Mai Tai

Diode-Pumped, Mode-Locked Ti:sapphire Laser

User's Manual

Spectra-Physics
The Solid-State Laser Company

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Mountain View, CA 94043

Part Number 0000-284A, Rev. G
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Preface

This manual contains information you need in order to safely install and operate your *Mai Tai*™ laser.

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

The "Introduction" contains a brief description of the *Mai Tai* laser, its power supply and the control devices.

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

"Laser Description" contains a brief exposition on solid-state cw pumping and Titanium:sapphire laser theory. This is followed by a more detailed description of the *Mai Tai* laser system. The chapter concludes with system specifications and outline drawings.

The middle chapters describe the *Mai Tai* controls, then guide you through its installation, the installation of the control software and laser operation. The last part of the manual covers options, maintenance and service. The latter includes a replacement parts list.

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

Appendix A provides information on short pulse formation in the mode-locked *Mai Tai* laser while Appendix B provides general information on pulse width measurement.

This product has been tested and found to conform to the provisions of Directive 73/23/EEC governing product safety using the EN 61010-1: 2001 and EN 60825-1: 1994 standards, and the provisions of Directive 89/336/EEC governing electromagnetic compatibility using the EN 61326-1 w/A1:

1997 standard. Refer to the “EC Declaration of Conformity” in Chapter 2, “Laser Safety.”

This product conforms to the requirements of 21 CFR 1040.10 CDRH and is compliant to Underwriters Laboratory UL1950 and is listed as ULR for recognized components. This equipment has been designed and tested to comply with the limits for a Class A digital device pursuant to Part 15 of the FCC Rules.

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.

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

Thank you for your purchase of Spectra-Physics instruments.

Environmental Specifications

CE Electrical Equipment Requirements

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

Environmental Specifications

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

Indoor use

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

FCC Regulations

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

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

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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

Abbreviations

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

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

Unpacking and Inspection

Unpacking Your Laser

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

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

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

Warning!

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

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

System Components

- *Mai Tai* laser head
- *Model J40* power supply
- A chiller with tubing and fittings and its own user's manual
- An accessory kit (see below)

Accessory Kit

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

- Hardware for mounting the *Mai Tai* laser head to a horizontal base plate
- RS-232 serial cable
- Interface control software on two 3.5 in. floppy diskettes or one CD-ROM
- Retail version cover (for scientific orders only)
- Fiber caps
- *Model J40* 10 A fuses (2)
- D-sub jumper plugs for the REMOTE and ANALOG ports (which are not used on this system)
- Specification summary form

Chapter 1 Introduction

The Mai Tai™ Laser System

A *Mai Tai* laser system comprises four main elements:

- The *Mai Tai* modelocked laser head (scientific or OEM version)
- The *Model J40* power supply
- A closed-loop chiller
- Windows®-based LabWindows™ control software for installation on your own personal computer or the optional notebook computer.
- Optional notebook personal computer with control software installed.

Figure 1-1 shows a typical *Mai Tai* laser system.

The *Mai Tai* comprises two lasers, a CW diode-pumped laser and a mode-locked Ti:sapphire pulsed laser. Each is substantially reduced in size and squeezed into a single small enclosure. The CW pump laser design is based on that of the popular Spectra-Physics *Millennia*® diode-pumped laser. The mode-locked Ti:sapphire laser design is based on that of the field-proven Spectra-Physics *Tsunami*® femtosecond (fs) pulsed laser.

Figure 1-1: Shown is the scientific version of the *Mai Tai* Ti:sapphire mode-locked laser system. The chiller is not shown.

The laser head has two chambers, a CW pump chamber and a pulsed output chamber. The CW pump chamber contains a diode-pumped, intracavity, frequency-doubled, solid-state *Millennia*-type 532 nm laser. The pulsed output chamber contains a mode-locked Ti:sapphire cavity. Because of Ti:sapphire broad absorption band in the blue and green, the 532 nm output of the CW laser is an ideal pump source for the Ti:sapphire laser.

The *Mai Tai* delivers continuously tunable output over a range of near infrared (IR) wavelengths, from 750 to 850 or 780 to 920 nm at <100 fs—all with solid state convenience.

For performance stability, both systems use a chiller to water-cool and control the temperature of the CW pump laser Nd:YVO_4 crystal, the pulsed chamber Ti:sapphire rod and the base of the laser head. (The chiller is fully described in its own manual shipped with the system.)

The *Mai Tai* laser head is sealed to prevent dust and water vapor from entering it. There are no user-serviceable parts inside. An umbilical connects the laser head to the power supply.

The CW Pump Chamber

The pump chamber contains an *all solid-state*, high power, visible CW laser that provides greater than 5 W of green 532 nm pump output from a standard 110 or 220 Vac, single-phase outlet. Optical noise is less than 0.04% rms (10 Hz to 2 GHz).

This performance is possible through the integration of our patented, high-efficiency **FC*bar***™ diode-pumping and QMAD intracavity-doubling technologies.

Fiber-coupling enables the astigmatic light from a diode bar to be transformed to a round beam of exceptional brightness that is suitable for an efficient end-pumping geometry. It also allows the diode bars to be located in the power supply, thereby removing their heat load from the laser head and facilitating their replacement without the need for realigning the cavity.

Because the entire cavity is sealed, performance and stability are further improved. This provides long-term operation without the need for cleaning or adjustment.

The Pulsed Output Chamber

This chamber contains the mode-locked Ti:sapphire cavity which includes the main elements include the Ti:sapphire rod, the rod focusing mirrors, cavity fold and end mirrors, an acousto-optic modulator for regenerative mode locking, prism dispersion control elements and a tuning element.

The chamber is sealed and there are no user controls. Chapter 6, “Operation,” describes the LabWindows control software and the on-screen controls for monitoring *Mai Tai* output power and controlling the shutter (all units) and for selecting the wavelength of the unit.

Patents

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

Mai Tai laser head, pump section and power supply

4,653,056	4,761,785	4,942,582
4,656,635	4,785,459	5,080,706
4,665,529	4,837,771	5,127,068
4,701,929	4,872,177	5,410,559
4,723,257	4,894,839	5,412,683
4,739,507	4,908,832	5,436,990
4.756.003	4,913,533	5,446,749

Mai Tai laser head, pulsed section

4,894,831	5,056,103	5,185,750
4,977,566	5,175,736	5,212,698
5,020,073		

Chapter 2 Laser Safety

Danger!

The *Mai Tai*™ is a Class IV-High Power Laser, whose beam is, by definition, a safety and fire hazard. Take precautions to prevent exposure to direct and reflected beams. Diffuse as well as specular reflections cause severe skin or eye damage.

Danger!
Laser Radiation

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

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

- Wear protective eyewear at all times; selection depends on the wavelength and intensity of the radiation, the conditions of use, and the visual function required. Protective eyewear vendors are listed in the *Laser Focus World, Lasers and Optronics,* and *Photonics Spectra* buyer's guides. Consult the ANSI or ACGIH standards listed at the end of this section for guidance.
- Maintain a high ambient light level in the laser operation area. This keeps the eye's pupil constricted, thus reducing the possibility of eye damage.
- Avoid looking at the output beam; even diffuse reflections are hazardous.
- Avoid wearing jewelry or other objects that may reflect or scatter the beam while using the laser.
- Use an infrared detector or energy detector (IR viewer) to verify that the laser beam is off before working in front of the laser.
- Operate the laser at the lowest beam intensity possible, given the requirements of the application.
- Expand the beam whenever possible to reduce beam power density.
- Avoid blocking the output beam or its reflection with any part of your body.
- Establish a controlled access area for laser operation. Limit access to those trained in the principles of laser safety.

- Post prominent warning signs near the laser operation area (Figure 2-1).
- Set up the laser so the beam is either above or below eye level.
- Provide enclosures for beam paths whenever possible.
- Set up shields to prevent specular reflections.
- Set up an energy absorbing target to capture the laser beam, preventing unnecessary reflections or scattering (Figure 2-2).

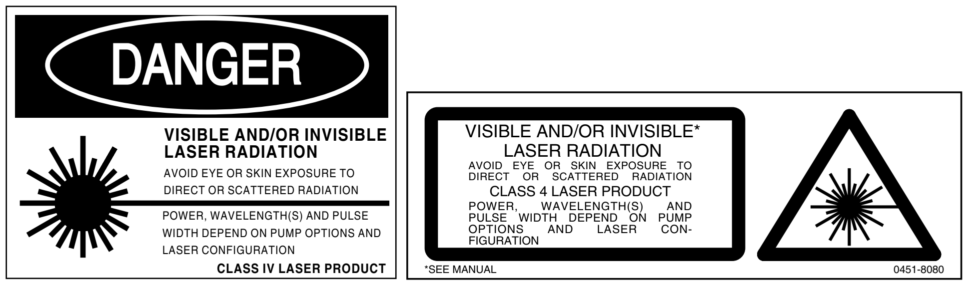


Figure 2-1: These CDRH and CE standard safety warning labels would be appropriate for use as entry warning signs (ANSI 4.3.10.1, EN 60825-1).

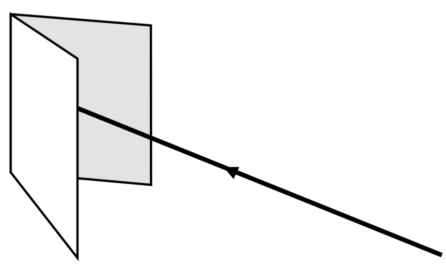


Figure 2-2: Folded Metal Beam Target

Caution!

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

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

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

Safety Devices

Emission Indicators

Figure 2-3 and Figure 2-5 show the locations of the emission indicators.

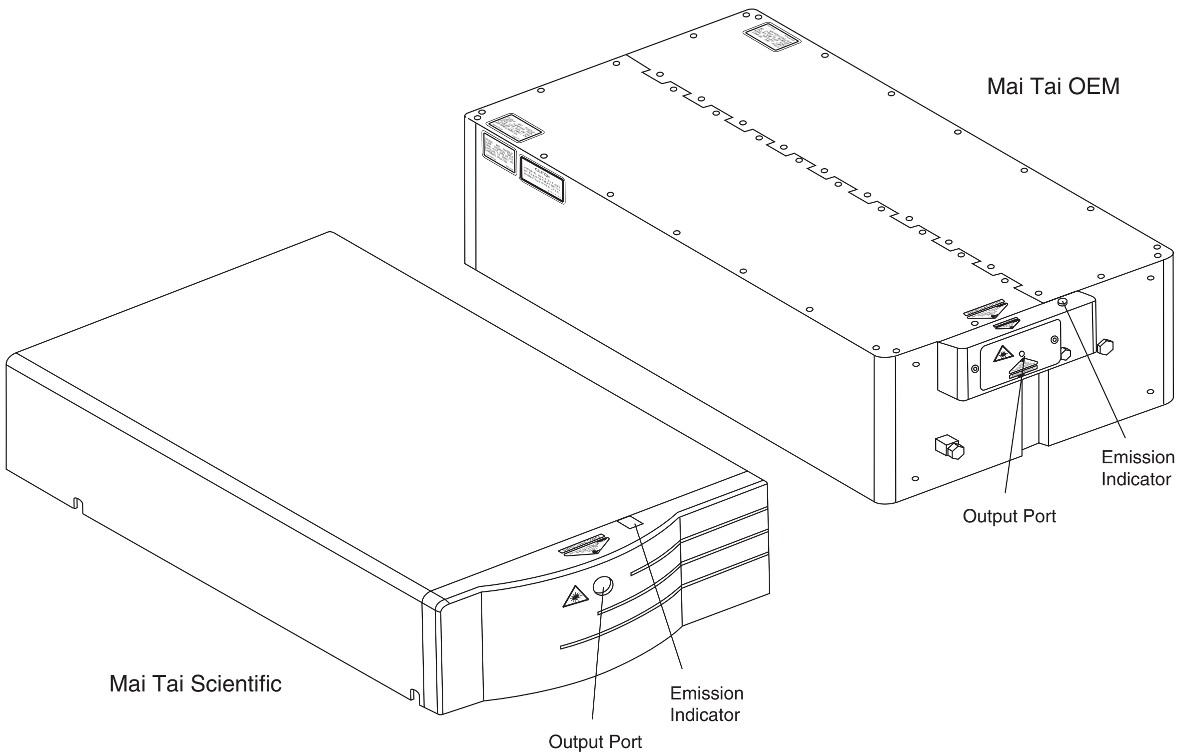


Figure 2-3: Laser Head Emission Indicator

The EMISSION connector on the back of the *Model J40* (see Figure 2-4 and Figure 2-5) can be used to turn on and off a user-installed emission indicator. When the laser is off (i.e., there is no emission), there is closure between pins 3 and 1 and an open between pins 3 and 2. The opposite is true when the laser is on, i.e., there is emission or emission is imminent. There is no power supplied by these terminals. The circuit is rated for 250 Vac at 5 A.

These indicators turn on 3 seconds before actual emission occurs.

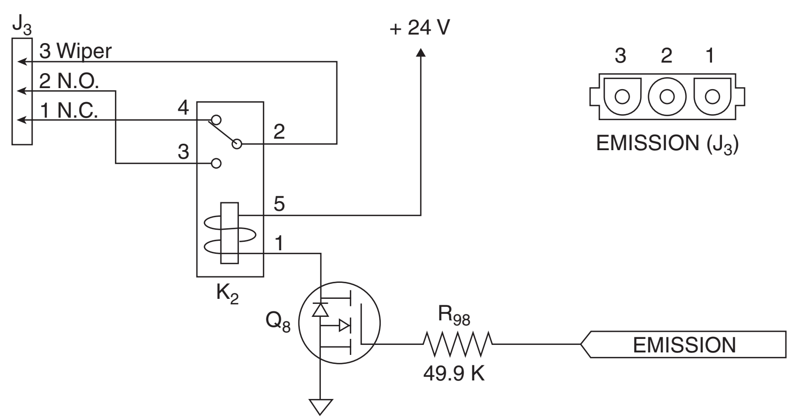
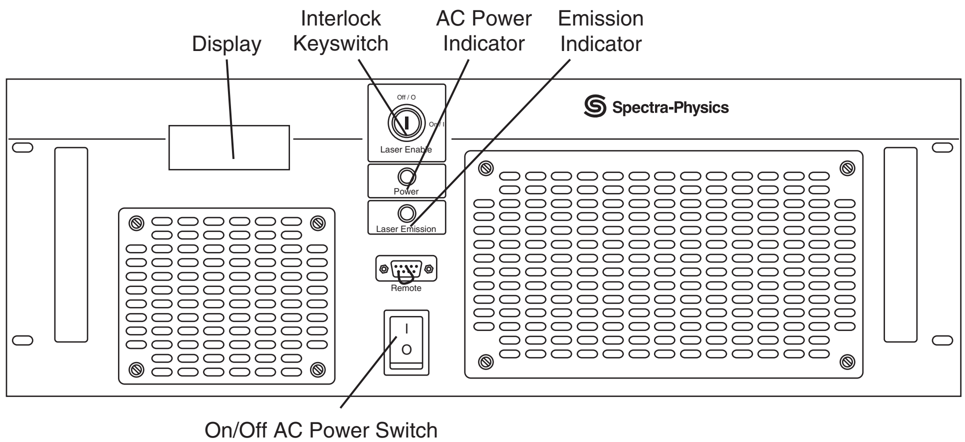
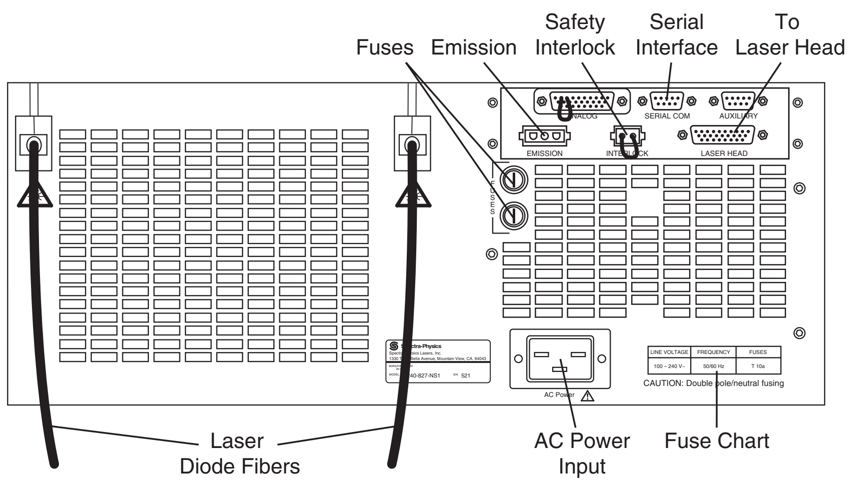


Figure 2-4: The EMISSION Connector Schematic



Front Panel, Model J40



Rear Panel, Model J40

Figure 2-5: The *Model J40* Safety Devices.

Shutter

The internal shutter is electromechanical and is controlled via the controller or by the software via the RS-232 interface. Its interlock fault and fail-safe mode is the *closed* position.

Cover Safety Interlocks

Neither the laser head or power supply contain user-serviceable parts and are not to be opened by the user. Therefore, no cover interlocks are required in the laser head or the power supply. Only someone trained by Spectra-Physics should be allowed to service the system. A non-interlocked warning label is attached to the laser head as shown in Figure 2-6.

Danger!
Laser Radiation

Operating the laser with the cover off may expose people to high voltages and high levels of radiation. It also increases the rate of optical surface contamination. There are no user-serviceable parts inside the *Mai Tai* laser head or the *Model J40* power supply. Therefore, operating the laser or power supply with the aluminum cover off is prohibited and will void your warranty.

Interlock Keyswitch

The LASER ENABLE keyswitch provides interlock safety to prevent unauthorized personnel from using the *Model J40* system when the key is turned to the "off" position and the key is removed. Turning the key to the "on" position closes the interlock and allows the diode to be energized if the POWER switch is also on.

POWER *Indicator*

When on, this green LED indicates that ac power is applied to the system control circuits.

Safety Interlock

The 2-pin INTERLOCK connector on the power supply connector panel (Figure 2-5) is to be wired to a CDRH external interlock switch. Remove the jumper plug supplied, and either rewire it or use a similar connector to wire to a perimeter safety switch that is attached to an access door or to other auxiliary safety equipment. Wire the switch as "normally closed" so that when the door or safety device opens and the switch opens, the power supply will immediately turn off the laser diodes as a safety precaution to prevent unaware personnel from getting hurt.

Note

The two INTERLOCK contacts must either be wired to a safety switch or be shorted together using the jumper plug provided in order of the power supply to turn on.

CDRH Requirements for Operating the *Mai Tai* Without the Optional PC Controller

The *Mai Tai* laser head and the *Model J40* power supply comply with all CDRH safety standards when operated with the *Mai Tai* optional pc controller. However when the laser is operated using the command language supplied in Chapter 6, you must provide the following in order to satisfy CDRH regulations:

- **An emission indicator—**that indicates laser energy is present or can be accessed. It can be a "power-on" lamp, a computer display that flashes a statement to this effect, or an indicator on the control equipment for this purpose. It need not be marked as an emission indicator so long as its function is obvious. *Its presence is required on any control panel that affects laser output, including the computer display panel.*

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

This laser product complies with Title 21 of the *United States Code of Federal Regulations*, Chapter 1, subchapter J, parts 1040.10 and 1040.11, as applicable. To maintain compliance 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 on the CDRH/CE Radiation Control Drawing (found later in this chapter) function properly. Also, make sure that all warning labels remain firmly attached.

1. Verify removing the auxiliary interlock (INTERLOCK) connector on the power supply prevents laser operation. Figure 2-5, "Part of the *Model J40* Power Supply Connector Panel," shows the interlock with the jumpered plug in place.
2. Verify the laser can only be turned on when the 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 provides a visible signal when the laser emits accessible laser radiation that exceeds the accessible emission limits for Class I.*
4. Verify the time delay between turn-on of the emission indicator and starting of the laser; it must give enough warning to allow action to avoid exposure to laser radiation.
5. Verify the beam attenuator (shutter) operates properly when commanded from the laptop pc controller and that it closes when the controller is disconnected or the key switch is turned off. Verify it actually blocks access to laser radiation.

