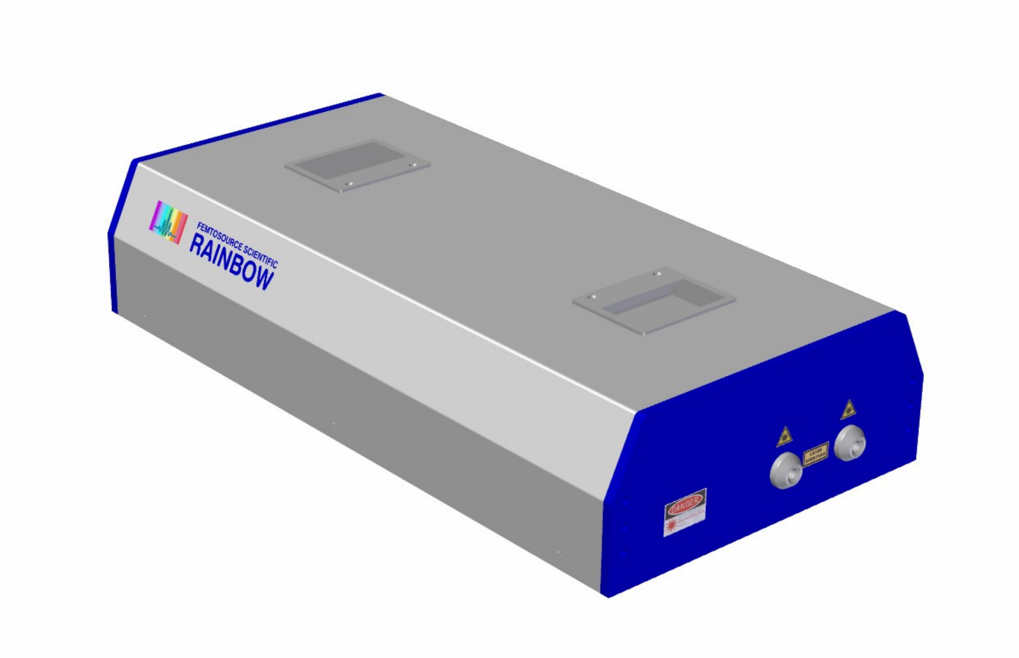
User's manual for

Mirror-dispersion-controlled Ti:Sapphire Oscillator

FEMTOSOURCE

Rainbow HP CEP



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Chapter 1: Laser Safety

The following is a partial list of precautions to follow when operating or using the FEMTOSOURCE Rainbow. This list is not intended to and can by no means replace a comprehensive laser training course.

The oscillators and amplifiers from FEMTOLASERS and their pump lasers are Class IV - High Power Lasers. The dangers associated with the light they generate must be taken very seriously. Take precautions to prevent accidental exposure to both direct and reflected beams. A split second exposure to even a small portion of a reflected laser beam is sufficient to cause permanent loss of vision. The safe use of the lasers requires that all laser users, and everyone near the laser system, are aware of the dangers involved.

Safety goggles: protective goggles must be worn every time. The selection depends on the wavelength (600-1100nm) and the intensity of radiation, the conditions of use, and the visual function required.

Output beam: never look directly into the laser light source or at scattered laser light from any reflective surface. Avoid direct exposure to the laser light in any case. The intensity of the beam can easily cause flesh burns or ignite clothing.

Warning signs: post prominent warning signs and lamps in the area of the laser beam.

Safety area: operate the laser in a room with controlled and restricted access. Limit the access to those trained in the principles of laser safety.

Maintain a high ambient light level in the laser operating area.

Be careful setting up your experiments:

Use protective enclosures for all portions of the beam where access is not necessary.

Set up beam dump(s) to capture the laser beam(s).

Set up shields to prevent unnecessary specular reflections.

Avoid direct exposure to the laser light. The laser beam is powerful enough to burn skin or clothing.

Shutter: close the shutter when leaving the laser area. Also block the beam when placing new components in the beam path.
Accidental reflections: watches must be taken off before any alignment. The same holds for other clothing or jewelry that could deflect a beam to eye level.
Exercise extreme caution when using reflecting tools (such as screwdrivers, rulers, a.s.o.) in vicinity of the beam.
Beam height: use a set up where the laser beam is either above or below the eye level.
Enclosures: provide enclosures for the beam paths whenever possible.
Shields: set up shields to prevent any unnecessary reflections.
Information: advise all those using the oscillator of these precautions.
Use of controls or adjustments or performance of procedures other than those specified in the manual may result in hazardous radiation exposure. Use of the system in a manner other than that described herein may impair the protection provided by the system.

Follow the instructions contained in this manual to ensure proper installation and safe operation of your laser.

1.1 Compliance to Government Regulations

The FEMTOSOURCE Rainbow is a part of a laser system according to the definition of Title 21 of the United States Code of Federal Regulations, Chapter 1, Subchapter J, Part 1040.10(b)(23).

The FEMTOSOURCE Rainbow complies with Title 21 of the United States Code of Federal Regulations, Chapter 1, Subchapter J, Parts 1040.10 and 1040.11 as applicable.
The FEMTOSOURCE Rainbow is to be used in combination with one laser energy source (pump laser):
The pump laser must be in compliance with United States Government regulations contained in 21 CFR, Subchapter J, Part II, administered by the Center of Devices and Radiological Health (CDRH)!

Refer to Appendix 2 for a list of recommended pump lasers.

1.2 Laser Classification

The FEMTOSOURCE Rainbow is classified as a Class IV based on 21 CFR, Subchapter J, Part II, Section 1040.10(d).

