OPA-800C

Ultrafast Optical Parametric Amplifier

User's Manual

Spectra-Physics
Lasers & Photonics
1335 Terra Bella Avenue
Mountain View, CA 94043

Part Number 0000-277A, Rev. G
November 2003

Preface

This manual contains information about the installation, alignment, operation, maintenance and service of your Spectra-Physics *OPA-800C* ultrafast, optical parametric amplifier.

The introductory chapter contains a brief description of the *OPA-800C* and explains its role as part of the Spectra-Physics ultrafast family of fs, ps and fs/ps products. It is designed for use with the Spectra-Physics *Spitfire/Hurricane* Ti:sapphire regenerative amplifier (pumped by the *Merlin* intracavity doubled Nd:YLF laser or *Evolution* diode-pumped, solid-state laser), and seeded with either the *Tsunami*® fs/ps mode-locked, Ti:sapphire laser pumped by either a *BeamLok*® argon ion or *Millennia*® solid-state laser or a *Mai Tai*™ fs/ps mode-locked, Ti:sapphire laser.

All these lasers are Class IV lasers, and they, as well as the *OPA-800C*, emit laser radiation that can permanently damage eyes and skin. The "Laser Safety" section contains information about these hazards and offers suggestions on how to safeguard against them. To minimize the risk of injury or expensive repairs, be sure to read this chapter and carefully follow these instructions.

"OPA Description" contains a discussion of optical parametric amplification and provides a more detailed description of the OPA. It concludes with *OPA-800C* system specifications and outline drawings.

The middle chapters guide you through the setup, installation, alignment and operation of the *OPA-800C*. The last part of the manual covers maintenance and service.

The "Maintenance" section contains information required to keep your *OPA-800C* clean and operational on a day-to-day basis; "Service and Repair" is intended to help guide you to the source of any problems. A replacement parts list is included as well as a troubleshooting guide. *Do not attempt repairs by yourself while the unit is still under warranty.* Instead, report all problems to Spectra-Physics for warranty repair.

"Customer Service" contains a general warranty statement, and it explains how to request service should you ever need it. Included is a list of Spectra-Physics world-wide service centers.

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" statements in Chapter 2.

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.

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, or encounter problems with the laser itself, please let us know. The last page of this manual is a form to aid in bringing such problems to our attention.

Thank you for your purchase of a Spectra-Physics instrument.

CE Environmental Specifications

CE Electrical Equipment Requirements

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

Environmental Specifications

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

Indoor use

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

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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

List of Abbreviations Used in this Manual

ac	alternating current
AR	antireflection
BBO	Beta Barium Borate
CDRH	Center of Devices and Radiological Health
CE	European Community
CW	continous wave
dc	direct current
fs	femtosecond or 10^{-15} second
GVD	group velocity dispersion
HR	high reflector
IR	infrared
OC	output coupler
OPA	optical parametric amplifier
OPO	optical parametric oscillator
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 Your System

Your *OPA-800C* laser accessory was packed with great care and all containers were inspected prior to shipment: your *OPA-800C* left Spectra-Physics in good condition. Upon receipt of your system, immediately inspect the outside of the shipping containers. If there is any major damage, such as holes in a box or cracked wooden frame members, insist that a representative of the carrier be present when you unpack the contents.

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

Keep the shipping containers. If you need to return the system for upgrade or service, the specially designed shipping containers assure adequate protection of your equipment. Spectra-Physics will only ship Spectra-Physics equipment in original containers; you will be charged for replacement containers if they are needed.

The *OPA-800C* is shipped in one crate with two containers inside. One container is the *OPA-800C*; the other contains the accessory kit and any other options you may have ordered. Chapter 1 contains a list of crystal options currently available.

You will find the following items packed in the accessory kit:

- This user's manual
- The *OPA-800C* crystals with holders
- An accessory case containing the following tools:
  - Allen (hex) wrench tool kit
  - Infrared detector card.
  - Disposable hemostat
  - Tweezer
  - Lens tissue
  - Finger cots
  - (3) ¼–20 screws with washers
  - (5) 6.3 cm alignment target cards (P/N 0454-1260)

Chapter 1 Introduction

The OPA-800C System

The Spectra-Physics *OPA-800C* produces high energy fs and/or ps pulses that are tunable over a broad wavelength region. It is designed for use with a Spectra-Physics ultrafast Ti:sapphire amplifier system, which comprises a mode-locked Ti:sapphire oscillator, such as the *Mai Tai*™ or a *BeamLok*® or *Millennia*® cw pump laser and *Tsunami*® mode-locked laser, and a chirped-pulse Ti:sapphire regenerative amplifier system, which comprises a *Merlin* intracavity-doubled Nd:YLF pump laser or *Evolution* diode-pumped laser and a *Spitfire* amplifier, or the one-box, all diode pumped *Hurricane*™ amplifier.

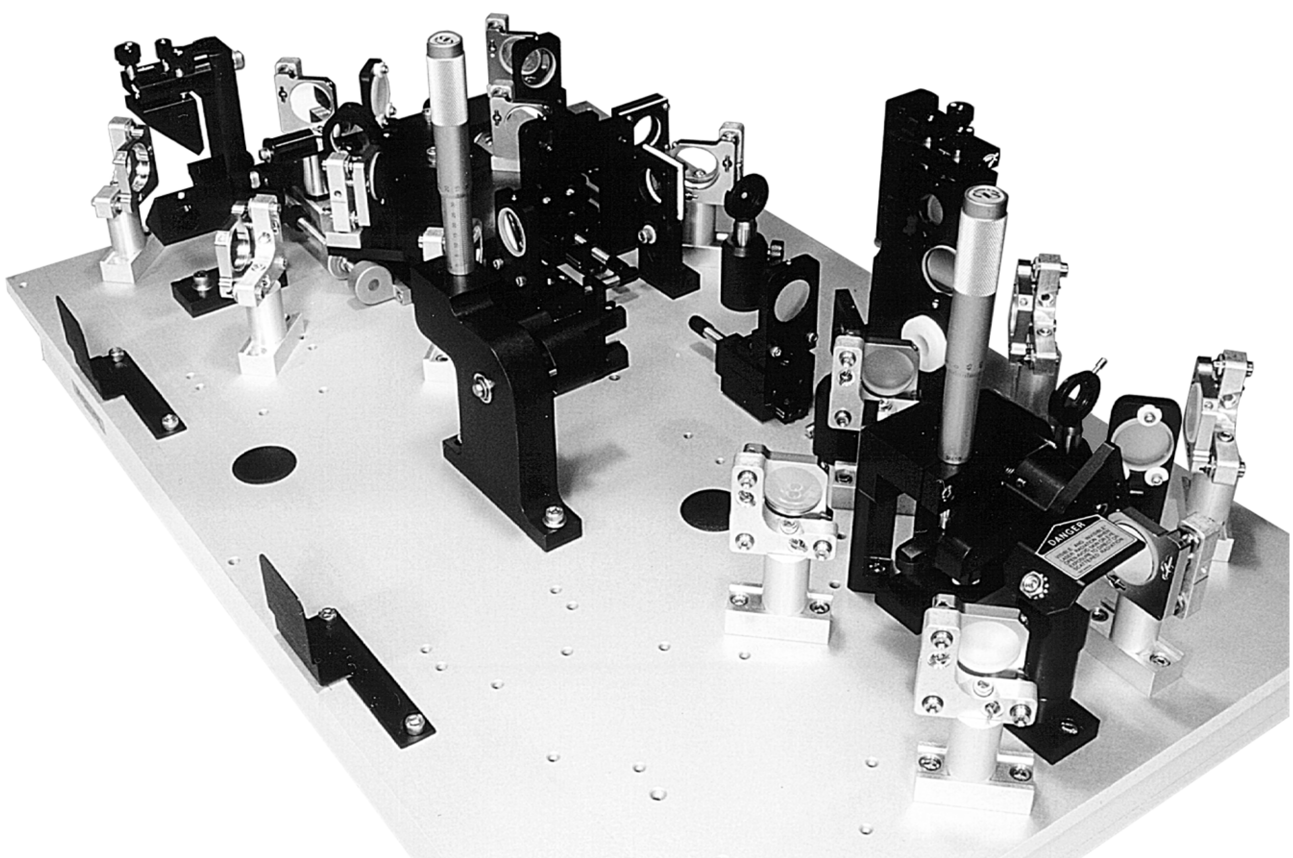
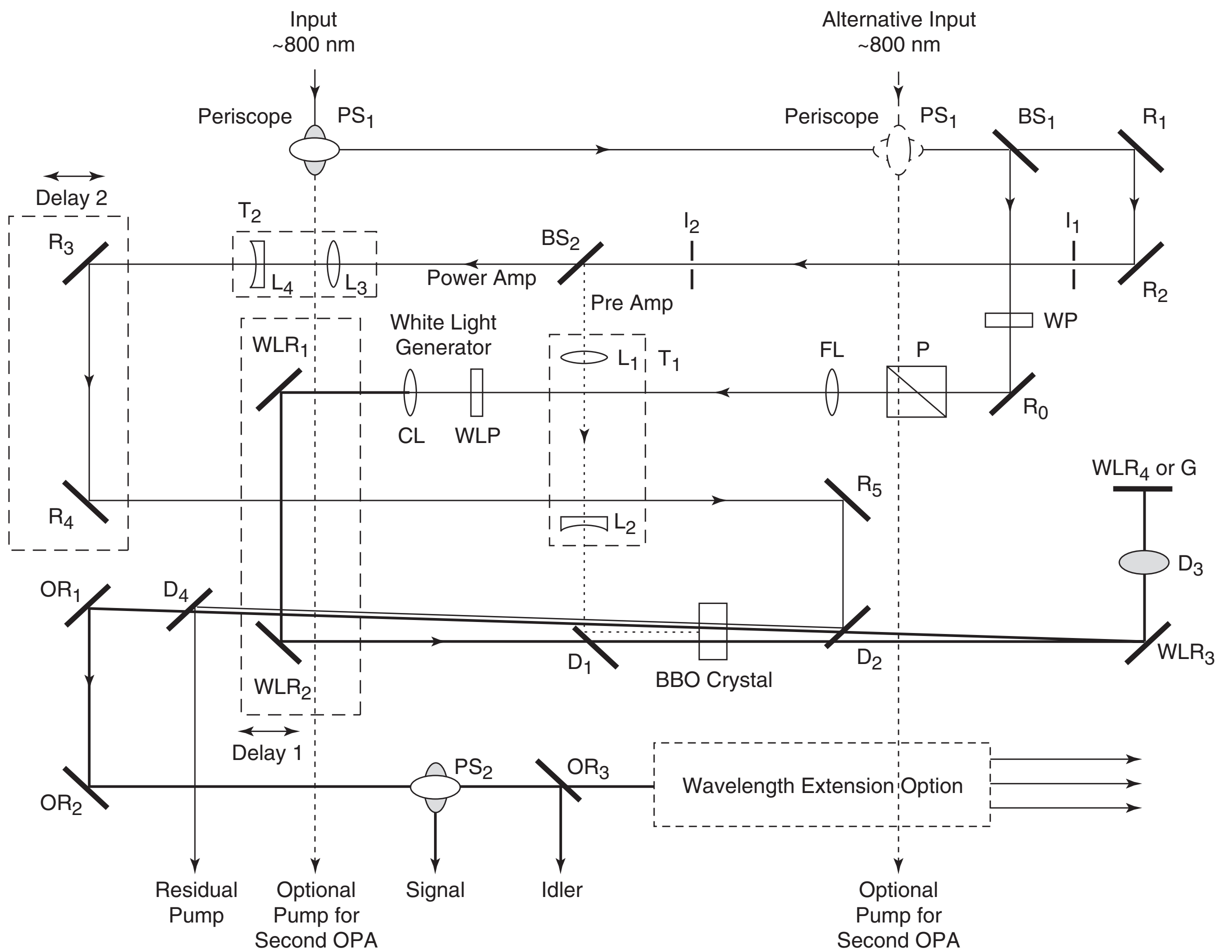


Figure 1-1: The *OPA-800C* Optical Layout

The *OPA-800C* consists of a single optical head (Figure 1-1) that is designed to be placed near the output of the *Spitfire/Hurricane* amplifier. Infrared wavelength extension is accomplished in a two-stage process with white light continuum generation and traveling-wave, optical parametric amplification. In a fs system, the output wavelength is changed by angle tuning the β-barium Borate (BBO) crystal. In ps systems, both the BBO crystal and the grating are tuned to change the output wavelength. Synchronized signal, idler, and residual pump beams are provided through three separate exit ports. Further wavelength coverage in the visible and mid-infrared spectral regions is possible using integrated harmonic generation (HGI and HGII), sum-frequency mixing (SFM), and difference-frequency mixing (DFM) options. These systems can also be converted from fs to ps operation, and vice versa.



$BS_{1,2}$	Beam Splitter	I_{1-2}	Irises	R_{0-5}	Reflectors for 800 nm
CL	Collimating Lens	L_{1-4}	Lenses	$T_{1,2}$	Telescopes
D_{1-4}	Dichroic Mirrors	OR_{1-3}	Output Reflectors	WLP	White-light Plate
FL	Focusing Lens	P	Polarizer	WLR_{1-4}	White-light Reflectors
G	Grating	$PS_{1,2}$	Periscope	WP	$\lambda/2$ Waveplate

Figure 1-2: The *OPA-800C* Beam Path

Configurations

The fs and ps *OPA-800Cs* are available in five configurations that generate the following:

- Signal and idler beams only.
- Signal and idler beams with the harmonic generation option HGI. The latter provides the second harmonic of the signal and idler, and the fourth harmonic of the idler.
- Signal and idler beams with the harmonic generation option HGII. The latter provides the second harmonic of the signal and idler, and the fourth harmonic of the signal and idler.
- Difference-frequency mixing (DFM), which combines the signal and idler beams in an $AgGaS_2$ crystal for wavelengths from 3 to 10 µm.
- Sum-frequency mixing (SFM), which combines the idler beam with the pump beam in a type I BBO crystal for higher energies at 533–600 nm. It also combines the signal beam and pump beams in a type II BBO crystal for higher energies at 480–533 nm for an 800 nm pumped *OPA-800C*.

Conversions and upgrades among these systems are straightforward. If you purchased the signal/idler-only configuration, you can add harmonic generation by purchasing the appropriate upgrade kit. The initial upgrade must be performed by an authorized Spectra-Physics service engineer but, once installed, you can convert between the various configurations yourself. Your system can be adapted for fs to ps conversion (or vice versa) at the time of purchase, or a conversion kit can be purchased at a later time.

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

Available Options

Upgrade From a fs OPA-800CF to a fs/ps OPA-800CFP

This option allows you to change a ps unit to one capable of fs operation. Once upgraded, you can change back and forth between ps and fs configurations. This conversion kit includes:

- a 4% reflector beam splitter
- a ps white-light plate
- a ps *OPA-800CP* crystal
- a wavelength tuning grating assembly
- a collimation lens for ps operation
- a cube polarizer with mount

Upgrade From a ps OPA-800CP to a fs/ps OPA-800CFP

This option allows you to change a ps unit to one capable of fs operation. Once upgraded, you can change back and forth between ps and fs configurations. This conversion kit includes:

- a 1%R reflector beam splitter
- fs white-light plate
- a fs *OPA-800CF* crystal
- a curved reflection mirror with mount
- a signal beam rejection mirror with mount
- a collimating lens

Harmonic Generation

HGI Harmonic Generation ($2\omega_s$, $2\omega_i$, $4\omega_i$)

Extends wavelength coverage from 400 nm to 1.2 µm via second harmonic generation of the signal and idler, and fourth harmonic generation of the idler. All harmonics demonstrate a spectral purity ratio of better than 100:1. With the direct output of the *OPA-800C*, the system delivers complete wavelength tuning from 400 nm to 3 µm. By switching harmonic crystals, the system can also be configured for $4\omega_i$, $2\omega_i$, or $2\omega_s$.

HGI/HGII Harmonic Generation ($2\omega_s$, $2\omega_i$, $4\omega_s$, $4\omega_i$)

Provides all the performance of the HGI option but also extends the uv wavelength coverage from < 300 nm to 400 nm through fourth harmonic generation of the signal. The $4\omega_s$ output has >10:1 spectral purity.

The HGI or HGII harmonic generation options include:

- 2 crystals for an *OPA-800CF*, 3 crystals for an *OPA-800CP* (HGII), and 2 crystals for an *OPA-800CP* (HGI)
- 2 polarizers with mounts
- 1 dichroic set of 3 mirrors and 2 mounts for HGI
- 2 dichroic sets of 3 mirrors and 2 mounts for HGII
- a focus lens assembly
- a collimating lens assembly
- 2 crystal angle-tuning mounts

SFM Sum-Frequency Mixing ($\omega_p + \omega_s$, $\omega_p + \omega_i$)

Generates high energy visible output from 480 nm to 600 nm by sum-frequency mixing the residual pump and signal and idler.

The SFM option includes:

- 2 crystals (or 1 extra crystal if the HGI/II option is included)
- 3 dichroic mirrors and 2 mounts
- a crystal angle-tuning mount

DFM Difference-Frequency Mixing ($\omega_s - \omega_i$)

Further extends wavelength coverage from 3.0 µm to more than 10 µm via difference-frequency mixing of the signal and idler. The output has >100:1 spectral purity.

The DFM option includes:

- a crystal
- a long-pass filter with mount
- a focus lens assembly
- a collimation lens
- a crystal angle-tuning mount

Chapter 2 Laser Safety

Danger!

The *OPA-800C*, *Spitfire* or *Hurricane*™ regenerative amplifier, *Merlin* or *Evolution* pump laser, *Mai Tai*™ or *Tsunami*® Ti:sapphire oscillator and *BeamLok*® or *Millennia*® pump lasers are Class IV High Power lasers or laser products that have output beams that are, by definition, safety and fire hazards. Take precautions to prevent exposure to direct and reflected beams. Even diffuse or specular reflections can cause severe skin or eye damage.

Danger!
Laser Radiation

Because the *OPA-800C*, the *Spitfire* or *Hurricane* amplifier and the *Tsunami* or *Mai Tai* lasers emit cw and pulsed infrared radiation, they are 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 and Accessories

Wear protective eye wear at all times. Selection depends on the wavelength and intensity of the radiation, the conditions of use, and the visual function required. Protective eye wear vendors are listed in the *Laser Focus World*, *Lasers and Optronics*, and *Photonics Spectra* buyer's guides. Consult the ANSI and ACGIH standards listed at the end of this section for guidance.

- Maintain a high ambient light level in the laser operation area. This keeps the eyes' pupils constricted, thus reducing the possibility of eye damage.
- Keep the protective cover on the *OPA-800C* and the lasers at all times.
- Avoid looking at the output beam; even diffused reflections are hazardous.
- Avoid wearing jewelry or other objects that may reflect or scatter the beam while using the *OPA-800C*, the lasers or the laser products.
- Use an infrared detector or energy detector to verify that the laser beam is off before working in front of the *OPA-800C* or the pump lasers.
- Operate the lasers 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).

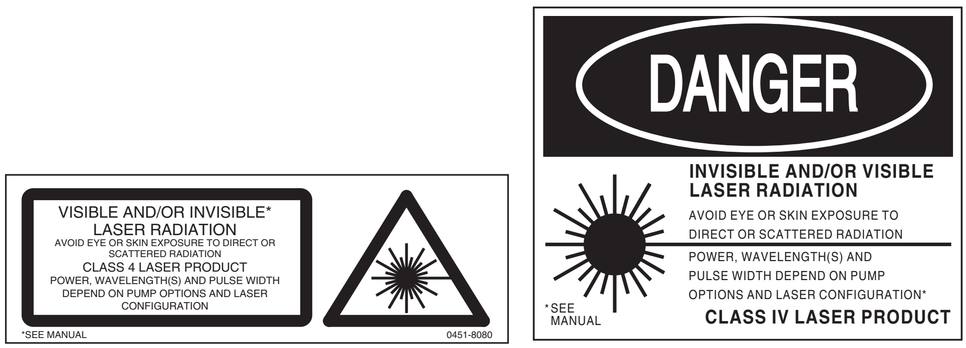


Figure 2-1: These CE and CDRH standard safety warning labels would be appropriate for use as entry warning signs (EN 60825-1, ANSI 4.3.10.1).

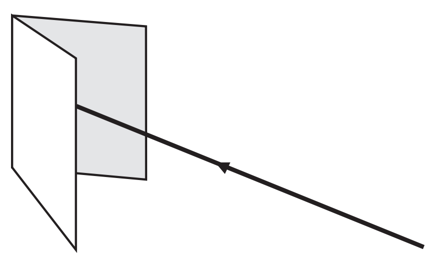


Figure 2-2: Folded Metal Beam Target

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, the *Tsunami User's Manual*, the *Millennia User's Manual, the Spitfire* or *Hurricane User's Manual*, the *Merlin User's Manual,* the *Evolution User's Manual* and the *BeamLok* ion pump laser user's manual for safe operation of the *OPA-800C* system. At all times during operation, maintenance, or service of your *OPA-800C*, 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.*

Danger!
Laser Radiation

Danger!

Operating the *OPA-800C*, the *Spitfire* or *Hurricane* amplifier, or the *Tsunami* laser with the cover removed may expose people to high voltages and high levels of infrared and visible radiation. It also increases the rate of optical surface contamination and defeats the purpose of the purgeable, sealed cavity. For these reasons, operating the system with these covers removed is not recommended.

The alignment procedures in this manual require internal adjustments while the laser beam is present—always use appropriate safety glasses while making these adjustments! Also, when the cover is removed and access to the beam is required, take care to block any stray reflections.

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

This section presents the maintenance required to keep this laser accessory product in compliance with CDRH Regulations.

This laser accessory 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 with these regulations, once a year, or whenever the product has been subjected to adverse environmental conditions (e.g., fire, flood, mechanical shock, spilled solvent, etc.), check to see that all features of the product identified below function properly. Also, make sure that all warning labels remain firmly attached (refer to the CDRH/CE drawing later in this chapter).

1. Verify that removing the remote interlock plug on the pump laser prevents laser operation.
2. Verify the laser system will only operate when the pump laser's interlock key switch is in the "on" position, and that the key can only be removed when the switch is in the "off" position.
3. Verify the emission indicator on the pump laser works properly; that is, it emits a visible signal whenever the laser is on.
4. Verify that the time delay between turn-on of the pump laser emission indicator and the starting of that laser gives you enough warning to allow action to avoid exposure to laser radiation.
5. Verify that removing the cover of the pump laser shuts off the laser.
6. Verify that when the cover interlock on the pump laser is defeated, the defeat mechanism is clearly visible and prevents installation of the cover until disengaged.

CDRH/CE Drawing

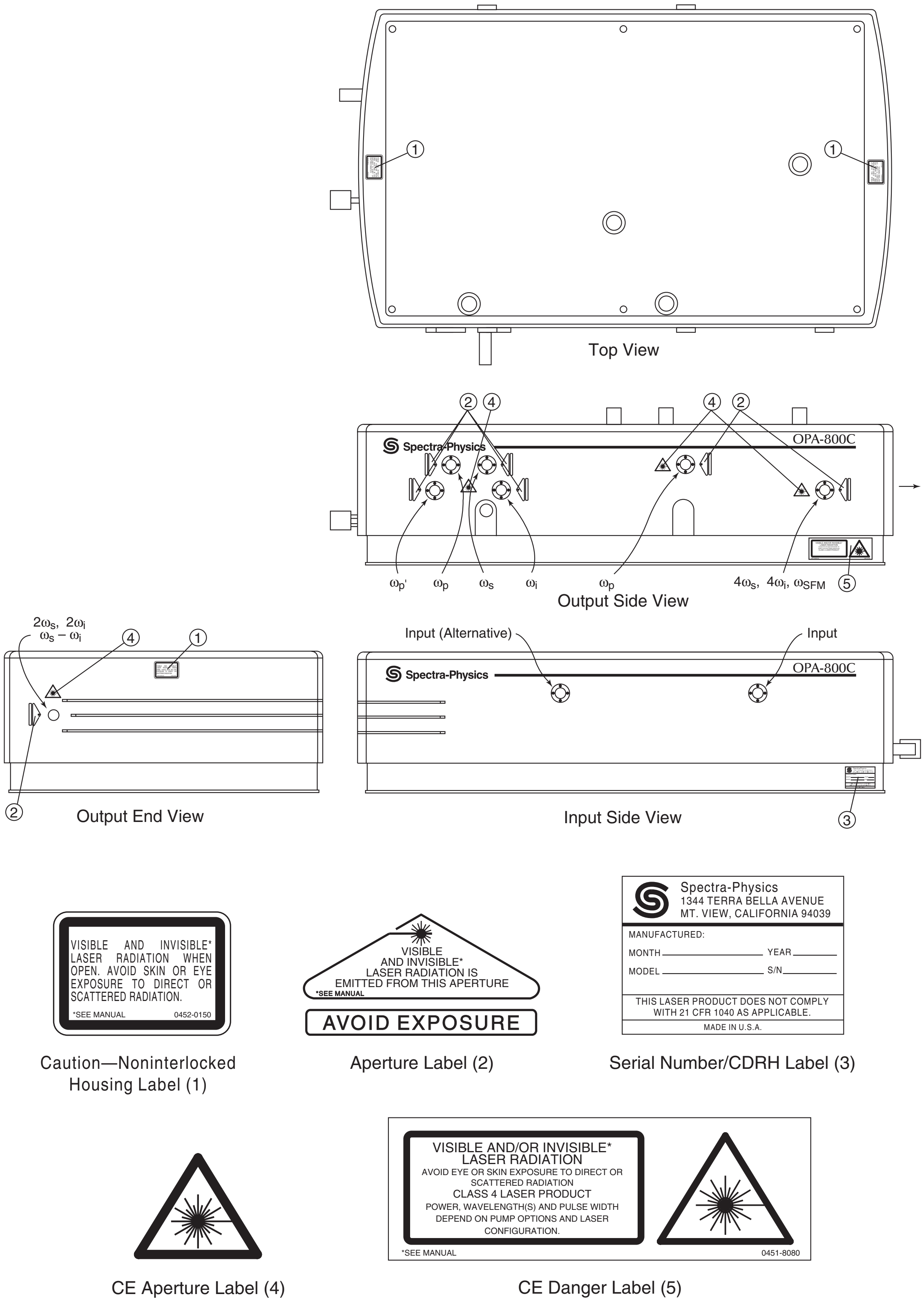


Figure 2-3: ***OPA-800C*** **Radiation Control Drawing**

Label Translations

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

Table 2-1: Label Translations

Label #	French	German	Spanish	Dutch
Non-Interlocked Label (1)	Attention; Rayonnement Laser Visible et Invisible en Cas D'Ouverture; Exposition Engereuse de L'Oeil ou de la Peau au Rayonnement Direct ou Diffus.	Vorsicht; beim Offnen Austritt von sichtbare und unsichtbare Laserstrahlung; Bestrahlung von Auge oder Haut durch direkte oder Streustrahlung vermeiden.	Peligro, Cuando se abre existe Radiacion Laser Visible e Invisible; Evite que los ojos y la piel queden expuestos tanto a la radaicion directa como a la dispersa.	Gevaar; zichtbare en niet zichtbare laser-straling wanneer geoend; vermijd blootsteling aan huid of oog aan disecte straling of weerkaatsingen.
Aperture Label (2)	Ouverture Laser – Exposition Dangereuse – Un Rayonnement laser visible et invisible est emis par cette ouverture.	Austritt von sichtbarer und unsictbarer Laserstrahlung; nicht dem Strahl aussetzen.	Por esta abertura se emite radiacion laser visible e invisible; evite la exposicion.	Vanuit dit apertuur wordt zichtbare en niet zichtbare laser-straling geemiteerd; vermijd blootstellilng.
CDRH/ European Safety Class 4 (4, 5)	Rayonnement Laser visible et invisible. Expostion dangereuse de l'oeil ou de la peau au Rayonnement direct ou diffus. Laser de classe 4	Sichtbare und/oder unsichtbare Laserstrahlung. Bestrahlung von Aude oder Haut durch direkte oder Streustrahlung vermeiden. Laserclasse 4	Radiacion Laser visible y/o invisible. Evite que los ojos y la piel queden expuestos tanto a la Radaicion derecta como a la dispersa. Producto Laser Clase 4	Zichtbare en niet zichtbare laserstraling. Vermijd blootstelling van huid of oog aan directe straling of weerkaatsingen. Klasse 4 Laser Produk.

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:

OPA-800C **Optical Parametric Amplifier and Harmonic Generator**

meet 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 Emissions:

EN55011 Class A Radiated
EN55011 Class A Conducted

EN 50082-1:1992 Immunity:

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

and that the:

OPA-800C **Optical Parametric Amplifier and Harmonic Generator**

also meet 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 60825-1:1993 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
July 1, 1999

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 Description

Introduction

Since the early 1990s, the mode-locked, Ti:sapphire laser has become the system of choice for ultrafast laser applications. The Spectra-Physics *Tsunami*® mode-locked Ti:sapphire oscillator provides the most flexible commercial system with (a) wavelength coverage from 690 to 1080 nm, (b) a pulse width range from < 35 fs to > 80 ps, (c) average power of up to 2 W, (d) outstanding long-term stability, and (e) active length stabilization for synchronization with external RF sources or other mode-locked laser sources.

However, many applications require access to wavelengths that are not directly covered by the fundamental Ti:sapphire output or through its direct frequency conversion with harmonic generation. Wavelength extensions to these regions have generally been accomplished through two approaches: (a) amplification with white light continuum generation and/or optical parametric amplification (OPA) and (b) a synchronously pumped optical parametric oscillator (SPPO). The former provides higher energies at lower repetition rates (typically µJ–mJ at kHz repetition rates), while the latter provides nJ pulse energies at repetition rates of about 80 MHz.

Spectra-Physics provides both SPPO and OPA systems. The latter uses a white light continuum as a seed. The Spectra-Physics *OPA-800C* series is a compact package with two input port options to facilitate system setup with a minimum footprint. Also, by replacing the first reflector mirror in periscope PS_1 (Figure 3-9) with a beam splitter, the pump input can be split between the primary OPA and a secondary OPA or a single harmonic generator (or other accessory).

Figure 3-10 through Figure 3-12 (toward the end of this chapter) show the mechanical/optical parts layout for a fs *OPA-800CF*, a ps *OPA-800CP* and a fs/ps *OPA-800CFP* configured for fs operation. Chapter 7, "OPA-800C Options," shows the layouts for optional second harmonic generation (SHG) of the signal and idler, fourth harmonic generation (FHG) of the signal and idler, sum-frequency mixing (SFM) and difference-frequency mixing (DFM).

Theory

OPAs and SPPOs operate on a very different principle from that of a laser. A laser derives its gain from inverted population distribution between different atomic or molecular states. These transitions have inherent linewidths that govern the maximum tuning range of the laser (e.g., a dye laser tunes over a range of 30 – 40 nm per dye, while a Ti:sapphire laser tunes over a 300 nm range).

In contrast, an OPA or SPPO derives gain from a nonlinear frequency conversion process. Figure 3-1 illustrates a three-wave interaction process, which could be either down conversion (a) or up conversion (b).

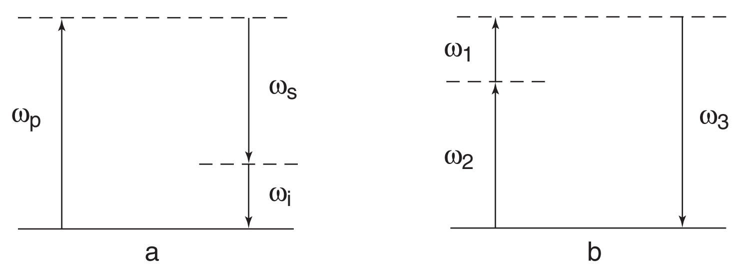


Figure 3-1: Optical frequency three-wave interaction process

This process originates from the interaction of the optical electromagnetic field with the bounded electrons in the nonlinear medium. It is governed by Maxwell's equation:

$$\nabla^2 E - \mu_0 \sigma \dot{E} - \mu\varepsilon \ddot{E} = \mu_0 \ddot{P} \qquad [1]$$

where E is the electromagnetic field, μ_o is the vacuum magnetic permeability, ε is the dielectric permeability, μ is the magnetic permeability, σ is the ohmic conductivity, and P is polarization.

The nonlinear polarization $P^{(2)}$ has three different frequency components in this three-wave process given by:

$$P^{(2)}(\omega_1) = 2\varepsilon_0 d\, E(\omega_3)\, E^*(\omega_2) \qquad [2a]$$

$$P^{(2)}(\omega_2) = 2\varepsilon_0 d\, E(\omega_3)\, E^*(\omega_1) \qquad [2b]$$

$$P^{(2)}(\omega_3) = 2\varepsilon_0 d\, E(\omega_1)\, E(\omega_2) \qquad [2c]$$

where it is assumed $\omega_3 > \omega_2 > \omega_1$.