* *0.39 µW for continuous-wave operation where output is limited to the 400 to 1400 nm range.*

CE/CDRH Radiation Control Drawings

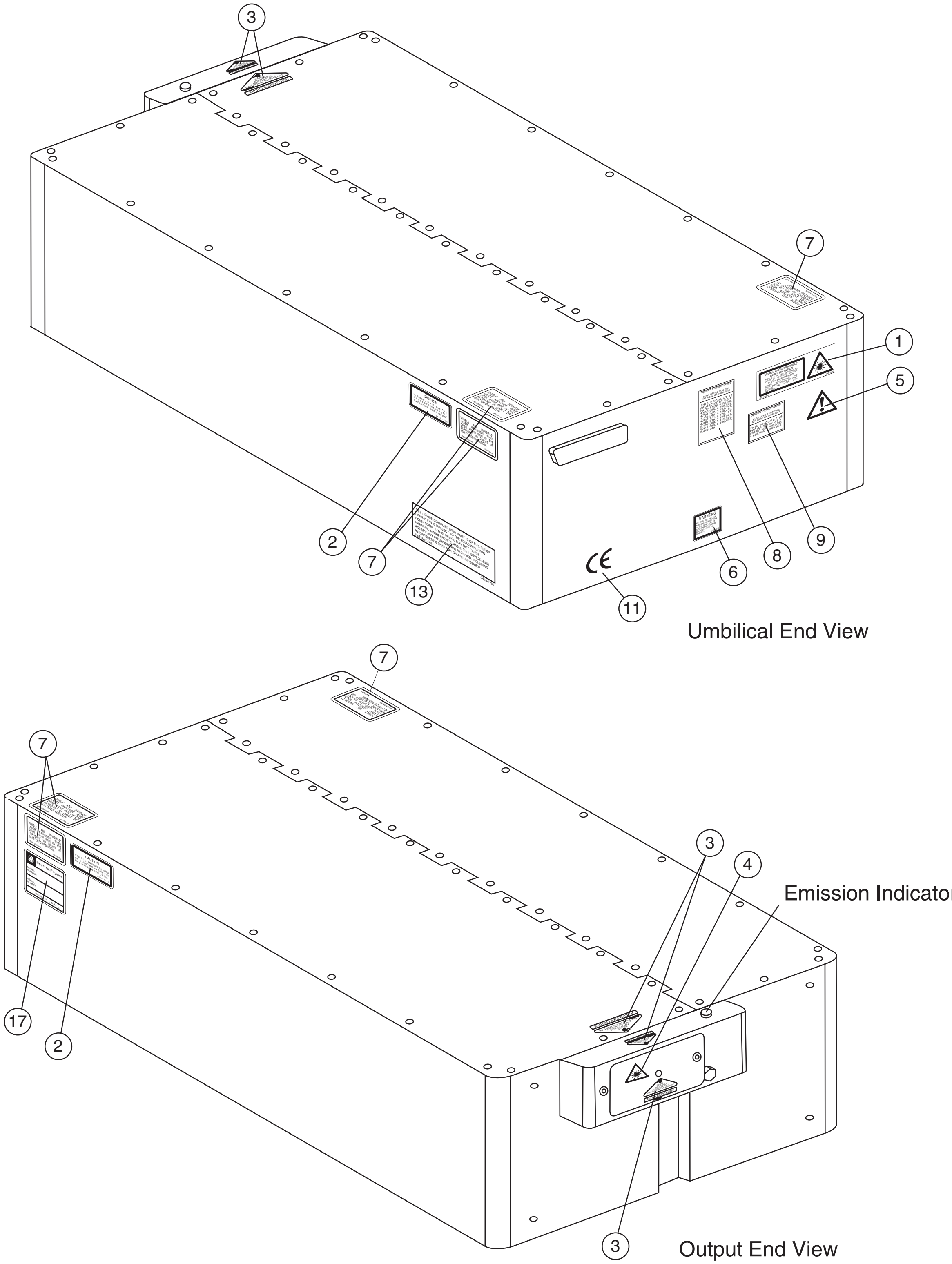


Figure 2-6: CE/CDRH Radiation Control Drawing, OEM Version (labels shown on page 2-10)

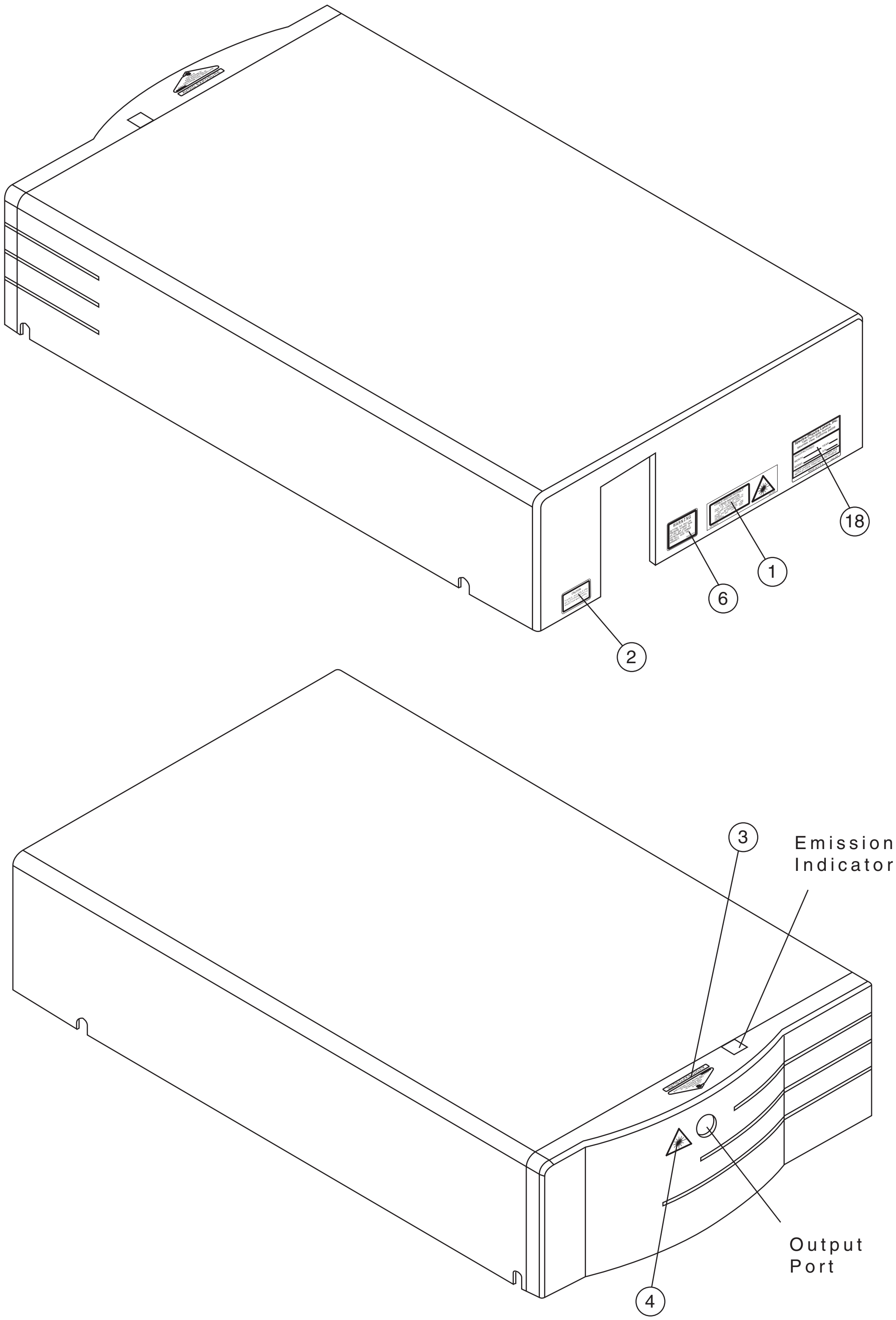


Figure 2-7: CE/CDRH Radiation Control Drawing, Scientific Version (labels shown on page 2-10)

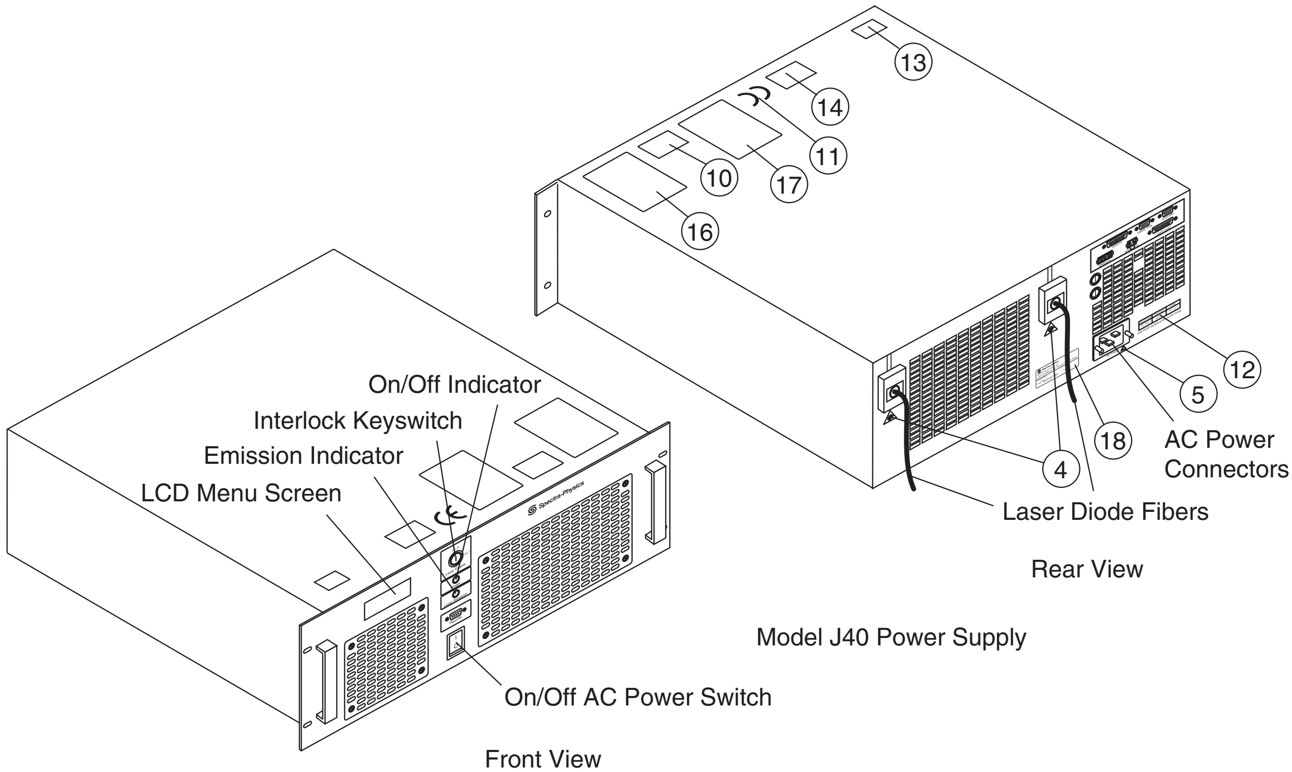


Figure 2-8: CE/CDRH Radiation Control Drawing, *Model J40* Power Supply (labels shown on page 2-10)

CE/CDRH Warning Labels

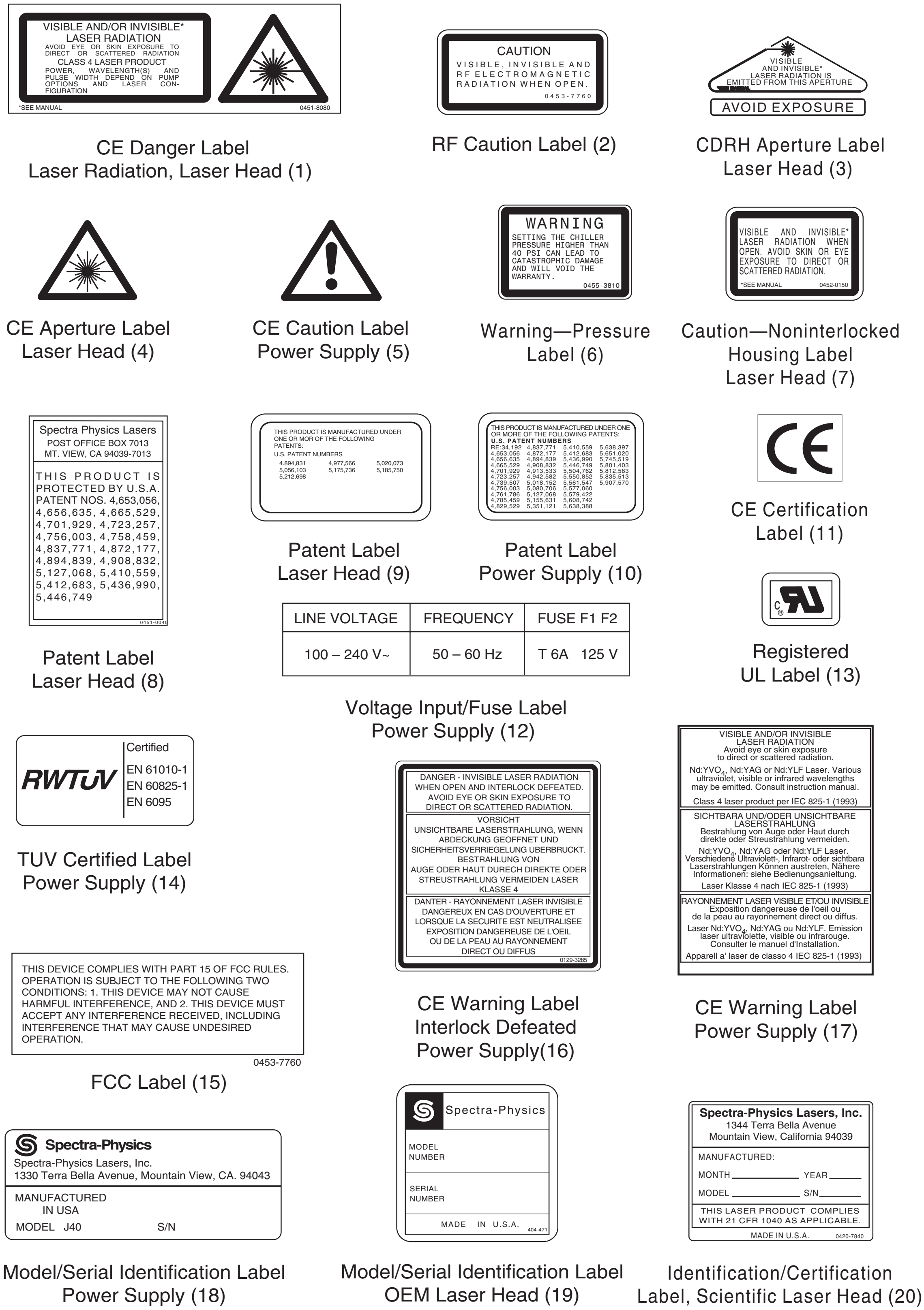


Figure 2-9: CE/CDRH Warning Labels

Label Translations

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

Table 2-1: Label Translations

Label	French	German	Spanish	Dutch
Danger Label (1)	Rayonnement Laser Visible et Invisible en Cas D'Ouverture et lorsque la securite est neutralisee; exposition dangereuse de l'œil ou de la peau au rayonnement direct ou diffus. Laser de Classe 4. Puissance et longueurs D'onde dependant de la configuration et de la puissance de pompe.	Gefahr! Sichtbare und unsichtbare Laserstrahlung! Bestrahlung von Auge oder Haut durch direkte oder Streustrahlung vermeiden! Laserklasse IV. Leistung, Wellenlänge und Pulsbreite sind abhängig von Pumpquelle und Laserkonfiguration. Bedienungsanleitung beachten!	Al abrir y retirar el dispositivo de seguridad exist radiación laser visible e invisible; evite que los ojos o la piel queden expuestos tanto a la radiación directa como a la dispersa. Producto laser clase 4. Potencia, longitud de onda y anchura de pulso dependen de las opciones de bombeo y de la configuracion del laser.	Gevaar! Zichtbare en onzichtbare laserstraling! Vermijd blootstelling van oog of huid aan directe straling of terugkaatsingen daarvan! Klas IV laser produkt. Vermogen, golflengte en pulsduur afhankelijk van pomp opties en laser konfiguratie.
Aperture Label (3)	Ouverture Laser - Exposition Dangereuse - Un Rayonnement laser visible et invisible est emis par cette ouverture.	Austritt von sichtbarer und unsichtbarer Laserstrahlung! Bestrahlung vermeiden!	Por esta abertura se emite radiacion laser visible e invisible; evite la exposicion.	Vanuit dit apertuur wordt zichtbare en onzichtbare laserstraling geemiteerd! Vermijd blootstelling!
Danger, Non Interlocked Label (7)	Attention; Rayonnement Laser Visible et Invisible en Cas D'Ouverture; Exposition Engereuse de l'œil ou de la Peau au Rayonnement Direct ou Diffus.	Vorsicht; beim Offnen Austritt von sichtbarer und unsichtbarer 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 radiaicion directa como a la dispersa.	Gevaar; zichtbare en niet zichtbare laserstraling wanneer geoend; vermijd blootsteling aan huid of oog aan disecte straling of weerkaatsingen.
Patent Label (8, 9, 15)	Ce produits est fabriqué sous l'un ou plusieurs des brevets suivants.	Dieses Produkt wurde unter Verwendung einer oder mehrerer der folgenden US-Patente hergestellt.	Este producto esta fabricado con una o más de las siguientes patentes de los Estados Unidos.	Dit product is gefabriceerd met een of meer van de volgende USA patenten.

CE Declaration of Conformity

We,

Spectra-Physics
1330 Terra Bella Avenue
Mountain View, CA. 94043
United States of America

declare under our sole responsibility that the:

Mai Tai diode-pumped, mode-locked Ti:sapphire laser system with Model J40 power supply, user-supplied or compliant pc-based controller, and Neslab Merlin 25 or Lytron Kodiak RC006 chiller

manufactured after July 1999.

to which this declaration relates is in conformance with:

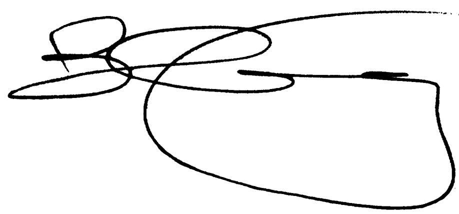
the provisions of Directive 73/23/EEC governing product safety using the following standards:

EN 60950: 1997
EN 61010-1: 2001
EN 60825-1: 1994

the provisions of Directive 89/336/EEC governing electromagnetic compatibility using the following standards:

EN 61326-1 w/A1: 1997

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



Bruce Craig
Vice President and General Manager
Spectra-Physics
Laser Group
April 5, 2002
Mountain View, California
USA

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
American Conference of Governmental and
Industrial Hygienists (ACGIH)
1330 Kemper Meadow Drive
Cincinnati, OH 45240
Tel: (513) 742-2020

Laser Institute of America
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Chapter 3 Laser Description

A Brief Review of Laser Theory

Emission and Absorption of Light

Laser is an acronym derived from Light Amplification by Stimulated Emission of Radiation. Thermal radiators, such as the sun, emit light in all directions, the individual photons having no definite relationship with one another. But because the laser is an oscillating amplifier of light, and because its output comprises photons that are identical in phase and direction, it is unique among light sources. Its output beam is singularly directional, monochromatic, and coherent.

Radiant emission and absorption take place within the atomic or molecular structure of materials. The contemporary model of atomic structure describes an electrically neutral system composed of a nucleus with one or more electrons bound to it. Each electron occupies a distinct orbital that represents the probability of finding the electron at a given position relative to the nucleus. Each orbital has a characteristic shape that is defined by the radial and angular dependence of that probability, e.g., all *s* orbitals are spherically symmetrical, and each of three all *p* orbitals lie parallel to the x, y or z axis in a double-lobed configuration with a characteristic node at the nucleus (Figure 3-1). The energy of an electron is determined by the orbital that it occupies, and the overall energy of an atom—its energy level—depends on the distribution of its electrons throughout the available orbitals. Each atom has an array of energy levels: the level with the lowest possible energy is called the ground state, and higher energy levels are called excited states. If an atom is in its ground state, it will stay there until it is excited by external forces.

Movement from one energy level to another—a transition—happens when the atom either absorbs or emits energy. Upward transitions can be caused by collision with a free electron or an excited atom, and transitions in both directions can occur as a result of interaction with a photon of light. Consider a transition from a lower level whose energy content is E_1 to a higher one with energy E_2. It will only occur if the energy of the incident photon matches the energy difference between levels, i.e.,

$$h\nu = E_2 - E_1 \qquad [1]$$

where h is Planck's constant, and ν is the frequency of the photon.

"Light" will be used to describe the portion of the electromagnetic spectrum from far infrared to ultraviolet.

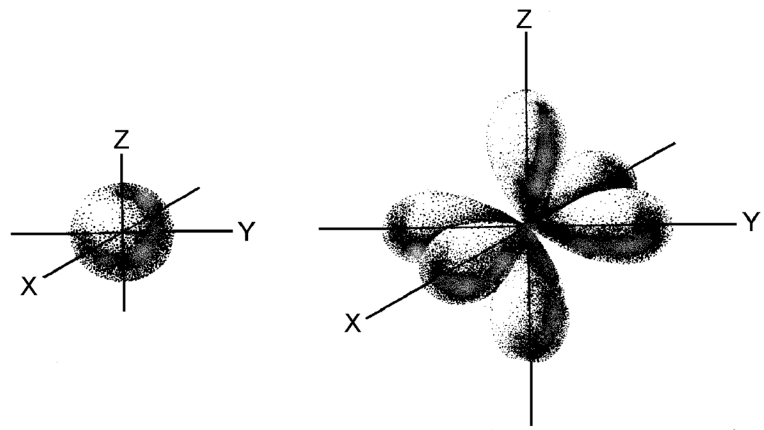


Figure 3-1: Electrons occupy distinct orbitals that are defined as the probability of finding an electron at a given position. The shape of the orbital is determined by the radial and angular dependence of this probability.

Likewise, when an atom excited to E_2 decays to E_1, it loses energy equal to $E_2 - E_1$. The atom may decay spontaneously, emitting a photon with energy $h\nu$ and frequency

$$\nu = \frac{E_2 - E_1}{h} \qquad [2]$$

Spontaneous decay can also occur without emission of a photon, the lost energy taking another form, e.g., transfer of kinetic energy by collision with another atom. An atom excited to E_2 can also be stimulated to decay to E_1 by interacting with a photon of frequency ν, emitting energy in the form of a pair of photons that are identical to the incident one in phase, frequency, and direction. This is known as stimulated emission. By contrast, spontaneous emission produces photons that have no directional or phase relationship with one another.

A laser is designed to take advantage of absorption, and both spontaneous and stimulated emission phenomena, using them to create conditions favorable to light amplification. The following paragraphs describe these conditions.

Population Inversion

The net absorption at a given frequency is the difference between the rates of emission and absorption at that frequency. It can be shown that the rate of excitation from E_1 to E_2 is proportional to both the number of atoms in the lower level (N_1) and the transition probability. Similarly, the rate of stimulated emission is proportional to the population of the upper level (N_2) and the transition probability. Moreover, the transition probability depends on the flux of the incident wave and a characteristic of the transition called its "cross section." The absorption coefficient depends only on the difference between the populations involved, N_1 and N_2, and the flux of the incident wave.

When a material is at thermal equilibrium, there exists a Boltzmann distribution of its atoms over the array of available energy levels with most atoms in the ground state. Since the rate of absorption of all frequencies exceeds that of emission, the absorption coefficient at any frequency is positive.

If enough light of frequency ν is supplied, the populations can be shifted until $N_1 = N_2$. Under these conditions the rates of absorption and stimulated emission are equal, and the absorption coefficient at frequency ν is zero. If the transition scheme is limited to two energy levels, it is impossible to drive the populations involved beyond equality; that is, N_2 can never exceed N_1 because every upward transition is matched by one in the opposite direction.

However, if three or more energy levels are employed, and if their relationship satisfies certain requirements described below, additional excitation can create a population inversion where the population of the intermediate state, N_3, exceeds N_1. This population scheme favors stimulated emission for the N_3–N_1 transition.

A model four-level laser transition scheme is depicted in Figure 3-2. A photon of frequency ν_1 excites—or "pumps"—an atom from E_1 to E_4. If the E_4 to E_3 transition probability is greater than that of E_4 to E_1, and if the lifetime of an atom at E_4 is short, the atom will decay almost immediately to E_3. If E_3 is metastable, i.e., atoms that occupy it have a relatively long lifetime, the population will grow rapidly as excited atoms cascade from above. The E_3 atom will eventually decay to E_2, emitting a photon of frequency ν_2. Finally, if E_2 is unstable, its atoms will rapidly return to the ground state, E_1, keeping the population of E_2 small and reducing the rate of absorption of ν_2. In this way the population of E_3 is kept large and that of E_2 remains low, thus establishing a population inversion between E_3 and E_2. Under these conditions, the absorption coefficient at ν_2 becomes negative. Light is amplified as it passes through the material, which is now called an "active medium." The greater the population inversion, the greater the gain.

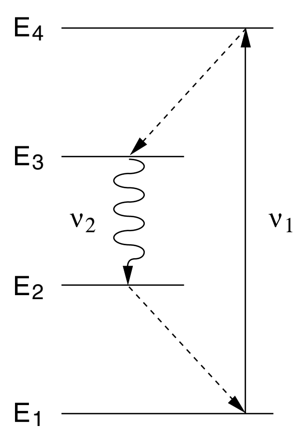


Figure 3-2: A Typical Four-level Transition Scheme

A four-level scheme has a distinct advantage over three-level systems, where E_1 is both the origin of the pumping transition and the terminus of the lasing transition. Also, the first atom that is pumped contributes to the population inversion in the four-level arrangement, while over half of the atoms must be pumped from E_1 before an inversion is established in the three-level system.