1.3 Safety Features Incorporated into the Laser

The following safety features are incorporated into the FEMTOSOURCE Rainbow to conform to Title 21 of the United States Code of Federal Regulations, Chapter 1, subchapter J, parts 1040.10 and1040.11, as applicable:

PROTECTIVE HOUSING	**The optical setup is enclosed in a protective housing that prevents human access to radiation in excess of the limits of Class I radiation as specified in 21 CFR, subchapter J, part II, section 1040.10 (f) (1), except for the oscillator output beam.**
REMOTE INTERLOCK CONNECTOR	**A remote interlock connector is provided that can be connected to a door switch or any other external On/Off switch to establish a safe operating area. The laser system can only be turned on when this connection is shorted. The system and its pump laser will immediately shut down when the connection is opened. Restart upon closure of the connection is disabled.**
MASTER KEY CONTROL	**The keyswitch located on the remote control unit is part of the interlock system. If the switch is not in the I-position the system cannot be started. The switch cannot be removed in I-position.**
EMISSION INDICATORS and AUDIBLE WARNING	**Emission indicators, that are illuminated when the beam attenuator is open, are located near the output aperture and on the remote control unit. The**

emission indicator will be blinking and a warning signal will sound for about eight seconds prior to opening of the shutter.

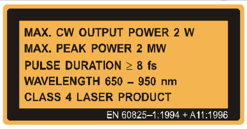
BEAM ATTENUATORS

A beam attenuator (electronic shutter) is provided for the laser output aperture. It prevents emission of laser radiation when closed.

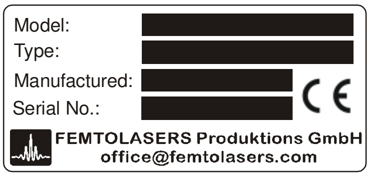
SAFETY INTERLOCKS

The FEMTOSOURCE Rainbow contains two cover safety interlock assemblies located inside the protective housing. Each safety interlock assembly consists of one mechanical interlock switch and one magnetic interlock switch. If one or more of the interlock switches are opened (by removing the cover) the system will immediately shut down. Simply closing the interlock switches will not allow restart of the system. The mechanical interlock switches can be defeated, thus allowing operation of the system with its cover removed. This should be done only by trained technicians aware of the hazards involved. The covers are designed so that they can not be replaced without shutting down the system.

1.4 Safety Labels (original size)



7* Product information label



9* Identification label

2* Warning logotype

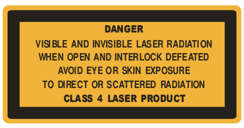
6* Classification label

3* Aperture label

1* Warning triangle

5* Patents label

8* Certification label



4* Defeatable interlocked protective housing label

* Numbers are referring to figure 1.1

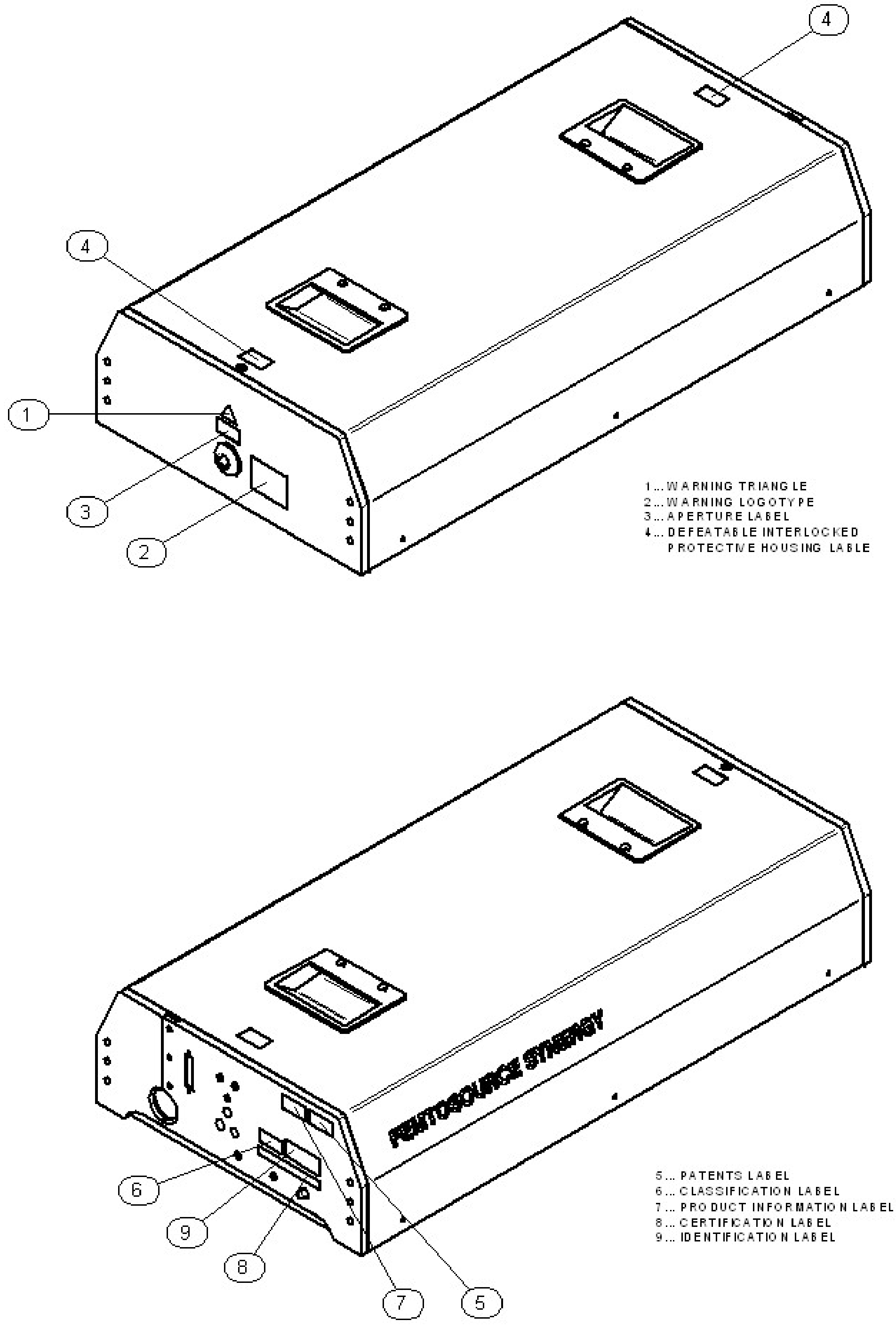
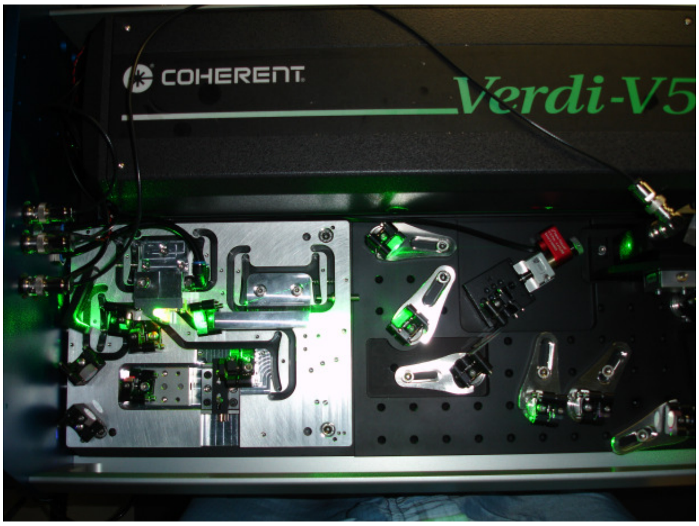


