DFM
Danish National Metrology Institute

Operator Manual

Stabiλaser 1542ε

SN XXXXJX0

Contents

Version 3.94, October 2024

Kogle Allé 5
2970 Hørsholm
Denmark

www.dfm.dk

0. Notices

Safety

The Stabiλaser 1542$^{\varepsilon}$ has been designed and tested in accordance with applicable industry standards. This manual contains information and warnings that must be followed by the user to ensure safe operation and to maintain the Stabiλaser 1542$^{\varepsilon}$ in a safe condition. The user must pay special attention to section *4 Laser safety*.

EU Declaration of Conformity (DoC)

DFM A/S declares that Stabiλaser 1542$^{\varepsilon}$ complies with the essential requirements of applicable European Directives, and carries the CE marking accordingly. A copy of the DoC is available on request.

FCC

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

Laser Safety Compliance

This equipment complies with the requirements in IEC 60825-1:2014 and is classified as a laser class 3B product. This laser complies with FDA performance standards for laser products except for deviations pursuant to Laser Notice No. 50, dated June 24 2007. FDA accession number 1910556-001.

Operational notices

Operate the Stabiλaser 1542$^{\varepsilon}$ only as described in this manual. Only operate the equipment indoors in a controlled laboratory environment as defined in section 5.1.

Product misuse may be hazardous. Do not put the Stabiλaser 1542$^{\varepsilon}$ into use if damaged. Do not substitute parts or attempt to modify the Stabiλaser 1542$^{\varepsilon}$. Use the product only with the accessories and cables specified in this manual. Do not install additional software and do not modify existing software on the Stabiλaser control PC.

If you need to clean the outside of the Stabiλaser 1542$^{\varepsilon}$, wipe only with a dry towel. You should never use liquids or abrasive products for cleaning the Stabiλaser 1542$^{\varepsilon}$.

Trademarks

Microsoft and Windows are registered trademarks of Microsoft Corporation.
All other trademarks are properties of their respective owners.

1. Specifications

The following specifications are valid for Stabiλaser 1542$^{\varepsilon}$, serial number XXXXJXO:

Optical specifications

Wavelength (nominal[1], vacuum) ..... 1542.384 3 nm
Wavelength (nominal, vacuum, optional) ..... 771.192 15 nm
Linewidth (short term, 1542 nm) .....≤300 Hz
Stability (Allan deviation, sampling time ≥ 1 s)[2] .....≤3 x 10^{-13}
Stability (Allan deviation, sampling time = 200 s)[2] .....≤3 x 10^{-14}
Long-term accuracy[3] (drift per year) .....≤2 x 10^{-12}
Output power @ 1542 nm *Laser Aperture* connector (nominal) ..... 20 mW
Output power @ 771 nm *Laser aperture* connector (nominal, optional) ..... 5 mW
Fiber connector (*Laser Aperture*) ..... FC/APC (PM)

Electrical and dimensional specifications

Power requirements .....100 – 240 VAC, 50 or 60 Hz
Dimensions ..... 13 cm (H) x 48 cm (W) x 50 cm (D)
TTL lock out.....5 V TTL/CMOS compatible

Environmental characteristics

Operating environment ..... Indoor laboratory
Ambient operating temperature ..... 18 °C – 28 °C
Maximum ambient operating temperature changes in one hour[4] ..... 1 °C
Relative humidity ..... 30 % - 60 %
Polution degree ..... 2 (non-conductive material)
Maximum operating altitude..... 2200 m (770 hPa)

Control PC specifications

PC type XXXXXXXX
Windows version XXXX
Stabiλaser 1542$^{\varepsilon}$ control software version XXXXXX
PC username ..... Stabilaser
PC password 1542

1.1 Custom modifications

None.

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[1] The laser is locked to the acetylene line at 1542.3837 nm, but the available output is shifted by a fixed frequency of typically 80 MHz, see also sections 7.1 and **Error! Reference source not found.**.

2 The specified stability may not be achieved if the Stabiλaser 1542$^{\varepsilon}$ is operated in a noisy and unstable environment.

3 This parameter reflects the annual drift of the average laser frequency when the laser is operated in a stable environment. Accuracy at the same level can be obtained by an in-situ calibration using a reference of better accuracy.

[4] The Stabiλaser 1542$^{\varepsilon}$ will maintain lock during a temperature change but might have reduced frequency stability.

2. Service

The Stabiλaser 1542$^{\varepsilon}$ does not contain any user serviceable parts. If the Stabiλaser 1542$^{\varepsilon}$ starts to malfunction, please contact DFM A/S.

If you need to return the Stabiλaser 1542$^{\varepsilon}$ for servicing, proceed as follows:

For service under warranty

Contact DFM A/S to obtain an RMA (Return Merchandise Authorization). Once DFM A/S has issued an RMA, you may return the Stabiλaser 1542$^{\varepsilon}$ to DFM A/S.

When returning the Stabiλaser 1542$^{\varepsilon}$, proceed as follows: First, power down the Stabiλaser 1542$^{\varepsilon}$. Package the Stabiλaser 1542$^{\varepsilon}$ in the transport case furnished with the Stabiλaser 1542$^{\varepsilon}$.

Include full contact details, and an unambiguous return address. Also, the RMA obtained from DFM A/S must be displayed on, or included in, the transport case.

Return the Stabiλaser 1542$^{\varepsilon}$ to:

DFM A/S
Kogle Allé 5
DK-2970 Hørsholm
Denmark.

NOTE: Misalignment of the spectroscopic unit that requires the Stabiλaser 1542$^{\varepsilon}$ to be returned to DFM A/S is not covered by the warranty. Realignment by DFM A/S according to the procedure in section 8.2 will be invoiced, and charges for return shipment will be added.

For service outside warranty

Consult DFM A/S for assistance.

3. General description

The Stabiλaser 1542$^{\varepsilon}$ is an acetylene-stabilized fiber laser that exhibits both narrow linewidth, excellent long-term stability, and high accuracy. The design maintains the short-term linewidth of a high-end fiber laser, and adds the long-term stability and accuracy from a molecular transition of acetylene.

The main components of the Stabiλaser 1542$^{\varepsilon}$ are industrial grade products, which ensures trouble-free operation and a long lifetime - even if the Stabiλaser 1542$^{\varepsilon}$ is used continuously or for extended periods of time. The Stabiλaser 1542$^{\varepsilon}$ operates fully automatically and requires no regular maintenance.

Long term stability and accuracy is obtained by referencing the fiber laser to the acetylene transition $^{13}C_2H_2$ P(16) ($\nu_1+\nu_3$) at λ_{vacuum} = 1542.3837 nm, corresponding to the frequency f = c/λ_{vacuum} = 194 369 569 384 (5) kHz. The actual output frequency for the locked Stabiλaser 1542$^{\varepsilon}$ differs from the P(16) frequency by typically 80 MHz (the actual frequency shift is given in section 10.1). The Stabiλaser 1542$^{\varepsilon}$ meets the conditions of the CIPM recommendation on standard frequencies, and it can be used as a primary standard with a relative standard uncertainty of 2.6×10^{-11}.