Resonant Optical Cavity

To sustain lasing action, the gain medium must be placed in a resonant optical cavity. The latter can be defined by two mirrors which provide feedback to the active medium, i.e., photons emitted parallel to the cavity axis are reflected back into the cavity to interact with other excited states. Stimulated emission produces two photons of equal energy, phase, and direction from each interaction. The two photons become four, four become eight, and the numbers continue to increase geometrically until an equilibrium between excitation and emission is reached.

Both cavity mirrors are coated to reflect the wavelength, or wavelengths, of interest while transmitting all others. One of the mirrors, the output coupler, transmits a fraction of the energy stored within the cavity, and the escaping radiation becomes the output beam of the laser.

The laser oscillates within a narrow range of frequencies around the transition frequency. The width of the frequency distribution, the "linewidth," and its amplitude depend on the gain medium, its temperature, and the magnitude of the population inversion.

Linewidth is determined by plotting gain as a function of frequency and measuring the width of the curve where the gain has fallen to one half maximum ("full width at half maximum", or FWHM, Figure 3-3).

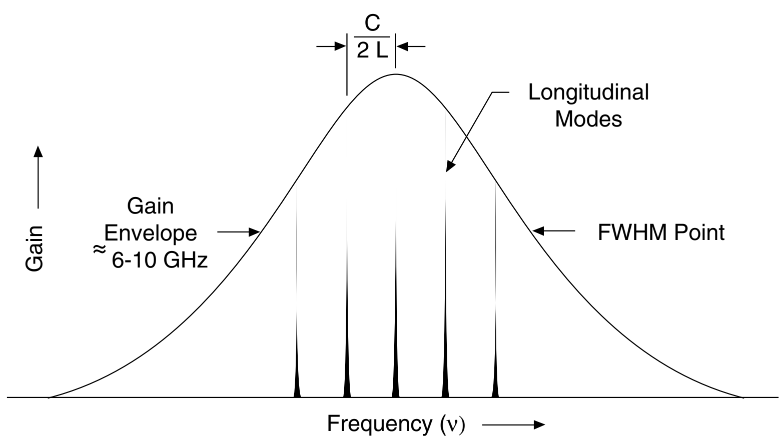


Figure 3-3: Frequency Distribution of Longitudinal Modes for a Single Line

The output of the laser is discontinuous within this line profile. A standing wave propagates within the optical cavity, and any frequency that satisfies the resonance condition

$$\nu_m = \frac{mc}{2L} \quad [3]$$

will oscillate, where ν_m is the frequency, c is the speed of light, L is the optical cavity length, and m is an integer. Thus, the output of a given line is a set of discrete frequencies, called "longitudinal modes," that are spaced such that

$$\Delta n = \frac{c}{2L} \quad [4]$$

Nd^{3+} as a Laser Medium

In commercial laser designs, the source of excitation energy for the gain medium is usually optical or electrical. Arc lamps are often employed to pump solid-state lasers, and the output of one laser can be used to pump another, e.g., a Ti:sapphire laser can be pumped by an argon ion laser or a diode laser can be used to pump a solid state laser. An electric discharge is generally used to excite gaseous media like argon or krypton. The *Mai Tai* pump laser uses the output from a diode laser to pump Nd^{3+} ions doped in a yttrium vanadate crystalline matrix ($Nd:YVO_4$).

The properties of neodymium-doped matrices, such as yttrium aluminum garnet (Nd:YAG) and yttrium lithium fluoride (Nd:YLF), are the most widely studied and best understood of all solid-state laser media. The four-level Nd^{3+} ion scheme is shown in Figure 3-4. The active medium is triply ionized neodymium which has principle absorption bands in the red and near infrared. Excited electrons quickly drop to the $^4F_{3/2}$level, the upper level of the lasing transition, where they remain for a relatively long time (about 60 µs for $Nd:YVO_4$).

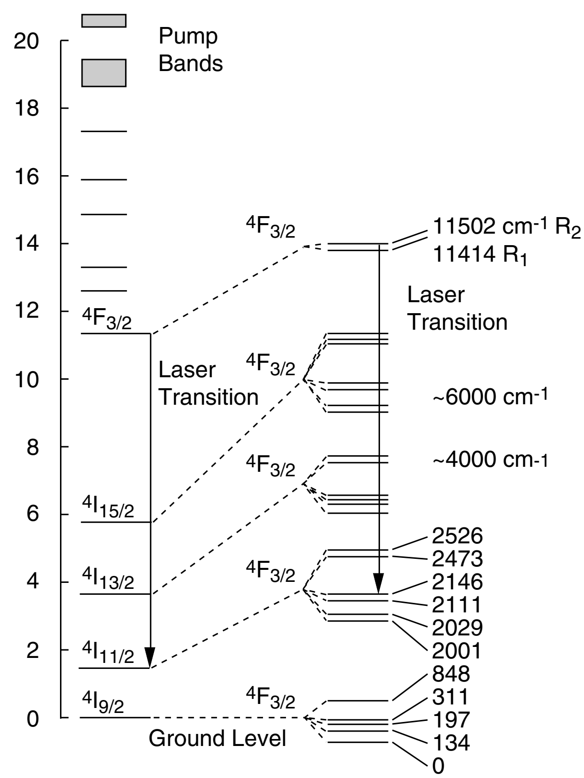


Figure 3-4: Energy Level Scheme for the Nd^{3+} Ion.

The most probable lasing transition is to the $^4I_{1/2}$state, where a photon at 1064 nm is emitted. Because electrons in that state quickly relax to the ground state, its population remains low. Hence, it is easy to build a population inversion. At room temperature the emission cross section of this transition is high, so its lasing threshold is low. While there are competing transitions from the same upper state, most notably at 1319, 1338, and

946 nm, all have lower gain and a higher threshold than the 1064 nm transition. In normal operation, these factors and wavelength-selective optics limit oscillation to 1064 nm.

Diode-pumped Laser Design

Laser diodes combine very high brightness, high efficiency, monochromaticity and compact size in a near-ideal source for pumping solid-state lasers. Figure 3-5 shows the monochromaticity of the emission spectra of a laser diode compared to a krypton arc lamp and a black body source and compares that with the absorption spectra of the Nd^{3+} ion. The near-perfect overlap of the diode laser output with the Nd^{3+} absorption band ensures that the pump light is efficiently coupled into the laser medium. It also reduces thermal loading since any pump light *not* coupled into the medium is ultimately removed as heat.

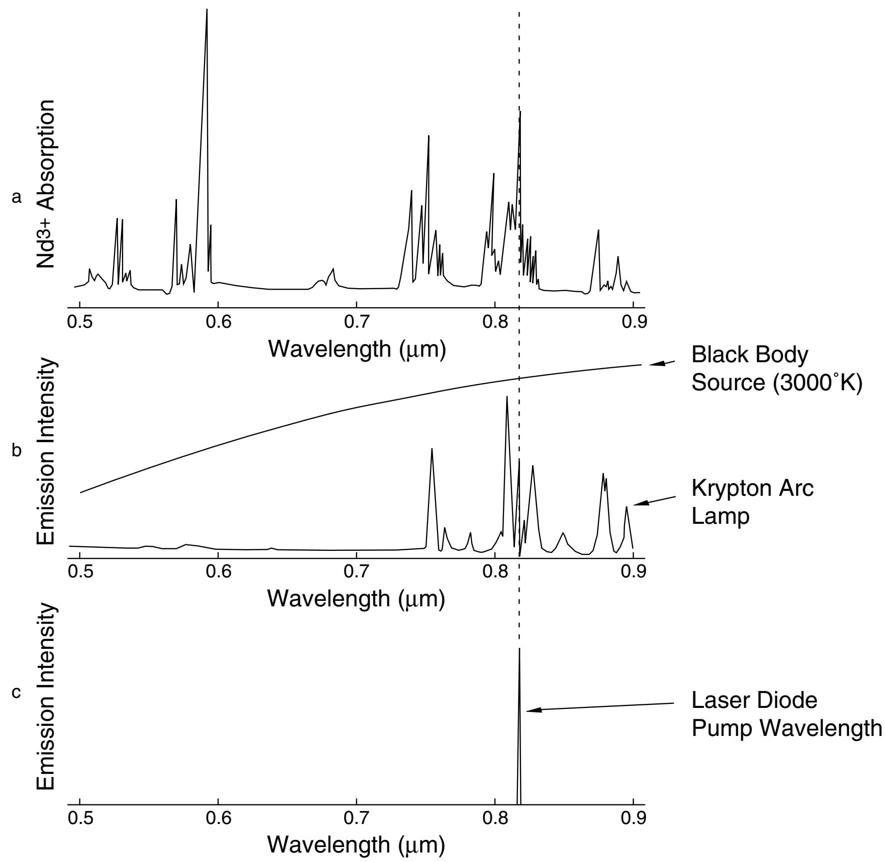


Figure 3-5: Nd^{3+} absorption spectra compared to emission spectra of (a) a Black Body Source, (b) a Krypton Arc Lamp and (c) a Laser Pump Diode.

One of the key elements in optimizing the efficiency of a solid-state laser is maximizing the overlap of the regions of the active medium excited by the pumping source and the active medium occupied by the laser mode. The maximization of this overlap is often called mode matching, and in most applications, TEM_{00} is the laser mode that is most desired. A longitudinal pumping geometry provides this sort of optimal mode-match.

Longitudinal pumping allows the diode output to be focused on a volume in the active medium that best matches the radius of the TEM_{00} mode. In general, the TEM_{00} mode radius is chosen to be as small as possible to minimize the solid-state laser threshold. Figure 3-6 shows a schematic of a mode-matching design of this type.

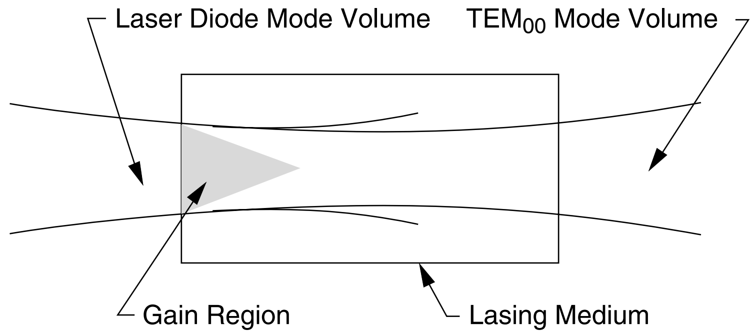


Figure 3-6: Mode Matching

For higher output power levels, a larger laser diode having a larger emission region is necessary. The diameter of the TEM_{00} mode volume must also be expanded to effectively mode-match the volume of the extended diode emission region. However, increasing the TEM_{00} mode volume raises the solid-state laser threshold. This is undesirable when attempting to create an efficient laser diode design.

At Spectra-Physics, we use laser diode bars made from a single monolithic piece of semiconductor material which typically contains ten to twenty laser diodes. The bars are ideal as high power pump sources. These devices have the same high efficiency as the discrete diode devices, yet they allow for the manufacture of a much simpler and more reliable high-power pump laser design than is possible in a design incorporating an equal number of discrete devices (for the same output power level). However, the active emission area for these new devices is increased from the 200 µm range found in low power diodes, to 1 cm: a "ribbon of light." The use of these bars has, therefore, been limited due to the difficulty of mode matching their outputs.

A number of attempts were recently made by some manufacturers to couple the output of a laser diode bar into a multimode optical fiber. The results have been discouraging, so far, with coupling efficiencies on the order of 60–70% with a numerical aperture of 0.4. This makes for an expensive, inefficient pump source.

At Spectra-Physics, we have developed and patented a vastly more efficient method of fiber coupling the output of the laser diode bar. It is called FC*bar*™. With this method, it is possible to achieve coupling efficiencies in excess of 90% with a numerical aperture of 0.1. With such high coupling efficiency and brightness, high power diode-pumped laser designs are readily achieved.

Frequency Doubling

In the *Mai Tai* pump laser, the high output power from the laser diodes is used to end-pump the $Nd{:}YVO_4$, or Vanadate, lasing medium. The resulting 1064 nm output is converted to the visible through frequency doubling or second harmonic generation in a nonlinear crystal. The *Mai Tai* pump laser uses a 90°, noncritically phase-matched, temperature-tuned lithium triborate (LBO) nonlinear crystal as its doubling medium. Although LBO has a lower nonlinear coefficient than other materials, it offers several advantages: (a) noncritical phase matching means collinear fundamental and second harmonic beams which facilitates alignment, (b) there is no spatial "walk-off" of the fundamental and second harmonic beams, which preserves the high spatial mode quality and favors a long interaction length for higher gain, and (c) the crystal can be easily optimized for maximum conversion efficiency by simply changing its temperature (with no realignment of the laser cavity).

In frequency doubling, the second harmonic power ($P_{2\omega}$) is given by:

$$P_{2\omega} \ \alpha \ \frac{d_{eff}^2 P_\omega^2 l^2 [\phi]}{A} \qquad [5]$$

where d_{eff} is the effective nonlinear coefficient, P_ω is the fundamental input power, l is the effective crystal length, $[\phi]$ is a phase-matching factor, and A is the cross-sectional area of the beam in the crystal. Since the second harmonic output is dependent upon the square of the fundamental peak power, very high conversion efficiencies can be achieved by enhancing the intensity of the fundamental wave through intracavity frequency doubling or through the use of an external-cavity resonant-doubler. The former is used in the *Mai Tai* pump laser.

Historically, free-running intracavity-doubled diode-pumped solid state lasers have typically yielded chaotic output with large amplitude fluctuations that render the laser output useless for most scientific applications. This was first identified at Spectra-Physics over ten years ago* in a short cavity diode-pumped Nd:YAG laser with a KTP intracavity doubler; it has since become known as the "green problem." Part of the cause of the instability arises from nonlinear coupling of axial modes via sum-frequency mixing in the laser cavity. The problem can be circumvented by forcing oscillation on a single longitudinal mode. However, this adds considerable complexity to the laser, since it requires an actively stabilized ring cavity (and it may also have power limitations). The *Mai Tai* pump laser overcomes this chaotic noise problem with the simple, patented, QMAD (quiet multiaxial mode doubling) solution, which makes use of many axial modes (see Figure 3-7).

* *T. Baer. J. Opt. Soc. Am. B3, 1175 (1986).*

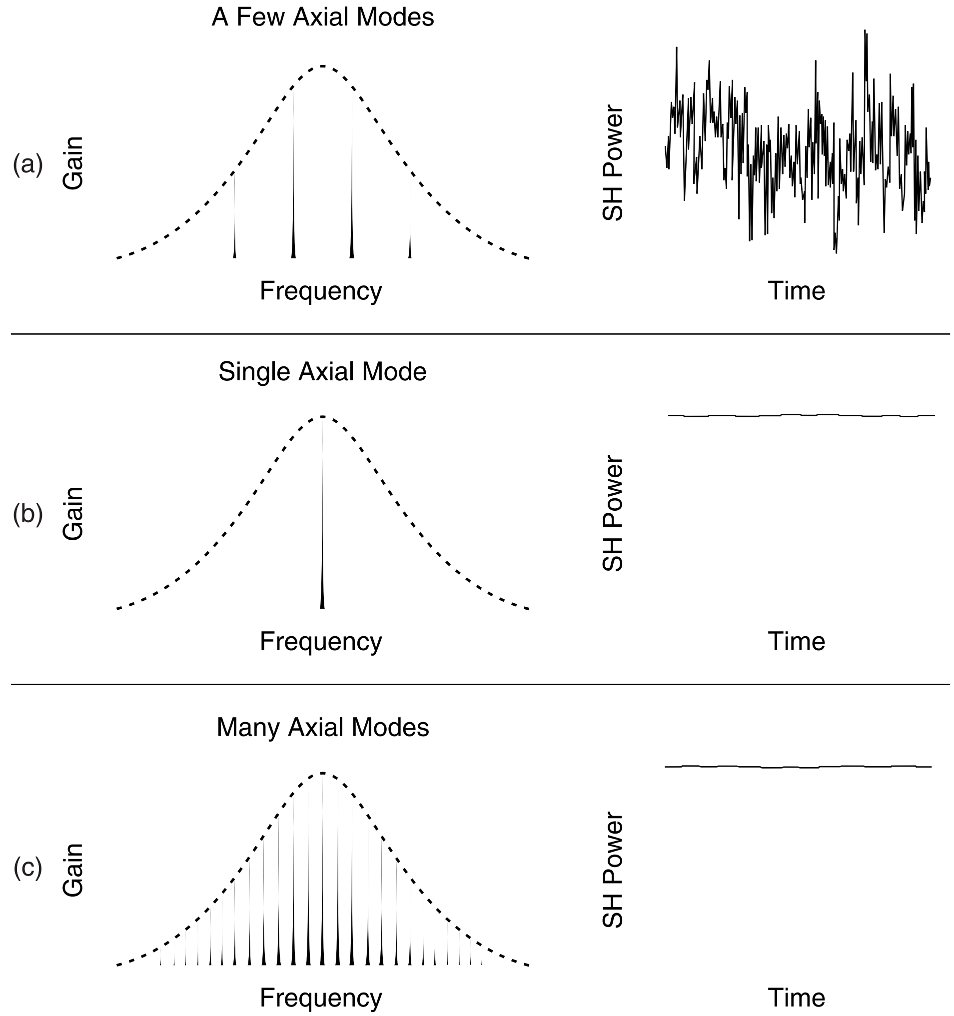


Figure 3-7: The quiet multiaxial mode-doubling (QMAD) solution to the "green problem." (a) The "green problem." Intracavity frequency doubling in a laser with a few axial modes produces large amplitude fluctuations in the second harmonic output resulting from nonlinear coupling of the modes through sum-frequency mixing. (b) The single-frequency solution forces oscillation on a single axial mode to eliminate mode coupling. (c) The QMAD solution produces oscillation on many axial modes, effectively averaging the nonlinear coupling terms to provide highly stable second-harmonic output.

In the *Mai Tai* pump laser, the laser cavity allows oscillation of over 100 longitudinal modes. This facilitates quiet intracavity doubling by reducing the relative power in each axial mode so that no one mode reaches sufficient peak power to induce high nonlinear loss. Effectively, there is an averaging of the nonlinear coupling terms and the resultant frequency-doubled output exhibits extremely low amplitude noise (about an order of magnitude lower than that of an ion laser).

Ti:sapphire as a Laser Medium

The Ti^{3+} titanium ion is responsible for the laser action of Ti:sapphire. Ti:sapphire is a crystalline material produced by introducing Ti_2O_3 into a melt of Al_2O_3. A boule of material is grown from this melt where Ti^{3+} ions are substituted for a small percentage of the Al^{3+} ions. The electronic ground state of the Ti^{3+} ion is split into a pair of vibrationally broadened levels as shown in Figure 3-8.

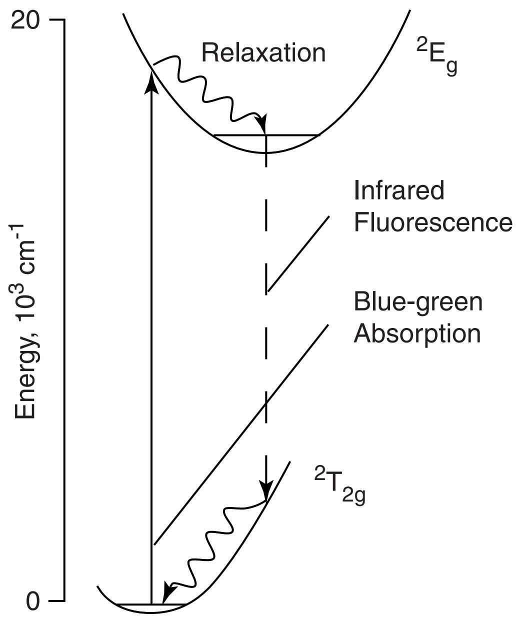


Figure 3-8: Absorption and emission spectra of Ti:sapphire

Absorption transitions occur over a broad range of wavelengths from 400 to 600 nm, only one of which is shown in Figure 3-8. Fluorescence transitions occur from the lower vibrational levels of the excited state to the upper vibrational levels of the ground state. The resulting emission and absorption spectra are shown in Figure 3-9.

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

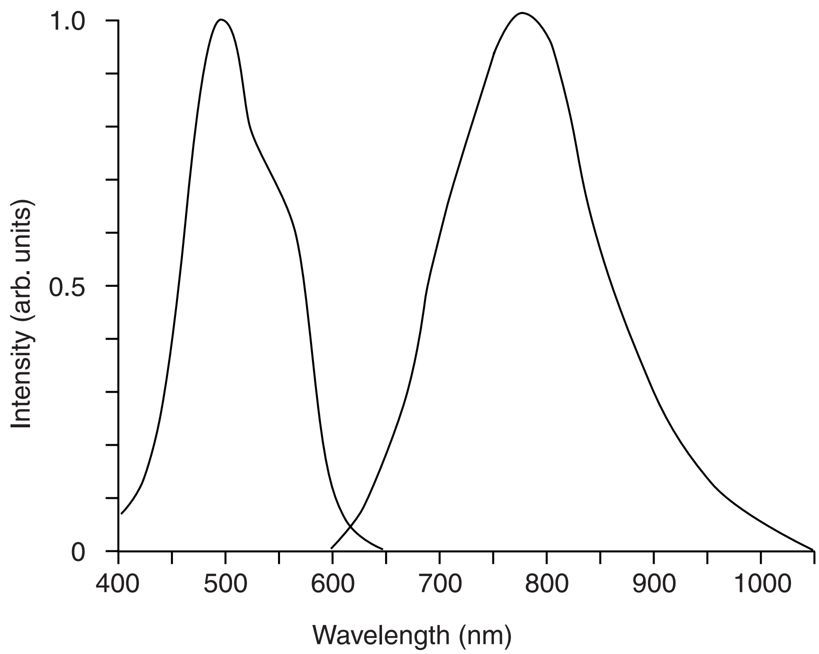


Figure 3-9: Energy level structure of Ti^{3+} in sapphire

Pumping Optimization

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

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

The Mai Tai CW Pump Chamber

General

The output from two high-power, fiber-coupled laser diode bars (**FC*bar***™*)* is used to end-pump the Vanadate laser gain medium in the *Mai Tai* pump laser. The **FC*bar*** design allows the diode bars to be placed in the power supply, which removes their heat load from the laser head. It also facilitates their field replacement without requiring a realignment of the *Mai Tai* pump laser.

The non-critically phase-matched LBO crystal in the cavity converts the intracavity light to the green 532 nm wavelength. The patented Quiet Multi-Axial Mode Doubling (QMAD) technique provides exceptionally low-noise performance. It uses a very large number of axial modes and balances gain, nonlinear conversion, and excited-state lifetime to provide high power and extremely stable amplitude.

Virtually all the doubled light passes through the dichroic output coupler where the beam is then directed out of the laser. A beam splitter and photodiode sample the output and provide feedback to the pump diode drivers to provide a constant output in power mode operation.

The laser head is designed for maximum reliability with minimum complexity. The inherent operation is so stable and the output so quiet that no adjustments are needed. Control of the entire system is provided via a simple Windows®-based program running on a laptop pc.

The Vanadate laser crystal is the "driving engine" of the *Mai Tai* pump laser. The crystal is end-pumped by two fiber-coupled diode bar (**FC*bar***) modules and it provides a very high CW, small-signal gain. It is capable of producing over 10 W of near diffraction-limited, 1064 nm infrared power with a conversion efficiency greater than 50%.