Figure 1.1 Location of labels

Chapter 2. Preface



Chirped multi-layer dielectric mirrors® [1] have revolutionized ultra-short pulse generation at the cutting edge of optical time resolution. The mirror-dispersion-control (MDC) set comprises specifically designed chirped mirrors for broadband intra-cavity group-delay-dispersion (GDD)-control in a Ti:Sapphire oscillator and low-dispersion quarter-wave mirrors for coupling the pump beam into and the mode-locked pulse out of the resonator. The MDC-set in combination with a thin highly-doped Ti:Sapphire crystal, which is mounted in the CLH laser head, offers the potential for the generation of optical pulses with unprecedented quality, stability and reproducibility. This potential can be exploited with a number of mode locking mechanisms, such as saturable absorber mode locking, additive-pulse mode locking or self mode locking. Using the MDC technology, 6-fs optical pulses have recently been generated from a self-mode-locked Ti:Sapphire oscillator [2]. This manual provides guidelines for the installation of a mirror-dispersion-controlled Ti:Sapphire oscillator including locking of the carrier-envelope phase drift.

Laboratory tests prior to delivery yielded highly stable sub-7fs pulse generation by self mode locking the MDC oscillator (see enclosed test results).

® US patent # 5,734,503, other patents pending

Chapter 3. Unpacking and inspection

3.1 Unpacking your oscillator

Your FEMTOSOURCE oscillator was packed with great care, and its container was inspected prior to shipment. It left FEMTOLASERS in good conditions. Upon receiving the system, immediately inspect the outside of the shipping container. If there is any major damage, insist that a representative of the carrier be present when you unpack the contents. If any damage is evident, such as dents or scratches on the covers or broken knobs, immediately notify the carrier and your FEMTOLASERS representative.

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

3.2 System components

The system comprises the following items already mounted in a thermally stabilized housing:

- **A central mechanical unit - the Compact Laser Head (CLH) - which contains the most delicate components such as the highly doped Ti:S crystal, the dichroic dispersive focusing mirrors for the resonator beam, the focusing lens for the pump beam and the end mirror of the short arm on a starting contraption. The CLH laser head will be assembled and aligned prior to delivery which allows you to set up the oscillator within a short time.**
- **Optics and opto-mechanical components for setting up the complete femtosecond oscillator.**
- **A periscope arrangement including steering optics and precision mirror mounts for coupling the pump beam into the oscillator.**
- **Extra-cavity dispersion control with a pair of chirped mirrors.**
- **An acusto-optical modulator for the pump beam (used for phase locking).**
- **A pair of intra-cavity wedges for coarse adjustment of the CE-phase.**
- **The optical setup for accessing the CE-phase.**

Furthermore, the following external system components are necessary for operation of the laser system:

- **Optical assembly (including a lens and a photodetector) for detecting the CE-phase drift (beat signal).**
- **Power supply for the photodetector.**
- **Electronics for generating the feed back signal for locking the CE-phase.**
- **RF driver for the AOM.**
- **A pico-motor driver for adjusting the intra-cavity wedges.**
- **A spectrum analyzer for monitoring the beat signal.**
- **An oscilloscope for monitoring the phase control loop error signal.**

Chapter 4. Installation of CLH-4

4.1. Preparations

1. **Put the whole housing on the optical table to the desired place and fix it with 4 screws.**
2. **Remove 2 stoppers from the water connectors.**
3. **Plug in a cooling tube (FESTO PUN tube with an inner diameter of 4mm/outer diameter 6mm) and connect it to a water cycling.**

Note: The chiller pressure must not exceed 20 psi / 1.35 bar to avoid leakage of the base plate, otherwise warranty will be void.

4. **Put the pumplaser in place (fixed by two pins) and fasten the holding forks.**

4.2. Water cooling

The *water-cooling* removes the heat from the Ti:S crystal. It stabilizes the temperature. Water-temperature should be set between 18 – 20 °C (> ambient dew point and < 25°C) Flow should be kept constant to guarantee a high long term stability of the system. The heat removing assembly is equipped with connections for water cooling which fit to the chiller of the pump source.

4.3. Pump source

Mode of the pump beam

The mode has to be fundamental mode (TEM00) from a DPSS green (532 nm) pump laser. Please refer to the list of qualified pump lasers in the appendix. For optimum mode locked operation the pump power should be in the specified range, and should *never exceed 10 W*.

Polarization of the pump-beam

Usually the output beam of a DPSS laser is vertically polarized (σ-polarization, SP). The CLH requires a horizontally polarized pump-beam (π-polarization, PP). Using the periscope for polarization rotation the polarization can be rotated and also the beam-height can be adjusted.

4.4 Setting up the MDC oscillator

Note: The pump power should never exceed 200mW during the first alignment!

Alignment of the pump-beam into the oscillator

The pump laser position is set at the factory to deliver an output beam parallel to the optical table (input of the polarization rotating periscope PER).The output beam of the periscope has to be aligned parallel to the base plate by rotating the periscope around the vertical axis. After passing the steering mirrors the pump beam again has to be aligned parallel to the base plate and pass through the center of the lens holder at the CLH (see Fig. 1).

