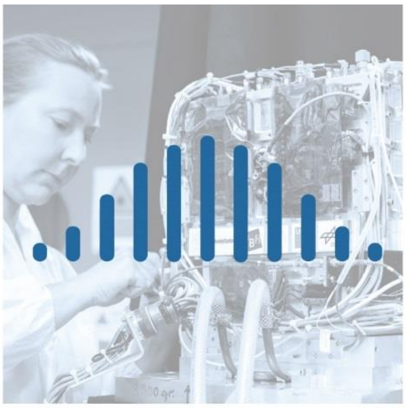
MenloSystems

User Manual

FC1500-250-ULN



Important Document

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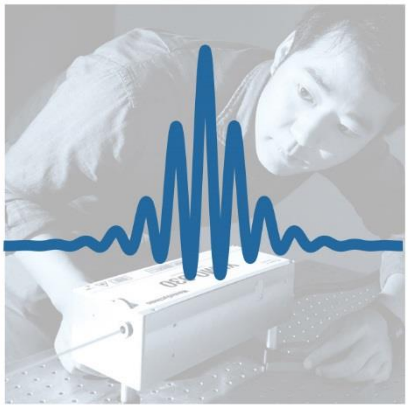

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PROOFED QUALITY MenloSystems GUARANTEE

Excitement Is Not Measureable. Light Is.

Menlo Systems, a leading developer and global supplier of instrumentation for high-precision metrology, was founded in 2001 as a spin-off of the Max-Planck-Institute of Quantum Optics. Known for the Nobel-Prize-winning Optical Frequency Comb technology, the Munich based company offers complete solutions based on ultrafast lasers, synchronization electronics and THz systems for applications in industry and research.

I. IMPRINT

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II. TABLE OF CONTENTS

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III. SAFETY INSTRUCTIONS

Please follow the directions given in this manual. If the directions in this manual are not followed, the level of safety the laser is designed to provide might be affected.

III.1 LASER SAFETY

III.1.1 INTENDED USE OF THE LASER

Your laser is a versatile light source for research and industry applications. The laser is designed for indoor use only (IP21, NEMA Type 1). It is not designed for use as a medical device or as part of a medical device.

III.1.2 LASER HAZARD CLASSIFICATION

Lasers and laser systems are classified by potential hazard according to a system described by the EN 60825-1:2007.

A laser's classification is based on several factors including its wavelength, power output, accessible emission level, and emission duration.

CLASSIFICATION OF THE LASER MODEL

Please read the following notes according to the Class of your laser carefully.

POTENTIAL HAZARDS ASSOCIATED WITH CLASS 1M LASERS

A Class 1M laser is safe for all conditions of use except when passed through magnifying optics such as microscopes and telescopes, or re-focusing optics such as a lens. Class 1M lasers produce large-diameter beams, or beams that are divergent.

POTENTIAL HAZARDS ASSOCIATED WITH CLASS 3B LASERS

A Class 3B laser can be hazardous if exposed to the eye directly. This includes intrabeam viewing or specular reflections. Exposition of the eye to diffuse reflections typically does not present a hazard. Class 3B lasers with higher output power can burn skin and ignite combustible material when the beam diameter is small or when the beam is focused. **Protective eyewear is imperatively required when working with Class 3B lasers.**

POTENTIAL HAZARDS ASSOCIATED WITH CLASS 4 LASERS

Class 4 lasers are hazardous to view under any condition including intrabeam viewing, specular reflections and diffuse reflections. Class 4 lasers can burn skin and ignite combustible material. **Protective eyewear is imperatively required when working with Class 4 lasers.**

III.1.3 LASER SAFETY PRECAUTIONS

This system may present a serious potential threat for eye injury resulting from intra-beam viewing. It generally does represent a diffuse reflection hazard, a skin hazard, or a fire hazard.

- Areas where lasers with accessible radiation are operated need to be marked with warning symbols according to local regulations
- Operate the laser only in a well-controlled area, for example in a closed room with covered or filtered windows and controlled access
- The plane of the laser beam should be closed off to all sides by protective screens
- Do not remove the cover or any sidewall of the system enclosure
- The laser beam path should be confined in a horizontal plane. Keep beam path above or below eye level, both for sitting and standing positions
- Do not aim at doorways or windows
- Mount the laser on a firm support to assure that the laser beam never deviates accidently from the intended path
- Assure that individuals who operate the laser are trained in laser safety and authorized to operate a laser
- Persons using the laser should be informed about safety measures according to local regulations
- Only experienced personnel should operate the laser. During operation the laser should not be left unattended if there is a chance that an unauthorized user may attempt to operate it. The key switch must be used if untrained persons may gain access to the laser. A warning light or buzzer must be used to indicate that the laser is in operation
- Do not wear watches, rings or other jewelry that could reflect laser radiation
- Make sure that the surfaces of tools do not produce specular reflections
- Remove unnecessary specular surfaces from the vicinity of the laser beam path and avoid aiming at such surfaces
- Never look into the laser beam on axis
- Never point the laser beam at anyone else’s eye
- Users should wear appropriate eye protection when operating class 3R, 3B or class 4 lasers
- Terminate laser beams at the end of their useful paths

- Use low power settings, beam shutters and laser output filters to reduce the beam power to less hazardous levels when the full output power is not required

III.1.4 PROTECTIVE EYEWEAR

The calculation for protective eyewear can be done according to the European standard EN 207:1998+A1:2002.

If your laser model is exclusively equipped with fiber output ports, the given safety ratings are based on the assumption of an open fiber end with a divergent laser beam. If the laser beam however is collimated after the fiber, the necessary safety ratings might be higher.

Commercial laser safety glasses are rated with an L-rating according to EN 207:1998+A1:2002 or with an Optical Density (OD) rating according to ANSI Z136.1 or with both.

This is just a recommendation. Every user is responsible to take care for proper eyewear safety.

III.2 ELECTRICAL SAFETY PRECAUTIONS

You should make sure that all electrical equipment used is safe. Here is a list of actions that should be taken to ensure this:

- Do not use wet hands when turning on electrical equipment
- Check that the electrical equipment is suitable for the work and way in which it is going to be used
- Check that the electrical equipment is in good condition
- Check that the equipment is suitable for the electrical supply with which it is going to be used, and that the electrical supply is safe
- Make sure that the user of the equipment is trained to use it safely and can keep others safe
- Make sure the user knows which personal protective equipment to wear, how to use it, and make sure they do
- Power failures should be avoided

Before starting the system make sure that the fuses installed for the power supply of the system are rated to the correct mains supply voltage. If the supply voltage differs from the value, the already installed fuses need to be replaced by ones which are appropriately rated.

1. PRINCIPLE OF OPERATION

1.1 PRINCIPLE OF AN OPTICAL FREQUENCY COMB

The FC1500 is based on a femto-second (fs) fiber laser. To understand the mode structure of a femto-second frequency comb and the techniques applied for its stabilization, one can look at the idealized case of a pulse circulating in a laser cavity with length L with a carrier frequency ω_c as shown in Figure 1. The output of this laser is a sequence of pulses that are essentially copies of the same pulse separated by the round trip time $T = 2\,L\,/\,v_g$, where v_g is the cavity's mean group velocity defined by the round trip time T and the cavity length L. The pulses however are not quite identical. This is because the pulse envelope A(t) propagates with v_g while the carrier wave travels with its phase velocity. As a result the carrier shifts with respect to the pulse envelope after each round trip by a phase angle $\Delta\varphi$ as shown in the following figure:

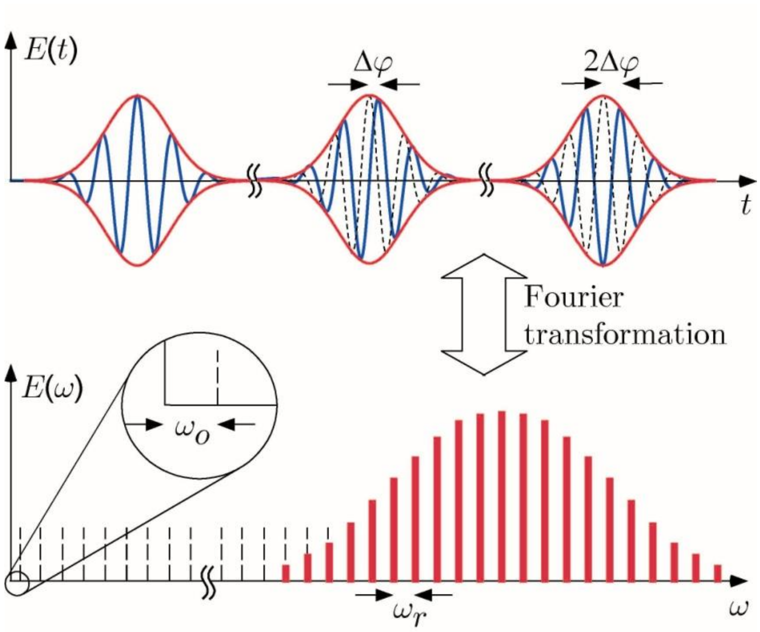


Figure 1: Top: consecutive pulses of the pulse train emitted by a mode locked laser and the corresponding spectrum. As the carrier wave at ω_c moves with the phase velocity while the envelope moves with a different group velocity the carrier wave (blue) shifts by $\Delta\varphi$ after each round trip with respect to the pulse envelope (red).

Bottom: This continuous shift results in a frequency offset $\omega_0=\Delta\varphi/T$, also called Carrier Envelope Offset (CEO), of the comb from being exact harmonics of the pulse repetition frequency ω_r.

Unlike the envelope function, which provides us with a more rigorous definition of the pulse repetition time $T = \omega_r^{-1}$ by demanding $A(t) = A(t-T)$, the electric field is, in general, not expected to be periodic in time. If the periodicity of the envelope function is assumed the electric field at a given place outside the laser resonator can be written as:

$$E(t) = \mathrm{Re}\left(A(t)\cdot\exp\left(-i\omega_c t\right)\right) = \mathrm{Re}\left(\sum_n A_n \cdot \exp\left(-i\left(\omega_c + n\omega_r\right)t\right)\right) \quad (1)$$

where A_n are the Fourier components of A(t).

This equation shows that, under the assumption of a periodic pulse envelope, the resulting spectrum consists of a comb of laser modes that are separated by the pulse repetition frequency. Since ω_c is not necessarily an integer multiple of ω_r the modes are shifted from being exact harmonics of the pulse repetition frequency by an offset ω_0 that can be chosen to obey $\omega_0 < \omega_r$ simply by renumbering the modes:

$$\omega_n = n\cdot\omega_r + \omega_0 \quad (2)$$

with a large ($\approx 10^6$) integer number n.

This equation maps two radio frequencies ω_r and ω_0 onto the optical frequencies ω_n. While ω_r is readily measurable, and usually lies between a few 10 MHz and a few GHz depending on the length of the laser resonator, ω_0 is not easy to access unless the frequency comb contains more than an optical octave. The intuitive picture given here can even cope with a frequency chirp, i.e. a carrier frequency that varies across the pulse. In this case the envelope function becomes complex in value and the comb structure derived above stays valid provided the chirp is the same for all the pulses. Under this assumption, which is reasonable for a stationary pulse train, A(t) remains a periodic function. Spectral broadening due to self-phase modulation via the intensity dependent index of refraction in an optical fiber is used to increase the width of the frequency combs.

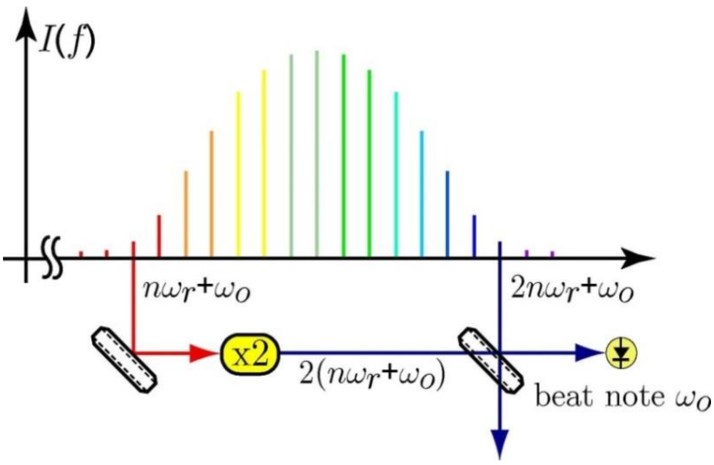


Figure 2: The principle of the optical frequency synthesizer: A mode with the mode number n at the red wing of the comb and whose frequency is given according to Eqn. (2) by $\omega_n = n\omega_r + \omega_0$ is frequency doubled in a non-linear crystal. If the frequency comb covers a full optical octave, a mode with the number 2n should oscillate simultaneously at $\omega_{2n} = 2n\omega_r + \omega_0$. The beat note between the frequency doubled mode and the mode at 2n yields the offset:

$$2(n\omega_r + \omega_0) - (2n\omega_r + \omega_0) = \omega_0.$$

To achieve a stabilized frequency comb two free parameters, i.e. the comb spacing and the comb offset have to be stabilized. To gain access to the offset frequency of the FC1500 optical frequency synthesizer, the laser output is amplified in an Erbium Doped Fiber Amplifier (EDFA). Its output is broadened to more than one octave in a nonlinear fiber. We frequency double the 2100 nm part of the comb and observe a beat with the 1050 nm part, see Figure 2. This is done in a completely fiber-coupled nonlinear interferometer inside the EDFA unit. Both the repetition rate and the offset frequency can thus be phase locked by controlling the laser cavity´s parameters.

1.2 SCHEMATIC SETUP

The FC1500-250-ULN optical frequency comb consists of several optical and electronical units.

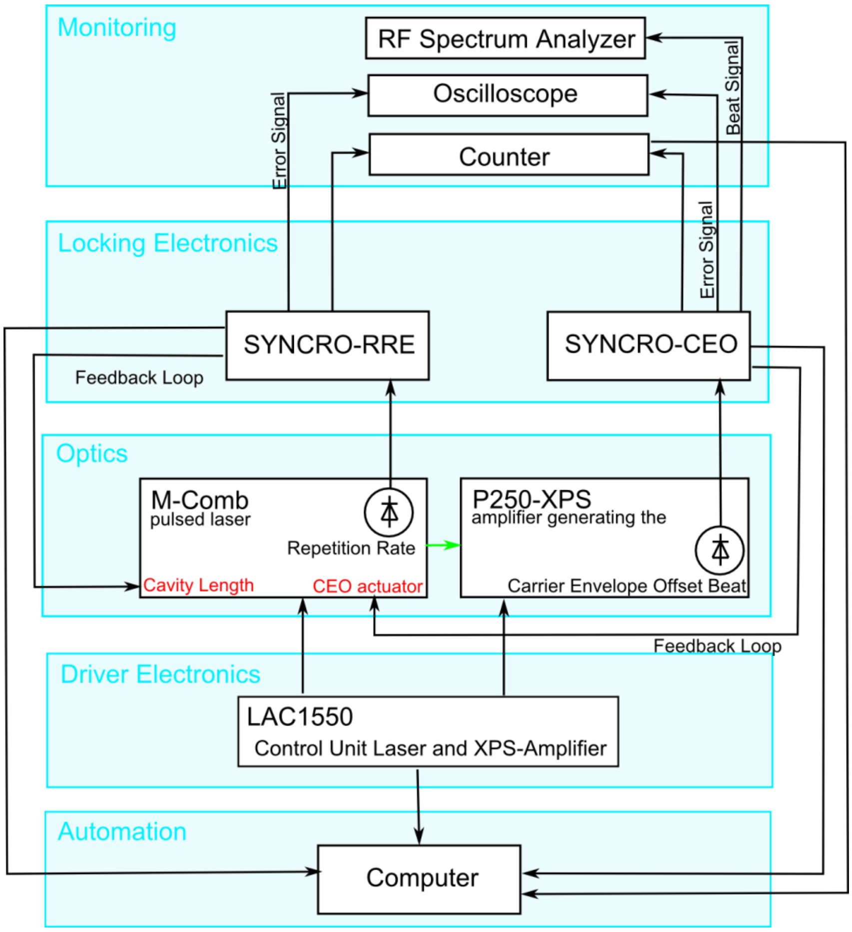


Figure 3: Schematic setup of a frequency comb. Green: Fiber connection, Black: electronic connection.

The M-Comb generates pulses at the desired repetition rate, driven by its control unit LAC1550. One output of the laser seeds the P250-XPS amplifier, which is also driven by the LAC1500. The P250-XPS amplifier generates an octave spanning spectrum and comprises a fully fiber-coupled all polarization maintaining f-2f interferometer, in order to detect the carrier envelope offset (CEO) beat.