Using slowly varying amplitude approximations, neglecting loss, and assuming steady-state solutions, Equation 1 becomes three, coupled, traveling wave equations:

$$dE_1/dz = i\kappa E_3 E_2^* \exp[i\Delta k\, z] \qquad [3a]$$

$$dE_2/dz = i\kappa E_3 E_1^* \exp[i\Delta k\, z] \qquad [3b]$$

$$dE_3/dz = i\kappa E_1 E_2 \exp[-i\Delta k\, z] \qquad [3c]$$

where $\kappa = \omega d/nc$ and d is the nonlinear polarization coefficient. $E_i(\omega)$ is now written as $E_i \exp(ik_i z)$ and $\Delta k = k_3 - k_1 - k_2$. where i is 1, 2 or 3.

These three equations describe the basic physics of second harmonic generation, sum-frequency and difference-frequency mixings, and parametric generation in the afore mentioned approximation, with appropriate boundary conditions. The general solutions to these equations indicate that high efficient conversion from one wave to another requires (a) high pump intensity wave or waves, (b) high nonlinear polarization coefficient *d* and (c) a better phase-match, e.g., a smaller Δk for continuous waves (cw).

To have a high conversion efficiency of the three-wave process, a high second-order nonlinear susceptibility of the nonlinear medium is desirable. In the OPA process shown in Figure 3-1a, a high intensity pump beam is used to amplify a low energy seed beam as shown in Figure 3-2. Either the signal or idler beam pulses can be used as the seed source to produce amplified signal and idler beams.

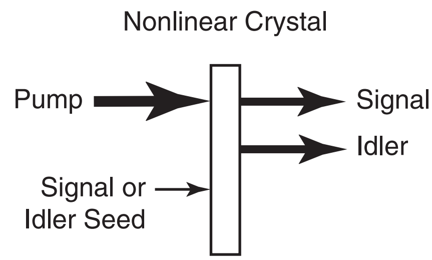


Figure 3-2: Optical Parametric Amplification

The parametric gain, G, at the phase-matched condition is given by:

$$G \propto d(\omega_s \omega_i I_p)^{1/2} \quad [4]$$

where I_p is the pump intensity. The gain is then greater for shorter pump wavelengths, higher pump intensities and when ω_s and ω_i approach degeneracy (i.e., when $\omega_s = \omega_i$). This favors using the high energy, second harmonic fs pulses from a Ti:sapphire amplifier as the pump wavelength. However, another key consideration in the amplification of ultrashort pulses is the effective interaction length between the pump and signal (or idler) pulses.

In cases where pulse duration is from the tens of fs to the ps range, high pump intensity is easily achieved by reducing the beam size, as long as it remains below the damage threshold of the nonlinear material. A high damage threshold, high nonlinear polarization coefficient and a large transparent wavelength range are major requirements when choosing a crystal for the nonlinear medium. In addition, the phase-matching condition must also be considered over the working wavelength range. In the case shown in Figure 3-1a, an input photon is split into two lower energy photons (signal and idler photons), and energy conservation determines the generated frequency or wavelengths, i.e.,

$$\omega_p = \omega_s + \omega_i \quad [5]$$

or

$$1/\lambda_p = 1/\lambda_s + 1/\lambda_i \quad [6]$$

Efficient conversion requires the best phase match, i.e.,

$$\Delta k \equiv k_p - k_s - k_i = 0 \qquad [7]$$

or wavelength

$$n_p/\lambda_p = n_s/\lambda_s + n_i/\lambda_i \qquad [8]$$

where $n_{p,s,i}$ is the refractive index of the nonlinear crystal at each wavelength.

The latter requirement (which is the equivalent of momentum conservation) shows the need for a constructional accumulation of the generated new wavelengths while they travel together in the crystal. Equations 6 and 8 determine the two down converted wavelengths. By tuning the crystal angle, which changes n_p, n_s and n_i, the two newly created wavelengths are tuned accordingly.

Since most OPAs are used with fs and ps lasers, group-velocity walk-off between pulses also needs to be accounted for in order to achieve best conversion. This becomes even more important when extremely short pump pulses are used.

For efficient energy exchange, the interaction length should be as long as possible without limiting the acceptance bandwidth. This is governed by the temporal "walk-off" of the pump and signal pulses after passing through a crystal of length *L* or their group velocity mismatch (GVM):

$$\mathrm{GVM} = L(1/T_{g(p)} - 1/T_{g(s)}) \qquad [9]$$

where $T_{g(p)}$ and $T_{g(s)}$ are the group delay times of the pump and signal, respectively. When considering GVM, the amplified Ti:sapphire fundamental is the preferred pump wavelength. Another benefit of using the fundamental pump frequency is that the signal and idler beams can be conveniently difference-frequency mixed to produce the important mid-infrared wavelengths that are required for investigating time-resolved vibrational processes in molecular systems. This is because the nonlinear crystals suitable for this difference-frequency mixing process have better transparency and a more favorable GVM for the signal and idler wavelengths (1.1 to 3.0 µm).

With high energy pump pulses, spatial walk-off is less of a problem due to the loose focusing geometry in the OPA.

The second harmonic generation and sum frequency mixing shown in Figure 3-1b could be viewed as the inverse process of the parametric down conversion shown in Figure 3-1a. However, parametric down converted signal and idler waves could build up from either the quantum noise or from a seeded beam. All OPAs require a pre-stage to generate the seed wave, either through parametric fluorescence (superfluorescence, i.e., optical parametric generation (OPG) initiated from quantum noise), or through white light generation.

A superfluorescence seed can be generated using the same OPA crystal at the same phase matched angle. However since it is generated by tightly focusing a small amount of split-off pump beam into the crystal, the resultant superfluorescence becomes color separated, and its stability is extremely sensitive to small variations when tuning the output wavelength. White light generation, on the other hand, is a higher order nonlinear process that includes self-phase modulation, self-focusing, Raman-shifting, multi-photon processes, etc. Since the white light generation seed is generated separately and is set for the whole tuning range, the OPA output becomes easier to align and has a stable output over a much wider tuning range.

For both fs and ps pulses, white light can easily be created by focusing a few µJ of energy into a variety of materials, such as quartz, sapphire, or a liquid cell. Thus, the broad spectral coverage of the white light continuum provides an ideal seed source for an OPA. Furthermore, this same seed source can be employed for multiple OPAs, each of which can provide independently tunable pulses for different spectroscopic applications.

In the ps regime, white light can be generated either through liquids or through solid state materials. In many laboratories, the circulating liquid cell has been used. However, stable consistent white light generation through flowing liquids is a challenge in practice and not very convenient because the liquids have to be changed from time to time and some of them are toxic.

Thus, a solid-state material is preferable. The white light can be saturatedly generated within.

The *OPA-800CFP* uses solid-state materials for white light generation. This allows the user to conveniently select wavelength content because it provides a means to easily convert the OPA from a ps application to one in the fs domain, and vice versa.

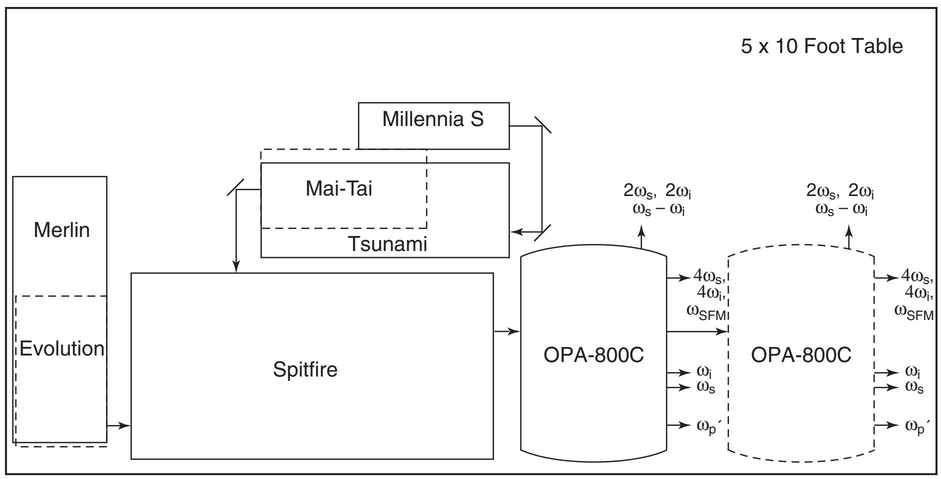
OPA-800C Systems

Typical layouts for the Spectra-Physics *OPA-800C* system are shown in Figure 3-3. The system includes, in addition to the *OPA-800C*, a *BeamLok*® argon ion- or *Millennia*® diode-pumped laser, a *Tsunami* or *Mai Tai*™ mode-locked Ti:sapphire laser, and a *Spitfire* or *Hurricane*™ regenerative Ti:sapphire amplifier. (*Spitfire* is pumped by either a *Merlin* intracavity-doubled, Nd:YLF laser or an *Evolution* diode-pumped, solid-state laser. *Hurricane* contains a diode-pumped cw source, a mode-locked Ti:sapphire laser and an *Evolution*.)

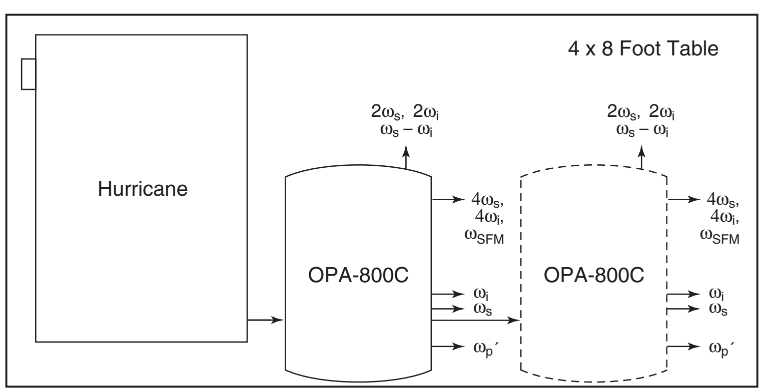
For your convenience in setting up your system, the *OPA-800C* has two pump input ports from which to choose. Both ports (Figure 3-9) can be configured to split the incoming pump beam, part of which is used by the OPA with the remaining directed out a port directly opposite the alternative input port.

A type II, angle-tuned, Beta-Barium Borate (BBO) crystal is used as the nonlinear gain medium in the Spectra-Physics *OPA-800C*. For the type II phase matching process, the signal beam is of opposite polarization to that of the pump and idler beams. This makes wavelength separation of the signal and idler beams straightforward using polarization-sensitive optics. Figure 3-4 shows the typical dependence of the signal and idler wavelengths upon phase matching conditions (usually the crystal angle) for a type I and a type II process. Unlike the type I phase-matching process that normally exhibits very large phase-matching bandwidths near degeneracy, the bandwidth of the signal and idler pulses are relatively independent of the phase-matching conditions. In fact, for a type II process, it is possible to tune right through the degeneracy point without obtaining pulses with abnormally large bandwidth. The signal and idler waves actually undergo a polarization flip at the degeneracy point. (This is sometimes referred to as type IIb phase matching.)

The *OPA-800C* can be pumped with any output wavelength from the *Spitfire/Hurricane* amplifier, which is tunable from 750 to 840 nm. However, the performance specifications are based upon pump energies up to 1 mJ, pulse widths of <130, <80 and <50 fs at 800 nm for an *OPA-800CF* and a 1 mJ, >1 ps pulse width at 800 nm for an *OPA-800CP*. Figure 3-5 and Figure 3-6 show typical tuning curves for 1 mJ pump conditions. The signal and idler outputs provide pulses with up to 80 µJ of energy with broad wavelength coverage from 1.1 µm to 3.0 µm. Refer to Table 3-1 and Table 3-2 at the end of this chapter.



(a) A Typical Spitfire and OPA-800C System Layout (with optional second OPA)



(b) A Typical Hurricane and OPA-800C System Layout (with optional second OPA)

Figure 3-3: Typical *OPA-800C* System Layouts

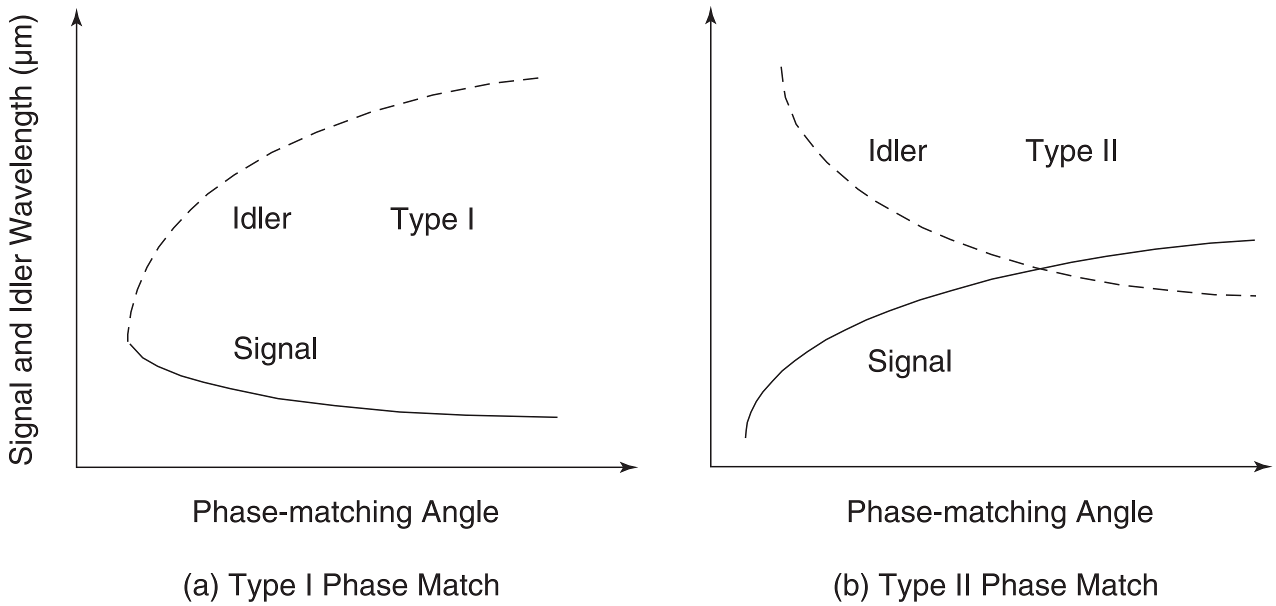


Figure 3-4: Wavelength vs. Phase-Matching Angle of Type I and Type II Crystals

Tuning Curves

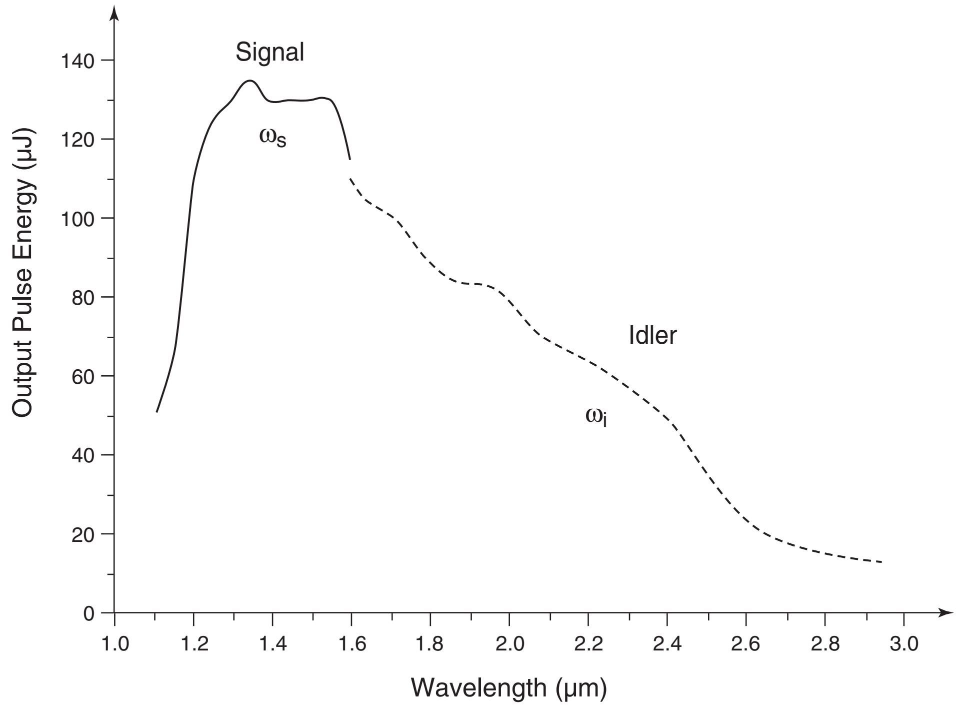


Figure 3-5: Typical Output Tuning Curves of an *OPA-800CF-1*.

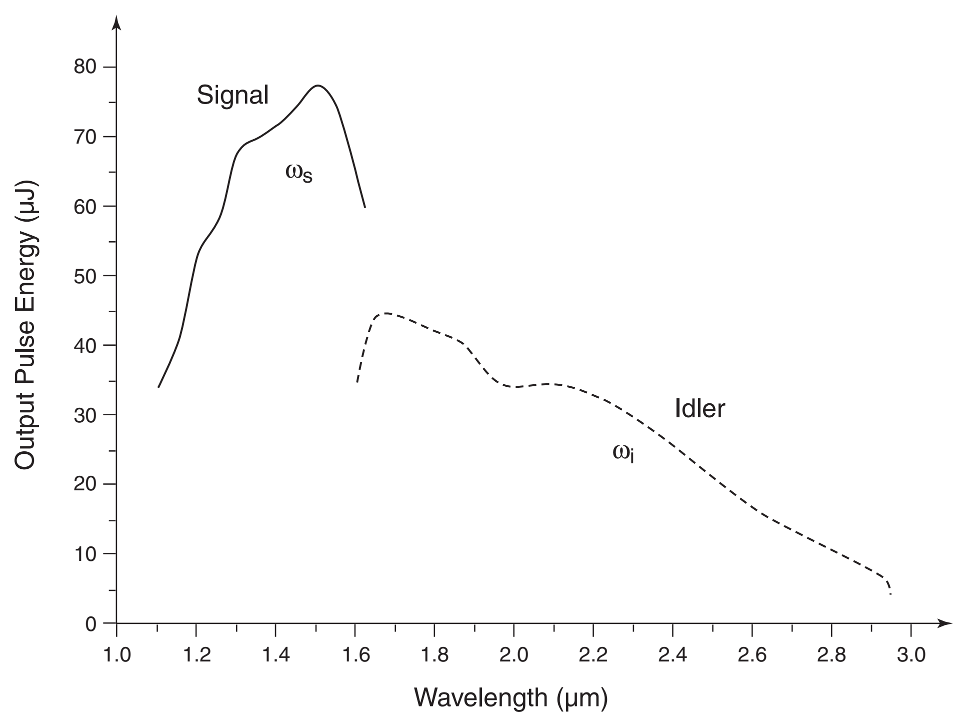


Figure 3-6: Typical Output Tuning Curves of an *OPA-800CP-1*.

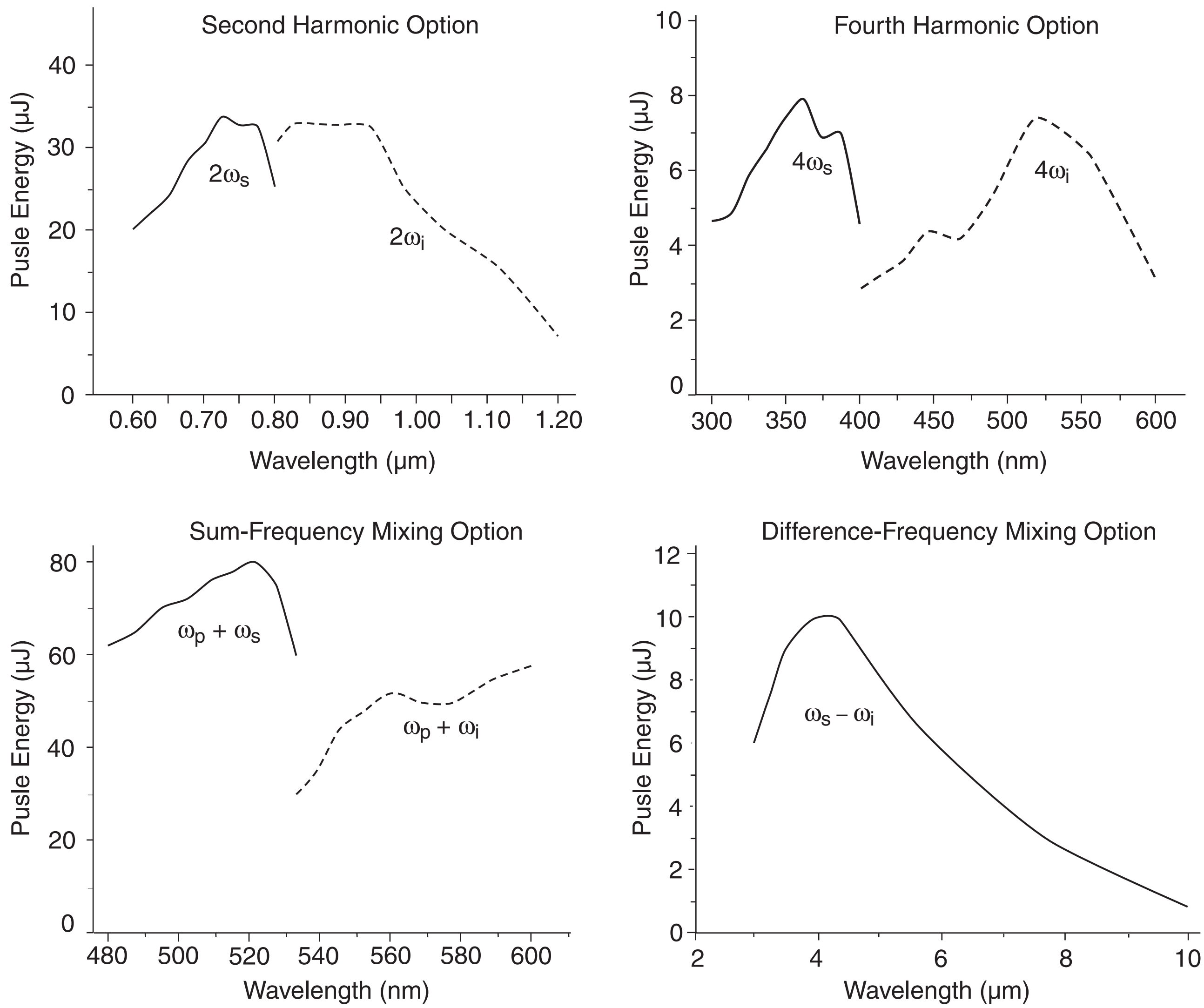


Figure 3-7: Typical Output Tuning Curves for Wavelength Extensions for an *OPA-800CF–1*.

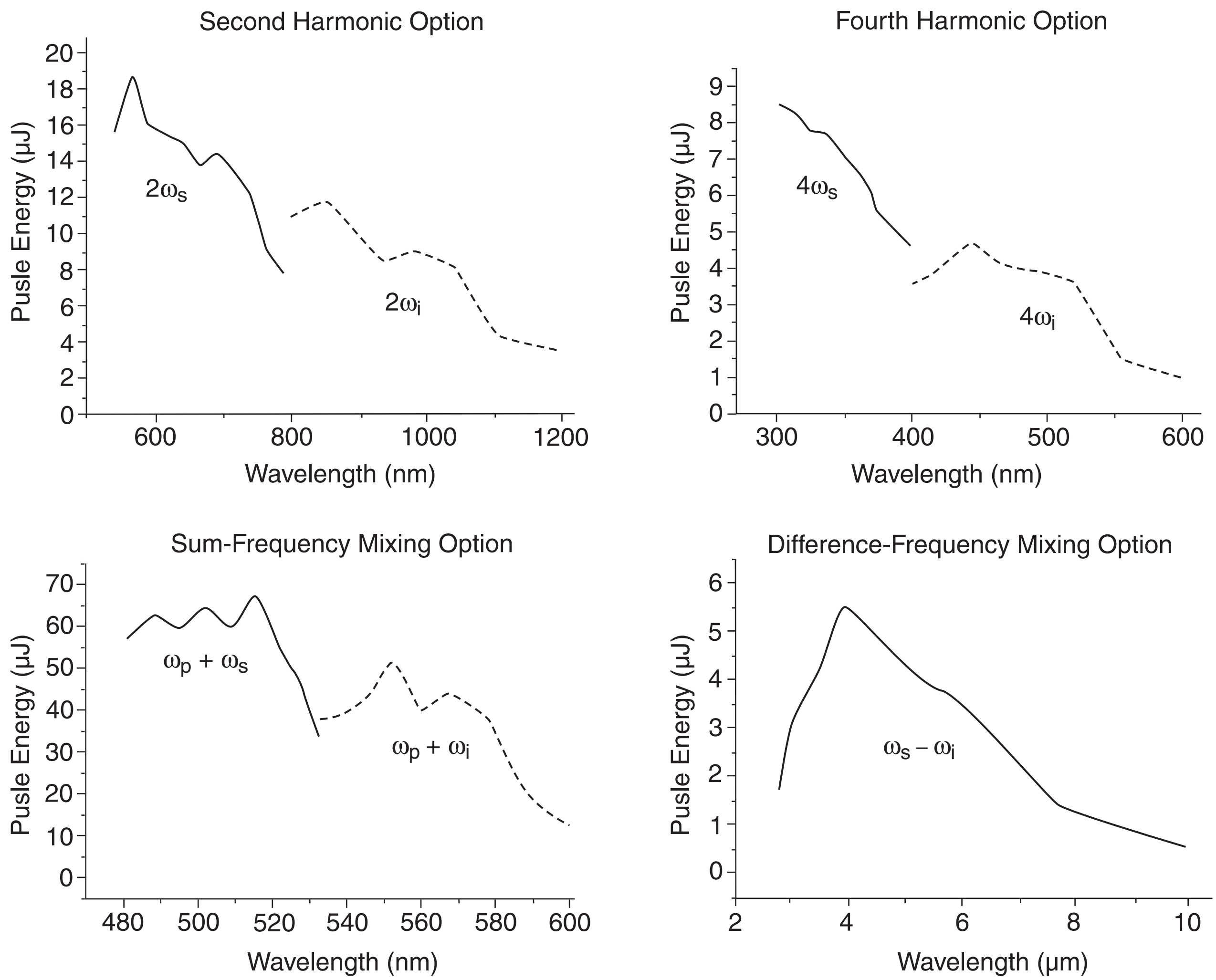
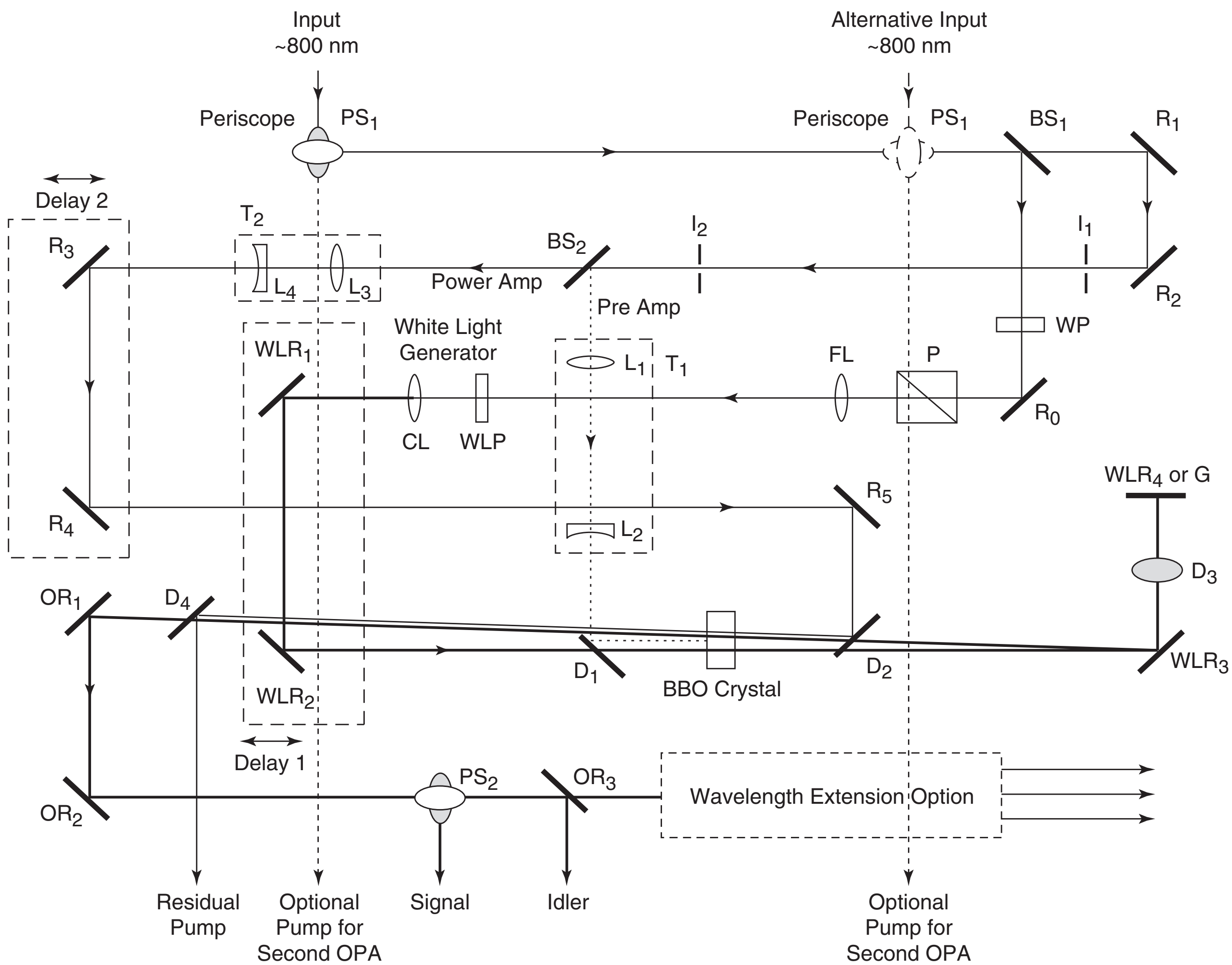


Figure 3-8: Typical Output Tuning Curves for Wavelength Extensions for an *OPA-800CP–1*.

Configuration

The fs/ps *OPA-800CFP* layout is shown in Figure 3-9. The input amplified Ti:sapphire beam is first reflected off two mirrors that flip the polarization from horizontal to vertical, then is split into two legs.

In the first leg, approximately 96% of the energy is transmitted and used for pumping the OPA. The remaining <4% is reflected by beam splitter BS_1 to produce a white light continuum that provides the seed pulse for the OPA. A half waveplate and a thin film or cube polarizer control the beam energy, and a lens focuses the beam into a solid-state material where the continuum is generated. It is re-collimated and relayed to the OPA crystal through variable delay stage DELAY 1.



$BS_{1,2}$	Beam Splitter	I_{1-2}	Irises	R_{0-5}	Reflectors for 800 nm
CL	Collimating Lens	L_{1-4}	Lenses	$T_{1,2}$	Telescopes
D_{1-4}	Dichroic Mirrors	OR_{1-3}	Output Reflectors	WLP	White-light Plate
FL	Focusing Lens	P	Polarizer	WLR_{1-4}	White-light Reflectors
G	Grating	$PS_{1,2}$	Periscope	WP	$\lambda/2$ Waveplate

Figure 3-9: Double-pass, single BBO crystal *OPA-800CFP*.

In the second leg, the major portion of the amplified beam is split into two pump beams, each of which are down-collimated to pump the *OPA-800C* crystal. About 15% of the beam is used to pump the first pass or pre-amplification stage, and the remainder is used to pump the second pass or power amplifier stage. In the pre-amplification stage, the pump beam is steered to the *OPA-800C* crystal using dichroic mirror D_1, which is a high reflector from 750 to 840 nm and highly transmissive for longer wavelengths. This dichroic mirror combines the pre-amplification pump beam with the white light that is generated in the WL arm. The white light is temporally overlapped and amplified by the pre-pump beam by optimizing DELAY 1.

The signal and idler beams generated in the BBO crystal in the pre-amplification stage then pass through dichroic mirror D_2. In an *OPA-800CF*, the amplified idler beam is reflected back through the *OPA-800CF* crystal by mirrors WLR_3 and WLR_4. In an *OPA-800CP*, the amplified idler beam is diffracted back through the *OPA-800CP* crystal by grating G that is mounted on a rotation stage. In either case, this returned beam provides the seed pulse for the power amplifier stage.

The power amplifier stage pump beam is steered to the crystal by five mirrors and the 800 nm dichroic mirror, D_2, where it is overlapped collinearly with the returning idler (signal) beam in the BBO crystal for final amplification. R_3 and R_4 are mounted on delay translation stage DELAY 2 to temporally overlap the power pump beam with the pre-amplified white light returning from WLR_4.