The long-term drift of the Stabiλaser 1542$^{\varepsilon}$ is better than 2×10^{-12} per year when operated in a stable environment, and the frequency stability (Allan deviation) is better than 3×10^{-13} for integration times from 1 s up to at least 10^5 s. The short-term linewidth of the Stabiλaser 1542$^{\varepsilon}$ is below 300 Hz, increasing to typically 600 Hz for sampling times above 10 s.

An optional optical frequency doubler provides frequency stable output at both 1542 nm and 771 nm. DFM A/S can retrofit existing Stabiλaser 1542$^{\varepsilon}$ units with the optional frequency doubler.

Stabiλaser 1542$^{\varepsilon}$ applications include stabilization and line narrowing of optical frequency combs, as well as a wavelength reference in length metrology. As a frequency comb reference, the Stabiλaser 1542$^{\varepsilon}$ can be used for line narrowing and frequency control of lasers used in, e.g., spectroscopy or laser cooling experiments involving narrow-line atomic or molecular transitions. Furthermore, the Stabiλaser 1542$^{\varepsilon}$ will also meet requirements as an optical frequency reference in dual comb spectroscopy.

4. Laser safety

Before operating the Stabiλaser 1542$^{\varepsilon}$ please read and follow the Laser Safety and Warning instructions in this chapter and read and follow the notices in chapter 0 (Notices).

IMPORTANT: The user of this device is responsible for following the legally specified safety measures in the country of operation.

4.1 General Laser Safety

The Stabiλaser 1542$^{\varepsilon}$ includes a fiber laser module (NKT Photonics BASIK module, laser model X15, dual output) and one or two optical fiber amplifiers (max 150 mW).

CAUTION / DANGER: The front panel 1542 nm *Laser Aperture* provides the normal Stabiλaser 1542$^{\varepsilon}$ output with a typical power level up to 40 mW at 1542 nm. With 771 nm option, the corresponding *Laser Aperture* provides typical power levels up to 5 mW at 771 nm.

CAUTION: The NKT Photonics *Koheras BASIK product guide* and *Koheras BASIK Laser Safety, Handling, and Regulatory Information* are delivered with the Stabiλaser 1542$^{\varepsilon}$. All the safety precautions in the NKT Photonics documents apply to the Stabiλaser 1542$^{\varepsilon}$ as well. **It is essential that the user is fully aware of these safety precautions before the Stabiλaser 1542$^{\varepsilon}$ is switched on!**

CAUTION: The Stabiλaser 1542$^{\varepsilon}$ is a Class 3B laser, and only people familiar with laser safety regulations are allowed to operate the Stabiλaser 1542$^{\varepsilon}$.

CAUTION: Protective eyewear must be used according to the *Koheras BASIK Laser Safety, Handling, and Regulatory Information*. Different protective eyewear may be needed for working with either 1542 nm output or 771 nm output.

DANGER: Do not look into the laser beam as the output of the Stabiλaser 1542$^{\varepsilon}$ can exceed the limits for class 1 as specified by Laser Safety Standard IEC 60825-1:2014.

WARNING/DANGER: The Stabiλaser 1542$^{\varepsilon}$ should never be switched on without optical fiber patch cables or protective metal caps mounted at the front panel connector(s) marked *Laser Aperture.*

CAUTION: Use of controls or adjustments or performance of procedures other than those specified herein may result in hazardous radiation exposure. The same holds true for not following the safety labelling on the device.

DANGER: The radiation emitted from this class 3B laser is very powerful and proper safety precautions need to be followed. This includes but is not limited to the setup of proper radiation shielding, laser warning systems in operation, setup of a safety

interlock at all access doors, wearing of protective eyewear and the operation, maintenance and service by trained personnel only.

4.2 Safety Labels on the Stabiλaser 1542$^{\varepsilon}$

The protective housing of the Stabiλaser 1542$^{\varepsilon}$ is furthermore protected by a surrounding protective cover that requires tools for removal and constitutes another barrier that prevents accidental access to laser radiation when operated according to these instructions.

4.2.1 Protective Cover

Warning signs for laser radiation are affixed to the protective cover. These are described in this section under paragraph 4.2.3 and paragraph 4.2.4.

DANGER / CAUTION: This protective cover must not be removed during normal operation. Operations that require removal of the protective cover are considered service operations.

DANGER: Never remove any cover during the operation of the laser. Switch off the device completely before removing any cover.

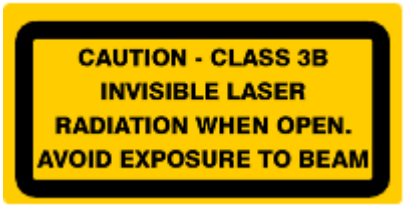
4.2.2 Protective Housing

The protective housing of the Stabiλaser 1542$^{\varepsilon}$ is located inside the protective cover according to paragraph 4.2.1, which requires tools for removal.

The user should never open the protective housing as this may lead to severe misalignment and will compromise the warranty.

DANGER: If the protective housing is opened, the laser may emit stray light in excess of class 1. Thus, the laser has to be switched off completely when opening the housing. When the housing is open apply appropriate safety precautions including but not limited to protective eyewear, access control and setup of laser warning systems. Avoid exposure of eyes and skin to the laser beam and stray light.

To the protective housing the following label is affixed according to IEC 60825-1:2014:



Size:	50mm x 25mm
Color:	yellow/black
Location:	On top of the protective housing. Only visible if the protective cover is removed.

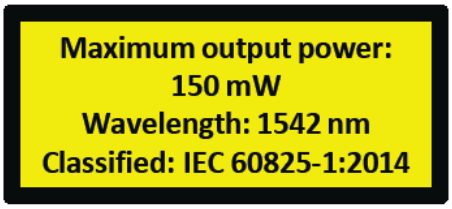
4.2.3 Laser Beam

The Stabiλaser 1542$^{\varepsilon}$ contains a fiber laser and one or two fiber amplifiers. It emits invisible continuous laser radiation at 1542 nm of up to 150 mW. If the optional frequency doubler is installed, the laser also emits continuous radiation at 771 nm. The frequency doubler pump power at 1542 nm is adjusted so that the 771 nm output power is 5 mW (max). The Stabiλaser 1542$^{\varepsilon}$ is classified as a class 3B laser product.

DANGER: The Stabiλaser 1542$^{\varepsilon}$ emits invisible continuous laser radiation of up to 150 mW power and is classified as a class 3B laser product. If the optional frequency doubler is installed, the laser also emits continuous radiation at 771 nm of up to 5 mW. Avoid exposure of eyes and skin to the laser beam and stray light.

The following labels are affixed to outside of the protective cover of the laser according to IEC 60825-1:2014:

Size: 39 mm x 16 mm
Color: yellow/black
Location: Outside of protective cover



Left: used on units without 771 nm option. Right: used on units with 771 nm option.
Size: 39 mm x 17 mm
Color: yellow/black
Location: Outside of protective cover

Size: 17 mm x 17 mm
Color: yellow/black
Location: Outside of protective cover

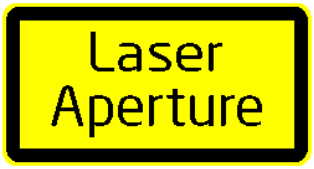
4.2.4 Aperture

During operation, laser radiation can be emitted from the aperture(s). For location of the aperture and associated warning labels on the front panel, please refer to Figure 1.
For regular operation a fiber patch cable is connected to the aperture(s). When the laser is not in operation for an extended time, the protective cap should be properly attached to the fiber connector around the aperture(s) to block the beam.

