Matisse User's Guide

Version 1.8

Sirah
Laser- und Plasmatechnik GmbH

Contents

CHAPTER 1

Matisse Preface

Thank you for purchasing the *Sirah Matisse* laser system.

This manual was written to show you how to safely install, operate, maintain and service your laser system. An attempt was made to describe the laser both accurately and completely. However, due to the continuous progress in technical development discrepancies between manual and delivered laser system may occur. Before applying pump laser power to the laser system it is strongly recommended to read this manual thoroughly and to understand its content.

The first chapter deals with *Laser Safety.* The *Matisse* laser, in combination with a powerful pump laser, is a class IV high power laser. Its laser radiation represents a serious hazard for your personal health, as it can permanently damage your eyes and skin. Moreover, inadequate operation of the laser system may damage other laboratory equipment, e.g. by ignition of combustible substances or by laser sputtering of surfaces, as well as the laser system itself, e.g. by focused back reflections. To minimize the risks connected to laser operation, read this Chapter thoroughly - and carefully follow the instructions. The *Laser Safety* Chapter should be read by all persons working in the laboratory where laser radiation occurs, even by those not directly involved in laser operation.

The next chapter contains a general *Laser Description*, with some details about the optimum performance range of your *Matisse*.

The laser's *Controls* are described in the following chapter.

An concise introduction into *Single-Frequency Tunable Laser Physics* and the techniques used for *Frequency Stabilization* follows.

The operation of your *Matisse* laser on a day-to-day basis is described in detail in the next chapter. This chapter contains both, basic operation hints necessary for your everyday work with the laser system, as well as more detailed alignment and optimization procedures for all relevant components of your laser. To keep the laser working at optimum performance is quite easy as long as you do not totally corrupt the laser optical set-up. Some effort has been undertaken to illustrate the different laser optimization possibilities as step-by-step procedures. Please always read the whole section corresponding to your task before doing the first step.

The following chapter serves as a description and reference for the *Matisse Commander* computer program, with which the *Matisse* laser is controlled.

The *Maintenance* chapter will deal with all relevant maintenance tasks necessary for a stable long term operation of your laser system.

If you have to move your *Matisse* laser to a different location, the *Matisse Installation* chapter contains procedures on how to set up the laser and bring it back to a lasing state.

Matisse Electronics gives additional and more detailed information on the electronics.

The *FAQ and Troubleshooting* chapter tries to help you solve some issues, that you may encounter at some time working with a Matisse laser

In the *Customer Service* section you will find the addresses of world wide Service and Sales Centres for *Sirah* instruments. In case of any question, remark or problem, please do not hesitate to contact us.

Please read the whole manual before starting to work with your system.

We strongly recommend to keep a laser logbook. You should note all changes of the mechanical or optical set-up of your laser. Regularly take notes about obtained laser powers, together with the corresponding pump power. These notes often simplify the identification of possible error sources.

Finally, if you encounter any difficulty with the content or the style of this manual, please let us know. For your convenience, a fax form has been added at the end of this manual, which will aid in bringing such problems to our attention.

Environmental Specifications

CE Electrical Equipment Requirements

AC power input:	100 .. 240 VAC 50/60 Hz
Power Consumption:	max. 700 W

Environmental Specifications

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

Indoor use.

Altitude:	maximum of 3000 m
Temperature:	15 °C to 35 °C
Humidity:	30% to 60%, non-condensing conditions
Insulation category:	1
Pollution degree:	2

Standard Units

The following units, abbreviation, and prefixes are used in *Sirah* Manuals:

Quantity	**Unit**	**Abbreviation**
mass	kilogram	kg
length	meter	m
time	second	s
frequency	Hertz	Hz
force	Hewton	N
energy	Joule	J
power	Watt	W
electric current	Ampere	A
electric charge	Coulomb	C
electric potential	Volt	V
resistance	Ohm	Ω
temperature	degree Celsius	°C
pressure	Pascal	Pa

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	milli	10^-3	m	femto	10^-15	f
kilo	10^3	k	micro	10^-6	µ	atto	10^-18	a

Unpacking and Inspection

Your *Sirah* laser system was assembled, checked and packed with great care. It was shipped in a container specially designed for this purpose. Upon receipt of your system, inspect the outside of the shipping container. If there is any major damage, insist that a representative of the carrier being present when you unpack the contents. All *Sirah* laser containers are equipped with shock and tilt indicators. Carefully inspect these indicators. If any of them is actuated, insist that a written confirmation is done on the shipping papers, signed by the carrier.

If the transport boxes are in good condition, and none of the shock and tilt indicators is actuated, then carefully unpack and inspect the laser system and all accessory parts. Each system is accompanied by a packing slip listing all the parts shipped. Verify that your system is complete and undamaged. In case of any problems, like damaged or missing parts, please immediately notify the carrier and your *Sirah* sales or service representative. Addresses may be found in the *Customer Service* Chapter.

Keep the shipping containers. If you file a damage claim, you may need them to demonstrate that damage occurred during transport. If you want to move your laser to another laboratory building, or if you need to return the system for service, the specially designed container assures adequate protection.

System Components

The following components comprise the *Matisse* laser system:

- *Matisse* laser head
- *Matisse* electronics box
- *Matisse* service box
- *Matisse* dye circulator system (only for dye laser version)

Further components may be supplied together with the laser system, according to the packing list.

Service Box

Each Matisse laser is delivered together with a service box, containing some laser accessories and service tools for your everyday work with the laser, as well as some spare parts. The following items are included in your service box:

Installation Accessories

1 x Matisse Laser Manual

1 x Matisse Commander Installation CD-ROM

1 x Mains cable

1 x USB cable

4 x Laser fixing clamps

1 x Filter for purging the laser head

1 x Beam tube, to be installed in between pump laser and Matisse

2 x Laser warning signs

Service Accessories

1 x Set of metric Allen head keys 1.5, 2, 2.5, 3, 4, 5 mm

1 x Set of neutral density filters, for Matisse laser head diodes

1 x Tool 1 : Pump mirror pinholes

1 x Tool 2 : Lyot filter dummy

1 x Tool 3 : Thick etalon dummy

1 x Tool 4 : Beam overlap tool

1 x Tool 5 : Pump beam filter (Ti:Sa laser only)

1 x Tool 6 : Mirror mount ring

Spare parts

1 x Set of spare O-rings, 25 mm x 1.5 mm and 25.1 mm x 1.6 mm, for mounting of mirrors

Additionally, depending on the configuration of your laser, the service box may contain further items, which are indicated in a list included in the box.

CE Declaration of Conformity

Manufacturer

Sirah Laser- und Plasmatechnik GmbH

Ludwig-Erhard-Str. 10

41564 Kaarst

Germany

Phone: +49 2131 660 651

Fax: +49 2131 668 095

Product Name

Matisse

Product Types

TR, DR, TS, DS, TX, DX

Directive

Council Directive 73/23/EEC, Low Voltage

Council Directive 89/336/EEC Apendix I, Electromagnetic Compatibility

Applicable Standards

EN 61010-1:2004, Safety requirements for electrical equipment, control, and laboratory use

EN 60825-1:2001, Safety of laser products Part 1: Equipment classification, requirements and user's guide

EN 61326-1:1997 + EN 61326-1:1998, Electrical equipment for measurement, control and laboratory use - EMC requirements

We herewith declare, in exclusive responsibility, that the above specified instruments were developed, designed and manufactured to conform with the above Directives and Standards.

Dr. Sven Hädrich

Geschäftsführer, Sirah Laser- und Plasmatechnik GmbH

Kaarst, November 30, 2005

CHAPTER 2

Safety Precautions

Precautions for the Safe Operation of Class IV High Power Lasers

The use of a dye laser system may cause serious hazards if adequate precautions are not taken. Most of these hazards can be avoided by appropriate operation of the laser device. However, after a period of problem-free operation, many users tend to become careless with safety precautions. Hence you should ensure that all safety rules described in the following section (and, of course, those prescribed by law) are observed.

The Sirah Matisse laser is operated in combination with a powerful pump laser (Nd:YAG or Ar+ laser). The laser power of the Matisse depends on the pump laser power and on the selected wavelength. In any case, the laser beam of the pump laser as well as the Matisse laser beam have an extremely high power density. Hence both lasers are able to cause severe eye and skin damages. Due to the high powers involved even scattered or specularly reflected laser light are sufficient to produce such injuries. Furthermore, absorbing and flammable material inadvertently used as a beam stop poses a fire hazard. Thus working with such laser systems utmost precautions have to be taken. Pay special attention to all advice given by the manufacturer of your pump laser.

In the following some general safety rules for the usage of lasers are given. These recommendations are by no means complete; rather they constitute the bare minimum of precautionary measures necessary to avoid laser induced dangers and damages.

- **Each person working with the laser or present in its operating room should wear laser-radiation safety goggles.** Note that the safety goggles should give protection against the radiation of all lasers used in the operating room, which are in each case the pump and the *Matisse* laser, but also radiation generated by up or down conversion of the laser light.
- **Keep the laser closed.** This means not only to keep the housing of the laser closed during laser operation, but also to enclose the emerging laser beam e.g. in tubes where feasible and to terminate the beam with a suitable beam stop.
- **Keep the internal protection sheets and beam stops in place.**
- **Under no circumstances look into the laser beam.** For security reasons, even when the laser is switched off, never look backwards in direction of the laser beam.
- **Avoid wearing reflective jewellery while using the laser.** Especially watches are excellent mirrors for laser radiation. Do not risk to reflect the beam into your eyes by them.

- **Never place reflecting surfaces into the laser beam before having verified where the reflected beam will go.** Even absorbers and beam dumps may reflect a considerable amount of laser power which can be sufficient to cause severe injuries or damages at the power levels common in the operation of your laser. The introduction of lenses into the laser beam requires special caution because its curved surfaces generate additional laser foci in the reflected beam which are able to destroy optical elements.
- **Use the pump laser at the lowest possible power level.** Especially for alignment purposes you should use the pump laser at a power level which is just slightly above the threshold power level of the Matisse laser.
- **Never expose your skin to the laser radiation.**
- **All laser beams have to be terminated with a beam stop.** All experiments to which the laser is applied have to be designed in such a way that the laser beams are confined to the experimental set-up. All laser beams for which the set-up itself does not provide a suitable beam stop have to be terminated with a beam dump.
- **Operate the laser only inside distinctly marked areas.** The laser should only be operated inside a room distinctly marked with respective warning signs and warning lamps. The access to this room has to be restricted to personnel properly trained.
- **Do not install the laser in a height that the output is at eye level.**
- **Maintain a high ambient light level in the laser operation area.** Eye's pupils remain constricted, and thus are less sensitive to scattered laser light.
- **Mark the laser operation area by prominent warning signs.**

Dangers Caused by Laser Dyes and Solvents

The physical, chemical, and toxicological properties of organic dyes are not well characterized. Just as the solvents they should be treated as poisonous. Thus an extreme caution is required in handling these substances.

During the work with laser dyes eating and drinking are strictly forbidden inside the laboratory. Always wear protective gloves and a protective mask when weighing out the laser dye. Following these measures an inadvertent ingestion of any dye can be excluded. A more likely hazard is the potential for absorption of solvent or dye solution through the skin. Even if the solvent itself is not extremely dangerous, some solvents can penetrate the skin easily and carry the toxic dyes into the body. This is especially true for solvents as e.g. benzyl alcohol, DMSO (dimethylsulfoxide), p-dioxane and methanol. Therefore we highly recommend always to wear protective gloves, laboratory overalls and a protective mask when handling laser dyes and solvents.

Your chemical supplier can give you further information concerning storage, handling and waste management of laser dyes and solvents.

Almost all solvents are highly inflammable and volatile, a fact that should always be remembered when handling these substances. Especially smoking is strictly forbidden.

In the following list some further safety precautions for the handling of dye solutions are given:

- If possible, use an outlet for handling solvents and dye solutions. Otherwise, ensure a sufficient ventilation of the workshop place.
- Do not eat, drink, and smoke during your work with solvents and dye solutions.
- Avoid all kinds of open fire.
- Repair damages or leakage in the dye circulator system immediately without modifying the technical construction of the pump systems.
- Install a suitable fire-extinguisher next to your dye laser.

Focused Back Reflection Danger

Focused back reflections of the pump as well as the Matisse laser's beam represent a serious hazard for both your personal safety and optical components. Remember that an uncoated glass surface reflects 4% of the impinging light, and even with an appropriate anti-reflective coating 0.5% of reflection are normal. These reflections may be focused from both convex and concave surfaces, depending on the orientation of the surface to the direction of light. In the focus, the light intensity is often high enough to damage the surfaces of other optical components, and to represent a serious hazard for eyes and skin.

The optical design of your Matisse laser has been set-up very carefully by Sirah Laser- und Plasmatechnik GmbH. If you intend to make any modifications to the pump laser beam path or to the Matisse laser beam path, then thoroughly check beforehand whether a focused back reflection may occur. Warranty does not cover damages due to focused back reflection!

CHAPTER 3

Matisse Laser Description

The present chapter gives a brief description of the optical set-up of the *Matisse*, as well as its main specifications. For a discussion of optical details, including step-by-step instructions for system optimizations, please refer to the next chapters.

Laser Head: Titanium:Sapphire Models

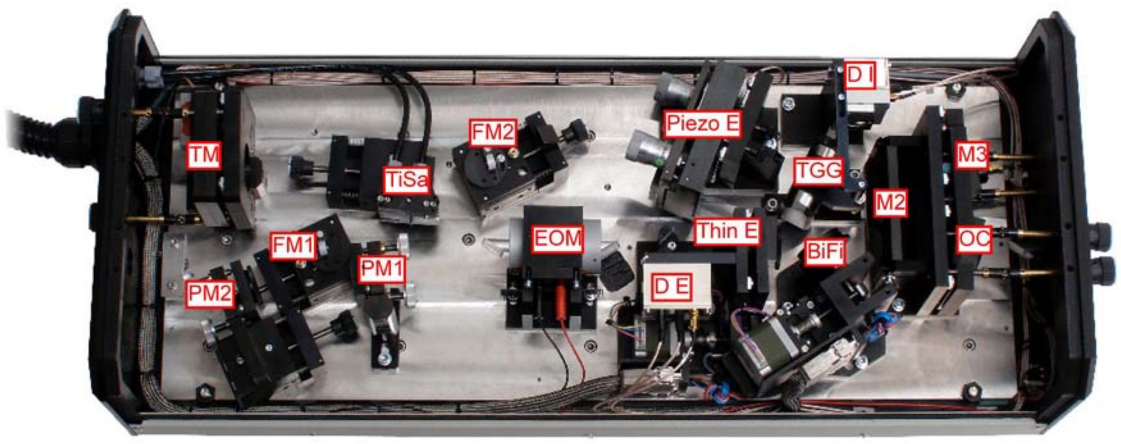

Figure 1: Top view of a Matisse TX laser head.

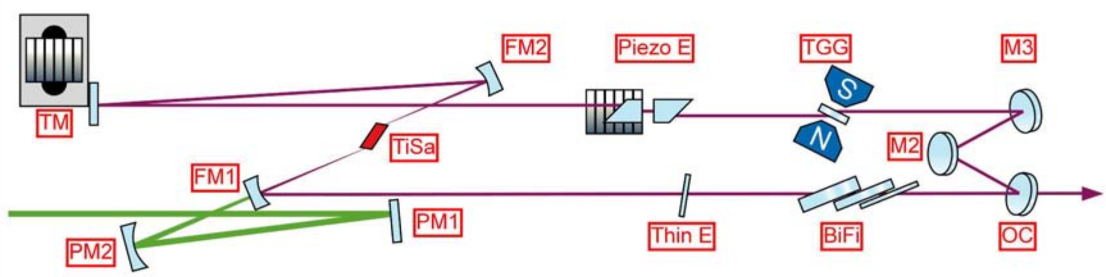

Figure 2: Optical layout of a Matisse Titanium:Sapphire laser.

PM1 Pump Beam Mirror 1. Re-directs the pump laser beam onto the second pump beam mirror PM2. The mirror is used for steering the pump laser beam.

PM2 Pump Beam Mirror 2. Focusses the pump laser beam into the crytsal, through the backside of folding mirror FM1.

FM1 Folding Mirror 1. Restores a parallel beam for the ring laser beam after amplification by the Titanium:Sapphire crystal.

FM2 Folding Mirror 2. Focusses the ring laser beam into the Titanium:Sapphire crystal for spatial mode matching with the pump laser focus.

TiSa Titanium Sapphire Crystal. The laser gain medium. The crystal is cooled by a temperature controlled water.

EOM Electro Optical Modulator. The non-resonant intra-cavity electro optical modulator is used for fast change of the optical path length of the ring cavity. The effect is used for high-bandwidth correction of the Matisse's emission wavelength. **Note:** The device is only present in the Matisse TX.

Thin E Thin Etalon. The thin etalon is used as a bandpass filter. To provide tunability, the tin etalon is attached to a motor driven mount. A step motor controls the horizontal tilt angle of the etalon.

BiFi Birefringence Filter. The birefringence filter is used as a coarse bandpass filter to determine the emission wavelength of the ring laser. The filter assembly is rotated by a stepper motor.

OC Output Coupler. The output coupler forms the exit for the laser beam. A fraction of the beam will be emitted by the laser the rest will be directed back into the ring cavity. The beam polarization is horizontal.

M2 Out-Of-Plane Mirror M2. This mirror is mounted at a different beam height level. This will introduce a geometrical rotation of the beam polarization. The combination of M2 and the TGG plate forms an optical diode that supports laser activity in a defined direction.

M3 Tweeter Mirror M3. This mirror is mounted on a piezoelectric actor. Changing the voltage applied to the actor will change the position of the mirror and ultimately the optical path length of the cavity. The effect is used for mid-bandwidth correction of the Matisse's emission wavelength. **Note:** The Matisse TR has no active control of the emission wavelength, in this case the mirror is fixed directly to the mount.

TGG TGG Plate. The TGG plate is made from Terbium-Gallium-Garnet and acts as a Faraday-rotator when exposed to a strong magnetic field. The combination of M2 and the TGG plate forms an optical diode that supports laser activity in a defined direction. **Note:** The magnetic field is generated by two powerful permanent magnets. Be careful when using tools close to the device.

Piezo E Piezo Etalon. The piezo etalon selects a single longitudinal mode from the spectral range that is determined by the configuration of output coupler, birefringence filter, and thin etalon. To maintain the exact match of etalon and longitudinal mode the spacing of the etalon is dithered by an piezoelectric actor and a lock-in scheme is used to control the etalon spacing.

TM Tuning Mirror. The exact emission wavelength of the cavity is determined by it's length. The tuning mirror is attached to a long stroke piezoelectric actor to allow the selection of this wavelength. This device is used for low-bandwidth (woofer) correction of the Matisse's emission wavelength, when active wavelength control is enabled (only available in Matisse TS and TX models).

D I Integral Diode. The lock-in control for the piezo etalon requires the measurement of the temporal behaviour of the integral intensity of the ring laser. For this purpose the leak intensity on the backside of the out-of-plane mirror M2 is used.

D E Etalon Diode. The control loop for the thin etalon requires the measurement of the back reflection of the entrance surface of the etalon. This diode measures the reflected intensity.

Optical Set-Up : Matisse-DR

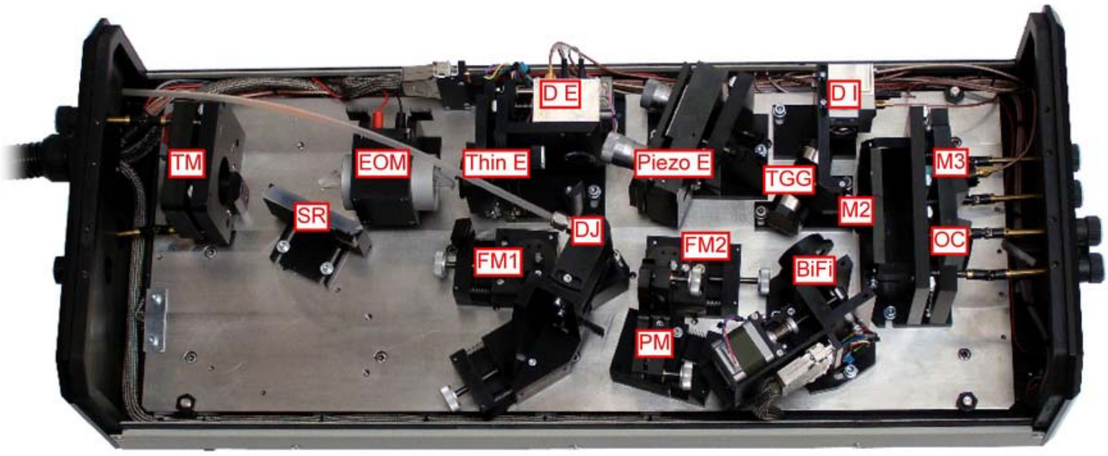

Figure 3: Top view of Matisse dye laser head.

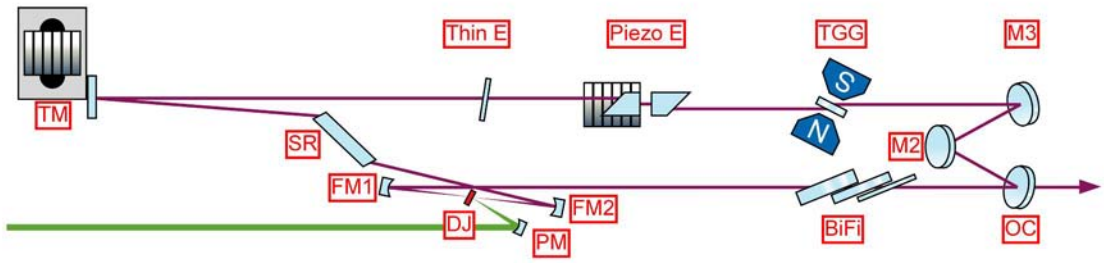

Figure 4: Optical layout of a Matisse dye laser.

PM **Pump Beam Mirror.** Re-directs and focusses the pump laser beam into the dye jet.

FM1 **Folding Mirror 1.** Restores a parallel beam for the ring laser beam after amplification by the dye jet.

FM2 **Folding Mirror 2.** Focusses the ring laser beam into the dye jet for spatial mode matching with the pump laser focus.

DJ **Dye Jet.** The laser gain medium. The jet is formed by a flow of dye solution that is pumped by the circulator system into the nozzle.

BiFi Birefringence Filter. The birefringence filter is used as a coarse bandpass filter to determine the emission wavelength of the ring laser. The filter assembly is rotated by a stepper motor.

OC Output Coupler. The output coupler forms the exit for the laser beam. A fraction of the beam will be emitted by the laser the rest will be directed back into the ring cavity. The beam polarization is horizontal.

M2 Out-Of-Plane Mirror M2. This mirror is mounted at a different beam height level. This will introduce a geometrical rotation of the beam polarization. The combination of M2 and the TGG plate forms an optical diode that supports laser activity in a defined direction.

M3 Tweeter Mirror M3. This mirror is mounted on a piezoelectric actor. Changing the voltage applied to the actor will change the position of the mirror and ultimately the optical path length of the cavity. The effect is used for mid-bandwidth correction of the Matisse's emission wavelength. **Note:** The Matisse DR has no active control of the emission wavelength, in this case the mirror is fixed directly to the mount.

TGG TGG Plate. The TGG plate is made from Terbium-Gallium-Garnet and acts as a Faraday-rotator when exposed to a strong magnetic field. The combination of M2 and the TGG plate forms an optical diode that supports laser activity in a defined direction. **Note:** The magnetic field is generated by two powerful permanent magnets. Be careful when using tools close to the device.

Piezo E Piezo Etalon. The piezo etalon selects a single longitudinal mode from the spectral range that is determined by the configuration of output coupler, birefringence filter, and thin etalon. To maintain the exact match of etalon and longitudinal mode the spacing of the etalon is dithered by an piezoelectric actor and a lock-in scheme is used to control the etalon spacing.

Thin E Thin Etalon. The thin etalon is used as a bandpass filter. To provide tunability, the tin etalon is attached to a motor driven mount. A step motor controls the horizontal tilt angle of the etalon.

EOM Electro Optical Modulator. The non-resonant intra-cavity electro optical modulator is used for fast change of the optical path length of the ring cavity. The effect is used for high-bandwidth correction of the Matisse's emission wavelength. **Note:** The device is only present in the Matisse DX.

TM Tuning Mirror. The exact emission wavelength of the cavity is determined by it's length. The tuning mirror is attached to a long stroke piezoelectric actor to allow the selection of this wavelength. This device is used for low-bandwidth (woofer) correction of the Matisse's emission wavelength, when active wavelength control is enabled (only available in Matisse DS and DX models).

D I **Integral Diode.** The lock-in control for the piezo etalon requires the measurement of the temporal behaviour of the integral intensity of the ring laser. For this purpose the leak intensity on the backside of the out-of-plane mirror M2 is used.

D E **Etalon Diode.** The control loop for the thin etalon requires the measurement of the back reflection of the entrance surface of the etalon. This diode measures the reflected intensity.

Controls Box Front and Rear Panel Features

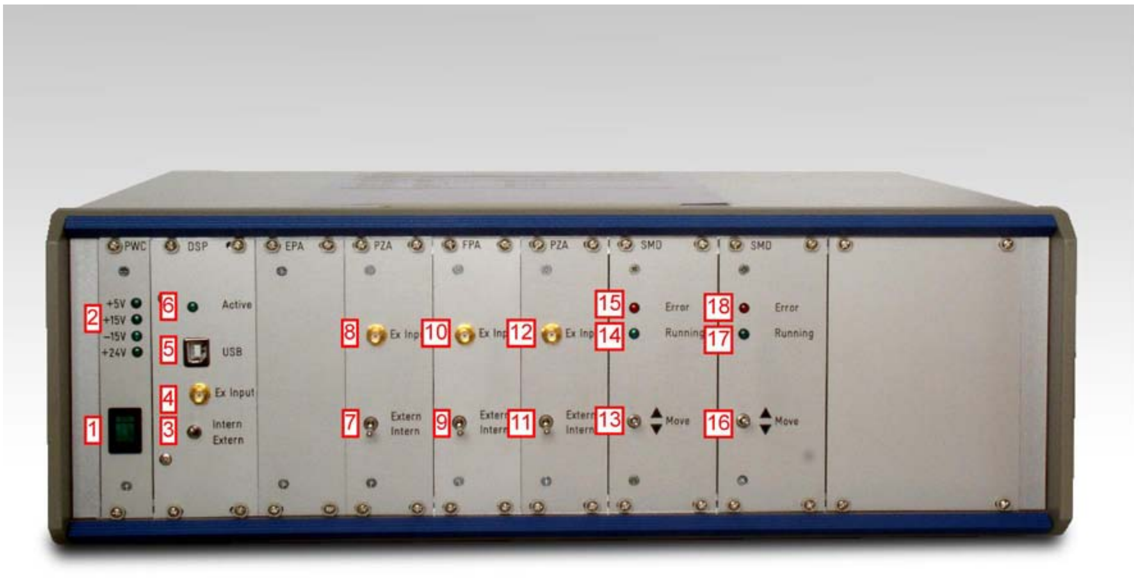

Figure 5: Front view of Matisse control box.

1 **Power switch.** Turns the entire unit On and Off.

2 **Voltage indicators.** Light up when the respective voltage is available in the control unit (LED).

3 **DSP signal input select.** Selects the internal or an external signal source for the digital signal processor (DSP).

4 **DSP external input.** SMA connector to feed an external signal into the DSP unit.

5 **USB connector.** Connects the unit to the USB.

6 **USB indicator.** Lights up when the USB is transferring data (LED).

7 **Tuning mirror input select.** Selects the internal or an external signal source for the piezoelectric actor that controls the tuning mirror.

8 **Tuning mirror external input.** SMA connector to feed an external signal into the amplifier module.

9 **Tweeter mirror input select.** Selects the internal or an external signal source for the piezoelectric actor that controls the tweeter mirror.

10 **Tweeter mirror external input.** SMA connector to feed an external signal into the amplifier module.

11 **Reference cell input select.** Selects the internal or an external signal source for the piezoelectric actor that controls the reference cell spacing.

12 **Reference cell external input.** SMA connector to feed an external signal into the amplifier module.

13 **Thin etalon manual control.** Two-way switch to control the stepper motor that controls the tilt of the thin etalon.

14 **Thin etalon indicator.** Lights up when the etalon motor is running (LED).

15 **Thin etalon error.** Lights up when an error condition is present at the etalon motor controller unit (LED).

16 **Birefringent filter manual control.** Two-way switch to control the stepper motor that controls the rotation of the birefringent filter assembly.

17 **Birefringent filter indicator.** Lights up when the etalon motor is running (LED).

18 **Birefringent filter error.** Lights up when an error condition is present at the etalon motor controller unit (LED).

Figure 6: Rear view of the Matisse electronics box.

1 **X1 Connector.** This mixed signal sub-D connector is used to connect the laser head to the control unit.

2 **X2 Connector.** This mixed signal sub-D connector connects the thin etalon stepper motor with the control unit.