The amplified signal and idler output wavelengths are determined by the phase-matching angle of the BBO crystal. For fs systems, wavelength tuning is accomplished by changing the BBO phase-matching angle and adjusting each delay stage for optimum output energy. For ps systems, the grating angle is also changed.

The residual 800 nm beam is separated from the amplified signal and idler beams by dichroic mirror D_4, and the signal and idler are then either separated and made available through different exit ports or are sent to the harmonic generation leg for wavelength extension through second and fourth harmonic generation.

Mechanical/Optical Configurations for the OPA-800C

The following pages show the mechanical/optical layouts for the fs, ps, and fs/ps versions. For all other options, the mechanical/optical layouts are shown in Chapter 7.

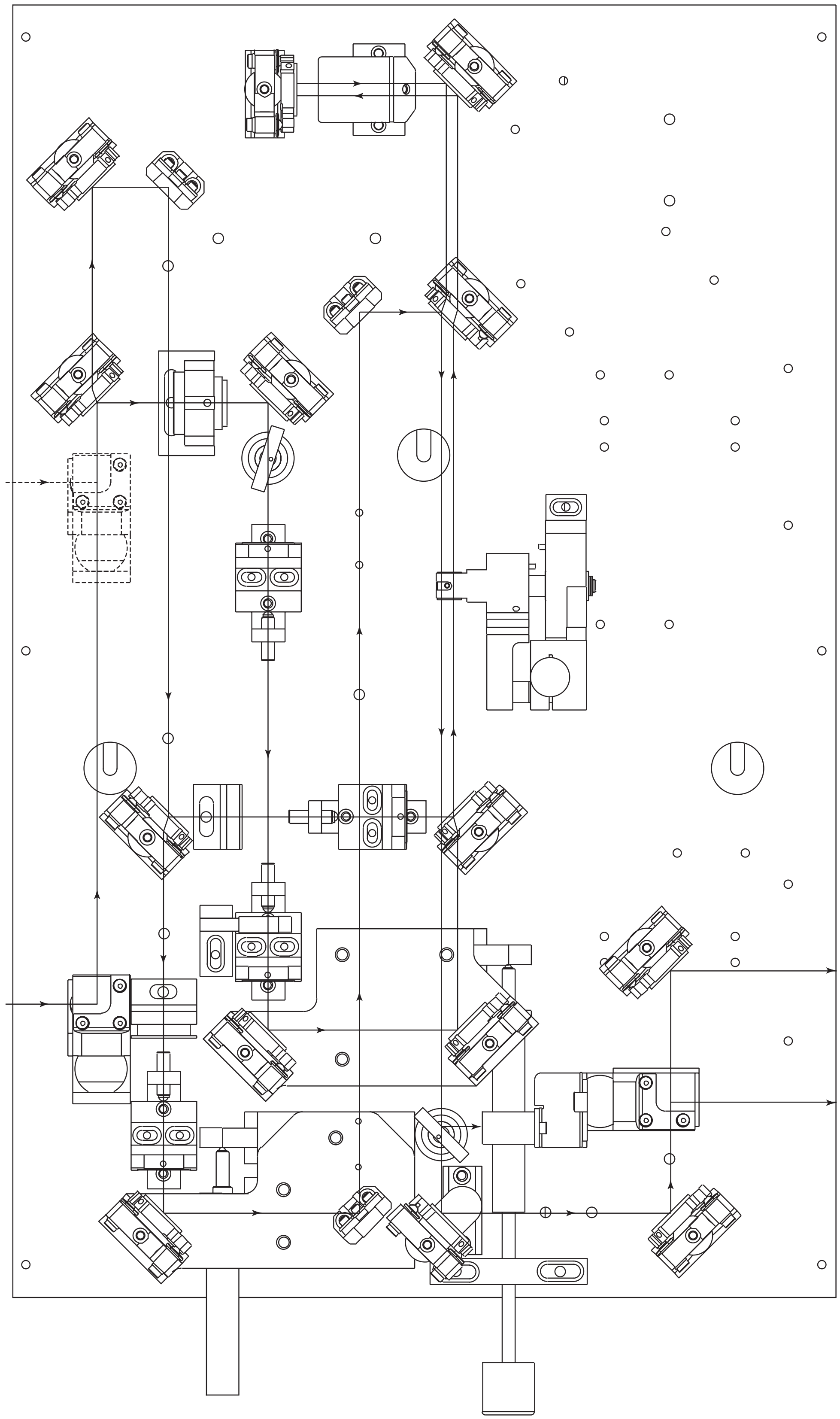


Figure 3-10: Mechanical Layout of the *OPA-800CF*

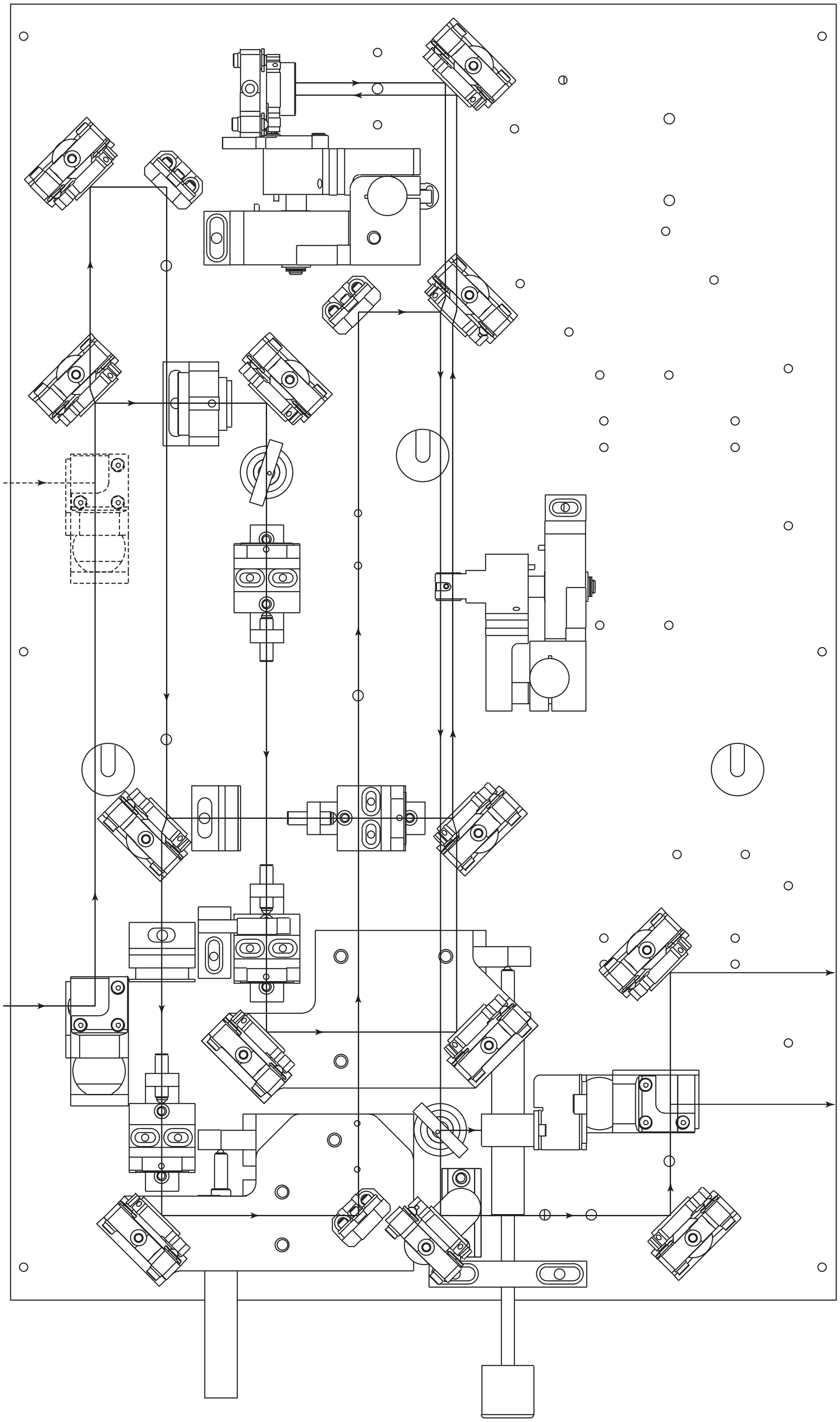


Figure 3-11: Mechanical Layout of the *OPA-800CP*

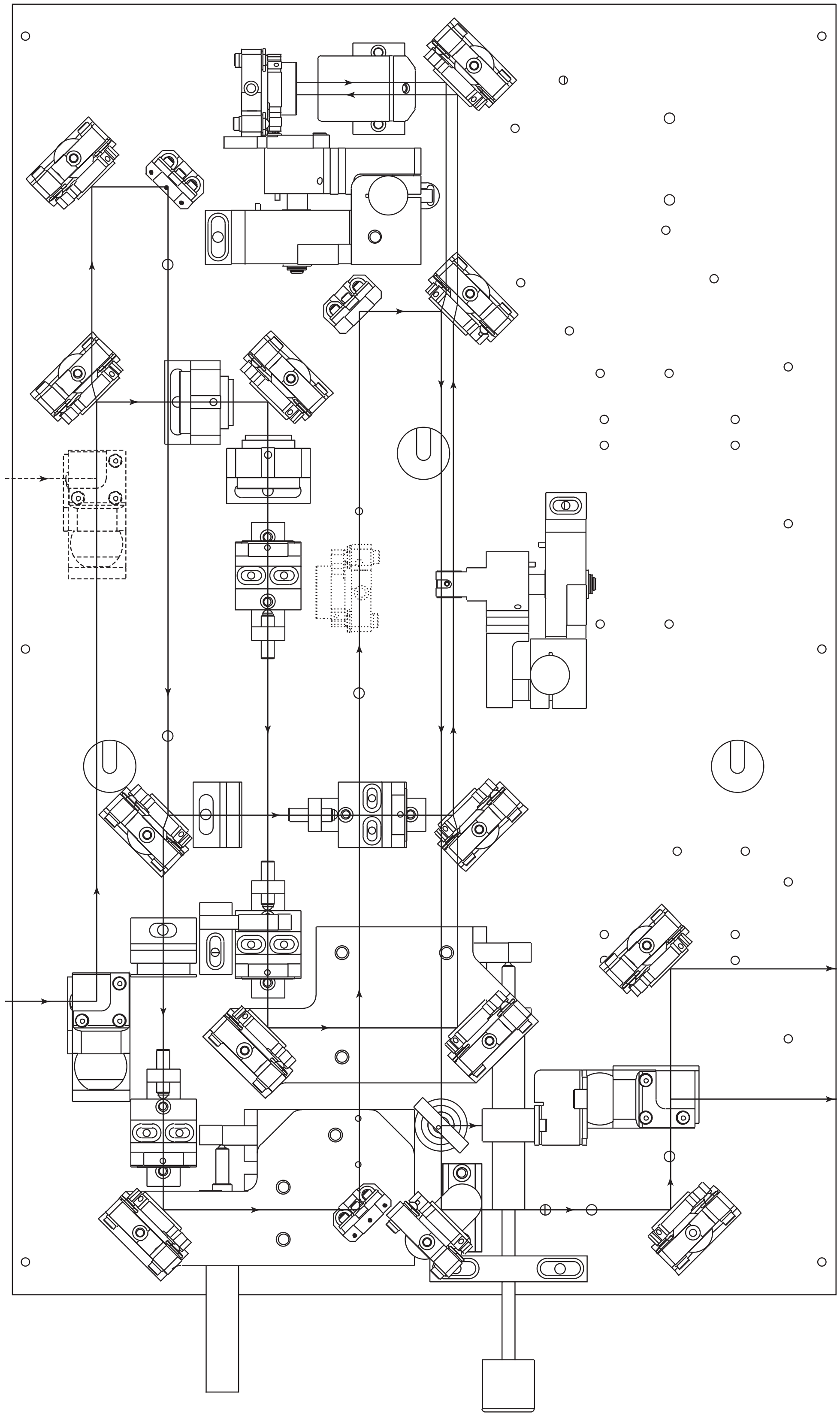


Figure 3-12: Mechanical Layout of the *OPA-800CFP*

Specifications

Table 3-1: *OPA-800CF* Specifications

	Pump Pulse Requirement	Output Performance[1] Signal Output (λ_s=1.3 µm)	Idler Output (λ_i=2.08 µm)
Pulse Energy[2,3,4]	1.0 mJ 0.5 mJ 0.3 mJ 0.7 mJ at 50 fs	75 µJ 35 µJ 18 µJ 53 µJ	35 µJ 20 µJ 10 µJ 25 µJ
Pulse Width[4,5]	<130 fs	< 130 fs	< 130 fs
Tuning Range	800 nm ±5 nm	1.10–1.60 µm	1.60 µm–3.00 µm
Repetition Rate (Nominal)	1–5 kHz	1 kHz/5 kHz	
Energy Stability[6]	<3%	< 3%	
Polarization	Horizontal	Linear, Vertical	

[1] *Due to our continuous improvement policy, specifications are subject to change without notice and only apply when the OPA-800CF is pumped by a Spectra-Physics Tsunami-Millennia or BeamLok and Merlin-Spitfire/Hurricane system. For a dual OPA system, contact Spectra-Physics.*

[2] *The pump pulse is the output of the Spectra-Physics Spitfire/Hurricane with a pulse width of <130 fs at 800 nm. For the OPA-800CF pumped by the Spitfire/Hurricane USF (<80 fs) at 800 nm, output energy is 75% of the standard system. When pumped by the Spitfire/Hurricane 50FS (<50 fs) at 800 nm, the output energy is 70% of the standard system.*

[3] *A 1 mJ pumped OPA-800CF-1 is normally configured for a standard 1 kHz Spitfire/Hurricane. A 0.5 mJ pumped OPA-800CF-0.5 is usually configured for dual OPA operation. A 0.3 mJ pumped OPA-800CF-0.3 is configured for a 5 kHz Spitfire/Hurricane or Spitfire/Hurricane LCX.*

[4] *Specifications apply to operation at the wavelength noted.*

[5] *A Gaussian pulse shape is used to determine the pulse width from the autocorrelation function (x 0.71). For the OPA-800CF pumped by the Spitfire/Hurricane USF/Spitfire/Hurricane 50FS, the OPA-800CF output pulse width is <80 fs or <50 fs at the noted wavelength.*

[6] *±% pulse-to-pulse stability.*

Table 3-2: *OPA-800CP* Specifications

	Pump Pulse Requirement	Output Performance[1] Signal Output (λ_s=1.3 µm)	Idler Output (λ_i=2.08 µm)
Pulse Energy[2,3,4]	1.0 mJ 0.5 mJ	60 µJ 30 µJ	25 µJ 13 µJ
Pulse Width[4,5]	≤1.5 ps	< 1.5 ps	< 1.5 ps
Line Width	≤22 cm^{-1}	<25 cm^{-1}	<25 cm^{-1}
Tuning Range	800 nm ±5 nm	1.10–1.60 µm	1.60 µm–3.00 µm
Repetition Rate (Nominal)	1 kHz	1 kHz	
Energy Stability[6]	<3%	< 3%	
Polarization	Horizontal	Linear, Vertical	

[1] *Due to our continuous improvement policy, specifications are subject to change without notice and only apply when the OPA-800CP is pumped by a Spectra-Physics Tsunami-Millennia or BeamLok and Merlin-Spitfire/Hurricane system. For a dual OPA system, contact Spectra-Physics.*

[2] *A 1 mJ pumped OPA-800CP-1 is normally configured for a standard 1 kHz Spitfire/Hurricane.*

[3] *Specifications apply to operation at the wavelength noted.*

[4] *A Gaussian pulse shape is used to determine the pulse width from the autocorrelation function (x 0.71).*

[5] *±% pulse-to-pulse stability*

Table 3-3: Specifications[1] of *OPA-800CF* Wavelength Extension Options[2]

Option	Wavelength Range	Pulse Energy[3]	Pulse Width[4]	Energy Stability[5]
ω_i	1.6 µm to 3.0 µm	35 µJ at 2.0 µm	< 130 fs	< 3%
ω_s	1.1 µm to 1.6 µm	75 µJ at 1.3 µm	< 130 fs	< 3%
HGI/HGII 2ω_i	800 nm to 1.2 µm	10 µJ at 900 nm	< 130 fs	< 5%
HGI/HGII 2ω_s	580 nm to 800 nm	15 µJ at 650 nm	< 130 fs	< 5%
HGI/HGII 4ω_i	400 nm to 600 nm	3 µJ at 450 nm	< 200 fs	< 7.5%
HGII 4ω_s	300 nm to 400 nm	3 µJ at 330 nm	–	< 7.5%
SFM $\omega_p + \omega_s$	480 nm to 533 nm	30 µJ at 500 nm	< 130 fs	< 5%
SFM $\omega_p + \omega_i$	533 nm to 600 nm	20 µJ at 560 nm	< 130 fs	< 5%
DFM $\omega_s - \omega_i$	3.0 µm to 10 µm	3 µJ at 4.0 µm	–	< 5%

[1] *Due to our continuous product improvement, specifications are subject to change without notice and only apply when the OPA-800CF is pumped by Spectra-Physics' Tsunami-Millennia or BeamLok and Merlin-Spitfire/Hurricane system. All specifications are based on a 1 mJ, 800 nm, <130 fs pump pulse from the Spectra-Physics Spitfire/Hurricane.*
[2] *All wavelength extension options are located within the OPA-800CF housing.*
[3] *The energy specifications are for an OPA-800CF-1, the 1 mJ pumped OPA. For OPA-800CF-0.5 (0.5 mJ pumped OPA), the output energy is 40% of the corresponding energy on the table. For OPA-800CF-0.3 (0.3 mJ pumped OPA), the output energy is 25% of the corresponding energy in the table. For the OPA pumped by the Spitfire/Hurricane USF (<80 fs), the output energy is 75% of the corresponding energy of the standard OPA. For the OPA pumped by the Spitfire/Hurricane 50 fs (<50 fs), the output energy is 70% of the corresponding energy of the standard OPA.*
[4] *Specifications apply to operation at the wavelength noted. A Gaussian pulse shape is used to determine the pulse width from the autocorrelation (x 0.71). For the OPA pumped by Spitfire/Hurricane-USP, please contact Spectra-Physics for the option's output pulse width.*
[5] *±% pulse-to-pulse stability.*

Table 3-4: Specifications[1] of *OPA-800CP* Wavelength Extension Options[2]

Option	Wavelength Range	Pulse Energy[3]	Pulse Width[4]	Energy Stability[5]
ω_i	1.6 µm to 3.0 µm	25 µJ at 2.0 µm	< 25 cm^{-1}	< 3%
ω_s	1.1 µm to 1.6 µm	60 µJ at 1.3 µm	< 25 cm^{-1}	< 3%
HGI/HGII 2ω_i	800 nm to 1.2 µm	7 µJ at 900 nm	< 25 cm^{-1}	< 5%
HGI/HGII 2ω_s	580 nm to 800 nm	14 µJ at 650 nm	< 25 cm^{-1}	< 5%
HGI/HGII 4ω_i	400 nm to 600 nm	2 µJ at 450 nm	< 30 cm^{-1}	< 7.5%
HGII 4ω_s	300 nm to 400 nm	4 µJ at 330 nm	< 30 cm^{-1}	< 7.5%
SFM $\omega_p + \omega_s$	480 nm to 533 nm	30 µJ at 500 nm	< 25 cm^{-1}	< 5%
SFM $\omega_p + \omega_i$	533 nm to 600 nm	20 µJ at 560 nm	< 25 cm^{-1}	< 5%
DFM $\omega_s - \omega_i$	3.0 µm to 10 µm	3 µJ at 4.0 µm	< 25 cm^{-1}	< 5%

[1] *Due to our continuous product improvement, specifications are subject to change without notice and only apply when the OPA-800CP is pumped by Spectra-Physics' Tsunami-Millennia or BeamLok and Merlin-Spitfire/Hurricane system.*
[2] *All wavelength extension options are located within the OPA-800CP housing.*
[3] *The energy specifications are for an OPA-800CP-1, the 1 mJ pumped OPA.*
[4] *Specifications apply to operation at wavelength noted.*
[5] *±% pulse-to-pulse stability.*

Outline Drawings

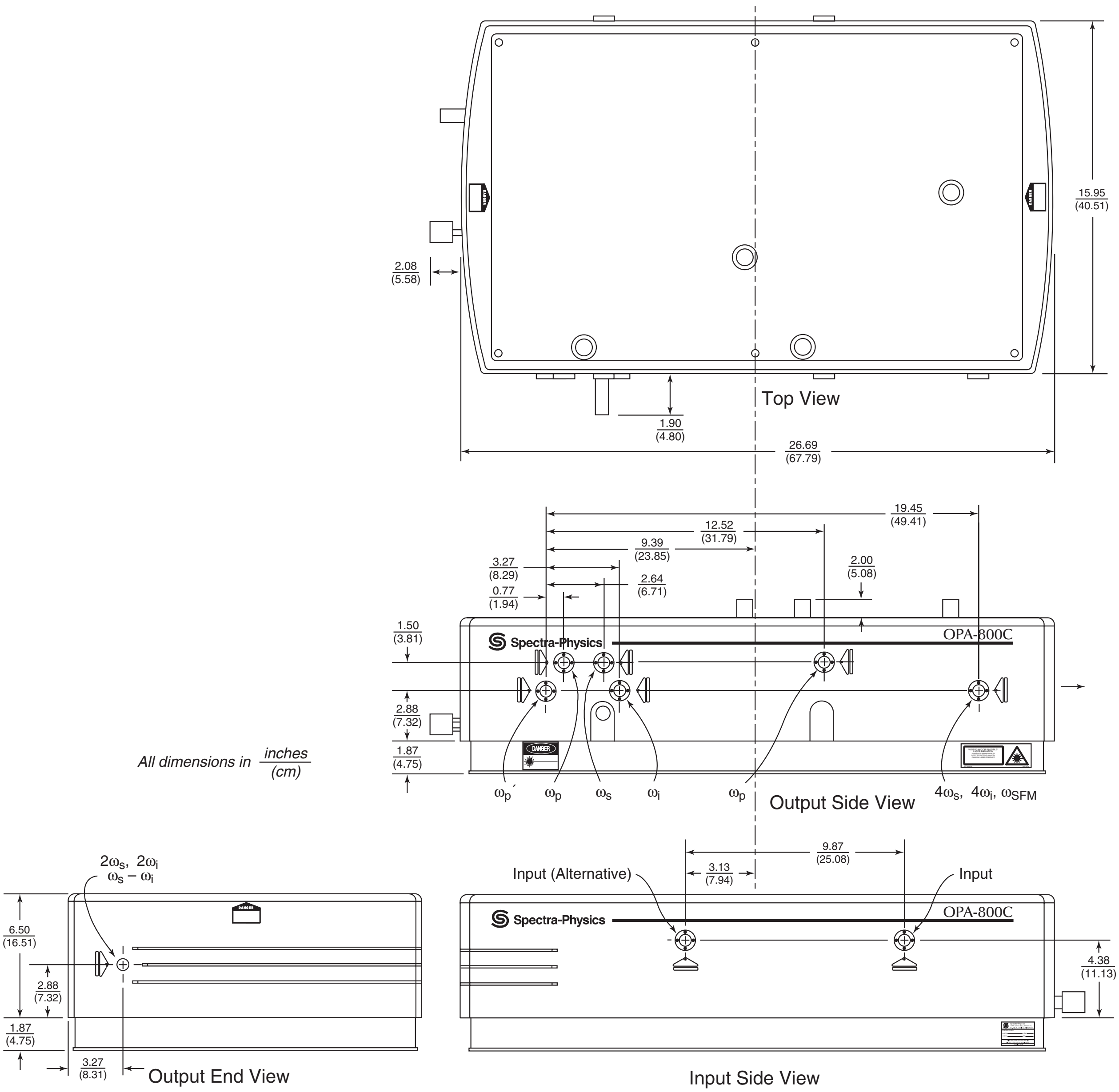


Figure 3-13: The *OPA-800C* Outline Drawing

Chapter 4 OPA-800CF Installation and Alignment

The Spectra-Physics *OPA-800CF* fs optical parametric amplifier (OPA) is designed to deliver high energy, near transform limited fs pulses with wavelengths ranging from <300 nm to >10 µm. The optical layout is very similar to that in the ps *OPA-800CP*, and this fs unit can be easily converted to a ps unit and vice versa. This chapter will guide you through the installation and alignment of your *OPA-800CF*. If you have a ps system, please refer to Chapter 5. Refer to Figure 4-1 while performing the following procedures.

Danger! Laser Radiation

Safety eyewear should be worn throughout this procedure.

Note

Refer to your *Spitfire*™ or *Hurricane*™ user's manual for proper installation of the amplifier system. Proper installation is essential for optimal *OPA-800CF* performance.

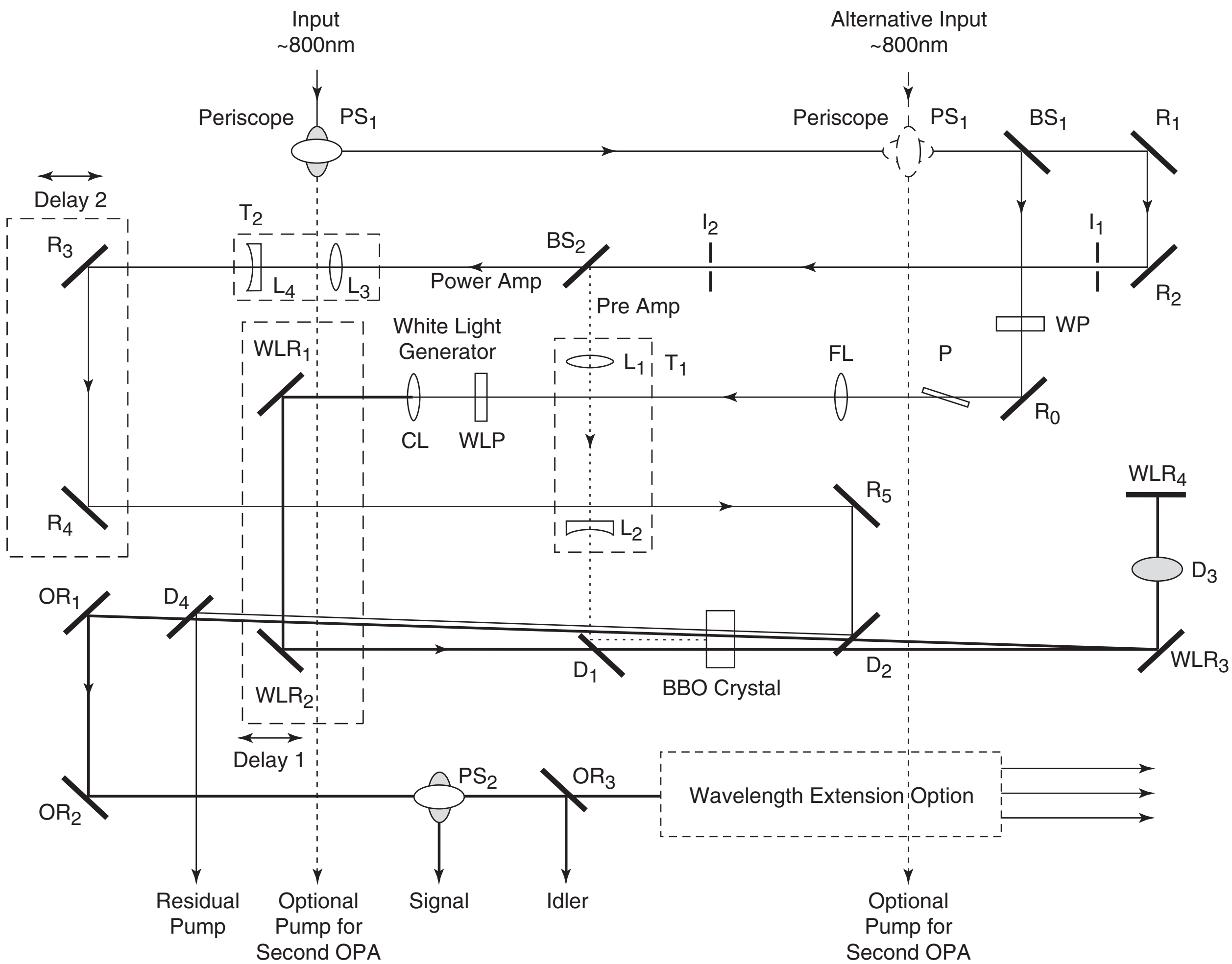
Required Equipment

The following equipment will help you properly align your fs *OPA-800CF*:

- Laser goggles that protect against laser wavelengths from 200 nm to >10 µm
- Infrared card
- Spectrometer
- Power meter
- Two 6.3 cm height alignment targets (provided in this manual)
- Ir detector and fast oscilloscope

Precautions

- Do not use the output of a fs *Spitfire/Hurricane* amplifier to pump an *OPA-800CFP* that is configured for ps operation. (An *OPA-800CFP* may be shipped as a ps configuration.)
- This *OPA-800CF* can be pumped by the output of the *Spitfire/Hurricane* amplifier with 1 mJ, 0.75 mJ, 0.5 mJ, or possibly 0.3 mJ per pulse with a pulse duration of less than 130 fs at the center wavelength of 800 nm. The *Spitfire/Hurricane* output spatial mode quality is critical for high OPA conversion efficiency.



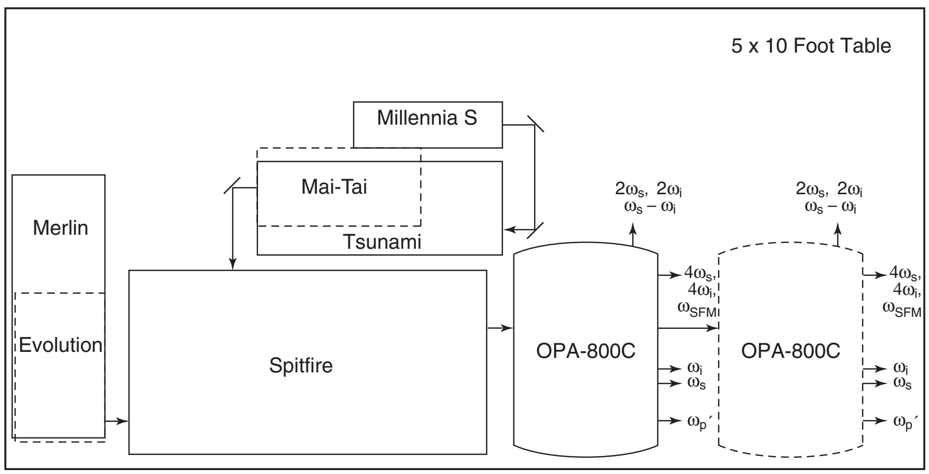
$BS_{1,2}$	Beam Splitter	I_{1-2}	Irises	R_{0-5}	Reflectors for 800 nm
CL	Collimating Lens	L_{1-4}	Lenses	$T_{1,2}$	Telescopes
D_{1-4}	Dichroic Mirrors	OR_{1-3}	Output Reflectors	WLP	White-light Plate
FL	Focusing Lens	P	Thin-film Polarizer	WLR_{1-4}	White-light Reflectors
		$PS_{1,2}$	Periscope	WP	$\lambda/2$ Waveplate

Figure 4-1: Double-Pass, Single BBO Crystal *OPA-800CF*

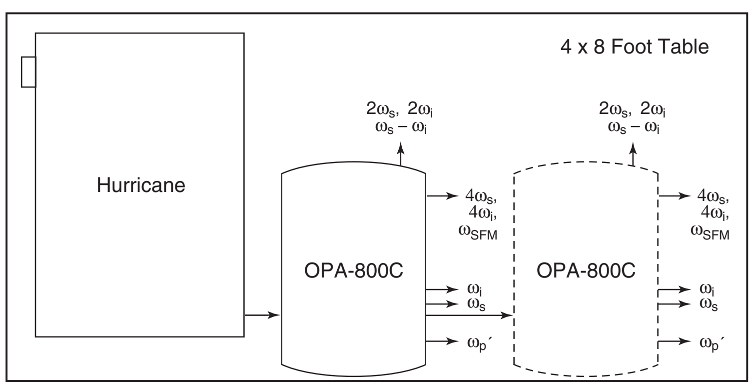
- Due to the variation of beam size and divergence in pump beams, the focused and collimated beam sizes of your pump beams can be quite different from those used at the factory. Therefore, while aligning an optic, *always protect the optics down stream, especially the BBO crystal, by keeping the beams at a safe intensity.*
- Do not frequently clean the crystals in the OPA (BBO, $AgGaS_2$). Most are made of hygroscopic materials. You can use Xylene to clean BBO *if it is very necessary. Do not use methanol or acetone!*
- Close I_1 and I_2 when aligning the white light generator.
- Always let the beam hit the center of the optical elements, except where noted. Keep the beam height 6.3 cm above the base plate after PS_1 and before PS_2. Use one of the alignment cards provided in this manual.

