



## QUANTUM CASCADE LASER USER'S MANUAL



Version number 3.2.12  
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## DOCUMENT VERSION

This is Version 3.2.12 of the manual, published on November 29th, 2024, superseding version 3.2.11 of the manual, published on October 30th, 2024. The following modifications have been applied since the publication of version 3.2.0:

Publication date	Version number	Changes
2024/11/29	3.2.12	Updated pulse length values of §4.2.2
2024/10/30	3.2.11	Updated values of Table 6.3
2024/09/17	3.2.10	Current values were reversed in Table 6.2
2021/12/14	3.2.9	LLH temperature sensor switches from pt-100 to thermistor
2020/12/8	3.2.8	Clarified in 1.3 that the S-2 pulser is suitable for low impedance loads
2020/11/25	3.2.7	Updated Fig. 5.10 and § 5.2.1
2020/08/28	3.2.6	Removed Linux support for S-2
2020/05/13	3.2.5	Added full name for S-2 in Table 2 and fixed general typographical errors.
2019/10/21	3.2.4	Clarified required compliance in § 3.1
2019/05/28	3.2.3	Added information in 5.2.3
2019/04/10	3.2.2	Updated Table 6.2
2018/11/09	3.2.1	Updated § 6.2
2018/07/25	3.2.0	Some deprecated items that were described in version 3.1.14 but are no longer available have been removed from the manual. For information on those legacy items, please contact ALPES LASERS directly.

# Preface

This manual is a reference tool for personnel using ALPES LASERS QCLs and electronic equipment. Its purpose is to provide the customer with sufficient information to carry out normal installation and operating procedures. It is not intended to replace or supersede any local directive. Table 1 gives a summary of the content of each chapter.



**CAUTION:**

All personnel must read and understand this manual before attempting to operate ALPES LASERS QCLs or electronic device. Failure to follow safety instructions could result in death or serious injury.

Chapter	Content
1. Overview	General overview of ALPES LASERS QCLs and Starter Kit components.
2. Safety	Information for ensuring safety during the installation, operation and maintenance of ALPES LASERS QCLs and electronic equipment.
3. Installation	Prerequisites, guidelines and list of connections for the installation of ALPES LASERS equipment.
4. QCL operation	Principle of operation of QCLs, ALPES LASERS datasheet and QCL parameters.
5. Starter Kit Operation	Procedures for setting up the Starter Kit and operating a QCL.
6. Technical specifications	Technical specifications and drawings of ALPES LASERS QCLs and electronic equipment.
7. Maintenance	Procedures for exchanging a laser in the LLH housing and calibrating ALPES LASERS electronic equipment.
Appendices	Informations and procedures for advanced users.

Table 1.: Structure of the QCL User's Manual.

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## Typesetting conventions

- Table 2 gives a list of the acronyms used in this manual.
- A boxed item indicates a hardware setting on an electronic device.

<b>Acronym</b>	<b>Full name</b>
AN	Aluminum Nitride Submount
AN-NSP	Aluminum Nitride Submount on copper mount
AR	Anti-Reflection Coating
DFB	Distributed FeedBack laser
ECLK	External Cavity Laser kit
EPS	External Power Supply
FP	Fabry-Perot laser
HP-GS	High Power Submount
LLH	Laboratory Laser Housing
NDR	Negative Differential Resistance
NTC	Negative Thermal Coefficient
NS	screwed laser submount
OEM	Original Equipment Manufacturer
QCL	Quantum Cascade Laser
QC-ET	Quantum Cascade Laser Extended Tuning
QC-XT	Quantum Cascade Laser eXtended Tuning
S-2	High current QCL pulsed driver
ST	clamped laser submount
TC-3	Temperature Controller
TEC	ThermoElectric Cooler (Peltier junction)

Table 2.: Acronyms used in this manual.

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# 1. ALPES LASERS Products

The following chapter gives a general overview ALPES LASERS lasers and equipment is given, as well as a brief introduction to the detection principle and fields of application of quantum cascade lasers (QCLs).

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## 1.1. ALPES LASERS Laser Types

ALPES LASERS manufactures several types of Quantum Cascade Lasers (QCLs): singlemode Distributed-Feedback (DFB) or multimode Fabry-Perot (FP), which can be operated in two modes: continuous wave (CW) or pulsed. ALPES LASERS lasers are available in different types of packaging, presented in section 1.2. ALPES LASERS developed dedicated electronics to control the temperature and current drive of its QCLs; see section 1.3 for details.

ALPES LASERS is constantly developing new QCLs and electronics to satisfy inquiries from its customers. Contact ALPES LASERS to find the best solution for your application.

### 1.1.1. Standard QCLs

This section describes the standard types of QCLs produced by ALPES LASERS.

#### Distributed Feedback (DFB)

Distributed Feedback (DFB) QCLs produce a beam with very precise wavelength. A grating is etched over the active region to force the operation of the laser at a very specific wavelength given by the grating periodicity. These lasers are tunable over a range of up to  $10\text{ cm}^{-1}$  and will emit with a maximum power from 1 mW to  $> 100\text{ mW}$ .

#### Fabry-Pérot (FP)

Fabry-Pérot (FP) QCLs are capable of producing higher powers, but are typically multi-mode. They emit in a broad range of wavelengths and can cover more than 10% of the central emitting wavelength. FP QCLs are well suited for applications such as liquid spectroscopy and high power emitting sources, for which broadband emission is acceptable, and when no signal purity is required. High Power FP lasers are available with up to 1.5 W of average power.

#### Broadgain (BG)

Broadgain (BG) QCLs consist in FP lasers designed for maximum width of the gain profile. They can be used as broad spectrum illuminators for spectroscopy or imaging. Combined with an anti-reflection coating, they are suitable for use in an external cavity to obtain a tunable laser with a wide tuning range.

## THz FP

THz FP QCLs can reach wavelengths of 70 to 200  $\mu\text{m}$ , but must be operated under cryogenic conditions; contact ALPES LASERS for more details.

### 1.1.2. ALPES LASERS exclusive QCLs

#### Extended Tuning DFB Source (QC-ET)

ALPES LASERS is the only laser manufacturer developing and producing this type of mid-IR lasers commercially. This ALPES LASERS product allows to reach a wide interval of wavelengths for a fixed heat-sink temperature with a speed of the order of kHz instead of the several seconds needed to change its temperature through the TEC and submount. The QC-ET carries a  $10\mu\text{m}$  resistor coupled directly on the active zone of the laser, therefore it is controlled through two current inputs instead of one.

#### QC-XT Laser Sources

ALPES LASERS is the only laser manufacturer developing and producing this type of mid-IR lasers commercially. This ALPES LASERS product allows to reach an even wider interval of wavelengths for a fixed heat-sink temperature by changing the laser's grating locally. The front-end and back-end of the QC-XT have different gratings and independent current input; the laser emission occurs when a front-end and a back-end etchings are aligned, allowing to jump from one wavelength to another with extreme speed.

#### Frequency Comb Quantum Cascade Laser (FCQCL)

ALPES LASERS is the only laser manufacturer developing and producing this type of mid-IR lasers commercially. This product is meant for expert users, for applications such as liquid spectroscopy, in which the signal may vary in much less time than the typical 10 ms needed to scan many wavelengths. Instead of scanning wavelengths, the FCQCL allows to record the whole signal within 1ms, and the signal is extracted from Fourier transform a posteriori.

### 1.1.3. Principle of operation

Quantum Cascade Lasers (QCLs) are unipolar lasers emitting in the mid-infrared from 4 to 20 microns. The laser is a ridge of InGaAs and AlInAs grown on InP providing gain and a Fabry-Pérot cavity in order to build up the laser oscillations. ALPES LASERS produces QCLs of two types:

## QCL parameters and performance

All ALPES LASERS lasers are thoroughly tested and characterized. The results are reported in datasheets, which are readily available on ALPES LASERS website. Each QCL is delivered with its datasheet, containing data on singlemode and multimode emission, IV curves, emitted power, maximum operating current and operation temperature. See section 4.1 for details.

## QCL geometry

Figure 1.1 shows an ALPES LASERS QCL growth and a laser chip mounted on an NS submount (see section 1.2.1). By convention, the vertical axis of the laser is parallel to the growth direction, as well as the beam polarization (i.e. electric field) and the NS submount screw holes axis. The emission axis is perpendicular to the growth direction and to the edges of the NS submount.

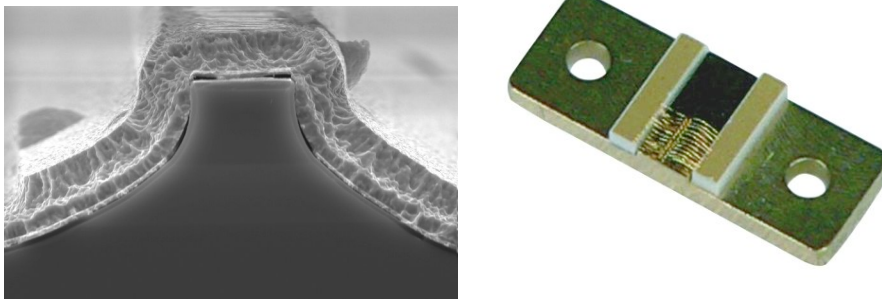


Figure 1.1.: ALPES LASERS QCL growth (left) and laser chip mounted on a submount (right).

The laser chip is soldered to a copper base and is bonded with gold bonds to two AlN ceramic pads, which are also mounted on the same copper base, as shown in figure 1.3. The surface of the ceramic pads is covered with a gold layer and their sides have a whitish ceramic color. The golden surface must be positioned upwards. When looking into the LLH from the top, the pad left of the direction of emission is labeled DN for down, and the right pad UP for up. Only one pad is characterized, as specified in the datasheet. If only one pad is present, it is in the DN position by default.

## Polarity

By default, the laser has negative polarity: the cathode is connected to the ceramic pads and the anode is connected to the submount copper plate (see figure 1.3). The laser may be mounted junction down; this is clearly indicated on the laser box. In this case, the laser has positive polarity: the cathode is connected to the submount copper plate and the anode to the ceramic pads.

### 1.1.4. Fields of applications

#### IR

The ALPES LASERS QCLs address the need for gas sensing and spectroscopy applications in the wavelength region from 3 to 15 $\mu\text{m}$ ; most chemical compounds have their fundamental vibrational modes in the mid-infrared. More specifically, the high transparency of the atmosphere in two so-called atmospheric windows at approximately 3-5 $\mu\text{m}$  and 8-12 $\mu\text{m}$  allows remote sensing and detection. The long wavelength reduces Rayleigh scattering from dust and rain drops dramatically, allowing applications such as radars, ranging, anti-collision systems, covert telecommunications, etc. As an example, Rayleigh scattering decreases by a factor  $10^4$  for wavelengths ranging from 1 $\mu\text{m}$  to 10 $\mu\text{m}$ . Examples of applications are:

- Industrial process monitoring:
  - contamination in semiconductor fabrication lines
  - food processing
  - brewing
  - combustion diagnostics
- Life sciences and medical applications
- Medical diagnostics, biological contaminants.
- Law enforcement
- Drug or explosive detection.
- Military:
  - chemical/biological agents detection
  - counter measures
  - covert telecommunications.

#### THz

Terahertz radiation is safe and non-ionizing. It bridges the gap between the mid-infrared and microwaves. It can penetrate most non-conductive materials and can be used in a wide range of applications, including:

- Water content mapping
- Tissue density mapping
- Metal detection

- Spectral identification

Terahertz QCLs operate in the range from 1 to 6 THz. Coherent polarized THz radiation is generated by means of direct stimulated optical transitions of electrons within the conduction band of a semiconductor heterostructure. THz lasers need cryogenic cooling, but at temperatures higher than 77K (boiling point of liquid nitrogen), making their operation non-prohibitive in terms of cooling equipment.

ALPES LASERS THz QCLs are available as Chip-on-Carrier (CoC) or readily mounted in a variable temperature cryostat. ALPES LASERS offers three types of cryogenic system solutions:

- LN<sub>2</sub> dewar
- cryostat
- standalone

Contact ALPES LASERS for more details.

*Note:* THz QCLs are not pre-tested; contact ALPES LASERS to discuss the requirements for a specific application.

## 1.2. QCL configurations

Figure 1.2 shows a generic setup to drive an ALPES LASERS QCL. This setup can be designed by the customer himself, or solutions can be provided by ALPES LASERS.

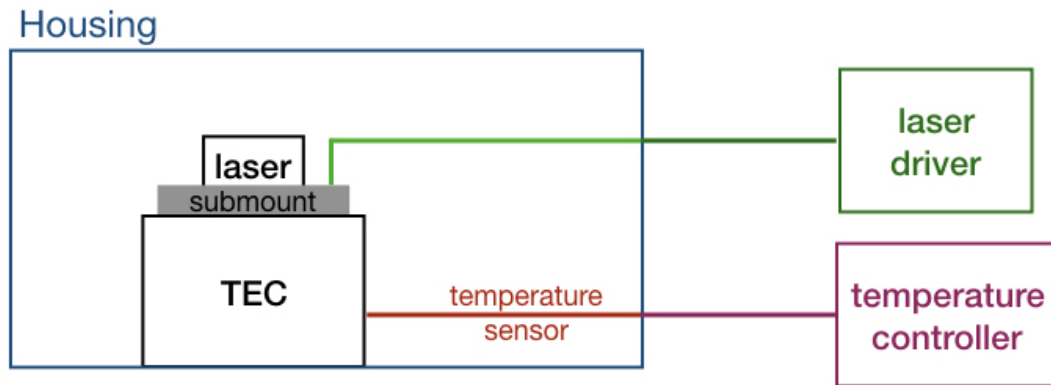


Figure 1.2.: Generic setup to drive a laser.

ALPES LASERS QCLs can be delivered in different kinds of configurations:

- Bare Chips: untested laser chips; contact directly ALPES LASERS for more information.
- CoC: A laser chip available on stock is mounted on either a NS, HP-GS or AN submount (see section 1.2.1). These submounts can be integrated into a LLH or HHL housing, or can be sold separately, to be integrated into a device designed by the customer.
- ALPES LASERS housings, described below;
- integrated in a kit, described below.

### 1.2.1. QCL mounting

ALPES LASERS QCLs can be mounted on different types of submounts:

**NS submount** or screwed mounting; see figure 1.3. The NS submount is a standard copper submount that can be mounted in a HHL or LLH housing, or installed in any other appropriate setup. The NS submount is typically attached mechanically (e.g. using screws) to a heatsink. The NS submount can hold single or twin laser chips.

**HP-GS submount** The HP-GS submount is a larger copper submount that is used only for high-power lasers.

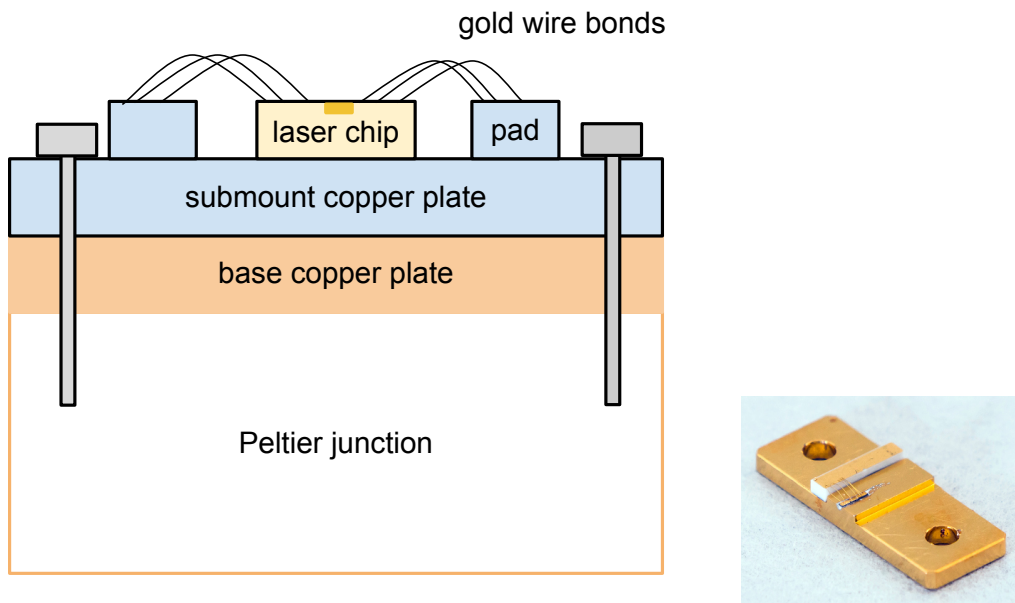


Figure 1.3.: ALPES LASERS QCL NS submount schematic (left) and picture (right).

**AN submount** The AN submount is an aluminium nitride thin submount with a metallized back-contact. It can be mounted in a HHL or TO-3 housing.

**AN-NSP submount** See figure 1.4. A laser on AN submount can also be mounted onto a NS-like copper submount, denominated AN-NSP submount.

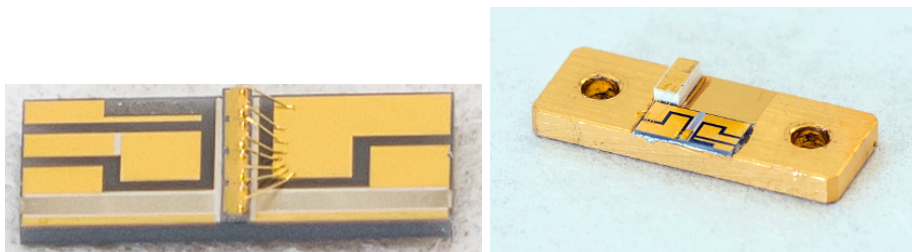


Figure 1.4.: ALPES LASERS AN submount (left) and AN-NSP submount (right).

The QCL submount can be integrated in a LLH, HHL or in any package designed by the customer. The QCL submount is mounted on a copper plate, which lies on a Peltier junction for heat dissipation, as shown in figure 1.3.

### Technical specifications

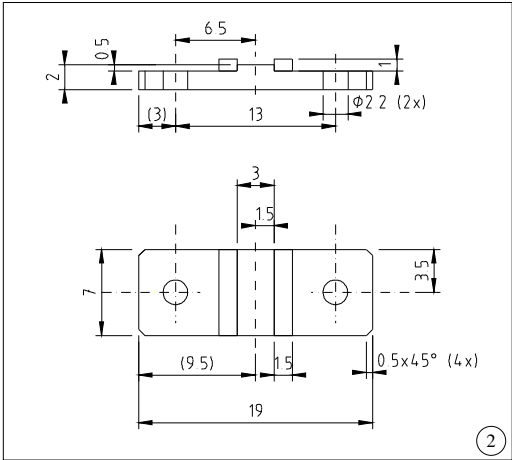


Figure 1.5.: NS submount.

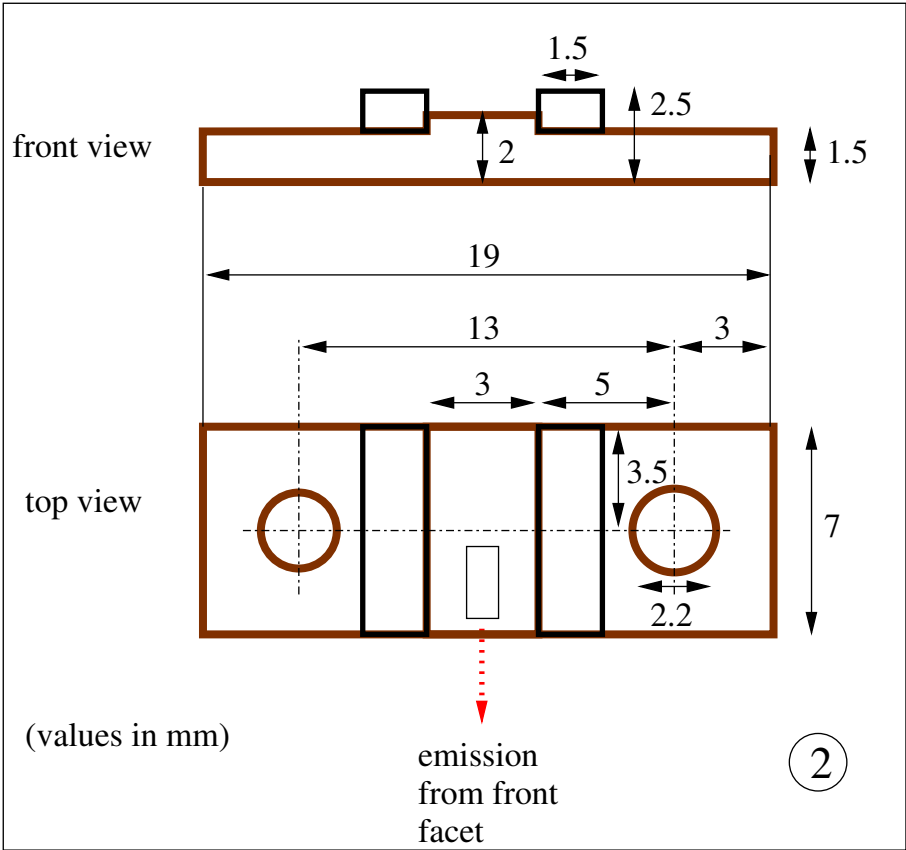


Figure 1.6.: NS submount.

## 1.2.2. Housings

ALPES LASERS produces three kinds of housings, shown in figure 1.7 and described below.

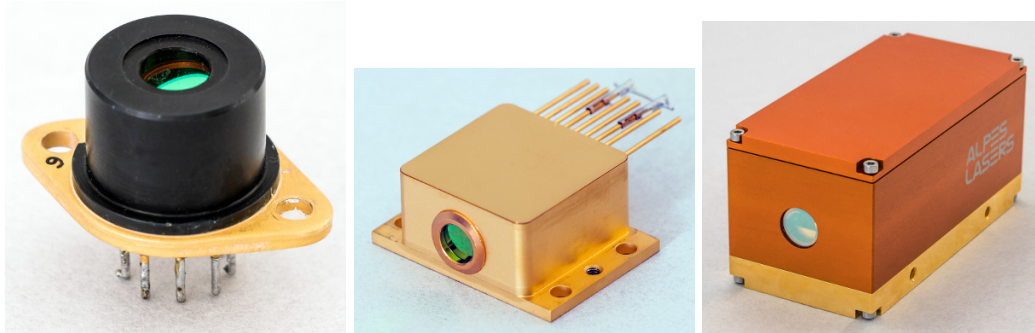


Figure 1.7.: ALPES LASERS TO3, HHL and LLH housings.

### TO3 housing

Pulsed lasers are available in TO3 cans, which are smaller and less power-intensive than the HHL packages. TO3 housings are sealed, include a TEC and are available with AR coated lenses for beam collimation or flat windows. Their small size and low dissipation (less than 4W in pulsed mode) make them ideal for integrating the QCL into a piece of equipment manufactured by the customer.