3 **X3 Connector.** This mixed signal sub-D connector connects the birefringent filter stepper motor with the control unit.

4 **AC Input Connector.** This connector also holds the fuse for the unit. Rating 1.6 A, 250 VAC

Matisse-TR Specifications

This section summarizes the specifications of the *Matisse*-TR laser. Please note that specifications are subject to change without notice.

Tuning range

Pump laser	**Optics set**	**Output range**
Millennia Pro 10s	MOS-1	700 .. 780 nm
Millennia Pro 10s	MOS-2	750 .. 870 nm
Millennia Pro 10s	MOS-3	860 .. 990 nm

Power Output

at approximately 780 nm

Pump laser	**Specified power**
Millennia Pro 5s	800 mW
Millennia Pro 10s	1800 mW

General Characteristics

Spatial Mode	TEM00
Beam Diameter (at Matisse output port)	typical 1.4 mm
Beam Divergence	< 2 mrad
Linewidth	< 10 MHz rms
Amplitude Noise	1.5% rms
Beam polarization	horizontal

Requirements

Pump laser	Millennia Pro Series (or similar)

Pump laser power	5 .. 20 W
Ambient conditions	constant temperature in the 20 .. 25°C range,
	non condensing humidity conditions
Cooling	required for crystal (< 10 W)
Laboratory	vibrational isolated optical table,
	dust-free air (flow box)
Electrical	100 .. 250 V, max. 2.5 Amps
Computer control	Windows 2000 or Windows XP system, USB port

Matisse-DR Specifications

This section summarizes the specifications of the Matisse-DR laser. Please note that specifications are subject to change without notice.

Tuning range

Pump laser	Optics set	Output range
Millennia Pro 10s	MOS-4	550 .. 660 nm
Millennia Pro 10s	MOS-5	650 .. 780 nm

Power Output

at the output maximum of the Rhodamine 6G tuning curve :

Pump laser	Specified power
Millennia Pro 5s	550 mW
Millennia Pro 10s	1600 mW

General Characteristics

Spatial Mode	TEM00
Beam Diameter (at Matisse output port)	typical 1.4 mm
Beam Divergence	< 2 mrad
Linewidth	< 20 MHz rms
Amplitude Noise	3.5% rms
Beam polarization	horizontal

Requirements

Pump laser	Millennia Pro Series (or similar)
Pump laser power	5 .. 20 W

Ambient conditions	constant temperature in the 20 .. 25°C range,
	non condensing humidity conditions
Laboratory	vibrational isolated optical table,
	dust-free air (flow box)
Electrical	100 .. 250 V, max. 2.5 Amps
Computer control	Windows 2000 or Windows XP system, USB port

Required Dye Solvents

Required solvents to be used with the Matisse dye circulators are Ethylene Glycol (EG), Ethylene Glycol Phenyl Ether (EPH) and Propylene Glycol Phenyl Ether (PPH), because of their lubricant properties. Other solvents will damage the dye circulators!

The dye concentration should be chosen in that way, that at least 85% of the pump power is absorbed. The following table contains solubility data (g/l) for various dyes in the required solvents (courtesy of Exiton Inc.)

Solubility of Dyes in EG / EPH / PPH (grams/liter)

Dye	EG	EPH	PPH
BPBD-365	-	17.3	7.5
PBD	-	16.5	10.4
Exalite 389	low	≥ 2.7	≥ 4.1
Exalite 392A	low	0.5	1
Exalite 400E	9.65	≈ 0.13	0.4
Coumarin 480	0.72	83	68
Coumarin 515	3.4	5.5	5.8
Coumarin 535	-	12.6	4.3
Coumarin 540	-	5.3	3.6
Pyrromethene 546	low	0.99	0.9
Pyrromethene 556	8.1	-	insol.
Pyrromethene 567	< 0.09	84	≈ 7
Pyrromethene 580	-	5.9	7.7
Pyrromethene 597	-	7	9.2
Pyrromethene 605	-	5.7	10
Pyrromethene 650	insol.	≈ 4.3	≈ 4.4
Rhodamine 560 Chloride	55	12	1.7
Rhodamine 590 Chloride	744	16	33

Kiton Red 620 Perchlorate	337	10.5	13.6
DODCI	3.4	> 95	10.3
DCM	0.07	2.6	1.4
LD688	-	1.6	1.3
LDS698	0.99	8.5	1
LDS722	-	2.6	0.5
LDS751	-	2.2	-
LDS759	-	1.5	0.66
LDS821	-	2.3	1.1
LDS867	-	0.96	0.16
LDS925	-	0.44	0.15
LD700 Perchlorate	2.5	98	54
Oxazine 750 Perchlorate	0.67	0.67	0.23

Matisse Reference Cell

The *Matisse* Reference Cell contains a highly stable, scannable optical resonator (made of an INVAR rod) serving as an external frequency reference in different frequency stabilization schemes for the *Matisse* S and X models.

The resonator itself is is evacuated. The reasons are:

- to prevent humidity-related problems that degrade the piezoelectric actuator
- to minimize the acoustic transmission of noise
- to support a better thermalization

Do not open the venting valve!

CHAPTER 4

Single-Frequency Tunable Laser Physics

This chapter intends to give a concise and simple introduction into the physics and technologies used to operate the tunable single-mode continuous-wave Matisse laser.

Principle Laser Set-up

As the acronym L(ight) A(mplification) by S(timulated) E(mission) of R(adiation) indicates one crucial part of a laser is an amplifying medium. This (gain) medium has in general to be exited ('pumped') by a adequate sources to act as an amplifier for electromagnetic radiation. The spectral bandwidth of a laser medium can be relatively small (e.g. just one atomic resonance) or very large, covering a wavelength range of under 700 nm to over 1000 nm in the case of Titanium-doped Sapphire (Ti:Sa) or a range of some 10 nm for various dyes.

The second prerequisite for a laser is an optical resonator, being in a simple case a pair of parallel spherical mirrors, which acts as a feedback loop for the amplifier medium. This system of an amplifier with feedback can produce self-exited electromagnetic fields in the form of laser beams, which have well-known special properties.

First they have a very high spatial coherence, i.e., they have a very small spotsize, when focused, they are the best practical approximation to an idealized light ray, etc. The simplest laser beam has a transverse intensity profile in form of a Gaussian distribution.

Second they can have a very high temporal coherence, i.e. the field has a relatively small frequency spectrum. For the latter property some conditions have to be fulfilled. Optical resonators have discrete resonances with well defined frequencies, separated in the case of a ring resonator by a frequency difference of $\Delta\nu = c/d$ (c velocity of light, d mirror distance); this is called the Free Spectral Range (FSR). These resonances are called resonator (eigen-)modes.

If you have a gain medium with a relatively small bandwidth compared to the FSR of the optical resonator, and one of the resonator modes' frequencies coincides with the (center-)frequency of the medium, your laser will emit radiation only with just this frequency; you then have a single-mode laser. In the case of the Ti:Sa, with its very large gain bandwidth, a vast number of modes could in principle oscillate for any practical resonator length. To achieve single-mode laser operation for Ti:Sa or dyes, additional frequency-selective elements have to be introduced into the resonator. These elements will be explained in detail in the next section.

Another important aspect for single-mode laser operations is to choose a ring-laser geometry instead of a standing wave resonator configuration. With electromagnetic standing waves, only part of the gain provided by the laser medium can used by a specific resonator mode; at the locations of the wave's nodes the gain cannot be depleted ('spatial hole burning' effect). This can lead to a situation, where another resonator mode, having its anti-nodes at the locations of the nodes of the former mode, can start to oscillate and produce a multi-mode laser operation case. Ring resonators with their running waves do not suffer from this problem, but there is the possibility for two modes with the same frequency but running in opposite direction to oscillate. This case produces complicated intensity dynamics and can be avoided by introducing an unidirectional device ('optical diode') to allow only modes in one propagation direction to oscillate.

Apart from adding new elements to the laser another way to reduce the number of modes is to use resonator mirrors that are highly reflective only for a certain range of wavelengths. For the Matisse there are five different optical sets:

Matisse Optical Set	Wavelength Range (nm)
MOS1	690 - 780 (Ti:Sa)
MOS2	750 - 880 (Ti:Sa)
MOS3	850 - 1020 (Ti:Sa)
MOS4	550 - 670 (Dye)
MOS5	650 - 780 (Dye) (has the same high-reflective mirrors as MOS1, but a different output coupler)

Frequency-Selective Elements

This section gives a description of the frequency-selective optical elements used in the Matisse. One important parameters of these elements (except for the Birefringent filter) is the Free-Spectral Range (FSR) as described above. The FSR of the Matisse ring resonator is about 160 MHz.

The following figure illustrates the effect on the laser mode spectrum of the Matisse Ti:Sa-laser by the various frequency-selective elements in the case of the MOS2 optics set:

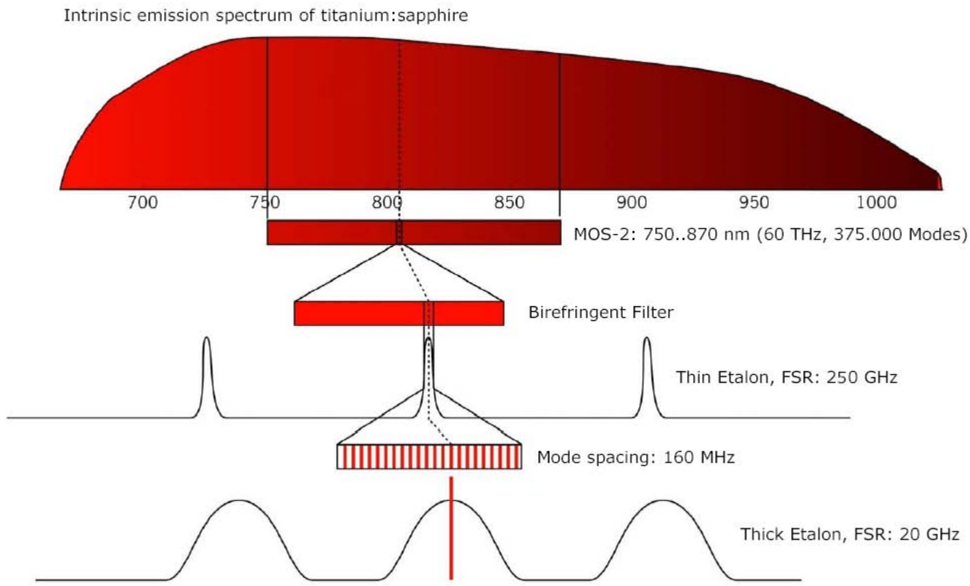

Figure 7: Laser mode spectrum in the case of the MOS2 optics set

The schematic setup of the Matisse TR is shown in the figure below to illustrate the geometric arrangement of the various frequency-selective elements.

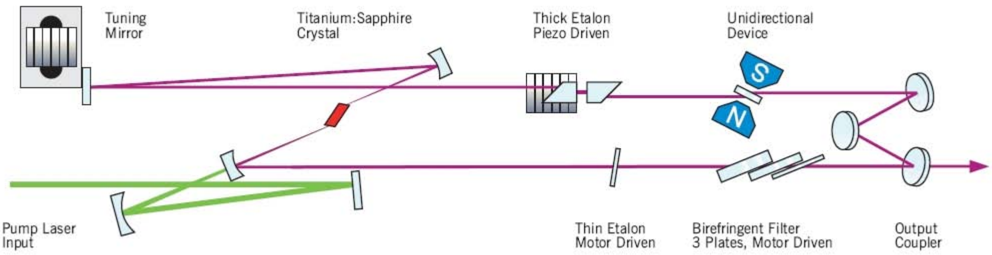

Figure 8: Matisse TR Setup

Birefringent Filter

The Birefringent Filter uses the effect of birefringence and the polarization-selective property of the laser resonator to achieve frequency selection. It consists of three plates, having thicknesses in the ratio of 1:3:15. For different optics sets Birefringent Filters with different plates thickness have to be used in general. For MOS-2 the thinnest plate has a thickness of 280 µm, for MOS-1 and MOS-3 the thickness is 325 µm.

The frequency range, in which lasing modes could exist, is narrowed down to several 100 GHz by the Birefringent Filter.

This filter serves as the main broad-range tunable element, determining the (approximate) absolute wavelength, where the Matisse laser will operate. To achieve single-frequency operation two additional etalons are necessary as described below.

Thin Etalon

The combination of the Birefringent Filter and the Thick Piezo Etalon is in general not sufficient to guarantee single-mode single-frequency laser operation. Therefore there is another frequency filter: a solid state Fabry-Perot etalon, called the Thin Etalon (TE). Its position in relation to the laser beam can be adjusted with the help of a motor-controlled mount. It has an FSR of about 250 GHz (for the standard etalon) and a relatively small Finesse. The TE is in a way adjusted, that will give no direct reflections from the etalon's facettes into the laser beam paths to avoid complicated laser intensity dynamics.

For the TE it also true, that one of its mode's frequency has to be the same as the laser resonator mode's frequency. For this purpose the reflection from one facette is monitored and compared to the total laser intensity. A control loop will adjust the TE position so that the ratio of these two signals is kept constant.

Piezo Etalon Description

The piezo etalon is formed by two prisms with parallel base sides, functioning as a Fabry-Perot interferometer with an air gap. One prism is mounted to an piezoelectric actuator to control the air gap thickness. The free spectral range of the interferometer is about 20 GHz and a Finesse of about 3.

The piezo etalon ensures that all except one longitudinal mode have so high losses, that lasing is not possible. Therefore, the spacing of the etalon must be matched to an multiple of the favored longitudinal mode's wavelength. Because of the tight spacing and in order to be able to perform a scan, the spacing is actively controlled. The control loop is based on a lock-in technique and the etalon spacing is varied by a piezo drive.

Figure 9: Front view of the piezo etalon assembly.

1 **Prism.** The etalon is formed by two prisms. The resonator beam enters and exits under Brewster's angle.

2 **Horizontal Alignment.** This screw controls the horizontal tilt of the entire etalon assembly.

3 **Vertical Alignement.** This screw control the vertical tilt of the entire etalon assembly.

4 **Piezo Voltage.** SMA connector that connects to the piezoelectric actor.

Figure 10: Side view of the piezo etalon assembly.

1 **Horizontal Alignment.** This screw controls the horizontal tilt of the entire etalon assembly.

2 **Vertical Alignement.** This screw control the vertical tilt of the entire etalon assembly.

3 **Piezo Voltage.** SMA connector that connects to the piezoelectric actor.

4 **Vertical Etalon Alignment.** This differential-micrometer screw controls the vertical alignment of the two prisms that form the etalon to each other.

5 **Horizontal Etalon Alignment.** This differential-micrometer screw controls the horizontal alignment of the two prisms that form the etalon to each other.

6 **Prism.** The etalon is formed by two prisms. The resonator beam enters and exits under Brewster's angle.

Piezo Etalon Dither

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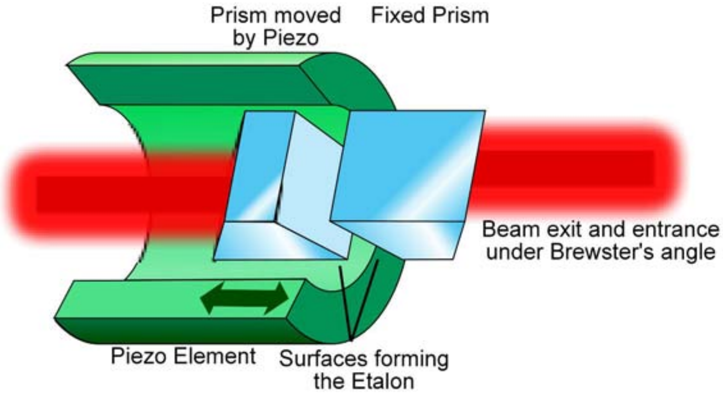


Figure 11: Piezo etalon principle.

Apart from further narrowing down the frequency range of possible laser modes, the piezo etalon has also to ensure that one of its mode's frequency coincides with the resonator mode's frequency of the laser. This is done by modulating the distance between the prisms with the help of the piezo actuator, so that the frequency spectrum of the etalon is slightly modulated. This results into a small intensity variation, that is monitored and used as the input for a control loop, that keeps the center frequency of the piezo etalon mode at the frequency of the laser resonator mode. The control loop principle is shown in the following figure:

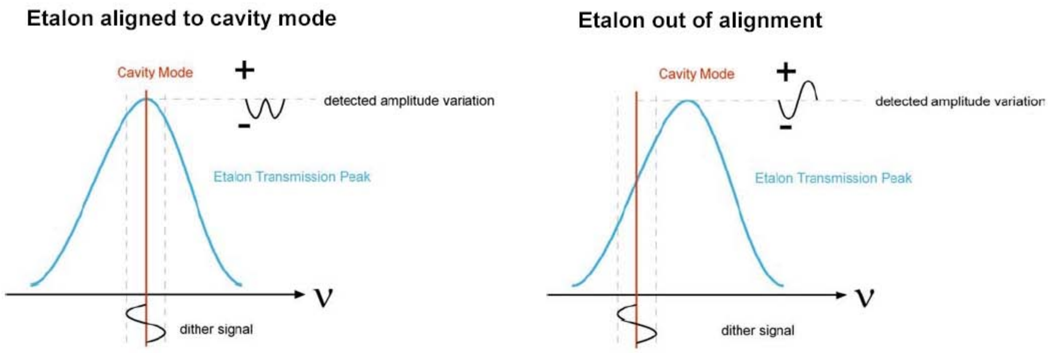


Figure 12: PZETL Phase-Locked-Loop Principle

Having the etalon aligned to the cavity mode is essential not only for getting the maximum laser power but also in the case of scanning the laser. Scanning is achieved by changing the laser resonator length continuously with the help of one of the resonator mirrors mounted on a piezo actuator. So when the laser frequency changes, the piezo etalon control loop will make sure that the piezo etalon's mode frequency will follow, by adapting the thickness of the air gap.

Optical Diode (Unidirectional Device)

Because the Matisse is a ring laser, two counter-propagating modes with the same frequency could co-exist. To prevent this an optical diode is also part of the optical set-up. It consists of a TGG crystal plate mounted in a strong magnetic filed, that will rotate the polarization vector of the electric field by some degrees irrespective of the propagation direction (Faraday effect). The M3 Matisse mirror of the three-mirror assembly is an out-of-plane mirror, causing also a rotation of the polarization vector of the electric field, but this time the direction of the rotation depends on the propagation direction. For the counter-clockwise running laser mode the effects of this mirror and the optical diode are canceled out. For the clockwise running mode the effects sum up, so that this mode will suffer additional losses at the various Brewster surfaces in the resonator.

C H A P T E R 5

Frequency Stabilization

For many laser applications is not only necessary to have a single-frequency laser but also to have a very stable frequency itself, i.e, a small effective laser linewidth. It is possible to suppress laser intrinsic frequency noise by using external frequency references. Frequency-stabilized Matisse are using highly stable reference resonators, that still allow to have a scannable laser by scanning the reference in contrast to using, e.g., atomic frequency standards. There are two stabilization schemes exploited with the Matisse: for the TS/DS version it is the 'side of fringe' scheme, for the TX/DX and TX/DX light version it is the Pound-Drever-Hall method. These two schemes differ in their complexity and achievable stabilization results as will be described in the following sections

'Side of Fringe' frequency stabilization

The concept for this method is relatively simple: when you scan the laser frequency and observe the transmitted light from the reference cell, you can observe the well-known Airy-function spectrum of the reference resonator. The stabilization idea is now to set the frequency of the laser so that it corresponds to a point of the flank of one of the resonator's transmission resonances ('side of fringe'). A control loop adapts the laser's frequency in a way, that keeps the transmitted intensity of the reference constant. The laser frequency is then locked to one of the reference resonator's modes.

To achieve this locking a second laser resonator mirror is mounted on a piezo actuator, the Fast Piezo. This Fast Piezo has to counteract relatively fast perturbations to reduce the effective laser bandwidth. The former scan piezo mirror (the Tuning Mirror) in the Matisse TR/DR now becomes a kind of auxiliary piezo, the so-called Slow Piezo. It has two tasks to fulfill: first in the not-lcoked case, it will scan the laser to a resonance of the reference resonator. Second when locking is achieved, it will keep the Fast Piezo at the center of its dynamics range and so cancelling out slow drifts of the laser in relation to the reference cell.

The schematic setup is shown in the following figure:

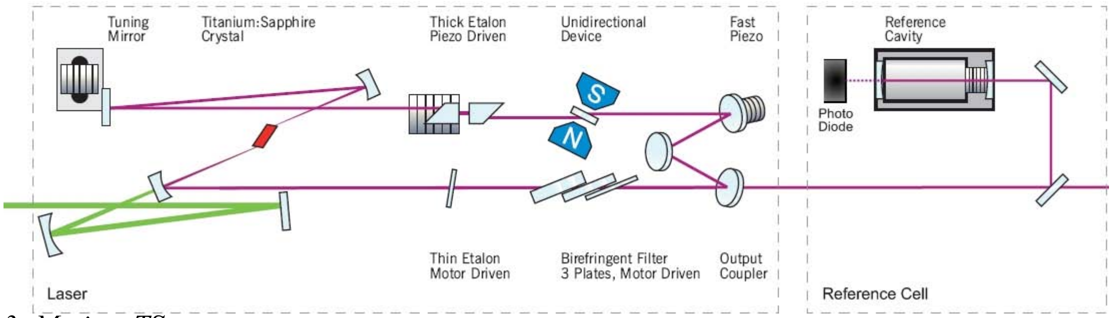


Figure 13: Matisse TS Setup

The reference cell in this case is a confocal resonator with a free spectral range of 600 MHz and a Finesse of about typically 15 to 20. The Airy Transmission spectrum is shown in the figure below.

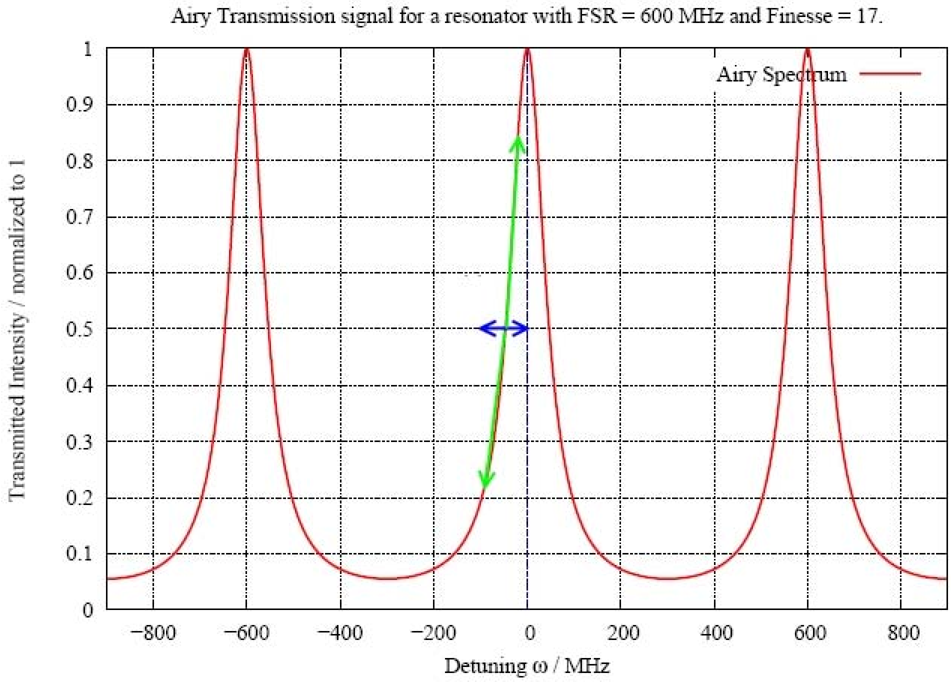


Figure 14: Airy Transmission Spectrum

The Fast Piezo control loop works as follows: any frequency deviation of the laser in relation to the reference resonator (shown as blue arrows in the figure above) will cause a change in the transmitted intensity (green arrows). This intensity difference to the desired transmitted intensity, the 'setpoint' (in this case 0.5), is then taken as an error signal for the FPZ control loop. There is also a control loop for the Slow Piezo, that manages the tasks for this piezo as explained above.

One drawback of this frequency stabilization method is its sensitivity to laser intensity noise. Because an intensity change is taken as a measure for a laser frequency deviation, intensity noise of the laser is wrongly interpreted as frequency deviations and actually transformed into real frequency noise. To minimize this intensity sensitivity the Finesse of the used reference resonator could be increased, i.e, the linewidth of the resonator decreased. This would increase the laser frequency deviation sensitivity (transmitted intensity change per frequency deviation) and in this sense decrease the sensitivity to laser intensity noise. But this will also decrease the catching range of the stabilization method, defined as the maximal allowed frequency deviation without loosing the laser lock. In this case it is about one quarter of the full linewidth of the reference resonator. If this range is too small, the laser lock becomes unstable. This trade-off situation finally limits the achievable laser bandwidth with the 'side-of-fringe' stabilization scheme.

Detailed instructions for the various control loop settings can be found in the ***S Stabilization*** (see page 88) section of the Matisse Commander chapter.

Pound-Drever-Hall frequency stabilization

For the PDH stabilization scheme there are additional elements in the optical path leading to the reference resonator in comparison to the Matisse S setup. The schematic setup is shown in the following figure:

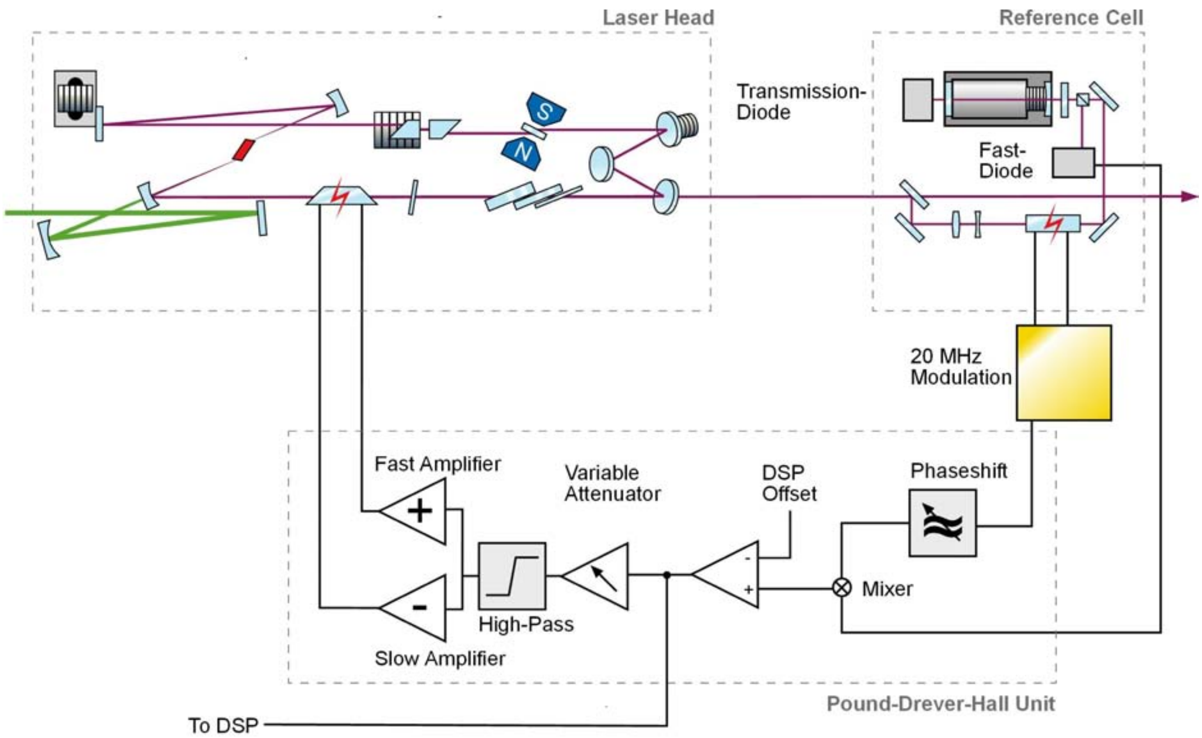


Figure 15: Matisse TX Setup

First of all there are two lenses acting as a telescope to mode-match the Matisse laser beam to the fundamental mode of the non-confocal reference resonator.

Then follows an Electro-optical Modulator (EOM) acting as a phase-modulator, which is modulated sinusoidally with a frequency of ν_{mod}. With this modulation the frequency spectrum of the laser beam after the EOM has now essentially three components: $\nu_0 + \nu_{mod}$, ν_0, $\nu_0 - \nu_{mod}$. Assuming that the reference cell is about resonant with the fundamental laser frequency ν_0 and its finesse is so high that the frequencies $\nu_0 + \nu_{mod}$ and $\nu_0 - \nu_{mod}$. are well outside of the resonator linewidth, only the laser radiation part with the fundamental frequency can effectively interact with the resonator, i.e., exciting a field inside the resonator. Part of this excited field will be coupled out back by the first reference cell mirror. The sideband parts are effectively just reflected back by the first reference resonator mirror.