The outputs from the two pump diode modules in the power supply are fiber-coupled into the laser head and focused into each end of the Vanadate crystal. The diode pump light is absorbed by the crystal and emitted as 1064 nm output, which resonates in the *Mai Tai* pump laser cavity and is amplified through stimulated emission.

Frequency Doubling

Frequency-doubling converts the 1064 nm light from the laser crystal to green 532 nm laser output.

For maximum intracavity frequency doubling conversion efficiency, a non-critically phase-matched, temperature-tuned LBO crystal is used. It offers a large acceptance angle, which makes it insensitive to any slight misalignment of the *Mai Tai* pump laser cavity. A compact, low-power, temperature-regulating oven is used to maintain the crystal at the appropriate phase-matching temperature to keep the 532 nm output power optimized.

Windows is a registered trademark of Microsoft Corporation.

QMAD technology (patent number 5,446,749) allows the *Mai Tai* pump laser to provide greater than 5 watts of exceptionally stable, low-noise, frequency-doubled light. It provides a stable balance of:

- a very large number of axial modes (typically hundreds),
- small signal gain,
- gain saturation,
- nonlinear conversion,
- long excited state lifetime, and
- long cavity lifetime.

This allows the *Mai Tai* pump laser to use intracavity doubling within a simple, linear, X-Cavity design. The result is a high-power, multiaxial-mode pump laser that exhibits extremely low noise performance with very high reliability, and a doubled beam that has a smooth intensity distribution and is near diffraction limited.

Beam Delivery

A dichroic output coupler allows the 532 nm light to exit the cavity while reflecting the 1064 nm light back into the cavity.

Unlike other systems that require multiple feedback loops to maintain stable output, the *Mai Tai* pump laser is inherently stable within its operating range. It requires only one simple feedback loop to maintain its exceptional performance and maintain constant output power. The light pick-off is an integral part of the system.

The Mai Tai Pulsed Output Chamber

The Folded Cavity

Because the second stage of the *Mai Tai* is a mode-locked laser, a cavity longer than that in a CW laser is required in order to allow it to run at convenient repetition frequencies near 80 MHz. Spectra-Physics modeled, analyzed, and optimized this cavity design for optimum performance in minimal space.

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

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

Mode Locking Device

The *Mai Tai* uses an acousto-optic modulator (AOM) to ensure reliable mode-locked operation when the laser starts up and provides smooth wavelength tuning. It also allows the laser to operate for extended periods without dropouts or shut-downs associated with pure Kerr lens mode locking. The AOM is driven by a regeneratively derived RF signal. To reduce complexity, the heater and RF driver circuits for the mode locker are located in the laser head.

Wavelength Tuning Characteristics

Because the Ti:sapphire rod is birefringent, uninterrupted tuning is achieved when the c-axis of the rod is aligned coplanar with the polarization of the electric field within the cavity.

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

The standard wavelength tuning range is 750 to 850 nm while the extended mid-tuning range is 780 to 920 nm. Tuning curves for these ranges are shown in the Specifications section later in this chapter.

The drivers and control circuits for wavelength selection are located in the laser head.

Wavelength Selection

The fs pulse laser is wavelength tuned using a prism sequence and a slit. The prism sequence provides a region in the cavity where the wavelengths are spatially spread, and the slit is placed in this dispersed beam. By changing the position of the slit in the dispersed beam, the output wavelength is tuned.

Pulse Width

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

Prism pairs are used in the *Mai Tai* to produce a net variable negative intracavity GVD in the cavity. This compensation scheme is fully automated and results in an optimized pulse at any chosen wavelength within the tuning range.

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

The Model J40 Power Supply

The *Model J40* contain the two laser diode modules, a TEC cooler to maintain the temperature of these two modules, a multi-output dc power supply that provides low voltage to all the control circuits and the two high-current supplies for the diode lasers, and an air-cooling system. The front panel provides boot information and system status and error codes during operation. Chapter 4 provides connection information and Chapter 6 provides information on operating the system and explains the software commands.

FCbar

The pump source for the *Mai Tai* pump laser consists of two diode laser bars, each capable of producing 20 W. Each "fiber-coupled bar," or **FC*bar***, is coupled to an optical bundle that transports the diode output to one end of the laser crystal in the laser head.

The FCbar System

FC*bar* technology enables the high power levels available from the laser diode bars to efficiently end-pump the Vanadate laser crystal. The output of the bar is collimated with a cylindrical microlens of high numerical aperture, which is bonded to the diode bar in order to reduce the fast-axis divergence of the diode bar. The highly asymmetric light is then coupled into a fiber bundle, which in turn delivers exceptional brightness to the crystal. To stabilize the output wavelength of the diodes, the modules are mounted directly on a temperature regulated cold plate.

Because the coupling technology is so efficient, the 20 W diode modules are typically derated to 75% to increase their operating lifetime.

The multimode optical fiber bundle is actually several fibers that are drawn together in a round bundle where the output end is typically 1 to 1.5 mm in diameter with a numerical aperture of about 0.1. Typically, 85 to 90 percent of the diode light is transmitted by the bundle; thus, up to 13 W of usable output is available from each derated laser diode bar at the output of the fiber bundle.

The **FC*bar*** modules mate with the fiber bundle through precision connections that are assembled and aligned at the factory. The bundles are then terminated at the laser head with industry standard fiber-optic connectors. This provides a precise and repeatable attachment of the bundle to the laser head and allows the **FC*bar*** modules to be replaced in the field, if necessary, without requiring an alignment of the cavity.

The Control Device

A special version of LabWindows™ software is provided by Spectra-Physics for controlling the *Mai Tai* system. It can be installed on your own Windows®-based personal computer or on the notebook computer optionally sold with the system. You can also use a remote computer or terminal to control the *Mai Tai* automatically using your own software program. The *Mai Tai* command language is described in Chapter 6, "Operation," as is operation of the laser using such a program.

LabWindows is a trademark of National Instruments Corporation
Windows is a registered trademark of Microsoft Corporation

Specifications

The table below lists performance specifications for the *Mai Tai* laser systems. The table on the following page lists the environmental specifications.

Table 3-1: *Mai Tai* Specifications

Output Characteristics[1]	**800 nm**	**850 nm**
Average Power[2]	> 700 mW	>650 mW
Peak Power[2]	> 88 kW	>82 KW
Pulse Width[2,3]	< 100 fs	<100 fs
Tuning Range[4,5]	750–850 nm	780–920 nm
Repetition Rate[6]	80 MHz	
Noise[7]	< 0.2%	
Stability[8]	< 2%	
Spatial Mode	TEM_{00}	
Beam Diameter at $^1/e^2$ points	< 2 mm	
Beam Divergence, full angle	< 1 mrad	
Polarization	> 500:1 horizontal	
Size (L x W x H)		
Laser Head, Scientific	23.44 × 13.79 × 5.38 in. (59,54 × 35,03 × 13,65 cm)	
Laser Head, OEM	19.50 × 13.25 × 5.08 in. (49,53 × 33,66 × 12,92 cm)	
Model J40 Power Supply	17.9 × 19.0 × 6.9in. (51,3 × 40,6 × 37,8 cm)	
Chiller	15.9 × 10.3 × 25.0 in. (45,5 × 48,3 × 17,5 cm)	
Umbilical Length	10 ft (3 m)	
Weight		
Laser Head, Scientific	70 lb (31,8 kg)	
Laser Head, OEM	65 lb (29,5 kg)	
Model J40 Power Supply	49.5 lb (22,5 kg)	
Chiller, Neslab Merlin 25	86 lb (39,0 kg)	
Power Requirements		
Model J40 Power Supply	90 to 260 Vac (auto-ranging), <10 A, 50/60 Hz	
Chiller, Neslab Merlin 25	110 Vac, < 10 A, 60 Hz or 220 Vac, <6 A, 50 Hz	

[1] *Due to our continuous product improvement program, specifications may change without notice.*
[2] *Specifications apply to operation at the wavelength noted.*
[3] *A $sech^2$ pulse shape (0.65 deconvolution factor) is used to determine the pulse width as measured with a Spectra-Physics Model 409 autocorrelator.*
[4] *For other tuning range requirements please call your local Spectra-Physics representative.*
[5] *Mai Tai is also available with a fixed factory preset wavelength within the wavelength ranges noted.*
[6] *Laser operation is specified at a nominal repetition rate of 80 MHz.*
[7] *Specification represents rms measured in a 10 Hz to 10 MHz bandwidth.*
[8] *Percent power drift in any 2-hour period with less than ±1°C temperature change after a 1-hour warm-up.*

Table 3-2: Environmental Specifications

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

Typical Tuning Curves

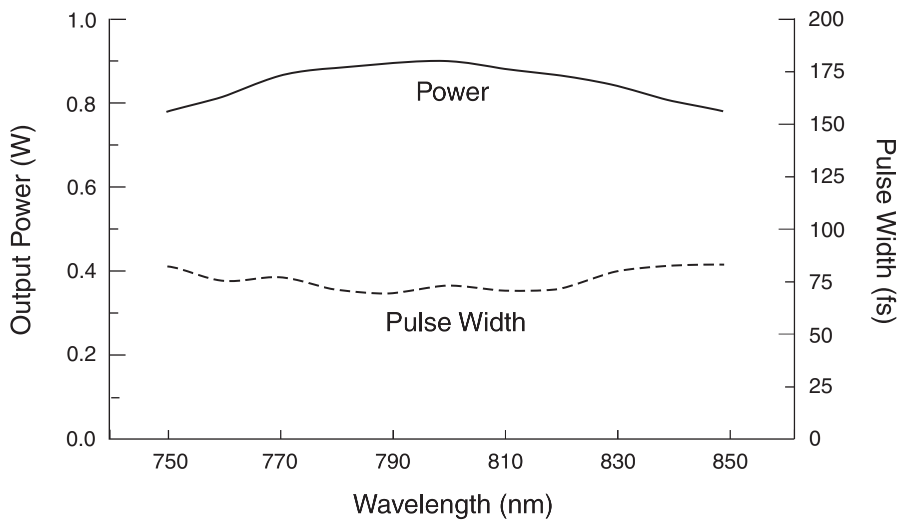


Figure 3-10: ***Mai Tai*** **fs tuning curves for the standard tuning range.**

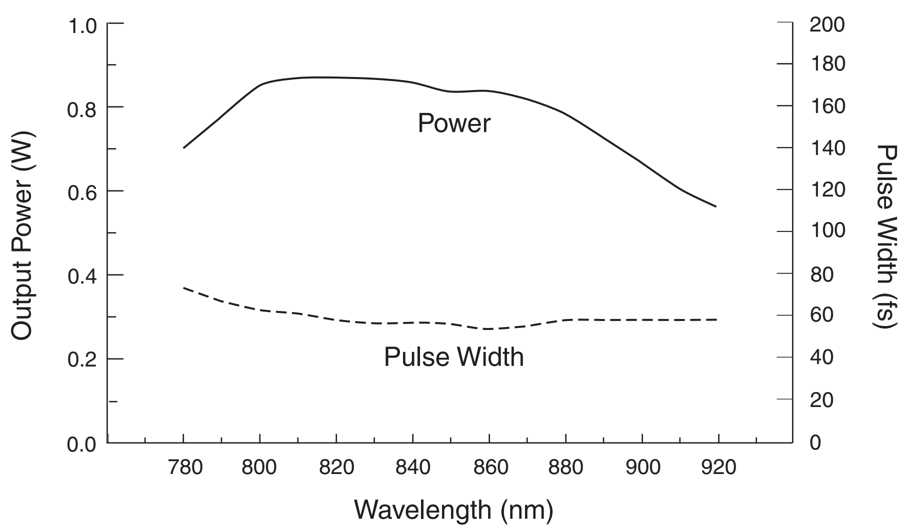
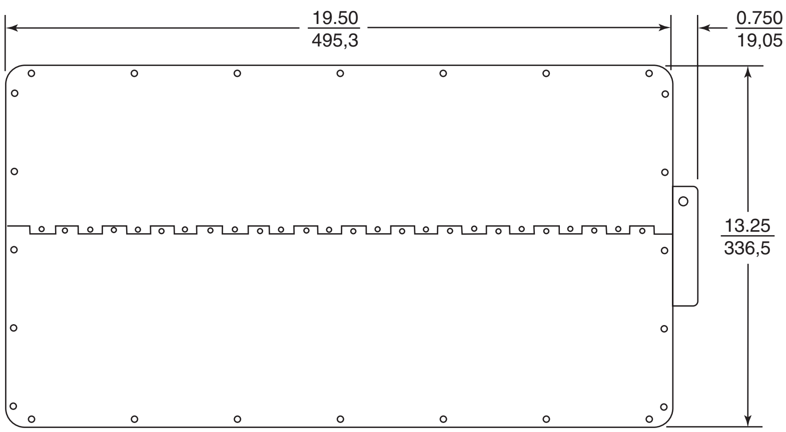
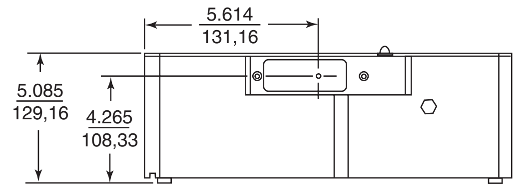


Figure 3-11: ***Mai Tai*** **fs tuning curves for the extended mid tuning range.**

Outline Drawings

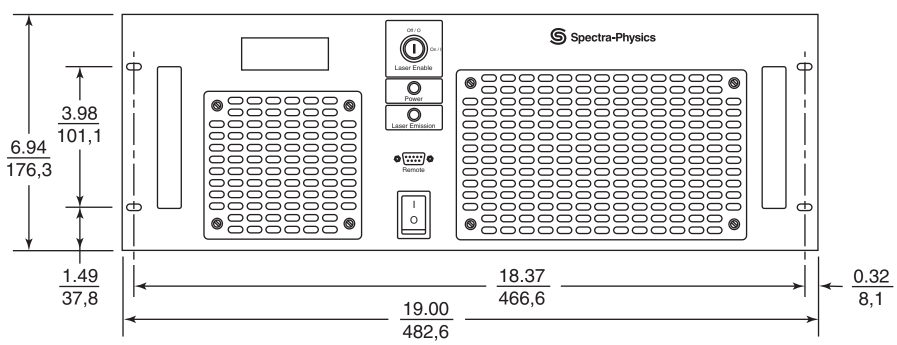


Mai Tai OEM, Top View

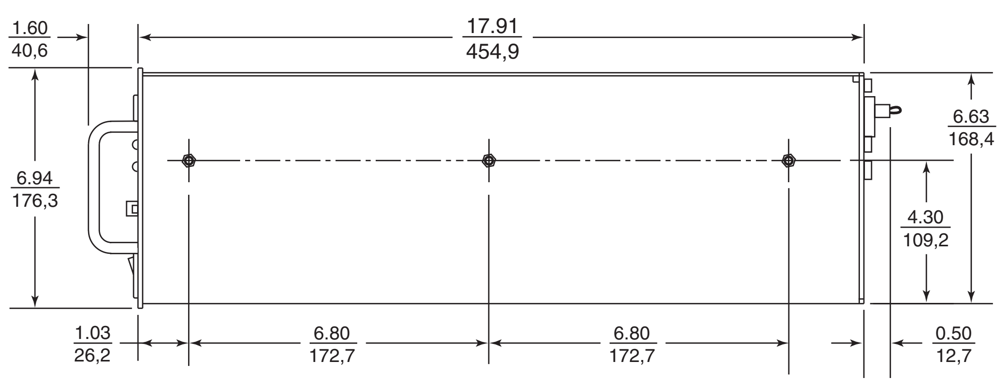


Mai Tai OEM, Output End View

All dimensions in inches/mm



Model J40 Control Panel



Model J40 Side View

Figure 3-12: Outline Drawing, *Mai Tai* OEM Laser Head and *Model J40* Power Supply

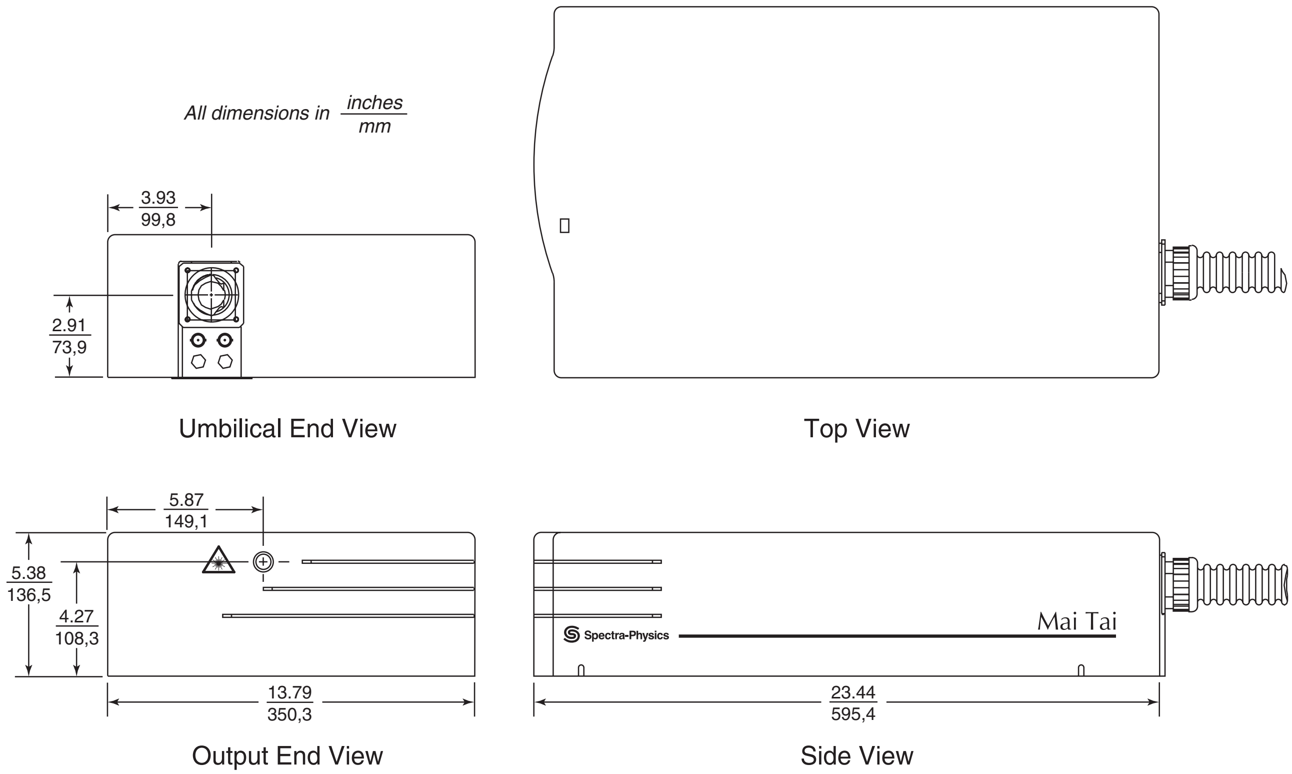


Figure 3-13: Outline Drawing, *Mai Tai* Scientific Laser Head

Chapter 4 Controls, Indicators and Connections

Introduction

This section defines the user controls, indicators and connections of the *Mai Tai*™ laser system. It is divided into three sections: the *Mai Tai* laser head, the *Model J40* power supply and the laptop pc controller. Information on the chiller can be found in the chiller user's manual.

The *Mai Tai* Laser Head

Controls

There are none.

Indicators

Emission indicator light—warns of present or imminent laser radiation. This white-light CDRH indicator is located on top of the laser near the output bezel. A built-in delay between the turn on of the lamp and actual emission allows for evasive action in the event the system was started by mistake and the shutter is open.

Connections

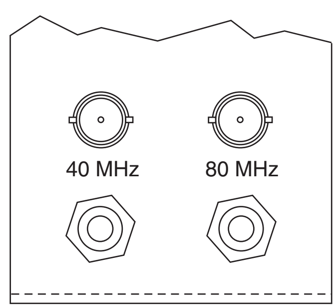


Figure 4-1: The umbilical attachment panel showing the 40 MHz and 80 MHz BNC connectors.

Umbilical attachment panel—(part of which is shown in Figure 4-1) anchors the umbilical to the rear of the laser head. The umbilical provides cooling water from the chiller and laser output from the diodes. *This umbilical is permanently attached: do not try to remove it.* To move the laser system, disconnect the chiller supply lines at the chiller and drain the lines, then set the power supply on top of a wheeled cart and the laser head on top of the power supply and roll the system to its new location. Make sure the cooling lines are reconnected and tightly fastened before you restart the laser after moving it.

40 MHz connector (BNC)—connects to a 1 MΩ oscilloscope trigger input for viewing the photodiode signal available from the 80 MHZ connector. A typical waveform is shown in Figure 4-2. This ac-coupled signal can also drive other Spectra-Physics products, such as the Model 3985 pulse selector. This is a negative signal. The signal amplitude shown is approximate and depends on operating wavelength, power and photodiode response.

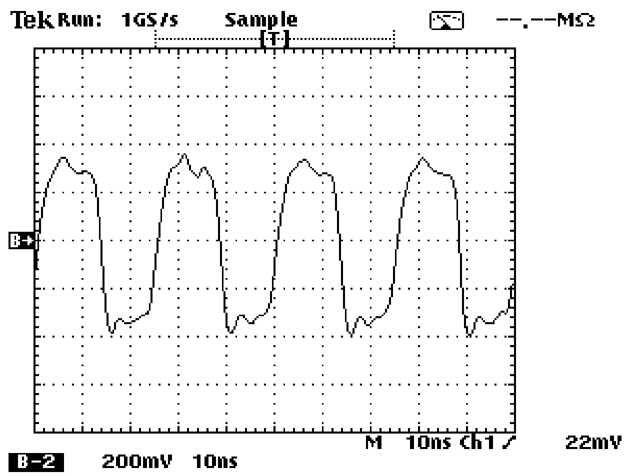


Figure 4-2: Sample waveform supplied by the 40 MHz connector into a 1 MΩ oscilloscope trigger input.

80 MHz connector (BNC)—connects to a frequency counter or to a 50 Ω oscilloscope input for monitoring the laser head photodiode signal. A typical waveform is shown in Figure 4-3. Use the ac-coupled output to trigger the oscilloscope. The signal amplitude shown is approximate and depends on operating wavelength, power and photodiode response.

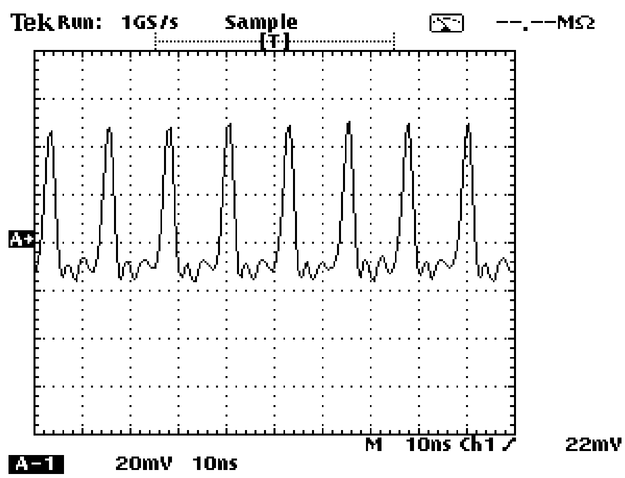


Figure 4-3: Sample waveform from the 80 MHz connector into a 50 Ω oscilloscope input.