Installation

1. Close all the irises in the OPA and block the *Spitfire* or *Hurricane* amplifier pump beam in front of periscope PS_1.
2. Verify the *Spitfire/Hurricane* output beam is 15.9 ±0.3 cm above and parallel to the optical table, and that the beam is directed toward the *OPA-800CF.*
3. Orient the *OPA-800CF* so that the *Spitfire/Hurricane* output beam is perpendicular to the input side panel (Figure 4-2) and hits the center of of the chosen input port.
4. Block the WL generation pump beam by placing a card in front of the white light generator.
5. Remove the window plug and let the pump beam into *OPA-800C*.
6. If you use a beam splitter to separate the beam for other outside requirements, temporarily block the transmitted beam through the first mirror of PS_1.



(a) A Typical Spitfire and OPA-800C System Layout (with optional second OPA)



(b) A Typical Hurricane and OPA-800C System Layout (with optional second OPA)

Figure 4-2: A Typical *OPA-800CF* Table Layout

7. Carefully position the *OPA-800C* and/or PS_1 so that the beam after PS_1 hits the center of R_1.

Caution!

For dual OPA operation or whenever you need to split part of the pump beam for use elsewhere, make sure the transmitted part of the pump beam through PS_1 is centered on the optional pump beam exit port and temporarily block it while you align the first OPA.

8. Place standard table bolts through the three plugged holes in the base plate and secure the *OPA-800CF* to the optical table.
9. Steer PS_1 and R_1 so that the pump beam is centered on both irises (I_1 and I_2) and make sure the beam is turned 90° through PS_1 and is 6.3 cm above the base plate (use an alignment card). Reposition PS_1 if necessary.

Alignment

If your *OPA-800CF* system is set up for ps operation, convert it for fs operation before continuing. Follow the conversion instructions at the end of this chapter.

White Light Generation

1. Place beam blocks, such as business cards, before telescopes T_1 and T_2 and the WLP white light plate (see Figure 4-1).
2. Adjust BS_1 to center the beam on waveplate WP and align the beam along the center line of the white light generator (WLG) arm, 6.3 cm above and parallel to the base plate (use an alignment card).
3. Rotate the WP to minimize the energy after the polarizer.
4. Move the business card from the front of the WLP to the front of CL.
5. Move the FL lens as close to the WLP as possible, then move it back and forth with your fingers and look for white light (WL) to be generated within the WLP on the card.
6. If you do not see the WL signal, optimize the *Spitfire/Hurricane* compressor delay (see *Spitfire/Hurricane* user's manual) and repeat Step 5.
7. If you still cannot find the WL signal, gradually increase the pump energy to the WLP (adjust the WP) and repeat the last two steps until you generate WL. Typically it needs <3 μJ energy pulse, depending on the pulse duration.
8. By translating the FL and optimizing the pulse duration and pump energy through WP, you should be able to get a symmetrical WL beam with a bluish-green spot at the center and a yellowish ring around it for use as a seed beam.

Note

If you have difficulty generating WL, check the pulse duration of the *Spitfire/Hurricane* output to see if it meets the requirement for pumping the *OPA-800CF* (see specifications at the end of Chapter 3). If the WL has a bright spot that moves around or is not stable or is not at the center of the WL beam, reduce the pump energy (<50 fs pulses) by carefully rotating the WP. If this is ineffective and this is a fs-only OPA, try rotating the thin film polarizer to create a large incidence angle to reduce the pump energy.
Take care to avoid the possibility of damaging components in the WLG.

9. Once WL is obtained, adjust R_0 to direct the light onto the center of WLR_1.
10. Position the CL lens to center it in the WL beam.
11. Adjust WLR_1 so the WL beam passes through D_1 on the side closest to L_2.
12. Adjust WLR_2 so that the WL beam passes through the BBO crystal near the inner side (the mount side—see Figure 4-3) and hits the center of WLR_3 and WLR_4.
13. Steer WLR_3 so that the reflected WL is 6.3 cm above the base plate and parallel to the short side of the base plate (use an alignment card).
14. Focus the WL beam on the WLR_4 by translating CL.
15. Adjust WLR_4 to bounce the WL beam back through the outer half of the BBO crystal without clipping it with the crystal, D_1 or WLR_2, and steer it through D_4 to OR_1.

Note

The WL spot on the BBO crystal should not move while varying DELAY 1. Once WL is generated, you may need to repeat some steps in this section to obtain a stable, symmetrically distributed WL with a bluish-green color in the middle surrounded by a yellowish ring.

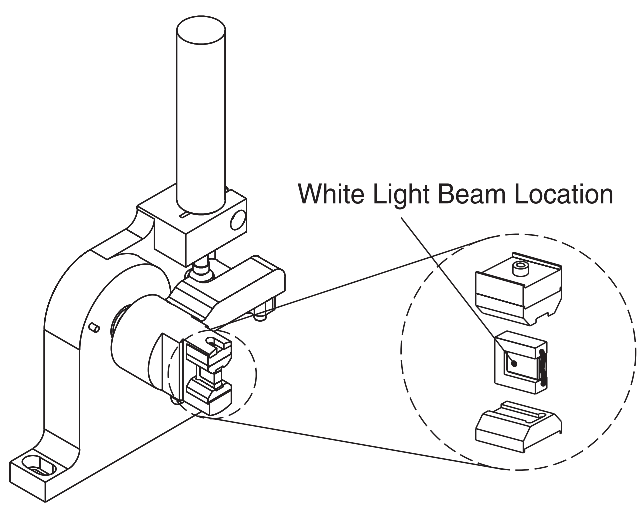


Figure 4-3: WL beam location on the crystal in the crystal mount.

Pre-amplification Stage

Warning! The pre-amplifier and power amplifier 800 nm pump beams should not be focused in the BBO crystal without careful monitoring. The crystal can be easily damaged.

Small distance variations between L_1 and L_2 in T_1 will cause a big change in the focus position of the pre-amplifier beam. Verify the pre-amplifier beam is not focused on any optical surface before allowing it to hit that same surface, and always monitor it while adjusting the separation of L_1 and L_2.

Warning! This is the pre-amplification of the WL. The amount of amplified WL is typically a few µJ before it hits the WLR_4. Although you can see the amplification, the use of a photodetector will simplify this search.

Do not perform these steps with the power amplifier beam present, nor let any beams burn ink or other material onto the surface of the BBO crystal, e.g., do not let the beam hit your alignment card when it is close to the crystal or optics. Using a white card cut to ½ x 10 cm may reduce the chance of this happening.

1. Block the two beams in front of T_2 with white cards.
2. Defocus the pre-amplifier beam by translating L_2 closer to L_1.

Warning! Keep the beam size from getting too small. A beam that is too small will damage the BBO crystal.

3. With irises I_1 and I_2 closed, adjust BS_2 so that the pre-amplifier beam and the WL beam are overlapped right after D_1.
4. Put a card in front of D_2 and adjust D_1 so that the pre-amplifier beam and the WL beam are overlapped before WLR_3.
5. Iterate Steps 3 and 4 until the two beams are well overlapped.
6. Use a business card to block the WL beam before CL.
7. Set the BBO crystal at the angle corresponding to λ_s=1.3 µm according to the setting on the *OPA-800CF* Final Test Performance Summary sheet shipped with this *OPA-800CF*.
8. To prevent damage to R_5, place a card in front of D_2.
9. Turn off the room lights and completely open I_1 and I_2, then gradually reduce the spot size of the pre-amplifier beam by translating L_2 until the pre-amplification pump beam is focused about 4 cm ±1 cm in front of D_2 and 8 cm ±1 cm after the BBO crystal. (a business card will easily burn at these points).

   A *small* amount of superfluorescent, optical parametric generation (OPG) light might appear in front of WLR_3 above and below the pre-amplifier beam.

10. Remove the cards from in front of D_2 and CL.
11. Translate DELAY 1 back and forth until the WL beam gets amplified and becomes brighter.
12. Optimize DELAY 1 for best WL amplification as determined by monitoring the amplified beam with a photodiode or power meter.

Note

To help find the WL amplification, use a fast oscilloscope with an infrared photodetector placed in front of a card located in front of WLR_3. If this is not possible, turn off the room lights and watch closely to see the changes in WL intensity.

Warning!

Avoid focusing the pre-amplification pump beam onto D_2 or R_5.

13. Gradually enlarge the pre-amplifier beam size at the BBO crystal by slowly translating L_2 closer to L_1 so that a smaller amount of OPG emerges, but so that there is still substantial WL amplification. Verify the latter by placing a card in front of CL to interrupt the WL seed.

If, after several attempts at performing Steps 12 and 13 you could not obtain amplification, check the WL and pre-amplifier beam overlap, and verify that DELAY 1 scans through a larger range.

Power Amplification Stage

1. Block the pre-amplifier beam just before L_1.
2. To keep from damaging the BBO crystal and all the optics downstream, de-focus the power amplifier beam by translating L_4 of T_2 closer to L_3.
3. Place a white business card in front of R_5.
4. Translate L_4 to collimate the power amplifier beam between R_3 and R_5.
5. Lower the *Spitfire/Hurricane* amplifier output by retarding the switchout time by 100 ns in the *Spitfire/Hurricane* SDG (see *Spitfire/ Hurricane* user's manual), and let the small energy beam hit R_5 and D_2 and the BBO crystal.
6. Adjust R_3 and D_2 to align the power amplifier beam to the BBO crystal so that it propagates collinearly with the reflected WL from WLR_4.
7. Use a white card to block the power amplifier beam in front of L_4.
8. Re-adjust the electronic delay of the *Spitfire/Hurricane* SDG back to its normal position for specified output energy level.
9. Put another white card in front of OR_1.
10. Turn off the room lights, then remove the card from in front of L_4 to see whether it generates OPG/WL through the BBO crystal before OR_1, then replace the white card quickly once a determination has been made.

11. Adjust L_4 until the beam does not generate any OPG/WL, then remove the card from in front of L_4.
12. Adjust R_3 and D_2 so that the power amplifier beam is still collinear with the WL beam from WLR_4 and so that is not clipped by the BBO crystal or D_1 and so it passes through D_4.
13. Remove the card from in front of L_1 and let the pre-amplifier beam pump the BBO crystal and amplify the WL.
14. Adjust DELAY 2 back and forth until you see an amplification flash in front of OR_1 that is caused by the power amplifier beam.
15. Using a power meter, optimize output power by adjusting DELAY 1 and DELAY 2, adjusting D_1 to overlap the pre-amplifier beam with WL, adjusting R_3 and D_2 to steer the power amplifier beam, and adjusting CL.
16. Iteratively adjust DELAY 1 then DELAY 2 to obtain optimum output.

Note

Typically, there are several delay positions for DELAY 1 that provide amplification. Usually, the optimum output is obtained with the largest optical path length for both delays.

Note

If at first Steps 14–16 are not successful in producing spec power, try again several times. You should always be able to find the power amplification by adjusting DELAY 2. Otherwise, repeat Step 15 under “White Light Generation.”

17. Block the WL seed and verify output from the OPA is significantly reduced. If this is not the case, de-focus both pump beams by gradually bringing L_2/L_4 closer to L_1/L_3.

For wavelength tuning and options, refer to Chapter 6, “Operation.” For converting back to ps operation, see Chapter 5.

Converting from ps to fs Operation

The *OPA-800CP* uses the same base plate as the fs *OPA-800CF*, and with the right components, can be converted from ps to fs operation and back again in the field.

Note

If yours is a ps-only *OPA-800CP* and not a fs/ps *OPA-800CFP*, do not make the following changes. A conversion is not necessary.

1. Rotate the waveplate (WP) to minimize the white light pump energy.
2. Block the *OPA-800CF* incoming pump beam from the *Spitfire/Hurricane* amplifier.
3. Close irises $I_1$and I_2.
4. Set the *Spitfire/Hurricane* amplifier for fs operating specifications according to its user’s manual.

5. Exchange the ps 8 mm WLP with the fs 3 mm sapphire plate by flipping the mount.
6. Change the second lens (L_4) in the power amplifier beam path to one with a focal length of −75 mm.
7. Move the L_3 lens to the threaded hole that is closest to L_4. as shown in Figure 4-4.
8. Move the L_4 lens closer to L_3 by 6.3 mm. Figure 4-4 shows how to change the L_4 and L_3 mounts for fs operation.

   In order to easily access the adjustment screw of L_4, you can assemble the top portion of the translation stage so that it is rotated 180° from that shown in Figure 4-4.
9. Replace the ps OPA BBO crystal with the 3 mm fs OPA crystal.

Caution!

The crystal holder comprises three parts that are clamped together in the mount by a spring-loaded mechanism (which is part of the holder). When the holder is removed from the mount, the spring is released and these three parts will fall apart unless held together. If they fall apart, reassemble them as shown in Figure 4-5.

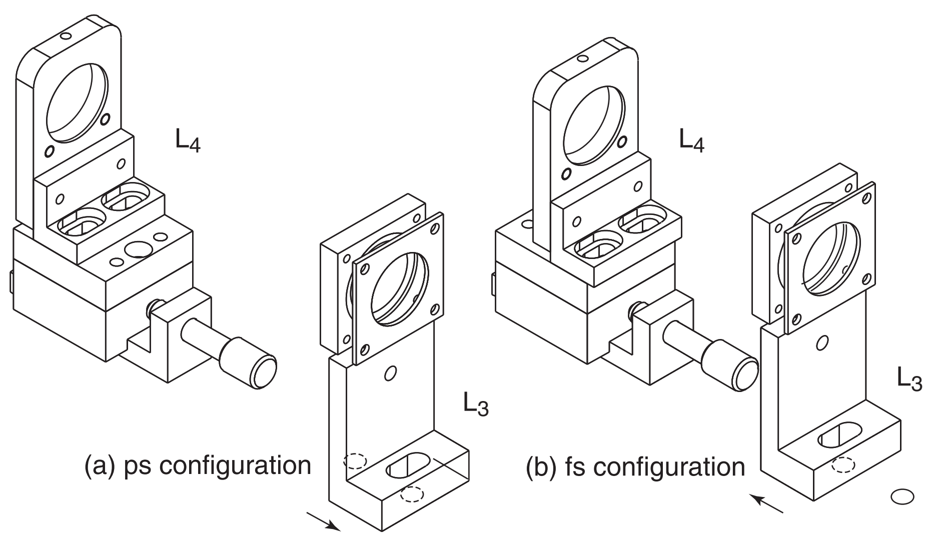


Figure 4-4: L_4/L_3 Placement for ps and fs Configurations

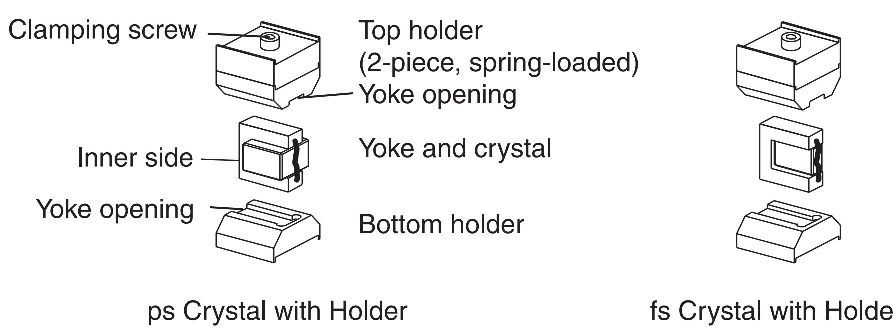


Figure 4-5: The ps and fs crystals with holders.

a. Remove the crystal holder from the mount by turning the clamping screw on the top holder *clockwise* to compress the spring mechanism, then carefully slide the holder out of the mount.

   Place some lens tissue under the crystal mount to prevent the crystal from directly falling onto the base plate if it becomes loose.

b. Assemble the fs 3-piece crystal holder and carefully slide it into place in the mount. Note which side of the yoke is the "inner side" that goes next to the mount. *Do not get the yoke and crystal turned around!*

c. Tighten the clamp by turning the screw *counterclockwise* until the holder assembly feels secure (typically less than 1 turn).

Caution! If you turn the screw too far, the screw will come out.

---

10. Remove the grating mount (the dashed component in Figure 4-6) from the mounting plate and fasten it into one of the 8-32 threaded holes in the middle of the base plate.
11. Remove the BP (see Figure 5-1).
12. Install dichroic mirror D_3 in front of WLR_4.
13. Mount the 1 in. mirror mount with a curved mirror post into the same position previously occupied by the grating.
14. If this unit uses a thin-film polarizer to control the white light pump energy, change BS_1 to a 1% reflection beam splitter. If a cube polarizer is present, you can still use the 4% R beam splitter for fs operation.

This completes the ps to fs mechanical and optical conversion. Continue with the "Alignment" section earlier in this chapter. To convert your system back to ps operation, please see Chapter 5.

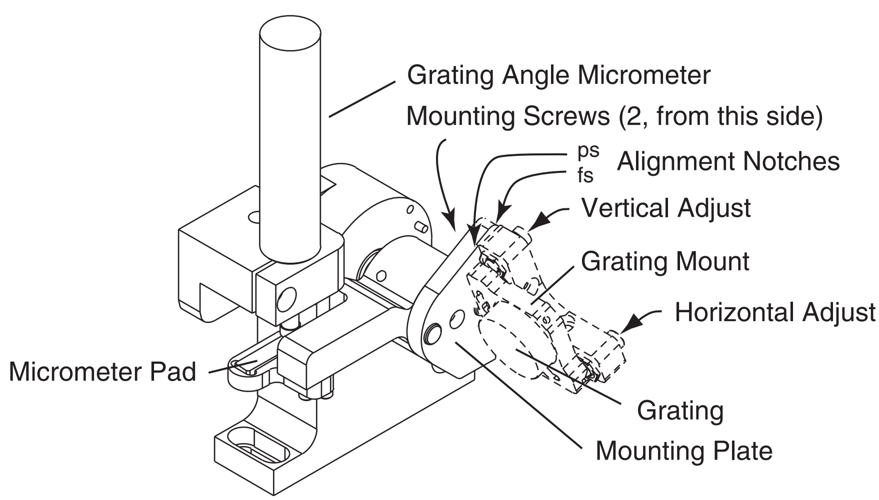


Figure 4-6: Conversion of the ps OPA grating assembly to the fs curved mirror.

Chapter 5 OPA-800CP Installation and Alignment

The Spectra-Physics *OPA-800CP* ps optical parametric amplifier is designed to deliver high energy, near transform limited ps pulses with wavelengths ranging from <300 nm to >10 µm. The optics layout is very similar to that in the fs *OPA-800CF*, and this ps unit can be easily converted to a fs unit and vice versa. This chapter will guide you through the installation and alignment of your *OPA-800CP*. If you are operating a fs system, please refer to Chapter 4.

Refer to Figure 5-1 while performing the following procedures.

Danger! Laser Radiation

Safety eyewear should be worn throughout this procedure.

Note

Refer to your *Spitfire/Hurricane* manual for proper installation of the amplifier system. Proper installation is essential for optimal *OPA-800CP* performance.

If you have a fs/ps *OPA-800CFP*, we recommend you first align your system and get it running as a fs OPA before aligning it as a ps unit. Chapter 4 contains the fs alignment procedure. If you have a fs-only *OPA-800CF*, ignore this chapter.

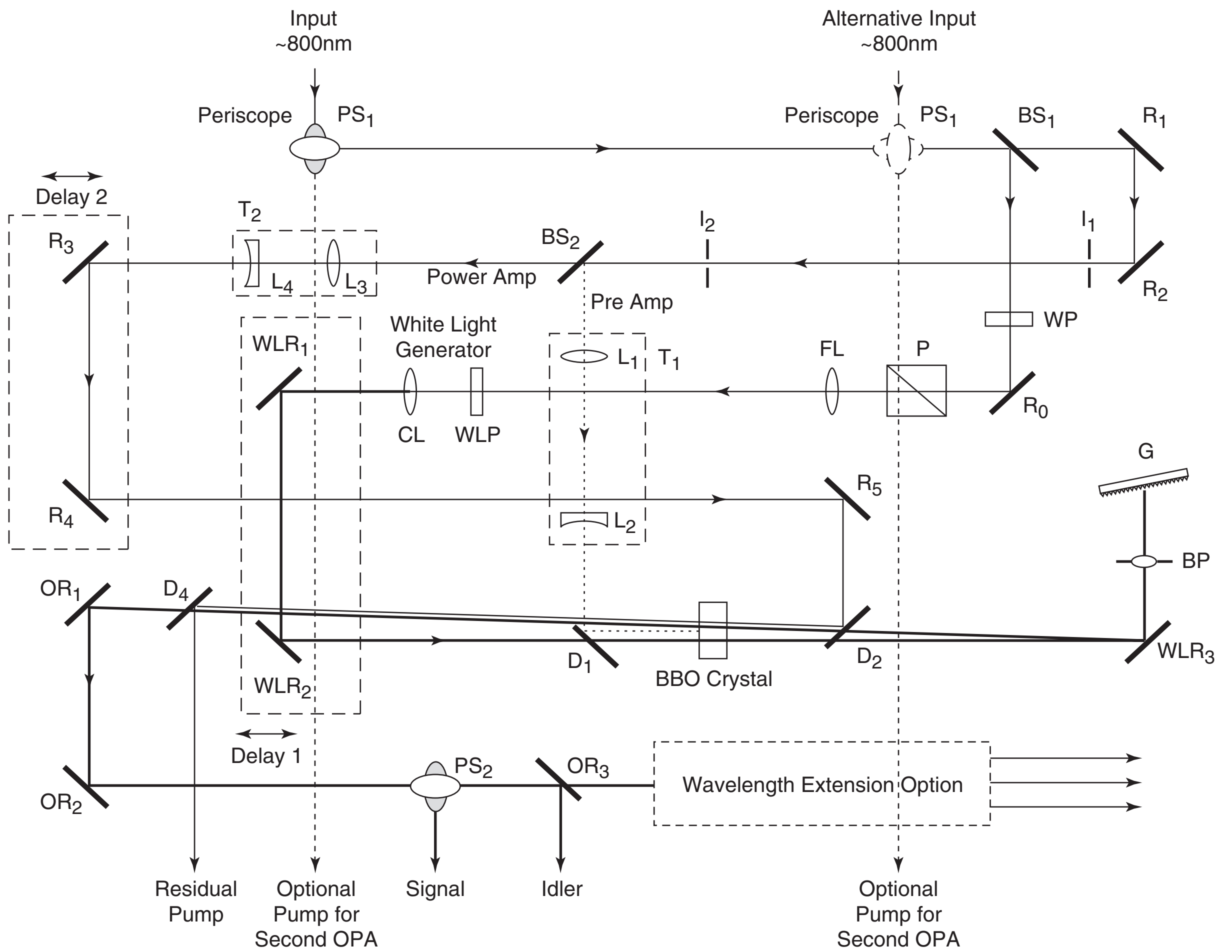
Required Equipment

The following equipment will help you properly align your ps OPA:

- Laser goggles that protect against laser wavelengths from 200 nm to >10 µm
- Infrared card
- Spectrometer
- Power meter
- Two 6.3 cm height alignment targets (provided in this manual)
- Ir detector and fast oscilloscope

Precautions

- Do not use the output of a ps *Spitfire/Hurricane* amplifier to pump an *OPA-800CFP* configured for fs operation. (A fs/ps unit may be shipped as a fs configuration.)



$BS_{1,\,2}$	Beam Splitter	I_{1-2}	Irises	R_{0-5}	Reflectors for 800 nm
BP	Beam Protector	L_{1-4}	Lenses	$T_{1,\,2}$	Telescopes
CL	Collimating Lens	OR_{1-3}	Output Reflectors	WLP	White-light Plate
$D_{1,\,2,\,4}$	Dichroic Mirrors	P	Cube Polarizer	WLR_{1-3}	White-light Reflectors
FL	Focusing Lens	$PS_{1,\,2}$	Periscope	WP	$\lambda/2$ Waveplate
G	Grating				

Figure 5-1: Double-Pass, Single BBO Crystal *OPA-800CP*

- This *OPA-800CP* has to be pumped with an 800 nm beam from a *Spitfire/Hurricane* amplifier with a bandwidth < 1.3 nm, < 1.5 x transform-limited pulse duration and 1 mJ energy per pulse. The *Spitfire/Hurricane* output spatial mode quality is critical for high *OPA-800CP* conversion efficiency.
- Due to the variation of the beam size and divergence, the focused and collimated beam sizes can be quite different from the factory setting. Therefore, while aligning an optic, *always protect the optics down stream, especially the BBO crystal, by keeping the beams at a safe intensity.*
- Do not frequently clean the crystals in the OPA (BBO, $AgGaS_2$). Most are made of hygroscopic materials. You can use Xylene to clean BBO *if it is very necessary. Do not use methanol or acetone!*

- Close I_1 and I_2 when aligning the white light generator.
- Always align the beam to hit the center of most optics except where noted. Keep the beam height 6.3 cm above the base plate after PS_1 and before PS_2. Use one of the alignment cards provided in this manual.

Caution!

For dual OPA operation or when splitting the pump beam for other purposes, make sure the transmitted part of the pump beam through PS_1 is centered on the optional pump beam exit port and block it temporarily while you align this OPA.

Installation

1. Close all the irises in the *OPA-800CP* and block the *Spitfire/Hurricane* amplifier pump beam in front of periscope PS_1.

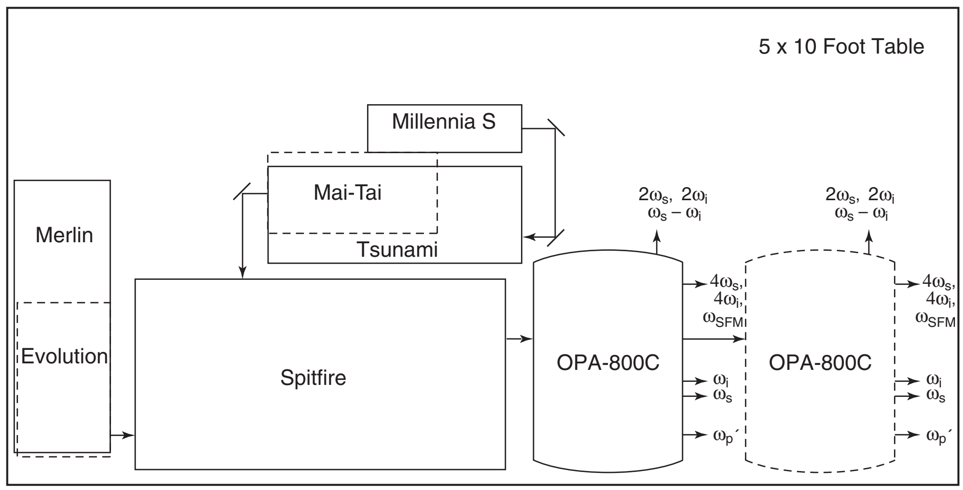


Figure 5-2: Typical *OPA-800CP* Table Layout (with optional second OPA)

2. Verify the *Spitfire/Hurricane* output beam is 15.9 ±0.3 cm above and parallel to the optical table, and that the beam is directed toward the *OPA-800CP*.
3. Orient the *OPA-800CP* so that the *Spitfire/Hurricane* output beam is perpendicular to the input side panel (Figure 5-2) and hits the center of the input port.
4. Block the white light (WL) generation pump beam by placing a white card in front of WLP.
5. Remove the window plug and let the pump beam into *OPA-800CP*.
6. Carefully position the *OPA-800CP* so that the beam after PS_1 hits the center of R_1
7. Place standard table screws through the three plugged holes in the base plate and secure the *OPA-800CP* to the optical table.
8. Steer PS_1 and R_1 so that the pump beam is centered on irises I_1 and I_2, and make sure the beam is turned 90° through PS_1 and is 6.3 cm above the base plate (use an alignment card). Reposition PS_1 if necessary.

Alignment

White Light Generation

1. Place beam blocks, such as white business cards, before telescopes T_1 and T_2 and the WLP (see Figure 5-1).
2. Adjust BS_1 to center the beam on waveplate WP, and align the beam along the center line of the white light generator arm so that it is 6.3 cm above and parallel to the base plate.
3. Place a power meter after lens FL and adjust WP so that the meter reads 12 ±4 μJ energy per pulse (12 ±4 mW at 1 kHz operation).
4. Place a business card before lens CL.
5. Remove the power meter.
6. Move the FL translation stage away from polarizer P, then move it back and forth with your fingers to search for white light generation on the business card.

Note

By translating the FL and optimizing the pulse duration, a symmetrical WL beam should appear with a green and white center (about 2–3 mm dia.) surrounded by a weak bluish outside ring (about 6 mm dia. right after the collimation lens). Use this signal to seed the *OPA-800CP*.

7. If you have difficulty generating white light, check the bandwidth and/or the pulse duration of the *Spitfire/Hurricane* output to see whether it meets the requirements for pumping the *OPA-800CP*.

Note

If the WL beam has a small bright spot that moves around or is not centrally located, try reducing the pump beam energy by carefully rotating the WP.

8. Look into the WLP from the exit side at a 20° to 30° angle and move the FL lens so that the WL filament gradually diminishes *before* the end of the plate. If this is not possible, translate the plate and adjust the pulse energy using the WP while looking for a stable WL.

Warning!

The WL filament should appear wedged and relatively centered in the WLP (Figure 5-3). If the WL filament appears to impinge the face, *the OPA-800CP will be less stable and damage may occur to the WLP within hours*. Make sure the WL filament diminishes *before* the end of the plate.

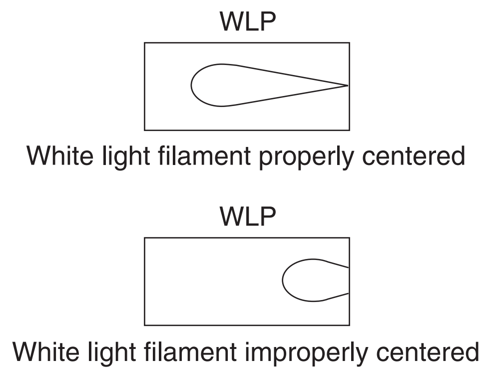


Figure 5-3: White light filament as seen in the white light plate.

9. Position CL so that it is centered in the beam.
10. If necessary, adjust WLR_1 so that the WL passes through D_1 on the side closest to L_2.
11. Adjust WLR_2 so that the WL passes through the BBO crystal on the inner side and hits WLR_3. Refer to Figure 5-4.
12. Steer WLR_3 so that the WL is still 6.3 cm parallel to the base plate before it hits grating G. (Use one of the alignment cards provided with this manual. You may need to temporarily remove the safety cover mounted on the grating stage.)
13. Translate CL to focus the WL at the BBO crystal or slightly behind it. (Leave it at least 2–3 mm from DELAY 1 for further optimization.)

The WL spot on the BBO crystal should not move while varying DELAY 1. Once WL is generated, you may need to repeat some steps in this section to make the WL stable and symmetrically distributed, i.e., the beam should be white and green in the middle with a weak bluish ring around the outside.

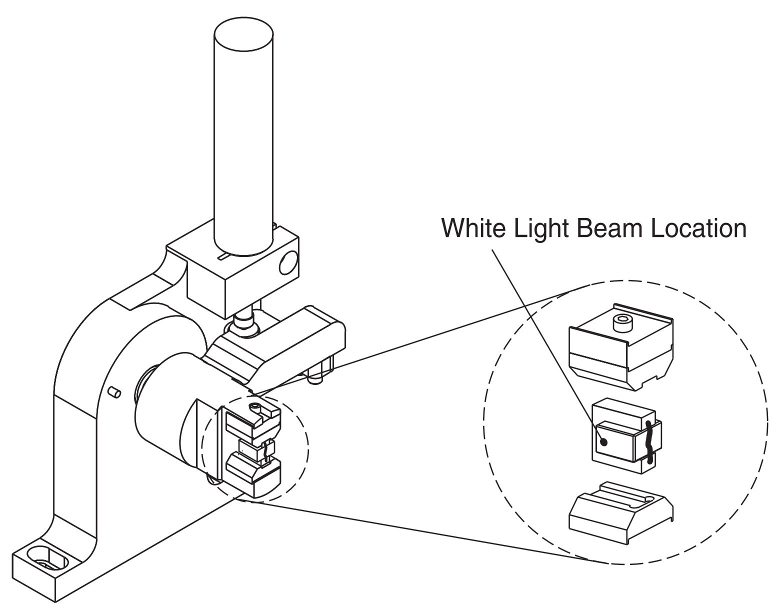


Figure 5-4: WL beam location on the crystal in the crystal mount.

Pre-amplification Stage

Warning!

The BBO crystal can be easily damaged. The pre-amplifier and power amplifier 800 nm pump beams should not be focused into the crystal without careful monitoring.

Warning!

This is the pre-amplification of the WL. The amount of amplified WL is typically about 1 – 2 µJ before reaching the grating. Although you can see the amplification, using a photodetector will simplify this search.

Do not perform these steps with the power amplifier beam present, nor let any beams burn ink or other material onto the surface of the BBO crystal, e.g., do not let the beam hit your alignment card when it is close to the crystal or optics. A white card cut to ½ x 10 cm may reduce the chance of this happening.