The quantity, that is now observed with a photo diode, is the light reflected back from the reference resonator. The reflected light is deflected from the in-going beam path by a combination of a doubly-passed quarter-wave plate and a polarizing beam splitter to the Fast Diode. In general photo diodes act as an intensity detector $I = E^2$ (square of the electrical field). Having three different frequencies in the spectrum means, that the resulting diode signal will not only contain a constant component but also beat signals with frequencies that corresponds to the various differences of the three optical frequencies. Especially the beat signals having a carrier frequency of the EOM modulation frequency ν_{mod} are now used for generating a suitable frequency error signal. For that purpose the diode signal is mixed with the modulation signal for the EOM, which filters out just the desired signals with the ν_{mod} carrier. As a complication there are actually two signals with this carrier frequency, but only one of which is usable as an error signal. Fortunately the two signal have carriers that have a oscillation phase shift of $\pi/2$, i.e, they are mathematically orthogonal like, e.g., a sine and a cosine wave. By applying a tunable phase-shift to the EOM modulation signal before the mixer only the desired signal can then be filtered out. The resulting theoretical Pound-Drever-Hall error signal in dependance of the laser detuning to the used non-confocal resonator with a free spectral range of 1320 MHz and a Finesse of about typically 250 to 300 and a modulation frequency for the EOM of 20 MHz is shown below.

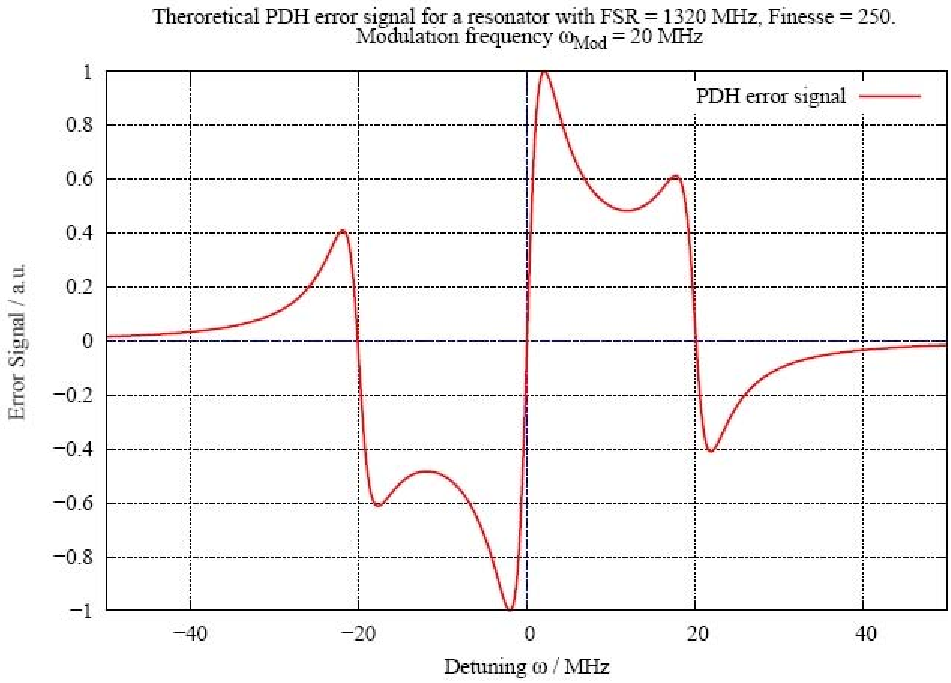


Figure 16: Theoretical PDH Error Signal

The interesting part of this graph is the relatively steep slope around the detuning of 0 MHz, giving a very sensitive measure for the laser detuning in relation to the reference resonator resonance. The fundamental principle producing this signal form is the following: assuming the laser frequency is exactly resonant with the reference resonator, then the beat signal terms of the fundamental frequency with the equidistant 'left' sideband and the 'right' sideband will cancel out (because the sidebands have a phase-difference of π), giving a PDH signal of 0. If the laser is slightly off-resonant, the exited field in the reference resonator will have an optical phase-shift in comparison to the laser field. The sidebands are then no longer equidistant in relation to the resonator field frequency (to be precise you have to look at the optical phases), resulting in non-zero terms for the PDH signal. The Pound-Drever-Hall method actually detects optical phase shifts rather than frequency shifts, making it very sensitive.

The PDH stabilization method is insensitive to laser intensity noise! The catching range for this method is given by the modulation frequency ν_{mod}. Together this makes the Pound-Drever-Hall stabilization a highly sophisticated tool for locking schemes.

In the Matisse TX/DX light versions the PDH error signal is used as the error signal for the Fast Piezo control loop, achieving a significant improvement in the laser bandwidth in comparison to Matisse S models. In the full Matisse TX/DX versions, an EOM is added to the laser resonator, that will also use this signal (after adequate signal-conditioning) as the error signal for its control loop. Because the EOM has a much larger control bandwidth a further significant improvement in the laser bandwidth can be seen.

Detailed instructions for the various control loop settings can be found in the ***X Stabilization*** (see page 98) section of the Matisse Commander chapter.

Frequency Drift Compensation

The frequency stabilization schemes described before will give small laser linewidths, i.e., frequency fluctuations on time scales of several 10 or a few 100 ms are reduced. When you look at the frequency behavior on time scales of several 10 s or minutes and some hours, the center frequency of the laser can drift in the order of some 100 MHz, depending on the ambient conditions of the reference cell environment. The drifts are due to temperature changes or piezo actuator relaxation processes acting on the optical properties of the reference cell.

To compensate these drifts, an absolute frequency reference, like an atomic resonance is needed. The following figure shows a possible Matisse setup, using the absorption/fluorescence signal of a gas exited by the laser radiation as an error signal for the laser frequency detuning. This signal is digitized by a DAQ card and processed by a software extension of the Matisse Commander control program. In reaction to the error signal this software extension will act via the Matisse controller on the RefCell piezo actuator to keep the master resonator on the atomic resonance.

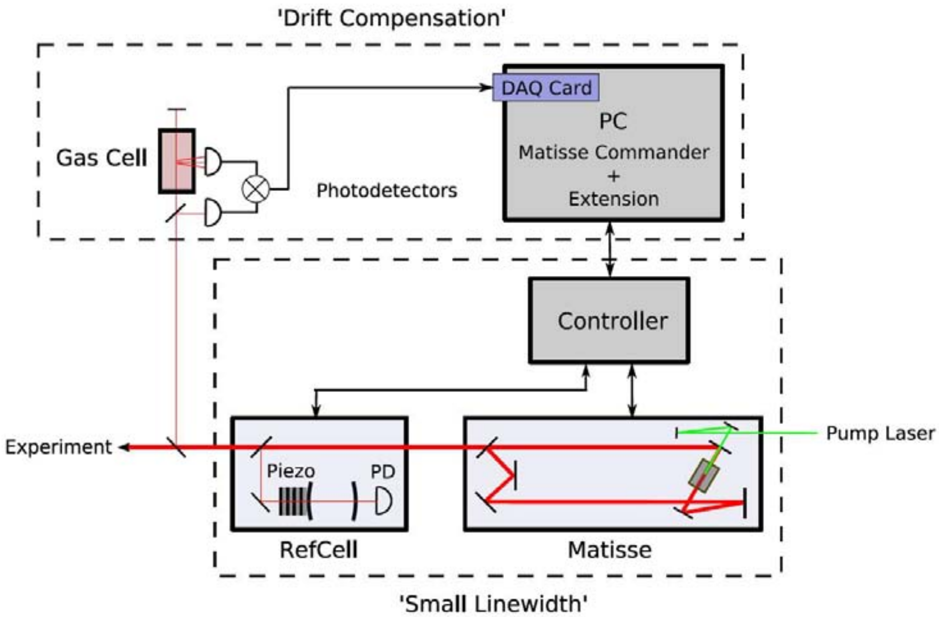


Figure 17: Possible Matisse Setup using an atomic resonance to compensate frequency drifts

This setup scheme does not need a stabilized Matisse to work. The drifts of lasers of the Matisse R type can be compensated as well.

The LabVIEW framework for the Matisse Commander extension is available on request.

Using your own reference for stabilizing

Instead of using the reference cell that comes with the stabilized Matisse versions, you can also use your own reference, generating an adequate error signal for the laser frequency deviation. For this the DSP controller card has an external input for your error signal, so you can take advantage of the control loop logics already implemented for the Fast and Slow Piezo. The section ***DSP Input Characteristics*** (see page 127) gives the technical details and constrains for your signal.

When you connect your error signal to the DSP's external input and set the switch from 'Intern' to 'Extern', you replace the internal error signal from the Matisse Reference Cell with your own signal. There is exactly one control loop DSP task, that uses this error signal to act on the Fast Piezo. So you can either stabilize on your reference or on the Matisse reference cell, but not on both at the same time.

You have to adapt the Fast Piezo and Slow Piezo control loop parameters to the characteristics of your error signal.

CHAPTER 6

Basic Matisse Operation

The present chapter deals with the standard start-up procedure. This procedure applies for systems which are well installed, and have been used under the same operating conditions in the near past. This holds true if you switch off your system in the evening, and switch it on again the next morning at the same wavelength.

CW lasers in general are temperature sensitive. Therefore, if the air conditioning in your laboratory is not running continuously, take care to switch on the air conditioning and wait for thermal equilibrium before switching on your laser. The best results will be obtained if your air conditioning is continuously running, with temperature variations of no more than +/- 1 K.

Start-Up Matisse-Ti:Sa

1 Switch on your pump laser, and allow for sufficient warm-up time. Please check your pump laser manual for details about the exact procedure and the necessary warm-up time. During this time, take care that the pump beam is blocked before entering the *Matisse* laser. If present, use the internal shutter of your pump laser, or any other suitable external beam dump.

2 In the case of a Matisse TX first switch on the XBox-Controller. Switch on the *Matisse* electronics box, and start up the *Matisse Commander* program.

3 Place a power meter or any other suitable beam dump at the Matisse output port.

4 Open the pump laser shutter, or remove the external beam dump, and apply pump power to the *Matisse*.

5 Increase the pump power until the *Matisse* laser threshold is reached. The energy level necessary for first laser operation depends on the mirror set and the current wavelength. As a rough indication, if pumped with a 532 nm beam and used at around 780 nm, the *Matisse* should start lasing at about 2.5 - 3 W input power.

6 Slowly increase the pump power up to 5 W. At this pump energy, most *Matisse* laser configurations should start lasing. However, for wavelengths at the edge of the tuning range of the used mirror set, or at the limit wavelengths of the Ti:Sa crystal itself, even higher pump power might be necessary. Your *Matisse* laser should now operate. In this case, please refer to the next Sections for a quick optimization of the *Matisse* output power. If, in contrast, your *Matisse* laser is not yet operating, carefully check the entire pump beam path.

Start-Up Matisse-D

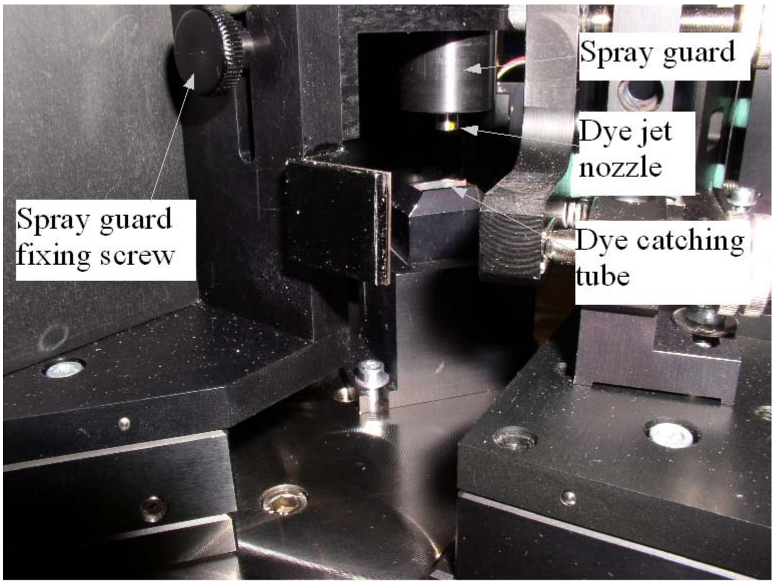
1 Switch on your pump laser, and allow for sufficient warm-up time. Please check your pump laser manual for details about the exact procedure and the necessary warm-up time. During this time, take care that the pump beam is blocked before entering the *Matisse* laser. If present, use the internal shutter of your pump laser, or any other suitable external beam dump.

2 In the case of a Matisse DX first switch on the XBox-Controller. Switch on the *Matisse* electronics box, and start up the *Matisse Commander* program.

3 Open the *Matisse* top cover. Place a power meter or any other suitable beam dump at the *Matisse* output port.

4 Move the spray guard to its upper position (see Figure below). Verify that the dye catching tube, situated underneath the dye nozzle, is centred with respect to the nozzle. If not, slightly move the dye drain, which should be screwed down to the optical table, to a different position. In order to avoid the transmission of vibrations to the laser base plate, the dye catching tube is not screwed to the laser. It is just squeezed in its holder by some foam. Therefore, moving the dye drain slightly will allow to re-centre the catching tube with respect to the nozzle.

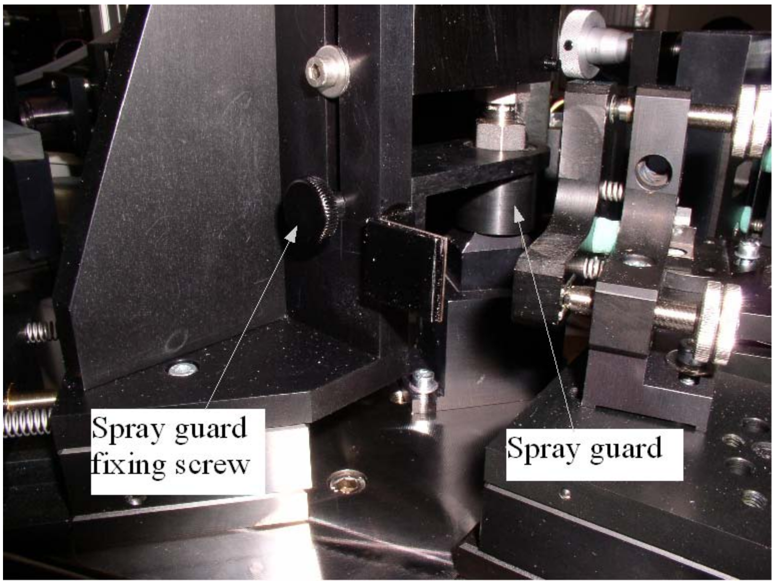
Figure 18: View of the dye jet nozzle and the dye catching tube. The spray guard is fixed at its upper position.



5

6 Set the spray guard back to the lower position (see Figure below).

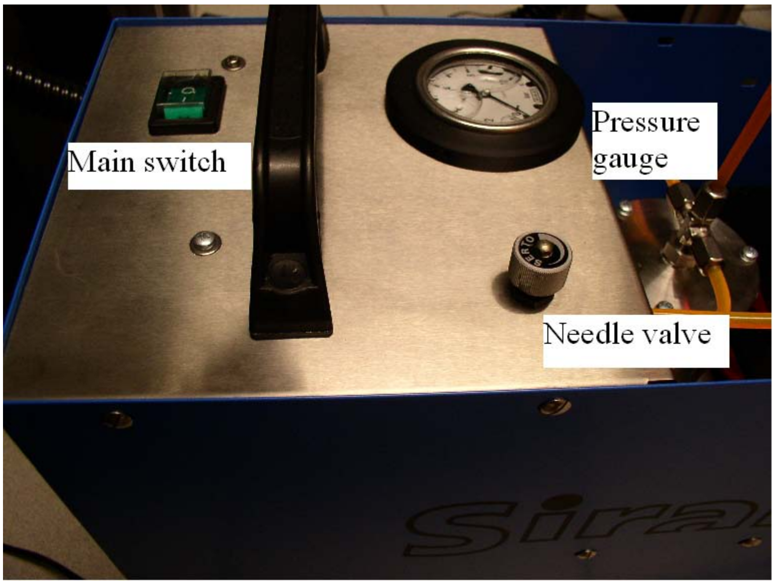
Figure 19: View of the spray guard in its lower position, to avoid dye spray during the start up procedure of the jet.



7

8 On the dye circulator, make sure that the dye by-pass is completely open. The by-pass is open if the needle valve shown on the next figure is turned counter-clockwise as far as possible. In this case, when switching on the dye pump the main fraction of the dye will follow the by-pass, and no pressure will build up in the circulator system.

Figure 20: View of the Matisse dye circulator. The dye jet pressure might be varied by adjusting the needle valve.



9

10 Switch on the dye pump. The cooling loop in your dye reservoir should be connected in series to the chiller of the pump laser, and thus already be operational. If you are using an external cooling system, then check that this system is operational.

11 Even with the by-pass open, some dye will enter the tube leading to the dye nozzle. Carefully observe the dye flowing towards the nozzle. Wait until the dye reaches the nozzle. Once the entire tube from the circulator to the nozzle is filled with dye, wait for another 5 minutes before proceeding.

12 DO NOT open the spray guard to watch the dye arriving in the nozzle, only check its appearance in the different tubing sections.

13 Slowly close the needle valve on the circulator, in order to increase the dye pressure. In a first step, only increase the pressure by 1/4 bar. Wait for 5 minutes. Increase the pressure by another 1/4 bar, wait another 5 minutes. Continue to increase the pressure in similar steps, until the pressure reaches 2.5 bar. Wait for 5 minutes. While doing these steps of increasing pressure, check the dye flow in the drain back from the dye catching tube towards the pump. Note that the dye drain is only driven by gravity. If ever you realize that the tube's position does not allow proper dye flow, e.g., because tube's slope is not sufficient, then immediately switch off the dye pump and change the position of the drain. If too much dye accumulates in the tube, and does not flow back to the pump properly, then in the worst case the dye may flow backwards out of the dye catching tube in your laser.

14 If the dye flows properly with a pressure of 2.5 bar, then carefully increase the pressure in one single step up to 4 bar. Wait for 5 minutes, increase the pressure to 6 bar and wait another 5 minutes. Depending on the type of dye solvent you use, this pressure may already be sufficient to operate your laser. Furthermore, laser operation is usually not limited to a single pressure value but is rather possible in a certain pressure range of up to some bar. If you start with a new solvent and/or dye you should carry out a series of tests of laser operation at different pressures to find optimal conditions and parameters. The aim is to obtain high output power which is as stable as possible, i.e., there should be no flickering visible within the output beam. Note that changing the pressure during the adjustment can slightly alter the shape of the dye jet so you may also have to change the pumping position and/or the location of the focus with the pumping mirror (PM) in order to regain optimal laser output. If you increase the pressure, continue in similar steps as before, i.e., wait 5 minutes after each increase of up to 2 bar. Do not increase the pressure in bigger steps than 2 bar at once and do not forget to watch the dye backflow.

15 During the first minutes of operation, characteristic noise from the nozzle indicates the presence of air bubbles in the dye. If the increase in pressure is done slowly enough, then the number and size of these bubbles will be at a minimum. The bubbles will vanish with time. When the final pressure is reached, do not continue working before at least 15 minutes of bubble free operation. Bubble free operation means that you do not hear any gurgling or splashing of dye under the spray guard.

16 Lift the spray guard to its upper position, and fix it there, as shown in the first figure. Carefully clean remaining spilled dye with a Q-tip. Take great care not to cross the dye jet with the Q-tip. Strong dye spray all over the laser would be the consequence.

17 Set your pump laser to a very low pump power, 0.2 W or less. Open the pump laser shutter, or remove the external beam dump, and apply pump power to the *Matisse*.

18 Make sure that the pump laser is correctly coupled into the dye laser.

19 Close the *Matisse* top cover.

20 Increase the pump power until the *Matisse* laser threshold is reached. The energy level necessary for the start of laser operation depends on the used dye and the wavelength. As a rough indication, if pumped with a 532 nm beam and used with a high gain red dye, the *Matisse* should start lasing at about 1.5 W input power.

21 Slowly increase the pump power up to 5 W. At this pump energy, most pump / *Matisse* laser configurations should result in an operating dye laser. However, for very low gain dyes, or at wavelengths at the edge of the tuning range, even higher pump power might be necessary. Before further increasing the pump power, please check again that the pump beam correctly enters the dye laser. Then slowly increase the pump power until the *Matisse* starts lasing.

22 Your *Matisse* dye laser should now operate. In this case, please refer to the following Sections for a quick optimization of the *Matisse* output power. If your *Matisse* laser is still not operating, then decrease the pump power to about 5 W, and carefully re-check the entire pump beam path.

Matisse Power Optimization

Once your *Matisse* laser is emitting radiation, you should follow the procedures given below for a fast and easy optimization of the laser ring cavity and the angular position of the thin etalon and the birefringent filter. On a daily working routine, this optimization should take only some minutes, and allow you to fully optimize the laser power.

Before starting the optimization, follow the start-up procedure given above.

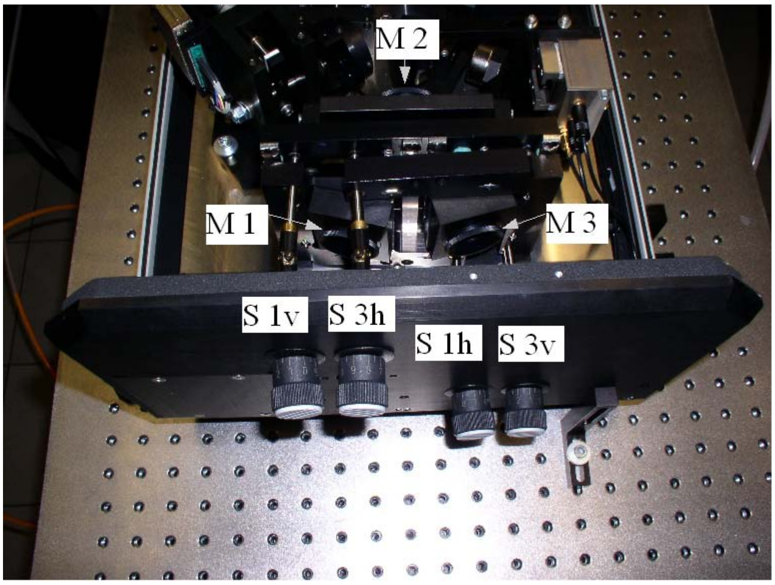
If not yet done, boot the laser control computer and start the *Matisse Commander*. Place a power meter in the *Matisse* beam and monitor the generated power.

Cavity Mirror Optimization

The *Matisse* laser cavity is designed for excellent long term stability. Therefore, only minor adjustments are necessary to keep the power of your laser system at maximum level. Once the laser is set up and fixed with respect to the pump laser only two screws will allow to compensate the small day-to-day shifts of the laser alignment.

The figure below shows the three off-plane folding mirrors M1, M2, and M3 in the *Matisse* cavity. As already mentioned in the Laser Description Chapter, M1 is the *Matisse* outcoupling mirror, whereas M3 is equipped with the fast piezo crystal in case of the actively stabilized models (-TS, -TX, -DS, and -DX).

Figure 21: Alignment screws of the Matisse three-mirror-set. Screws S 1v and S 1h allow to adjust the reflection direction of Mirror M 1 in the vertical and horizontal direction, respectively. Screws S 3h and S 3v act similarly on mirror M3.



The Mirrors M1 and M3 are adjustable even with the top cover of the Matisse closed, by means of the four tuning knobs shown above.

- Knob S 1v tunes mirror M 1 in the vertical sense.
- Knob S 1h tunes mirror M 1 in the horizontal sense.
- Knob S 3h tunes mirror M 3 in the horizontal sense.
- Knob S 3v tunes mirror M 3 in the vertical sense.

For a fast optimization of a laser already running close to its maximum power, it is sufficient to tune one of the two mirrors M 1 or M 3.

Observe the *Matisse* power on your power meter. Then, *very carefully*, either tune knobs S 1v and S 1h, or tune knobs S 3v and S 3h, in order to maximize the *Matisse* power. In general the necessary amount of tuning will be very small, in the order of a knob rotation of only 1-2 degrees, or even less. If you turn too far, the *Matisse* will stop lasing. In this case, immediately come back to the starting position in order to re-obtain laser operation, and re-start optimizing.

Thick Piezo Etalon Optimization

If the cavity mirror optimization does not give you the expected or usual laser power (within a range of -10 to -15%) for the current wavelength, it may be necessary to adjust the Piezo Etalon. Before adjusting this etalon with the help of the two (big) micrometer screws as shown in the ***Matisse Ti:Sa Optical Setup*** (see page 16), note down the current setting using the scale on the upper side of the two screws. The upper screw determines the vertical adjustment, the lower one the horizontal one.

Start adjusting the lower (horizontal) screw. Observe the Matisse power on your power meter. Then, *carefully*, turn the lower micrometer screw to maximize the Matisse power. There should be one position where the laser power peaks. There might be a slight hysteresis, so maximize the power twice approaching the peaking point from the two different directions to see which direction gives the maximum power.

Adjusting the upper (vertical) screw can reveal the existence of two different peaking points having similar laser power (not due to hysteresis!). Use the one with maximum power. Here also a slight hysteresis may exist, so apply the same procedure as described above.

If you turn too much, the Matisse will stop lasing. In this case, immediately come back to the starting position in order to re-obtain laser operation, and re-start optimizing.

Thin Etalon and Birefringent Filter Optimization

During laser operation, especially when the laser wavelength is scanned, the position of the thin etalon is actively controlled by the laser electronics. The error signal for the electronics it the laser power reflected from the etalon (as measured by diode D 2), divided by the total laser power (as measured by diode D 1). This error signal is minimum for the optimum etalon position. The set-point of the thin etalon and also the position of the birefringent filter need to be checked and optimized for each wavelength. Execute the optimization process in the following order:

Birefringent Filter

Click on **Scan** in the *Birefringent Filter* menu of the *Matisse Commander* main window. **Start** a Birefringent Filter scan. A typical result is displayed in the next figure, where the total laser power (blue curve) and the Thin Etalon reflection are shown as function of the Birefringent Filter motor position (in stepper motor steps). The third element in the graph is a red vertical line ('cursor'), indicating the original motor position before the scan was executed.

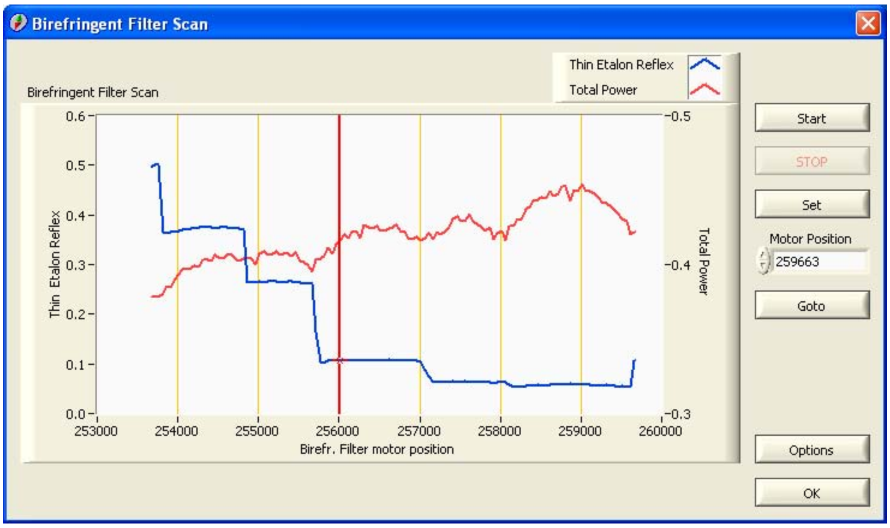


Figure 22: Result of a Birefringent Filter motor scan. Blue curve: thin etalon reflex. Red curve: total Matisse power. Both in arbitrary units.

The blue curve has a step function form. Within each step the Birefringent Filter might be set to an arbitrary position, without changing the Matisse laser frequency. If you change the motor position from one step to the next one the Matisse frequency will change normally by one Free Spectral Range of the Thin Etalon (see the ***Single-Frequency Tunable Laser Physics*** (see page 30) chapter for more details).

The Birefringent Filter position can be set by moving the red vertical cursor shown in the graph. Once the acquisition is finished, move the mouse cursor on the red vertical line, and drag the line by clicking on it with the left mouse button pressed. Move the filter to about the center of the step of the blue curve, where the original motor position was located, so that it coincides with the corresponding local maximum of the total laser power (red curve), as shown in the figure below. Click on **Set** in order to physically move the Birefringent Filter motor. Thus the total laser power will be optimized, without any influence on the current wavelength.

You need to hit **Set** even if the default position of the red cursor is the position you want to keep, because otherwise the Birefringent Filter will stay in the utmost right position on the displayed motor position scale.