*Note:* the TO3 housing requires a specific type of QCL mounting, not readily available on stock; please address your inquiry directly to ALPES LASERS.

### Laboratory Laser Housing (LLH)

The LLH housing is designed for research applications. It can be cooled down to  $-30^{\circ}\text{C}$  with water cooling. It is designed to allow exchanging the QCL in a straightforward way. It is compatible with all ALPES LASERS peripherals, and all ALPES LASERS QCLs available in stock can be used in a LLH housing, making it the most versatile housing available. See section 5.3 for details.

### High Heat Load (HHL) housing

The HHL housing is a sealed collimated housing with a TEC for CW or pulsed lasers. The optional collimating lens is protected by a plane window, making it ideal for operating in aggressive environments. The integrated TEC comes in three options: 1-stage, 2-stage and HP (high power). See section 5.2 for details.

## 1.3. ALPES LASERS Peripherals

ALPES LASERS developed the TC-3 temperature controller and the S-2 and S-3 pulsers for optimal performances of its QCLs. They are shown in figure 1.8 and details are given in sections 6.1, 6.2 and 6.3.



Figure 1.8.: ALPES LASERS TC-3 temperature controller, S-2 pulser and S-3 pulser..

### 1.3.1. TC-3 temperature controller

The TC-3 temperature controller is set in factory making it ready-to-use with HHL or LLH housings. It can also be fully programmed by the customer to use with a variety of NTC and RTD sensors. It can power a Peltier cooler with up to 5.0 A of current.

### 1.3.2. S-2 Pulser

The S-2 QCL Pulser is designed to provide fast, high compliance and low impedance current pulses to non-linear current driven devices such as QCLs. The generated pulses have a rise time between 5 and 15 ns. The S-2 driver can be directly controlled through a computer. Drivers are available for Mac OS X and Windows. If needed, the firmware can be upgraded to the latest version using the firmware upgrader for Mac OS X and Windows.

### 1.3.3. S-3 Pulser

The S-3 High Power Pulse Generator is designed to drive devices requiring short or long pulses of high current with a non-linear response, including optical devices such as high power QCLs, IR laser diodes, LEDs or electronic devices such as Gunn diodes or high speeds transistors and rectifiers.

The S-3 Pulser is an extensively versatile device, of which a few features are listed below:

- it can be operated fully programmed by a computer, or as a stand-alone hardware device, through direct commands using an API;

- drivers for for Mac OS X and Windows are available. If needed, the firmware can be upgraded to the latest version using the firmware upgrader for Mac OS X and Windows.
- it can be operated as a slave, reproducing a control pulse, or its internal clock can be used to produce pulses or trains of pulses in meaningful configurations;
- external enable/disable TTL control that allows full operation in Quasi-CW mode of a QCL, Laser Diode or any load;
- internal DC bias Tee allowing to add a DC dither in between the pulses to create a DC additional dissipation, with independent control from the pulse current. This is a great feature when driving a QCL in pulsed mode, as the wavelength can be adjusted without changing the pulse current or heat sink temperature.

## 1.4. External Cavity Laser Kit (ECLK)

The External Cavity Laser Kits (ECLK) are designed for single-mode operation with wide spectral tunability. Its main features are listed below, see chapter 7 for details.

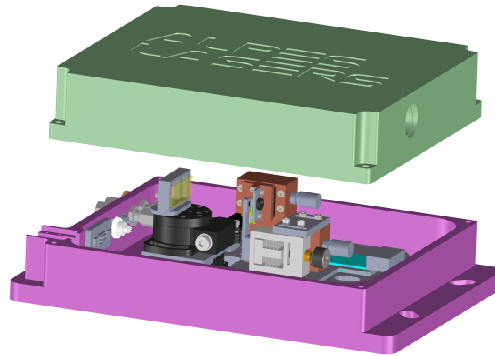


Figure 1.9.: ECLK kit.

- The ECLK consists of a QCL gain chip, a grating-tuned extended optical cavity in Littrow configuration, a S-2 pulser, a TC-3 temperature controller, and a graphical user interface software.
- The kit is delivered pre-aligned and ready to use, with fully-tested specifications on a datasheet.
- The ECLK is compatible with ALPES LASERS Broad Gain QCLs, which tune over up to 25% of their center wavelength, and standard Fabry-Perot QCLs with a narrower gain. For performances at other wavelengths, please contact ALPES LASERS.
- Additional gain chips with different wavelength coverage and/or output power can be purchased from ALPES LASERS and installed in the instrument by the user.

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## 2. Safety

ALPES LASERS electronic equipment operates at high voltages and includes a LASER that may cause serious injury if not handled properly. The guidelines in this document follow as closely as possible the IEC 60825-1 International Standard for safety of laser products.

**IMPORTANT:**

This document provides general safety instructions. Site specific safety regulations on electricity and lasers must be followed if they supersede the recommendations in this manual.

When working with the Starter Kit, some potential hazards include environmental, electrical or radiation due to LASER; they are explained in more detail in sections 2.3.1, 2.3.2 and 2.3.3. The access to potentially dangerous operations is not controlled and is left to the supervision of the owner.

**IMPORTANT:**

Any personnel working directly or in the surroundings of ALPES LASERS equipment must read carefully and understand the safety issues discussed in this chapter.

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## 2.1. General safety considerations

If any of the following conditions exist, or are suspected, do not use the instrument until safe operation can be verified by trained service personnel:

- Visible damage
- Severe transport stress
- Prolonged storage under adverse conditions
- Failure to perform intended measurements or functions

If necessary, return the instrument to ALPES LASERS for service or repair to ensure that safety features are maintained.

## 2.2. Notation

The use of DANGER, WARNING and CAUTION notation in this manual is in compliance with the SEMI standard S-13-0298<sup>1</sup>; their definition is given below. They may also be used to alert against unsafe practices.



### DANGER:

Indicates an **immediate** hazardous situation, which, if not avoided, may result in death or serious injury.



### WARNING:

Indicates a **potentially** hazardous situation, which, if not avoided, may result in death or serious injury.

The use of IMPORTANT and *Note* notations is defined below.

### IMPORTANT:

Contains instructions or practices associated with maintenance and operation of the Starter Kit. Highlights specific actions or steps to be followed in order to avoid defeating equipment functionality or cause product damage.

---

<sup>1</sup>SEMI S13-0298: *Safety Guidelines for Operation and Maintenance Manuals Used with Semiconductor Manufacturing Equipment*, Semiconductor Equipment and Materials International (Mountainview, CA) 1998

**CAUTION:**

Indicates a potentially hazardous situation, which, if not avoided, may result in minor or moderate injury or property damage.

*Note:* contains instructions or practices associated with maintaining the Starter Kit. Clarifies issues needing the reader's attention.

### 2.2.1. Symbols and labels

The danger and warning symbols used in this manual are shown in table 2.1.



general danger



electrical hazard



LASER radiation hazard



safety eyewear mandatory

Table 2.1.: Safety symbols most commonly used in the ALPES LASERS user's manual.

## 2.3. Health hazard

There are three main sources of hazard associated with the Starter Kit:

- LASER radiation, detailed in section 2.3.1;
- electrical, detailed in section 2.3.2;
- environmental, detailed in section 2.3.3.

### 2.3.1. LASER radiation hazard

The eyes and skin are the body parts the most likely to be injured. Warnings for tasks that may potentially adversely affect the health of the operator of a QCL are shown below.

ALPES LASERS can provide special eye protection glasses that are guaranteed to protect from all radiation emitted by ALPES LASERS lasers. The Laser Safety Goggles (LSG) come in two models: the LSG1 (see figure 2.1) and the LSG2, to be worn over a pair of corrective glasses. Both models provide 6+ OD in the mid-IR.



**WARNING:**  
Never insert shiny objects in the LASER beam path: stray reflections can be extremely hazardous to eyes and skin.



Figure 2.1.: ALPES LASERS protection glasses and case.

### 2.3.2. Electrical hazard

Work on live electrical circuits must be performed using all appropriate precautions and site specific procedures. Those tasks must be performed by qualified service personnel familiar with the wiring schematics of ALPES LASERS electronic equipment **only**; electrical cabinets shall *not* be accessed during normal operation nor during maintenance tasks.



**DANGER:**  
Contact with the AC line can cause death or serious injury: ramp down power from all the equipment before attempting any maintenance procedure.

### 2.3.3. Environmental hazard

Always consult the material manufacturer's Material Safety Data Sheets (MSDS), paying close attention to dust and combustion by-products.

# 3. Installation

This chapter presents the general workflow between delivery and operation of ALPES LASERS QCLs and electronic equipment:

**IMPORTANT:**

The facility must fulfill all prerequisites listed in section 3.1, all utilities must be duly prepared in a suitable location. The location of ALPES LASERS QCLs and electronic equipment must comply to the environmental conditions listed in section 3.1.1.

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## 3.1. Prerequisites

This section describes the environmental conditions in which ALPES LASERS QCLs and other electronic equipment should be stored, handled and the prerequisites for its operation.

### Peripherals from other manufacturers

ALPES LASERS recommends the use of the peripherals developed in factory specifically for ALPES LASERS QCLs. Other peripherals are suited for operating ALPES LASERS lasers; this section gives a non-exhaustive list.

Drivers for CW lasers should be high compliance. Drivers with 2.5A/15V output should be sufficient for a majority of CW DFB lasers, while some specific lasers can be handled with a smaller current output. ALPES LASERS distributes and recommends the LDX-3232 High Compliance Quantum Cascade Laser Diode Driver from ILX Lightwave which achieves up to 4A/15V. Some short wavelength devices may require up to 20V of compliance.

**CW laser driver** : precision laser diode current source such as

- ILX LIGHTWAVE LDX-3232 High Compliance Quantum Cascade Laser Diode Driver  
(<http://www.ilxlightwave.com/propgs/laser-diode-driver-3232.html>)

*Note:* cables compatible with the LLH or HHL housing can be provided by ALPES LASERS.

- KEITHLEY Model 2420 High-Current SourceMeter w/ Measurements up to 60V and 3A, 60W Power Output  
(<http://www.keithley.com/products/dcac/currentvoltage/highcurrent/?mn=2420>)
- ARROYO INSTRUMENTS Model 6340-QCL ComboSource Laser Diode Controller with output up to 4A, 15V  
(<http://www.arroyoinstruments.com/product-lines/6300>)
- WAVELENGTH ELECTRONICS QCL series QC laser drivers  
(<http://www.teamwavelength.com/product-category/qc-laser-drivers/>)

**Powermeter** To measure the laser output power, semiconductor powermeters such as those from OPHIR can be used ([www.ophiropt.com](http://www.ophiropt.com)).

**Spectrometer** Low resolution measurements can be done with monochromators such as a TRIAX320 from JOBIN YVON (<http://www.jobinyvon.com>), special measurements (high resolution and CW) with a spectrometer such as the NICOLET 800 and 860 FTIR ([www.nicolet.com](http://www.nicolet.com)), or BRUKER INSTRUMENTS ([www.bruker.com](http://www.bruker.com)).

**Fast detectors** For time-critical measurements, detectors from VIGO SYSTEM SA ([www.vigo.com.pl](http://www.vigo.com.pl)).

**Monitoring** For monitoring laser emission, simple pyroelectric detectors can be used, such as the LGTP101 by MEMTEK ([memtek.lgcit.com](http://memtek.lgcit.com)).

**Beam collimation** Due to the large divergence of the beam, it is recommended to use fast optics ( $f/1$  . . .  $f/0.8$ ) to collect most of the emitted light, like lens system aspheres from JANOS (<http://www.janostech.com>) or Optical solutions (<http://www.opticalsolutionsinc.com>).

An RS-232 to USB converter (shown in figure 3.1) is needed to connect computers without an RS-232 hardware port to the S-2 pulser. It is available with drivers for Windows and Mac OS.



Figure 3.1.: USB-RS232 adapter cable.

### 3.1.1. Environmental conditions

The following guidelines are standard for all ALPES LASERS products:

- Indoor use only
- Dry environment: ALPES LASERS product are NOT protected against harmful exposure to moisture.
- Maximum Relative Humidity: <80% RH, non-condensing
- Operating temperature range of 0°C to 40°C
- Storage and transportation temperature of -40°C to 70°C

### 3.1.2. Storage for NS and AN-NSP mounted QCLs

NS and AN-NSP mounted ALPES LASERS lasers are delivered in a hermetic waterproof storage box . This box should always be used when storing the laser out of its

housing. The laser chip is soldered to the pads using In soldering, which melts at 120°C, therefore the storage temperature should not exceed 80°C.

QCLs can be stored at ambient temperature (10 to 30°C) in normal atmosphere. Humidity should not exceed 80%, and condensation is to be avoided. The laser must be operated in a dry atmosphere below 50% relative humidity. If possible, it should be completely dried using a desiccant material or by flushing with N<sub>2</sub>.

**IMPORTANT:**

Even when packed, ALPES LASERS equipment should not be exposed to rain, snow or direct sunlight. Extreme temperature changes must be avoided.

### 3.1.3. Storage for AN and HP-GS mounted QCLs

AN and HP-GS mounted ALPES LASERS lasers are delivered in a hermetic waterproof gel pack, shown in figure 3.2, in which the laser chips are held in place on a special gel. This box should always be used when storing the laser out of its housing, and the lasers should always be manipulated using tweezers. The laser chips are organised in a grid inside the gel pack; the position of each laser is given in the delivery order. In any case, the serial number of each laser is printed on its submount.



Figure 3.2.: AN and HP-GS mounted ALPES LASERS QCL gel pack.

### 3.1.4. Cooling

The laser's performance is highly dependent on its operating temperature, it is therefore necessary to cool down the laser accordingly. The following setups can be used:

- for LLH only: closed loop cooling system with chiller
- for LLH only: tap water, Swagelok fitting to the tap, 4 mm tubing
- good mechanical contact between the LLH or HHL housing or QCL submount and the heat sink, such as an optical table
- heat sink and fan



**CAUTION:**  
Overheating the laser chip may result in permanent damage.

The temperature controlling system should be adapted to the thermal resistance of the system, which depends on the specifics of installation. It is good practice to target a thermal resistance of at most  $0.1^{\circ}\text{C}/\text{W}$ .

## 3.2. Receiving procedure

Upon delivery of ALPES LASERS products, the following procedure must be performed:

1. check that all of the components are included in the shipment. By default, the QCL is included in its housing<sup>1</sup>; the remainder consists of different sets of components depending on the housing and operation mode of the laser.

**IMPORTANT:**

The customer must control the incoming deliveries and inform ALPES LASERS about incomplete shipments or defective goods within 30 days of delivery.

2. before unpacking ALPES LASERS products, make sure that all environmental conditions and prerequisites are fulfilled (see sections 3.1.1 and 3.1).
3. for LLH, in case the laser is shipped separately only: mount the laser submount into the LLH housing following the procedure presented in section 5.3.4.
4. check that the temperature controller voltage setting is appropriate. For the TC-3, the procedure for changing the fuse is outlined in the TC-3 OEM manual.

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<sup>1</sup>Replacement lasers are delivered in their storage box.

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# 4. QCL Operation

In this chapter, the general operation principle of a QCL is presented, and its main characteristics are illustrated using actual plots included in the datasheet provided with each ALPES LASERS QCL upon delivery.

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## 4.1. ALPES LASERS datasheet

Each ALPES LASERS QCL is provided with a datasheet collating the data obtained from standardized quality control tests performed at ALPES LASERS production site. The tests are performed on the QCL installed in a test-bench LLH housing operated at a temperature ranging from  $-30^{\circ}\text{C}$  up to their maximal operating temperature (up to  $+50^{\circ}\text{C}$ ). If the QCL is then encapsulated in a different type of housing, the tests are repeated and a new datasheet is provided to the user. The datasheet shows a selection of operation points which can be extrapolated for a specific application, or more precise testing can be performed at ALPES LASERS on demand.

**IMPORTANT:**

The operating parameters are specified in the datasheet provided with each laser upon delivery; any operation outside the specified range must be agreed with ALPES LASERS or may result in the loss of warranty.

In the following sections, examples of plots shown in the datasheets are presented, in order to help the user in operating ALPES LASERS QCLs in a safe and efficient manner.

## 4.2. QCL spectra

A QCL is characterized by its emission frequency (spectral domain), wavelength or wavenumber (spatial domain); all three are equivalent. The following table gives typical values for ALPES LASERS QCLs.

wavelength ( $\lambda$ )	frequency ( $f$ )	wavenumber ( $\nu$ )
4 - 20 $\mu\text{m}$ 4000 - 20 000 nm	15 - 75 THz	500 - 2500 $\text{cm}^{-1}$

### 4.2.1. Temperature and current tuning

QCL emission can be precisely tuned with temperature (slow tuning) or current (quick tuning), but the later is in fact just apparent, as it results from the increase of temperature of the active region<sup>1</sup>.

#### DFB QCL

Figure 4.1 shows the temperature and current tuning on a DFB laser operated in CW and pulsed modes. The wavelength increases (or the wavenumber decreases) by a factor varying between  $7 \cdot 10^{-5}$  and  $9 \cdot 10^{-5}$  for a temperature increase of 1 degree. For example, the total tuning for a  $2000 \text{ cm}^{-1}$  QCL operating over a range of  $-30$  to  $+30^\circ\text{C}$  will vary between  $8.4$  and  $10.8 \text{ cm}^{-1}$ , depending on the laser.

#### FP QCL

The spectrum of a FP laser of figure 4.2 shows an interference structure caused by the Fabry-Perot effect of the reflections at both ends of the laser chip, superimposed on a wide gain envelope. A temperature change will modify both these structures: the FP spectrum evolution is driven by the length of the laser cavity, which can vary, and the gain envelope evolves in unpredictable ways due to mode competition. The ALPES LASERS datasheet provides spectra taken at regular temperature intervals; additional requests on the spectral shape should be discussed with ALPES LASERS.

Figure 4.3 shows the spectrum of broadgain lasers.

<sup>1</sup>The temperature changes the apparent optical length of the grating, tuning the waveguide refraction index.

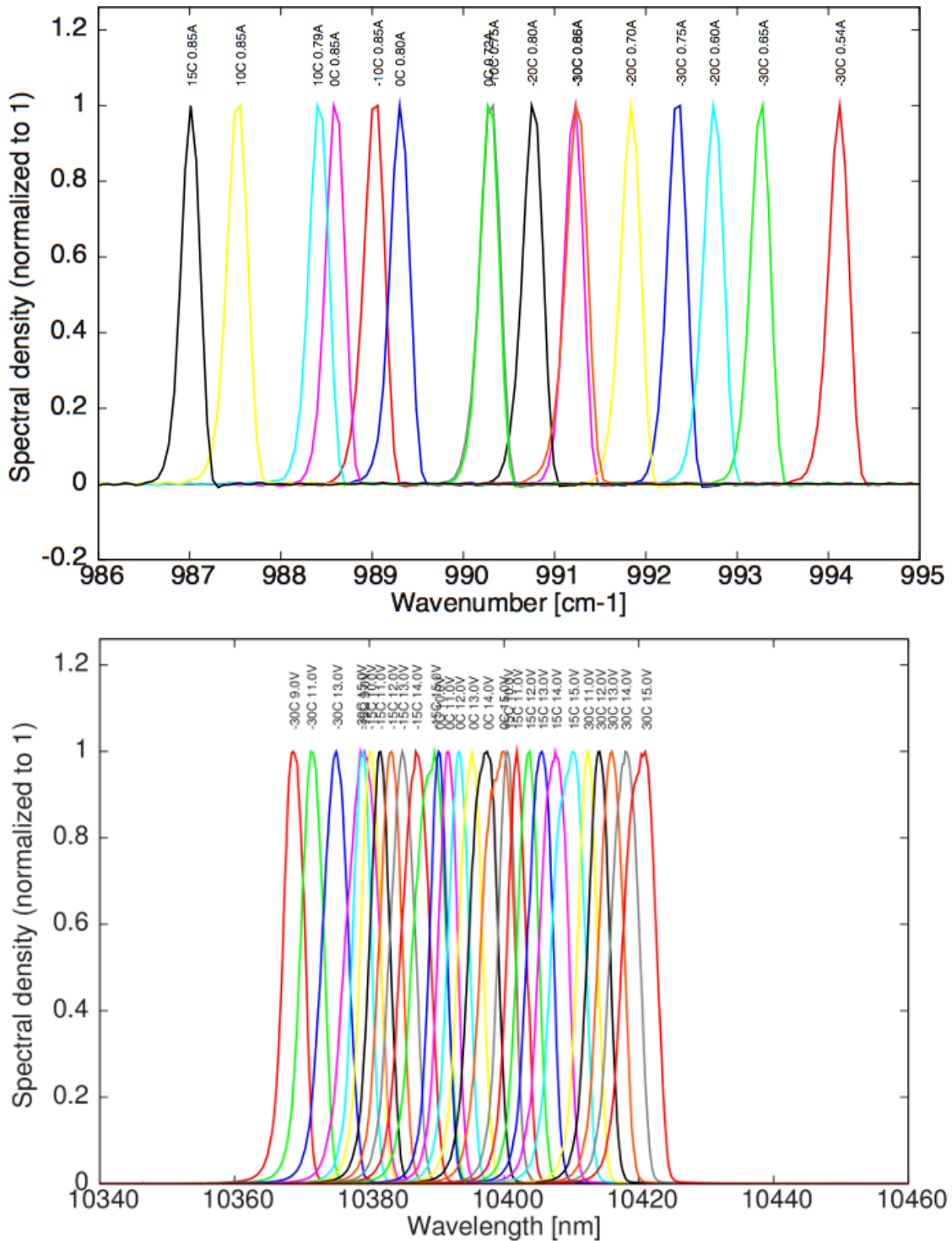


Figure 4.1.: Spectra of a DFB laser operated in CW mode (top) and pulsed mode (bottom) with different currents and temperatures.

