3910* purge unit filters, dries, and regulates the flow of nitrogen gas into the sealed laser head to purge dust and water vapor from it. For performance stability, the chiller maintains the Ti:sapphire rod at a constant temperature by removing heat that is generated in the rod from pump beam absorption.

The *Tsunami* system includes dust tubes to enclose the pump beam path for improved performance and for personal safety. Also included are a tool kit, a separate box for the GTI (if you ordered a ps system), and a box for the PZT M_4 mirror (if you ordered the optional *Lok-to-Clock* system).

System Configurations

The *Tsunami* is available in several configurations, several of which can be upgraded so they can be converted from ps to fs, or vice versa, or be converted for use with the *Model 3930 Lok-to-Clock* system. While some can be purchased ready for field conversions, most require the initial upgrade work be performed at an authorized Spectra-Physics service facility. Call your Spectra-Physics service representative if you have upgrade questions.

The following models are ps-only systems:

- Standard configuration *Model 3950*
- *Lok-to-Clock Model 3950C*
- *Lok-to-Clock* upgradeable *Model 3950D* (i.e., it is shipped without the *Model 3930* electronics module or the M_4 PZT mirror)

The following systems are fs-only systems:

- Standard configuration *Model 3941*
- *Lok-to-Clock Model 3941C*
- *Lok-to-Clock* upgradeable *Model 3941D* (i.e., it is shipped without the *Model 3930* electronics module or the M_4 PZT mirror)

The following systems can operate either as ps or fs systems:

- Standard configuration *Model 3960*
- *Lok-to-Clock Model 3960C*
- *Lok-to-Clock* upgradeable *Model 3960D* (i.e., it is shipped without the *Model 3930* electronics module or the M_4 PZT mirror)

Conversions

Tsunami picosecond and femtosecond lasers are inherently different, and various mounts, components, and optics must be changed when converting them from ps to fs operation, or vice versa. These two systems differ in the following ways:*

- the transmission of the output coupler.
- the method of wavelength selection: a birefringent filter (bi-fi) for ps versions and a slit for fs versions.

**These components and differences are discussed in Chapter 3, “Laser Description.”*

- the method of dispersion compensation: a Gires-Tournois interferometer (GTI) for ps versions and a prism sequence for fs versions.
- cavity configuration of M_4 and M_5

Upgradeability

If you purchased a *Model 3960* fs laser, you can convert it to a ps system by purchasing an upgrade kit and performing the fs to ps conversion yourself by following the fs to ps conversion procedure in Chapter 6, "Alignment."

If you purchased a *Model 3950* ps laser (no prism mounts installed), you can purchase an upgrade kit for fs operation. However, the initial upgrade work must be performed by an authorized Spectra-Physics service engineer. Once these components are installed, you can convert between ps and fs configurations yourself by following the ps to fs conversion procedure in Chapter 6.

The *Lok-to-Clock* option can be purchased as an upgrade if you have an upgradeable *Model 3941D*, *3950D* or *3960D*. However, the initial upgrade work must be performed by an authorized Spectra-Physics service engineer.

The *Model 3941 Tsunami Lite* system is designed as a fs-only unit and cannot be converted.

For more information on upgrades, please contact your Spectra-Physics sales representative.

Patents

The *Tsunami* Laser contains technology that is unique among Ti:sapphire lasers and is covered by the following United States patents:

4,894,831	oscillator design
5,056,103	oscillator design
5,020,073	rod alignment
4,977,566	purged laser head design
5,175,736	birefringent filter
5,185,750	dispersion compensation
5,212,698	dispersion compensation

Chapter 2 Laser Safety

Danger!

The *Tsunami*® and its pump laser are Class IV-High Power Lasers, whose beams are, by definition, safety and fire hazards. Take precautions to prevent exposure to direct and reflected beams. Diffuse as well as specular reflections cause severe skin or eye damage.

Danger!
Laser Radiation

Because the *Tsunami* laser emits cw and pulsed infrared radiation, it is extremely dangerous to the eye. Infrared radiation passes easily through the cornea, which focuses it on the retina, where it can cause instantaneous permanent damage.

Precautions for the Safe Operation of Class IV-High Power Lasers

- Wear protective eyewear at all times; selection depends on the wavelength and intensity of the radiation, the conditions of use, and the visual function required. Protective eyewear vendors are listed in the *Laser Focus World, Lasers and Optronics,* and *Photonics Spectra* buyer's guides. Consult the ANSI or 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 cover on the laser at all times.
- Avoid looking at the output 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.
- Expand the beam whenever possible to reduce beam power density.
- 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 the principles of laser safety.
- 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 specular reflections.
- Set up an energy absorbing target to capture the laser beam, preventing unnecessary reflections or scattering (Figure 2-2).

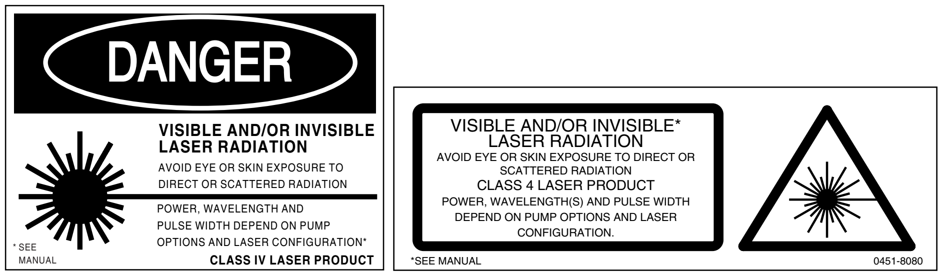


Figure 2-1: These CDRH and CE standard safety warning labels would be appropriate for use as entry warning signs (ANSI 4.3.10.1, EN 60825-1).

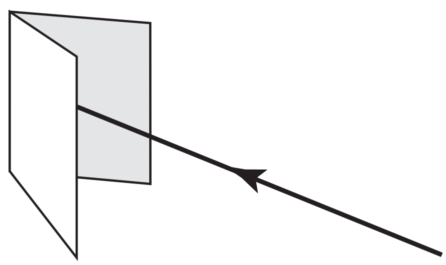


Figure 2-2: Folded Metal Beam Target

Caution!

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 laser. At all times during operation, maintenance, or service of your laser, avoid 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).

* *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.*

Interlocks

Because the energy to drive the lasing process in the *Tsunami* comes from another laser and not from an internal source (such as electrical discharge), the interlock differs slightly from that of other lasers.

The *Tsunami* laser system has only one interlock: the shutter interlock on the laser head. It blocks the pump beam at the entrance to the laser head housing to prevent the *Tsunami* from lasing. When installed, the laser head cover holds the shutter interlock open for normal operation. When the cover is removed, the shutter closes automatically. Figure 2-3 shows the *Tsunami* shutter interlock.

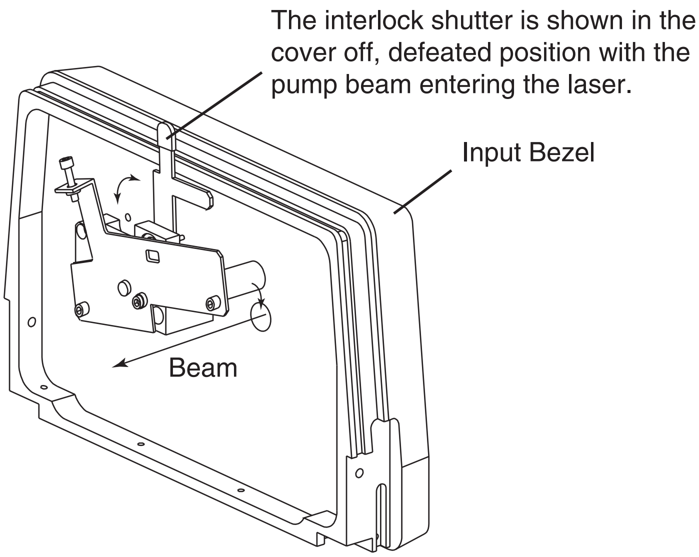


Figure 2-3: Laser Head Shutter Interlock

Operating the laser with the cover off may expose people to high voltages and high levels of radiation. It also increases the rate of optical surface contamination. Therefore, operating the laser with the cover off is not recommended.

The alignment procedures in this manual require internal adjustments while the laser is operating. The interlock can be defeated to allow this. When the cover is removed and access to the pump beam is required, raise the red shutter lever to defeat the interlock and hold the shutter open. In this position, the red lever clearly shows the defeat and prevents cover installation until the shutter lever is lowered to the closed position.

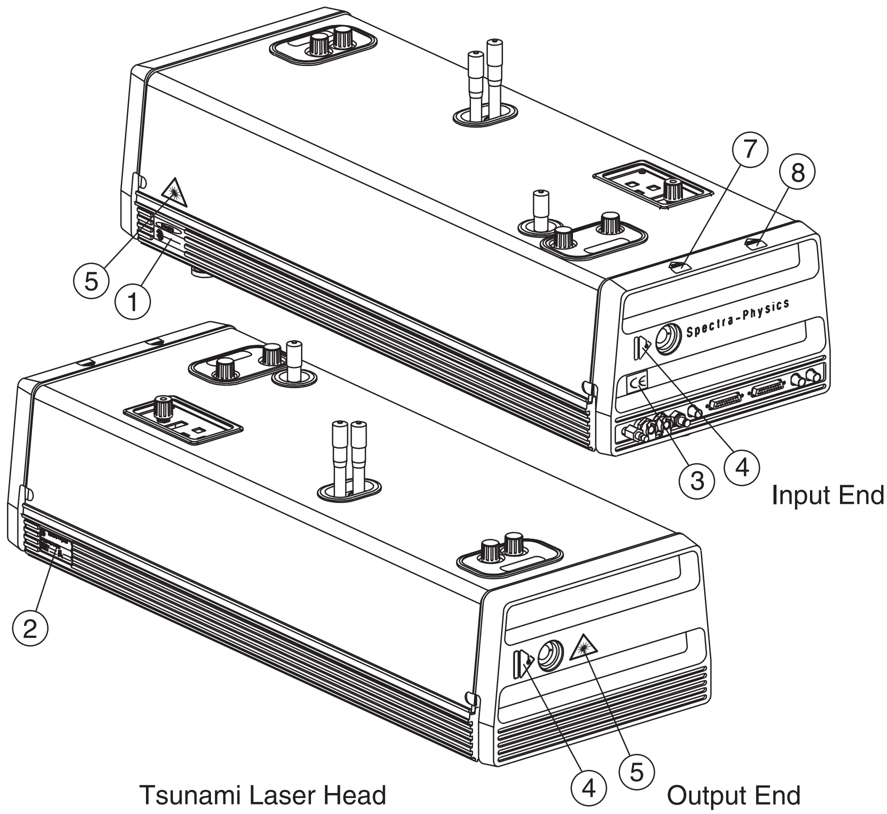
Maintenance Required to Keep this Laser Product in Compliance with Center for Devices and Radio logical Health (CDRH) Regulations

The actions listed below are required in order to keep the *Tsunami* laser product in compliance with CDRH Regulations.

This laser product complies with Title 21 of the *United States Code of Federal Regulations*, Chapter 1, Subchapter J, Parts 1040.10 and 1040.11, as applicable. To maintain compliance, verify the operation of all features listed below, either annually or whenever the product has been subjected to adverse environmental conditions (e.g., fire, flood, mechanical shock, spilled solvents). This maintenance is to be performed by the user, as outlined below.

1. Verify that removing the laser head cover closes the laser shutter.
2. Verify that, when the cover interlock is defeated, the defeat mechanism is clearly visible and prevents installation of the cover until disengaged.
3. Verify that all labels listed in Figure 2-4, "*Tsunami* Radiation Control Drawing," are present and are firmly affixed.

CD/CDRH Radiation Control Drawing



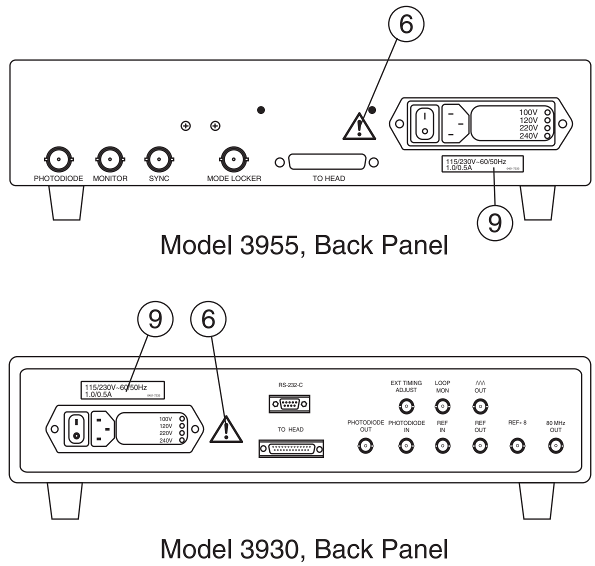


Figure 2-4: *Tsunami* Radiation Control Drawing (refer to labels on next page)

CE/CDRH Warning Labels

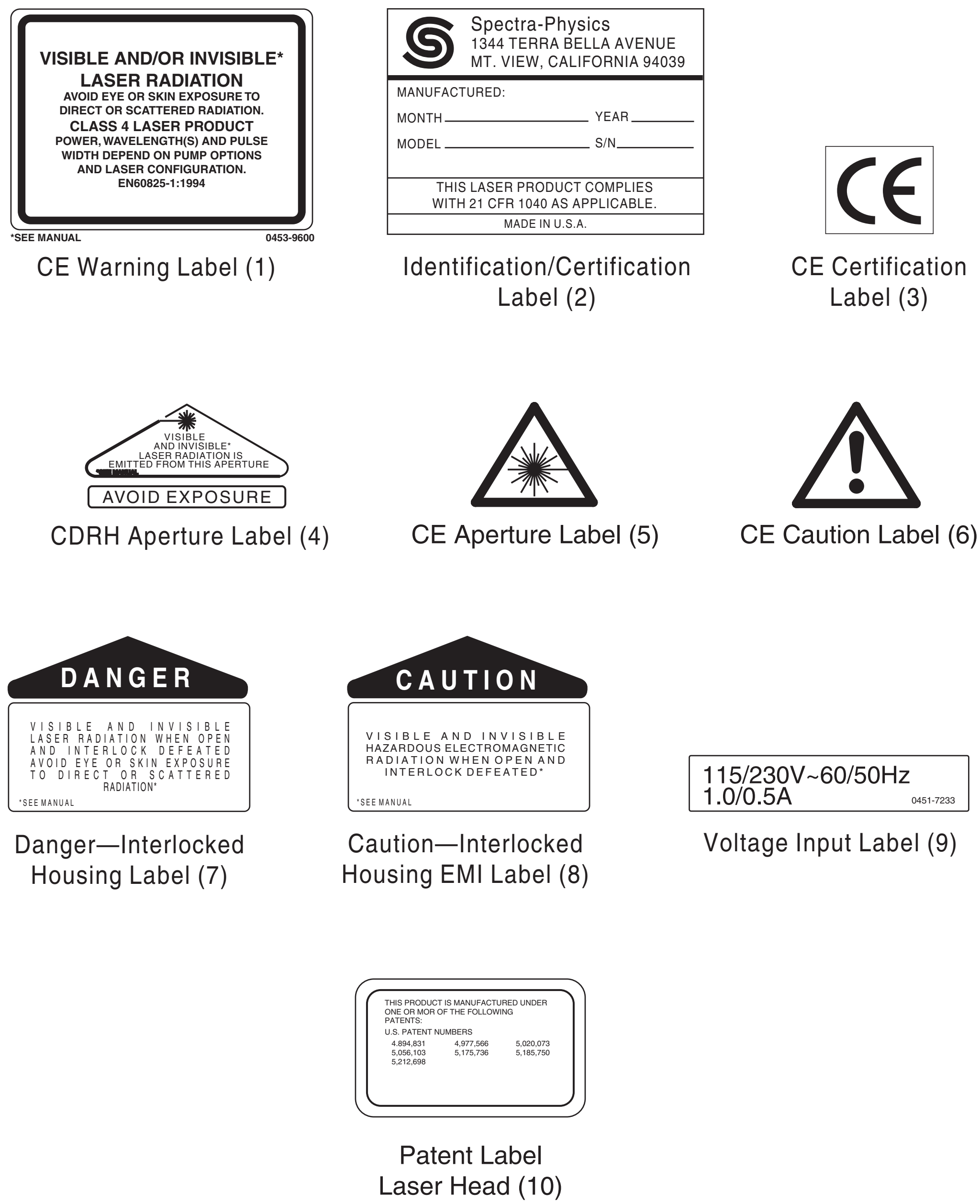


Figure 2-5: CE/CDRH Warning Labels

Label Translations

For safety, the following translations are provided for non-English speaking personnel. The number in parenthesis in the first column corresponds to the label number listed on the previous page.

Table 2-1: Label Translations

Label #	French	German	Spanish	Dutch
CE Warning Label (1)	Rayonnement Laser Visible et Invisible en Cas D'Ouverture et lorsque la securite est neutralisee; exposition dangereuse de l'œil ou de la peau au rayonnement direct ou diffus. Laser de Classe 4. Puissance et longueurs D'onde dependant de la configuration et de la puissance de pompe. EN60825-1:1994	Gefahr! Sichtbare und unsichtbare Laserstrahlung! Bestrahlung von Auge oder Haut durch direkte oder Streustrahlung vermeiden! Laserklasse IV. Leistung, Wellenlänge und Pulsbreite sind abhängig von Pumpquelle und Laserkonfiguration. Bedienungsanleitung beachten! EN60825-1:1994	Al abrir y retirar el dispositivo de seguridad exist radiación laser visible e invisible; evite que los ojos o la piel queden expuestos tanto a la radiación directa como a la dispersa. Producto laser clase 4. Potencia, longitud de onda y anchura de pulso dependen de las opciones de bombeo y de la configuracion del laser. EN60825-1:1994	Gevaar! Zichtbare en onzichtbare laserstraling! Vermijd blootstelling van oog of huid aan directe straling of terugkaatsingen daarvan! Klas IV laser produkt. Vermogen, golflengte en pulsduur afhankelijk van pomp opties en laser konfiguratie. EN60825-1:1994
Aperture Label (4)	Ouverture Laser - Exposition Dangereuse - Un Rayonnement laser visible et invisible est emis par cette ouverture.	Austritt von sichtbarer und unsictbarer Laserstrahlung! Bestrahlung vermeiden!	Por esta abertura se emite radiacion laser visible e invisible; evite la exposicion.	Vanuit dit apertuur wordt zichtbare en onzichtbare laserstraling geemiteerd! Vermijd blootstelling!
Danger, Defeatable Interlock (7)	Attention- Rayonnement Laser visible et invisible en cas D'Ouverture et lorsque la securite est neutralisse; exposition dangereuse de l'oeil ou de la peau au rayonnement dirct ou diffus.	Gefahr! Austritt von sichtbarer und unsichtbarer Laserstrahlung, wenn Abdeckung geöffnet und Sicherheitsverschluß überbrückt! Bestrahlung von Auge oder Haut durch direkte oder Streustrahlung vermeiden! Bedienungsanleitung beachten!	Peligro, al abrir y retirer el dispositivo de seguridad exist radiacion laser visible e invisible; evite que los ohos o la piel queden expuestos tanto a la radiacion dircta como a la dispersa.	Gevaar! Zichtbare en onzichtbare laserstraling wanneer geopend en interlock uitgeschakeld! Vermijd blootstelling van oog of huid aan directe straling of terugkaatsingen daarvan!
Caution, Defeatable Interlock (EMI) (8)	Attention. Rayonnement visible et invisible dangereux en cas d'ouverture et lorsque la sécurité est neutralisée.	Vorsicht! Austritt von sichtbarer und unsichtbarer schädlicher elektromagnetischer Strahlung, wenn Abdeckung geöffnet und Sicherheitsverschluß überbrückt. Bedienungsanleitung beachten!	Precaución, radiación peligrosa electromagnética visible e invisible con el dispositivo de seguridad abierto o con su indicación alterada.	Let op! Zichtbare en onzichtbare gevaarlijke electromagnetische straling wanneer geopend en interlock uitgeschakeld!
Patent (10)	Ce produits est fabriqué sous l'un ou plusieurs des brevets suivants.	Dieses Produkt wurde unter Verwendung eines oder mehrerer der folgenden US-Patente hergestellt.	Este producto esta fabricado con una o más de las siguientes patentes de los Estados Unidos.	Dit product is gefabriceerd met een of meer van de volgende USA patenten.

CE Declaration of Conformity

We,

Spectra-Physics, Inc.
Industrial and Scientific Lasers
1330 Terra Bella Avenue
P.O. Box 7013
Mountain View, CA. 94039-7013
United States of America

declare under sole responsibility that the:

***Tsunami* Mode-locked, Ti:sapphire Laser with Controller**

Manufactured after February 21, 1997

meets the intent of "Directive 89/336/EEC for Electromagnetic Compatibility."

Compliance was demonstrated (Class A) to the following specifications as listed in the official *Journal of the European Communities*:

EN 50081-2:1993 Safety Requirements for Emissions:

EN 55011 Class A Radiated
EN 55011 Class A Conducted

EN 50082-1:1992 Immunity:

IEC 801-2 Electrostatic Discharge
IEC 801-3 RF Radiated
IEC 801-4 Fast Transients

I, the undersigned, hereby declare that the equipment specified above conforms to the above Directives and Standards.

Steve Sheng
Vice President and General Manager
Spectra-Physics, Inc.
Industrial and Scientific Lasers
February 21, 1997

CE Declaration of Conformity

We,

Spectra-Physics, Inc.
Industrial and Scientific Lasers
1330 Terra Bella Avenue
P.O. Box 7013
Mountain View, CA. 94039-7013
United States of America

declare under sole responsibility that the

Tsunami **Mode-locked, Ti:sapphire Laser with Controller**

Manufactured after February 21, 1997

meets the intent of "Directive 73/23/EEC, the Low Voltage directive."

Compliance was demonstrated to the following specifications as listed in the official *Journal of the European Communities*:

EN 61010-1: 1993 Safety Requirements for Electrical Equipment for Measurement, Control and Laboratory use:

EN 60825-1: 1994 Safety for Laser Products.

I, the undersigned, hereby declare that the equipment specified above conforms to the above Directives and Standards.

Steve Sheng
Vice President and General Manager
Spectra-Physics, Inc.
Industrial and Scientific Lasers
February 21, 1997

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 Laser Description

General Overview

The *Tsunami*® laser head contains the Ti:sapphire rod and the optics that form the resonator cavity. Elements include pump beam mirrors, rod focusing mirrors, an output coupler (OC), a high reflector (HR), beam folding mirrors, dispersion control elements, and tuning elements. A femtosecond (fs)-configured system uses prisms for dispersion control whereas a Gires-Tournois Interferometer (GTI), which contains the HR, is the dispersion control element in a picosecond (ps)-configured system. The fs configuration uses a slit for wavelength selection while the ps configuration uses a birefringent filter. The laser head also houses the GTI high-voltage circuit for the ps configuration. For your convenience, the major tuning controls are located on top of the laser head so the cover does not have to be removed under normal circumstances.

Connections to the head include power and control from the *Model 3955* electronics module, power and control from the optional *Model 3930 Lok-to-Clock*® electronics module, nitrogen gas from the *Model 3910* purge unit, and cooling water from the chiller.

The *Model 3955* electronics module included with the laser contains heater and rf driver circuits for the mode locker and for the GTI. All indicators and controls are located on the front panel, and three cables connect it to the laser head input bezel. These cables include the control cable, the mode locker BNC cable and the photodiode BNC cable.

The optional Lok-to-Clock system provides phase-locked loop (PLL) stabilization of output pulses and allows you to precisely synchronize output pulses to either its internal 80 MHz reference source or to an external one, such as an rf synthesizer, or to another mode-locked laser. The *Model 3930 Lok-to-Clock* electronics module contains the PLL circuit and the drive circuits for the M_1 HR motor drive and M_4 PZT-controlled mirror (Figure 3-3 and Figure 3-4). Two cables connect the *Model 3930* to the laser head input bezel: the control cable and the photodiode BNC cable. The *Model 3930* is the same shape and size as the *Model 3955* and should be placed under it. Chapter 8 contains a complete description of the *Lok-to-Clock* system.

The *Model 3910* purge regulator/filter unit connects between an external nitrogen gas supply and the laser head, and it removes dust and water vapor from the purge gas to provide clean, dry nitrogen for purging the sealed laser head. A flow gauge, flow control knob, and the gas in/out connections are located on the front panel.

The separate chiller unit keeps the *Tsunami* Ti:sapphire rod at a constant temperature for long-term stable performance. The chiller is fully described in its own manual shipped with the system.

Ti:sapphire Laser Theory

The Ti^{3+} titanium ion is responsible for the laser action of Ti:sapphire. Ti:sapphire is a crystalline material produced by introducing Ti_2O_3 into a melt of Al_2O_3. A boule of material is grown from this melt where Ti^{3+} ions are substituted for a small percentage of the Al^{3+} ions. The electronic ground state of the Ti^{3+} ion is split into a pair of vibrationally broadened levels as shown in Figure 3-1.

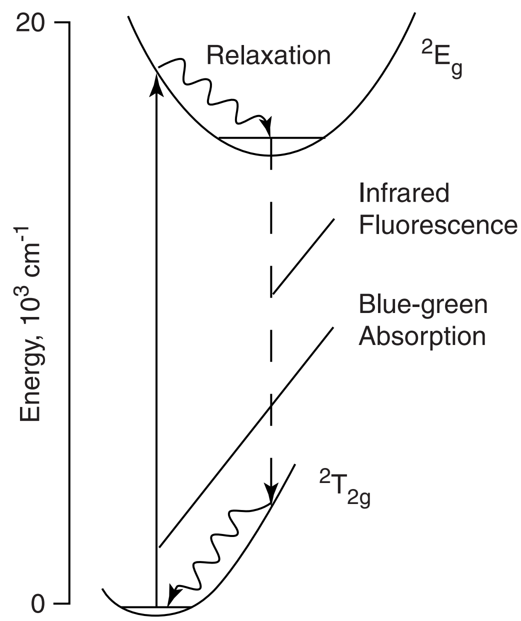


Figure 3-1: Absorption and emission spectra of Ti:sapphire

Absorption transitions occur over a broad range of wavelengths from 400 to 600 nm, only one of which is shown in Figure 3-1. Fluorescence transitions occur from the lower vibrational levels of the excited state to the upper vibrational levels of the ground state. The resulting emission and absorption spectra are shown in Figure 3-2.

Although the fluorescence band extends from wavelengths as short as 600 nm to wavelengths greater than 1000 nm, the lasing action is only possible at wavelengths longer than 670 nm because the long wavelength side of the absorption band overlaps the short wavelength end of the fluorescence spectrum. The tuning range is further reduced by an additional weak absorption band that overlaps the fluorescence spectrum. This band has been traced to the presence of Ti^{4+} ions, but it is also dependent on material growth techniques and Ti^{3+} concentration. Additionally, the tuning range is affected by mirror coatings, tuning element losses, pump power, atmospheric absorption (both oxygen and water vapor) and pump mode quality.

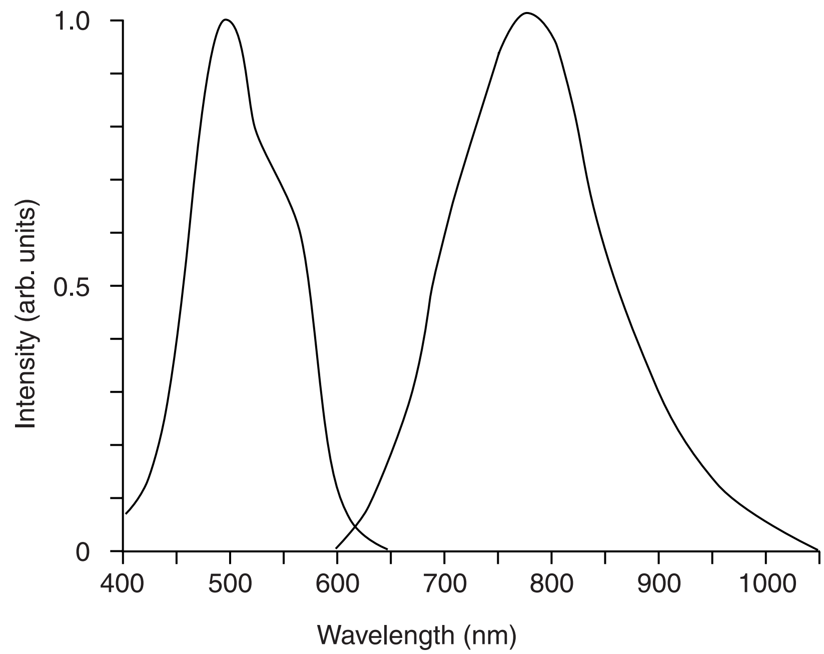


Figure 3-2: Energy level structure of Ti^{3+} in sapphire

Pumping Optimization

For continuous-wave (CW) pumping, there is one basic requirement for lasing action: the unsaturated round-trip CW gain must exceed the round-trip loss from all sources. The cw gain is obtained by having a high inversion density and an adequate length of Ti:sapphire material. A high inversion density comes from having a high pump intensity and a high Ti^{3+} ion concentration. Losses in the Ti:sapphire laser come from losses in mirror coatings and polished surfaces, and more importantly, the residual loss in the Ti:sapphire material itself. This loss is proportional to the rod length and varies with the Ti^{3+} concentration, generally increasing as the Ti^{3+} concentration increases.

Unlike a dye laser, the pump illumination in a Ti:sapphire laser must be collinear with the cavity mode over a relatively long length of the laser rod. A continuous, high inversion density over the entire volume of a rod several millimeters in diameter is difficult to achieve. To circumvent this problem, the pump light is focused to a narrow line within the rod and the oscillating laser mode is similarly focused and overlapped within the same volume–a technique known as longitudinal pumping. The output beam is then collimated and expanded to normal size. The residual pump beam is dumped through the second cavity focus mirror (Figure 3-3).

Tsunami Laser Description

Pump Laser

Specifications for the *Tsunami* laser are guaranteed only when pumped by a *Millennia*® V, VIII or X diode-pumped, cw solid-state laser operating in *power* mode.

A *Millennia* X can supply 10 W of 532 nm power to *Tsunami* while the *Millennia* V provides 5 W. Performance values given in this manual are provided for various *Millennia* pump powers. For optimum performance, the optics need to be changed to accommodate different pump powers. Refer to Chapter 10, "Options and Accessories," for a list of available optics.

The Folded Cavity

Because *Tsunami* is a mode-locked laser, a cavity longer than that in a cw laser is required in order to allow it to run at convenient repetition frequencies near 80 MHz. Spectra-Physics modeled, analyzed, and optimized the cavity design for optimum performance in minimal space. For the fs configuration, the result was a ten-mirror, folded cavity as shown in Figure 3-3. A six-mirror folded cavity design resulted for the ps configuration shown in Figure 3-4.

While folding the cavity optimizes space utilization, it makes pumping more complex. A focusing mirror used at an angle other than normal incidence creates astigmatism in the beam unless corrected by some other element, e.g., a Brewster-angle rod. In folded cavities where this astigmatism is not eliminated, output beams are elliptical and hard to focus. But by carefully choosing the angles of the cavity focus mirrors and the rod length, astigmatism in the *Tsunami* output beam is virtually eliminated.

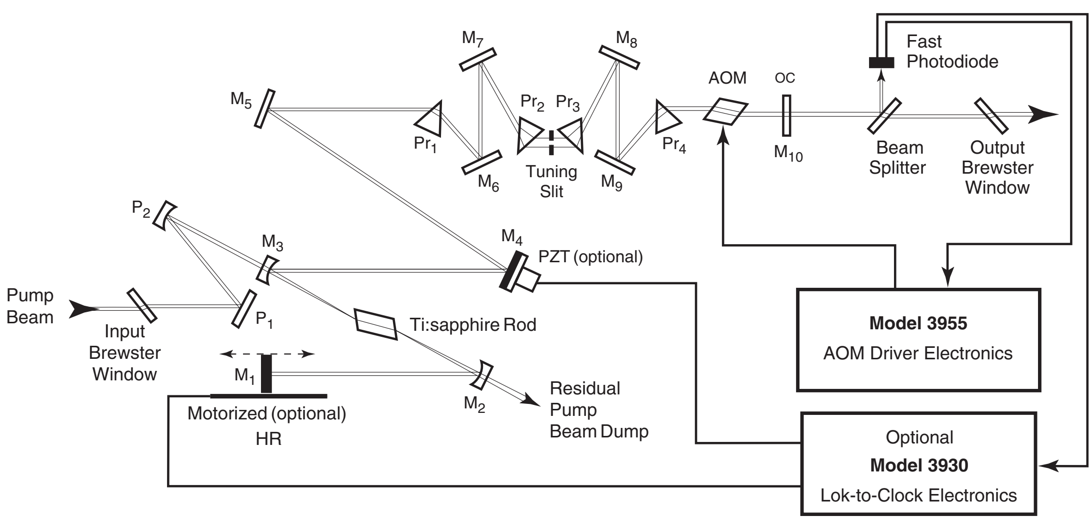


Figure 3-3: Beam Path for *Tsunami Models 3960* and *3941* Femtosecond Configurations

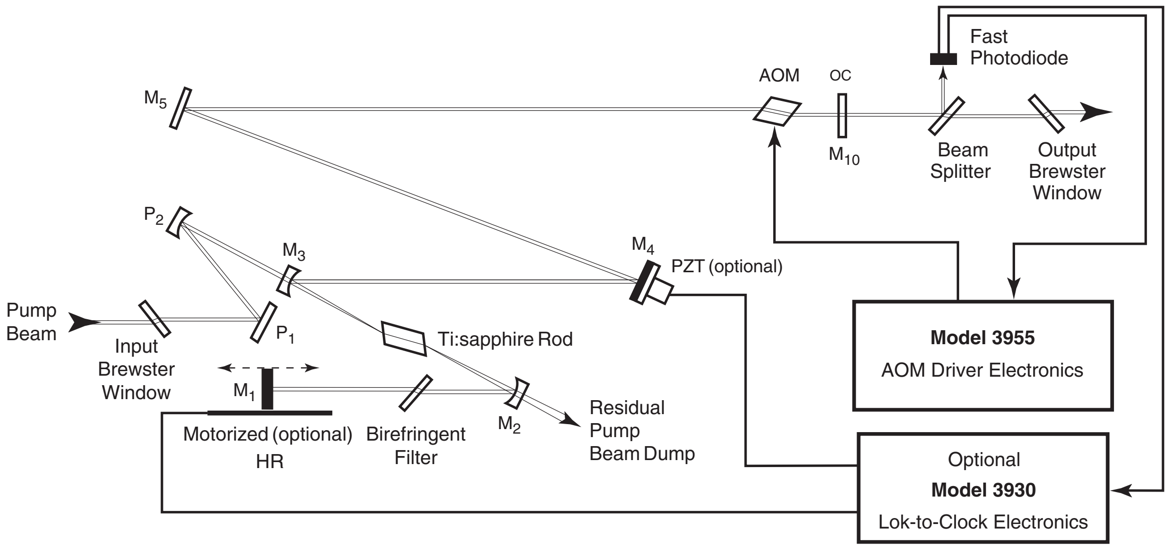


Figure 3-4: Beam Path for *Tsunami Model 3950* Picosecond Configuration

However, astigmatism still exists within the laser rod. Therefore, the pump beam must also be astigmatic for efficient coupling between the pump and intracavity beam. A concave focusing mirror used at the proper angle induces astigmatism in the pump beam that matches that of the *Tsunami* cavity mode. The result is a laser with high conversion efficiency and good beam quality.

A/O Modulator (AOM)

The *Tsunami* acousto-optic modulator (AOM) ensures reliable mode-locked operation at laser start-up. It also allows the laser to operate for extended periods without dropouts or shut-downs associated with standard passively mode-locked systems. The AOM is driven by a regeneratively-derived rf signal.

Wavelength Tuning Characteristics

Because the Ti:sapphire rod is birefringent, uninterrupted tuning is achieved when the c-axis of the rod is aligned coplanar with the polarization of the electric field within the cavity. Since the Ti:sapphire rod and the birefringent filter plates or prism surfaces represent a total of ten Brewster's angle surfaces, the polarization within the cavity is largely determined by the orientation of these surfaces. Furthermore, cavity losses are minimized and tuning is optimized when all these surfaces are accurately aligned at Brewster's angle.

The *Tsunami* laser uses a proprietary Ti:sapphire rod holder that orients the rod surfaces at Brewster's angle and allows the c-axis of the rod to be aligned coplanar to the electric field vector. This technique compensates for unavoidable errors in rod orientation that occur when the rod is cut and polished.

The wavelength tuning range of the *Tsunami* laser is 675 nm to 1100 nm (i.e., the rod and system are capable of continuous tuning over this range). However, to facilitate stable, high output performance at any wavelength within this range, several optimized, over-lapping mirror sets are available. Three general-purpose sets cover the majority of the entire tuning range:

- Standard (S) for 720–850 nm
- Long (L) for 840–1000 nm
- Extra-long (X) for 970–1080 nm

Two other sets permit operation in these optional ranges:

- Blue (B) for 690–800 nm
- Mid-range (M) 780–900 nm

With the optional broadband set, the *Tsunami* can be tuned over almost the entire range without exchanging intracavity optics:

- from <690 nm to >1025 nm

The *Tsunami* laser comes with the optics set(s) yo specified when you ordered your system. The tuning curves for these mirror sets are shown in Figure 3-5 through Figure 3-10. Figure 3-5 and Figure 3-6 show the femtosecond and picosecond tuning curves for the broadband mirror sets for systems pumped by the various *Millennia* lasers indicated. Tuning curves for the femtosecond and picosecond narrowband mirror sets are shown in Figure 3-7 through Figure 3-10. For information on optic sets for different wavelength ranges, refer to Chapter 10, “Options and Accessories.”

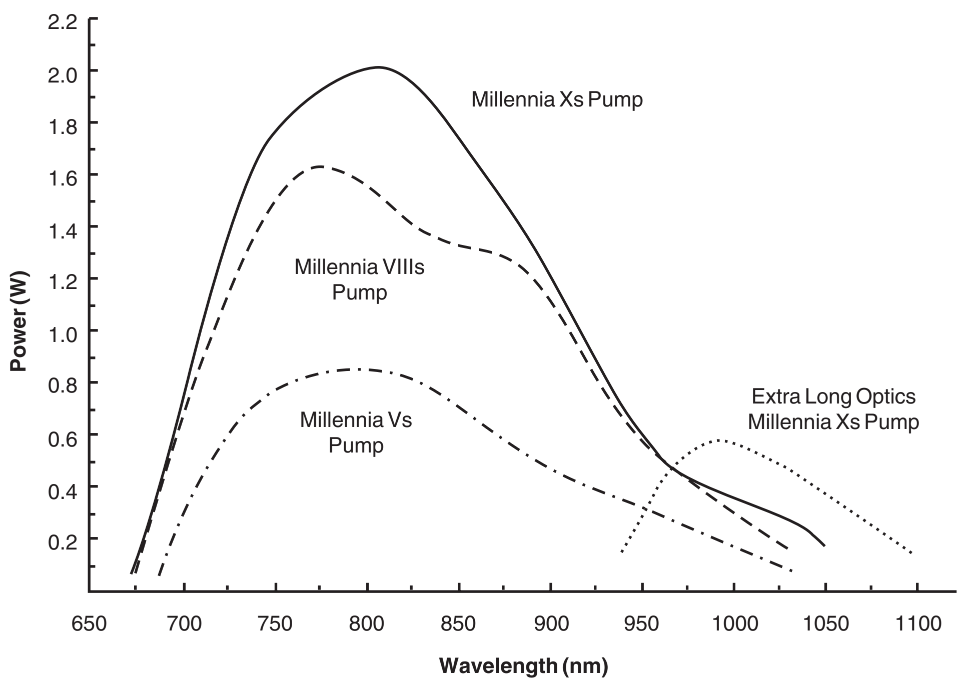


Figure 3-5: *Tsunami* femtosecond tuning curves for broadband optics when pumped by the various *Millennia* diode-pumped cw lasers shown.

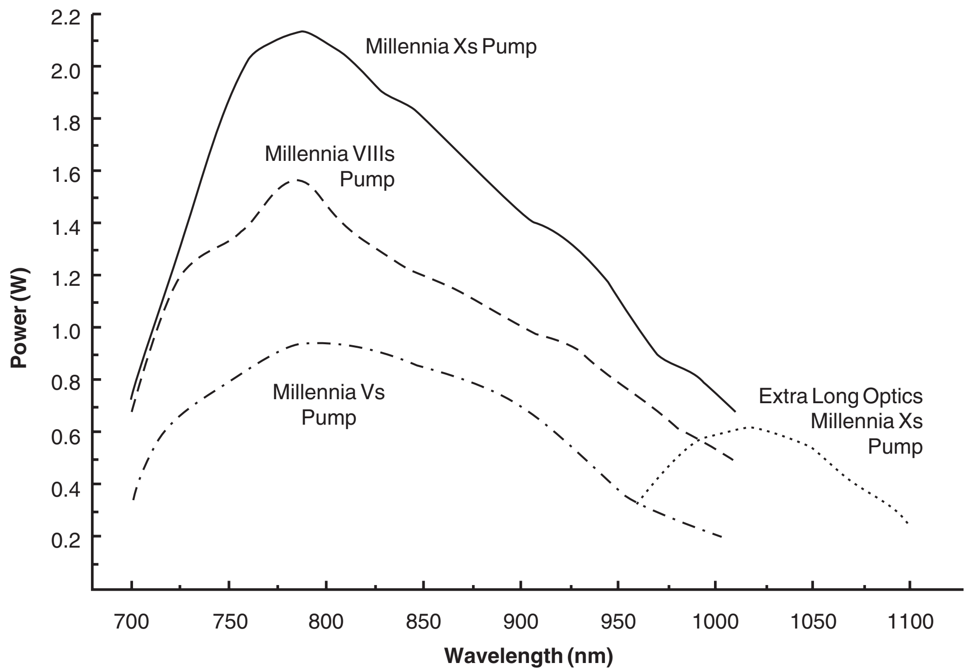


Figure 3-6: ***Tsunami*** **picosecond tuning curves for broadband optics when pumped by the various** ***Millennia*** **diode-pumped CW lasers shown.**

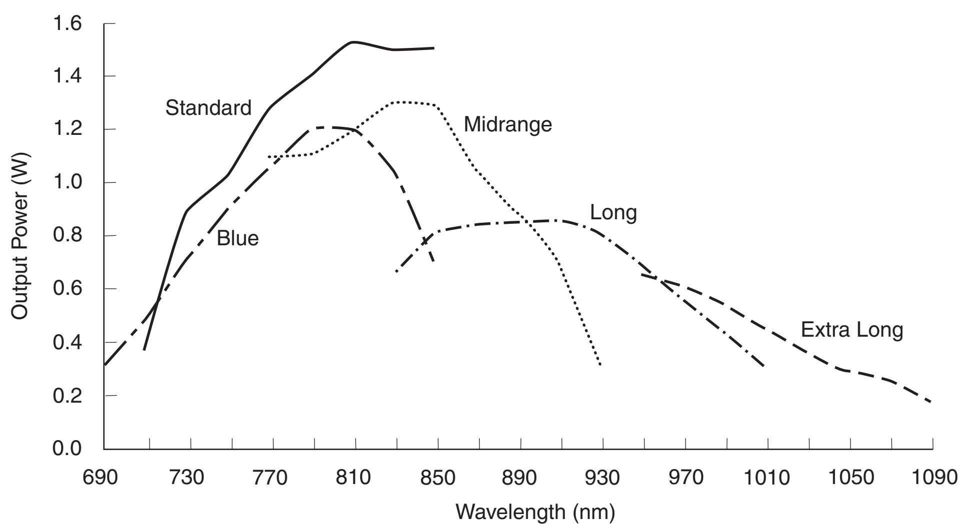


Figure 3-7: ***Tsunami*** **femtosecond tuning curves for the optics sets shown when pumped by a 10 W** ***Millennia*** **Xs diode-pumped CW laser.**

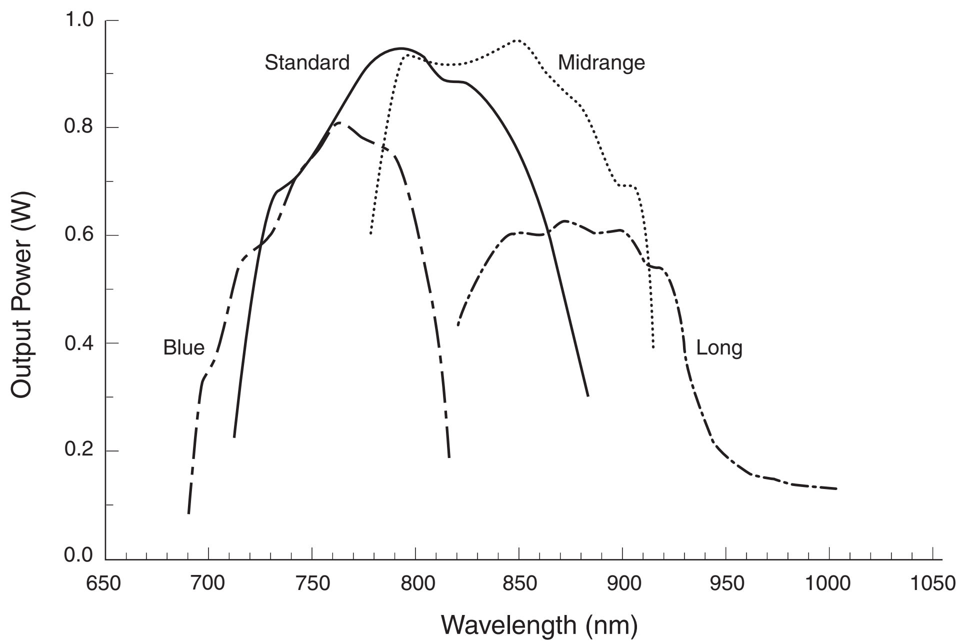


Figure 3-8: ***Tsunami*** **femtosecond tuning curves for the optics sets shown when pumped by a 5 W** ***Millennia*** **Vs diode-pumped CW laser.**

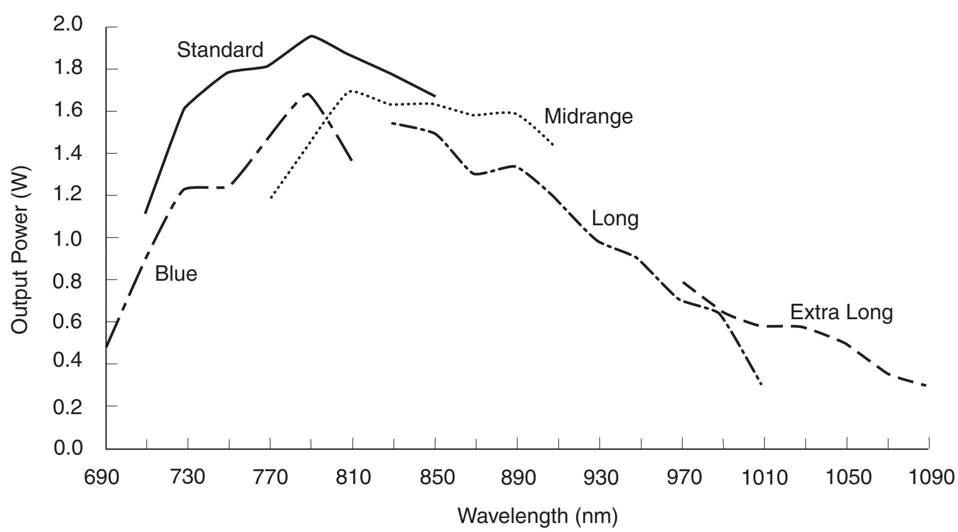


Figure 3-9: ***Tsunami*** **picosecond tuning curves for the optics sets shown when pumped by a 10 W** ***Millennia*** **Xs diode-pumped CW laser.**

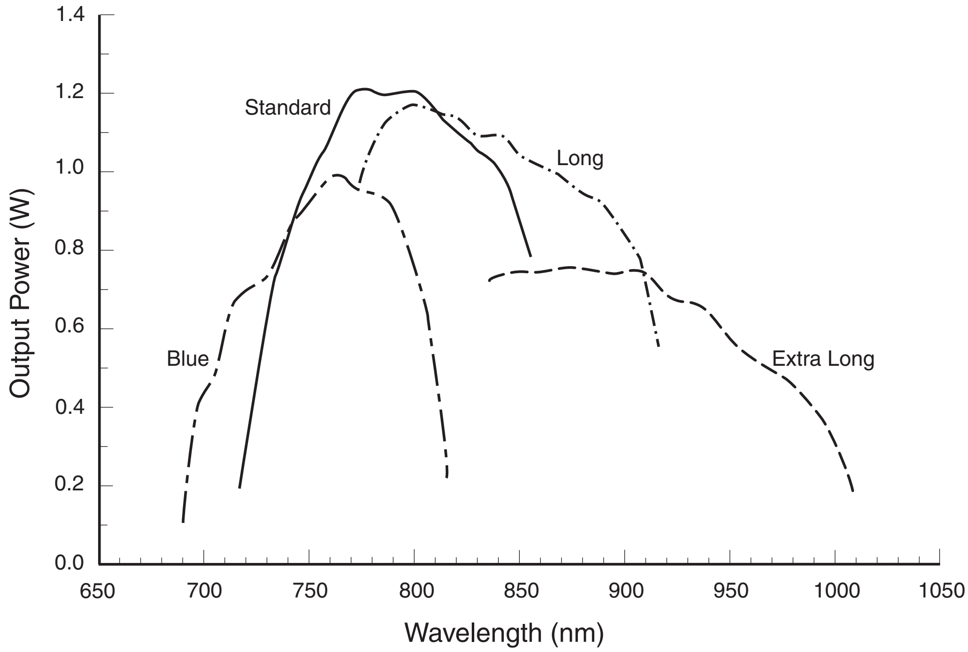


Figure 3-10: *Tsunami* picosecond tuning curves for the optics sets shown when pumped by a 5 W *Millennia* Vs diode-pumped CW laser.

Wavelength Selection

The method used for wavelength tuning depends on whether the laser is configured for fs or ps operation (Figure 3-3 and Figure 3-4).

fs systems. The fs *Tsunami* laser is wavelength tuned using a prism sequence and a slit. This sequence provides a region in the cavity where the wavelengths are spatially spread. A variable slit is located in this dispersed beam. The output wavelength is tuned by changing the position of the horizontal slit in the vertical plane. The width of the slit can also be changed so that the bandwidth (and, hence, the temporal width) of the output pulse can be varied. This simple, straight-forward method covers the entire Ti:sapphire range for ultrashort pulses.

ps systems. The ps *Tsunami* laser is wavelength tuned using a birefringent filter (or “bi-fi”). The bi-fi consists of crystalline quartz plates placed within the laser cavity at Brewster's angle. These plates are cut parallel to their optical axes, and their birefringence causes the linear polarization of the incident laser beam to become elliptical. A narrow range of wavelengths makes a complete 180° (or multiple thereof) polarization flip and remains linearly polarized; all other wavelengths remain elliptically polarized and suffer losses at each Brewster-angle surface within the cavity and, thus, fail to reach lasing threshold. The free spectral range of the bi-fi is the difference between adjacent eigenwavelengths—those wavelengths that remain linearly polarized after traversing the filter. Rotating the filter about an axis normal to the plates changes these eigenwavelengths and allows the output wavelength to be tuned.

Pulse Width Selection

The pulse width tuning characteristics of the Ti:sapphire laser are influenced by two factors: those inherent in the Ti:sapphire material itself and those from cavity parameters. While we cannot readily modify the Ti:sapphire material to change pulse width, we can modify the net group velocity dispersion (GVD) of the cavity. The optical components in the laser cavity introduce positive GVD and cause pulse spreading. Further pulse spreading is caused by self-phase modulation (SPM) in the Ti:sapphire rod, which results from the interaction of the short optical pulse with the nonlinear refractive index. In order to obtain stable, short output pulses, these effects must be compensated with negative GVD.

fs systems. Prism pairs are used to produce a net negative intracavity GVD in the fs system. Varying the amount and type of prism glass through which the intracavity beam travels changes the net intracavity GVD. Pulse widths from <35 to 150 fs can be obtained with various cavity configurations. Pulse width also depends on the operating wavelength.

ps systems. In the ps configuration, a GTI is used to provide negative GVD in a patented mode locking design. This device is similar to a Fabry-Perot interferometer, except the first mirror is a partial reflector instead of a high reflector. It has the advantage of being highly reflective over a broad spectral range, yet provides a frequency-dependent optical phase shift. It also provides adjustable negative GVD when the distance between the mirrors is varied. The GTI produces a fairly large negative GVD that is linear over a narrow bandwidth. It must, therefore, be readjusted whenever a new wavelength is selected. The GTI POSITION control adjusts this spacing and allows optimization of the pulse width. A range of < 2 to > 80 ps can be obtained with different GTI spacings and bi-fi types over most of the *Tsunami* wavelength regime.

For a full review of GVD and compensation, please refer to Appendix A, "Mode Locking: Group Velocity Dispersion."

Purging the Tsunami

The *Tsunami* head is sealed so it can be purged. The *Model 3910* regulator/filter purge unit is provided for filtering and drying bottled nitrogen gas. Purging the laser cavity with this gas not only eliminates the typical problems associated with dust and contamination, but also prevents tuning discontinuities caused by oxygen and water vapor. Reduction of the latter is important for operation in the long wavelengths (see Figure 3-11).

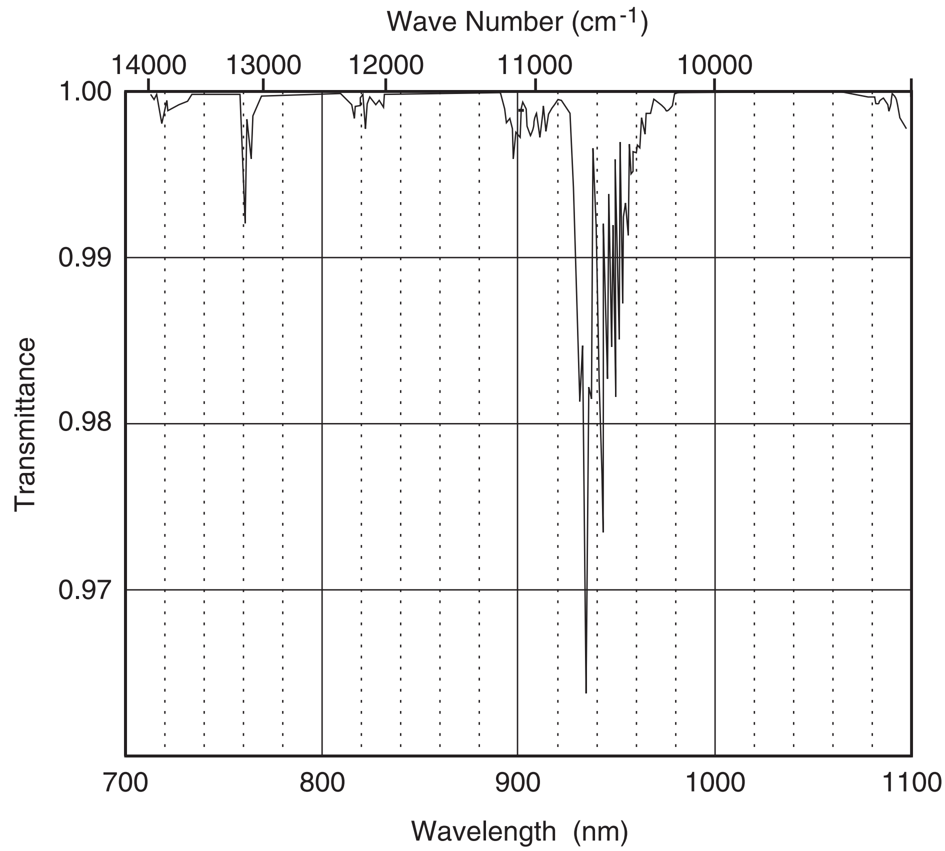


Figure 3-11: Transmittance vs. Wavelength for Oxygen and Water Vapor.