The two degrees of freedom of the optical frequency comb, the repetition rate and the carrier envelope offset frequency, are controlled in two independent phase locked loops. The repetition rate is controlled by the SYNCRO-RRE and the carrier envelope offset beat is controlled by the SYNCRO-CEO. Frequency counters without dead time are used to measure the beat signals between the frequency comb and the CW lasers and to control the phase locked loops for cycle slips. An oscilloscope and a spectrum analyzer are also included for monitoring purposes. Furthermore, a computer and a comb specific software help for control, automation and monitoring purposes.

2. SYSTEM OVERVIEW

2.1 CONTENT OF THE FC1500-250-ULN CONFIGURATION

The FC1500-250-ULN is a setup of the Optical Frequency Comb consisting of optical parts pre-aligned on a baseplate, a 19” rack for the electronics, and monitoring. It consists of the following items, listed in the table below.

Dependent on the necessary characteristics, the FC1500-250-ULN can be delivered in three options:

- FC1500-250-ULN, Option 1
- FC1500-250-ULN, Option 2 *
- FC1500-250-ULN^{plus}*

Item	Description	
Frequency comb housing	Baseplate able to be water-cooled and complete housing for the optical part of the frequency comb	
M-Comb	Laser head with intra-cavity actuators for repetition rate and offset locking	
P250-XPS	Amplifier with internal f-2f interferometer for detection of the CEO beat	
Chiller*	Chiller for water-cooling of the optical baseplate	

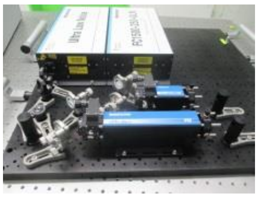
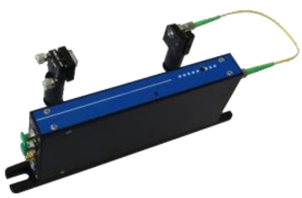
Electronics board	Electronics board with all electronics and monitoring	
Interlock	Interlock distribution for connection to an external interlock	
Reference rack	Rack including power supply for reference distribution RFD10, PLO and supply for detectors	
Counter rack	Rack including power supply for all counters (FXM50 or FXE65*)	
Computer	Computer to control the frequency comb and to enable data acquisition, logging and analyzing	
LAC1550	Control unit for the M-Comb and the P250-XPS	
SYNCRO-RRE (freescale or embedded*)	Locking electronics for the repetition rate including pen for touch screen	
SYNCRO-CEO (freescale or embedded*)	Locking electronics for the CEO beat including pen for touch screen	
DSO1052B / DSOX2004A	2- or 4- channel oscilloscope for monitoring error signals	

HMS-X	RF spectrum analyzer for monitoring beat signals	
Rb clock*	Rubidium clock for RF reference	
M-Comb cable umbilical	All cables for laser control	
P250 cable umbilical	All cables for amplifier control	
CWPM	Replacement CWPM pump module	

Item	Description	
Accessories	19” TFT monitor including DVI cable	
	Keyboard and mouse	
	USB extension	
	Accessories for computer	
	Manuals for spectrum analyzer and oscilloscope	
	Rubber pins for housing holes	
	4x Handles for Plexiglas® cover including mounting screws	

	FC/APC-FC/APC non-PM fiber-patchcord and FC/APC – LC/APC PM fiber patchcord	
	IEC extension cable	
	Country-specific power supply cable	
	Mounting screw for baseplate (metric and imperial)	
	Fiber Cleaner	
	Set of Allen® keys	
	Set of Sorbothane feet for vibration-cushioning of the baseplate	
User Manuals	FC1500-250-ULN Optical Frequency Comb (this document)	
	Femtosecond Laser	
	SYNCRO	
	Fiber Comb Control	
	Comb Watch	
	AC1550	
Test Report	Test report and other documentation, including software CD	
	Certificate for Optical Frequency Comb qualification	

2.2 AVAILABLE OPTIONS

Item	Description	
P250 Pulse EDFA	Amplifier including control unit AC1550 (able to control up to three amplifiers)	
HMPxxx	High power measurement port for custom wavelengths in the UV, visible and infrared spectral range; available in combination with P250 Pulse EDFA	
M-780	Amplifier with subsequent frequency doubling for generation of high power at 780nm and including control unit AC1550	
M-VIS	Amplifier and control unit with Second Harmonic Generation (SHG) and broadening of the spectrum in the visible range using a Photonic Crystal Fiber (PCF)	
M-NIR	Amplifier and control unit with spectral broadening in the infrared spectral range	
BDU-FS	Free space Beat Detection Unit	
BDU-FG	Fiber-coupled BDU with external grating	

BDU-FF	Fully fiber-coupled BDU	
SYNCRO-LLE	Laser Locking Electronics for locking a cw laser to the frequency comb; including pen for touch screen	
WLM-VIS /-NIR	Wavemeter for visible or near infrared spectral range	
GPS	GPS frequency reference optimized for frequency comb applications	
ORS1500	Optical Refence System for optical locking; ultra stable cw laser	
Ultra Low Noise Microwave Generation	Ultra low noise microwave generation in the MHz und GHz range	

2.3 OPTICS OVERVIEW

The basic opto-mechanical setup of the FC1500-250-ULN optical frequency synthesizer consists of the fiber laser head with six output ports (up to nine ports are available), an amplifier head containing the P250-XPS EDFA with subsequent spectral broadening for generating the octave-spanning supercontinuum and the fully fiber-coupled nonlinear interferometer for detection of the CEO beat frequency.

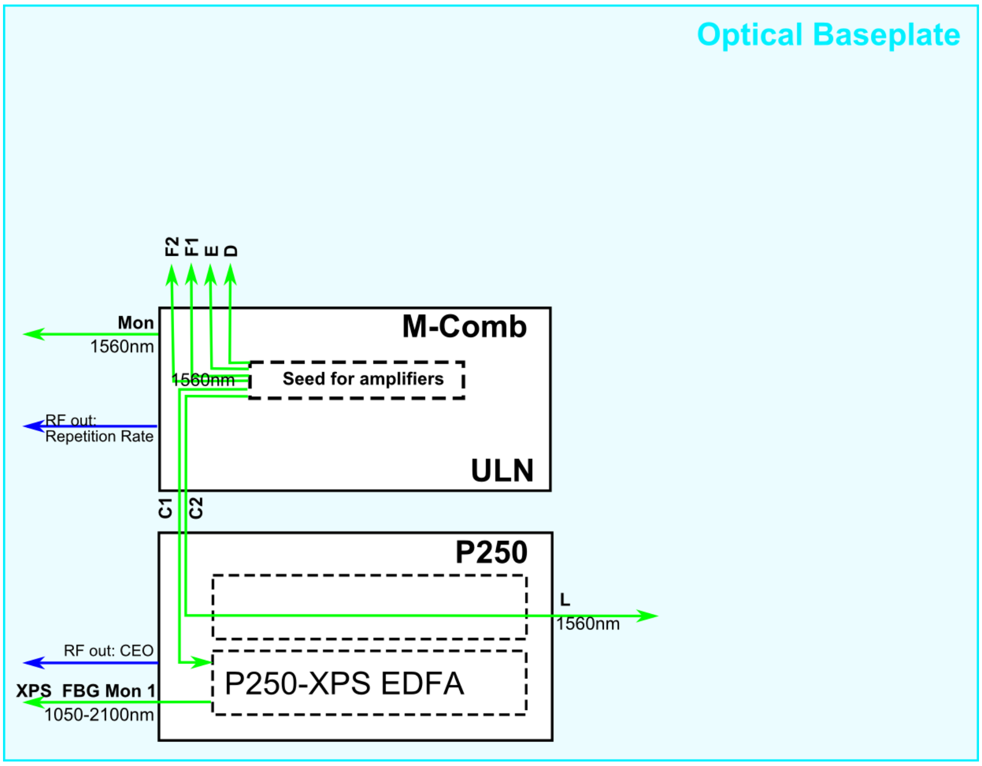


Figure 4: The standard configuration of the optics overview. CEO: Carrier Envelope Offset beat; EDFA: Erbium Doped Fiber Amplifier. You will find the sketch of the setup of your system in the add-on to the test report, called CUSTOMER SYSTEM DETAILS.

Depending on the configuration of your system, the FC1500 includes:

- Several EDFA amplifiers, either in standard, supercontinuum, wavelength-shifted or tunable wavelength version
- Several frequency doubling stages for generation of 780 nm or custom wavelengths
- Several Photonic Crystal Fiber (PCF) setups for generation of a supercontinuum in the visible spectral region
- Several BDU's in free-space or semi- or fully- fiber-coupled specification
- Wavelength meter for visible or infrared spectral range

2.4 OPTICS IN DETAIL

2.4.1 M-COMB: FEMTOSECOND FIBER LASER

The M-Comb femto-second fiber laser has been especially designed for metrology applications and features an adjustable repetition rate as well as intra-cavity actuators for convenient control of the CEO frequency. Together with the temperature stabilization of the laser, twenty-four-seven operation of the locked frequency comb is routinely possible.

For a better understanding of the laser itself, please refer to the fiber laser manual.

CAUTION: Take action to protect the environment against laser radiation. Wear appropriate safety goggles. See chap. III for further safety instructions.

2.4.2 P250-XPS: CEO FREQUENCY GENERATION AND DETECTION

The P250-XPS EDFA is a polarization-maintaining high power fiber amplifier with internal spectral broadening of a 1.56 µm input spectrum to an octave-spanning spectrum from roughly 1 µm … 2.1 µm. This is accomplished by means of the effects in a Highly NonLinear Fiber (HNLF). The output of the HNLF is directly attached to an all polarization maintaining and all fiber-coupled non-linear interferometer.

The amplifier input is fiber-coupled. The LAC1550 control unit supplies the pump modules of the P250-XPS. All pump currents are user adjustable.

A sketch of the fiber-setup of the amplifier is given below.

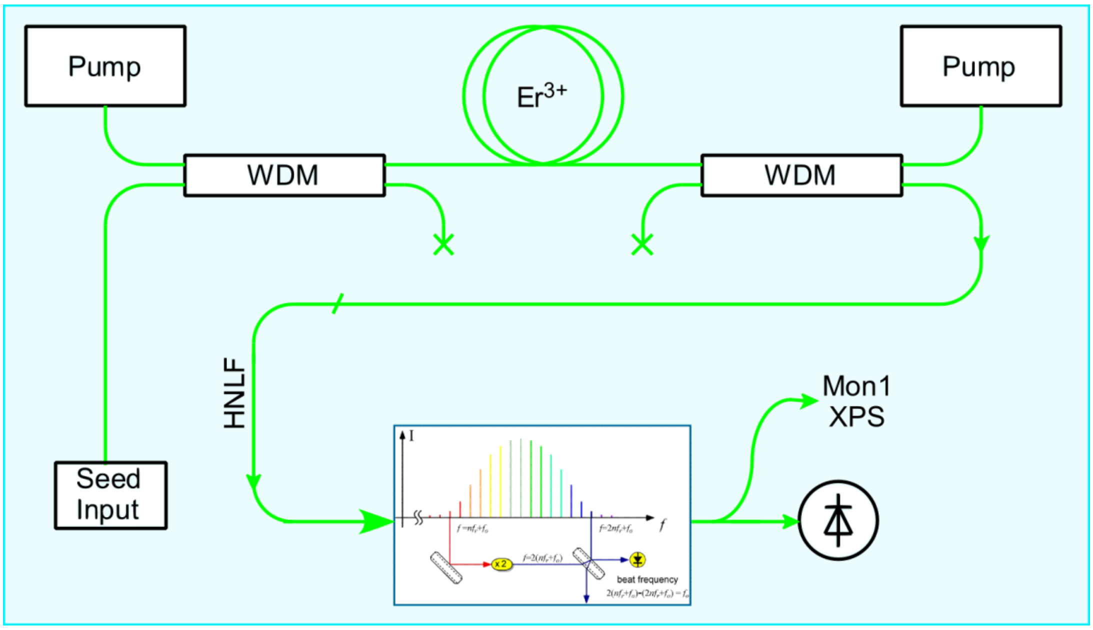


Figure 5: Schematic of the P250-XPS fiber amplifier with internal spectral broadening and fully fiber-coupled f-2f interferometer. WDM: Wavelength Division Multiplexer; HNLF: Highly NonLinear Fiber. Green: fiber connection.

The non-linear interferometer for the CEO frequency detection is set up in a completely adjustment-free, one-arm, all fiber-coupled and polarization maintaining configuration. By frequency doubling the far infrared part of the octave-spanning spectrum at approximately 2100 nm and comparing it to the non-doubled part at approximately 1050 nm, the CEO beat is generated. After splitting up and filtering the relevant part of the spectrum the CEO beat note is detected on a PIN diode.

The Signal to Noise Ratio (SNR) of the CEO beat frequency can be adjusted by changing the pump currents of the P250-XPS EDFA on the LAC1550. It should reach at least 35 dB in 100 kHz resolution bandwidth to ensure accurate measurements with the FXM50/FXE65 frequency counter and a reliable phase lock of the offset frequency.

CAUTION: Operate all amplifiers only with a laser operation in mode-locked condition.

2.4.3 P250 PULSE EDFA: HIGH POWER AMPLIFIER

The P250 Pulse EDFA is a polarization-maintaining high power fiber amplifier that delivers intense near infrared pulses with high power at 1560 nm. The output can be either freespace or fiber-coupled.

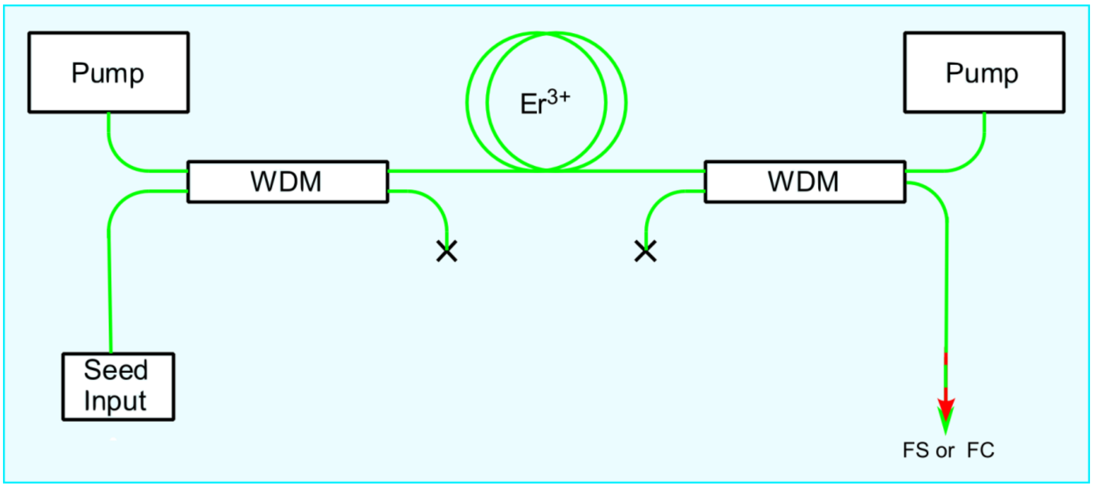


Figure 6: Schematic of the P250 Pulse EDFA. WDM: Wavelength Division Multiplexer. Green: fiber connection; Red: free-space radiation.

Several amplifiers with different options (HMP,SHG,…) can be added for multiple, simultanously usable measurement ports.

The output of one amplifier can be split up, to get two output ports with different options but cannot be used simultanously. The option is called P250 PM Dual. Each output port can be either freespace or fiber-coupled.

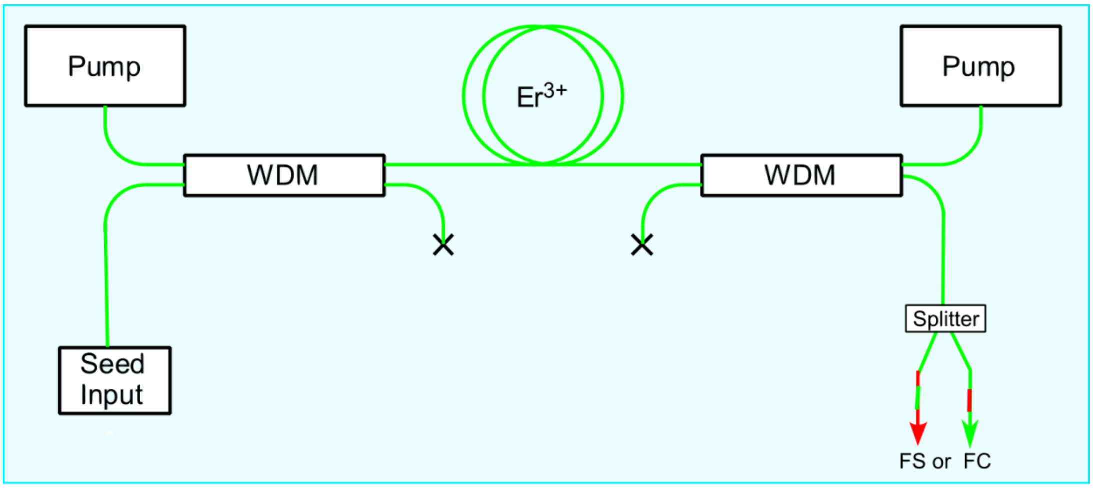


Figure 7: Schematic of the P250 PM Dual Pulse EDFA with the output in split version. WDM: Wavelength Division Multiplexer. Green: fiber connection; Red: free-space radiation.