The Model J40 Power Supply

This power supply is air-cooled and has two fiber outputs on the rear panel that provide laser diode pump power to the *Mai Tai* laser head.

This section defines the user controls, indicators and connections of the *Model J40* power supply. The control SERIAL port is fully described below. However, instructions for controlling the system via this port are located in Chapter 7, "Operation." The front and rear panels are described below from left to right, top to bottom, starting with the front panel.

Caution!

Provide at least 6 in. of room on the front and back of the *Model J40* power supply to allow cool air to enter the front and for the heated exhaust air to exit the rear panel. Inadequate cooling will cause the system to overheat and shut down. Damage to components caused by insufficient cooling is not covered by your warranty.

Front Panel

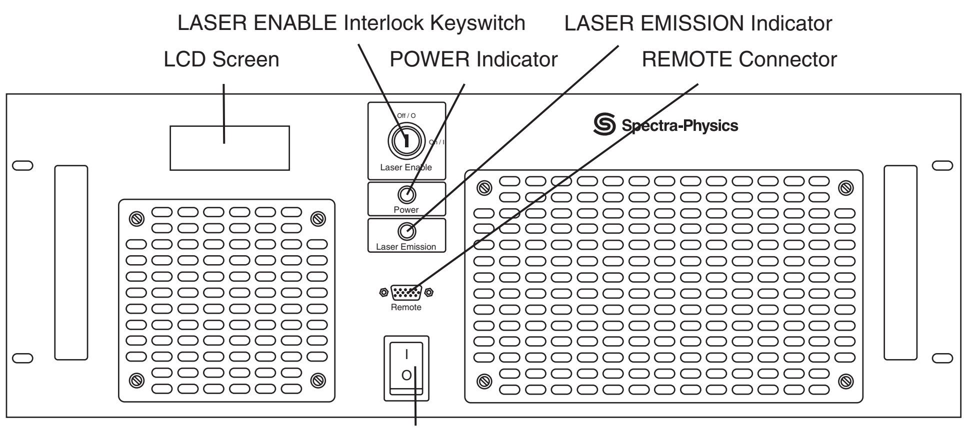


Figure 4-4: The *Model J40* Power Supply Front Panel

LCD display—displays the status of the power supply during normal operation and any status codes generated by the power supply. During start up, this panel displays the status of the self-diagnostics program. If problems ever occur, monitor this panel to see where it occurs. All warnings, including errors generated by the system and indications related to proper system operation, are displayed on the control device as well.

LASER ENABLE interlock keyswitch—provides interlock safety to prevent unauthorized personnel from using the *Mai Tai* laser system when the key is turned to the "off" position and the key is removed. Turning the key to the "on" position allows the laser diode to be energized if the ac power switch is also on.

POWER indicator (Green)—when on, indicates that ac power is applied to the system.

LASER EMISSION indicator (Red)—shows that power is supplied to the laser diode and that diode emission is present or imminent.

Air intake—allows cooling air to be drawn into the power supply. The heated exhaust air is then vented from the rear panel.

REMOTE connector (15-pin D-sub)—is used for controlling the laser locally with the control module (provided).

AC power on/off switch—provides ac power to the *Model J40* when the LASER ENABLE interlock keyswitch is also on.

Rear Panel

Air exhaust—these two grills allow heated air to be expelled from the power supply.

Laser diode fiber-optic cable—is permanently attached to the diode module inside the power supply and must be replaced along with the diode module. The clamping device on the panel provides strain relief for the cable and must be loosened to unclamp the cable prior to removing the laser diode from the system. The fiber cable provides 808 ±1 nm pump power.

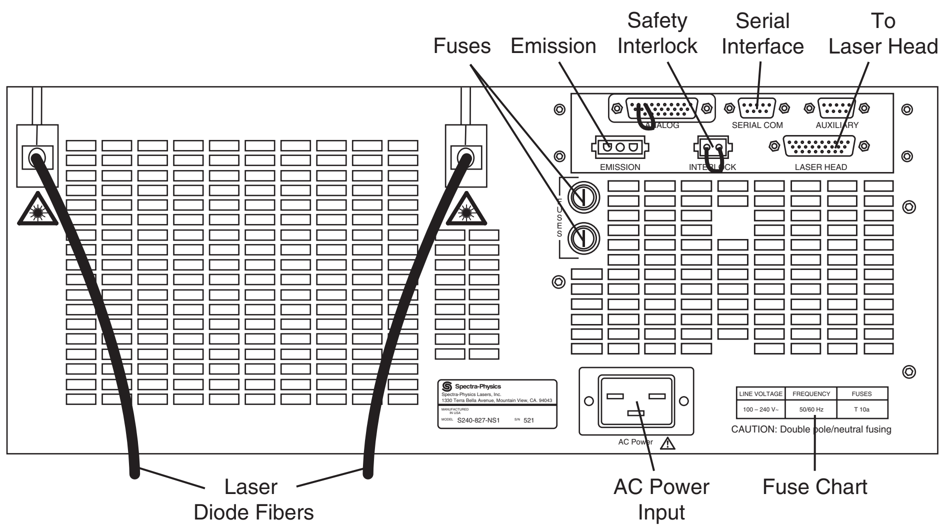


Figure 4-5: The *Model J40* Power Supply Rear Panel

ANALOG connector (25-pin, D-sub)—is jumpered as it comes from the factory and is not used on the *Mai Tai* laser system. The jumper plug (Figure 4-6) must *always* be attached to the connector or the diode pump laser will not turn on.

Figure 4-6: The ANALOG Jumper Plug

SERIAL COM connector (9-pin, D-sub)—is used as a computer control port. Connect your computer to this connector. Refer to the pin descriptions in Table 4-1 at the end of this chapter and to the section on “Using the Serial Interface” in Chapter 7, “Operation.” When the system is controlled in this manor, RS-232 ENABLED is shown on the controller LCD display.

EMISSION connector (3-pin)—provides access to a relay that can be used to turn on and off a remote emission indicator on an OEM system (Figure 4-8). When the laser is off (i.e., there is no emission), there is closure between pins 3 and 1 and an open between pins 3 and 2. The opposite is true when the laser is on or emission is imminent. There is no power supplied by these terminals. The circuit is rated for 250 Vac at 5 A.

INTERLOCK connector (2-pin)—provides attachment for a safety switch. These two contacts must be shorted together before the laser will operate. A defeating jumper plug is installed at the factory to permit operation without a safety switch. This plug can be replaced with a similar, non-shorting plug that is wired to auxiliary safety equipment (such as a door switch) to shut off the laser when actuated (opened). Such a switch must be designed for a low-voltage, low-current digital signal.

LASER HEAD connector (27-pin, D-sub)—provides attachment for the control cable to the *Mai Tai* laser head.

AC POWER connector—provides connection for an IEC power cable to provide ac power to the *Model J40* power supply.

Connector Interface Descriptions

SERIAL COM Port Connector

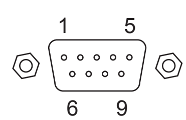


Figure 4-7: The 9-Pin SERIAL COM Port

Table 4-1: The SERIAL COM Port Connections

	Computer or Terminal			**Model J40**	
RS-232-C Signal Name	**Signal**	**Pin No. (25-Pin)**	**Pin No. (9-Pin)**	**Pin No.**	**Signal**
Transmit Data	TXD	2	3	3	RXD
Receive Data	RXD	3	2	2	TXD
Not Connected	RTS	4	7	–	CTS
Not Connected	CTS	5	8	–	RTS
Not Connected	DSR	6	6	–	DTR
Not Connected	DCD	8	1	–	DCD
Not Connected	DTR	20	4	–	DSR
Signal Ground		7	5	5	
Protective Ground		1	SHELL	SHELL	

EMISSION Connector

This connection can be used to turn on and off an external EMISSION light. It consists of a relay-driven, single-pole, double-throw relay that closes pins 3 and 2 when emission occurs or is imminent. The circuit is rated for 250 Vac at 5 A.

Pin #	Description
3	Wiper
2	Normally Open
1	Normally Closed

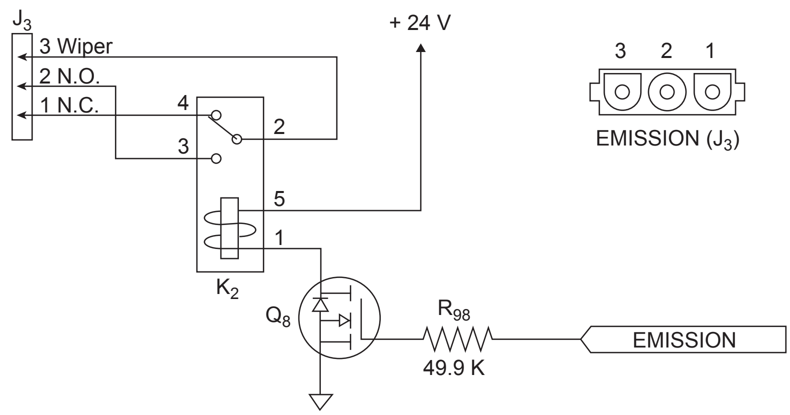


Figure 4-8: ***Model J40*** **Emission Connector Circuit**

Safety INTERLOCK Connector

This is a system interlock that must be *closed* for operation. It is provided for safety to shut the diode current *off* if the connection is opened.

Pin #	Description
1	System Interlock
2	System Interlock Return

The Chiller

Refer to your chiller’s user’s manual.

Chapter 5 Installation

There are no internal controls to adjust or optics to change in the *Mai Tai*™ laser, which makes it very easy to set up and operate. The following instructions will get you operational in a very short time.

When you received your laser, it was packed with the laser head and power supply already connected via an umbilical. *Do not disconnect the umbilical cables from either end!*

Note

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

Moving the Laser System

Remove the laser head, power supply and, if present, the control laptop pc from the shipping crate and inspect for damage. Refer to the "Unpacking and Inspection" notes at the front of this manual.

To move the laser system, set the power supply on a cart and place the laser head on top of it, then roll them to the table or mounting area. The power supply weighs about 22 kg (50 lbs), the laser head approximately 32 kg (70 lb). Ask for help when moving these units; do not attempt it by yourself.

Installing the Mai Tai Laser Head

The tools and equipment you need to set up the *Mai Tai* laser are in your accessory kit.

Warning!

Be careful when moving the laser head that any bend in the umbilical does not exceed the 6 in. (15 cm) minimum radius. Exceeding this limit can fracture and/or break the fiber bundle inside. Also, be careful not to snag any of the various cables extending from the power supply. Such damage is not covered by your warranty.

---

1. Place the *Mai Tai* laser head on the table with the power supply nearby, and orient the laser head toward the target.

Warning!

Be careful when you set the laser head on the table that the umbilical does not snake off the table and pull the laser head with it. You may wish to temporarily clamp the laser head to the table with the clamps provided while you move the power supply to a temporary location before it is installed.

2. Two slots are provided in the center of the output and rear panels for clamping the laser head to an optical table or other flat mounting surface. Once you place the laser head where you want it, use standard table screws to fasten the laser to the table using these slots and the holes in the table.

This completes the installation of the laser head.

Installing the Power Supply

Power Supply Mounting Considerations

Allow 6 in. of clearance to the front and back panels of the *Model J40* power supply for proper cooling air flow. If the power supply is to be placed in an enclosure, take measures to prevent heated air exhausted from the back panel from returning to the intakes on the front panel. Failure to do so will cause over-heating.

Ensure that the electrical and fiber optic cables are safely routed and not under any strain or compression. Use caution when moving the power supply to prevent fiber damage. Avoid conditions in which the cables can be stepped on by personnel or rolled over by mobile units.

Installation in a Rack

Although it is not necessary to install the power supply in a standard 19 in. rack-mount unit, it is often done to save space, especially if there is other rack-mountable equipment to be used. If a rack is not used, simply locate the power supply near the laser head.

The following installation procedures assume you are installing the power supply into a rack. Use a rack that can provide positive filtered ventilation air that flows into the bottom of the unit, past the mounted units without obstruction, and exhausts from the top. Do not add solid shelves between units or heated exhaust air will be trapped and cause over-heating. Instead, provide rails or slides to support the mounted units. Also provide enough environment cooling capacity to counter the heat produced by the system and to prevent room overheating (refer to system specifications at the end of Chapter 3).

Because the laser head and power supply are permanently connected via the umbilical, it will require two people to safely support and install the power supply from the rear of the rack.

1. The laser head must be secured in place before the power supply can be installed.
2. Move the mounting rack as close to the laser head as possible.
3. With one person standing in front of the rack, have the second person pass the power supply through the back of the rack, turning the power supply on its side so that it can pass entirely through the front of the unit, then orient it right side up and slide it backward into place and set it on the rails or slides.
4. Fasten the power supply in place via the front panel flanges using 4 standard rack-mount screws.

Caution!

These four screws are only meant to secure the power supply in place, *not support it*. Provide slides or rails to support the weight of the power supply. Mounting holes are provided on the side of the power supply for attaching slides. Refer to the outline drawing at the end of Chapter 3 for hole locations and sizes.

Connecting the System

Refer to interconnect drawing Figure 5-1.

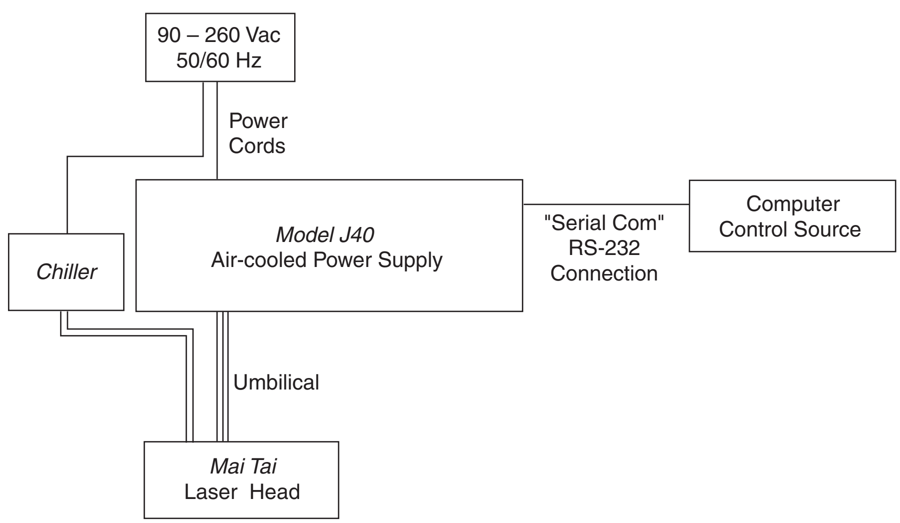


Figure 5-1: The *Model J40* Interconnect Drawing

5. Set the computer in a convenient location.

Front Panel

6. Verify the jumper plug is in place on the REMOTE connector (Figure 5-2). This connection is not used on the *Mai Tai* laser system and *must* be jumpered to enable the system to turn on.
7. Verify the jumper plug is in place on the ANALOG interface on the back panel (Figure 5-3). This connection, too, is not used on the *Mai Tai* laser system and *must* be jumpered to enable the system to turn on.

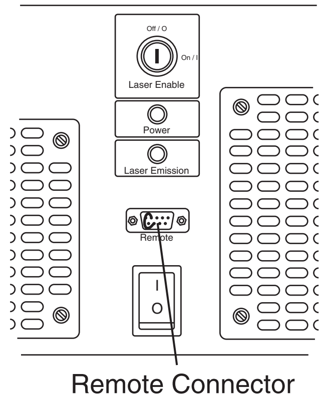


Figure 5-2: The REMOTE Connector on the Power Supply Front Panel

Back Panel

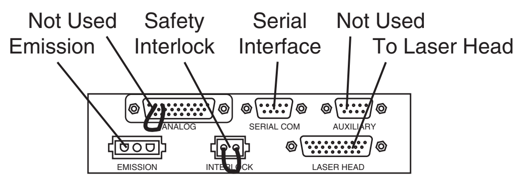


Figure 5-3: *Model J40* Rear Panel Connectors

8. Connect a serial cable of ample length between the serial port on the computer and the SERIAL COM connector on the back of the power supply. Refer to Table 4-1 at the end of Chapter 4 for pin descriptions
9. If emission indicators other than the one on top of the laser head and the red LED on the front panel of the *Model J40* is required, use the EMISSION relay connector on the power supply rear panel as a switch to turn a lamp on and off (Figure 5-4). To use the relay, attach a wire to pins 3 and 2 of the connector. When the laser is off (i.e., there is no emission), there is closure between pins 3 and 1 and an open between pins 3 and 2. The opposite is true when the there is emission or emission is imminent. There is no power supplied by these terminals. The circuit is rated for 250 Vac at 5 A.

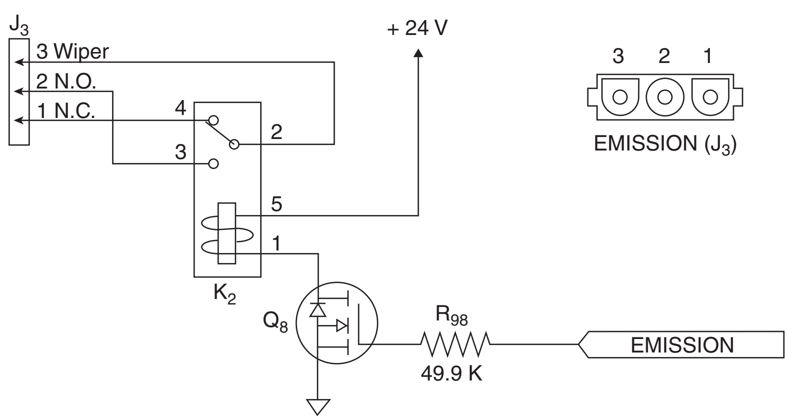


Figure 5-4: The EMISSION Connector Schematic

10. Verify the INTERLOCK jumper plug is in place or, if a safety interlock is desired, remove the plug and rewire it (or a similar non-jumpered connector plug) to a safety switch. The switch must be wired so that when the device is actuated (e.g., a door is opened), the switch opens. This will turn off the laser.
11. Attach the provided IEC power cord to the power connector on the power supply and fasten it to the receptacle using the retaining screws provided so that it does not pull out. Plug the other end into a facility power outlet. The outlet must supply 100 to 240 Vac, 15 A single-phase power.

This completes the wiring connection for the power supply.

Installing the Controller

To control *Mai Tai*, you can either install the supplied LabWindows™ control software on the optional notebook computer or on your own personal computer. Or you can use a computer or terminal to control the *Mai Tai* remotely using your own software program. If you choose the latter, refer to Chapter 6, "Operating the System Using the LabWindows Software" and "Commands and Queries Used by the Mai Tai" for information on controlling the system using the SERIAL COM interface.

If you are using your own computer with the supplied LabWindows control software, verify your unit meets these minimum requirements.

- 486 (or higher) processor, 66 MHz or higher
- 16 MB RAM or more, (32 MB RAM recommended)
- 3 MB available disk space for installation
- a Windows®* -compatible pointing device, such as a mouse
- a video display with 640 x 480 (VGA) or higher resolution (800 x 600 or 1024 x 768 preferred)
- an available RS-232 serial port properly configured for 8 bits, 2 stop bits, no parity.
- Microsoft Windows 95, 98, ME, 2000 or XP operating system

If your computer meets these requirements, or if you are going to operate the laser remotely using your own software, continue:

1. If you have not already done so, attach the 9-pin serial cable (supplied with the *Mai Tai*) between the serial port (COM port) of the control device and the 9-pin SERIAL COM connector on the rear of the power supply.
2. Use the fastening screws on the cable to secure it at each end, otherwise the cable will very likely disengage and the laser will shut off. This can be very inconvenient when it happens in the middle of an experiment.

**Windows is a registered trademark of Microsoft Corporation.*
LabWindows is a trademark of National Instruments Corporation.

Installing the LabWindows Control Software

A special version of LabWindows software is provided by Spectra-Physics on two 1.4 Mb floppy diskettes. To install the software, place Disk 1 in the floppy drive, then double-click "My Computer" > "Floppy A:" > "Setup.exe" and follow the prompts. The software will create and install itself into the "c:\maitai" directory on a drive of your choice (default drive: c:). It will also install LabWindows run-time components into the "windows/system" directory on drive C and place a "*Mai Tai*" icon on the Windows desktop for convenient program startup. Please note: an uninstall program is also placed in the "*Mai Tai* Program" directory. Run this program if and when you wish to remove these program components from your system (e.g., when you wish to change or upgrade your personal computer).

This completes the installation of the control device.

Installing the Chiller

The instructions below for installing and starting the chiller are sufficient for a typical installation. For more instructions, refer to the chiller manual.

1. Place the chiller on the floor close enough to the *Model J40* power supply so that the cooling hoses from the *Mai Tai* umbilical reach the connectors on the back of the chiller.

Warning!

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

2. Screw both hoses onto the chiller and tighten.

   The hoses are polarized. Connect the red hose to the input of the chiller and the black hose to the output of the chiller. Finger tight is enough: do not overtighten.
3. Fill the chiller reservoir with tap water.
4. Turn on the chiller and verify water is flowing. Inspect for leaks at the hose connections.

   Refer to the chiller manual for instructions.
5. Adjust the chiller temperature for 21°C.

Caution!

Position the chiller so that its warm air exhaust does not adversely affect the stability of the laser or any other components on the table.

6. Turn off the chiller.

   Please note: it takes the chiller about 15 minutes to stabilize the temperature of the laser head cold plate and, thus, the output of the laser. Leaving the chiller on between periods of laser use will eliminate this stabilization period. In general, if the laser is used often, leave the chiller on between laser usage; if it is used infrequently, turn off the *Model J40* power supply first, then the chiller.

Warning!

The chiller must always be on when the *Mai Tai* power supply is on, even if the laser diodes are not switched on!

This completes the chiller installation.

Chapter 6 Operation

Danger!

The *Mai Tai*™ is a Class IV-High Power Laser, whose beam is, by definition, a safety and fire hazard. Take precautions to prevent exposure to direct and reflected beams. Diffuse as well as specular reflections cause severe skin or eye damage.

Danger!
Laser Radiation

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

The *Mai Tai* laser can either be controlled locally using the supplied LabWindows™ control software or it can be controlled remotely using your own software program running on a computer or terminal. The supplied LabWindows control software installs either on your own personal computer or on the Windows®-based notebook computer optionally sold with this system. Chapter 5 explains how to connect the various components of your system and install the LabWindows control software. This chapter assumes this has already been done.

The first part of this chapter is dedication to operating the laser using the LabWindows software; the latter part lists and explains the commands and queries required for controlling the system using your own program.

Operating the System Using the LabWindows Software

Operating the *Mai Tai* is very simple when using the supplied LabWindows control software. When the laser system is turned on and the control software is run, a Main menu appears that allows you to monitor the laser, turn it on and off, set the wavelength and open and close the shutter. It monitors pump laser power and pulsed laser output power, and it shows the system status, including whether or not the laser is emitting pulses. From this menu you can access three other menus: Setup, Info and Scan. The menus and their functions are described on the next few pages.