Specifications

Table 3-3 lists performance specifications for fs configurations pumped with a *Millennia*-series laser. Table 3-4 lists performance specifications for ps configurations pumped with a *Millennia*-series laser. Table 3-5 lists the electrical, mechanical and physical specifications for the *Tsunami* laser. Table 3-6 lists the environmental specifications. Specifications for the optional Lok-to-Clock system are found in Table 3-7. Figure 3-5 through Figure 3-10 earlier in this chapter show the tuning curves for typical fs and ps systems, respectively.

Table 3-1: *Tsunami* Femtosecond Broadband Performance when Pumped by a *Millennia* laser[1]

	720 nm	790 nm	850 nm	950 nm	1050 nm[2]
Average Power[3]					
Millennia Xs	700 mW	1.4 W	1.2 W	400 mW	250 mW
Millennia VIIIs	500 mW	1.1 W	900 mW	250 mW	N/A
Millennia Vs	300 mW	700 mW	500 mW	100 mW	N/A
Peak Power[3]					
Millennia Xs	> 65 kW	> 170 kW	> 145 kW	> 48 kW	> 24 kW
Millennia VIIIs	> 47 kW	> 134 kW	> 109 kW	> 30 kW	N/A
Millennia Vs	> 28 kW	> 85 kW	> 61 kW	> 12 kW	N/A
Pulse Width[3,4]	< 130 fs	< 100 fs	< 100 fs	< 100 fs	< 130 fs
Tuning Range					
Millennia Xs		700–1000 nm			970–1080 nm
Millennia VIIIs		700–1000 nm			N/A
Millennia Vs		710–980 nm			N/A
Repetition Rate (nominal)[5]			80 MHz		
Noise[6]			< 0.2%		
Stability[7]			< 5%		
Spatial Mode			TEM_{00}		
Beam Diameter at 1/e2 points			< 2 mm		
Beam Divergence, full angle			< 1 mrad		
Polarization			> 500:1 vertical		

[1] *Specifications subject to change without notice and only apply when the Tsunami is pumped by a Spectra-Physics Millennia X or V diode-pumped CW laser.*
[2] *Specifications apply to operation using the optional X-Long optics set.*
[3] *Specifications apply to operation at the wavelength noted*
[4] *A sech^2 pulse shape (0.65 deconvolution factor) is used to determine the pulse width as measured with a Spectra-Physics Model 409 autocorrelator.*
[5] *Laser operation is only specified at a nominal 80 MHz repetition rate.*
[6] *Rms, measured in a 10 Hz to 2 MHz bandwidth.*
[7] *Percent power drift in any 2-hour period with less than a ±1°C temperature change after a 1-hour warm-up.*

Table 3-2: *Tsunami* Picosecond Broadband Performance when Pumped by a *Millennia* laser[1]

	720 nm	790 nm	850 nm	950 nm	1050 nm[2]
Average Power[3]					
Millennia Xs	700 mW	1.5 W	1.3 W	600 mW	250 mW
Millennia VIIIs	600 mW	1.1 W	900 mW	400 mW	N/A
Millennia Vs	400 mW	700 mW	550 mW	200 mW	N/A
Pulse Width	> 2 ps	> 2 ps	> 2 ps	> 2 ps	> 2 ps
Long Pulse Average Power[4]					
Millennia Xs	700 mW	1.5 W	1.3 W	600 mW	250 mW
Millennia VIIIs	600 mW	1.1 W	900 mW	400 mW	N/A
Millennia Vs	400 mW	700 mW	550 mW	200 mW	N/A
Pulse Width	30/60 ps	30/60 ps	30/60 ps	30/60 ps	30/60 ps
Tuning Range					
Millennia Xs	700−1000 nm				970−1080 nm
Millennia VIIIs	700−1000 nm				N/A
Millennia Vs	710−980 nm				N/A
Repetition Rate (nominal)[5]	80 MHz				
Noise[6]	< 0.2%				
Stability[7]	< 5%				
Spatial Mode	TEM_{00}				
Beam Diameter at 1/e2 points	< 2 mm				
Beam Divergence, full angle	< 1 mrad				
Polarization	> 500:1 vertical				

[1] *Specifications subject to change without notice and only apply when the Tsunami is pumped by a Spectra-Physics Millennia X or V diode-pumped CW laser.*
[2] *Specifications apply to operation using the optional X-Long optics set.*
[3] *Specifications apply to operation at the wavelength noted*
[4] *A sech^2 pulse shape (0.65 deconvolution factor) is used to determine the pulse width as measured with a Spectra-Physics Model 409 autocorrelator.*
[5] *Laser operation is only specified at a nominal 80 MHz repetition rate.*
[6] *Rms, measured in a 10 Hz to 2 MHz bandwidth.*
[7] *Percent power drift in any 2-hour period with less than a ±1°C temperature change after a 1-hour warm-up.*

Table 3-3: *Tsunami* Femtosecond Performance when Pumped by a *Millennia* laser[1]

	710 nm Blue (B)	790 nm Standard (S)	850 nm Mid (M)	900 nm Long (L)
Average Power[2]				
with < 10 W TEM_{00} pump	400 mW	1.1 W	1.1 W	600 mW
with 5 W TEM_{00} pump	300 mW	750 mW	700 mW	400 mW
Peak Power[2]				
with < 10 W TEM_{00} pump	>37 kW	>165 kW	>165 kW	>90 KW
with 5 W TEM_{00} pump	>28 kW	>114 kW	>107 kW	>61 kW
Pulse Width[3,7]	<130 fs	<80 fs	<80 fs	<80 fs
Tuning Range (nm)				
with < 10 W TEM_{00} pump	690–800	720–850	780–900	840–1000
with 5 W TEM_{00} pump	690–800	720–850	780–900	840–990
Repetition Rate (nominal)[4]	80 MHz			
Noise[5]	<0.5%			
Stability[6]	<5%			
Spatial Mode	TEM_{00}			
Beam Diameter at 1/e2 points	<2 mm			
Beam Divergence, full angle	<0.6 mrad			
Polarization	>500:1 vertical			

[1] Specifications subject to change without notice and only apply when the Tsunami is pumped by a Spectra-Physics Millennia X or V diode-pumped CW laser.
[2] Specifications apply to operation at the wavelength noted.
[3] A $sech^2$ pulse shape (0.65 deconvolution factor) is used to determine the pulse width as measured with a Spectra-Physics Model 409 autocorrelator.
[4] Laser operation is only specified at a nominal 80 MHz repetition rate.
[5] Rms, measured in a 10 Hz to 2 MHz bandwidth.
[6] Percent power drift in any 2-hour period with less than a ±1°C temperature change after a 1-hour warm-up.
[7] Pulse widths below 50 fs and between 150 fs and 1 ps are also available. Contact your local Spectra-Physics representative for more details.

Table 3-4: *Tsunami* Picosecond Performance when Pumped by a *Millennia* Laser[1]

	710 nm Blue (B)	790 nm Standard (S)	850 nm Mid (M)	900 nm Long (L)
Average Power[2]				
with <10 W TEM_{00} pump	500 mW	1.3 W	1.3 W	700 mW
pulse width[3]	<2 ps	<2 ps	<2 ps	<2 ps
with 5 W TEM_{00} pump	400 mW	1 W	800 mW	500 mW
pulse width[3]	<2 ps	<2 ps	<2 ps	<2 ps
Long Pulse Average Power[2]				
with <10 W TEM_{00} pump	500 mW	1.3 W	1.3 mW	700 mW
pulse width[3,4]	30/60 ps	30/60 ps	30/60 ps	30/60 ps
with 5 W TEM_{00} pump	400 mW	1 W	800 mW	500 mW
pulse width[3,4]	30/60 ps	30/60 ps	30/60 ps	30/60 ps
Tuning Range (nm)				
with <10 W TEM_{oo} pump	690–800	720–850	780–900	840–1000
with 5 W TEM_{00} pump	690–800	720–850	780–900	840–1000
Repetition Rate (nominal)[5]	80 MHz			
Noise[6]	<0.5%			
Stability	<5%			
Spatial Mode	TEM_{00}			
Beam Diameter at 1/e2 points	<2 mm			
Beam Divergence, full angle	<.06 mrad			
Polarization	>500:1 vertical			

1 *Specifications subject to change without notice and only apply when the Tsunami is pumped by a Spectra-Physics Millennia X or V diode-pumped CW laser.*
2 *Specifications apply to operation at the wavelength noted.*
3 *A sech² pulse shape (0.65 deconvolution factor) is used to determine the pulse width as measured with a Spectra-Physics Model 409 autocorrelator.*
4 *Pulse width specified at the time of ordering.*
5 *Laser operation is only specified at a nominal 80 MHz repetition rate.*
6 *Specification represents rms noise measured in a 10 Hz to 2 MHz bandwidth.*
7 *Percent power drift in any 2-hour period with less than ±1°C temperature change after 1-hour warm-up.*

Table 3-5: Electrical, Mechanical and Physical Specifications

Electrical	
Model 3955 Electronics Module	220 Vac, 0.5 A/110 Vac, 1.0 A
Model 3930 Electronics Module	220 Vac, 0.5 A/110 Vac, 1.0 A
Chiller	(Refer to the instruction manual supplied with unit)
Mechanical	
Model 3910 Pressure Range	
Maximum	67 kPa (10 psi)
Inlet Temperature Range/Coolant for Ti:sapphire Rod	
Minimum	15°C (59°F)
Maximum	20°C (69°F)
Physical	
Weight:	
Model 3960C Laser Head	35.38 kg (78.0 lb)
Model 3950C Laser Head	35.38 kg (78.0 lb)
Model 3941C Laser Head	35.38 kg (78.0 lb)
Model 3955 Electronics Module	7.17 kg (15.8 lb)
Model 3930 Lok-to-Clock Module	7.35 kg (16.2 lb)
Model 3910	2.36 kg (5.2 lb)
Chiller	(Refer to the instruction manual supplied with unit)

Table 3-6: Environmental Specifications

For Indoor Use Only	
Altitude	Up to 2000 m
Ambient temperature	10–40°C
Maximum relative humidity	80% non-condensing for temperature up to 31°C
Mains supply voltage	See Table 3-5
Installation category	II
Pollution degree	2

Table 3-7: Lok-to-Clock *Tsunami* Specifications[1]

Variation in repetition[2,3]	< ±1 Hz
Tuning range (for fixed rep. rate)[4]	720–1080 nm
Timing jitter (rms)[2,3,5]	< 1 ps

[1] *Specifications subject to change without notice and only apply when the Lok-to-Clock Tsunami system is pumped by a Spectra-Physics Millennia laser. For output characteristics, refer to the tables at the end of Chapter 3.*
[2] *Measured over 1 second with respect to the internal 80 MHz oscillator over a 2- hour period after a 1-hour warm-up and less than ± 1°C temperature change.*
[3] *Performance with external reference input is dependent upon the quality of the reference signal. For requirements on the external reference repetition rate, call your local Spectra-Physics representative.*
[4] *Testing for other wavelengths is in progress; call your local Spectra-Physics representative for current information.*
[5] *As measured between the laser output pulse and the internal 80 MHz reference oscillator, over a bandwidth of 100 Hz to 10 kHz.*

Outline Dimensions for Models 3941, 3950 and 3960

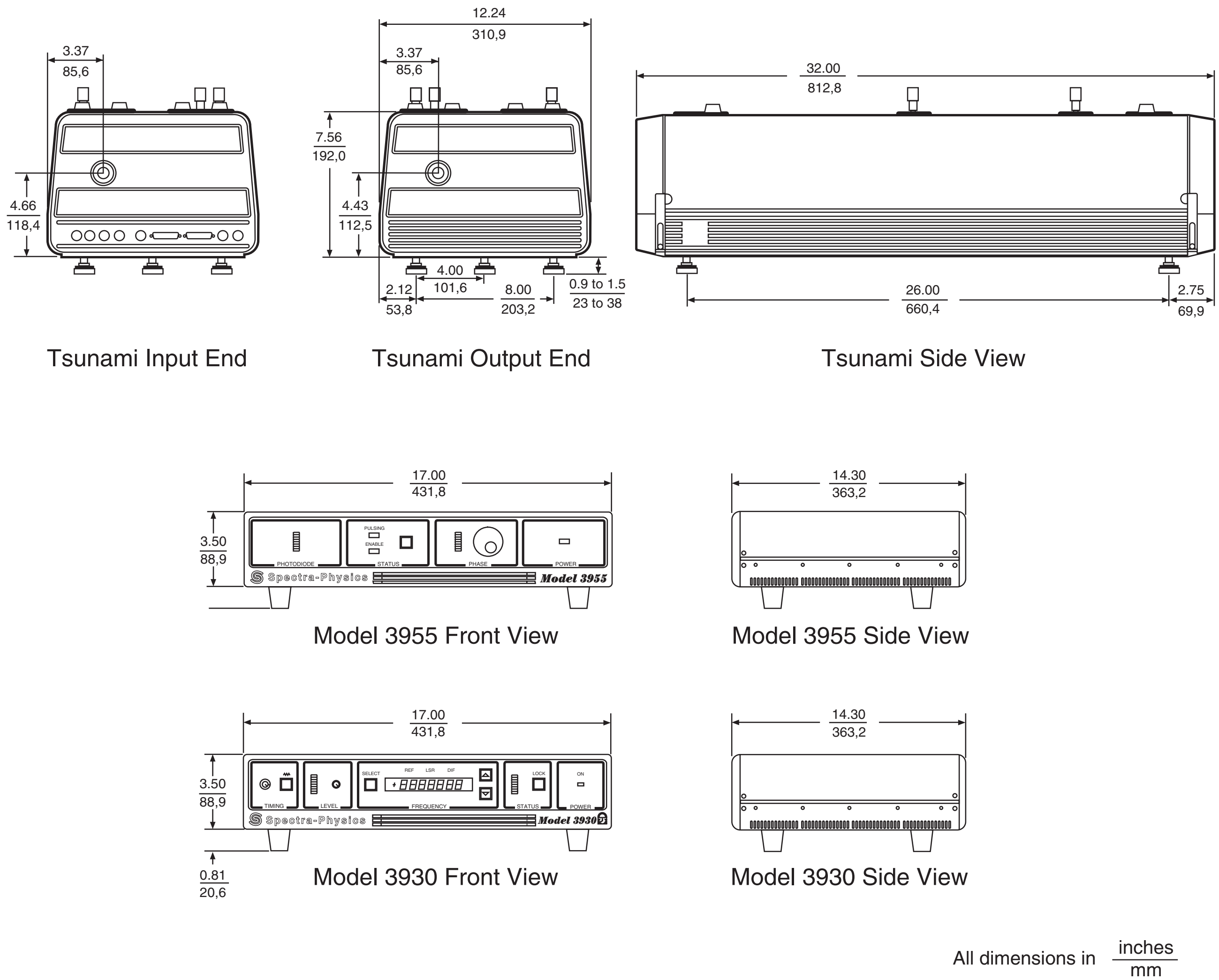


Figure 3-12: Outline Drawing

Chapter 4 Controls, Indicators and Connections

Introduction

This section defines the user controls, indicators and connections of the *Tsunami*® laser system. It is divided into three sections: the *Tsunami* laser head, the electronics module, and the *Model 3910* purge unit. Information on the chiller can be found in the user's manual that accompanies the chiller. The optional *Model 3930 Lok-to-Clock*® electronics module is covered in Chapter 8.

Figure 4-3 and Figure 4-4 are large fold-out diagrams of the *Tsunami* laser head that show its many internal components and controls.

Laser Head Controls

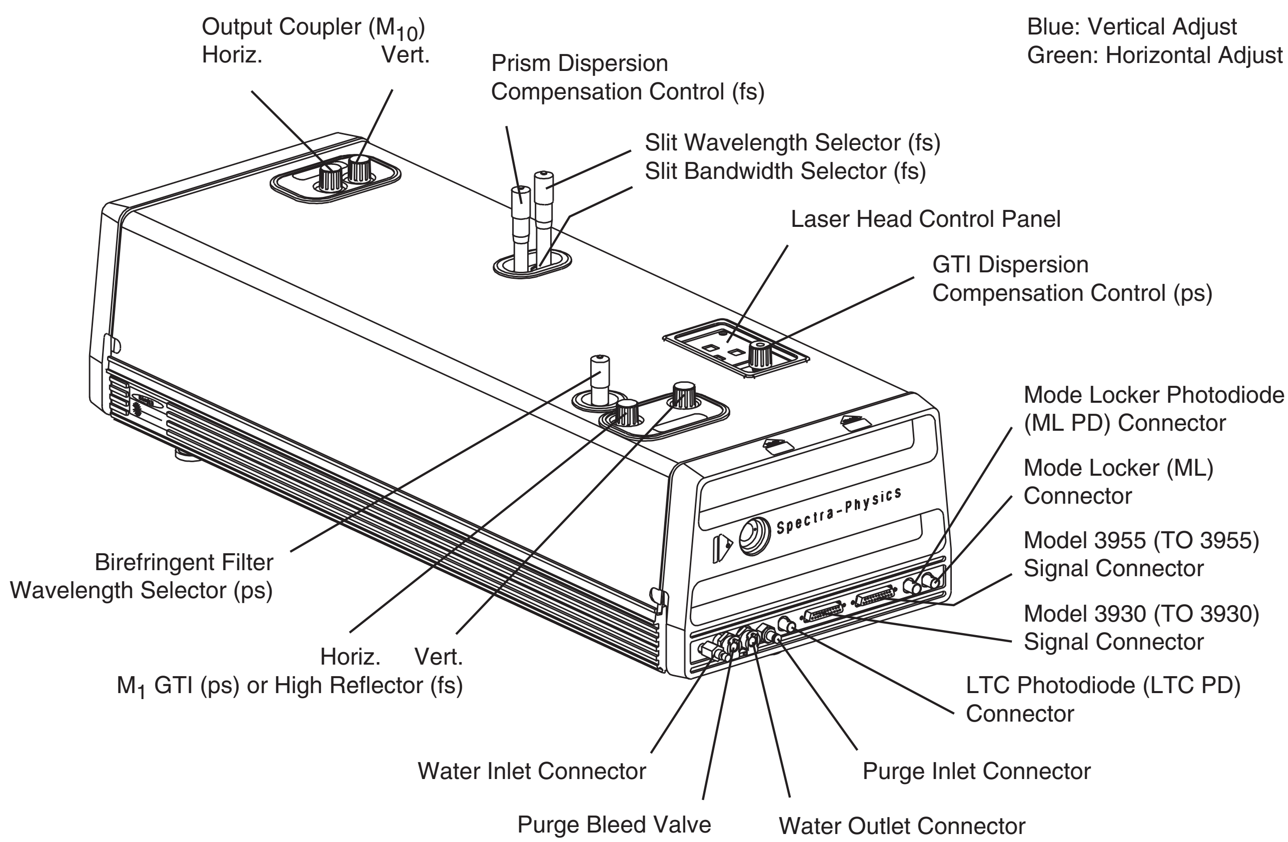


Figure 4-1: *Tsunami* external laser head controls. Not all controls are present on some models.

Input Bezel Connections

The input bezel connections attach to the *Model 3910* purge unit (optional on the *Model 3941*), the chiller, the optional *Model 3930 Lok-to-Clock* electronics module, and the standard *Model 3955* electronics module. Refer to Figure 4-1 or Figure 4-3.

Purge bleed valve—when open, allows more purge gas to flow through the laser head during initial start-up. It is closed for normal operation.

Water inlet connector—input for the laser rod cooling water from the chiller.

Water outlet connector—output for the laser rod heated water to the chiller.

Purge inlet connector—inlet for clean, dry gas from the *Model 3910*.

LTC PD photodiode BNC connector—sends the reference photodiode signal to the phase detector circuit in the optional *Model 3930 Lok-to-Clock* electronics module. If the latter is not present, a 50 Ω terminator must be attached.

TO 3930 main signal D-sub connector (25-pin female)—sends and receives signals to and from the optional *Model 3930 Lok-to-Clock* electronics module.

TO 3955 main signal D-sub connector (25-pin male)—receives heater, power, and control signals from the *Model 3955* electronics module.

ML PD photodiode BNC connector—sends the reference photodiode signal to the acousto-optic modulator (AOM) driver in the *Model 3955* electronics module.

ML mode locker BNC connector—receives the AOM RF signal from the electronics module.

Control Panel

The laser head control panel indicates whether or not pulses are detected, and shows the temperature status of the mode locker. For ps systems, it also provides GTI temperature status and dispersion control for the GTI (Figure 4-2). This panel is not present on the *Model 3941*.

PULSING indicator—when green, it indicates either pulses are present or conditions are correct for pulses.

MODE LOCKER TEMPERATURE indicator—when green, it indicates mode locker temperature has stabilized; red indicates the opposite. From a “cold” laser start-up, expect a stabilization time of about 20 minutes.

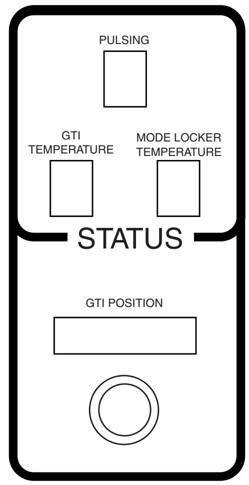


Figure 4-2: ***Tsunami*** **Laser Head Control Panel**

GTI TEMPERATURE indicator—when green, it indicates temperature has stabilized; red indicates the opposite. It flashes red when no GTI is installed (this is normal for fs configuration) or when its cable is left unplugged. From a "cold" start-up, expect a stabilization time of about 15 minutes.

GTI POSITION display—indicates the relative position of the GTI dispersion control (ps configuration), or displays an arbitrary setting when no GTI is installed (fs configuration).

GTI POSITION dispersion compensation control—optimizes the group velocity dispersion (GVD) compensation for pulse length adjustment in ps systems, and is inactive when no GTI is installed (fs configuration).

Mechanical Controls

Shutter—blocks the pump beam at the entrance to the *Tsunami* laser head housing to prevent the *Tsunami* from lasing. When the cover is in place, it holds the shutter open for normal operation. When it is removed, the shutter closes automatically, blocking the input beam. The shutter can be defeated (opened) when the cover is off by pulling up on the red-tipped lever until the lever is in the full upright position (Figure 2-3). In this position, the lever prevents the cover from being properly installed, and reminds the user to reset the shutter before closing up the laser head.

Foot height adjustment—two on the input end and one on the output end allow the laser head height to be adjusted to the height of the pump laser input beam. The legs are large screws with swivel feet that can be screwed up and down from inside the laser using a $^5/_{32}$ in. Allen (hex) driver. Once adjusted, jam nuts on the legs are tightened against the bottom of the base plate to secure the set position and provide mechanical stability.

Cover clamps—one on each corner of the base plate, secure the cover in place. To release the cover, pull outward on the bottom of each of the four cover latches until it snaps. Then, while pressing downward on the cover to release the pressure on the latches, pull the top portion of the latch away from the notch in the cover. Perform the opposite to latch the cover.

Opto-Mechanical Controls All systems

The following is a description of the opto-mechanical controls common to fs- and ps-configured systems. Refer to Figure 4-3 and Figure 4-4.

Caution!

The mirror control knobs are color-coded for easy identification: blue for vertical, green for horizontal.

P_1 pump beam steering mirror—directs the input pump beam onto the center of pump beam focus mirror P_2. It has vertical and horizontal adjustments.

P_2 pump beam focus mirror—directs the pump beam through the cavity focus mirror M_3 and focuses the pump beam into the Ti:sapphire rod. It has vertical and horizontal adjustments, and it sits on a dovetail slide so that its distance from the Ti:sapphire rod can be adjusted. A setscrew on the edge of the slide holds it in place. The mirror is translated with respect to the rod to create a uniform focused spot size in the rod and to compensate for the difference in beam divergence among different pump lasers.

M_2 and M_3 cavity focus mirrors—center and focus the cavity beam waist in the Ti:sapphire rod. They have vertical and horizontal adjustments, and their distances from the rod are adjustable: M_2 has a micrometer adjustment. M_3 has a dovetail slide that is held in place with a setscrew (Figure 6-3).

M_4 and M_5 cavity fold mirrors—fold the beam and allow for a compact laser. M_4 directs the cavity beam to M_5, and M_5 directs it either to the AOM (ps configuration) or Pr_1 (fs configuration). In the *Lok-to-Clock* version, the M_4 contains the PZT for cavity length stabilization and has a short cable and connector for plugging into the driver cable near it in the tray. Both mirrors have vertical and horizontal adjustments.

AOM—is driven by the *Model 3955* electronics module to insure proper pulsing at start-up and, when the optional *Model 3930 Lok-to-Clock* module is present, assists in synchronizing *Tsunami* pulses to another source. The AOM has pitch and Bragg-angle controls.

M_{10} output coupler (OC)—one of two cavity end mirrors. Whereas the high reflector reflects all light back into the cavity, the output coupler allows a small percentage to pass through as the output beam. Its vertical and horizontal adjustments allow you to align the laser cavity and to optimize output power and mode quality. These controls are accessible when the laser head cover is in place.

Rod translation control—vertically translates the Ti:sapphire rod in a plane parallel to the face of the rod. Use it to maximize output power during alignment. The dovetail slide is held in place with two screws (refer to Figure 6-4).

This page is a position holder.
Substitute the B-size, Figure 4-3 fold-out for this page and the next.

Figure 4-3: Laser Head, Rod Side View

This page is a position holder.
Substitute the B-size, Figure 4-4 fold-out for this page and the previous one.

Figure 4-4: Laser Head, Output Coupler Side View

Opto-Mechanical Controls fs Configuration

The following describes the opto-mechanical controls that are present only on *Tsunami* lasers configured for femtosecond only operation (*Model 3941*) or on picosecond systems designed for conversion to femtosecond operation (*Model 3960*). Refer to Figure 4-3 and Figure 4-4.

Pr_1 and Pr_4 prisms—in conjunction with Pr_2 and Pr_3, compensate for positive GVD in a fs system. Each prism mount has a translation control for driving the prism into the beam path for fs operation, and completely out of the beam path for ps operation. Once set, a setscrew on the slide locks each in position.

Caution!

Prisms Pr_1 and Pr_4 are pre-aligned at the factory. *DO NOT* adjust these prisms until specifically told to do so elsewhere in this manual.

M_6 through M_9 prism mirrors—direct the cavity beam from M_5 through the prisms and into the AOM. Each mirror has vertical and horizontal alignment adjustments. The inside control adjusts the mirror vertically, the outside control adjusts it horizontally.

Prism dispersion compensation control (Pr_2 and Pr_3)—adjusts prism-pair Pr_2 and Pr_3 for overall cavity dispersion balance and shortest output pulse. It is used interactively with the nearby slit control. The micrometer control is accessible when the laser head cover is in place.

Slit wavelength selector—selects laser wavelength. The micrometer control is accessible when the laser head cover is in place.

Slit bandwidth selector—changes the output pulse bandwidth. This Allen screw adjustment is set at the factory for a specified output, depending on the optics set installed. Reset it if you change optics set. If set too wide, it causes cw breakthrough; if set too narrow, it limits bandwidth and produces long pulses.

M_1 high reflector (HR)—one of two cavity end mirrors that reflect all of the laser light back into the cavity. The HR replaces the GTI that is used in the ps configuration. Its vertical and horizontal adjustments allow you to align the laser cavity and to optimize output power and mode quality. These controls are accessible when the laser head cover is in place.

Opto-Mechanical Controls ps Configuration

The following describes the opto-mechanical controls present on *Tsunami* lasers that are configured for picosecond only operation (*Model 3950*) or on femtosecond systems designed for conversion to picosecond operation (*Model 3960*). Refer to Figure 4-3 and Figure 4-4.

M_1 Gires-Tournois interferometer (GTI)—compensates for dispersion and can be adjusted for shortest output pulse. The GTI replaces the HR that is used in the fs configuration. Its vertical and horizontal adjustments allow you to align the laser cavity and to optimize output power and mode quality. These controls are accessible when the laser head cover is in place.

Birefringent filter (bi-fi) wavelength selector—selects the laser wavelength. Its micrometer control is accessible when the laser head cover is in place.

Model 3955 Electronics Module Controls

Front Panel

The following is a description of the displays and controls on the front panel of the *Model 3955*. Refer to Figure 4-5.

PHOTODIODE indicator—displays relative photodiode signal strength with full-scale = maximum signal. This is an uncalibrated reference indicator.

STATUS: PULSING mode locker indicator—when lit, it indicates the system is mode locked. When off, it indicates no pulses are detected.

STATUS: ENABLE mode locker indicator—when lit, it indicates mode locking is enabled.

STATUS mode locker enable/disable button—turns on or off RF power to the AOM. Note: even when RF power is off, power to the heater is still applied.

PHASE display—indicates the relative position of the fine PHASE control. This is an uncalibrated reference indicator.

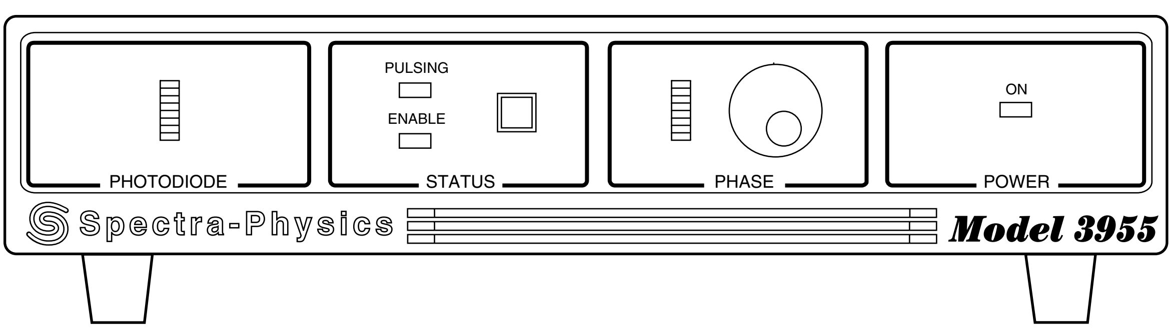


Figure 4-5: ***Model 3955*** **Electronics Module Front Panel Controls and Indicators**

Fine PHASE control—adjusts the phase relationship between the AOM signal and the photodiode signal to provide a pulse-locking mechanism. Its adjustment range is about 100 ps. Adjust this control to sync the mode locker to the pulse rate.

NOTE: If you use cables other than those shipped with the system, or if you convert from a ps to a fs configuration, or vice versa, or convert from extra-long (X) to standard (S) wavelength, or vice versa, the phase signal may move outside the 100 ps range of this control. If this happens, you need to adjust the coarse control located on the Main pc board inside the *Model 3955*. Refer to "Coarse Phase Adjustment..." at the end of Chapter 6.

POWER: ON indicator—indicates power is applied to the *Model 3955* electronics module, the AOM heater and GTI heaters, and that high voltage is applied to the GTI. The GTI is present only in the ps configuration.

Rear Panel

The following is a description of the connections and switches on the *Model 3955* rear panel. Refer to Figure 4-6.

PHOTODIODE BNC connector—receives the control signal from the laser head photodiode. It attaches to the ML PD photodiode connector on the right side of the laser head input bezel. Use the MONITOR connector on the rear panel to monitor this signal on an oscilloscope or frequency counter. Use the SYNC output (sine wave) to trigger the oscilloscope.

Warning!

Do not attach the ML PD photodiode connector to the LTC PD connector! The three BNC connectors on the laser head provide different output signal levels that can damage the receiving device if they are connected to the wrong receiver.

MONITOR BNC connector—connects to a frequency counter or to a 50 Ω oscilloscope input for monitoring the laser head photodiode signal. A typical waveform is shown in Figure 4-7. Use the SYNC output (sine wave) to trigger the oscilloscope. The signal amplitude shown is approximate and depends on operating wavelength, power and photodiode response.

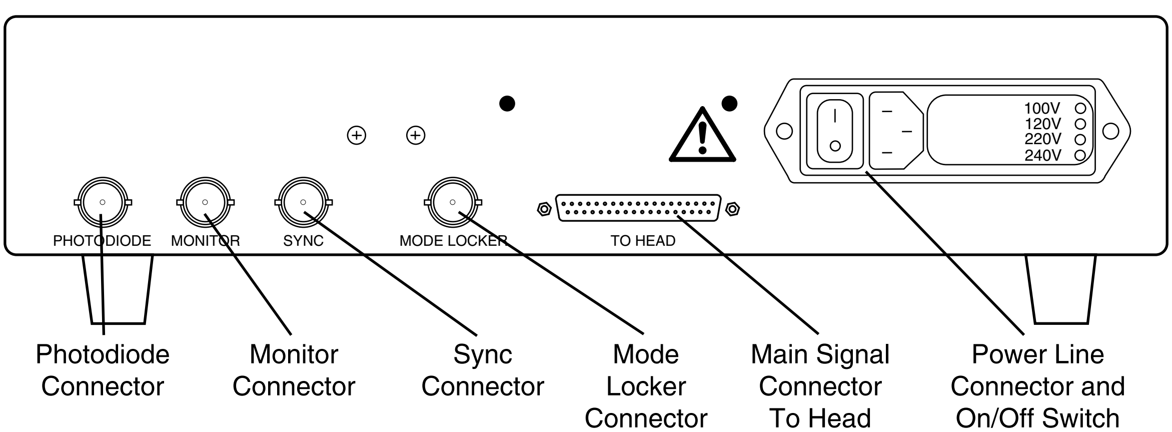


Figure 4-6: ***Model 3955*** **Electronics Module Rear Panel Controls and Connections**

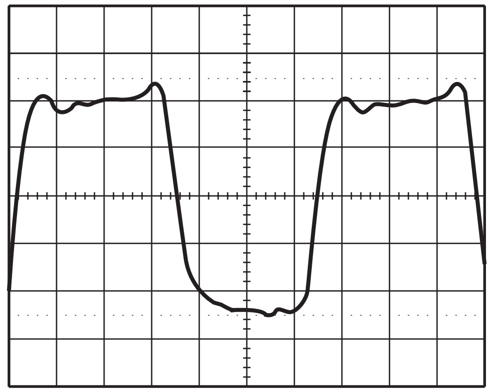


Figure 4-7: Typical MONITOR signal (DC offset: 0 V) as shown on a 1 GHz bandwidth oscilloscope.

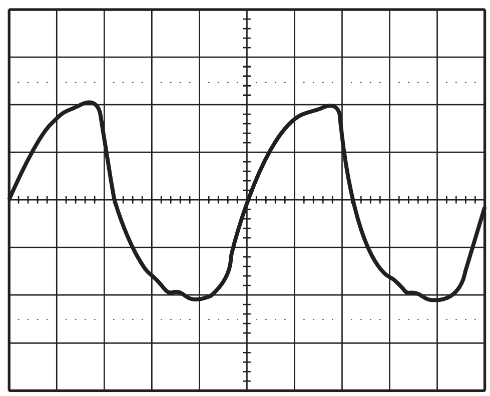


Figure 4-8: Typical SYNC signal (DC offset: –1.25 V) as shown on a 1 GHz bandwidth oscilloscope.

SYNC BNC connector—connects to a 1 MΩ oscilloscope trigger input for viewing the MONITOR photodiode signal. A typical waveform is shown in Figure 4-8. This signal can also drive other Spectra-Physics products, such as the *Model 3985* pulse selector. This is a negative signal. The signal amplitude shown is approximate and depends on operating wavelength, power and photodiode response.

MODE LOCKER BNC connector—sends the RF signal to the laser head AOM. Attach it to the ML connector on the right side of the laser head input bezel.

Warning!

Do not attach the ML connector to the LTC PD or ML PD connectors! The three BNC connectors on the laser head provide different output signal levels that can damage the receiving device if they are connected to the wrong receiver.

TO HEAD main signal D-sub connector (25-pin)—connects the signal, heater, and power supply lines to the male, 25-pin, TO 3955 connector on the laser head input bezel.

Power cord connector—connector for a standard line cord to attach the *Tsunami* electronics to facility line power. (It is part of the power switch assembly.)

Power switch—turns power on and off to the *Model 3955* and the *Tsunami* electronics located in the laser head. It is located next to the power cord connector.

Voltage select switch—provides the means to match the electronics input power to your facility line voltage. Input voltage selections are 100, 120, 220, and 240 Vac. Appendix C describes how to set the switch and select the fuse rating for your location.

Warning! Verify the voltage select switch is set to match the ac line voltage of your facility. An improper selection will damage the electronics. Refer to Appendix C for information on changing the setting.

Model 3910 Purge Unit Controls

The *Model 3910* contains oil and air filters and a molecular-sieve assembly to dry and clean nitrogen gas for purging the *Tsunami* laser head. It has one control and two connectors. Refer toFigure 4-9.

FLOW ADJUST knob—used to set the laser head purge rate (gas flow) from 0.3 to 3.0 m^3/hr (1.0 to 10.0 SCFH).

Flow adjust indicator—displays the nitrogen gas flow rate.

OUTPUT connector—connects the *Model 3910* to the laser head to provide dried, filtered, nitrogen gas.

INPUT FROM GAS CYLINDER connector—connects the *Model 3910* to a dry nitrogen gas supply. Limit the input pressure to 67 kPa (10 psi).

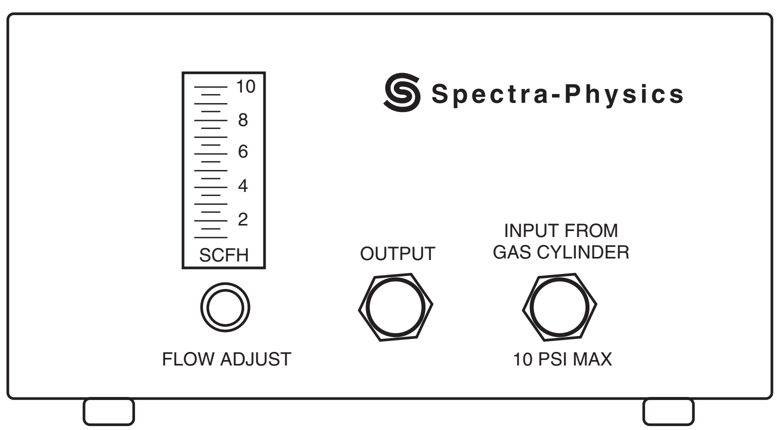


Figure 4-9: ***Model 3910*** **Regulator/Filter Purge Unit**

Chapter 5 Installation

The external *Tsunami*® system components are shown in Figure 4-1 of the previous chapter. The internal components are shown in Figure 4-3 and Figure 4-4 of that chapter. If you need information on specific components, refer to Chapter 4.

Laser Installation

Note

The following installation procedures are provided for reference only; they are not intended as guides to the initial installation and setup of your laser. Please call your Spectra-Physics service representative to arrange an installation appointment, which is part of your purchase agreement. Allow only personnel qualified and authorized by Spectra-Physics to install and set up your laser. You will be charged for repair of any damage incurred if you attempt to install the laser yourself, and such action might also void your warranty.

Most of the tools and equipment you need to set up the *Tsunami* and pump lasers are in your accessory kit. Some pieces, like the GTI for ps-configured systems, are in separate containers.

Installing the Pump Laser

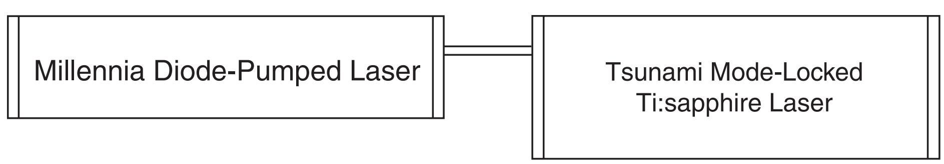


Figure 5-1: Typical *Tsunami* Head and Pump Laser Head Layout

1. Set the *Millennia*® pump laser on a suitable optical table and align it so you can configure your system as shown in Figure 5-1.

Caution!

Position the pump laser power supply and chiller so that their warm air exhaust does not adversely affect the stability of the lasers on the table.

2. Turn on the pump laser according to its instruction manual and allow it to warm up.

3. Verify the output of the pump laser meets specifications for power and mode quality. Specifications for the *Tsunami* pump source are located at the end of Chapter 3.
4. Reduce pump laser output power to minimum.

Danger!
Laser Radiation

The pump laser is a Class IV High Power Laser. Always wear proper eye protection and follow the safety precautions in Chapter 2, "Laser Safety."

---

5. Close the pump laser shutter.

This completes the installation of the pump laser.

Initial Placement of the Tsunami Laser Head

1. Place the *Tsunami* laser head on the table parallel to the pump laser as shown in Figure 5-1, and position it so its input window is roughly in the same plane as the output window of the pump laser.
2. Remove the *Tsunami* laser head cover.
   a. Pull outward on the bottom of each of the four cover latches until it snaps.
   b. Press downward on the cover to release the pressure on the latches, then pull the top portion of the latch from the notch in the cover.
   c. Use the slotted finger grips at each end of the cover (Figure 4-1) and remove the cover from the laser.

      The shutter will close automatically when the cover is removed.
3. Adjust the *Tsunami* laser head height.
   a. Loosen the locking nut on each foot.

      The nuts are threaded onto each leg and jam against the bottom of the base plate to lock the foot in place and to add stiffness to the foot.
   b. Inside the laser head, use a $^{5}/_{32}$ in. Allen (hex) wrench to adjust the feet so the vertical center of the input window is 14.5 cm above the table and the base plate is parallel to the table top.
   c. Tighten the locking nuts.

This completes the initial placement of the *Tsunami* laser.

Aligning the Tsunami Laser Head to the Pump Beam

Warning!

Verify the pump laser is set to minimum current before proceeding with the next step. A high-power beam may damage the Ti:sapphire crystal when the chiller is not hooked up and operating.

---

1. Open the pump laser shutter.

2. Align the *Tsunami* laser head input port to the pump beam.
   a. Open the *Tsunami* interlock shutter by raising the red-capped lever to the vertical override position.

Danger! Laser Radiation

Tsunami is a Class IV High Power Laser. Bypassing the safety interlock shutter might expose the user to hazardous radiation. Always wear proper eye protection and follow the safety precautions in Chapter 2, "Laser Safety."

Danger! Laser Radiation

Be aware that during steps b and c invisible radiation could emit from the output of the *Tsunami* laser and from various optical components as well.

---

   b. Move the *Tsunami* until the pump beam passes through the center of the input window and strikes the center of pump mirror P_1 (refer to Figure 4-3).

      The laser head should now appear to be aligned parallel to the beam.
   c Close the pump laser shutter.
   d. Secure the *Tsunami* laser head to the table with the three foot clamps provided.

      The clamps slide over the lower portion of each foot.
   e. Verify the height adjust locking nuts on the feet are tight.

This completes the installation of the *Tsunami* laser head.

Installing the Chiller

Detailed information on installing and starting the chiller can be found in the manual supplied with the chiller.

1. Place the chiller on the floor close enough to the *Tsunami* laser head so that the 3.5 m long hoses will reach from the chiller connectors on the back of the unit to the *Tsunami* front bezel connectors and the *Millennia* pump laser as shown in Figure 5-2.

Warning!

Do not place the chiller above the lasers. Should the unit not be installed properly and a leak develop, dripping water may damage one or both lasers.

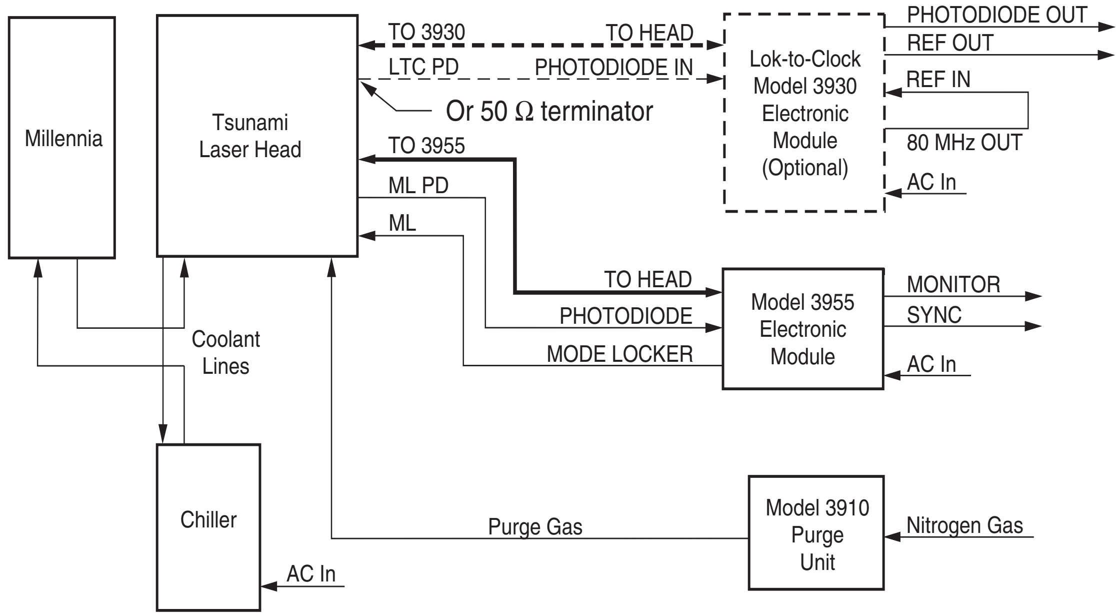


Figure 5-2: Typical System Interconnect Diagram

2. Unscrew the knurled nuts holding the large barbed hose fittings to the back of the chiller and remove the barbed fittings.
3. Find the two hoses in the accessory kit and locate the ends without fittings. Slide one of the knurled nuts just removed over each hose end with the threads facing the end of the hose.

   One end of each hose has a quick-disconnect fitting already attached.
4. Find the two small, barbed hose fittings in the accessory kit and push them into the ends of the two hoses.

   It may be a tight fit. The polyurethane hose can be stretched either using long-nosed pliers or by warming the ends a little with a flame less heater. Note: overheating the hose will damage it and can result in leaks later.
5. Screw both hoses onto the chiller and tighten.

   The hose connections are not polarized. Finger tight is enough: do not overtighten.

Water should first flow to the *Millennia* laser, then to the *Tsunami*. To do this, a third hose with quick-disconnects on each end is required in order to bring water from the *Millennia* to the *Tsunami* laser.

6. Push the quick-disconnect fittings of the hose(s) into either of the two water fittings on the *Tsunami* or *Millennia* input bezel (refer to Figure 4-3). When seated, the connectors will fasten with a click.
7. Turn on the chiller and verify water is flowing.

   Refer to the chiller manual for instructions.

Warning!

Setting the chiller pressure higher than 275 kPa (40 psi) can lead to catastrophic damage and will void the warranty.

8. Inspect for leaks at the hose connections just made, and also inside the laser head where the polyurethane hoses attach to the front bezel and to the rod holder.
9. Set the chiller temperature for 18°C (64°F).

Caution! Position the chiller so that its warm air exhaust does not adversely affect the stability of the lasers on the table.

This completes the installation of the chiller.

Removing the Chiller Hoses from the Laser Head and Chiller

When you need to remove the hoses from the laser head, press on the side button and pull the hose out. The quick-disconnect connectors are self-sealing and no water will spill from the hoses.

Before removing the hoses from the chiller, refer to the chiller manual for instructions on draining the unit or for capping the hose fittings.

Installing the Model 3910 Regulator/Filter Purge Unit

1. Verify the hoses inside the *Model 3910* are still properly connected to the plastic filters.

   Turn the *Model 3910* upside-down and visually inspect for loose connections.
2. Place the *Model 3910* in a convenient place within 3.5 m of the *Tsunami* laser head.

Warning! PTFE tubing is included in the accessory kit for use when purging the *Tsunami* laser with dry nitrogen. Using PTFE tubing avoids introducing outgassed impurities into the cavity that may degrade system performance and/or cause damage to the optical coatings.

3. Connect the purge line from the *Model 3910* purge unit to the *Tsunami* laser head.

   Use the 3.5 m PTFE purge line provided to connect the *Model 3910* to the laser head. It comes with a *Clip-Lok*®* connector on one end and a quick-disconnect connector on the other. The purge line is attached by pressing the hose connectors onto their mating connectors until they snap in place.

   a. Attach the *Clip-Lok* connector to the output of the *Model 3910*.

   b. Attach the quick-disconnect connector to the purge input on the *Tsunami* laser head input bezel.

* *Clip-Lok® is a registered trademark of Anarak, Inc.*

Warning! Do not connect the *Model 3910* to a boil-off tank or other non-lab-grade nitrogen gas source, nor to any source with a pressure greater than 67 kPa (10 psi), or damage to the filters will result

4. Connect the gas supply line from the *Model 3910* purge unit to the nitrogen supply. Make sure you use dry, oil-free, Electronic Grade 5 (or better) nitrogen (99.999% pure) to prevent contamination of the *Model 3910* or your laser optics.

   Use the 2 m, $^{1}/_{8}$ in. i.d. PTFE gas supply line provided to connect the *Model 3910* to the nitrogen supply. It comes with a *Clip-Lok* connector on both ends.

   a. Attach one end of the gas supply line to the INPUT FROM GAS CYLINDER connector on the *Model 3910*.
   b. Attach the other end of the gas supply line to your nitrogen supply.

      If your nitrogen supply does not accept a *Clip-Lok* connector, cut off the existing connector and install your own. A *Clip-Lok* connector for $^{1}/_{4}$ in. i.d. PTFE tubing is also included in the accessory kit.

      To attach barbed connectors to PTFE tubing, heat the tubing with a flameless heat source (heat gun), then quickly slide the tubing onto the barbed fitting while the tubing is still warm. Do not move the connection until it has cooled. Install the line and check for leaks.

This completes the installation of the *Model 3910* purge unit.

Removing the Purge Line from the Laser Head and Model 3910

To release the purge line from the laser head, press inward on the metal locking flange on the quick-disconnect, while gently pulling on the hose.

To release the purge line from the *Model 3910* purge unit, press inward on the wire clip-spring while gently pulling on the hose.

Installing the Tsunami Model 3955 Electronics Module

If you have a *Lok-to-Clock* system, install the *Model 3930* at this time. Refer to Chapter 8.

1. Verify the power switch on the rear panel is off.
2. Verify the voltage select switch on the rear panel is set to match the ac line voltage of your facility outlet.

   The white indicator for the voltage setting is located next to the power cord connector. Voltage choices are 100, 120, 220, and 240 Vac. If the voltage setting does not match your facility outlet voltage, refer to Appendix C, “Setting the Line Voltage Switch,” to reset it.

Warning!

An improper voltage selection will damage the electronics.

3. Place the *Model 3955* electronics module in a convenient location within 3 m of the laser head. If the *Lok-to-Clock* option is used, place the *Model 3955* on top of the *Lok-to-Clock Model 3930*.
4. Attach one end of the control cable (provided in the accessory kit) to the male D-sub TO 3955 connector on the input bezel of the laser head (Figure 4-3), and the other end to the TO HEAD connector on the rear panel of the *Model 3955* (Figure 4-6).
5. Connect one of the BNC cables (provided in the accessory kit) to the ML PD photodiode connector on the input bezel of the laser head (Figure 4-3) and the other end to the PHOTODIODE connector on the rear of the *Model 3955*.

Caution!

Do not connect the PHOTODIODE BNC cable to the LTC PD connector!

Warning!

Be careful when connecting the photodiode and mode locker cables. Connecting the *Model 3955* MODE LOCKER RF output cable to the *Tsunami* ML PD mode locker photodiode connector will cause permanent damage to the photodiode pc board.

Caution!

It is critical to the performance of the system (and ease of installation) that you use the RF and photodiode BNC cables provided. The system was calibrated for the type and length of these cables to provide proper phase matching between the photodiode and mode locker signals. If RF and/or photodiode cables other than those shipped with *Tsunami* are used, an adjustment for cable length is required. Refer to Chapter 6, "Alignment: Coarse Phase Adjustment..."

6. Connect a second BNC cable to the mode locker connector (ML) on the laser head input bezel (Figure 4-3), and the other end to the MODE LOCKER connector on the rear of the *Model 3955*.
7. Connect the ac power cord to the back of the *Model 3955*.

This completes the installation of the *Model 3955* electronics module.

Installing the GTI (ps configuration)

For a ps system, you must install the GTI prior to operating your laser the first time (refer to Figure 5-3). If you purchased a *Model 3960* fs-only or a *Model 3941* laser, skip this GTI installation procedure; a high reflector is already installed in your system.

Danger!

The pc board on the floor of the laser head contains high voltage for driving the GTI. Verify the *Model 3955* electronics module is *off* to disable this board before continuing.

1. Remove the GTI from its shipping container and inspect it for damage.
2. Install the GTI into the laser head (Figure 5-3).

   The GTI installs into the M_1 mirror plate from the input bezel side.

   a. Turn the D-shaped cam lock washers under the three screws so the flat sides face the mounting hole and permit the GTI to slide in.
   b. Pull the gray cable from the GTI through the mounting hole first before installing the GTI.
   c. Set the GTI into the mounting hole, and push it all the way in until the shoulder ring seats against the mount.
   d. Rotate the GTI so the gold connector is near the bottom. A cable will be attached later.
   e. Turn the cam locks around so the round portion of the washer captures the GTI shoulder ring, and tighten the screws.

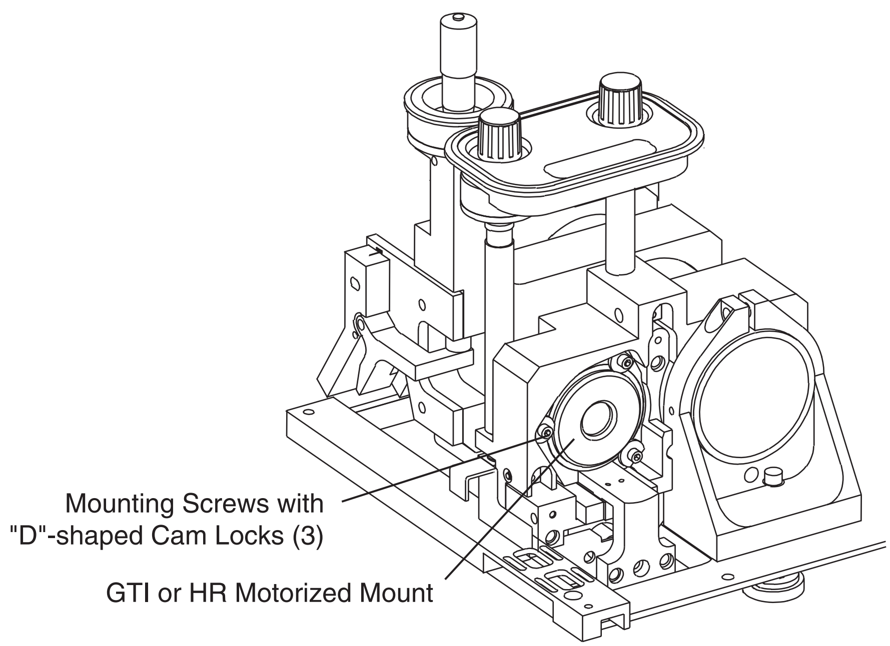


Figure 5-3: The Gires-Tournois Interferometer (GTI). The input bezel and side rail are removed for clarity and the motorized mount shown is available only on *Lok-to-Clock* systems.

3. Route the gray GTI cable along the side of the resonator, from the GTI to the pc board located on the floor near M_4.
4. Remove the plastic cover protecting the pc board (3 screws).

Danger!

The pc board on the floor of the laser head normally contains high voltage. Verify the *Model 3955* electronics module is off to insure this board is disabled.

5. Plug the GTI cable into connector J_2 on the pc board (Figure 5-4).
6. Connect the black, high-voltage, coaxial cable (provided with the GTI) to the SMA connector at J_6 on the pc board.

   Remove the red plastic cap from the SMA connector and attach the screw-on end of the cable to the connector.
7. Route the coaxial cable along the side of the resonator and connect the other end of the cable to the gold connector on the GTI. Push the connector on until it snaps.

   Do not allow the cables to interfere with any resonator mechanical assemblies or the beam path.