2.4.4 M-VIS AND SHG780

The extension package M-VIS includes a polarization-maintaining high power fiber amplifier with subsequent frequency doubling stage and its control unit AC1550. The amplifier output at 1560 nm uses an integrated SHG stage to convert the 1560 nm input radiation to the second harmonic at 780 nm. The output can either be free space or fiber-coupled.

The M-VIS option also includes the PCF setup (see chapter 2.4.5).

A sketch of the fiber setup is given below.

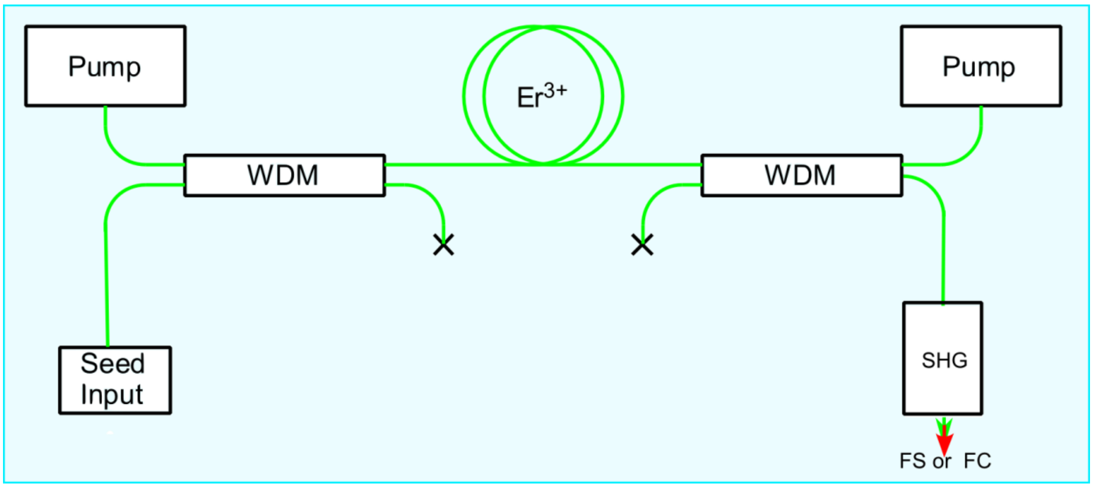


Figure 8: Schematic of the M-VIS or M-780 EDFA. WDM: Wavelength Division Multiplexer. Green: fiber connection; Red: free-space radiation.

CAUTION: Depending on the pump currents, up to 600 mW of IR radiation can be emitted from the port of this amplifier. Take action to protect the environment against laser radiation. Wear appropriate safety goggles. See chap. III for further safety instructions.

CAUTION: Operate all amplifiers only with a laser operation in mode-locked condition.

2.4.5 PHOTONIC CRYSTAL FIBER SETUP

The PCF setup is part of the M-VIS extension package (See chapter 2.4.4.).

A fixed mirror mount houses a dichroic mirror which splits off the fundamental part of the radiation and thus reflecting only the 780 nm radiation to the PCF. The not converted fundamental after the SHG is blocked. Two precision mirror mounts for beam steering are used to optimize the coupling into the PCF. A cage system, holding the in- and the out-coupling lens of the PCF, is directly mounted to the PCF fiber holder. The output of the PCF is free space.

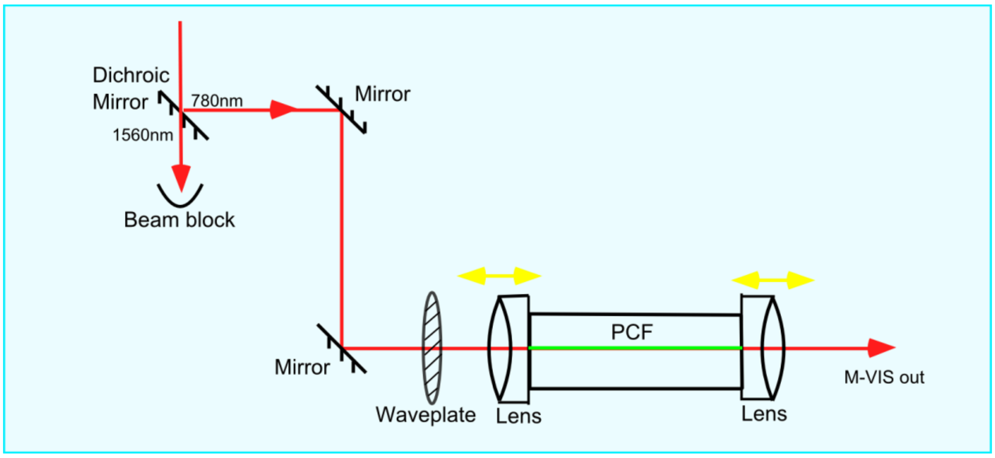


Figure 9: Schematic of the PCF setup. PCF: Photonic Crystal Fiber. Red: free-space radiation; Green: fiber connection; Yellow: direction of movement.

In addition, a half-wave plate at 780 nm is used for polarization control of the incident radiation, which slightly changes the spectrum structure after broadening.

CAUTION: The fiber setup should be handled with great care. It should not be touched with bare fingers. It should always be kept in a covered, dust-free place. If cleaning should be necessary for any reason, please contact Menlo Systems GmbH for further assistance.

CAUTION: If the coupling into the fiber is only partially achieved, up to 200 mW of the input radiation at 780 nm can be back-scattered and/or reflected from the fiber end. Take action to protect the environment against laser radiation. Wear appropriate safety goggles.

The actual shape of the broadened spectrum strongly depends on the optical power coupled into the fiber, the polarization at the fiber input and the shape of the spectrum (at 1.56 µm) before the frequency doubling. All mentioned parameters can be remotely controlled and optimized for convenient optimization of a beat note with an external CW laser.

2.4.6 M-780: BROADBAND FREQUENCY DOUBLING MODULE

The M-780 package consists of an amplifier P250 Pulse EDFA and its control unit AC1550 for high power generation at 1.56 µm. It also consists of free-space components to convert the 1.56 µm input radiation to the second harmonic at 780 nm. The main parts are aspheric focusing lenses and a special broadband frequency doubling crystal. The figure below shows the setup of the module.

With the translation stage of the aspheric lens after the crystal, the collimation of the output beam can be changed.

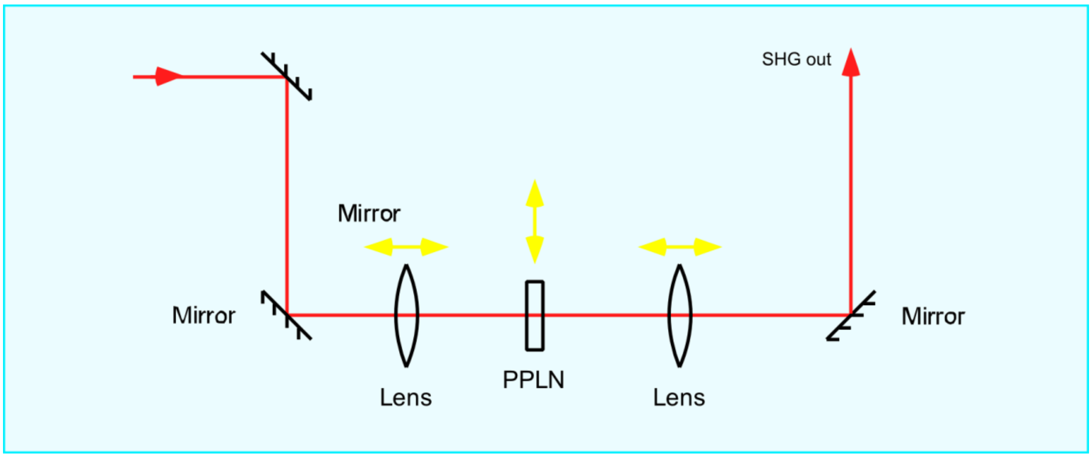


Figure 10: Schematic of the SHG frequency-doubling module. Red: free-space radiation; Yellow: direction of movement.

2.4.7 M-NIR: GENERATION OF AN OCTAVE-SPANNING SPECTRUM

The M-NIR EDFA is a high power fiber amplifier with internal spectral broadening of a 1.56 µm input spectrum to an octave-spanning spectrum from roughly 1 µm to 2.1 µm. This is accomplished by means of the effects in a Highly Non-Linear Fiber (HNLF). The output port is free-space.

The shape and width of the broadened spectrum can be modified with the pump currents of the amplifier. By changing the pump currents, it is possible to optimize the SNR of the beat signal with a cw-laser. The polarization of the output is polarization maintaining.

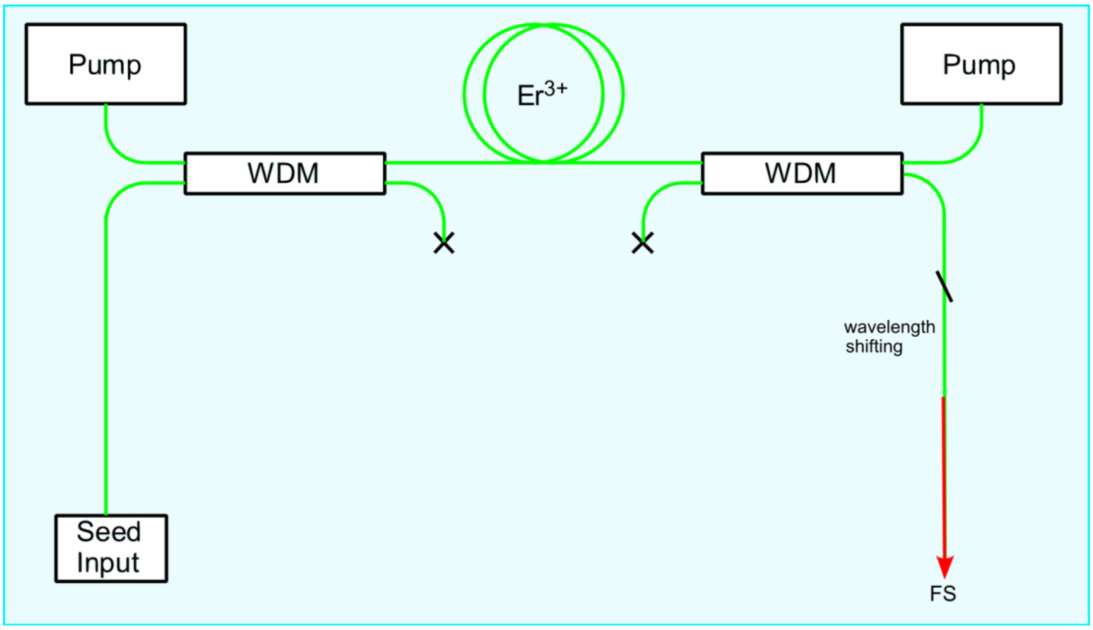


Figure 11: Schematic of the M-NIR EDFA with internal spectral broadening. WDM: Wavelength Division Multiplexer; HNLF: Highly Non-Linear Fiber. Green: fiber connection; Red: free-space radiation.

CAUTION: Depending on the pump currents, up to 600 mW of IR radiation can be emitted from either port of this amplifier. Take action to protect the environment against laser radiation. Wear appropriate safety goggles. See chap. III for further safety instructions.

CAUTION: Operate all amplifiers only with a laser operation in mode-locked condition.

2.4.8 P250-HMP-NIR/-VIS/-UV PULSE EDFA

The output of the P250-HMP EDFA provides high power output radiation shifted to either lower or higher wavelengths of the fundamental spectrum, using different physical effects. Additionally, an internal second or higher harmonic generation stage is possible. The output can be either freespace or fiber-coupled.

For the wavelengths lower than the fundamental, the output port is designed to provide high power radiation at this certain wavelength by a specific dispersion management together with appropriate lengths of highly nonlinear fibers at the amplifier outputs (see J.M.Dudley, G. Genty, Reviews of Modern Physics 78, 1135 (Oct-Nov 2006)).

For the wavelengths higher than the fundamental, the output port is designed to provide high power radiation at a certain wavelength via the so-called self-soliton Raman shift (see F.M.Mitschke, L.F. Mollenauer, Optics Letters 11, 659 (1986)). An increasing pump power shifts the output to larger wavelengths. The basic operation principle is as follows: in a special optical fiber spliced to the output of the EDFA, a soliton is formed which does not spread during further propagation. Due to a Raman process, the short wavelength end of the soliton pumps the long wavelength end, thus shifting the peak wavelength to higher values.

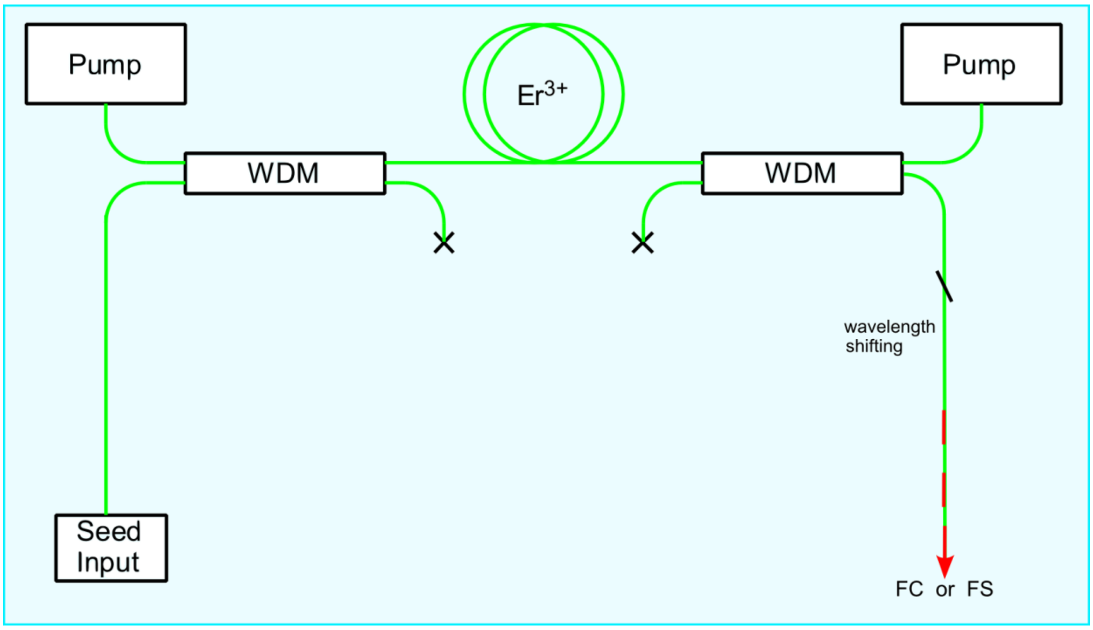


Figure 12: Schematic of the P250-HMP Pulse EDFA. WDM: Wavelength Division Multiplexer; Green: fiber connection; Red: free-space radiation

CAUTION: Depending on the pump currents, up to 600 mW of IR radiation can be emitted from the port of this amplifier. Take action to protect the environment against laser radiation. Wear appropriate safety goggles. See chap. III for further safety instructions.

CAUTION: Operate all amplifiers only with a laser operation in mode-locked condition.

2.4.9 BDU-FS: FREE-SPACE BEAT DETECTION UNIT

For generating and measuring beat notes between the frequency comb light and external CW lasers, the BDU-FS is a setup to spatially overlap both comb and cw laser light, to filter the broad spectrum accordingly and to finally detect the resulting beat note between the cw laser frequency and the adjacent comb mode.

The BDU-FS can be set up for a broad working range. The input beams can be either freespace or fiber-coupled.