DANGER: The aperture of the StabiλLaser 1542$^{\varepsilon}$ may emit invisible continuous laser radiation of up to 150 mW power (typically up to 40 mW). If the optional frequency doubler is installed, the laser also emits continuous radiation at 771 nm of up to 5 mW. The device is thus classified as a class 3B laser product. Avoid exposure of eyes and skin to the laser beam and stray light.

WARNING: The StabiλLaser 1542$^{\varepsilon}$ should never be switched on without an optical fiber patch cable or a protective metal cap mounted at the front panel connector(s) marked *Laser Aperture.*

The following labels are affixed on the lasers front plate next to the aperture(s) according to IEC 60825-1:2014:



Size: 25 mm x 13 mm
Color: yellow/black
Location: Below laser beam aperture

Size: 16 mm x 15 mm
Color: yellow/black
Location: Below laser beam aperture

4.2.5 CFR Compliance

Compliance with US laws according to FDA performance standards is declared by the following label:

Complies with FDA performance standards for laser products except for deviations pursuant to Laser Notice No. 50, dated June 24 2007.

Size:	55 mm x 9 mm
Color:	Yellow/Black
Location:	Outside of protective cover

5. Installation

5.1 Environment

The Stabiλaser 1542$^{\varepsilon}$ is designed for use in a low vibrational indoor laboratory environment with characteristics as given in section 1. The main unit should not be directly exposed to airflow from a heat or air conditioning register or air circulating fan. Do not place hot items close to the Stabiλaser 1542$^{\varepsilon}$. To avoid overheating, provide an air gap of at least 10 cm behind the Stabiλaser 1542$^{\varepsilon}$ and ensure adequate ventilation. When the Stabiλaser 1542$^{\varepsilon}$ is moved to a new location, allow the device to acclimatize to its environment for about 12 hours.

The Stabiλaser 1542$^{\varepsilon}$ can be placed on a stable shelf or a table, for instance. The Stabiλaser 1542$^{\varepsilon}$ is too heavy to be mounted in a 19" rack using only the front brackets – it needs to sit on a suitable rack shelf or slide rails. Vibrations and temperature fluctuations may influence the frequency stability of the Stabiλaser 1542$^{\varepsilon}$. Do not place heavy items (i.e., above 2 kg) on top of the Stabiλaser 1542$^{\varepsilon}$.

Warning, be aware of laser safety risks when the Stabiλaser 1542$^{\varepsilon}$ is operated as intended, see section 4 for details. Be aware of risks for electrical shock if electrical power is applied while the main unit is disassembled.

5.2 Individual parts

The Stabiλaser 1542$^{\varepsilon}$ comes with the following parts:

- Stabiλaser 1542$^{\varepsilon}$ main unit in a 19 inch 3U rack chassis, 13 cm (H) x 48 cm (W) x 50 cm (D)
- Power cord
- 50 Ω BNC terminator for closing the interlock loop.
- Two 2 mm Allen keys, needed in case the Stabiλaser 1542$^{\varepsilon}$ requires realignment.
- One T20 Torx key, needed in case the Stabiλaser 1542$^{\varepsilon}$ requires realignment.
- One noise-suppression ferrite for use on an HDMI cable (see section 6.5)
- Stabiλaser 1542$^{\varepsilon}$ Operator Manual, including test report (this document)
- Koheras BASIK Laser Safety, Handling, and Regulatory Information (NKT Photonics, paper copy)
- Test Reports for fiber laser (NKT Photonics, paper copy)

Units with the 771 nm option come with the additional parts:

- Manual and test data sheet for the wavelength conversion module.

A compact PC with pre-installed control software is integrated in the main unit. Monitor, HDMI cable, and keyboard/mouse are **not** included.

5.3 Electrical and optical connections

The Stabiλaser 1542$^{\varepsilon}$ main unit should be connected to the mains, see section *1 Specifications*. The main unit is a Safety Class I instrument, which means that it has a protective earth terminal. That terminal must be connected to earth ground through a power source with a 3-wire ground receptacle.

An optical fiber patch cable with FC/APC connector may be connected to the front panel output(s). **The patch cable connector should be clean and undamaged, and insertion of the patch cable must be done with great care to avoid contamination and damage of the fiber connectors.** Protective caps must be used on the front panel adaptor(s) whenever a patch cable is not inserted.

An external interlock can be connected to a BNC connector on the back of the main unit. Alternatively, the supplied 50 Ω BNC terminator is connected to close the interlock loop.

The back of the main unit has connectors for the internal control PC, including an RJ45 connector for Ethernet connection, a HDMI connector for attaching an external monitor and 2 x USB connectors for e.g. mouse and keyboard.

5.4 Internal control PC

The internal PC controls the Stabiλaser 1542$^{\varepsilon}$ via the dedicated preloaded control software. For normal operation, it is not required to have a monitor or a keyboard/mouse connected to the PC. However, temporary use of a monitor and keyboard/mouse is recommended when installing the Stabiλaser 1542$^{\varepsilon}$ at a new location. Furthermore, Internet access is not required for normal operation of the Stabiλaser 1542$^{\varepsilon}$.

The PC is prepared for remote access, which can be used for support/training or troubleshooting. Remote access is only possible when the PC has internet access via Ethernet cable. WIFI connection is disabled on the control PC and should remain disabled to avoid unplanned tasks to start up.

For normal operation, there is no need to access the software control interface. However, for troubleshooting or monitoring purposes, the control interface is accessible by connecting keyboard/mouse (USB interface) and a monitor (HDMI interface) to the back of the main unit. Alternatively, access can be obtained by running the Windows' *Remote Desktop Connection* application on a remote PC on the same Ethernet. Username and password are listed in section 1 *Specifications*. The control PC is from the factory set up to acquire an IP address automatically. The actual IP address is displayed on the software control interface, see section 7 *Software control interface.*

No other software is installed on the PC, except for a standard Microsoft Windows installation with firewall and Microsoft virus protection, and relevant instrument drivers. The user should not install additional software on the control PC as this may influence the Stabiλaser 1542$^{\varepsilon}$ performance. Automatic software updates (including

Windows updates) are deactivated by DFM A/S to avoid unwanted PC activity, which may compromise the Stabiλaser 1542$^{\varepsilon}$ performance.

6. Normal operation

6.1 Principle of operation

The fiber laser inside the Stabiλaser 1542$^{\varepsilon}$ is locked to the acetylene transition by wavelength modulation saturated absorption spectroscopy and balanced detection of the harmonic signals. The basic principles have been published in Optics Express[5].