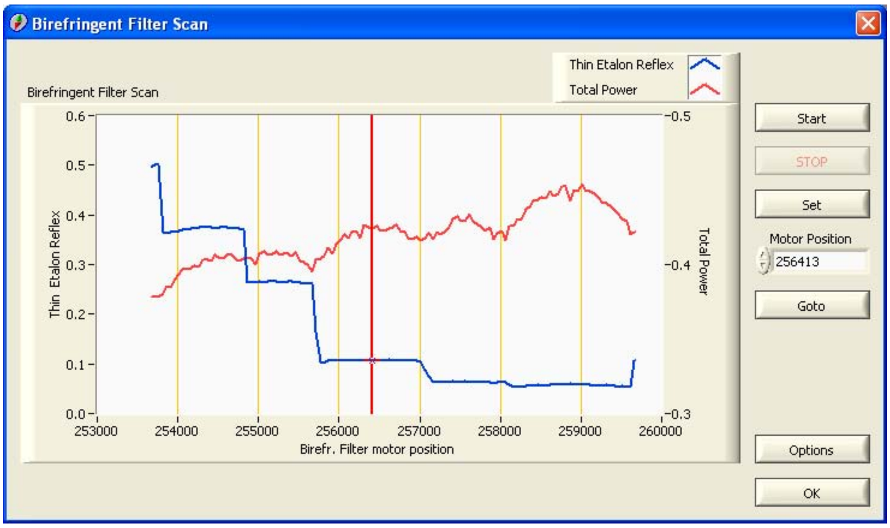


Figure 23: Move the Birefringent filter to the position correspoding to maximum laser power, without hopping onto another step of the blue curve.

Thin Etalon

Click on **Control Position / Scan** in the **TE** (Thin Etalon) menu. Press **Start**. The Thin Etalon performs a scan in the vicinity of of its current position. A typical result is shown in the figure below. The power reflected from the Thin Etalon and the total laser power are measured simultaneously as function of the etalon position. The third element in the graph is a red vertical line (indicating the original motor position before the scan), which will allow you to move the etalon in a well controlled way near a minimum of the curve representing the reflected power.

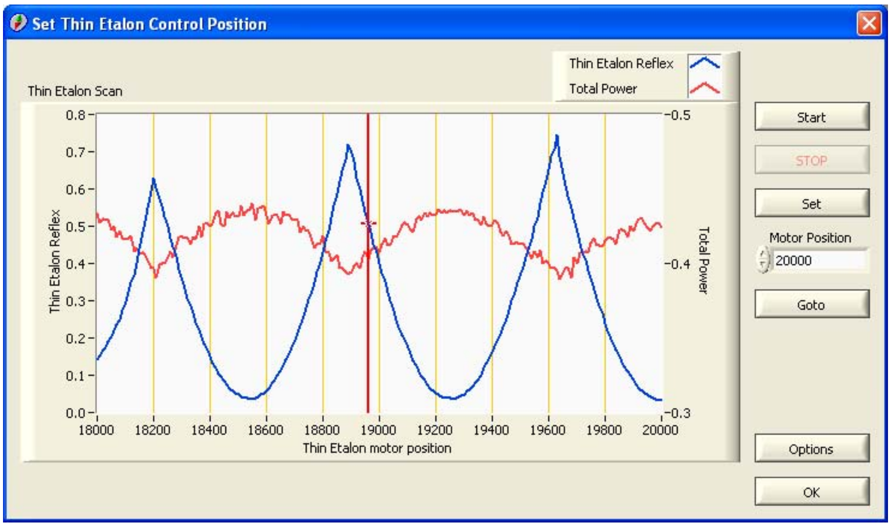


Figure 24: This window indicates the power reflected from the thin etalon, as well as the total laser power, for different positions of the thin etalon.

The blue curve looks similar to a sequence of parabolas with minima. Changing the thin etalon's position within such a parabola will not change the *Matisse* wavelength. If you change the motor position from one parabola to the next one the Matisse frequency will change normally by one Free Spectral Range of the Thick Piezo Etalon (see the ***Single-Frequency Tunable Laser Physics*** (see page 30) chapter for more details).

Once the acquisition is finished, drag the line towards the minimum of the parabola, where the original thin etalon motor position was located. Set the line on the **left** hand side of the minimum, as shown in the next Figure. Click on **Set**, and the thin etalon will be moved to the stepper motor position indicated by the red cursor. You have to hit **Set** even if the default position of the red cursor is the position you want to keep, because otherwise the etalon will stay in the utmost right position on the displayed motor position scale. The software operates with the gradient of the reflected power, therefore the cursor needs to be set well outside the minimum of the curve. On the other hand, setting the etalon too far away from the minimum of the blue curve will decrease the emitted laser power, because the minimum of the curve indicating the reflection from the etalon coincides with the maximum of the laser power curve.

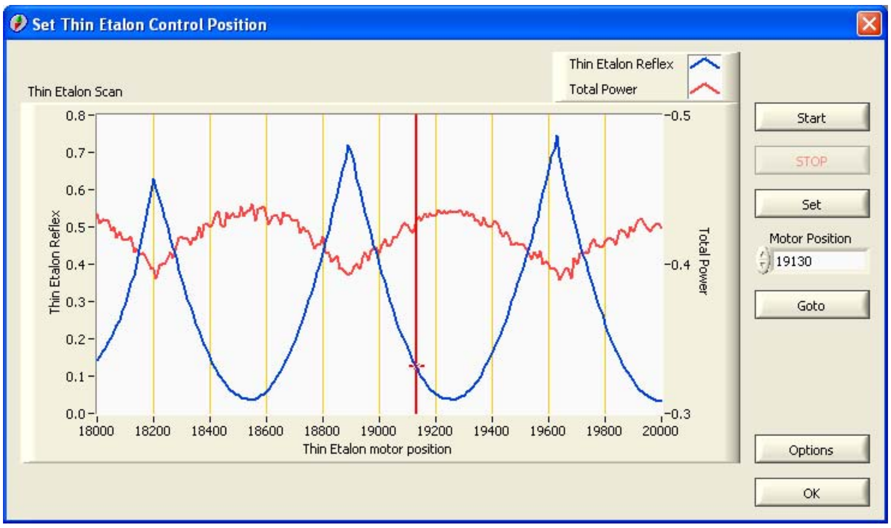


Figure 25: Drag and drop the red cursor on the left hand side of a minimum of the blue curve, indicating the power reflected from the thin etalon.

When the cursor is properly set to a position corresponding to a reflection minimum, leave the dialog window by hitting the respective button. In the *Matisse Commander* main window click on the **TE Control** indicator. The dark green indicator will switch to bright green (as shown below), indicating that the electronics is now continuously controlling the etalon position in order to minimize the reflection, and maximize the laser power. The blue bar underneath the **TE Control** lamp, labelled **TE Signal**, monitors the thin etalon error signal, allowing for a rapid check of proper etalon operation by just a glimpse.

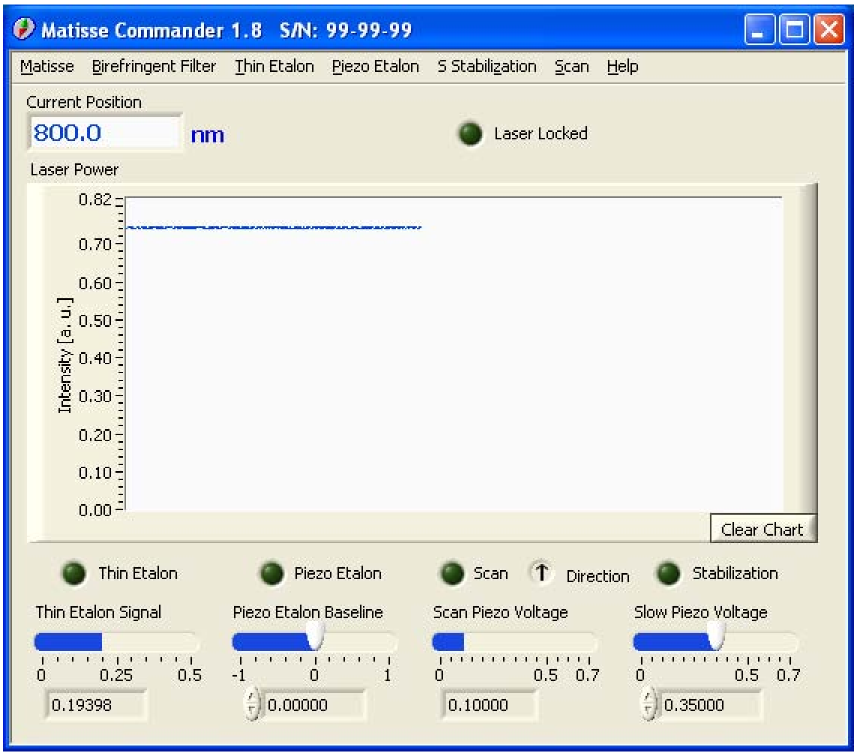


Figure 26: Main Window

Your laser is now ready to work.

Frequency Setting

Setting the Matisse to a specific frequency needs a step-by-step setting and optimization of Birefringent Filter, Thin Etalon (TE) and Thick Piezo Etalon (PZETL). In order to approach a specific frequency f, you first need to set the Birefringent Filter. Doing so will allow you to set the laser wavelength within a range of f +/- 0.5 × FSR(TE), where FSR(TE) = 250 GHz is the free spectral range of the Thin Etalon (This is the standard value, it might be different for your laser. Older Matisse lasers were shipped with a TE with a FSR(TE) = 130 GHz). Then you need to set the Thin Etalon, resulting in a laser frequency within the range of f +/- 0.5 × FSR(PZETL), where FSR(PZETL) = 20 GHz is the free spectral range of the Thick Piezo Etalon. Finally, tuning the PZETL will allow you to set the laser to the desired frequency f. The recommended method for this last step is to scan the laser to the goal frequency, instead of manipulating the baseline voltage directly.

Fine frequency adjustments of the Matisse are only possible by using an external frequency reference, either a high resolution wavemeter, or the atomic line or any other frequency selective phenomenon of your experimental set-up.

The Matisse laser is delivered with a rough calibration for the Birefringent Filter. This calibration is accurate enough to set the laser wavelength with an accuracy of about +/- 1 nm to the desired value. If the laser wavelength is already in the range of the calibration accuracy, skip the next step. Otherwise open the **Goto Position** dialog in the **Birefringent** menu of the Matisse Commander program. Type the desired laser position (in THz, nm, or 1/cm) in the respective field. You can choose whether to indicate the laser position in THz, nm, or 1/cm in the **Display Options** dialog in the **Matisse** menu.

For further tuning the Birefringent Filter and the Thin Etalon a procedure very similar to the one for the Thin Etalon and Birefringent Filter Optimization is applied.

For tuning the Birefringent Filter setting open the **Birefringent => Scan** dialog and execute an corresponding motor scan. A typical result is shown below (for a description of the graph's elements and the signal forms see the ***Thin Etalon and Birefringent Filter Optimization section*** (see page 54))

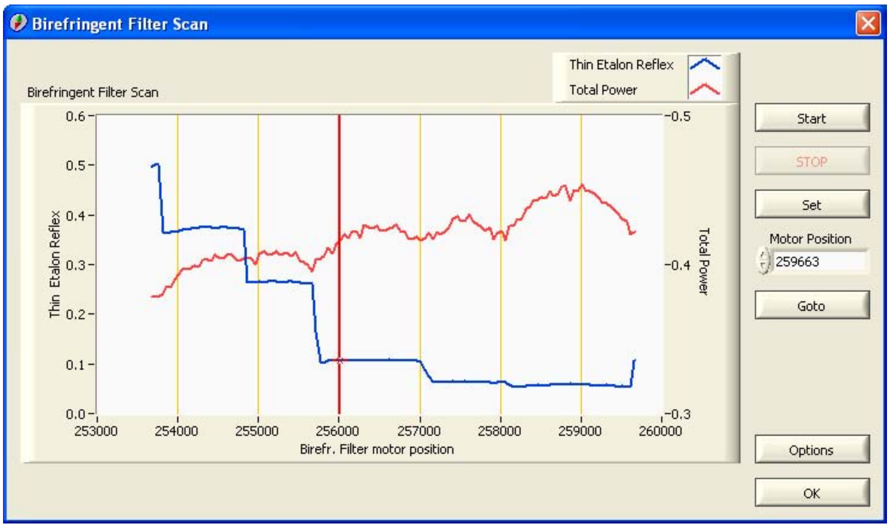


Figure 27: Result of a Birefringent Filter motor scan. Blue curve: thin etalon reflex. Red curve: total Matisse power. Both in arbitrary units.

Press **Set** and note down the wavelength/ frequency. Now move the (red) cursor to the center of the next step of the Thin Etalon reflex signal and press **Set** again. A comparison between the current and former frequency should reveal a difference with an absolute value of one FSR(TE). The change in frequency going from step to step in one direction is monotonous. So what you have to do is to find the direction and motor position range (step), in which the absolute value of difference between current and desired frequency decreases and gets minimal.

This positioning procedure of the Birefringent Filter motor will allow you to set the laser within the range of +/- 0.5 × FSR(TE) around the desired frequency (for a standard configuration this corresponds to about +/- 125 GHz).

The tuning procedure for the Thin Etalon is analogous to the one for the Birefringent Filter. Open the **Thin Etalon => Control Position / Scan** dialog and execute a motor scan resulting in the figure below.

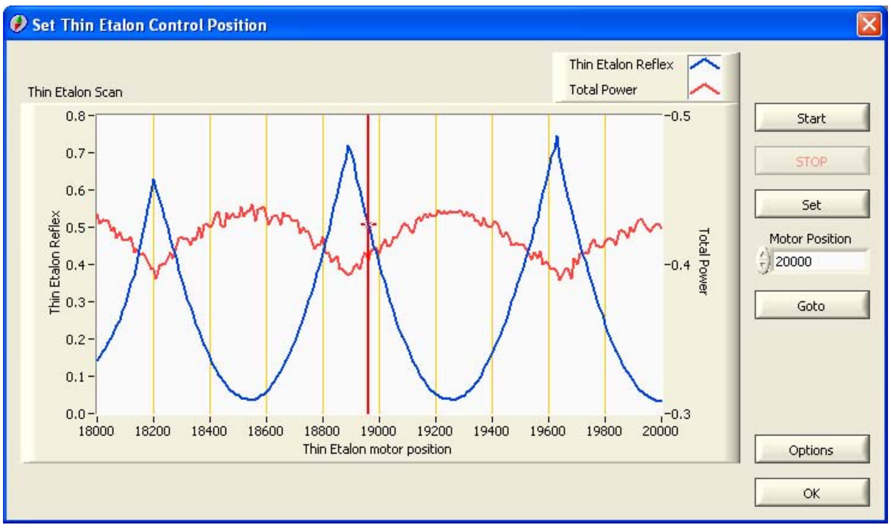


Figure 28: This window indicates the power reflected from the thin etalon, as well as the total laser power, for different positions of the thin etalon.

Press **Set** and note down the wavelength/ frequency. Now move the (red) cursor to the minimum of the next parabola of the Thin Etalon reflex signal and press **Set** again. A comparison between the current and former frequency will normally reveal a difference with an absolute value of one FSR(PZETL). The change in frequency going from parabola to parabola in one direction is **not** necessarily monotonous. There can be differences of up to one FSR(TE). Finding a parabola by going from one to the next one, that has a minimal absolute value for the frequency difference is here the goal.

It should be possible to approach the desired frequency within a range of +/- 0.5 × FSR(PZETL) (for a standard configuration this corresponds to about +/- 10 GHz). If you cannot get close to this value, please have a look at the full range of TE motor positions, where there is a TE reflex signal and try to find a parabola with a frequency difference in the stated range.

Before doing the final approach to your frequency f, you have to optimize the position of first the Birefringent Filter, and then the Thin Etalon, as described in the ***Thin Etalon and Birefringent Filter Optimization section*** (see page 54). Finally scan the laser to the desired frequency (see the following section).

In most cases, the procedure described above allows a direct approach to the selected frequency. In some cases, however, the interaction of Birefringent Filter, Thin and Piezo Etalon leads to an unstable optics configuration. In this case, more stable operation can be achieved by tuning the Birefringent Filter and Thin Etalon settings described above more than once.

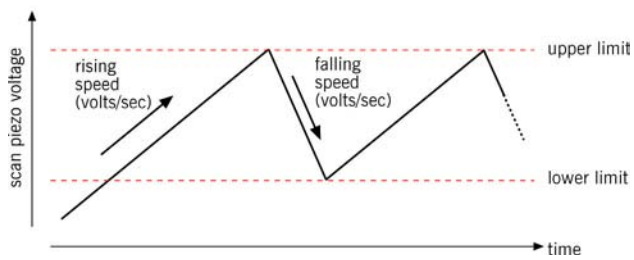
Frequency Scanning

The Matisse is scanned by acting on the logical scan piezo. For the Matisse R version this is the long-travel piezo the tuning mirror TM is mounted on, for the stabilized Matisse versions this is the reference cell piezo. Before starting a scan, you need to optimize the Birefringent filter, the Thin and the Thick Piezo Etalons at the scan reference frequency as described in previous sections. Take care to activate automatic tuning of the Thin and Thick Piezo Etalons by clicking on **TE Control** and **PZETL Control** and additionally for the stabilized versions to enable the reference cell lock in the Matisse Commander window.

To define a scan open the **Scan** => **Scan Setup** menu.

Scans are defined by the current Scan Piezo **Position**, **Start** (lower limit) and **Stop** (upper limit) positions, that have a nominal voltage range of 0 to .65. Set the voltage applied to the scan piezo and the upper and lower limits of the scan, respectively. The value written in the **Position** field when opening the **Scan Setup** represents the current voltage on the scanning piezo, which is driving the scan piezo. If you set the laser to a specific position (e.g. the start frequency of the scan to be performed) prior to opening the **Scan Setup** menu, then you can easily deduce the piezo voltage corresponding to this laser frequency just by checking the **Position** value.

Figure 29: Scan Timing.



Rising Speed (V/s) and **Falling Speed (V/s)** are the voltage change per second (see diagram above). **Scan Stop Mode** determines if and when the scan stops (at upper or lower limit). There are eight pre-defined scan modes: first you may choose if the scan starts with increasing or decreasing voltage. Additionally, you may choose if the scan stops once it arrives at the upper voltage limit, the lower voltage limit, either of them, or neither of them.

Scan Control switches the scan off or on.

Once the scan is defined it can be started or stopped by simply clicking on **Scanning** in the **Scan** menu, or on the **Scan** LED in the Matisse Commander window.

Shut-Down Matisse-T

1. Switch off the pump laser.
2. Exit the *Matisse* Commander.
3. Switch off the *Matisse* electronics box and in the case of a *Matisse X* also the XBox-controller

Shut-Down Matisse-D

1. Switch off the pump laser.
2. Open the *Matisse* top cover.
3. Loosen the fixing screw of the spray guard and move the guard to its lowest position. The dye jet should be completely hidden inside the spray guard.
4. Open the needle valve on the dye circulator. The dye will no longer flow to the sapphire nozzle, but follow the bye-pass. Decrease the pressure until, the dye jet starts to contract itself to a V-shape form. The indicated pressure is not 0!
5. Switch off the dye circulator.
6. Close the laser cover.
7. Exit the *Matisse Commander*.
8. Switch off the *Matisse* electronics box and in the case of a *Matisse X* also the XBox-controller.

CHAPTER 7

Matisse Commander

Installation

The Matisse Commander program runs on Windows 2000, Windows XP and Windows Vista (32 and 64 bit versions). Installing the program requires Administrator privileges. A USB port is needed to connect the laser to the PC.

First install the software by executing **setup.exe** in the Matisse Commander Installer subdirectory, then connect the laser to the computer. Windows should detect the new device and ask for a driver. Let Windows execute an automatic search.

The Matisse Commander is based on LabVIEW 8.6, for device communications National Instruments' VISA software is used. Corresponding required software (LabVIEW runtime 8.6, VISA runtime 4.3 or higher, etc.) will be installed or updated during the Matisse Commander installation, if no appropriate software is already present on the computer.

Version Changes

Matisse Commander 1.6

Matisse Commander 1.6.x rescales parameters with small values (<< 1) by a factor of 10000. This is true for the FPZ and SPZ control loop gain parameters as well as for the PZETL modulation amplitude. These parameters are rescaled only for display purposes. The internally used values in the Matisse Controller stay the same!

Matisse Commander 1.8

Version 1.8 is based on LabVIEW 8.6. The dialog window for the piezo etalon was re-programmed to accommodate the new feed-forward parameters and to clarify the usage of the control. The fast piezo dialog was modified to reflect the changes in the firmware.

General

With the help of the Matisse Commander program you can manipulate the positions of the frequency selective elements and the settings of control loops, respectively, to achieve maximal, stable single-mode output from the Matisse laser device. Moreover this program allows you to configure and execute scans over the laser's wavelength.

The following chapters, ordered in analogy to the menu structure of the program, gives you information on the various functions of Matisse Commander. References to indicators or controls of dialogs are set in bold type.

The following subsections provides information concerning Matisse Commander in general.

Start-Up

At the start-up of the program, Matisse Commander will try to detect the presence of a Matisse laser device, either with the help of information in the Matisse Commander's configuration file 'Matisse Commander.ini' or by directly accessing USB devices, that have the correct Manufacturer and Model ID. If no Matisse laser can be located, the following dialog will appear, requesting you to power-up the Matisse controller box and restarting Matisse Commander or to choose the **Dummy Mode**.

Figure 30: Device Not Found dialog

The **Dummy Mode** is useful for getting familiar with the control program without needing an actual physical device or using it as a test environment for software plug-ins for the Matisse Commander (see the 'Matisse Programmer's Guide' for further details). This mode tries to simulate the Matisse controller box with an idealized laser, but it does not completely implement all device commands, so you might encounter error messages in some dialogs.

Error Dialog

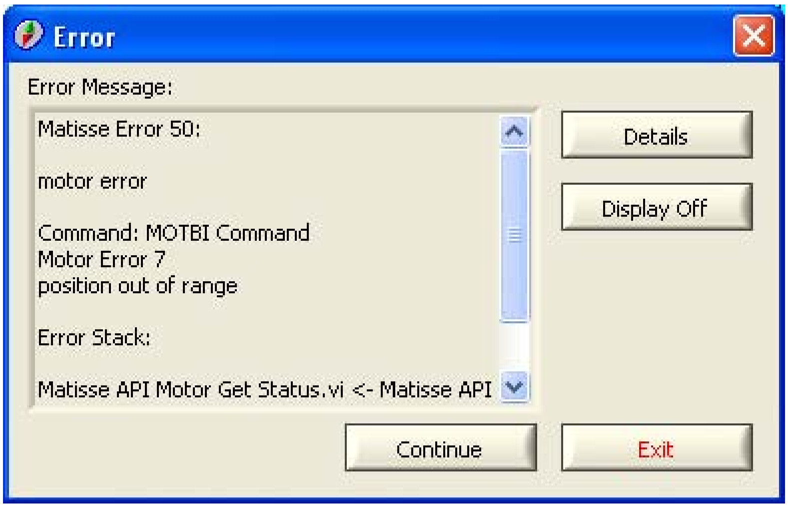


Figure 31: Error Dialog

If an error occurs, this dialog will display basic error information. **Details** will provide more information. **Display Off** will switch off the controls on the ***Main Window*** (see page 68). This may be helpful if the error occurs repeatedly in the data gathering loop for the various indicators. You can switch on the display again in the ***Display Options dialog*** (see page 76). You have to choose, if you wish to **Continue** with the application execution or if you want to **Exit** Matisse Commander.

Key Navigation

Matisse Commander and all its dialogs follow a key navigation standard:

Key(s)	Function
<Enter>	Execute Function, Change Settings
<Esc>	Abort Dialog, Function
F1	Show context-sensitive Help
F2	Open Dialog Options

Wavemeter Support

The functionality of the Matisse Commander software can be enhanced by using devices capable of measuring the laser's current wavelength (further referred to as 'wavemeters'). New functions like a 'Goto Wavelength' routine, that sets the laser to any desired wavelength position within its tuning range, could be implemented.

Wavemeter support for the Matisse Commander program, which is developed with LabVIEW, is achieved by using LabVIEW application libraries ('plug-ins') for different kinds of wavemeters, that conform to a specific interface. Further details are given in the 'Matisse Programmer's Guide' available on the Sirah website ***www.sirah.com*** http://www.sirah.com.

Firmware Update

The firmware of the hardware controller can be updated via the Firmware Updater program available on the Sirah website ***http://www.sirah.com*** http://www.sirah.com

Main Window

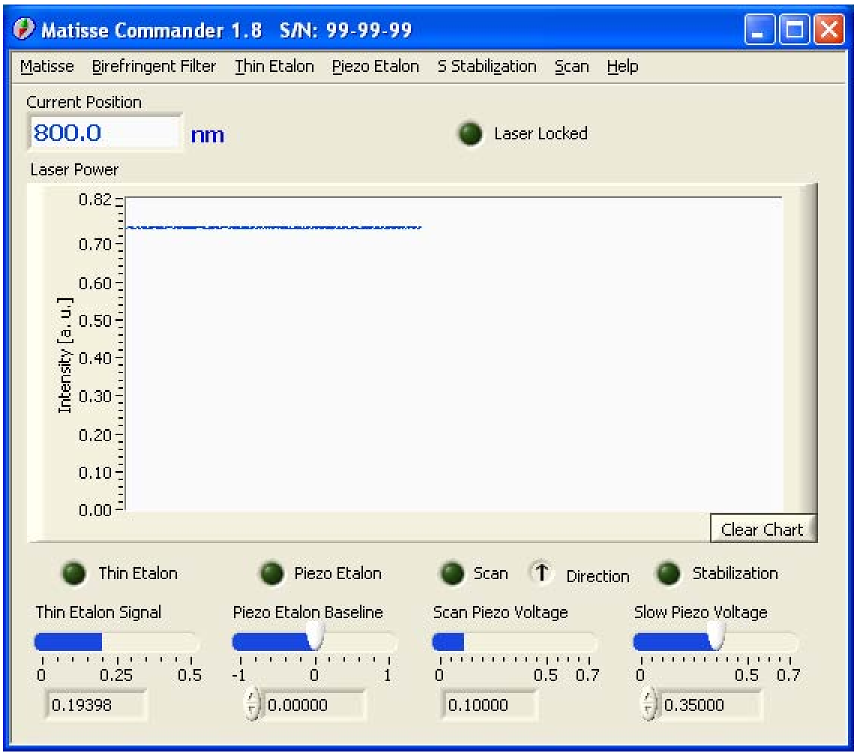


Figure 32: Main Window

The window contains an indicator for the **Current Position** of the laser (***Display Options dialog*** (see page 76)) and a time chart of the total **Laser Power**. **Clear Chart** will erase the time chart history. **Thin Etalon** and **Piezo Etalon Control** are simultaneous indicator/control displays, determining the status of the corresponding control loops for the Thin and the Piezo-Etalon. **Thin Etalon Signal** displays the Thin Etalon reflex signal and the **Piezo Etalon Baseline** indicator/control gives the voltage baseline applied to the piezo element. If this voltage exceeds critical values, the numerical indicator will start blinking red. In this case, use the slider to reset value. Changing this value might cause a shift in the laser frequency! The **Scan** indicator/control displays the current scan status and there is also the **Scan Piezo Voltage** shown. With the **Direction** indicator/control the scan direction (up or down) can be quickly toggled.

For Matisse models TS or higher the main window contains also the **Stabilization** indicator/control display, with which you can turn on or off the locking of the laser to the reference cavity. For this control loop the voltage applied to the slow piezo, given by the **Slow Piezo Voltage** indicator/control, is of importance. It should not exceed critical values: if the slider is at the limits of the control, use the slider to reset the value. The **Laser Locked** indicator/control indicates if the locking state is reached and maintained. Clicking on it will toggle the **Stabilization** state.

Matisse (Tools and Options)

Device Configuration

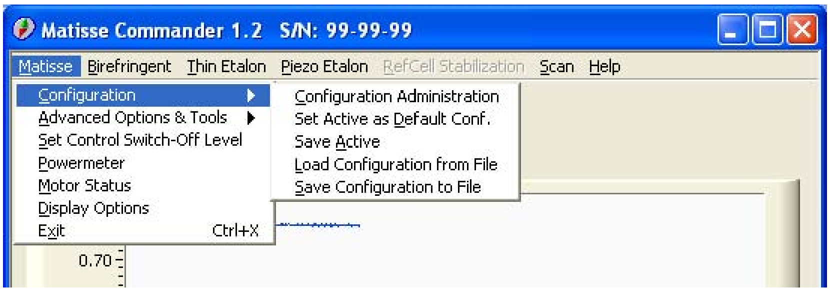


Figure 33: Device Configuration Menu

A device configuration comprises the various parameters for the control loops, the Birefringent Filter calibration parameters, the scan setup, the switch-off level, etc., that are stored on the Matisse DSP controller board. Two different kinds of configurations are available: Factory and User configurations. Factory configurations are preset and can not be changed. It is possible to have several user configurations that can be newly created, changed and saved. There is a default configuration that is used at every start-up of the Matisse controller. To fully administer the various device configurations see ***Device Configuration Administration*** (see page 70). This menu lets you make the active configuration the default one, save the active configuration to the Matisse DSP board or to a human readable text file. Also you can load configurations from a file.