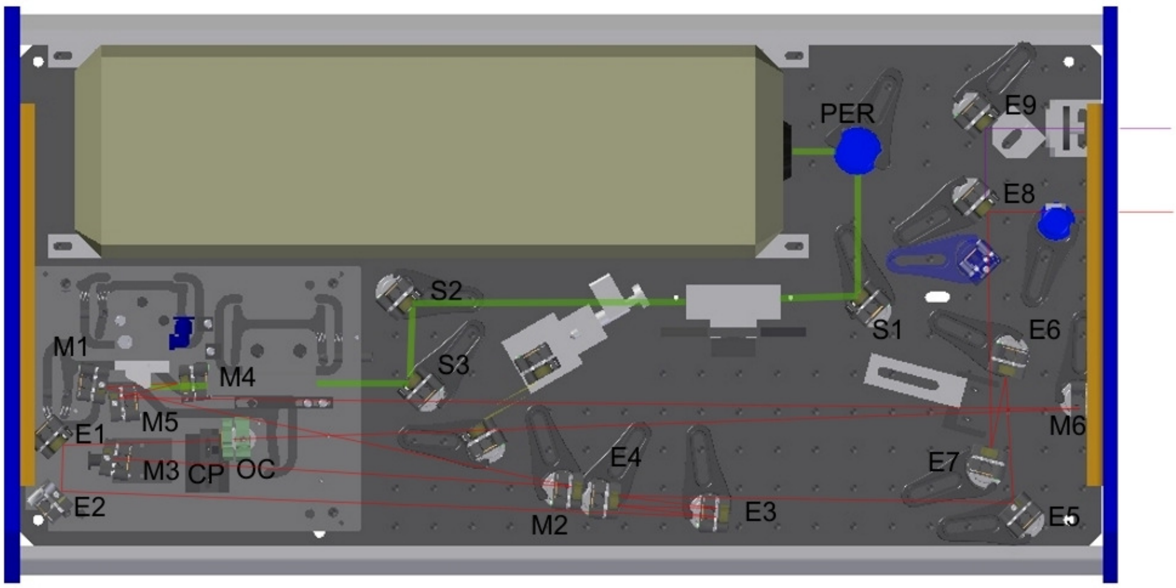


Fig. 1 Aligning the pump beam through the lens holder

The alignment can be done with the pump beam steering mirrors. The transmitted pump-beam on the backside of the housing must not show rings, it should be a clear circle (Fig. 2).

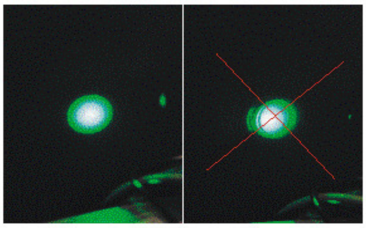


Fig. 2 Transmitted pump beam at the backside of the housing

Alignment of the resonator beam

Once the output beam from the pump-laser is coupled through the lens into the CLH, it can be used to define the resonator axis for a rough alignment of the cavity. This crystal transmits some 30% of the incident pump laser radiation. Both cavity arms are pre-aligned, and the long cavity arm can be aligned using amplified spontaneous emission (ASE) from the Ti:S crystal or the transmitted green light from the pump laser. The output coupler (OC) can be aligned by reflecting back the ASE beam collinearly into the gain medium. Next, the ASE signal transmitted through the OC should be detected with a large-area Si-photodetector. The detector signal should then be maximized by fine alignment of the end mirror OC, the end mirror of the short cavity arm, the stability range, as well as the crystal and the focusing lens in an iterative way. This procedure should rapidly give rise to laser oscillation if the optics are clean and the pump power is of the order of 3 W. Once cw oscillation is obtained, the output power can be maximized by following the same iterative approach using a powermeter.

With the laser oscillation one can trace out the *stability range,* the range of distances between the two curved focusing mirrors, for which the cavity is stable, i.e. laser oscillation is possible. The maximum cw power is achieved near the outmost position, mode locking can be introduced near the innermost position. For more details on tightly-focused 4-mirror cavities one should refer to Ref. 3.

Note: Make sure that the reflections on the mirrors M7, M8 (long cavity arm) are well placed on the mirror´s surface. Each visible reflection must be clearly off the edge of the mirror! No beam passing by may touch their edges!

Chapter 5. Phase locking

5.1 Setup of the system components

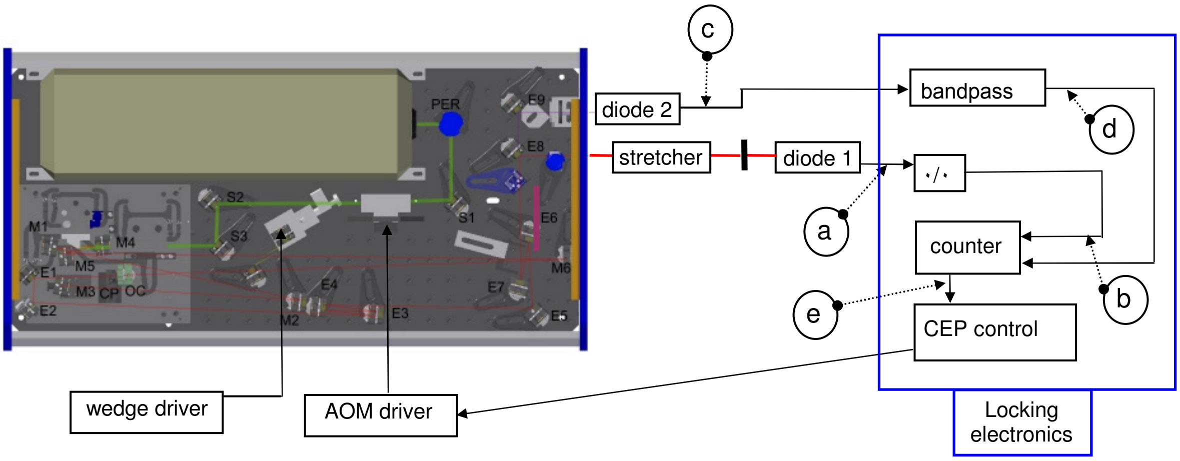


Fig. 3 Overview of the phase locking system

Reference frequency

A small portion of the oscillator output beam (leakage of a mirror in the stretcher) is directed towards diode 1. Diode 1 delivers the oscillator repetition rate from which the reference frequency (locked CE-phase drift) will be derived. It is connected to the divider input of the locking electronics (LE) box. The output signal of the diode (a) should be checked on an oscilloscope with 50Ω termination. A stable and clean pulse train should be visible according to fig. 4. The amplitude must be more than 200 mV.