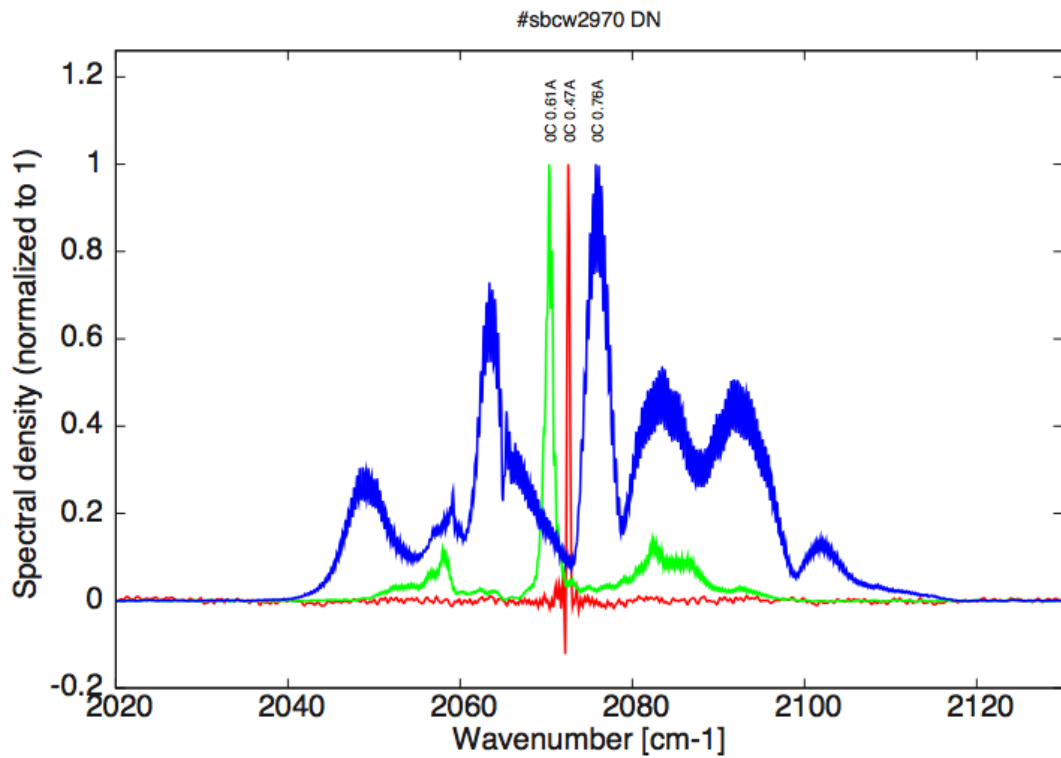


Figure 4.2.: Spectra of a FP laser operated in CW mode at fixed temperature and different currents.

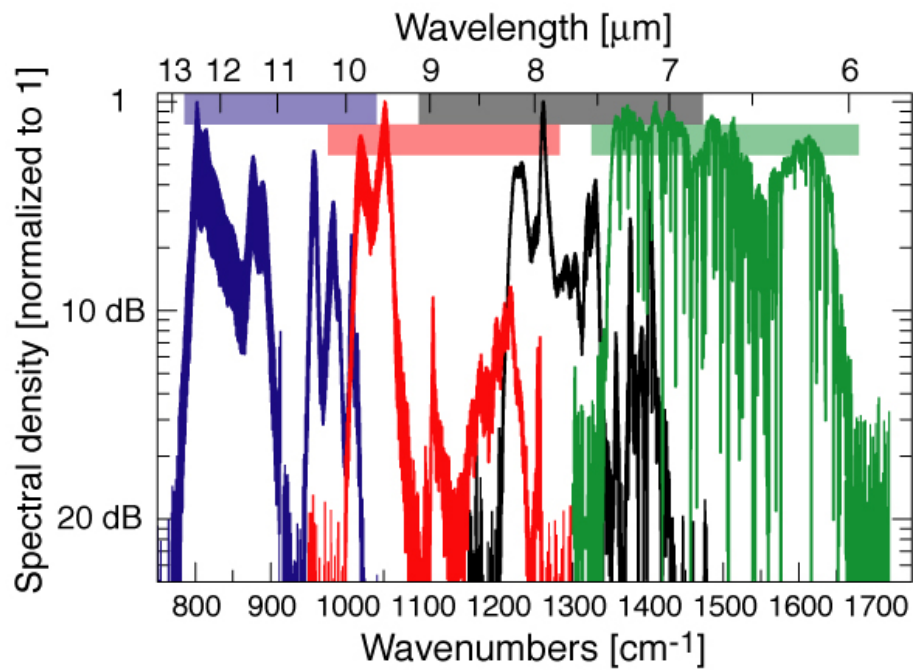


Figure 4.3.: Spectra of four different broadgain lasers.

### 4.2.2. Linewidth of pulsed single-mode DFB QCLs

The linewidth of DFB QCLs operated in pulsed mode depend on the pulse length and is affected by chirping. Chirping occurs because of thermal variations of the laser.

- By default ALPES LASERS QCLs are tested using a pulse length of 500 ns, showing a linewidth  $0.5 \text{ cm}^{-1}$ .
- A very fine linewidth ( $< 0.1 \text{ cm}^{-1}$ ) is obtained with pulses of 10 ns, which can be produced by dedicated equipment only.
- The minimum pulse length attainable by a QCL will depend on details of the interaction between the driver and laser and can be affected by housing, cables, impedance matching and other elements external to the laser chip itself.
- Longer pulses ( $> 500 \text{ ns}$ ) induce chirping and produce a broader linewidth when detected with a slow detector.

ALPES LASERS standard tests verify that DFB QCLs are spectrally singlemode.

**IMPORTANT:**

The maximum pulse length an ALPES LASERS DFB QCL operated in pulsed mode can withstand is of typically 500 ns. Requirements for operation with pulses longer than 500 ns must be specified before purchasing a laser.

**IMPORTANT:**

The operating parameters are specified in the datasheet provided with each laser upon delivery; any operation outside the specified range must be agreed with ALPES LASERS or may result in the loss of warranty.

### 4.2.3. Linewidth of CW single-mode DFB QCLs

DFB QCLs operated in CW mode reach thermal equilibrium with pulse length of 10 ms and longer. In this case, transient behavior affects only the beginning of the pulse, and can be neglected. The linewidth is therefore limited by thermal noise and electronic noise produced by the driver. Very long pulses ( $> 100 \text{ ms}$ ) will behave in a CW manner, and shorter pulses will exhibit chirping as pulsed lasers do, and may induce multi-mode behavior.

**IMPORTANT:**  
ALPES LASERS QCLs operated in CW mode are guaranteed to be single mode if operated with long pulses (> 10 ms) only.

#### 4.2.4. Bandwidth of multi-mode FP QCLs

In the case of FP QCLs, the bandwidth is defined as the wavelength range in which 99% of the power is emitted. It depends on the driving current and is not affected by the operating temperature. ALPES LASERS QCLs operated in CW mode can withstand any pulse length.

### 4.3. I-V curve and emitted power

Figures 4.4 show the IV curves of typical DFB and FP lasers operated in CW at different temperatures. On the same graph the emitted power is plotted as a function of operation current, showing the threshold current for each temperature. For example, the DFB laser operated in CW mode (figure 4.4 ) has a threshold current of 0.6 A at 20°C. It can be seen that cooling the QCL during operation enhances its performance as the threshold current decreases and output power increases.



**CAUTION:**  
Do not operate the laser with a temperature and current above the values specified in the ALPES LASERS datasheet. This may result in permanent damage.

Figure 4.5 can be used to illustrate the temperature and current tuning of a DFB QCL operated in pulsed mode:

- the power increases from 3 to 6 mW using a peak current of 4 A and varying the temperature from -30 to 30°C.
- for a temperature of 0°C, the power increases from 0 to 5.5 mW by increasing the peak current from 2 to 5 A.

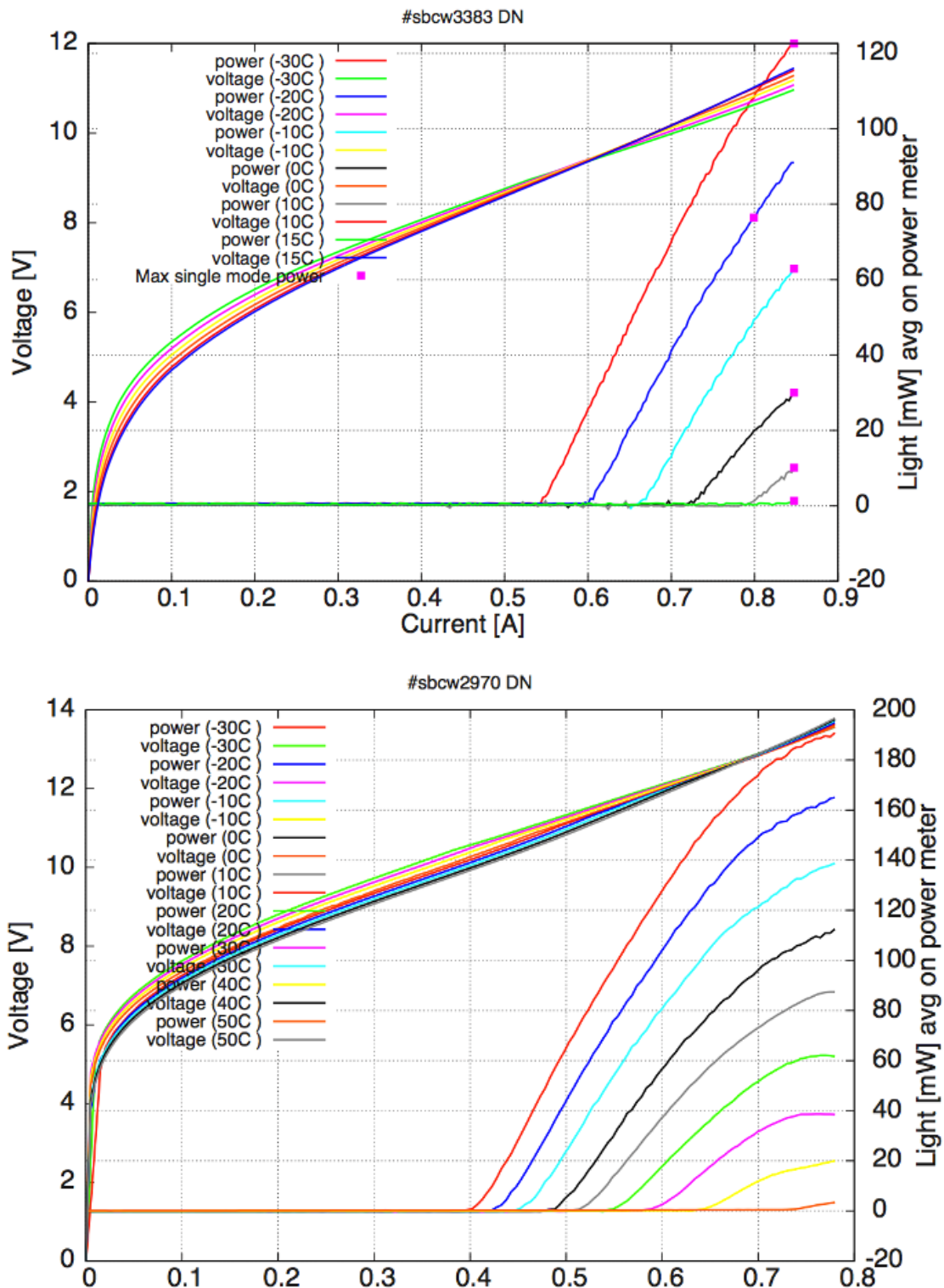


Figure 4.4.: IV curves of DFB laser (top) and FP laser (bottom) operated in CW mode at different temperatures.

### 4.3.1. Maximum operating current

All QCLs have a maximum operating current above which a Negative Differential Resistance (NDR) appears and may destroy the laser. As an example, figure 4.5 shows the IV curve and emitted power of a DFB QCL operated in pulsed mode: the green squares indicate the maximum current for monomode operation, 4.7 A from -30 to 30°C in the present case.



#### CAUTION:

The maximum operating current of each ALPES LASERS QCL is indicated in the IV and emitted power plots caption of the datasheet. Do not operate the laser with a current above those values; permanent damage may result.

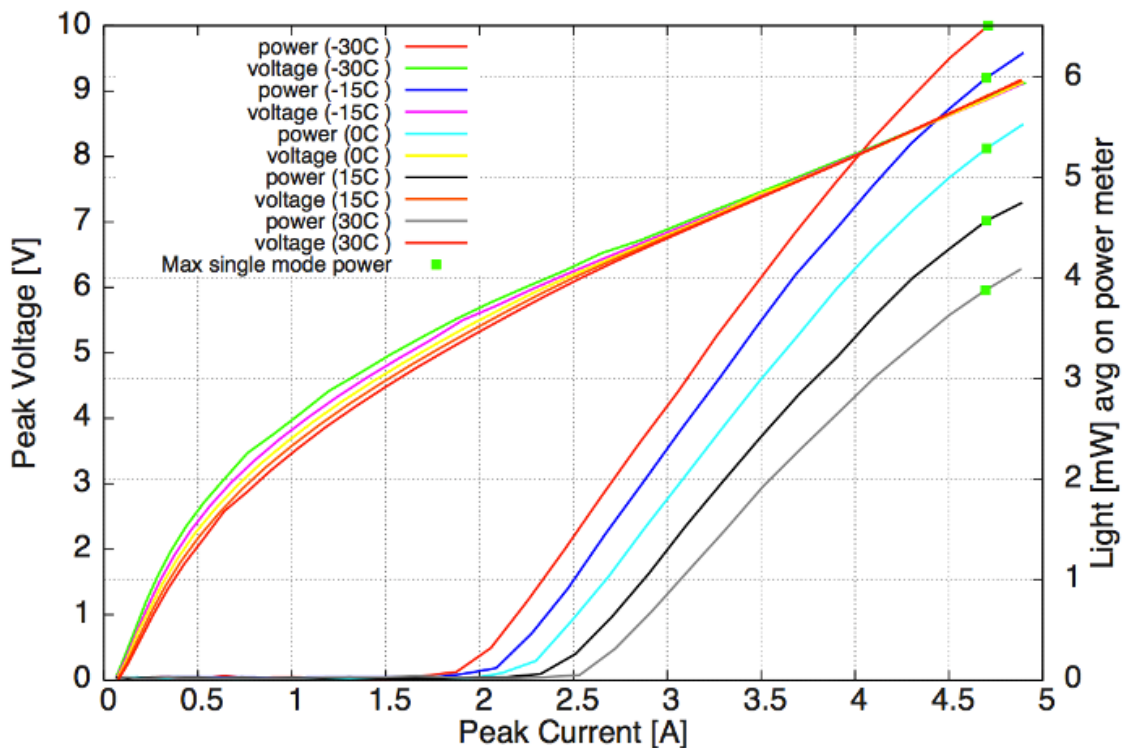


Figure 4.5.: IV curves of a DFB QCL operated in pulsed mode at different temperatures.

### 4.3.2. Maximum LDD voltage

The LDD device is now obsolete, ignore the LDD voltage values specified in the datasheet.

## 4.4. Beam Properties

### Divergence

Figure 4.6 shows a typical uncollimated ALPES LASERS QCL beam profile. Unipolar lasers consist of tightly confined waveguides; for this reason, the beam diffracts strongly at the output facet and has a full divergence angle of about 60 degrees perpendicular to the layer (vertical angle) and 40 degrees parallel to the layers (horizontal angle). A f/1 optics will typically collect about 70% of the emitted output power. Note that the collected output power will decrease with the square of the f-number of the collection optics.

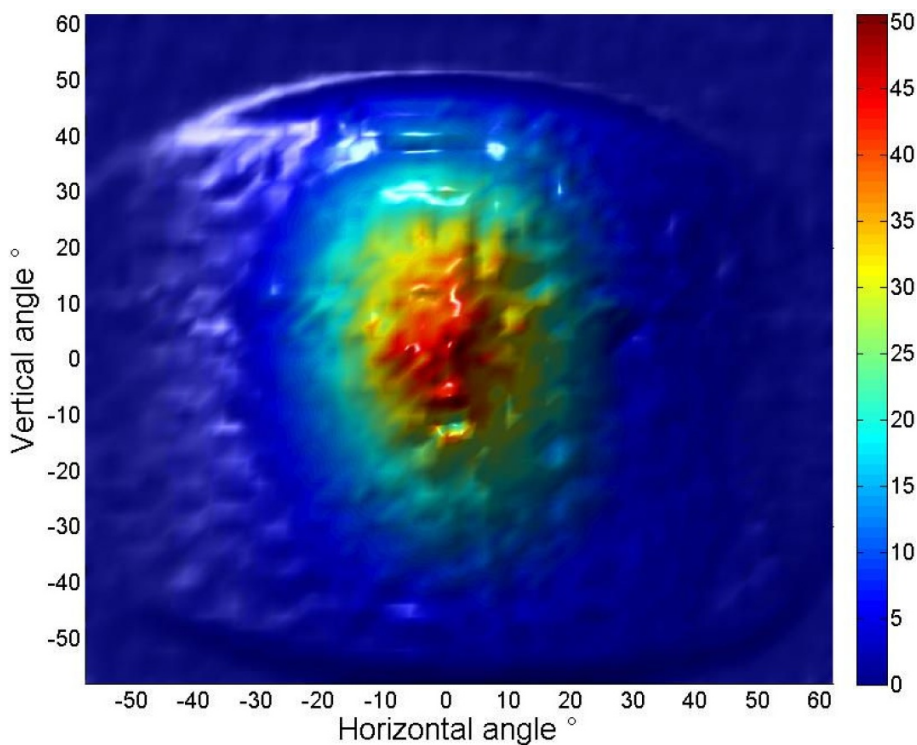


Figure 4.6.: QCL beam profile.

### Polarization

Because the intersubband transition exhibits a quantum mechanical selection rule, the emission from a unipolar laser is always polarized linearly with the electric field

perpendicular to the layers (and the submount). With the submount or the base of the housing on a table, the light is emitted with vertical polarization. The exception to this rule is for the External Cavity Kit where the submount is mounted vertically and therefore the output beam has horizontal polarization.

### **Mode**

ALPES LASERS QCLs are designed to have a single spatial mode, typically the Gaussian TEM00 mode. A mode measurement can be performed by ALPES LASERS on demand for a specific application.

## 4.5. Startup and shutdown procedures



**CAUTION:**

The laser shall only be operated under conditions as specified in the datasheet or by ALPES LASERS directly: all other operation may result in the destruction of the laser and loss of warranty.

### 4.5.1. QCL startup

In order to insure the laser's performance and enhance its lifetime, the following steps must be followed thoroughly:

1. make sure all devices are turned off
2. startup the TC-3 following procedure 6.1, or the local temperature controller, and stabilize the QCL housing temperature to a value available from the datasheet above room temperature<sup>2</sup> (see section 3.1 for prerequisites)



**CAUTION:**

The laser must be used at the temperature specified in the datasheet. Operating the laser below or above the given temperature is likely to damage the laser and will result in the loss of warranty.

Contact ALPES LASERS or a representative before using the laser at a temperature outside the range specified in the datasheet.

3. if the laser is operated in CW mode, follow procedures included in the CW laser driver OEM manual. Always keep the current 1mA above 0 to avoid reversing the polarity.
4. if the laser is operated in pulsed mode with a S-2 Pulser:
  - a) before connecting the laser, ensure the S-2 software is set so that it respects the maximum specification of the laser
  - b) connect the S-2 pulser in the setting in which you intend to use it (be it to the TC-3, to an external computer, or to your own control setup)
  - c) connect the laser to the S-2 pins



**CAUTION:**

Make sure the laser temperature is below specifications before turning on the external power supply. Overheating the laser chip may result in permanent damage.



**CAUTION:**

Do not exceed maximum voltage or current specified in ALPES LASERS datasheet. Permanent damage to the laser chip may occur.

5. increase the current slowly and monitor the voltage (current) according to the QCL IV curve included in the ALPES LASERS datasheet (see section 4.3):
  - if no current is flowing, a misconnection might be the cause, repeat step 8 of the installation procedure described in section 3.2
  - if a current above 100 mA is read with a voltage below 100 mV, a ground loop might be the cause, review all connections
6. monitor the laser power using a powermeter:
  - a) make sure that the range complies with the power range of the laser (see datasheet)
  - b) reset it to 0
  - c) align the laser beam with the powermeter

The power should start rising around the threshold of the ALPES LASERS datasheet IV curve (see section 4.3).

7. if needed, cool down the housing to the desired operation temperature

*Note:* exact power measurement of an IR beam are very difficult to reproduce as they depend on the room temperature and powermeter characteristics. Therefore the exact values shown in the datasheet might not be reproduced in a different setup as the one used by ALPES LASERS for routine tests.

---

<sup>2</sup>It is best to power the laser before cooling the laser to lower temperatures, as the heat dissipated may provide a degree of protection against unwanted condensation.

### 4.5.2. QCL shutdown



**CAUTION:**

Make sure the polarity of the laser is correct at all time, especially at turn-on and turn-off. Permanent damage may occur.

1. set the temperature controller to a temperature close to room temperature
2. wait until the temperature setting is reached
3. reduce the current in the laser slowly, do *not* reach 0 as the polarity might reverse
4. turn off the laser driver and temperature controller

# 5. Housings

In this section, the three types of housings, their purpose and their operation are described in detail, and their technical specifications are given. An overview is given in table 5.1.

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	Laser Laboratory Housing (LLH)	High Heat Load (HHL)	TO3	TO3W
Main purpose	Easy laser exchange	Sealed	with lens	with window
Size	100 mm X 50 mm X 50 mm	70 mm X 54 mm X 25.5 mm	38.8 mm X 25.4 mm X 20.5 mm	38.8 mm X 25.4 mm X 20.5 mm
Input	LBI connector, CTL connector, water connectors	Ten-Pin connector	8 pins connector	8 pins connector
Output port	Anti-reflection coated ZnSe protective window	Anti-reflection coated ZnSe protective window	Anti-reflection coated ZnSe collimating lens	Anti-reflection coated ZnSe window
Output beam	Divergent beam	Collimated, divergence < 6 mrad, 4 mm beam diameter	Collimated beam, divergence < 10 mrad, 4 mm beam diameter	Divergent beam 40° X 60° FWHM
Thermoelectric cooler	Peltier cooled laser-stage inside, minimal temperature -30°C	Peltier cooled laser-stage inside, minimal temperature -20°C	Peltier cooled laser-stage inside, max. dissipation 4W	Peltier cooled laser-stage inside, max. dissipation 4W
Temperature monitoring	Pt100	Pt100 or NTC temperature measurement.	NTC thermistor	NTC thermistor
Max TEC current	5.0 A	3.0 A (2.5A on some items)	3.0A	3.0A
Max TEC voltage	17 V	11.6 V (11.0 V on some items)	2.85V	2.85V
Laser Capacity	Supports all NS-mounted CW and pulsed lasers from Alpes Lasers	Supports CW or pulsed lasers with dissipation <10W on NS or AN mount	Supports lasers with <4W average dissipation	Supports lasers with <4W average dissipation
Cooling needs	The backplate is equipped with a water cooling circuit and connections suitable for 4mm flexible pipes. Water cooling is only necessary for operation temperatures <0°C.	The backplate must be kept at room temperature, up to 35W of heat dissipation needed.	The backplate must be kept at room temperature, up to 10W of heat dissipation needed.	The backplate must be kept at room temperature, up to 10W of heat dissipation needed.

Figure 5.1.: Technical specifications of ALPES LASERS QCL housings.