1. Block the two beams in front of T_1 and T_2 with white cards.
2. De-focus the pre-amplifier beam by translating L_2 closer to L_1.

Warning!

Too small of a beam will damage the BBO crystal!

3. Adjust BS_2 so that the pre-amplifier beam and the WL beam are overlapped right after D_1.
4. Adjust D_1 so that the pre-amplifier pump beam and the WL are overlapped before WLR_3.
5. Iterate Steps 3 and 4 until the two beams are well overlapped.
6. Block the WL before CL with a business card.
7. Set the BBO crystal at the angle corresponding to λ_s=1.3 µm according to the setting on the *OPA-800CP* Final Test Performance Summary Sheet shipped with this *OPA-800CP*, or see Figure 6-3.
8. To prevent damage to R_5, place a card in front of D_2.
9. With the room lights off and I_1 and I_2 fully open, gradually focus the pre-amplifier beam by translating L_2 until some superfluorescence (optical parametric generation or OPG) light above and below the beam appears on the card in front of D_2. The pre-amplification pump beam should be focused about 6 cm after the BBO crystal or 6 cm before D_2.
10. Remove the card from in front of CL.
11. Translate DELAY 1 back and forth until the WL beam gets amplified and becomes brighter or increases slightly in size.
12. Remove the card from in front of D_2.
13. Optimize DELAY 1 for best WL amplification as determined by using a photodiode or by simple visual observation.

Caution!

To help find the WL pre-amplification, use an infrared photodetector placed in front of a card located in front of WLR_3. Otherwise, visually examine the amplification (a change in WL intensity). Generating a reasonable amount of OPG with the pre-amplifier pump beam can help obtain amplification.

Caution! Avoid generating white light in the BBO crystal with the pre-amplifier pump beam. This can damage the crystal!

Grating Setup

In order to obtain narrow line width output, ps OPAs use a grating after the amplification stage to select a narrow portion of the amplified WL spectrum as a seed for the power amplifier stage. Since wavelength tuning is primarily performed by rotating both the grating and the BBO crystal around the horizontal axes, it is important that the grating be set up correctly so the *OPA-800CP* can function over the entire tuning range, especially with automated tuning.

The grooves in the grating must be parallel to the base plate, and the rotational axis of the grating assembly should be parallel to and in the plane of the grooves and normal to the incident WL beam. By carefully following the steps in this section, you will be able to correctly align this grating.

You **should not** need to perform this alignment often, especially once it is set up correctly. This alignment will slightly affect your wavelength setting; thus, you may have to record the grating angle vs. wavelength when you are done. It is repeatable to better than 20 cm^{-1}.

Note

Block the pre-amplifier pump beam in front of L_1 to keep it from amplifying the WL.

1. Mount the grating mount to the upper 8-32 threaded holes in the mounting plate so that the grating mount is placed at the ps alignment notch as shown in Figure 5-5.

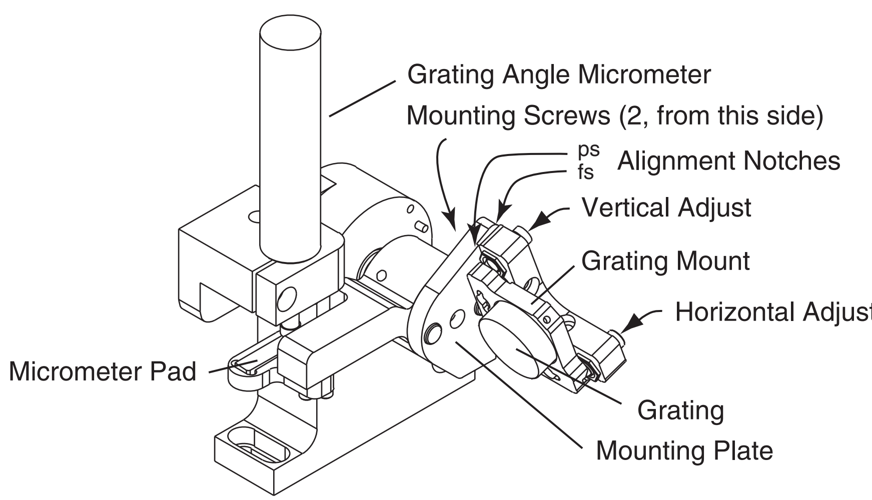


Figure 5-5: ***OPA-800CP*** **Grating Assembly**

2. Set the grating micrometer position to the number found on the *OPA-800CP* Final Test Performance Summary for $\lambda_s = 1.3$ µm, or see Figure 6-4.
3. Rotate the grating (Figure 5-5) relative to the grating mount so that the diffracted WL is in a plane that is perpendicular to the base plate. Skip this step if the plane is already perpendicular to the base plate.
4. Reposition the whole grating assembly so that the WL is diffracted back to the outer half of the BBO crystal as shown in Figure 5-1.
5. Rotate the grating mount up and down by pressing on the micrometer pad, and adjusting the grating horizontal control so that the diffracted colors move in a vertical line perpendicular to the base plate (i.e., when viewed on a white card, there is no lateral shifting of the diffracted beam while changing the grating angle).
6. If the diffracted beam does not return to the BBO crystal, reinstall the whole grating assembly so that it does.

   If you move the grating assembly, you might have to iterate Steps 3–6 to place the diffracted beam back into a single vertical plane and so that it reflects back to the outer half of the BBO crystal.
7. Move the grating mount to the lower 8-32 threaded holes in the mirror mount mounting plate.
8. Adjust the grating angle micrometer so that it **reflects** the WL back onto the outer half of the BBO crystal.

In the event you need to realign the grating relative to the 1 in. optic mount, perform the following. Otherwise skip to the next section.

9. Verify the WL beam is parallel to the base and/or optic table.
10. Loosen the 1 in. grating *mount* and rotate it 90° to that shown in Figure 5-5, then mount the 1 in. grating, using the lower 8-32 hole of the grating mount. The diffracted WL should be parallel to the base plate.
11. Loosen the set screw holding the grating optic in place and rotate the grating optic until the diffracted stripe is *exactly* parallel to the base plate and/or table, then tighten the set screw.
12. Remove the 1 in. grating mount again and rotate it –90° and remount it in the lower 8-32 hole as it was before (shown in Figure 5-5).

Power Amplification Stage

1. Block the pre-amplifier beam just before L_1.
2. To keep from damaging the BBO crystal and all the optics downstream, de-focus the power amplifier beam by translating L_4 closer to L_3.
3. Place a white business card in front of R_5.
4. Verify the power amplifier beam is collimated between R_3 and R_5.
5. Lower the *Spitfire/Hurricane* amplifier output by changing the switch-out time in the *Spitfire/Hurricane* Synchronization and Delay Generator (SDG) for 100 ns (see your *Spitfire/Hurricane* user’s manual), and let the small energy beam hit R_5 and D_2 and the BBO crystal.

6. Align the power amplifier beam to the BBO crystal using R_3 and D_2 so that it propagates collinearly with the zero-order diffracted (reflected) WL from the grating.
7. Use a white card to block the power amplifier beam in front of L_4.
8. Set the D_2 of the *Spitfire/Hurricane* SDG back to its normal position for the specified output energy level.
9. Remove the white card from in front of R_5 and place it in front of OR_1.
10. Remove the card from in front of L_4 to see whether it generates OPG/WL through the BBO crystal before it reaches OR_1, then replace the card quickly once a determination has been made.
11. Adjust L_4 until it generates some OPG in front of OR_1, then remove the card from the front of L_4.
12. Adjust R_3 and D_2 so that the power amplifier beam remains collinear with the WL beam from G and is not clipped by the BBO crystal, D_1 or D_4, and that it hits OR_1. The two beams are collinear when the colored spots of the output line up vertically.
13. Remove the card from in front of L_1 and let the pre-amplifier beam amplify the WL.
14. Move DELAY 2 back and forth until you see an amplification flash of the power amplifier beam in front of OR_1, then, using a power meter, adjust DELAY 2 for maximum amplifier output power.
15. Optimize output power by adjusting DELAY 1, DELAY 2, D_1, D_2 and CL.
16. Re-mount the grating mount to the *upper* 8-32 threaded hole of the mounting plate.
17. Set the grating angle and the BBO crystal to the angles corresponding to λ_s=1.3 µm according to the setting listed in the *OPA-800CP* Final Test Performance Summary Sheet or see Figure 6-4.
18. Scan the crystal angle or the grating angle within a small range to find a flash of the power amplifier beam, then adjust for maximum optical output.
19. Optimize output power again by adjusting DELAY 1, DELAY 2 , D_1, D_2 and the BBO crystal angle.
20. Optimize output power by adjusting the delay in the *Spitfire/Hurricane* compressor.

Note

If Steps 18–19 are unsuccessful, you may have to try several times. However, you should always be able to find the power amplification by adjusting DELAY 2 while scanning the grating angle. With 1 mJ, 1.5 ps pulse pumping, the output energy (signal + idler) of this *OPA-800CP* should be between 90 and 140 µJ for most of its spectral range.

To further improve the stability of the *OPA-800CP* output, optimize the *Spitfire/Hurricane* SDG switch-in and switch-out timing by changing them in ns increments. Adjusting the *Tsunami* output wavelength slightly might also help stabilize the system.

For ps wavelength tuning and options, refer to Chapter 6.

Converting from fs to ps Operation

A fs *OPA-800CF* uses the same base plate as a ps *OPA-800CP* and can be converted from fs to ps operation and back again in the field. If this is a fs/ps *OPA-800CFP* configured for fs operation, use the following procedure to convert it to a ps configuration. The ps *OPA-800CFP* requires a 4%R beam splitter at BS_1 and a thin-film/cube polarizer. It also requires an 8 mm BBO crystal.

Note

If this is a fs-only *OPA-800CF* and not a fs/ps *OPA-800CFP*, do not make the following changes. A conversion is not necessary.

1. Rotate waveplate WP to minimize the WL pump beam energy.
2. Block the *OPA-800CP* incoming *Spitfire/Hurricane* pump beam.
3. Convert the *Spitfire/Hurricane* for ps operation ($\leq$2 cm^{-1}, <1.5 ps, 1.0 mJ per pulse at 800 nm).
4. Close irises I_1 and I_2.
5. Exchange the fs WLP (sapphire plate) with the ps WLP by flipping the mount.
6. Replace the fs 3 mm OPA BBO crystal with the 8 mm ps OPA BBO crystal as shown in Figure 5-6.

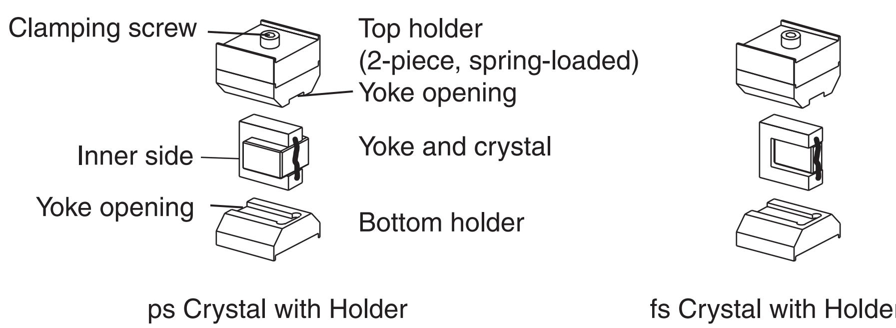


Figure 5-6: The ps and fs crystal holders.

Caution!

The crystal holder comprises three parts that are clamped together in the mount by a spring-loaded mechanism that is part of the holder. When the holder is removed from the mount, the spring is released and these three parts will fall apart unless held together. If they fall apart, reassemble them as shown in Figure 5-6.

a. Remove the crystal holder from the mount by turning the clamping screw on the top holder *clockwise* to compress the spring mechanism, then carefully slide the holder out of the mount.

Place some lens tissue under the crystal mount to prevent the crystal from directly falling onto the base plate if it becomes loose.

b. Assemble the ps 3-piece crystal holder and carefully slide it into place in the mount. Note which side of the yoke is the "inner side" that goes next to the mount. *Do not get the yoke and crystal turned around!*

c. Tighten the clamp by turning the screw *counterclockwise* until the holder assembly feels securely in place (typically less than 1 turn).

Caution!

If you turn the screw too far, the screw will come out.

---

7. Change the L_4 lens in T_2 to a lens with a focal length of −50 mm.
8. Increase the separation between L_3 and L_4 by (a) moving L_3 away from L_4 to the next ¼–20 threaded hole and (b) moving the L_4 lens bracket backward by 6.3 mm. Figure 5-7 shows how to change the L_4 mount for ps operation.

   In order to easily access the adjustment screw of L_4, you can assemble the top portion of the translation stage so that it is rotated 180° from that shown in Figure 5-7.

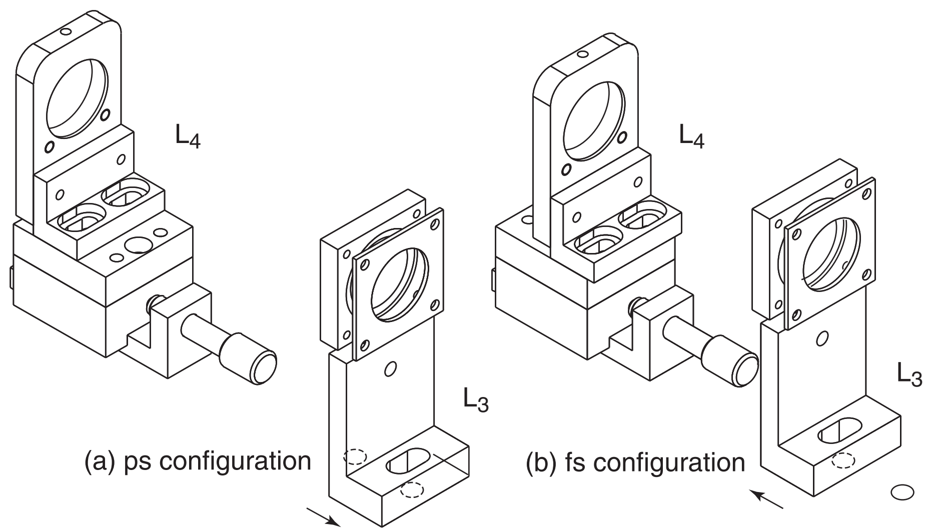


Figure 5-7: L_4/L_3 Placement for ps and fs Configurations

9. Remove the 1 in. curved mirror mount from the base plate grating assembly (Figure 5-5).
10. Remove dichroic mirror D_3 from the beam path in front of G.
11. Mount the grating mount to the mounting plate on the grating assembly.
12. Install the beam protector (BP) plate into its position as shown in Figure 5-1.

13. If BS_1 is a 1%R beam splitter, it must be replaced with a 4%R beam splitter for standard pump pulse energy.

This completes the fs to ps mechanical and optical conversion. Continue with the Alignment section earlier in this chapter. To convert your system back to fs operation, please see Chapter 4.

Chapter 6 Operation

Since the *OPA-800C* is a passive device and is pumped by a *Tsunami*®*/Millennia*® or *Mai Tai*™ with a *Merlin* or *Evolution*/*Spitfire* or a *Hurricane*™ system (described in Chapter 3), the pumping system must be turned on in order to operate the OPA. The output of the OPA also depends upon the quality of the pump beams and is sensitive to environmental change. Always verify that the output of the pump systems meets specifications before operating the *OPA-800C*.

Once the *OPA-800C* has been installed and aligned, the day-to-day operation is consistent and repeatable. Provided that nothing is disturbed between operation sessions, little adjustment is required to optimize the *OPA-800C* performance. To use either the signal or idler beam, simply tune for the desired wavelength then adjust the delays for optimum output power.

For the *OPA-800CF*, optimum output in the 1.1 to 1.15 µm range is obtained by removing the D_3 optic and using the signal beam to seed the system. For highest output power and stability from the *OPA-800CP* at signal wavelength <1.2 µm, use the signal beam to seed by tuning the grating to the proper angle as described in "OPA-800CP Wavelength Selection" later in this chapter.

If you are operating the *OPA-800CP* at the first-order, idler-seeded wavelength but second-order, signal-seeded wavelength at the degeneracy point (such as λ_s=1.2 µm, λ_i=2.4 µm with 800 nm pump), to get stable output when using fs pulses to seed the Ti:sapphire amplifier overlapped-order, shift the pump wavelength by 2 to 3 nm by slightly rotating the *Spitfire*/*Hurricane* stretcher and compressor gratings.

The following procedures show how to perform a typical turn on and turn off of the *OPA-800C* system and how to select output wavelengths.

Turning On the System

1. Turn off OUTPUT ENABLE on the *Spitfire* or *Hurricane* Synchronization and Delay Generator (SDG) controller.
2. Turn on the *Tsunami* pump source or the *Mai Tai* and verify it is set to its required power level. Let it warm up and stabilize (typically 15–30 minutes, depending on laboratory conditions).
3. Verify that the *Tsunami* or *Mai Tai* power and wavelength are set to the required settings.

4. Using an infrared viewer, look at the *Spitfire* or *Hurricane* grating (see Figure 6-1) and verify that the *Tsunami* or *Mai Tai* bandwidth has no CW breakthrough. Adjust the *Tsunami* or *Mai Tai* amplifier as necessary to ensure the spectrum is free of any CW component or Q-switched mode-locking.

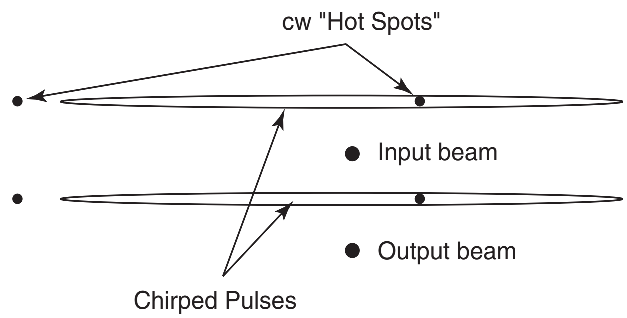


Figure 6-1: Diffracted spectra as seen on the *Spitfire/Hurricane* stretcher grating with examples of CW "hot spots."

5. Turn on the *Merlin* or *Evolution* power supply and cooling chiller.
6. Turn on the *Merlin* or *Evolution* controller's LAMP ENABLE and SHUTTER and verify the Q-switch is set to "on."
7. If no CW was observed in Step 4, turn on the *Spitfire* or *Hurricane* OUTPUT ENABLE on its SDG controller.
8. Verify that *Spitfire/Hurricane* output power, mode and pulse width meet the pumping requirements of the *OPA-800C* (see Tables 3-1 and 3-2). Use a single-shot autocorrelator, such as a Spectra-Physics SSA, to measure pulse width.
9. Allow the *Spitfire/Hurricane* output beam to enter the *OPA-800C* (remove the power meter if necessary), and allow the *OPA-800C* to warm up for a few minutes.
10. Adjust the *OPA-800C* delays for optimum output power.
11. Adjust the *OPA-800C* BBO crystal angle for optimum output power.
12. Optimize the *Spitfire/Hurricane* compression delay stage for optimum *OPA-800C* output power and compare this power to specified power.

    If the laboratory environment is the same as it was the last time the OPA was used, OPA performance now should be similar to what it was then and little optimization should be required. Adjusting DELAY 1 and DELAY 2 may change the wavelength slightly.

Turning Off the System

1. Turn off the *Spitfire* or *Hurricane* SDG OUTPUT ENABLE.
2. Close the *Merlin* or *Evolution* shutter, then shut off its LAMP ENABLE.
3. Turn off the *Merlin* pump laser or the *Evolution* according to its user's manual.
4. Turn off the *Tsunami* pump laser or the *Mai Tai* according to its user's manual.

OPA-800CF Wavelength Selection

To monitor the spectrum of the *OPA-800CF* output for the signal beam, we suggest using a monochromator with a CCD detector (for example: a germanium-based, Electrophysics 7290) as shown in Figure 6-2. In addition, an infrared viewer or card, beam splitter and suitable attenuator will be needed for the following procedure.

1. Using either an ir card, beam splitter, and suitable attenuator, or a silver mirror and the visible light in the beam, pick off some or all of the *OPA-800CF* output beam, attenuate it if necessary, and center it on the input slit of the monochromator.
2. Set the monochromator wavelength to the desired *OPA-800CF* operation wavelength.

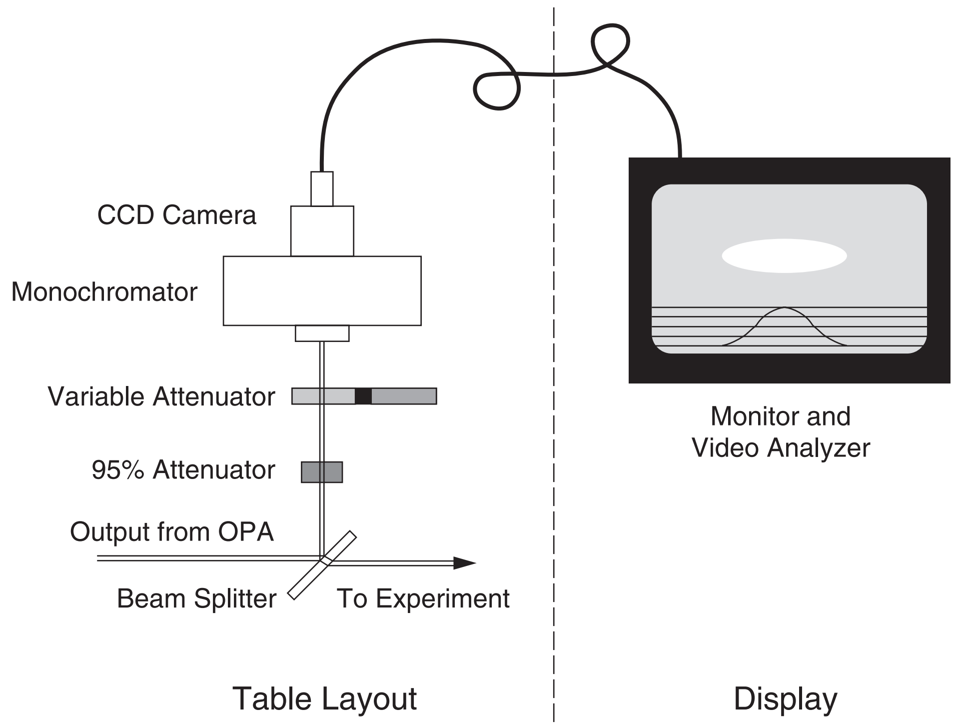


Figure 6-2: A Typical Monochromator/CCD Camera Setup

Note Verify your monochromator can measure the wavelength you have selected.

3. Set the *OPA-800CF* crystal angle micrometer to the position corresponding to the desired operation wavelength.

   Figure 6-3 gives the approximate relationship between the *OPA-800C* signal output wavelength and the crystal angle micrometer setting.

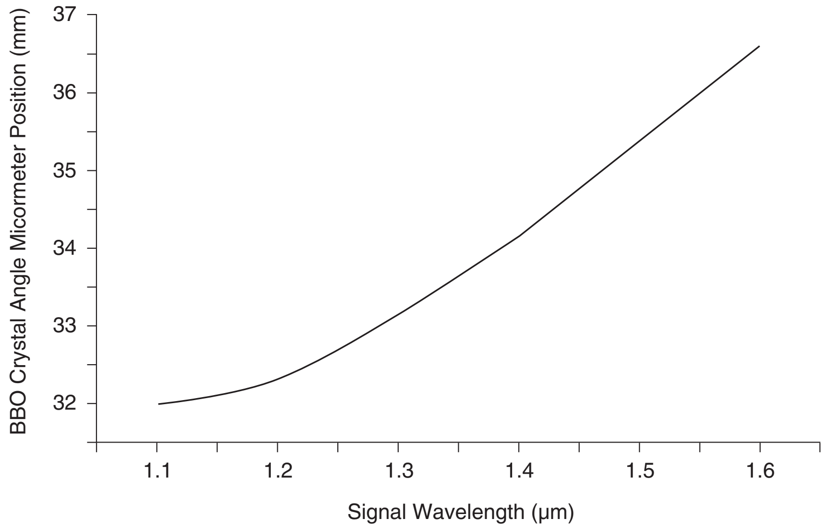


Figure 6-3: Typical Signal Wavelength vs. BBO Crystal Angle Position

Note The relationship between the wavelength and micrometer setting may change due to alignment changes. Figure 6-3 is only intended to be used as an approximate reference.

4. Adjust DELAY 2 to optimize *OPA-800C* output. This will slightly shift the output wavelength by a few nm.
5. Adjust the micrometer to obtain the exact desired wavelength.
6. Iterate between adjusting the crystal angle micrometer and DELAY 2 to obtain the optimum power at the desired wavelength.

To select the idler beam wavelength, measure it with a spectrometer or, if you know the pump wavelength accurately, calculate the corresponding signal wavelength. Follow the same procedure as above to select the calculated signal wavelength and the desired wavelength of the idler. Please refer to the tables in Appendix A and B.

This completes the wavelength selecting procedure.

For operating a selected output option, refer to Chapter 7, "OPA-800CF Options."

OPA-800CP Wavelength Selection

In the *OPA-800CP*, either the signal or idler can be used as a seed beam. However, it is best to use the idler beam to seed the final amplification for most of the spectral range. It permits continuous wavelength tuning over the full spectral range.

Wavelength selection is determined by the diffraction angle of the grating according to the diffraction formula in the Littrow-diffraction configuration:

$$2 \operatorname{Sin}(\theta_L) = m\, \lambda/\Lambda\,, \qquad m = 0, \pm 1, \pm 2, \ldots \qquad [1]$$

Where θ_L is the Littrow diffraction angle, λ is the wavelength, Λ is the grating groove space, and m is the diffraction order.

You can distinguish the idler-seeded case from the signal-seeded case by monitoring the wavelength change while tuning the grating angle. The longer the diffracted wavelength, the larger the grating angle. If the *OPA-800CP* is seeded with the idler, then as the grating is tuned to a larger angle, the selected idler wavelength becomes longer and the generated signal wavelength becomes shorter. If it is signal seeded, then as the grating is tuned to a larger angle, the signal wavelength becomes longer and the idler wavelength becomes shorter.

For example, if the BBO crystal is mounted in the recommended manner, i.e., the pre-pump beam is reflected downward from the BBO crystal, the smaller the BBO crystal micrometer reading, the shorter the signal wavelength (Figure 6-3). In the idler seeded case, increasing the grating angle requires you to decrease the BBO micrometer reading in order to get good output energy. This ensures that the *OPA-800CP* is idler seeded. Figure 6-4 shows a typical wavelength vs. grating angle micrometer readout for a first-order, diffracted, idler-seeded case. Both curves assume that the crystal and grating are mounted correctly and that the pump wavelength is 800 nm and the WL is parallel to the base plate between the BBO crystal and the grating.

An idler-seeded ps *OPA-800CP* gives best performance and continuous wavelength tuning from 1.1 to 3.0 µm. When the signal wavelength is below 1.2 µm, the output energy might decrease significantly because of absorption of the idler and smaller gain. Focusing both pump beams slightly tighter will help get higher output between 1.1 and 1.2 µm.

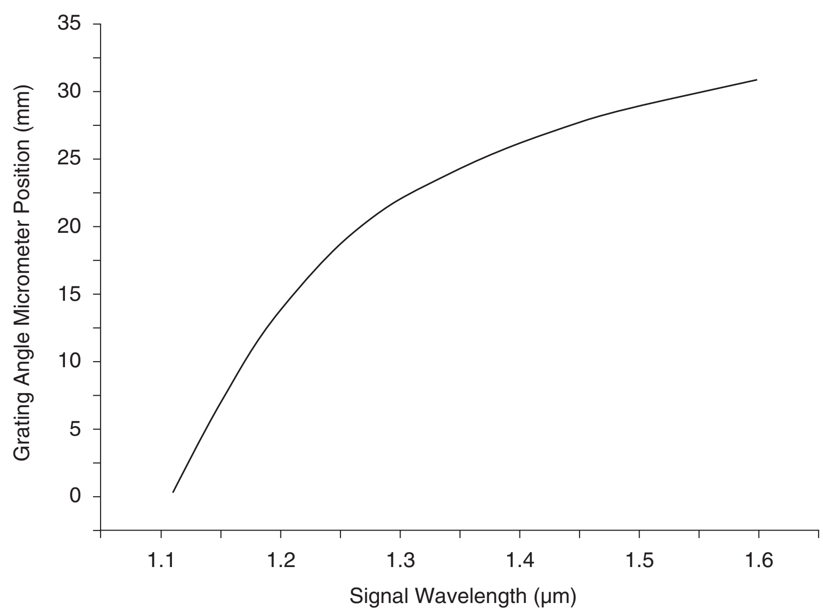


Figure 6-4: Typical Signal Wavelength vs. Grating Angle Position

Table 6-1: 600 g/mm Grating Angles for Idler- or Signal-Seeded Cases[1]

Grating Angle (°)	λ_i (μm)	Grating Angle (°)	Grating Angle (°)	λ_s (μm)
1st-order Idler seed		2nd-order Signal Seed	1st-order Signal Seed	
61.6	2.933	41.3	19.3	1.10
52.1	2.629	43.6	20.2	1.15
46.1	2.400	46.1	21.1	1.20
41.3	2.222	48.6	22.0	1.25
38.6	2.080	51.3	22.9	1.30
36.1	1.964	54.1	23.9	1.35
34.1	1.867	57.1	24.8	1.40
32.4	1.785	60.5	25.8	1.45
30.9	1.714	64.2	26.7	1.50
29.7	1.653	68.4	27.7	1.55
28.7	1.600	73.7	28.7	1.60

[1] *Spectra-Physics tested this system for operation from 1.1 to 1.6 using the first-order idler seeding. However, for higher energy between 1.1 and 1.2 μm, use the second-order signal seed.*

A first-order, signal-seeded *OPA-800CP* outputs a slightly broader spectral bandwidth, but a second-order, signal-seeded *OPA-800CP* produces an output bandwidth that is as narrow as the idler-seeded case but with higher output power between 1.1 and 1.2 nm.

The major operating difference between an *OPA-800CP* and *OPA-800CF* is the method of wavelength tuning. *OPA-800CP* wavelength tuning is accomplished by tuning both the grating angle and the BBO crystal instead of just the crystal. In fact, since the acceptance bandwidth of the BBO crystal is much larger than the selected spectral bandwidth, wavelength tuning is basically determined by the grating angle; the BBO crystal angle only affects output energy. Changing DELAY 2 will also tune the output wavelength slightly. Table 6-1 compares the first-order idler and first- and second-order signal-seeded case grating angles for the 600 g/mm grating provided with the system.

By comparing the required grating angle for the first-order idler-seeded case versus that for the second-order signal-seeded case and knowing the grating angle for the first-order diffracted idler seed versus the micrometer reading, you can set the grating micrometer to seed the *OPA-800CP* with the second-order diffracted signal beam. The calculated grating angles listed in Table 6-1 can help you do this.

If the power amplification beam is not aligned and/or not synchronized well with the pre-amplified white light, you may see three separate output spots at OR_1. If these three spots are separated in a single vertical line, bring them together by adjusting the DELAY 2. If they fall into a line but off vertical, then either the power amplifier beam is not perfectly collinear with the seed beam (which is diffracted by the grating), or the grating groove orientation is not parallel to the BBO crystal or the base plate. This spatial overlap can be corrected by aligning the second pump beam through the R_3 and D_2 mirrors or by orienting the grating grooves so that the diffracted beam is vertical, and also by optimizing DELAY 2. To set up the grating groove orientation correctly, follow the steps under "Grating Setup" in Chapter 5.

If the separated spots fall into one vertical line while changing the grating angle, adjust DELAY 2 to bring them together. You should see the same pattern for a wide wavelength range.

Stable ps *OPA-800CP* output can be obtained with some optimization. If you can operate the *OPA-800CP* in a regime that generates about 20–40 μJ of output (signal + idler) with the white light seed blocked, it is a good indication that it is in the saturation regime. This amount of OPG will be suppressed substantially when it is seeded with white light (WL). Stable WL generation and optimal temporal overlaps between WL and pump beams are crucial for stable *OPA-800CP* outputs. At some strong water absorption wavelengths, the *OPA-800CP* output becomes unstable and a very small amount of detuning can stabilize the output. Sometimes, 1–2 ns changes in the switch-in and switch-out times of the of the *Spitfire* SDG will stabilize the pump pulses, which will stabilize your *OPA-800CP* output. The absorption lines can show up in the spectrum as deep notches.

This concludes the operating procedure.

Chapter 7 OPA-800C Options

In addition to the fs to ps or ps to fs *OPA-800C* conversion kit, Spectra-Physics provides the following options to extend the wavelength coverage for fs and ps OPAs:

- Harmonic Option I
- Harmonic Option II
- Sum-Frequency Mixing (SFM) of the pump with the signal or the idler
- Difference-Frequency Mixing (DFM) of the signal with the idler.