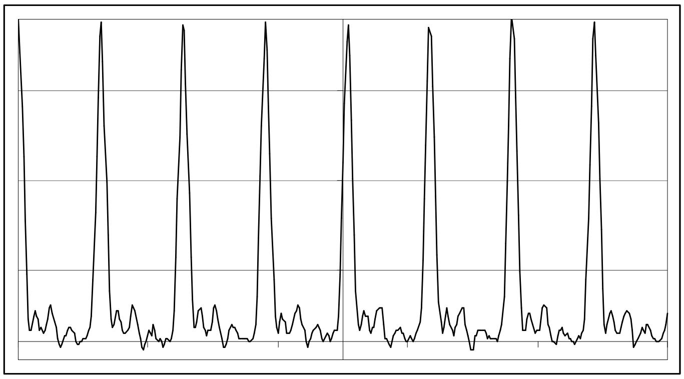


Fig. 4 Oscillator frequency signal

Also the output of the frequency divider (b), usually the 1/4-output, can be checked on an oscilloscope. It should be a square wave with the respective fraction of the input frequency and an amplitude of 2.5 V into 50Ω. This signal is connected to one of the counter inputs of the digital phase detector in the LE box.

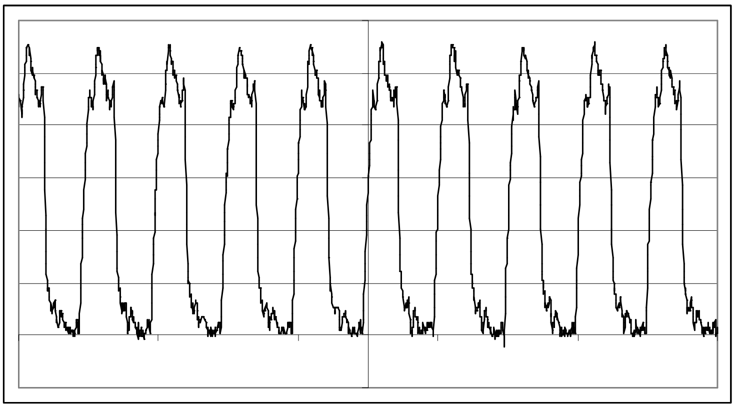


Fig. 5 Reference frequency signal

CE drift frequency

The CE phase signal is detected by diode 2 which is connected to the 'APD' input of the LE box. First the output of the diode (c) is checked on a spectrum analyzer. By moving the intra-cavity wedge the CE phase signal can be shifted close to the desired locking frequency (quarter of the oscillator repetition rate). A signal/noise ratio (SNR) of at least 35 db @ 100 kHz resolution bandwidth is required to obtain stable phase locking.

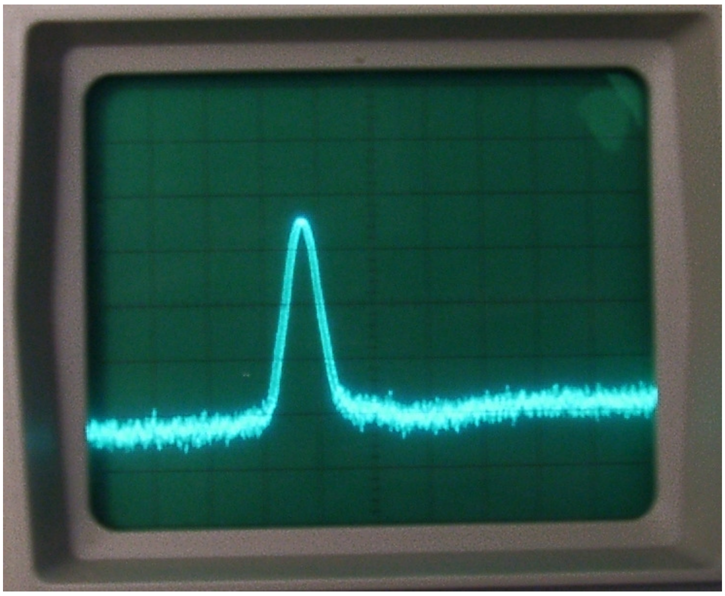


Fig. 6 CE phase signal in the frequency domain

In the time domain one should see the oscillator pulse train with a clear amplitude modulation of a quarter of the oscillator repetition frequency.

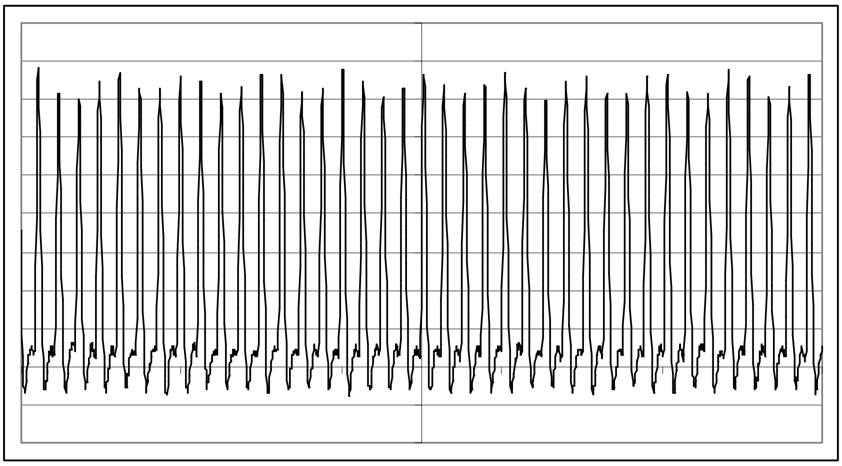


Fig. 7 CE phase signal in the time domain

Checking the output *(not the monitor!)* of the band pass amplifier of the LE box (d) on an oscilloscope, one should see a sine wave at the CE phase drift frequency. The amplitude into 50Ω should be more than 100 mV. This signal is connected to the other counter input of the digital phase detector.