## 5.1. TO3 and TO3W housings

The TO3 housing is a hermetically sealed small-footprint housing designed to be integrated into commercial devices. It is available in two versions: the TO3-W has a divergent output through an AR coated window, and the TO3-L (shown in figure 5.2) has a collimated output. The TO3W housing is mechanically and thermally identical to the TO3, except it doesn't carry a lens, allowing the customer to use a divergent beam.



Housing	$I_{lim}$
$I_{max}$	3.0 A
$V_{max}$	2.85 V
$Q_{max}$	5.7 W
Clear Aperture	4 mm
Divergence	< 10 mrad

Figure 5.2.: TO3 housing with lens picture (left) and specifications (right).

The TO3 contains a TEC and a NTC temperature sensor (model 10K4CG). The TO3 TEC power is lower than the HHL and LLH housings TECs; only low-dissipation lasers can be encapsulated in TO3 housings.

### 5.1.1. Connections

Figure 5.3 shows the TO3 housing connector; the pinout is detailed in table 5.1. TO3-L and TO3-W housing have identical pinouts. The polarity of the laser connection is specified on the datasheet provided by ALPES LASERS with each QCL.

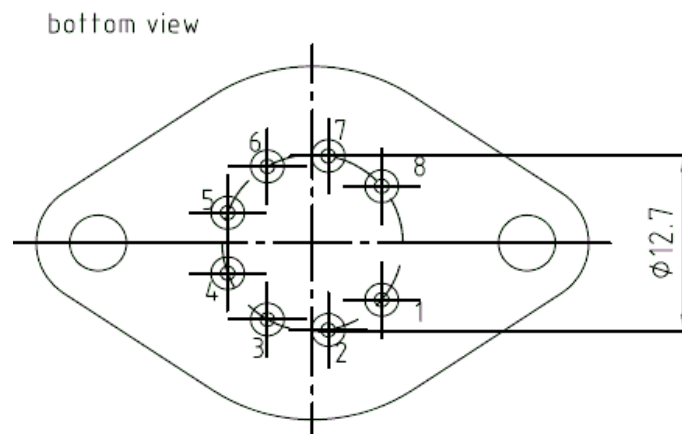


Figure 5.3.: TO3 housing connector.

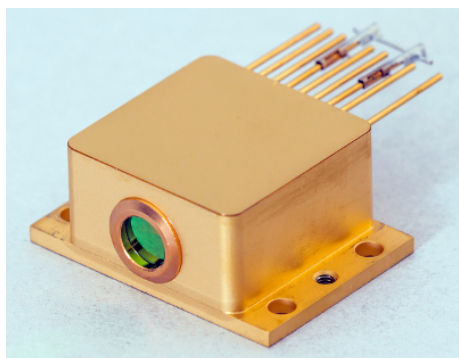
*Note:* ALPES LASERS does not provide cables for connections to TO3 housings.

Pin nb	Purpose
1	TEC +
2	Thermistor
3	Thermistor
4	laser bondpad
5	laser substrate
6	Not connected
7	Not connected
8	TEC -

Table 5.1.: TO3 housing pinout.

## 5.2. High Heat Load (HHL) Housing

The HHL housing is much smaller than the LLH and is completely sealed, making it suitable for more demanding environmental conditions and instrument integration. The IR beam is collimated through a chalcogenide glass lens and goes through an AR-coated ZnSe window.



Housing	$I_{lim}$
$I_{max}$	3.0 A
$V_{max}$	11 V
$Q_{max}$	10 W
Clear Aperture	4 mm
Divergence	< 6 mrad

Figure 5.4.: HHL housing picture (left) and specifications for 1-stage (right). Check the datasheet provided by ALPES LASERS for accurate values, as the TEC type and its current limit may vary.

### 5.2.1. Cooling

The HHL contains a Peltier junction and a PT-100 or NTC temperature sensor (model 10K4CG). The TEC may be operated by any temperature controller; it is recommended to use the ALPES LASERS TC-3 (see section 6.1), as its parameters are specifically designed for ALPES LASERS QCLs. Heat dissipation is performed by thermal contact between the Peltier junction and the HHL copper base; the heat dissipation capacity depends on the operation mode and environmental conditions. The HHL is available with varied TEC models, up to date comparisons can be seen on ALPES LASERS's website.

The HHL copper base will get warm if the power dissipated by the laser chip and TEC is not efficiently dissipated. It is required to install the HHL on a heatsink to remove this heat which can reach up to 40W, although in many cases it will be much lower at the operation point. Alpes can provide a metallic heatsink with a water-cooling circuit as can be seen on Fig. 5.5 but third party or home-made options are also available.

When fixing the HHL onto a heatsink use one of these two methods:

1. Use the central thread (M3) from below to ensure a good mechanical contact, or
2. Use the four 4.2mm diameter holes with M3 screws (or smaller) from above. With bigger screws, the head of the screws will damage the housing lateral walls.

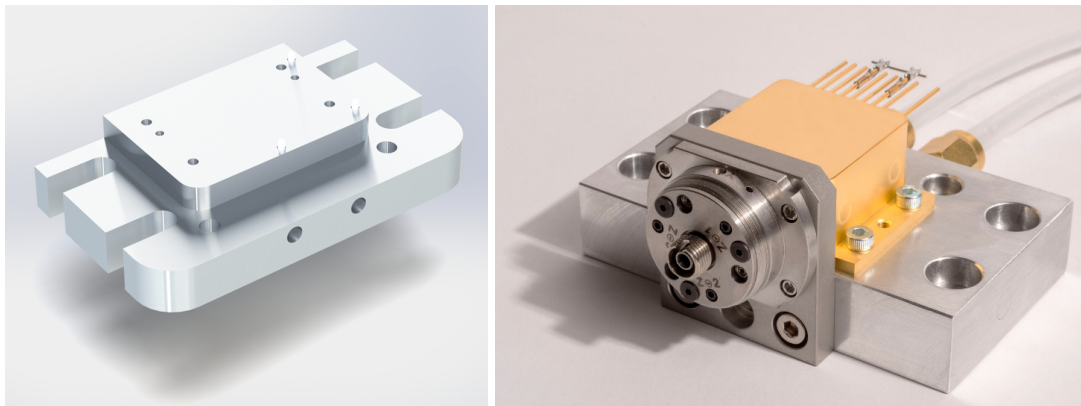


Figure 5.5.: HHL heatsink (left) and example of a HHL fixed on a heatsink with fiber collimator (right).

### 5.2.2. Connection to S-2 driver and TC-3 temperature controller

The S-2 pulser is designed to connect directly to a HHL housing, as show in figure 6.10. This allows to greatly reduce signal distortion. Cables are available to use the S2 with a LLH housing on demand.

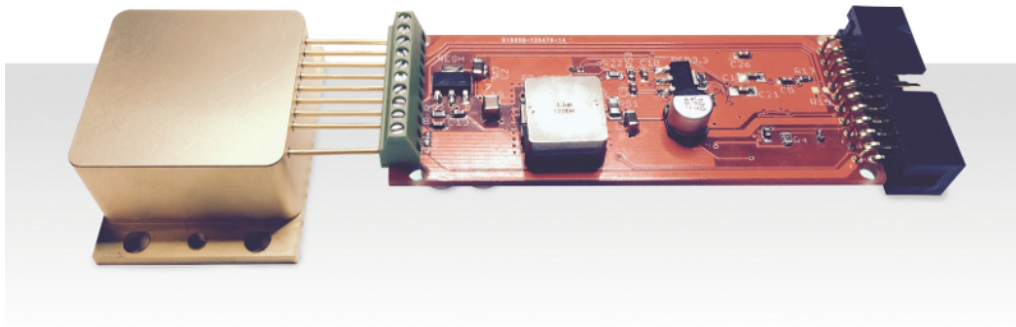


Figure 5.6.: S-2 OEM configuration with HHL.

The S-2 pulser is designed such that the electrical connections necessary for the laser temperature control go through unaltered from the TEC to the C-S-2-TC-3 cable. Figure 5.7 shows a schematic of the connections.

#### C-S-2-TC3 cable

In the case of the HHL housing, the C-S-2-TC3 cable connects the S-2 pulser to its power supply, the computer and the TC-3 temperature controller (see figure 5.8).

The C-S-2-TC3 cable splits into three ends:

- a coupling socket for the S-2 pulser power supply;
- an RS-232 cable for computer communication signals;

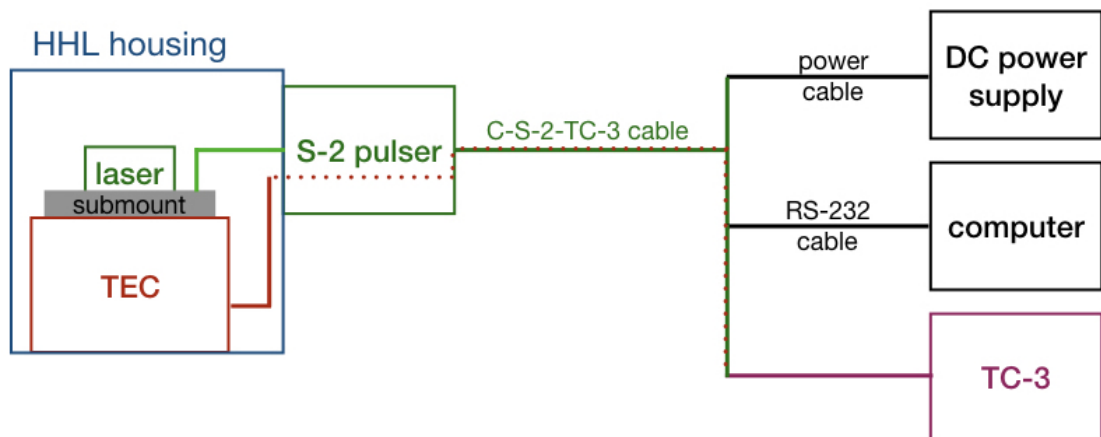


Figure 5.7.: Connection schematic for the HHL housing controlled with the S-2 pulser and the TC-3 temperature controller.



Figure 5.8.: HHL housing connected directly to the S-2 pulser, itself connected to the C-S-2-TC3 cable, with the the S-2 pulser power supply.

- and a DB 15 connector for temperature control.

The pinout is shown in table 5.2.

**Note:** the C-S-2-TC3 cable does not give access to all of the S-2 pulser parameters.

**Temperature control: Male DB15 connector**

1	TEC +	9	
2		10	
3	TEC -	11	
4		12	
5	Ground	13	
6	Ground	14	
7	Temperature sensor +	15	
8	Temperature sensor -		

**Computer communication: Female RS232 connector**

1		6	
2	Rx	7	
3	Tx	8	
4		9	
5	GND		

**Power supply: Coupling socket for 2.1 mm 5.5 mm coaxial power plug**

Tip	Power supply +	Sleeve	GND
-----	----------------	--------	-----

Table 5.2.: C-S-2-TC3 cable pinout.

### 5.2.3. Connection to other drivers and TC-3 temperature controller

When driving a QCL in a HHL housing with any other driver than the S-2 pulser, the C-TC-3-HHL cable must be used for temperature control with the TC-3 temperature controller. In addition to connectors for the HHL and TC-3, the C-TC-3-HHL contains a BNC connector through which current can be sent to the laser. Figure 5.9 shows a schematic of the connections when using a LDX-3232 driver.

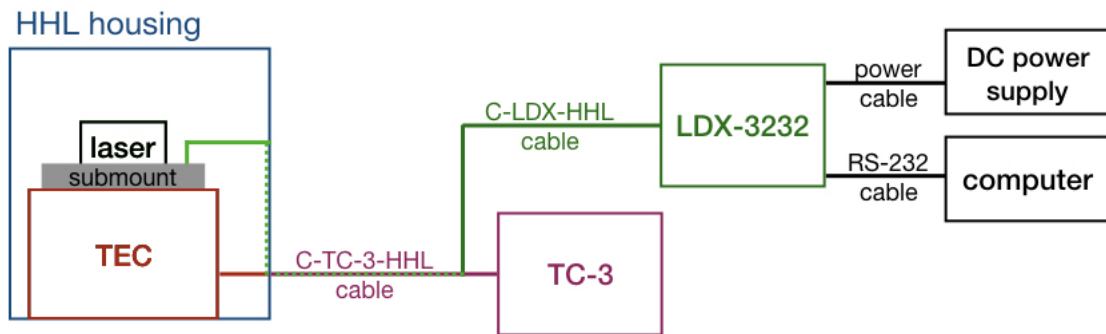


Figure 5.9.: Connection schematic for the HHL housing controlled with LDX-3232 and TC-3 temperature controller.

**Note:** ALPES LASERS does not provide cables for other drivers than the S-2 pulser and LDX-3232 driver.

#### C-TC-3-HHL cable

The TC-3 controls the temperature of the HHL with a Peltier junction and monitors the temperature with a PT100 or NTC sensor through the C-TC-3-HHL cable, shown in figure 5.10.

**Connection to HHL housing:** The C-TC-3-HHL cable connector to the HHL housing must be connected according to the HHL housing connector description given in table 5.3.

**Connection to TC-3 temperature controller:** The C-TC-3-HHL cable connector to the TC-3 is a DB-15 connector as described in table 5.4. The Fans, ID and Remote Sensor pins are not used by the ALPES LASERS products.

#### C-LDX-HHL cable

The C-LDX-HHL cable allows to control the HHL housing and QCL with a LDX-3232 driver. The C-LDX-HHL cable, shown in figure 5.11, connects to the C-TC-3-HHL cable BNC connector. The laser (-) signal is connected through the center pin of the BNC and the base (+) signal through the sheath of the cable.



Figure 5.10.: C-TC-3-HHL cable (left) and C-TC-3-HHL cable connected to HHL housing (right).

pin nb	purpose
1	-power supply for Peltier element
2	(no corresponding pin)
3	(not connected)
4	+power supply for laser
5	-signal PT100
6	+signal PT100
7	-power supply for laser
8	(not connected)
9	(not connected)
10	+power supply for Peltier element

Table 5.3.: C-TC-3-HHL cable connector to HHL housing pinout.

Pin number	Description
1, 2 & 9	TE (+)
3, 4 & 10	TE (-)
5 & 6	Ground
7	Sensor +I
8	Sensor -I
11	Fan +
12	Fan -
13	ID
14	Remote Sensor signal +
15	Remote Sensor signal -

Table 5.4.: DB-15 connector pinout. The Fan+, Fan- and ID pins are not used by ALPES LASERS products.



Figure 5.11.: C-LDX-HHL cable connecting the HHL housing to the LDX-3232 driver.

### 5.2.4. Technical specifications

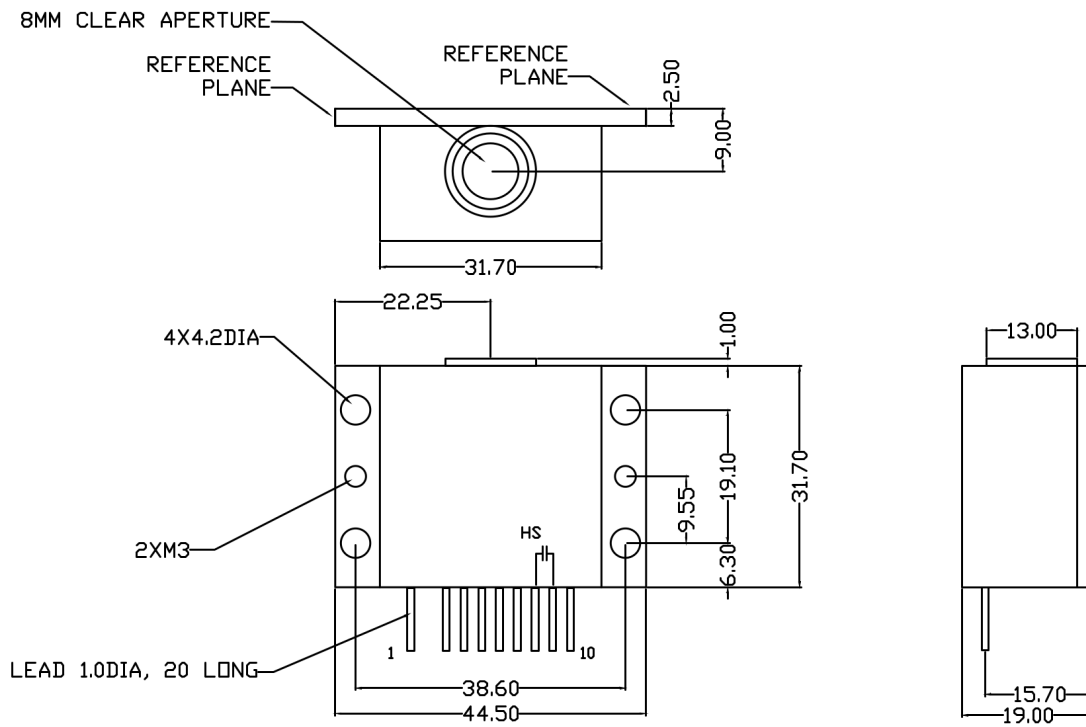


Figure 5.12.: HHL housing.

## 5.3. Laboratory Laser Housing (LLH)

The LLH consists of a housing unit that includes a TEC and encapsulates the QCL chip; it is designed to ease its installation and replacement. Its internal temperature is controlled by a Peltier junction and a NTC 10K4CG thermistor as temperature sensor <sup>1</sup>, and can reach temperatures lower than -30°C. Heat should be dissipated using one of the setups described in section 3.1.4. The LLH temperature is controlled by the ALPES LASERS TC-3 (see section 6.1).



Figure 5.13.: LLH housing front side window (left) and rear panel (right).

Housing	$I_{lim}$
$I_{max}$	5.0 A
$V_{max}$	15.8 V
$Q_{max}$	40 W
Clear Aperture	4 mm
Divergence	approx. 60 ° x 40 °

Table 5.5.: HHL housing Specifications (1-stage)

### 5.3.1. Connectors

The LLH front and rear panels are shown in figure 5.14. The different parts are described below:

- (1) anti-reflective (3.5 to 12  $\mu\text{m}$ ) ZnSe coated laser beam window

<sup>1</sup>LLH delivered in December 2021 or later have a 10K4CG thermistor; earlier versions may have used a PT-100 temperature sensor.

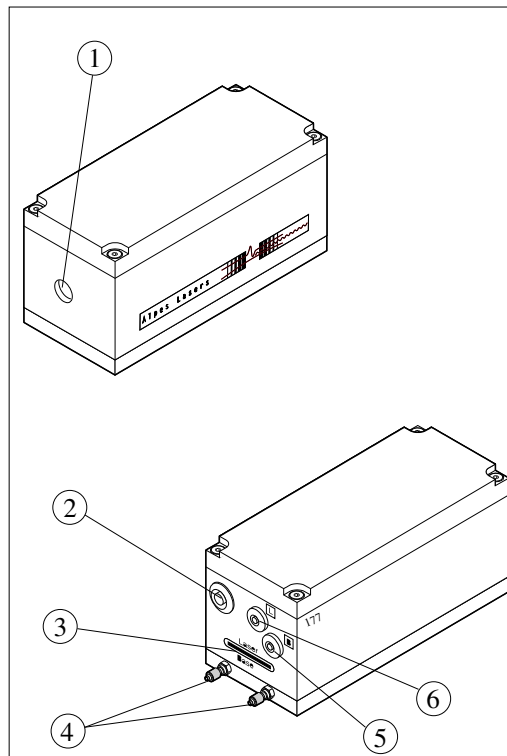


Figure 5.14.: LLH housing description.

- (2) connector for C-TC-3-LLH cable for Peltier junction and thermistor sensor
- (3) connector for C-LDX-LLH cable
- (4) cooling water flow fittings for 4 mm flexible cables
- (5) and (6) monitoring `base` connector (5) and `laser` connector (6) for direct voltage measurement on the laser. The cables are not supplied by ALPES LASERS as this is a non-standard measurement. <sup>2</sup>

**IMPORTANT:**  
IN the standard configuration, the low impedance line and laser chip are floating and connected to the `laser` connector and have negative polarity; the `base` connector must have positive polarity. However some lasers have reversed polarity - in such cases it will be clearly written on the laser's datasheet.

<sup>2</sup>These connections are used when the datasheet of pulsed lasers is measured to evaluate the true power dissipation in the laser. In practice, they are not needed for using the laser as the current is the determining parameter for laser operation. If a voltage monitor is nevertheless needed, you can connect to these pins using a LEMO Push-Pull Connector HGP.00.250.CTLPV, available at various distributors of electronic parts. Alpes does not distribute a cable for these connectors.

The Peltier connector (2) shown in figure 5.14 is zoomed in figure 5.15. It carries 6 pins, described in table 5.6. Pin 1 is circled, and a half-moon engraving runs from pin 1 to pin 6. A fixed current is supplied to pin 3 and 6 (typically  $10 \mu\text{A}$ ). The resistance of the thermistor varies as a function of temperature and the temperature measurement is given by the voltage between pin 4 and 5.

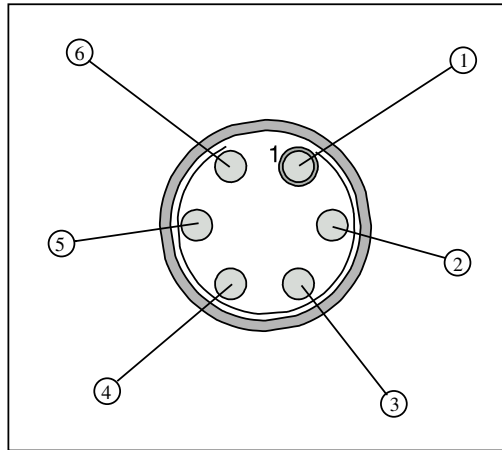


Figure 5.15.: LLH housing connector (2).

pin nb	name	purpose
1	1	+power supply for Peltier element
2	2	-power supply for Peltier element
3	3	+I thermistor
4	4	+signal thermistor
5	5	-signal thermistor
6	6	-I thermistor
7	GND	ground

Table 5.6.: LLH housing connector (2) pinout.

### 5.3.2. Connections to S-2 driver and TC-3 temperature controller

The LLH housing connections to the S-2 pulser and TC-3 temperature controller are shown in figure 5.16.