These options provide wide spectral coverage and easy wavelength tuning from deep UV (<300 nm) to mid IR (>10 µm) with high energy pulses. For convenience, they install inside the *OPA-800C* chassis.

To use these options, you do not need to change *anything* on the basic *OPA-800C* except for tuning to the desired wavelength and adjusting the delays for optimum output. When operating your *OPA-800CF* at a signal wavelength in the <1.15 µm range, better output power and stability is obtained by removing the D_3 dichroic mirror and using the signal beam to seed the system.

The *OPA-800CP* harmonic generation (HGI and HGII), sum-frequency mixing (SFM) and difference-frequency mixing (DFM) options are similar to those used for the *OPA-800CF.* The only difference is that ps crystals are longer than fs crystals. Both systems have similar setup procedures.

When the SFM option is used, the D_4 dichroic mirror (a flip mirror mount) is placed in its down position (out of the beam path), and the residual pump beam propagates to the proper crystal and is mixed with either the signal or idler beam, depending on which type of nonlinear crystal is in use.

The crystal thicknesses mentioned below for the various wavelength extension options are for the standard 130 fs or 80 fs *OPA-800CF* and 1.5 ps *OPA-800CP* systems. Please note that thinner crystals are employed in the sub-50 fs *OPA-800CF.*

Harmonic Generator I Option (HGI)

Harmonic option HGI allows you to generate the second and fourth harmonic of the idler and the second harmonic of the signal. The wavelength coverage is 800–1200 nm for the second harmonic of the idler, 400–600 nm for the fourth harmonic of the idler and 600–800 nm for the second harmonic of the signal. Figure 7-1, Figure 7-2 and Figure 7-3 show the mechanical layouts for these configurations.

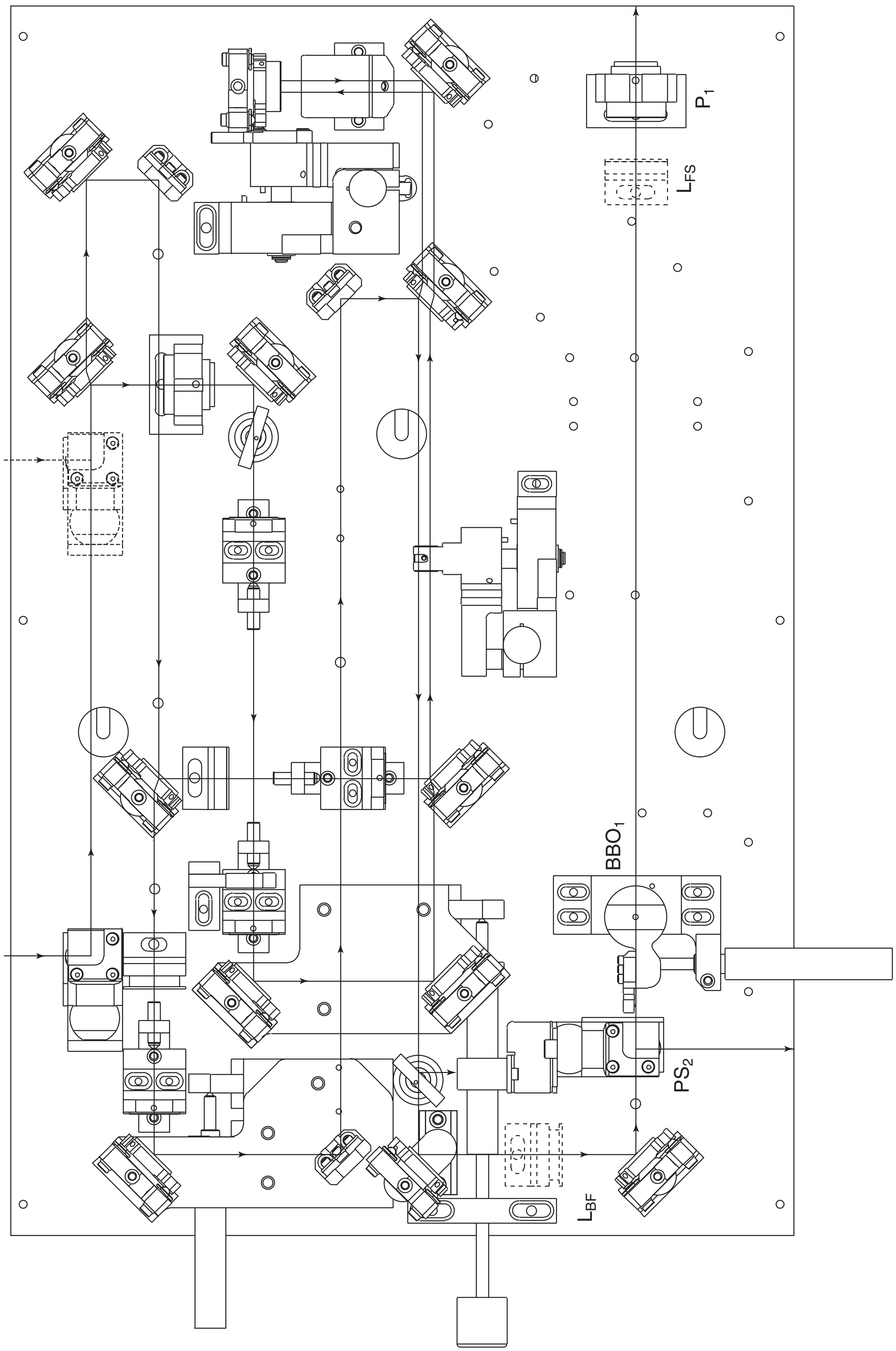


Figure 7-1: Mechanical Layout of the *OPA-800CF* Arranged for SHG of the Idler

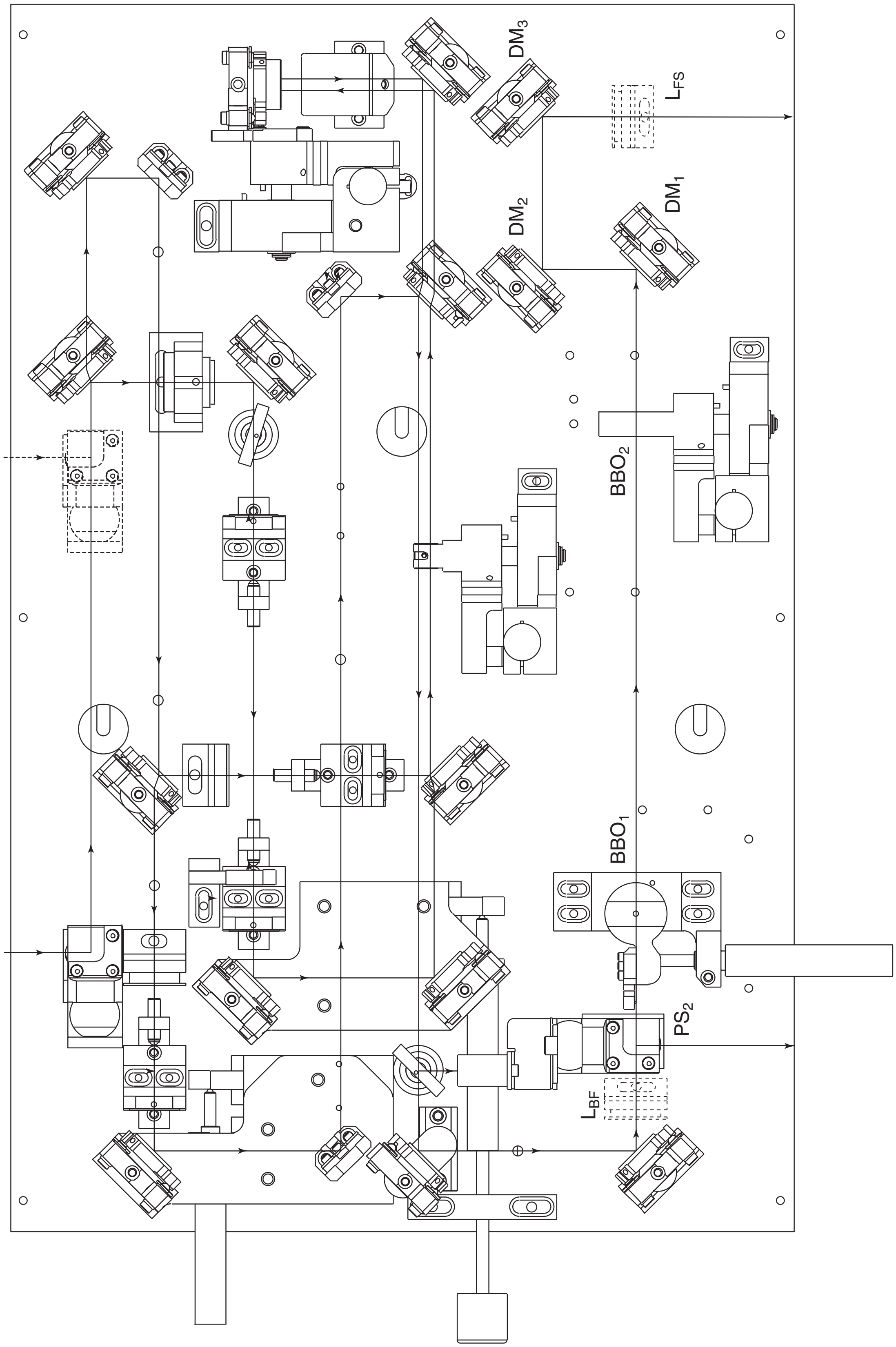


Figure 7-2: Mechanical Layout of the *OPA-800CF* Arranged for FHG of the Idler

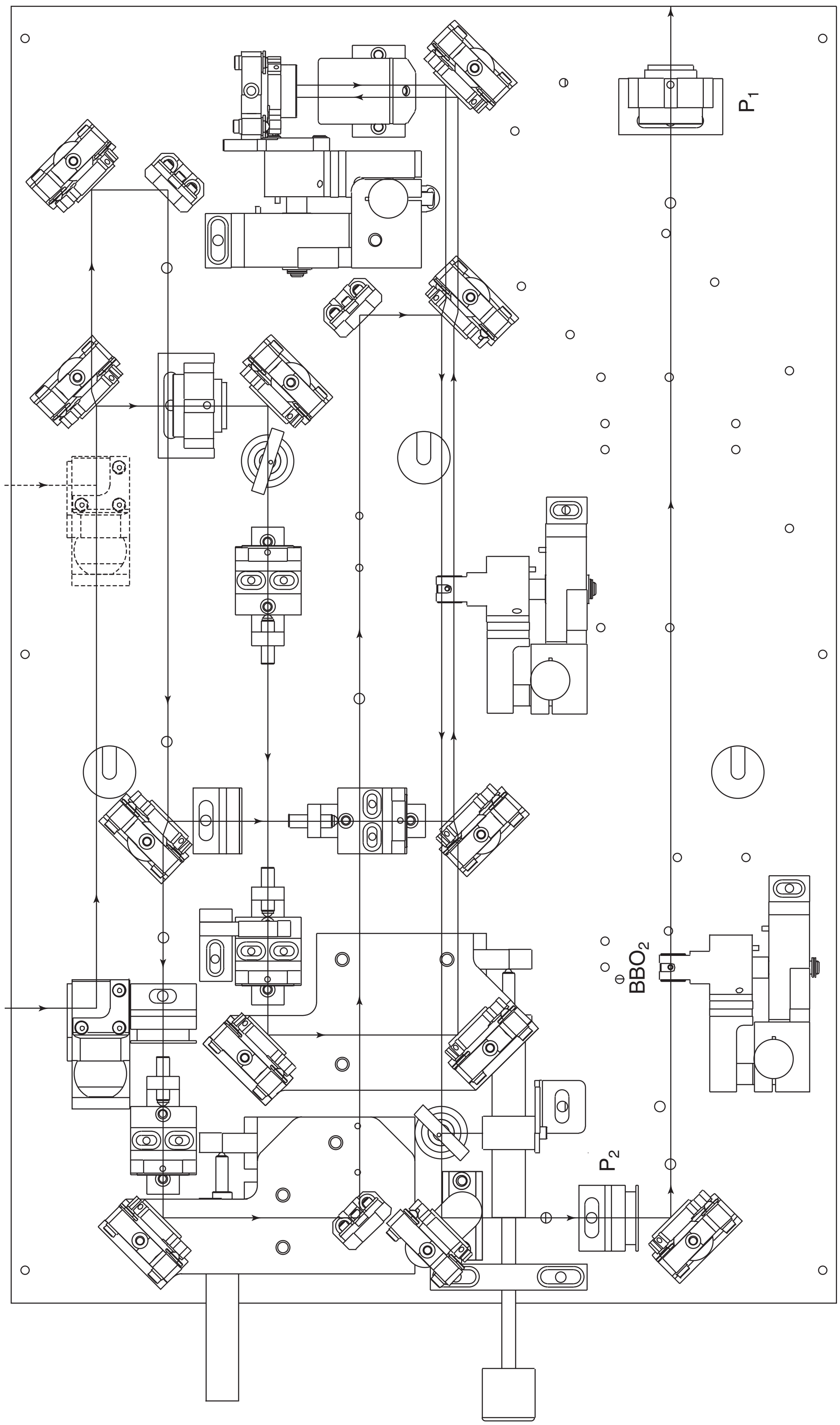


Figure 7-3: Mechanical Layout of the *OPA-800CF* Arranged for SHG of the Signal

For the second harmonic generation (SHG) of the idler, periscope PS_2 separates the idler beam from the signal. A BaF_2 lens (L_{BF}) is also mounted on the hole in front of PS_2 as shown in Figure 7-1, and a BBO type I crystal is placed in the beam about 13 cm after this lens. A fused silica lens (L_{FS}) is mounted in the beam path about 41 cm away from the crystal to collimate both the fundamental and its second harmonic. In most circumstances, you might not need to use these two lenses in order to get better second and fourth harmonic generation output (energy and mode) for of the idler, especially if the curved mirror is placed at the WLR_4 position as shown in Figure 4-1. A cube polarizer P_1 is mounted after the lens (as shown in Figure 7-1) to separate the SHG from the idler. This polarizer allows a horizontally polarized beam to pass through (i.e., the marked line should be horizontal). The separated SHG of the idler exits the chassis through the exit port as shown in outline drawing Figure 3-13.

The *OPA-800CP* uses a 6 mm thick, type I, BBO crystal, whereas the *OPA-800CF* uses a 0.7 mm thick crystal. Install the crystal in a mount that allows it to be rotated about a vertical axis as shown in Figure 7-4(a) (the micrometer should be horizontal). The SHG of the idler is optimized for best output power by rotating the crystal to the phase-matching angle and optimizing the delays. The generated second harmonic is horizontally polarized for both the *OPA-800CF* and *OPA-800CP*.

For the fourth harmonic generation (FHG) of the idler, a second 4 mm thick type I BBO crystal is used in the *OPA-800CP* and a 0.5 mm thick crystal is used in the *OPA-800CF*. This FHG crystal is placed in the beam path about 25 cm after the first BBO crystal, and it is mounted so that it is tuned about a horizontal axis (the micrometer is vertical).

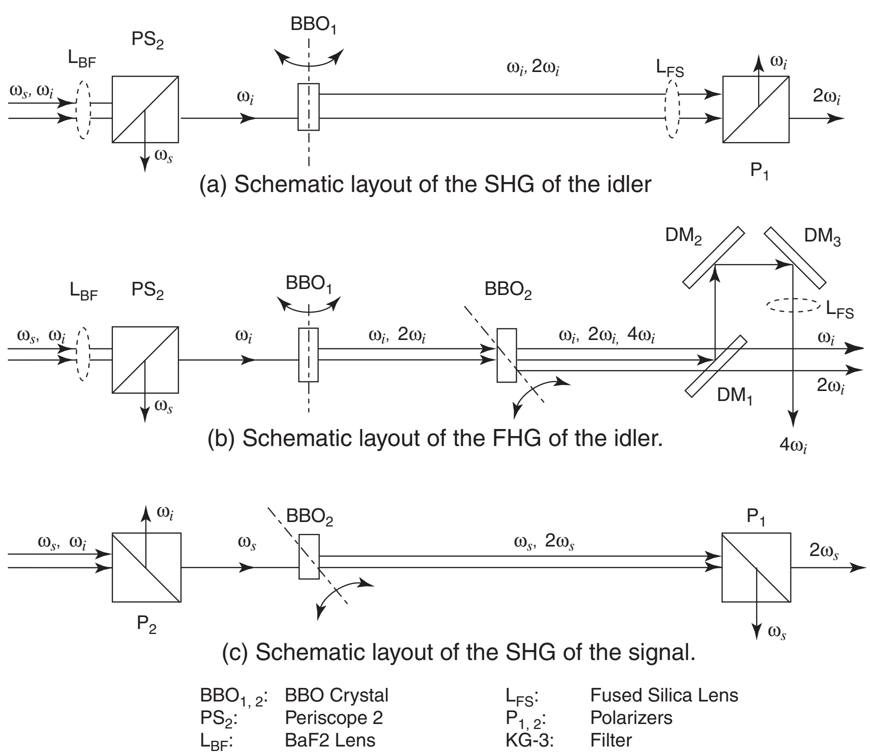


Figure 7-4: Configuration for SHG (a) and FHG (b) of the idler and SHG of the signal (c).

To separate the FHG from the SHG and idler, one set of dichroic mirrors are used to reflect the FHG within the 400−600 nm wavelength range (and the mirrors are so marked) as shown in Figure 7-4(b). Figure 7-2 shows the layout for this harmonic configuration. To generate optimum fourth harmonic idler energy, first optimize the SHG energy, then tune the FHG crystal to generate the highest FHG output at the exit port. The FHG pulse is vertically polarized.

To generate the second harmonic of the signal beam, a second cube polarizer, P_2, replaces periscope PS_2 and is mounted so that the horizontally polarized light passes through it. The two lenses are then removed from both the fs and ps OPAs. The 4 mm/0.7 mm crystal used for the idler HG in the *OPA-800CP* or *OPA-800CF* is used as the SHG crystal for the signal beam. This crystal must be kept in the correct mount in order to tune its angle about a horizontal axis. The original cube polarizer (P_1) used in the harmonic generation of the idler must be rotated to transmit the vertically polarized beam as shown in Figure 7-4(c). The mechanical/optical layout relative to the base plate is shown in Figure 7-3. The SHG pulse energy is optimized again by adjusting the BBO crystal phase-matching angle micrometer. The SHG signal is vertically polarized.

Harmonic Generation II Option (HGII)

Harmonic option HGII permits the generation of the fourth harmonic of the signal in addition to the other harmonics generated with the HGI. The wavelength coverage is from 300 to 400 nm. The first crystal stage is configured as shown in Figure 7-4(c). Figure 7-5 and Figure 7-6 show the optical/mechanical layout for this option.

To generate the FHG of the signal, the *OPA-800CP* uses a 3 mm thick, type I, BBO crystal for the second crystal stage, whereas the *OPA-800CF* uses the same 0.5 mm thick crystal used in Figure 7-4(b) to generate the FHG of the idler. The two lenses are again removed in both the fs and ps OPAs. The FHG crystal is placed in the beam about 25 cm after the SHG crystal and is angle tuned about a vertical axis as shown in Figure 7-5. (In some circumstances, better forth harmonic signal output might be obtained by using a flat silver mirror in the WLR_4 position.)

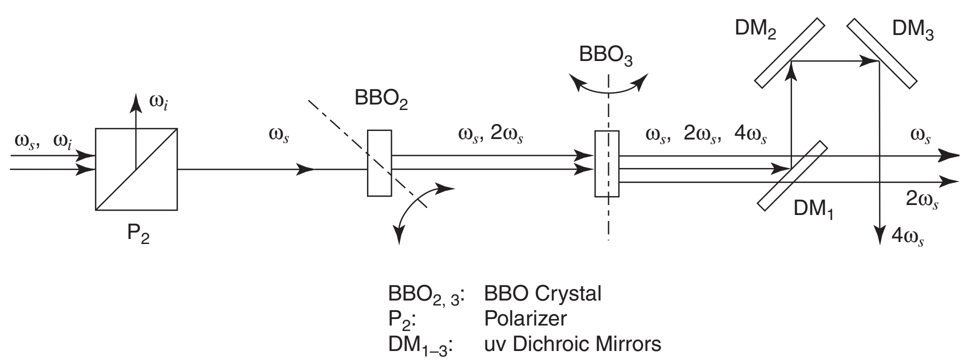


Figure 7-5: Schematic layout of the FHG of the signal.

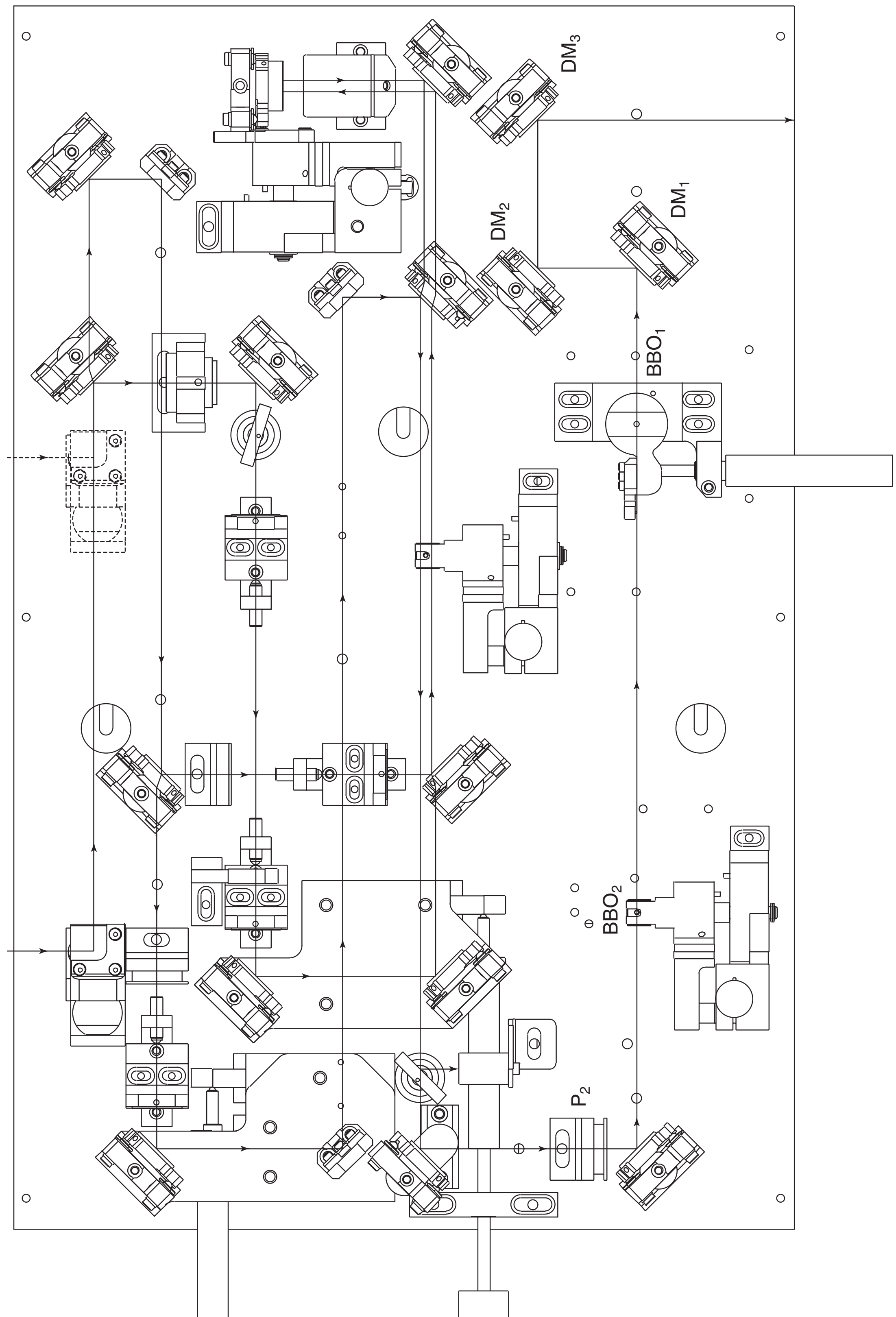


Figure 7-6: Mechanical Layout of the *OPA-800CF* Arranged for FHG of the Signal

To avoid pulse broadening due to strong dispersion and high absorption, and to have the best spectral purity in this UV wavelength range, two sets of dichroic mirrors are used to separate the FHG beam from the signal SHG and signal beams. Each set covers a specific wavelength range as indicated. These mirrors are designed for 45° incidence-angle use. P_2 can be removed to achieve the highest output energy possible. The signal FHG beam is horizontally polarized, and it exits from the port as shown in outline drawing Figure 3-13.

Sum-Frequency Mixing Option (SFM)

The SFM option allows you to mix the signal or idler with the residual pump beam. This sum-frequency mixed output covers the wavelength range from 480 to 533 nm or from 533 to 600 nm by mixing the signal or the idler with the residual pump, respectively.

In order to mix the residual pump beam with the signal or idler, the lower mirror (dichroic) on the PS_2 mount must be out of the beam path to allow these beams to propagate to the conversion crystal. First, block the OPA pump beam, then safely fold down the D_4 mirror. Remove either the lower mirror or the whole PS_2 mount.

In the *OPA-800CF*, a 0.5 mm thick, type I FHG BBO crystal (used in the HG options) is used to mix the idler beam with the residual pump beam, and a 0.5 mm thick, type II crystal is used to mix the signal beam with the residual pump beam. For the *OPA-800CP*, the SFM option uses the same 3 mm thick, type I FHG crystal from the HGII option to mix the idler with the residual pump, and a 3 mm thick, type II BBO crystal is used for mixing the signal with the residual pump. The optical beam path is shown in Figure 7-7.

In order to have the signal or the idler mixed with the residual pump beam, remove the PS_2 from the beam path and, after blocking the OPA pump beam, safely fold down the D_4 mirror.

The two lenses should not be used in either the fs or ps OPA; remove them if they are present. Place the SFM crystal at the SHG crystal position. Both SFM crystals must be mounted so that they can be tuned about a vertical axis at the same location using the same type mount. Output power is best optimized by tuning the crystal to the phase-matching angle, ensuring all the colors are propagating collinearly, and optimizing DELAY 2.

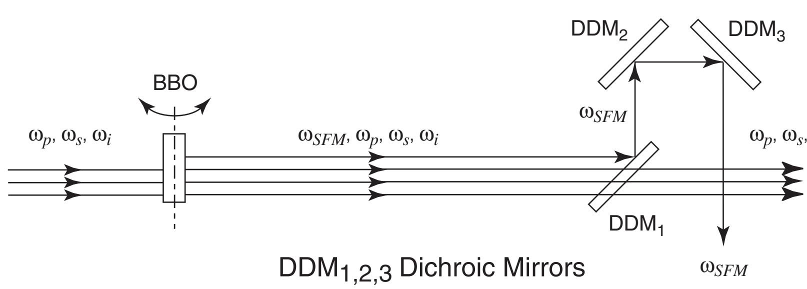


Figure 7-7: Schematic layout of the SFM of the signal/idler with the residual pump.

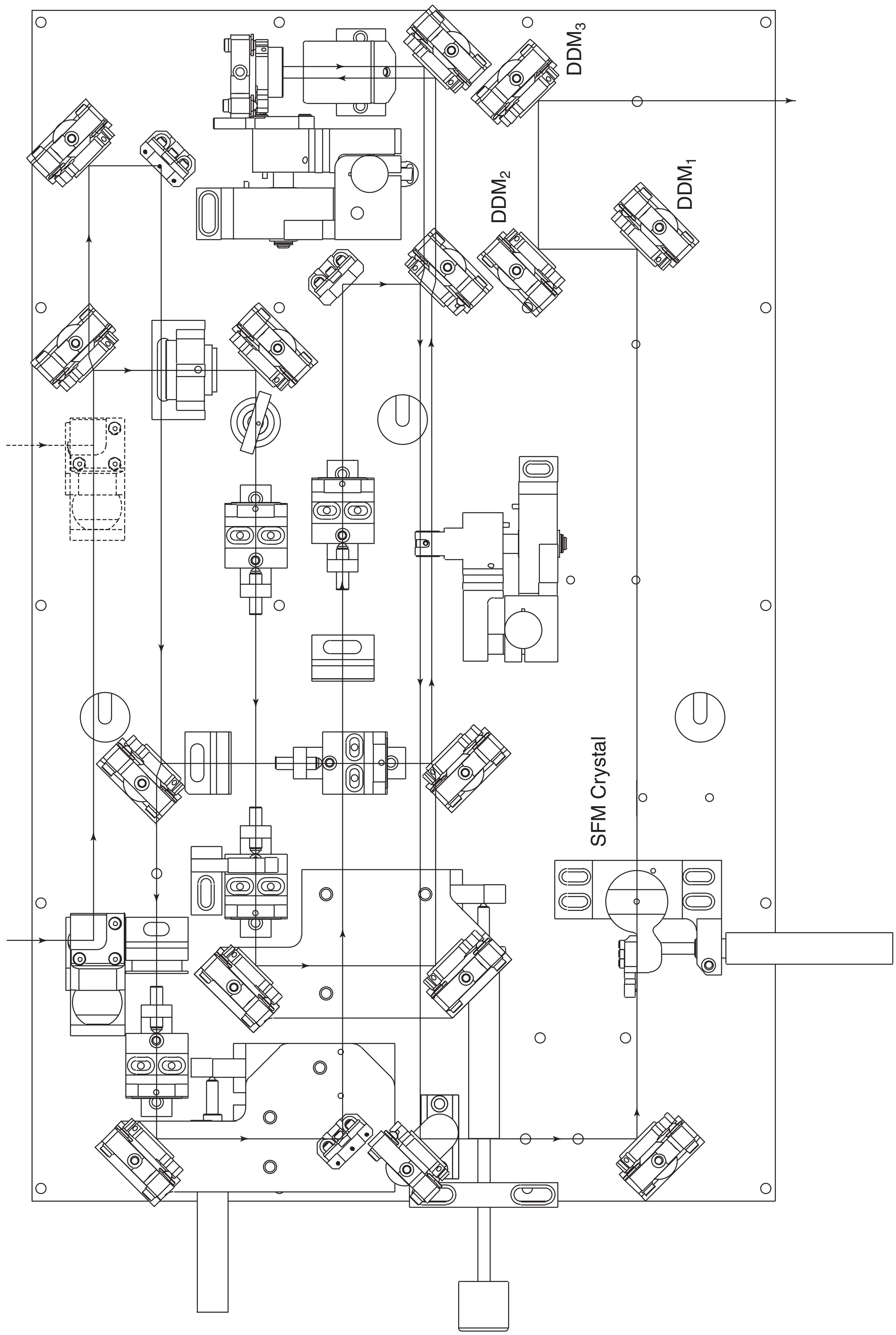


Figure 7-8: Mechanical Layout of the *OPA-800CF* Arranged for SFM

Three dichroic mirrors, DDM_{1-3}, should be mounted in the same way they were for the HGII with $4\omega_s$ output (refer to Figure 7-7). The SFM beam is directed out the SFM/FHG exit port as shown in outline drawing Figure 3-13. The three dichroic mirrors cover the full SFM output range and give good spectral purity. The mechanical/optical layout is shown in Figure 7-8.

The output sum-frequency mixed beam is horizontally polarized for either the signal or idler mixed with the residual pump beam.

Difference-Frequency Mixing Option (DFM)

The DFM option mixes the signal with the idler to extend the wavelength from 3 µm to 10 µm. This is a very important frequency region for the study of molecular vibrational transitions.

The DFM signal within the 3 µm to 10 µm wavelength range can be efficiently generated using a silver gallium sulfide ($AgGaS_2$) crystal. Remove the PS_2 from the beam and align the output signal and idler beams to propagate along the central line of the option. Verify the beams are 6.3 cm above the base plate. Place a marker at the beam before the long-pass filter and then place the fused silica lens L_{FS} into the beam at the position shown in Figure 7-9 so that the beam still remains on the marker. Also, place the L_{BF} lens in a position so that the beam still remains on the marker and is collimated. The $AgGaS_2$ crystal is placed into the beam about 15 cm after lens L_{FS}.

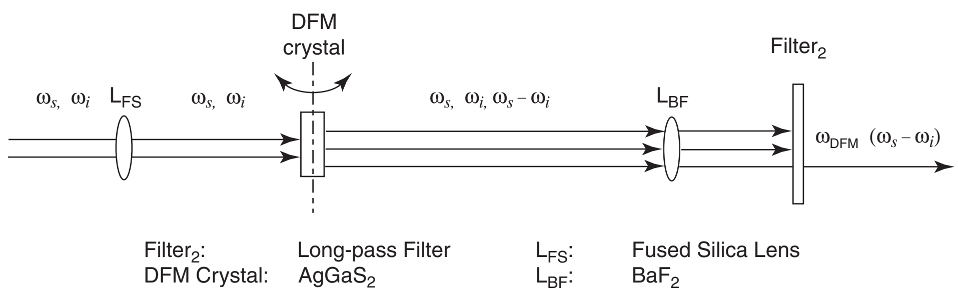


Figure 7-9: Schematic layout of the DFM option.