LabWindows is a trademark of National Instruments Corporation.
Windows is a registered trademark of Microsoft Corporation.

The Main Menu

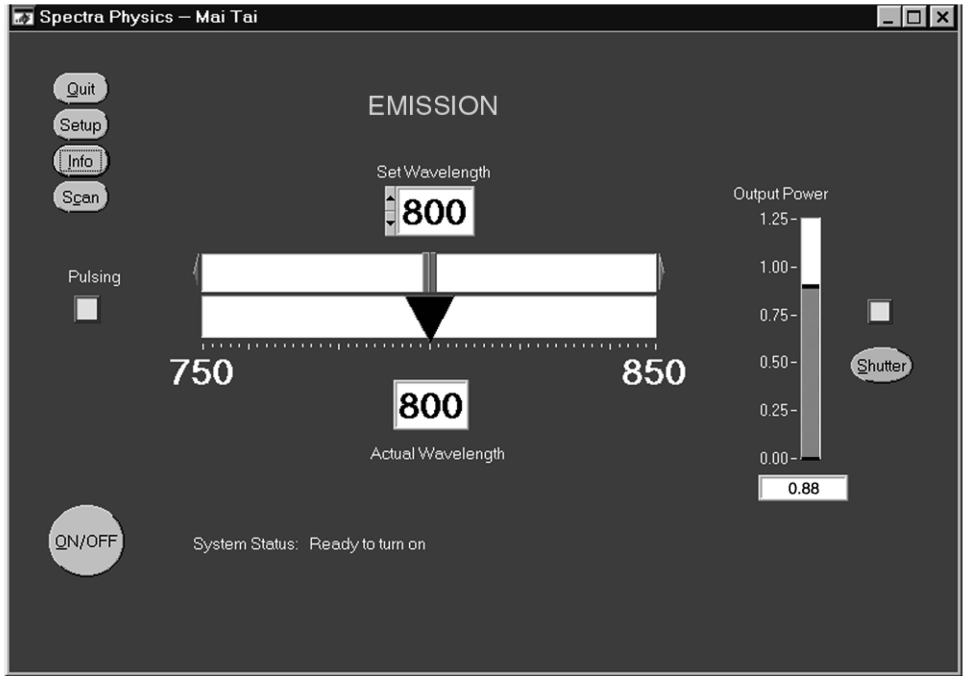


Figure 6-1: The Main Menu

The Main menu (Figure 6-1) is the first screen that appears when you start the software (after the Com Port Confirm menu). Large and easily seen from a distance, it serves as both monitor and input screen.

The five control features include:

- Sub-menu selection
- On/off control
- Wavelength select/monitor
- Output power monitor
- Shutter open/close

The menu functions are described below as they appear on the screen from left to right, top to bottom.

Submenu Selection—allows you to select Quit, the Setup menu, the Info menu and the Scan menu.

> **QUIT**— exits the program. Press this button prior to powering down the computer.
>
> **SETUP**—takes you to the Setup menu.
>
> **INFO**—takes you to the Info menu.
>
> **SCAN**—takes you to the Scan menu.

EMISSION indicator—when on, shows that pulsed laser output is available, even though there may actually be no emission if the shutter is closed; when off, indicates that the laser is turned off.

PULSING indicator—when on, indicates the output beam is pulsing; when off, there is no output (laser is off) or the output beam is not pulsing (i.e., it is running CW).

SET WAVELENGTH controls and indicators—allows you to select an operation wavelength between 750 and 850 nm or 780 and 920 nm.

There are several ways to set the wavelength: by using the up/down arrows to the left of the "Set Wavelength" window, by typing in a number in the window itself, by dragging the bar in the upper bar graph to the desired location (wavelength numbers corresponding to its position will display in the window), and by using the left and right arrows on the bar graph to move the bar. Each tick on the bar graph is 2 nm.

ACTUAL WAVELENGTH indicators—indicate a relative output wavelength value in the lower bar graph and an absolute value in the lower numeric window.

When the system is active, the arrow in the lower bar graph indicates the current output wavelength. When the requested wavelength is changed by the operator in the "Set Wavelength" window, the arrow will move toward that same value as the unit automatically compensates. When the desired value and actual value are equal, the arrow will stop and will be in line with the upper bar and the "Actual Wavelength" value in the window will match the "Set" value.

OUTPUT POWER indicator—is displayed in Watts as a relative value via a mark on a bar graph, and as an absolute value in the lower window.

The system is automatically optimized for maximum output power at each wavelength; there is no power setting control.

SHUTTER button—opens and closes the internal shutter.

To open the shutter, click on the SHUTTER button and hold down the mouse button about 3 seconds (for safety reasons) until the shutter light over the button turns on. Actual emission will occur only if and when the laser is turned on using the ON/OFF button (see below). To close the shutter, simply click on the SHUTTER button again. The shutter closes immediately, blocking the laser beam.

ON/OFF button—turns the laser on and off.

To turn on the laser, click on the ON/OFF button and hold the mouse button down about 3 seconds until the EMISSION light over the wavelength display turns on. To turn off the laser, simply click on the ON/OFF button again. The laser turns off immediately. Actual emission will occur only when the shutter is open (see above).

SYSTEM STATUS monitor—provides status information at the bottom of the screen.

The Setup Menu

The Setup menu (Figure 6-2) is for Spectra-Physics service personnel only.

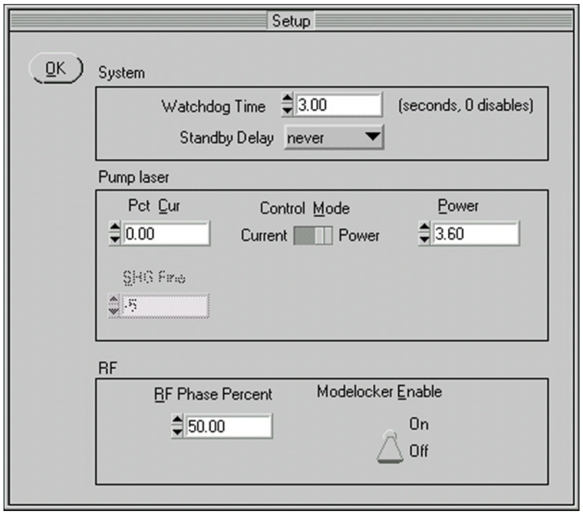


Figure 6-2: The Setup Menu

Caution!

The parameters shown in Figure 6-2 are set at the factory for optimum system performance. Do not use this menu to modify any parameters. In particular, do not set the unit to current mode or change the power setting. Increasing power may actually decrease output performance! These controls are for diagnostic purposes only and are to be used only by someone trained on this laser by Spectra-Physics.

The Info Menu

The Info menu (Figure 6-3) provides information on several parameters, the most important of which are the “SHG Status,” the “History Buffer” and the “Software Rev” (required when calling Spectra-Physics for help). The other indicators are to be used for diagnostic purposes only by persons trained on this laser by Spectra-Physics.

PUMP POWER indicator—shows the output of the internal pump laser in Watts and is to be used only for diagnostic purposes by persons trained on this laser by Spectra-Physics. Different wavelengths require different power settings, so this value is dependant on the wavelength selected.

CURRENT (AMPS) indicators—show the current output in amperes of each diode laser and are to be used only for diagnostic purposes by persons trained on this laser by Spectra-Physics. Current is related to pump output power, and the current required to maintain a given output power will increase as the diodes age. This is normal.

TEMPERATURE (DEG C) indicators—show the current temperature of each diode laser and are to be used only for diagnostic purposes by persons trained on this laser by Spectra-Physics.

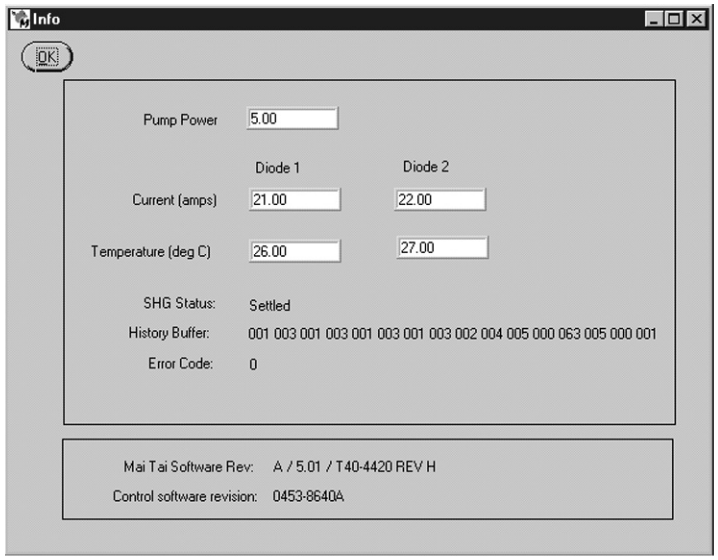


Figure 6-3: The Info Menu

SHG STATUS monitor—indicates when the SHG crystal is at operating temperature. Stable output is only possible when this crystal is "settled."

HISTORY BUFFER list—shows you the last 16 operations performed by the system. Although typically used by persons operating the system remotely, this list can be used for diagnostic purposes or just to see the most recent sequence of events.

ERROR CODE indicator—displays the last error code generated by the system. Although typically used by persons operating the system remotely as a feedback source for branching operations, it can be used for local diagnostic purposes as well.

SOFTWARE REV statement—shows the revision level of the current firmware. When calling for service, you will be asked for this number. It is used to determine the capability of your system, as well as its expected performance.

The Scan Menu

The Scan menu (Figure 6-4) provides a means to scan from a beginning wavelength to an end wavelength in presettable steps, and to stop at each step for a preset period of time.

OK button—returns you to the Main menu regardless of the WAVELENGTH SCAN switch setting.

START WAVELENGTH control—sets the wavelength at which to begin a scan.

STOP WAVELENGTH control—sets the wavelength at which to end a scan.

WAVELENGTH SCAN ON/OFF switch—enables/disables the scan function. The system will continue to scan even if you press the OK button and return to the Main menu. This switch must be set to off to stop the scan.

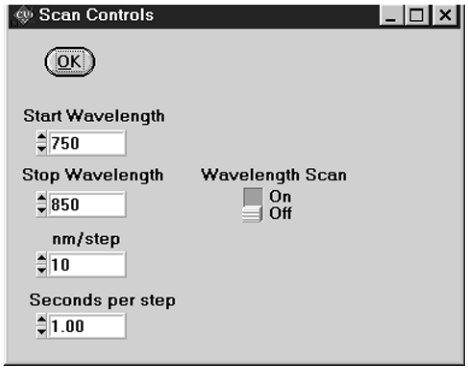


Figure 6-4: The Scan Menu

nm/STEP control—sets the interval in nanometers between stops during a scan. When set to "0," stepping is defeated and the system will scan continuously between the begin and end wavelengths; the SECONDS PER STEP function is ignored.

SECONDS PER STEP control—sets the stop duration in tens of milliseconds during a scan.

Turning On and Off the System

To turn on the system:

Warning! The chiller must always be on when the *Mai Tai* power supply is on, even if the laser diodes are not switched on!

1. Verify that all connectors are plugged into the power supply (they should never be disconnected—if they were, refer to Chapters 4 and 5, for information on reconnecting them).
2. Verify the reservoir in the chiller has been filled to the correct level.
3. Turn on the chiller and verify it is set to 21°C.

   It takes the chiller about 15 minutes to stabilize the temperature of the laser head cold plate and, thus, the output of the laser. To eliminate this stabilization period, leave the chiller on between periods of laser use. As a rule, if the laser is used often, leave the chiller on; if it is used infrequently, turn off the *Model J40* power supply, then turn off the chiller. Refer to the chiller user's manual for more detailed instructions.
4. Turn on the power supply power switch.
5. Turn on the power supply key switch.

Power Supply Start-up

As the system starts up, the following message sequence is displayed on the power supply LCD screen:

- "Spectra-Physics" followed by the software version number.
- Self tests 1 through 12 will complete, followed by the announcement:

- "Success. Boot test passed."

  This is the final display from the *Model J40* power supply, which indicates it is ready for use.

1. Turn on the computer as you would normally, then double-click the "*Mai Tai*" icon on the desktop to start the control program. The Com Port Setup menu shown below will appear.

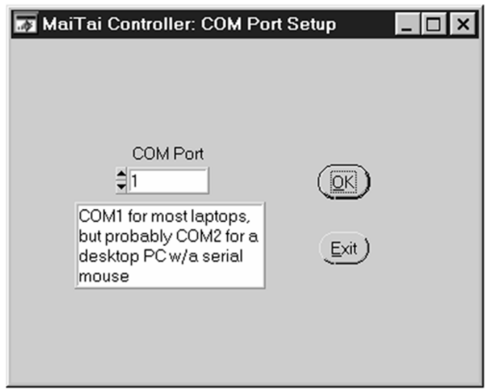


Figure 6-5: The Com Port (SERIAL COM) Setup Menu

2. Verify the com port setting is correct for your system, then press OK.

   The system will look for the *Mai Tai* and, when found, will display the Main menu (Figure 6-1).

3. Wait until the status warning on the control screen says "Ready to turn on," then turn on the laser.

   Click on the ON/OFF button and hold down the mouse button for about 3 seconds until the "EMISSION" light turns on (the emission light on the laser will also turn on). The laser is on when the EMISSION light is on. However, no light is emitted until the shutter is opened in Step 6.

4. Set the desired wavelength from the Main menu.
5. Observe the PULSING indicator to verify pulses are present.
6. Open the shutter.

   Click on the SHUTTER button and hold down the mouse button for about 3 seconds until the SHUTTER light turns on. The shutter will open and emission will be present.

7. Observe the output power. It should reach specified power within 30 minutes.
8. To temporarily turn off laser emission without turning off the laser, press the SHUTTER button. Emission will stop immediately and the SHUTTER light will turn off. However, the EMISSION light will remain on to warn of possible emission. To open the shutter again, simply press the SHUTTER button again.

To turn off the system:

1. Press the ON/OFF button to shut off the system.

   The system will turn off immediately, as will the EMISSION light.
2. Press the SHUTTER button to close the shutter.
3. If you are done for the day and wish to turn off the computer, press the QUIT button to exit the program, then turn off the computer as you would normally.
4. Turn the *key switch* on the power supply to OFF and remove the key to prevent unauthorized use. To minimize start-up stabilizing time, leave the *power switch* on the power supply in the "on" position and leave the chiller on.

   This is the preferred "off" mode for day-to-day operation. If you are not going to use the laser for an extended period of time, turn off the power supply completely, then turn off the chiller.

Warning! The chiller must always be on when the *Mai Tai* power supply is on, even if the laser diodes are not switched on!

This completes the turn on/off sequence.

The RS-232 Serial Port

Pinout/Wiring

The *Mai Tai* RS-232 serial port on the power supply accepts a standard 9-pin D-sub male/female extension cable for hookup. Only three of the pins are actually used:

Pin Numbers	Usage
2	transmit data (*Mai Tai* out)
3	receive data (*Mai Tai* in)
5	signal ground

Communications Parameters

Communications must be set to 8 data bits, no parity, one stop bit, using the XON/XOFF protocol (do not use the hardware RTS/CTS setting in your communications software). The baud rate is set to 9600 at power up.

Command/Query/Response Format

In the interest of standardization, the RS-232 commands and queries used on the *Mai Tai* follow the SCPI protocol (Standardized Commands for Programmable Instruments). This protocol was developed with the user in mind, thus all commands are easily readable by the user. The following rules apply:

- All commands and responses are in ASCII format.
- Commands to the *Mai Tai* system are terminated by an ASCII carriage return, line feed, or both.

  In this document, a carriage return is indicated by <CR> and a line feed by <LF>.
- All responses from the *Mai Tai* are terminated by an ASCII line feed character.
- All queries end with a question mark (?). If a query has no command associated with it, it is preceded with READ.
- The *Mai Tai* will not generate any signals on the RS-232 unless a query command is received first.
- Parameters are separated from commands by spaces.
- Commands have both a "short" and "long" form.

  The long form is the completely written command. The short form is derived from the long form by dropping every character after the fourth character. If the fourth character is a vowel, a three-letter form is used. The only exceptions to this pattern are "OFF" and "ON".

  Example:

  Long form: SHUTTER 1

  Short form: SHUT 1

  In the examples in this document, the long form of the command is used with the short form portion of it written in capital letters and, when contained within text, the entire command is italicized (e.g., SHUT*ter* 1).
- Several commands have variations or subcommands which are separated by semicolons (:). Short and long forms of the various commands and subcommands may be freely mixed. For example, all of the following are equivalent:

  READ:PLAS:DIOD1:CURR?
  READ:PLASER:DIODE1:CURRENT?
  READ:PLAS:DIODE1:CURR?

  However, for consistency and readability, it is best to choose one form and stay with it throughout.

Typical Command Usage

The control flow of a *Mai Tai* program might look like this:

1. Turn on the system, then wait approximately 15 seconds for the computers to initialize.
2. Begin issuing a series of READ:PCTW*armedup*? queries and wait for it to return a 100 to indicate the system is fully warmed up (i.e., 100% warm).
3. Set the output wavelength to 800 nm by issuing the WAV*elength* 800 command.
4. Turn on the laser by issuing the ON command.
5. Open the shutter by issuing the SHUT*ter* 1 command.

Commands and Queries Used by the Mai Tai

Quick Reference

The following is a list of the commands and queries used by the *Mai Tai* and are provided as a reference guide. A list with explanations follows in the next section.

CONTrol:PHAse
CONTrol:PHAse?

CONTrol:MLENable
CONTrol:MLENable?

ON

OFF

MODE
MODE?

PLASer:ERRCode?

PLASer:HISTory?
PLASer:AHISTory?

PLASer:PCURrent
PLASer:PCURrent?

PLASer:POWer
PLASer:POWer?

READ:PCTWarmedup?
READ:PLASer:POWer?
READ:PLASer:PCURrent?
READ:PLASer:SHGS?
READ:PLASer:DIODe(n):CURRent?
READ:PLASser:DIODe(n):TEMPerature?
READ:POWer?
READ:WAVelength?

SAVe

SHUTter (n)
SHUTter?

SYSTem:COMMunications:SERial:BAUD (nnnn)

SYSTem:ERR?

TIMer:WATChdog (n)

WAVelength (nnn)
WAVelength?
WAVelength:MIN?
WAVelength:MAX?

*IDN?

*STB?

Full Description

This sections explains the commands and queries in detail. The form of the command is followed by the form of the associated query, which is followed by an explanation of each.

CONTrol:PHASe nn.nn

CONTrol:PHASe?

Sets/reads the RF phase control. You should not have to use this control. Phase is reset to the factory setting every time the wavelength command is used.

CONTrol:MLENable n (1, 0)

CONTrol:MLENable?

Turns the mode locker RF drive signal on (1) or off (0). The query returns a 1 or 0. You should not have to use this control. The modulator RF is disabled whenever the pump laser is off and enabled when the pump laser is turned on (unless overridden by this command).

ON

Turns on the pump laser. Unless overridden by the *MODE* and/or PLASer:POWer commands, the laser will turn on in power mode at the power level set by the factory.

The shutter is not automatically opened when the ON command is issued.

The response to this command depends on whether or not the system is warmed up. Use the READ:PCTW*armedup?* query to determine the progress of the warm-up cycle. When the response to the READ:PCTW*armedup?* query reaches 100, the laser can be started. Do not issue an *ON* command while the response to READ:PCTW*armedup?* query is 1 to 99.

If the response to READ:PCTW*armedup?* is...	The response to *ON* is...
0	to begin diode temperature stabilization. (approximately 2 minutes)
1 to *99*	an execution error. (The EXE_ERR bit in the status byte is set.)
100	the laser diodes turn on, and the system output ramps to the most recently set power/current.

OFF

Turns off the pump laser diodes, but the SHG crystal oven temperature is maintained for a quick warm-up time.

The shutter is not automatically closed.

MODE nnnn (PPOWer/PCURrent)

The system defaults to power mode and output power is set at the factory for optimum system performance. Do not set the unit to current mode or change the power setting. Increasing power may actually decrease output performance! This control is for diagnostic purposes only and is to be used only by someone trained on this laser by Spectra-Physics.

MODE?

The legal parameters are PPOW*er* for "pump laser power" and PCUR*rent* for "pump laser percent current". The system always turns on in PPOW*er* mode by default.

The query returns PPOW*er* or PCUR*rent*.

PLASer:ERRCode?

Returns the pump laser error code. See Table 6-1 and Table 6-2.

PLASer:HISTory?

Returns the contents of the history buffer. It returns a 16-byte (16 code) status code list from the history buffer with the most recent status codes listed first. The history buffer only stores status codes 0 – 126 generated by the power supply. Status codes from the *Mai Tai* laser head are not recorded and, therefore, will not be returned.

PLASer:AHISTory?

Returns an ASCII version of the history buffer.

PLASer:PCURrent nn.n (0 to 20.0)

PLASer:PCURrent?

Sets the pump laser percentage of available current. This is only useful when the mode is set to MODE:PCUR*rent*.

The query returns the last commanded pump laser current percentage.

Do not change the power setting. Increasing power may actually decrease output performance! This control is for diagnostic purposes only and is to be used only by someone trained on this laser by Spectra-Physics.

PLASer:POWer n.nn (0 to 5.0)

PLASer:POWer?

Sets the pump laser output power. This is useful only when the mode is set to MODE:PPOW*er*. It is overridden whenever the WAV*elength* command is issued.

The query returns the last commanded pump laser power in Watts. Use the query READ*:*PLAS*er:*POW*er?* if you want to get the actual output power.

Do not change the power setting. Increasing power may actually decrease output performance! This control is for diagnostic purposes only and is to be used only by someone trained on this laser by Spectra-Physics.

READ:PCTWarmedup?

Reads the status of the system warm-up time as a percent of the predicted total time (see the table below). The system responds with a value similar to "050%<LF>." When the response is "100%<LF>", the laser can be turned on.

READ:PLASer:POWer?

Reads and returns the output power of the pump laser (0 to 5.5 W).

READ:PLASer:PCURrent?

Reads and returns the percentage of full operating current for the pump laser.

READ:PLASer:SHGS?

Reads and returns the pump laser SHG status. The system responds "ØS<LF>" if the temperature is settled, "1S<LF>" if the oven is heating, and "2S<LF>" if it is cooling. Values less than zero indicate an error (such as a broken wire or loose cable).

READ:PLASer:DIODe1:CURRent?

READ:PLASer:DIODe2:CURRent?

Reads and returns the current, in Amperes, of the specified pump diode (diode 1 or 2). The value is equal to the actual operating percentage of maximum diode current. A typical response might be "75.1%<LF>".

READ:PLASer:DIODe1:TEMPerature?

READ:PLASer:DIODe2:TEMPerature?

Reads and returns the current temperature, in degrees C, of the specified pump diode (diode 1 or 2). A typical response might be "20.5<LF>".

READ:POWer?

Reads and returns the output power, from 0 to 2.00 W, of the *Mai Tai*.

READ:WAVelength?

Reads and returns the operating wavelength of the *Mai Tai*. The returned value may not match the commanded wavelength until the system has finished moving to the newly commanded wavelength.