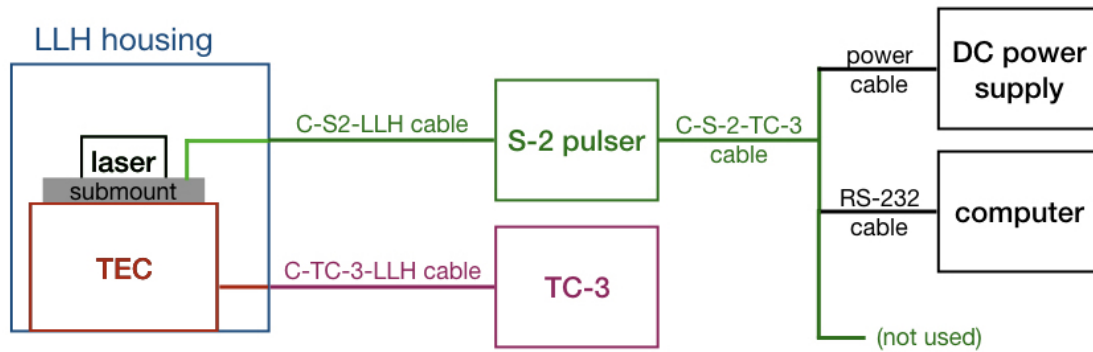


Figure 5.16.: Connection schematic for the LLH housing controlled with S-2 pulser and TC-3 temperature controller.

#### C-S-2-LLH cable

The C-S-2-LLH cable, shown in figure 5.17, connects the LLH housing to the S-2 pulser.

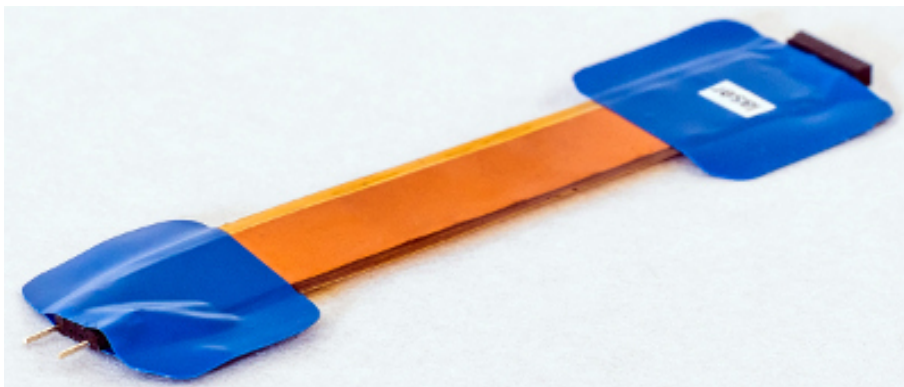


Figure 5.17.: C-S-2-LLH cable connecting the LLH housing to the S-2 pulser.

#### C-TC-3-LLH cable

The TC-3 controls the temperature of the LLH with a Peltier junction and monitors the temperature with a temperature sensor<sup>3</sup> through the C-TC-3-LLH cable, shown in figure 5.18. The Peltier connector is identical to the connector shown in figure 5.15. The controller connector is a DB-15 connector described in table 5.4.

<sup>3</sup>Older versions of the LLH use a pt100 temperature sensor while newer versions use a NTC 10K4CG thermistor.



Figure 5.18.: C-TC-3-LLH cable connecting the LLH housing to the TC-3 temperature controller.

### **C-S-2-TC3 cable**

The C-S-2-TC3 cable is the same as in the S-2-HHL configuration (see section 5.2.2), but in the case of the LLH housing, the C-S-2-TC3 cable connects the S-2 pulser to its power supply and the computer only, the third end is not in use (see figure 5.7).

**Note:** the C-S-2-TC3 cable does not give access to all of the S-2 pulser parameters.

### 5.3.3. Connection to LDX-3232 driver and TC-3 temperature controller

When driving a QCL in a LLH housing with the LDX-3232 driver, the C-LDX-HHL cable must be used. To control the LLH housing temperature with the TC-3 temperature controller, the same C-TC-3-LLH cable is used as in the S-2 pulser configuration. Figure 5.19 shows a schematic of the connections for this configuration.

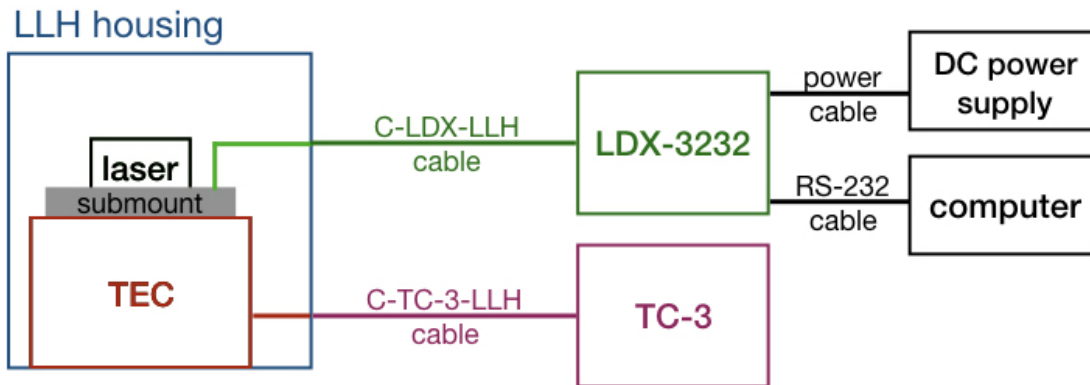


Figure 5.19.: Connection schematic for the LLH housing controlled with LDX-3232 and TC-3 temperature controller.

**Note:** ALPES LASERS does not provide cables for other drivers than the S-2 pulser and LDX-3232 driver.

#### C-LDX-LLH cable

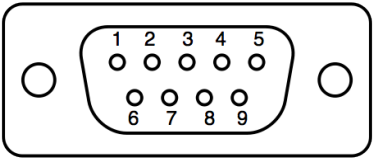
The C-LDX-LLH cable, shown in figure 5.20, connects the LLH housing to the LDX-3232 driver.



Figure 5.20.: C-LDX-LLH cable connecting the LLH housing to the LDX driver.

The **LLH end** consists of two rows of pin slots; all slots of each row are connected together, resulting in two terminals. In order to insure the correct polarity, some slots are filled with solder, to match the broken pins on the LLH connector (see section 5.2).

The **LLH end** consists of a D-sub-9 connector, described in table 5.7.



pin nb	purpose
1	shorted with pin 2
2	shorted with pin 1
3	(not connected)
4	LLH connector (negative polarity)
5	LLH connector (negative polarity)
6	(not connected)
7	(not connected)
8	LLH connector (positive polarity)
9	LLH connector (positive polarity)

Table 5.7.: C-LDX-LLH cable connector to LDX-3232, pinout numbering (left) and pinout description (right).

### 5.3.4. Laser installation in LLH housing

The guidelines for manipulating NS or AN-NSP lasers safely and the procedure for exchanging the laser in a LLH housing are outlined in this section.

**IMPORTANT:**

The maintenance procedures included in this section have to be followed carefully by expert users only. Delicate operations may result in permanent damage to the laser if not carried out properly.

#### Handling

The laser should always lay flat, with its vertical axis upwards, on a flat and stable surfaces. There should be nothing touching the edges. When mounted in an appropriate and stable holder, it can be operated in any orientation.



**CAUTION:**

Do not position the laser upside down. This may damage the bonding wires and possibly the laser itself.

The most delicate parts of a QCL are the laser chip itself and the bonds connecting it to the ceramic pads (see section 1.1.3 for details). Therefore the QCL should be manipulated using tweezers touching the submount, as shown in figure 5.21. Whenever possible, carry the QCL laying flat on a stable surface. Avoid contact of the front facet of the QCL with any object, like the walls of its storage box.

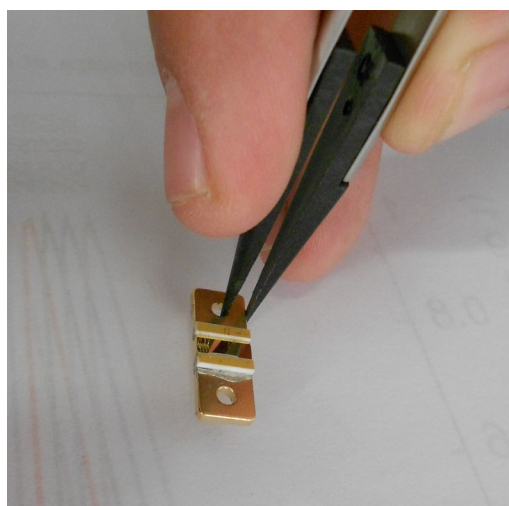


Figure 5.21.: Handling of QCL.



**CAUTION:**

Do not touch the bonds nor the laser chip itself, as the QCL may be permanently damaged.



**CAUTION:**

Avoid the deposition of dust on the laser chip or any laser submount item. Malfunctioning or permanent damage to the laser may occur.

### Contact set

The contact set shown in figures 5.22 connects the laser active pad to the low impedance line of the LLH through a copper contact, as shown in figure 5.23.

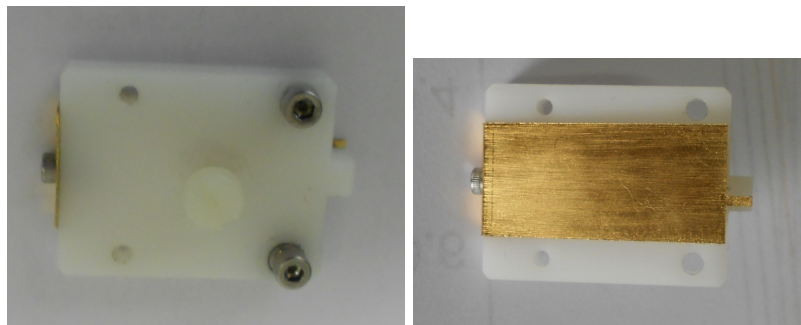


Figure 5.22.: LLH contact set, top (left) and bottom (right).

The laser submount is screwed onto the LLH base copper plate, on which the contact set is screwed to insure electrical contact between the selected pad and the low impedance line, as shown in figure 5.24. The low impedance line (LBI) connects the laser chip to the LDD in pulsed mode, or external power supply in CW mode, through the LLH `laser` and `base` connectors.

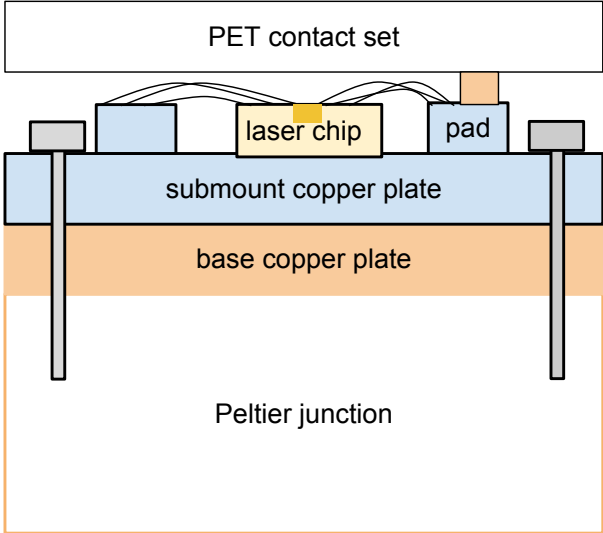


Figure 5.23.: Schematic side view of the laser submount, contact set and LLH.

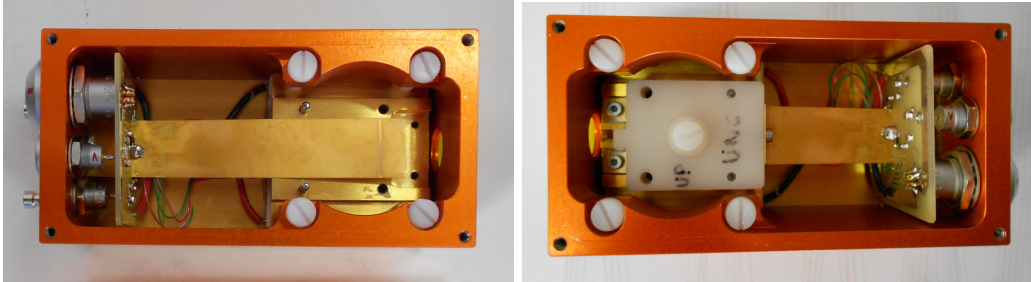


Figure 5.24.: Inside view of the LLH, without (left) and with (right) contact set.

## Procedure

This procedure allows the installation of a new laser into the LLH housing.

1. disconnect the LLH and open its cover (2), as shown in figure 5.25

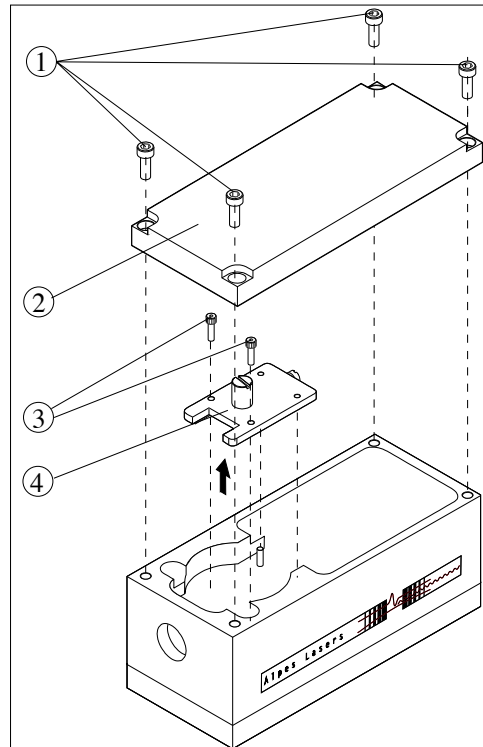


Figure 5.25.: Exchanging the laser in the LLH housing.

2. remove the two screws (3) holding the contact set (4) using a 2mm hex key
3. remove the contact set using the central PET<sup>4</sup> knob, as show in figure 5.26.  
*Note:* this PET screw is used as a knob, do not remove it.
4. remove the two screws holding the laser submount using a 1.5 mm hex key, as show in figure 5.26
5. remove the laser submount from its storage box using tweezers

**IMPORTANT:**  
The guidelines presented in section 5.3.4 must be followed carefully.

6. secure the laser submount into the LLH with the two dedicated screws; use tweezers to hold the screw in place while screwing with an allen wrench.

<sup>4</sup>PET refers to polyethylene teraphthalate, a common plastic.

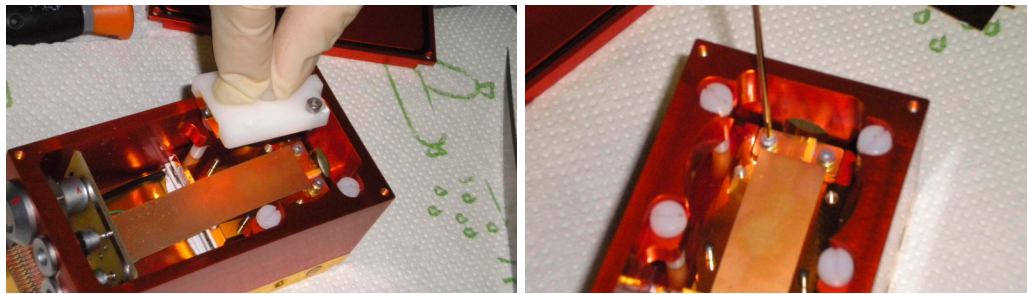


Figure 5.26.: Laser exchange procedure: removing the contact set (left), securing the laser submount (right).



**CAUTION:**

Do not drop the screws onto the submount. This may result in permanent damage to the laser.

7. put the contact set on top of the laser submount into the LLH housing:
  - a) use the middle knob to hold the contact set
  - b) position the two rear holes above the pins for proper alignment
  - c) tighten the two dedicated screws through the front holes
  - d) press slightly for good electrical contact
8. use a multimeter to measure the resistance between the `base` and the `laser` connectors. It should lie between  $30\ \Omega$  and  $300\ \text{k}\Omega$ ; no resistance indicates a shortcut, infinite resistance indicates a misconnection<sup>5</sup>. In those two cases, perform step 7 until a good contact is obtained.
9. close the LLH cover.

---

<sup>5</sup>The laser's resistance is measured between the submount copper base and the ceramic pad. The resistance between the `base` and the `laser` connectors on the LLH should be the same as the laser's resistance ( $\pm 2\Omega$ ).

### 5.3.5. UP and DN contact exchange

Follow procedure 5.3.4, adding those additional steps to step 7:

1. remove the screw (5) located at the back of the contact set, as shown in figure 5.25
2. remove the copper contact (6)
3. replace it with the copper contact supplied by ALPES LASERS with the new laser
4. tighten back the screw (5)

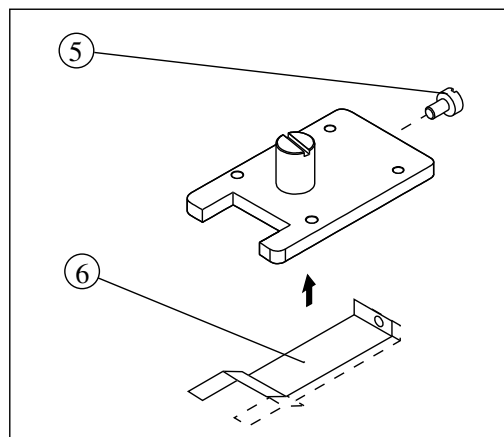


Figure 5.27.: Exchanging the laser submount UP and DN contact (right).

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# 6. Peripherals

In this chapter are presented the operation instructions for the ALPES LASERS temperature controller and laser drivers. An overview of their technical specifications are given in table 6.1.

**IMPORTANT:**  
The operating parameters are listed in the datasheet provided with each laser; any operation outside the specified range must be agreed with ALPES LASERS or may result in the loss of warranty.  
These operation ranges are not pre-set in the drivers.

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<b>Temperature Controller (TC-3)</b>	
Size	9cm x 21.5cm x 28cm
Power Input	Mains power (120/240V, 50/60Hz)
Input/Output	Through supplied TC-LLH(HHL) cable
Internal Control	Front panel buttons
External Control	USB connectors
Max Current	5.0 A
Temperature setpoint range	-99°C-+250°C (limited range with allowed for QCL use)
Temperature sensor	pt100, NTC, user-defined
<b>QCL Pulser (S-2)</b>	
Size	75mm x 42.75mm x 22mm
Power Input	Mains power (120/240V, 50/60Hz)
Input/Output	DC 8-24V
Control	USB interface or direct access to pins
Output voltage	0 to 25V in 5 mV increments
Output current	Up to 8A peak current, up to 2.5A average current
Rise/fall time	5 to 15 ns (package dependent)
Pulse duration	20 ns up to CW in 20 ns increment
Repetition Rate	up to 1 Mhz
Operation Temperature	0°C to 60°C

Figure 6.1.: ALPES LASERS peripherals technical specifications.

## 6.1. ALPES LASERS TC-3 Temperature Controller

The TC-3 purpose is to control the laser temperature inside the LLH or HHL housing; it is also integrated into the ECLK package. It controls the TEC and reads the temperature sensor coupled to the laser chip (see section 5.3). ALPES LASERS sets the TC-3 software in factory if it was purchased as a package. It can be largely customized by the customer to work with different types of laser housing.



Figure 6.2.: TC-3 temperature controller.



**CAUTION:**  
The OEM feature `AutoTune` is NOT RECOMMENDED with the ALPES LASERS housings of Alpes Lasers. The TEC Peltier elements may be damaged or their lifetime reduced.

The OEM TC-3 manual is available on the ALPES LASERS website:  
<http://www.alpeslasers.ch/?a=142,144>

### 6.1.1. Local voltage setting

After unpacking the unit, make sure that the voltage selection on the Input Power Connector (IPC) on the back of the unit, shown in figure 6.3, is set to the correct voltage.



Figure 6.3.: TC-3 temperature controller back panel.

1. The TC-3 is typically shipped in your local 120V or 220V configuration from the factory, and may be set to a different voltage. However, make no assumptions and change the voltage as needed.

**IMPORTANT:**  
The TC-3 voltage setting must be adapted to the local voltage, or it may result in permanent damage.

2. plug the AC cord into the unit and into the wall outlet.
3. Turn on the power switch located on the IPC, and the unit will power up. It will then display the model information and firmware version number.

### 6.1.2. Initial parameters

First, the TC-3 parameters need to be adjusted to the laser housing and temperature sensor. These values ensure the correct behaviour of the system. Figure 6.4 shows the TC-3 front panel.

1. Press the **MENU** button to enter the menu and turn the knob to the right until the **lim** setting is displayed.
2. Press the knob to edit the setting and adjust the limit to the setting indicated in the ALPES LASERS datasheet provided with your laser. Refer to Table 6.1.

Housing	$I_{lim}$
HHL (single stage)	3.0 A
HHL (double stage)	2.5 A
LLH	5.0 A

Table 6.1.: Current limits settings

3. Press the knob again to save the value.
4. Press the **MENU** button to enter the menu and turn the knob to the right until the **T-High Lim** setting is displayed.
5. Press the knob to edit the setting and adjust the limit to the setting indicated in the ALPES LASERS datasheet provided with your laser.
6. Press the knob again to save the value.
7. Press the **MENU** button to enter the menu and turn the knob to the right until the **T-Low Lim** setting is displayed.
8. Press the knob to edit the setting and adjust the limit to the setting indicated in the ALPES LASERS datasheet provided with your laser.
9. Press the knob again to save the value.
10. Press the **MENU** button to enter the menu and turn the knob to the right until the **Sensor type** setting is displayed.
11. Press the knob to edit the setting and adjust the limit to the setting indicated in the ALPES LASERS datasheet provided with your laser. Refer to Table 6.2.
12. Press the knob again to save the value.

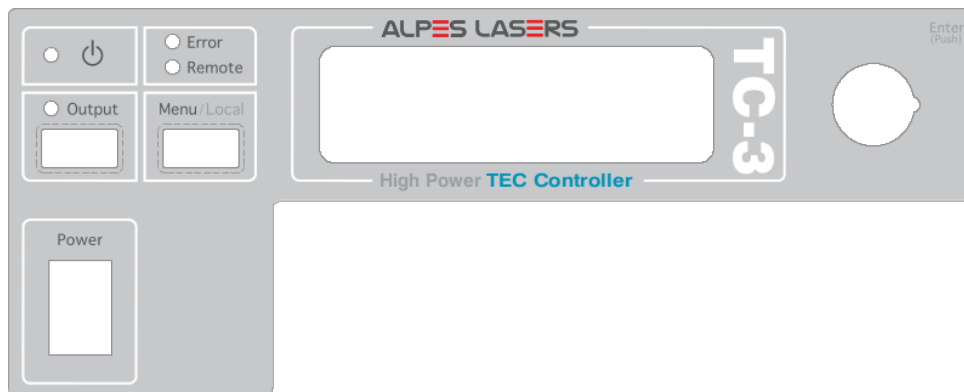


Figure 6.4.: TC-3 front panel.



Figure 6.5.: TC-3 temperature controller GUI `I Lim` and `T High Lim`.



Figure 6.6.: TC-3 temperature controller GUI sensor type.