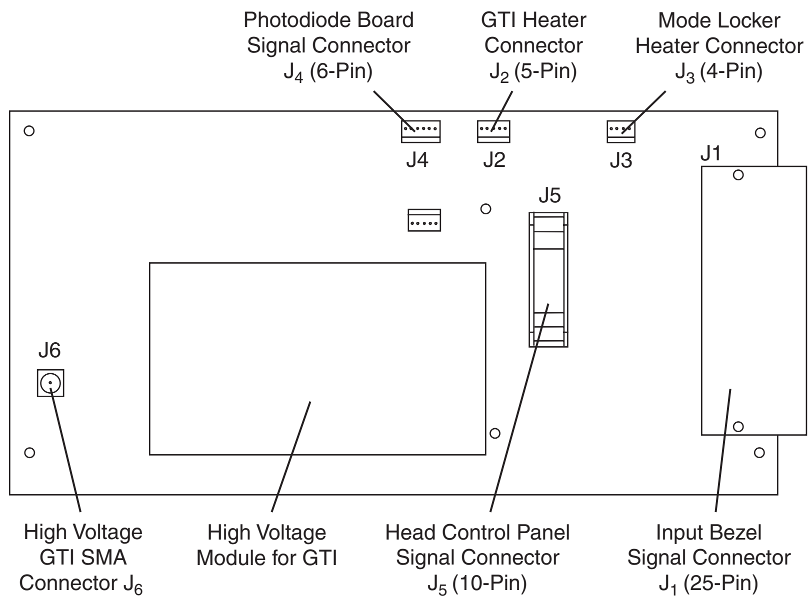


Figure 5-4: *Tsunami* Laser Head PC Board Connections

This completes the GTI installation.

Verifying Cable Connections

1. Verify the A/O modulator (AOM) heater cable is connected to J_3 on the laser head pc board.
2. Verify a black coaxial cable is connected between the gold SMA connector on the AOM and the ML mode locker connector on the inside of the input bezel.

Warning!

Be careful when connecting the AOM and photodiode cables. Connecting the AOM coaxial RF cable to the photodiode connector can cause permanent damage to the photodiode pc board.

3. Verify the internal gray photodiode cable is connected between the photodiode pc board and J_4 on the laser head pc board.
4. Verify the two internal photodiode coaxial cables are connected between the photodiode board (Figure 5-5) and the appropriate input bezel connector (Figure 4-1).

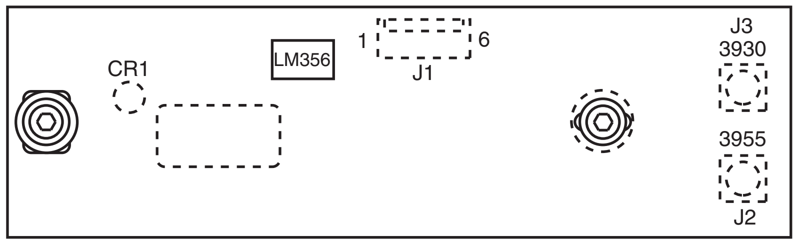


Figure 5-5: Photodiode PC Board

There are two sine wave photodiode output signals, one for the *Model 3955 Tsunami* electronics module and one for the *Model 3930 Lok-to-Clock* electronics module. Because these signals have different amplitudes, it is important that the pc board connectors are attached to their respective BNC connectors on the input bezel.

Caution!

If you do not have the optional *Model 3930 Lok-to-Clock* electronics unit, the LTC PD connector *must be terminated with a 50 Ω terminator* to prevent improper functioning of the mode locker feedback loop.

5. Verify the external RF and photodiode coaxial cables and the main signal cable between the *Model 3955* electronics module and the laser head are properly connected. If you have any doubt, refer to "Installing the *Tsunami Model 3955* Electronics Module" earlier in this chapter.

Caution!

It is critical to the performance of the system (and ease of installation) that you use the RF and photodiode BNC cables provided. The system was calibrated for the type and length of these cables to provide proper phase matching between the photodiode and mode locker signals. If RF and/or photodiode cables other than those shipped with *Tsunami* are used, an adjustment for cable length is required. Refer to Chapter 6, "Alignment: Coarse Phase Adjustment..."

6. Install the plastic cover over the laser head pc board.
7. Install the laser head cover.

Caution!

Direct back reflections into the oscillator can cause serious instabilities in laser performance. Please take precautions to avoid such reflections.

This completes the *Tsunami* and pump laser installation. If you have a *Lok-to-Clock* system, refer to Chapter 8 for installation and operating instructions.

Chapter 6 Alignment

This chapter contains several alignment procedures for the *Tsunami*® laser. Most have been categorized into two sections, one for fs alignment and one for ps. A Spectra-Physics service representative will perform the initial cavity alignment and cleaning when he installs your new laser. Thereafter, there should be little need to do a full alignment. Allow only qualified personnel to align your laser. The "Cavity Alignment" section below is provided in the event a gross misalignment has occurred and your system is out of warranty.

The sections that cover conversions between overlapping and non-overlapping optics sets describe how to change from one set to another and how to perform a minimum realignment in order to use the new optics. Also included are sections that describe how to convert your system between ps and fs configurations.

Caution!

In order to protect the optical components from contaminants, always wear clean, power-free finger cots when handling them.

With the exception of pump mirror P_1 and the GTI (ps configuration only), all mirrors are captured and held in place by a screw-in holder. Unscrew the holder and the mirror will come out with it. The optic is retained by a Teflon o-ring and is removed by simply grabbing the exposed barrel of the optic and pulling it straight out of the holder. *Do not press on the optical surface when reinstalling the optic to its holder—always hold it by the barrel.* The v-shaped arrow on the barrel points to the coated, intracavity surface. When screwing the holder back in, finger tight is sufficient—excessive force will damage the optic.

If you need to verify the location of the optic in the laser, refer to the tables located at the end of Chapter 10, "Options and Accessories."

Caution!

If your laser meets specified power, do not perform this procedure. This section is provided in the event a gross misalignment has occurred. Only personnel authorized and trained by Spectra-Physics should attempt it.

Teflon is a registered trademark of the DuPont corporation.

Caution!

Do not move any mirror mounts until specifically told to do so. Do not change the configuration of the laser at this time, and do not move mirrors M_4 or M_5—all reference might be lost. Instead, first, align the laser as is, then change its configuration afterward if you wish, following the instructions later in this chapter.

Caution!

DO NOT remove or adjust mirrors M_6, M_7, M_8, or M_9, or the prisms in a fs *Tsunami* laser. These optics are prealigned at the factory and are not to be disturbed until specifically told to do so elsewhere in this manual. A service call may be required if disturbed.

Equipment Required:

- Spectrometer (optical spectrum analyzer)
- Autocorrelator—*Model 409-08* (or equivalent)
- IR viewer, such as a FJW Industries "Find-R-Scope."

Front-End Alignment

Refer to Figure 6-1(fs configuration) and Figure 6-2 (ps configuration) as you proceed through the appropriate alignment procedures. The two configurations use common parts from pump beam entry through M_3 and the procedure is the same for both. From M_4 on, the alignment procedure is separated into "Cavity Alignment for fs Systems" and "Cavity Alignment for ps Systems." Refer to the appropriate section when you finish aligning M_3.

1. Close the pump laser shutter and turn on the pump laser. Set it to minimum current.

   Refer to the pump laser manual for information on turning it on and the time required for warm-up.
2. Remove the *Tsunami* laser head cover.

Danger! Laser Radiation

The *Tsunami* is a Class IV High Power Laser. Bypassing the safety interlock shutter can expose the user to hazardous radiation. Always wear proper eye protection and follow the safety precautions in Chapter 2, "Laser Safety."

   a. Pull outward on the bottom portion of the four latches, two on each side, until the latch snaps.
   b. Press downward on the cover to relieve pressure on the latches, and pull the top portion of the latch from the notch in the cover.
   c. Use the slotted finger grips on top at each end of the cover to remove it.

      The safety shutter will close when you remove the cover.

3. Verify the optics are clean and the proper optics are installed in the right positions.

   Refer to the tables at the end of Chapter 10, "Options and Accessories," to match mirror part numbers to the respective mirror positions. Optic part numbers are written on the barrel of each optic along with a v-shaped arrow that points to the coated, intracavity surface. Always close the shutter when replacing optics.

4. Clean the *Tsunami* windows.

   Refer to Chapter 9, "Maintenance: Removing and Cleaning *Tsunami* Optics: Brewster Windows."

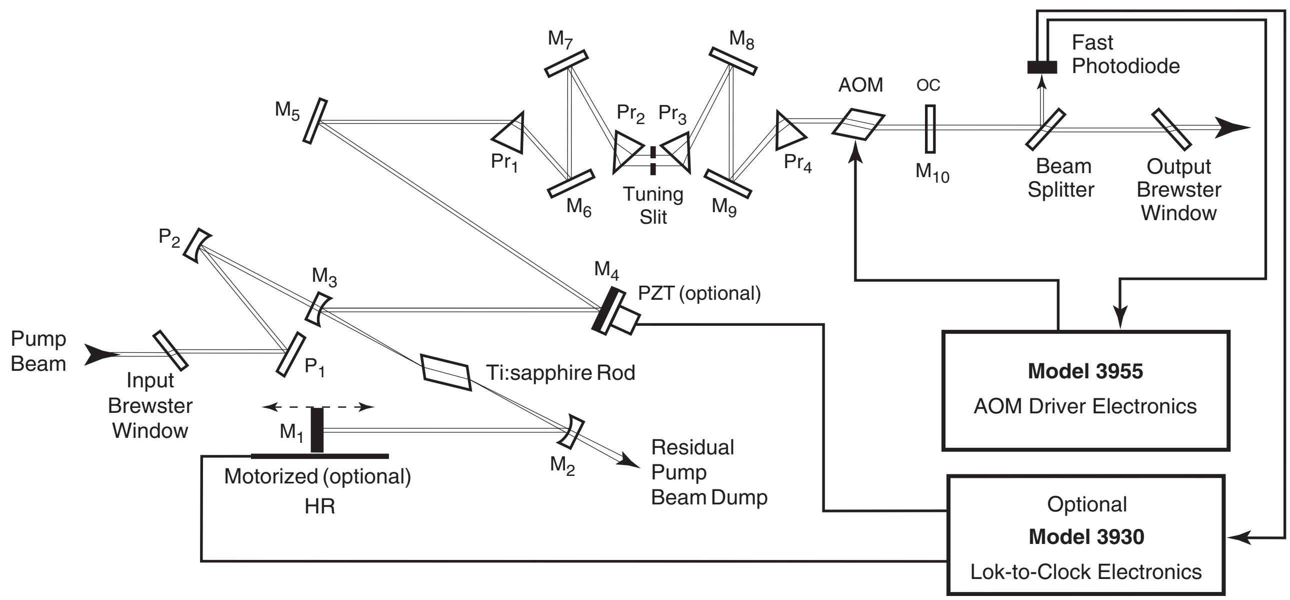


Figure 6-1: *Tsunami* fs Configuration.

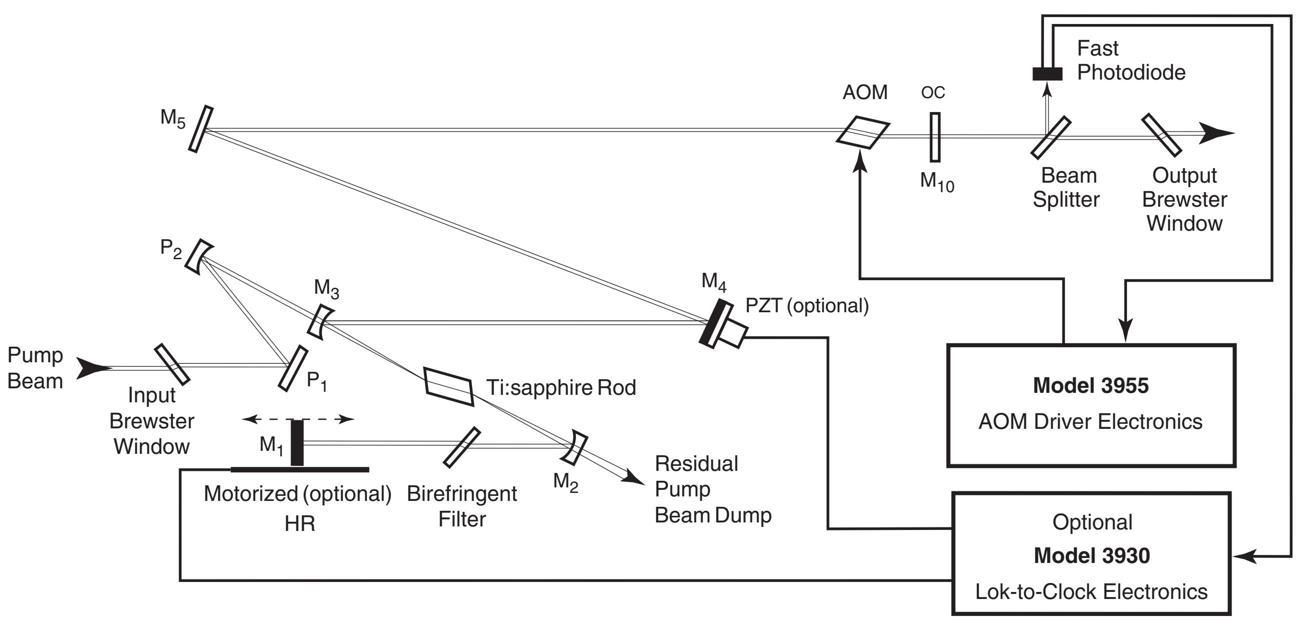


Figure 6-2: *Tsunami* ps Configuration.

5. Open both laser shutters and check the alignment of the pump beam entering the *Tsunami* laser.

   Refer to Chapter 5, "Installation: Installing the Pump Laser" and "Installing the *Tsunami* Laser Head," for initial alignment information. Close the shutter when done.

6. Verify pump laser performance.

   a. Once the pump laser is warmed up, open its shutter and set the laser for nominal output power:

Table 6-1: Pump Power Requirements

Wavelength	Pump Laser	Pump Power
Broadband	Millennia X	7 to 8 W
	Millennia VIII	7 to 8 W
	Millennia V	4 to 5 W
Blue	Millennia X	5 to 6 W
	Millennia VIII	5 to 6 W
	Millennia V	4 to 5 W
Standard	Millennia X	7 to 8 W
Medium	Millennia VIII	7 to 8 W
Long	Millennia V	4 to 5 W
Extra-long	Millennia X	9 to 10 W

   b. Return pump laser power to minimum and close the shutter.

Caution!

Do not adjust mirrors M_2 and M_3 to their initial position (Steps 7 and 10) *unless you are sure* they have been moved since the initial installation. If they have *not* been moved, skip to Step 9.

7. Set the initial position for cavity focusing mirror M_3.

   a. Hold the M_3 translation stage in place with one hand as you loosen its clamping setscrew (Figure 6-3).

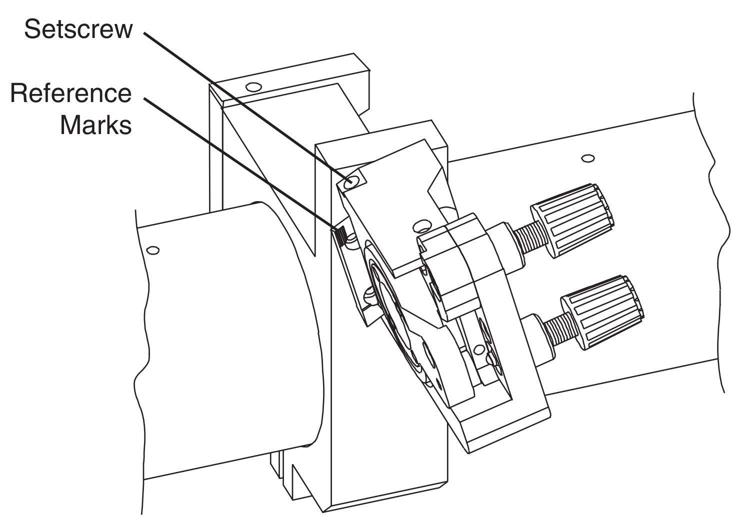


Figure 6-3: The M_3 Translation Stage

b. Move the stage by hand and set it so the vertical edge facing the rod is placed at the third reference mark from the end of the slide.

There are reference marks scribed on the vertical surface of the nonmoveable dovetail. They are very fine and can be hard to see.

c. Tighten the setscrew.

8. Set the initial position for cavity focusing mirror M_2 by adjusting the M_2 micrometer for “7” on the gradation scale (Figure 6-4).

9. Align pump beam steering mirror P_1.

a. Verify the pump laser is set for minimum current.

b. Open the pump laser and *Tsunami* shutters.

c. Center the pump beam on P_1 (Figure 6-5) using the vertical and horizontal adjustments on the routing mirrors.

d. Adjust P_1 vertically and horizontally to center the pump beam on P_2.

10. Align pump beam focusing mirror P_2.

Vertically and horizontally adjust the tilt of P_2 to direct the pump beam through M_3 and the rod, and center the emerging beam on M_2 (Figure 6-4 and Figure 6-5).

Centering the beam on the intracavity surfaces of M_2 and M_3 is *critical* for proper mode overlap in the rod. If the beam is centered on M_2 but not on M_3, walk the pump beam on P_2, adjusting both P_1 and P_2, until proper alignment is achieved.

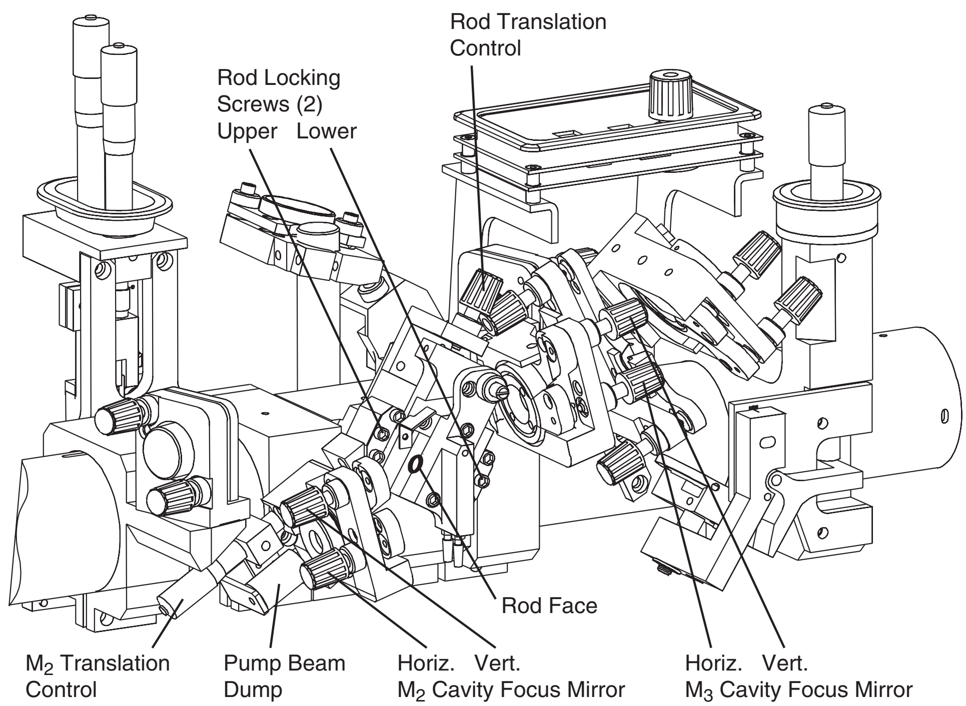


Figure 6-4: Cavity Focus Mirrors M_2 and M_3 and the Laser Rod

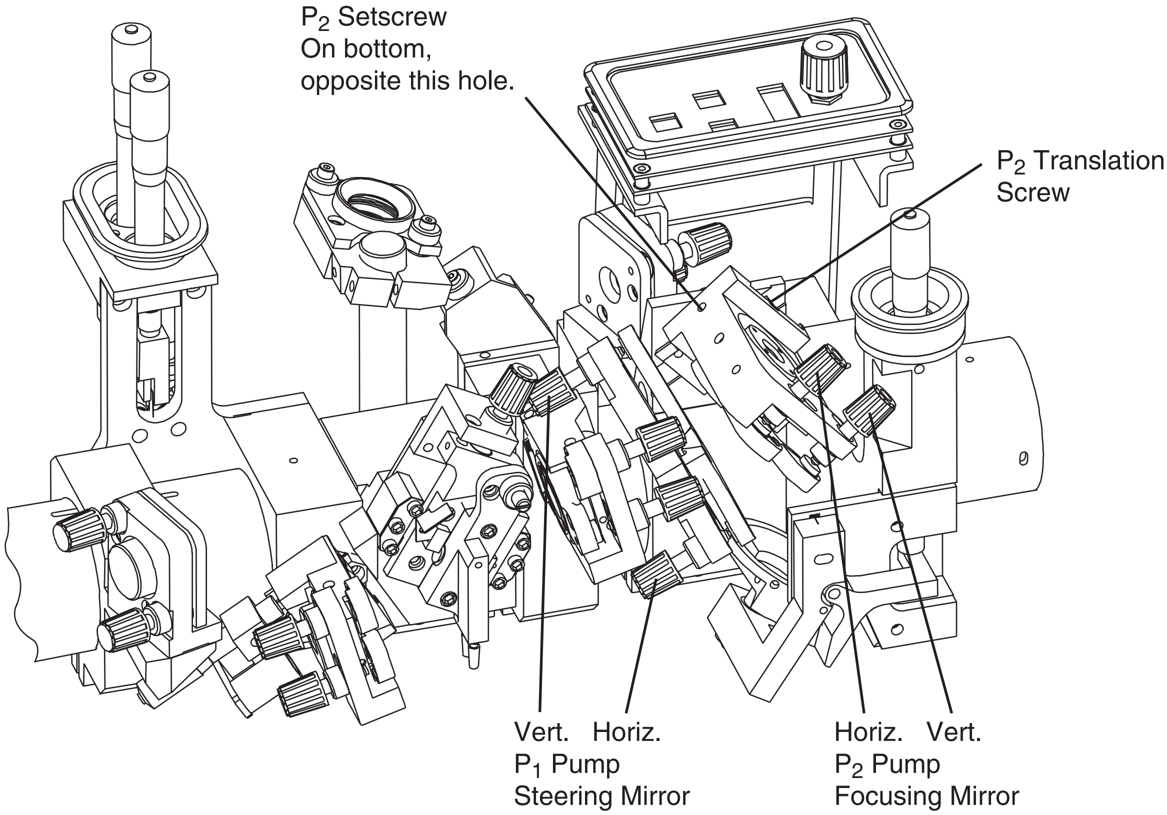


Figure 6-5: Pump Mirrors P_1 and P_2

11. Align cavity focus mirror M_2.

    Adjust M_2 vertically and horizontally to direct the small amount of pump light reflected from M_2 through the center of M_1.

12. Adjust the focus of M_2 and M_3.

    Use an IR viewer and white card for the following steps.

    a. Place the white card in front of M_4.

    b. Increase the pump laser to maximum power.

    c. Adjust M_3 vertically and horizontally to center the image on M_4.

       There will be one or two reflected images visible on the card: one from M_3 and perhaps one from M_1. If only one image is visible, adjust M_1 until two are present. The stationary image is from M_3. Note: they need not over-lap at this time.

    d. Remove the white card.

Caution!

Perform Steps e, f, h, i, and j only if you changed the focus of P_2, M_2 or M_3 during this alignment session, otherwise skip to the next section.

e. Temporarily remove the M_4 mirror to allow the fluorescence to shine on the output bezel, then tape a white card in the florescence image on the bezel. An IR viewer may be necessary to see the image when using the long or x-long optics set.

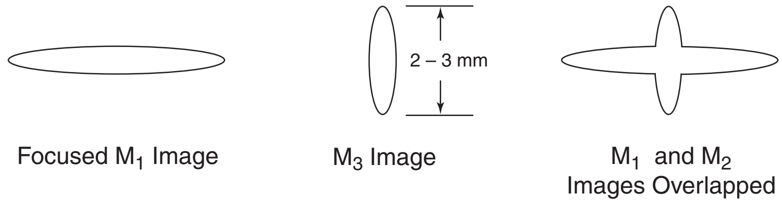


Figure 6-6: M_1 and M_3 Images Focused on the White Card

f. Move the M_3 translation stage until the vertically-oriented elliptical image displayed on the card becomes focused.

Hold the M_3 translation stage in place and loosen its setscrew (located over the dovetail slide, Figure 6-3). Carefully slide the stage until the image becomes focused on the card (Figure 6-6), then tighten the setscrew.

g. Adjust M_1 vertically and horizontally to overlap its reflected image onto the centered elliptical image from M_3.

h. Focus M_2 by moving its translation stage.

Adjust the M_2 micrometer to focus the weak fluorescence reflected from M_1 as a horizontally elliptical image on the white card.

i. Remove the white card.

j. Verify the pump beam is still centered on the intracavity surfaces of M_1, M_2 and M_3.

If it is not, repeat Steps 10 and 11 to recenter the beam on the intracavity surfaces of M_1, M_2 and M_3.

This completes the alignment of the “front end.” If you are aligning a fs laser, continue with the next section below. For a ps system, skip to “Cavity Alignment for ps Systems,” which starts on page 6-14.

Cavity Alignment for a FS System

1. Turn the pump laser up to the nominal power found in Table 6-2 according to the optic set installed. Refer to Table 10-5, Table 10-6 and Table 10-7 to correlate between optics and the optic set.

Table 6-2: Pump Power Requirements

Optic Set	Pump Laser	Pump Power (Watts)
Extra Long	Millennia X	9 to 10
Blue	Millennia X Millennia VIII	7 to 8
	Millennia V	4 to 5
Standard, Mid., Long and Broadband	Millennia X	8 to 9
	Millennia VIII	7 to 8
	Millennia V	4 to 5

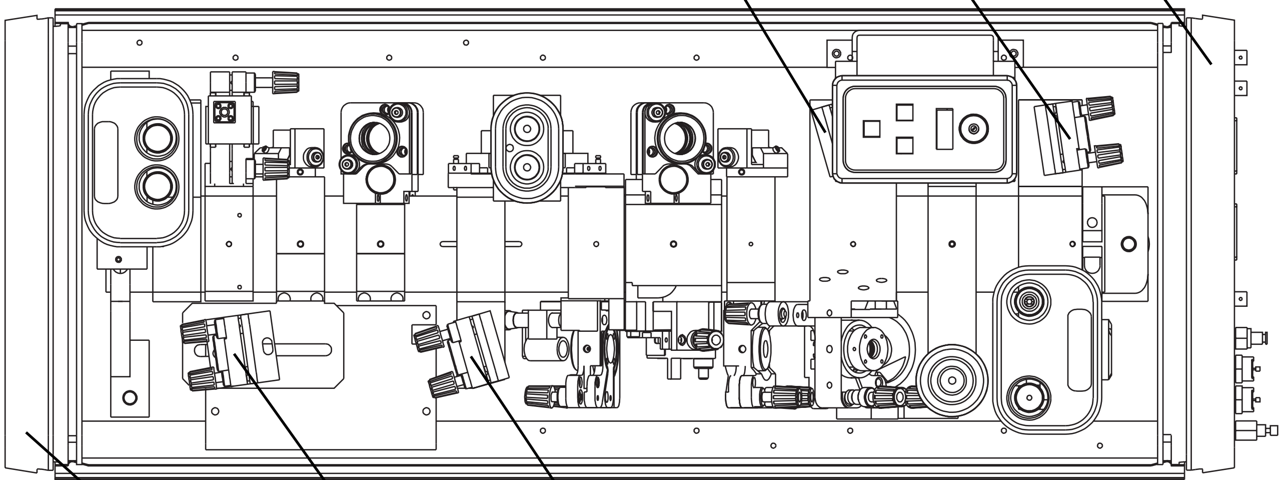


Figure 6-7: Locations of M_4 and M_5 for fs operation.

2. Align fold mirrors M_4 and M_5.
   a. Verify M_4 and M_5 are in their correct positions for fs operation (Figure 6-7).
   b. Adjust M_3 to center the fluorescence on M_4.

      Take into account the horizontal positional offset of M_4 by placing the beam horizontally $^2/3$ the distance from the center of the plate.
   c. Adjust M_4 to center the reflected images from M_3 and M_1 onto M_5.

      Take into account the horizontal positional offset of M_5 by placing the beam horizontally $^1/3$ the distance from the center of the plate.
   d. Remove the slit assembly.

Warning! Support the slit assembly with your hand when loosening the screw to prevent it from falling off the shaft and damaging the optics below.

Loosen the screw holding the slit assembly to the spindle of the control micrometer, then slide the slit down and off the micrometer shaft (Figure 6-8).

   e. Lower prisms Pr_2 and Pr_3 to the bottom of their travel to intercept all the fluorescence for ease of alignment.
   f. Place a white card in front of the input to the A/O modulator (AOM).
   g. Using an IR viewer, adjust M_5 so that the fluorescent spots go through the prism sequence Pr_1 through Pr_4 and are displayed on the white card.

Caution!

Do not place the card between the optical components from M_6 to M_9. The refraction of fluorescence through the prisms causes the spots to spread in the vertical plane and, thus, are not representative of the laser beam path. *DO NOT* adjust M_6 through M_9, nor the prism angles.

h. Remove the white card and place it about 10 cm outside the output window.

i. Adjust M_5 to direct the fluorescent spots through the AOM, through M_{10} and onto the card. The spots should be centered in the background scatter that is shaped by the AOM and M_{10}.

An IR viewer may be required in order to view the small, cross-shaped image centered in the background scatter on the white card (Figure 6-6). If the image is absent, it may be blocked by one or both of these components. Place another white card between the AOM and M_{10} and, using it as a knife edge and slowly moving it into the fluorescent spots, detect the position of the beam relative to the two components and properly center it on M_{10}.

j. Remove the white card.

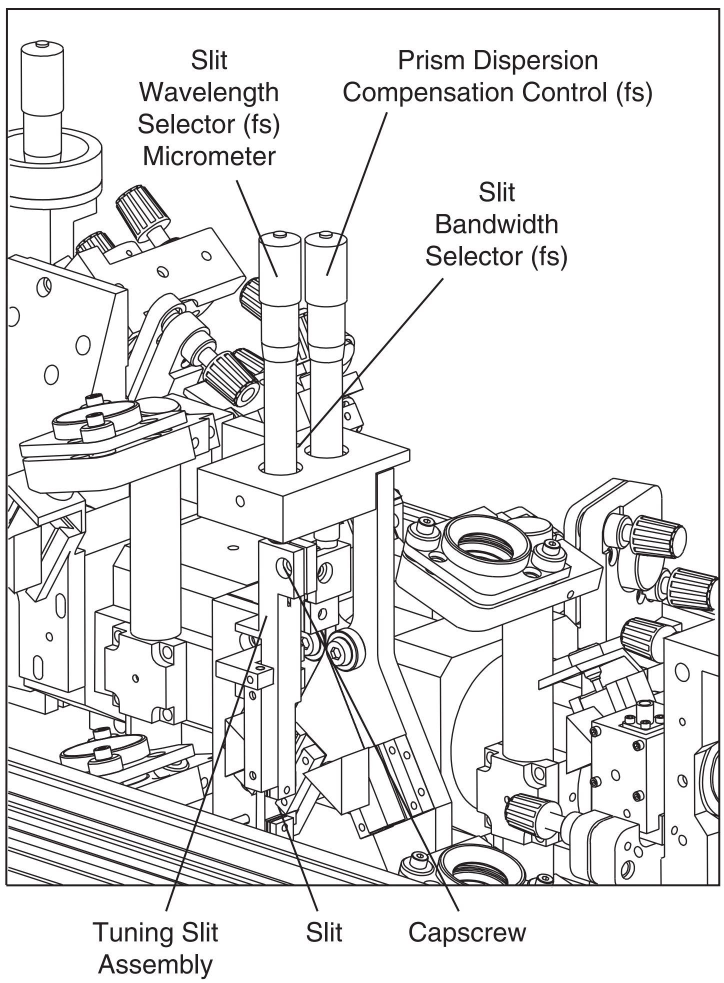


Figure 6-8: The Slit Control

Caution!

DO NOT remove or adjust mirrors M_6, M_7, M_8, or M_9, or the prisms (Figure 6-9). These optics are prealigned at the factory and are not to be disturbed unless specifically told to do so elsewhere in this manual. A service call may be required if disturbed.

3. Align M_{10}.
   a. Place a power meter in the *Tsunami* output beam path as a beam block.
   b. Place a white card with a 2.5 mm diameter hole in it between M_4 and M_5 so the hole is centered on the reflected fluorescent image from M_4.
   c. Direct the reflected image from M_{10} back through the hole in the card and overlap it with the image coming from M_4.

      To determine which reflected image comes from M_{10}, watch the M_5 side of the card and slightly adjust M_{10} until you see which image moves.
   d. Remove the card; lasing should begin.

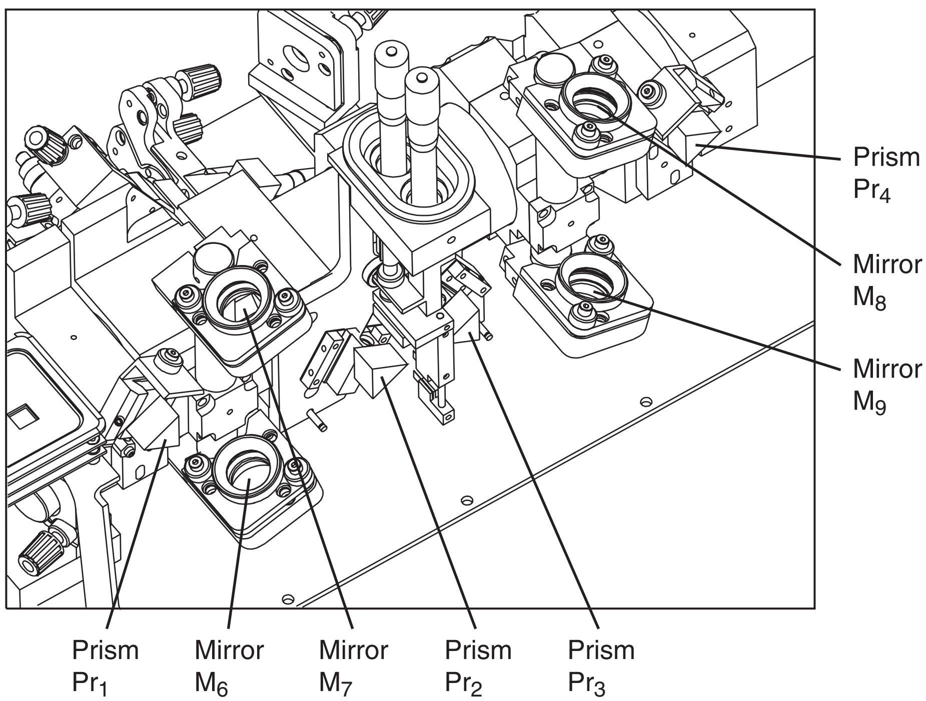


Figure 6-9: Four Prism/Four Mirror Section of fs Laser Cavity

4. Adjust M_{10} and M_1 for maximum output power.
   a. Adjust the vertical axis of M_{10} and M_1 for maximum output power. Slightly rotate M_{10} clockwise and optimize output power by adjusting M_1. If power increases, continue the same direction, otherwise reverse direction until power is maximized.
   b. Repeat, using the horizontal controls.
   c. Iterate these two steps to obtain maximum power in both axis.

5. Iterate Steps 2 through 4 until the beam is centered on M_4, M_5 and M_{10} and power is maximized.

   Avoid parallax error when noting beam position on the mirrors by putting the line-of-sight normal to the mirror axis. It is important that the beam is centered on M_5 and M_{10} because this restores the alignment of the prism sequence so that the beam passes through all the prisms at the angle of minimum deviation. This minimizes beam walk and angular change throughout the wavelength tuning range.

6. Install the tuning slit assembly.

Warning! To avoid damaging nearby optics when installing the slit, carefully move it into place and use your hand to support it while you tighten the mounting screw.

   a. Verify the slit width is about 2.0 mm wide.
   b. Place the tuning slit assembly into the laser head and onto the micrometer shaft. Refer to Figure 6-8.
   c. Rotate the slit width adjustment screw until the dowel pin on the mating shaft can slide into the slot.
   d. Seat the slit assembly against the micrometer stop.
   e. Tighten the screw.

7. Set up the spectrometer to view the wavelength and, later, the mode-locked spectrum. Use ND filter(s) and/or a variable OD attenuator to attenuate the signal into the instrument to avoid saturation.

8. Tune the wavelengths to the center of the tuning range for the optic set installed, but set it for 890 nm for the Long mirror set in order to stay away from the water absorption region. Verify the beam is within the two metal strips that make up the slit.

9. Align the photodiode pc board.

   a. Loosen the two photodiode pc board mounting screws.
   b. Move the pc board around until a maximum signal is observed on the PHOTODIODE bar graph on the front of the *Model 3955*, then tighten the mounting screws. If the LED bar graph is saturated, reduce the pump power to bring the signal below saturation before aligning the pc board.

Aligning the A/O Modulator (AOM)

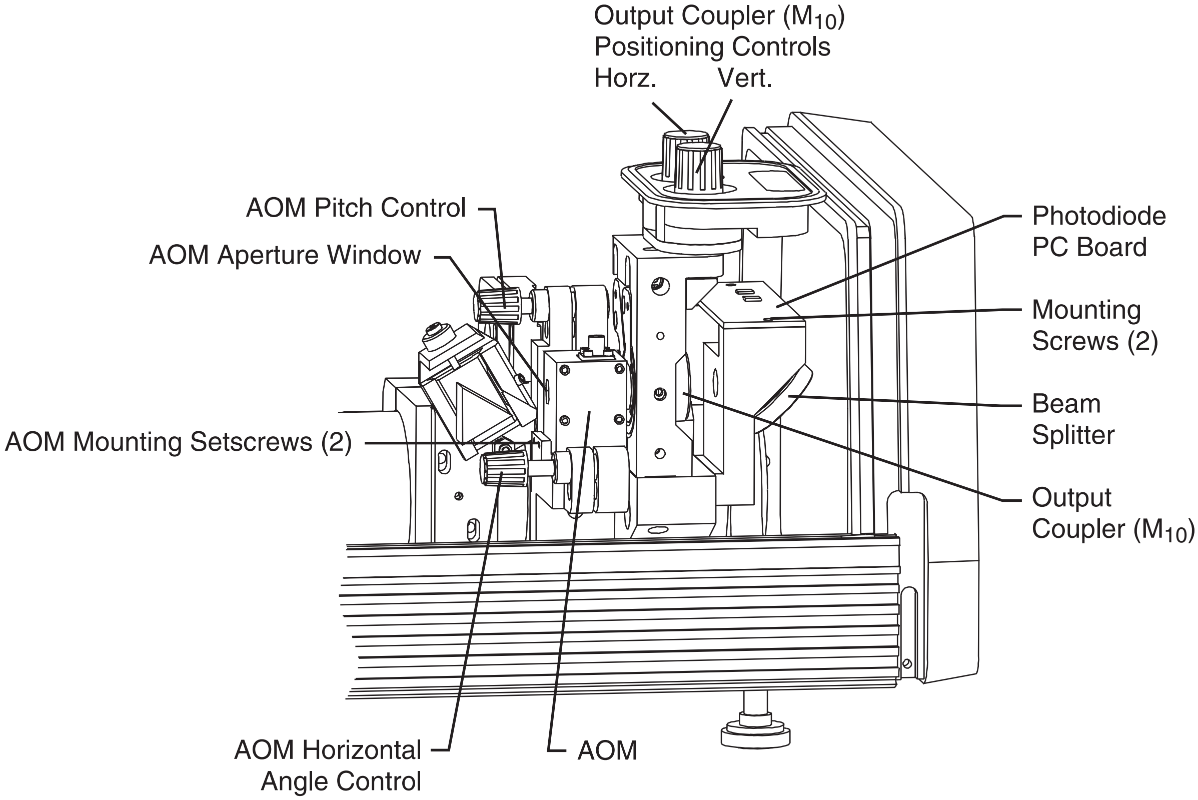


Figure 6-10: AOM, Output Coupler, Photodiode PC Board, and Beam Splitter

The photodiode pc board must be aligned before you align the AOM. This assures a maximum photodiode signal for reliable modelocking. Refer to “Aligning the Photodiode PC Board” later in this chapter.

If you have not already done so, perform the “Test for Proper Modelocking” later in this chapter before you attempt this alignment. If the laser modelocks properly, you do not have to perform this procedure.

1. Verify the output beam is centered on M_{10}.

   Place a white card between M_{10} and the beam splitter, and use the edge of the card to detect the position of the beam.

2. Use the vertical control knob of M_{10} to detune the laser until it stops lasing.

3. Verify the intracavity beam is centered in the AOM.

   Use an IR viewer to see that the M_3/M_1 fluorescence is centered through the silhouette of the AOM crystal. The fluorescence should not be near the edges of the crystal. If necessary, loosen the AOM mounting bracket to adjust it vertically and horizontally. Two 2-56 setscrews hold it horizontally while two $^9/_{64}$ in. cap screws keep it secured vertically.

4. Readjust M_{10} vertically to reestablish lasing and to optimize output.

Establish Modelocking

1. Push the STATUS mode locker enable button (the ENABLE LED should be lit).
2. Adjust Pr_2 and Pr_3 so that the beam passes through them about $^1/_4$ to $^1/_3$ from the apex.
3. Set up an optical spectrum analyzer to view the wavelength signal, then adjust the fine PHASE control on the *Model 3955* electronics to initiate modelocking. When the system becomes modelocked, the single wavelength CW component will change into a Gaussian-shaped spectrum.

   If the signal displayed is not a short pulse (about 80 fs), adjust the fine PHASE control on the *Model 3955* electronics module until either a short pulse appears on the oscilloscope or the autocorrelator signal is maximized.

   If the phase adjustment is far from the optimum setting, the pulses might be too broad to see individual pulses on the oscilloscope. If this occurs, see “Symptom: Laser will not modelock” in the troubleshooting guide in Chapter 11.

   If you are using cables other than those shipped with the system, or you recently converted this system from ps to fs, or changed from extra-long to standard wavelength, or vice versa, the phase signal might have moved outside the range of the fine PHASE control and a coarse adjustment is necessary.

   Note: an 80 MHz pulse train corresponds to a pulse every 12.5 ns and the fine PHASE control provides about 100 ps of phase adjustment. If you cannot see pulses, adjust the coarse control located inside the *Model 3955*. Refer to “Coarse Phase Adjustment...” at the end of this chapter for instructions on locating and changing the setting of the coarse control.

Optimizing Modelocking

1. Adjust the prism dispersion compensation control until the spectrum increases in bandwidth when more prism glass is inserted into the beam. You should not see, however, the presence of any CW breakthrough throughout the spectrum. Adjust for a FWHM bandwidth that is 1.2 times that of the value calculate based on specified pulse width and wavelength according to Figure 6-11.
2. Optimize *Tsunami* output power.

   Place a power meter in the *Tsunami* beam path and adjust M_{10} and M_1 for maximum output power as specified in Step 4 on page 6-10.

   The PHOTODIODE light bar level indicator on the *Model 3955* front panel should indicate maximum for standard wavelengths and >30% for x-long wavelengths.

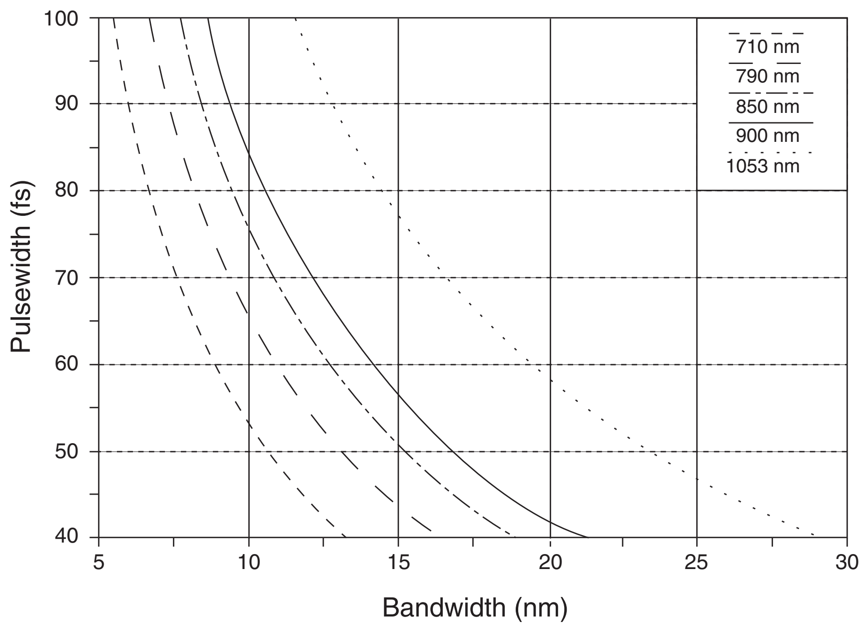


Figure 6-11: Bandwidth vs. Pulse Width for a Transform-limited sech^2 Pulse Shape.

3. Vary pump power and dispersion compensation to obtain the desired output power and pulse width. (Bandwidth is subject to pump power level as well as dispersion compensation in the cavity.)
4. Repeat Steps 1 through 3 until the *Tsunami* pulse is optimized and the test in Step 4 of "Test for Proper Modelocking" later in this chapter is successful.

This completes the AOM alignment and the fs cavity alignment.

Cavity Alignment for a PS System

1. Turn the pump laser up to the nominal power found in Step 6 of "Front End Alignment" for the installed optic set. Refer to the tables in Chapter 10 to correlate between the optics and the optic set.
2. Align fold mirrors M_4 and M_5.
   a. Verify M_4 and M_5 are in their correct positions for ps operation (Figure 6-12).
   b. Adjust M_3 to center the fluorescence on M_4.
   c. Adjust M_4 to center the reflected images from M_3 and M_1 onto M_5.
   d. Place a white card in front of the input to the A/O modulator (AOM).
   e. Using an IR viewer, adjust M_5 to guide the fluorescent spots directly onto the card.
   f. Remove the white card and place it about 10 cm outside the output window.

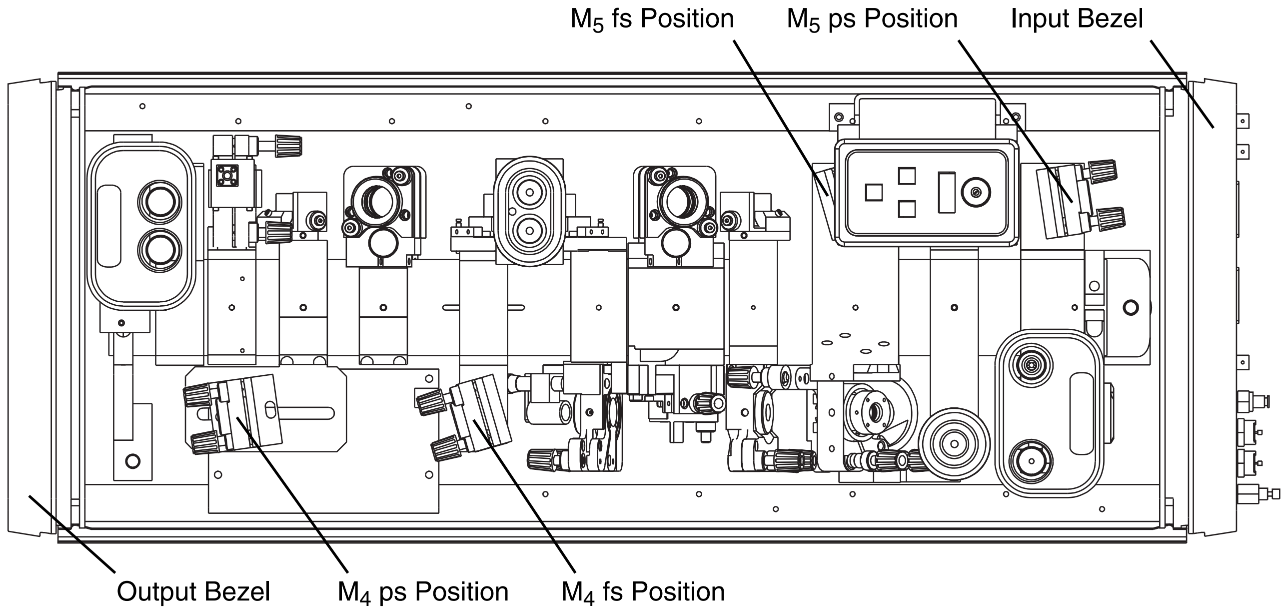


Figure 6-12: Locations of M_4 and M_5 for ps operation.

g. Adjust M_5 to direct the fluorescent spots through the AOM, through M_{10}, and onto the card. The spots should be centered in the background scatter that is shaped by the AOM and M_{10}.

   An IR viewer may be required in order to view the small, cross-shaped image centered in the background scatter on the white card (Figure 6-6). If the image is absent, it may be blocked by one or both of these components. Place another white card between the AOM and M_{10} and, using it as a knife edge and slowly moving it into the fluorescent spots, detect the position of the beam relative to the two components and properly center it.

h. Remove the white card.

3. Align M_{10}.

   a. Place a power meter in the *Tsunami* output beam path as a beam block.

   b. Place a white card with a 2.5 mm diameter hole in it between M_4 and M_5 so the hole is centered on the reflected fluorescent image from M_4.[a]

   c. Direct the reflected image from M_{10} back through the hole in the card and overlap it with the image coming from M_4.

      To determine which reflected image comes from M_{10}, watch the M_5 side of the card and slightly adjust M_{10} until you see which image moves.

   d. Remove the card; lasing should begin.

4. Adjust M_{10} and M_1 for maximum output power.

   a. Adjust the vertical axis of M_{10} and M_1 for maximum output power.

Rotate M_{10} vertically in one direction a small amount and optimize output power using M_1. If power increases, continue the same direction until power reaches a new maximum. However, if power decreases, turn M_{10} the other way and optimize with M_1.

b. Repeat the last step using the horizontal controls.

c. Iterate the last two steps to obtain maximum power in both axis.

5. Reiterate Steps 2 through 4 above until M_4, M_5 and M_{10} are centered and power is maximized. When reading the beam position on mirrors, put your line of sight normal to the mirror axis to avoid parallax error.
6. Install and align the bi-fi according to “Selecting, Installing, and Aligning the Birefringent Filter...”, then adjust the bi-fi for output peak wavelength. Consult Table 7-1 and the tables in Chapter 10 for the proper filter type for the installed optic set.
7. Set up a spectrometer to view the wavelength. In order to see the effect of modelocking, reduce the signal level to avoid saturation using ND filters and/or a variable OD attenuator.
8. Tune to the specified wavelength for the tuning range of the installed optic set, but tune to 890 nm for the long set in order to stay away from the water absorption region.
9. Align the photodiode pc board.
   a. Loosen the two mounting screws on the photodiode pc board.
   b. Move the photodiode pc board around until the maximum signal is observed on the photodiode bar graph on the front of the *Model 3955*, then tighten the mounting screws. If the LED bar graph is saturated, reduce the pump power to bring the signal below saturation before aligning the pc board.
10. Test for proper modelocking.

    Refer to “Test for Proper Modelocking” later in this chapter.

Continue with the next section.

Aligning the A/O Modulator (AOM)

The photodiode pc board must be aligned before you align the AOM. This assures a maximum photodiode signal for reliable modelocking. If you have not just done this, refer to “Aligning the Photodiode PC Board” later in this chapter.

If you have not already done so, perform the “Test for Proper Modelocking” later in this chapter before you attempt this alignment. If the laser modelocks properly, you do not have to perform this procedure.

Proper AOM alignment is critical for both ps and fs *Tsunami* lasers. This procedure assures good AOM beam alignment for optimum modelocking. Figure 5-2 is a system interconnect diagram to assist you in verifying correct cable connections. Figure 6-13 shows the location of the AOM.

1. Verify the output beam is centered on M_{10}.

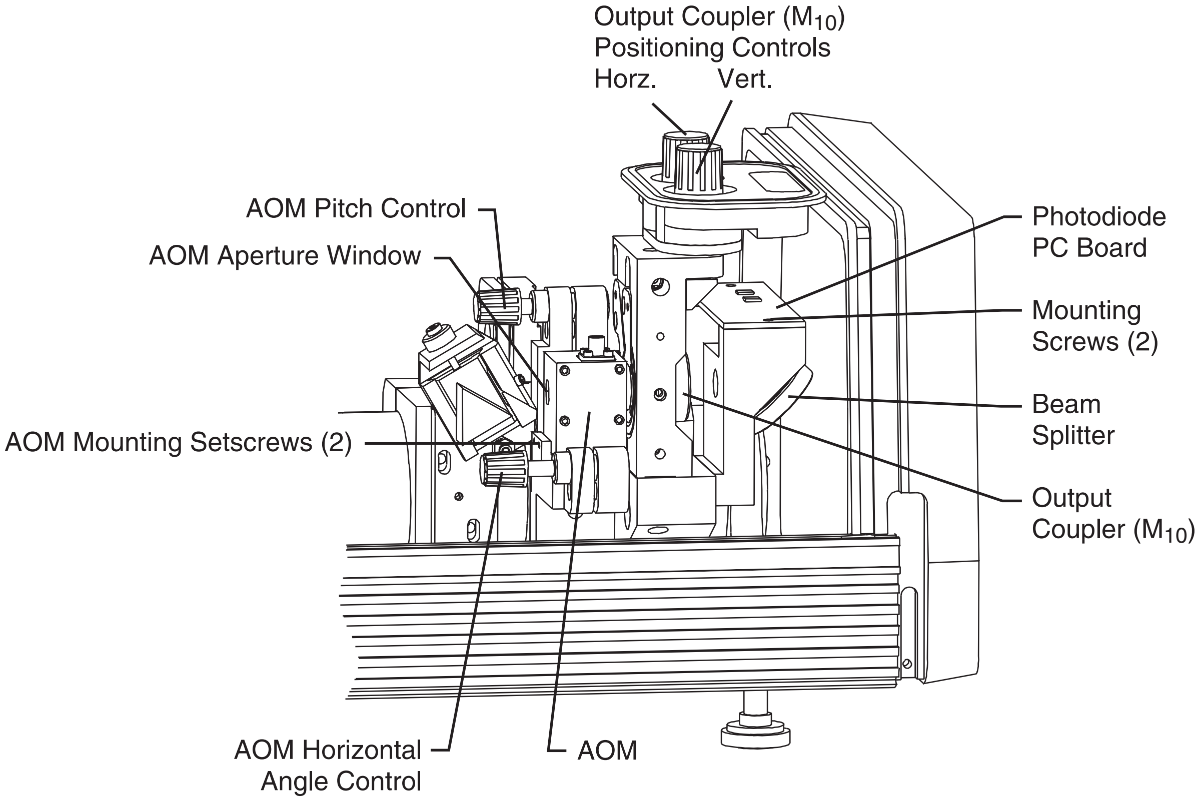


Figure 6-13: AOM, Output Coupler, Photodiode PC Board, and Beam Splitter

Place a white card between M_{10} and the beam splitter, and use the edge of the card to detect the position of the beam.

2. Use the vertical control knob of M_{10} to detune the laser until it stops lasing.
3. Verify the intracavity beam is centered in the AOM.

   Use an IR viewer to see that the M_3/M_1 fluorescence is centered through the silhouette of the AOM crystal. The fluorescence should not be near the edges of the crystal. If necessary, loosen the AOM mounting bracket to adjust it vertically and horizontally. Two 2-56 setscrews hold it horizontally while two $^9/_{64}$ in. cap screws keep it secured vertically.
4. Readjust M_{10} vertically to reestablish lasing and to optimize output.

Establish Modelocking

1. Push the STATUS mode locker enable button (the ENABLE LED should be on).
2. Set up an autocorrelator to aid in determining proper phase and GTI POSITION dispersion compensation.
   a. Increase the gain on the autocorrelator.
   b. Adjust the crystal angle on the autocorrelator to obtain an oscilloscope signal trace (Figure 6-14, a–c).