Half-wave plates in both arms allow setting orthogonal polarizations in the two beams which leads to a combination after the Polarizing Beam Splitter cube. Another half-wave plate and a second PBS cube project the orthogonal polarizations of the two beams onto the same polarization axis. Afterwards, the comb light is filtered with a suitable grating and the beat signal is detected with a photodetector. Depending on the wavelength of the external CW laser and the power after the grating, the detector model is chosen. For a better SNR of the beat signal, it might be necessary to add a focusing lens and/or aperture in front of the detector.

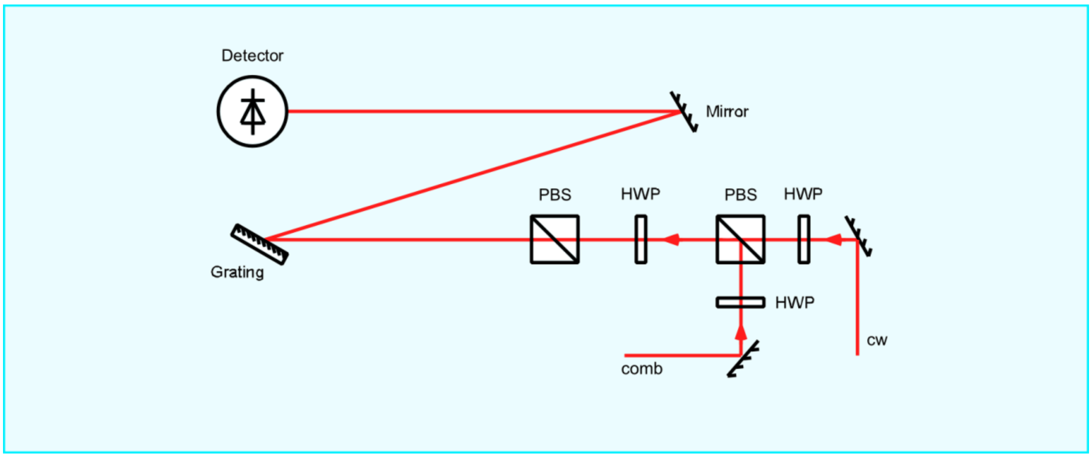


Figure 13: Schematic of the BDU-FS setup. HWP: Half-Wave Plate; PBS: Polarizing Beam Splitter cube. Red: free-space radiation.

2.4.10 BDU-FG: FIBER-COUPLED BEAT DETECTION UNIT WITH EXTERNAL GRATING

For generating and measuring a beat note between the comb light and an external laser, the BDU-FG is a setup to spatially overlap both comb and cw laser light, to filter the broad spectrum accordingly and to finally detect the resulting beat note between the cw laser frequency and the adjacent comb mode. The filtering and detection is performed with freespace optics for more flexibility.

The input beams can be either freespace or fiber-coupled.

The comb light is filtered with a suitable grating and the beat signal is detected with a photodetector. Depending on the wavelength of the external CW laser and the power after the grating, the detector model is chosen.

2.4.11 BDU-FF: FULLY FIBER-COUPLED BEAT DETECTION UNIT

For generating and measuring a beat note between the comb light and an external laser, the BDU-FF is a setup to spatially overlap both comb and cw laser light, to filter the broad spectrum accordingly and to finally detect the resulting beat note between the cw laser frequency and the adjacent comb mode.

The input beams can be either freespace or fiber-coupled.

The BDU-FF is all fiber-coupled and only works for a single wavelength which is known to a hundredth of a nanometer.

2.4.12 WLM-VIS/-IR WAVEMETER AND CALIBRATION SOURCE

The WLM-VIS/-IR Wavemeter is used to coarsely determine the wavelength of cw lasers. It can be automatically and regularly calibrated using the Wavelength Reference IR calibration source. Please, refer to the WLM-VIS/-IR and Wavelength Reference manuals for more detailed information. The wavemeter is controlled by the computer via USB.

2.5 ELECTRONICS OVERVIEW

The locking schemes for the repetition rate and the offset beat are schematically shown and explained below. There are some differences between FC1500-250 Option 1, 2 and plus. All synthsizers and counters are referenced to an external reference, e.g. atomic clock. The repetition rate and the CEO are thus phase-locked to the external reference.

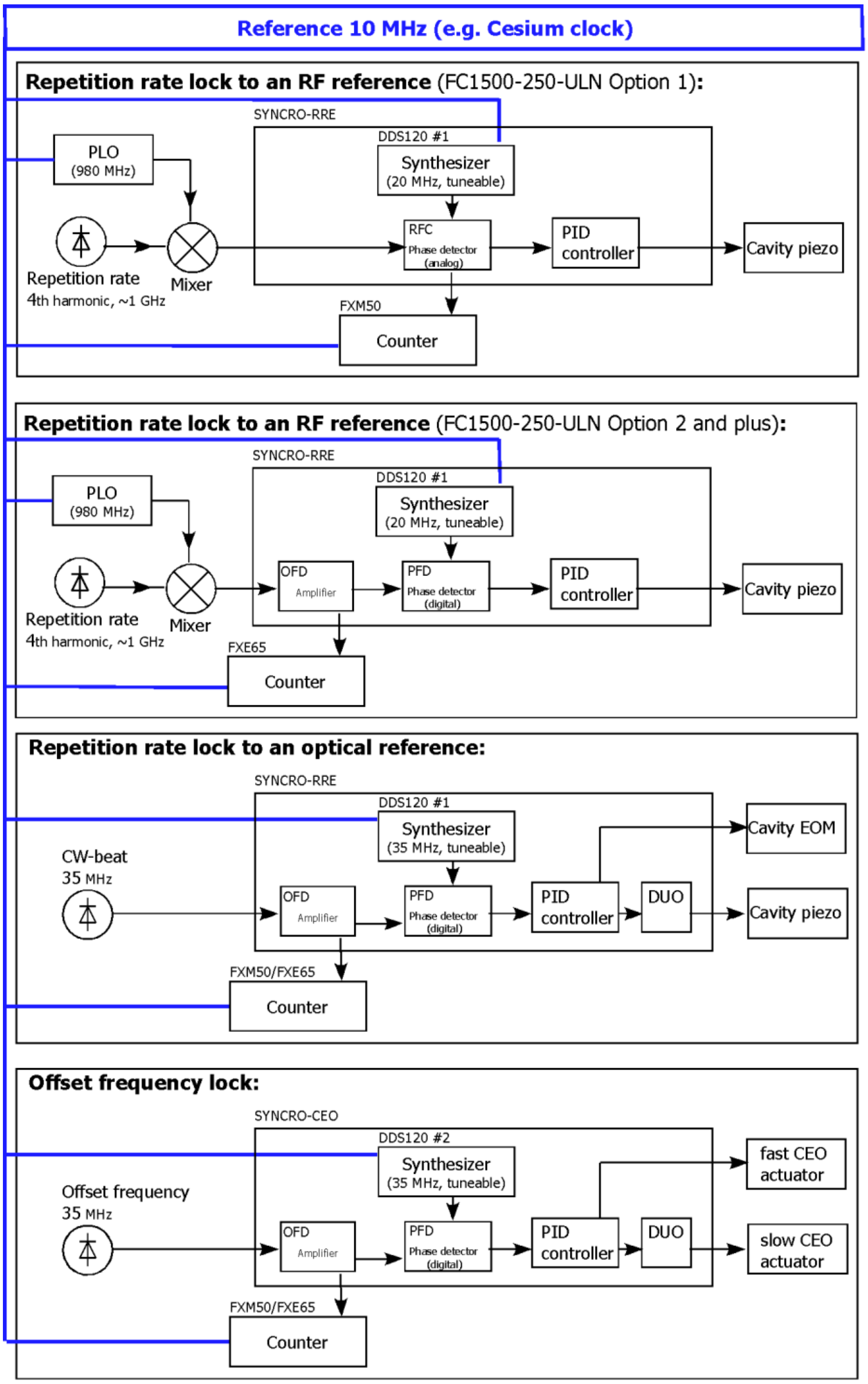


Figure 14: Electronic setup of the FC1500-250-ULN optical frequency synthesizer system. Blue: reference; Black: other electronic connections.

- **Repetition rate lock to an RF reference (for FC1500-250, Option 1):** For increased phase sensitivity, the fourth harmonic of the repetition rate at ~1 GHz is mixed with 980 MHz from a PLO (Phase Locked Oscillator - a very clean fixed frequency synthesizer) to a ~20 MHz intermediate frequency. This intermediate frequency is counted in the FXM50. In the RFC unit, it is further mixed to DC unit with a tunable low frequency synthesizer DDS. The output signal of the phase detector is fed into a PID circuit to establish a phase lock of the repetition rate to the external RF reference (via the synthesizer).

- **Repetition rate lock to an RF reference (for FC1500-250, Option 2 and plus):** For increased phase sensitivity, the fourth harmonic of the repetition rate at ~1 GHz is mixed with 980 MHz from a PLO (phase locked oscillator) to a ~20 MHz intermediate frequency. The OFD unit filters and amplifies the down-mixed repetition rate signal. One output is connected to the digital phase detector PFD which is referenced to the output of a tunable low frequency synthesizer DDS. Another output of the OFD unit is connected to the counter FXE65 for analysis. The output signal of the phase detector is fed into a PID circuit to establish a phase lock of the repetition rate to the external RF reference (via the synthesizer). One servo signal for the intra-cavity piezo is provided. The integrator within the DUO is bypassed for this purpose.

- **Repetition rate locked to an optical reference:** The repetition rate of the oscillator is adjusted in a way that the beat note between the frequency comb and an ultra-stable cw-laser is centered at ~35 MHz. The OFD unit filters and amplifies the beat signal. One output is connected to the digital phase detector PFD which is referenced to the output of a low frequency synthesizer DDS. Another output of the OFD unit provides the counter FXM50/FXE65 with its signal for analysis. The output signal of the phase detector is fed into a PID circuit to lock one comb tooth to the cw laser. Two servo signals are provided: A high bandwidth output for an intra-cavity EOM and a low bandwidth output via another integrator within the DUO for an intra-cavity piezo.

- **Carrier envelope offset frequency lock:** The carrier envelope offset (CEO) frequency is tuned to 35 MHz. The OFD unit filters and amplifies the offset beat signal. One output is connected to the digital phase detector PFD which is referenced to the output of a low frequency synthesizer DDS. Another output of the OFD unit provides its signal to the counter FXM50/FXE65 for analysis. The output signal of the phase detector is fed into a PID circuit to establish a phase lock of the carrier envelope offset to the external RF reference (via the synthesizer). Two servo signals are provided: A high bandwidth output for a fast CEO actuator and a low bandwidth output via another integrator within the DUO for a slow CEO actuator.

For further information about the lockboxes please refer to the SYNCRO manual.

2.6 ELECTRONICS IN DETAIL

2.6.1 LAC1550 UNIT

The LAC1550 controller unit includes the laser / amplifier diode driver electronics and a micro-controller for automated control of the fs fiber laser. The LAC1550 operation can be controlled via USB and the FiberCombControl software.

Please, refer to the fiber laser manual for detailed information.

CAUTION STATIC VOLTAGES: If the amplifiers and/or laser have to be disconnected from the controllers always disconnect the cables at the amplifier/laser side first. Otherwise the pump modules may suffer from static voltages.

2.6.2 AC1550 UNIT

The AC1550 includes up to three four-channel laser diode drivers for external EDFA units in the frequency comb system and up to six three-channel high voltage controllers.

The AC1550 operation can be controlled via USB and the FiberCombControl software. The status and settings of the pump diodes and high voltage lines are displayed in the front panel screen and can be adjusted by front panel controls or via FiberCombControl software.

Please, refer to the AC1550 manual for detailed information.

CAUTION STATIC VOLTAGES: If the amplifiers and/or laser have to be disconnected from the controllers always disconnect the cables at the amplifier/laser first. Otherwise the pump modules may suffer from static voltages.

2.6.3 RFD10 UNIT

The RFD10 unit distributes a 10-MHz reference signal (+5 to +10 dBm, e.g. from a primary frequency standard) to all referenced units (PLO, synthesizers, counters). The RFD10 features additional outputs with a frequency-doubled signal of 20 MHz. The reference signal must be supplied by the customer. The → *Ref Synthesizer* and → *Ref DRO* output ports are located at the backside of the unit.

A diode at the front panel indicates whether there is a sufficient RF power at the 10-MHz input port.

The unit is mounted at the backside of the electronics rack and requires +5 V DC and +15 V DC, with a corresponding current consumption of 30 mA and 150 mA, respectively. All connectors are 50 Ohms coupled.

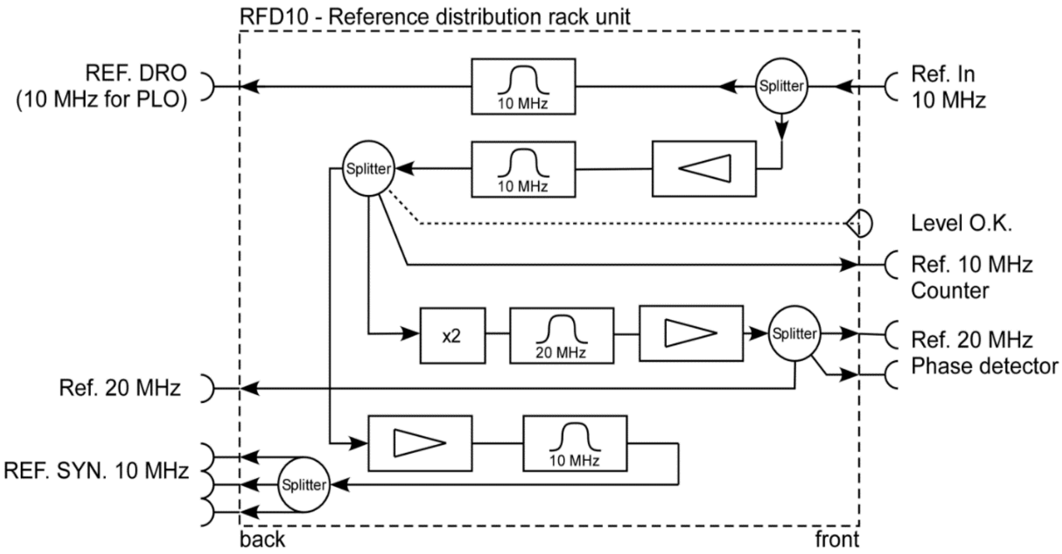


Figure 15: Schematic of the RFD10 unit. The actual number of outputs may differ for your system.

2.6.4 SYNCRO ("LOCKBOX") UNIT

The SYNCRO is a universal Phase Locked Loop (PLL) mainframe featuring a versatile Proportional Integral Differential (PID) loop filter. It is capable of housing different modules for signal conditioning. Therefore, it can be equipped with modules, so that it is able to lock the repetition rate, the CEO or even external cw lasers.

Please, refer to the SYNCRO manual for detailed information.

2.6.5 RF SPECTRUM ANALYZER

The HMS-X spectrum analyzer is used to visualize a beat signal. Please, refer to the HMS-X manual for detailed information.

2.6.6 OSCILLOSCOPE

The Agilent Technologies DSO1052B / DSOX2004A 2-and 4- channel oscilloscopes are used to visualize the error signals of the phase-locked loops. Please, refer to the oscilloscope manual for detailed information.

2.7 SOFTWARE AND AUTOMATION

The FC1500-250-ULN package includes software control for the complete system. The frequency comb system can be controlled directly at the control units or remotely via software, see FiberCombControl manual for more details.

The CombWatch software is provided for monitoring and logging purposes. It logs the data over time and directly calculates and plots different mathematical formulas, e.g. the Allan Deviation.

For hands off 24/7 operation the frequency comb is equipped with an automation function.

The repetition rate can be controlled in 4 ways with different step sizes and locking bandwidths:

- The stepper motor can set the repetition rate to any value in the specified range It is only used for large changes not during locks and it cannot be varied in the SYNCRO. It can be only accessed via FiberCombControl software.
- The temperature of the fiber box is used to keep the lockbox centered. It is limited to a working range of 23-27°C.
- The piezo is the slow actuator for locking the repetion rate.
- The EOM has the smallest effect on the repetition rate but it is the fast actuator for locking the repetition rate with highest bandwidth. It is only used for locking to an optical reference.

The carrier envelope offset beat is controlled by:

- A slow actuator with a large travel range
- A fast actuator for high locking bandwidth

Both actuators are directly controlled by the SYNCRO-CEO.

2.8 FC1500-250-ULN LASER HAZARD CLASSIFICATION AND LASER SAFETY

2.8.1 SAFETY LABELS AND SYMBOLS ON THE LASER

Next to each output there are labels that indicate what kind of radiation is expected.