Note: Saving the active configuration will interrupt the execution of the Thick Piezo Etalon control loop!

Device Configuration Administration

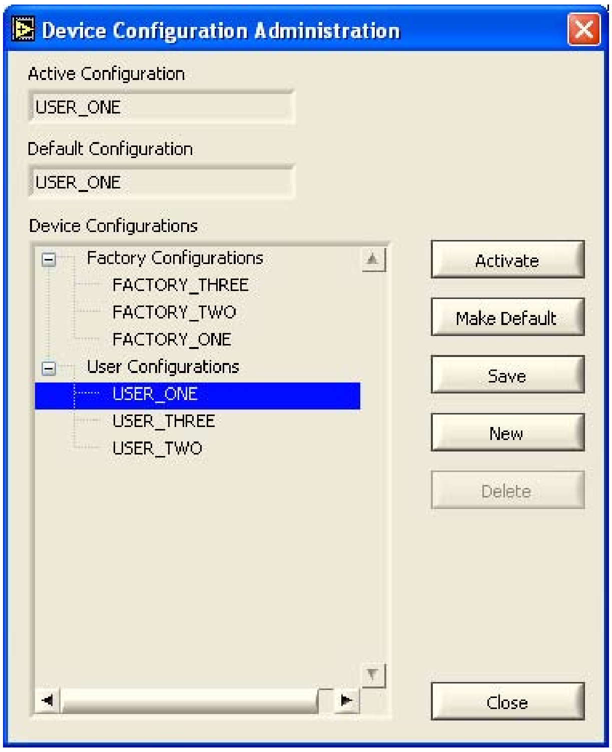


Figure 34: Device Configuration Administration dialog

The Device Configurations control lists all available configurations, differentiated by Factory and User configurations (for a description what 'configuration' means, see ***Device Configurations*** (see page 69))

There is also the Active and the Default Configuration displayed. With **Activate** or **Make Default** you can give any of the available configurations the corresponding status. Only User Configurations can be saved, deleted or newly created.

Active -> File will save the active configuration to a text file, **File -> Active** will load a configuration from such a file.

Note: Listing the various configurations, saving or creating a configuration will interrupt the execution of the Thick Piezo Etalon control loop

Advanced Options & Tools

Interactive Shell

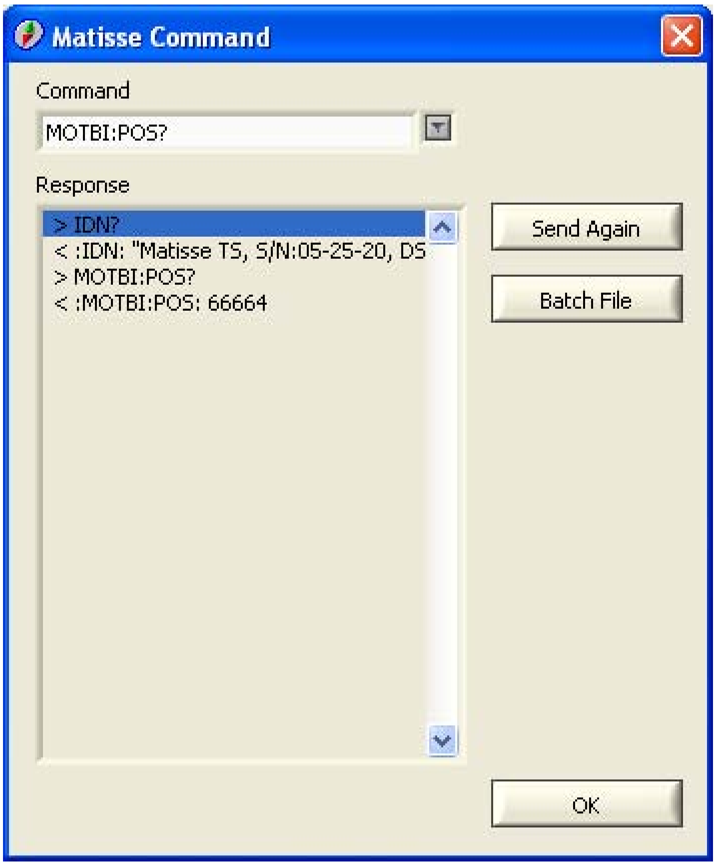


Figure 35: Interactive Command Shell

You can directly communicate with the laser device using low-level device commands.

Commands typed into the **Command** control, followed by pressing <Enter>, will be sent to the Matisse controller and executed. The controller's response will be shown in the **Response** indicator. A history of sent commands to choose from can be accessed by using the pull-down menu of the **Command** control. To send the current command repeatedly you have to press **Send Again**. You can also arrange commands line-wise in a text file and load this file via **Batch File**. The text lines will be sent until an 'End Of File' or the word 'END' is encountered.

Thin Etalon Signal Monitor

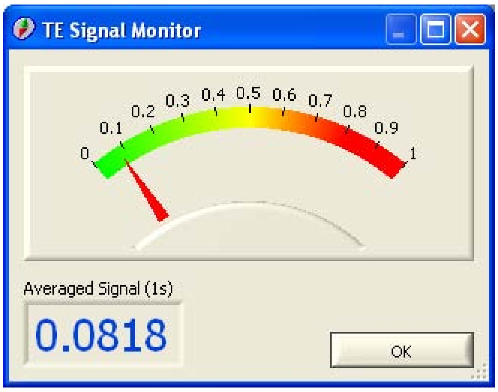


Figure 36: TE Signal display

The Thin Etalon's reflex signal is displayed to be used when adjusting the reflex on the corresponding detector.

Integrate Wavemeter

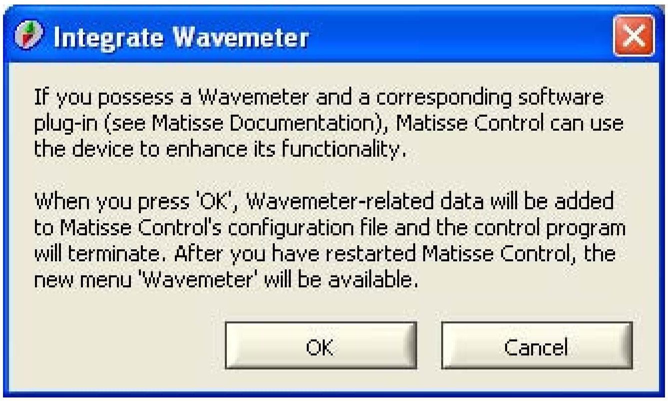


Figure 37: Wavemeter Integration dialog

If you have a wavelength measuring device (wavemeter) available, the functionality of the Matisse Commander can be enhanced provided that a corresponding software plug-in can be created. Further information concerning the software plug-in can be found in the 'Matisse Programmer's Guide'.

Remove Wavemeter

Figure 38: Wavemeter Removal

The integrated support for a wavemeter (***Integrate Wavemeter*** (see page 72)) will be removed, i.e., the Matisse Commander program will not search for wavemeter plug-ins at the start-up.

Control Loop Live View

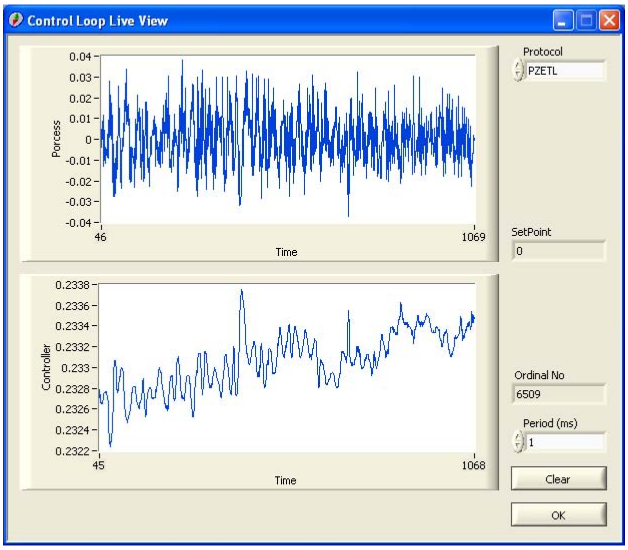


Figure 39: Control Loop Live View Dialog

This dialog lets you view the internal variables used by the various control loops (**Process**, **Controller** and **Setpoint** value) and can be used to optimize the control loop parameters. It is a non-modal window, i.e., it runs in parallel to the main program.

From the **Protocol** control you can choose which control loop (none, Thin Etalon, Thick Piezo Etalon, Slow Piezo, Fast Piezo) is to be logged. The logging process uses a 256 value ring buffer to record the data. If the selected control loop is not active the ring buffer may hold random data.

There are two **Sample Modes** available: Continuous or Snapshot. Continuous will give a steady data stream. Because of the different time scales the control loops are working on, you may have a real live view for the slower loops or just a sampling view for the faster ones. An indicator which kind of behavior you experience is the **Ordinal Number**. If it stays the same all the time or increase only slightly over time, the current control loop values are read out; if it increases rapidly, you only have a time sampled view of the control loop. The debug view behavior can be influenced by changing the **Period** time interval, with which the logging buffer is read out. **Options** will open the ***Control Loop Live View Options dialog*** (see page 74), where the default values for the period times can be changed. Choosing too small a period value may lead to communication errors due to the parallel access to the Matisse device by the status data gathering loop of the Matisse Commander.

The Snapshot mode will wait until the ring buffer contains new data and will display therefore a fully real-time snapshot of the control loop behaviour, regardless of the time-scale it it working on. **Snap** will trigger another snapshot.

Clear will erase the data displays.

Control Loop Live View Options

These controls determine the delay time for the continuous read-out of the various control loops' data in the ***Control Loop Live View dialog*** (see page 73).

Device Hardware Configuration

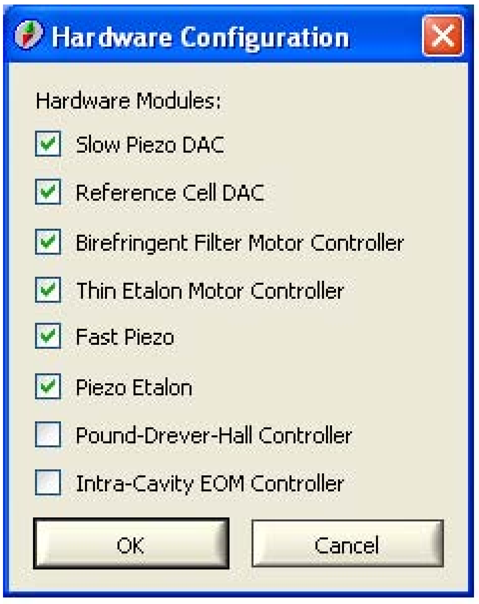


Figure 40: Hardware Configuration dialog

The various Matisse models possess different (electronic) hardware components. In this dialog you can activate or deactivate these components. To make this change permanent you have save the active configuration (see ***Device Configuration*** (see page 69)). Changes will come into effect at the next start of the Matisse hardware controller.

Control Switch-Off Level

Figure 41: Switch-Off Level dialog

The **Switch-Off Level** is the total laser power level, below which the control loops are deactivated.

Powermeter

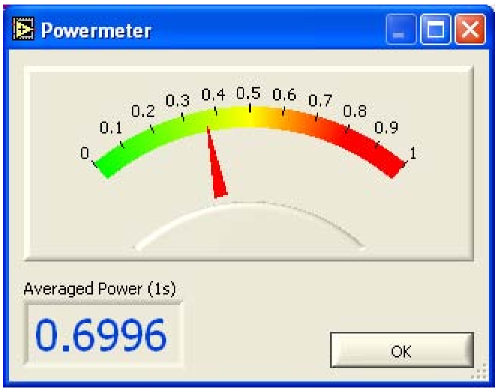


Figure 42: Powermeter

The powermeter displays the total laser power and can be used for adjusting purposes.

Motor Status

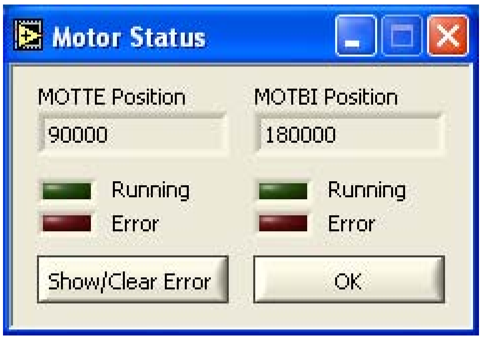


Figure 43: Motor Status Display

This windows display the current position and status of both the Thin Etalon and the Birefringent Filter motors. It is updated every 500 ms and runs in parallel to the main program.

Show/Clear Error will show you an error dialog indicating which motor error occurred and clear the error status, if the Thin Etalon or the Birefringent Filter motor controller are in an error condition

Display Options

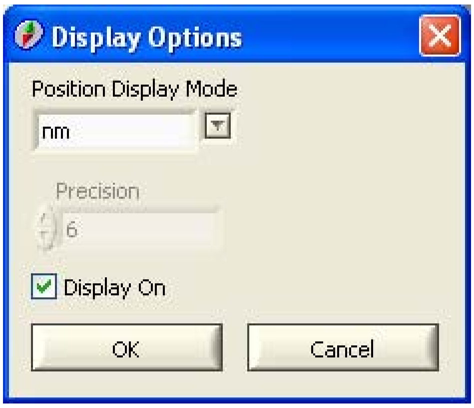


Figure 44: Display Options dialog

The **Position Display Mode** control determines the physical unit the program uses to display the position of the laser device. **Precision** sets the number of digits to be shown after the decimal point. It has only an effect,if a wavemeter is used, otherwise the precision is fixed to one digit.

Display On switches the controls and indicators in the ***Main Window*** (see page 68) on or off.

Birefringent Filter

Goto Birefringent Filter Position

Figure 45: Birefringent Filter Goto Dialog

In this dialog you can move the laser to a new position in units determined by the ***Display Options*** (see page 76). The position of the Birefringent Filter motor position is computed with the help of a calibration function, the parameters of which can be calculated in the ***Birefringent Filter Calibration Table*** (see page 79).

Birefringent Filter Scan

Figure 46: Birefringent Filter Scan dialog

In this dialog a scan over the Birefringent Filter motor positions can be executed. Two signals are recorded: the total laser power and the intensity of the thin etalon's reflex. The scan is centered around the current Birefringent Filter motor position. The scan range and increment can be set in the ***Birefringent Filter Scan Options*** (see page 78) (press the **Options** button or F2). The current motor position is shown as a cursor (vertical red line) in the **Birefringent Filter Scan** graph and in the **Motor Position** control. You can change this position by changing the position control and pressing **Goto**.

Pressing **Start** will execute the scan, that can be aborted by the **Stop** button. **Set** will move the motor to the position the cursor in the graph points to.

Achieving maximal laser output requires the Birefringent Filter to be positioned optimal in relation to the thin and thick etalon. After a scan you should see a curve for the thin etalon's reflex, that looks like a step function. Set the graph's cursor by dragging it with the left-mouse button pressed about into the center of such a step, so the position coincides with a local maximum of the total laser power, and press **Set**.

If **Set** is not used the motor will stay in the scan's end position, when you close the dialog!

Birefringent Filter Scan Options

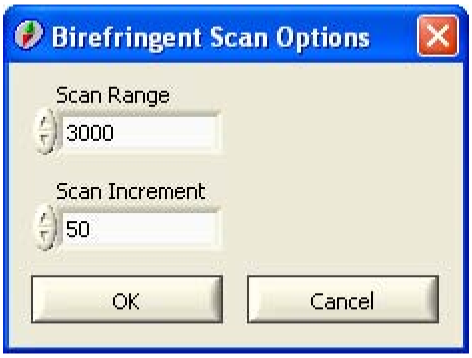


Figure 47: Birefringent Filter Scan Options dialog

These controls determine the **Scan Range** and **Scan Increment** of the Birefringent Filter Scan.

Birefringent Filter Calibration Table

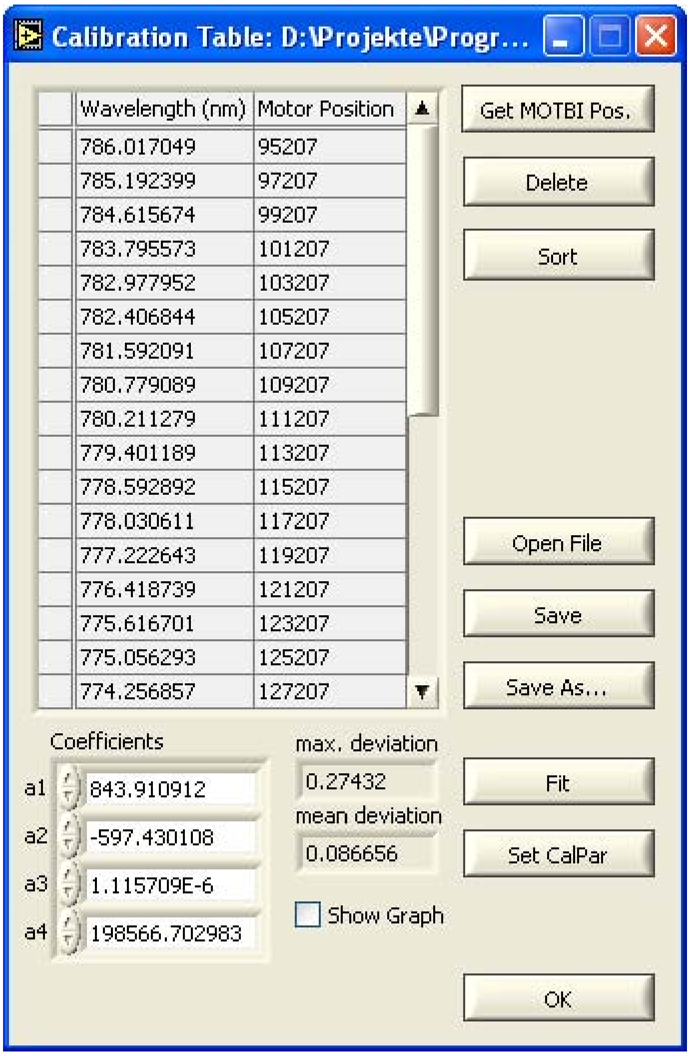


Figure 48: Birefringent Filter Calibration Table Editor

The laser's wavelength can be calculated to an accuracy of +/- 1 nm if there is an adequate calibration function for the Birefringent Filter motor positions. The calibration table represents the relationship between wavelengths and motor positions, that will be used to calculate a corresponding function. To get data, set the laser to a known wavelength and enter it into the table. **Get MOTBI Pos** will retrieve the current MOTBI position and fill it into the active row (Click into a row, to make it the active one). **Sort** will sort the table row in descending order of the wavelengths. You can **Delete** marked rows. Mark rows by selecting them with the left mouse-button pressed.

With **Open File**, **Save**, **Save As...** you can open or save files containing calibration table data.

Fit will fit the table data to the calibration function: Wavelength = **WLOff** + **WLFac***sin^2 [arctan (**LLen***(pos + **LOff**))]

The **Coefficients** have to fulfill certain conditions. **WavelengthOffset (WLOff)** has to be greater than the maximum wavelength occurring in the table. **WavelengthFactor (WLFac)** has to be negative. Good start values might be (maximum wavelength in table + 50) for **WavelengthOffset**, -400 for **WavelengthFactor**, 2e-6 for **LeverLength (LLen)** and 100000 for **LinearOffset (LOff)**.

On opening the Calibration Table dialog the **Coefficients** indicator gives the current function parameters (WLOff, WLFac, LevLen, LinOff) used by the Matisse controller. After a fit is executed it will contain the newly calculated numbers together with the **Maximum Deviation** and the **Mean Deviation** of the fit result. If **Show Graph** is ticked a graphical representation of the fit result and its errors is shown, after a fit has been executed.

Set CalPar will program the displayed **Coefficients** into the Matisse controller. To make this change permanent you have to save the active configuration (see ***Device Configuration*** (see page 69)).

available only with wavemeter support:

Birefr. Scan will open the ***Birefringent Filter Calibration Table: Birefr. Filter Scan*** (see page 80) dialog, where a scan over the Birefringent Filter motor positions is executed, simultaneously measuring the wavelength with the help of an external wavemeter.

Birefringent Filter Calibration Table: Birefr. Filter Scan

(only available with wavemeter support)

In this dialog a scan over the Birefringent Filter motor positions can be executed, while simultaneously measuring the current wavelength with the help of an external wavemeter. The scan start and end positions and increment can be set in the ***Birefringent Filter Calibration Table: Birefr. Filter Scan Options*** (on page 80) (press the **Options** button or F2). The range of motor position that is imported into the ***Calibration Table*** (see page 79) is determined by the two red cursor (vertical red line) in the **Birefringent Filter Scan** graph. Change this range by dragging the cursors to other positions.

Pressing **Start** will execute the scan, that can be aborted by the **Stop** button

Birefringent Filter Calibration Table: Birefr. Filter Scan Options

(only available with wavemeter support)

These controls determine the **Scan Start**, **Scan Start** and **Scan Increment** of the ***Birefringent Filter Calibration Table: Birefr. Filter Scan*** (see page 80).

Thin Etalon

Thin Etalon Control Setup

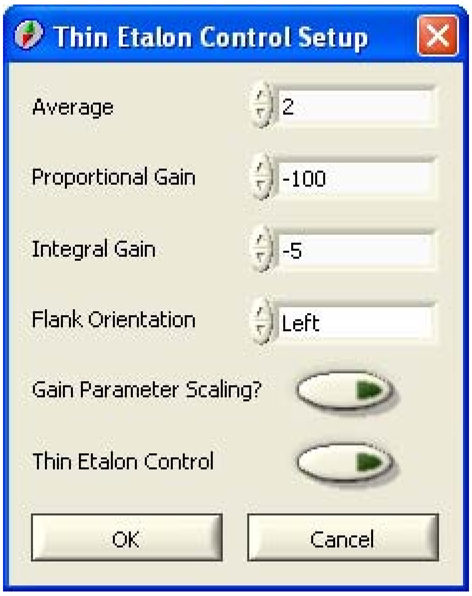


Figure 49: TE Control Setup dialog

In this dialog you can determine the behavior of the Thin Etalon control loop by setting the loop's parameters, like the **Proportional Gain, Integral Gain** and **Average**, which is the number of measurements the loop is averaging to compute the error signal. **Thin Etalon Control** will switch the control loop on or off.

Flank Orientation determines on which flank of the Thin Etalon parabola structure in ***the Thin Etalon*** Scan (see page 82) the laser is stabilized

Gain Parameter Scaling? enables the linear scaling of the two control loop gain parameters with the control loop setpoint, set with the ***Thin Etalon Scan*** (see page 82) procedure.

Changing the controls' values has an immediate effect on the control loop.

Thin Etalon Scan

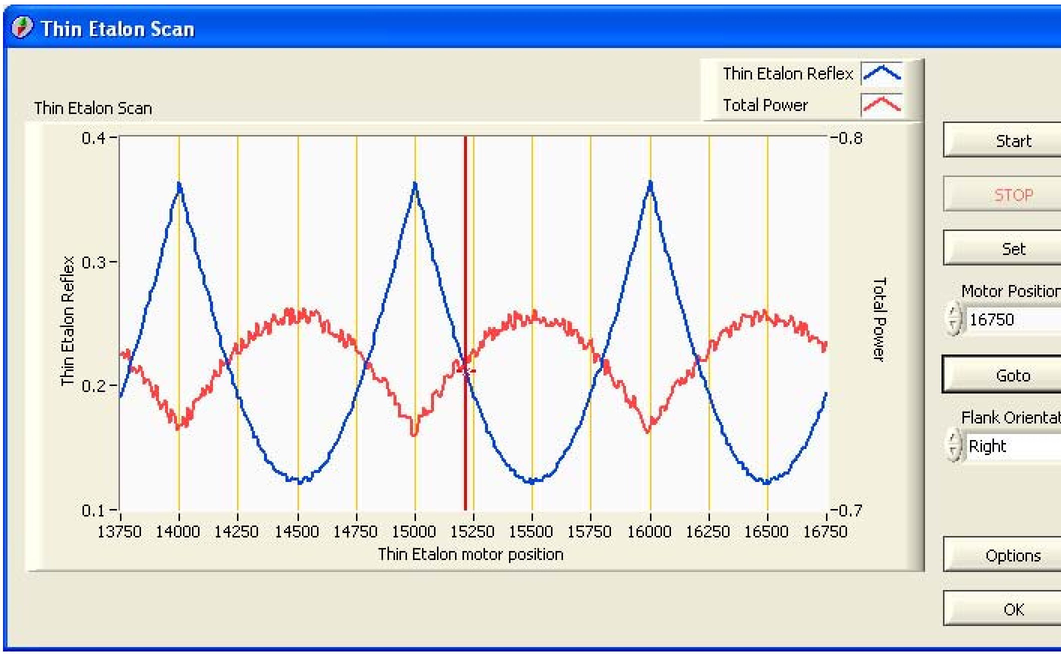


Figure 50: TE Control Position dialog

In this dialog a scan over the Thin Etalon motor positions can be executed to set the control position for the Thin Etalon control loop. Two signals are recorded: the total laser power and the intensity of the thin etalon's reflex. The scan is centered around the current TE motor position. The scan range, scan increment and the initial motor position can be set in the ***Thin Etalon Control Position Options*** (see page 83) (press the **Options** button or F2). The current motor position is shown as a cursor (red line within the graph) in the **Thin Etalon Scan** graph and in the **Motor Position** control. You can change this position by changing the position control and pressing **Goto**.

Pressing **Start** will execute the scan, that can be aborted by the **Stop** button. **Set** will move the motor to the position the cursor in the graph points to and the control goal value will be set. (It is the ratio of the thin etalon's reflex and the total power at that position).

For keeping the Thin Etalon synchronized with the movements of the Piezo Etalon the reflection from one etalon facette is monitored and compared to the total laser intensity. The TE control loop will adjust the TE position so that the ratio of these two signals is kept constant.

Choosing the right control point is important for achieving stable modehop-free single-mode operation of the laser. After a scan you should see a curve for the thin etalon reflex, that consist of a succession of parabolas with minima. Set the cursor by dragging it with the left-mouse button pressed on the **left** flank of a parabola close to its minimum and press **Set**, if **Flank Orientation** is selected to be 'Left'. Set the cursor by dragging it with the left-mouse button pressed on the **right** flank of a parabola close to its minimum and press **Set**, if **Flank Orientation** is selected to be 'Right'.

If **Set** is not used, the motor will stay in the scan's end position, when you close the dialog!

Thin Etalon Control Position Options

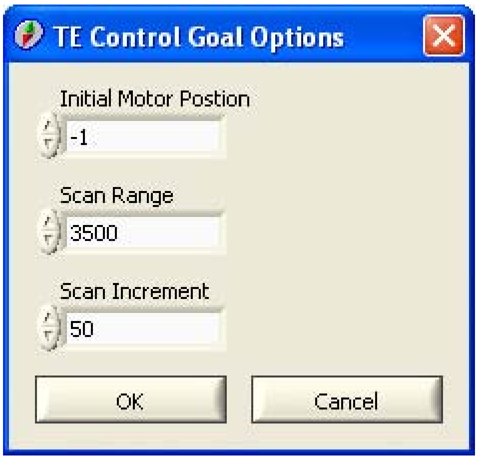


Figure 51: TE Control Position Options dialog

These controls determine the **Scan Range** and **Scan Increment** of the TE Control Position setting procedure.

The **Initial Motor Position** is the position the TE motor is moved to, when you call the TE Control Goal dialog. If it is set to a negative number, the motor will not not be moved.

Piezo Etalon

The thick piezo-etalon ensures that all except one longitudinal mode have so high losses, that laser emission is not possible. Therefore, the spacing of the etalon must be matched to an multiple of the favored longitudinal mode's wavelength. Because of the tight spacing and in order to be able to perform a scan, the spacing is actively controlled. The control loop is based on a lock-in technique and the etalon spacing is varied by a piezo drive.

The lock-in measures the response of the laser to an externally introduced perturbation. The perturbation is a slight modulation of the etalon spacing. The modulation follows the amplitude of a sine wave with a modulation frequency f_mod. The response of the laser is the variation in the total laser power, measured at the power diode.

Piezo Etalon Control Setup

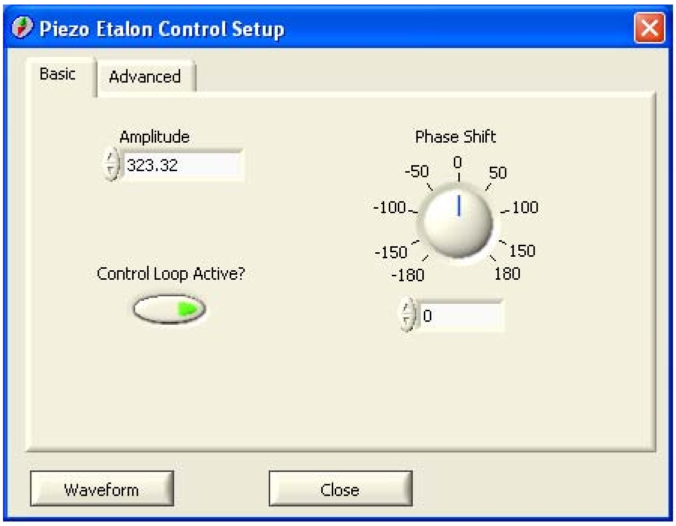


Figure 52: Basic setup for piezo etalon.