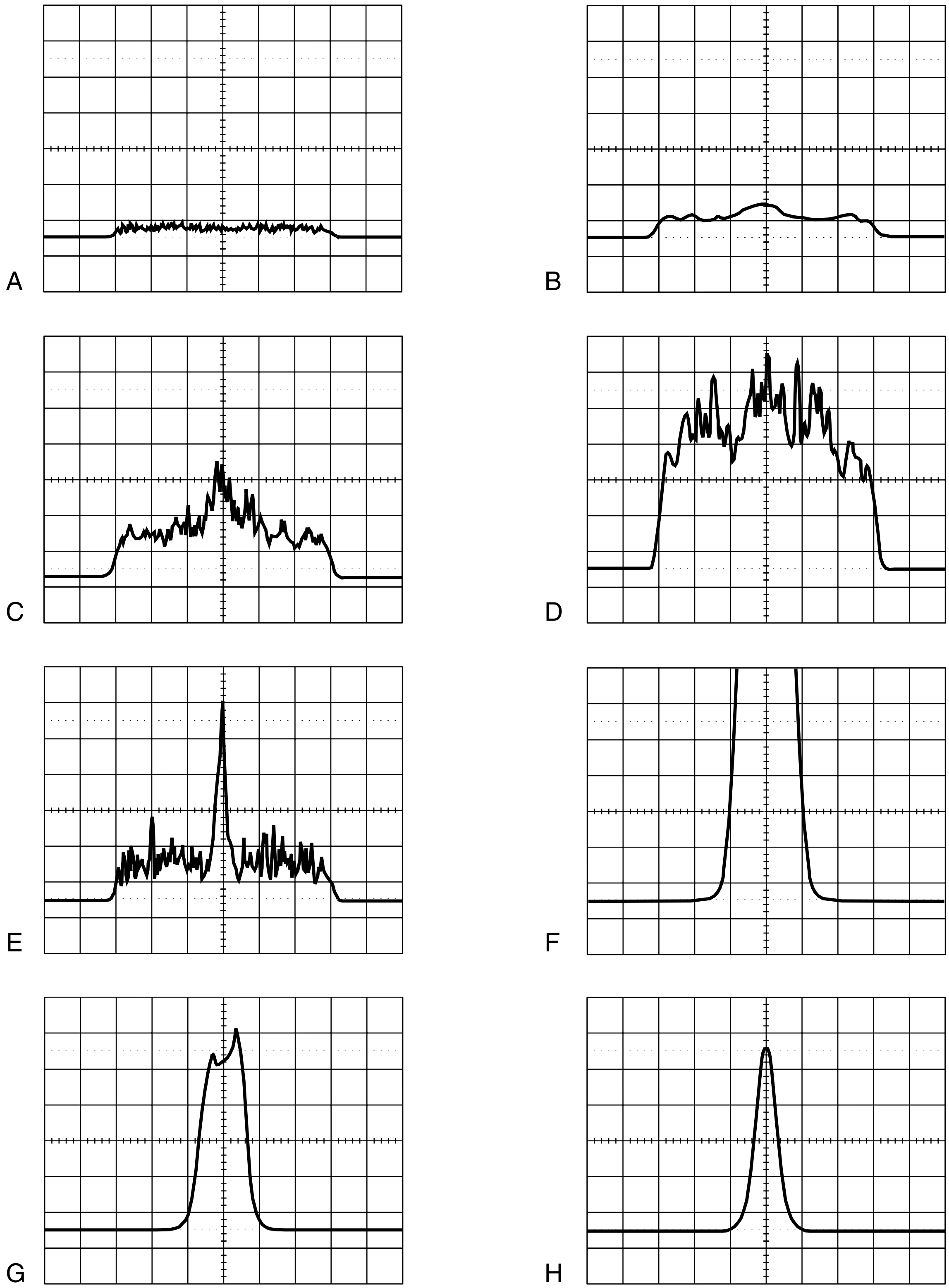


Figure 6-14: Precursor to modelocking a ps pulse as seen using an autocorrelator and oscilloscope.

3. Adjust the GTI POSITION dispersion compensation control on the *Tsunami* laser head control panel to initiate modelocking (Figure 6-14, b–f).
4. If modelocking is not evident, adjust the fine PHASE control on the *Model 3955* one full turn and repeat the last step to initiate modelocking (Figure 6-14, b–f).
5. Iterate the last two steps until modelocking occurs.

   Modelocking occurs when the oscilloscope signal on the spectrum analyzer drops in amplitude and becomes slightly broader at the base or when the autocorrelation signal appears (Figure 6-14, b–f).
6. Repeat Steps 3 through 5 until the pulse remains present. The amplitude will drastically increase and the pulse will be well defined.

   If the autocorrelator gain is too high and/or the signal is saturated (Figure 6-14g), lower the gain until a clean pulse is present and increase the oscilloscope sweep speed to broaden the pulse for viewing (Figure 6-14h).

Optimize Modelocking

1. Optimize *Tsunami* output power.

   Place a power meter in the *Tsunami* beam path and adjust M_{10} and M_1 for maximum output power as described in Step 4 under "Cavity Alignment for a PS System."

   The PHOTODIODE light bar level indicator on the *Model 3955* front panel should indicate maximum for standard wavelengths and > 30% for x-long wavelengths.
2. Since bandwidth is subject to pump power as well as dispersion compensation in the cavity, vary pump power and the GTI POSITION dispersion compensation to obtain the desired output power and pulse width.

   Too much pump power can cause CW breakthrough, which is evident when there is no increase in the autocorrelation or pulse amplitude when using a fast photodiode detector.
3. Test for proper modelocking.

   Too much bandwidth can make it difficult for the regenerative modelock loop to acquire modelocking from CW operation. In addition, operating at wavelengths at or near water and oxygen absorption lines would be either difficult or impossible without sufficient cavity purging (see Figure 3-11 for details).

   a. Temporarily disable the regenerative modelock RF loop (push the STATUS button on the *Model 3955* front panel).
   b. Close and reopen the pump laser shutter to take the system off modelocking.
   c. Adjust the fine PHASE control so that only the bottom bar of the PHASE LED bar graph glows.
   d. Enable the regenerative modelock RF loop (push the STATUS button again).

e. Adjust the fine PHASE control slowly to find the position on the PHASE LED bar graph where modelocking occurs.

f. Turn the PHASE knob to set the PHASE LED to the top bar. Repeat the last four steps to find the other LED position for initiating modelocking.

g. Adjust the fine PHASE control to center the LED position between these two limits.

h. Repeat Steps a, band d above. If the phase adjustment is correct, the system will return to modelocked status within a second.

After proper purging, the system should modelock over the entire tuning range within a second or two if the fine PHASE control is tested as described above. However, as cavity length changes as a function of wavelength (except when the cavity frequency is locked to a constant when the *Lok-to-Clock* option is used), the fine phase setting changes as well. Provided that the cavity frequency throughout the entire tuning range is within the frequency limit of the AOM, the fine PHASE LED position goes upwards as the wavelength increases for non *Lok-to-Clock* systems.

This completes the AOM alignment.

Selecting, Installing and Aligning the Birefringent Filter

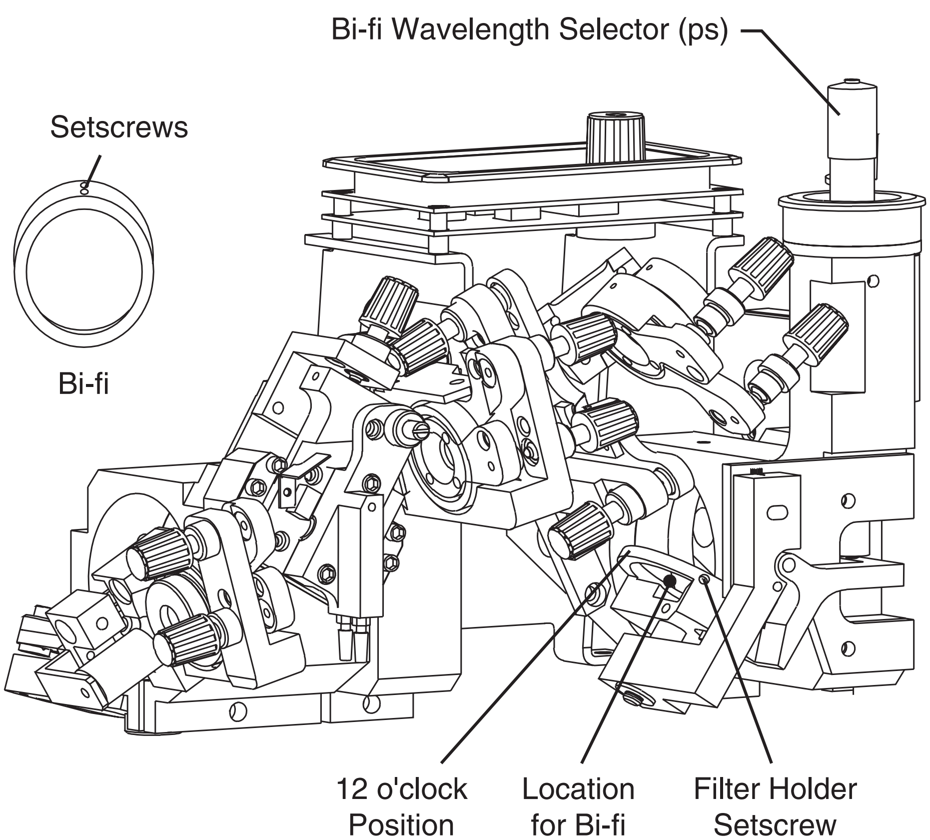


Figure 6-15: The Birefringent Filter

There are two birefringent filter (bi-fi) sets that cover the *Tsunami* ps wavelength range. The “A” plate bi-fi has a yellow dot on the filter ring, the “B” plate bi-fi has a white dot. Use the “A” plate with the blue, standard, long, or extra-long optic sets. Use the “B” plate with the midrange optic set.

Caution! The alignment of each filter stack is set at the factory and does not require adjustment. *Never try to disassemble the stack.*

After you choose an operating wavelength, select a filter from Table 6-3 and follow this procedure to install and align the filter.

Table 6-3: Bi-Fi Alignment for Picosecond Operation

Optic Set	Plate Type/ Dot Color	Setscrew Position (o’clock)	Lowest Wavelength	Highest Wavelength
Blue (B)	A/Yellow	1:00	688 nm	790 nm
Standard (S)	A/Yellow	12:00	715 nm	850 nm
Mid-range (M)	B/White	1:00	775 nm	900 nm
Long (L)	A/Yellow	1:00	835 nm	1000 nm
X-Long (X)	A/Yellow	12:00	965 nm	1080 nm
Broadband	NA/Yellow-Red	12:00	695 nm	1005 nm

A monochromator is required for this procedure.

1. Close the pump laser shutter.
2. Set the bi-fi micrometer to its maximum clockwise position.
3. Install the appropriate filter in the holder.
   a. Back out the clamping setscrew and place the filter into the holder.
   b. Rotate the filter until the pair of setscrew holes on the outer edge of its ring (Figure 6-15) is near the position listed in Table 6-3 for your wavelength. Note: the “12 o'clock” position is the highest point and is nearest to you as seen from the output bezel. The position listed is your “starting” position.
   c. Open the pump laser shutter.
   d. While watching the monochromator, rotate the filter slightly clockwise by hand until you obtain the lower wavelength listed in Table 6-3.
   e. Close the pump laser shutter.
   f. Tighten the clamping setscrew to hold the filter in place.
4. Open the pump laser shutter.
5. Recenter the beam on the M_1 GTI using the M_2 vertical and horizontal mirror controls.
6. Adjust M_1 to overlap the fluorescent spots and reestablish lasing.
7. Rotate the micrometer counterclockwise as far as needed to verify the *Tsunami* reaches the upper wavelength listed in Table 6-3.

This completes the bi-fi alignment.

Aligning the Photodiode PC Board

Prior to aligning the photodiode pc board, the laser cavity must be properly aligned (up to the AOM (fs) or bi-fi (ps) alignment). If necessary, align the cavity according to the "Front-End Alignment" and either the "Cavity Alignment for FS Systems" or "Cavity Alignment for PS Systems" section earlier in this chapter.

Figure 6-16 shows the layout of the *Tsunami* photodiode pc board. It is located directly over the beam splitter as shown in Figure 6-13. The photodiode is a small, round can soldered to the bottom of the pc board. To align the photodiode to the reference beam from the beam splitter, the pc board is adjusted slightly to center the photodiode in the beam. Looking at the pc board from the output bezel, note that the right mounting screw passes through a narrow slot to allow lateral movement while a large rectangular slot under the left mounting screw allows movement in all directions. The photodiode is called out as CR_1 and is located just to the right of the left mounting screw. To monitor the photodiode output signal level as you move the board, observe the PHOTODIODE indicator on the front of the *Model 3955* electronics module.

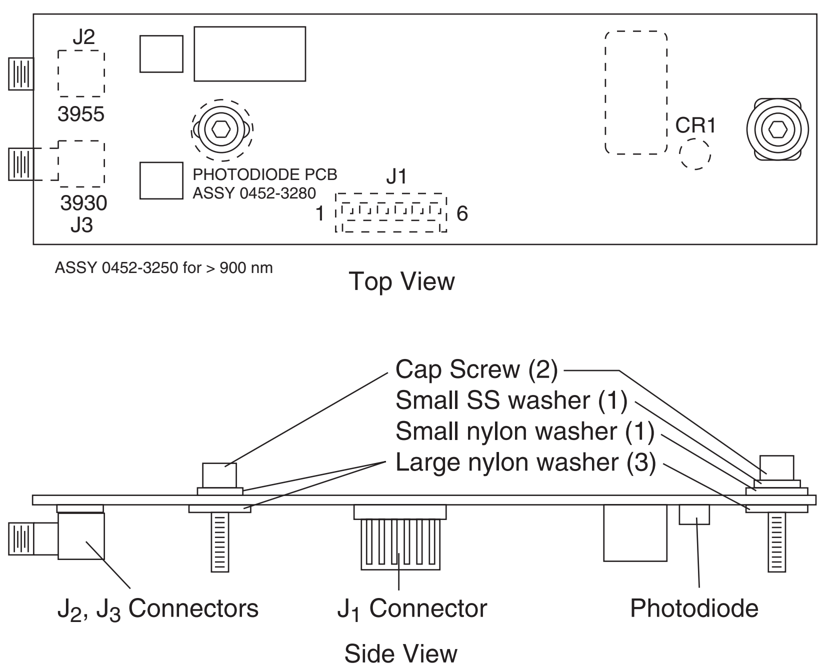


Figure 6-16: Photodiode PC board

1. Refer to Table 6-4 and verify the correct photodiode board is installed for the wavelength you are using. The assembly part number is located in the lower left corner below the photodiode (Figure 6-16). If the correct board is installed, skip to Step 3.

Table 6-4: Photodiode part Numbers

Assembly Part Number	Wavelength (λ)
0452-3280	< 900 nm
0452-3250	> 900 nm

2. Change the pc board.

Warning! ESD

Observe proper static electricity control prior to changing the pc board.

---

a. Turn off the *Model 3955* electronics module.

b. Remove the two mounting screws, then gently raise the pc board off the mount. Be careful, there are still three cables connected to it. *Do not lose the five (5) washers.*

c Remove the plug from J_1, then unscrew and remove the cables from J_2 and J_3. Note which cable goes to which connector. Set the pc board aside.

d. Install the appropriate pc board by reattaching the cables and replacing the screws. Refer to Figure 6-16 for the correct placement of cables and washers. Leave the screws loose.

e. Verify the cables to J_2 and J_3 are attached to their respective BNC connectors on the input bezel (Figure 4-1).

f. Turn on the *Model 3955* electronics module.

3. If you have not already done so, loosen the two photodiode pc board mounting screws and move the board around until a maximum signal is observed on the PHOTODIODE bar graph on the front of the *Model 3955*, then tighten the mounting screws. If the LED bar graph is saturated, reduce the pump power to bring the signal below saturation before aligning the pc board.

This completes the alignment of the photodiode pc board.

Test for Proper Modelocking

This procedure assures good cavity performance and tests whether or not an alignment of the AOM is necessary.

1. If not already on, turn on the *Model 3955* electronics module and push the STATUS mode locker enable button. The ENABLE LED will light.

   If you just turned on the *Model 3955*, allow about 20 minutes for the heaters and electronics to reach operating temperature. The two TEMPERATURE indicators on the laser control panel will turn from red to green when the heaters stabilize.

   A *flashing* red GTI TEMPERATURE indicator means either (a) the GTI is not installed or (b) there is a cable problem. *Note: a flashing indicator is normal for a fs laser because there is no GTI.*

2. Set up an autocorrelator to measure the *Tsunami* output pulse width.

   To measure pulses, use a Spectra-Physics *Model 409-08* autocorrelator (or equivalent). Avoid saturating the autocorrelator. Subtle adjustments to the phase-matching angle of the nonlinear crystal will be required to obtain an optimum autocorrelation signal. Refer to the autocorrelator manual for setup and operation instructions.

3. Open the pump and *Tsunami* shutters and adjust the pump laser until your *Tsunami* achieves the output power specified in the appropriate table at the end of Chapter 3.

4. Test for proper modelocking.

   Too much bandwidth can make it difficult for the regenerative mode-lock loop to acquire modelocking from CW operation. In addition, operating at wavelengths at or near water and oxygen absorption lines would be either difficult or impossible without sufficient cavity purging (see Figure 3-11).

   a. Temporarily disable the regenerative modelock RF loop (push the STATUS button on the *Model 3955* front panel).

   b. Close and reopen the pump laser shutter to take the system off modelocking.

   c. Adjust the fine PHASE control so that only the bottom bar of the PHASE LED bar graph glows.

   d. Enable the regenerative modelock RF loop (push the STATUS button again).

   e. Adjust the fine PHASE control slowly to find the position on the PHASE LED bar graph where modelocking occurs.

   f. Turn the PHASE knob to set the PHASE LED to the top bar. Repeat the last four steps to find the other LED position for initiating modelocking.

   g. Adjust the fine PHASE control to center the LED position between these two limits.

   h. Repeat Steps a, band d above. If the phase adjustment is correct, the system will return to modelocked status within a second.

   After proper purging, the system should modelock over the entire tuning range within a second or two if the fine PHASE control is tested as described above. However, as cavity length changes as a function of wavelength (except when the cavity frequency is locked to a constant when the *Lok-to-Clock* option is used), the fine phase setting changes as well. Provided that the cavity frequency throughout the entire tuning range is within the frequency limit of the AOM, the fine PHASE LED position goes upwards as the wavelength increases for non *Lok-to-Clock* systems.

Converting Between Non-overlapping Optics Sets

The following procedure contains instructions for changing non-overlapping optics sets. An IR viewer is required for this procedure.

Read the entire section before you begin conversion.

Danger! Laser Radiation

This procedure requires you to replace optics while using the laser at high power. For safety, close the pump laser shutter every time you change an optic, and only open it during alignment. Protect yourself with appropriate eyewear at all times.

During this procedure, with the exception of P_1 and P_2, which are the same for either configuration, replace and align each optic one at a time, starting with M_1. Refer to Figure 6-17 or Figure 6-18 as you proceed. When you replace the first optic with one from a different set, the laser will no longer lase. Therefore, the system is aligned by referencing fluorescent spots, not the laser beam. The spots will appear on each optic and on a card placed in front of the output window.

All mirrors are registered on 3-point mirror seats for repeatability. The exceptions are M_3, where the overlap of M_3 and M_1 might change due to the change in optics and/or different rotation orientations, and M_6 and M_9, where the wedge of the optic can change the plane of the reflected coating.

Note the part number printed on the barrel of the optic to verify the correct optic is being installed. Optic descriptions and their part numbers are found in the tables in Chapter 10, “Options and Accessories.”

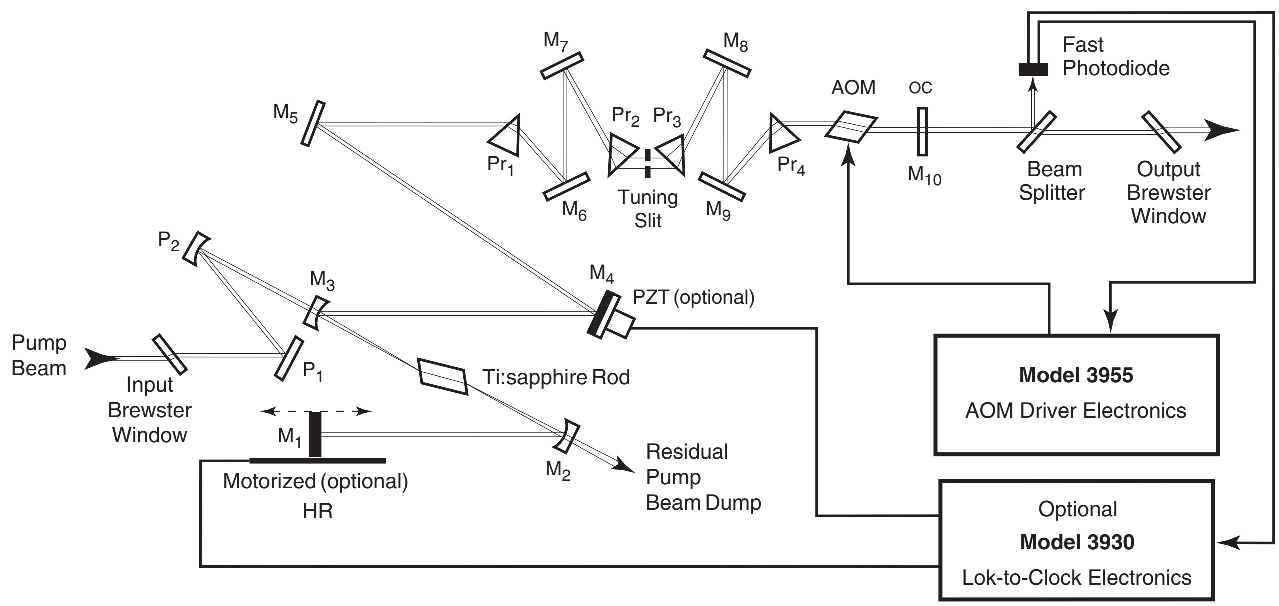


Figure 6-17: ***Tsunami*** **fs Configuration.**

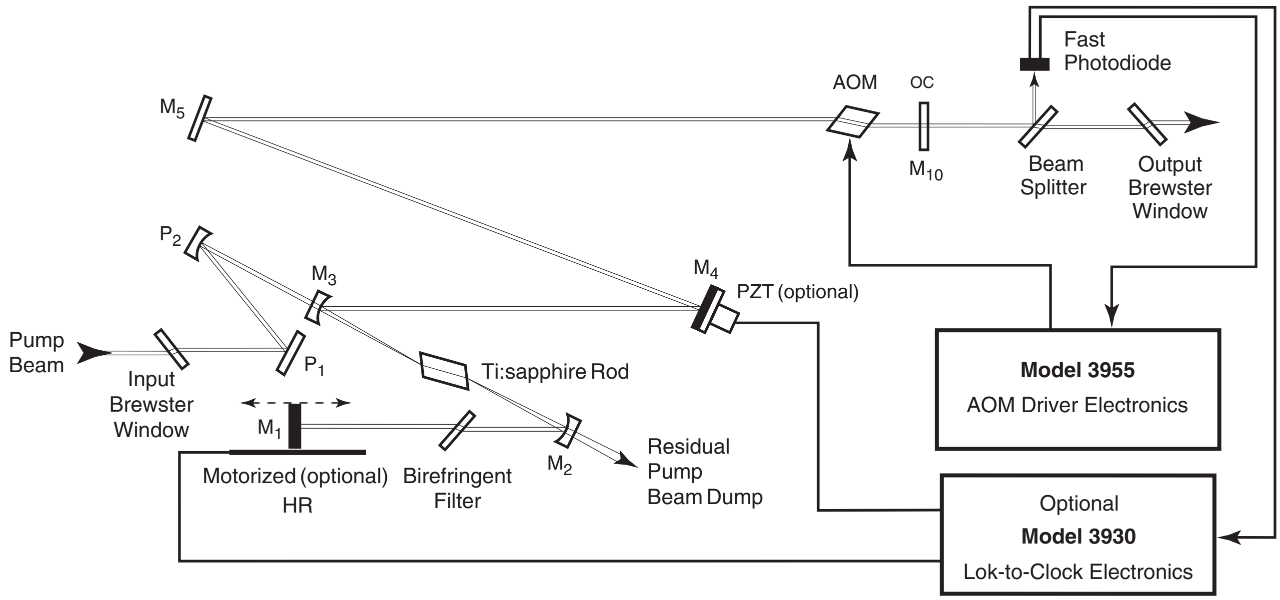


Figure 6-18: *Tsunami* ps Configuration.

Unless you are certain the new optics are clean, clean each one as it is placed in the laser. Refer to Chapter 9, "Maintenance," for cleaning procedures.

Caution!

Always use clean finger cots or powderless gloves when handling optics.

To observe the intracavity fluorescence throughout the following procedure, place a white card about 10 cm outside the laser output port.

After each optic is replaced and adjusted, verify the fluorescent cross created in Step 9 below is still evident on the white card. It is important the steps below be followed in sequence and that each is completed before starting the next step. The laser will not lase until every optic is replaced with optics from a single set. If you cannot get the system to lase and you feel the cavity is misaligned, install the standard optics set (which is easier to get lasing) and refer to the cavity alignment procedures earlier in this chapter to check the alignment of the system. Once the system lases, repeat this procedure.

Caution!

Verify the *Tsunami* meets specified power for the installed optic set before changing optic sets. Refer to Chapter 7, "Operation: System Start-up," and to the specifications listed in the tables at the end of Chapter 3.

1. Turn off the AOM by pressing the STATUS mode locker enable button on the *Model 3955*.
2. Verify the beam is centered on M_1, M_4, M_5 and M_{10}.

Go to Step 3 if your laser is configured for fs operation, otherwise skip to Step 6.

3. Carefully remove the slit assembly (if present).
   a. Close the shutter.
   b. Support the slit assembly with your hand and loosen the setscrew that holds it onto the spindle of the micrometer (Figure 6-8), then slide the assembly down and off the micrometer shaft.

Warning! Be sure to support the slit assembly as you loosen its clamping setscrew to prevent it from falling off and damaging the optics below.

   c. Open the shutter.
   d. Using the prism dispersion compensation control, adjust the prism Pr_2/Pr_3 assembly so the beam is at least 5 mm from the apex.
4. Replace the high reflector at M_1.

   Unscrew the high reflector holder, replace the high reflector in the holder with the appropriate optic for the chosen wavelength, and screw the holder back in.
5. Set the position of Pr_1 and Pr_4 (Figure 6-9) to maintain the position of the fluorescent spots outside the cavity.

   The fluorescence from the beam might pass over the apex of Pr_1 and Pr_4, missing them, and pass through the AOM and out the laser. To ensure the alignment is performed correctly, temporarily move the prisms a bit further into the beam to ensure the fluorescence passes through them. Refer to Table 6-6 and Figure 6-22.
   a. Loosen the setscrew that locks prism Pr_1 in place, and move the prism up by turning its prism translation adjust screw 3 to 4 turns (Figure 6-19). Small holes in the beam shields provide access to the drive screws. Tighten the setscrew.
   b. Repeat Step a for prism Pr_4.
   c. Skip to Step 8.
6. Temporarily remove the bi-fi filter and set it aside.

7 Replace the GTI at M_1 with the new GTI.

Danger! The pc board on the floor of the laser head contains high voltage. Turn off the *Model 3955* electronics module to disable this board when changing the GTI.

   a. Turn off the *Model 3955* electronics module.
   b. Remove the plastic cover from the laser head pc board (3 screws) and disconnect the gray GTI heater cable from connector J_2 (Figure 6-20).
   c. Disconnect the black coaxial control cable from the GTI by pulling it straight off.

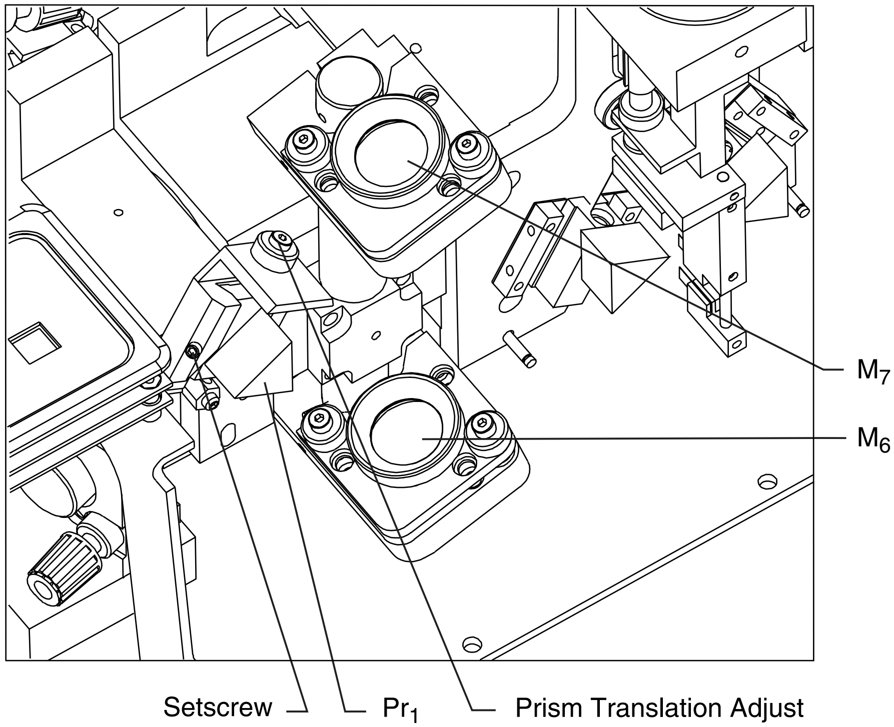


Figure 6-19: Pr_1 Prism Translation Adjust and Setscrew

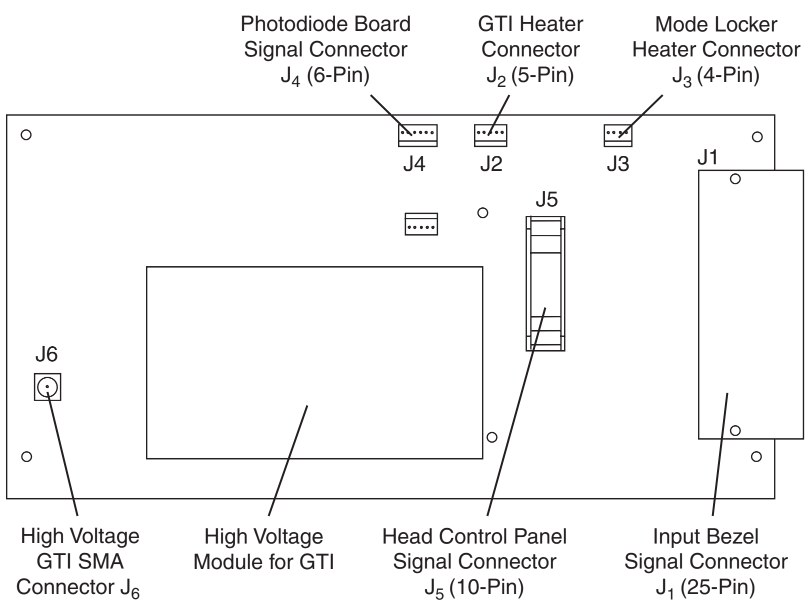


Figure 6-20: *Tsunami* Laser Head PC Board Connections

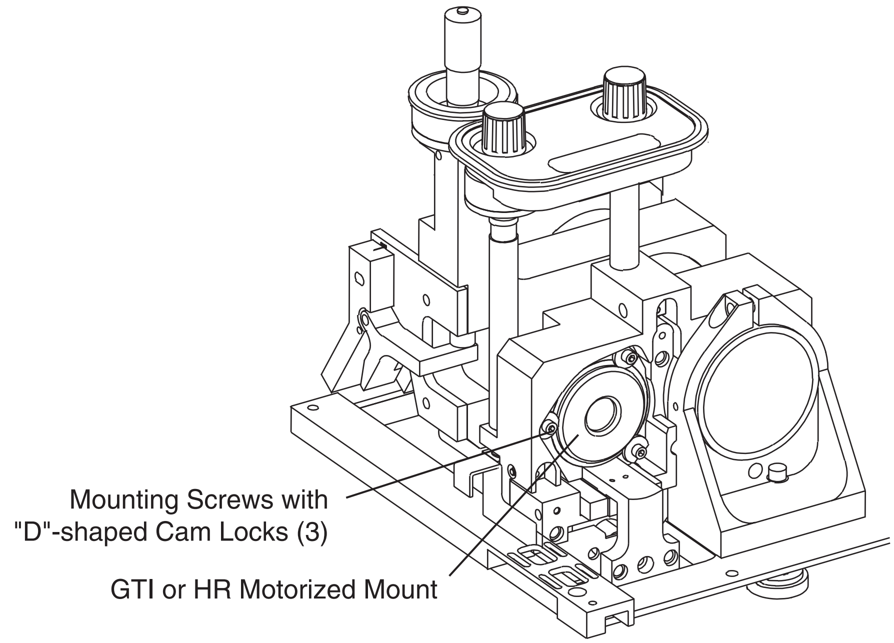


Figure 6-21: The Gires-Tournois Interferometer (GTI). The input bezel and side rail are removed for clarity and the motorized mount shown is available only on *Lok-to-Clock* systems.

d. Loosen the three screws holding the GTI to the rear mirror plate, and turn the 3 D-shaped cam locks so the flat portion of the cam disengages the GTI mounting ring (Figure 6-21).

e. Slide the GTI out of the mirror plate and remove it from the laser head, pulling the gray heater cable through the mounting hole. Take care not to snag it on anything. Store the GTI in its box.

f. Slide the appropriate GTI for the chosen wavelength into the mirror plate, pulling the gray heater cable through first. Then rotate the GTI so the gold connector is accessible for attaching the black coaxial control cable to it.

g. Rotate the 3 cam locks so they capture the GTI mounting ring, and tighten the screws.

h. Connect the black coaxial control cable to the gold connector on the GTI, and push it in until it snaps.

i. Route the GTI heater cable along the side of the resonator, from the GTI to the laser head pc board, then plug it into connector J_2 on the pc board.

j. Turn on the *Model 3955* electronics module. It will take about 20 minutes for the GTI heater to warm up, but you can continue with this procedure.

8. Place a white card in front of M_5.
9. Adjust M_1 vertically and horizontally to overlap the two fluorescent images from M_1 and M_3 that are displayed on the card and create a cross-shaped image.

10. Replace M_2.
    a. Unscrew the M_2 holder and replace the optic in the holder with the appropriate one for the chosen wavelength. Screw the holder back in.
    b. Adjust M_2 vertically and horizontally until the fluorescent images are again overlapped on M_5.
    c. Verify the cross image is also visible on the card outside the output window.
11. Replace M_3.

    Adjust P_2 vertically and horizontally until the fluorescent images are once again overlapped on M_5. Slight adjustments to M_3 might be required to direct the fluorescence from M_1 and M_3 back to the card outside the output window.
12. For fs systems, replace M_4 through M_9 with the new optics; for ps systems, replace M_4 and M_5.

    Change optics in sequence, one at a time, adjusting each to obtain the cross image on the white card outside the output window before moving on to the next optic.
13. Replace M_{10}.
    a. Reach in from both sides of the M_{10} mount and unscrew the knurled mirror holder (Figure 6-13).
    b. Replace the optic in the holder with the new one and screw the holder back in.
14. Align M_{10}.
    a. Place a white card with a 2.5 mm diameter hole in it between M_4 and M_5 so the hole is centered on the reflected fluorescent image from M_4.
    b. Direct the reflected image from M_{10} back through the hole in the card and overlap it with the image from M_4. When you remove the card, lasing should begin.

       To determine which reflected image comes from M_{10}, watch the output side of the card and slightly adjust M_{10} until one image moves.
    c. Remove the card.
15. Replace the card in front of the output window with a power meter.
16. On ps systems, reinstall and align the bi-fi according to the section “Selecting, Installing and Aligning the birefringent Filter” earlier in this chapter. When the bi-fi is installed, you are done.

Changing the Prism Setting (fs Systems Only)

If you have a *Model 3950* ps-only laser without prism mounts, skip to Step 6.

Due to the difference in the index of refraction for the different wavelengths, the intracavity beam will be either too high or too low on prisms Pr_2 and Pr_3 when you change wavelength ranges and it is necessary to adjust the vertical controls for mirrors M_6, M_7, M_8 and M_9 to reposition the beam properly on the prisms. Lasing should resume when the last vertical adjustment is made.

Once the beam is properly positioned on the prisms, the prisms themselves must be adjusted to provide the right amount of GVD compensation for the wavelength range selected. It is the amount of prism glass exposed to the laser beam that determines the amount of GVD compensation added to the system. In general, the blue range requires the most prism glass to minimize the pulse width. Thus, when converting from blue or standard to long or x-long, or vice versa, Pr_1 and Pr_4 must be adjusted according to Table 6-6 and Figure 6-22 to provide the proper amount of glass in the cavity beam.

1. Adjust the vertical controls on M_6 through M_9 (top screw) according to Table 6-5 to reestablish the correct beam position on prisms Pr_2 and Pr_3.

   The prism type can be identified by the apex angle written on it:

   SF-10: 60° 40’
   LaFN28: 59° 12’

Table 6-5: Vertical Mirror Adjustment (Turns) for Changing Wavelengths

From \ To	Blue		Std./Mid.		Long		X-Long		Broadband	
	SF-10	**LaFN28**	**SF-10**	**LaFN28**	**SF-10**	**LaFN28**	**SF-10**	**LaFN28**	**SF-10**	**LaFN28**
Blue	NA	NA	1½ ccw	NA	3 ccw	NA	3 ccw	1 ccw	NA	NA
Std./Mid.	1½ cw	NA	NA	NA	1½ ccw	NA	1½ ccw	1 ccw	NA	NA
Long	3 cw	NA	1½ cw	NA	NA	NA	NA	1 ccw	NA	NA
X-Long	3 cw	1 cw	1½ cw	1 cw	NA	1 cw	NA	NA	1½ cw	1 cw
Broadband	NA	NA	NA	NA	NA	NA	1½ ccw	1 ccw	NA	NA

2. Adjust prisms Pr_1 and Pr_4 according to Table 6-6 and Figure 6-22 for proper GVD compensation. Small holes in the beam shields provide access to the drive screws.

Table 6-6: Nominal Distance from Beam to Apex (see Figure 6-22)

Wavelength Range	Pr1/Pr4 Center of beam to apex (x) with beam centered on M_5 and M_{10}	
	SF-10	LaFN28
Blue	4–5 mm	3–4 mm
Std/Mid/Long/Broadband	3–4 mm	2–3 mm
X-Long[1]	< 1 mm (as close as possible without clipping	

[1] *For X-Long, ensure the beam is not clipped by prism edges of Pr_1 and Pr_4.*

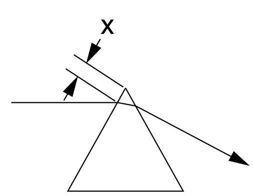


Figure 6-22: Pr_1/Pr_4 prisms showing placement of beam. Refer to Table 6-6 for the value of *x*.

3. Adjust M_1 then M_{10} for maximum output power. Refer to Chapter 7, "Operation: Optimizing Laser Output."
4. Install the tuning slit assembly.
   a. Close the shutter.

Warning! To avoid damaging nearby optics when installing the slit, carefully move it into place and use your hand to support it while you tighten the mounting setscrew.

---

   b. Place the tuning slit assembly into the laser head and onto the micrometer shaft. Refer to Figure 6-8.
   c. Rotate the slit width adjustment screw until the dowel pin on the mating shaft can slide into the slot.
   d. Seat the slit assembly against the micrometer stop.
   e. Tighten the screw that holds the slit assembly on the shaft.
   f. Open the shutter.
   g. Verify the slit opening is in the beam path.
   h. Adjust M_1 and M_{10} for maximum output power.
5. Tune the slit for the desired wavelength.

   Refer to Chapter 7, "Operation: Selecting Wavelength, fs Configuration."
6. When changing from < 900 to > 900 nm, or vice versa, change the photodiode pc board accordingly. (*Do not change the pc board with the broadband optics set.*) Refer to "Aligning the Photodiode PC Board" earlier in this chapter. Refer to Table 10-1 and Table 10-2 in Chapter 10 for the pc board type required.
7. Re-enable the AOM by pressing the STATUS mode locker enable button.
8. Modelock the *Tsunami* laser.

   Refer to Chapter 7, "Operation: Modelocking the Laser."
9. Adjust M_1 and M_{10} for maximum output power.

   Verify pump laser power is at the optimum setting. Refer to Table 6-1 on page 6-4.

Converting Between Overlapping Optics Sets

The following procedure is applicable only when converting from ps to ps or from fs to fs-only.

With the exception of pump mirror P_1 and the GTI (ps configuration only), all mirrors are captured and held in place by a screw-in holder. Unscrew the holder and the mirror will come out with it. The optic is retained by a small o-ring and is removed by simply grabbing the exposed barrel of the optic and pulling it straight out of the holder.

Each optic has a v-shaped arrow on its barrel along with its part number. The arrow points to the coated surface that faces the intracavity beam. If you need to verify the location of the optic in the laser, refer to the tables located at the end of Chapter 10, "Options and Accessories."

Danger!
Laser Radiation

This procedure requires you to replace optics while using the laser at high power. For safety, close the pump laser shutter every time you change an optic, and only open it during alignment. Protect yourself with appropriate eyewear at all times.

Unless you are certain the new optics are clean, clean each one as it is placed in the laser. Refer to Chapter 9, "Maintenance," for information on cleaning optics.

Caution!

Always use clean finger cots or powderless gloves when handling optics.

Warning!

Verify the *Tsunami* meets specified power for the installed optic set before changing optic sets. Refer to Chapter 7, "Operation: System Start-up," and to the specifications listed in the tables at the end of Chapter 3.

To change between overlapping wavelength ranges, follow the same procedure outlined under "Converting Between Non-overlapping Optics Sets" above. However, note the following:

1. Before making the conversion, tune the laser to a region overlapped by the two optic sets, and optimize laser output. Refer to the tuning curves in Chapter 3.
2. During each adjustment following the installation of an optic, instead of only verifying that the cross-shaped fluorescent image is visible on the white card, adjust the optic to get the system lasing. Once lasing, adjust only that optic for optimum output at that wavelength. Do this for all optics except mirror M_3. Mirror M_3 is changed last.
3. When M_3 is replaced, place a white card in front of M_5, and adjust P_2 to overlap the two fluorescent ovals so they form a cross-shaped image.
4. Remove the white card and adjust P_2 until the system lases and output power is optimized.

5. Adjust M_3 to center the beam on the OC.
6. Iterate adjustments of the end mirrors to optimize output power while adjusting M_3 to keep the beam centered on the OC.
7. Verify the laser beam is centered on mirrors M_1 to M_5, as well as M_{10}. Adjust the photodiode pc board if required (refer to the earlier section on pc board alignment in this chapter).

Converting Between fs and ps Configurations

The following procedure assumes you are converting between fs and ps configurations using either the same optics set or a set that overlaps the wavelengths of the current set.

Danger! Laser Radiation

This procedure requires you to replace optics while using the laser at high power. For safety, close the pump laser shutter every time you change an optic, and only open it during alignment. Protect yourself with appropriate eyewear at all times.

If changing optics sets, unless you are certain the optics are clean, clean each one as it is placed into the laser. Refer to Chapter 9, "Maintenance," for information on cleaning optics.

Caution!

Always use clean finger cots or powderless gloves when handling optics.

Caution!

Verify the *Tsunami* meets specified power for the installed optic set before changing optic sets. Refer to Chapter 7, "Operation: System Start-up," and to the specifications listed in the tables at the end of Chapter 3.

The *Tsunami* laser comes in several configurations. Please refer to "System Configurations" in Chapter 1. Some of these systems can be converted, most cannot without being upgraded at a Spectra-Physics service facility. Check with your service representative before attempting to convert your system.

Requirements for Conversion

Tsunami ps and fs lasers are inherently different, and various mounts, components, and optics must be changed when converting them from ps to fs operation, or vice versa. These two systems differ in three ways:

- the transmission of the output coupler.
- the method of wavelength selection: a birefringent filter (bi-fi) for ps versions and a slit for fs versions.
- the method of dispersion compensation: a Gires-Tournois interferometer (GTI) for ps versions and a prism sequence for fs versions.

To convert the *Tsunami* from fs to ps operation requires the following:

- Changing output coupler M_{10}.
- Removing the tuning slit and adding the appropriate bi-fi into the cavity.
- Moving Pr_1 and Pr_4 out of the beam path.
- Replacing the high reflector at M_1 with the GTI.

To convert from ps to fs operation, simply reverse this procedure.

Fs to ps Conversion

Note

When changing between fs and ps measurements, the scan range of the Spectra-Physics *Model 409-08* autocorrelator must be modified in order to accommodate for the large change in pulse width. Consult your autocorrelator manual for this procedure.

The following procedure assumes you are using the same set of optics (same wavelength set) or an overlapping wavelength optics set.

Verify the *Tsunami* laser is lasing prior to beginning this procedure, and maximize its output power.

1. Close the pump laser shutter.
2. For electrical safety, turn off the *Model 3955* electronics module.
3. Remove the high reflector assembly.
   a. Loosen the three screws holding the high reflector mounting ring in the rear mirror plate, and turn the three D-shaped cam locks so the flat portion of the cam disengages the mounting ring. The high reflector assembly is removed in a manner similar to that for the GTI shown in Figure 6-21.
   b. Pull the high reflector assembly with its mounting ring from the rear mirror plate and store it in a safe place.
4. Install the GTI into the M_1 position (Figure 6-21).

   Refer to Chapter 5, “Installation: Installing the GTI.”
5. Turn on the *Model 3955* and allow about 20 minutes for the GTI and AOM to warm up.

   You may continue with the installation while waiting for the optics to warm up and stabilize.
6. Open the shutter, and reestablish lasing.
   a. Place a white card in front of mirror M_5.
   b. Using an IR viewer, adjust M_1 vertically and horizontally to overlap the reflected horizontal oval fluorescent image onto the vertical oval from M_3 as seen on the white card. A cross-shaped image results (Figure 6-6).
   c. Remove the card: lasing should begin.
7. Adjust the laser for maximum output power.

8. Close the shutter and remove the tuning slit.

Warning! Support the slit assembly with your hand when loosening the setscrew to prevent it from falling off and damaging the optics below.

Loosen the screw holding the slit assembly to the spindle of the micrometer (Figure 6-8), and slide the slit down and off the micrometer shaft.

9. Move Pr_1 and Pr_4 out of the beam path.
   a. Loosen the setscrew on each prism dovetail mount (Figure 6-19).
   b. Using a hex ball driver, adjust the screw on each mount exactly 10 turns clockwise to drive the prisms out of the beam path.

      Be exact in your turns because the prism has to be returned to its original position when you convert the laser back to fs operation.

      Small holes in the beam shields provide access to the drive screws.
   c. Tighten the setscrews, but do not over-tighten.
10. Install the bi-fi.

    Refer to “Selecting, Installing, and Aligning the Birefringent Filter” earlier in this chapter for information on installing the bi-fi.
    a. Once installed, open the pump laser shutter.
    b. If lasing is not reestablished, perform Step 6.
    c. Adjust M_2 to recenter the beam on the GTI.
    d. Place a white card in front of M_5 and overlap the two fluorescent images of M_1 and M_3 on the card (the image again becomes cross-shaped).
    e. Remove the card.

Caution! During the next two steps, do not disturb the M_4 and M_5 mirror mounts themselves. Their positions were preset at the factory.

---

11. Remove the M_4 mirror *holder* from its fs mounting position and install it into the ps mounting position near the output end of the laser head (see Figure 6-7).
12. In like manner, remove the M_5 mirror *holder* from its fs mounting position and install it into the ps mounting position near the input end of the laser head (Figure 6-7).

    Note: these last two steps are required to reestablish correct cavity length now that the prisms are out of the beam path.
13. Verify the fluorescence from M_4 is centered on M_5.

    If not correctly positioned, adjust M_4 vertically and horizontally until it is correctly positioned. If you adjust M_4, readjust M_5 to recenter the beam from M_5 on the AOM.

14. Place a white card outside the output window, and adjust M_5 to direct the images onto the card. Use an IR viewer to see the fluorescent images.

    You should see a cross-shaped figure centered in a circular background fluorescence. The fluorescence is created by the scattered light through the AOM and output coupler.

15. Remove M_{10} and replace it with the M_{10} for ps operation.
16. Open the shutter.
17. Align M_{10}.
    a. Place a white card with a 2.5 mm diameter hole in it between M_4 and M_5 so that the hole is centered on the reflected fluorescent image from M_4.
    b. Adjust M_{10} vertically and horizontally to direct the reflected image from M_{10} back through the hole in the card and overlap it with the image coming from M_4.

       To determine which reflected image comes from M_{10}, watch the M_5 side of the card and slightly adjust M_{10} until one image moves.
    c. Remove the card; lasing should begin.
    d. Adjust M_1 and M_{10} to optimize *Tsunami* output power.
18. Verify the beam is centered on M_{10}. If necessary, adjust M_3 to recenter it.
19. Optimize laser output.

    Refer to Chapter 7, "Operation: Optimizing Laser Output."
20. Adjust the photodiode pc board if required.

    Because M_{10} is wedge-shaped, the photodiode pc board might require adjustment in order to maximize the photodiode signal (as seen on the *Model 3955* photodiode indicator). Refer to "Aligning the Photodiode PC Board" earlier in this chapter.
21. Modelock the *Tsunami*.

    Refer to Chapter 7, "Operation: Mode-locking the Laser."

This completes the fs to ps conversion.

Ps to fs Conversion

The following procedure assumes you are using the same set of optics (same wavelength set) or an overlapping wavelength optics set.

Verify the *Tsunami* is lasing prior to beginning this procedure.

1. Close the pump beam shutter and, for electrical safety, turn off the *Model 3955* electronics module.

Danger!

The pc board on the floor of the laser head contains high voltage. Turning off the *Model 3955* electronics module disables this board while you remove the GTI.

2. Remove the plastic cover from the laser head pc board (3 screws).
3. Disconnect the GTI cables.
   a. Disconnect the gray GTI heater cable at connector J_2 on the laser head pc board (see Figure 6-20).
   b. Disconnect the black coaxial cable from the GTI (pull it straight off), then disconnect it from the J_6 connector on the pc board (unscrew it).

      The black cable can be left in the bottom of the laser head for storage, but it *must* be disconnected from the pc board because it is a high voltage connection.
4. Remove the GTI module.
   a. Loosen the three screws holding the GTI to the rear mirror plate, and turn the three D-shaped cam locks so the flat portion of the cam disengages the GTI mounting ring (Figure 6-21).
   b. Slide the GTI from the mirror plate and pull the gray heater cable through the mount hole, taking care not to snag it on anything. Store it in its box.
5. Install the high reflector (HR).
   a. Verify the correct optic is installed in the mounting ring.

      Note the part number printed on the optic barrel. The description and part number of the correct optic is found in the tables at the end of Chapter 10, "Options and Accessories." The v-shaped arrow on the barrel points to the coated, intracavity surface.
   b. Slide the HR mounting ring into the rear mirror plate, turn the three cam locks so the round portion of the cam captures the ring, and tighten the screws.
6. Open the shutter and reestablish lasing.
   a. Place a white card in front of mirror M_5.
   b. Adjust M_1 vertically and horizontally to overlap the horizontal oval fluorescent image from M_1 over the vertical image from M_3 on the card to form a cross-shaped image (Figure 6-6).
   c. Remove the card; lasing should begin.

Caution!

During the next two steps, do not disturb the M_4 and M_5 mirror mounts themselves. Their positions were preset at the factory.

7. Remove the M_4 mirror *holder* from its ps mounting position and install it into the fs mounting position near the input end of the laser head (see Figure 6-7).
8. In like manner, remove the M_5 mirror holder from its ps mounting position and install it into the fs mounting position near the output end of the laser head (Figure 6-7).

Note: these last two steps are required to reestablish correct cavity length because the prisms are being added to the beam path.

9. Verify the fluorescence from M_4 is centered on M_5.

   If not centered, adjust M_4 vertically and horizontally until it is centered.

10. Move Pr_1 and Pr_4 into the beam path.
    a. Loosen the dovetail setscrew on each prism dovetail mount (see Figure 6-22).
    b. Physically push the prism all the way down to the bottom of its travel.
    c. Tighten the setscrews, but do not over-tighten.
11. Place a white card about 10 cm outside the output window and use an IR viewer to see the fluorescent image.
12. Adjust M_5 to direct the fluorescence through the prism sequence and out the laser.
13. Align M_{10}.
    a. Place a white card with a 2.5 mm diameter hole in it between M_4 and M_5 so that the hole is centered on the reflected fluorescent image from M_4.
    b. Adjust M_{10} vertically and horizontally to direct the reflected image from M_{10} back through the hole in the card, and overlap it with the image coming from M_4.

       To determine which reflected image comes from M_{10}, watch the M_5 side of the card and slightly adjust M_{10} until one image moves.
    c. Remove the card; lasing should begin.
    d. Adjust M_1 and M_{10} to optimize *Tsunami* output power.
14. Close the shutter and remove the bi-fi.
    a. Turn the bi-fi micrometer fully clockwise.
    b. Loosen the setscrew on the bi-fi mount holding the filter (Figure 6-15), and carefully lift the filter out. Store the filter in its case.
15. Remove M_{10} and replace it with the appropriate optic for fs operation. Refer to the optics tables in Chapter 10.
16. Open the shutter.
17. Repeat Step 13, then adjust M_3 to center the beam on M_{10}.
18. Turn on the *Model 3955* electronics module and let it warm up for 20 minutes.
19. Adjust the photodiode pc board if required.

    Because M_{10} is wedge-shaped, the photodiode pc board might require adjustment in order to maximize the photodiode signal (as seen on the *Model 3955* photodiode indicator). Refer to "Aligning the Photodiode PC Board" earlier in this chapter.
20. Install the tuning slit assembly.

Warning!

To avoid damaging nearby optics when installing the slit, carefully move it into place and use your hand to support it while you tighten the mounting screw.

a. Close the shutter.
b. Place the tuning slit assembly into the laser head and onto the micrometer shaft. Refer to Figure 6-8.
c. Rotate the slit width adjustment screw until the dowel pin on the mating shaft can slide into the slot.
d. Seat the slit assembly against the micrometer stop.
e. Tighten the screw.

21. Open the shutter and tune the laser to the desired wavelength.

    Refer to Chapter 7, "Operation: Selecting Wavelength, fs Configuration."

22. Modelock the *Tsunami*.

    Refer to Chapter 7, "Operation: Modelocking the Laser."

This completes the ps to fs conversion.

Coarse Phase Adjustment and Changing the RF and Photodiode Cables

Caution!

It is critical to system performance that you use the RF and photodiode cables provided with the *Model 3955*. The system was calibrated for the type and length of these cables. If RF and/or photodiode cables other than those shipped with the *Tsunami* laser are used, follow the procedure below to adjust for the difference in cables.

If the cables used to connect the photodiode and RF signals are other than those shipped with the unit, a coarse phase adjustment might be required to compensate for any change in cable length.

Before this adjustment can be made, the *Tsunami* must be lasing and a photodiode and/or autocorrelator and oscilloscope must be set up to detect pulses. Refer to your autocorrelator instruction manual for directions on its setup and use.

When the *Tsunami* laser is oscillating at about 80 MHz, an output pulse is produced every 12.5 ns. The fine PHASE control on the front panel provides a 100 ps delay to provide proper mode locker adjustment in most cases. However, by changing cables, the loop delay is changed and can easily be outside the limits of this control. The coarse control inside the *Model 3955* provides about 14 ns delay and can be adjusted so the fine PHASE control is once again effective.

1. Use a photodiode or autocorrelator to see if the *Tsunami* is creating short output pulses.

   Look for a short output pulse (80 fs or 2 ps, depending on laser configuration) when the mode locker is enabled (the ENABLE lamp is illuminated on the STATUS panel of the *Model 3955* electronics).

   If short pulses are present, the laser is aligned and properly mode-locked, and you are done. If the pulses are broader than specified for your configuration, proceed.

2. Remove the cover (4 screws) from the *Model 3955* electronics module.

Danger!

Removing the cover exposes you to high voltage and current circuits. Do not attempt repairs or alterations other than for those expressly outlined in these instructions. Otherwise, you may be harmed or the unit damaged. Such damage is not covered by your warranty.

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3. Set the fine PHASE control to its center of rotation (the center bar of the PHASE indicator will be lit).
4. Locate the large, white, coarse control knob on the pc board and note its current setting in case you wish to return to it later.
5. Turn the coarse control knob until an autocorrelation signal appears on the oscilloscope, then adjust for maximum signal.