Label / Symbol	Location on the laser
	Next to all optical outputs
AVOID EXPOSURE LASER RADIATION IS EMITTED FROM THIS APERTURE	Next to all optical outputs
INVISIBLE LASER RADIATION AVOID EXPOSURE TO BEAM CLASS 3B LASER PRODUCT	Front side of the laser head
AVERAGE OUTPUT POWER <500mW PULSE DURATION <2ps EMITTED WAVELENGTH 1450-1650nm EN 60825-1:2007	M-Comb Front side of the laser head
AVERAGE OUTPUT POWER < 500mW PULSE DURATION <2ps EMITTED WAVELENGTH 760-2500nm EN 60825-1:2007	P250-XPS EDFA; P250 EDFA internal SHG; M780 SHGxxx frequency doubling module; P250-HMP/-SCG EDFA Front side of the laser head
AVERAGE OUTPUT POWER <500mW PULSE DURATION <2ps EMITTED WAVELENGTH 1450-1650nm EN 60825-1:2007	P250 EDFA Front side of the laser head

2.8.2 SAFETY FEATURES

Several safety features are foreseen to avoid laser radiation accidents:

- Key operated mains switch at the control units.
- Interlock circuit.

- Optical emission indicator at the control unit.
- Mechanical shutter at free-space output ports at the laser head.
- Metal caps at fiber output ports at the laser head.

2.9 CONNECTORS AND CONTROLS

All connectors of your system are listed in the CUSTOMER SYSTEM DETAILS.

2.10 SPECIFICATIONS

For the FC1500-250-ULN, Option 2 the following specifications are achieved. For details about the differences between the available options, please refer to the individual specs sheets:

Main Output Type	
Comb Spacing	250 MHz
Accuracy	1 x 10^{-17} in 100 s
Stability (modified Allan deviation)	1 x 10^{-16} in 1s, 1 x 10^{-18} in 1000 s
Integrated phase noise	<100 mrad [100 Hz-2 MHz]
Linewidth (optically locked)	<1 Hz (limited by resolution bandwidth of analyzer)
Tuning Range of Spacing Between Individual Comb Lines	> 2 MHz
Tuning Range of CEO Frequency	> 250 MHz
Optical Output	five fiber-coupled, linearly polarized, PM output ports
Central Wavelength	(1560±20) nm
Spectral Range	> 25 nm
Average Output Power	> 12 mW from each laser port

Electrical and Environmental specifications	
Mains voltage	100 / 115 / 230 VAC
Frequency	50 to 60 Hz
Maximum power consumption	<500 W <3 kW including chiller
Operating temperature	22 ± 5 °C
Storage temperature	0…+40 °C
Relative humidity	Maximum 90% up to 31°C decreasing to 50% at 40°C
Pollution degree	2
Operational altitude	< 2000 m

Dimensions	
Dimensions of the electronics rack (depending on configuration)	Mounted in a 19” rack cabinet: either 800 x 600 x 1700 mm or 800 x 600 x 1900 mm
Weight of the electronics rack (depending on configuration)	170-200 kg
Dimensions of the optical part (depending on configuration)	716 x 706 x 139 mm or 826 x 706 x 139 mm or 976 x 706 x 139 mm
Weight of the optical part (depending on configuration)	60-100 kg

2.11 TECHNICAL DRAWINGS

2.11.1 OPTICAL TECHNICAL DRAWING

The base-plate shown in the figure in the test report contains all optics and laser sources to generate high power radiation in the near infrared and, depending on the extensions ordered, in the visible spectral range.

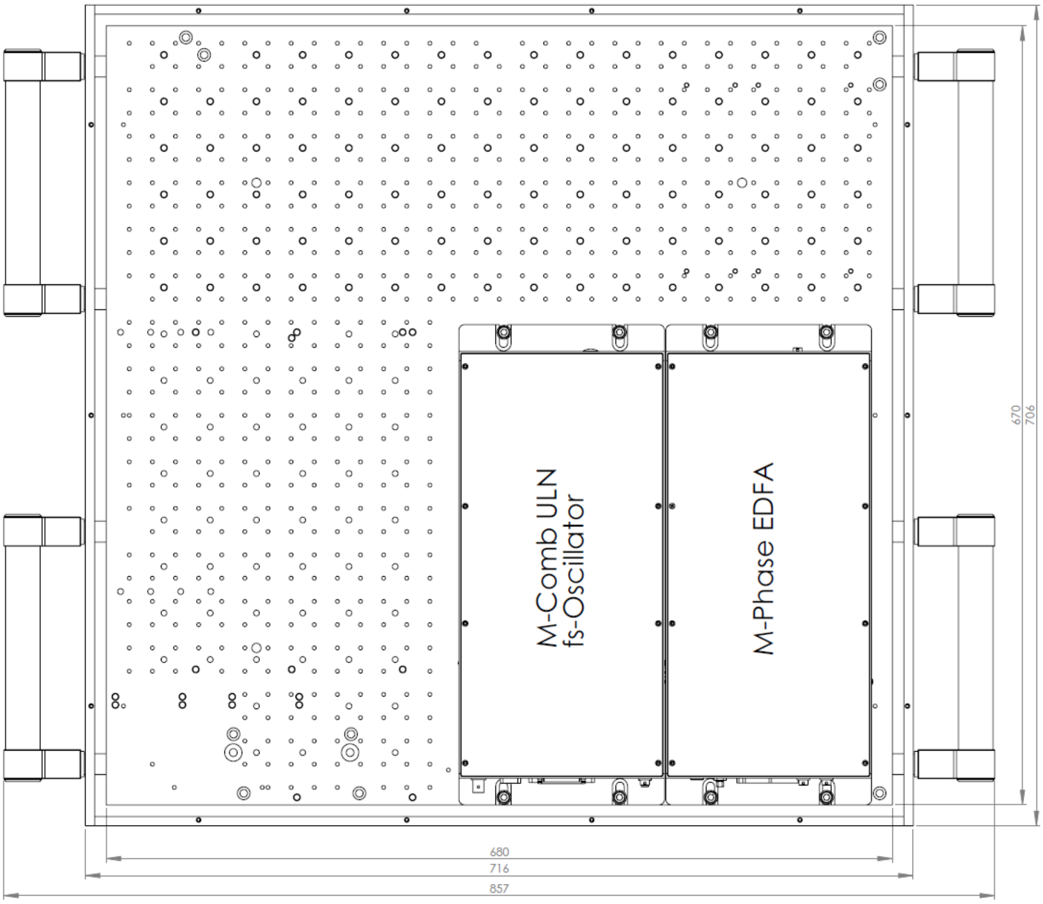


Figure 16: The standard configuration of the standard OFC configuration.
fs: femto second; EDFA: Erbium Doped Fiber Amplifier;
You´ll find the sketch of the setup of your system in the customer system details that is added to the test report.

2.11.2 ELECTRONIC TECHNICAL DRAWING

The electronics rack in the figure below contains the standard configuration depending on the extensions ordered. The height of your rack or the configuration might differ.

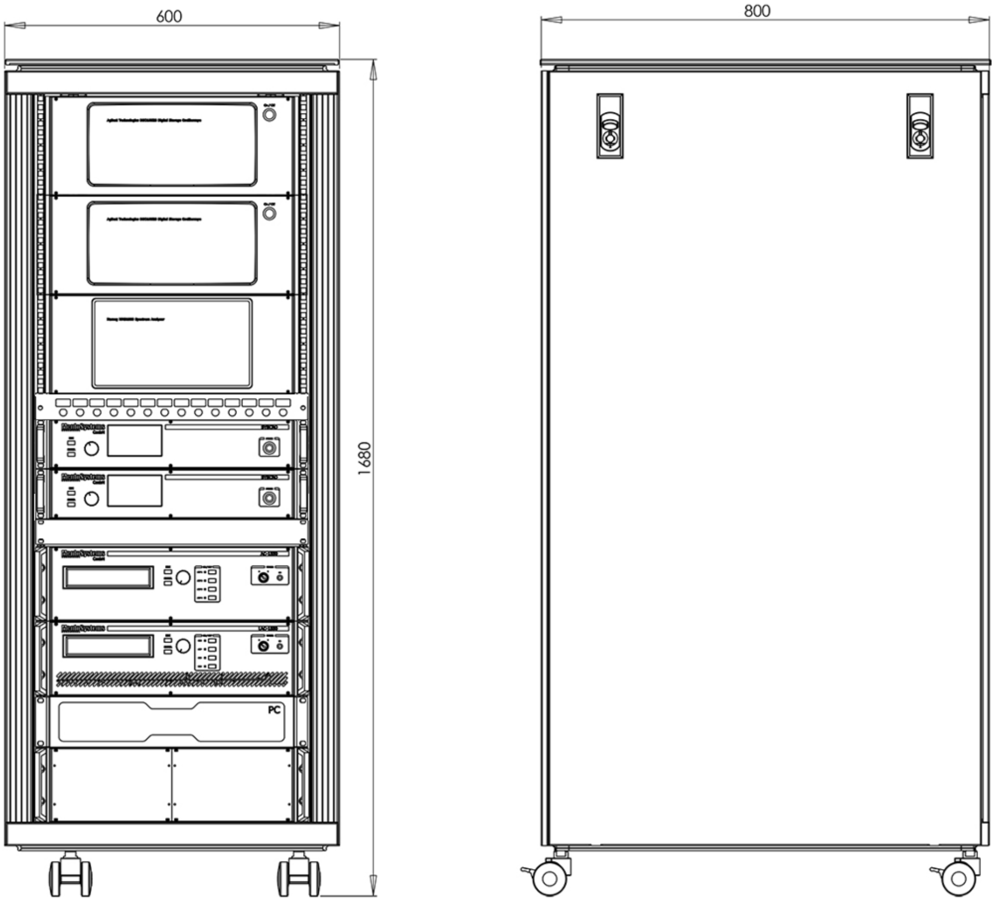


Figure 17: Mechanical setup of the FC1500 optical frequency synthesizer´s electronic rack

In the front of the rack you will find the following modules from top to bottom:

- 2x Spectrum Analyzer (One is optional with the optical lock)
- Oscilloscope
- SYNCRO-RRE
- SYNCRO-CEO
- A feed through bar to get signal from the backside of the rack to the frontside
- AC1550 control unit (optional)
- LAC1550 control unit
- Computer

In the back of the rack, further modules are mounted, which don't neet direct access:

- FXM50/FXE65 counter
- Reference distribution RFD10
- Interlock
- Power supplies

3. INSTALLATION

A Menlo Systems service engineer will be there for installation, first operation and user training.

***Note:* To prevent humidity condensation after unpacking, if the laser was stored or shipped at low temperatures, leave the system in its original packaging in a room until it reaches room temperature.**

For the optical frequency comb setup:

- Unpack both the electronics and the optical setup
- Place the optical setup of the optical frequency comb on an optical table and place the 19" rack next to it
- Mount the baseplate of the optical frequency comb to the optical table. Included in the delivery are M6 metric and imperial screws to mount the frequency comb´s baseplate on an optical table
- Remove the handles from the baseplate. They should only be mounted for transportation purposes. Rubber pins to close the holes are included in the accessories box.
- Check if the mains voltage selector on the rear panel of the LAC1550 / AC1550 /FXM/FXE rack /RFD10 rack are set to your local mains voltage. If the mains voltage selector is not set to the right mains voltage change the setting as described in section 5.1
- Connect the rack to the mains before you start wiring the system.
- Connect the cables on the electronics rack first. Afterwards, connect the cables between the electronics rack and the optical part according to the list in the “Customer System Details”. All cables and connectors are labeled.
- Unpack the accessories and set up the monitor, the keyboard and mouse

4. OPERATION

4.1 START-UP PROCEDURE:

At the backside of the rack, when the back wall is open:

- Switch on the interlock by turning the key "MAIN SWITCH" on the backside of the electronics rack
- Switch on the multi-outlet power strip at the backside of the electronics rack

Go to the front side of the electronics rack:

- Switch on the computer by pushing the ON button
- Switch on the monitor
- Switch on the LAC1550 by turning the key to I
- (Optional) Switch on the AC1550 by turning the key to I
- Switch on the SYNCROs by pushing the POWER buttons
- Switch on the oscilloscope by pushing the ON button
- Switch on the RF spectrum analyzers by pushing the ON button
- Switch on the Fiber Comb Control software on your computer with the short cut on the desktop
- Wait for the SYS LED light on the LAC1550 to stop blinking orange and turn green. That means the laser temperature has stabilized. The laser can now be switched on. Refer to section 6.1 and the following sections for more details
- After the laser is modelocked the amplifiers can be switched on
- Lock the CEO beat and the repetition rate

To switch off the system follow the start-up procedure in reverse order.

4.2 LONG-TERM OPERATION

The laser is developed and produced to run 24/7. It can run all times. Also the P250-XPS, that generates the CEO beat can run all times.

For safety aspects, it is recommended to switch off all other amplifiers when they are not in use.

5. MAINTENANCE

The standard configuration of the FC1500-250-ULN system is maintenance free. It does not have user-serviceable parts.

5.1 MAINS VOLTAGE SELECTION FUSE REPLACEMENT

The FC1500-250-ULN must be operated with mains fuses appropriate for the local mains voltage. If Menlo Systems is informed, Menlo Systems will deliver the frequency comb system with the fuses for the country-specific mains voltage.

Use only 5x20 mm cartridge fuses rated for the mains voltage with slow response and high breaking capacity (IEC60127-2/V). The appropriate fuse types dependent on the mains voltage are:

Unit	Fuse Type for mains voltage 100-120V	Fuse Type for mains voltage 230V
LAC1550 / AC1550	T6.3A	T3.15A
FXM50 rack	T2A	T1A
FXE65 rack	T2,5A	T1.25A
RFD10 rack	T2A	T1A

In order to change the fuses or change the mains voltage setting, do the following:

- Turn off the complete frequency comb and all units (switch control position OFF) See chapter 4.1 for details.
- Disconnect all cables from the laser head connectors labeled with Pump Control x in order to prevent static charges
- Remove the AC power cord of the FC1500 rack
- Pull out the fuse holder of the counter rack, the RFD10 rack, the LAC1550 and the AC1550 (if available).
- Replace the fuses

- **Step 1:** Remove the fuse holder by pressing the small clip down with a screwdriver and pulling out the fuse holder.

- **Step 2:** Remove the fuse holder and its two active fuses completely and pull out the white plastic inlay of the fuse-holder.
- **Step 3:** Re-insert the white plastic inlay in such a way, that the desired line voltage gets visible in the small window of the fuse-holder.
- **Step 4:** Put in the two fuses with the appropriate values and push back the fuse holder until it is locked in position again.

- Connect the AC power cord of the FC1500 rack again
- Connect the cables to the pump modules, labelled “Pump Control x”
- Switch the rack back on

5.2 CONNECTING OPTICAL FIBERS

At the tip of the output fiber very significant laser intensity can be present. Even the slightest scratch or dust particle in this area can result in the fiber being destroyed by its own output power when the laser is switched on. Also, stray back reflections can create small burns that darken the fiber resulting in a catastrophic failure of the fiber.

Handle the fiber with the utmost care!

- Never operate the laser at any power level with a protective cap on the output fiber
- Connect the fiber cable only when the corresponding amplifier or oscillator is switched off
- Make sure to use fibers with the correct type of connector and a matching fiber type for the connections you make. Typically all optical monitor ports in the scientific line oscillators are using FC/APC connectors and SMF28 fibers
- Every single time you connect the output fiber to another fiber or another optical component clean both the fiber tip and the other optical component. Use the provided fiber cleaner (FCRC from FIS) delivered with your system

- Regularly check the fiber condition with a (fiber) microscope. Switch off all electronics and disconnect the pump cables (labelled “Pump Control x”) for laser safety reasons. If you notice any dust, clean it. If you notice any surface defects, replace the fiber with a new one. Connecting a dirty or damaged fiber to a clean and good one will destroy the latter as well

  CAUTION: FC/APC connectors have to be plugged in with the correct angular orientation. While inserting the output fiber into an FC/APC receptacle, make sure the fiber is in correct alignment along the axis.

- Never leave output fibers lying around or exposed to free airflow without a protective cap

- Make sure that the fiber is under no circumstances (even for short moments) forced into a bend radius < 20mm (0.8 inch)

- Make sure that the fiber is never clamped or squeezed with great force or by sharp edges

- If you connect a fiber to another fiber: only use FC/APC fiber cables and receptacles. Never mix two types of fiber connectors, for example FC/APC with FC/PC. Never use a type changing cable FC/APC to FC/PC.

To clean your fiber tip please follow the steps below:

1. Press the push button on the Fiber cleaner (the cleaning area will open and advance the cloth automatically)

2. Remove the protective plastic cap of your connector. Clean the fiber tip by moving the tip of the connector over the cloth in the cleaning area in the direction indicated by the arrow on the cleaner.