Housing	Standard	Sensor type	TC-3 setting
HHL	Standard	NTC 10K4CG	10 uA or 100 uA Therm
HHL	Custom only	PT-100	4wire RTD
LLH	Obsolete	PT-100	4wire RTD
LLH	Standard	NTC 10K4CG	10 uA or 100 uA Therm

Table 6.2.: Temperature sensor settings. The default sensor in the HHL is the NTC with the pt100 on request only. The default in the LLH is NTC for housing delivered after Dec. 2021. With the NTC choosing the 100 uA option will result in finer resolution at high temperature while the 10 uA option will be best at low temperatures.

13. Press the `MENU` button to enter the menu and turn the knob to the right until the `PID` setting is displayed.
14. Press the knob to edit the setting and adjust the limit to the setting indicated in the ALPES LASERS datasheet provided with your laser. Refer to Table 6.3.
15. Press the knob again to save the value.
16. Press the `MENU` button to exit the menu.

**Note:** if a single value needs to be changed, it is not necessary to go through the whole procedure. Pressing the MENU button while changing a value will save the value and exit.

Housing	Temperature Range	PID values
HHL NTC	-30 °C to -12 °C	PID P = 0.47 PID I = 0.014
HHL NTC	-12 °C to +12 °C	PID P = 0.3 PID I = 0.0048
HHL NTC	+12 °C to +37 °C	PID P = 0.195 PID I = 0.09
HHL NTC	+37 °C to +55 °C	PID P = 0.155 PID I = 0.0046
HHL NTC 2-stage	-41 °C to -17 °C	PID P = 0.47 PID I = 0.014
HHL NTC 2-stage	-17 °C to -7 °C	PID P = 0.47 PID I = 0.012
HHL NTC 2-stage	-7 °C to +55 °C	PID P = 0.2 PID I = 0.0075
HHL HP NTC	-35 °C to -13 °C	PID P = 0.42 PID I = 0.04
HHL HP NTC	-13 °C to +13 °C	PID P = 0.4 PID I = 0.012
HHL HP NTC	+13 °C to +23 °C	PID P = 0.3 PID I = 0.01
HHL HP NTC	+23 °C to +55 °C	PID P = 0.25 PID I = 0.01
LLH NTC	-30 °C to +55 °C	PID P = 0.8 PID I = 0.0025
LLH pt100	-30 °C to +55 °C	Gain setting = 300

Table 6.3.: Optimal PID settings for various housing type and temperature range. The D value is omitted to save space and should always be set to zero.

### 6.1.3. Startup procedure

1. connect the TC-3 to the laser housing using the C-TC-3-HHL/LLH cable if connecting directly, or the C-S-2-TC-3 if connecting through the S-2 pulser. If using another kind of cable, make sure it is properly wired according to the pin-out of the TEC and your setup.

**IMPORTANT:**  
The ALPES LASERS C-TC-3-HHL/LLH cable was designed for optimal use of the TC-3 with the HHL or LLH housings. The customer may use another manufacturer's cable at its own risk.

2. Press the **MENU** button to enter the menu and turn the knob to display the **T set** setting
3. Press the knob to edit the setting and adjust it to a temperature close to room temperature (typically +15°C)
4. Press the **Output** button; the temperature measured by the sensor will be displayed on the TC-3 display, the TEC will be powered, and the voltage and current will gradually reach the set point. Depending on the thermal size of the setup, it may take up to several minutes to reach room temperature.

**IMPORTANT:**  
The TEC temperature as displayed by the TC-3 must reach a stable point before turning the laser on, or else the power and wavelength emitted will also oscillate with the temperature.

If you notice the temperature is oscillating around the set point and not stabilizing, you may need to adjust the **Gain** setting in the menu. If the temperature is quickly jumping up and down, the Gain will typically need to be reduced. If the temperature is slowly moving up and down, try a higher Gain. You may need to experiment with several gain settings to find the ideal value. For even finer control, you can set the Gain to PID and directly set the PID control values.

5. edit the **T set** setting to the desired set point. It is good practice to adjust the set point by intervals of 5°C or less and wait for the actual temperature to stabilize before changing the set point again, as the HHL and TO3 housings age prematurely with large temperature swings. The LLH is less sensitive and can withstand larger temperature swings. The recommended temperature change rates are given in table 6.4. Using the settings of table 6.2 ensures these rates are respected.



Figure 6.7.: TC-3 temperature controller GUI Gain.

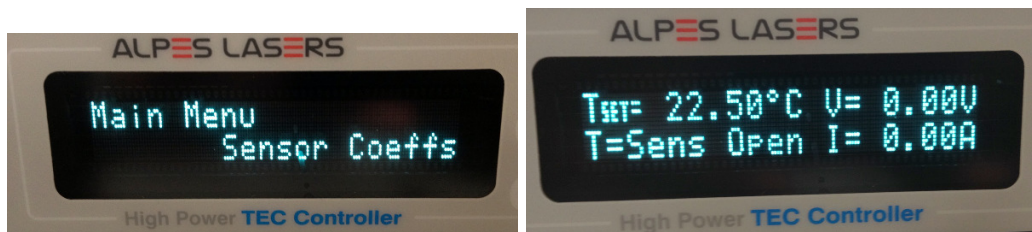


Figure 6.8.: TC-3 temperature controller GUI.

Housing	Maximum temperature change rate
HHL	0.2°C/s
TO-3	0.2°C/s
LLH	1.0°C/s

Table 6.4.: Recommended temperature change rates

## 6.2. S-2 Pulser

The S-2 pulser provides short electrical pulses to the laser. It can generate a maximum peak current of 8 A and a maximum average current of 2.5 A. The maximum peak current as function of duty cycle and pulse repetition rate is shown in Fig. 6.9.

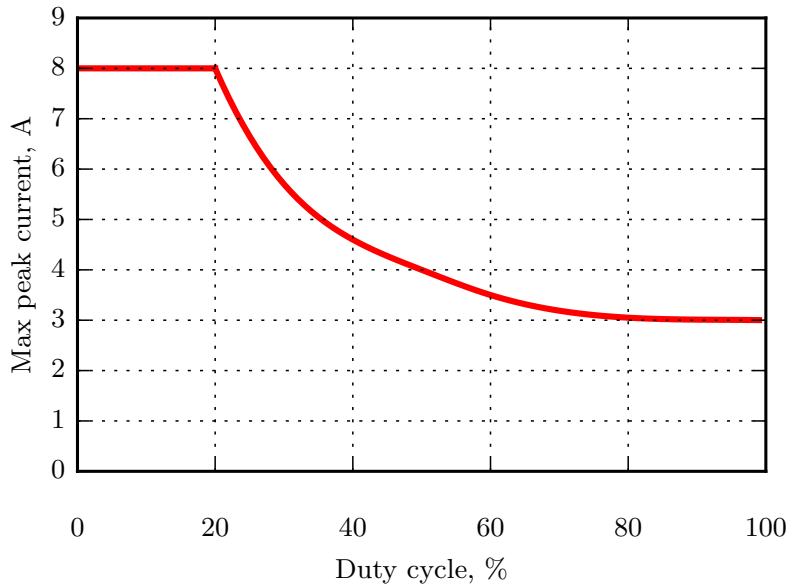


Figure 6.9.: ALPES LASERS S-2 pulser maximum peak current as function of duty cycle.

**IMPORTANT:**

The S-2 pulser is designed for pulsed operation only. Its range of operation can be pushed to continuous-wave, but in that case its stability is not considered suitable for spectroscopy.

The S-2 pulser is available in different configurations:

- as a bare circuit, as shown in Fig. 6.10 (see technical drawing in Fig. 6.15), to be integrated in the customer's device;
- integrated by ALPES LASERS in a 75 mm×42.75 mm×22 mm eloxed aluminium box for laboratory use (see figure 6.11);
- provided with the ALPES LASERS C-S-2-TC-3 cable, for connection to the TC-3 temperature controller; see sections 6.1 and 5.2.2 for details.

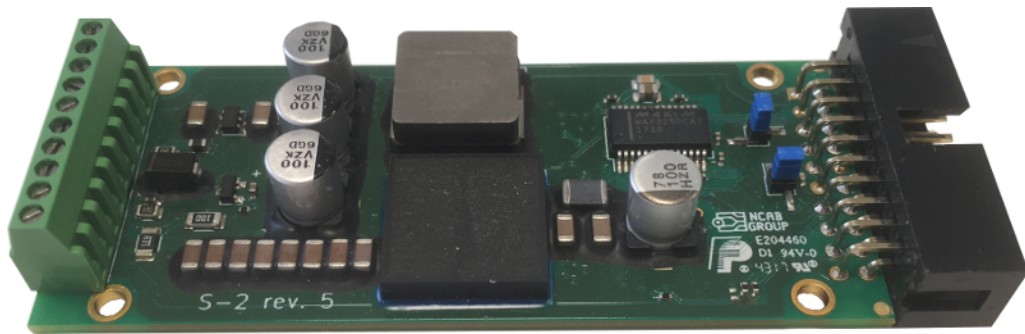


Figure 6.10.: S-2 pulser bare configuration.

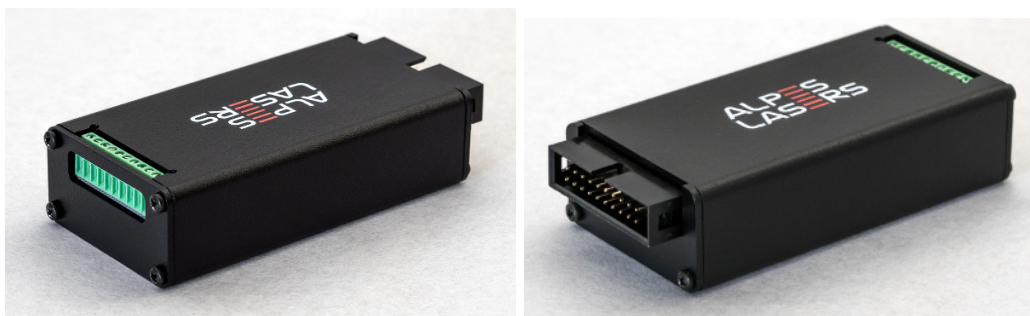


Figure 6.11.: S-2 Pulser in eloxed aluminum box, front end (left) and back end (right).

### 6.2.1. S-2 pulser back pinout

It is recommended to use the S-2 pulser with the ALPES LASERS C-S-2-TC-3 and C-S-2-LLH cables, but if you use third-party housings or temperature controllers it is possible to build your own cable to connect the S-2 to your setup. To that end, the back pinout of the S-2 is shown in figure 6.12 and table 6.5. The S-2 pulser can be controlled with the computer software provided by ALPES LASERS. The pulse sequence can be either generated by the board itself, or can be provided by an external TTL pulse generator.

**IMPORTANT:**

The values to be considered when driving a laser with an S-2 pulser are the *Peak Voltage* and the *Peak Current* values as provided by ALPES LASERS on the laser datasheet. The values  $U_{LDD}$  and *DC Voltage fed to LDD* shown on some older datasheet are deprecated and not to be considered.

The S-2 back pins 2 and 4 provide an RS-232 serial interface to the pulser (see Fig. 6.12). The RS-232 connector of the C-S-2-TC-3 cable connects to the serial port of a computer (Mac or Windows).

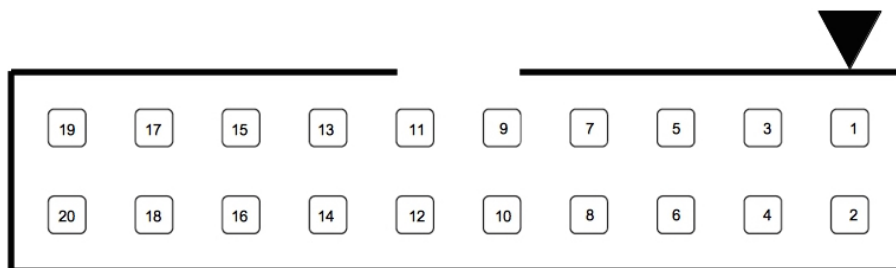


Figure 6.12.: S-2 back end pinout. The position of pin 1 is marked by a triangle on the top of the connector.



**CAUTION:**

Do not apply more than 3.3V on any external input excepting the supply. There is a risk of damaging the S-2 pulser.

**IMPORTANT:**

During normal use, the S-2 RS232 connection is isolated. If needed you can connect the RS232 ground to the S-2 ground by placing the jumper JP3 (see Fig. 6.13

1.	TEC Input (+)	Power + of the TEC
2.	RS232 Rx	Communication receive line
3.	RS232 Ground	Communication GND
4.	RS232 Tx	Communication transmit line
5.	Ground	S-2 ground (power supply negative)
6.	LASER ON output	In burst mode, Sync signal that follows burst envelope. In other modes, Output status: 3.3V when output is enabled, 0V when output is OFF
7.	Ground	S-2 ground (power supply negative)
8.	Sync output	Pulses sync signal (3.3V)
9.	Temperature Sensor (-)	Temp. sensor negative line
10.	Do not connect	
11.	Temperature sensor (+)	Temp. sensor positive line
12.	Interlock	Short with pin 14 to enable laser. Alternatively, the interlock can be shorted on the board by placing the Jumper JP2 as in Fig. 6.13 (default)
13.	Power supply input	6-25V
14.	Interlock	MCU Interlock output (3.3V)
15.	Analog Output	Programmable analog output (3.3V)
16.	External Trigger Input	In the External Trigger mode, triggers the pulse (3.3V) In the External Control mode the signal determines completely the output waveform, limited to 80 kHz (3.3V)
17.	Analog Input	Programmable analog input (3.3V)
18.	Do not connect	
19.	TEC input (-)	Power - of the TEC
20.	Do Not Connect	

Table 6.5.: S-2 back pinout.

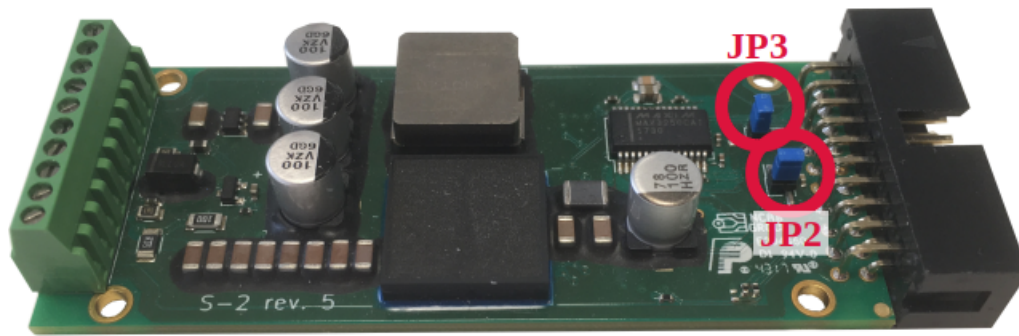


Figure 6.13.: Jumpers location

### 6.2.2. Graphical User Interface Control

This section shows how to program the S-2 pulser with the provided GUI.

**Note:** by default, the S-2 pulser is powered up with the settings stored at the last session.

1. open the S-2 graphical user interface to connect the S-2 pulser to the customer's computer: a dialog similar to the one shown in figure 6.14 will appear;
2. set the pulse width, repetition period and pulse amplitude using the dialog box:
  - pulse width and repetition period can be adjusted in 10 ns increments;
  - Note:** if the pulse width is set to a value larger than the repetition period, the current will be on continuously.
  - pulse width of the **Sync Out** TTL signal can be set in 10 ns increments.

Type the new values and select an output mode:

**Pulsing** In pulsing mode, the S-2 outputs pulses corresponding to the selected period, pulse width and voltage.

**External Control** In external control mode, the pulses are shaped using the External Trigger Input signal. The signal shapes the pulse when the GUI parameters are set to output a continuous current, otherwise the signal acts as a gate (High: pulses ON, Low: pulses OFF). This function is limited to 80 kHz.

**Burst** In Burst mode, the pulses are following a burst envelope defined by a BURST ON and a BURST OFF period.

**External Trigger+Burst** In the external trigger + burst mode, a single burst (BURST ON) is triggered by the External Trigger Input signal. The pulses and BURST ON parameters are defined via the GUI.

**External Trigger** In the External trigger mode, each pulse is triggered by the External Trigger Input signal. The width of the pulse and the voltage are set using the GUI.

3. save the current settings permanently in the driver by clicking on .

*Note:* The **Peak current limit, A** line displays the maximum allowed peak current for the current duty cycle and repetition rate. If this value is exceeded during operation, the driver will shutdown in order to protect the laser.

*Note:* **Pulse current, A** and **Idle current, A**: the measurements provided in the graphical user interface are indicative only; they are accurate for pulse width >200 ns and above the minimum measurable value, which can be as high as 0.15 A in some conditions.

4. Click on  to start the selected operating mode with the defined settings.

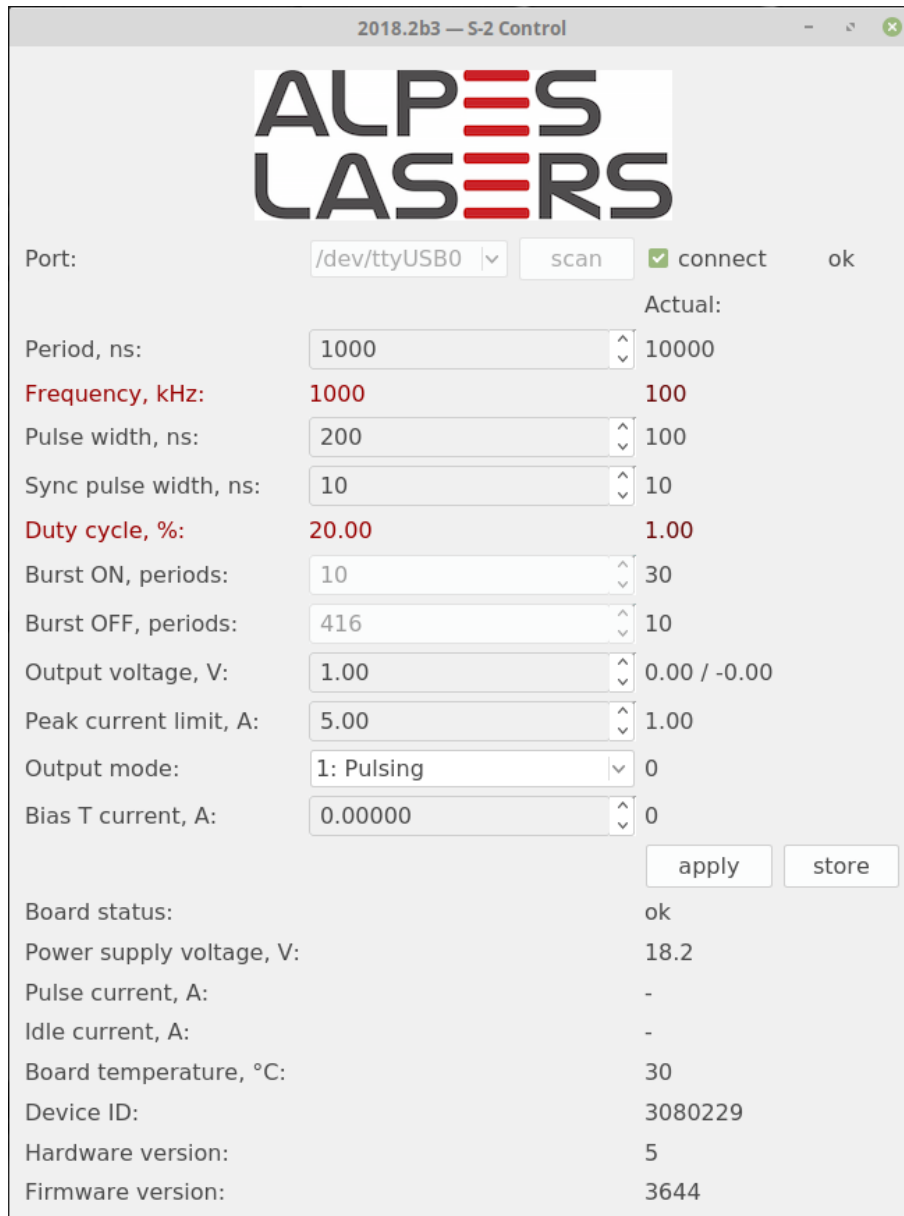


Figure 6.14.: Dialog Box for internal control.

### Direct Software Commands

The S-2 pulser can also be driven using a pure Python driver which can be integrated into another software at users convenience. The python driver is available at the following address : <https://bitbucket.org/AlpesLasersSA/> **Note:** ALPES LASERS offers this Python driver for convenience only. Software support will not be provided.

### 6.2.3. Technical specifications

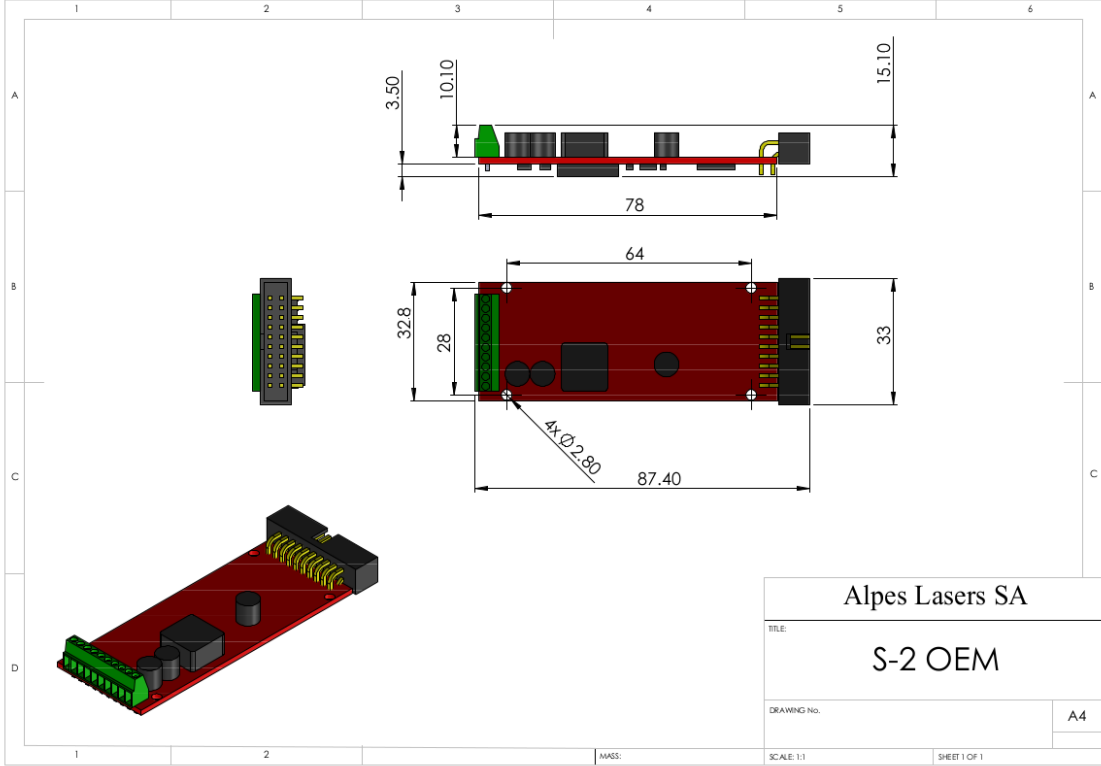


Figure 6.15.: S-2 driver in OEM configuration (protective box also available).