6.2 Start up

The Stabiλaser 1542$^{\varepsilon}$ is first switched on by the power switch on the back of the main unit. Subsequently, the key switch on the front panel is switched to the '1' (on) position. If the key switch was already in the '1' position when applying power to the main unit, the key switch must be switched to '0' and then back to '1'. It is recommended to wait about five minutes before switching the key to '1'. **The Stabiλaser 1542$^{\varepsilon}$ should never be operated with the front panel key switch in the 'on' position unless optical fiber patch cables or metal caps are mounted at the FC/APC output connectors.**

The internal control PC is switched on when the key switch is turned to the '1' position, and the PC is switched off when the key switch is turned to the '0' position. At the same time, laser output is always disabled with the key switch in the '0' position.

The Stabiλaser 1542$^{\varepsilon}$ will automatically tune to the acetylene resonance and lock. It may take about 30-60 minutes for the Stabiλaser 1542$^{\varepsilon}$ to lock after a "cold start", sometimes even longer, in particular after moving to a new environment. If the Stabiλaser 1542$^{\varepsilon}$ does not lock within 2 hours, it is recommended to restart the locking sequence by turning the key switch to the '0' position, wait 30 seconds and then turn it back to '1'.

After moving the Stabiλaser 1542$^{\varepsilon}$ it is recommended to connect a monitor (or use a remote access) to the control PC and verify that operating parameters are at their optimum, see also section **Error! Reference source not found.**.

6.3 Shut down

The control PC is first shut down by turning the key switch to the '0' position. It takes typically around 10 seconds for the control PC to shut down, which is indicated on the blue 'Controller' LED on the front. It is safe to switch off power to the main unit using the power switch on the back once the blue 'Controller' LED is off.

6.4 Front panel

The front panel indicators and connectors are illustrated in Fig. 1.

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[5] Thomas Talvard, Philip G. Westergaard, Michael V. DePalatis, Nicolai F. Mortensen, Michael Drewsen, Bjarke Gøth, and Jan Hald, "*Enhancement of the performance of a fiber-based frequency comb by referencing to an acetylene-stabilized fiber laser*," Opt. Express **25**, 2259-2269 (2017)

When the key switch is in ‘0’ position, the main unit can be switched on, but laser emission is disabled, the internal control PC is off and the laser cannot be locked to the acetylene line. Laser emission is possible with the key in the ‘1’ position. With the main unit switched on (switch on the back side), the internal control PC boots up when the key is switched from ‘0’ to ‘1’. The internal control PC shut down when the key is switched from ‘1’ to ‘0’. The key switch can be used to switch off emission when mounting or unmounting optical fibers in the FC/APC connector(s). Note, in order to enable laser emission again, the key switch must be switched to the ‘1’ position and the emission is not enabled until the internal control PC has finished booting.

Two LEDs indicate the status of the Stabiλaser 1542$^{\varepsilon}$. The green LED indicates that the Stabiλaser 1542$^{\varepsilon}$ is locked to the acetylene line. The blue ‘Status’ LED is on when power is applied to the Stabiλaser 1542$^{\varepsilon}$, but it is not yet attempting to lock. When the blue ‘Status’ LED flashes with a period of about 1 second, the Stabiλaser 1542$^{\varepsilon}$ is slowly tuning towards the acetylene line. The second blue LED (‘Controller’) indicates whether the internal control PC is on or off.

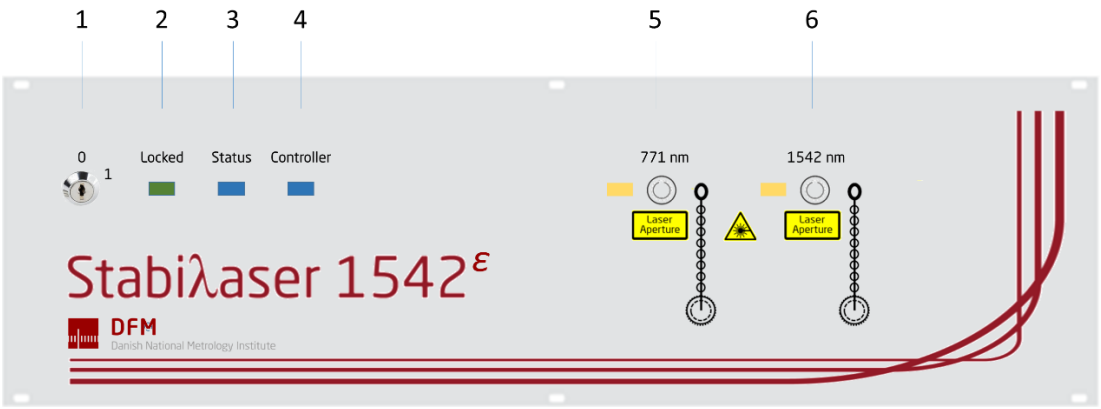


Figure 1: *Front panel with indicators and connectors. 1: Key switch for switching laser output on/off and booting/shutting down internal control PC. 2, 3: LED status indicators. 4: LED indicator for internal control PC. 5: Metal cap, laser output connector and emission LED for 771 nm laser output (optional). 6: Metal cap, laser output connector and emission LED for 1542 nm laser output.*

The optical output marked *1542 nm* provides the narrow-line, high-stability output of the Stabiλaser 1542$^{\varepsilon}$. The user should connect a suitable optical cable with an FC/APC connector. The output polarization is aligned parallel to the connector key. The available power is typically around 30 mW. To the left of the FC/APC connector is an LED, which indicates when laser emission is on. To right of the connector is a chain mounted protective metal cap, which is used to block light from the output. Note, the Stabiλaser 1542$^{\varepsilon}$ **emission should never be switched on unless a fiber patch cable or the metal cap is mounted at the FC/APC connector**.

6.4.1 771 nm output (optional)

The optical output marked *771 nm* is an optional frequency doubled output. The user should connect a suitable optical cable with an FC/APC connector. The output polarization is aligned parallel to the connector key. The available power is typically

1 mW - 5 mW. To the left of the FC/APC connector is an LED, which indicates when laser emission is on. The Stabiλaser 1542$^{\varepsilon}$ automatically adjusts the temperature of the nonlinear frequency conversion crystal to the correct phase matching temperature. Before this temperature is reached, the LED may indicate emission although actual output power can be very low. To right of the connector is a chain mounted protective metal cap, which is used to block light from the output. Note, the Stabiλaser 1542$^{\varepsilon}$ **emission should never be switched on unless a fiber patch cable or the metal cap is mounted at the FC/APC connector**.

6.5 Back panel

The following outputs are available from the back panel:

NETWORK (RJ45), MONITOR (HDMI), USB1 and USB2:
These outputs connect directly to the internal control PC.

If a monitor is connected to the Stabiλaser 1542$^{\varepsilon}$, a noise-suppression ferrite should be applied around the HDMI cable to ensure that the Stabiλaser 1542$^{\varepsilon}$ meets the EMC standards applicable to your country. The ferrite should be installed so that it is located approximately 25–50 mm from the end of the cable that plugs into the Stabiλaser 1542$^{\varepsilon}$. An appropriate model is included in the Stabiλaser 1542$^{\varepsilon}$ shipping kit (see section 5.2).