This dialog has two tabs Basic and Advanced.

Amplitude

This parameter controls the amplitude of the sine modulation that is applied to the piezoelectric actor. The value for the **Amplitude** should never exceed 50. Depending on the actual etalon values between 5 and 25 should work for almost all cases. Bigger values make for a 'cleaner' waveform (less amplitude noise), but might decrease the power output of the laser. Too big values for the **Amplitude** will show up as more than one mode per FSR in the monitor spectrum.

Phase Shift

This parameter controls the phase shift that is applied before the convolution of modulation waveform and waveform detected at the integral diode is calculated. You should find a range of values (or just one value), where for each value the Piezo Etalon Waveform is stationary, i.e., its form stays the same apart from some amplitude noise. Choose a value from the center of the range. Note: The **Phaseshift** parameter can only be changed in discrete steps of (180° / oversampling points).

Control Loop Active?

This button controls if the action that is calculated by the control loop is applied to the piezo. If the control loop is inactive the modulation is still applied.

Waveform

This button opens the ***Piezo Etalon Waveform*** (see page 86) window.

Advanced Settings:

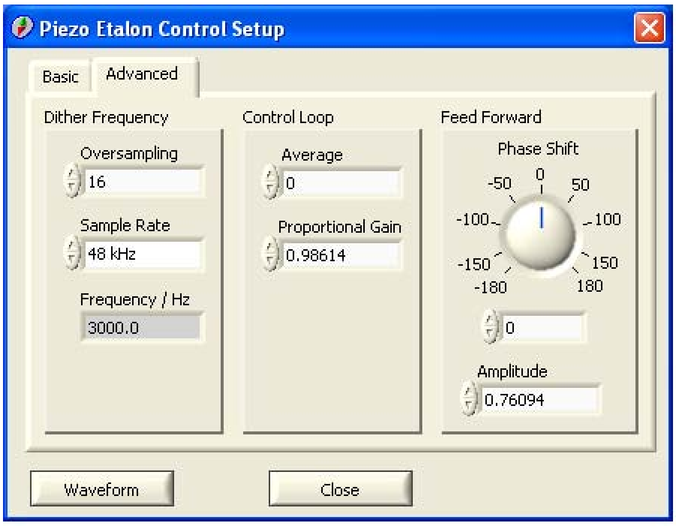


Figure 53: Advanced tab of the piezo etalon control dialog.

The advanced tab is divided into three sections, each section controls a different aspect of the piezo etalon. **Oversampling** and **Sample Rate** control the modulation frequency, **Average** and **Proportional Gain** control the action of the control loop, **Phase Shift** and **Amplitude** the action of the feed forward to the tweeter.

Oversampling

This parameter determines how many samples are used to synthesize the modulation waveform. The minimum value is 8, the maximum value is 64 samples per period.

Sample Rate

This parameter determines the rate at which each of the sample points is transferred to the piezo etalon. The combination of **Oversampling** and **Sample Rate** determines the frequency of the modulation: f_mod = Sample Rate / Oversampling. Valid **Sample Rates** are 8 kHz, 32 kHz, 48 kHz, 96 kHz. Hence, the limits for the modulation frequency are 125 Hz and 12 kHz.

Frequency (Output)

Displays the calculated modulation frequency for the selected combination of Sample Rate and Oversampling.

Average

This parameter determines how many cycles of the modulation are averaged before the controller action is calculated. An increase in the number of averaged cycles lead to a betters signal-to-noise ratio of the control signal but makes the control loop less responsive.

Proportional Gain

The **Proportional Gain** determines the magnitude of the controller action. Low Proportional Gain will result in a slow reaction from the controller, but overshoot will be avoided.

Phase Shift

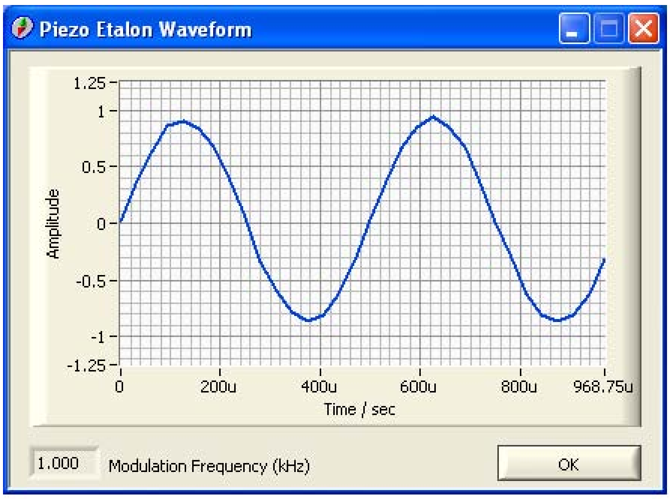
This parameters controls the phase shift that is applied to the modulation signal that is applied to the tweeter. The modulation of the piezo etalon results in a small modulation of the cavity length and subsequently of the emission wavelength. A direct feedback of the modulation to the tweeter removes some workload from the tweeter control loop. For an optimal setting of the Phase Shift parameter you require an external optical spectrum analyser.

Amplitude

This parameters controls the amplitude of the modulation signal that is applied to the tweeter. The modulation of the piezo etalon results in a small modulation of the cavity length and subsequently of the emission wavelength. A direct feedback of the modulation to the tweeter removes some workload from the tweeter control loop. For an optimal setting of the Phase Shift parameter you require an external optical spectrum analyser.

Changing the controls' values has an immediate effect on the control loop. To make changes permanent you have to save the active configuration (see ***Device Configuration*** (see page 69)).

Piezo Etalon Waveform



The graph shows the AC-part of the total laser power. The curve should be stationary, when the Piezo Etalon control loop is on, and should have a sine-like (w-shaped), harmonic form starting with a maximum.

S Stabilization

(only available for Matisse TS/DS)

The Matisse laser frequency can be stabilized by locking the frequency to a mode of an external reference resonator (using the 'side-of-fringe locking technique). Pertubations that might destroy this lock are counteracted by an actively controlled laser cavity mirror mounted on a fast piezo actuator (FPZ). An actively controlled slow piezo (SPZ) acting on another laser mirror ensures that the FPZ will always have its full dynamical range to react on pertubations.

How to lock the Laser:

- open the ***RefCell Waveform*** (see page 93) display and set **Scan Upper Limit** to 0.1, **Scan Lower Limit** to 0, **Oversampling** to 128 and **Sampling Mode** to 'Average'. Optimize the adjustment of the laser beam into thee reference resonator. The photo diode signal for the transmitted light has a nominal value range from about -0.2 to 0.4. The signal maximum value should be lower than 0.25. Adapt the filters accordingly.
- open the ***Fast Piezo Control Setup*** (see page 90) dialog, set the **Setpoint** to a value about half of the maximum peak signal seen in the Waveform display.
- make sure the slow piezo baseline is in the middle of its range. activate the lock by clicking on the **RefCell Control** LED indicator in the main window or ticking the 'Control On' item in the RefCell Stabilization menu

Troubleshooting

If no lock can be obtained, stop the RefCell Control loop. Open 'Matisse' -> 'Advanced Tools & Options' -> 'Control Loop Live View'. Set **Protocol** to 'FPZ'. The upper graph in this case will show the photo diode signal, the red line corresponds to the FPZ Lockpoint. Let this window open and switch on the RefCell Control loop. Observe now the upper graph. When you switch on the control loop and there is no lock, then the slow piezo starts scanning the laser to find a resonance of the reference resonator. You should see after a while in the upper graph the peaks of the resonator spectrum appear. If you cannot see, that the FPZ lock is setting in, then you should decrease the **Free Proportional Gain** parameter in the ***Slow Piezo Control Setup*** (see page 92) dialog. This parameter determines the scan speed of the slow piezo.

If you see that the fast piezo control loop tries to lock to the setpoint, but looses the lock quickly, than you have to increase the fast piezo control loop parameters in the ***Fast Piezo Control Setup*** (see page 90) (e.g. multiply the values by a factor of 2).

Optimizing the lock

- open the ***RefCell Properties Measurement dialog*** (see page 95). Measure the spectrum and choose about half of the maximum peak signal seen in the spectrum graph as the new **Setpoint** for the fast piezo control loop.
- open the Frequency Noise display.
- increase the **Integral Gain** for the fast piezo control loop (multiply by factors of 2) until you see an increase in the displayed frequency noise. There is a threshold for this parameter, above which the control loop starts to oscillate and frequency noise rises strongly. Decrease the **Integral Gain** until you find this threshold value. Choose a value that is about 10% smaller than the threshold value. If you cannot find a threshold you might have already started above it, so decrease the **Integral Gain** until you will find a decrease in the frequency noise.

Fast Piezo Control Setup

(only available for Matisse TS/DS and TX/DX)

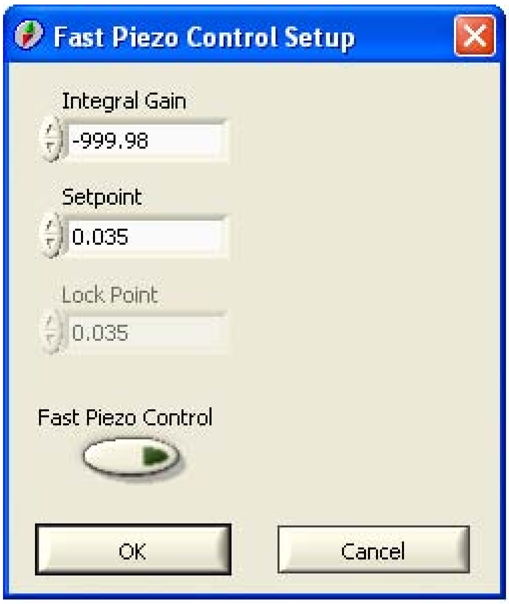


Figure 54: Fast Piezo Control Setup dialog

In this dialog you determine the behavior of the Fast Piezo (Tweeter) control loop by setting the loop's parameters. For optimizing the control loop's gain parameters see either the ***S Stabilization*** (see page 88) and ***X Stabilization*** (see page 98) sections.

Integral Gain

The **Integral Gain** determines the magnitude of the controller action that is applied to the fast piezo. Low **Integral Gain** will result in a slow reaction of the piezo and not all perturbations of the laser will be compensated. Excessive **Integral Gain** will result in overshoot and uncontrolled oscillations of the fast piezo.

Setpoint

This value defines the control goal for the fast piezo control loop. The control loop will try to stabilize the laser at a wavelength that corresponds to the Setpoint value at the DSP input.

Matisse TS/DS: Use a position in the centre of the transmission flank as value for **Setpoint**. See ***Reference Cell Waveform*** (see page 93) on how to determine this point. For Matisse TS/DS systems the **Lock Point** will be automatically set to the same value as the **Setpoint**.

Matisse TX/DX: The **Setpoint** defines the point on the steep flank of the ***Pound-Drever-Hall mixer signal*** (see page 102) to which the laser's wavelength is stabilized. Choose a value that has has the same value as the signal has far from any resonance.

Lock Point

This value defines an initial **Setpoint** that will be used when the laser starts a lock or re-lock process. The **Lock Point** is useful for Pound-Drever-Hall systems where it is not possible to distinguish between a laser system that is on the resonance or far awway from the resonance. Hence, the laser will first lock to a non-zero value (determined by the **Lock Point** parameter) that is only present at a resonance. After the lock is attained, the laser will be smoothly moved from the **Lock Point** to the **Setpoint**.

Fast Piezo Control

The **Fast Piezo Control** button will switch the control loop on or off.

Changing the controls' values has an immediate effect on the control loop.

Slow Piezo Control Setup

(only available for Matisse TS/DS and TX/DX)

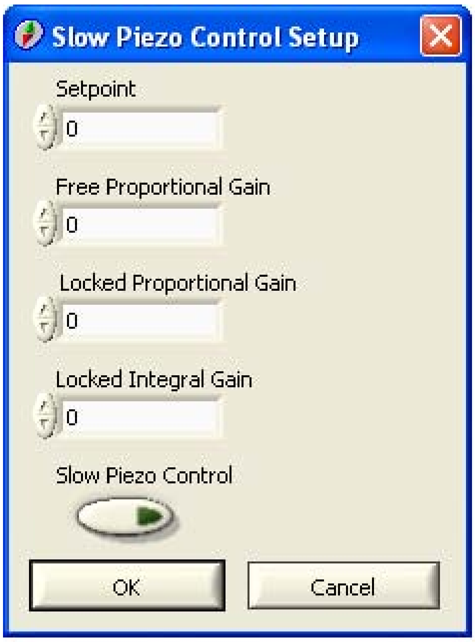


Figure 55: SPZ Control Setup dialog

In this dialog you can determine the behavior of the Slow Piezo control loop by setting the loop's parameters. The **Setpoint** defines the point in the (nominal) voltage range of the Fast Piezo from 0 to 0.7, to which the Fast Piezo is kept with the help of the Slow Piezo. It should be set to 0.5, so that the Fast Piezo has the full dynamical range available to react on pertubations to keep the laser locked to the reference resonator. The **Lock Proportional Gain** and the **Lock Integral Gain** are the control loop parameters used, when the laser is in the lock.

The **Free Proportional Gain** determines the scan speed of the slow piezo for the scan, that is executed to find or regain a resonance of the reference resonator to lock the laser to, if the lock was lost.

Slow Piezo Control will switch the control loop on or off.

Changing the controls' values has an immediate effect on the control loop.

RefCell Waveform

(only available for Matisse TS/DS)

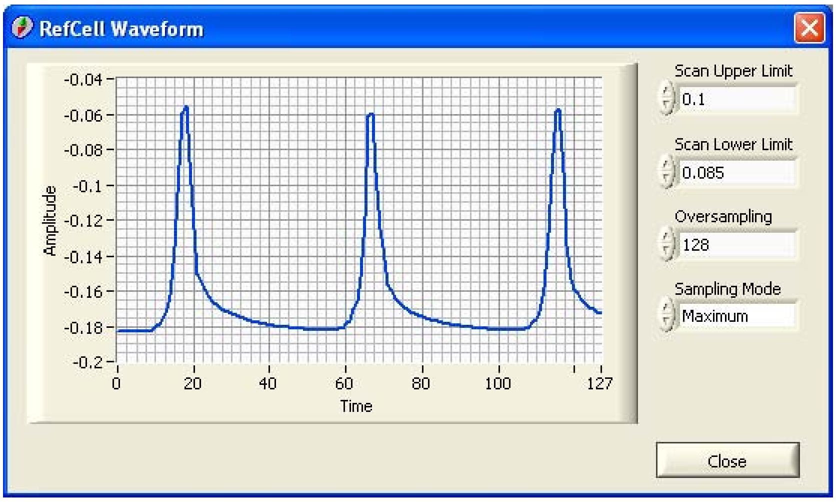


Figure 56: RefCell Waveform display

The graph shows the transmission spectrum for the confocal reference cell. A scan over the cell's piezo actuator voltage is performed within an interval determined by **Scan Upper Limit** and **Scan Lower Limit** (values are in a range of 0 to 0.7). The **Oversampling** parameter gives the number of sampling points. It cannot be higher than 512. The **Sampling Mode** decides which characteristics of the waveform the DSP is looking for (finding Maximums, Minimiums or computing the Average) using the full internal waveform at the ADC.

The **Autoscale Y-Axis** property determines whether to automatically adjust the maximum and minimum values of that axis. If the property is set to false, you can manually adjust these values by clicking onto the axis with the left mouse-button and entering new numbers.

Set Setpoint will set the setpoint of the ***Fast Piezo control loop*** (see page 90) to the displayed **FPZ Setpoint**. The value is calculated to be the amplitude value at the Full-Width-At-Half-Maximum points of the currently displayed transmission spectrum.

RefCell Frequency Noise

(only available for Matisse TS/DS)

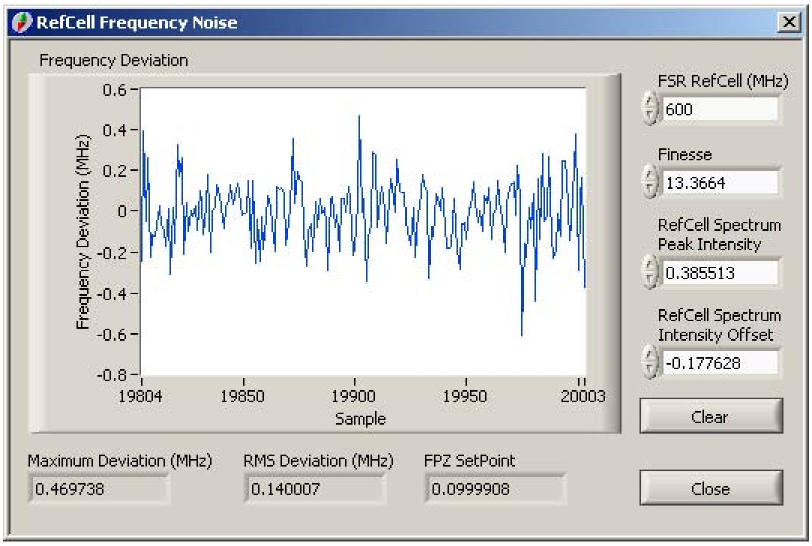


Figure 57: RefCell Frequency Noise display

This dialog shows the relative **Frequency Deviation** from the current lock frequency of the Reference Cell calculated with the help of the (inverse) Airy function for a resonator with a free spectral range of **FSR RefCell (MHz)** and a finesse of **Finesse**. These values have to be adapted to your Reference Cell (for an S Matisse model the FSR has normally a value of 600 GHz). You also need the **RefCell Spectrum Peak Intensity** and **RefCell Spectrum Intensity Offset** values, that can be determined with the ***RefCell Properties Measurement*** (see page 95) dialog.

The **Maximum Deviation (MHz)** and the **RMS Deviation (MHz)** gives you some statistical properties for the displayed sample series.

RefCell Properties Measurement

(Only meaningful for Matisse TS/DS)

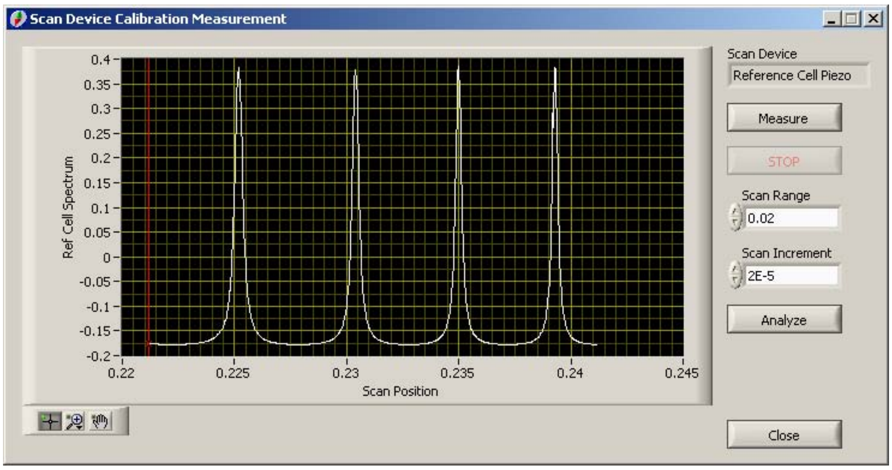


Figure 58: Scan Device Calibration Measurement dialog

Measure will perform a sampled scan with a range of **Scan Range** and an increment of **Scan Increment** with the current **Scan Device** (either RefCell or Slow Piezo), while measuring the transmitted intensity of the Reference Cell. The result will be the transmission spectrum of the Reference Cell, that should have 2 or more peaks separated from their neighbor peaks by the Free Spectral Range (FSR), that can be used to calculate a scan range - frequency factor for the current scan device. For the scan to be successful the positions of the Thick and Thin Etalon have to be optimized and the corresponding control loops have to be active beforehand. In the case of the RefCell as scan device the RefCell control loops will be switched off automatically (After closing the dialog the original control loops' status will be restored).

Analyze will call up the ***RefCell Spectrum Analysis dialog*** (see page 96), that will calculate the above mentioned conversion factor, as well as the Finesse of the Ref Cell cavity and other properties, that will be needed for the ***Ref Cell Frequency Noise display*** (see page 94). For the analysis to be successful, the spectrum has to contain at least two peaks!

RefCell Spectrum Analysis

(Only available for Matisse TS/DS)

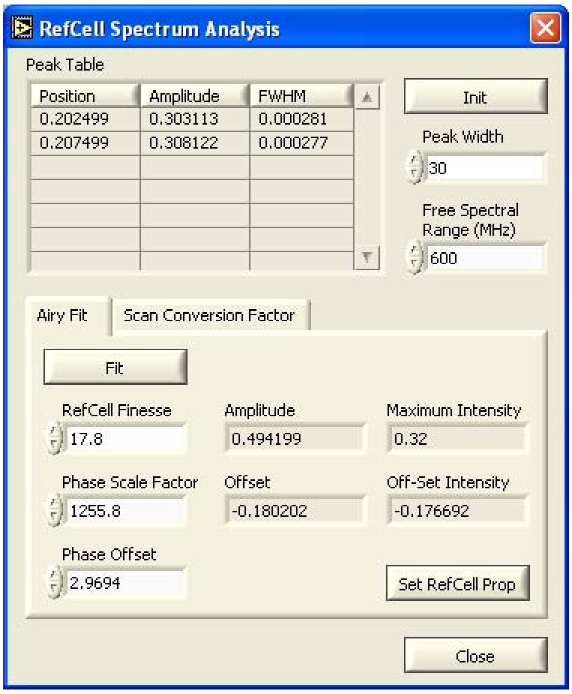


Figure 59: Scan Device Calibration Measurement Analysis dialog

The **Peak Table** contains the position, amplitude and the full width at half maximum (FWHM) value for each found transmission peak of the RefCell spectrum, measured in the ***RefCell Properties Measurement dialog*** (see page 95). If more peaks are found than there are clearly visible ones, increase the value for **Peak Width**, until the correct number of peaks appear in the **Peak Table**.

With the information in the **Peak Table** it is possible to calculate the **RefCell Finesse**. The **Maximum Intensity** and **Off-Set Intensity** of the spectrum are given as well.

Airy Fit tab:

A **Fit** for the RefCell spectrum can be made according to the following function for the transmitted intensity:

Intensity (Scan Piezo Position) = **Offset** + **Amplitude** / (1 + (2 × **RefCell Finesse** / π)^2 × sin^2((**Phase Scale Factor** × Scan Piezo Position - **Phase Offset**) / 2))

The best fit result is shown in the graph of the ***RefCell Properties Measurement dialog*** (see page 95). If the fit does not lead to reasonable fit parameters, press again **Fit** and see if the result improves. If not, press **Init**, to initialize the start parameters again, change the Phase Offset and repeat the fitting procedure.

Set RefCell Properties stores the calculated RefCell Finesse, the RefCell's FSR, the Maximum and the Off-Set Intensity into the Matisse Commander's configuration file, making it possible to calculate the frequency noise in the the ***Ref Cell Frequency Noise display*** (see page 94). Also the setpoint of the ***Fast Piezo control loop*** (see page 90) will be set to the displayed **FPZ Setpoint** value. The value is calculated to be the amplitude value at the Full-Width-At-Half-Maximum points of the measured transmission spectrum.

Scan Conversion Factor tab:

Calculate Conv. will perform the calculation of the **Conversion Factor (MHz / full nominal scan range of 1)** utilizing the **Free Spectral Range (MHz)** information for the RefCell, the **Number of FSR** and the **Scan Range**.

Set Conv. stores the calculated conversion factor into the Matisse Commander's configuration file to be used by the ***Scan Setup dialog*** (see page 106).

X Stabilization

(only available for Matisse TX/DX and TX/DX light)

The Matisse laser frequency can be stabilized by locking the laser frequency to an external reference resonator using the Pound-Drever Hall control scheme. Fast perturbations that might destroy this lock are counteracted by an intra-cavity electro-optical modulator (EOM).

Slower perturbations are cancelled by an actively controlled laser cavity mirror mounted on a fast piezo actuator (FPZ). An actively controlled slow piezo acting on another laser mirror ensures that the FPZ will always have its full dynamical range to react on perturbations.

How to lock the Laser

- optimize the mode-matching of the laser beam into the reference resonator
- open the ***Pound-Drever-Hall Waveforms*** (see page 102) display and set **Scan Upper Limit** to 0.1, **Scan Lower Limit** to 0, **Oversampling** to 128 and **Sampling Mode** to 'Average'. Set the **Multiplexer** control to 'Diode Signal'. Minimize the signal strength by adjusting the mirror reflecting the back-reflected light from the resonator onto the photo diode. The signal has a nominal value range from 0.5 to -0.5 and is inverted. Lower numbers mean higher signal value! Adapt the filters, so that you have good signal-to-noise ratio
- set the **Multiplexer** control to 'Mixer Output'. Choose a scan interval and decrease its size (about 0.03), so that you can clearly see the PDH error waveform with the biggest amplitude. Adapt the value of the DSP Offset, so that the signal's baseline (outside of the PDH error signal) is around zero. The mixer signal has a nominal value range from 0.5 to -0.5. The PDH error signal should be in the range of 0.2 to -0.2.
- open the ***Fast Piezo Control Setup*** (see page 90) dialog, set the **Lock Point** to either a value slightly lower than the maximum of the PDH error signal or to a value slightly higher than the minimum value. Set **Setpoint** to 0.
- make sure the slow piezo Baseline is in the middle of its range. Activate the lock by clicking on the **RefCell Control** LED indicator in the main window or ticking the 'Control On' item in the PDH Stabilization menu

Troubleshooting

If no lock can be obtained, stop the RefCell Control loop. Open 'Matisse' -> 'Advanced Tools & Options' -> 'Control Loop Live View'. Set **Protocol** to 'FPZ'. The upper graph in this case will show the PDH error signal, the red line corresponds to the FPZ Lockpoint. Let this window open and switch on the RefCell Control loop. Observe now the upper graph. When you switch on the control loop and there is no lock, then the slow piezo starts scanning the laser to find a resonance of the reference resonator. You should see after a while in the upper graph PDH error waveforms appear. If you cannot see, that the FPZ lock is setting in, then you should decrease the **Free Proportional Gain** parameter in the ***SPZ Control Setup*** (see page 92) dialog. This parameter determines the scan speed of the slow piezo.

If you see that the FPZ control loop tries to lock to the PDH error signal, but looses the lock quickly, than you have to increase the FPZ PID loop parameters in the ***FPZ Control Setup*** (see page 90) (e.g. multiply the values by a factor of 2).

Optimizing the lock

- open the Frequency Noise display.
- go to the ***Fast Piezo Control Setup*** (see page 90) dialog.
- increase the **Integral Gain** for the fast piezo control loop (by factors of 2), until you see an increase in the displayed frequency noise. There is a threshold for this parameter, above which the control loop starts to oscillate and frequency noise is increased. Decrease the **Integral Gain** until you find this threshold value. Choose a value that is about 10 % smaller than the threshold value. If you cannot find a threshold you might have already started above it, so decrease the **Integral Gain** until you will find a decrease in the frequency noise.
- go to the ***Pound-Drever-Hall Control Setup*** (see page 100) dialog, decrease the **Attenuator** value by steps of 5, until you see an increase in the displayed frequency noise. There is a threshold for this parameter, below which the control loop starts to oscillate and to increase the frequency noise. increase the **Attenuator** until you find this threshold value. Choose a value that is about 3 lower smaller than the threshold value. If you cannot find a threshold you might have already started above it, so increase the **Attenuator,** until you will find a decrease in the frequency noise.

Pound-Drever-Hall Control Setup

(Only available for Matisse TX/DX and TX light)

These control parameters influence the various input and output signals of the Pound-Drever-Hall unit.

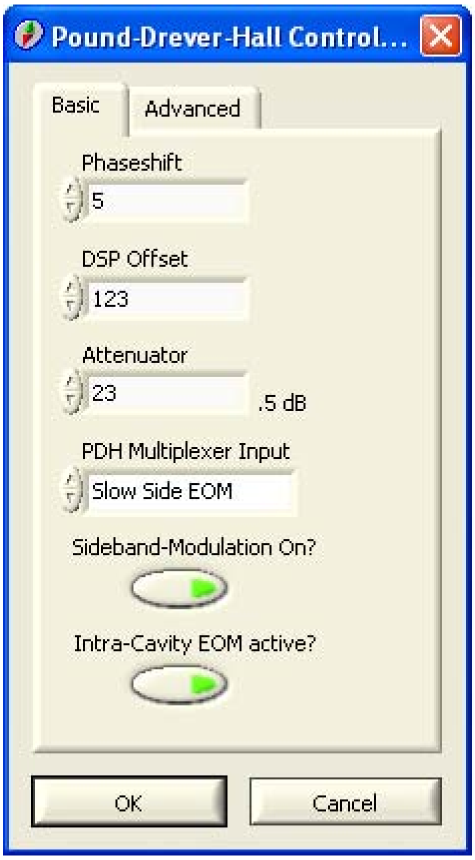


Figure 60: Pound-Drever-Hall Control Setup basic parameters.