The DFM beam is separated from the signal and idler beams using a long-pass filter, and it exits the end panel as shown in outline drawing Figure 3-13. This filter has a unidirectional property and must be correctly installed for optimal DFM signal transmission. Since signal and idler pulses must overlap temporally and spatially in the DFM process, DFM pulse energy can be optimized by tuning the DFM crystal angle and adjusting both DELAY 1 and DELAY 2 for temporal overlap and by slightly adjusting steering mirrors R_3 and/or D_2 in Figure 4-1 or Figure 5-1 for spatial overlap while monitoring the output power.

The output DFM pulse is horizontally polarized. For best conversion efficiency and spectral preservation, use a thicker $AgGaS_2$ crystal for the *OPA-800CP* DFM option and a thinner, 1 mm one for the *OPA-800CF* DFM option. The mechanical/optical layout is shown in Figure 7-10.

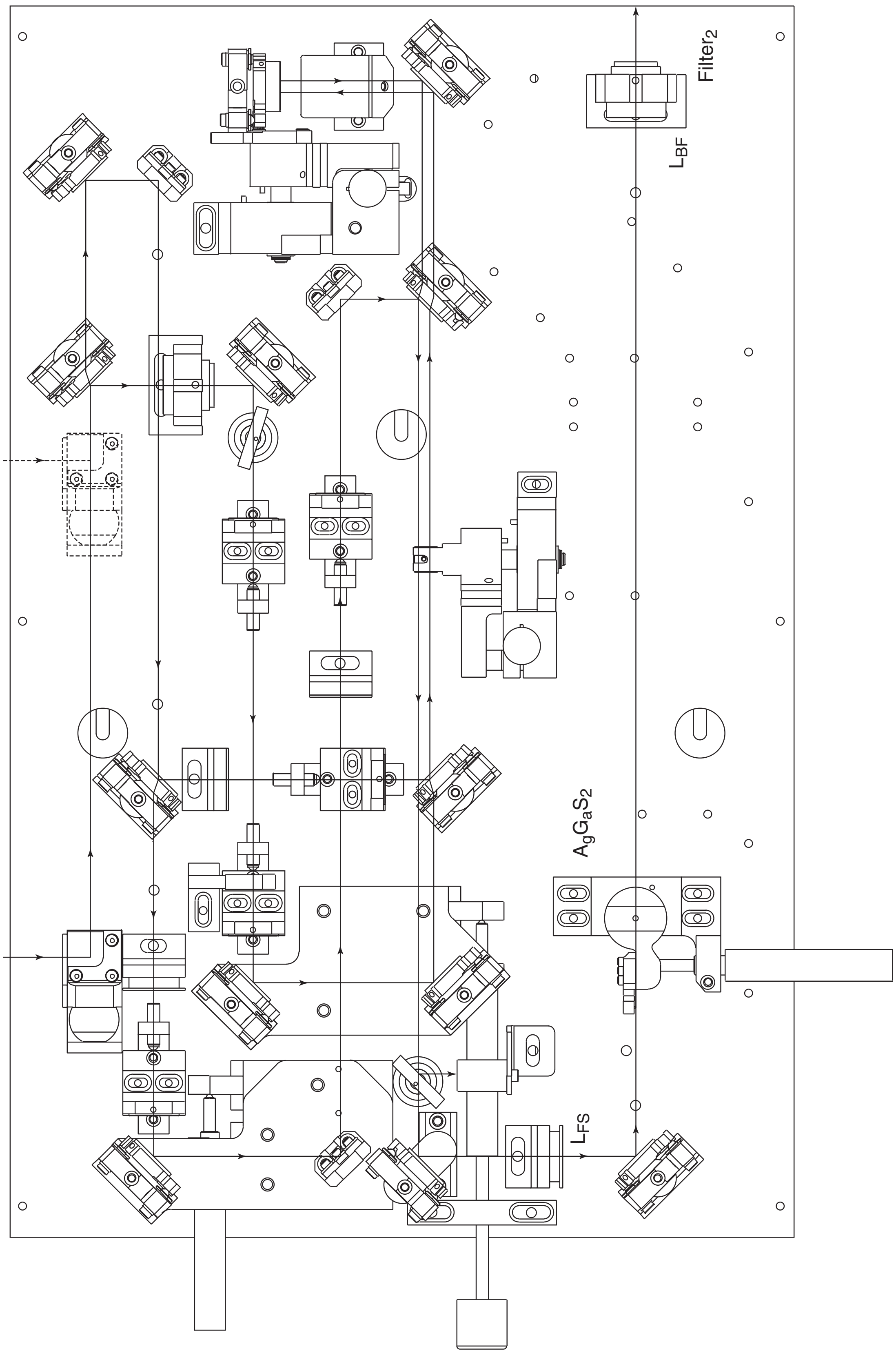


Figure 7-10: Mechanical Layout of the *OPA-800CF* Arranged for DFM

Polarization Summary

The polarization of each possible output beam is listed in Table 7-1 for your convenience, assuming you use the configurations shown in this manual.

Table 7-1: Output beam polarization from *OPA-800C*

Output	ω_p	ω_s	ω_i	$2\omega_s$	$2\omega_i$	$4\omega_s$	$4\omega_i$	$\omega_{SFM(\omega_s+\omega_p)}$	$\omega_{SFM(\omega_i+\omega_p)}$	ω_{DFM}
Polarization[1]	V	V	V	V	H	H	V	H	H	H

[1] *V: vertical, H: horizontal*

Chapter 8 Maintenance

OPA-800C optics are made by vacuum-depositing microthin layers of materials of varying indices of refraction on to different substrates. If the surface is scratched to a depth as shallow as 0.01 mm (0.0004 in.), the operating efficiency of the optical coating can be reduced significantly and the coating can degrade.

Energy losses due to unclean optics will reduce the output power. Dirty optics can be potentially disastrous due to the high power optical pulse inside the *OPA-800C*. A small speck of dust or other contaminant on the optics can produce permanent optical damage which can cause the *OPA-800C* to fail. Cleanliness is essential, and you must apply laser optics maintenance techniques with extreme care and attention to detail.

Remember, "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.

The condition of the laboratory environment and the amount of time the *OPA-800C* is operated affects its periodic maintenance schedule. All coated optical surfaces such as the high reflector, beam splitters, dichroics, lenses, and crystal surfaces are easily contaminated.

Do not allow smoking in the laboratory: the optics stay clean longer. Condensation due to excessive humidity can also contaminate optical surfaces. This is particularly true for the BBO crystal. In short, the cleaner the environment is, the slower the rate of contamination.

If the *OPA-800C* cover is left in place, there is little that must be done day-to-day to maintain the system.

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

Equipment Required

- Rubber squeeze bulb
- Optical-grade lens tissue
- Spectrophotometric-grade methanol and/or acetone (for general optics)
- Spectrophotometric-grade (HPLC) toluene or xylene (Aldrich Gold Label) for cleaning the crystal
- Hemostats
- Clean, lint-free finger cots or powderless latex gloves

Removing and Cleaning OPA-800C Optics

Danger!
Laser Radiation

The *Tsunami*® oscillator and its pump laser (or the *Mai Tai*™ oscillator) and the *Spitfire* regenerative amplifier and its pump lasers (or Hurricane™ regenerative amplifier) are Class IV High Powers lasers and, with the *OPA-800C*, have output beams that emit high power laser radiation. Bypassing the safety interlock shutters on these systems can lead to exposure 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 adjust the mirror vertically and horizontally for maximum output power.

Clean all optics, *except for the* BBO *crystal and grating* (if present) Clean the crystal only when absolutely necessary and only with toluene or xylene. *Do not clean the grating with anything but puffs of air!*

All mirrors are captured and held in place by a set screw. Unscrew the set screw and the mirror will come out. Take care not to touch the optical surface (use a piece of lens tissue to capture the optic if necessary). In some cases, you do not have to remove the optic from its holder to clean it.

Each optical element has a v-shaped arrow on its outer surface. This arrow points to the coated surface used to reflect the beam. Also written on the barrel is the optic part number. If you need to verify the location of the optic in the *OPA-800C*, the part number for each optic is listed at the end of Chapter 9, "Service and Repair."

If your *OPA-800C* becomes misaligned, refer to the appropriate installation and alignment instructions in Chapter 4 (fs) or 5 (ps).

Standard Cleaning Procedures

Follow the principles below whenever you clean any optical surface.

1. Clean only one element at a time, then realign that element for maximum output power. Only remove an optic for cleaning when it cannot be accessed in its optical mount.

   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.
2. Work in a clean environment and, whenever possible, over a soft lint-free cloth or pad.
3. Wash your hands thoroughly with liquid detergent. Body oils and contaminants can render otherwise fastidious cleaning practices useless.
4. 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 will transfer oils and acids on to the optics.*

5. Use 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.

Caution!

Do not use canned air to clean the crystal. A rapid change in temperature due to freon sputter can cause permanent damage to the crystal. Freon sputter is common if the can is not held vertically.

6. Use spectroscopic-grade solvents to clean all optics except the crystal. Use spectrophotometric-grade hydrocarbon solvents to clean the crystal.

   Since cleaning simply dilutes contamination to the limit set by solvent impurities, solvents must be as 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.
7. Store all solvents in small glass bottles. Solvents collect moisture during prolonged exposure to air. Avoid storing solvents in bottles where a large volume of air is trapped above the solvent.
8. Use Kodak Lens Cleaning Paper™ (or equivalent photographic cleaning tissue) to clean optics.
9. 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 in the cotton tip, resulting in contaminated coatings. Only use photographic lens tissue to clean optical components.

General Procedures for Cleaning all Optics Except the Crystal and Grating (ps only)

Warning!

Do not use these instructions for cleaning the crystal. Refer to "General Procedures for Cleaning the Crystal" later in this chapter.

Most optics can be cleaned in place. Remove optics only when necessary: it is best to not disturb the alignment by removing the optics.

1. Use a squeeze bulb to clean away any dust or grit before cleaning optics with solvent. If using canned air (not recommended), avoid tilting the can. This prevents freon from being sputtered onto the optic.

2. 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 one cm square, and clamp it in a plastic hemostat (Figure 8-1).

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, re-saturate, and shake again. Do not allow excess solvent to flow onto unwanted areas (such as optic adhesives and mounts).
   d. Wipe the surface in a single motion from the setscrew toward the nylon holder. Be careful that the hemostat does not touch the optic surface or the coating may be scratched.
3. Clean the optic using the "drop and drag" method (Figure 8-2) when you have to remove the optic.

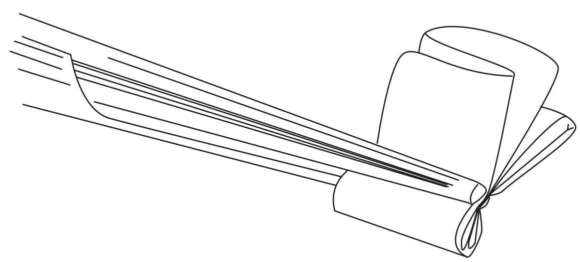


Figure 8-1: Lens Tissue Folded for Cleaning

Figure 8-2: Drop and Drag Method

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 on to it.

b. Slowly draw the tissue across the surface to remove dissolved contaminants and to dry the surface. Pull the tissue slowly enough so the solvent evaporation front follows the tissue (i.e., the solvent dries only after leaving the optic surface).

4. After replacing the optic you just cleaned in the beam, inspect it using an ir viewer or a collimated light source (recommended) to verify that the optic is actually cleaner; i.e., you did not replace one contaminant with another.

General Procedure for Cleaning the Crystal

Warning!

Do not clean the crystal unless absolutely necessary. It can be destroyed if excess pressure is used.
Do not use acetone or methanol on the crystal. Use a spectrophotometric-grade hydrocarbon solvent such as toluene or xylene to clean the crystal. Do not allow the solvent to touch the mounting plate or it will destroy the glue holding the crystal to the mount. Such damage is not covered under your warranty.

Do not remove the crystal for cleaning. Clean it in place.

1. Block the input beam to the *OPA-800C*, then wait about 5 minutes for the crystal to cool down.
2. Use a squeeze bulb to clean away any dust or grit. Proceed with cleaning the crystal with a spectrophotometric-grade solvent only if cleaning with air was not effective.
3. Use a tissue in a hemostat to clean the crystal.

a. Fold a piece of tissue in half repeatedly until you have a pad about ½ cm square, and clamp it in a hemostat (Figure 8-1).

Caution!

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

b. Saturate the tissue with toluene or xylene, shake off the excess, resaturate, and shake again.

Caution!

Do not use excess solvent! The excess might penetrate below the crystal and dissolve the glue which bonds the crystal to the mount. The glue can then migrate to the crystal surface and permanently damage it.

c. Wipe the surface in a single motion and direction, and wait for the solvent to evaporate. Do not touch the aluminum holder if possible. Be sure that the hemostat does not scratch the crystal surface.

General Procedure for Cleaning the Grating

Warning!

Only clean the grating with puffs of air. Anything else will destroy the grating surface!

This completes the cleaning procedure.

Chapter 9 Service and Repair

This chapter contains a general service and 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 this system. A complete repair and/or upgrade procedure is beyond the scope of this chapter. For information concerning repair by Spectra-Physics, refer to Chapter 10, "Customer Service."

At the end of this chapter are replacement parts tables listing components that can be replaced by you for the fs and ps systems.

The *OPA-800C* is a passive unit typically pumped by a *Spitfire*™ or *Hurricane*™ Ti:sapphire amplifier and seeded by a *Tsunami*® Ti:sapphire oscillator, which is pumped by a *Millennia*® diode-pumped green laser, or a *Mai-Tai*™ Ti:sapphire oscillator. As such, it is important to pay close attention to the *OPA-800C* pump pulse spatial and temporal qualities whenever the *OPA-800C* output does not meet specifications. This troubleshooting guide includes some corrections that can be made to the Ti:sapphire amplifier and oscillator when needed. This guide assumes you are using Spectra-Physics *Tsunami* or *Mai Tai*, *Spitfire* or *Hurricane* and pump lasers.

Troubleshooting Guide

The comments below are intended to help you resolve poor performance from the *OPA-800C*. However, for complete alignment and operating procedures of the seed laser and regenerative amplifier, please refer to the appropriate user's manual.

Part I: OPA-800CF

Symptom: Unstable or No white light

Possible Causes	Corrective Action
The white light pump energy is too high.	Lower the white light pump energy.
The pump pulse duration is incorrect.	Check the pulse duration and make sure it meets the specified requirements.
The pump pulse energy is too low or too high.	Increase the energy to meet regenerative amplifier specifications.
The pump beam spatial mode is bad.	Optimize it by steering the regenerative amplifier pump beam. Aperture the regen. beam mode using the intra-cavity irises.
The pump beam can not be focused.	Refer to the *Spitfire* or *Hurricane* amplifier user's manual.
The seed wavelength drifted.	Adjust the seed wavelength slightly (refer to your Tsunami or Mai Tai user's manual).
Unstable pump pulse energy/duration.	Verify the pump energy stability is within $\pm 3\%$. Make sure the pump pulse width is stable.
The white light plate is not at the right position.	Translate the FL back and forth and look for a position with stable WL generation.

Symptom: No pre-amplifier amplification

Possible Causes	Corrective Action
The BBO crystal angle is incorrect.	Set the BBO crystal angle for the desired wavelength.
Poor spatial overlap.	Overlap the white light with the pre-amplifier pump beam between D_1 and WLR_3.
Pre-amplifier pump beam intensity is too low.	Tighten its focusing by moving L_2 until you see some OPG.
Beams are not temporally overlapped.	Change DELAY 1 and search for amplification using ir detectors. Verify the CL stage does not interfere with the movement of DELAY 1. Verify WLP is not mounted in the farthest position from FL.

Symptom: No power amplifier amplification

Possible Causes	Corrective Action
The BBO crystal angle is incorrect.	Set the BBO angle for the desired wavelength or for λ_s = 1.3 µm
Poor spatial overlap.	Verify the power amplifier pump beam is overlapped with the pre-amplifier WL beam.
Power amplifier pump beam intensity is too low.	Tighten its focusing gradually until you see proper amplification but no OPG/white light generation.
Beams are not temporally overlapped.	Verify the L_4 stage does not interfere with the movement of DELAY 2.

Symptom: Low OPA output (signal + idler)

Possible Causes	Corrective Action
The BBO angle is incorrect.	Set the BBO crystal angle for the desired wavelength.
The DELAYS are not optimized.	Optimize both DELAY 1 and DELAY 2 for power.
Pre-amplifier pump beam does not overlap with the white light.	Steer the D_1 mirror for higher power. Adjust the focusing of the white light by translating CL for power.
Pre-amplifier and/or power amplifier pump beam focusing are not optimized.	Adjust L_2 and/or L_4 for higher power, but < 10 µJ OPG.
The pump pulse duration is too long.	Optimize the compressor grating separation in the Spitfire with the remote controller.
The pump beam mode is bad.	Aperture the amplifier output beam using the apertures in the regenerative amplifier cavity. Optimize the green pump beam to the regen. Refer to the *Spitfire* or *Hurricane* amplifier user's manual.
The pump beam has moved.	Steer periscope PS_1 slightly to correct it. Check the alignment of each arm in the *OPA-800C*.

Symptom: Unstable OPA output (signal/idler)

Possible Causes	Corrective Action
The *Spitfire* or *Hurricane* amplifier output is not stable.	See the *Spitfire* or *Hurricane* user's manual troubleshooting section. Sometimes changing the SDG switch-in/out by 1–2 ns will stabilize the output.
Delay 1/Delay 2 spacing is incorrect.	Adjust Delay 1/Delay 2 spacing for most stable output.
The output wavelength is shifted or there is low pulse energy from the oscillator.	Adjust the seed wavelength slightly for stable output. Optimizing the power of the oscillator may help.
The white light is too strong or too weak.	Optimize the WL pump energy by optimizing WP and pulse duration.
The white-light crystal is not at the focus point.	Move the FL stage or the white-light generation crystal to the focus point.
See "Low output causes."	See "Low output correct actions."

Symptom: Abnormal spectrum for OPA output

Possible Causes	Corrective Action
OPA output is not optimized.	Optimize the output of the *OPA-800C*. (See above).
The pump wavelength is not at 800 nm.	Verify the pump wavelength is at 800 ±5 nm.
Spectrum is asymmetrical.	Optimize DELAY 2 and DELAY 1.
There are side lobes on the spectrum.	Optimize the white light seed. Optimize the overlap of the white light with the pre-amplifier and power amplifier pump beam.
Notches on the spectrum.	Purge the OPA to eliminate water absorption.

Symptom: Bad output beam quality.

Possible Causes	Corrective Action
There is a bad OPA pump beam.	Optimize the quality of the *Spitfire* or *Hurricane* amplifier output beam.
The power amplifier pump beam size is too large or too small.	Optimize the pre-amplifier or power amplifier pump beam size at the BBO crystal.
Damaged optics.	Replace the damaged optics.
Damaged BBO crystal.	Replace the damaged crystal or shift the crystal to a good spot.
Conversion efficiency is too high.	Reduce the focus of both pump beams by adjusting L_2 and L_4.

Symptom: Lower output or bad beam quality with the HG/SFM option installed.

Possible Causes	Corrective Action
The output beam is too large.	Optimize the pre- and power amplifier pump beam size by slightly adjusting L_2 and /or L_4.
	Use the collimation lenses for HG of the idler beam.
The output beam is too small.	Don't use collimation lenses in the signal HG and SFM options.
	Optimize the power amplifier pump beam size by slightly adjusting L_4.
The pulse duration is incorrect.	Use the *Spitfire* or *Hurricane* controller to optimize the OPA pump pulse duration.
	Verify the correct crystal is installed in the OPA.
The crystal orientation is incorrect.	Refer to Chapter 4.
The beams are not temporally overlapped.	Adjust DELAY 2 for best SFM output.
The beams are not spatially overlapped.	Align the pre-amplifier WL and the power pump beam for overlapped output as measured in front of SFM.
Lenses are still installed.	Remove L_{BF} and L_{FS} for $2\omega_s$, $4\omega_s$ and perhaps $2\omega_i$ and $4\omega_i$.
Polarizers are still installed.	Do not use polarizer P_2 for $4\omega_s$, $2\omega_i$ or $4\omega_i$.
Output energy is too high.	Optimize OPA output energy for best beam quality.

Symptom: Low or bad output with the DFM option installed.

Possible Causes	Corrective Action
Lenses are not installed.	Install the lenses. Center both with the signal and idler beams.
The signal and idler beams are not properly aligned.	Verify the signal and idler beams are collinear and temporaly synchronized.
Poor crystal orientation.	Verify the DFM crystal is oriented correctly.

Symptom: Incorrect spectra of signal, idler or their harmonics.

Possible Causes	Corrective Action
Incorrect temporal overlap.	Optimize DELAY 1 and DELAY 2 while checking the spectrum.
Misaligned pump beams.	Verify the pre- and power pump beams are parallel to the base plate and collinear with WL.
Misaligned crystals.	Optimize the OPA and the harmonic crystals for the best spectral shape.

Part II: OPA-800CP

Symptom: No white light

Possible Causes	Corrective Action
The pump pulse duration is incorrect.	Check the pulse duration and make sure it meets the specified requirements.
The pump pulse energy is too low.	Increase it to meet *Spitfire* amplifier specifications. Rotate the WP to have 8–16 µJ to the WLP.
The pump beam spatial mode is bad.	Correct it by steering the regen. amplifier green pump beam. Aperture the regen. beam mode using the intracavity irises.
The white light plate is not at the right position.	Translate the FL back and forth while changing its pump pulse duration and energy.

Symptom: Unstable white light

Possible Causes	Corrective Action
The pump pulse duration is incorrect.	Check the pulse duration and make sure it meets required specifications.
The pump pulse energy is too low/high.	Make sure the pump energy is between 8 and 16 µJ. Vary the pump energy within 8–16 µJ while searching for stable white light.
The pump beam spatial mode is bad.	Correct it by steering the green pump beam to the regenerative amplifier. Aperture the regenerative amplifier beam mode using the intracavity irises.
The white light plate is not at the right position or is damaged.	Translate the FL back and forth and look for stable white light. Shift the WLP laterally to avoid the damaged spot.
The seed wavelength has drifted.	Adjust the seed wavelength slightly (refer to your *Tsunami* or *Mai Tai* user's manual).
Unstable pump pulse energy/duration.	Verify pump energy stability is within ±3%. Make sure the pump pulse width is stable.

Symptom: No pre-amplifier amplification

Possible Causes	Corrective Action
Beams are poorly spatially overlapped.	Overlap the white light with the pre-amplifier pump beam from D_1 to after D_2.
Pre-amplifier pump beam intensity is too low.	Tighten its focusing to generate some OPG by moving L_2.
Beams are poorly temporally overlapped.	Change DELAY 1 and search for amplification using ir detectors. Verify the CL stage does not interfere with the movement of DELAY 1. Verify WLP is not mounted in the farthest position from FL.
BBO angle is incorrect.	Set the BBO angle for roughly the desired wavelength and within the specified range.

Symptom: No power amplifier amplification

Possible Causes	Corrective Action
BBO angle is incorrect.	Set the BBO angle for the desired wavelength.
Grating angle is incorrect.	Set the grating angle for a wavelength that corresponds to the BBO phase-matching angle (see Figure 6-3 and 6-4). Swing the grating angle around the setting while changing DELAY 2.
Spatial overlap is incorrect.	Make sure the power amplifier pump beam is parallel to the OPA base plate and overlap with the diffracted seed beam.
Power amplifier pump beam intensity is low.	Carefully tighten its focusing to generate some OPG at OR_1 by slightly moving L_4.
Not temporally overlapped.	Change DELAY 2 to search for amplification. L_4 stage should not interfere with DELAY 2. Otherwise, properly install L_4 bracket.
Lens L_4.	Make sure L_4 is a –50 mm fl lens for an *OPA-800CP*.

Symptom: Low OPA output (signal + idler)

Possible Causes	Corrective Action
BBO angle is incorrect.	Set the BBO angle for the desired wavelength.
Grating angle is incorrect.	Set the grating angle for a wavelength that corresponds to the BBO phase-matching wavelength (see Figure 6-3 and 6-4).
OPA seed wavelength is incorrect.	Check Table 6-1 for the grating angle setting for the idler seed. You can use the second-order diffracted signal beam to seed at $\lambda_s < 1.25$ µm.
Delays are not optimized.	Optimize both DELAY 1 and 2 for power.
Pre-amplifier beam does not overlap with the white light.	Steer the D_1 mirror for higher power. Adjust the focusing of the white light by translating CL.
Pre-amplifier and/or power amplifier pump beam focusing are not optimized.	Adjust L_2 and/or L_4 for higher power (One indication of the proper focusing is that the amount of OPG should be 10–25 µJ for a 1 mJ pumped OPA-800P when the WL seed is blocked.)
Pump pulse duration is too long.	Optimize the compressor grating separation in the *Spitfire* or *Hurricane* with the remote controller.
Pump beam mode is bad.	Aperture the amplifier output beam by using apertures in the regenerative amplifier cavity. Optimize the green pump beam to the regenerative amplifier.
OPA pump beam has moved.	Steer periscope PS_1 slightly to correct it. Check the alignment of each arm in the OPA.
Pump beam spectrum is too narrow.	Verify the mask is properly aligned with the stretcher.

Symptom: Unstable OPA output (signal/idler)

Possible Causes	Corrective Action
White light is unstable	Adjust the pump power and focusing to stabilize the white light.
Amplifier output is unstable.	See the *Spitfire* or *Hurricane* manual troubleshooting section. (Sometimes changing the SDG switch-in/out by 1–2 ns will stabilize the output).
Oscillator output wavelength or pulse energy is unstable.	Optimizing the power/wavelength of the oscillator may help. Adjust the seed wavelength slightly for stable output.
White light is too strong or too weak.	Optimize it by adjusting WP.
See “Low output causes.”	See “Low output correct actions.”

Symptom: Non-Gaussian spectrum shape

Possible Causes	Corrective Action
Non-optimized OPA output.	Optimize the output of the *OPA-800CP* (see above).
Pump wavelength is not at 800 nm.	Verify the pump wavelength is 800 ±5 nm.
Beam spectrum is asymmetrical.	Optimize DELAY 2, DELAY 1 and the grating angle.
Side lobes are seen on the spectrum.	Optimize the white light seed and verify it is overlapped with the pump beams. Verify that the diffracted beam to the BBO crystal and the power amplifier pump beam are overlapped and are propagating collinearly.
Poor crystal orientation.	Verify the correct crystal is used in each position and that each crystal is properly oriented.
Poor crystal angle.	Verify that the harmonic crystals are optimized for the best spectral shape.
Notches on the spectrum.	Purge the OPA to eliminate water absorption.

Symptom: Bad output beam quality

Possible Causes	Corrective Action
Bad OPA pump beam.	Optimize output amplifier beam quality.
Pre-amplifier or power amplifier pump beam size is too big or too small.	Optimize the power amplifier pump beam size at the BBO crystal.
Damaged optics.	Replace the damaged optics (check R_5 and $OR_{1,2}$ to see any damages).
Damaged BBO crystal.	Replace the damaged crystal or shift the crystal to a good spot.
Conversion efficiency is too high.	Reduce the focusing of both pump beams by adjusting L_2 and L_4.

Symptom: OPA output at OR_1 has three separate spots not in a vertical line

Possible Causes	Corrective Action
DELAY 2 is not optimized.	Optimize DELAY 2.
Grating groove orientation is incorrect.	Rotate the grating so the diffracted beam is vertical.
Grating rotational axis is off.	Remount the whole mount onto the translation stage so the diffracted beam reflects back to the BBO crystal and does not move while changing the angle of the grating (see Chapter 5).
Power amplifier pump beam is not collinear with the white light.	Steer R_3 and D_2 to make sure they are collinear. When this is the case, three spots are visible in a single vertical line when DELAY 2 synchronization is off. Make sure it is the same for other wavelengths.
BBO angle is not optimized.	Optimize the BBO crystal for power.

Symptom: Lower output in HG/SFM/DFM Option

Possible Causes	Corrective Action
Output beam is too large.	Optimize the size of the pump beams by adjusting L_2 and/or L_4. Use the collimation lenses for HG for the idler beam and DFM.
Output beam is too small.	Do not use collimation lenses in the signal HG and SFM options. Optimize the size of the pump beams by adjusting L_4.
Pulse duration is too long.	Optimize the OPA pump pulse duration using the Spitfire controller. Make sure the correct OPA crystal is used.
Crystal orientation is wrong.	Check the operation procedures in Chapters 5–7.
Temporal overlap inadequate.	Adjust DELAY 2 for best DFM/SFM output.
Long-pass filter orientation is wrong.	Try flipping the long-pass filter.
T_2 is not optimized.	Translate L_4 for best FHG (SHG) output power/mode.

Symptom: HG spectrum spectral width is incorrect

Possible Causes	Corrective Action
Wrong crystal installed.	Verify the correct thickness crystal is installed (see Chapter 7). Verify the SHG and FHG crystals are not exchanged or misplaced.
Imperfect pump beam.	Improve the pump beam quality in this region using the aperture. Avoid clipping the beam.
OPA pump beam is not optimized.	Optimize the pump beam. Do not make the power pump beam too small.

Symptom: DFM spectrum has side lobes

Possible Causes	Corrective Action
Check the two collimation lenses.	Center the two lenses with the signal and idler beams.
Signal and/or idler spectra have side lobes.	Realign the OPA and white light generator.
DELAY 1 and 2 are not optimized.	Optimize them.
Pump pulse has wrong spectrum.	Check the pump pulse spectrum shape and correct it if necessary.