LOCK TTL:
This output provides a TTL/CMOS compatible signal, which is high (+5 V) when the Stabiλaser 1542$^{\varepsilon}$ is locked to the acetylene line. Otherwise, the *Lock TTL* voltage is at 0 V.

INTERLOCK:
This output is connected to the interlock loop. The output must be connected with a low-impedance load (e.g. 50 Ω or smaller) in order to enable laser output. It can be connected to an external switch or the supplied 50 Ω BNC terminator can be used to close the interlock loop.

7. Software control interface

For normal operation, there is no need to access the software control interface. However, for troubleshooting or monitoring purposes, the control interface is available either by connecting a monitor to the HDMI connector at the back of the main unit or by remote access to the internal control PC.

When the internal control PC boots up, it launches the Stabiλaser 1542$^{\varepsilon}$ control software automatically and the user interface panel is shown, see Fig. 2.

A number of parameters are available from the interface panel, and several of these parameters can be compared to the initial values found in section **Error! Reference s ource not found.**. Significant deviation between current values and initial values can indicate potential problems and compromised performance.

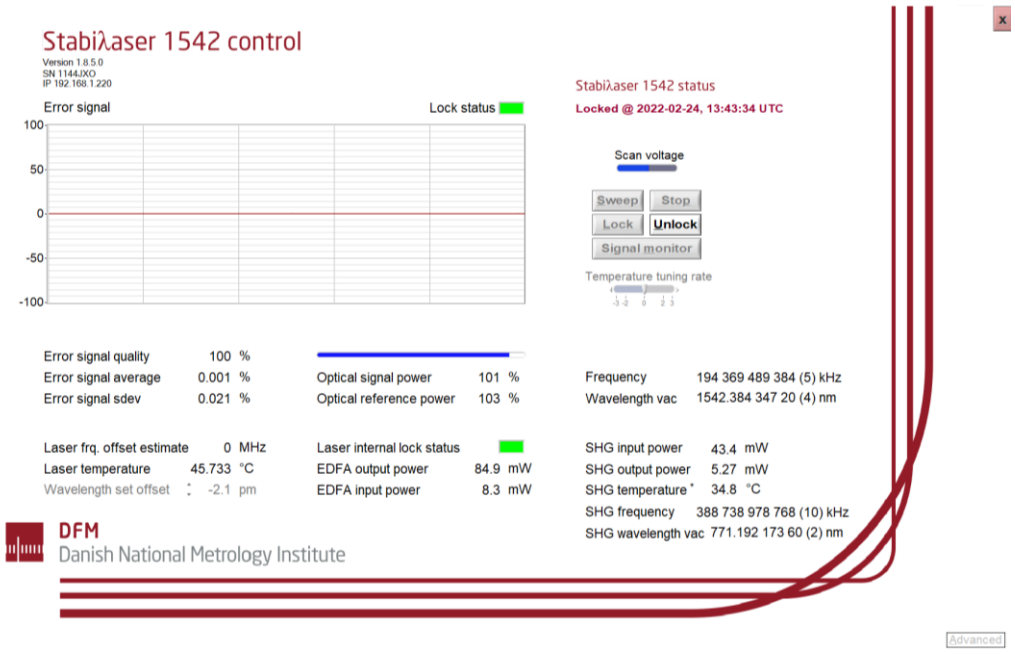


Figure 2 *Stabiλaser 1542$^{\varepsilon}$ control interface panel when locked to the acetylene line. The SHG parameters in the lower right corner are only shown on devices with the optional 771 nm output.*

7.1 Main indicators in the control software

Graphical window

The graphical window displays the error signal for the acetylene lock as a “strip chart”. The scale is given in percent of the nominal maximum error signal amplitude. The Stabiλaser 1542$^{\varepsilon}$ is locked in Fig. 2 and the error signal shown in this figure is very close to zero.

Error signal parameters

Below the graphical window are four blocks of parameters. The top left block shows the *Error signal quality*, *Error signal average* and *Error signal sdev* (standard deviation).

The *Error signal quality* is a measure of the slope of the error signal when the Stabiλaser 1542$^{\varepsilon}$ is locked. When the performance is optimized and the Stabiλaser 1542$^{\varepsilon}$ is locked, the *Error signal quality* should be close to 100 %. Values below about 85 % indicate a possible problem and realignment may be needed (see section 8.2).

The *Error signal average* is a 20 s average of the error signal. This parameter should not deviate much more than about 0.020 % from zero when the Stabiλaser 1542$^{\varepsilon}$ is locked.

The *Error signal sdev* is the standard deviation of the error signal over 20 s. This parameter can be used to identify excess noise in the detection system by monitoring the parameter when the laser is unlocked and tuned more than about 1 MHz away from the acetylene resonance. The parameter can also be used to evaluate the performance of the lock feedback loop when the laser is locked. *Error signal sdev* values similar to (or below) the reference values given in section **Error! Reference s ource not found.** ***Error! Reference source not found.*** are an indication of optimal laser performance.

To the right of the *Error signal quality* is a graphical representation of the same parameter (the blue 'bar' in Fig. 2). This indicator is convenient when optimizing the alignment, see section 8.2.

Optical power parameters

The two parameters *Optical signal power* and *Optical reference power* represent the average optical power on the two photo detectors in the balanced acetylene spectroscopy setup. Values below about 90 % indicate that an alignment may be needed, see section 8.2.

Fiber laser parameters

The following parameters refer to the internal status of the NKT Photonics fiber laser and optical amplifier (EDFA):

The *Laser frq. offset* is an estimate of the fiber laser detuning with respect to the acetylene absorption line. The estimate is based on the fiber laser temperature and can have quite a large uncertainty (hundreds of MHz) – in particular if the Stabiλaser 1542$^{\varepsilon}$ has been moved to a different environment. The estimate is recalibrated whenever the Stabiλaser 1542$^{\varepsilon}$ is locked to the acetylene line. After the first lock of the Stabiλaser 1542$^{\varepsilon}$ in a stable environment, the uncertainty is reduced to typically about 5 MHz or 5 % of the detuning, whichever is larger. Note that the *Laser frq. offset* parameter has no influence on the accuracy and stability of the frequency of the Stabiλaser 1542$^{\varepsilon}$ output.

The *Laser temperature* is the internal temperature of the fiber laser, which basically sets the optical frequency of the fiber laser.

The *Wavelength set offset* parameter is the current set wavelength offset for the fiber laser module. This parameter will remain unchanged if the laser is temperature tuned (see below), and it is therefore not a good indicator for the actual fiber laser wavelength or frequency. However, if the Stabiλaser 1542$^{\varepsilon}$ is not locked to the acetylene line, it is possible to manually set the *Wavelength set offset* parameter. If coarse tuning of the fiber laser is needed, this parameter may be adjusted. However, changes of more than 1.0 pm may start a new internal fiber laser locking cycle, which may end up at a somewhat different wavelength. The minimum change is 0.1 pm, which corresponds to about 13 MHz.