   This action matches the phase of the mode locker electronics to the actual pulse.

6. Tune the modulator for short pulses.

   Refer to “Aligning the A/O Modulator (AOM)” earlier in this chapter.

7. Test for proper modelocking.

   Refer to “Test for Proper Modelocking” earlier in this chapter for information on verifying stable mode-locked operation. Note: if you are running in the long wavelength range, block the incoming pump beam instead of opening the laser head to perform this test. Removing the cover introduces water vapor into the cavity (which can severely compromise performance in this range), and it can take some time before the purge is again effective. Refer to “System Start-up” in Chapter 7.

8. Replace the cover and screws. *Do not leave the cover off!*

This completes the coarse phase adjustment.

Chapter 7 Operation

System Start-up

Danger!

The *Tsunami*® and its pump laser are Class IV—High Power Lasers, whose beams are, by definition, safety and fire hazards. Take precautions to prevent exposure to direct and reflected beams. Diffuse as well as specular reflections cause severe skin or eye damage.

Danger! Laser Radiation

Because the *Tsunami* laser emits continuous wave (CW) and pulsed infrared radiation, it is extremely dangerous to the eye. Infrared radiation passes easily through the cornea, which focuses it on the retina, where it can cause instantaneous permanent damage.

Once the *Tsunami* laser has been installed and aligned, we suggest you leave the *Model 3955* and optional *Model 3930* electronics modules powered on at all times. By doing so, the day-to-day operation remains consistent and repeatable, and only minor adjustments and purging are required to return the *Tsunami* laser to optimum performance levels (provided nothing is disturbed between operating sessions).

1. If not already on, turn on the *Model 3955* (or *Model 3930*) electronics module and leave it on at all times.

   Leaving it on overnight vastly reduces the warm-up time the next time the system is used. We urge you to leave the unit on at all times, except when moving the system or when you will not use it for an extended period of time.

   It takes about 20 minutes for the acousto-optic modulator (AOM) and GTI (ps configuration) to reach operating temperature. If your system includes the optional Lok-to-Clock® system, refer to Chapter 8, "Lok-to-Clock: Operation," for start-up information for the *Model 3930*. In the meantime, continue with system start-up.

2. Verify the pump laser shutter is closed, then turn on the pump laser and set it for its anticipated power level.

   If using an ion laser, allow it to warm up according to its instruction manual. Continue with start-up while these systems are warming up.

3. Verify the *Tsunami* optics are clean.

   If the cover was left in place and the system was purged the last time it was used, it is safe to assume the optics are still clean. If you are not confident that this is the case, remove the cover for inspection. If they are dirty, refer to Chapter 9 for information on cleaning optics.

4. Turn on the chiller according to its instruction manual and verify its temperature is set for 18°C (64°F).

Warning! Setting the chiller pressure higher than 275 kPa (40 psi) can lead to catastrophic damage and will void the warranty.

5. Begin the dry nitrogen purge.

   The *Model 3910* regulator/filter purge unit is provided for use with bottled nitrogen gas to eliminate problems associated with dust, contamination and the tuning discontinuities caused by oxygen and water vapor. The latter exhibits strong absorption lines in the long wavelength region between 840–1000 nm, especially at 944, 950, 981.2 and 984.1 nm (Figure 7-1). Due to the strength of these absorption lines, the moisture level within the laser head must be below 1000 ppm to allow problem-free modelocking. For these wavelengths, we recommend using 99.999% pure, dry, oil-free, Electronic Grade 5 nitrogen at a starting purge rate of 0.3 m^3/hr (10 SCFH) for at least 1.5 hours with the purge bleed valve open. Then reduce it to 0.17 m^3/hr (6 SCFH) with the purge valve closed to maintain positive pressure within the system during system use.

   a. Verify the laser head cover is in place and clamped down, sealing the cavity.

   b. Verify the nitrogen tank output regulator is set to minimum, then turn on the nitrogen supply.

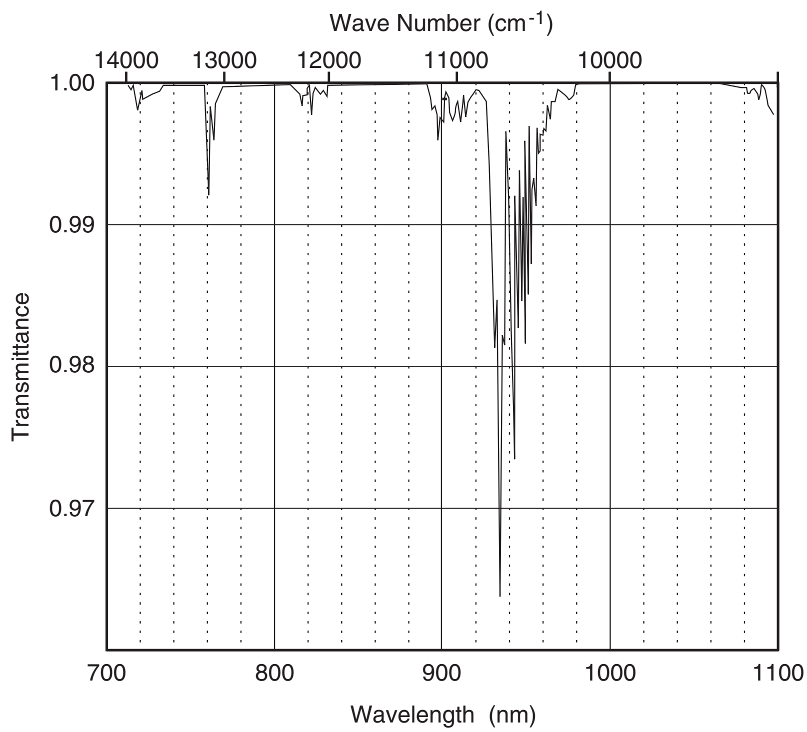

Figure 7-1: Transmittance vs. Wavelength for Oxygen and Water Vapor.

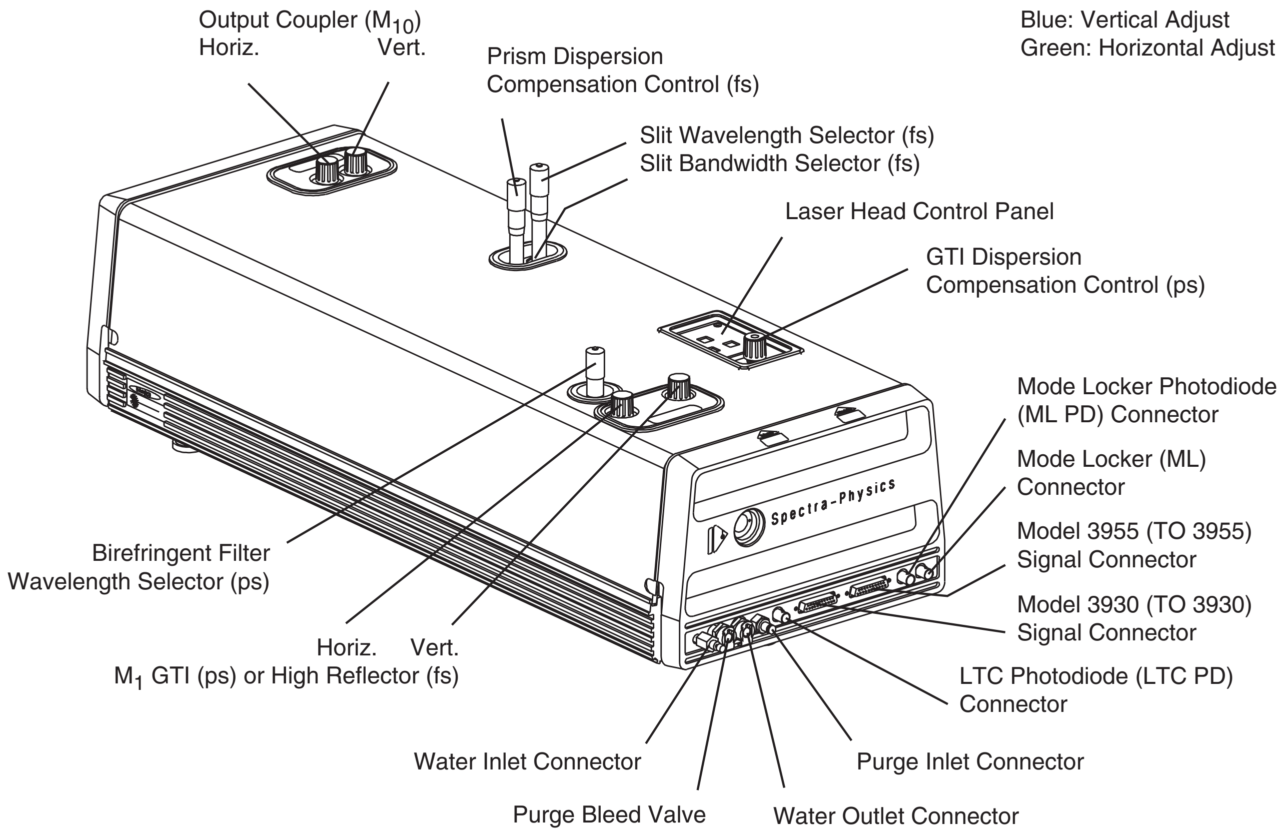

Figure 7-2: *Tsunami* External Laser Head Controls

c. Set the output regulator to limit pressure to less than 67 kPa (10 psi).

d. Open the *Tsunami* purge bleed valve (Figure 7-2).

e. Use the *Model 3910* flow control (Figure 4-9) to set the nitrogen flow rate as outlined above.

Optimizing Laser Output

Caution!

Direct back reflections into the oscillator can cause serious instabilities in laser performance. Please take precautions to avoid such reflections.

1. Place a power meter in front of the *Tsunami* output window.
2. Open the pump laser shutter. The *Tsunami* laser should begin lasing if it was not adjusted since the last time it was used.
3. Adjust M_{10} and M_1 (Figure 7-2) for maximum output power and note the power level.

   You can often increase output power a little more by “walking the beam.” The following procedure may improve the overlap of the cavity beam and the pump beam in the rod.
4. Slightly detune M_1 vertically (power will decrease). Note the direction you turned the control.

5. Adjust M_{10} vertically for maximum power.

   Did power increase or decrease compared to the power level measured in Step 3? If it increased, repeat Steps 4 and 5, turning the vertical knob in the same direction until power begins to drop. If it decreased, turn the vertical tilt control in the opposite direction so that it increases again and repeat these steps until output power drops again.
6. When the laser is optimized in the vertical direction, repeat Steps 3 through 5 using the horizontal controls.
7. If necessary, recenter the beam on M_{10}. Carefully adjust M_3 (and M_4 and M_5 if necessary), then adjust M_{10} to maximize output power.
8. To recenter the beam on M_1, carefully adjust M_2. Then again adjust M_1 to maximize output power.
9. Repeat this entire procedure, starting at Step 3, until no further increase in power is noted.

This completes the procedure for “walking the beam” to optimize laser output.

Modelocking the Laser

Proceed to modelock the laser once the pump laser and the *Model 3955* are warmed up.

1. Push the STATUS mode locker enable button (the ENABLE LED should turn on).

   The two TEMPERATURE indicators on the *Tsunami* laser control panel turn from red to green when the AOM and GTI (ps configuration) heaters stabilize. Proceed to Step 2 when the indicators are green.

   A *flashing* red indicator means either: (a) the GTI is not installed (which is normal for a fs configuration) or (b) there is an unplugged cable.
2. To measure the *Tsunami* output pulse width, use an autocorrelator such as a Spectra-Physics *Model 409-08*, and avoid saturating the autocorrelator (refer to the autocorrelator manual).

   For a brief discussion on autocorrelation and measuring pulse widths, refer to Appendix B, “Pulse Width Measurement.”

   Skip to Step 4 if you just optimized output power in the previous section.
3. Maximize *Tsunami* output power.

   Place a power meter in the *Tsunami* beam path and adjust M_{10} and M_1 for maximum output power.
4. Adjust the autocorrelator for maximum signal.
5. Adjust the mode locker fine PHASE control for most stable pulse.

   If laser output pulses are not present, adjust the fine PHASE control on the *Model 3955* electronics module until either a short pulse appears on the oscilloscope or the autocorrelator signal is maximized.

If you are using cables other than those shipped with the system, or if you converted the laser from a ps to a fs configuration, or vice versa, or if you changed optics sets, the phase signal may have moved outside the range of the fine PHASE control. If this seems to be the case, refer to the section, "Coarse Phase Adjustment...," at the end of Chapter 6 for instructions on locating and changing the setting of the coarse control.

6. Adjust the dispersion control to optimize the pulse.

   Adjust the prism dispersion compensation control (fs configuration) or GTI POSITION dispersion control (ps configuration) until a short pulse appears.
7. Vary pump power to optimize power and pulse stability.
8. Repeat Steps 5 through 7 until the *Tsunami* pulse is optimized.
9. Perform the test for proper modelocking. Refer to Chapter 6, "Alignment: Test for Proper Modelocking."

This completes the system start-up and mode-locking procedures.

Selecting Wavelength, fs Configuration (Using the Slit)

Use an IR viewer, beam splitter, suitable attenuator, and a monochromator as described in Appendix B to monitor the *Tsunami* laser as you perform the following procedure.

1. Using the IR viewer, beam splitter, and attenuator, pick off a portion of the *Tsunami* output beam, attenuate it, and center it on the input slit of the monochromator.
2. Set the monochromator wavelength to the desired laser operating wavelength.
3. Using the *Tsunami* slit wavelength selector, tune the laser until the IR viewer detects light exiting the monochromator, then optimize the output from the monochromator.
4. Adjust the prism dispersion compensation control for the desired pulse width.

   Turn the prism dispersion compensation control micrometer in the same direction as the slit wavelength selector to selected the wavelength.
5. When you change to a wavelength that requires a different optics set, you may have to change and realign the photodiode pc board. Refer to "Aligning the Photodiode PC Board" in Chapter 6.
6. Set the optimum slit width using the slit bandwidth selector (shown in Figure 7-2).
7. Optimize pulse width by adjusting the pump power and prism dispersion compensation control.

   Iterate between adjusting pump power and the prism dispersion compensation control to obtain the desired pulse width. The process will merge to a point where the shortest pulse width at highest output power is achieved without CW breakthrough (refer to Appendix B.) The graph in Figure 7-3 shows the relationship between bandwidth and pulse width for the five specified wavelengths for a sech^2-shaped pulse.

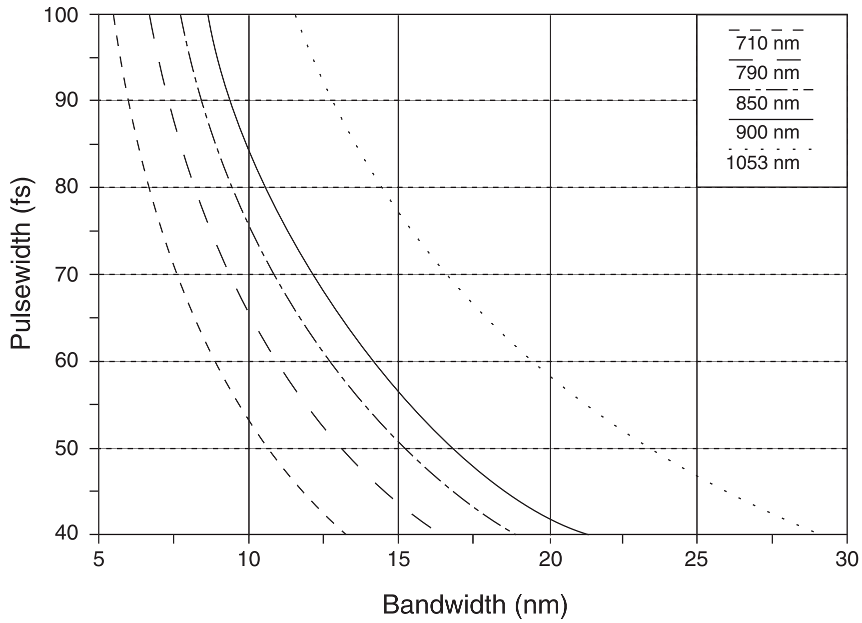

Figure 7-3: Bandwidth vs Pulse Width for a Transform-limited sech^2 Pulse Shape.

8. Perform the procedure outlined under "Optimizing Laser Output" earlier in this chapter.

This completes the fs wavelength selection procedure.

Selecting Wavelength, ps Configuration (Using the Birefringent Filter)

Use an IR viewer, beam splitter, suitable attenuator, and a monochromator to monitor the *Tsunami* laser as you perform the following procedure.

1. Using the IR viewer, beam splitter, and attenuator, pick off a portion of the *Tsunami* output beam, attenuate it, and center it on the input slit of the monochromator (refer to the monochromator manual for instructions).
2. Set the monochromator wavelength to the desired laser operating wavelength.
3. Adjust the birefringent filter (bi-fi) micrometer to tune the laser until the IR viewer detects light exiting the monochromator, then optimize the output from the monochromator.
4. Adjust the GTI POSITION control for shortest pulse.
5. Perform the procedure outlined under "Optimizing Laser Output" earlier in this chapter.

This completes the ps wavelength selection procedure.

Operating in the Broad fs Regime
(150 fs – 1 ps)

The *Tsunami* laser is capable of providing pulses in the range of 150 fs to 1 ps by using a combination of special GTIs and the prism sequence used for dispersion compensation.

Tsunami System Verification

Verify the following before you start the conversion process for broad fs pulses:

1. Verify the coarse and fine PHASE settings on the *Model 3955* are correct.

   Refer to Chapter 6, "Alignment: Coarse Phase Adjustment...," for information on setting the coarse and fine PHASE controls.
2. Verify the beam is centered on the M_{10} and that output power is optimized.

   If the beam is not centered on M_{10}, refer to "Optimizing Laser Output" earlier in this chapter to "walk the beam" and recenter it on M_1 and the M_{10}.

Conversion for Broad Femtosecond Operation

1. Replace the M_1 HR with the appropriate GTI.

   Refer to Chapter 5, "Installation: Installing the GTI."
2. Place a white card in front of M_5 and adjust the GTI vertical and horizontal controls to overlap the two fluorescent images from M_1 and M_3 on the card so they form a cross. Once overlapped, the laser should lase when you remove the card.
3. Adjust the GTI vertical and horizontal controls to optimize output power.
4. Select the desired wavelength using the slit wavelength selector.

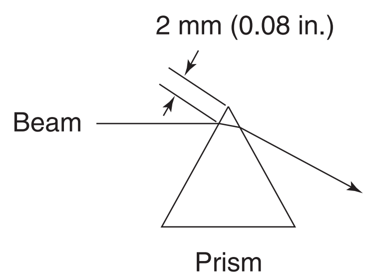

Figure 7-4: Placement of Pr_1 and Pr_4 in beam

5. Move prisms Pr_1 and Pr_4 so that the beam passes through them about 2 mm from their apices (Figure 7-4). For x-long wavelengths, ensure the beam is not clipped by these prisms.

   Access holes through the beam protection plates provide access to the prism adjustment screws.

6. Use the prism dispersion compensation control to adjust Pr_2 and Pr_3 so the beam also passes through them about 2 mm from the their apices.
7. Verify the beam is in the center of M_{10}. Adjust M_5 if necessary, then repeat Steps 5 and 6.
8. Refer to “Optimizing Laser Output” earlier in this chapter to “walk the beam” and optimize laser output.
9. Purge the system with clean, dry nitrogen gas when you are operating within water and oxygen absorption regions (Figure 7-1).
10. Push the STATUS mode locker enable button (the ENABLE LED should be on).
11. Set up an autocorrelator such as the *Model 409-08* according to its user's manual, then maximize the signal by adjusting the angle of the nonlinear crystal for the optimum phase-matching condition.
12. Maximize the intensity of the autocorrelated waveform by adjusting the coarse and fine PHASE controls.

    Refer to Chapter 6, “Alignment: Coarse Phase Adjustment...,” for information on setting the coarse and fine PHASE controls.
13. Adjust the GTI POSITION control to obtain a pulse.
14. Optimize system performance by iterating between the following adjustments:
    a. Adjust the fine PHASE control.
    b. Adjust the pump laser output power to obtain a stable pulse.
    c. Adjust the GTI POSITION control, prisms Pr_2 and Pr_3, the slit width, and pump source to obtain the desired pulse width.

       These controls operate interactively on the output pulse width, and an iterative approach is necessary.

Description	Typical Setting	
	Millennia Xs	Millennia Vs
Pump Laser Power	7–9 W	4–5 W
Slit Width	1.8–2.2 mm	1.8–2.2 mm

Typically, the pulse width can be varied with these controls by a factor of 2 to 3.

Operating in the Broad Picosecond Regime

The *Tsunami* laser is capable of producing pulses in the range 2 – 80 ps by using special GTIs and either a 2- or 3-plate bi-fi.

Tsunami System Verification

Verify the following before you start the conversion process for broad pulses:

1. Verify the coarse and fine PHASE settings on the *Model 3955* are correct.

Refer to Chapter 6, "Alignment: Coarse Phase Adjustment...," for information on setting the coarse and fine PHASE controls.

2. Verify the beam is centered on M_{10} and output power is optimized.

   If the beam is not centered on M_{10}, refer to "Optimizing Laser Output" earlier in this chapter to "walk the beam" and recenter it on M_1 and $M_{10.}$

Conversion for Long Picosecond Operation

1. Install the desired bi-fi filter assembly.

   Refer to Table 7-1 and Chapter 6, "Alignment: Selecting, Installing, and Aligning the Birefringent Filter."

. *Replace the M_1 HR with the appropriate GTI.*[*]

   Refer to Chapter 5, "Installation: Installing the GTI."

2. Adjust M_2 vertically and horizontally to center the beam on the GTI.
3. Adjust the GTI vertical and horizontal controls to optimize output power.
4. Install the special matching network assembly in series with the AOM for systems with pulse width capability over 10 ps.

   The network assembly is a small box with an SMA connector on one end and a short cable on the other. The cable end attaches to the AOM.

Table 7-1: Bi-fi Selection for Broad Picosecond Operation

	Bi–Fi Type	Bi–Fi Dot Color	Part Number
Blue			
< 20 ps	2–plate	Yellow	0434–8953
≥ 20 ps	3–plate	Green	0434–8973
Standard			
< 20 ps	2–plate	Yellow	0434–8953
≥ 20 ps	3–plate	Green	0434–8973
Mid-range			
< 20 ps	2–plate	White	0434–8954
≥ 20 ps	3–plate	Orange	0434–8974
Long			
< 20 ps	2–plate	Yellow	0434–8953
≥ 20 ps	3–plate	Green	0434–8973
X-Long			
< 20 ps	2–plate	Yellow	0434–8953
≥ 20 ps	3–plate	Green	0434–8973
Broadband			
< 20 ps	2–plate	Yellow/Red	0454–1120
≥ 20 ps	3–plate	Yellow/Red	0454–1130

[*] *For a list of available GTIs, refer to Table 10-17.*

5. Verify the beam is in the center of M_{10}, and adjust M_5 if necessary.
6. Again, refer to “Optimizing Laser Output” earlier in this chapter to “walk the beam” and optimize laser output.
7. Adjust the bi-fi for the desired wavelength.

   Purge the system with clean, dry nitrogen gas when you are operating within water and oxygen absorption regions (Figure 7-1).
8. Push the STATUS mode locker enable button (the ENABLE LED should be on).
9. Set up an autocorrelator such as the *Model 409-08* according to its user's manual, then maximize the signal by adjusting the angle of the nonlinear crystal for the optimum phase-matching condition.
10. Maximize the intensity of the autocorrelated waveform by adjusting the coarse and fine PHASE controls.

    Refer to Chapter 6, “Alignment: Coarse Phase Adjustment...,” for information on setting the coarse and fine PHASE controls.
11. Adjust the GTI POSITION control to obtain a pulse.
12. Optimize system performance by iterating between the following adjustments:
    a. Adjust the fine PHASE control.
    b. Adjust the pump laser output power to obtain a stable pulse.
    c. Adjust the GTI POSITION control for the desired pulse width.

Operating with the Ultrashort Pulse Option (USP)

The USP option allows operation of the *Tsunami* laser in the standard wavelength region (720–850 nm) with < 50 fs output pulses. The basic operation of the USP option with regard to pump power, Pr_2/Pr_3 adjustment, slit width adjustment, etc., is identical to laser operation in the standard fs regime. However, the USP option uses prisms with a lower refractive index which requires less glass to be inserted into the beam in order to produce short output pulses.

Operating in the Sub-35 fs Regime

The following alignment procedure is provided for those persons interested in operating their *Millennia*/*Tsunami* system in the sub-35 fs region. While performing these steps, remember that it is a combination of pump power, slit width, fold mirror position, and prism position that produces the maximum amount of bandwidth.

If you encounter problems while performing this alignment, refer to the “Troubleshooting in the Sub-35 fs Regime” section that starts on page 7-13.

1. Set the *Millennia* up for pumping a standard *Tsunami*. Make sure that the *Millennia* is secure to the table and that its output beam is level to the table.

2. Align the *Tsunami* so that the *Millennia* beam passes through the center of the brewster window and hits P_1 above its center.

   The beam must hit the top of the mirror without missing the coating. This ensures that the beam from P_2 to M_3 does not clip P_1.
3. Direct the beam to the center of both M_2 and M_3.

   Use the vertical and horizontal controls on P_1 and P_2 to direct the beam to the center of M_2 and M_3. This step is critical if you are to realize performance consistent with that of a system aligned at the factory.
4. Direct the beam from M_2 onto M_1. *Do not hit the top of* M_1 *nor clip the bottom of the* P_1 *bracket.*
5. Set the *Millennia* output power to 5.0 W.
6. Close the shutter and remove the tuning slit.

Warning! Support the slit assembly with your hand when loosening the setscrew to prevent it from falling off and damaging the optics below.

   Loosen the setscrew holding the slit assembly to the spindle of the micrometer (Figure 6-8), and slide the slit down and off the micrometer shaft.
7. Move Pr_1 and Pr_4 out of the beam path.
   a. Loosen the setscrew on each prism dovetail mount (Figure 6-19).
   b. Using a hex ball driver, adjust the screw on each mount exactly 10 turns clockwise to drive the prisms out of the beam path.

      Be exact in your turns because the prism has to be returned to its original position when you convert the laser back to normal fs operation.

      Small holes in the beam shields provide access to the drive screws.
   c. Tighten the setscrews, but do not over-tighten.
8. Place a business card in front of M_5.
9. Adjust M_3 so that the fluorescence from it hits where the center of M_5 would be.

   This fluorescence looks like a square, approximately 3 by 4 mm.
10. Adjust M_1 so that the fluorescence from M_1 is centered in the square seen in Step 9. This fluorescence should look like a small spot.
11. Remove the card from in front of M_5.
12. Place a white card about 6 in. outside the laser cavity in front of the output window and, using an IR viewer, view the fluorescence through the output coupler. Adjust M_3 for the brightest spot.
13. Adjust M_1 for the brightest spot.
14. Adjust the OC to until the unit lases.
15. Using an IR viewer, look at the back of M_8 and adjust the OC so that the reflection from the OC overlaps the intracavity fluorescent spot as

seen through M_8. Once unit lases, optimize the output as you would normally.

16. Install the slit assembly.

Warning!

To avoid damaging nearby optics when installing the slit, carefully move it into place and use your hand to support it while you tighten the mounting setscrew.

   a. Close the shutter.
   b. Place the tuning slit assembly into the laser head and onto the micrometer shaft. Refer to Figure 6-8.
   c. Rotate the slit width adjustment screw until the dowel pin on the mating shaft can slide into the slot.
   d. Seat the slit assembly against the micrometer stop.
   e. Tighten the setscrew.

17. Open the shutter and verify the beam is still centered on M_4, M_5 and the OC.
18. Adjust the pump focus as you would normally for maximum output power.

    With 5.0 W of pump power, the *Tsunami* should output between 650 and 900 mW.

19. Adjust P_1 and P_4 so that the beam passes through the very tips of these prisms.

    Since the system design requires very little positive GVD compensation, it is critical that the smallest amount of glass possible is inserted into the beam. Ideally, the prisms should be adjusted so that about 20 mW per prism is lost over the tops of the prisms.

20. Turn down the pump power so that *Tsunami* output power is between 300 and 350 mW.
21. Install a spectrum analyzer or other bandwidth diagnostic tool to measure the laser output.
22. Turn on the mode locker and adjust P_2 and P_3 counterclockwise until the system modelocks.
23. Adjust P_2 and P_3 and vary the pump power to achieve at least 40 nm of bandwidth at > 300 mW. When no more bandwidth can be gained by adjusting the prisms, turn the slit micrometer counterclockwise for maximum bandwidth.
24. Adjust the fine phase control to obtain mode locker-initiated pulsing.

    The phase is much more sensitive in the sub-fs regime than in a standard system so the fine phase control must be used.

25. Verify the *Tsunami* tunes from 750 to 850 nm.
26. Gently tap on various mechanics and press on M_6 through M_9 to verify laser does not detune.

Troubleshooting in the Sub-35 fs Regime

1. If the fluorescent spots do not look like those described in Step 10 of the sub-35 fs alignment section, the positions of the fold mirrors are incorrect and the pump beam may not be going through the centers of M_3 and M_2. Before proceeding, verify this is not the case.

   If the spot from M_2 is not a bright dot, adjust the M_2 micrometer to make it bright. When it is as bright as it will get, recenter the beam using the M_2 adjustments.

   If the spot from M_3 is not rectangular-shaped image or is not the size described in Step 9, perform the following.

   a. With the prisms and slit assembly out of the beam path, remove the OC and look for the fluorescence outside of the laser.

   b. Place a business card approximately 22 in. (55 cm) from the output bezel.

   c. Adjust M_1 so that the fluorescence does not make it out of the laser.

   d. Adjust M_3 so that the fluorescence can be seen on the business card.

   e. Slide M_3 back and forth on the dovetail until the fluorescent spot comes to a focus and secure M_3.

   f. After M_3 is secured, verify the spot from M_2 has not degraded or moved.

2. If the unit does not lase, check the following:

   a. Clean the prisms with acetone or methanol.

   b. Verify pump power is optimized according to Table 6-1 on page 4-4.

   c. Verify the spots look like those described in Step 10.

   d. Verify the fluorescent spots outside the cavity are overlapped.

      Make sure the beam (the fluorescence) is going through the prisms and not over the tops of the prisms.

   e. If you have a problem seeing the overlapped spots through M_8, insert a business card in front of M_5.

   f. If none of the above steps work, chances are that the pump focus is incorrect. If so, move P_2 one turn in either direction, then adjust the overlap using the controls on P_2. If the unit still does not lase, try one more turn in the same direction. If the unit still does not lase, repeat this step, turning the control in the opposite direction.

3. If power is less than 650 mW, try the following:

   a. Clean all prisms and mirrors. Also make sure that both sides of the mode locker are clean.

   b. Verify the beam from M_2 to M_1 is not clipping on the bottom of the P_1 bracket.

   c. Adjust P_2 for maximum output power.

   d. Adjust M_2 for maximum output power.

Because M_2 does not translate along the optical axis, the system will stop lasing when the micrometer is moved. If this happens, adjust the horizontal and vertical knobs to return it to lasing operation, then adjust M_1 for maximum output power.

4. If you cannot get the system to modelock, either the phase is incorrect, the wrong amount of glass is in the cavity, the fold mirrors are in the wrong positions or pump power is too high. Try the following:
   a. Verify the beam is not going through too much prism glass.

      The beam should pass through right at the tips of P_1 and P_4.
   b. Verify pump power is not too high.

      Tsunami output should be between 300 and 350 mW. This corresponds to a pump power of approximately 3.2 to 4.0 W.
   c. Turn the M_2 micrometer one-eighth turn in either direction, then repeak the mirror and try adjusting the prisms again. If the system does not modelock, try moving the micrometer in the opposite direction. Make sure that during the adjustments, mode remains good.
   d. Verify the phase is set correctly. While watching the spectrum on an oscilloscope, adjust the coarse phase knob (inside the *Model 3955*) until the signal peaks in the vertical direction, then try adjusting the prisms again. If this fails, adjust the coarse phase knob one more click and try again. Repeat, turning the coarse phase knob one click each time until the unit modelocks.
5. If at least 35 nm of bandwidth cannot be attained, try the following:
   a. Decrease the pump power and turn P_2 and P_3 one turn clockwise.
   b. Turn the slit micrometer counter-clockwise.
   c. Open the slit width.
   d. Make small adjustments to M_2 as described in Step 4 above.
   e. Slide M_3 either in or out slightly, then optimize laser output and check bandwidth.

      Before moving M_3 however, make a mark on the dovetail bracket so you can return the mirror to this position if this step fails. The procedure described in Step 1 above should put M_3 at the right position. Make very small adjustments to this mirror, no more than 1 mm at a time.

Operating with Lok-to-Clock

Refer to Chapter 8 for installation and operating instructions for the optional Lok-to-Clock system.

System Shut-down

1. Turn off the pump laser according to its user's manual.
2. Turn off the chiller.

   To prevent condensation on the surface of the rod, *do not* run the chiller when the laser is off.
3. Turn off the nitrogen supply at the tank, then close the regulator valve on the *Model 3910* purge unit.

Do not turn off the *Model 3955* or the optional *Model 3930* if you plan on using the laser within the next week or so. The *Model 3930* takes about 2 hours to warm up properly for stable 80 MHz operation.

This completes the system shut-down procedure.

Chapter 8 Lok-to-Clock Electronics

Note: you must have a *Model 3960C*, *3950C* or *3941C* version *Tsunami*® laser head to use the *Lok-to-Clock*® (*LTC*) system.

Functional Overview

The optional *Model 3930 Lok-to-Clock* electronics module provides phase-locked loop (PLL) stabilization of *Tsunami* output pulses. It allows you to precisely synchronize those output pulses to either the internal 80 MHz reference source or to an external one, such as an rf synthesizer or to another mode-locked laser. The *LTC* system is capable of reducing timing jitter to < 0.5 ps when pumped by a *Millennia*® laser.

The phase (timing) of the output pulse train (as monitored on a photo diode) is compared to the phase of a stable reference oscillator. Any phase difference (where a phase difference of 360° or 2π corresponds to a timing error of about 12 ns) is converted to an error voltage. This error signal is filtered, amplified, and used to drive a piezo-electric transducer (PZT) that is mounted on intracavity mirror M_4. The mirror movement changes the cavity length of the *Tsunami* laser and modifies the pulse repetition rate to minimize the phase difference. When the pulses are perfectly overlapped, there is no phase error and the cavity length and pulse repetition rate are held constant. Figure 8-1 illustrates the phase-locked loop (PLL) control circuit.

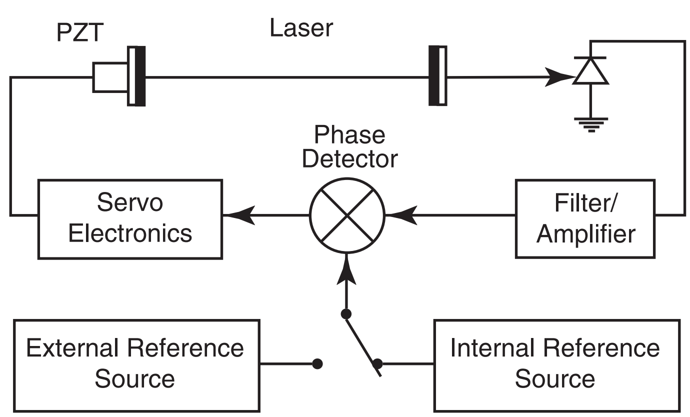

Figure 8-1: The *Lok-to-Clock* Phase-locked Loop.

To ensure the *Tsunami* laser can be tuned over its entire wavelength range with a fixed repetition rate, it is necessary to have a coarse cavity length adjustment in addition to the fine length control provided by the PZT-con trolled M_4 mirror. To this end, mirror M_1 is mounted on a motorized micrometer that is controlled via the up/down buttons on the *Model 3930*. The M_1 control is typically a manual coarse control, while M_4 is an automatic fine control. However, if the difference between the reference and the laser cavity frequency is < 50 kHz when the LOCK button is pressed, the system will automatically servo the M_1 motor micrometer in order to bring the frequency difference within the locking range (< 100 Hz) of the PZT-controlled M_4 mirror. A bar graph indicator on the *Model 3930* indicates the relative position of M_4 so that you can tell when it is nearing its out-of-range point.

The electronics module also provides controls and indicators for setting and viewing the photodiode signal level and the reference frequency. A built-in 10 Hz sweep generator can be used to create a 2 ns phase shift in the *Tsunami* photodiode signal. This facilitates locating pulses when trying to lock the *LTC Tsunami* to another laser.

An optional RS-232 serial interface is also available for controlling the *LTC* functions from a remote source. The second half of this chapter is devoted to its operation and command structure. A LabView interface that uses the RS-232 port is also available and is explained in Appendix D. Specifications for the *LTC* system are at the end of this chapter.

System Controls

The following describes the displays and controls on the front and rear panels of the *Tsunami Model 3930 LTC* electronics module.

Front Panel

TIMING coarse/fine control—sets the timing between the reference source and the *Tsunami* laser. Both the coarse (outer knob) and fine (inner knob) controls have a 10-turn resolution. The range for the coarse control is approximately 2 ns; it is 100 ps for the fine control. When the sweep generator (see below) is off, the coarse/fine controls set the timing reference; when the sweep generator is on, the coarse/fine controls are disabled.

TIMING sweep generator on/off push button—toggles the triangle wave sweep generator on and off (default = off). The sweep runs at about 10 Hz, and produces a linear timing change of about 2 ns. When the generator is off, the coarse/fine controls set the timing reference; when on, the coarse/fine controls are disabled.

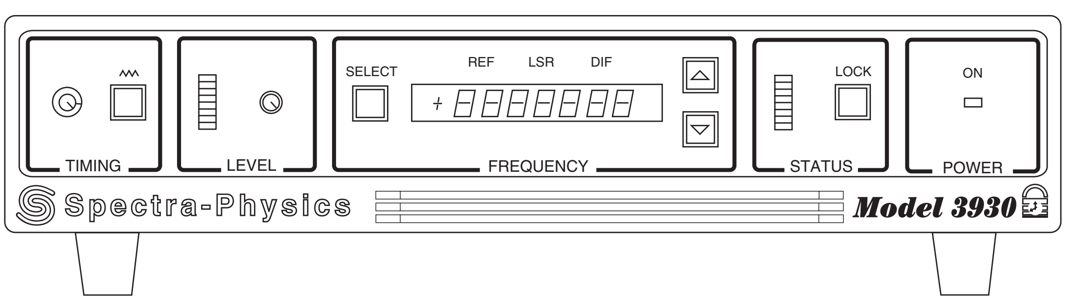

Figure 8-2: ***Model 3930*** **Electronics Module Front Panel Controls and Indicators**

LEVEL indicator—displays relative photodiode signal strength with full-scale = maximum signal. This is an uncalibrated reference indicator.

LEVEL control—allows you to adjust the photodiode input signal gain. This control is typically fully clockwise (full on).

FREQUENCY: SELECT button—sets the frequency display to show either the reference frequency (REF—which can be either an internal or an external reference source), the actual laser pulse frequency (LSR), or the difference between the two (DIF).

FREQUENCY: REF indicator—shows that it is the system reference frequency that is being displayed.

FREQUENCY: LSR indicator—shows that it is the actual laser frequency, as measured by the *Tsunami* laser photodiode output, that is being displayed.

FREQUENCY: DIF indicator—shows that it is the difference between the reference frequency and actual laser pulse frequency that is being displayed.

FREQUENCY display panel—an 8-digit LED panel that displays either an internal or external reference frequency (REF), the actual laser pulse frequency (LSR), or the difference between the two (DIF). Frequency is shown in MHz to the nearest 10 Hz. The display has a 1 Hz refresh rate.

FREQUENCY up/down push buttons—increases or decreases the laser repetition rate by adjusting the laser cavity length via the M_1 motorized micrometer.

STATUS indicator—a bar display that, when lit, shows the relative position of the M_4 PZT mirror within its range. When no segments are lit, the *Lok-to-Clock* function has been disengaged via the STATUS: LOCK button.

STATUS: LOCK push button—toggles the *Lok-to-Clock* PLL circuit on and off. If the difference between the reference and the laser cavity frequency is < 50 kHz when the LOCK button is pressed, the system will automatically servo the M_1 motor micrometer in order to bring the frequency difference within the locking range (< 100 Hz) of the PZT-controlled M_4 mirror. When LOCK is on, one or two segments of the STATUS bar display are on.

POWER: ON indicator—shows that power is applied to the *Model 3930* electronics module.

Rear Panel

Power cord connector—provides connection for a standard power cord.

Power switch—turns power on and off to the *Model 3930*. It is located next to the power cord connector.

Voltage select switch—provides a means to match the electronics input power to your local line voltage. Input voltage selections are 100, 120, 220, and 240 Vac. Appendix C describes how to set the switch and select the fuse rating for your line voltage.

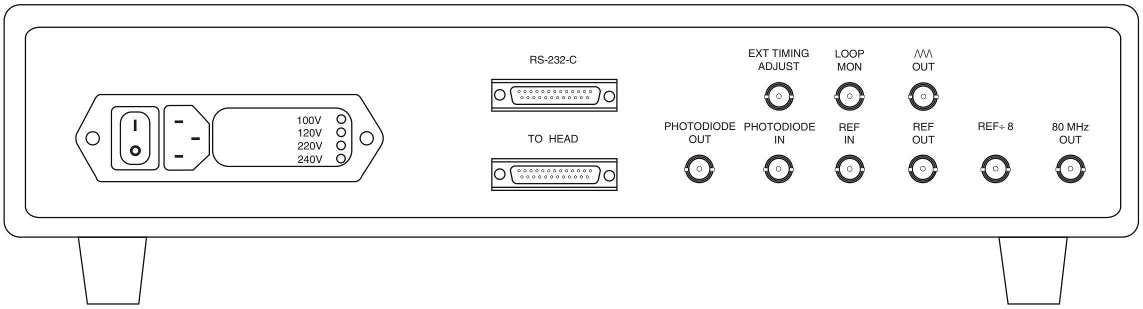

Figure 8-3: ***Model 3930*** **Electronics Module Rear Panel Controls and Connections**

RS-232-C **serial input (9-pin male)**—connects to a standard RS-232-C control source for remote control of the *Model 3930* and the *Lok-to-Clock* functions. Refer to "Lok-to-Clock Computer Interface" in the second half of this chapter for detailed information on the use of this connection. Also available is a PC-based LabView interface that also uses this connector. Refer to Appendix D for information on the use of the LabView software.

TO HEAD main signal D-sub connector (25-pin female)—connects to the female 25-pin TO 3930 connector on the *Tsunami* laser head input bezel.

EXT TIMING ADJUST connector—provides connection for an external error input signal (supplied by user). Input impedance is 20 kΩ Signal sensitivity is approximately 7.5 $^{mV}/_{ps}$. This signal is summed with the signal from the coarse and fine TIMING controls (Figure 8-4).

LOOP MONitor connector—provides a buffered feedback signal for monitoring the system using an oscilloscope or volt meter. The best system performance is achieved when the laser is adjusted for the smallest output signal. Output impedance is 1 kΩ Signal sensitivity is approximately 100 $^{mV}/_{ps}$. Output voltage range is approximately ±15 V.

/\/\/\ **OUT connector—**provides a fixed, buffered, 10 Hz triangle wave from the internal sweep generator that can be used to drive the horizontal sweep on an oscilloscope (it provides a synchronized timing function). The signal is present even when the sweep generator is not selected on the front panel. Output impedance is 1 kΩ

PHOTODIODE OUT connector—provides a buffered *Tsunami* laser photodiode output signal for monitoring on an oscilloscope. Output impedance is 50 Ω at –10 dBm for a sine wave. dBm is dB with respect to one milliwatt.

For example:

–10 dBm = 200 mVpp

0 dBm = 0.63 Vpp

10 dBm = 2 Vpp

To convert to watts: $Watts = 0.001 \cdot 10^{\frac{dbm}{10}}$

To convert to volts, peak-to-peak: $voltspp = 2 \cdot \sqrt{2} \cdot \sqrt{Watts \cdot 50}$

PHOTODIODE IN connector—attaches to the LTC PD photodiode output connectors on the *Tsunami* laser input bezel. This feedback signal is used by the *Lok-to-Clock* system to lock the *Tsunami* cavity to a set frequency. Input impedance is 50 Ω at –10 dBm for a sine wave.

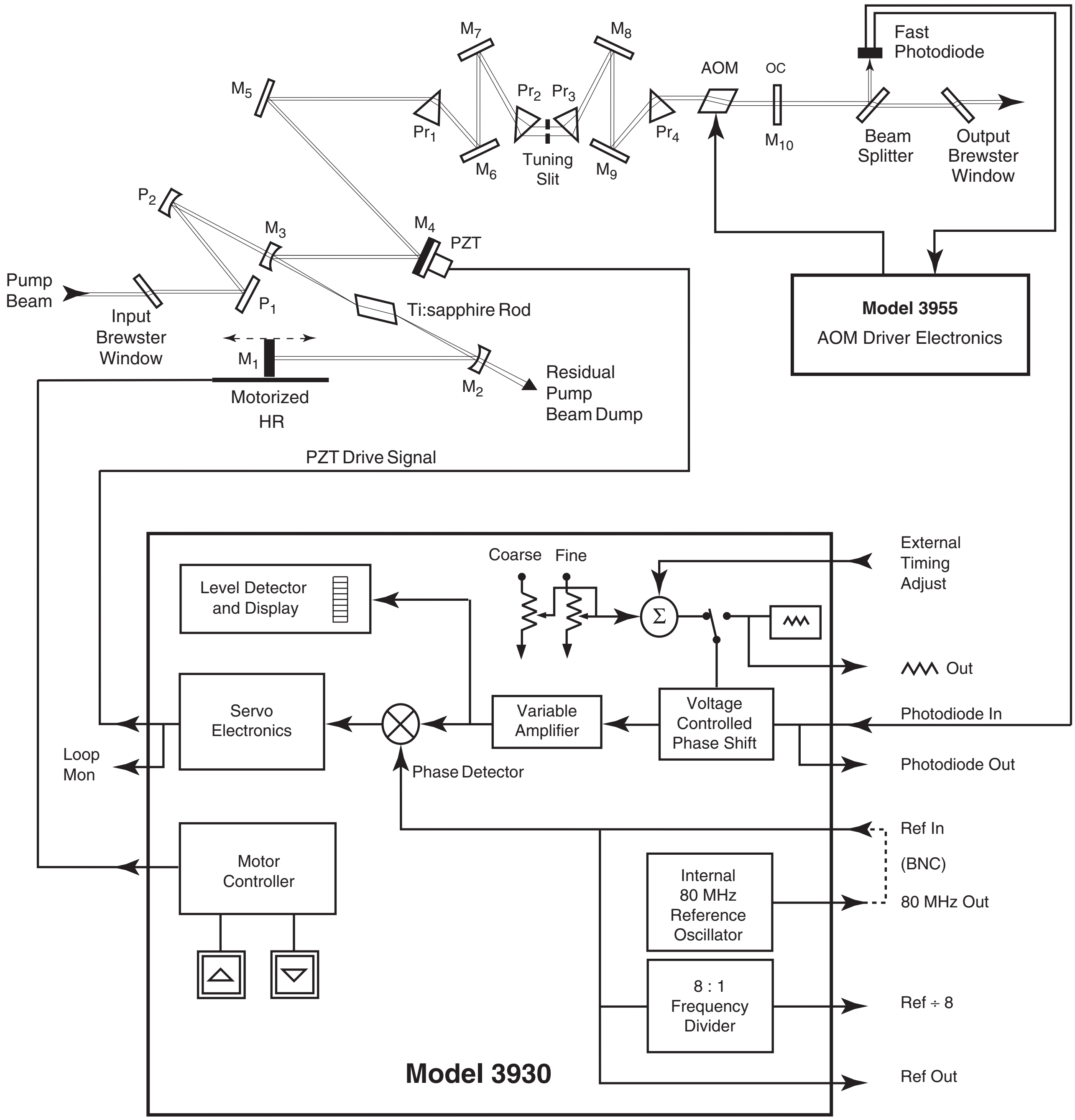

Figure 8-4: ***Lok-to-Clock*** **fs System Block Diagram**

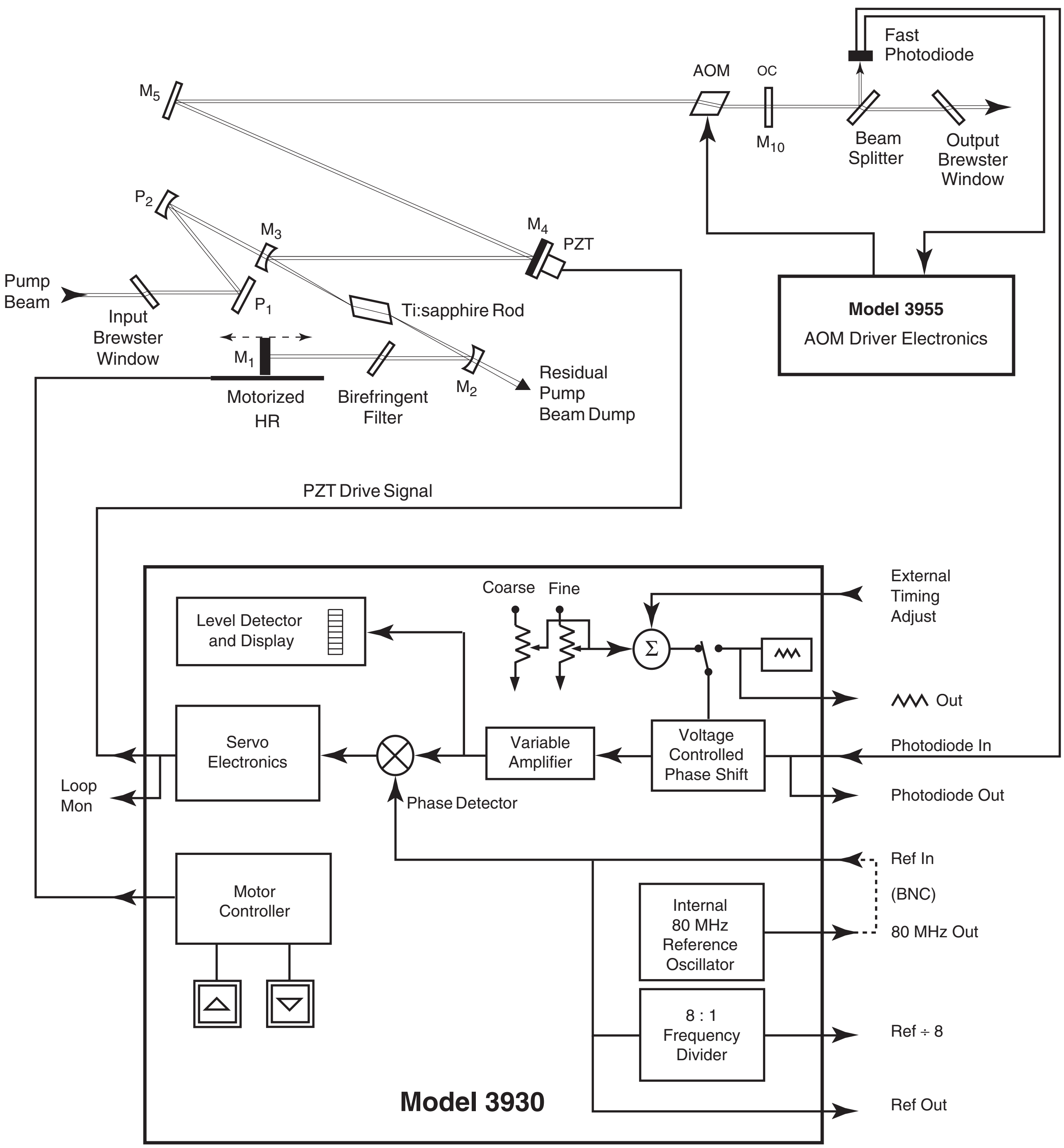

Figure 8-5: ***Lok-to-Clock*** **ps System Block Diagram**

Caution!

Do not connect the BNC cable from the PHOTODIODE IN connector to the ML PD connector on the laser head. The photodiode signals from ML PD and LTC PD are calibrated differently and ML PD will over-drive the PHOTODIODE IN connector if swapped.

REF IN connector—provides connection for either a user-defined external reference signal (defined at time of purchase) or the 80 MHz internal reference signal. When the internal reference is used, a BNC cable connects from the 80 MHz OUT connector to this connector (Figure 8-5). An input rf signal of between 76 and 83 MHz can be accepted provided the laser cavity length has been factory preset. Input impedance is 50 Ω at 0 dBm for a sine wave.

REF OUT connector—provides a buffered signal from the selected reference input signal for use with an external frequency counter or other user equipment. Output impedance is 50 Ω at 0 dBm for a sine wave.

REF ÷ 8 connector—provides a buffered 8:1 frequency-divided signal from the selected reference input signal for use with an external frequency counter or other user equipment. When the internal reference is used, output is 10 MHz. Output impedance is 50 Ω at 0 dBm for a sine wave.

80 MHz OUT connector—provides a buffered 80 MHz sine wave signal from the internal reference source. It can be used for the REF IN reference input signal in lieu of an external, user-supplied signal. Output impedance is 50 Ω at 0 dBm for a sine wave.

Installing the Model 3930

Note: you must have a *Model 3960C*, *3950C*, or *3941C* version *Tsunami* laser head to use this system.

The *Model 3930* is easy to install. Merely install the PZT-controlled M_4 mirror in the *Ts*unami laser head and connect the BNC and ribbon cables between the *Model 3930* and the laser head. There may be other connections depending on the requirements of the experiment or lab setup (for oscilloscope, external photodiode, etc.). The following procedure covers most standard installations and assumes the *Tsunami* laser is properly aligned according to Chapter 6, “Alignment,” and is running according to Chapter 7, “Operation.”

1. Place the *Tsunami Model 3955* electronics module on top of the *Model 3930*. Both modules should be within 1 m of the *Tsunami* laser head.
2. Attach the 25-pin ribbon connector (from the accessory kit) between the TO HEAD connector on the rear panel of the *Model 3930* and the TO 3930 female connector on the input bezel of the *Tsunami* laser head.
3. Disconnect the 50 Ω terminator on the LTC PD connector and place it in the tool kit.
4. Attach a BNC cable between the PHOTODIODE IN connector on the *Model 3930* and the LTC PD connector on the *Tsunami* laser head.

Caution!

Whenever this BNC cable is removed, the 50 Ω terminator must be reconnected to prevent oscillation of the photodiode gain circuit.

5. If you are going to use the 80 MHz internal reference, attach the short BNC cable from the accessory kit between the 80 MHz OUT and REF IN connectors on the rear panel of the *Model 3930*. If, instead, you are using an external reference to monitor another laser (e.g., the output of a *Model 3932*), verify the output is 0 dbm into an 50 Ω termination (0.63 V_{pp}) for the REF IN input, then attach a BNC cable from the signal source to REF IN.
6. Verify the voltage and fuse rating of the *Model 3930* are correct.

   They are a part of the power switch assembly on the rear panel. Refer to Appendix C for instructions on how to change the setting and the fuse.
7. Connect the power cord from the *Model 3930* power connector to your facility power outlet.
8. Verify the pump laser shutter is closed or that the laser is not on, then open the *Tsunami* laser head.

   For information on how to open the laser head, refer to Chapter 5, "Installation: Installing the *Tsunami* Laser Head."
9. Remove the standard, non-PZT M_4 mirror by unscrewing it from its mount (Figure 6-8).
10. Install the PZT-controlled mirror that is provided with the *LTC* system into the M_4 mount, then attach its short cable to the mating cable laying in the tray near it.
11. Open the pump laser shutter and adjust the horizontal and vertical controls of M_4 to get the *Tsunami* lasing again and to optimize output power.
12. Optimize laser output again by adjusting M_{10} and M_1.

This completes the standard installation of the *Lok-to-Clock* system. Before you proceed with the next section on operating the *Lok-to-Clock* system, verify you have complied with the instructions for general operation in Chapter 7.

Operation Notes

Please note that the front panel controls on the *Model 3930* work in parallel with the optional RS-232 SCPI interface on the back panel. Whenever you change a setting with one interface, the other is affected as well; there is no switch to change from one command source to the other.