Basic Parameters:

DSP Offset will change the baseline of the Phase Mixer signal. Choose a value, so that the baseline is around zero.

The **Phaseshift** determines the phase between the 20 MHz sine modulation and the detector signal. This phase will determine the shape of the PDH error signal. Choose a value that results in an symmetric error signal with a steep slope in its center.

The **Attenuator** value determines how strong the intra-cavity EOM will react on deviations from the zero-crossing of the PDH signal.

All above mentioned quantities have a range of 0 to 255, except the **Attenuator**, which has a range of 0 to 63. Smaller or bigger values will be coerced to the corresponding limit value.

PDH Multiplexer Input shows which signal is currently as output from the multiplexer. **Modulation On?** indicates/sets the status of the 20 MHz sideband generation and **EOM active?** shows/sets the control status of the intra-cavity EOM?

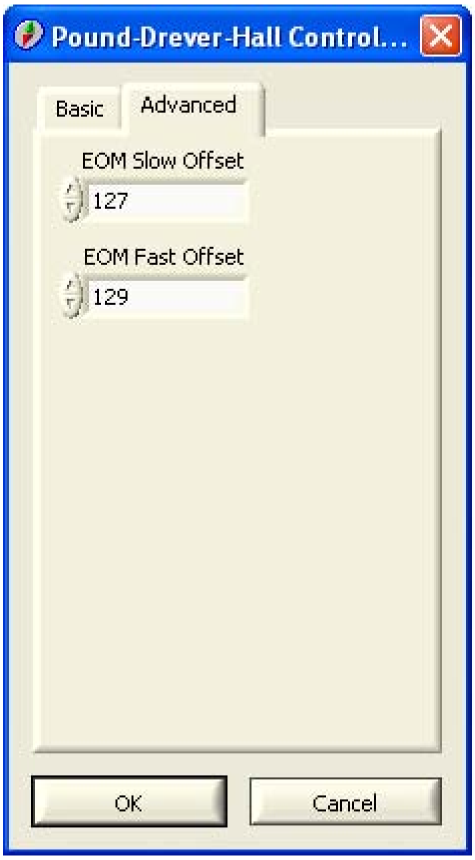


Figure 61: Pound-Drever-Hall Control Setup advanced parameters.

Advanced Parameters:

With **Fast and Slow Offset** offsets in the fast and slow control signal branch for the intra-cavity EOM can be compensated.

TX light remark:

Fast and **Slow Offset** and **Attenuator** are disabled.

Pound-Drever-Hall Waveforms

(only available for Matisse TX/DX and TX/DX light)

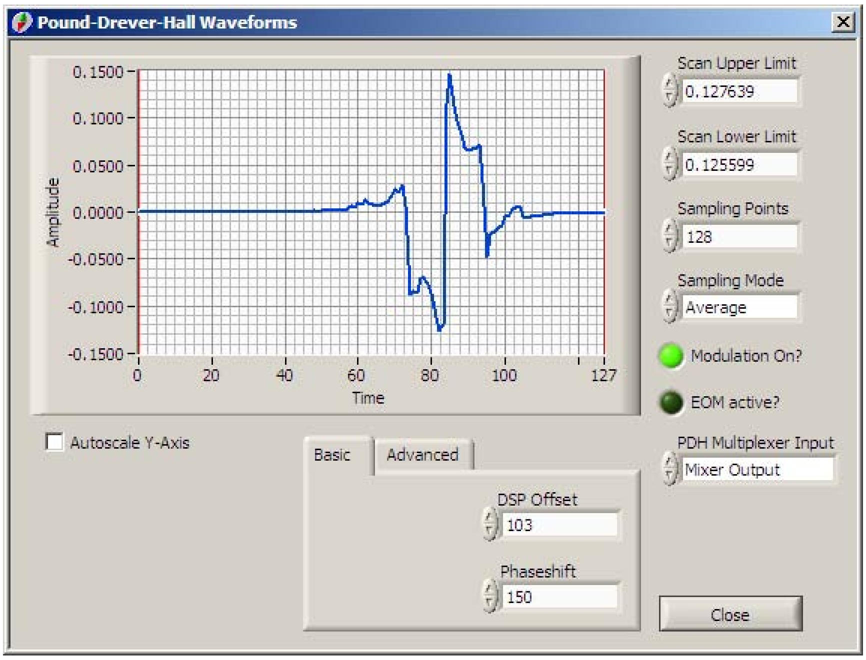


Figure 62: PDH Waveforms dialog

The graph shows the various signals ('Photo Diode signal', 'Phase Mixer output', 'Slow Side EOM signal', 'Transmission Diode signal') that play a role for the PDH stabilization scheme, by choosing the **PDH Multiplexer Input**. **Modulation On?** indicates/sets the status of the 20 MHz sideband generation and **EOM active?** shows/sets the control status of the intra-cavity EOM?

PDH Multiplexer Input shows which signal is currently as output from the multiplexer. **Modulation On?** indicates/sets the status of the 20 MHz sideband generation and **EOM active?** shows/sets the control status of the intra-cavity EOM?

Basic Parameters:

DSP Offset will change the baseline of the Phase Mixer signal. Choose a value, so that the baseline is around zero.

The **Phaseshift** determines the phase between the 20 MHz sine modulation and the detector signal. This phase will determine the shape of the PDH error signal. Choose a value that results in an symmetric error signal with a steep slope in its center.

Advanced Parameters:

The **Attenuator** value determines how strong the intra-cavity EOM will react on deviations from the zero-crossing of the PDH error signal.

With the **EOM Fast Offset** and **EOM Slow Offset** controls offsets in the fast and slow control signal branch for the intra-cavity EOM can be compensated.

A scan over the cell's piezo actuator voltage is performed within an interval determined by **Scan Upper Limit** and **Scan Lower Limit** (values are in a range of 0 to 0.7). The **Sampling Points** parameter gives the number of points used to display the internal waveform. It cannot be higher than 512. The **Sampling Mode** decides which characteristics of the full internal waveform at the ADC the DSP is looking for (finding Maxima, Minima or computing the Average).

The two red cursors at the edges of the graph can be dragged inside or outside to adapt the scan limits interactively to have an optimal view on the corresponding waveforms.

The **Autoscale Y-Axis** property determines whether to automatically adjust the maximum and minimum values of that axis. If the property is set to false, you can manually adjust these values by clicking onto the axis with the left mouse-button and entering new numbers for the minimum and maximum values.

Pound-Drever-Hall Frequency Noise

(only available for Matisse TX/DX and TX/DX light)

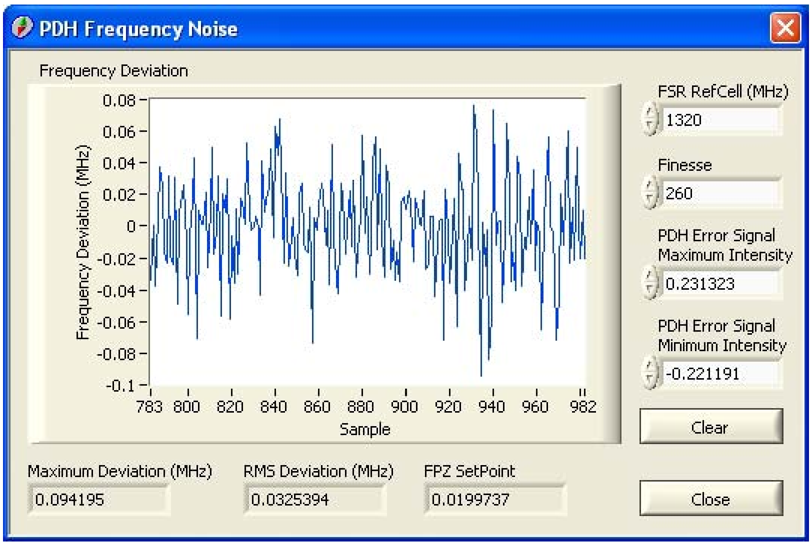


Figure 63: PDH Frequency Noise display

This dialog shows the relative **Frequency Deviation** from the current lock frequency of the Reference Cell calculated with the help of the PDH error function for a resonator with a free spectral range of **FSR RefCell (MHz)** and a finesse of **Finesse**. These values have to be adapted to your Reference Cell (for an X Matisse model the FSR has normally a value of 1320 GHz). You also need the **PDH Error Signal Maximum Intensity** and **PDH Error Signal Maximum Intensity** values, that can be determined with the ***PDH Error Signal Measurement*** (see page 105) dialog.

The **Maximum Deviation (MHz)** and the **RMS Deviation (MHz)** gives you some statistical properties for the displayed sample series.

Pound-Drever-Hall Error Signal Measurement

(Only available for Matisse TX/DX and TX/DX light)

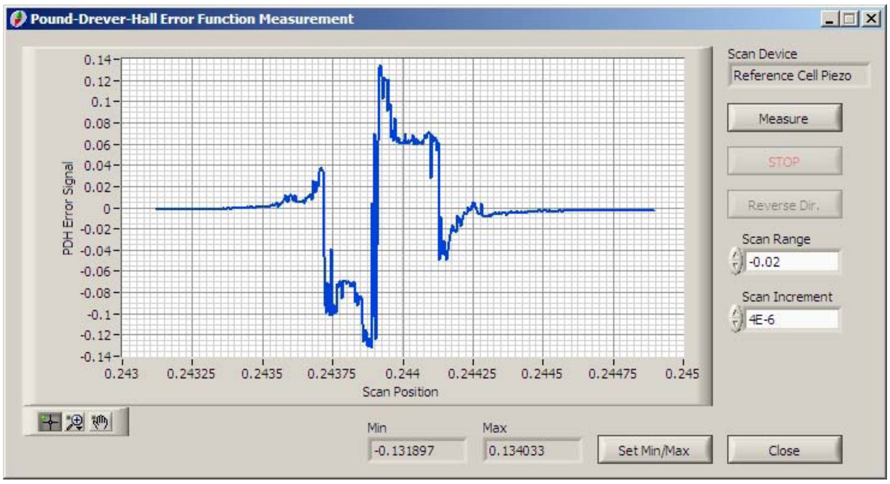


Figure 64: PDH Error Signal Measurement

Measure will perform a sampled scan with a range of **Scan Range** and an increment of **Scan Increment** with the current **Scan Device** (either RefCell or Slow Piezo), while measuring the PDH error signal value. For the scan to be successful the positions of the Thick and Thin Etalon have to be optimized and the corresponding control loops have to be active beforehand. In the case of the RefCell as scan device the RefCell control loops will be switched off automatically (After closing the dialog the original control loops' status will be restored).

Set Min/Max will store the **Min** and **Max** values of the PDH error signal, that are needed for the ***PDH Frequency Noise display*** (see page 104).

Scan

Scan Setup

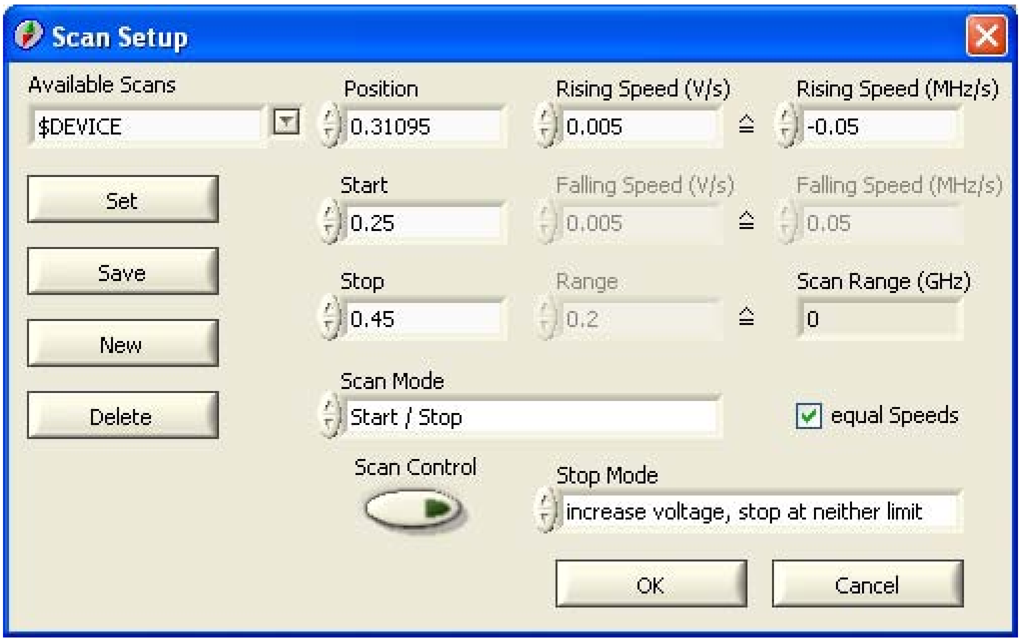
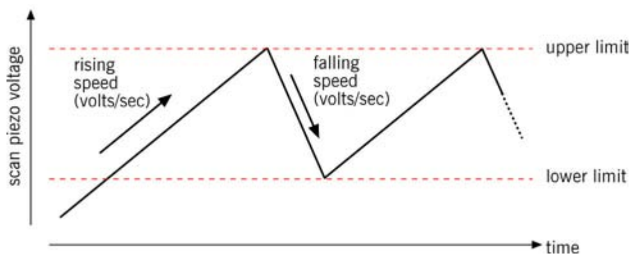


Figure 65: Scan Setup dialog

This dialog determines the scan behavior. **Position**, **Start** and **Stop** have a range of 0 to 0.65 and set the voltage applied to the scan piezo and the upper and lower limits of the scan, respectively. **Rising Speed (V/s)** and **Falling Speed (V/s)** are the voltage change per second (see diagram below). The **Stop Mode** determines if and when the scan stops (at upper or lower limit). **Rising Speed (MHz/s)** and **Falling Speed (MHz/s)** are about values for the frequency change per second. These serve as a hint for the order of magnitude of the change. **Scan Range (GHz)** gives the frequency range that corresponds to the scan range between Upper and Lower Limit. To calculate the frequency quantities there has to be a conversion factor, that can be set in the ***Scan Device Configuration*** (see page 108) dialog. **Equal Speeds** determines if the scan is symmetric in scan speed terms.

Figure 66: Scan Timing.



Scan Control switches the scan off or on.

Scan Mode allows you to define scan limits in three different ways:

- 'Start / Stop' defines the scan by its upper and lower limits
- 'Start / Range' defines the scan by its lower limit and and scan range, from which an upper limit can be calculated
- 'Position / Range' defines the scan using the current position and a scan range to calculate the following lower and upper limits: current position - range/2 and current position + range/2

You can store different scan setups, including **Scan Mode**, to the Matisse Commander configuration file. **Available Scans** shows all stored scans. Its default value is '$DEVICE', i.e., it shows the current scan setup in the Matisse DSP controller. When you select a stored scan setup, the scan data will be shown in the respective fields (the current scan position will not change!). With **Set** this scan setup will be sent to the Matisse controller. You can create new scans with **New**, prompting you for a scan setup name (do not use names starting with a '$' sign). Save and Delete will do the corresponding actions for the displayed scan setup (except in the case of '$DEVICE').

Changing the controls' values (except **Position**) has an immediate effect on an active scan.

Scan Device Configuration

Figure 67: Scan Device Configuration

This dialog lets you select the **Scan Device** that is used during a scan. Possible devices are 'Reference Cell Piezo', 'Slow Piezo' or 'No Device'. 'Slow Piezo' means that the intra-cavity piezo is scanned, which will cause a direct change of the laser's frequency (Matisse TR/DR setup). 'Reference Cell Piezo' means shifting the transmission spectrum of the Reference Cell, which will cause an indirect change of the laser's frequency via the locking of the laser to the cell. For the scan to be effective in this case the RefCell Control Loop has to be active! (Only meaningful for Matisse TS/DS or higher)

You can also set a **Conversion Factor** that gives a relation between the nominal scan piezo range and the effective laser frequency change. If you have a Matisse TS/DS you can measure this factor with the help of the Reference Cavity (see ***RefCell Properties Measurement*** (see page 95)). If you have a wavemeter and a corresponding Wavemeter plugin (e.g. the HighFinesse wavemeter plugin available at the Sirah website) integrated into the Matisse Commander, then you should use the 'Scan Device Calibration with Wavemeter' procedure in the 'Wavemeter' (see page 71) menu, because this gives also the sign of the conversion factor, that is important for advanced function of the wavemeter plugin.

Determining the **Conversion Factor** in the general case for a Matisse and a wavelength/frequency device is as follows: define a a scan for the Matisse with a specific scan range, e.g. 0.1 (see ***Scan Setup dialog*** (see page 106)). Measure the laser frequency at the start of the scan, execute the scan and measure the laser frequency at the end of the scan. Divide the frequency difference in MHz by the scan range and enter the result into the **Conversion Factor** control.

ControlScan Setup

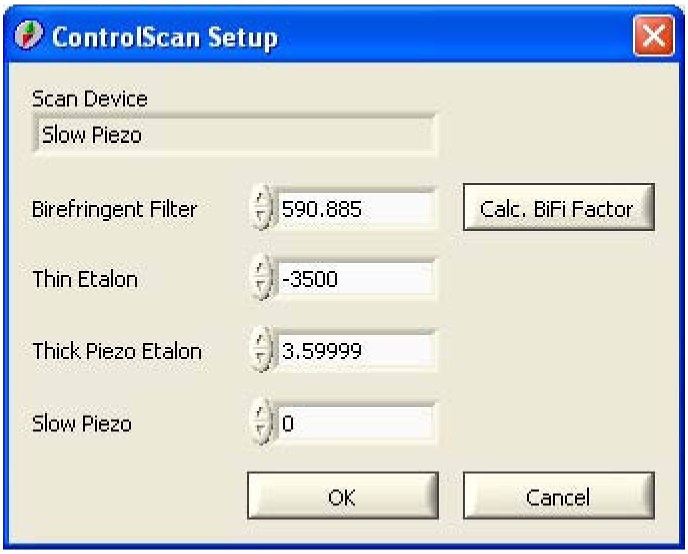


Figure 68: ControlScan Setup dialog

The ControlScan parameters are factors, that are multiplied by the change of the (nominal) scan piezo voltage change and added to the position of the corresponding elements (**Birefringent Filter**, **Thin Etalon**, **Thick Piezo Etalon** and the **Slow Piezo**; the latter element is only of importance for Matisse models TS/DS or higher). These parameters are essential for fast scans (scan speed of 1 GHz/s). The position changes will be executed, even if the control loops for these elements are not active. The values determined here correspond to a change of the scan piezo by the full (nominal) range of 1.

Calc. BiFi Factor will calculate the corresponding factor using information from the calibration function for the Birefringent Filter (see ***Calibration Table*** (see page 79)) and the conversion factor for the current scan device (see ***Scan Device Configuration*** (see page 108)).

There are different sets of ControlScan parameters, depending on the selection of the **Scan Device** (see ***Scan Device Configuration*** (see page 108)).

Pressing **OK** will set these parameters for the active configuration. To make changes permanent you have to save the active configuration (see ***Device Configuration*** (see page 69)).

ControlScan Values Measurement

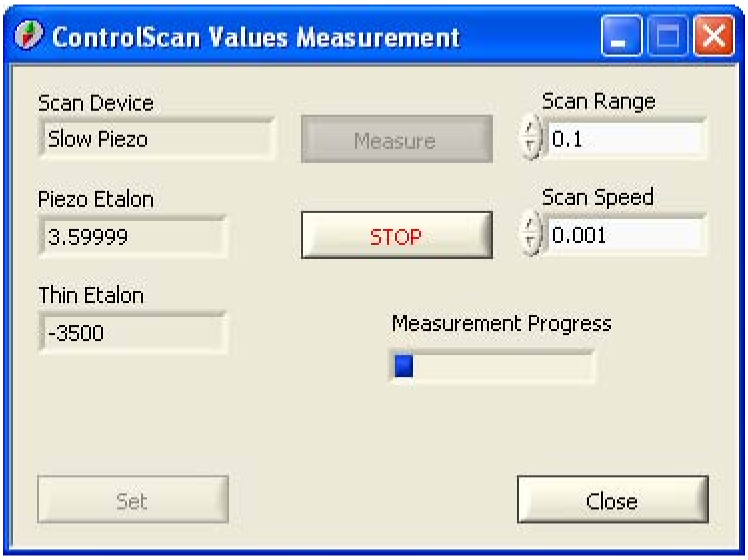


Figure 69: ControlScan Values' Measurement

The ControlScan parameter values (see ***ControlScan Setup*** (see page 109)) for the active **Scan Device** (see ***Scan Device Configuration*** (see page 108)) can be measured by executing a scan over a range of **Scan Range** with a speed of **Scan Speed** while calculating the position change for the Thin Etalon, Thick Piezo Etalon and in the case of a Matisse TS/DS or higher the Slow Piezo as well at the start and end. During the scan all ControlScan parameters are set to zero.

Before executing the scan position the scan piezo at 0.3, set the PZETL baseline to 0 and optimize the BiFi and the Thin Etalon positions. For a Matisse TS/DS or higher also set the Slow Piezo to 0.35 and lock the laser. Set **Scan Range** to 0.1 and **Scan Speed** to 0.001 and press the **Measure** button to start the scan. All control loops have to be active, otherwise the function will abort and give a corresponding warning. The scan may take several minutes to complete. It can be aborted with the **Stop** button.

After completion the ControlScan values for the various optical elements are calculated. Pressing **Set** will set these values for the active configuration. To make the change permanent you have to save the active configuration (see ***Device Configuration*** (see page 69)).

Motor Control

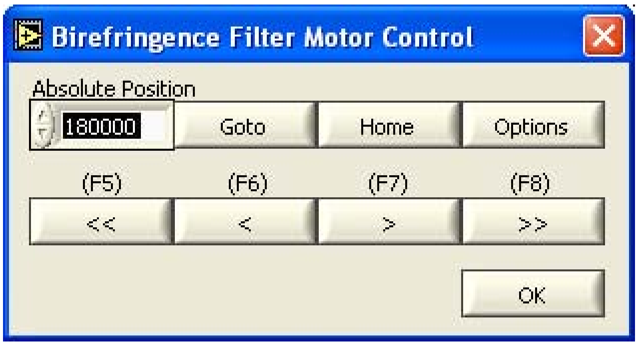


Figure 70: Motor Control dialog

The motors for the Thin Etalon and the Birefringent Filter can be controlled directly. You can move a motor to an **Absolute Position** by pressing **Goto**. Keys F5 to F8 (Big Increment down, Small Increment down, Small Increment up, Big Increment up) will change the motor position relative to the current one. The increments can be set in the ***Motor Control Options dialog*** (see page 111) (press the **Options** button). The **Home** button will set the motor to its home (zero) position (defined by a hardware switch)

Motor Control Options

Figure 71: Motor Control Options dialog

Big Increment and **Small Increment** sets the steps a motor will be moved relative to its current position in the ***Motor Control dialog*** (see page 111).

Wavemeter

(only available with ***Wavemeter Support*** (see page 67))

If the **Use Wavemeter** menu entry is ticked, the **Current Position** display in the main Matisse Commander window will show the wavemeter readout.

Scan Device Calibration with Wavemeter

(only available with ***Wavemeter Support*** (see page 67))

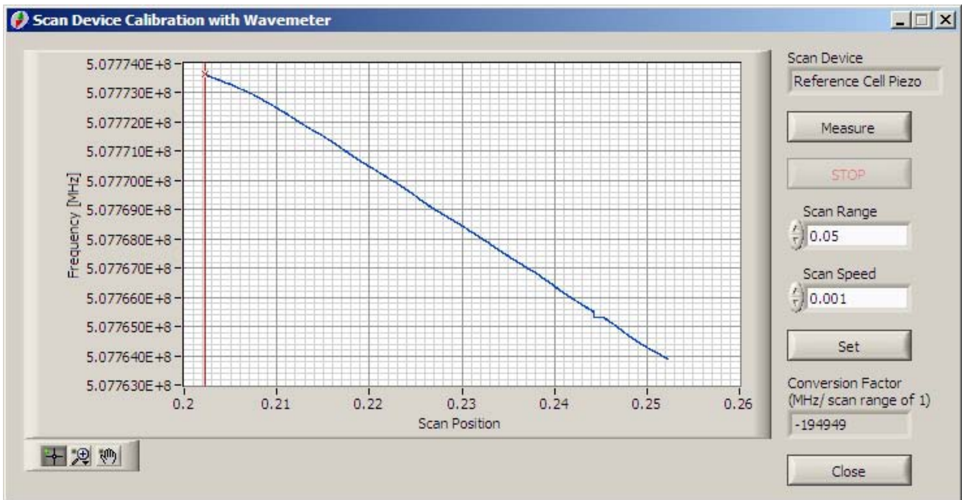


Figure 72: Scan Device Calibration with Wavemeter

Measure will perform a scan with a range of **Scan Range** and a speed of **Scan Speed** with the current **Scan Device** (either RefCell or Slow Piezo), while measuring the laser frequency over the current scan position. After completion of the scan, the **Conversion Factor (MHz / scan range of 1)** can be calculated. **Set** stores the conversion factor into the Matisse Commander's configuration file to be used by the ***Scan Setup dialog*** (see page 106).

For the scan to be successful the positions of the Thick and Thin Etalon have to be optimized and the corresponding control loops have to be active beforehand.

About

Figure 73: About dialog

The About dialog displays **System Information** like the **Model Name** and the **Serial Number(S/N)** of your Matisse Device as well as the **DSP** and **Firmware** version of the hardware controller. This information is important in case of a support request.

The clickable www-link www.sirah.com will open the Sirah homepage in the default web browser on your computer, where you can find news about and updates for the Matisse laser systems and accompanying software

CHAPTER 8

Maintenance

Handling of Optical Components

The good condition of all optical components (mirrors, beam splitters, etc.) is an essential requirement for optimal performance of your *Matisse* laser. Hence you should routinely check and clean all its optical components.

Avoid to touch optical elements with your fingers. The fat persistent at the fingers collects on the surfaces of the optical elements from which it can hardly be removed. In particular, visually non perceptible layers may remain that considerably increase the losses in your laser cavity, thus reducing the laser output power or destroying the surface itself.

The first condition to keep the optics clean, and make your laser work at highest power, is to always keep your laser under a permanently operating flow box. Additionally, from time to time you should wipe the optical surfaces with a soft, clean Q-tip. Only apply very gentle pressure, in order not to scratch the surface with the dry cotton. The advantage of dry cleaning is to avoid smears from residual cleaning liquids on the optics, but once again dry cleaning supposes only very gentle pressure!

In the case of important dust on the optics you may clean them by using isopropanol spectranalyzed (or equivalent) grade (e.g. spetranal) and lens cleaning paper (e.g. Kodak lens cleaning paper). In this case, if ever possible, you should remove the optics from their mounts in order to have easy and full access to the surface. A part of the lens cleaning paper is wetted with isopropanol and wiped over its surface with low pressure. In the ideal case it is sufficient to draw the wetted paper over the surface. In this case the cleaning effect is caused by adhesion. Be careful when cleaning half wave plates. They are relatively thin and tend to break if too strong pressure is applied. The best solution is to remove dust by applying a gentle flow of clean air or nitrogen, rather than wiping the surface of these plates.

Of course you should clean the optics of your laser system only when not operated. That means no pump laser beams should be applied to the *Matisse*, and the entire system should be protected against unintended application of the pump laser. In case you are removing optics for cleaning, please remove them one by one, and switch on and re-optimize the laser between two successive optics removals. In that way switching on the laser again, and keeping its full output power, is relatively straight forward. Do not forget to completely block the pump beam before removal of each *Matisse* optics.

If you observe a significantly increased level of scattered light in your laser that cannot be reduced by thorough cleaning, check your laser optics for defects. In case of damages caused by wrong adjustment of your laser optics you should make sure to correct the alignment to avoid further damaging right before changing the defect optical elements.

Mirror Exchange

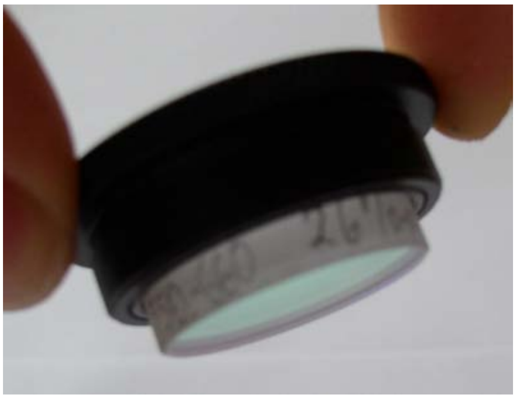
The Matisse has been designed with the aim to keep mirror exchange as simple as possible.