The *Laser internal lock status* refers to the internal lock of the NKT Photonics fiber laser module. Green colour indicates 'locked', whereas red colour indicates 'trying to lock'. It may take between 10 minutes and 1 hour (sometimes even longer) to establish this internal fiber laser lock. Internal lock is required before the Stabiλaser 1542$^{\varepsilon}$ can be locked to the acetylene line. Note that the laser internal lock status indicator is white if laser emission is off.

The *EDFA input power* and *EDFA output power* represent the optical power going into the Erbium Doped Fiber Amplifier and the amplifier output power. The EDFA will switch off if the input power is below a given threshold, typically around 1 mW.

Stabiλaser 1542$^{\varepsilon}$ status

The *Lock status* indicator located above the error signal graphical window indicates whether the Stabiλaser 1542$^{\varepsilon}$ is locked to the acetylene line. This indicator is green when the Stabiλaser 1542$^{\varepsilon}$ is locked and red when it is unlocked.

To the right of the *Lock status* indicator is a short status line, which explains, as text, the current status/activity of the Stabiλaser 1542$^{\varepsilon}$.

When the Stabiλaser 1542$^{\varepsilon}$ is locked, the actual wavelength and optical frequency is displayed in the lower right part of the screen. The frequency and wavelength correspond to the CIPM recommended value for the $^{13}C_2H_2$ P(16) ($\nu_1+\nu_3$) transition, corrected for the frequency shift of the internal acousto-optical modulator (AOM).

Tuning indicators

The *Scan voltage* is a graphical representation of the voltage applied to the fiber laser wavelength modulation input. It is not possible to set the scan voltage manually, but the indicator can be used to monitor the progress when the Stabiλaser 1542$^{\varepsilon}$ is about to lock.

The *Temperature tuning rate* represents the rate of thermal tuning applied to the fiber laser module. The maximum rates (±3) correspond to frequency tuning rates of about ∓1 MHz/s. When the laser is in *Signal monitor state* (see below), it is possible to manually set the temperature tuning rate. Thermal tuning has a significant time lag, and it may take tens of seconds before the actual tuning reacts to changes in the

temperature tuning rate. Thus, the fiber laser will typically ‘overshoot’ by about 20 MHz when the tuning rate is changed from ‘3’ to ‘0’. The *Temperature tuning rate* can be used to manually tune the laser for applications where frequency/wavelength tunability is required. The Stabiλaser 1542$^{\varepsilon}$ cannot be tuned when it is locked to the acetylene line.

PP temperature

PP temperature refers to the internal temperature of the physics package. The temperature when the Stabiλaser 1542$^{\varepsilon}$ achieved lock is printed in the top right in °C. While locked, the maximum and minimum temperature is recorded and displayed together with the current temperature in the bottom left corner.
If the current temperature changes more than ~0.5 °C, the long term stability is no longer guaranteed. The stability can be restored by either relocking the laser or bringing the temperature back to the temperature at lock.

771 nm / SHG parameters (optional)

The SHG parameters (Second Harmonic Generation) shown in the lower right corner in Fig. 2 are only displayed on devices with the 771 nm option. *SHG input power* is the optical input power for the nonlinear optical frequency/wavelength conversion module (SHG device), which converts radiation from 1542 nm to 771 nm. This power is supplied from a second EDFA optical amplifier. *SHG output power* is the power output at 771 nm. *SHG Temperature* is the temperature of the SHG device. When a star (*) is shown after the text “SHG Temperature”, the value is the *set* temperature. When the star is not shown, the value is the *actual* temperature. Whenever the control software is launched, the SHG device temperature is first tuned to the phase matching temperature for optimum conversion efficiency. The temperature is continuously adjusted for maximum conversion efficiency when the laser is locked. The parameters *SHG frequency* and *SHG wavelength (vac)* are optical frequency and vacuum wavelength for the 771 nm output. These two parameters are only visible when the Stabiλaser 1542$^{\varepsilon}$ is locked.

7.2 Control software states

The control interface has four states, which can be activated by clicking the following control buttons: *Lock*, *Unlock*, *Sweep*, *Stop*, and *Signal monitor*. Each of these states are described below. For normal operation, the laser will lock automatically and the user does not have to activate any specific state. Manual selection of state may be useful for special applications, where the Stabiλaser 1542$^{\varepsilon}$ is not required to be locked to the acetylene line. The laser emission is switched on when either the *Locking*, *Sweeping* or *Signal monitor* states are activated.

Ready state

The *Ready state* is the default state for the Stabiλaser 1542$^{\varepsilon}$, which is active when none of the other states are selected. In the *Ready state*, parameters for the fiber laser and the optical fiber amplifier are continuously updated. The Stabiλaser 1542$^{\varepsilon}$ is in the *Ready state* when the status indicator in the top of the control panel indicates ‘Ready’. In the *Ready state* the laser emission is switched off, and the internal lock indicator is therefore white.

Locking state

The control software is, by default, configured to go into the *Locking state* when launched. Alternatively, the *Locking state* can be activated by pressing the “Lock” button.

When in this state, the software will first complete an internal calibration cycle and then try to tune the laser into resonance by tuning the scan voltage (see section 7.1). If the resonance is observed during this scan, the Stabiλaser 1542$^{\varepsilon}$ goes into lock. If the resonance is not observed, the laser will temperature tune into resonance and then lock. This temperature tuning process can take up to about 30 minutes. If the initial locking sequence fails to achieve locking, the Stabiλaser 1542$^{\varepsilon}$ will make multiple attempts with larger and larger temperature tuning scans.

If the fiber laser is not locked internally (see section 7.1), or if internal lock is lost during the temperature tuning process, it may take an additional 10 minutes to 1 hour (sometimes even longer) to establish this internal fiber laser lock.

It is possible to return from *Locking state* to *Ready state* by clicking the “Unlock” button.

Sweeping state

The *Sweeping state* is activated from the *Ready state* by clicking the “Sweep” button. In the *Sweeping state* the control software continuously sweeps the scan voltage. If the resonance is observed during the sweep, the sweep direction is changed. This function allows the user to monitor the spectroscopic error signal as a function of laser frequency, which can be useful for troubleshooting.

It is possible to return from the *Sweeping state* to the *Ready state* by clicking the “Stop” button.

Signal monitor state

In the *Signal monitor state* all indicators[6] and the error signal graph are active, but the locking sequence is not activated. This state is engaged by pressing the “Signal monitor” button. The software will return to the *Ready state* if the “Stop” button is pressed.

While in the *Signal monitor state*, it is possible to slowly temperature-tune the frequency of the fiber laser as described in section 7.1 *Tuning indicators*. It is also possible to coarse tune the fiber laser frequency by adjusting the *Wavelength set offset* parameter as described in section 7.1 under *Fiber laser parameters*.

It is possible to return from the *Signal monitor state* to the *Ready state* by clicking the “Stop” button.

[6] For devices with the 771 nm option, the SHG temperature reading is *only* active in the *Ready state*.