3. Release the push button in order to close the cover of the fiber cleaner after cleaning

CAUTION: Use the cloth surface only once for each cleaning procedure to make sure that no dirt will be placed on your fiber tip.

5.3 GENERAL CLEANING

The outside of the laser head and the control unit can be cleaned with a cloth dampened with a small amount of water and a mild soap.

6. TROUBLESHOOTING

This section lists error conditions users may be able to troubleshoot themselves. If the information in this section does not help to fix the issue, please contact Menlo Systems support team using the contact information at the end of this manual (see chapter **Fehler! Verweisquelle konnte nicht gefunden werden.**).

6.1 THE LASER MODELOCK STATE

6.1.1 MLD/AC AND DC VALUES

The laser´s modelock state is described by two parameters. The MLD/AC and the DC value. Please compare your actual values to the values in the test report. If those values show a huge difference, please do also compare the monitor of the pump currents on the LAC1550 display with the values in the test report.

A change of the AC value of up to about 20 counts or about 1% is uncritical.

6.1.2 TEMPERATURE

Another important parameter is the fiber box temperature, please compare it to the value in the test report if you find the laser parameters conspicuous. If the temperature is far (several degrees) off the preset value after delivery, please move the temperature controller in the FiberCombControl software to get the temperature back close to the value at delivery. The fiber box temperature is supposed to be operated between 23 °C and 27 °C.

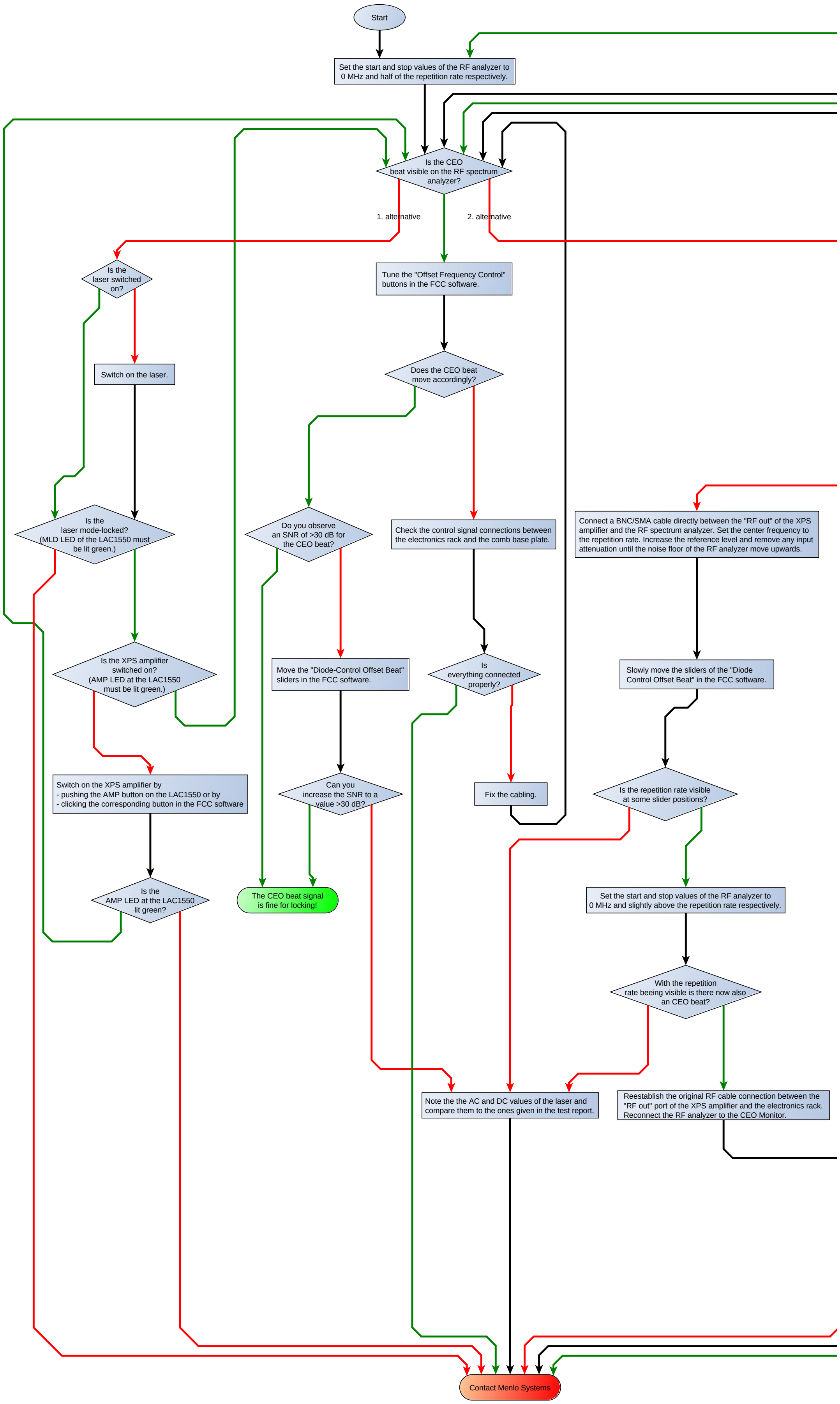
6.2 THE CARRIER ENVELOPE OFFSET BEAT

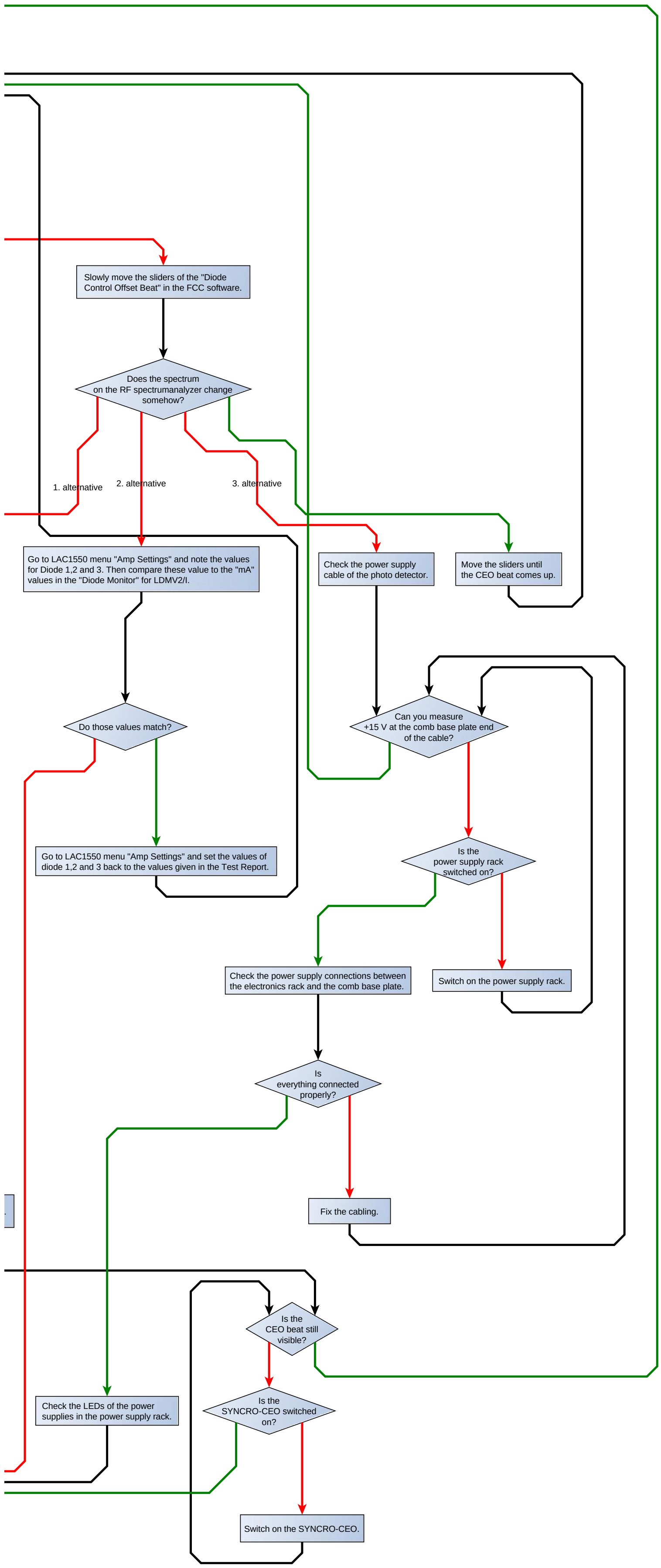
6.2.1 FIND AND OPTIMIZE THE SNR OF THE CEO BEAT

The following two pages show a procedure of how to find the CEO beat and find possible reasons if it is not visible. There are some abbreviations used in the flow chart:

- CEO: Carrier Envelope Offset
- FCC: Fiber Comb Control (software)
- SNR: Signal to Noise Ratio

Follow the green lines if answering questions with “yes” and follow the red lines otherwise. In some cases you have several alternative choices.


Start
Set the start and stop values of the RF analyzer to 0 MHz and half of the repetition rate respectively.
Is the CEO beat visible on the RF spectrum analyzer?
1. alternative
2. alternative
Is the laser switched on?
Switch on the laser.
Tune the "Offset Frequency Control" buttons in the FCC software.
Does the CEO beat move accordingly?
Is the laser mode-locked? (MLD LED of the LAC1550 must be lit green.)
Do you observe an SNR of >30 dB for the CEO beat?
Check the control signal connections between the electronics rack and the comb base plate.
Connect a BNC/SMA cable directly between the "RF out" of the XPS amplifier and the RF spectrum analyzer. Set the center frequency to the repetition rate. Increase the reference level and remove any input attenuation until the noise floor of the RF analyzer move upwards.
Is the XPS amplifier switched on? (AMP LED at the LAC1550 must be lit green.)
Move the "Diode-Control Offset Beat" sliders in the FCC software.
Is everything connected properly?
Slowly move the sliders of the "Diode Control Offset Beat" in the FCC software.
Switch on the XPS amplifier by
- pushing the AMP button on the LAC1550 or by
- clicking the corresponding button in the FCC software
Can you increase the SNR to a value >30 dB?
Fix the cabling.
Is the repetition rate visible at some slider positions?
Is the AMP LED at the LAC1550 lit green?
The CEO beat signal is fine for locking!
Set the start and stop values of the RF analyzer to 0 MHz and slightly above the repetition rate respectively.
With the repetition rate beeing visible is there now also an CEO beat?
Note the the AC and DC values of the laser and compare them to the ones given in the test report.
Reestablish the original RF cable connection between the "RF out" port of the XPS amplifier and the electronics rack. Reconnect the RF analyzer to the CEO Monitor.
Contact Menlo Systems


Slowly move the sliders of the "Diode Control Offset Beat" in the FCC software.
Does the spectrum on the RF spectrumanalyzer change somehow?
1. alternative
2. alternative
3. alternative
Go to LAC1550 menu "Amp Settings" and note the values for Diode 1,2 and 3. Then compare these value to the "mA" values in the "Diode Monitor" for LDMV2/I.
Check the power supply cable of the photo detector.
Move the sliders until the CEO beat comes up.
Do those values match?
Can you measure +15 V at the comb base plate end of the cable?
Go to LAC1550 menu "Amp Settings" and set the values of diode 1,2 and 3 back to the values given in the Test Report.
Is the power supply rack switched on?
Check the power supply connections between the electronics rack and the comb base plate.
Switch on the power supply rack.
Is everything connected properly?
Fix the cabling.
Is the CEO beat still visible?
Is the SYNCRO-CEO switched on?
Check the LEDs of the power supplies in the power supply rack.
Switch on the SYNCRO-CEO.

6.2.2 OFD DC VALUE

The electronic translation of the value for the SNR of the offset beat signal is the DC value shown in the FiberCombControl software. This value is used for automation purposes.

Please optimize it before starting the auto control function in order to achieve best results with the phase detector PFD.

6.3 LOCKING THE COMB

6.3.1 RF-LOCK

- First improve the SNR of the CEO frequency peaks by alternating the pump currents via the “Diode-Control Offset Beat” sliders in the Fiber Comb Control software or the LAC1550’s *Amp. Settings* menu. At least 35 dB in 100 kHz bandwidth are required, the more, the better. Check the *Slow Output* voltage of the SYNCRO-CEO and recenter it. Use that or, alternatively, the *Offset Frequency Control* buttons in the Fiber Comb Control software to move the CEO beat into the vicinity (±1 MHz) of the reference frequency given by the DDS (e.g. 35 MHz). You can use either the RF analyzer or the *Counter View* of the Fiber Comb Control software for this purpose. The period of the error signal should get significantly longer.

- Check the *Slow Output* voltage of the SYNCRO-RRE and recenter it. Use the *Counter View* in the Fiber Comb Control software to monitor the down-mixed repetition rate. Use the *Repetition Rate Control* buttons in the FiberCombControl software to move the repetition rate into the vicinity (±100 Hz) of the reference frequency given by the DDS (e.g. 20 MHz). Alternatively you can set the synthesizer frequency to the actual value of the down-mixed repetition rate. The period of the error signal should get significantly longer.

- Engage the CEO frequency and repetition rate locks. Check the error signals, they should be slightly noisy around the respective zero. If not, check whether both the repetition rate and offset frequency can be freely tuned using the respective *Slow Output* and *Fast Output* voltage controller of the SYNCROs, and whether these are centered. If the CEO frequency lock error signal shows large excursions, change the sign of the phase-locked loop by flipping the plus/minus sign in the SYNCRO’s Home menu or PID menu.

- Check the counter readings. The repetition rate reading should be equal to the synthesizer reading with deviations only on the millihertz digit. The CEO frequency reading should be 35 MHz with deviations below 100 mHz. If the counter readings are different, check the locking circuits and the excursions of the error signals.

6.3.2 OPTICAL LOCK

- First improve the SNR of the CEO frequency peaks by alternating the pump currents via the “Diode-Control Offset Beat” sliders in the Fiber Comb Control software or the LAC1550’s *Amp. Settings* menu. At least 35 dB in 100 kHz bandwidth are required, the more, the better. Check the *Slow Output* voltage of the SYNCRO-CEO and recenter it. Use it or, alternatively, the *Offset Frequency Control* buttons in the Fiber Comb Control software to move the CEO beat into the vicinity (±1 MHz) of the reference frequency given by the DDS (e.g. 35 MHz). You can use either the RF analyzer or the *Counter View* of the Fiber Comb Control software for this purpose. The period of the error signal should get significantly longer.

- First improve the SNR of the CW beat. At least 35 dB in 100 kHz bandwidth are required, the more, the better. Check the *Slow Output* voltage of the SYNCRO-RRE and recenter it. Use that or, alternatively, the *Repetition Rate Control* buttons in the FiberCombControl software to move the CW beat into the vicinity (±1 MHz) of the reference frequency given by the DDS (e.g. 35 MHz). You can use either the RF analyzer or the *Counter View* of the Fiber Comb Control software for this purpose. The period of the error signal should get significantly longer.

- Engage the CEO frequency and CW beat frequency locks. Check the error signals, they should be slightly noisy around the respective zero. If not, check whether both the CW beat frequency and offset frequency can be freely tuned using the respective *Slow Output* and *Fast Output* voltage controller of the SYNCROs, and whether these are centered. If the CEO and CW beat frequency lock error signals show large excursions, change the signs of the phase-locked loops by flipping the plus/minus sign in the SYNCROs’ Home menu or PID menu.

- Check the counter readings. Both the CEO and CW beat frequency reading should be 35 MHz with deviations below 100 mHz. If the counter readings are different, check the locking circuits and the excursions of the error signals.

6.3.3 STABILITY

In order reach high long term stabilities in the order of the 10E-17, it is absolutely necessary to control, fix and temperature stabilize all fibers.

Vibrations and temperature fluctuations change the index of refraction of the fibers, which plays a huge role at measurements with such high stabilities.

6.4 ALIGNING THE PCF

The PCF setup is pre-aligned and only little adjustments should be necessary on a days scale. Anyway, if somehow you lose the alignment, please follow the alignment procedure below.

6.4.1 PRE-ALIGNMENT

- Remove the output coupling objective (after the PCF) by sliding it away from the PCF with the translation stage

  CAUTION: The working distance between the PCF and output objective is in the order of millimeters. Take extreme care when removing the objective.

- Guide the seed light at 780 nm from the frequency comb through the in-coupling lens (mounted on the PCF cage system) without clipping. Use the two precision mirror mounts installed before the cage system. If necessary, remove the in-coupling lens to verify the correct alignment of the beam

- The working distance between the in-coupling lens and the input side of the PCF is approximately 3 to 4 mm. Check that the distance between the PCF and the lens is about 1mm longer than the correct working distance (i.e.: 4 to 5 mm). Verify that the side of the PCF with the slope is facing the in-coupling lens

  CAUTION: A white paper card should be placed above the PCF holder because there might be some light reflected from the in-coupling facet.