SAVe

Saves the *Mai Tai* status. Use this command before turning off the ac power in order to return to this mode the next time the unit is turned on.

SHUTter n (1, 0)

SHUTter?

SHUT*ter* 1 opens the shutter.

SHUT*ter* 0 closes the shutter.

SHUT*ter?* Reads and returns the shutter status. It is normal for SHUT*ter?* to return a "0" for approximately 1 second after issuing the SHUT*ter* 1 command or a "1" after issuing the SHUT*ter* 0 command.

SYSTem:COMMunications:SERial:BAUD nnnn

Sets the baud rate to 300, 600, 1200, 4800, 19200, 38400, or 57600 baud. The system always powers up at 9600 baud.

Note: the demonstration program uses 38400 baud.

Note: the XON/XOFF protocol is used regardless of baud rate. Hardware handshaking is not used.

SYSTem:ERR

Returns a numerical error and a text message (Table 6-1 and Table 6-2). These errors/messages are contained in a buffer which is gradually emptied as this command is used. These errors/messages are not the same as the ones you can obtain with READ:HIST*ory?* SYST*em:*ERR primarily indicates whether or not a command was properly received and executed.

TIMEr:WATChdog n

Sets the number of seconds for the software watchdog timer. A value of zero disables the software watchdog timer.

If the *Mai Tai* does not receive a valid command (or Query) every n seconds, the pump laser is turned off.

WAVelength nnn (in nm)

WAVelength?

Sets the *Mai Tai* wavelength between 750 and 850 or 780 and 920 nm. It will also set the modulator RF phase and the pump laser output power to factory calibrated values.

The query reads and returns the most recent value of the WAV*elength* command. Use it to verify the command was properly received.

WAVelength:MAX?

WAVelength:MIN?

These queries return the maximum and minimum values for the WAV*elength* command.

***IDN?**

Returns a system identification string that contains 4 fields separated by commas such as:

"Spectra-Physics,MaiTai,xxx,0453-8620A/5.10/J40-4420H."

The first field indicates the laser was made by Spectra-Physics; the second is the model name; the third is reserved; the fourth is the software revision, in this case, the model number, head software revision and power supply software revision.

Table 6-1: Query Errors

Binary Digit	Decimal Value	Name	Interpretation
0	1	CMD_ERR (CE)	Command error. Something was wrong with the command format, the command was not understood
1	2	EXE_ERR (EE)	Execution Error A command was properly formatted, but could not be executed. For example, a power command of “P:0<CR>” was sent, when the minimum allowed power is 0.2 watts.
2	4	(reserved)	
3	8	(reserved)	
4	16	(reserved	
5	32	SYS_ERR (SE)	Any “system” error. (An open interlock, or an internal diagnostic)
6	64	LASER_ON (LO)	Indicates that laser emission is possible.
7	128	ANY_ERR (AE)	Any of the error bits are set.

Table 6-2: Error Return List

Binary DigitS	Decimal Value	Errors Returned
0100 0000	64	LO
1000 0001	129	CE + AE
1000 0010	130	EE + AE
1000 0011	131	CE + EE + AE
1010 0000	160	SE + AE
1010 0001	161	CE + SE + AE
1010 0010	162	EE + SE + AE
1010 0011	163	CE + SE + EE + AE
1100 0001	193	CE + LO + AE
1100 0010	194	EE + LO + AE
1100 0011	195	CE + EE + LO + AE
1110 0000	224	SE + LO + AE
1110 0001	225	CE + SE + LO + AE
1110 0010	226	EE + SE + LO + AE
1110 0011	227	CE + EE + SE + LO + AE

***STB?**

Returns the product status byte. This is a number between 0 and 255 and consists of the sum of the following weighted values:

1	Emission is possible (this bit follow the emission indicator light on the product). Note that the shutter may still be closed, even if this bit is set.
2	The *Mai Tai* is modelocked.
4	Reserved
8	Reserved
16	Reserved
32	Reserved
64	Reserved
128	Reserved

This completes the RS-232 command descriptions.

Using the Chiller

Please refer to the manual that came with the chiller for information on how to operate it. In general, the reservoir should always be full before turning the unit on and the chiller should be set to 21°C whenever the laser is running.

Please note: it takes the chiller about 15 minutes to stabilize the temperature of the laser head cold plate and, thus, the output of the laser. Leaving the chiller on between periods of laser use will eliminate this stabilization period. In general, if the laser is used often, leave the chiller on between laser usage; if it is used infrequently, turn off the power supply, then turn off the chiller.

This completes the operation section.

Chapter 7 Customer Service

At Spectra-Physics, we take pride in the durability of our products. We place considerable emphasis on controlled manufacturing methods and quality control throughout the manufacturing process. Nevertheless, even the finest precision instruments will need occasional service. We feel our instruments have favorable service records compared to competitive products, and we hope to demonstrate, in the long run, that we provide excellent service to our customers in two ways. First, by providing the best equipment for the money, and second, by offering service facilities that restore your instrument to working condition as soon as possible.

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

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

To order optional items or other system components, or for general sales assistance, dial **1 (800) SPL-LASER** in the United States, or **1 (650) 961-2550** from anywhere else.

Warranty

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

The *Mai Tai*™ laser system is protected by a 12-month warranty. All mechanical, electronic, optical parts and assemblies are unconditionally warranted to be free of defects in workmanship and material for one the warranty period.

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

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

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

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

Return of the Instrument for Repair

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

We encourage you to use the original packing boxes to secure instruments during shipment. If shipping boxes have been lost or destroyed, we recommend you order new ones. Spectra-Physics will only return instruments in Spectra-Physics containers.

Warning!

Always drain the cooling water from the laser head before shipping. Water expands as it freezes and will damage the laser. Even during warm spells or summer months, freezing may occur at high altitudes or in the cargo hold of aircraft. Such damage is excluded from warranty coverage.

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Appendix A Modelocking

In this chapter, we provide a brief discussion of modelocking and the regenerative modelocking technique employed in the Ti:sapphire cavity of the *Mai Tai*™ laser. A description of the group velocity dispersion (GVD) found within the cavity is also presented, and the role of nonlinear effects (due to intense pulses passing through the gain medium) is considered. Finally, GVD compensation techniques employed within the *Mai Tai* are discussed since they ultimately determine the output pulse width.

General

In any laser system, the allowed oscillating wavelengths (or frequencies) are determined by two factors: the longitudinal modes determined by the laser cavity (subject to threshold conditions) and the gain-bandwidth of the laser medium. In a laser cavity, the electric field of the oscillating optical frequencies must repeat itself after one round-trip; i.e., the oscillating wavelengths must satisfy a standing wave condition in the laser cavity or an integral number of half-wavelengths must exactly fit between the end mirrors. The small group of frequencies that satisfy this condition are the longitudinal modes of the laser. The gain-bandwidth of the laser medium is determined by its atomic or molecular energy levels. Atomic gas lasers tend to have relatively narrow bandwidth, while molecular dye and solid state systems exhibit broader bandwidth.

In a CW or free-running laser, the longitudinal modes operate independently. Cavity perturbations cause some modes to stop oscillating and when they re-start they have a different phase. Thus, the laser output comprises various randomly phased mode frequencies. In a mode-locked laser, the longitudinal modes must be "locked" in phase, such that they constructively interfere at some point in the cavity and destructively interfere elsewhere in order to create a single circulating pulse. Each time this intracavity pulse reaches the partially reflective output coupler, an output pulse is produced. The time between the output pulses is the time it takes for the cavity pulse to make one complete round trip. For a *Mai Tai* system, this corresponds to about 12.5 ns. The output pulse frequency, or repetition rate (rep rate), is about 80 MHz (refer to Figure A-1).

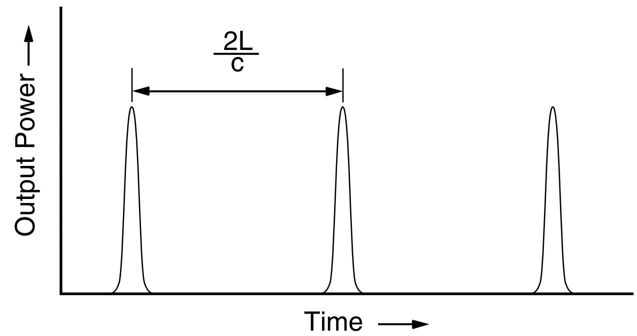


Figure A-1: Typical output of a mode-locked laser, where *L* is the cavity length and *c* is the velocity of light.

Modelocking Techniques

A variety of approaches have been used to obtain a train of mode-locked pulses from different laser systems including active modelocking, passive modelocking, additive pulse modelocking, and self modelocking.

Active modelocking is by far the most common approach used to obtain short optical pulses (ps duration) from solid state or gas lasers. A loss modulation is applied to the laser cavity at the same frequency as the pulse rep rate. This is equivalent to introducing an optical shutter into the laser cavity—only light that arrives at the shutter at precisely the correct time passes through and is amplified in the gain media. Since the shutter is closed at all other times, a second pulse cannot be formed.

The most common active modelocking element is an acousto-optic modulator (AOM) which is placed inside the optical cavity close to one of the end mirrors. The modulator comprises a high quality optical material (such as quartz) with two highly polished surfaces that are parallel to the direction of light propagation. Attached to one of these surfaces is a piezoelectric transducer that is driven at an RF frequency to generate an acoustic wave within the modulator (Figure A-2). Using the reflection off the opposite surface, a standing acoustic wave is generated within the modulator. This induces a time-dependent refractive index grating along an axis perpendicular to the light propagation. As the light interacts with this grating, a portion of it is both diffracted and shifted in frequency by an amount equal to the acoustic frequency. After passing through the modulator, the diffracted and undiffracted rays are reflected back through the modulator where a portion of each beam is diffracted once again.

If the RF drive is at frequency ω_{mL}, the acoustic grating generated by the standing wave will turn on and off at a rate of $2\omega_{mL}$. The value for $2\omega_{mL}$ is chosen to be the same as the laser repetition rate $^{c}/_{2L}$. The AOM diffracts light out of the cavity only when the acoustic grating is present and, thus, functions as a time-dependent loss. In the frequency domain, this loss imparts modulation sidebands when a wave passes through the modulator (Figure A-2). In this manner, the AOM "communicates" the phase between the longitudinal modes of the laser cavity. The final amplitude and frequency of the phase-locked longitudinal modes is shown in Figure A-3.

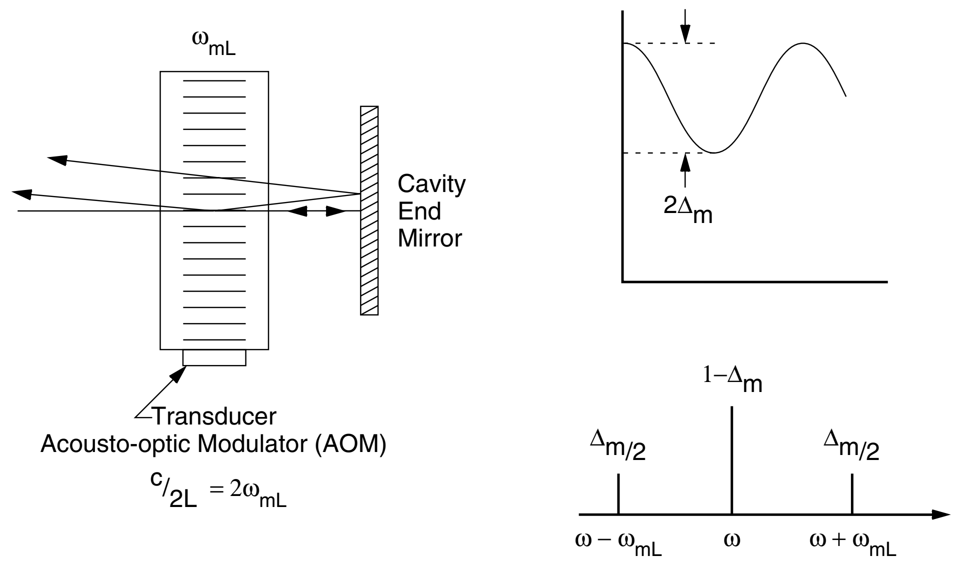


Figure A-2: Active modelocking using an AOM. Modulation sidebands are produced when a wave passes through an amplitude modulator.

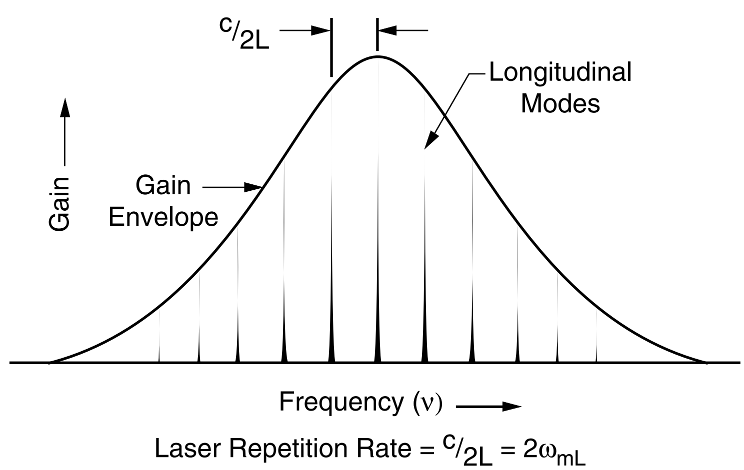


Figure A-3: Amplitude and frequency of longitudinal modes in a mode-locked laser.

The modulation frequency $2\omega_{mL}$ must be precisely matched to the repetition rate of output pulses which is $c/2L$. The RF signal used to drive the AOM is, thus, usually generated by a temperature-stabilized crystal oscillator, and the cavity length of the laser is adjusted to obtain the appropriate frequency.

The duration of the mode-locked pulses depends on several factors including the gain bandwidth of the laser and the modulation depth of the AOM. Laser media with greater gain bandwidth have the capability of generating shorter pulses. Consequently, active modelocking a Nd:YAG laser produces pulse widths of 30 to 150 ps, while for an ion laser, durations are usually 120 to 200 ps.

In passively mode-locked systems, the pulse itself generates the periodic modulation. This can be accomplished with a saturable absorber dye that responds to the instantaneous light intensity in a nonlinear manner. At low light intensity the dye is opaque, but at higher intensities the dye is bleached and becomes transparent. The bleaching time of the dye is the effective time of the optical shutter. In the 1980's, a colliding pulse geometry was used with the passive modelocking technique to produce a colliding pulse mode-locked (CPM) dye laser. When intracavity GVD compensation (described later in this chapter) was used with a CPM laser, sub-100 fs pulses were generated for the first time.

Also, during the 1980's, several new developments in broad bandwidth, solid-state laser materials occurred. The most notable of these was titanium-doped sapphire which allowed lasers to be tuned over a continuous range from < 700 to 1100 nm. In 1989, Spectra-Physics was the first company to offer a commercial CW Ti:sapphire laser.

The broad bandwidth and good thermal properties of this new material motivated several new modelocking approaches. Additive pulse modelocking (APM) used an interferometrically-coupled, external nonlinear fiber cavity to induce modelocking. In 1991, self-modelocking in Ti:sapphire was observed to be induced through the intensity-dependent, nonlinear refractive index of the laser medium. At Spectra-Physics, the Tsunami laser was developed, a commercial, mode-locked Ti:sapphire laser based upon a regeneratively initiated technique.

Regenerative Modelocking

Like active modelocking, regenerative modelocking in the *Mai Tai* laser employs an AOM within the cavity to generate a periodic loss. However, unlike active modelocking, the RF drive signal used to drive the AOM is derived directly from the laser cavity (Figure A-4). This removes one of the greatest drawbacks of active modelocking, i.e., the requirement that the cavity length match the external drive frequency. In the *Mai Tai*, if the laser cavity length L changes slightly, the drive signal to the modulator changes accordingly.

When the *Mai Tai* is initially aligned, the laser is operating CW with oscillations from several longitudinal modes. These are partially phase-locked, and mode beating generates a modulation of the laser output at a frequency of $c/2L$. This mode beating is detected by a photodiode and then amplified. Since this signal is twice the required AOM modulation frequency (ω_{ML}), it is divided by two, then the phase is adjusted such that the modulator is always at maximum transmission when the pulse is present. Finally, the signal is reamplified and fed to the AOM.

Most actively mode-locked systems run on resonance for maximum diffraction efficiency. The AOM in a *Mai Tai* is operated off-resonance with a diffraction efficiency of about 1%. The output pulse width is not controlled by the AOM diffraction efficiency. Rather, pulse broadening in the *Mai Tai* occurs through a combination of positive GVD and nonlinear effects (self phase modulation) in the Ti:sapphire rod. Ultimately, the output pulse width is controlled by adding net negative GVD to the cavity to balance these effects. (Refer to the following section on GVD.)

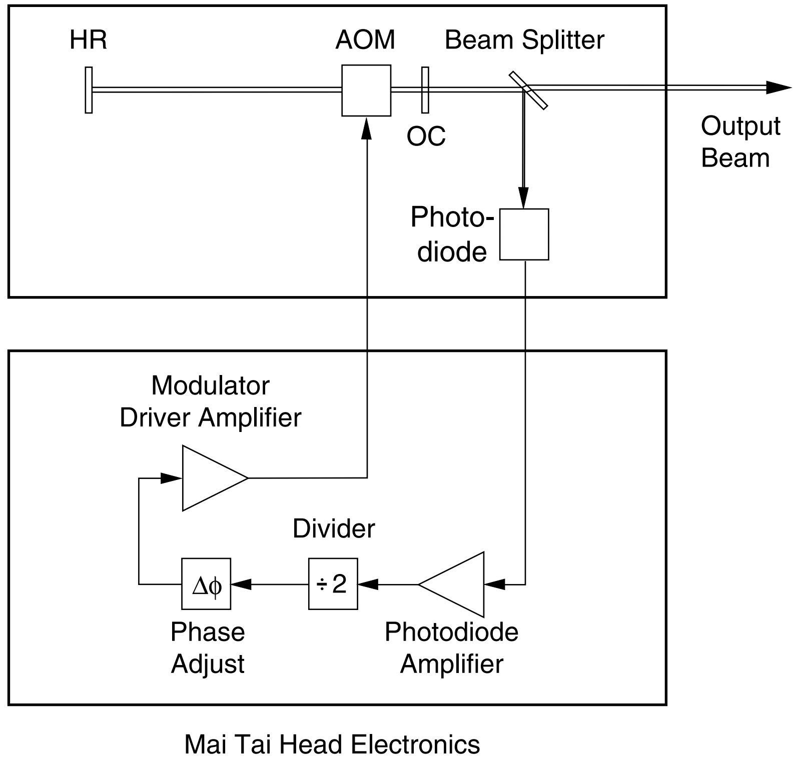
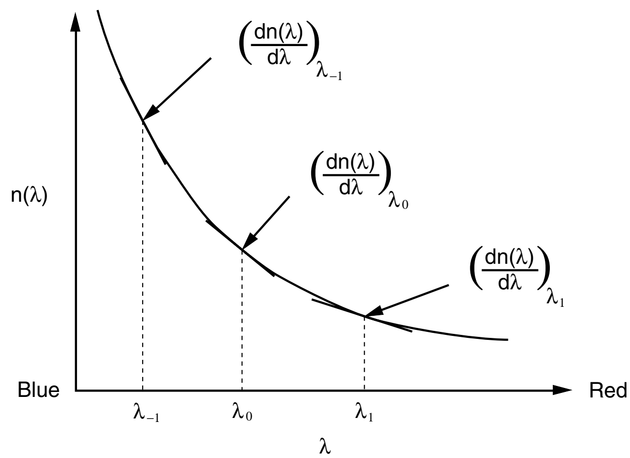


Figure A-4: Configuration of the electronics for a regenerative mode-locked laser.

Group Velocity Dispersion

Fourier analysis (or as consequence of the Heisenberg uncertainty principle) imposes a restriction on the bandwidth of an ultrashort pulse. For a pulse of duration Δt_p and bandwidth $\Delta\nu$, it is always true that $\Delta\nu$ @Δt_p will be greater than a constant with a value of about 1. The exact nature of the constant depends on the exact shape of the pulse (examples are given in Appendix B). It is apparent that, the shorter the pulse, the larger the bandwidth and, thus, the greater the difference from the lowest to highest frequency within a pulse. Since the index of refraction of any material is frequency dependent, each frequency in a pulse experiences a slightly different index of refraction as it propagates. This index of refraction difference corresponds to a velocity difference, causing a time separation between the different frequencies of a pulse. GVD is defined as the variation in transit time as a function of wavelength. For positive GVD, the lower frequencies (red) travel faster than higher frequencies (blue). The effect is more pronounced for shorter pulses (because of their larger bandwidth).

Figure A-5 shows the refractive index n versus wavelength λ for a typical transparent optical material. For any given wavelength, the refractive index $n(\lambda)$ determines the phase velocity. The slope of the curve, $dn(\lambda)/d\lambda$, determines the group velocity, or the velocity of a short pulse with a center wavelength of λ.



Phase Velocity = $^{c}/_{n}$

Group Velocity = $^{c}/(n(\lambda) - \lambda^{dn}/_{d\lambda})$

Group Delay Time, Tg = $(^{L}/_{c}) \cdot (n(\lambda) - \lambda^{dn}/_{d\lambda})$

where L is material length

Figure A-5: Typical wavelength dependence of the refractive index of a material.

The second derivative of the curve, $d^2n(\lambda)/d\lambda^2$, determines the GVD, which is the rate at which the group velocity changes as a function of wave length, i.e., it governs the rate at which the frequency components of a pulse change their relative time. GVD can change the temporal shape of the pulse by broadening it or narrowing it, depending on the "chirp" of the original pulse. A pulse is said to be positively chirped, i.e., it has experienced positive GVD, if the low frequencies lead the high (red is in front), and negatively chirped if the opposite is true. Pulses are typically positively chirped as they pass through normal materials at visible and near IR wavelengths.

Nonlinear Effects

In addition to GVD, the output pulse width and pulse shape from the *Mai Tai* are governed by the interaction of the pulse with the nonlinear index of the Ti:sapphire. The nonlinear index of refraction n_2 introduces an intensity-dependent index at high intensities:

$$n = n_0 + n_2 I \qquad [1]$$

where n_0 is the linear index of refraction and I is the instantaneous pulse intensity. This results in self phase modulation (SPM) of the pulse. As the pulse propagates through the Ti:sapphire material, the leading edge experiences an increasing index of refraction. This causes a delay in the individual oscillations of the electric field and results in a "red-shifted" leading edge. Conversely, the trailing edge of the pulse is "blue-shifted." SPM will, thus, broaden the spectrum of the pulse and provide a positive chirp.

In order to achieve near transform-limited output pulses, it is necessary to compensate for the pulse spreading caused by positive GVD and SPM. In the *Mai Tai*, this is accomplished with prism pairs (which provide negative GVD linear over a large bandwidth).

GVD Compensation

The materials in the *Mai Tai* contribute positive GVD and, in combination with SPM in the Ti:sapphire rod, induce a positive chirp on the pulse. Consequently, the circulating pulse continues to broaden as it propagates through the cavity unless negative GVD is present to balance these effects.