8. Troubleshooting

8.1 The Stabiλaser 1542$^{\varepsilon}$ never locks to the acetylene line

The Stabiλaser 1542$^{\varepsilon}$ will normally tune and lock to the acetylene absorption line by itself. In order to find the absorption line, the Stabiλaser 1542$^{\varepsilon}$ keeps track of the fiber laser temperature whenever the laser frequency is at the acetylene line. However, this reference temperature may be too far off if the Stabiλaser 1542$^{\varepsilon}$ has been moved to a laboratory with a different room temperature, if the Stabiλaser 1542$^{\varepsilon}$ has been switched off for a long time (typically several months), or if the Stabiλaser 1542$^{\varepsilon}$ has not fully reached thermal equilibrium before attempting to lock to the acetylene line.

If the Stabiλaser 1542$^{\varepsilon}$ does not lock to the acetylene line (green LED remains off) when following the procedure in section 6.2, it is recommended to do the following:

1. Turn the key switch on the front panel to off ('0'). Wait 15 seconds and turn the power switch on the pack panel off.
2. Connect monitor, mouse and keyboard to the back of the Stabiλaser 1542$^{\varepsilon}$.
3. Set the power switch on the back panel to on.
4. With the electronics now switched on, leave the Stabiλaser 1542$^{\varepsilon}$ in this state for at least 10 hours to reach thermal equilibrium.
5. After >10 hours, turn the key switch to on ('1') and wait for the Stabiλaser control software to be launched on the internal PC.
6. Click on the "Advanced" button in the lower right corner of the screen. A message input box will show up asking to enter a key. Type "log" (without the "") and then click OK. This will start a detailed log of laser parameters, which may be needed later.
7. Click on the "Unlock" button to bring the Stabiλaser 1542$^{\varepsilon}$ in the *Ready state*.
8. Click on the "Signal monitor" button to bring the Stabiλaser 1542$^{\varepsilon}$ in the *Signal monitor state.*
9. Click on the "Advanced" button in the lower right corner of the screen. Type "ResetFiberLaser". This will reset parameters in the internal fiber laser. After about 10 min. to maybe 1 hour the *Laser internal lock status* should change from red to green. When this indicator becomes green, wait another 5 minutes and take a picture of the screen; this may be needed later.
10. Click on the "Lock" button.
11. The laser will now try to find the absorption line by doing wider and wider temperature scans. If the laser does not lock within 5 hours, you may either contact DFM A/S or try the steps below.

If the reference temperature is too far off for the acetylene line to be identified, the set reference temperature may have to be readjusted manually. Assuming the steps above has been completed, continue with the following:

12. The Stabiλaser 1542$^{\varepsilon}$ automatically logs the fiber laser temperature when locked to the acetylene line (i.e. the reference temperature). These data can be used to estimate a new reference temperature, typically as the average reference

temperature the last few days the laser was locked or by extrapolating from previous data. Click on the “Advanced” button in the lower right corner of the screen. A message input box will show up asking to enter a key. Type “Tplot” (without the “”) and then click OK. A graph is now shown with a plot of the fiber laser temperature when locked (i.e. reference temperature) versus days after the first reference temperature was logged. Use the plot to estimate a new value for the reference temperature. This estimate should be within 0.2 °C of the actual (unknown) reference temperature for the Stabiλaser 1542$^{\varepsilon}$ to find the absorption line and lock automatically. Note, if the last few temperature data differs significantly from the overall history of data, then they could be “bad” data that should be discarded when estimating the new reference temperature.

13. Click on the “Advanced” button in the lower right corner of the screen. Type “Tset:43.123” (without the “” and with 43.123 replaced with the reference temperature estimate) and then click OK.
14. Engage the *locking state* either by clicking “Unlock” and then “Lock” or by rebooting the internal PC by setting the key switch to ‘0’, wait about 10 seconds and then set the key switch to ‘1’.

If the laser does not lock within 2-5 hours, you may either contact DFM A/S or try to manually readjust the estimated reference temperature according to the following procedure:

15. Repeat steps 7-9 above.
16. Change the displayed error signal in the strip chart graph so it becomes sensitive to the Doppler-broadened acetylene absorption line, see section **Error! Reference source not found.** and Fig. 6.
17. If the *Wavelength set offset* parameter is outside the interval 2.0 pm – 4.0 pm, then set it to 3.0 pm. Wait for the laser temperature to become stable.
18. Start a manual search by changing the *Wavelength set offset* parameter in steps of ±1.0 pm. Wait 40 s after each change. If the displayed error signal in the strip chart is below 0 %, you should use a step of +1.0 pm. If the error signal value is above 0 %, you should use a step of -1.0 pm. If you see the narrow sub-Doppler signal (see Fig. 6), you should try with smaller steps in the opposite direction and have the fiber laser temperature become stable as close as possible to the sub-Doppler signal. Thus, each time the error signal strip chart shows the narrow sub-Doppler signal, you should change the sign of your steps and reduce the absolute step size. If you do not see the sub-Doppler signal, continue changing the *Wavelength set offset* with the same step as before. If you never see the Doppler-broadened signal after a change of about 15 pm, you should go back to step 17 above and do a search in the opposite direction.
19. When the fiber laser temperature at (or very close to) the sub-Doppler signal has been identified, use this temperature as the new reference temperature estimate and go back to step 13 above.

8.2 Alignment of the spectroscopic unit

If the Stabiλaser 1542$^{\varepsilon}$ is exposed to excessive vibrations or mechanical shocks, the free space optics in the spectroscopic unit (protective housing) may become misaligned.

Minor misalignment is identified as a reduced *Error signal quality* level when the Stabiλaser 1542$^{\varepsilon}$ is locked as compared to the initial test value in section **Error! R eference source not found.**. Typically, *Error signal quality* levels below 85% indicate some minor misalignment.

Major misalignment is identified as a reduced *Optical signal power* level in the *Signal monitor state* as compared to the initial test value in section **Error! Reference source n ot found.**. Typically, *Optical signal power* levels below 85% indicate some major misalignment. Note however, if both *Optical signal power* and *Optical reference power* are low (below about 85 %), the problem may be more severe than just simple realignment, and DFM A/S should be contacted immediately according to section 2 *Service.*

Alignment of the spectroscopic unit requires that the Stabiλaser 1542$^{\varepsilon}$ be operated with the top cover removed. High voltage (240 V) cables inside the main unit may become exposed, and care should be taken not to touch these parts. Removement of the top cover does not lead to exposure to infrared radiation since radiation is contained in optical fiber patch cables and in the sealed black spectroscopic unit (protective housing). However, exposure to IR radiation may become possible if fiber patch cables are disassembled or if the lid on the spectroscopic cell is removed. It is possible to misalign the spectroscopic unit completely, which requires that the Stabiλaser 1542$^{\varepsilon}$ is returned for repair. Therefore, **alignment of the spectroscopic unit should only be performed by personnel with appropriate qualifications and after consulting with DFM.**

Misaligment of the spectroscopic unit that requires the Stabiλaser 1542$^{\varepsilon}$ to be returned to DFM A/S is not covered by the warranty. Realignment by DFM A/S according to the procedure below will be invoiced, and charges for return shipment will be added.

The following alignment procedure should be followed:

1. Switch off the Stabiλaser 1542$^{\varepsilon}$ and remove the power cord. Place the Stabiλaser 1542$^{\varepsilon}$ on a table, which allows easy access to the device. Remove the two side panels by lifting the panels with a small screw driver from back as shown in Fig. 3A. The side panels are attached with snap-locks and are removed by carefully pulling the panels off the main unit.