- The easiest way to pre-align the light into the PCF is using a test laser that shines throught the PCF from the back side. You can use a laser pointer, a multimode fiber and a collimation package, as shown in Figure 18.

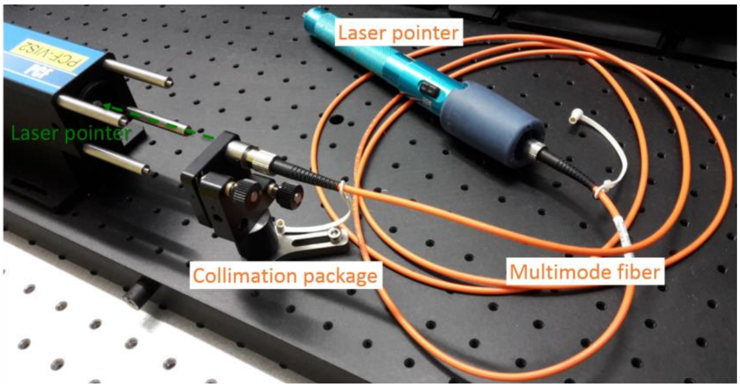
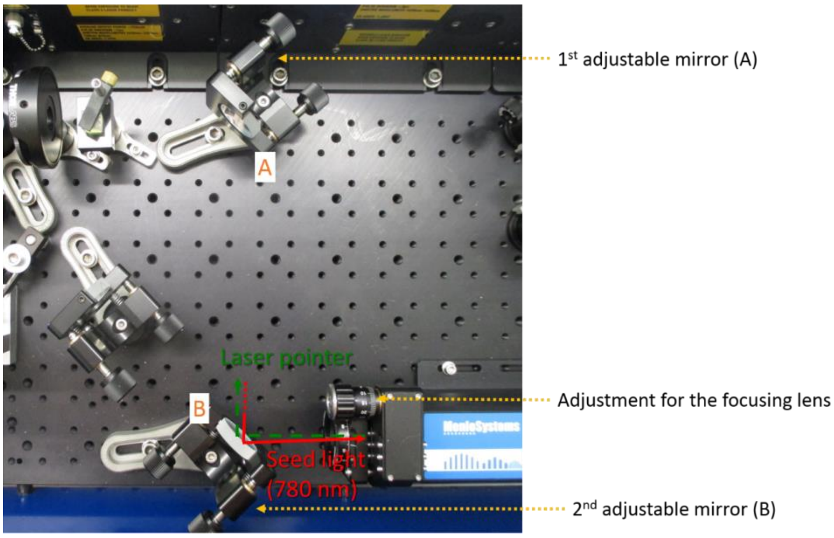
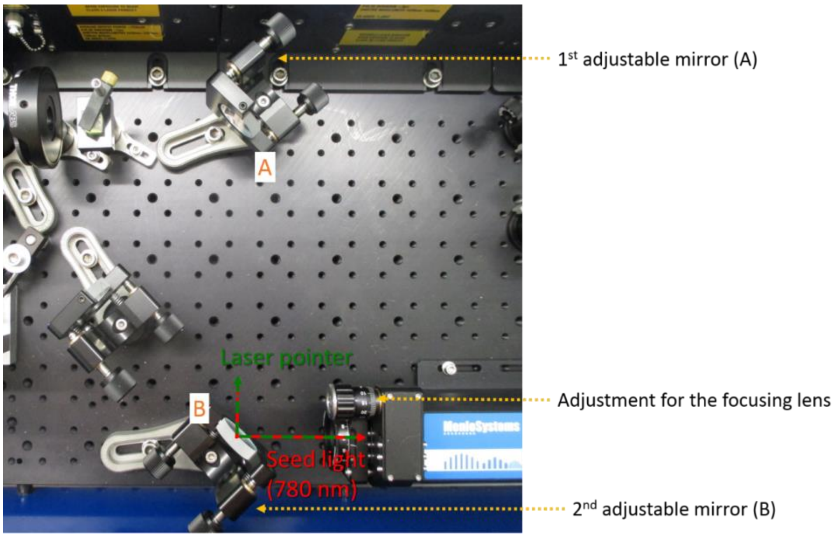


Figure 18: Incoupling of laser pointer light from the backside of the PCF.

- Then, the seed light at 780 nm from the frequency comb can be directly overlapped with light from the laser pointer, see Figure 19(1) and (2). Use mirrors A and B to achieve the overlap of the two beams in the space between mirror B and the PCF holder.



(1)



(2)

Figure 19: Light from the laser pointer and the seed light at 780 nm from the frequency comb are initially not overlapping (1). The overlap can be achieved by using the adjustable mirrors A and B (2).

- Without an IR Viewer, coupling through the fiber can be quite difficult. You should definitely have an IR viewer in the lab (Menlo Systems uses the 84499 from FJW Optical Systems, Inc. or the “NightVision” from Conrad, but others will do as well). You might try with an IR card, but the coupling is not easy to see.

  CAUTION: Wear laser googles as protection against the 780 nm SHG radiation.

6.4.2 ALIGNMENT PROCEDURE: CLADDING COUPLING

- After you achieve the overlap between the seed light at 780 nm and the light from the laser pointer, remove the laser pointer
- Place a white card vertically to visualize the beam after the PCF

- Use an IR viewer and try to get some light through the PCF setup by using the two adjustable mirrors before the PCF. First, the in-coupling lens and the first few millimeters of the PCF begin to glow. This glowing can be extended along the full PCF length by performing a beam walk with the adjustable mirrors, initially without caring about the focus position.

- At the beginning, you usually get the light through the cladding instead of through the core. This gives you some round structure on the card after the PCF.

- You should try to make the round structure symmetric and diffuse with the beam walk and by adjusting the focus position, until it starts to glow brightly.

  CAUTION: Do not hit the PCF with the in-coupling lens. It would irremediably damage the PCF.

a) b) c)

Figure 20: a) IR image of the cladding mode, a bright sharp dot inside a ring. b) IR image of the out coupling mode, core and cladding mode are mixed. c) IR image of the core mode.

- Place a power meter at the PCF's output, set at 780 nm. Optimize the transmitted power through the PCF by continuing to perform the beam walk and adjusting the focus position, until a maximum is reached. Typically the transmission should be higher than 50 %, unless otherwise specified by Menlo Systems.

6.5 ADJUSTING CW BEAT SIGNALS

A beat signal between a cw laser and your optical frequency comb can be detected by overlapping the two beams and optimizing the matching between the two laser modes. There are several methods to do this. Depending on the kind of BDU, a few things need to be checked.

6.5.1 BDU-FF: FULLY FIBER-COUPLED BEAT DETECTION UNIT

- Connect the comb light to the fiber input port “comb”

- Check that the repetition rate (250 MHz) is visible on the spectrum analyzer. Optimize the signal if necessary by changing the pump currents of the amplifier, the SHG alignment or any other parameters from the comb.

  NOTE: You may need to connect the output of the photodetector directly to the spectrum analyzer to by-pass eventual band-pass and low-pass filters contained in the electronics in order to visualize RF signals around 250 MHz.

- Connect the cw laser light to the fiber input port “cw”
- Adjust the power of the cw laser until you get a beat signal

  NOTE: The wavelength of the cw laser has to be close (accuracy +/- 0.1 nm) to the specified value.

  NOTE: If there are several RF signals at the photodiode output, change the comb repetition rate - only the CW beat note will move, other peaks will remain at the same frequencies.

6.5.2 BDU-FG: FIBER-COUPLED BEAT DETECTION UNIT WITH EXTERNAL FILTERING

- Connect the cw laser light to the fiber input port “cw”
- You’ll see the cw laser light exit the collimation package and hit the diffraction grating
- Find the first order of diffraction and send it back to the collimation package
- To make sure that the cw laser light is incoupled back into the collimation package, connect the output of the photodetector to an oscilloscope. You should see a clear DC voltage signal appearing
- Connect the comb light to the other fiber input port
- Check that the repetition rate (250 MHz) is visible on the spectrum analyzer. Optimize the signal if necessary by changing parameters of the comb light and by incoupling alignment into the collimation package

  NOTE: You may need to connect the output of the photodetector directly to the spectrum analyzer to by-pass eventual band-pass and low-pass filters contained in the electronics in order to visualize RF signals around 250 MHz.

- **NOTE:** If there are several RF signals at the photodiode output, change the comb repetition rate - only the CW beat note will move, other peaks will remain at the same frequencies.

6.5.3 BDU-FS: FREE-SPACE BEAT DETECTION UNIT

- Align the cw laser so that it is well centered on all optics
- Overlap the comb light with the cw laser light on the first Polarizing Beam splitter Cube (PBC)
- Make iterative steps in order to completely mode match the comb light onto the well-centered cw laser beams by
    - Checking the overlapping beams close to the PBC and match them using the first mirror of the comb light
    - Match the two beams far away from the PBC by using the second mirror of the comb beam (the one which is closer to the PBC)
    - Repeat the procedure until both beams are completely matched close and far away from the PBC
- If the two beams have a different geometry use lenses in order to match them to each other
- Choose the first order after the grating and reflect it to the detector after having maximized the distance between the grating and the detector
- Make sure that the cw laser light hits the detector by aligning the laser mirror mount before the photodetector until you find the maximum increase of noise
- Verify that the polarization of both the comb and CW laser radiations is rotated properly by optimizing the half wave plates
- The power ratio of the two beams onto the detector can be adjusted with the half wave plate before the second PBC
- **NOTE:** If there are several RF signals at the photodiode output, change the comb repetition rate - only the CW beat note will move, other peaks will remain at the same frequencies.

7. APPENDIX A: REPETITION RATE CALCULATION

The repetition rate f_{rep} of the laser is approximately 250 MHz, depending on the actual position of the intra-cavity stepper motor translation stage. This can be easily verified using a spectrum analyzer or a referenced counter. In this example, let us assume f_{rep} = 250.01 MHz. This frequency and its higher harmonics are detected with a fast photodetector whose signal is available at the → *RF out* port at the backside of the laser head. A high-pass at 1000 MHz is used to suppress the lower harmonics. The high-pass filtered signal is mixed with 980 MHz directly synthesized from the 10 MHz reference by the PLO. From the resulting difference frequencies (intermediate frequencies IF), the one generated by mixing down the 4^{th} harmonic at 1000.04 MHz is the strongest, giving an IF frequency at 20.04 MHz. The frequencies resulting from the other harmonics have smaller amplitudes and are at least one repetition rate of approximately 250 MHz away. This IF signal is fed to the FXM50/FXE65 counter. For locking purposes, an additional referenced DDS synthesizer generates the appropriate frequency (in this case, 20.04 MHz) for mixing down the IF signal to DC. In locked condition, f_{rep} can be adjusted by changing the frequency of the DDS, and possible adjustment of the cavity length using the stepper motor and/or the laser temperature. The repetition rate f_{rep} can be directly calculated from the counter reading $f_{counter}$ = IF as follows:

$$f_{rep} = \frac{f_{counter}}{4} + 245 \text{ MHz} \quad (3)$$

8. APPENDIX B: DETERMINATION OF CW LASER FREQUENCIES

The expected effect on changing the actuators is given in the actuators sign table in the testreport.

8.1 GENERAL CONSIDERATIONS

The fundamental equation which has to be considered is:

$$f_{cw} = n \cdot f_{rep} \pm f_0 \pm f_{beat} \quad (4)$$

where f_{CW} is the frequency of the CW laser to be measured, f_{rep} is the repetition rate of the frequency comb system (thus the spacing between adjacent comb modes), f_0 is the CEO frequency of the frequency comb and f_{beat} is the measured beat note between the CW laser and the nearest adjacent comb mode with the mode number n.

For simplicity, we use frequencies f instead of angular frequencies ω in this example.

$$n = \frac{c}{\lambda \cdot f_{rep}} \quad (5)$$

is a big integer, e.g. 1894423 for a repetition rate of 250 MHz and a CW laser at 633 nm (the actual number certainly depends on the exact CW laser frequency and the exact repetition rate). If a precise wave meter (accuracy better than half the repetition rate) is available, n can be calculated from the repetition rate and the wave meter reading. Sometimes the laser frequency is known already with an accuracy better than some MHz, e.g. of metrology lasers like Iodine-stabilized HeNe lasers. n can then be calculated directly using the above equation. If the laser frequency is completely unknown or if the laser has to be measured without using additional measurement devices, refer to the last paragraph of this chapter. The signs in the fundamental equation depend on the actual measurement conditions and can be determined by changing f_0 and f_{rep} both in locked condition while monitoring the resulting change of the beat note f_{beat}.

A change of f_{rep} in locked condition affects the spacing between the modes and can be imagined like pulling at a rubber band fixed at one end (at zero frequency), with equidistant markers (comb modes). Increasing f_{rep} equals pulling at the rubber band: the marker spacing increases and the markers at the highest frequencies are shifted the most. In the lower part of the figure below the repetition rate is considerably larger than in the upper part.

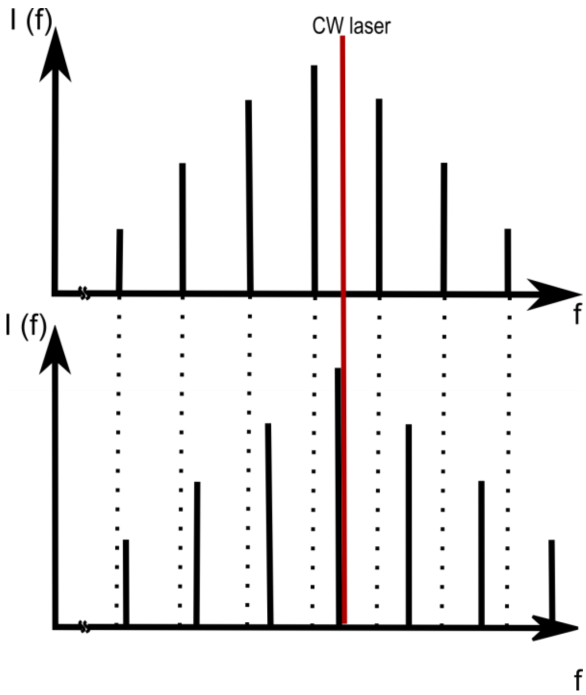


Figure 21: Frequency comb modes for different repetition rates. Top: small repetition rate; Bottom: large repetition rate.

Changing the CEO frequency f_0 in phase locked condition affects the comb in a different manner. When tuning the synthesizer's frequency of the SYNCRO-CEO while the offset beat and the repetition rate are phase locked: all the comb modes move in frequency space with equidistant spacing depending on the sign of f_0. In case of a positive sign, an increase of Δf in f_0 shifts the full comb to frequencies higher by Δf, as sketched below.

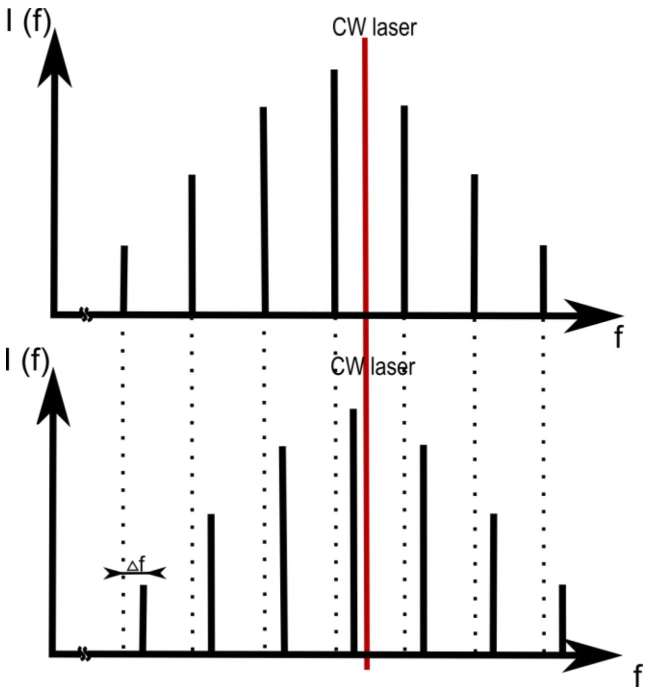


Figure 22: Frequency comb modes for different offset frequencies. Top: f0 = f00; Bottom: f0 = f00 + Δf.