The following sequences for start-up and shut down are appropriate for both command sources but are written with the front panel in mind. Simply adapt these commands accordingly when using the SCPI interface. Refer to "The Lok-to-Clock Computer Interface" section later in this chapter for information on setting up and using the SCPI interface.

Start-up

In addition to the normal start-up procedures outlined in Chapter 7, "Operation," the following are general procedures to observe whenever using the *Model 3930 Lok-to-Clock* electronics module.

1. Turn on the *Model 3930* and allow it to stabilize for at least two hours. Once on, never turn it off except to move it to a new location.
2. Mode lock the *Tsunami* laser and verify output performance (i.e. output power, bandwidth, pulse width, etc. should meet published specifications).

   You can monitor the external or internal reference signal frequency by monitoring the REF OUT signal. Set the panel view mode to REF using the SELECT button.
3. Verify the photodiode LEVEL indicator on the front panel is fully lit.

   The LEVEL control should be fully clockwise.
4. Press the SELECT button to set the panel view to LSR to monitor the laser repetition frequency and to verify it is stable. If it is not stable, verify the *Tsunami* laser is operating correctly.
5. Press the LOCK button to lock the system (if DIF is < 50 kHz)[*].

Caution! Always unlock the system before tuning to a new wavelength, then optimize the *Tsunami* output and lock it again.

Shut Down

As a general procedure, unlock the system before turning off the laser. However, leave the *Model 3930* powered on when the system is not in use in order to minimize frequency drift during the next start-up.

Typical Set-ups

Example 1: Synchronizing Pulses from Two LTC Tsunami Lasers

A typical experiment set-up is shown in Figure 8-6. *Tsunami* "A" is the master oscillator, and the 80 MHz REF OUT from its *Model 3930 Lok-to-Clock* electronics module is used for the *Model 3930* REF IN signal of *Tsunami* "B." The output beams of both lasers are combined and overlapped as shown in the figure.

In an experiment using synchronized pulses from two *LTC Tsunami* lasers, the timing function (using either the manual TIMING controls or the sweep generator) facilitates locating your pulses by adjusting the timing of one pulse with respect to the other. Use the sweep to find the pulses and the TIMING controls to overlap them. Note: modifying the laser frequency by 50 Hz is equal to about 1 μm of motion at mirror M_1.

[*] *If the frequency is > 50 kHz, use the up/down buttons to bring it within range.*

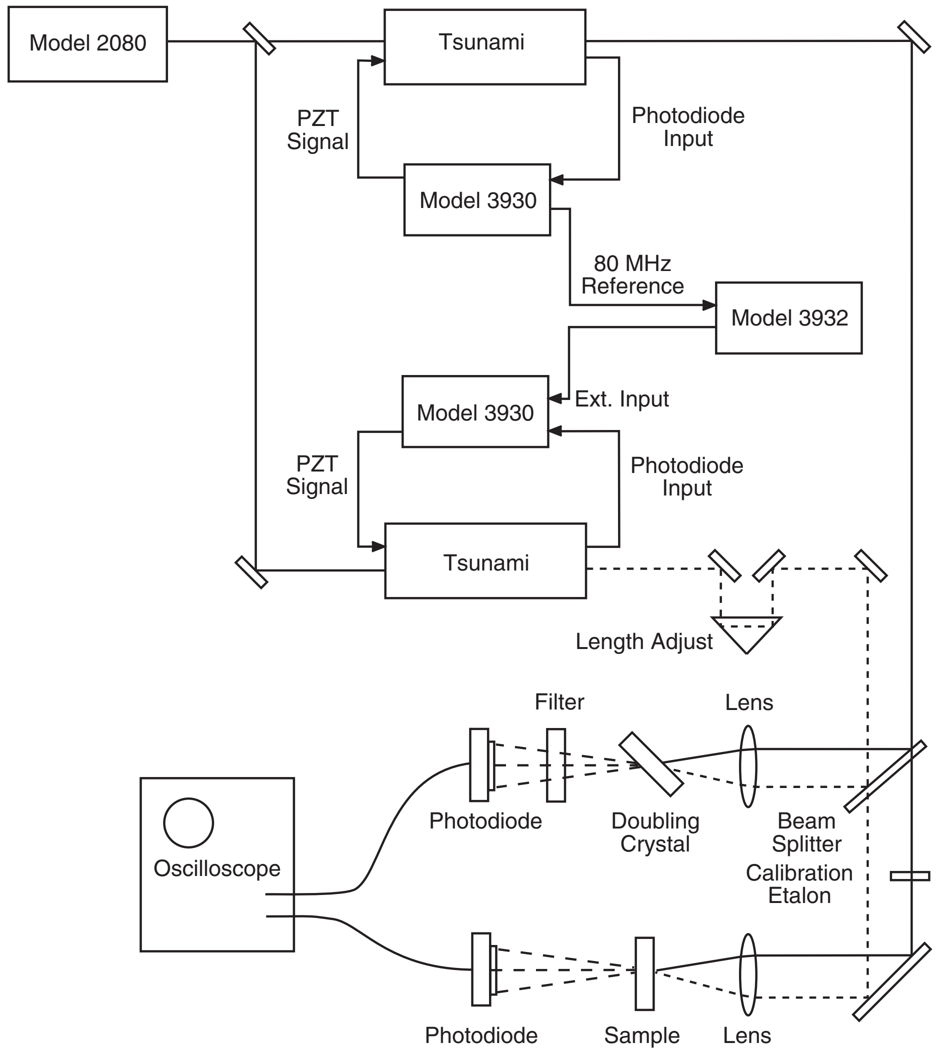

Figure 8-6: Synchronization of two *Lok-to-Clock Tsunami* Lasers

1. Adjust each *Tsunami* laser for optimum performance at the desired wavelengths.
2. With each *Model 3930* unlocked (there are no illuminated segments in either STATUS display), place a photodiode (e.g., an Electro Technology ET2000) at the source of the experiment.
3. Adjust the optical alignment so that the pulse train for each *Tsunami* laser can be identified.
4. Set up and lock *Tsunami* “A” as outlined in “Operation Notes” above.
5. Repeat Step 4 for *Tsunami* “B.”

The oscilloscope display should now show two pulse trains with a fixed delay. The pulse trains are now synchronized but are probably not overlapped in time.

6. Verify the time between the pulse trains can be varied by using the coarse TIMING control.

The TIMING control on each system provides up to 2 ns of adjustment. If the pulses are more than 2 ns apart, change the length of the cable between the two *Model 3930*s (30 cm of cable corresponds to about 1 ns of delay). *Do not modify the cables between the laser head and the Model 3955!* When the cable length is optimized, activate the sweep generator (by pressing the TIMING button) on the *Tsunami* "B" *Model 3930* and observe the pulses from *Tsunami* "B" sweeping back and forth over those from *Tsunami* "A."

To overlap the pulses more precisely in time, focus the two *Tsunami* output beams in a nonlinear crystal such as BBO.* As you sweep through the phase-matching angle of the BBO crystal, a frequency-doubled signal should be observed from each laser. Set the crystal for an intermediate angle to observe the sum-frequency mixed signal from both lasers. By activating the sweep generator, the crystal can be easily phase-matched for observation of this signal. It will be modulated at the 10 Hz sweep period. Once the sum-frequency mixed signal is observed, deactivate the sweep generator and use the coarse/fine TIMING controls to optimize this signal.

A cross-correlation of the two pulses can be generated by displaying the sum frequency mixed signal on a photodetector and activating the sweep generator. Alternatively, the cross-correlation signal can be observed by sending the spatial and temporally overlapped beams into an autocorrelator, such as the *Model 409-08*. Figure 8-7 shows a typical cross-correlation trace for two ps *Tsunami* lasers, each having 1.5 ps pulse widths.

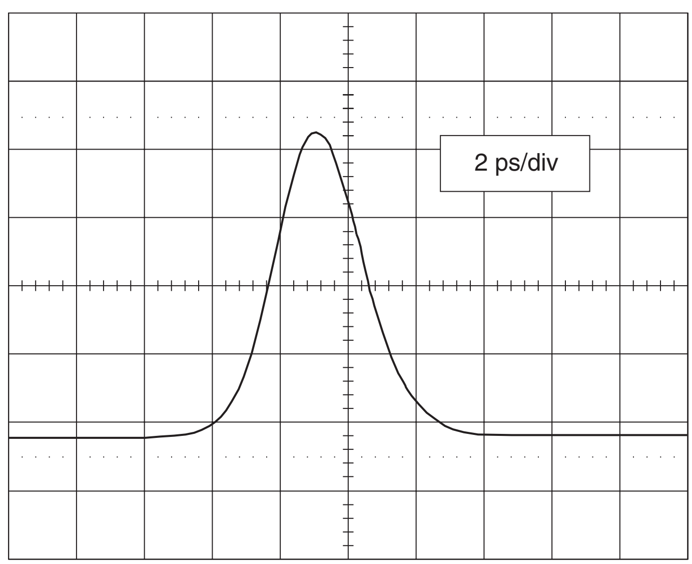

Figure 8-7: Typical cross-correlation signal for two *LTC Tsunami* lasers. The waveform averaged over five seconds. $\Delta\tau$ = 2.8 ps FWHM.

* *The nonlinear crystal must be cut such that it can frequency-double the output of each laser. Verify this by temporarily placing a white card at the output of the crystal and then changing the phase-matching angle of the crystal while watching the laser output on the card.*

Example 2: Synchronizing Pulses from a mode-locked laser with an LTC Tsunami

A similar procedure can be applied for locking a *LTC Tsunami* to another mode-locked laser operating close to 80 MHz (e.g., a standard *Tsunami* laser operating at 82 MHz). The cross-correlation signal obtained from such a system is dependent upon the phase noise of the mode-locked laser. Figure 8-8 shows a typical setup.

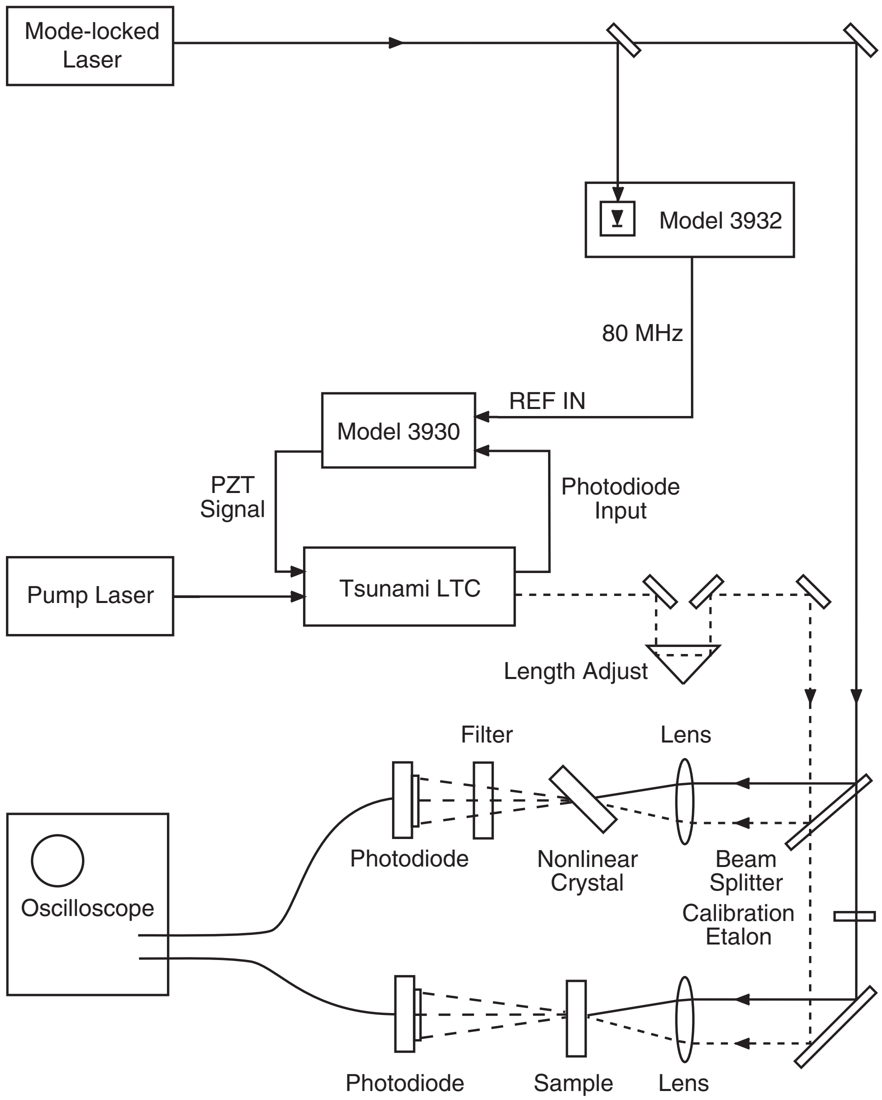

Figure 8-8: Synchronization of a Standard *Tsunami* Laser to a *Lok-to-Clock Tsunami* Laser.

A beam splitter picks off a small amount of output from the mode-locked source, which is then sent to a *Model 3932-BSM* for operation with wavelengths below 900 nm or a *Model 3932-LX* for wavelengths beyond 900 nm. The output of these photodetectors provide the appropriate waveforms for the REF IN signal of the *Model 3930*.

1. Verify the output of the *Model 3932* is 0 dbm into a 50 Ω termination (0.63 V_{pp}).
2. With the *Model 3930* unlocked, place a photodiode (e.g., an ET2000) at the source of the experiment.
3. Adjust the optical alignment so that the pulse train for each laser can be identified.
4. Mode lock the non-*LTC* laser.
5. Using the *Model 3930*, set up and lock the *LTC Tsunami* as outlined in "Operation Notes" above.

The oscilloscope display should now show two pulse trains with a fixed delay. The pulse trains are now synchronized but are probably not overlapped in time.

6. Verify the time between the pulse trains can be varied by using the coarse TIMING control on the *LTC Tsunami* laser.

   The timing control provides up to 2 ns of adjustment. If the pulses are more than 2 ns apart, change the length of the cable between the *Model 3930* and the *Model 3932* (30 cm of cable corresponds to about 1 ns of delay). *Do not modify the cables between the LTC laser head and its Model 3955!* When the cable length is optimized, activate the sweep generator (press the TIMING button) on the *Model 3930* and observe the pulses from the *LTC Tsunami* sweeping back and forth over those from the mode-locked laser.

   To overlap the pulses more precisely in time, focus the two laser output beams in a nonlinear crystal such as BBO.* As you sweep through the phase-matching angle of the BBO crystal, a frequency-doubled signal should be observed from each laser. Set the crystal for an intermediate angle to observe the sum-frequency mixed signal from both lasers. By activating the sweep generator, the crystal can be easily phase-matched for observation of this signal. It will be modulated at the 10 Hz sweep period. Once the sum-frequency mixed signal is observed, deactivate the sweep generator and use the coarse/fine TIMING controls to optimize this signal.

   A cross-correlation of the two pulses can be generated by displaying the sum frequency mixed signal on a photodetector and activating the sweep generator. Alternatively, the cross-correlation signal can be observed by sending the spatial and temporally overlapped beams into an autocorrelator, such as the *Model 409-08*. Figure 8-9 shows a typical cross-correlation trace for a ps *LTC Tsunami* lasers and a second mode-locked ps laser, each having 1.5 ps pulse widths.

* *The nonlinear crystal must be cut such that it can frequency-double the output of each laser. Verify this by temporarily placing a white card at the output of the crystal and changing the phase-matching angle of the crystal while watching the laser output on the card.*

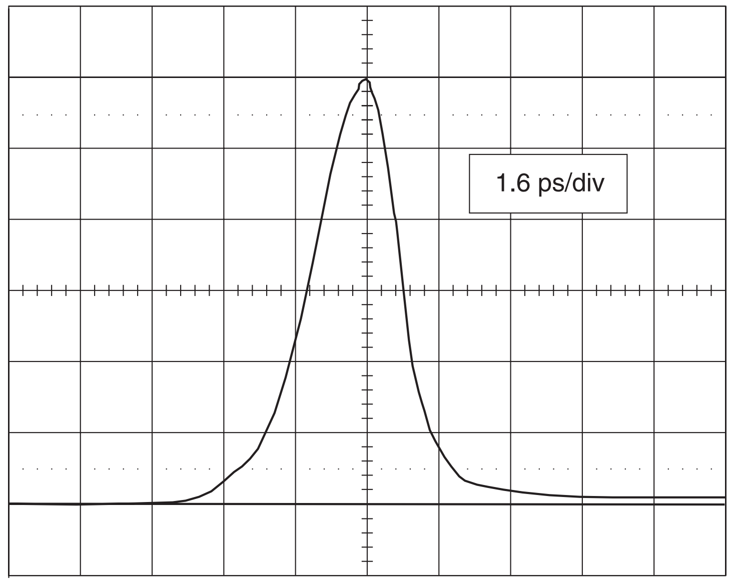

Figure 8-9: Typical Cross-correlation Signal for an *LTC Tsunami* Laser and Mode-locked Laser. Δτ = 2.4 ps FWHM.

Operating a Model 3941D/3950D/3960D Without the Model 3930

Refer to Figure 8-10 for pin descriptions of the D-sub *Lok-to-Clock Tsunami* To 3930 connector. It also shows the schematic for the M_1 limit switch optointerruptor electronics incorporated in the *Tsunami*.

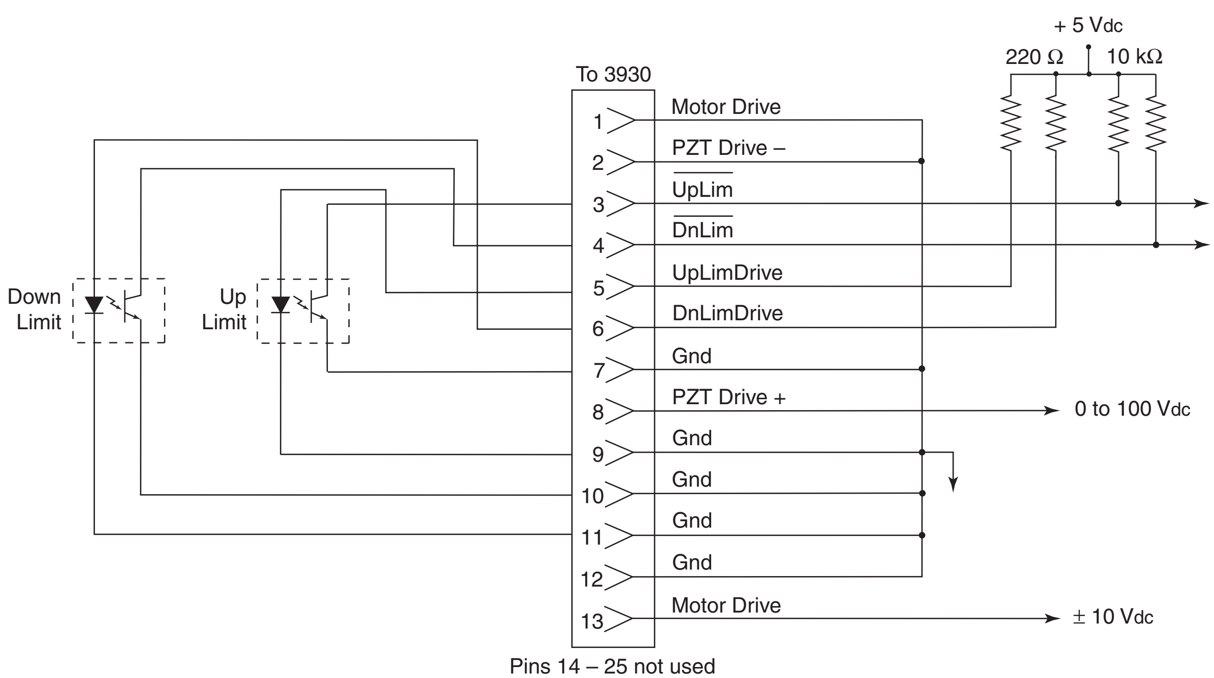

Figure 8-10: The TO 3930 Connector

To set the position of M_1, the coarse cavity length control, apply a 0 to +10 Vdc signal across pins 13 and 1 to lengthen the cavity and reduce the frequency, or a 0 to −10 Vdc signal to shorten the cavity and increase the frequency. To set the position of PZT-driven mirror M_4 (the fine cavity length control), apply a 0 to 100 Vdc signal across pins 8 and 2 to modify the position of the M_4 mirror. In most cases, unless you also provide a closed-loop feedback circuit for monitoring power output, driving the M_4 mirror with user-supplied equipment is not recommended and serves little purpose. If you need this high-speed noise reduction, upgrade your system to a *Model 3941C*, *3950C* or *3960C* and purchase the *Model 3930*.

Warning!

You must employ the limit switches if you intend to drive M_1 using your own equipment. This insures the motor drive mechanism will not be damaged if you exceed the drive limits. Any such damage is not covered under your warranty!

When operating between end limits, the limit switch signals $\overline{\text{UpLim}}$ and $\overline{\text{DnLim}}$ are high. A low signal indicates the limit has been reached. A suggested motor drive circuit is shown in Figure 8-11 which includes relays that are used to disable the drive signal when the limit is reached in each direction. Provide an off switch as shown to ensure there is no creep after M_1 has been properly positioned. Make all the appropriate connections to ground. Remember to provide the +5 Vdc and the 220 Ω pull-up resistors as shown in Figure 8-10 to drive the optical side of the limit switches, and the 10 kΩ pull-up resistors for the limit switch output signals. The +5 Vdc in Figure 8-10 is the same +5 Vdc that should be used to drive the relays in Figure 8-11.

The limit switches restrict the total range of coarse travel to about 1.25 cm. This corresponds to a change in laser repetition rate of over 500 kHz. Note that when you tune a fs *Tsunami* laser over a given optics set, as the dispersion is adjusted for optimum pulse width performance, the repetition rate (cavity length) is changed by over 300 kHz. The coarse control allows you to maintain a reasonably constant cavity length as the wavelength is tuned.

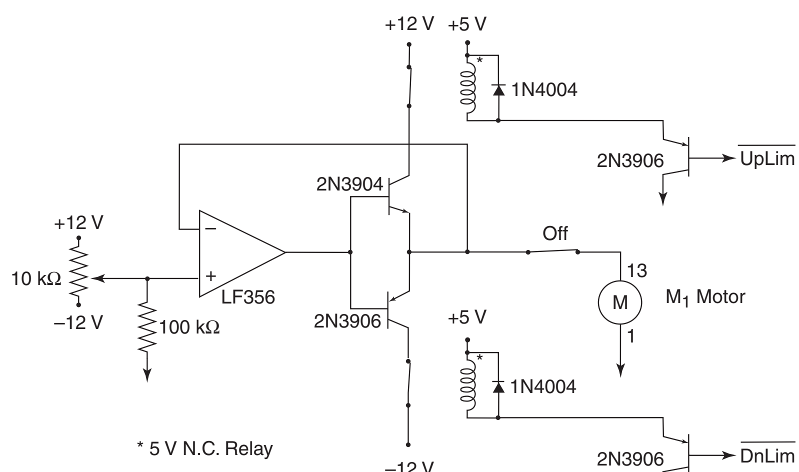

Figure 8-11: A suggested schematic for driving the coarse position M_1 motor.

Lok-to-Clock Computer Interface

The *Lok-to-Clock* computer interface allows for computer control and monitoring by any computer which has an RS-232 interface. Communications are at 9600 baud, with no parity, 8 data bits, and one stop bit, using the XON/XOFF protocol.

The 9-pin D-subminiature connector is designed for easy use with "PC-compatible" computers. A one-to-one, 9-wire "extension" cable, available from your local supplier, should be all that is required. Here are the pin definitions, in case you need to build your own cable:

Pin Number	Name	Interpretation
2	TXD	Data output from the Model 3930
3	RXD	Data input to the Model 3930
5	SIGGND	Signal ground

The same pinout is used on the *Model 3931* long-range phase shifter (2π shifter ~12 ns of delay). If you have purchased a *Model 3931*, connect the extension cable from the TO 3930 connector on the *Model 3931* to the RS-232 input connector on the Model 3930, and attach your computer to the RS-232 connector of the *Model 3931*.

The Model 3930 Command Set

The table below lists the RS-232 commands and queries for the *Model 3930*. The sections that follow describe each command in detail. These commands and queries follow the Standard Commands for Programmable Instruments, or SCPI, standard. However, since the SCPI consortium did not have lasers in mind when they developed the standard, many of these commands are specific to the *Model 3930* and are not part of the SCPI standard. Also, only the "short" form, 4-letter command/query of the SCPI command set is recognized by the *Model 3930*.

Table 8-1: The SCPI Command Set

SOURce	STATus	SYSTem	*CLS
:LOOP	:OPERation	:ERRor?	*ESE
:LOOP?	:EVENt?	:VERSion?	*ESE?
:LMON	:CONDition?		*ESR?
:DC?	:ENABle		*IDN
:AC?	:ENABle?		*OPC
:PZT	:QUEStionable		*OPC?
:DC?	:EVENt?		*RST
:AC?	:CONDition?		*SRE
:DLY	:ENABle		*SRE?
:DLY?	:ENABle?		*STB?
:LDLY	:PRESet		*TST?

Table 8-1: The SCPI Command Set

:LDLY?	*WAI
:FREQ	
:UP	
:DN	

General comments on the SCPI Standard Protocol

a. Commands are always terminated by an ASCII line feed character (Indicated by <LF>.)

b. Commands may be combined if separated by semicolons. Commands which branch from the same tree level need not repeat the headers leading to that level.

c. Parameter and return values for the status registers are spelled out in ASCII, not sent as single characters. For example, if the only non-zero bit in the status register is bit 1, then *STB command returns the ASCII character “2” (hex value 0x32, binary 0010). To set all bits in a mask register to one, use a parameter value of 255.

Examples:

DLY 100<LF>	sets the delay to 100
DLY 100;DLY?<LF>	sets the delay to 100, then reads the set value
LMON:AC?;DC?<LF>	reads the AC and DC components of the loop monitor
LMON:AC?;:PZT:AC?<LF>	reads the AC value of the loop monitor, then the AC value of the PZT monitor.
*ESE 255<LF>	sets all bits in the Event Status Enable register to one

:SOURce—optionally precedes the commands which branch out below it.

For example,

SOUR:LOOP 1

and

LOOP 1

are equivalent.

:LOOP <parameter>—turns the locking loop off (if the parameter is zero) or on (if the parameter is non-zero). The following sequence occurs when the loop is turned on:

a. The system enters the “acquisition mode” where the coarse cavity length control (motor mike) is used to bring the laser repetition rate to within the range of the fine length control (the PZT). During this phase, the “acquisition” and “loop on” bits of the status byte are set.

b. The system enters "locked" mode, and the PZT locking loop is engaged. The "acquisition" bit of the status byte is cleared, the "loop on" bit stays set.

c. The PZT voltage is continuously monitored, and the motor mike is servoed to keep it in range. The status byte remains unchanged.

Examples:

LOOP 0	turns loop off
LOOP 1	turns loop on

:LOOP?—returns a "1" if the loop is on, a "0" if it is off. If the system is in acquisition mode, this query returns a "1". (This query mirrors the "loop on" bit in the status byte.)

:LMON:DC? and **:LMON:AC?**—return the DC and AC portions of the loop monitor signal. These are essentially meaningless when the loop is off. When the loop is on, the absolute value of the DC portion is typically less than about 40, while the AC component is typically 5 or less. The loop monitor is a more sensitive indicator of loop operation than the PZT voltage.

:PZT:DC? and **:PZT:AC?**—return the DC and AC portions of the PZT voltage. These are essentially meaningless when the loop is off. When the loop is on, the DC value is 0 when the PZT is centered. Auto-centering will keep the absolute value of the DC value less than about 400. The AC reading is typically less than 10.

:DLY <parameter>—sets the value of the timing adjustment, with parameter values from 0 to 4095 adjusting the timing by approximately 2 ns.

This setting is added to the timing adjustment set by the front panel knobs. For consistent results, the front panel coarse and fine timing adjustment controls should be set fully clockwise.

:DLY?—returns the delay set by the DLY command (which is zero at power-up).

:LDLY <parameter> and **:LDLY?**—are similar to the :DLY and :DLY? command and query. The difference is that the values of the parameter and reply range from 0 to 65535 and the timing adjustment range is greater than or equal to 12.5 ns (2π radians at 80 MHz).

Note

The DAC used is not guaranteed to be monotonic beyond 14 bits, and the phase shifter itself is not perfect. It is possible that small changes in the LDLY setting will not move the delay in the expected direction.

Note

If this command is issued to the *Model 3930*, a "Hardware not present" error will be generated. This command is only valid if the *Model 3931* is present.

Note

This command and query are the only ones which do not allow the normal flexibility of the SCPI standard. The command/query must be the only item before the <CR> or <LF> termination. No error is generated if commands/queries are not properly formatted. Commands/queries may not be combined on one command line.

Examples:

LDLY 10000 sets the delay to 10000

LDLY? the system would respond “10000<LF>”

:LDLY 100 is ignored, because of the leading colon

:FREQ:UP and **:FREQ:DN**—“jog” the coarse cavity length control to bring the laser to a slightly higher or lower repetition rate when the loop is not locked. The change in repetition rate is approximately 15 Hz. If the loop is locked, the net effect will be to move the PZT operating position until the servo pushes it back toward center.

The following SCPI commands are not valid for use with the *Model 3930* because the bits in these registers are defined by SCPI with meanings that do not apply. Event and condition queries will always return “0<LF>”.

:STATus
- **:OPERation**
  - **:EVENt?**
  - **:CONDition?**
  - **:ENABle**
  - **:ENABle?**

:QUEStionable
- **:EVENt?**
- **:CONDition?**
- **:ENABle**
- **:ENABle?**

:STATus:PRESet—performs the following:

a. Sets the STAT:OPERation and STAT:QUES event enable registers to 0.

b. Has no effect on the STAT:OPER and STAT:QUES event registers.

c. Has no effect on the error/event queue.

d. Has no effect on the Standard Event Status Register (*ESE?), service request enable (*SRE?), or status byte (*STB?) registers.

:SYSTem:ERRor?—returns the next entry in the error/event queue. The return format is <number><comma><“description”>.

For example,

–100,”Command Error”

:SYSTem:VERSION?—returns “1994.0”, which corresponds to the relevant version of the SCPI standard.

***CLS**—performs the following:

a. Clears the Standard Event Status Register (SESR).
b. Clears the STAT:OPER event status register.
c. Clears the STAT:QUES event status register.
d. Clears the error/event queue.
e. Updates the status byte to reflect these changes.

***ESE <parameter> and *ESE?**—set/read the Event Status Enable Register (ESER). This is used as a mask for the bits in the Standard Event Status Register (SESR), which is read with the *ESR command. Both the parameter and the return value are in the range 0 to 255.

***ESR?**—reads and clears the Standard Event Status Register (SESR). The value is in the range 0 to 255.

***IDN?**—returns the product identification string. This string contains four fields, separated by commas. The fields are, in order from left to right, the manufacturer, the product, the serial number of the product (optional) and the firmware revision of the product (optional). A typical response from the *Model 3930* is "Spectra Physics,3930,0,1.00"

***OPC**—is one of the synchronization commands, and indicates that the product should set the Operation Complete (OPC) bit when the current operation is finished. Since this device implements only sequential commands, the "current operation" is the interpretation of this command; thus, the OPC bit is set immediately.

***OPC?**—returns a "1" when the operation is complete (when this command has executed).

***RST**—resets the *Model 3930*. Reset means:

a. The loop is turned off (if on)
b. The status structures are not affected.
c. The delay setting (DLY) is set to zero.
d. The long delay setting (LDLY) in the *Model 3931* is not affected.

***SRE <parameter> and** *SRE?—sets/reads the Service Request Enable (SRE) mask register. Note that bit 6 is ignored (decimal value 64), since that is the service request bit of the status byte. Both the parameter and the return value are in the range 0 to 255.

***STB?**—reads the status byte. The returned value is 0 through 255. The bits in the status byte are:

Bit	Name	Comments
0	ACQ	1 if the system is in acquisition mode
1	LON	1 if the loop is on
2	QUEUE	1 if the error/event queue is not empty 0 if the error/event queue is empty
3	QUES	Summary bit for the STAT:QUES condition (EVENT????) register

Bit	Name	Comments
4	MAV	Message Available
5	SESR	Summary bit for the Standard Event Status Register
6	RQS	Service request summary
7	OPER	Service request summary

***TST?**—executes a self test. The reported value is:

0 – test was successful
1 – no reference oscillator input signal
2 – no laser photodiode input signal

***WAI**—executes a "no-op." The *Model 3930* implements only sequential commands (no command is executed until the previous one is completed). Thus, this "wait" command is essentially a "no-operation."

Differences between the Lok-to-Clock implementation and the SCPI standard

1. Only the four-letter forms of the commands are implemented. The "long form" of a command will not be recognized.
2. STATus:OPERation:EVENt and STATus:QUEStionable:EVENt must be sent in their entirety. The *Model 3930* will not recognize the default "EVENt" node.
3. MIN and MAX may not be sent when numeric data is expected. For example, ":LDLY MIN" will generate an error, whereas the SCPI standard requires it to be interpreted the same as ":LDLY 0".
4. Rounding and interpretation of numeric data is not as robust as the SCPI standard requires. Do not send numbers in exponential format. For example, ":LDLY 100" will be interpreted correctly, whereas ":LDLY 1E2" will not.
5. The *Model 3930* interprets a carriage return as a legal terminator (SCPI mandates line feed). A carriage return/line feed combination is also acceptable.
6. The :LDLY <parameter> command and :LDLY? query must be sent individually. They may not be combined with other commands, or with each other.

Chapter 9 Maintenance

The condition of the laboratory environment and the amount of time you use the laser affects your periodic maintenance schedule. The coated surfaces of the elements forming the laser cavity—the output coupler, GTI or high reflector, prisms, birefringent filter (ps version), mode locker, fold and focus mirrors, and rod surfaces—most directly affect the performance of the laser.

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

If the laser head cover is left in place, there is little you must do day-to-day to maintain the laser. To create a dust-free environment, allow purging, and eliminate time-consuming maintenance, the *Tsunami*® laser head is sealed. All controls required for day-to-day operation are accessible from the outside. The *Model 3910* purge regulator/filter is provided as part of the system to facilitate cavity purging. The clean, dry, nitrogen gas keeps dust and moisture out of the laser head. Therefore, the laser head cover should only be removed when absolutely necessary, e.g., when changing its configuration from ps to fs and vice versa, or when changing optic sets.

Although rarely required, you must change the filters in the *Model 3910* purge unit from time to time when the desiccant in the sieve assembly turns pink. Refer to the *Model 3910* section at the end of this chapter.

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, the operating efficiency of the optical coating can be reduced significantly and the coating can degrade.

Lasers are oscillators that operate with gain margins of a few percent. Losses due to unclean intracavity optics, which might be negligible in ordinary optical systems, can disable a laser. Dust on optical surfaces can cause loss of output power, damage to the optics or total failure. Cleanliness is essential, and you must apply laser optics maintenance techniques 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 or canned air
- rubber squeeze bulb
- optical-grade lens tissue
- spectroscopic-grade methanol and/or acetone
- hemostats
- clean, lint-free finger cots or powderless latex gloves

Standard Cleaning Procedures

Follow the principles below whenever you clean any optical surface.

- Clean only one element at a time, then realign that element for maximum output power.

  If optics are removed and replaced as a group, some might get swapped. At best, all reference points will be lost, making realignment extremely difficult.
- Work in a clean environment and, whenever possible, over a soft, lint-free cloth or pad.
- 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 finger cots or gloves when handling optics and intracavity parts.

  Remember not to touch any contaminating surface while wearing gloves; you can 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.

[*]*Kodak Lens Cleaning Paper is a trademark of the Kodak Corporation*

- 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

With the exception of the rod, the AOM, the GTI (ps configuration), and prisms (fs configuration), all optics must be removed from their mounts for cleaning. However, only mirrors M_3, the output coupler M_{10}, the Brewster windows, and the beam splitter must be removed from their holder to clean the second surface.

Caution!

DO NOT remove or adjust fs prisms Pr_1 to Pr_4, or adjust the mirror mounts of M_6, M_7, M_8, or M_9. These optics are prealigned at the factory and are not to be disturbed unless specifically told to do so elsewhere in this manual. A service call might be required if disturbed.

Warning!

When replacing optics holders, *DO NOT* tighten them too much or you will press the optic against the three steel alignment balls too hard and chip the optic. Simply screw on the holder until you feel contact. Also, be careful not to cross-thread the holder when you screw it on.

1. Use a squeeze bulb or dry nitrogen to clean away any dust or grit before cleaning optics with solvent. If canned air is used, hold the can in an upright position to avoid liquid freon from contaminating the optic.
2. Whenever possible, clean the optic using the "drop and drag" method (Figure 9-1).
   a. Hold the optic horizontal with its coated surface up. Place a sheet of lens tissue over it, and squeeze a drop or two of acetone or methanol onto it.
   b. Slowly draw the tissue across the surface to remove dissolved contaminants and to dry the surface.

      Pull the tissue slow enough so the solvent evaporation front immediately follows the tissue.

Q-Tips is a trademark of the Johnson & Johnson Corporation

Figure 9-1: Drop and Drag Method.

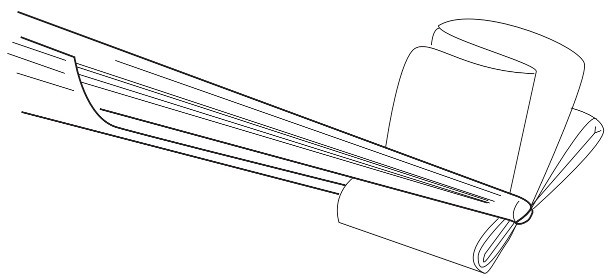

Figure 9-2: Lens Tissue Folded for Cleaning

3. For stubborn contaminants and to access hard-to-reach places, 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 square, and clamp it in a plastic hemostat (Figure 9-2).

Caution!

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

   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.
   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. Inspect the cleaned optic under ample light to verify the optic actually got cleaner, i.e., you did not replace one contaminant with another.

Removing and Cleaning Tsunami Optics

Danger!
Laser Radiation

Tsunami is a Class IV High Power Laser. Bypassing the safety inter lock shutter can expose the user to hazardous radiation. Always wear proper eye protection and follow the safety precautions in Chapter 2, "Laser Safety."

For safety, always close the pump laser shutter when you change optics. Remove, clean, and install mirrors one at a time, in sequence, to avoid accidental exchanges and loss of alignment reference. After cleaning and replacing each mirror, open the pump laser shutter, and (with the exception of M_3) adjust the particular mirror vertically and horizontally for maximum output power, followed by an adjustment of M_1 and M_{10} for maximum output power. Iterate your adjustment of M_1 and M_{10} until no further increase in power is possible. Only then proceed to clean the next optic.

Inspect the optics for dirt or contamination. If dirty, clean the optics in the following order until the system meets specifications. This list orders the optics by influence in power loss. Naturally, clean those that are obviously dirty first. You should not have to clean every optic. Note: if an optic is dirty, an IR viewer will usually show unusual scatter.

1. Input and output Brewster window surfaces
2. Prisms
3. Rod surfaces
4. Bi-fi (ps configuration), *outside surfaces only*
5. P_1, P_2
6. M_3 (both surfaces)
7. M_2
8. M_4, M_5
9. M_7, M_8
10. M_6, M_9
11. M_{10}, M_1 (fs) or GTI (ps)
12. A/O modulator (AOM)
13. Beam splitter (highly unlikely that it will need cleaning)

With the exception of pump mirror P_1 and the GTI (ps configuration), all mirrors are captured and held in place by a screw-in holder. Unscrew the holder and the mirror will come out with it. The optic is retained in the holder by a small o-ring, and it is removed by simply grabbing the exposed barrel and pulling it straight out of the holder. In most cases, the optic does not have to be removed from its holder to clean it.

Each optical element has a v-shaped arrow on its barrel along with its part number. The arrow points to the coated surface that faces the intracavity beam. If you need to verify the location of the optic in the laser, refer to the tables located at the end of Chapter 10, "Options and Accessories."

If your laser becomes badly misaligned, refer to Chapter 6, “Alignment,” for alignment procedures.

The cleaning procedures that follow are placed in the order of importance that the optics described contribute to loss of laser output power.

Brewster Windows

Brewster-angle windows are incorporated at the input and output ends of *Tsunami* to seal the laser head, to allow it to be purged with nitrogen. From time-to-time the windows require cleaning.

1. Close the pump laser shutter.
2. Remove the windows.

   Remove the screws (2) holding each window in place, and remove the windows by pressing them out from inside the cavity. *Take care not to damage the window.*
3. Clean each surface.

   Use a folded tissue and hemostat according to Step 3 of “General Procedures for Cleaning Optics.”
4. Install the windows.

   Referenced from the outside, the input window should face downward, and the output window upward.
5. Install and tighten the mounting screws. Do not overtighten.
6. Open the pump laser shutter.

Prisms (fs Configuration)

Caution!

DO NOT remove or adjust the prisms to clean them: they are aligned at the factory and are not to be disturbed unless specifically told to do so elsewhere in this manual. A service call might be required if disturbed. Clean them in place.

1. Close the pump laser shutter.
2. Clean the prisms in place. Use a separate folded tissue and a hemostat to clean the surface of each prism as outlined in Step 3 of “General Procedure for Cleaning.”
3. Open the pump laser shutter.

Ti:sapphire Rod

Laser performance is extremely sensitive to dirt on the rod surfaces. A small portion of rod protrudes from the end of the holder to allow easy access for cleaning. Refer to Figure 6-5.

Warning!

NEVER remove the rod from its mount. The rotational alignment of the Ti:sapphire rod is critical and has been optimized at the factory. Any modification or adjustment other than that made by a qualified Spectra-Physics Lasers service engineer will void the warranty.

1. Close the pump laser shutter.
2. Clean the rod surface using a folded tissue in a hemostat according to Step 3 of “General Procedure for Cleaning Optics.”
3. Open the pump laser shutter.

Birefringent Filter (ps configuration)

Typically, only the upward-facing surface of the birefringent filter gets dusty, and it can be cleaned without removing the filter.

1. Close the pump laser shutter.
2. Clean the top surface using a tissue and hemostat according to Step 3 of “General Procedure for Cleaning Optics.”

Warning!

The birefringent filter stack is carefully aligned at the factory. *NEVER* disassemble the filter stack.

On rare occasions, the lower surface requires cleaning:

3. Remove the filter from its mount.
   a. Turn the micrometer counterclockwise until the mounting set screw of the filter holder is accessible (Figure 9-3).
   b. Loosen the setscrew using the Allen wrench provided in the tool kit, and gently lift the filter assembly out by its mounting ring.
4. Clean each surface using a folded tissue and hemostat according to Step 3 of “General Procedure for Cleaning Optics.” Use very little pressure; the filter is made of thin material and is easily damaged.
5. Install the filter assembly.
   a. Install the filter into the holder.
   b. Refer to Table 6-3 in Chapter 6 for information on aligning the filter in the holder.
   c. Once the filter is properly oriented, tighten the mounting setscrew to clamp it in place, but do not clamp it too tight or you will break the filter.

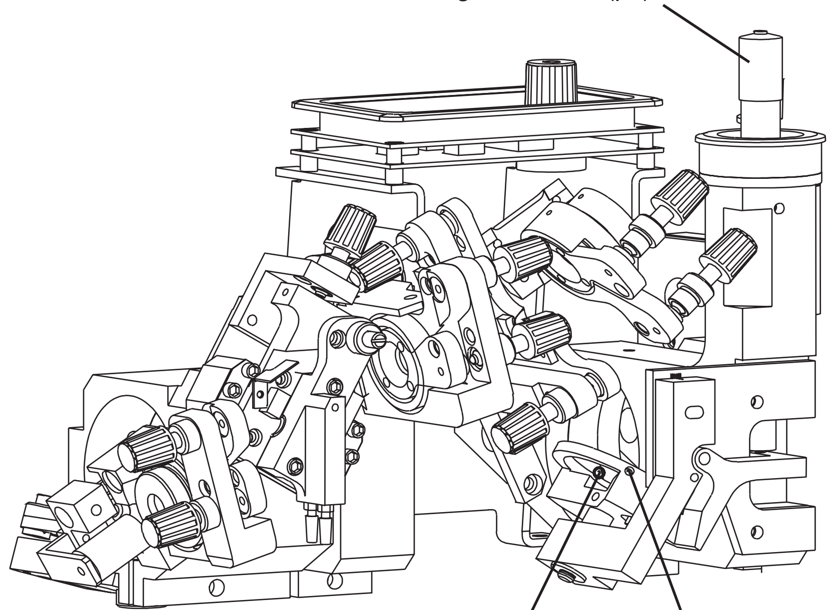

Figure 9-3: Birefringent Filter

6. Open the pump laser shutter and use the vertical and horizontal controls of M_{10} to adjust for maximum output power.

Pump Mirrors P_1 and P_2

The P_1/P_2 mirror set is not changed when wavelength ranges are changed. And because they are not part of the laser cavity, they are less sensitive to contamination and need little cleaning. Therefore, they rarely need to be removed. Furthermore, since the pump beam alignment is very dependent on the orientation of these mirrors, any removal or replacement might require a more extensive realignment of the entire laser. However, if these mirrors do become excessively dusty, cleaning them might improve laser performance.

Unlike the other mirrors, P_1 is held in place by a spring-clip (Figure 6-5).

1. Close the pump laser shutter.
2. Remove the beam shield to access P_1.
3. Remove the P_1 optic by pulling back on its retaining spring with a small, clean screwdriver while extracting the optic with a plastic hemostat.
4. Wearing clean gloves or finger cots, clean the surface using the "drop and drag" method outlined in Step 2 of "General Procedures for Cleaning Optics."
5. Return the optic to its mount. Be sure the optic seats properly.

6. Open the pump laser shutter and align the mirror vertically and horizontally for maximum output power.
7. Replace the beam shield if you do not intend to clean M_3.

Pump mirror P_2 is cleaned in the same manner as focus mirror M_2 below.

Focus Mirror M_3 and Output Coupler M_{10}

1. Close the pump laser shutter.
2. Reach in from both sides of the OC mount and unscrew the knurled M_{10} mirror holder (Figure 9-4).
3. Wearing clean finger cots or gloves, hold the mirror by its barrel and pull it from its holder.
4. Clean the output surface using the "drop and drag" method outlined in Step 2 of "General Procedures for Cleaning Optics."
5. Install the optic in its holder with the output surface facing into the holder.

   Press it in until the O-ring captures it. *Do not press on its optical surface.*
6. Clean the cavity side in the same manner.
7. Screw the mirror holder into its mount.

   Finger tight is sufficient.
8. Open the pump laser shutter, and adjust M_{10} to restore maximum power.
9. Close the pump laser shutter.
10. Remove and clean the M_3 focus mirror as you did M_{10}, cleaning the pump beam input surface first, then the intracavity surface.
11. Install the mirror holder into its mount.
12. Replace the beam shield removed for cleaning P_1.
13. Open the pump laser shutter and adjust M_3 vertically and horizontally for maximum output power. *Do not adjust the slide.*
14. When M_3 is replaced, place a white card in front of M_5, and adjust P_2 to overlap the two fluorescent ovals so they form a cross-shaped image. Then remove the white card and adjust M_3 until the system lases.
15. Verify the laser beam is centered on mirrors M_1 to M_5, as well as M_{10}. Adjust the photodiode pc board if required (refer to the "Aligning the Photodiode PC Board" in Chapter 6).

High Reflector M_1, Focus Mirror M_2, Fold Mirrors M_4 and M_5, and Prism Mirrors M_6 to M_9

1. Close the pump laser shutter.
2. Remove each mirror, one at a time, starting at M_1 and ending at M_9 (but not M_3), but do not remove the element from its holder. Refer to Figure 4-3 and Figure 4-4.

3. Wearing clean gloves or finger cots, clean each mirror surface using the “drop and drag” method outlined in Step 2 of “General Procedures for Cleaning Optics.”
4. After each mirror is cleaned, screw the mirror holder back in place. Take care not to cross-thread the holder.
5. Open the pump laser shutter and adjust the optic just cleaned for maximum output power.
6. Close the pump laser shutter again before removing the next mirror.

Continue in this manner until either specified power is reached, or all the optics are clean.

GTI (ps configuration)

1. Close the pump laser shutter.
2. Remove the GTI for cleaning. Clean the exposed optic using a folded tissue and hemostat as described in Step 3 of “General Procedure for Cleaning Optics.”

Warning! Do not disassemble the GTI for cleaning. You will damage it and void the warranty. If internal contamination is evident, contact your Spectra-Physics service representative.

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3. Open the pump laser shutter and adjust the GTI vertically and horizontally for maximum output power.

A/O Modulator (AOM)

The AOM is a very delicate, electrical acousto-optic device, and must be disconnected from the laser head pc board and removed from the laser head for cleaning. *Do not clean it unless absolutely necessary.*

Danger! The pc board on the floor of the laser head contains high voltage to drive the GTI (ps configuration). Turn off the *Model 3955* electronics module to disable this board.

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1. Close the pump laser shutter.
2. Turn off the *Model 3955* electronics.
3. Disconnect the SMA cable from the top of the AOM SMA connector (Figure 9-4) by unscrewing it.
4. Remove the cover to the laser head pc board (3 screws).
5. Disconnect the AOM heater cable from the J_3 connector on the laser head pc board.
6. Loosen the mounting setscrews (2) at the base of the AOM and carefully slide the modulator from its mount.

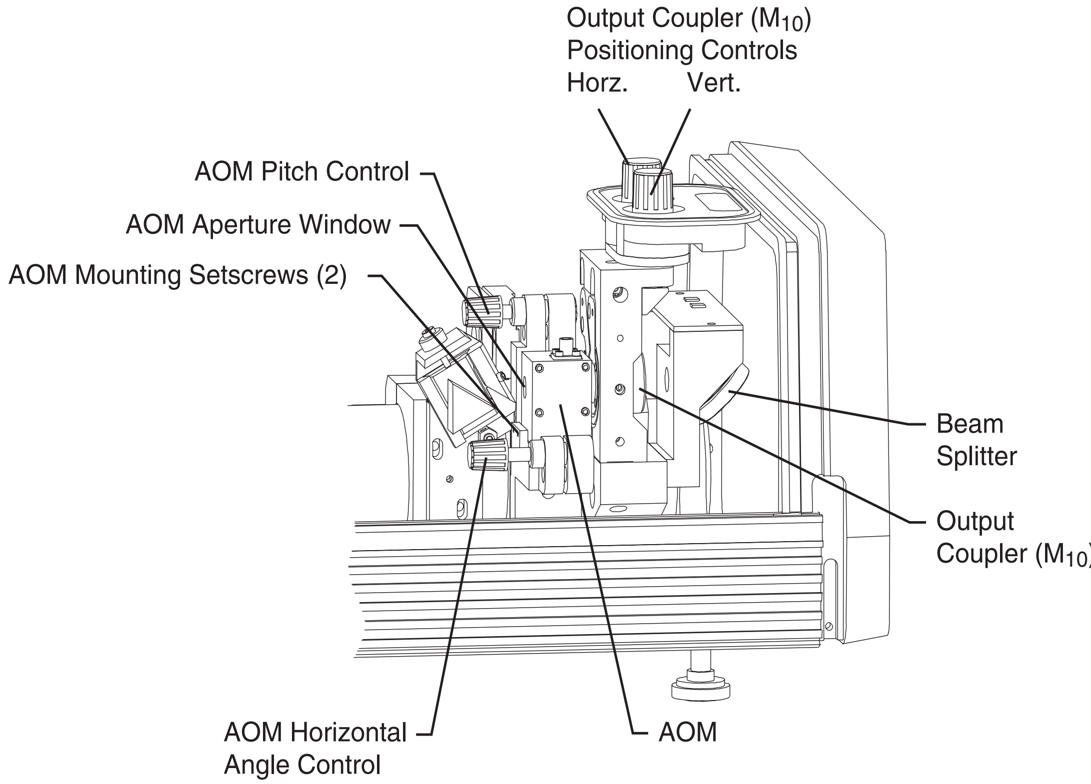

Figure 9-4: AOM, Output Coupler M_{10}, and Beam Splitter

7. Remove the screws (4) holding the input and output cover plates in place and remove the cover plates to expose the crystal.
8. Clean the two sides of the crystal using a folded tissue and hemostat as described in Step 3 of "General Procedure for Cleaning Optics."

Warning! The small wires attached to the crystal can be easily broken. Exercise care when handling them.

9. When finished cleaning, reverse Steps 2 through 7 to install the AOM in the laser.
10. Open the pump laser shutter and adjust M_1 and M_{10} vertically and horizontally for maximum output power. *Do not adjust the slide.*
11. Verify the beam is still centered on M_{10}. If it is not centered, iterate adjustments of M_5 and M_{10} until it is.
12. Verify the beam is still centered on the AOM.

If realignment of the AOM is required, refer to Chapter 6, "Alignment: Aligning the A/O modulator (AOM)."

Beam Splitter

Because the beam splitter is outside the cavity and covered by a housing, and because the laser head is sealed and purged, it is unlikely the beam splitter will require cleaning. We urge you to refrain from doing so.

1. Close the pump laser shutter.
2. Remove the beam splitter by unscrewing its holder from the mount (Figure 9-4).
3. Remove the optic from its holder, and follow Step 2 of "General Procedure for Cleaning Optics" to clean both sides.
4. Install the optic in its holder (either side can face upward), and screw the holder back into place. Take care not to cross-thread the holder.
5. Because the beam splitter is wedge-shaped (i.e., there is a natural beam offset, but the direction is unknown), the photodiode pc board might require realignment. Refer to Chapter 6, "Alignment: Aligning the Photodiode PC Board."
6. Open the pump laser shutter.

Routing Mirrors

Because the routing mirrors are outside the cavity and are enclosed, it is unlikely they will require cleaning unless the dust tubes are removed for a long period of time. Cleaning them is easy. Refer to Figure 5-2.

1. To access the mirror, unscrew the two screws on top of the unit and remove the cover.
2. Clean the mirror in place using a folded tissue and hemostat as described in Step 3 of "General Procedure for Cleaning Optics."
3. Replace the cover and the two screws.

Replacing Filters in the Model 3910 Purge Unit

The schedule for replacing the filters and dryer/sieve assembly depends on the amount and quality of purge nitrogen used. Change all three filters (Figure 9-5) when the blue desiccant in the sieve assembly turns pink. In some areas, the indicator dye in the desiccant is considered a hazardous material. Consult your materials manager and/or local government environmental agency for guidelines on proper disposal methods. Refer to the Material Safety Data Sheets in Appendix D for information on the materials contained in these filters.

Part numbers for filters are listed in Table 11-3, "*Model 3910* Purge Unit Filter Hardware."

To replace the filters and sieve assembly:

1. Turn the unit upside down with the flow gauge facing away from you, and remove the small screws (2) on the side nearest you.
2. Disconnect the filter assembly from the flow gauge and output port.

   Press in on the connector spring-clips and pull out the hoses.

3. Rotate the entire filter assembly so the small filters point upward, then move the assembly to the right (away from the flow gauge) and lift it out.
4. Remove the filter hose fittings.

   Note the placement and orientation of each filter before disassembling the hoses (Figure 9-5). Loosen the screws and remove the filter assemblies.
5. Discard the filter assemblies.
6. Assemble a new filter assembly from new parts.

   The screws at each end of the two small filters should be tight. However, over-tightening will crack the plastic.
7. Place the new filter assembly in the box and connect and secure it in reverse order of disassembly.

   Push the hose fittings into their mating connectors until they snap into place.