2. Remove the four Torx T20 head screws from the top as shown in Fig. 3B.

3. Use a small screw driver to release the top cover in each corner as shown in Fig. 3C. The top cover is now only fixed with snap-locks and is removed by carefully pulling the cover off the main unit. The top cover is still attached to the main unit

with a green/yellow ground wire. Disconnect the wire from the top cover as shown in Fig. 3D. Check that the internal parts of the Stabiλaser 1542$^{\varepsilon}$ are undamaged, in particular that none of the accessible fiber patch cables are broken.

4. Carefully insert two 2 mm Allen keys into the alignment screws as shown in Fig. 3E. Use a flash light from the side to illuminate the alignment screws inside the spectroscopic unit.

5. Connect a monitor (HDMI) and keyboard/mouse (USB) to the Stabiλaser 1542$^{\varepsilon}$. Switch on the Stabiλaser 1542$^{\varepsilon}$ and wait for thermal stabilization. Check if the Stabiλaser 1542$^{\varepsilon}$ can lock to the acetylene resonance by activating the “locking state” (see section 7.2); note that it may take up to 1 hour (maybe even longer) for the laser to lock. If the Stabiλaser 1542$^{\varepsilon}$ locks, and if the “error signal quality” is above 5 % (see section 7.1), go to step 7. If not, continue with step 6.

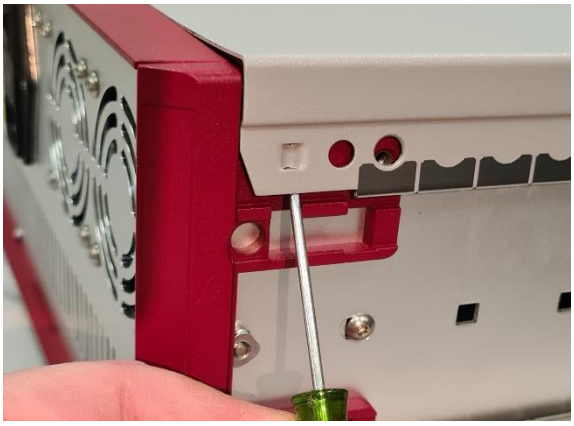
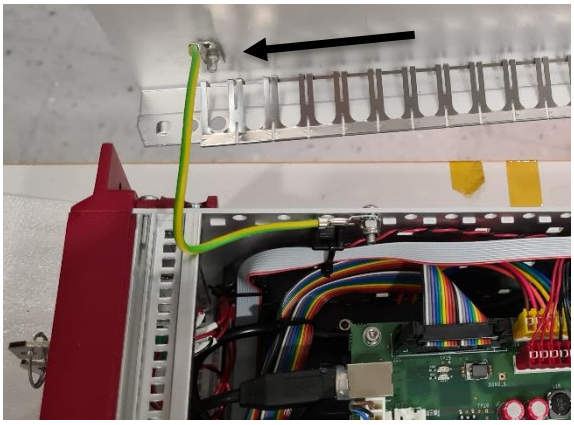
6. Click the “Signal monitor” button on the software control panel to engage the *Signal monitor state* (see section 7.2). After initialization of this state, maximize the *Optical signal power* using small adjustments (typically about 10°) with the two Allen keys (horizontal and vertical alignment). The *Optical signal power* should reach a value above 90 % and preferably close to 100 %. At the same time, it is important to monitor the stability of the *Optical signal power*, the *Reference signal power*, and the *error signal* graph. The optical and reference signal power levels should be stable within about ±3%, and the *error signal* graph should show a constant value at zero (or very close to zero).

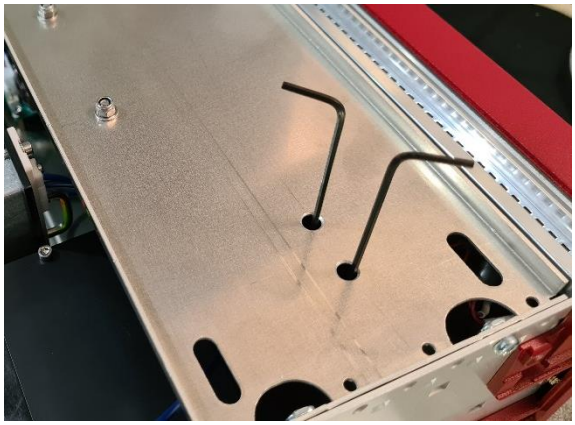
7. Check if the Stabiλaser 1542$^{\varepsilon}$ can lock to the acetylene resonance by activating the “locking state”; note this may take up to 1 hour. Contact DFM A/S if the Stabiλaser 1542$^{\varepsilon}$ does not lock, see section 2 *Service*.

8. While the Stabiλaser 1542$^{\varepsilon}$ is locked to the acetylene line, maximize the *Error signal quality* parameter by the slightest adjustments in steps of about 5 ° with the two Allen keys. The *Error signal quality* should reach a value above 90 % for optimum performance. The lock will be quite sensitive to disturbances, so alignments should be done with the slightest possible adjustments. If the laser goes out of lock during alignment, relock the laser before further alignment. If the laser does not lock, go back to step 5.

9. Carefully remove the Allen keys and install the top cover.

10. Verify performance according to section 9 *Performance verification*.

	*Fig. 3A:* *Lifting the side panels with a small screw driver in order to release snap-locks.*
	*Fig. 3B:* *Screws holding top cover.*
	*Fig. 3C:* *Lifting the top cover with a small screw driver in order to release snap-locks.*
	*Fig. 3D:* *Arrow shows where to disconnect ground wire.*

	*Fig. 3E:* *Two Allen keys (hex) inserted into alignment screws through two holes in the top plate. Use a flash light from the side to easily see the alignment screws.*

9. Performance verification

The readout of various parameters by the control software can be used to verify that the Stabiλaser 1542$^{\varepsilon}$ operates under optimal conditions. This is particularly relevant after relocation of the Stabiλaser 1542$^{\varepsilon}$ or after re-alignment of the spectroscopic unit.

The various parameters and their normal operating ranges are described in section 7.1. The readings in the control software can also be compared to the test measurements determined during production, as listed in section **Error! Reference s ource not found.**.

The most important performance indicator is the *Error signal quality* when the laser is locked. If this parameter is below 85 % to 90 %, the specifications for the short- and long-term frequency instability may be compromised and alignment of the spectroscopic unit may be required (see section 8.2). This parameter should be verified after relocation, and after realignment.

Direct verification of the frequency stability, frequency linewidth and frequency accuracy requires an additional optical frequency reference of similar or better performance[7].

[7] Thomas Talvard, Philip G. Westergaard, Michael V. DePalatis, Nicolai F. Mortensen, Michael Drewsen, Bjarke Gøth, and Jan Hald, "*Enhancement of the performance of a fiber-based frequency comb by referencing to an acetylene-stabilized fiber laser*," Opt. Express **25**, 2259-2269 (2017)