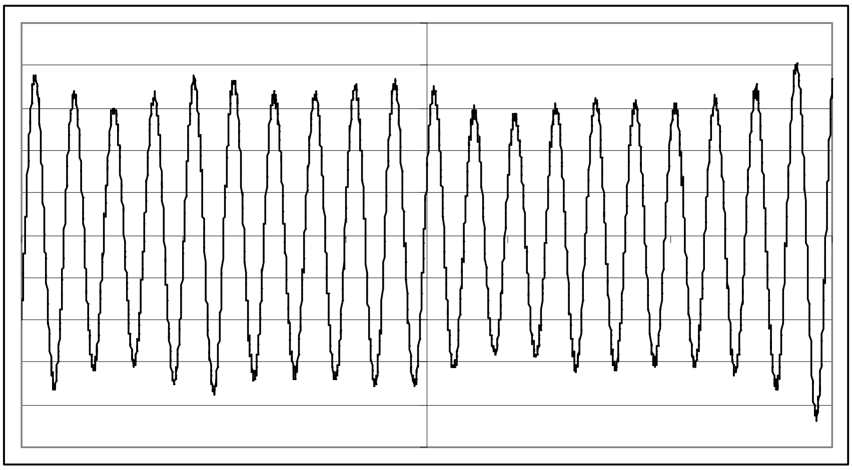


Fig. 8 CE phase signal after band pass filtering

Phase error signal

The monitor output of the phase detector provides the phase error signal (e) which corresponds to the time integrated difference between the reference frequency (b) and the CE phase signal (d). It should be measured on an oscilloscope with high input impedance (1MΩ). With the feedback loop deactivated and the CE phase signal in close proximity (within ~1 MHz) to the locking point (the reference frequency) one can observe a clean saw-tooth like signal (fig. 9). Adjusting the intra-cavity wedge one can move the CE phase frequency in a coarse manner.

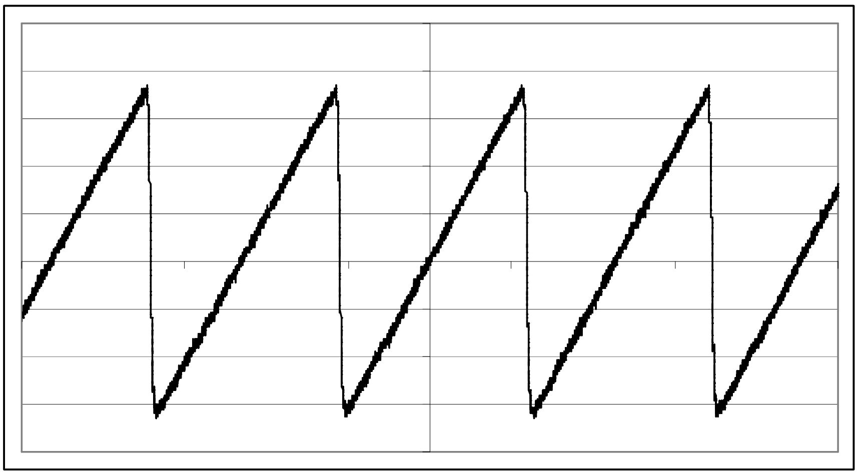


Fig. 9 Phase error signal with feedback loop deactivated

The output of the controller unit (lockbox) is connected to the AOM driver's input. The RF output of the AOM driver is connected to the AOM device. The offset knob of the lockbox should be set to a value around 5, the 'Level' knob on the AOM driver is set to zero. Make sure that the CE phase frequency can be shifted freely around the locking point by adjusting the offset knob of the lockbox. If the introduced shift is too much (i.e. causing a cw-spike or a loss of mode lock) an additional attenuator can be installed at the input of the AOM driver. Upon activating the phase locking mechanism the phase error signal will be close to zero (fig. 10).

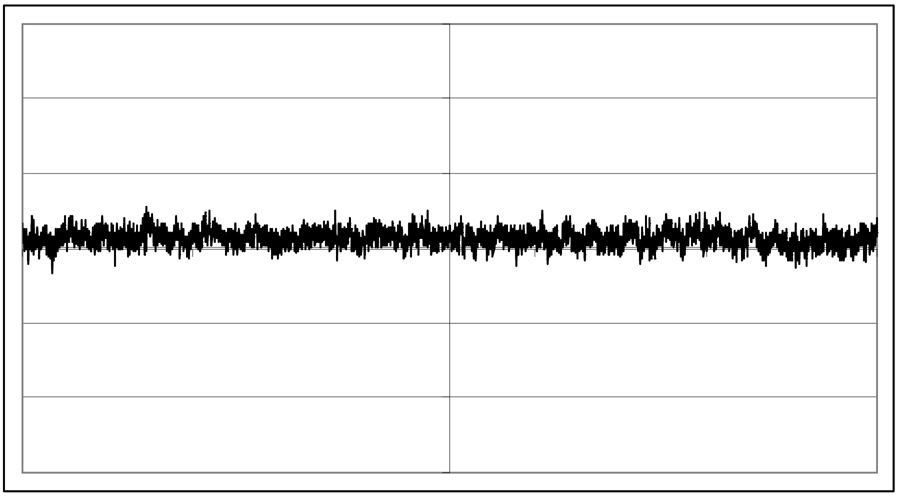


Fig. 10 Phase error signal with feedback loop activated

Adjustments on the lockbox

There are three parameters that can be adjusted on the lockbox:

- **the polarity of the gain**
- **the DC loop gain**
- **the HF (high frequency) loop gain**

The polarity of the gain will cause either a negative feedback (which is necessary for stable locking) or a positive feedback (resulting in an oscillating behavior of the loop). The correct polarity has to be determined experimentally.