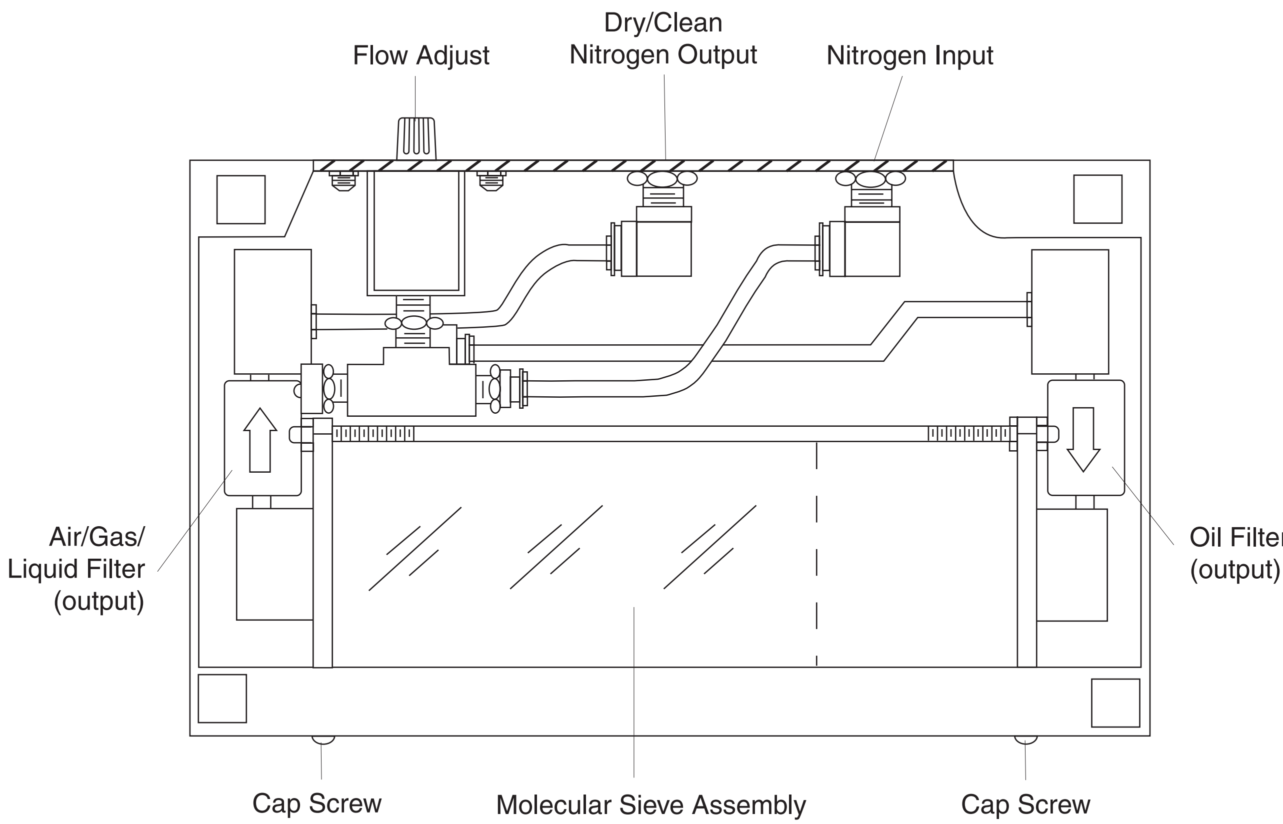

Figure 9-5: Underside of *Model 3910* showing filter assembly placement and orientation.

Chapter 10 Options and Accessories

Spectra-Physics provides options and accessories to enhance and expand the performance and flexibility of your *Tsunami*® laser. If you need additional information on these items, contact your Spectra-Physics sales representative.

Options

Ultrashort (< 50 fs) Pulse Option

All *Tsunami* systems with a serial number suffix "G" can be upgraded to provide output pulses of < 50 fs. The ultrashort pulse option is available only for the standard wavelength region with a specification of < 50 fs at > 1.0 W at 790 nm for a *Millennia Xs* pump source. The upgrade part number is 0449-1050S.

Ultrashort (< 35 fs) Pulse Option

For this configuration, the pulse width of the *Tsunami* is specified at < 35 fs over a tuning range from 780 to 820 nm. With a *Millennia Vs* pump laser, output energies at 800 nm exceed 400 mW.

Because major changes to the cavity configuration are required, this upgrade is only available as a factory option.

Broad Femtosecond Pulse Option

The broad fs pulse option provides 150 fs to 1 ps output pulse capability. The option comprises special GTIs that are used for dispersion compensation in conjunction with the prism sequence.

Broad Picosecond Pulse Option

The broad ps pulse option delivers transform limited 10 to 80 ps pulses. Power is specified at 1.5 W at 30 and 60 ps for a *Millennia Xs* pump source. The broad pulse option uses special GTIs and a 2 or 3-plate birefringent filter.

76 MHz Option

The *Tsunami* cavity can optionally operate at 76 to 83 MHz in addition to the standard 80 and 82 MHz repetition rates. This is a factory option. Contact your Spectra-Physics service representative for more information.

Lok-to-Clock® System

The *Lok-to-Clock* system comprises the *Model 3930* electronics module, a motor-driven high reflector in the *Tsunami* laser, and a PZT-driven mirror at M_4. Using a phase-locked loop, the pulse train of the *Tsunami* laser is precisely synchronized to a reference source. An internal 80 MHz reference oscillator is provided with the system. Alternatively, an external RF source or another laser can be used as the reference source. If another mode-locked laser is used as the reference source, then an external photodiode, such as the *Model 3932*, is required to provide the appropriate signals to the *Model 3930* electronics. The *Model 3930* also provides a 10 MHz reference for use with other equipment.

Accessories

Model 409-08 Scanning Autocorrelator

The *Model 409-08* is an essential accessory for the *Tsunami* laser system for measuring ultrashort laser pulse widths from < 60 fs to > 25 ps for wavelengths from 600 nm to 1.6 µm. It provides a real-time signal of the second order autocorrelation function for convenient display on any high impedance oscilloscope.

Model 3980 Frequency Doubler/Pulse Selector

The *Model 3980* can be used with the *Tsunami* system to provide fs or ps pulse selection (from single-shot to 4 MHz), frequency doubling, or a combination of each. There are six versions available.

Model 3931

The *Model 3931* adds approximately 12 ns of adjustment to the *Tsunami* laser system. Ask your Spectra-Physics representative for details.

GWU Harmonic Generator System

The GWU harmonic system offers second, third and fourth harmonic options for the *Tsunami* laser. It extends the tuning range to the blue and UV to provide output from 210 to 540 nm. It is also compatible with the *Model 3980* pulse selector.

Opal® System

Opal is a fs synchronously pumped optical parametric oscillator (SPPO) that extends the ease and convenience of the *Tsunami* Ti:sapphire laser to an entirely new infrared wavelength range. It produces both a signal and an idler output having a total wavelength coverage from 1.1 to 2.6 µm. Frequency doubling the signal output also provides access to the “missing” visible region of the Ti:sapphire spectrum. The output is specified as > 150 mW at 1.3 and 1.5 µm with a pulse width of < 130 fs. It is controlled by an electronics module and uses simple, menu-driven software to provide computer-assisted setup and automated tuning.

GWU-OPO-PS

The GWU-OPO-PS is an SPPO that extends the *Tsunami* laser output to longer wavelengths. It provides a signal output from 1.04 to 1.2 µm with a corresponding idler of 2.37 – 2.82 µm. Output power is specified as > 150 mW at 1.14 µm with a pulse width of < 2 ps.

Regenerative Amplifier Systems

Spectra-Physics offers high and low repetition rate regenerative amplifier systems to extend the performance of the *Tsunami* laser to higher output power levels.

- **TSA Low Repetition Rate Amplifier**—The TSA Ti:sapphire regenerative amplifier series provides output pulse energies up to more than 100 mJ for both fs and ps pulse widths at repetition rates from 1 to 100 Hz. The TSA system uses one or more Quanta-Ray pulsed Nd:YAG lasers as pump sources and a seed pulse train, which is derived from the *Tsunami*. The overall output energy and repetition rate is determined by the Quanta-Ray pump source.
- **Spitfire High Repetition Rate Amplifier**—The Spitfire Ti:sapphire regenerative amplifier series produces output pulse energies up to 3 mJ for both fs and ps pulse widths at repetition rates from 1 to 5 kHz. It is pumped either by a Merlin, an intracavity, frequency-doubled, CW, lamp-pumped Nd:YLF laser, or by an Evolution, an intracavity frequency-doubled, diode-pumped, Nd:YLF laser.

  The seed pulse train is provided by the *Tsunami*. The output energy is determined by the configuration of the Spitfire and the Merlin/Evolution pump laser.

  For the above-mentioned regenerative amplifier systems, a complete portfolio of accessories is available. For example, the Spectra-Physics *OPA-800C* optical parametric amplifier provides wavelength tunability from < 300 nm to > 10 µm for both fs and ps pulses.

  For more information, please contact your local Spectra-Physics representative.

Accessory and Conversion Optics Sets

These tables are subject to change. Please call the factory for current part numbers.

Table 10-1: Standard fs *Tsunami* Mirrors—*Millennia Xs* Pump Laser[1]

λ	M_1	M_2, M_3	M_4, M_5	M_6 to M_9	M_{10}	PD PCB	LTC M_4
Blue	G0324-027	G0079-027	G0324-028	G0382-029	G0058-030[3]	0452-3280	0448-0570
Standard	G0324-021	G0079-029	G0324-021	G0382-016	G0058-027	0452-3880	0448-0580
Mid-range	G0324-006	G0079-024	G0324-006	G0382-017	G0058-028	0452-3280	0448-0590
Long	G0324-004	G0079-023	G0324-004	G0382-014	G0058-025	0452-3250	0448-0600
X-Long	G0324-008	G0079-025	G0324-008	G0382-015	G0058-026[4]	0452-3250	0448-0610

Table 10-2: Standard fs *Tsunami* Mirrors—*Millennia Vs* Pump Laser[2]

λ	M_1	M_2, M_3	M_4, M_5	M_6 to M_9	M_{10}	PD PCB	LTC M_4
Blue	G0324-027	G0079-027	G0324-028	G0382-029	G0058-030	0452-3280	0448-0570
Standard	G0324-021	G0079-029	G0324-021	G0382-016	G0058-021	0452-3880	0448-0580
Mid-range	G0324-006	G0079-024	G0324-006	G0382-017	G0058-022	0452-3280	0448-0590
Long	G0324-004	G0079-023	G0324-004	G0382-014	G0058-029	0452-3250	0448-0600

Table 10-3: Standard ps *Tsunami* Mirrors—*Millennia Xs* Pump Laser[1]

λ	GTI	M_2, M_3	M_4, M_5	M_{10}	Bi-Fi	PD PCB	LTC M_4
Blue	0448-0720	G0079-027	G0324-028	G0058-030	0434-8953	0452-3280	0448-0570
Standard	0445-9010	G0079-029	G0324-021	G0058-021	0434-8953	0452-3280	0448-0580
Mid-range	0455-9010	G0079-024	G0324-006	G0058-022	0434-8954	0452-3280	0448-0590
Long	0445-9940	G0079-023	G0324-004	G0058-025	0434-8954	0452-3250	0448-0600
X-Long	0445-9940	G0079-025	G0324-008	G0058-026	0434-8953	0452-3250	0448-0610

Table 10-4: Standard ps *Tsunami* Mirrors—*Millennia Vs* Pump Laser[2]

λ	GTI	M_2, M_3	M_4, M_5	M_{10}	Bi-Fi	PD PCB	LTC M_4
Blue	0448-0720	G0079-027	G0324-028	G0058-030	0434-8953	0452-3280	0448-0570
Standard	0445-9010	G0079-029	G0324-021	G0058-037	0434-8953	0452-3280	0448-0580
Mid-range	0455-9010	G0079-024	G0324-006	G0058-022	0434-8954	0452-3280	0448-0590
Long	0445-9940	G0079-023	G0324-004	G0058-029	0434-8953	0452-3250	0448-0600

[1] *Millennia Xs–Blue: 690–800, Standard: 720–850, Mid-range: 780–900, Long: 840–1000, X-Long: 970–1080 nm.*
[2] *Millennia Vs–Blue: 690–800, Standard: 735–840, Mid-range: 800–900, Long: 850–990 nm*
[3] *G0058-030 contains 4 possible types: G0058-0300, G0058-0301, G0058-0302 and G0058-0303*
[4] *G0058-026 contains 4 possible types: G0058-0260, G0058-0261, G0058-0262 and G0058-0263*

Table 10-5: Broadband fs *Tsunami* Mirrors—*Millennia Xs* Pump Laser

λ	M_1	M_2, M_3	M_4 to M_9	M_{10}	PD PCB
700-1000	G0380-005	G0079-030	G0380-005	G0058-039	0452-3250

Table 10-6: Broadband fs *Tsunami* Mirrors—*Millennia VIIIs* Pump Laser

λ	M_1	M_2, M_3	M_4 to M_9	M_{10}	PD PCB
700-1000	G0380-005	G0079-030	G0380-005	G0058-042	0452-3250

Table 10-7: Broadband fs *Tsunami* Mirrors—*Millennia Vs* Pump Laser

λ	M_1	M_2, M_3	M_4 to M_9	M_{10}	PD PCB
710-980	G0380-005	G0079-030	G0380-005	G0058-044	0452-3250

Table 10-8: Broadband ps *Tsunami* Mirrors—*Millennia Xs* Pump Laser

λ	GTI	M_2, M_3	M_4, M_5	M_{10}	Bi-Fi	PD PCB
700-1000	0453-7810	G0079-030	G0380-005	G0058-042	0454-1120	0452-3250

Table 10-9: Broadband ps *Tsunami* Mirrors—*Millennia VIIIs* Pump Laser

λ	GTI	M_2, M_3	M_4, M_5	M_{10}	Bi-Fi	PD PCB
700-1000	0453-7810	G0079-030	G0380-005	G0058-043	0454-1120	0452-3250

Table 10-10: Broadband ps *Tsunami* Mirrors—*Millennia Vs* Pump Laser

λ	GTI	M_2, M_3	M_4, M_5	M_{10}	Bi-Fi	PD PCB
710-980	0453-7810	G0079-030	G0380-005	G0058-038	0454-1120	0452-3250

Note

For broadband Lok-to-Clock systems, use PCT mirror assembly 0453-6690 for M_4 instead of G0380-005.

Table 10-11: fs *Tsunami*—Wavelength Conversion Sets[1]

		Millennia Xs			
From λ (nm)	To λ (nm)	Optics	Fold Mirror	PD PCB[2]	Part No.
690–800	720–850	✓	✓		0446-5830X
	780–900	✓	✓		0446-5850X
	840–1000	✓	✓	✓	0446-7450X
	970–1080	✓	✓	✓	0446-7490X
720–850	690–800	✓	✓		0448-0410X
	780–900	✓	✓		0446-5850X
	840–1000	✓	✓	✓	0446-7450X
	970–1080	✓	✓	✓	0446-7490X
780–900	690–800	✓	✓		0448-0410X
	720–850	✓	✓		0446-5830X
	840–1000	✓	✓	✓	0446-7470X
	970–1080	✓	✓	✓	0446-7510X
840–1000	690–800	✓	✓	✓	0448-0420X
	720–850	✓	✓	✓	0446-7460X
	780–900	✓	✓	✓	0446-7480X
	970–1080	✓	✓		0446-7540X
970–1080	690–800	✓	✓	✓	0448-0420X
	720–850	✓	✓	✓	0446-7500X
	780–900	✓	✓	✓	0446-7520X
	840–1000	✓	✓		0446-7530X

Table 10-12: fs *Tsunami*—Wavelength Conversion Sets[1]

		Millennia Vs			
From λ (nm)	To λ (nm)	Optics	Fold Mirror	PD PCB[2]	Part No.
690–800	735–840	✓	✓		0446-5820M
	790–900	✓	✓		0446-5840M
	850–990	✓	✓	✓	0447-3400M
735–840	690–800	✓	✓		0448-0390M
	790–900	✓	✓		0446-5840M
	850–990	✓	✓	✓	0447-3400M
790–900	690–800	✓	✓		0448-0390M
	735–840	✓	✓		0446-5820M
	850–990	✓	✓	✓	0447-3410M
850–990	690–800	✓	✓	✓	0448-0400M
	735–840	✓	✓	✓	0447-3420M
	790–900	✓	✓	✓	0447-3430M

[1] *Asterisk marks indicate which elements are included with the kit.*
[2] *Photodiode board*

Table 10-13: ps *Tsunami*—Wavelength Conversion Sets[1]

Millennia Xs						
From λ (nm)	To λ (nm)	Optics	GTI[2]	Bi-Fi[3]	PD PCB[4]	Part No.
690–800	720–850	✓				0448-0340X
	780–900	✓	✓	✓		0448-0350X
	840–1000	✓	✓		✓	0446-7420X
	970–1080	✓	✓		✓	0446-7440X
720–850	690–800	✓	✓			0448-0360X
	780–900	✓		✓		0445-6550X
	840–1000	✓	✓		✓	0446-7420X
	970–1080	✓	✓		✓	0446-7440X
780–900	690–800	✓	✓	✓		0448-0370X
	720–850	✓		✓		0445-6540X
	840–1000	✓	✓	✓	✓	0446-8080X
	970–1080	✓	✓	✓	✓	0446-8100X
840–1000	690–800	✓	✓		✓	0448-0380X
	720–850	✓	✓		✓	0446-7410X
	780–900	✓	✓*	✓	✓	0446-8070X
	970–1080	✓				0446-6150X
970–1080	690–800	✓	✓		✓	0448-0380X
	720–850	✓	✓		✓	0446-7430X
	780–900	✓	✓	✓	✓	0446-0890X
	840–1000	✓				0446-6140X

Table 10-14: ps *Tsunami*—Wavelength Conversion Sets[1]

Millennia Vs						
From λ (nm)	To λ (nm)	Optics	GTI[2]	Bi-Fi[3]	PD PCB[4]	Part No.
690–800	735–840	✓				0448-0290M
	790–900	✓	✓	✓		0448-0300M
	850–900	✓	✓		✓	0447-3350M
735–840	690–800	✓	✓			0448-0310M
	790–900	✓		✓		0445-6530M
	850–990	✓	✓		✓	0447-3350M
790–900	690–800	✓	✓	✓		0448-0320M
	735–840	✓		✓		0445-6520M
	850–990	✓	✓	✓	✓	0447-3360M
850–990	690–800	✓	✓		✓	0448-0330M
	735–840	✓	✓		✓	0447-3370M
	790–900	✓	✓	✓	✓	0447-3380M

[1] *Asterisk marks indicate which elements are included with the kit.*
[2] *Gires-Tournois interferometer*
[3] *Birefringent filter*
[4] *Photodiode board*

Table 10-15: fs to ps *Tsunami*–Wavelength Conversion Sets[1]

Millennia Xs				
λ (nm)	Optics	GTI[2]	Bi-Fi[3]	Part No.
690–800	✓	✓	✓	0448-0440X
720–850	✓	✓	✓	0445-9610X
780–900	✓	✓	✓	0446-7570X
840–1000	✓	✓	✓	0446-7580X
970–1080	✓	✓	✓	0446-7590X
Millennia Vs				
690–800	✓	✓	✓	0448-0430M
735–840	✓	✓	✓	0446-7550M
790–900	✓	✓	✓	0446-7560M
850–990	✓	✓	✓	0447-3440M

Table 10-16: ps to fs *Tsunami*–Wavelength Conversion Sets[1]

Millennia Xs		
λ (nm)	Optics	Part No.
690–800	✓	0448-0460X
720–850	✓	0446-7870X
780–900	✓	0446-7620X
840–1000	✓	0446-7630X
970–1080	✓	0446-7640X
Mechanics (prisms, mounts, slit tuning)[4]		0445-9600X
Millennia Vs		
690–800	✓	0448-0450M
735–840	✓	0446-7600M
790–900	✓	0446-7610M
850–990	✓	0447-3390M
Mechanics (prisms, mounts, slit tuning)[3]		0445-9600M

[1] *Asterisk marks indicate which elements are included with the kit.*
[2] *Gires-Tournois interferometer*
[3] *Birefringent filter*
[4] *Required with appropriate optic set when upgrading from picosecond to femtosecond operation.*

Table 10-17: GTI and Bi-Fi for Broad Pulse Operation

	GTI	
Pulse Width (ps)	**Standard/Mid-range**	**Long/X-Long**
5	0445-9010-05	0445-9940-05
10	0445-9010-10	0445-9940-10
30	0445-9010-30	0445-9940-30
60	0445-9010-60	0445-9940-60
	Bi-Fi[1]	
	Blue/Standard/Long/X-Long	**Mid-range**
5–10	0434-8953	0434-8954
30–60	0434-8973	0434-8974

[1] *3-plate bi-fi required for operation > 20 ps. Standard 2-plate bi-fi is required for operation at < 20 ps.*

Table 10-18: Photodiode PC Board

Assembly Part Number	Wavelength (λ)
0452-3280	< 900 nm
0452-3250	> 900 nm

Chapter 11 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 system. A complete repair procedure is beyond the scope of this manual. For information concerning repair by Spectra-Physics, see Chapter 12, “Customer Service.”

At the end of this chapter is a replacements parts table listing components that can be replaced by you. A complete list of available optics can be found in the tables at the end of Chapter 10, “Options and Accessories.”

Troubleshooting Guide

Use this guide if *Tsunami* performance drops unexpectedly. We strongly suggest you check the possible causes in the order listed as the most likely causes are listed first. If you try the following suggestions and are unable to bring your *Tsunami* performance up to specification, call your Spectra-Physics service representative for help.

Danger!
Laser Radiation

These procedures may require you to adjust or replace optics while using the laser at high power. For safety, close the pump laser shutter every time you change an optic or interfere with the intracavity beam in any way, and only open it during actual alignment. Protect yourself with appropriate eyewear at all times.

Generic Troubleshooting (Non-Lok-to-Clock Systems)

Symptom: No output

Possible Causes	**Corrective Action**
Pump laser shutter is not open.	Open the pump laser shutter.
Insufficient pump power.	Adjust pump power to: ~8 to 10 W for a 10 W pump configuration. ~5 W for the > 5 W pump configuration.
Chiller mishap or is not on.	Turn on the chiller. Check that the reservoir water level is filled to the proper level. Check temperature setting; should be set to 18°C. Check for a water flow obstruction in the chiller and *Tsunami* laser head.
Obstruction in the cavity.	Check for misaligned components or other objects that obstruct the beam path in the cavity.
Fluorescence not aligned.	Check for misalignment in the pump beam and/or the *Tsunami* cavity. Refer to “Cavity Alignment” in Chapter 6 for details. Overlap of the M_1 and M_3 fluorescence image. Fluorescence position from M_4 through the cavity to the center of the OC. Overlap of the OC retro-reflection to the cavity. Femto specific: M_6 through M_9 were not adjusted after an optic conversion.
Slit orientation is incorrect (femto configuration only)	When it is necessary to rotate M_6 through M_9 for optic set conversion (i.e., Standard to Long λ set), the slit position must be reoriented to bisect the fluorescence. Remove slit assembly prior to M_6 through M_9 adjustment. Lower the slit position to intercept the altered fluorescence path after the M_6 through M_9 adjustment for converting to longer λ set and vise versa.
Bi-fi is incorrectly set (ps configuration only)	When changing optic set or converting to ps, it is necessary to orient the bi-fi to the proper rotation for the optic set, otherwise lasing is not possible. Refer to Chapter 6, “Alignment: Selecting, Installing and Aligning the Birefringent Filter” for details.
Wrong optic(s) in the cavity and/or cavity location.	Verify that all cavity optics are correct to their location according to Table 10-10 in Chapter 10.
One or more optics are installed backwards.	Verify that the arrow on all the optics point towards the laser cavity.
A white card was left in the beam path.	Remove the card.
Cavity Optics Are Out Of Alignment.	Adjust M_1 and M_{10} as described in Chapter 6, “Alignment: Cavity Alignment.” If these adjustments fail to restore output, refer to the next cause below.

Symptom: Low output power	
Possible Causes	**Corrective Action**
Insufficient pump power.	Adjust pump power to: ~8 to 10 W for a 10 W pump configuration. ~5 W for the > 5 W pump configuration.
Chiller mishap or is not on.	Turn on the chiller. Check that the reservoir water level is filled to the proper level. Check temperature setting; should be set to 18° C. Check for a water flow obstruction in the chiller and *Tsunami* laser head.
Tsunami is not optimized.	Adjust M_1 and M_{10} as described in Chapter 6, "Alignment: Cavity Alignment." If these adjustments fail to restore output, refer to the next cause below.
Optics are dirty.	Inspect the optics for dirt or contamination. If dirty, clean the optics using the cleaning procedure in Chapter 9, "Maintenance." If an optic is dirty, an IR viewer will show unusual scatter.
System is not properly aligned.	Check that the pump beam is centered on M_2 and M_3 (the side facing the Ti:Sapphire rod). Avoid parallax error. Check for beam centering on mirrors M_1 through M_5, prisms, AOM and OC. Check for the location of the cavity beam on M_6 through M_9 (M_8 should be a mirror image of M_7). SF-10 prism (G0360-000 (apex ~60° 42')) use in systems without the Blue set, a must for X-long systems. At 800 nm, the beam should be centered on M_7 and M_8. LaFn28 Prism (G0383-000 (apex ~ 59° 15')) used in Blue, Broadband and USP options. At 800 nm, the beam should be $^3/_4$ of the way toward PR_2/Pr_3 assembly.
Slit width too narrow (Femto configuration only)	Slit width should be 2.2 mm > x > 1.33 mm. Proper slit width depends on pump power and the amount of prism glass in the cavity (dispersion control).
Poor pump laser mode quality.	Check pump laser power and mode (requires TEM_{00} pump mode).
Dirty optics and/or beam splitters in the pump laser.	Clean the optics if necessary. Refer to the cleaning procedure in the pump laser user's manual.
Wrong optic(s) in the cavity and/or cavity location.	Verify that all cavity optics are correct to their location according to Table 10-10 in Chapter 10.

Symptom: Laser will not mode lock	
Possible Causes	**Corrective Action**
Model 3955 electronics module is not on.	Turn on the electronics module. Enable the RF by pushing the STATUS button. For pico configuration, it is necessary to wait > 20 minutes to allow the GTI to warm up for stable dispersion compensation.
RF power is not enabled.	Enable the RF by pushing the STATUS button.
Chiller mishap or is not on.	Turn on the chiller. Check that the reservoir water level is filled to the proper level. Check temperature setting; should be set to 18°C. Check for a water flow obstruction in the chiller and *Tsunami* laser head.
Wavelength on or near water or oxygen absorption lines.	Consult Chapter 7, "Operation," Figure 7-1 for the location of water and oxygen absorption. Purge when necessary.

Symptom: Laser will not mode lock	
Possible Causes	**Corrective Action**
Pump laser is not warmed up.	Refer to pump laser instruction manual for required warm-up time.
Tsunami is not optimized.	Adjust M_1 and M_{10} as described in Chapter 6, "Alignment: Cavity Alignment." If these adjustments fail to restore output, refer to the next cause below.
Optics are dirty.	Inspect the optics for dirt or contamination. If dirty, clean the optics using the cleaning procedure in Chapter 9, "Maintenance." If an optic is dirty, an IR viewer will show unusual scatter.
System is not properly aligned.	Check that the pump beam is centered on M_2 and M_3 (the side facing the Ti:Sapphire rod). Avoid parallax error. Check for beam centering on mirrors M_1 through M_5, prisms, AOM and OC. Check for the location of the cavity beam on M_6 through M_9 (M_8 should be a mirror image of M_7). SF-10 prism (G0360-000 (apex ~60° 42')) use in systems without the Blue set, a must for X-long systems. At 800 nm, the beam should be centered on M_7 and M_8. LaFn28 Prism (G0383-000 (apex ~ 59° 15')) used in Blue, Broadband and USP options. At 800 nm, the beam should be 3/4 of the way toward PR_2/Pr_3 assembly.
Improper phase adjustment.	Adjust the fine PHASE control on the *Model 3955* for the highest signal. If unsuccessful, refer to Chapter 6, "Alignment: Coarse Phase Adjustment..." for details.
Improper pump power (too high or too low).	Lower the pump power in 5% increments from the recommended setting. Raise the pump power in 5% increments from the recommended setting.
Improper dispersion in the cavity.	Femto configuration: Verify beam position on Pr_1/Pr_4 according to Table 6-4. Turn the Pr_2/Pr_3 micrometer counterclockwise until there is an abrupt change in power (Pr_2/Pr_3 are moved away from the beam path). Turn the Pr_2/Pr_3 assembly clockwise and watch for signs of mode locking (i.e., spectral spread of the wavelength using a CCD camera behind a monochromator. Pico configuration: Adjust the GTI POSITION and fine PHASE controls while watching the autocorrelation signal for pulses. Refer the Chapter 6, "Alignment: Mode Locking" for details.
AOM is misaligned in the cavity.	With the beam already centered on M_5 and M_{10}, center the AOM substrate on the beam. Refer to Chapter 6, "Alignment: Aligning the A/O Modulator (AOM)" for details.
Photodiode pc board is not properly aligned.	Refer to Chapter 6, "Alignment: Aligning the Photodiode PC Board" for details.
Cavity frequency is near or on an AOM resonance frequency (femto configuration only).	The cavity frequency of the system approaches the AOM resonance frequency as the wavelength approaches the edges of the tuning range. At this point, the amount of prism adjustment in the cavity is limited by the cavity frequency closing in on the AOM resonance frequency. Together with optic conversion from one set to another, it becomes necessary to alter the cavity length in order to avoid running into this problem. Occasionally, it is necessary to move the femto M_4 bracket to avoid this problem.

Symptom: Laser will not mode lock	
Possible Causes	**Corrective Action**
Possible Feedback	Feedback occurs when a reflection of the output returns to the laser cavity. Feedback radiation of a few mW may disrupt mode locking. To test for possible feedback, set up a means for monitoring the *Tsunami* pulse before the suspected feedback source. If stable pulse operation is obtained after blocking the beam to the suspected source, you have a feedback problem. Try realigning the suspected device to the *Tsunami* laser. If this does not work, install a Faraday isolator before the suspected source of feedback. When selecting an isolator, be sure it can accommodate the *Tsunami* wavelength tuning range.
The matching network is not connected for >10 ps output, and/or the coarse phase is not set to accommodate its presence in the circuit, and vice versa.	Connect the matching network in series with the mode locker, then adjust the coarse and fine phase controls and the GTI position to achieve mode locking.

Symptom: Unable to mode lock for specific ps wavelengths (after ruling out all possible causes for general inability to mode lock).	
Possible Causes	**Corrective Action**
Wavelength is specific to H_2O, CO_2 or O_2 absorption.	There is a gas leak in the purge system: Set the flow rate to 0.28 m^3/hr (10 SCFH), then disconnect the purge line from the Tsunami laser head. The fitting shuts off all flow when disconnected. If flow does not fall to <0.02 m^3/hr (0.5 SCFH) within a few seconds, inspect the filters and connections inside the *Model 3910* for leaks (refer to Figure 9-5). The *Tsunami* laser head gaskets and/or seals are leaky. Inspect all the gaskets and seals for damage or debris stuck to them. Look for possible missing gaskets under the *Tsunami* cover. There is a water leak inside the *Tsunami* laser head. Check the quick-disconnect waterline fittings inside the *Tsunami* laser head near the front panel for leaks. Push in the fittings to make sure they are fully engaged. Also verify there is no moisture around the barbed fittings near the rod.
The bi-fi is misaligned (or other mishaps).	There is dirt in the beam path of the bi-fi and/or the GTI. Clean. The wrong order is present as a result of mis-orienting the bi-fi.
The Bi-fi assembly is not at Brewster's angle to the beam.	The beam is not centered on the GTI. Changing from a 2-plate to a 3-plate bi-fi requires a correction to the Brewster's angle. Note the tick marks on the bi-fi Brewster's angle adjustment bracket, then loosen the bracket lockdown screw and rotate the bracket 1.5 marks toward the input bezel. Reverse the direction of rotation when going back to the 2-plate bi-fi.
The wrong bi-fi is installed.	Consult Chapter 10, "Options and Accessories," Table 10-10, for the appropriate bi-fi for the installed optic set.

Symptom: Poor Long-term Stability

Possible Causes	Corrective Action
Chiller mishap or is not on.	Turn on the chiller. Check that the reservoir water level is filled to the proper level. Check temperature setting; should be set to 18°C. Check for a water flow obstruction in the chiller and *Tsunami* laser head.
Tsunami is not optimized.	Adjust M_1 and M_{10} as described in Chapter 6, "Alignment: Cavity Alignment."
Optics are dirty.	Inspect the optics for dirt or contamination. If dirty, clean the optics using the cleaning procedure in Chapter 9, "Maintenance." If an optic is dirty, an IR viewer will show unusual scatter.
System is not properly aligned.	Check that the pump beam is centered on M_2 and M_3 (the side facing the Ti:Sapphire rod). Avoid parallax error. Check for beam centering on mirrors M_1 through M_5, prisms, AOM and OC. Check for the location of the cavity beam on M_6 through M_9 (M_8 should be a mirror image of M_7). SF-10 prism (G0360-000 (apex ~60° 42')) use in systems without the Blue set, a must for X-long systems. At 800 nm, the beam should be centered on M_7 and M_8. LaFn28 Prism (G0383-000 (apex ~ 59° 15')) used in Blue, Broadband and USP options. At 800 nm, the beam should be 3/4 of the way toward PR_2/Pr_3 assembly.
Poor pump laser mode quality.	Check pump laser power and mode (requires TEM_{00} pump mode).
Dirty optics and/or beam splitters in the pump laser.	Clean the optics if necessary. Refer to the cleaning procedure in the pump laser user's manual.
Environmental problem	Verify that any heat source (e.g., power supplies, chiller, etc.) are exhausting away from under the table. Avoid temperature swings ≥ ± 1° C. Avoid turbulent airflow over the entire system. For ion pump systems, avoid cooling water temperature swings of ± 2° C.
Improper alignment of the routing mirror assemblies.	Check the alignment of the routing mirror assemblies between the pump laser and the *Tsunami* laser. The dust tubes may be binding against the mirrors.
There is contact between the routing mirror housing and screws.	Relocate the housing to avoid contacting the adjustment screw(s).
A dust tube in the routing mirror assembly is not properly installed.	Each tube should slide freely inside the mirrors, over the laser snout or input window, and with respect to each other. All tubes should be at the same height and parallel with the table, and the beam should be centered in the tubes. Refer to Chapter 5, "Installation: Set up the Routing Mirrors."
A mirror in the *Tsunami* is not properly seated.	Optimize *Tsunami* laser output, then, one at a time, tap the back side of each mirror holder while watching the output power level. If the power falls, you have a seating problem with that mirror. Reseat the mirror, then optimize the laser output by adjusting that mirror before proceeding on to the next mirror.
Loose mechanics.	Optimize *Tsunami* laser output, then systematically verify that all the mechanics are secured. Start with the ion laser locknuts on the feet, then proceed to the lock-down clamps, and the routing mirror assemblies. Next, check the internal *Tsunami* mechanics, then its locknuts and, finally, its foot clamps.

Symptom: Poor Long-term Stability	
Possible Causes	**Corrective Action**
Electronics phase shifts because the electronics cover(s) is/are off.	Verify that the top covers of the electronics are on. This is especially important on a broad picosecond pulse system.
Poor beam mode profile.	With the beam directed to far field (e.g., displayed on a wall), adjust M_2 to obtain a solid, slightly elliptical mode with high contrast. There should be no spikes on the outer edges of the beam profile.
The pump laser is unstable.	Refer to the pump laser manual for troubleshooting.

Symptom: Laser is mode locked but has noisy >2 ps pulses with side lobes or baseline noise (ps configuration only)	
Possible Causes	**Corrective Action**
Improper phase adjustment.	Adjust the fine PHASE control on the *Model 3955* electronics module. If this is unsuccessful, refer to Chapter 6, “Alignment: Coarse Phase Adjustment...” for details on making further adjustments.
Improper dispersion in the cavity (ps configuration only)	Adjust the GTI position and fine phase while watching the autocorrelation signal for pulses. Refer to Chapter 6, “Alignment: Mode Locking,” for more details.
Improper pump power (too high or too low).	Lower the pump power in 5% increments from the recommended setting. Raise the pump power in 5% increments from the recommended setting.
M_2 is too close to the Ti:sapphire rod.	Move M_2 away from the Ti:sapphire rod in increments of 1/4 turns. Reiterate these adjustments to phase, GTI position and pump power to eliminate the satellite pulses.

Symptom: Pulses are broad with low power	
Possible Causes	**Corrective Action**
Improper phase adjustment.	Adjust the fine PHASE control on the *Model 3955* electronics module. If this is unsuccessful, refer to Chapter 6, “Alignment: Coarse Phase Adjustment...” for details on making further adjustments.
Improper dispersion in the cavity (ps configuration only)	Adjust the GTI position and fine phase while watching the autocorrelation signal for pulses. Refer to Chapter 6, “Alignment: Mode Locking,” for more details.
Pump power is too low.	Raise the pump power in 5% increments from the recommended setting.
Wavelength on or near water or oxygen absorption lines.	Consult Chapter 7, “Operation,” Figure 7-1 for the location of water and oxygen absorption. Purge when necessary.
The bi-fi is misaligned (or other mishaps).	There is dirt in the beam path of the bi-fi and/or the GTI. Clean. The wrong order is present as a result of mis-orienting the bi-fi.
The Bi-fi assembly is not at Brewster’s angle to the beam.	The beam is not centered on the GTI. Changing from a 2-plate to a 3-plate bi-fi requires a correction to the Brewster’s angle. Note the tick marks on the bi-fi Brewster’s angle adjustment bracket, then loosen the bracket lockdown screw and rotate the bracket 1.5 marks toward the input bezel. Reverse the direction of rotation when going back to the 2-plate bi-fi.
The wrong bi-fi is installed.	Consult Chapter 10, “Options and Accessories,” Table 10-10, for the appropriate bi-fi for the installed optic set.

Symptom: Satellite pulses are evident when viewed on an autocorrelator	
Possible Causes	**Corrective Action**
Fluorescent lights cause phantom signals that look like satellite pulses.	Turn off fluorescent room lights. Cover the autocorrelator to shield the unit from fluorescent room light.
Improper dispersion in the cavity.	Femto configurations: Turn prisms Pr_2 and Pr_3 counterclockwise to get rid of the satellite pulses. Pico configurations: Adjust the GTI POSITION control to get rid of the satellite pulses. The satellite pulses are real if they move in time with respect to the main pulse when the GTI POSITION control is adjusted.
Pump power is too high (fs configuration)	Lower the pump power in 5% increments from the recommended setting.
There is a secondary reflection from the beam splitter, attenuator, etc.	Avoid thin and unwedged beam splitters or attenuators that may have a secondary reflection in the beam that travels toward or into the autocorrelator.

Symptom: Cannot see individual pulse on the oscilloscope	
Possible Causes	**Corrective Action**
The system is not mode locked.	See the troubleshooting symptom: “System will not mode lock.”
Autocorrelator is not properly aligned to the beam.	Refer to the autocorrelator manual for proper alignment. The non-linear crystal is not at the proper phase matching angle. The focus lens is not at the correct distance from the non-linear crystal.

Troubleshooting LTC Systems

Symptom: When LOCK is enabled, only the top and bottom LEDs are illuminated on the STATUS display.	
Possible Causes	**Corrective Action**
The M_4 PZT cable is not connected.	Verify the driver cable is attached to the M_4 PZT mirror.
The M_4 PZT is bad.	Replace.

Symptom: The entire STATUS bar display flashes when *Model 3930* LOCK is enabled.	
Possible Causes	**Corrective Action**
Improper cavity dispersion.	Femto configuration: Use the Pr_2 and Pr_3 prisms to add or subtract glass in the cavity. Pico configuration: Adjust the GTI POSITION control.
Improper phase adjustment.	Adjust the FINE PHASE control.
Improper pump power.	Raise or lower the pump power in 5% increments from he recommended setting.
Tsunami is not properly aligned and optimized.	Adjust M_1 and M_{10} as described in Chapter 6, “Alignment: Cavity Alignment.” Adjust M_2 in or out to reduce fluctuations in the LED.

Symptom: A single LED lights on the bar graph, but the laser frequency is different than the reference frequency.	
Possible Causes	**Corrective Action**
The difference between the cavity and reference frequencies exceeds the detection range of 50 kHz.	Manually adjust the laser frequency to correct the difference.

Table 11-1: Optics

Designation	Description	Coating Range	Part Number
P_1	Pump beam, flat	450 – 532 nm	G0324-024
P_2	Pump beam, focus	450 – 532 nm	G0323-004
Beam splitter		uncoated	G0020-000
Routing mirrors		458 – 514 nm	G0234-003
Routing mirrors		532 nm	G0382-023

Table 11-2: Hardware

Description	Part Number
Manual	0000-232A
Assembly, Brewster window	0441-8110S
GTI high-voltage cable	0446-0810
Harness cables	0447-1550
Gasket kit	0447-1560
Washers, o-ring kit	0447-1570
Mirror holder set (M_1, M_6 – M_9)	0448-0560
Mirror holder set (M_2 – M_5, OC)	0447-6300
Water chiller, 110 Vac	2203-0084
Water chiller, 230 Vac	2203-0085
Purge tubing, 1/8 in. with Clip-Lok connectors	0447-1590
Tool kit	0445-2460

Table 11-3: *Model 3910* Purge Unit Filter Hardware

Description	Part Number
Filter assembly kit	0449-7240

Chapter 12 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 favorable service records compared to competitive products, and we hope to demonstrate, in the long run, that we provide excel lent service to our customers in two ways. First, by providing the best equipment for the money, and second, by offering service facilities that restore your instrument to working condition 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 numbers available when you call. Service data or shipping instructions will be promptly supplied.

To order optional items or other system components, or for general sales assistance, dial **1 (800) SPL-LASER** in the United States, or **1 (650) 961-2550** from anywhere else.

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 Tsunami® laser system is protected by a 12-month warranty. All mechanical, electronic, optical parts and assemblies are unconditionally warranted to be free of defects in workmanship and material for one the warranty period.

Liability under this warranty is limited to repairing, replacing, or giving credit for the purchase price of any 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 replacement equipment is warranted only for the remaining unexpired portion of the original warranty period applicable to the re paired or replaced equipment.

This warranty does not apply to any instrument or 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 boxes to secure instruments during shipment. If shipping boxes have been lost or destroyed, we recommend you order new ones. Spectra-Physics will only return instruments in Spectra-Physics containers.

Warning!

Always drain the cooling water from the laser head before shipping. Water expands as it freezes and will damage the laser. Even during warm spells or summer months, freezing may occur at high altitudes or in the cargo hold of aircraft. Such damage is excluded from warranty coverage.

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Appendix A Modelocking

In this chapter, we provide a brief discussion of modelocking and the regenerative modelocking technique employed in the *Tsunami* laser. A description of the group velocity dispersion (GVD) found within the cavity is also presented, and the role of nonlinear effects (due to intense pulses passing through the gain medium) is considered. Finally, GVD compensation techniques employed within the *Tsunami* are discussed since they ultimately determine the output pulse width.

General

In any laser system, the allowed oscillating wavelengths (or frequencies) are determined by two factors: the longitudinal modes determined by the laser cavity (subject to threshold conditions) and the gain-bandwidth of the laser medium. In a laser cavity, the electric field of the oscillating optical frequencies must repeat itself after one round-trip; i.e., the oscillating wavelengths must satisfy a standing wave condition in the laser cavity or an integral number of half-wavelengths must exactly fit between the end mirrors. The small group of frequencies that satisfy this condition are the longitudinal modes of the laser. The gain-bandwidth of the laser medium is determined by its atomic or molecular energy levels. Atomic gas lasers tend to have relatively narrow bandwidth, while molecular dye and solid state systems exhibit broader bandwidth.

In a continuous wave (CW) or free-running laser, the longitudinal modes operate independently. Cavity perturbations cause some modes to stop oscillating and when they re-start they have a different phase. Thus, the laser output comprises various randomly phased mode frequencies. In a mode-locked laser, the longitudinal modes must be “locked” in phase, such that they constructively interfere at some point in the cavity and destructively interfere elsewhere in order to create a single circulating pulse. Each time this intracavity pulse reaches the partially reflective output coupler, an output pulse is produced. The time between the output pulses is the time it takes for the cavity pulse to make one complete round trip. For a *Tsunami* system, this corresponds to about 12.2 ns. The output pulse frequency, or repetition rate (rep rate), is 80 to 82 MHz (refer to Figure A-1).

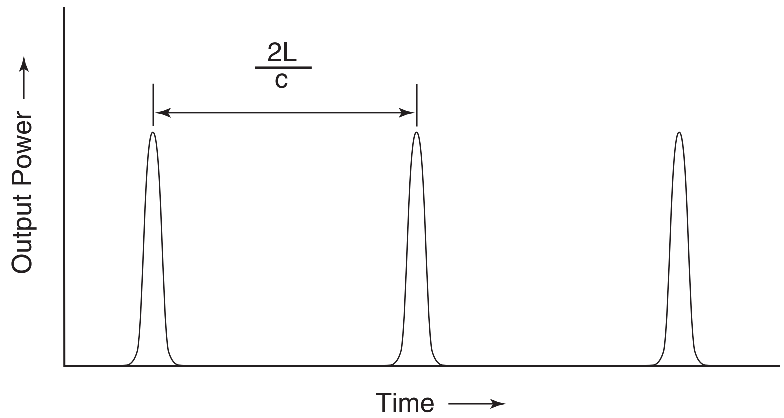


Figure A-1: Typical output of a mode-locked laser, where *L* is the cavity length and *c* is the velocity of light.

Modelocking Techniques

A variety of approaches have been used to obtain a train of mode-locked pulses from different laser systems including active modelocking, passive modelocking, additive pulse modelocking, and self modelocking.

Active modelocking is by far the most common approach used to obtain short optical pulses (ps duration) from solid state or gas lasers. A loss modulation is applied to the laser cavity at the same frequency as the pulse reprate. This is equivalent to introducing an optical shutter into the laser cavity—only light that arrives at the shutter at precisely the correct time passes through and is amplified in the gain media. Since the shutter is closed at all other times, a second pulse cannot be formed.

The most common active mode-locking element is an acousto-optic modulator (AOM) which is placed inside the optical cavity close to one of the end mirrors. The modulator comprises a high quality optical material (such as quartz) with two highly polished surfaces that are parallel to the direction of light propagation. Attached to one of these surfaces is a piezoelectric transducer that is driven at an RF frequency to generate an acoustic wave within the modulator (Figure A-2). Using the reflection off the opposite surface, a standing acoustic wave is generated within the modulator. This induces a time-dependent refractive index grating along an axis perpendicular to the light propagation. As the light interacts with this grating, a portion of it is both diffracted and shifted in frequency by an amount equal to the acoustic frequency. After passing through the modulator, the diffracted and undiffracted rays are reflected back through the modulator where a portion of each beam is diffracted once again.

If the RF drive is at frequency ω_{mL}, the acoustic grating generated by the standing wave will turn on and off at a rate of $2\omega_{mL}$. The value for $2\omega_{mL}$ is chosen to be the same as the laser repetition rate $^{c}/_{2L}$. The AOM diffracts light out of the cavity only when the acoustic grating is present and, thus, functions as a time-dependent loss. In the frequency domain, this loss imparts modulation sidebands when a wave passes through the modulator (Figure A-2). In this manner, the AOM "communicates" the phase between the longitudinal modes of the laser cavity. The final amplitude and frequency of the phase-locked longitudinal modes is shown in Figure A-3.

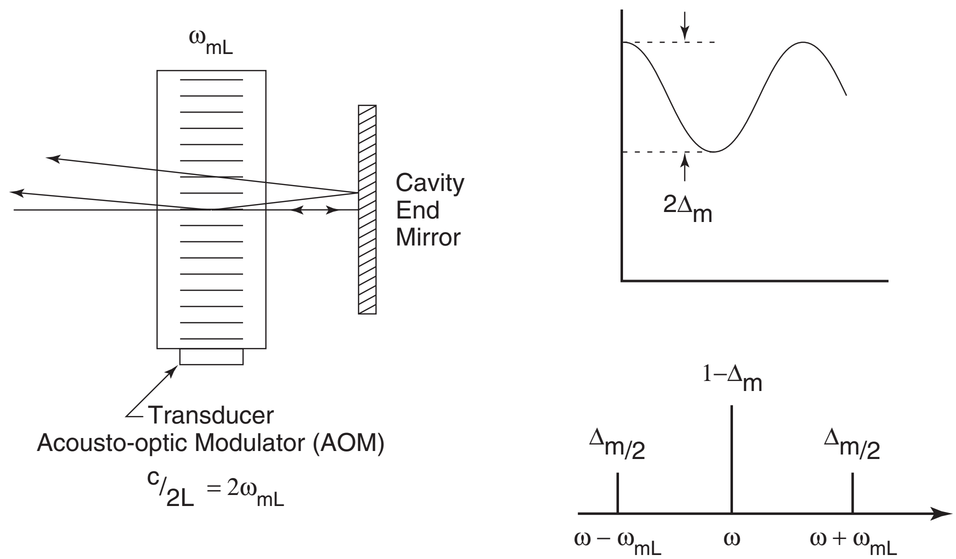


Figure A-2: Active modelocking using an AOM. Modulation sidebands are produced when a wave passes through an amplitude modulator.

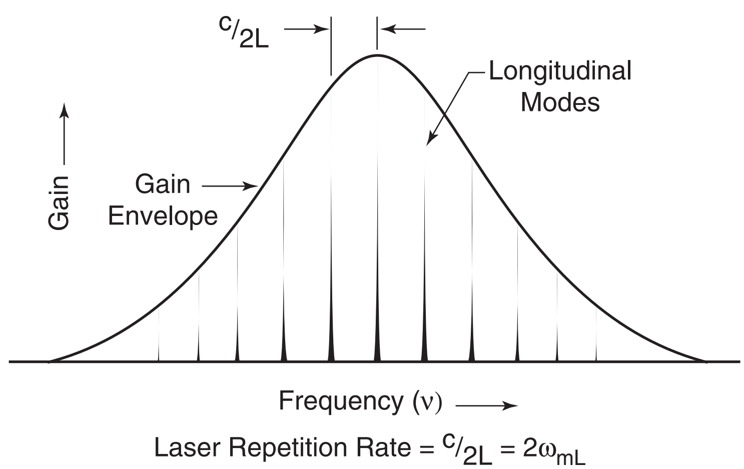


Figure A-3: Amplitude and frequency of longitudinal modes in a mode-locked laser.

The modulation frequency $2\omega_{mL}$ must be precisely matched to the repetition rate of output pulses which is $^c/_{2L}$. The RF signal used to drive the AOM is, thus, usually generated by a temperature-stabilized crystal oscillator, and the cavity length of the laser is adjusted to obtain the appropriate frequency.

The duration of the mode-locked pulses depends on several factors including the gain bandwidth of the laser and the modulation depth of the AOM. Laser media with greater gain bandwidth have the capability of generating shorter pulses. Consequently, active modelocking a Nd:YAG laser produces pulse widths of 30 to 150 ps, while for an ion laser, durations are usually 120 to 200 ps.

In passively mode-locked systems, the pulse itself generates the periodic modulation. This can be accomplished with a saturable absorber dye that responds to the instantaneous light intensity in a nonlinear manner. At low light intensity the dye is opaque, but at higher intensities the dye is bleached and becomes transparent. The bleaching time of the dye is the effective time of the optical shutter. In the 1980's, a colliding pulse geometry was used with the passive modelocking technique to produce a colliding pulse mode-locked (CPM) dye laser. When intracavity GVD compensation (described laser in this chapter) was used with a CPM laser, sub-100 fs pulses were generated for the first time.

Also, during the 1980's, several new developments in broad bandwidth, solid-state laser materials occurred. The most notable of these was titanium-doped sapphire which allowed lasers to be tuned over a continuous range from < 700 to 1100 nm. In 1989, Spectra-Physics was the first company to offer a commercial CW Ti:sapphire laser.

The broad bandwidth and good thermal properties of this new material motivated several new modelocking approaches. Additive pulse modelocking (APM) used an interferometrically-coupled, external nonlinear fiber cavity to induce modelocking. In 1991, self-modelocking in Ti:sapphire was observed to be induced through the intensity-dependent, nonlinear refractive index of the laser medium. At Spectra-Physics, the *Tsunami* laser was developed, a commercial, mode-locked Ti:sapphire laser based upon a regeneratively initiated technique.

Regenerative Modelocking in the Tsunami

Like active modelocking, regenerative modelocking in the *Tsunami* laser employs an AOM within the cavity to generate a periodic loss. However, unlike active modelocking, the RF drive signal used to drive the AOM is derived directly from the laser cavity (Figure A-4). This removes one of the greatest drawbacks of active modelocking, i.e., the requirement that the cavity length match the external drive frequency. In the *Tsunami*, if the laser cavity length L changes slightly, the drive signal to the modulator changes accordingly.

When the *Tsunami* is initially aligned, the laser is operating CW with oscillations from several longitudinal modes. These are partially phase-locked, and mode beating generates a modulation of the laser output at a frequency of $c/2L$. This mode beating is detected by a photodiode and then amplified. Since this signal is twice the required AOM modulation frequency (ω_{ML}), it is divided by two, then the phase is adjusted such that the modulator is always at maximum transmission when the pulse is present. Finally, the signal is reamplified and fed to the AOM.

Most actively mode-locked systems run on resonance for maximum diffraction efficiency. The AOM in a *Tsunami* is operated off-resonance with a diffraction efficiency of about 1%. The output pulse width is not controlled by the AOM diffraction efficiency. Rather, pulse shortening in the *Tsunami* occurs through a combination of positive GVD and nonlinear effects (self phase modulation) in the Ti:sapphire rod. Ultimately, the output pulse width is controlled by adding net negative GVD to the cavity to balance these effects. (Refer to the following section on GVD.)

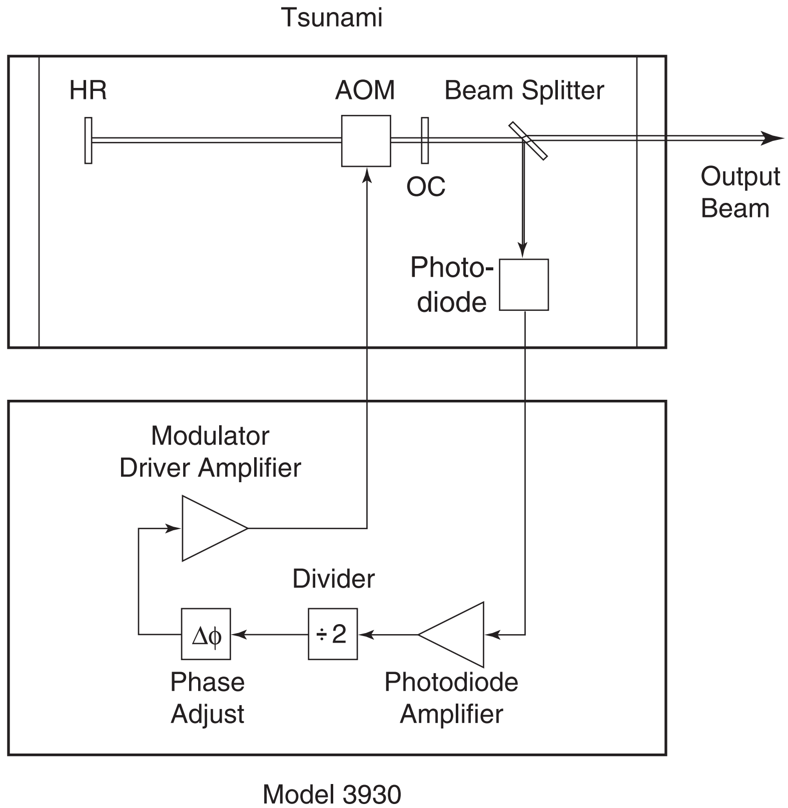
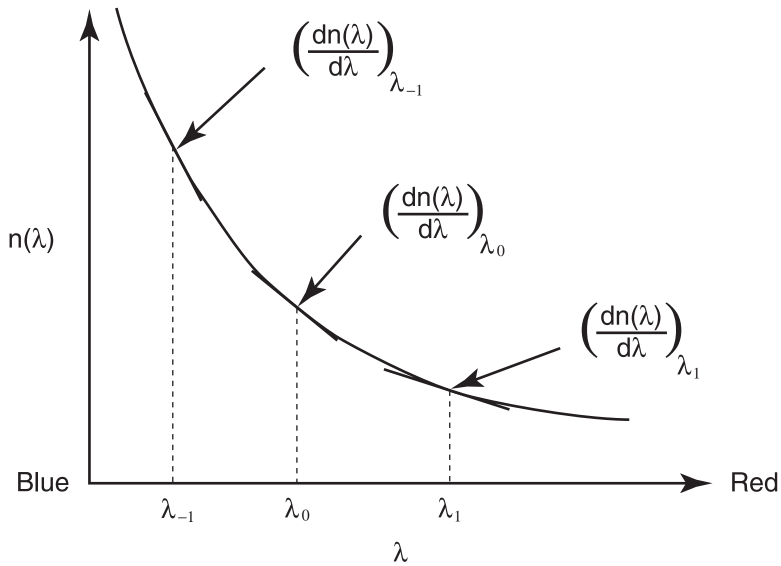


Figure A-4: Configuration of the electronics for a regenerative mode-locked laser.