## 6.3. S-3 High Power Pulse Generator

The S-3 High Power Pulse Generator is designed to drive devices requiring short or long pulses of high current with a non-linear response, including optical devices such as high power quantum cascade lasers, infrared laser diodes, LEDs or electronic devices such as Gunn diodes or high speeds transistors and rectifiers.



Figure 6.16.: S-3 High Power Pulse Generator

The S-3 pulser can be operated in three ways:

- hardware operation (without computer) using the back panel connectors, to directly trigger and monitor the output signal. The connectors are described in table 6.6.
- fully programmed by a computer through the USB port located on the front panel; The software commands to control the S-3 are identical to those for the S-2 shown in § 6.2.2.
- a combination of hardware and software controls.

### 6.3.1. S-3 input/output connectors

The back panel connectors of the S-3 are shown in figure 6.17.

Via signals	<p>Allows to send DC currents/voltages to the low impedance head through its umbilical cable.</p> <p>Pin 1 -&gt; Pin 10 of low-impedance head (max. 4 A/50V)  Pin 3 -&gt; Pin 1 of low-impedance head (max. 4 A/50V)  Pin 7 -&gt; Pin 5 of low-impedance head (max. 0.5 A/50V)  Pin 8 -&gt; Pin 6 of low-impedance head (max. 0.5 A/50V)</p> <p>Can be used with ALPES LASERS TC-3 temperature controller to stabilize the temperature of a laser encapsulated in an HHL package.</p>
Sync Output TTL 3.3V	Provides a TTL 3.3V synchronization signal of a configurable width synchronized to the driver output when it is operated in internal modulation mode.
External Modulation Input TTL	Provide a TTL trigger signal to this input in external modulation mode. The width of the driver output pulse is independent of the trigger signal width and is configured via software.
RS-232 IN	Serial communication port to a computer. Pin 9: provides 3.3V when the driver output is enabled.
Burst trigger input TTL	When operating in the 'external trigger burst' mode, provide a TTL trigger signal to this input. The burst is triggered by the leading edge of the TTL pulse and is independent of its width. The count of pulses in the burst is configured via software.
Gate Input TTL	Provide a TTL signal to modulate with a low jitter the output pulse train in internal mode.
Output	For the umbilical cable to the low-impedance head of the S-3.
Interlock	Safety interlock. A short circuit has to be provided to enable the driver output.
USB In	USB communication port to a computer.

Table 6.6.: S-3 connectors.

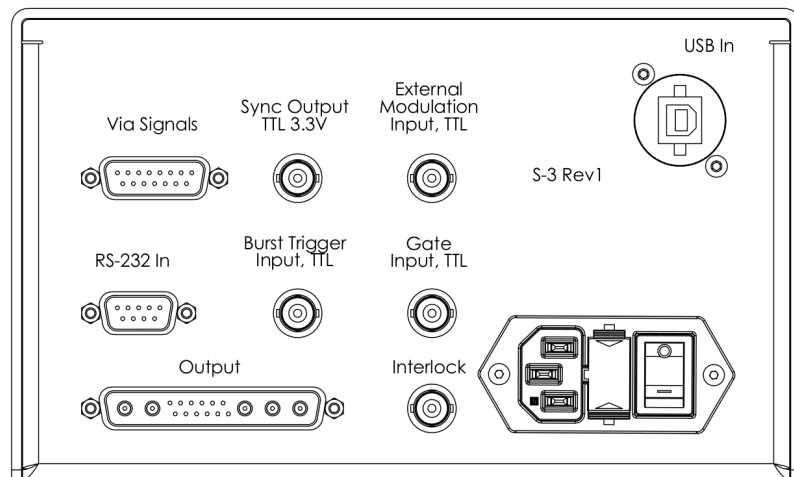


Figure 6.17.: S-3 pulser back panel connectors.

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## 7. External Cavity Laser Kit (ECLK)

The ALPES LASERS External Cavity Laser Kit (ECLK) contains a housing in which different laser chips can be installed, controlled by a TC-3 temperature controller and an S-2 pulser, with all connection cables and software. The kit is delivered pre-aligned and ready to use. Each ECLK and QCL are provided with their specific datasheet.

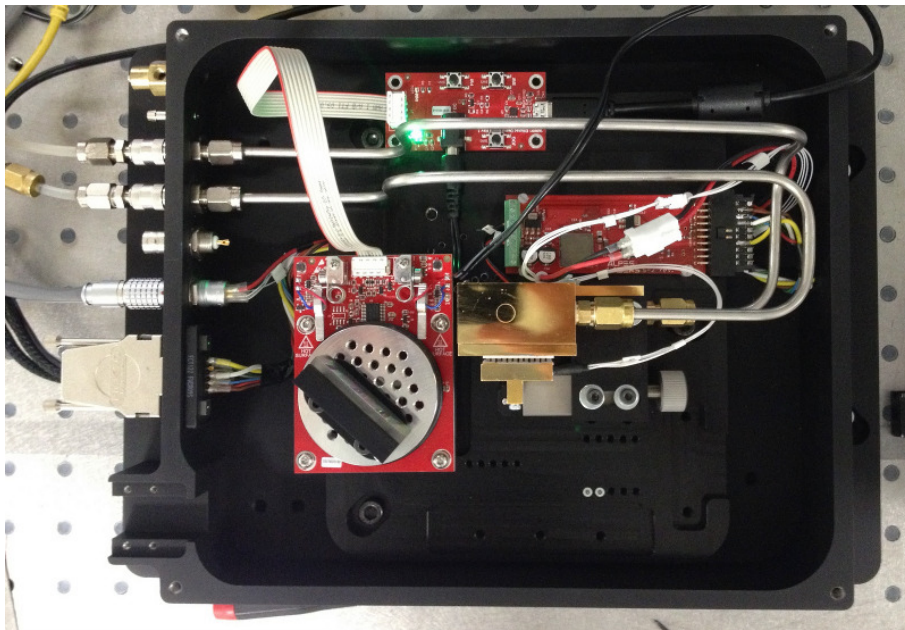


Figure 7.1.: ECLK kit.

### 7.1. Overview

ALPES LASERS External Cavity Laser Kit (ECLK) is designed for single-mode operation with wide spectral tunability. It consists of:

- a laser housing;
- an ALPES LASERS BG QCL, which can be tuned over a range up to 30% of their central wavelength. Additional QCL chips with different wavelength coverage and/or output power can be purchased from ALPES LASERS and installed in the ECLK housing by the user.

**IMPORTANT:**

The replacement of the laser chip must be performed by an experienced user. When installing a new QCL into the ECLK housing, initial alignment and calibration are necessary.

- a grating-tuned extended optical cavity in Littrow configuration;
- a heatsink assembly that includes a TEC and water cooling for improved heat dissipation for active temperature regulation;
- an ALPES LASERS S-2 pulser for driving the QCL;
- a graphical user interface allowing for automatic wavelength tuning.

### **Grating**

The back facet beam is collimated with an aspherical collimator lens onto a diffraction grating mounted on a motorized rotation stage. The first order diffracted beam is fed back into the gain chip. The laser frequency is tuned by rotating the grating. The front facet (output) beam is collimated by another aspherical collimator and is collected at the front side of the kit after passing through a one-inch-diameter AR coated output window.

## 7.2. Installation

The ECLK enclosure comes equipped with a servo driver, a temperature controller and a Raspberry Pi unit for overall control. These units should be wired to the enclosure according to the diagram shown in Fig. 7.2.

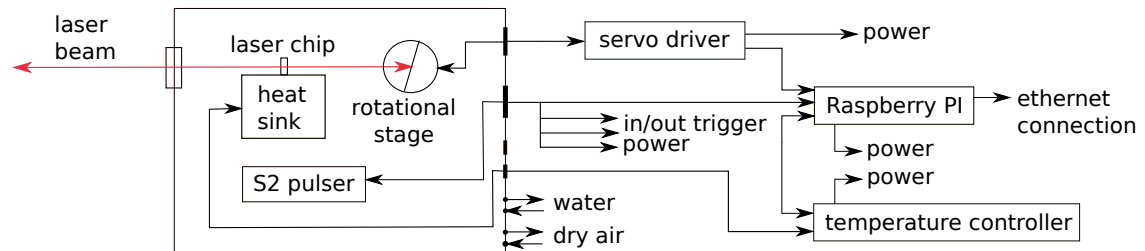


Figure 7.2.: Alps Lasers External Cavity Laser Kit - Diver connections block diagram.

### 7.2.1. Prerequisites

- Computer;
- mid-infrared detector or imaging system for the installation of a new QCL;
- mid-infrared spectrometer (e.g. Fourier Transform Infrared (FTIR) spectrometer) for wavelength calibration;
- nitrogen flushing system for improved performance. The electrical connectors and plugs for water cooling and gas purging are found at the back panel of the ECLK.

#### WARNING:

The QCL housing must be purged with dry air or nitrogen when the QCL is operated below the dew point. The housing is not thermally sealed, condensation may occur and cause irreparable damages to the laser chip.

### 7.2.2. Connections

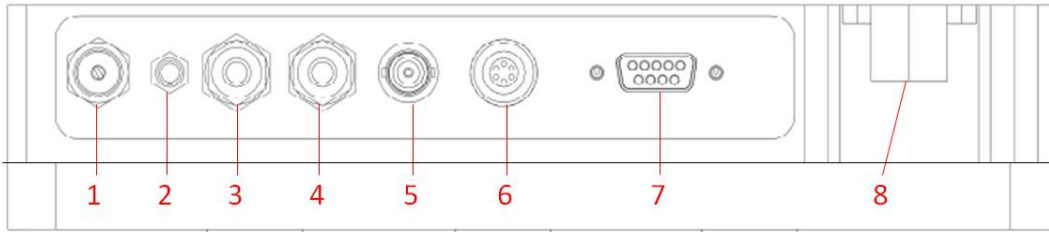


Figure 7.3.: ECLK back panel connectors and feed-through; see table 7.1.

Slot	Use	Parameters
1	Gas purge outlet with regulation valve	West Group Needle Valve 'NV-32'
2	Gas purge inlet	Serto Hose Nozzle 'LO CV 1100-4-M5'
3,4	Water cooling inlet & outlet	2x Serto Quick Coupler for a 4 mm pipe 'CO KA 205'
5	CW operation	Radial BNC female 'R141.605.000'
6	Temperature control	Lemo Female 6 pins 'HGG.1B.306.CLLP'
7	Pulsed operation	FCT DB9 female 'FWDR09S'
8	Hot glued lid	—

Table 7.1.: ECLK back panel connectors and feed-through; see figure 7.3

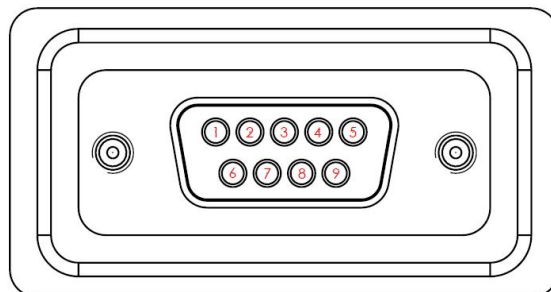


Figure 7.4.: D-sub connector to ALPES LASERS S-2 pulser; see table 7.2 for pin description.

Pin	Signal	Pin	Signal
1	Ground	6	RS232 Rx
2	Ground	7	RS232 Tx
3	Ground	8	Sync Output, TTL (3.3 V)
4	Not connected	9	External Modulation Input, TTL
5	Power Supply Input, 9-20 V		

Table 7.2.: D-sub connector to ALPES LASERS S-2 pulser; see figure 7.4.

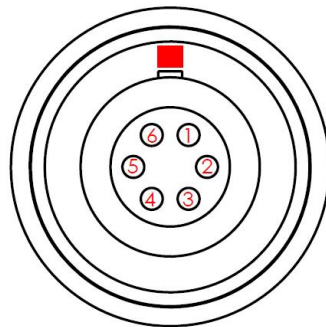


Figure 7.5.: Lemo connector to ALPES LASERS TC-3 temperature controller; see table 7.3 for pin description.

Pin	Signal	Pin	Signal
1	Temp sensor, current +	4	Temp sensor, current -
2	Temp sensor, sense +	5	Peltier element, black (-)
3	Temp sensor, sense -	6	Peltier element, red (+)

Table 7.3.: Lemo connector to ALPES LASERS TC-3 temperature controller; see figure 7.5.

## 7.3. Operation

### 7.3.1. Graphical user interface

In order to access the GUI, connect the Raspberry Pi to your local network using a standard ethernet cable. The MAC address of the embedded computer is listed on the instrument. Write down the IP address and/or the network name attributed to the ECLK computer.

#### Connection and login

To connect to the ECLK computer, open a browser on any computer which is connected to the same local network and type the IP address or the network name of the ECLK computer followed by the port number `:5000`, for example `192.168.0.8:5000`, or `alpeslasers:5000`. The login screen should appear in your browser (see Fig. 7.6).

The first time you connect, there is only one user registered by default in the system, with the username `admin1`. Enter the administrator password and click `Login`. The user `admin1` can then create additional user profiles.

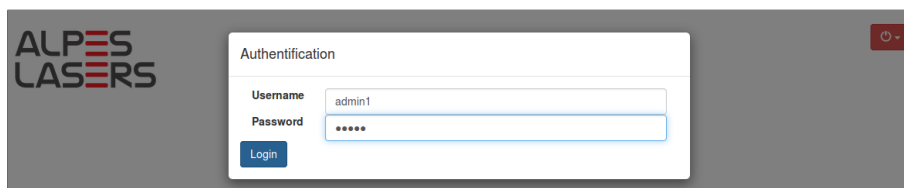


Figure 7.6.: Login screen.

The start screen appears upon successful user identification (see Fig. 7.7). From this screen, you can log out, access the administrator screen, start the instrument, or shut down the ECLK computer.

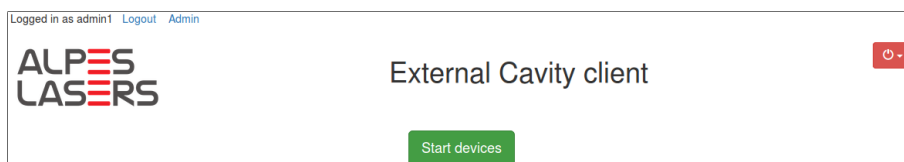


Figure 7.7.: Start screen.

The graphical user interface can be opened simultaneously on several different computers using the same or different user names. For optimal performance, it is recommended not to exceed three connections at the same time.

## Server administration screen

To access the server administration screen (see Fig. 7.8), click *Admin* on the top left of the start screen or the instrument control screen. You can only access the administrator screen if you are connected with the *admin1* account. Other accounts do not have administrator rights.

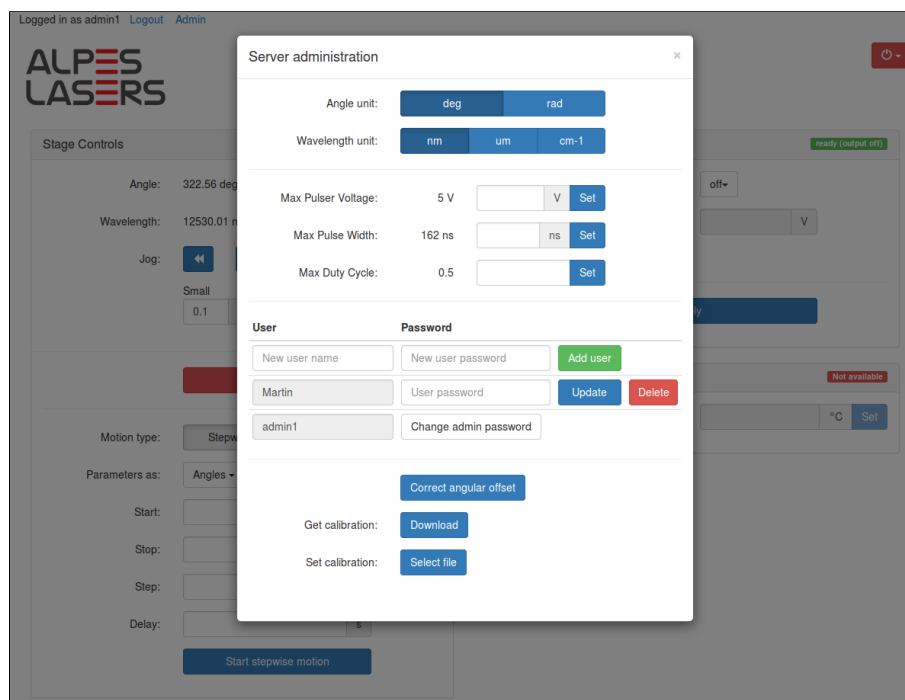


Figure 7.8.: Server administration screen.

From the server administration screen, you can set angle and wavelength units, set maximum voltage, pulse width and duty cycle limits for the pulsed QCL driver, create and delete user accounts, correct an angular offset of the calibration curve, and download the current wavelength calibration file, or upload a new one.

To select desired angle and wavelength units, click the corresponding buttons. To set maximum voltage, pulse width, and duty cycle for the pulse QCL driver, enter the desired values in the corresponding text boxes and click the *Set* buttons on the right.

To create a new user, enter the new user name and password in the corresponding text boxes and click *Add user*. The new user will be added to the list below. Passwords of existing users can be changed by entering a new password in the text box next to the user name and clicking *Update*. To delete a user, simply click *Delete* and confirm.

If an offset is observed between set and measured wavelength values, it is possible to correct for it without having to upload a new calibration curve. To do so, click *Correct*

*angular offset* and enter the measured wavelength value for the current settings in the dialog window (see Fig. 7.9). The software will calculate the corresponding angular offset and correct accordingly.

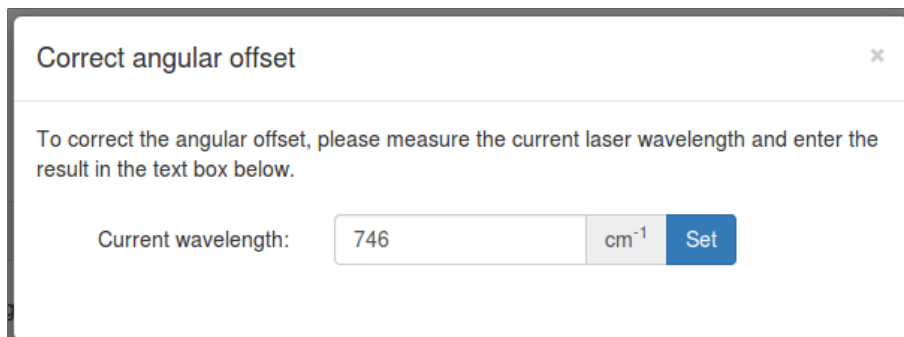


Figure 7.9.: Offset correction input screen.

To download the calibration file which is currently being used by the system, click *Download* and follow the instructions in your browser's download window. To upload a new calibration file, click *Select file* and select a file using the browse window of your browser. The name of the file that you selected will then appear in the administrator window. Click *Upload* to upload the file.

An example of calibration file is shown in Fig. 7.10. The file should consist of two columns labeled *angle [units]* and *wavelength [units]* with a comma separator and should be saved in .csv format. Units should be specified in square brackets []. Allowed units are [deg] and [rad] for angles, and [um], [nm], and [cm-1] for wavelengths/wavenumbers. Linear interpolation is used between points therefore, for improved tuning precision, the calibration file should provide a dense spectral coverage of the laser tuning range.

angle [deg]	wavelength [cm-1]
315.0110	823.0471
316.0107	823.1074
317.0087	823.1074
318.0396	823.1074
319.0057	743.8581
319.2151	747.2330
319.4116	749.1614
319.6027	753.3801
319.8059	756.2728
320.0183	759.0450

Figure 7.10.: Example of wavelength calibration file.

### Instrument control screen

To access the instrument control screen (Fig. 7.11), click *Start devices* on the start screen. The control screen is divided into three parts: rotation stage controls are grouped in the left panel, pulsed driver controls in the top right panel, and temperature

control in the bottom right panel. The current status of each subsystem is indicated in the top right corner of the corresponding panel.

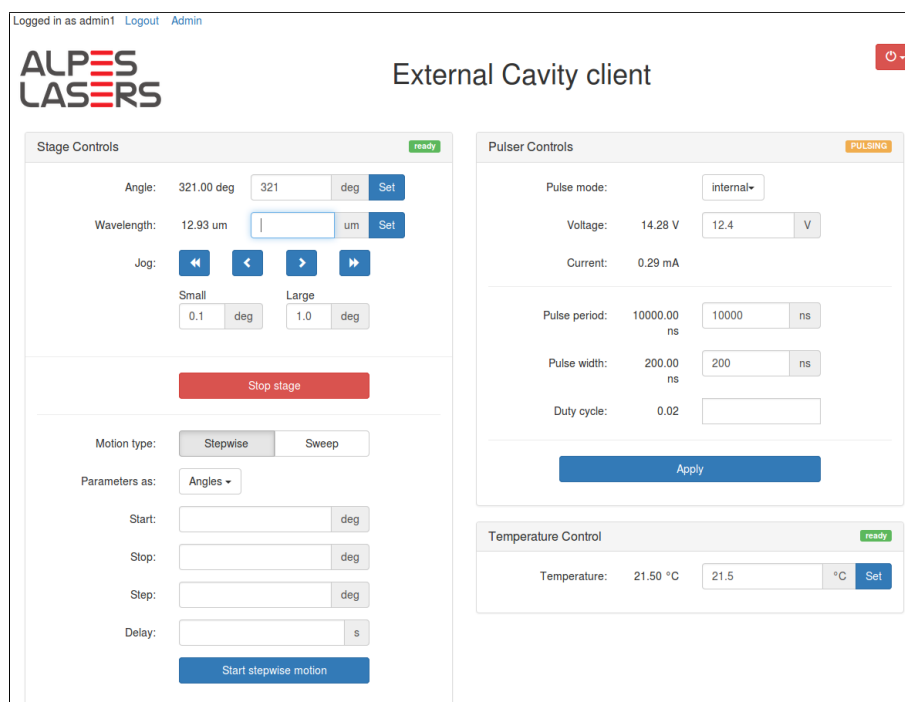


Figure 7.11.: Instrument control screen.