For a negative sign, a Δf increase in f_0 shifts the comb modes to frequencies which are lower by Δf. Having in mind that f_0 is a CEO frequency it might be hard to understand how the sign can be negative at all. Think of the generation of the offset frequency as a beat note between two laser fields, one around 1100 nm and one from the 2nd harmonic of 2200 nm: while the photodiode can only measure the unsigned beat frequency, there is a physical difference whether 1100 nm is smaller or larger than the 2nd harmonic of 2200 nm, and this difference must manifest itself in the absolute frequencies of the comb modes: they depend on the sign of f_0.

To determine the absolute frequency of a CW laser, we measure a beat frequency with the frequency comb modes. Although we see beats with all the comb modes which are in the bandwidth of the photodetector (therefore the reading at the spectrum analyzer repeats itself with a periodicity of the repetition rate), we are only interested in the beat note with the smallest frequency, arising from the beat with the nearest comb mode.

The appropriate sign of the beat note (positive for case A in the figure below, negative for case B) can be determined by slightly changing the repetition rate using the DDS output frequency of the SYNCRO-RRE in locked condition: for increasing f_{rep}, the beat note must increase in case B, and must decrease in case A. The opposite holds for decreasing f_{rep}.

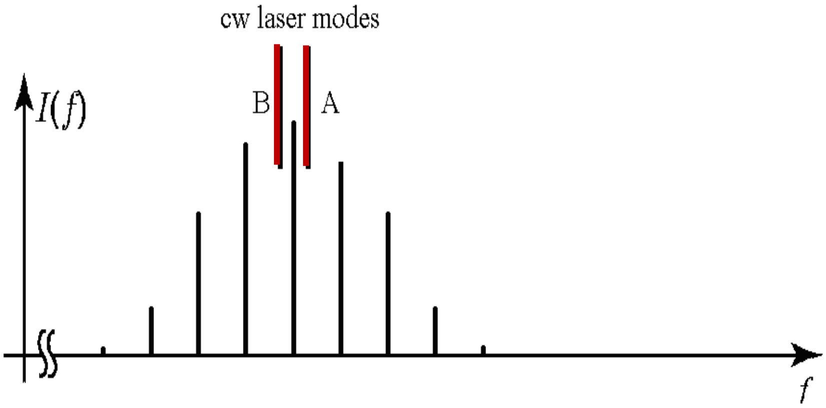


Figure 23: Possible CW laser frequencies for the same value of f_{beat}.

After having determined the sign of the beat note, change the CEO frequency using the DDS output frequency of the SYNCRO-CEO in locked condition. Four cases are possible:

- Case A and f_{beat} gets smaller with increasing f_0: comb moves to higher frequencies, positive sign of f_0
- Case A and f_{beat} gets larger with increasing f_0: comb moves to lower frequencies, negative sign of f_0
- Case B and f_{beat} gets smaller with increasing f_0: comb moves to lower frequencies, negative sign of f_0
- Case B and f_{beat} gets larger with increasing f_0: comb moves to higher frequencies, positive sign of f_0

Now, all the signs in the fundamental equation are well known.

As already mentioned, in most cases the integer number n can be estimated. If the CW laser frequency is completely unknown, two measurements with different repetition rates can be performed, yielding two equations with the two unknown quantities n and f_{CW}, which can be solved for n and f_{CW}. This will be explained in more detail in the section 8.3.

8.2 CARRIER ENVELOPE OFFSET FREQUENCY AFTER SHG

If visible CW lasers are measured after SHG, Equation. (4) has to be modified to take the SHG process into consideration: the CEO frequency has to be multiplied by a factor of two:

$$f_{cw} = n \cdot f_{rep} \pm 2 f_0 \pm f_{beat} \qquad (6)$$

The repetition rate remains unchanged due to the fact that the dominant process in the SHG process is sum frequency generation. Let us consider two adjacent modes with mode numbers *n* and *n+1* with the frequencies:

$$f_n = n \cdot f_{rep} + f_0 \quad \text{and} \quad f_{n+1} = (n+1) \cdot f_{rep} + f_0$$

The doubled frequencies of these modes are:

$$2 f_n = 2n \cdot f_{rep} + 2 f_0$$

$$2 f_{n+1} = 2(n+1) \cdot f_{rep} + 2 f_0 = 2n \cdot f_{rep} + 2 f_{rep} + 2 f_0$$

Their difference frequency is two times the repetition rate:

$$2 f_{n+1} - 2 f_n = 2 f_{rep}$$

Besides generation of doubled frequencies of single modes, all sum frequencies of adjacent modes are created. The sum frequency of modes with frequencies f_n and f_{n+1} is:

$$f_n + f_{n+1} = n \cdot f_{rep} + f_0 + (n+1) f_{rep} + f_0 = 2n \cdot f_{rep} + f_{rep} + 2 f_0$$

This mode has a frequency difference of f_{rep} with respect to the doubled modes $2f_n$ and $2f_{(n+1)}$.

8.3 DETERMINATION OF THE INTEGER COMB MODE NUMBER N

Performing two measurements of the unknown but time constant CW laser frequency at different repetition rates gives access to the unknown mode number n as follows: we notice again the fundamental Eqn. (4). For simplicity, let us assume that f_0 and f_{beat} are signed numbers, so that we can write $f_{cw} = n \cdot f_{rep} + f_0 + f_{beat}$. Keeping in mind that the measurement of f_{beat} will include an uncertainty Δ, Eqn. (4) changes to:

$$f_{cw} = n \cdot f_{rep} + f_0 + f_{beat} + \Delta$$

Except n and f_{CW}, all parameters and their signs can be measured and determined as described above.

By significantly changing the repetition rate, the integer number n will change too: e.g. for smaller repetition rates, n will increase. The repetition rate can be adjusted smoothly by moving the synthesizer's frequency of the SYNCRO-RRE by small step sizes (~tens of Hz), while the reprate is still phase locked. By monitoring the CW beat laser frequency change, we can determine when the comb mode has changed by +1 or –1: e.g. reducing f_{rep} will lead first to increasing f_{beat}, then decreasing f_{beat} after the comb mode has moved “through” the CW laser mode and again increasing f_{beat} during approaching approximately the same f_{beat} frequency, this time measured against the comb mode with n-1. The pattern “increase → decrease → increase” is the sign of a change in n by -1 (“increase → decrease → increase” in case A above). Be careful not to miscount the change in n.

Defining n_1, n_2 and f_{rep1}, f_{rep2} as the mode numbers and repetition frequencies of the two measurements and the change in n as $m = n_2 - n_1$, we can write:

$$n_1 f_{rep\,1} + f_{01} + f_{beat\,1} + \Delta_1 = n_2 f_{rep\,2} + f_{02} + f_{beat\,2} + \Delta_2 \qquad (7)$$

which can be solved for n_1, yielding:

$$n_1 = \frac{(m.f_{rep2} + f_{02} + f_{beat2} - f_{01} - f_{beat1})}{(f_{rep1} - f_{rep2})} - \frac{\Delta_1 - \Delta_2}{(f_{rep1} - f_{rep2})} \qquad (8)$$

The second part of Eqn. (8) gives the uncertainty of the determination of the integer number n_1. Typical values for Δ are 1 kHz for short measurements around 100 s, thus an uncertainty for n of ± 0.5 requires a change in the repetition rate around 4 kHz. This can be achieved by adjusting the repetition rate with the piezo only.

Another possible approach which might be easier to realize is to measure at two repetition rates with a relatively big difference, e.g. at 250 MHz and 250.1 MHz. In this case, the second part of Eqn. (8) is on the order of 1/100 which is negligible, but we do not know the number m as difference between the two mode numbers. Nevertheless, we can rewrite Eqn. (7) omitting the measurement uncertainty as already discussed:

$$n_1 = \frac{n_2 f_{rep\,2}}{f_{rep\,1}} + \frac{(f_{02} + f_{beat\,2} - f_{01} - f_{beat\,1})}{f_{rep\,1}} \quad (9)$$

As additional condition to Eqn. (9), we know that n_1 and n_2 are integer numbers. Both conditions lead to a set of possible integer numbers for n_1 and n_2. Consecutive numbers of n_1 differ by:

$$1 \Big/ \left(\frac{f_{rep\,2}}{f_{rep\,1}} - 1 \right), \quad (10)$$

e.g. in case of 250 MHz and 250.1 MHz the difference is about 2500. The same holds for n_2. Therefore, a very coarse knowledge of the CW laser wavelength is sufficient to determine the mode number. By determining *n* with an uncertainty of plus or minus few numbers with the first approach, the analysis of the second approach is simplified.

9. APPENDIX C: ABBREVIATIONS

A	**A**mpere
APD	**A**valanche **P**hoto **D**etector
A(t)	Pulse envelope
AC	**A**mplifier **C**ontroller
BDU	**B**eat **D**etection **U**nit
BFD	**B**eat **F**requency **D**istribution
CB	**C**onnect **B**ox
CD	**C**ompact **D**isk
CEO	**C**arrier **E**nvelope **O**ffset
cw	**C**ontinuous **w**avelength
$\Delta\varphi$	Phase angle
dB	**D**eci**b**el
DC	**D**irect **C**urrent
DDS	**D**irect **D**igital **S**ynthesizer
DIO	**D**igital **I/O**
DRO	Kind of PLO
DSO	**D**igital **S**ampling **O**scilloscope
DUO	**DU**al Integrator l**O**op
DXD	**D**igital mi**X**er phase **D**etector
EC	**E**uropean **C**ommunities
EDFA	**E**rbium-**D**oped **F**iber **A**mplifier
EN	**E**uropean **N**ormative
Er	**Er**bium
EOM	**E**lectro **O**ptical **M**odulator
f	**F**requency

FC	**F**iber **C**oupled
FC	**F**requency **C**omb
FC/APC	**F**errule **C**onnector or **F**iber **C**hannel / **A**ngled **P**hysical **C**ontact
FC/PC	**F**errule **C**onnector or **F**iber **C**hannel / **P**hysical **C**ontact
FDT	**F**requency **D**ivider uni**T**
FF	**F**ully **F**iber-coupled
FG	**F**iber-coupled with external **G**rating
FPD	**F**ast **P**hoto **D**etector
fs	**F**emto**s**econd
FS	**F**ree **S**pace
FXE	4-channel frequency counter
FXM	4-channel frequency counter
GHz	**G**iga**H**ert**z**
GPS	**G**lobal **P**ositioning **S**ystem
HWP	**H**alf **W**ave**P**late
kg	**K**ilo**g**rams
kHz	**K**ilo **H**ert**z**
HFS	**H**igh **F**requency **S**witch (RF switch module)
HMP	**H**igh power **M**easurement **P**ort
HMS	Name of RF spectrum analyzer type
HNLF	**H**ighly **N**on**L**inear **F**ibre
HVA	**H**igh **V**oltage **A**mplifier
I	**I**n (module label)
IEC	**I**nternational **E**lectrotechnical **C**ommission
IF	**I**ntermediate **F**requency
IR	**I**nfra**R**ed
L	Cavity **L**ength

LAC	**L**aser **A**mplifier **C**ontroller
LC/APC	**L**ittle **C**ontacts / **A**ngled **P**hysical **C**ontact
LLE	**L**aser **L**ocking **E**lectronics
m	**M**eter
M	**M**onitor (module label)
mA	**M**illi**A**mpere
mm	**M**illi**m**eter
MHz	**M**ega**H**ert**z**
n	Integer number
nm	**N**ano**m**eter
O	**O**ut (module label)
OD	**O**ptical **D**ensitiy
OFC	**O**ptical **F**requency **C**omb
OFD	**O**ffset beat **F**requency **D**istribution (module for frequency amplification)
PBC	**P**olarizing **B**eam splitter **C**ube
PBS	**P**olarizing **B**eam **S**plitter
PCF	**P**hotonic **C**rystal **F**iber
PID	**P**roportional / **I**ntegral / **D**erivative
PIN	**P**ositive **I**ntrinsic **N**egative
PLL	**P**hase-**L**ocked **L**oop
PLO	**P**hase-**L**ocked **O**scillator
PM	**P**olarization **M**aintaining
QWP	**Q**uarter **W**ave **P**late
Ref	**Ref**erence
RF	**R**adio **F**requency
RFC	**R**adio **F**requency phase detector & **C**ounter output
RFD	**R**eference **F**requency **D**istribution

RFS	**RF**C **S**imple (module with an analogue mixer)
RRE	**R**epetition **R**ate **E**lectronics
s	**S**econd
SCG	**S**uper **C**ontinuum **G**eneration
SNR	**S**ignal to **N**oise **R**atio
SYNCRO	**S**YNCRO **Y**ields **N**icely **C**orrelated **R**eferenced **O**scillations
T	Round trip **T**ime
TFT	**T**hin **F**ilm **T**ransistor
THz	**T**era**H**ert**z**
USB	**U**niversal **S**erial **B**us
V	**V**olt
VA	**V**olt **A**mpere
VAC	**V**oltage in **A**lternating **C**urrent
v_g	**G**roup **v**elocity
VIS	**VIS**ible spectrum
v_p	**P**hase **v**elocity
ω_c	**C**arrier **f**requency
ω_r	Pulse **r**epetition **f**requency
WDM	**W**avelength **D**ivision **M**ultiplexing
WEEE	**W**aste **E**lectrical and **E**lectronic **E**quipment
WLM	**W**ave**l**ength **M**eter
XPS	**Cross P**hase **S**tabilization
°C	Degrees **C**elsius

A. CUSTOMER SERVICE

Your system is designed to be maintenance free.

Opening the chassis of the system voids the warranty and exposes the user to hazardous voltage that is present inside the laser housing.

A.1 FACTORY SERVICE & REPAIR

For factory service or repair please call the Menlo Systems customer service department. Together with the product specialist they will determine if the equipment requires service, repair, calibration or replacement.

If it has been decided your system has to be shipped to Menlo Systems for service or repair, we will provide you with an RMA number. For more information about the RMA procedure please read the information about returning a system to Menlo Systems online at:

http://www.menlosystems.com/legals/service-plans-returns-rma/

A.2 ADDITIONAL SERVICE PLAN

Menlo Systems offers a Service Plan for all products. The Service Plan includes on-site service for installation, on-site training, and on-site repair service when this is technically feasible. We also support our customers during measurement campaigns. Travel time and travel costs for any on-site service are included. In-house training at Menlo Systems main facility in Martinsried, Germany or in our US-office in Newton, NJ is also available within the Service Plan. For more information please see:

http://www.menlosystems.com/legals/service-plans-returns-rma/

Support Contact (except North America)**:**	**Support Contact North America:**
Menlo Systems GmbH Am Klopferspitz 19a 82152 Martinsried Germany	Menlo Systems, Inc. 56 Sparta Avenue Newton, NJ 07860 USA
Phone: +49 89 189166 0 Fax: +49 89 189166 111 Timezone: CET (UTC+1)/CEST (UTC+2)	Phone: +1 973 300 4490 Fax: +1 973 300 3600 Timezone: UTC-5

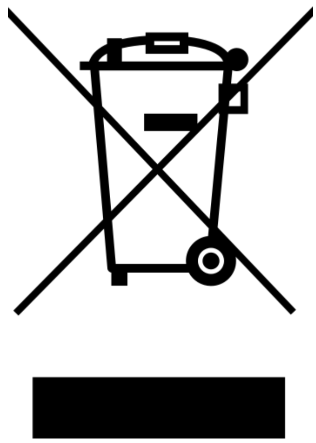
Email: service@menlosystems.com

B. REGULATORY

As required by the WEEE (Waste Electrical and Electronic Equipment) Directive of the European Community and the corresponding national laws, Menlo Systems offers all end users in the EC the possibility to return "end of life" units without incurring disposal charges.

This offer is valid for Menlo Systems electronic equipment:

- Sold after August 13, 2005
- Marked correspondingly with the crossed out "wheelie bin" logo (see figure to right)
- Sold to a company or institute within the EC
- Currently owned by a company or institute within the EC
- Still complete, not disassembled and not contaminated



As the WEEE directive applies to self-contained operational electrical and electronic products, this end of life take back service does not refer to other Menlo Systems products, such as:

- Pure OEM products, that means assemblies to be built into a unit by the user
- Components
- Mechanics and optics
- Left over parts of units disassembled by the user (PCB's, housings etc.)

If you wish to return a Menlo Systems unit for waste recovery, please contact Menlo Systems for further information.

B.1 WASTE TREATMENT IS YOUR OWN RESPONSIBILITY

If you do not return an "end of life" unit to Menlo Systems, you must hand it to a company specialized in waste recovery.

B.2 ECOLOGICAL BACKGROUND

It is well known that WEEE pollutes the environment by releasing toxic products during decomposition. The aim of the European RoHS directive is to reduce the content of toxic substances in electronic products in the future.

The intent of the WEEE directive is to enforce the recycling of WEEE. A controlled recycling of end of live products will thereby avoid negative impacts on the environment.