The DC loop gain can be adjusted in coarse steps (with the step adjustment knob) and fine tuned with the 10-gear pot. It determines the overall tightness of the lock. With the gain too low large noise and fluctuations will occur. With the gain too high the loop will start to oscillate. A reasonable starting value is around 5. The gain should be increased until the loop becomes instable and then decreased until stable operation is achieved.

The HF loop gain will affect fast fluctuations and HF-noise and can be adjusted with the corresponding 10-gear pot. For determining the correct setting the above statement applies.

Note: For further information please refer to the Menlo locking electronics manual and the AOM driver manual.

Chapter 6. System specifications and requirements

FEMTOSOURCE Rainbow seed HP CEP	
Pulse duration	< 7fs (output before ppln)
Spectral width (-10 db)	> 250nm
Output power (average)	> 150 mW (each output)
Output energy @ 80 MHz	> 2.5 nJ
Pump beam diameter	2 mm ($1/e^2$), TEM_{00}
Pump power @ 532nm	5 W
Cooling water	19℃, 10 W
Size	728 x 378 mm

6.1 Important notice

It should be stressed that pulses in the sub-10 fs region are extremely "fragile" and can be significantly distorted (broadened) by even small amounts of dispersion in standard optical components. Hence, extreme care has to be taken, when steering the pulse external to the cavity and measuring it in an autocorrelator. Our autocorrelator and steering optics have been designed to meet the high requirements for high-fidelity pulse width measurements in the sub-10 fs range. Precise compliance with our guidelines for setting up and optimizing the sub-10 fs MDC system guarantees a reproduction of the results demonstrated previously in our laboratory *only* if our state-of-the-art steering and autocorrelator optics is used for pulse-width measurements (FEMTOMETER).

Chapter 7: Daily Operation and Maintenance

7.1 Daily Operation

Read Chapter 1: Laser Safety carefully before operating the laser the first time. It is assumed that all personnel operating the laser is familiar with laser safety practices and the dangers involved.

Use extreme caution when operating the laser system. The FEMTOSOURCE Rainbow and its pump lasers are CLASS IV high power laser systems. Reflections from both optical and non-optical surfaces may cause permanent eye damage or blindness.

All personnel in the area of the laser system should wear appropriate laser safety glasses.

SAFETY GLASSES: All personnel in the area of the laser system should wear laser safety glasses appropriate for Titanium-sapphire laser systems producing ultrashort-pulse 600 nm to 1100 nm radiation with average powers of 2 Watts and pulse energies of 2 mJ.

Daily Turn-On Procedure:

1. Check the status of the water chiller: water level, flow rate and cooling water temperature should be within safe operation limits. Note that while it is possible to turn the chiller off at system shut-down, it is recommended to keep the chiller running at all times. This will reduce the warm-up time of the system.

2. Check the status of the indicators on the Remote Control Unit (RCU):
POWER indicator should be on
SHUTTER indicator should be off
INTERLOCK OK should be on.

3. Insert the master key into the SAFETY KEY switch on the RCU and turn it to position I.

4. Confirm that you are aware of the system status and intend to turn on the system by pressing the RESET button on the Remote Control Unit for about three seconds. At this point the control logic will enable both pump lasers (CW oscillator pump laser and kHz amplifier pump laser) by deactivating their remote interlocks.

5. Turn on the oscillator pump laser following the instructions detailed in the oscillator pump laser's Operator's Manual. Set the output power of the oscillator pump laser to the value given in the Final Test Sheet of the FEMTOSOUCE SYNERGY.

6. Wait until the oscillator has reached thermal equilibrium (approx. 15 mins.).

7. Push the STARTER button of the oscillator to initiate mode-locking.

8. If you want to use the oscillator output from FEMTOSOURCE SYNERGY, press and hold the SHUTTER button on the Remote Control Unit for approx. 5 seconds. The oscillator emission indicators on the Remote Control Unit as well as near the oscillator output aperture on the FEMTOSOURCE SYNERGY will start blinking and an audible warning signal will sound to indicate that laser emission from the oscillator output aperture is immanent.

After a time delay of approx. 8 seconds the control logic will open the shutter and the emission indicators on the Remote Control Unit as well as near the oscillator output aperture on the FEMTOSOURCE SYNERGY will be on (lit).

Turn-Off Procedure:

1. ***Close the oscillator output shutter by pressing the SHUTTER button on the Remote Control Unit. The emission indicators on the Remote Control Unit as well as near the aperture on the FEMTOSOURCE SYNERGY should be off (not lit).***
2. ***Close the shutter of the oscillator pump laser. Shut down the pump laser following the instructions detailed in the pump laser's Operator's Manual.***
8. ***Turn the master key on the Remote Control Unit into OFF position and remove the master key from the SAFETY KEY SWITCH.***

7.2 Maintenance

Some maintenance procedures require operation of the FEMTOPOWER compact PRO with one or more of the covers of the protective housing removed and ist corresponding safety interlocks defeated, thus allowing access to hazardous visible and invisible radiation. Maintenace procedures should only be performed by trained personnel cognizant of the hazards involved. Strictly follow the procedures specified in this chapter.

Always wear appropriate laser safety glasses. Reflections from both optical and non-optical surfaces may cause permanent eye damage or blindness.

CLEANING OF OPTICS

Over time, the coated laser optical components of the FEMTOSOURCE SYNERGY, such as mirrors or the laser crystal will be contaminated by a variety of airborne particles or surrounding vapors, leading to a degradation of the performance. The rate of contamination depends on the cleanliness of the environment. The cleanliness of the optical surfaces should be checked periodically or whenever a degradation of the performance of the laser system is noticed.

Optics and optical coatings can easily be scratched. Never touch the surfaces with your fingers and use only gentle force. Extra care is needed when cleaning

chirped mirrors, these coatings are softer than standard mirrors.