As discussed earlier, a material exhibits GVD when the second derivative of its refraction index, with respect to wavelength $(d^2n/d\lambda^2)$, is non-zero. This is a special case that is only valid when all wavelengths follow the same path through a material. This can be extended to any optical system having a wavelength dependent path length (P). GVD is then governed by the second derivative of the optical path with respect to wavelength $(d^2P/d\lambda^2)$.

For this reason, a prism pair can be used to produce negative GVD in the *Mai Tai*. This is generally the preferred intracavity compensation technique for ultrashort pulse lasers because (a) losses can be minimized by using the prisms at Brewster's angle, and (b) the negative GVD is nearly linear over a large bandwidth. Ideally, for stable short-pulse formation, the round trip time in the cavity must be frequency independent, i.e., $Tg(\omega) = d\phi/d\omega$ = constant, where $Tg(\omega)$ is the group delay time, ϕ is the phase change, and ω is the frequency. In reality, dispersion is not purely linear, and higher order dispersion terms become significant for shorter output pulse widths (larger bandwidths).

In the *Mai Tai* laser, a two-prism sequence configuration is used to provide negative GVD (for clarity, Figure A-6 shows a four-prism sequence to illustrate the point).

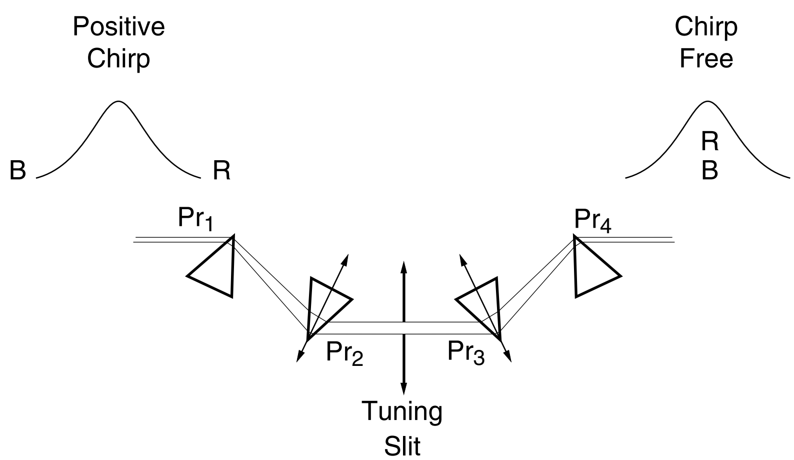


Figure A-6: A four prism sequence used for dispersion compensation. An input pulse with a positive chirp (red frequencies at the leading edge of the pulse) experiences negative GVD (red frequencies have longer group delay time) in the prism sequence. The net effect is that the prism sequence compensates for the positive GVD and produces a pulse which has no chirp.

The different spectral components of the pulse are spatially spread between prisms Pr_2 and Pr_3. This allows wavelength selection to be conveniently accomplished by moving a slit between these two prisms in the direction of the spectral spread.

Appendix B Pulse Width Measurement

Introduction

In this chapter we discuss how to measure pulses using an autocorrelator.

The Autocorrelation Technique

Measurement of Ultrashort Pulses

An autocorrelator is the most common instrument used for measuring an ultrafast femtosecond (fs) or picosecond (ps) optical pulse. By using the speed of light to convert optical path lengths into temporal differences, we use the pulse to measure itself.

The basic optical configuration is similar to that of a Michelson interferometer. An incoming pulse is split into two pulses of equal intensity and an adjustable optical delay is imparted to one. The two beams are then recombined within a nonlinear crystal for second harmonic generation. The efficiency of the second harmonic generation resulting from the inter action of the two beams is proportional to the degree of pulse overlap within the crystal. Monitoring the intensity of UV generation as a function of delay between the two pulses produces the autocorrelation function directly related to pulse width.

Two types of autocorrelation configurations are possible. The first type, known as interferometric and shown in Figure B-1, recombines the two beams in a collinear fashion. This configuration results in an autocorrelation signal on top of a constant dc background, since the second harmonic generated by each beam independently is added to the autocorrelation signal. Alternatively, if the two beams are displaced from a common optical axis and then recombined in a noncollinear fashion (Figure B-2), the background is eliminated because the UV from the individual beams is separated spatially from the autocorrelator signal. This configuration is called “background-free.”

The Spectra-Physics *Model 409-08* scanning autocorrelator operates in a background-free configuration according to the principles of noncollinear autocorrelation. It allows the autocorrelator signal to be conveniently displayed on a high impedance oscilloscope, providing the user with instantaneous feedback of laser performance. The *Model 409-08* uses a rotating block of fused silica for varying the relative path lengths of both beam paths, and the scanning time base is calibrated by moving a calibration etalon of known thickness in and out of one of the beam paths. The *Model*

409-08 can be used over the wavelength range from 650 to 1600 nm and, by changing the rotating blocks, it can be used to measure pulse widths from 25 ps to < 80 fs.

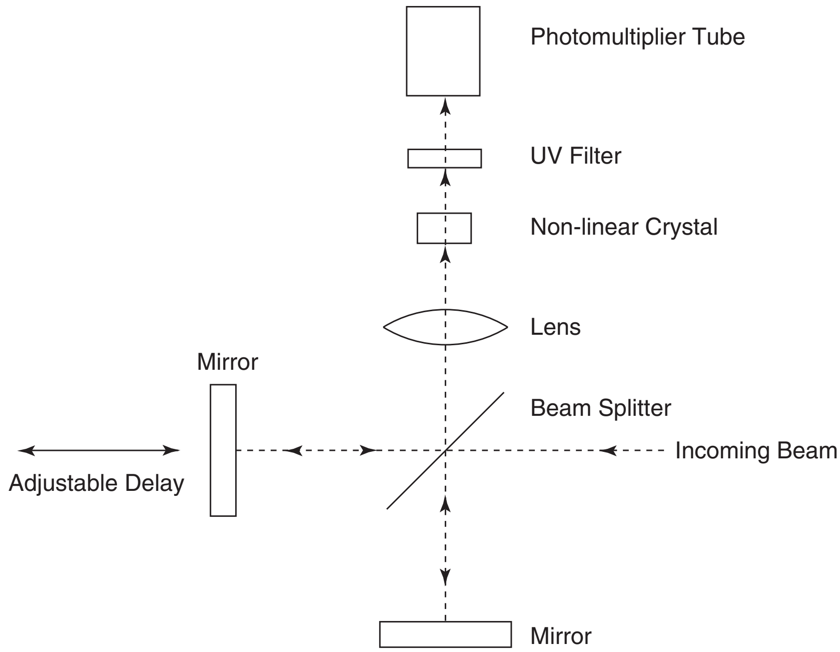


Figure B-1: Interferometric (Collinear) Autocorrelation

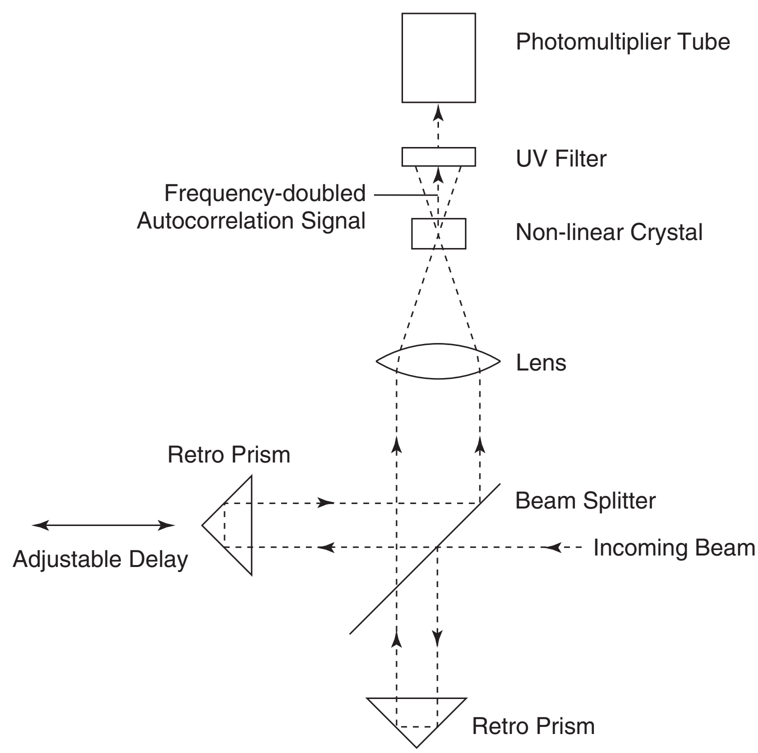


Figure B-2: Background-free (Non-collinear) Autocorrelation

Signal Interpretation

In order to determine the actual pulse width from the displayed autocorrelation function, it is necessary to make an assumption about the pulse shape. Table B-1 shows the relationship between pulse width, Δt_p, and the autocorrelation function, Δt_{ac}, for several pulse shapes. It also shows the time-bandwidth product, $\Delta tp \;\; \Delta n$, for transform-limited pulses.

Table B-1: Second-order Autocorrelation functions and Time-Bandwidth Products for Various Pulse Shape Models

Function	I(t)	Δt_p*/Δt_{AC}**	$\Delta t_p \Delta \upsilon$***
Square	$I(t) = \begin{cases} 1; \lvert t\rvert \le t_p/2 \\ 0; \lvert t\rvert > t_p/2 \end{cases}$	1	1
Diffraction Function	$I(t) = \frac{\sin^2(t/\Delta tp)}{(t/\Delta tp)}$	0.751	0.886
Gaussian	$I(t) = \frac{\exp-(4\ln 2)t^2}{\Delta t^2{}_p}$	0.707	0.441
Hyperbolic Secant	$I(t) = \operatorname{sech}^2\frac{(1.76t)}{\Delta tp}$	0.648	0.315
Lorentzian	$I(t) = \frac{1}{1+(4t^2/\Delta t^2{}_p)}$	0.500	0.221
Symmetric two-sided exponential	$I(t) = \exp\frac{-(\ln 2)t}{\Delta tp}$	0.413	0.142

* Δt_p *(sec) is FWHM of intensity envelope of the pulse.*
**Δt_{AC} *(sec) is FWHM of autocorrelator function of the pulse.*
***Δt_n *(Hertz) is FWHM of the spectrum of the pulse.*

GVD Compensation in Measurement of Ultrashort Pulses

Because the pulses produced by the *Mai Tai*™ laser are extremely short (< 100 fs), the pulse broadening in optical materials from GVD makes measurement of its true pulse width difficult. Also, because the GVD of glass causes the pulse width to broaden, the pulse that reaches the target after traveling through beam splitters, lenses, etc., may not be the same pulse that is measured in the autocorrelator. It is thus important to ensure that the measurement technique and optical set up incorporate the same amount of glass and some GVD compensation if the shortest pulses are to be measured and delivered to a sample.

Even before the pulse leaves the laser, it travels through extra glass. For example, if we assume the pulse in a *Mai Tai* laser is at its shortest as it passes through the coating of the output coupler, it then travels through the output coupler substrate, the photodiode beam splitter and the output window. The total thickness of these optics is about 1.9 cm (0.75 in.). Thus, a pulse that is 60 fs at the output coupler coating becomes 66 fs by the time it exits the laser. Include the glass of the autocorrelator and that in any optical setup and the pulse can be broadened substantially.

Since most autocorrelators use beam splitters, a lens, and often a spinning block (as in the *Model 409-08*), the pulse is also broadened before it is measured. This means the pulse out of the *Mai Tai* may be actually shorter than that indicated by direct measurement. Consequently, GVD must also be compensated when using an autocorrelator.

Since the sign of GVD in material is generally positive for the wavelengths produced by the *Mai Tai* laser, introducing negative GVD into the beam path compensates for the broadening effect of the material. Negative GVD can be introduced into a system with prism pairs, grating pairs, or a Gires-Tournois Interferometer (GTI). The prism pair provides the easiest, lowest loss means for compensating for the positive GVD of materials.

To compensate for pulse broadening from materials, a simple setup using two high index prisms (SF-10) is all that is necessary. Figure B-3 shows the layout (top and side views) for an easily built pre-compensation unit. The laser pulse travels through the first prism where different frequency components are spread in space. Then the broadened pulse travels through the second prism, strikes a high reflector, and reflects back along its original path–with one exception. The high reflector is slightly tilted in the plane perpendicular to the spectral spreading and causes the pulse to travel back through the prisms at a slightly different vertical height. After the beam returns through the first prism it is reflected by another mirror to the autocorrelator and/or the experiment.

This setup allows the higher frequencies (blue) to catch up with the lower frequencies (red). This is not intuitively obvious, since it appears that the higher frequencies actually travel a longer path length than the lower frequencies. However, it is the second derivative of the path with respect to wavelength, $d^2P/d\lambda^2$, that determines the sign of the GVD. In Table B-2 and Table B-3, dispersion values at 800 nm are provided for materials and grating prism pairs. The dispersion, D_w, is expressed in units fs^2/cm of path length.

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

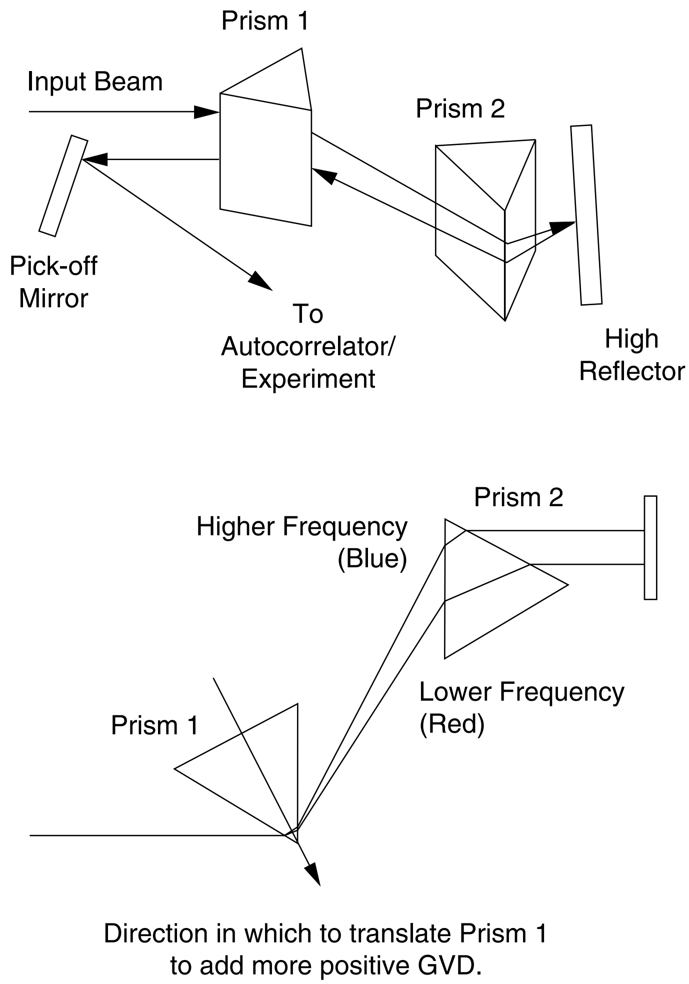


Figure B-3: Using two prisms to compensate for positive GVD.

Table B-2: Positive Dispersion Values @ 800 nm

Material	**Dω (fs^2/cm)**
Fused Silica	300
BK-7	450
Ti:sapphire	580
SF-10	1590

Table B-3: Negative Dispersion Values @ 800 nm

System	Dω (fs^2/cm)
SF-10 Brewster Prism pair, double pass	–80.2
BK-7 Brewster Prism pair, double pass	–12.8
Grating pair, 400 lines/cm @ 30° incidence angle, double pass	–1500
Grating pair, 1000 lines/cm @ 30° incidence angle, double pass	–10,000

For an initial setup based on your *Mai Tai* and a *Model 409-08* autocorrelator, set the prisms approximately 30 cm apart at Brewster's angle to the beam with the high reflector a few cm from the second prism. With this spacing, the prism pair should start with excess negative GVD. By moving the prism tips into the beam, we can balance the GVD for minimum pulse width. To do this, place the first prism on a translation stage that moves the prism in the direction of the bisector of the apex. This way, more glass can be pushed into the beam path without displacing the beam or changing its angular direction. This allows the negative GVD of the prism system to balance the positive GVD created by all the glass. By moving the prism into the beam path and monitoring the output from a *Model 409-08*, the pulse should get narrower as the dispersion is balanced. If a minimum cannot be found, adjust the prism spacing and search for the minimum again.

Calculating Pulse Broadening

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

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

$$B = \frac{t_{out}}{t_{in}} = \left\{1 + \left[7 \cdot 68 \cdot \left(D_w \cdot \frac{L}{t_{in}^2}\right)^2\right]\right\}^{\frac{1}{2}} \qquad [1]$$

where t_{in} is the input pulse width in femtoseconds, and D_w is a dispersion value normalized for a given length and wavelength. Table B-2 gives values for different materials at 800 nm. Also given in Table B-3 are the values for some negative dispersion setups, prisms, and grating pairs for compensation at 800 nm. Using these values, *B* is calculated directly; we define *S* as:

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

Using Figure B-4, you can relate the value of *S* to a value for the broadening *B*.

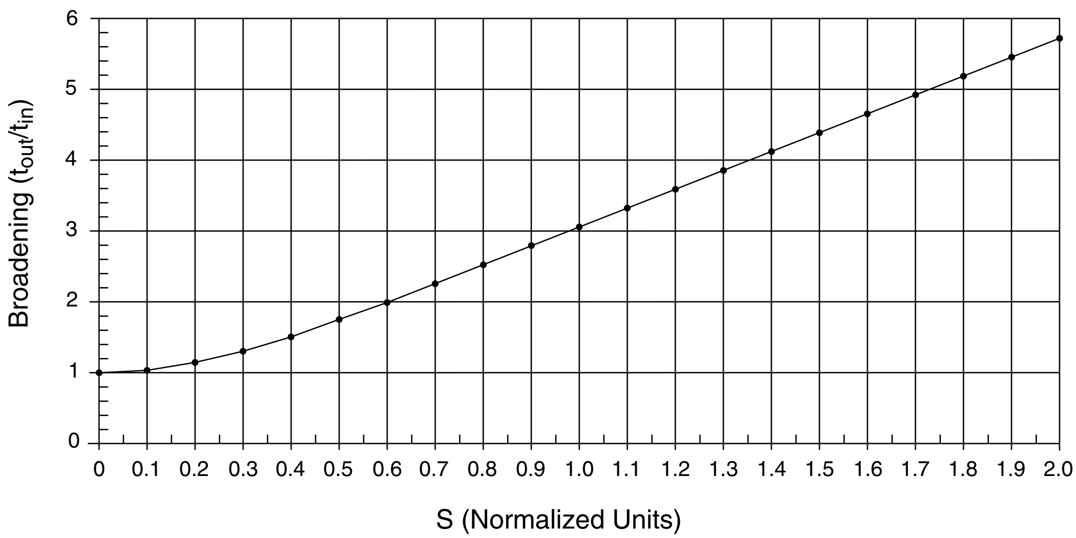


Figure B-4: Broadening Curve

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

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

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

Example 1: Calculating pulse width measured by a *Model 409-08* without pre-compensation.

Assume an 800 nm pulse at the output coupler surface of a *Mai Tai* laser is 55 fs long and transform limited. It passes through 1.9 cm of fused silica before exiting the *Mai Tai*, and 0.25 cm of BK-7 glass and 0.26 cm of fused silica in the *Model 409-08*.

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

$$= 300@1.9 + 300@0.26 + 450@0.25 = 760\ fs^2$$

Therefore $\quad S = 760(fs^2)/(55\ fs)^2 = 0.251$

Then, looking at our normalized curve (Figure B-5) $S = 0.251$, and $B = 1.22$, $t_{out} = 1.22 @ t_{in} = 67$ fs.

Example 2: Calculating the prism spacing necessary for pre-compensating the *Model 409-08*.

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

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

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

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

Therefore L = 25.3 cm (10 in.).

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

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

Appendix C Status Codes

Listed below are all the status codes and messages that might be displayed on the controller while using the *Mai Tai*™ system. Most codes are self-explanatory and most errors can be corrected by the user. In the event the error cannot be corrected, or the action required to correct the error is not known, call your Spectra-Physics service representative. Before calling, however, write down the code and message.

Code 0 to 126 are generated by the *Model J40* power supply, codes 127 and up are generated by the *Mai Tai* laser head. Codes 142 to 147 are latched interlock messages that indicate the *Model J40* shut off without a command to do so. These latched interlock messages are cleared by either:

a. pressing the LASER POWER switch on the controller, or

b. sending the OFF command through the RS-232 port.

The Info menu HST line on the controller lists the three most recent status codes with the most recent listed first. The RS-232 *?H* query reports the most recent 16 codes, again with the most recent listed first.

Table C-1: Status Codes

Code	Message
0	Everything is fine
1	Power Mode Ready
2	Current Mode Ready
3	Power Mode Adjust
4	Current Mode Adjust
5	Diodes off, temperature stable, ready to turn on
8	Power Supply in Standby mode
61	EEPROM data read error
62	AC Fault, >50ms
63	System Boot Marker
64	Communications error
65	Laser Power Outside Ready Range
66	Power adjust timeout
67	Passbank over temp
68	Passbanks current limited
69	Diode Module ilock test: bad voltage
70	Diode Module ilock test: bad logic
71	Diode Module Safety Check 2: bad voltage

Table C-1: Status Codes

Code	Message
72	Diode Module Safety Check 2: bad logic
73	Diode Module Safety Check 1: bad voltage
74	Diode Module Safety Check 1: bad logic
81	EEPROM data not available @ startup
82	EEPROM fault on write condition
83	Bad config for uP
84	Compressor failed startup test
85	Heater failed startup test
86	Shorted therm #2 in power supply
87	Open thermistr #2 in power supply
88	Shorted therm #1 in power supply
89	Open thermistr #1 in power supply
90	Multiple errors
91	Diode over temperature
92	Diode under temperature
93	Current limit passbank 2 active
94	Current limit passbank 1 active
95	Power supply interlock active
96	Safety relay for D2 closed, s.b. open
97	Safety relay for D2 open, s.b. closed
98	Safety relay for D1 closed, s.b. open
99	Safety relay for D1 open, s.b. closed
127	Everything's fine
133	SHG duty cycle error
134	SHG thermistor shorted
135	SHG thermistor or heater open (check cable)
140	Controller interlock open
141	Communications error between head & supply
142	System shut off: check HST on info menu
143	System shut off: pwr sply interlock
145	System shut off: REMOTE interlock
146	System shut off: power adjust timeout
147	System shut off: current limit
148	Controller communications time out
200	Diode calibration required
201	Diode1 curr calib required
202	Diode2 curr calib required
203	Diode3 curr calib required
204	Diode4 curr calib required
205	Diode1 temp calib required
206	Diode2 temp calib required
207	Diode3 temp calib required
208	Diode4 temp calib required

Notes

Report Form for Problems and Solutions

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

Thank you.

From:

Name ______________________________

Company or Institution ______________________________

Department ______________________________

Address ______________________________

____

Instrument Model Number ____________________ Serial Number ____________________

Problem: ______________________________

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____

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Suggested Solution(s): ______________________________

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