Replacement Parts, OPA-800CF

Description	Designation	Part Number
$AgGaS_2$, DFM Crystal	DFM Option	0452-9891/0451-5070
*$AgGaS_2$, DFM Crystal**	*DFM Option*	*0453-3610*
BBO Crystal, Coated with mount	BBO xtal	0453-6020 (glued assy., 0451-5120)
*BBO Crystal, Coated with mount**	*BBO xtal*	*0454-7170* *(glued assy., 0453-3620)*
BBO Crystal, Type I, 0.7 mm	HG $BBO_{1, 2, 3}$	0451-5062
BBO Crystal, Type I, 0.5 mm	HG $BBO_{1, 2, 3}$	0451-5061
BBO Crystal, Type II, 0.5 mm	SFM	0451-8301
Beam Splitter	BS_1	G0020-032
Beam Splitter	BS_2	0450-9840 or 0450-9850
Beam Splitter	OPA-800C dual assy.	G0501-002
Dichroic 1	D_{1-4}	G0501-001
Dichroic 2	D_3, PS_2	G0502-001
Dichroic Mirrors, DDM_{1-3}, 480−600 nm	SFM, DDM_{1-3}	G0020-036
Dichroic Mirrors, 300−360 nm	HGII	G0020-035
Dichroic Mirrors, 360−400 nm	HGII	3827-1547
Dichroic Mirrors, 400−600 nm	HGI	G0020-036
High Damage Mirror, 800 nm	R_4	3827-1552
Lens, BaF_2, FL = +250 mm	Options HG, DFM	3827-1544
Lens, Fused Silica, FL = +350/+250 mm	Options HG, DFM	3827-1687/3827-1543
Lens, Opt., PLN-CNV	L_2	3827-1532
Lens, Opt., PLN-CNV, 25.5D	L_4	3827-1533
Lens, Opt., PLN-CNX	L_1,	3827-1651
Lens, Opt., PLN-CNX	L_3	3827-1535
Lens, Opt., PLN-CVX	CL	3827-1534
Lens, Opt., PLN-CVX	FL	3827-1643
Long-pass Filter	DFM	2702-0271
Mirror, Opt., 25.4D x 6, Plano	Silver Mirror	3827-1581
Mirror, Opt., 1 in. x 0.25 tk, Plano	Gold Mirror	3827-1739
Mirror, Opt., PLN-CCV, 1.0D x 50Rd	WLR_3	3827-1537
Polarizer, Thin-film	P	0450-9780
Reflector, 720−860 nm	R_1, R_2, R_3	G0382-016
W.P. 1/2 0-Ord, Retarder	WP	3827-1520
Window, Opt., 0.50 DX 0.12T, Plane, Sap	SPL	3825-0092

** For OPA-800CUSF and its options.*

Replacement Parts Diagram, OPA-800CF

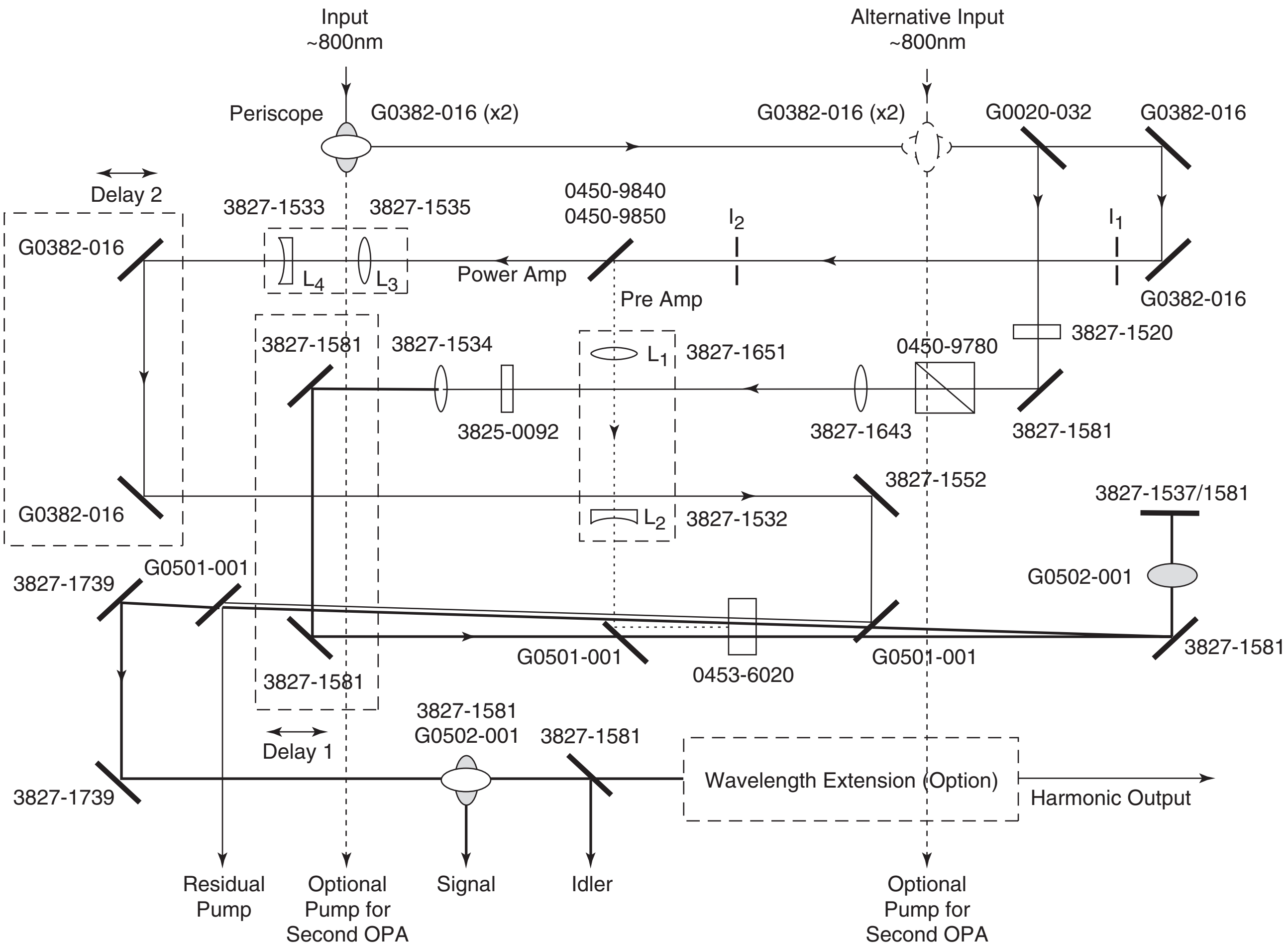


Figure 9-1: ***OPA-800CF*** **Optics Part Numbers by Location**

Replacement Parts, OPA-800CP

Description	Designation	Part Number
$AgGaS_2$	DFM Option	0452-9892
BBO Crystal, Coated with mount	BBO xtal	0454-0860 (glued assy., 0451-5121)
BBO Crystal, HGI, 4 mm	HG BBO_2	0452-9901
BBO Crystal, HGI, 6 mm	HG BBO_1	0452-9902
BBO Crystal, HGII, 3 mm	HGII BBO_3	0452-9900
BBO, II, SFM, 3 mm	SFM Option	0452-9920
Beam Splitter	BS_1	G0020-031
Beam Splitter	BS_2	0450-9840 (0450-9850)
Beam Splitter	OPA-800C dual assy.	G0501-002
Dichroic 1	D_1, D_2, D_4	G0501-001
Dichroic 2	PS_2	G0502-001
Dichroic Mirrors, $DDM_{1\text{-}3}$, 480−600 nm	SFM, DDM_{1-3}	G0020-036
Dichroic Mirrors, 300−360 nm	HGII	G0020-035
Dichroic Mirrors, 360−400 nm	HGII	3827-1547
Dichroic Mirrors, 400−600 nm	HGI	G0020-036
Grating, 600 G/mm	G	3828-0635
High Damage Mirror, 800 nm	R_4	3827-1552
Lens, BaF_2, FL = +250 mm	Option HG, DFM	3827-1544
Lens, Fused Silica, FL = +350/+250 mm	Options HG, DFM	3827-1687/3827-1543
Lens, Opt., PLN-CNV	L_2, L_4	3827-1532
Lens, Opt., PLN-CNX	L_1,	3827-1651
Lens, Opt., PLN-CNX	L_3	3827-1535
Lens, Opt., PLN-CVX	CL	3827-1534
Lens, Opt., PLN-CVX	FL	3827-1643
Long-pass Filter	DFM_0	2702-0271
Mirror, Opt., 25.4D x 6T, Plano	Silver Mirror	3827-1581
Mirror, Opt., 1 in. x 0.25 tk, Plano	Gold Mirror	3827-1739
Polarizer, cube, Apt, 8 mm or Polarizer, thin-film	P	3828-0613
Reflector, 720−860 nm	R_1, R_2, R_3	G0382-016
W.P. 1/20-Ord, Retarder	WP	3827-1520
White Light Plate	WLP	3828-0634

Replacement Parts Diagram, OPA-800CP

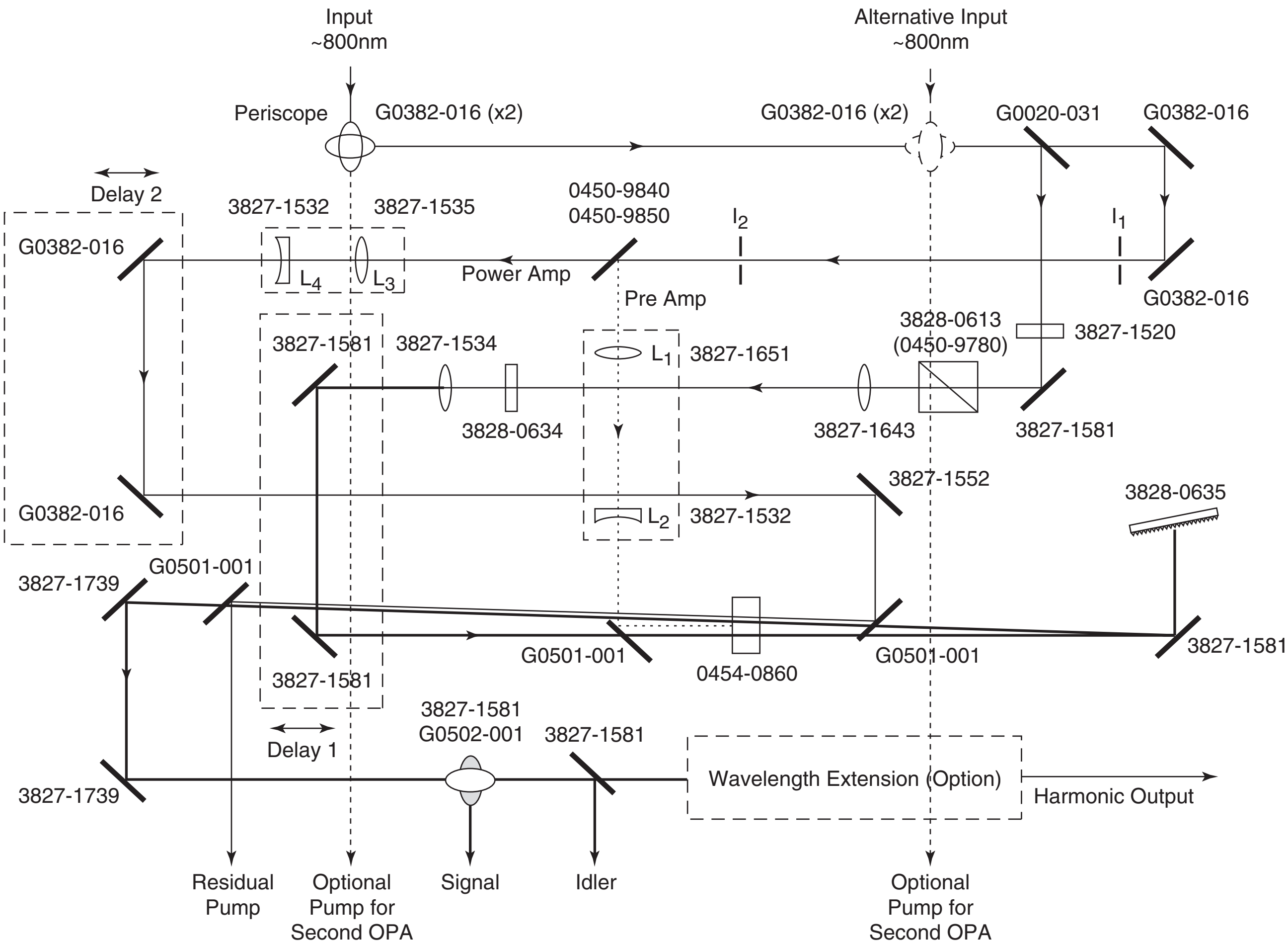


Figure 9-2: ***OPA-800CP*** **Optics Part Numbers by Location**

Chapter 10 Customer Service

Customer Service

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

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

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.

Unless otherwise specified, all parts and assemblies manufactured by Spectra-Physics, except optics, are unconditionally warranted to be free of defects in workmanship and materials for a period of one (1) year following delivery of the equipment to the F.O.B. point. All optics and crystals are warranted for 90 days.

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 repaired 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.

This warranty also 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 the control of 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 is in lieu of all other warranties, expressed or implied, and does not cover incidental or consequential loss.

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.

Service Centers

Benelux

Telephone: (31) 40 265 99 59

France

Telephone: (33) 1-69 18 63 10

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

Japan (East)

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

Japan (West)

Spectra-Physics KK
West Regional Office
Nishi-honmachi Solar Building
3-1-43 Nishi-honmachi
Nishi-ku, Osaka 550-0005

Telephone:	(81) 6-4390-6770
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United Kingdom

Telephone: (44) 1442-258100

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

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

Appendix A Pumping an OPA-800CP with Spitfire

This appendix gives you a simple guideline for setting up a fs pulse-seeded, spectrally masked ps *Spitfire* to pump your Spectra-Physics *OPA-800CP*. The requirements for *Spitfire* output are: ≥ 1 mJ pulse energy, ≤ 22 cm^{-1} of bandwidth at 800 ±2 nm and < 1.6 ps in pulse width.

Danger! Do not pump the *OPA-800CP* while you are working on the *Spitfire!*

In order to generate a bandwidth of less than 25 cm^{-1} for the *OPA-800CP*, the *Spitfire* output bandwidth has to be <25 cm^{-1} (typically <22 cm^{-1} is required). To achieve this, it is necessary to first ensure that the ps *Spitfire* gratings (2200 g/mm) are installed and that a spectral mask is placed inside the stretcher to select a small portion of the seed spectrum (since we use fs pulses to seed the *Spitfire*). A basic stretcher setup with a mask installed is shown in Figure A-1.

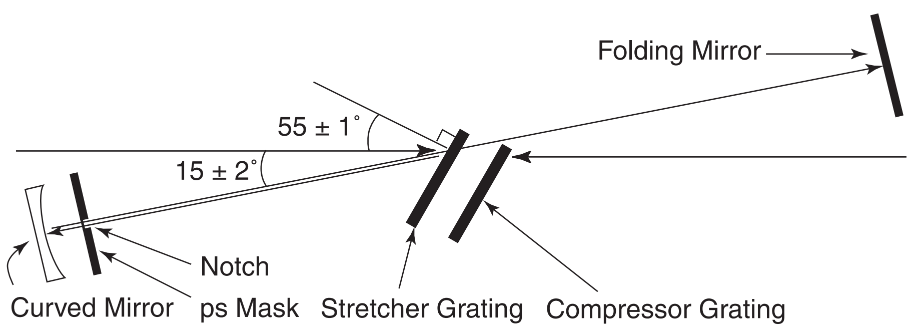

Figure A-1: Schematic of a Stretcher with ps Mask.

The curved mirror has a radius of curvature of 166 cm, or a focal length of 83 cm at normal incidence. If the curved mirror has a large curvature, be careful that the spectrum reflected back from the curved mirror is centered on the notch on the mask. Both stretcher and compressor gratings should be 2200 g/mm. The stretcher grating should be about 41 cm away from the 1 x 4 in. folding mirror, and the mask has to be about 41 cm away from the grating (in front of the curved mirror). Place the incidence angle at 55 ±1° and the diffracted 800 nm beam will be 70.3 ±1.7°.

The angle between the incident and diffracted beams should be 15 ±2° for a standard *Spitfire*. Clip only the top spectrally-spread beam on the mask by using the top fixed-width notch of the mask. For this configuration, the bandwidth of the spectrum coming out of the *Spitfire* versus the different masks is listed in Table A-1.

Table A-1: Spectral bandwidth at 800 nm vs. the width of the mask slit for a ps-masked *Spitfire*

Mask (unit and P/N)		Slit width (mm)	Measured bandwidth (nm)	Measured bandwidth (cm^{-1})
1	-9780	7.5	0.95	15.0
2	-9781	8.3	1.05	16.4
3	-9782	9.1	1.15	18.0
4	-9783	9.9	1.25	19.5
5	-9784	10.7	1.35	21.1

This set of fixed-width masks is supplied with your ps OPA to be selectively used to achieve the appropriate output bandwidth. They are fully tested and work well with the ps OPA, but the amount of energy required to pump the white light should be adjusted accordingly, and the two telescopes in both pump beams should also be adjusted accordingly to obtain optimum output. Make sure the first and the last beam spots on the stretcher grating are in a single vertical line. Otherwise check the stretcher alignment before turning on the amplifier.

The amplifier should be seeded with >350 mW of *Tsunami* power, and the power seeding the regenerative amplifier should be ≥25 mW.

The *Spitfire* should generate 1 mJ pulse energy after the compression stage. The output spectrum shape is squarish. Refer to the *Spitfire* user's manual for general information on operating the ps masked *Spitfire*.

In the compressor, the compression grating needs to be mounted correctly in order to compress all the seeded spectrum. Sometimes part of the spectrum misses the grating. If this occurs, mount the compressor grating forward and slide the compression grating off-center, or slide the whole rotation mount accordingly. You can also rotate both grating mounts relative to the mounting plate. Figure A-2 shows a standard, symmetrical grating configuration and the proper position of the compression grating.

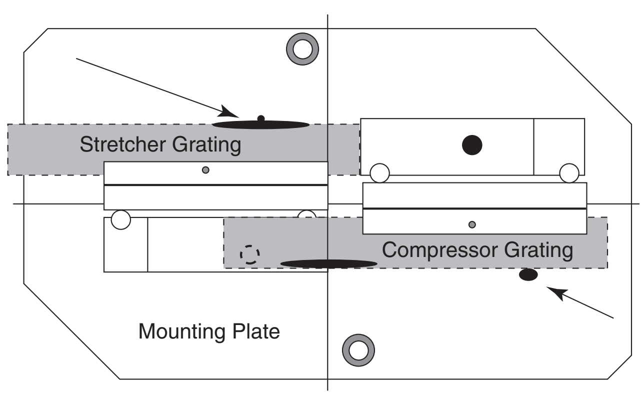

Figure A-2: Standard Symmetrical Grating Configuration

Figure A-3 shows an alternative mounting of these two gratings in case there are difficulties upgrading in the field.

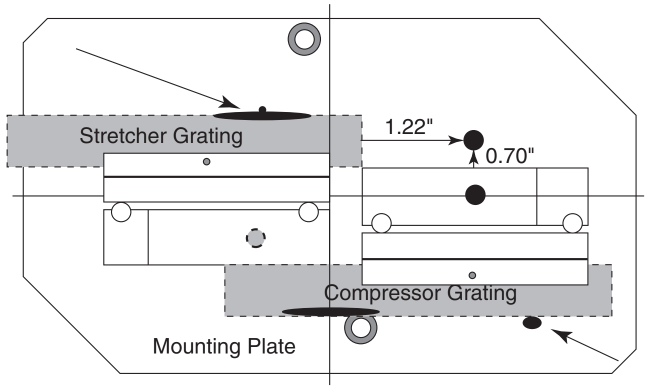

Figure A-3: Grating Configuration Modified for ps-masked *Spitfire*.

As in the fs OPA, the beam profile leaving the *Spitfire* directly affects the ps OPA efficiency and output beam quality. Set the ps masked *Spitfire* for the best performance before starting the ps OPA alignment.

In general, after setting up the *Spitfire* as outlined above, the output should be 1 mJ per pulse, < 22 cm^{-1} in spectral bandwidth and < 1.6 ps in duration. The compressed pulse duration should be very close to the transform limit.

A square-shaped spectrum pulse has a Sinc function or a diffraction function temporal shape, assuming it is transform limited.

The time-bandwidth product of a transform-limited square spectrum pulse is:

$$\Delta\upsilon\,\tau = 0.8859.$$

The ratio of pulse width and autocorrelation width for a square spectrum, transform-limited pulse is:

$$\tau/\tau_{ac} = 0.7511.$$

Spectrum bandwidth is often measured in spectroscopy as the width of $^1/\lambda$ or as “wavenumbers” in cm^{-1}:

$$\left|\Delta\left(\frac{1}{\lambda}\right)\right| = \left|\frac{1}{\lambda^2}\cdot\ \Delta\lambda\right|$$

For your convenience, spectral bandwidth in nm versus wavenumber for 25 cm^{-1} at different wavelengths is listed in Table A-2.

Table A-2: Corresponding bandwidth in nm of 25 cm^{-1} spectrum at different wavelengths

λ (nm)	$\Delta\lambda$ (nm)	λ (µm)	$\Delta\lambda$ (nm)	λ (µm)	$\Delta\lambda$ (nm)
300	0.23	1.1	3.0	3.0	23
325	0.26	1.2	3.6	3.5	31
400	0.40	1.3	4.2	4.0	40
450	0.51	1.4	4.9	4.5	51
500	0.63	1.5	5.6	5.0	63
550	0.76	1.6	6.4	5.5	76
560	0.78	1.7	7.2	6.0	90
600	0.90	1.8	8.1	6.5	106
650	1.06	1.9	9.0	7.0	123
700	1.23	2.0	10.0	7.5	141
750	1.41	2.1	11.0	8.0	160
800	1.60	2.2	12.1	8.5	181
850	1.81	2.3	13.2	9.0	203
900	2.03	2.4	14.4	9.5	226
950	2.26	2.5	15.6	10.0	250
1000	2.50	2.6	16.9		
1050	2.76	2.7	18.2		
		2.8	19.6		
		2.9	21.0		
		3.0	22.5		

Appendix B OPA-800C Wavelength Tables

The following tables are provided for your convenience. They show the corresponding signal and idler output wavelengths for fs and ps OPAs at the given pump wavelength. Table B-1 shows the corresponding values at 800 nm, the pump wavelength specified for this system and at which the system is tested in the factory. The other tables show corresponding output for pump wavelengths other than 800 nm. These input wavelengths are not specified or guaranteed because the crystal cut/phase matching may not be appropriate at these wavelengths. However, these values are “typical” and are listed in the event you want to operate the OPA at these pump wavelengths.

Table B-1: Corresponding *OPA-800C* Output Wavelengths for an 800 nm Pump Input

λ_S	λ_i	λ_{SHG}	λ_{SHG}	λ_{FHG}	λ_{FHG}	λ_{DFM}	λ_{SFM}	λ_{SFM}
	$1/(1/\lambda_p - 1/\lambda_s)$	$\lambda_s/2$	$\lambda_i/2$	$\lambda_s/4$	$\lambda_i/4$	$1/(1/\lambda_s - 1/\lambda_i)$	$1/(1/\lambda_p + 1/\lambda_s)$	$1/(1/\lambda_p + 1/\lambda_i)$
Signal	**Idler**	**SHG Signal**	**SHG Idler**	**FHG Signal**	**FHG Idler**	**DFM**	**SFM (P+S)**	**SFM (P+I)**
(µm)	**(µm)**	**(nm)**	**(µm)**	**(nm)**	**(nm)**	**(µm)**	**(nm)**	**(nm)**
1.090	3.007							
1.100	2.933							
1.125	2.769							
1.150	2.629							
1.175	2.507							
1.200	2.400	600.0	1.20	300.0	600.0		480	600
1.225	2.306	612.5	1.15	306.3	576.5		484	594
1.250	2.222	625.0	1.11	312.5	555.6	2.86	488	588
1.275	2.147	637.5	1.07	318.8	536.8	3.14	492	583
1.300	2.080	650.0	1.04	325.0	520.0	3.47	495	578
1.325	2.019	662.5	1.01	331.3	504.8	3.85	499	573
1.350	1.964	675.0	0.98	337.5	490.9	4.32	502	568
1.375	1.913	687.5	0.96	343.8	478.3	4.89	506	564
1.400	1.867	700.0	0.93	350.0	466.7	5.60	509	560
1.425	1.824	712.5	0.91	356.3	456.0	6.51	512	556
1.450	1.785	725.0	0.89	362.5	446.2	7.73	516	552
1.475	1.748	737.5	0.87	368.8	437.0	9.44	519	549
1.485	1.734	742.5	0.87	371.3	433.6	10.33	520	547
1.500	1.714	750.0	0.86	375.0	428.6		522	545
1.525	1.683	762.5	0.84	381.3	420.7		525	542
1.550	1.653	775.0	0.83	387.5	413.3		528	539
1.575	1.626	787.5	0.81	393.8	406.5		531	536
1.600	1.600	800.0	0.80	400.0	400.0		533	533

Table B-2: Corresponding *OPA-800C* Output Wavelengths for a 780 nm Pump Input (Not for specified performance)

λ_S	λ_i	λ_{SHG}	λ_{SHG}	λ_{FHG}	λ_{FHG}	λ_{DFM}	λ_{SFM}	λ_{SFM}
	$1/(1/\lambda_p-1/\lambda_s)$	$\lambda_s/2$	$\lambda_i/2$	$\lambda_s/4$	$\lambda_i/4$	$1/(1/\lambda_s-1/\lambda_i)$	$1/(1/\lambda_p+1/\lambda_s)$	$1/(1/\lambda_p+1/\lambda_i)$
Signal	**Idler**	**SHG Signal**	**SHG Idler**	**FHG Signal**	**FHG Idler**	**DFM**	**SFM (P+S)**	**SFM (P+I)**
(μm)	**(μm)**	**(nm)**	**(μm)**	**(nm)**	**(nm)**	**(μm)**	**(nm)**	**(nm)**
1.000	3.545	500.0	1.77	250.0	886.4			
1.050	3.033	525.0	1.52	262.5	758.3			
1.100	2.681	550.0	1.34	275.0	670.3			
1.125	2.543	562.5	1.27	281.3	635.9			
1.150	2.424	575.0	1.21	287.5	606.1			
1.175	2.320	587.5	1.16	293.8	580.1			
1.200	2.229	600.0	1.11	300.0	557.1	2.60	480	578
1.225	2.147	612.5	1.07	306.3	536.8	2.85	484	572
1.250	2.074	625.0	1.04	312.5	518.6	3.15	488	567
1.275	2.009	637.5	1.00	318.8	502.3	3.49	492	562
1.300	1.950	650.0	0.98	325.0	487.5	3.90	495	557
1.325	1.896	662.5	0.95	331.3	474.1	4.40	499	553
1.350	1.847	675.0	0.92	337.5	461.8	5.01	502	548
1.375	1.803	687.5	0.90	343.8	450.6	5.80	506	544
1.400	1.761	700.0	0.88	350.0	440.3	6.83	509	541
1.425	1.723	712.5	0.86	356.3	430.8	8.23	512	537
1.450	1.688	725.0	0.84	362.5	422.0	10.28	516	533
1.475	1.655	737.5	0.83	368.8	413.8	13.54	519	530
1.485	1.643	742.5	0.82	371.3	410.7	15.44	520	529
1.500	1.625	750.0	0.81	375.0	406.3	19.50	522	527
1.525	1.597	762.5	0.80	381.3	399.2		525	524
1.550	1.570	775.0	0.79	387.5	392.5		528	521
1.575	1.545	787.5	0.77	393.8	386.3		531	518
1.600	1.522	800.0	0.76	400.0	380.5		533	516

Table B-3: Corresponding *OPA-800C* Output Wavelengths for a 790 nm Pump Input (Not for specified performance)

λ_S	λ_i	λ_{SHG}	λ_{SHG}	λ_{FHG}	λ_{FHG}	λ_{DFM}	λ_{SFM}	λ_{SFM}
	$1/(1/\lambda_p - 1/\lambda_s)$	$\lambda_s/2$	$\lambda_i/2$	$\lambda_s/4$	$\lambda_i/4$	$1/(1/\lambda_s - 1/\lambda_i)$	$1/(1/\lambda_p + 1/\lambda_s)$	$1/(1/\lambda_p + 1/\lambda_i)$
Signal	**Idler**	**SHG Signal**	**SHG Idler**	**FHG Signal**	**FHG Idler**	**DFM**	**SFM (P+S)**	**SFM (P+I)**
(μm)	**(μm)**	**(nm)**	**(μm)**	**(nm)**	**(nm)**	**(μm)**	**(nm)**	**(nm)**
1.090	2.870	545.0	1.44	272.5	717.6	1.76		
1.100	2.803	550.0	1.40	275.0	700.8	1.81		
1.125	2.653	562.5	1.33	281.3	663.2	1.95		
1.150	2.524	575.0	1.26	287.5	630.9	2.11		
1.175	2.411	587.5	1.21	293.8	602.8	2.29		
1.200	2.312	600.0	1.16	300.0	578.0	2.49	480	589
1.225	2.225	612.5	1.11	306.3	556.2	2.73	484	583
1.250	2.147	625.0	1.07	312.5	536.7	2.99	488	577
1.275	2.077	637.5	1.04	318.8	519.2	3.30	492	572
1.300	2.014	650.0	1.01	325.0	503.4	3.67	495	567
1.325	1.957	662.5	0.98	331.3	489.1	4.10	499	563
1.350	1.904	675.0	0.95	337.5	476.1	4.64	502	558
1.375	1.857	687.5	0.93	343.8	464.2	5.30	506	554
1.400	1.813	700.0	0.91	350.0	453.3	6.14	509	550
1.425	1.773	712.5	0.89	356.3	443.2	7.26	512	546
1.450	1.736	725.0	0.87	362.5	433.9	8.81	516	543
1.475	1.701	737.5	0.85	368.8	425.3	11.10	519	539
1.485	1.688	742.5	0.84	371.3	422.0	12.35	520	538
1.500	1.669	750.0	0.83	375.0	417.3	14.81	522	536
1.525	1.639	762.5	0.82	381.3	409.8		525	533
1.550	1.611	775.0	0.81	387.5	402.8		528	530
1.575	1.585	787.5	0.79	393.8	396.3		531	527
1.600	1.560	800.0	0.78	400.0	390.1		533	524

Table B-4: Corresponding *OPA-800C* Output Wavelengths for an 810 nm Pump Input (Not for specified performance)

λ_S	λ_i	λ_{SHG}	λ_{SHG}	λ_{FHG}	λ_{FHG}	λ_{DFM}	λ_{SFM}	λ_{SFM}
	$1/(1/\lambda_p-1/\lambda_s)$	$\lambda_s/2$	$\lambda_i/2$	$\lambda_s/4$	$\lambda_i/4$	$1/(1/\lambda_s-1/\lambda_i)$	$1/(1/\lambda_p+1/\lambda_s)$	$1/(1/\lambda_p+1/\lambda_i)$
Signal	**Idler**	**SHG Signal**	**SHG Idler**	**FHG Signal**	**FHG Idler**	**DFM**	**SFM (P+S)**	**SFM (P+I)**
(µm)	**(µm)**	**(nm)**	**(µm)**	**(nm)**	**(nm)**	**(µm)**	**(nm)**	**(nm)**
1.000	4.263	500.0	2.13	250.0	1065.8			
1.050	3.544	525.0	1.77	262.5	885.9			
1.100	3.072	550.0	1.54	275.0	768.1			
1.125	2.893	562.5	1.45	281.3	723.2			
1.150	2.740	575.0	1.37	287.5	684.9			
1.175	2.608	587.5	1.30	293.8	651.9			
1.200	2.492	600.0	1.25	300.0	623.1	2.31	480	611
1.225	2.391	612.5	1.20	306.3	597.7	2.51	484	605
1.250	2.301	625.0	1.15	312.5	575.3	2.74	488	599
1.275	2.221	637.5	1.11	318.8	555.2	2.99	492	594
1.300	2.149	650.0	1.07	325.0	537.2	3.29	495	588
1.325	2.084	662.5	1.04	331.3	521.0	3.64	499	583
1.350	2.025	675.0	1.01	337.5	506.3	4.05	502	579
1.375	1.971	687.5	0.99	343.8	492.8	4.55	506	574
1.400	1.922	700.0	0.96	350.0	480.5	5.15	509	570
1.425	1.877	712.5	0.94	356.3	469.2	5.92	512	566
1.450	1.835	725.0	0.92	362.5	458.8	6.91	516	562
1.475	1.797	737.5	0.90	368.8	449.2	8.24	519	558
1.485	1.782	742.5	0.89	371.3	445.5	8.91	520	557
1.500	1.761	750.0	0.88	375.0	440.2	10.13	522	555
1.525	1.728	762.5	0.86	381.3	431.9		525	551
1.550	1.697	775.0	0.85	387.5	424.2		528	548
1.575	1.668	787.5	0.83	393.8	416.9		531	545
1.600	1.641	800.0	0.82	400.0	410.1		533	542
1.625	1.615	812.5	0.80	406.3	403.8		536	535

Table B-5: Corresponding *OPA-800C* Output Wavelengths for an 825 nm Pump Input (Not for specified performance)

λ_S	λ_i	λ_{SHG}	λ_{SHG}	λ_{FHG}	λ_{FHG}	λ_{DFM}	λ_{SFM}	λ_{SFM}
	$1/(1/\lambda_p-1/\lambda_s)$	$\lambda_s/2$	$\lambda_i/2$	$\lambda_s/4$	$\lambda_i/4$	$1/(1/\lambda_s-1/\lambda_i)$	$1/(1/\lambda_p+1/\lambda_s)$	$1/(1/\lambda_p+1/\lambda_i)$
Signal	**Idler**	**SHG Signal**	**SHG Idler**	**FHG Signal**	**FHG Idler**	**DFM**	**SFM (P+S)**	**SFM (P+I)**
(μm)	**(μm)**	**(nm)**	**(μm)**	**(nm)**	**(nm)**	**(μm)**	**(nm)**	**(nm)**
1.000	4.714	500.0	2.36	250.0	1178.6			
1.050	3.850	525.0	1.93	262.5	962.5			
1.100	3.300	550.0	1.65	275.0	825.0			
1.125	3.094	562.5	1.55	281.3	773.4			
1.150	2.919	575.0	1.46	287.5	729.8			
1.175	2.770	587.5	1.38	293.8	692.4			
1.200	2.640	600.0	1.32	300.0	660.0	2.20	480	629
1.225	2.527	612.5	1.26	306.3	631.6	2.38	484	622
1.250	2.426	625.0	1.21	312.5	606.6	2.58	488	616
1.275	2.338	637.5	1.17	318.8	584.4	2.81	492	610
1.300	2.258	650.0	1.13	325.0	564.5	3.06	495	604
1.325	2.186	662.5	1.09	331.3	546.6	3.36	499	599
1.350	2.121	675.0	1.06	337.5	530.4	3.71	502	594
1.375	2.063	687.5	1.03	343.8	515.6	4.13	506	589
1.400	2.009	700.0	1.00	350.0	502.2	4.62	509	585
1.425	1.959	712.5	0.98	356.3	489.8	5.23	512	581
1.450	1.914	725.0	0.96	362.5	478.5	5.98	516	577
1.475	1.872	737.5	0.94	368.8	468.0	6.95	519	573
1.485	1.856	742.5	0.93	371.3	464.1	7.43	520	571
1.500	1.833	750.0	0.92	375.0	458.3	8.25	522	569
1.525	1.797	762.5	0.90	381.3	449.3		525	565
1.550	1.764	775.0	0.88	387.5	440.9		528	562
1.575	1.733	787.5	0.87	393.8	433.1		531	559
1.600	1.703	800.0	0.85	400.0	425.8		533	556
1.625	1.676	812.5	0.84	406.3	419.0		536.1	541.5
1.650	1.650	825.0	0.83	412.5	412.5		538.8	538.8

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.

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