EQUIPMENT REQUIRED	**Clean air aerosol** **Optical-grade lens-cleaning paper** **Spectroscopic-grade methanol or acetone** **Clean, lint-free finger cots or powderless gloves** **Hemostat** **Eyedropper**
CLEANING PROCEDURE	**Try cleaning the optic with pulsed air first. Only if dust or streaks persist continue cleaning with the following steps.** **Put on gloves or finger cots.** **Fold a piece of lens-cleaning paper to the size of approx. 1 inch and clamp it with the hemostat.** **Place a few drops of methanol or acetone onto the lens-cleaning paper.** **Wipe gently across the optic in one direction.** **Repeat these steps with a clean lens-cleaning paper if necessary. Do not re-use the paper !**
'HARD-TO-REACH' OPTICS	**Apply a few drops of solvent onto a cotton-tipped applicator and shake off the exceess.** **Swab the optic gently with the applicator.** **Blow off any residual cotton with clean air.**
CHILLER MAINTENANCE	**Check the water filter and replace as necessary.** **Please refer to the chiller's user manual for detailed information regarding maintenance intervals and procedures.**

OSCILLATOR OPTIMIZATION

Small drifts in the pump laser's beam pointing and of the mirror mounts can result in a reduction of output power, narrowing of the spectrum, instabilities on the emitted pulse train or difficulties in initiating mode-locking, making a periodic optimization of the oscillator performance necessary. The laboratory environment and the amount of time the laser is operated affects the periodic maintenance schedule.

EQUIPMENT REQUIRED

appropriate laser safety glasses.
a suitable laser power meter (detector aperture size > 1 cm, range 1W)
a suitable spectrometer (wavelength range: 600 to 1000 nm, resolution < 2nm)
metric Allen key, SW5IR-viewer and sensitive screen
a broadband (600-1000 nm) beam-splitter to pick off a small percentage (< 1%) of the beam

OSCILLATOR OPTIMIZATION PROCEDURE

Shut down the system, but keep the water-to-air chiller running.
Place the laser power meter at the oscillator output aperture of the FEMTOSOURCE Rainbow. Use the beam-splitter to direct part of the beam onto the spectrometer as required.
Remove the cover from the protective housing.
Check the status of the indicators on the Remote Control Unit:
POWER indicator should be on (lit).
SHUTTER OSC indicator should be off (not lit).

INTERLOCK FAULT indicator should be on (lit).

Defeat the two safety interlocks by pulling the pins outwards until they snap in. The interlock defeat indicators next to the safety interlocks should be on (lit) and the INTERLOCK DEFEATED on the Remote Control Unit should be on (lit).

Insert the master key into the SAFETY KEY switch on the Remote Control Unit and turn it to position I.

Confirm that you are aware of the system status (*interlocks defeated !*) and intend to turn on the system by pressing the RESET button on the Remote Control Unit twice for about three seconds. At this point the control logic will enable the pump laser by enabling its remote interlock.

Turn on the pump laser following the instructions detailed in the pump laser's Operator's Manual. Set the output power of the oscillator pump laser to the value given in the final test sheet of the FEMTOSOURCE SYNERGY.

Using the Allen key, turn the stability range setscrew counterclockwise until the power meter reading is at maximum.

WARNING ! Laser radiation present from this point on.

Maximize the cw output power by adjusting the pump steering mirror and the output coupler mirror. You should achieve a value P(cw,max) close to the one given in the final test sheet. If this is not the case, also adjust the cavity end mirror until the power is OK.

Using the Allen key, slowly turn the stability range setscrew clockwise until the output power has dropped to the value P(cw,ml) given in the final test sheet.

Push the starter-button to initiate mode-locking.

Check the spectrum using the spectrometer. There should be no cw-spike and the FWHM spectral width should be close to the value given in the final test sheet.

Check the mode-locked output power.

Shut down the system and replace the cover on the protective housing.

Chapter 8. Ultrashort pulses from the Rainbow - laboratory tests

The quality of intra-cavity dispersion control is crucial for the generation of high-quality optical pulses in the sub-10 fs range, regardless of the mode-locking technique used. The chirped mirrors employed in the MDC Ti:S oscillator provide nearly constant GDD over bandwidths as broad as 80 THz, which is substantially higher than demonstrated with any other low-loss dispersion compensating technique previously.
In order to test the capability of the MDC Ti:S oscillator to generate high-quality optical pulses in the sub-10 fs range, the oscillator was mode locked via self mode locking prior to delivery.

8.1 Self mode locking

For optimum self-mode-locked operation, the length of the tightly-focused cavity arm was adjusted close to the shorter end of the stability region.

Initiating mode locking

A small perturbation of the cavity length was introduced by shifting mirror M3 mounted on a translation stage towards OC and releasing it afterwards. If the oscillator was optimized the moving mirror M3 introduced enough cavity perturbation for starting mode locking.
If the oscillator was optimized, mode locking is started in the center of the stability range. Moving the adjustment screw for the stability range clockwise increases the spectral width.

Note: mode locking has started when the spectrum becomes brighter and the speckles disappear!

Steady-state performance

After getting mode locking started, we optimized the position of the curved mirror M1 and the position of the gain medium along the resonator beam, until a stable pulse train was observed on the oscilloscope. The output of the laser was monitored with a fast (1 ns-response-time) photodiode. The spectrum and the pulse duration of the self-mode-locked MDC Ti:S oscillator were measured with a standard spectrometer and a specifically-designed broad-band low-dispersion collinear autocorrelator. The results are shown in the appendix. The clear visibility of the fringes in the wings of the interferometric autocorrelation provide clear evidence for the nearly transform-limited nature of the generated pulse.

8.2 Extracavity chirp compensation:

Compensation of spatial chirp

The output-coupler is wedged (10°) to prevent unwanted reflections from the rear side of the substrate. Additionally the rear side is AR-coated. The *spatial chirp* (angular dispersion) introduced by the wedged plate has to be compensated by a compensating plate (CP) which is mounted as close as possible to the OC.

Compensation of material dispersion

Material dispersion is introduced by the OC, the CP and the beam splitter of the autocorrelator. To compensate for this positive dispersion the extra-cavity mirror pair E3 and E4 is introduced. For compensating the substrate of the OC, the CP and 1 mm fused silica at 45° (BS of the autocorrelator) 4 - 6 reflections of the extra-cavity mirror pair are required.

Chapter 9. Appendix

9.1. List of qualified pump lasers

Coherent Verdi (all types incl. chiller, no chill plate required)

9.2. Phone numbers and e-mail for service

Profit Center Manager:

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