Group Velocity Dispersion (GVD)

Fourier analysis (or as consequence of the Heisenberg uncertainty principle) imposes a restriction on the bandwidth of an ultrashort pulse. For a pulse of duration Δt_p and bandwidth $\Delta\nu$, it is always true that $\Delta\nu$ @Δt_p will be greater than a constant with a value of about 1. The exact nature of the constant depends on the exact shape of the pulse (examples are given in Appendix B). It is apparent that, the shorter the pulse, the larger the bandwidth and, thus, the greater the difference from the lowest to highest frequency within a pulse. Since the index of refraction of any material is frequency dependent, each frequency in a pulse experiences a slightly different index of refraction as it propagates. This index of refraction difference corresponds to a velocity difference, causing a time separation between the different frequencies of a pulse. Group velocity dispersion (GVD) is defined as the variation in transit time as a function of wavelength. For positive GVD, the lower frequencies (red) travel faster than higher frequencies (blue). The effect is more pronounced for shorter pulses (because of their larger bandwidth).

Figure A-5 shows the refractive index n versus wavelength λ for a typical transparent optical material. For any given wavelength, the refractive index $n(\lambda)$ determines the phase velocity. The slope of the curve, $dn(\lambda)/d\lambda$, determines the group velocity, or the velocity of a short pulse with a center wavelength of λ..



Phase Velocity = $^c/_n$

Group Velocity = $^c/\left(n(\lambda) - {}^{\lambda dn}/_{d\lambda}\right)$

Group Delay Time, Tg = $\left(^L/_c\right) \cdot \left(n(\lambda) - {}^{\lambda dn}/_{d\lambda}\right)$

where L is material length

Figure A-5: Typical wavelength dependence of the refractive index of a material

The second derivative of the curve, $d^2n(\lambda)/d\lambda^2$, determines the GVD, which is the rate at which the group velocity changes as a function of wave length, i.e., it governs the rate at which the frequency components of a pulse change their relative time. GVD can change the temporal shape of the pulse by broadening it or narrowing it, depending on the "chirp" of the original pulse. A pulse is said to be positively chirped, i.e., it has experienced positive GVD, if the low frequencies lead the high (red is in front), and negatively chirped if the opposite is true. Pulses are typically positively chirped as they pass through normal materials at visible and near IR wavelengths.

Nonlinear Effects

In addition to GVD, the output pulse width and pulse shape from the *Tsunami* are governed by the interaction of the pulse with the nonlinear index of the Ti:sapphire. The nonlinear index of refraction n_2 introduces an intensity-dependent index at high intensities:

$$n = n_0 + n_2 I \qquad [1]$$

where n_0 is the linear index of refraction and I is the instantaneous pulse intensity. This results in self phase modulation (SPM) of the pulse. As the pulse propagates through the Ti:sapphire material, the leading edge experiences an increasing index of refraction. This causes a delay in the individual oscillations of the electric field and results in a “red-shifted” leading edge. Conversely, the trailing edge of the pulse is “blue-shifted.” SPM will, thus, broaden the spectrum of the pulse and provide a positive chirp.

In order to achieve near transform-limited output pulses, it is necessary to compensate for the pulse spreading caused by positive GVD and SPM. In the *Tsunami*, this is accomplished with prism pairs in the femtosecond regime (which provide negative GVD linear over a large bandwidth) and with a Gires-Tournois interferometer (GTI) in the picosecond regime (which provides larger net negative GVD, but linear over a narrow bandwidth).

GVD Compensation

The materials in the *Tsunami* contribute positive GVD and, in combination with SPM in the Ti:sapphire rod, induce a positive chirp on the pulse. Consequently, the circulating pulse continues to broaden as it propagates through the cavity unless negative GVD is present to balance these effects.

As discussed earlier, a material exhibits GVD when the second derivative of its refraction index, with respect to wavelength $(d^2n/d\lambda^2)$, is non-zero. This is a special case that is only valid when all wavelengths follow the same path through a material. This can be extended to any optical system having a wavelength dependent path length (P). GVD is then governed by the second derivative of the optical path with respect to wavelength $(d^2P/d\lambda^2)$.

For this reason, a prism pair can be used to produce negative GVD. This is generally the preferred intracavity compensation technique for ultrashort pulse lasers because (a) losses can be minimized by using the prisms at Brewster’s angle, and (b) the negative GVD is nearly linear over a large bandwidth. Ideally, for stable short-pulse formation, the round trip time in the cavity must be frequency independent, i.e., $Tg(\omega) = d\phi/d\omega$ = constant, where $Tg(\omega)$ is the group delay time, ϕ is the phase change, and ω is the frequency. In reality, dispersion is not purely linear, and higher order dispersion terms become significant for shorter output pulse widths (larger bandwidths).

In the fs *Tsunami* laser, a four-prism sequence configuration is used to provide negative GVD (Figure A-6).

The net intracavity GVD can be changed by translating prisms Pr_2 and Pr_3 perpendicular to their bases. This is achieved using a single micrometer adjustment. By translating Pr_2 and Pr_3 further into the intracavity beam, more optical material is inserted into the cavity and the net intracavity GVD becomes less negative.

The different spectral components of the pulse are spatially spread between prisms Pr_2 and Pr_3. This allows wavelength selection to be conveniently accomplished by moving a slit between these two prisms in the direction of the spectral spread. Varying the slit separation selects the output bandwidth (and hence pulse width). As the output wavelength is tuned, it is necessary to optimize intracavity dispersion by adjusting Pr_2 and Pr_3, in order to maintain the shortest output pulse width. To a first approximation, the prisms need to be translated at the same rate as the slit to maintain the minimum pulse duration.

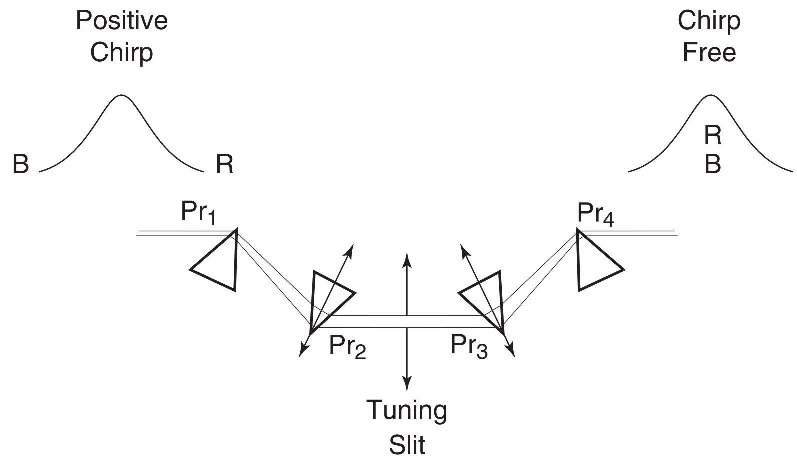


Figure A-6: The four prism sequence used for dispersion compensation in the *Tsunami* laser. An input pulse with a positive chirp (red frequencies at the leading edge of the pulse) experiences negative GVD (red frequencies have longer group delay time) in the prism sequence. The net effect is that the prism sequence compensates for the positive GVD and produces a pulse which has no chirp.

In the picosecond configuration of the *Tsunami* laser, wavelength selection and tuning are achieved by a birefringent filter, and dispersion compenstion is accomplished with a Gires-Toumois interferometer (GTI). The GTI introduces a larger net negative GVD than a prism pair, but it is linear over a smaller wavelength region.

A GTI is a pair of parallel surfaces where the first surface is a partial reflector and the second has 100% reflectivity. The two qualities which characterize these interferometers are the spacing between the surfaces (d), and the reflectivity (r) of the first surface. The round-trip time through the GTI may be expressed as:

$$t_0 = \frac{2d}{c} \qquad [2]$$

For a short pulse, the group delay time is given by:

$$Tg(\omega) = \left[\frac{t_0(1+r)}{1-r}\right] \cdot \frac{1}{\left[1 + \left(\frac{4r}{(1-r)^2}\sin\theta^2\left(\frac{\omega t_0}{2}\right)\right)\right]} \qquad [3]$$

Figure A-7 shows Tg for a typical GTI as a function of wavelength. The GVD is proportional to the slope of this curve (actually, – $dTg/d\lambda$), and is periodic with regions of both positive and negative GVD.

When a GTI is used in a tunable laser, the spacing between the surfaces of the GTI must be adjusted to obtain the appropriate dispersion at the lasing wavelength. In the *Tsunami* laser, this is achieved by using a piezo-electric transducer (PZT) between the GTI plates. By changing the applied voltage to the PZT, the distance between the plates is varied (which varies the dispersion) and, for any given wavelength, the pulse width can be optimized.

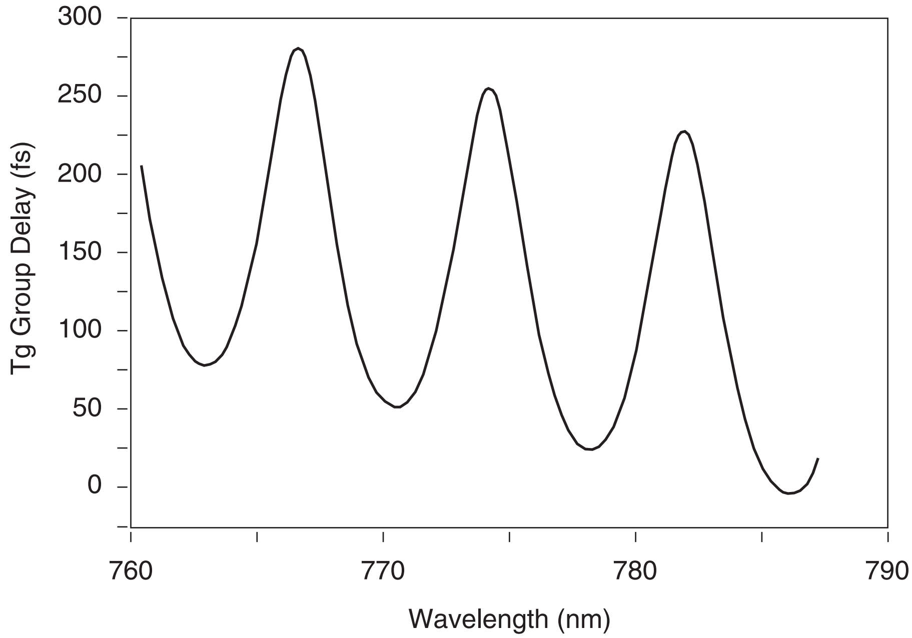


Figure A-7: Group delay time as a function of wavelength for a GTI with a 40 µm spacing and a 4% reflector.

For a given reflectivity *r*, the magnitude of *Tg* is proportional to t_0 and, thus, the spacing *d* (GVD is proportional to d^2). By increasing the spacing between the GTI surfaces, the amount of GVD can be increased significantly. The bandwidth over which a GTI provides linear GVD is inversely proportional to the spacing *d*. Thus, for large values of GVD, the bandwidth over which the GVD is linear will become quite small. By using several GTIs with different spacings, it is possible to generate transform-limited pulses from the *Tsunami* laser with a duration as short as 1 ps to as broad as 80 ps. Pulse widths beyond 10 ps require a 3-plate birefringent filter to eliminate the next order of the GTI. For a given GTI, the pulse width can be varied by fine adjustments of the spacing *d* since different portions of the dispersion curve generate varying values of GVD. Typically, it is possible to change the pulse width by a factor of about two for any particular GTI.

Appendix B Pulse Width Measurement

Introduction

In this chapter we discuss how to measure pulses using an autocorrelator. Also included are sections on bandwidth diagnostics and continuous wave (CW) breakthrough.

The Autocorrelation Technique

Measurement of Ultrashort Pulses

An autocorrelator is the most common instrument used for measuring an ultrafast femtosecond (fs) or picosecond (ps) optical pulse. By using the speed of light to convert optical path lengths into temporal differences, we use the pulse to measure itself.

The basic optical configuration is similar to that of a Michelson interferometer. An incoming pulse is split into two pulses of equal intensity and an adjustable optical delay is imparted to one. The two beams are then recombined within a nonlinear crystal for second harmonic generation. The efficiency of the second harmonic generation resulting from the inter action of the two beams is proportional to the degree of pulse overlap within the crystal. Monitoring the intensity of uv generation as a function of delay between the two pulses produces the autocorrelation function directly related to pulse width.

Two types of autocorrelation configurations are possible. The first type, known as interferometric and shown in Figure B-1, recombines the two beams in a collinear fashion. This configuration results in an autocorrelation signal on top of a constant dc background, since the second harmonic generated by each beam independently is added to the autocorrelation signal. Alternatively, if the two beams are displaced from a common optical axis and then recombined in a noncollinear fashion (Figure B-2), the background is eliminated because the uv from the individual beams is separated spatially from the autocorrelator signal. This configuration is called "background-free."

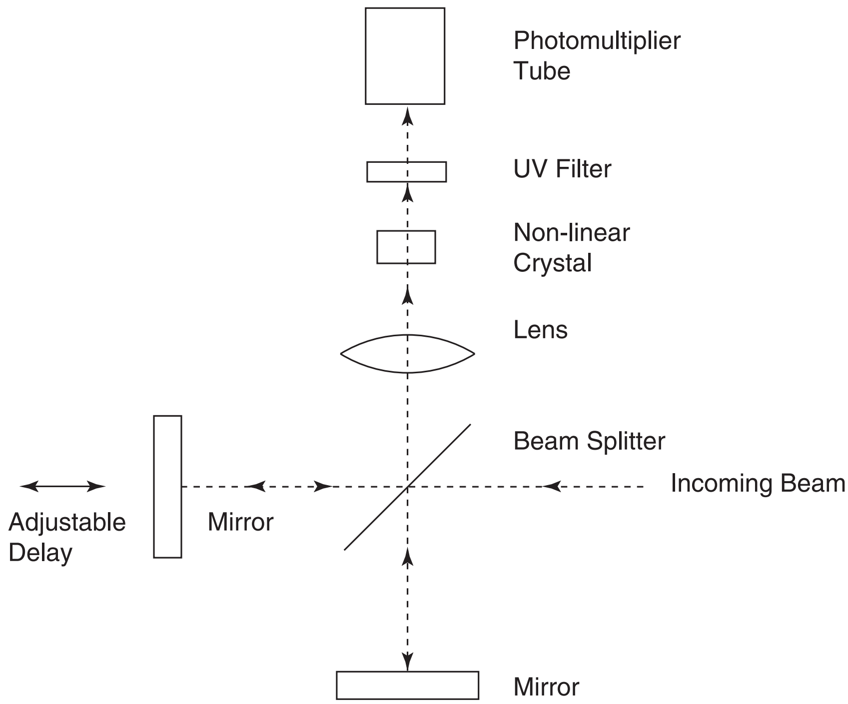


Figure B-1: Interferometric (Collinear) Autocorrelation

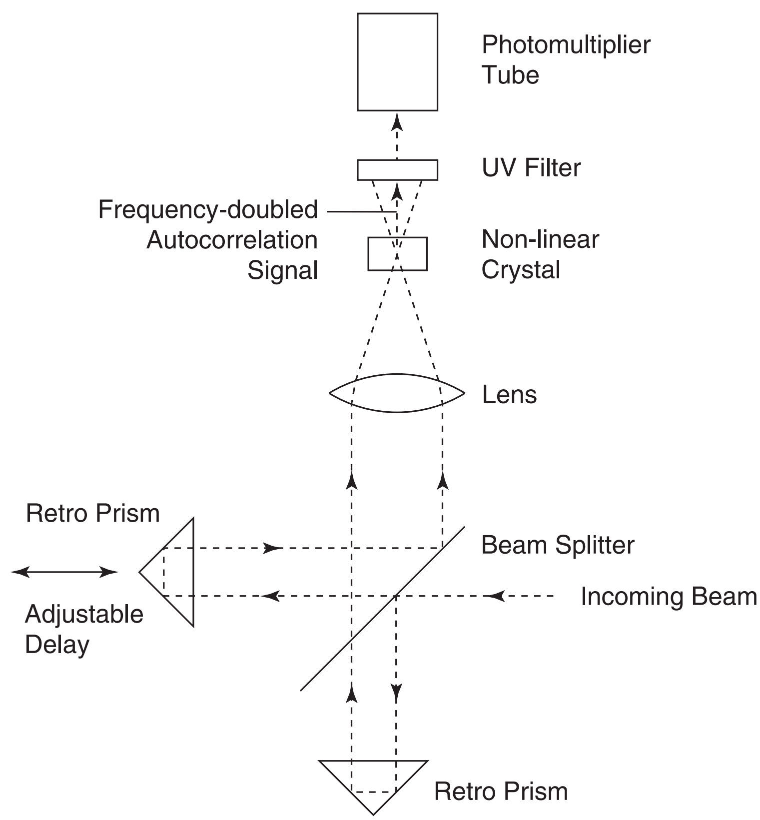


Figure B-2: Background-free (Non-collinear) Autocorrelation

The Spectra-Physics *Model 409-08* scanning autocorrelator operates in a background-free configuration according to the principles of noncollinear autocorrelation. It allows the autocorrelator signal to be conveniently displayed on a high impedance oscilloscope, providing the user with instantaneous feedback of laser performance. The optical path of the *Model 409-08* is shown in Figure B-3. The *Model 409-08* uses a rotating block of fused silica for varying the relative path lengths of both beam paths, and the scanning time base is calibrated by moving a calibration etalon of known thickness in and out of one of the beam paths. The *Model 409-08* can be used over the wavelength range from 650 to 1600 nm and, by changing the rotating blocks, it can be used to measure pulse widths from 25 ps to < 80 fs.

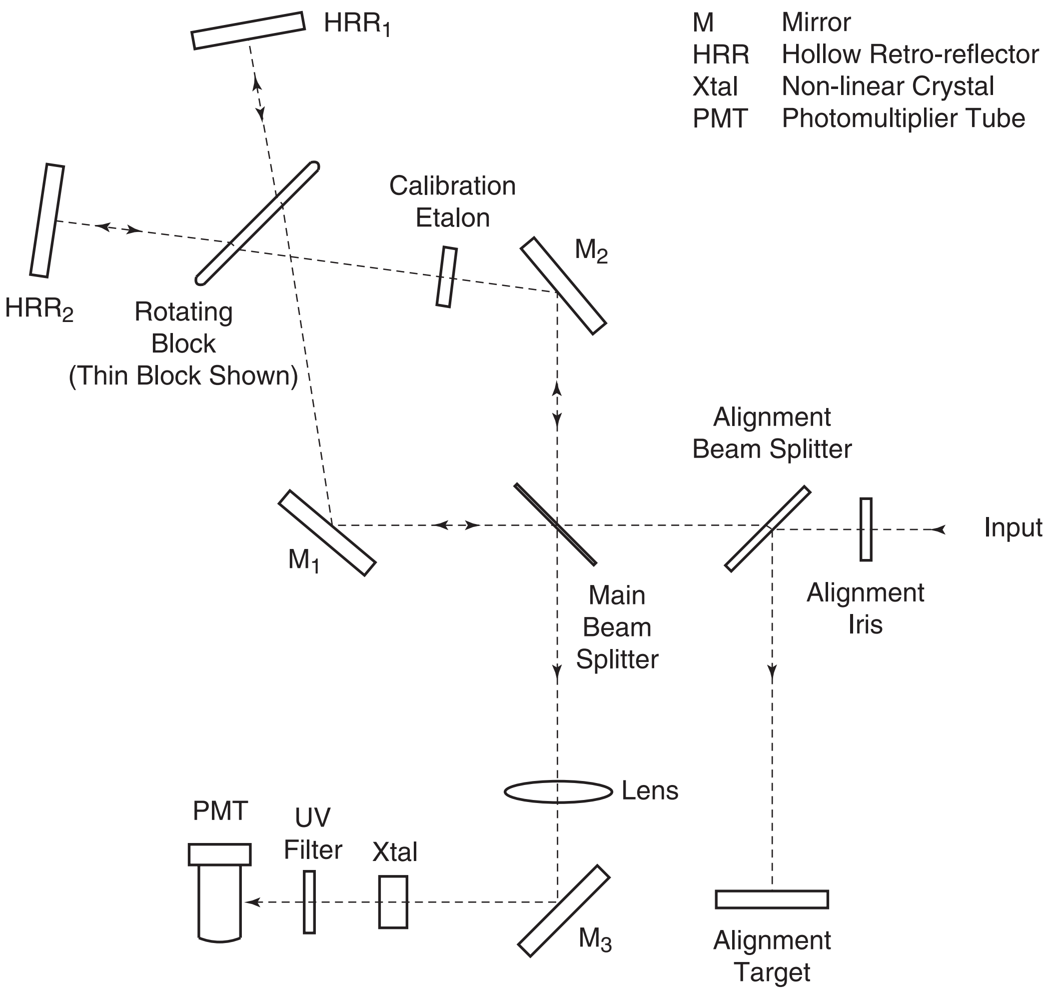


Figure B-3: The *Model 409-08* Autocorrelator Optical Path. The beam paths are displaced by HRR_1 and HRR_2 in and out of the plane of the paper, so the configuration corresponds to the background-free method shown in Figure B-2.

Signal Interpretation

In order to determine the actual pulse width from the displayed autocorrelation function, it is necessary to make an assumption about the pulse shape. Table B-1 shows the relationship between pulse width, Δt_p, and the autocorrelation function, Δt_{ac}, for several pulse shapes. It also shows the time-bandwidth product, $\Delta tp \ \Delta n$, for transform-limited pulses.

Table B-1: Second-order Autocorrelation functions and Time-Bandwidth Products for Various Pulse Shape Models

Function	I(t)	Δt_p*/Δt_{AC}**	$\Delta t_p \Delta \upsilon$***
Square	$I(t) = \begin{cases} 1; \lvert t\rvert \le t_p/2 \\ 0; \lvert t\rvert > t_p/2 \end{cases}$	1	1
Diffraction Function	$I(t) = \dfrac{\sin^2(t/\Delta tp)}{(t/\Delta tp)}$	0.751	0.886
Gaussian	$I(t) = \dfrac{\exp-(4\ln 2)t^2}{\Delta t^2 p}$	0.707	0.441
Hyperbolic Secant	$I(t) = \operatorname{sech}^2\dfrac{(1.76t)}{\Delta tp}$	0.648	0.315
Lorentzian	$I(t) = \dfrac{1}{1+(4t^2/\Delta t^2 p)}$	0.500	0.221
Symmetric two-sided exponential	$I(t) = \exp\dfrac{-(\ln 2)t}{\Delta tp}$	0.413	0.142

* Δt_p *(sec) is FWHM of intensity envelope of the pulse.*

**Δt_{AC} *(sec) is FWHM of autocorrelator function of the pulse.*

***Δt_n *(Hertz) is FWHM of the spectrum of the pulse.*

GVD Compensation in Measurement of Ultrashort Pulses

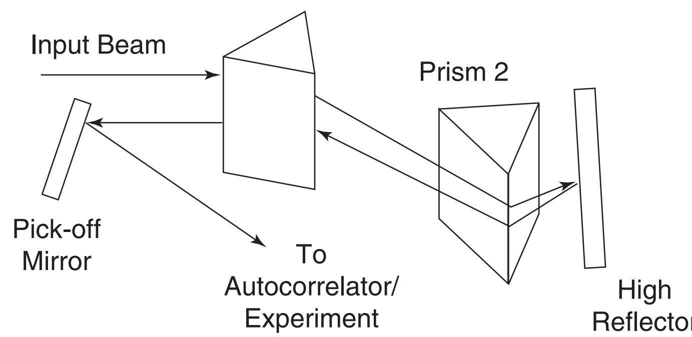
Because the pulses produced by the *Tsunami*® laser are extremely short (< 80 fs), the pulse broadening in optical materials from GVD makes measurement of its true pulse width difficult. Also, because the GVD of glass causes the pulse width to broaden, the pulse that reaches an experimental sample after traveling through beam splitters, lenses, etc., may not be the same pulse that is measured in the autocorrelator. It is thus important to ensure that the measurement technique and experimental set up incorporate the same amount of glass and some GVD compensation if the shortest pulses 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 (0.75 in.). Thus, 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.

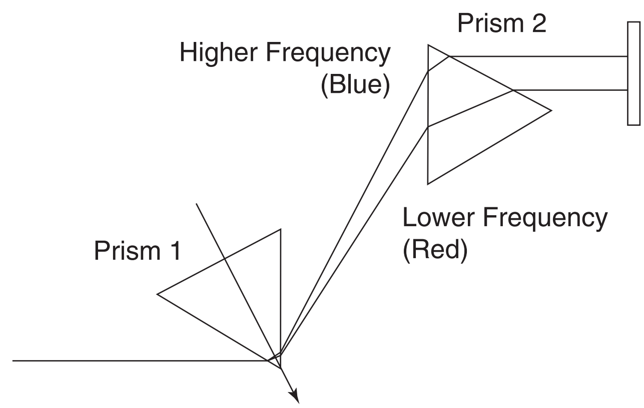
Since most autocorrelators use beam splitters, a lens, and often a spinning block (as in the *Model 409-08*), the pulse is also broadened before it is measured. This means the pulse out of the *Tsunami* may be actually shorter than that indicated by direct measurement. Consequently, GVD must also be compensated when using an autocorrelator.

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

To compensate for pulse broadening from materials, a simple setup using two high index prisms (SF-10) is all that is necessary. Figure B-4 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 reflected by another mirror to the autocorrelator and/or the experiment.



Side View: Beam path shown for a particular frequency component of the pusle.



Direction in which to translate Prism 1 to add more positive GVD.

Top View: Dispersion shown.

Figure B-4: 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, $d^2P/d\lambda^2$, that determines the sign of the GVD. In Table B-3 and Table B-4 dispersion values at 800 nm are provided for materials and grating prism pairs. The dispersion, D_w, is expressed in units fs^2/cm of path length.

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.

Table B-3: Positive Dispersion Values @ 800 nm

Material	$D\omega\,(fs^2/cm)$
Fused Silica	300
BK-7	450
Ti:sapphire	580
SF-10	1590

Table B-4: Negative Dispersion Values @ 800 nm

System	$D\omega\,(fs^2/cm)$
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

For an initial setup based on your *Tsunami* and a *Model 409-08* autocorrelator, set the prisms approximately 30 cm apart 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, we can balance the GVD for minimum pulse width. To do this, place the first prism on a translation stage that 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. This allows the negative GVD of the prism system to balance the positive GVD created by all the glass. By moving the prism into the beam path and monitoring the output from a *Model 409-08*, 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 $B = t_{out}/ t_{in}$. Consequently, knowing the input pulse width, *B* can be calculated and then $t_{out} = B \bullet t_{in}$.

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

$$B = t_{out}/t_{in} = \left\{1 + [7 \cdot 68 \cdot (D_{\omega} \cdot L/t_{in}^2)^2]\right\}^{\frac{1}{2}} \qquad [1]$$

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 B-3 gives values for different materials at 800 nm. Also given in Table B-4 are the values for some negative dispersion setups, prisms, and grating pairs for compensation at 800 nm. Using these values, *B* is calculated directly; we define *S* as:

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

Using Figure B-5, you can relate the value of *S* to a value for the broadening *B*.

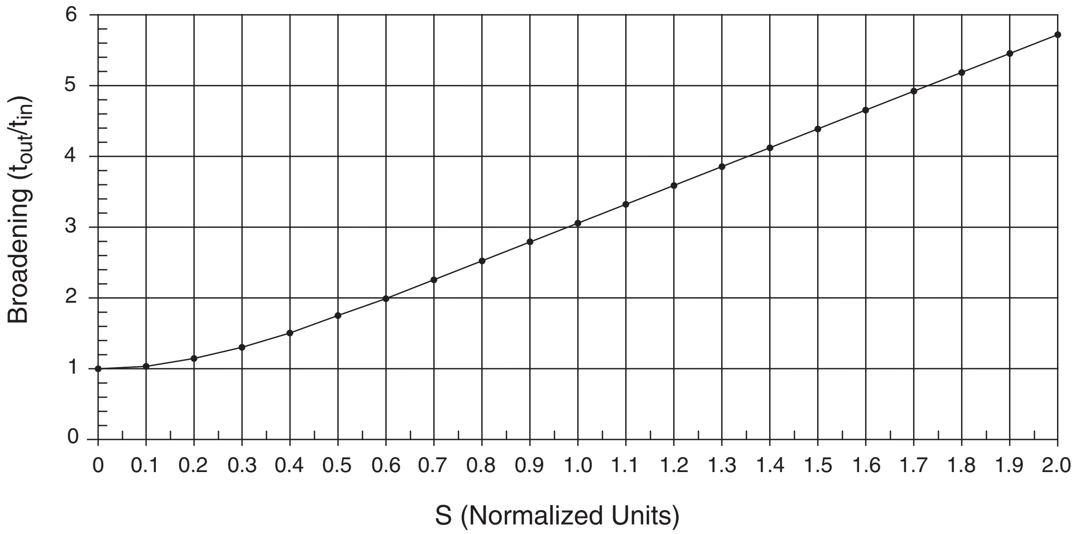


Figure B-5: Broadening Curve

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 measured by a *Model 409-08* without pre-compensation.

Assume an 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 0.25 cm of BK-7 glass and 0.26 cm of fused silica in the *Model 409-08*.

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

$$= 30 \cdot 1.9 + 300 \cdot 0.26 + 450 \cdot 0.25 = 760 \text{ fs}^2$$

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

Then, looking at our normalized curve (Figure B-5) $S = 0.251$, 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 409-08*.

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 a large amount of positive GVD, thereby balancing out the prism spacing.

CW Breakthrough

Under certain circumstances, it is possible for a mode-locked *Tsunami* laser to exhibit a small continuous wave (CW) component along with the pulsed output. This phenomenon is generally restricted to systems operating in the fs regime where intracavity prisms are used for dispersion compensation. It usually occurs when either the input pump power is too high or the intracavity dispersion compensation is incorrect. It can easily be removed by reducing the ion laser pump power or by adjusting the prism dispersion compensation control on the *Tsunami* laser. There appears to be no analogous dual mode operation in the ps regime (where a GTI is used for dispersion compensation). Too high an input power in a ps system usually results in satellite temporal pulses.

Because of the dynamic range limitation of photodetectors, a direct measurement of the CW background for a fs mode-locked *Tsunami* is impossible. For a mode-locked repetition rate of 100 MHz (10^5 duty cycle), with 1% of the energy in a CW component, this amounts to a base line signal 10^7 times smaller than the peak pulse height. In order to detect this CW signal level directly, a detector with a resolution of 100 fs and dynamic range of $> 10^7$ is required. A successful measurement can be made if we take into account the fact that the CW component has a very different bandwidth than that of a sub 100 fs pulse. It is possible to deter mine a CW component of less than 1% with a conventional detector in conjunction with a spectrally selective device. We recommend a monochromator with a CCD detector. This also provides an accurate measurement of the output wavelength (usually required for an experiment) and the bandwidth of the pulse (required for determining the pulse time-bandwidth product and, thus, its relationship to a transform-limited pulse).

Figure B-6 shows a standard setup. For a typical < 80 fs output pulse, the ratio of bandwidth to the CW linewidth is about 100 (10 nm vs. 0.1 nm). Consequently, a 1% CW component has the same peak height as the spectral peak of the pulse. The signal detection limit of this technique is governed by the ultimate resolution of the monochromator but, with a conservative signal detection limit of about 10% of the peak height, it is possible to detect a CW component of about 0.1% (Figure B-7). During final test procedures at Spectra-Physics, all *Tsunami* systems are tested using an external monochromator and CCD diagnostic to ensure any CW component is less than 0.1%.

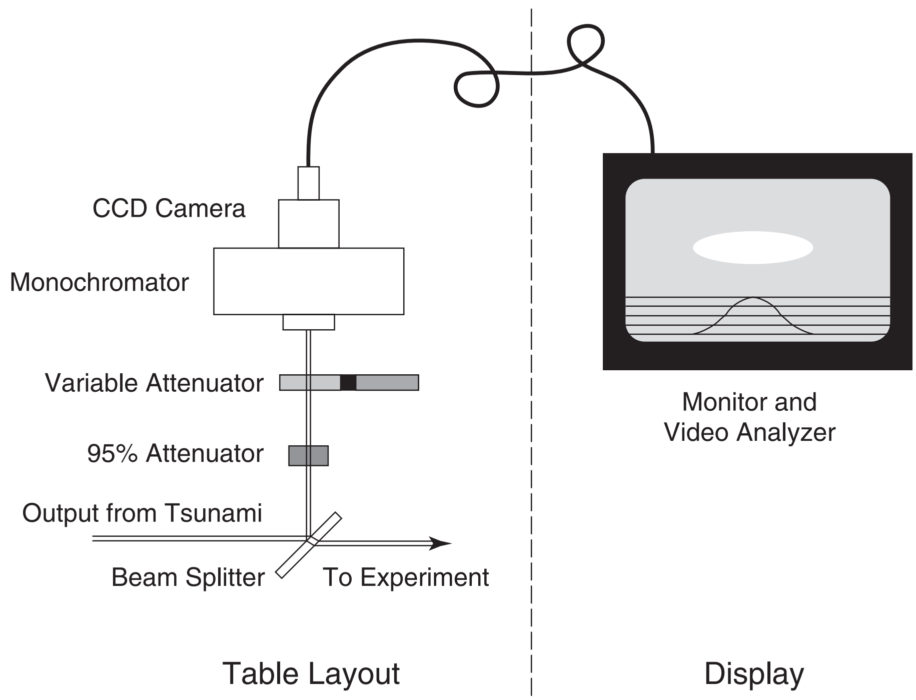


Figure B-6: A Typical Monochromator/CCD Setup

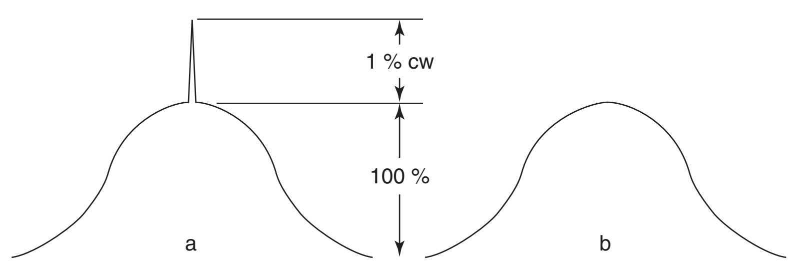


Figure B-7: Output spectrum of the *Tsunami* monitored with an external monochromator/CCD system. (a) shows a CW component of 1%, (b) shows a CW component of less than 0.1%.

A list of recommended components for the monochromator/CCD diagnostic is given in Table B-5.

Table B-5: Recommended Monochromator/CCD Components

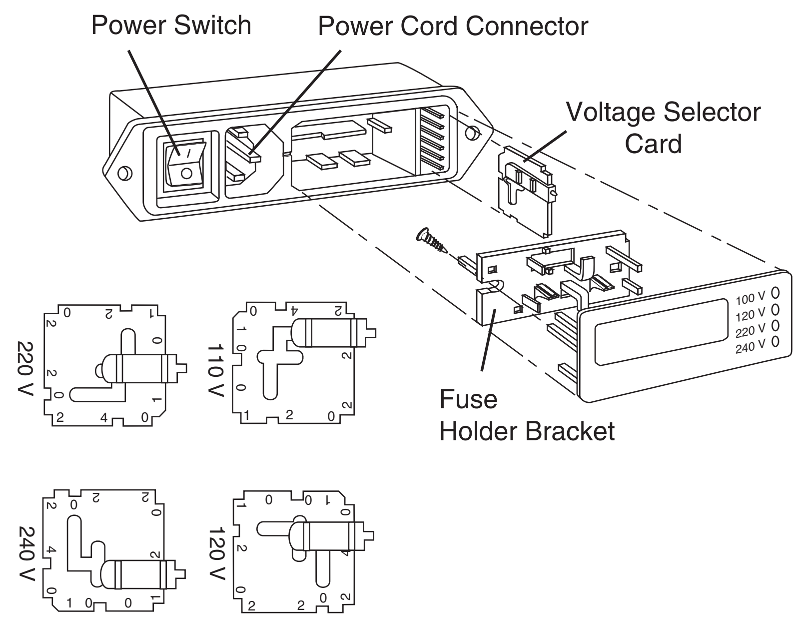
Item	Manufacturer/Model Number
Video Analyzer	Colorado Video (Optional)
Monochromator	Oriel / 77250
Grating	Oriel / 77229
Slit	Oriel / 77269
CCD Camera	Pulnix America / TM-7CN
Power Supply	Pulnix America / PD-12P
Variable Attenuator	Newport / 50G00 AV.1
Mount	Newport / 941
Monitor	Video Media / TC1910A
Beam Splitter	Spectra-Physics / G0020-000
95% Attenuator	Andover Corporation / 150FN46-25

Appendix C Setting the Line Voltage Switch

The line voltage switch, which is part of the power connector on the *Model 3955* electronics module, must match your local line voltage. The *Model 3955* and optional *Model 3930* are shipped from the factory with the line voltage selected for the location of intended use. If the incorrect setting is selected, you must change it prior to applying power to the system. The following directions are provided so you can make the change yourself.

1. Remove the cover plate/fuse block assembly to expose the voltage selector card. Refer to Figure C-1

   Use a small screwdriver to gently pry off the cover plate. A slot is provided for screwdriver access.



The four orientations of the voltage selector card.

Figure C-1: Power Switch, Line Cord, and Voltage Selector Module

2. Remove the voltage select card.

   The voltage select card comprises a white plastic indicator pin and a small pc board about 2 cm square. Refer to Figure C-1.

   Using needle-nose pliers, gently grasp the pc board and pull it out and from side to side to remove it from the module.

3. Select the voltage.

   There are four voltage selections, one written on each edge of the pc board with a small arrow pointing to it.

   a. Measure your facility outlet voltage, then rotate the pc board until the edge with the measured voltage printed on it faces the inside of the module (the arrow points into the module).
   b. Move the white indicator pin in the pc board slot so it points away from your selection and so it will protrude through the correct hole in the cover plate when the plate is replaced in Step 6.

4. Replace the voltage selector card.

   Make sure the pc board seats properly for good electrical contact.

5. Verify the correct fuse is installed.

   Remove the small screw holding the fuse block to the cover plate to access the fuse. Use the table below to determine the correct fuse size for your facility line voltage, then verify the correct one is installed.

Line Voltage	Fuse Value
100 to 120 Vac	1 A slow blow
220 to 240 Vac	½ A slow blow

6. Snap the cover plate into place.

   If the indicator pin is not in the correct position, repeat Steps 3 and 4.

This completes the procedure for changing the voltage setting.

Overview

This sections describes the controls and indicators of the LabView™ Windows® software (P/N 0453-4740) available from Spectra-Physics. The software runs on an IBM-PC with LabView installed and mimics the functions of the *Model 3930 Lok-to-Cloc*k® electronics module. Because LabView and the Model 3930 function in parallel and because LabView overrides the controller in a one second cycle, some controller functions should be disabled when LabView. For example, if LabView is on and the LOK CONTROL is set to "on" in LabView but turned "off" on the controller, LabView will reset Lok to "on" in about one second. Also, for consistent results, "turn off" the coarse and fine timing adjustment controls on the *Model 3930* by turning them fully clockwise.

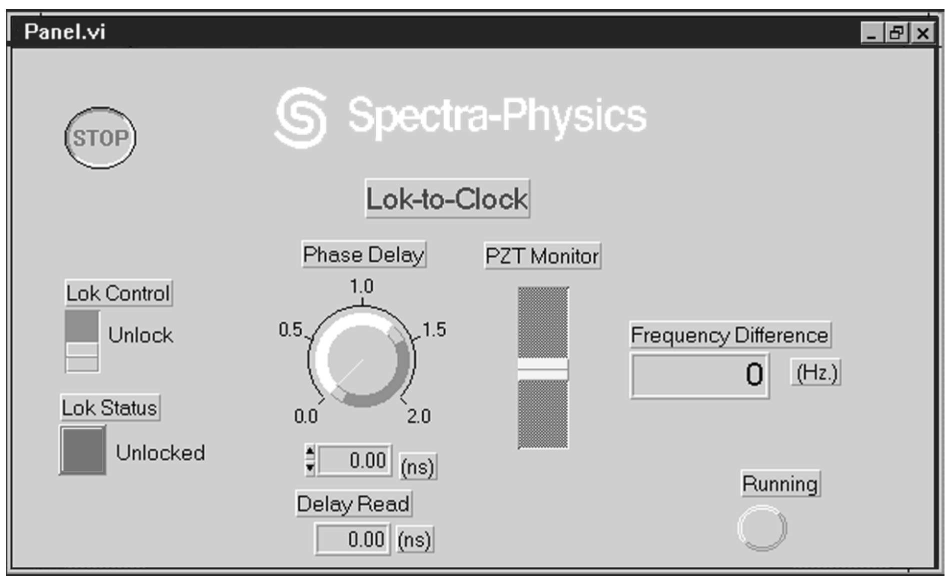


Figure D-1: The *Lok-to-Clock* LabView Control Panel

Setup

1. Connect a serial interface cable between the RS-232 interface on the PC to the RS-232-C connector on the back of the *Model 3930* electronics module. Refer to Chapter 8 regarding cable wiring requirements.
2. Turn on the pc and start Windows. Then, from the Windows Control Panel, select the Com port you are using for the RS-232 interface and set it for 9600 baud, no parity, 8 data bits, one stop bit, using the XON/XOFF protocol.

3. Copy the *Lok-to-Clock* software module into the LabView subdirectory where the other modules reside.
4. Start the LabView software, then select and run the *Lok-to-Clock* software module.
5. From the LabView *Lok-to-Clock* Control Panel, select “Controls” from the menu and chose the appropriate COM port.
6. Use the mouse and keyboard to select and set the parameters displayed on the screen. A description of the controls are listed below. For detailed functional descriptions of the *Lok-to-Clock* system, refer to Chapter 8.

Controls Description

STOP button—when pressed, aborts the current LabView process.

LOK CONTROL switch—turns on the *Lok-to-Clock* lock function when the switch is set to the up position. “Lock” or “Unlock” is displayed to indicate its position.

LOK STATUS light—turns on when the LOK CONTROL switch is set to the lock position and the system is locked. “Locked” or “Unlocked” is displayed to the right of the lamp to indicate its status as well.

PHASE DELAY control—allows you to set the phase delay for locking the system to an input signal. It sets the timing between the reference source and the *Tsunami* laser from 0 to about 2 ns. This is a nominal setting, not a calibrated function. Because the delay timing control on LabView and the *Model 3930* are interactive, for consistent results when using LabView, “turn off” the coarse and fine timing adjustment controls on the *Model 3930* by turning them fully clockwise.

DELAY READ indicator—displays the actual delay between the original signal and the lock signal. This is a nominal setting, not a calibrated function. Use it for reference only.

PZT MONITOR indicator—similar to the STATUS indicator on the *Model 3930*, it shows the relative position of the M_4 PZT mirror within its range. When the position bar is not present, the *Lok-to-Clock* function has been disengaged via the LabView LOK STATUS switch or the *Model 3930* STATUS: LOCK button.

FREQUENCY DIFFERENCE indicator—similar to the FREQUENCY indicator on the *Model 3930*, it indicates the difference between the reference frequency and actual laser pulse frequency.

Note: the *Model 3930* and LabView indicators may disagree slightly because different measurement devices are used. Also, the *Model 3930* need not be set to DIF for the LabView indicator to display properly.

RUNNING indicator—flashes to indicate *Lok-to-Clock* is under LabView control.

Appendix E Material Safety Data Sheets

This section contains scanned copies of material safety data sheets (MSDS) that are supplied by the vendor and cover the various chemicals and compounds used in the *Tsunami* laser system, e.g., the compounds used in the filters in the *Model 3910* filter/purge unit.

Danger!

Read the MSDS sheets carefully before handling or disposing of filter elements. They may contain hazardous chemicals. Spectra-Physics has not independently determined the accuracy of the Material Safety Data Sheets, which were developed by the manufacturer of each chemical; therefore, we do not warrant the information contained therein. Dispose of these filter elements properly as indicated on the appropriate data sheet, and refer to your local environmental regula tions regarding disposal. For further information, contact the chemical manufacturer at the address listed on each sheet.

Alltech MATERIAL SAFETY DATA SHEET

Alltech Associates, Inc. • 2051 Waukegan Road • Deerfield, IL 60015 • Phone: 708-948-8600 • Fax: 708-948-1078

STOCK NO:4034 PAGE: 1
ALSO APPLIES TO:*4034,4037,*4037
DATE:2/7/86

IDENTIFICATION

NAME: Borosilicate glass wool, silyated

REMARKS

The manufacturer of the glass wool used in these products indicates that an MSDS is not needed for their material. We have elected to provide some of the safety and common sense information we believe is useful.

The basic product has been treated with a silyation reagent to react with the silanol groups to make it more suitable for its intended application in chromatography. The glass wool is rendered hydrophobic. The excess reagent is removed and, to the best of knowledge, should not present any additional hazard.

CAS#:65997-17-3

SYNONYMS

Angel hair, fiberglass

TOXICITY HAZRDS

TOXICITY DATA

HEALTH HAZARD DATA

ACUTE EFFECTS

Overexposure: may cause temporary skin and upper respiratory irritation.

APPEARANCE AND ODOR

FIRST AID

Wash exposed areas with soap and warm water after handling.

FIRE AND EXPLOSION HAZARD DATA

EXTINGUISHING MEDIA

SPECIAL FIREFIGHTING PROCEDURES

UNUSUAL FIRE AND EXPLOSIONS HAZARDS

REACTIVITY DATA

INCOMPATIBILITIES

STABILITY

Alltech MATERIAL SAFETY DATA SHEET (cont'd)

STOCK NO:4034 PAGE: 2
ALSO APPLIES TO:*4034,4037,*4037
DATE:2/7/86

HAZARDOUS COMBUSTION OR DECOMPOSITION PRODUCTS

HAZARDOUS POLYMERZATION WILL NOT OCCUR.

SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED
While wearing suitable protective devices, gather and sweep up. Place in plastic bags for disposal.

WASTE DISPOSAL METHOD
According to federal, state and local ordinances.

SPECIAL PROTECTION INFORMATION

SPECIAL PRECAUTIONS
Use respirator, such as 3M model 8710 or equivalent, for protection against nuisance dusts. Wear long sleeves and loose fitting clothing. Wash work clothes separartely from other clothing: then rinse washer thoroughly.

NOTICE: The information contained in the MSDS description is applicable exclusively to the chemical substances identified herein and for its intended use as an analytical reference standard or reagent and to the unit quantity intended for that purpose. The information does not relate to, and may not be appropriate for, any other applications or larger quantity of the substance described. Our products are intended for use by individuals possessing sufficient technical skill and qualification to use the material with suitable discretion and understanding of risk of handing any potentially hazardous chemical. The information has been obtained from sources believed to be reliable and accurate but has not been independently verified by Alltech Associates, Inc. Accordingly, NO REPRESENTATION OR WARRANTY, EXPRESS OR IMPLIED, WITH RESPECT TO MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE is made with respect to the information contained herein.

ATTENTION: THIS PRODUCT IN TERMS OF CHEMICAL IDENTITY AND THE UNIT AMOUNT PROVIDED IS INTENDED FOR USE IN CHEMICAL ANALYSIS AND FOR HUMAN CONSUMPTION, NOR ANY OTHER PURPOSE.

Alltech MATERIAL SAFETY DATA SHEET

Alltech Associates, Inc. • 2051 Waukegan Road • Deerfield, IL 60015 • Phone: 708-948-8600 • Fax: 708-948-1078

STOCK NO:5779 PAGE:1
ALSO APPLIES TO:57720, 5779A, 8124, 5779
DATE:2/5/86

IDENTIFICATION

NAME: Activated Carbon

CAS#: 7740-44-0

SYNONYMS
Charcoal

TOXICITY HAZRDS

TOXICITY DATA
Activated carbon base material non-hazardous per Office of Materials Operation

HEALTH HAZARD DATA

ACUTE EFFECTS
Eyes: like any solid, mechanical irritation can occur.

APPEARANCE AND ODOR
Black irregular granules; free flowing when dry; without odor.

FIRST AID
Eyes: Flush with large volumes of water for 15 minutes. If irritation persists, see a physician. Skin: Wash with soap and water; rinse well; dry.

FIRE AND EXPLOSION HAZARD DATA

EXTINGUISHING MEDIA

SPECIAL FIREFIGHTING PROCEDURES

UNUSUAL FIRE AND EXPLOSIONS HAZARDS
Dust can present a potential for dust explosion.

REACTIVITY DATA

INCOMPATIBILITIES

STABILITY
Stable.

AVOID
Close proximity to violate solvents; open flames; strong oxidizing or reducing chemicals.

HAZARDOUS COMBUSTION OR DECOMPOSITION PRODUCTS

HAZARDOUS POLYMERZATION WILL NOT OCCUR.

SPILL OR LEAK PROCEDURES

Alltech MATERIAL SAFETY DATA SHEET (cont'd)

STOCK NO:5779 PAGE:2
ALSO APPLIES TO:57720, 5779A, 8124, 5779
DATE:2/5/86

STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED

Collect with broom and shovel. Wear a particle mask, goggles and gloves. If media becomes wet, store for waste disposal in plastic-lined containers. Do not enter large closed vessels without a self-contained breathing apparatus-especially when carbon is wet as wet activated carbon removes oxygen from air.

WASTE DISPOSAL METHOD

Dispose of unspent carbon in refuse container.

SPECIAL PROTECTION INFORMATION

Respiratory: Dust or particle mask.
Mechanical: Dust filter
Protective Gloves: Corrosive chemical resistant

SPECIAL PRECAUTIONS

While handling, use a particle mask, goggles and gloves. Store away from violate organic solvents and moisture (to preserve media)

NOTICE: The information contained in the MSDS description is applicable exclusively to the chemical substances identified herein and for its intended use as an analytical reference standard or reagent and to the unit quantity intended for that purpose. The information does not relate to, and may not be appropriate for, any other applications or larger quantity of the substance described. Our products are intended for use by individuals possessing sufficient technical skill and qualification to use the material with suitable discretion and understanding of risk of handing any potentially hazardous chemical. The information has been obtained from sources believed to be reliable and accurate but has not been independently verified by Alltech Associates, Inc. Accordingly, NO REPRESENTATION OR WARRANTY, EXPRESS OR IMPLIED, WITH RESPECT TO MERCHANTABILITY AND FITNESS FOR A PARTICULAR PURPOSE is made with respect to the information contained herein.

ATTENTION: THIS PRODUCT IN TERMS OF CHEMICAL IDENTITY AND THE UNIT AMOUNT PROVIDED IS INTENDED FOR USE IN CHEMICAL ANALYSIS AND FOR HUMAN CONSUMPTION, NOR ANY OTHER PURPOSE.

UNION CARBIDE

MATERIAL SAFETY DATA SHEET

(Essentially similar to U. S. Department of Labor Form OSHA-20)

Do Not Duplicate This Form. Request an Original

I. PRODUCT IDENTIFICATION

PRODUCT	Molecular Sieve Type 5A		
CHEMICAL NAME	Molecular Sieve Type 5A		
SYNONYMS	Zeolites	CHEMICAL FAMILY	Calcium Sodium Alumino Silicates
FORMULA	CaNa $SiO_2AL_2O_3$	MOLECULAR WEIGHT	----
TRADE NAME AND SYNONYMS	Linde Molecular Sieve and MOLSIV		

II. HAZARDOUS INGREDIENTS

No TLV's have been established for this product in OSHA 29 CFR 1910.1000 (1976) or ACGIH 1977

MATERIAL	Wt (%)	ACGIH (1977) TLV-TWA (Units)	MATERIAL	Wt (%)	ACGIH (1977) TLV-TWA (Units)

III. PHYSICAL DATA

BOILING POINT, 760 mm. Hg	NA	FREEZING POINT	----
SPECIFIC GRAVITY (H_2O = 1)	1.1	VAPOR PRESSURE AT 20°C.	NA
VAPOR DENSITY (air = 1)	NA	SOLUBILITY IN WATER, % by wt.	Negligible
PER CENT VOLATILES BY VOLUME	NA	EVAPORATION RATE (Butyl Acetate = 1)	NA
APPEARANCE AND ODOR	No odor — depending on product may appear as a bead, pellet, mesh or powder.		

IV. FIRE AND EXPLOSION HAZARD DATA

FLASH POINT (test method)	Nonflammable	AUTOIGNITION TEMPERATURE	NA
FLAMMABLE LIMITS IN AIR, % by volume -----	LOWER NA	UPPER NA	
EXTINGUISHING MEDIA	NA		
SPECIAL FIRE FIGHTING PROCEDURES	NA		
UNUSUAL FIRE AND EXPLOSION HAZARDS	None known		

EMERGENCY PHONE NUMBER

IN CASE OF EMERGENCIES involving this material, further information is available at all times at this telephone number:

304: 744-3487

For routine information contact your local Linde Supplier.

While Union Carbide Corporation believes that the data contained herein are factual and the opinions expressed are those of qualified experts regarding the tests conducted, the data are not to be taken as a warranty or representation for which Union Carbide Corporation assumes legal responsibility. They are offered solely for your consideration, investigation, and verification. Any use of these data and information must be determined by the user to be in accordance with applicable Federal, State, and local laws and regulations.

UNION CARBIDE CORPORATION ▪ LINDE DIVISION ▪ 270 PARK AVENUE, NEW YORK, N.Y. 10017

PRODUCT: Molecular Sieve Type 5A

V. HEALTH HAZARD DATA

THRESHOLD LIMIT VALUE See Section II

EFFECTS OF OVEREXPOSURE AND EMERGENCY AND FIRST AID PROCEDURES

Irritation of eyes, nose and throat by dust.

In case of eye contact, immediately flush eyes with plenty of water for at least 15 minutes. If irritation persists, see a physician.

VI. REACTIVITY DATA

STABILITY		CONDITIONS TO AVOID
UNSTABLE	STABLE	
	X	None known

INCOMPATIBILITY (materials to avoid) Sudden contact with high concentrations of chemicals having high heats of adsorption such as Olefins, HCL, etc.

HAZARDOUS DECOMPOSITION PRODUCTS None known

HAZARDOUS POLYMERIZATION		CONDITIONS TO AVOID
May Occur	Will not Occur	
	X	None known

VII. SPILL OR LEAK PROCEDURES

STEPS TO BE TAKEN IF MATERIAL IS RELEASED OR SPILLED
Sweep up and place in a waste disposal container. Flush area with water. Avoid raising dust.

WASTE DISPOSAL METHOD Bury in a landfill.

VIII. SPECIAL PROTECTION INFORMATION

RESPIRATORY PROTECTION (specify type)
If there is excessive dustiness, wear a respirator selected as per OSHA 29 CFR 1910.134

VENTILATION	LOCAL EXHAUST See OSHA 29 CFR 1910.134	SPECIAL None
	MECHANICAL (general) See OSHA 29 CFR 1910.134	OTHER None
PROTECTIVE GLOVES	Not required but recommended	EYE PROTECTION – Safety glasses or goggles selected as per OSHA 29 CFR 1910.133
OTHER PROTECTIVE EQUIPMENT	----	

IX. SPECIAL PRECAUTIONS

Causes eye irritation. Breathing dust may be harmful. May cause skin irritation.

Open container slowly to avoid dust. Do not get in eyes. Avoid breathing dust and prolonged contact with skin. Use with adequate ventilation. Keep container closed. Wash thoroughly after handling.

Do not ingest.

OTHER HANDLING AND STORAGE CONDITIONS
pH Range if in Aqueous Slurry – 8 - 11

F-4503 80-0946 11/80 5C Lithographed in U.S.A.

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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