Depending on the specific configuration as dye or Titanium:Sapphire laser, five mirror sets, which include the mirrors TM, and M 1 through M 3, are sufficient to cover the entire wavelength spectrum (see the *Laser Description* chapter). Some effort has been undertaken, so that the complete mirror change is possible in less than 30 minutes. The focusing mirrors, FM 1 and FM 2, are supplied with broadband coatings, covering the entire tuning range of either the dye or the Titanium:Sapphire laser. Therefore, changing the focusing mirrors is only necessary when changing from dye to Ti:Sa set-up, or from Ti:Sa to dye.

When changing from one mirror set to another the most simple procedure is to set the laser to a wavelength where the two mirror sets overlap. Then, operate the *Matisse* laser with medium pump power, in order to have a stable output beam. One by one unscrew all four mirrors to be changed, and replace the removed mirror with the respective new one, from the new mirror set. After each replaced mirror the *Matisse* should restart lasing immediately, and you should do a rapid optimization by tuning the exchanged mirror in order to come back (or close to) the initial power. ATTENTION: You are working and operation inside a laser. Take great care to use the correct laser safety goggles, and make sure that your work does not represent any danger for anyone else present in the laboratory.

The mirrors TM, M 1, M 2, and M 3 are squeezed in metals rings, which are then screwed in the massive body of the mirror mount. Squeezing the mirrors in the rings by using o-rings allows to unscrew the rings, together with the mirrors, from the mounts without the risk of mirrors dropping on the floor, as shown on the Figure below.

Figure 74: Matisse mirror, squeezed in a metal ring. The mirror will not fall, even when the ring is turned upside down.

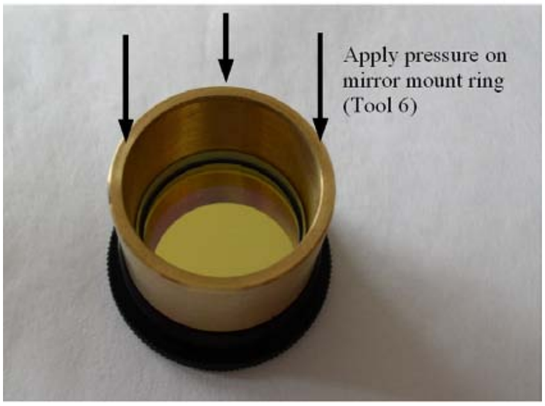


To remove the mirror from the mount just gently pull the mirror with your fingers. Two o-rings are used in the mirror mounts. When mounting the new mirror in the ring, make sure that both of these o-rings are present as shown on the figure below. One thick o-ring covers the bottom of the mirror's metal ring. Another thinner o-ring is used for squeezing. This one needs to be wrapped around the mirror as shown in the figure.

Figure 75: Matisse mirror and mirror mount ring with the two o-rings in place.

Then, place the mirror on the ring, and squeezed it in the ring by using tool 6 (see figure below).

Figure 76: Use mirror mount ring to press the mirror in the metal ring.



CHAPTER 9

Matisse Installation

The first installation of your *Matisse* is done by a *Sirah* or other qualified service engineers. This includes the mechanical set-up as well as the adjustment of the pump optics and the *Matisse* laser beam path. Therefore the installation procedure described in the present chapter is not intended for your everyday work with the *Matisse*, but for those users who have to move their laser to another location and to re-install it afterwards, e.g. in another laboratory.

Your *Matisse* is mounted in an extremely stable housing, and transport does not cause any major problem. Installation is also quite simple, if the transport has been well prepared. So please do not touch your system before having read the present chapter completely.

Installation Requirements

The installation of the *Matisse* laser requires an area of about 1050 mm x 360 mm. The laser needs to be mounted on a vibrational isolated optical table, together with the corresponding pump laser.

The *Matisse* housing is equipped with legs designed for vibrational isolation, allowing to set the height of the entrance for the pump laser beam to a value between 140 .. 155 mm for the Ti:Sa model, and to a value between 145 .. 155 mm for the Dye model. In a first step you have to set your pump laser in such a way, that its beam runs in a height within these limits, and parallel to the plane on which the *Matisse* is to be mounted. Advantageously you perform this setting before mounting the *Matisse*.

Matisse models TS and TX are equiped with a reference cell. This cell requires additional space of about 450 mm x 360 mm.

Transport

The main condition to keep installation after transport easy is to start with a running system. Before moving the system, you should operate your laser at the wavelength of maximum power output of the current configuration. This wavelength and the obtained power will be mainly defined by the mirror set and dye / crystal your are using. Optimize the system for that wavelength, and take notes about pump power, *Matisse* wavelength, and obtained *Matisse* power. After moving the system, you should re-install the laser for with the same configuration, before eventually changing the wavelength or the pump power.

During transport your laser is exposed to unavoidable vibrations which might cause damages to the laser system if no adequate precautions are taken. One precaution is to install transport safeties for the four linear translations and for the Birefringent Filter lever inside the Matisse laser.

Do not forget to remove the transport safeties, when reinstalling the laser!

Optical Alignment Procedures

Optical Alignment Procedure: Matisse Ti:Sa

This section gives a procedure how to align the various optical components of the *Matisse* Ti:Sa laser to achieve lasing. The optical components are described in the ***Matisse Ti:Sa Optical Setup section*** (see page 16).

1 The pump radiation has to be p-polarized. Your laser might have a half-wave-plate installed in the entrance opening for rotation of the polarization. Step 6 below describes how to adjust the half-wave-plate.

2 The distance between pump laser and Matisse laser should not be too big (about 10 to 30 cm). You might find a beam tube (grey plastic tube) in your laser service box that should be installed between pump and Matisse laser to minimize perturbations caused by air flows.

3 Position the Matisse on your optical table, so that the pump beam will pass through the center of the entrance opening. Align the long side of the laser base plate, so that it is parallel to the pump beam direction. The pump beam will hit the first pump mirror (PM1) rather on its edge that in its center!

4 For Matisse operation, the pump beam path as well as the ring cavity beam path have to run at a height of 60 mm above the baseplate. This height is marked by the center of the beam overlap tool (see Fig. 73 below) if it is placed on the baseplate.

To determine whether the Matisse height is set correctly, set your pump laser to the lowest possible output level. Right after the Matisse pump beam input, further attenuate the beam to avoid damage to the beam overlap tool. This may be done using the mount from the color filter (see figure below) and mounting one of the spare neutral density filters from the service box instead. Put the beam overlap tool into the attenuated beam and check whether it has got the correct height.

If the Matisse height needs to be adapted, loosen the counter-nuts on the Matisse feet (wrench size 17 mm) and the adjust the height by turning the nuts near the bottom of the feet (wrench size 10 mm). One revolution corresponds to 2 mm of vertical movement. Make sure you turn each of the nuts by the same amount to avoid instabilities and tilting of the Matisse housing. Finally, gently tighten the counter-nuts (without holding the nuts at the bottom of the feet).

5 In the service box you will find two pin-holes that can be set on the two half-inch mirrors directly located at the Ti:Sa crystal (FM1 and FM2). Set the pin-holes on the mirror side facing the crystal. Adjust the pump beam with the help of the pair of pump mirrors (PM1 and PM2), so that it passes through the centers of the two pin-holes.

Figure 77: Pin Holes

6 Make sure that the pump beam has got the correct polarization (p-polarized). Loosen the plastic screw at the half-wave-plate on the Matisse input and rotate it so that the power of the pump beam reflex from the Ti:Sa crystal (on the little beam blocking sheet) is minimized.

7 In the service box you will find a mounted green filter (red glass plate). Put it into the laser between the crystal mount and the second folding mirror (FM2), so that residual pump beam radiation circulating through the resonator is filtered out. Align it perpendicularly so that the back reflected green spot hits the pinhole center on FM2.

Figure 78: Color Filter

8 Increase pump power to about 1 W. An IR viewer will help you in observing the fluorescence spots. Note that the spots may not have the same size at different positions within the ring cavity. Place the beam overlap tool between the output coupler (M1) and the Brewster window at the output. Make sure that the fluorescence spot (originating from FM1) has got the correct height. To adjust the height, slightly adjust the height of the beam path through the two pinholes using PM1 and PM2.

9 Place the beam overlap tool between the Piezo Etalon (Thick E) and the TGG plate (TGG). Adjust the beam height with the vertical adjustment of the tuning mirror mount (TM). Remove the beam overlap tool and, using a small strip of paper, make sure that the beam passes through the TGG plate and hits the middle of M3. This is especially important for the actively stabilized Matisse versions because there M3 is rather small.

Figure 79: Beam Overlap Tool

10 Superimpose the propagation paths of the two fluorescence spots: the beam path from FM1 to the output coupler (M1) serves as the "fixed" path to which the beam from FM2 will be aligned using M1 and M3. Put the beam overlap tool between the Birefringent Filter (BiFi) and the output coupler (M1). Bring the spot from FM2 closer to the "fixed" spot using only M3. Then, put the beam overlap tool between FM1 and the Thin Etalon mount (Thin E). Overlap the spot from FM2 with the "fixed" spot using only M1. Put the beam overlap tool back to the first position between BiFi and M1 and repeat the procedure. To distinguish between the two spots as they get closer, alternately block one of the beams while watching the overlap tool. After some iterations a precise overlap of the two spots at both positions can be achieved. Do a check by putting the beam overlap tool between FM2 and the Piezo Etalon (Thick E). If the adjustment is good, the two spots will also be superimposed here.

11 Remove the color filter and the two pin-holes. Make sure that there is no obvious dust on the optics where the pump light is inciding or going through. If there is dust, refer to chapter 8 ('Handling of Optical Components') for cleaning. Increase the pump power to at least 5 W.

12 If the laser is not already lasing, observe the fluorescence shapes in the laser output. Carefully pull at the mirror knobs at the laser output side (M1 and M3) to see if there is a short 'laser flash', and adjust the respective mirrors to reach lasing.

Optical Alignment Procedure: Matisse Dye

This section gives a procedure how to align the various optical components of the Matisse Dye laser to achieve lasing. The optical components are described in the ***Matisse Dye Optical Setup*** (see page 19) section.

1 The pump radiation has to be p-polarized. Your laser might have a half-wave-plate installed in the entrance opening for rotation of the polarization. Step 6 below describes how to adjust the half-wave-plate.

2 The distance between pump laser and Matisse laser should not be too big (about 10 to 30 cm). You might find a beam tube (grey plastic tube) in your laser service box that should be installed between pump and Matisse laser to minimize perturbations caused by air flows.

3 Position the Matisse on your optical table, so that the pump beam passes through the entrance opening and runs parallel to the Matisse housing. The focusing pump mirror (PM) needs to be hit exactly in the middle. Its distance should be about 40 mm from the pump spot in the dye jet. The transmitted pump light should hit the beam dump next to the folding mirror (FM 1). With these conditions fulfilled, the beam may not pass exactly through the middle of the entrance opening.

   If the height of the beam on PM is not right, you may need to adapt the Matisse height: loosen the counter-nuts on the Matisse feet (wrench size 17 mm) and the adjust the height by turning the nuts near the bottom of the feet (wrench size 10 mm). One revolution corresponds to 2 mm of vertical movement. Make sure you turn each of the nuts by the same amount to avoid instabilities and tilting of the Matisse housing. Finally, gently tighten the counter-nuts (without holding the nuts at the bottom of the feet).

4 For Matisse operation, the pump beam path as well as the ring cavity beam path have to run at a height of 60 mm above the baseplate. This height is marked by the center of the beam overlap tool (see figure above) if it is placed on the baseplate.

5 Set the distance between the two folding mirrors (FM 1 and FM 2) to about 113-115 mm. The distance between the pump spot in the dye jet and FM 1 should be about 50-52 mm and the distance between the pump spot and FM 2 should be about 62-64 mm. In the service box you will find two pin-holes that can be set on FM1 and FM2. Put the pin-holes on the mirror side facing the dye jet. Set the pump laser to the lowest possible output and put the beam overlap tool between FM1 and the dye drain mount. Adjust the height of the transmitted pump beam using the vertical adjustment of PM, so that the center of the spot is in the middle of the beam overlap tool.

6 Make sure that the pump beam has got the correct polarization (p-polarized). Loosen the plastic screw at the half-wave-plate on the Matisse input and rotate it so that the power of the pump beam reflex off the dye jet (visible on the little beam blocking sheet on the dye nozzle mount) is minimized.

7 The nozzle' height should be adjusted so that the pump spot is about 3 to 5 mm underneath the nozzle. Adjust the nozzle's horizontal position so that the dye jet enters the drain tube at reasonable distances from the tube edges to avoid turbulences in the drain.

8 Increase the pump power to max. 1 W. Locate the two fluorescence spots - one going from FM1 to the output coupler (M1) and one going from FM2 to the beam displacement rhomb (PS). Make sure that their height is 60 mm by putting the beam overlap tool between PS and the tuning mirror (TM) and then between M1 and the output opening. If the height is not right, correct it using the vertical adjustment of PM. If you notice clipping of the spots at the rhomb or at the Birefringent Filter (BiFi), correct it using the horizontal adjustment of PM.

9 Put the beam overlap tool between TM and the Thin Etalon mount (Thin E) and check the beam height. Correct it using the vertical adjustment of TM. Remove the beam overlap tool and, using a small strip of paper, make sure that the beam passes through the TGG plate and hits the middle of M3. This is especially important for the actively stabilized Matisse versions because there M3 is rather small.

10 Superimpose the propagation paths of the two fluorescence spots: the beam path originating from FM2 and going from the tuning mirror (TM) to M3 serves as the "fixed" path to which the beam from FM1 will be aligned using M1 and M3. Put the beam overlap tool between the TGG plate (TGG) and the Thick Piezo Etalon (Thick E). Bring the spot from FM1 closer to the "fixed" spot using only M1. Then, put the beam overlap tool between TM and the Thin Etalon mount (Thin E). Overlap the spot from FM1 with the "fixed" spot using only M3. Put the beam overlap tool back to the first position between TGG and Thick E and repeat the procedure. To distinguish between the two spots as they get closer, alternately block one of the beams while watching the overlap tool. After some iterations a precise overlap of the two spots at both positions can be achieved. Do a check by putting the beam overlap tool between the beam displacement rhombus (PS) and FM1. If the adjustment is good, the two spots will also be superimposed here.

11 Remove the two pin-holes. Make sure that there is no obvious dust on PM. If there is any dust, refer to the chapter 'Handling of Optical Components' for cleaning. Then, increase the pump power to at least 5 W.

12 If the laser is not already lasing, observe the fluorescence shapes in the laser output. Carefully pull at the mirror knobs at the laser output side (M1 and M3) to see if there is a short 'laser flash', and adjust the respective mirrors to reach lasing.

Optical Alignment Procedure for the Matisse S Reference Cell

The schematical setup of the confocal reference cell and beam paths are shown in the figure below. For a basic adjustment of the reference cell you should first make sure that the Matisse laser beam passes approximately through the center of the entrance opening, beam splitter BS and the exit opening.

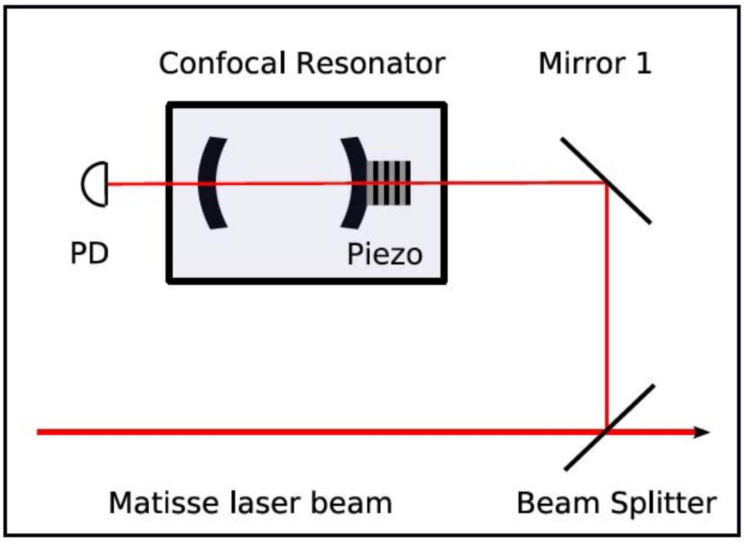


Figure 80: RefCell S Scheme

Align the partial beam from BS with the help of mirrors BS and M1 (Mirror 1) in that way that it will pass approximately through the center of the reference cavity. Keep in mind, that you have actually two partial beams: one from the front side of BS and one from the back side. Block the back side beam and use only the front side beam for the following procedure:

- Place a screen (e.g. a business card) behind the reference cavity. Use an infra-red viewer to look at the screen. You should see one or several laser spots. Try to concentrate these spots into one by adjusting mirrors BS and M1.

- If you have not already done so, switch on the Matisse electronics box. Start the 'Matisse Commander' program and choose 'Ref Cell Waveform' from the 'Ref Cell Stabilization' menu. Adjust the position of the reference cell detector diode so that you have maximum signal for the waveform. The detector is screwed on an L-mount; loosening the screw allows you to adjust the detector's vertical position. The L-mount in turn is screwed on the reference cell's base plate; loosening this screw allows you to adjust the horizontal position. If you have trouble getting a signal at all, remove the neutral glass filters in front of the diode. Keep in mind that without the filters the detector will be probably saturated resulting in a 'flat line'-waveform with high intensity. (Annotation: The waveform graph in the 'Ref Cell Waveform' dialog is autoscaling the signal (Y) axis by default. You can change this behavior by deactivating the 'Autoscale Y-Axis' control. Click then on the maximum and minimum values for the y-axis and directly type in new values.)

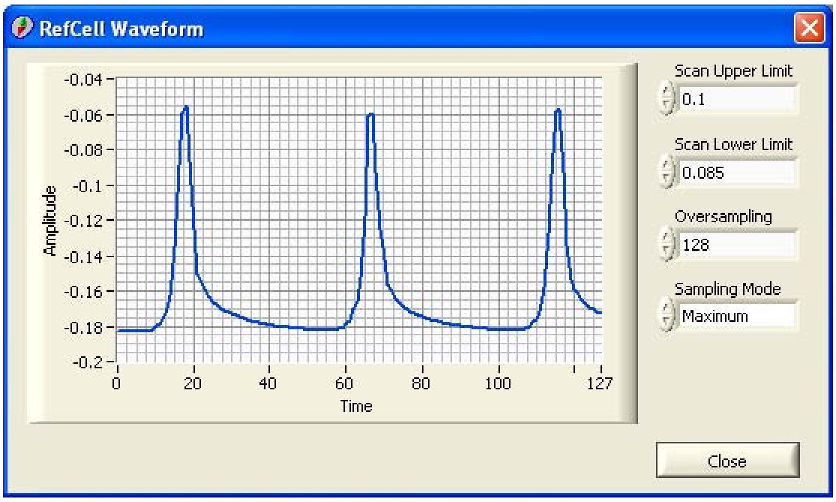


Figure 81: RefCell Waveform display

- You may further adjust the laser beam to optimize the spectral output of the reference cavity. You can achieve a situation where every other transmission peak will have a strongly reduced peak value. In this case the Gaussian laser mode is matched to the Gaussian reference resonator mode, so that no higher order modes are excited. This situation is highly sensitive to deadjustment and may be difficult to find. It is not necessary to reach this situation to obtain optimal laser locking to the reference cell!
- Choose a set of neutral glass filters, so that you have a good signal-to-noise ratio for the waveform but are still below the saturation threshold.

CHAPTER 10

Matisse Electronics

DSP Input Charcteristics

The external input of the DSP has the following electrical characteristics:

Parameter	**Value**
Connector Type	SMA jack connector (MIL-C-39012)
Voltage Range	-5.0 .. +5.0 Volts
Input Impedance	3.4 kΩ

Piezo Amplifier Board Input Characteristics

The external input of the Piezo Amplifier Boards for the Scan Device or the Thick Piezo Etalon has the following electrical characteristics:

Parameter	**Value**
Connector Type	SMA jack connector (MIL-C-39012)
Voltage Range	0.0 .. +3.0 Volts
Input Impedance	> 1 MΩ

Fast Piezo Amplifier Board Input Characteristics

The external input of the Piezo Amplifier Board for the Fast Piezo has the following electrical characteristics:

Parameter	**Value**
Connector Type	SMA jack connector (MIL-C-39012)
Voltage Range	0.0 .. +4.0 Volts
Input Impedance	> 1 MΩ

CHAPTER 11

Frequently Asked Questions and Troubleshooting

I cannot get the expected or usual power output from the laser!

- apply the procedures given in the ***Power Optimization*** (see page 51) section.
- check the laser optics for damages or dust particles. Observe the information given in the ***Maintenance chapter*** (see page 114).
- check, if the clockwise running mode of the ring resonator is exited (see question below)
- check, if the laser beam shows spatial instabilities (see question below)

I experience strong power fluctuations / a big drop in power output (more than 30%) and I can see a second laser spot in the laser on its housing about 4 cm right to the normal laser beam exit!

In this case the clockwise running mode of the ring resonator is exited. This can happen, if the two surfaces forming the Piezo Etalon are adjusted perpendicularly to the laser beam, so that reflected parts of the beam fully interact with the laser gain medium. This may lead to complex intensity and polarization dynamics of the laser, making the optical diode inoperable. Therefore the orientation of the Piezo Etalon relative to the laser beam can be adjusted. For this purpose there are two screws (with black knobs) on the opposite side of the two (silver-colored) micrometer screws of the Piezo Etalon. Observe the 'wrong' laser spot on the laser housing and turn the screws to get rid of it. Instead of the laser spot you will see two fluorescence spots, which relative horizontal and vertical position to each other will change with turns of the corresponding screws.

There is normally a trade-off situation for the adjustment of the Piezo Etalon orientation: the closer the etalon gets to the perpendicular case, the higher is the laser output power. If it is too close, the output (for the counter-clockwise running mode) will sharply drop.

As a rule of thumb introduce a vertical separation of the fluorescence spots by 5 to 10 mm.

I experience spatial instabilities / spatial mode fluctuations of the laser beam!

A laser pumped with higher pump powers might show spatial mode instabilities, if not adjusted well enough or because of saturation effects in the lasing medium, causing decreased power and making single-mode operation difficult. You can easily check the laser mode 'quality', by looking at the laser spot of the transmitted light of one of the laser cavity folding mirrors.

Ti:Sa Matisse

Look at the spot coming from mirror FM 1 and going through mirror PM2 (***Optical Setup Ti:Sa*** (see page 16)) on the inner laser housing about 7 cm left to the pump beam entrance. The laser spot is horizontally elongated because of the oblique angle, under which it hits the housing. When you use an infra-red viewer, pay attention to look at the Matisse laser spot and not at the pump laser spot, that will be close-by.

Dye Matisse

Look at the spot coming from mirror FM 1 hitting the laser housing between pump beam entrance and TM mirror mount (***Optical Setup Dye*** (see page 19)).

Complex pattern or pattern dynamics in the central spot are the result of these instabilities. Some dynamics on the spot fringes does not play any role

Getting a better laser mode, may require changing the distances between folding mirrors FM 1 and FM 2 and the gain medium with the help of the translation stages. For the Matisse Dye changing the distance between pump mirror PM and the dye jet can also help.

Before you start using the translation stages, make sure the knobs of the corresponding lead screws have marks, so that you can clearly identify the amount of change you introduce. If there is no clearly visible mark, make one with, e.g., a felt-tip pen.

Note down the turns and their directions, so that you can easily get back to original positions, if necessary!

One full (360°) turn of a knob will change the distance by an amount of 0.25 mm. Turning knobs clockwise will decrease the corresponding distances mentioned above, turning counter-clockwise will increase them.

Ti:Sa Matisse

Decreasing the mirror distances will increase the laser mode volume and so mitigating saturation effects in the Ti:Sa crystal.

Start using the translation stage for mirror FM 2. Decrease the distances in steps of one full knob turn. At each step, compensate the changes of the beam path in the resonator by using mirror TM. Observe the mode pattern on the laser housing, to see, if it is improves. Do not make more than 4 to 6 steps. When you find a good position, you can use FM 1 and FM 2 in parallel (decrease FM 1 and increase FM 2 by the same amount) to shift the position of the beam waist in the crystal to further improve the mode quality. Changes of the beam path introduced by a position change of FM 1 are compensated with mirror M1.

Dye Matisse

Changing the pump focus position can mitigate saturation effects in the dye jet.

Increase the distance between PM and dye jet by turning the translation stage knob of the pump mirror in steps of 1/8 turns. Compensate for pump beam path changes with two adjustements screws of the pump mirror. Observe the mode pattern on the laser housing, to see, if it is improves. With increasing distance you will probably experience decreasing power.

If the pump mirror position change does not porduces the desired results, start changing mirrors FM 1 and FM 2 as described for the Matisse Ti:Sa case. Instead of changing the position of one full turn per step, use one half turn per step.

CHAPTER 12

Customer Service

Sirah lasers are thoroughly designed and assembled, and we take great pride in the reliability of our instruments. Nevertheless, each precision instrument will need occasional service. Therefore, our aim is not only to provide high performance scientific instruments, but also to offer an excellent after-sales service.

In case of any problem, please feel free to contact your local service centre. Addresses may be found at the end of the present chapter. You will need your instrument model and serial numbers available when you call. Service data will be promptly supplied.

Warranty

Warranty conditions are defined in our *General Sales Conditions*. They may be modified by agreements made in your specific sales order. In case of any conflict between documents, the terms and conditions of the sales order shall prevail.

Sirah warrants that the products except optics shall be free from defects in materials and workmanship under normal use and service for a period of twelve (12) months from the date of installation or from 30 days after shipment from *Sirah*. Optics and filters are warranted for 90 days. This warranty is subject to *Sirah* products being installed, maintained, and operated in accordance with the operating and maintenance instructions accompanying the shipment.

Warranty shall be void if *Sirah* products are modified by the customer or used in other than the recommended manner or applications. In no case shall *Sirah* be liable for consequential or special damages.

Material under warranty will be repaired or replaced (FOB our shipping point) by *Sirah*. *Sirah* will provide an on-site field service representative in a reasonable amount of time, provided the customer issues a valid purchase order to *Sirah* covering all transportation and subsistence costs.

For warranty field repairs, the customer will not be charged for the cost of labour and material. Material not under warranty may be returned to *Sirah* for repair or replacement. *Sirah* will advise you of the cost and delivery time to repair the equipment, before beginning work on it.

Return of the Instrument for Repair

Before any return of instrument, please contact your local *Sirah* service or sales centre for shipping instructions or an on-site service appointment. You are responsible for the one-way shipment of the defective instrument to the *Sirah* service centre.

Always use the original packing boxes for shipment. If shipping boxes have been destroyed or lost we recommend you to order new ones. We will return instruments only in *Sirah* transport boxes.

Service Centres

- *Central Europe*

Spectra-Physics Europe

Guerickeweg 7

D - 64291 Darmstadt

Telephone: +49 - (0)6151 - 708 - 0

- 251 (Dutch spoken)

- 257 (French spoken)

Fax: +49 - (0)6151 - 708 - 217

- *Europe and Middle Eastern Countries*

Spectra-Physics

Guerickeweg 7

D - 64291 Darmstadt

Telephone: +49 - (0)6151 - 708 - 219

Fax: +49 - (0)6151 - 708 - 217

- *Germany*

Sirah Laser- und Plasmatechnik GmbH

Ludwig-Erhard-Str. 10

D - 41564 Kaarst

Telephone: +49 - (0)2131 - 66.06.51

Fax: +49 - (0)2131 - 66.80.95

E-mail: info@sirah.com

Internet: www.sirah.com

➢ *Japan (East)*

Spectra-Physics KK

East Regional Office

Daiwa-Nakameguro Building

4-6-1 Nakameguro

Meguro-ku, Tokyo 153

Telephone:	+81 - 3 - 3794 - 5511
Fax:	+81 - 3 - 3794 - 5510

➢ *Japan (West)*

Spectra-Physics KK

West Regional Office

Cycnas Building

2-19 Uchihirano-Cho

Chuo-ku, Osaka

Telephone:	+81 - 3 - 6941 - 7331
Fax	+81 - 3 - 6941 - 2700

➢ *United States and Export Countries*

Spectra-Physics Lasers

1330 Terra Bella Avenue

Mountain View, CA 94043

Telephone:	+1 - (800) - 456 - 2552 (Service)
	+1 - (800) - 775 - 5273 (Sales)
Fax:	+1 - (650) - 964 - 3584
E-mail:	service@splasers.com
	sales@splasers.com
Internet:	www.spectra-physics.com

Problems and Solutions

This form should encourage you to tell us about difficulties you have experienced when using your Sirah instruments or this manual - problems that did not require a formal call or letter, but which you should feel free to communicate. We are always interested in improving our products and manuals, and we appreciate your suggestions. Thank you.

- *From*

Name:

University / Company:

Institute / Department:

Address:

- *Instrument*

Type:

Serial Number:

Date of installation:

- *Problem*

Please give as much details as possible:

Mail to:	Sirah Laser- und Plasmatechnik GmbH; Ludwig-Erhard-Str.10 10; D - 41564 Kaarst; Germany
Email to:	info@sirah.com
Or fax to:	Sirah Laser- und Plasmatechnik GmbH; Fax: +49 - 2131 - 66 80 95

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