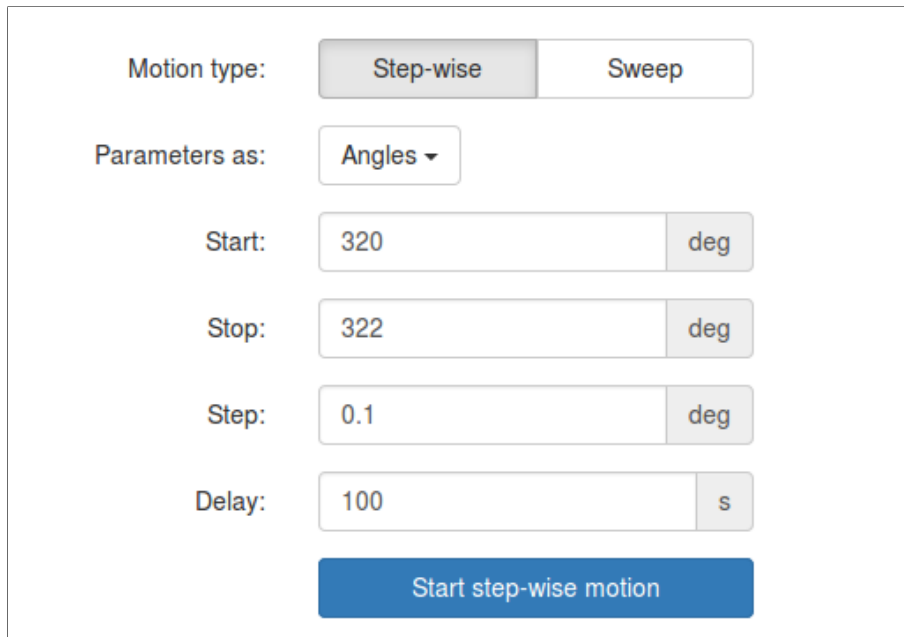
### Rotation stage controls

The rotation stage can be controlled by specifying either angle or wavelength. Wavelength is converted into angle using the calibration curve. To tune the laser to a desired wavelength, enter the target wavelength or the corresponding grating angle in the appropriate text box and click *Set*.

To move the grating by a fixed angular step, use the *Jog* function. Click on the single and double arrows to rotate the grating by *Small* or *Large* angular steps, respectively. The values of the *Small* and *Large* steps can be changed by entering the desired values in the corresponding text boxes.

### Stepwise and sweep motions

The rotation stage control offers two different ways to scan a wavelength region: *Stepwise* and *Sweep* motions (see Fig. 7.14). With the *Stepwise* motion, the stage stops at every position and waits for a user-specified *Delay* time before moving to the next point. With the *Sweep* motion, on the other hand, the stage moves continuously at constant speed between the *Start* and *Stop* points.



Motion type:  Step-wise  Sweep

Parameters as:

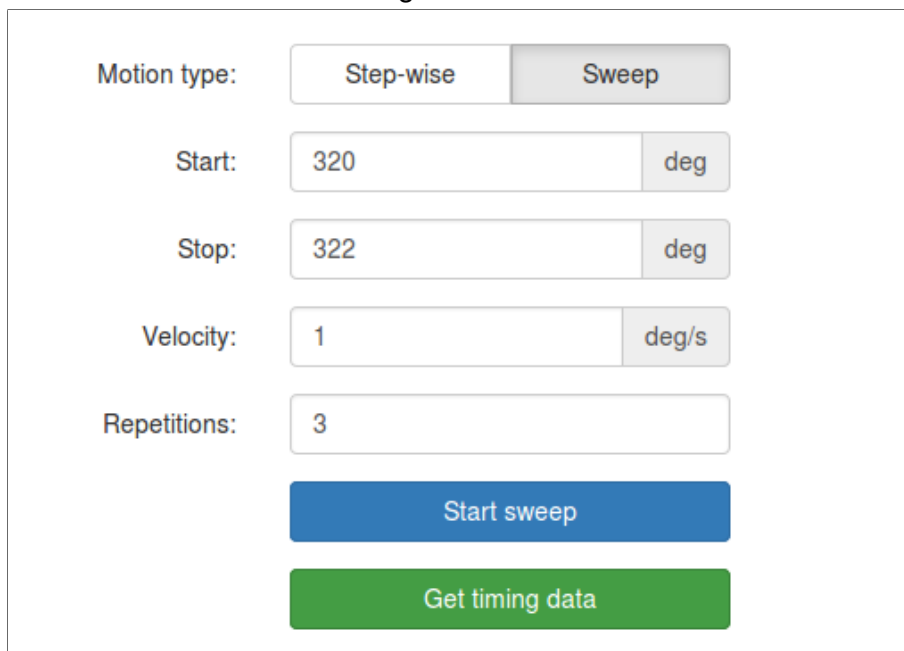
Start:

Stop:

Step:

Delay:

Figure 7.12.:



Motion type:  Step-wise  Sweep

Start:

Stop:

Velocity:

Repetitions:

Figure 7.13.:

Figure 7.14.: Step-wise (a) and sweep (b) motion control panels.

To perform a stepwise wavelength scan, click *Stepwise*, select how you want to specify the scan parameters (*Angles* or *Wavelengths*), enter the scan *Start*, *Stop*, *Step*, and *Delay*, and click *Start step-wise motion* (see Fig. 7.14(a)).

To perform a wavelength sweep, click *Sweep*, enter the sweep *Start*, *Stop*, *Velocity* in degrees per second, and number of *Repetitions*, and click *Start sweep*. Once the sweep is finished, a green *Get timing data* button will appear (see Fig. 7.14(b)). Click this button to download a csv file with the timing data of all the repetitions of the last sweep motion that was executed. An example of such file is shown in Fig. 7.15

#Sweep 0		
sweep_time[s]	angle[deg]	wavelength[nm]
0.0000	320.0995	13158.6327
0.0597	320.2997	13107.5389
0.1148	320.3998	13075.1590
0.1701	320.4999	13054.1704
0.2296	320.6000	13033.6956
#Sweep 1		
sweep_time[s]	angle[deg]	wavelength[nm]
0.0000	320.1996	13139.1319
0.0599	320.2997	13107.5389
0.1153	320.3998	13075.1590
0.1725	320.4999	13054.1704
0.2278	320.6000	13033.6956

Figure 7.15.: Example of sweep timing data.

## Pulser controls

The *Pulse mode* field of the pulsed QCL driver can take three values *Internal*, *External*, and *Off*. To select the QCL setpoint, enter the desired QCL voltage in the *Voltage* text box and click *Apply* at the bottom of the panel. Note: the *Voltage* text box is not active in *Off* mode. The measured output voltage and peak current are shown in real time in the pulser control panel.

In *Internal* mode, the pulse sequence is generated internally by the pulser. To specify a pulse sequence, fill two of the three fields *Pulse period*, *Pulse width*, *Duty cycle*. The third value is calculated using the following relationship:

$$\text{Duty cycle} = \frac{\text{Pulse width}}{\text{Pulse period}} \leq 1 \quad (7.1)$$

In *External* mode, the pulse sequence has to be provided by the user in the form of a TTL signal. The *Pulse period*, *Pulse width*, and *Duty cycle* fields are not available when this mode is selected.

In *Off* mode, the output of the pulser is disabled.

## Temperature control

To change the temperature setpoint, enter the desired value in the text box of the temperature control panel and click *Set*. The actual temperature, measured by a

Pt100 platinum resistor, is shown in real time on the left of the text box.

### 7.3.2. Shut down

Two options are available in the shutdown menu: *Shutdown devices* and *Power off server*. *Shutdown devices* closes communication with the ECLK subsystems but does not power them off. Click *Power off server* to power off the ECLK computer. You will need to reboot the server manually to access the external cavity client again.

## 7.4. Maintenance

The External Cavity Laser Kit is shipped assembled and aligned. The system is highly sensitive to optical alignment and any manipulation of its opto-mechanical components might lead to a suboptimal operation. In this case, or in the case of any intentional reconfiguration, such as the installation of a new gain chip or a new diffraction grating, it is essential to set up the system properly in order to produce a well-performing laser action. The following sections describe the optical alignment procedure.

The alignment leads to beam of a gaussian profile collimated along the z-axis of the system. Figure 7.16 shows schematically the degrees of freedom available on placing the components. To install a gain chip in the external cavity system, complete the following steps:

1. Install the new chip-on-carrier on the laser module.
2. Connect the QCL wires to the pulsed driver (pay attention to polarity).
3. Install the front and back lenses.
4. Remove the rotation stage from the grating module.
5. Turn on the temperature controller and the laser driver.
6. Adjust the back lens to collimate the beam using an IR detector or camera.
7. Put the rotation stage back on the grating module.
8. Monitor power of the front facet with an IR camera.
9. Optimize the grating tilt using the goniometer and the back lens focal distance using the focus adjuster to minimize laser threshold.
10. Adjust the front lens to collimate the output beam.

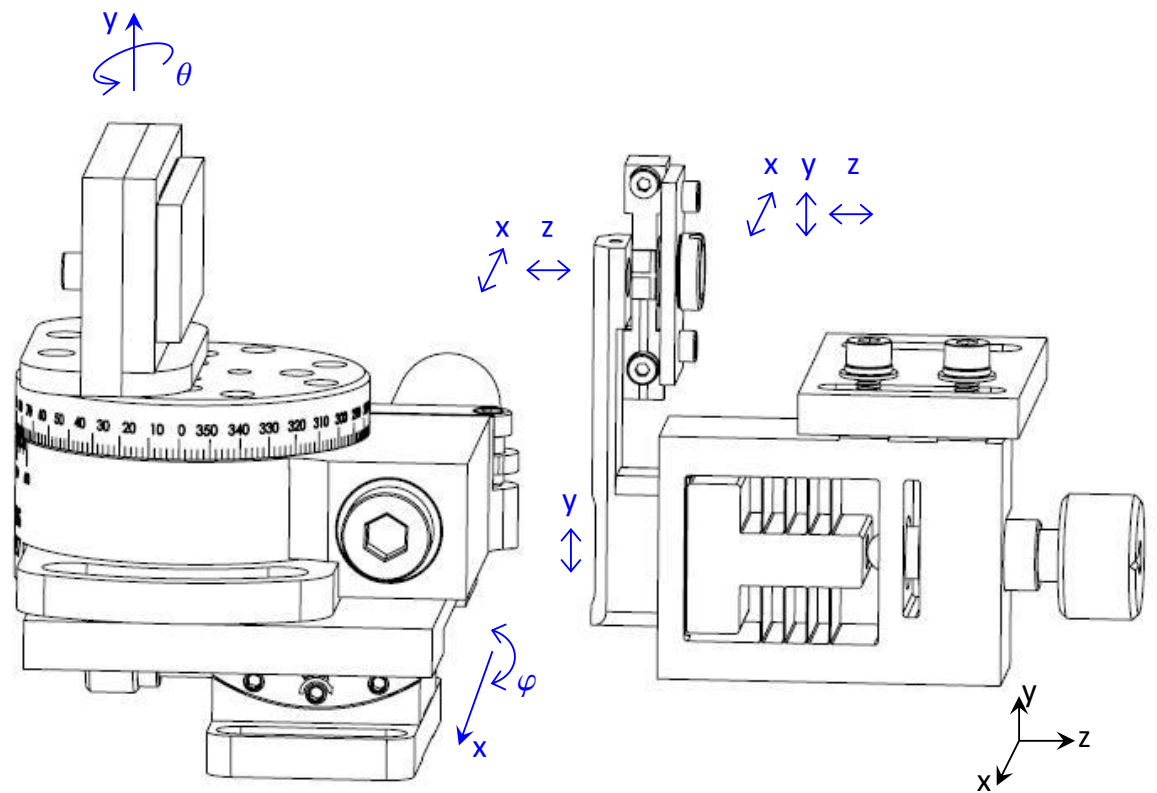


Figure 7.16.: Schematics of freedom degrees in the optical system.

### 7.4.1. Preparation

This step is required only if the kit was not assembled at the factory or if the previous configuration was not the Alpes Lasers original one. For the installation of a quantum cascade laser source only, go directly to section 7.4.2.

Attach the heat sink assembly to the base module by the two available M4 screws in the orientation as shown in Fig. 7.17(a). Attach the base module to the bottom part of the enclosure by the three available M6 screws in the positions indicated in Fig. 7.17(b). Attach the two stainless-steel pipe lines for water cooling (the inlet/outlet direction is arbitrary) in the respective sockets. Plug the drive wires from the TEC element to the respective intermediate connector. Place carefully the temperature sensor into the socket (Nb.19 in Fig. 7.24) and plug the other end of the wires to the respective intermediate connector. Plug the connector of the S-2 driver board.

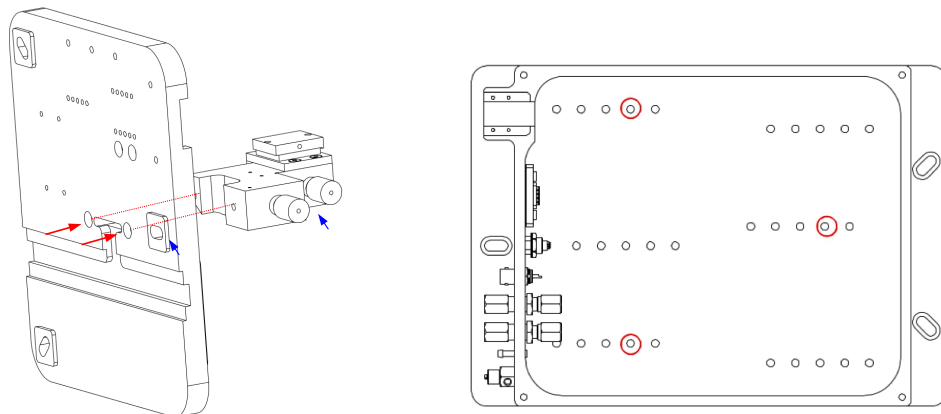


Figure 7.17.: (a) Attachment of the heatsink assembly to the base plate. Blue arrows indicate the orientation. (b) Indication of screw holes positions used to attach the base plate.

### 7.4.2. QCL chip installation

Make sure that all drive power connections are disabled. Keep at hand the QCL datasheet.

Attach tightly the gain chip carrier to the heat-sink assembly using two M2 screws. Always hold the carrier by its extremities (Fig. 7.18) and avoid touching the narrow section - an inappropriate manipulation may result in damages to the wire bonds and/or to the chip facets. There is a very little freedom in positioning the submount in yz-plane. Attach the carrier vertically by eye. If necessary, the small angular freedom can be exploited to achieve a better lens alignment.

Pass the drive cables underneath the heatsink assembly and attach the free ends into the indicated slots on the S-2 driver screw terminal: black on minus, red on plus (see Fig. 7.19). If not yet done, attach the driver board to the base module by the available four M2.5 screws.

Make sure the encapsulated temperature sensor is well in its socket. Set up the TC-3 temperature controller to '4 wire RTD', enable the connection and let the temperature stabilize. Notice that in an unpurged environment, the minimal operation temperature is limited by the dew point to about  $17^{\circ}\text{C}$ <sup>1</sup>. Lower temperature may lead to condensation on the gain chip and cause damages. In a purged environment, the minimal operation temperature is given by the power consumption of gain chip and is typically about  $-30^{\circ}\text{C}$ . Set the TEC current limit to  $\leq 5\text{ A}$ .

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<sup>1</sup>depending on meteorological conditions

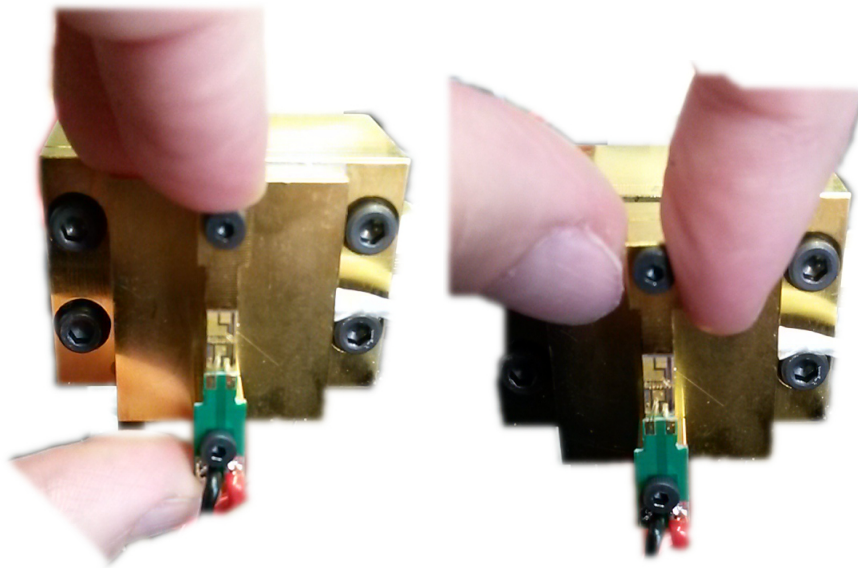


Figure 7.18.: Correct ways to hold the laser carrier.

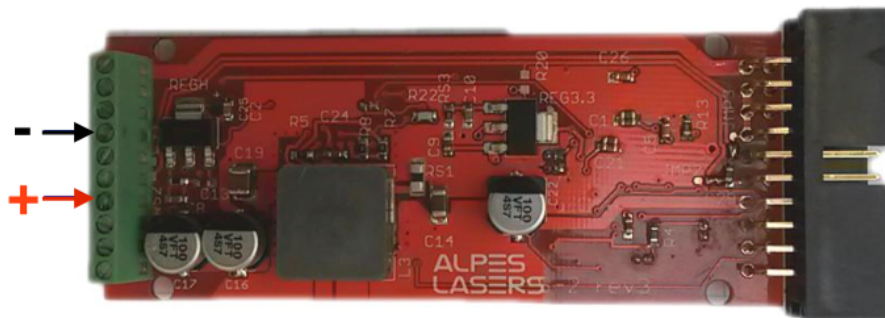


Figure 7.19.: S-2 pulsed driver. Connect QCL wires to screw terminals 4 and 7 as indicated.

### 7.4.3. Back lens alignment

Place the back lens as shown in Fig. 7.20. The back lens is mounted in a holder attached by two M3 screws to the focus adjuster flexure mechanism; this position is fixed and does not allow any movement. The adjuster is attached via an adapter plate to the heatsink assembly using two pairs of M3 screws and spring washers. There is a quite large freedom in positioning the adjuster with respect to the adapter plate which allows the lens alignment in the xz-plane. Do not tighten the screws completely at this moment.

A coarse geometrical alignment of the back lens follows. The adjuster knob is tightened in the middle of the allowed moving range. In the z-axis, the lens holder is posi-

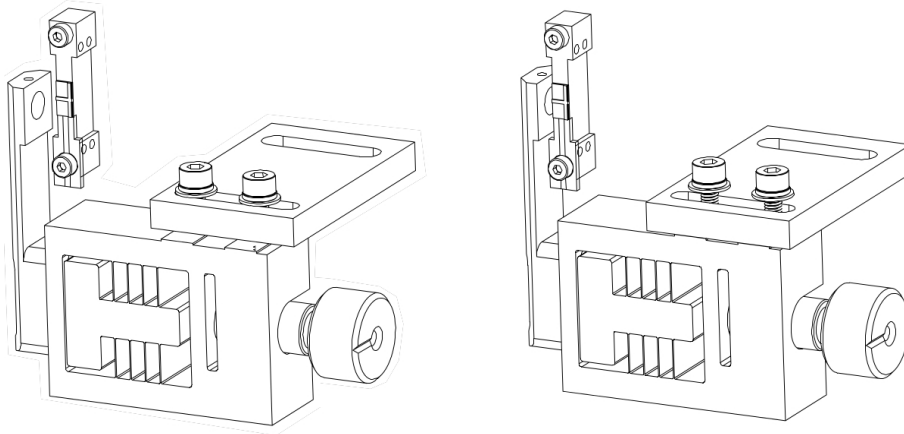


Figure 7.20.: (left): Initial attachment of the front lens mounted on its adjuster. (right): After a coarse geometrical alignment.

tioned as close as possible to the gain chip. Notice, that the shape of the lens holder prevents any direct contact between the laser facet and the surface of the lens. In the x-axis, the lens holder is shifted such, that the nylon-tip screw holding the lens lies in the same plane as the gain chip. In the y-axis, by tightening the adjuster screws, the center of lens is aligned with the laser facet. The final position is shown in Fig. 7.20 (left). Fasten the screws tightly to ensure that they do not move when manipulating the focus adjuster knob.

Prepare at hand a suitable mid-infrared detector or imager.

Connect the pulser board, connect to the ECLK server and open the external cavity client. Set up the pulsing scheme according to the laser specifications. Set the drive voltage on laser to zero volts and switch on the electrical connection. Set up the value of threshold voltage and gradually increase up to the maximum voltage value. See Section 7.3.1 for details on how to operate the pulser board.

Place the detector in front of the back lens, move it in the xy-plane and find the signal. As the lens is not well aligned, the beam spot lies out of the optical axis. Unscrew little bit the adjuster screws (half thread is enough) and shift gently the lens mount. Observe if the beam shape improves with a non-axial shift.

If you do not find any signal, the reason can be a large distance of the lens from the laser facet. In such a case, the intensity of the signal is very small and difficult to track with an insufficiently sensitive detector. Untighten the adjuster screw and make sure that the lens holder is as close as possible to the laser submount.

Fine back lens alignment follows. Touch the adjuster knob to optimize the collimated spot. You should notice a change from a divergent beam spot over a collimated one

to a divergent one again. If you, on the other hand, notice a progressive improvement (towards one or other direction), it means that the lens is placed too far or too close and you have to modify it.

You can notice from the beam shape and its position with respect to the optical axis if the lens needs to be shifted in the xz-plane.

Move the detector along z-axis and verify that the beam is well collimated. To optimize collimation, minimize the beam size at a distance  $\geq 0.5$  m away from gain chip.

If the beam spot is still not gaussian, it can indicate a bad position in y-axis direction. This can be improved by adjusting the tilt of the laser carrier.

#### 7.4.4. Front lens alignment

The front lens is molded in a threaded cylindrical mount that is screwed into a plate holder. To attach the lens plate holder onto the laser carrier, align its two holes with two threaded holes along the diagonal of the rectangle formed by the four holes on the side of carrier. Attach first lightly the upper screw to the side of the laser submount, then add the bottom one. There is a quite large freedom in moving it in the xy-plane. Align it geometrically and tighten well to ensure for a close contact of the lens and the laser facet.

Place the detector facing the front lens and find the signal. Adjust the lens focus in z-axis by screwing the lens holder in its mount.

The beam has to be parallel to the optical axis in order to go through the output window of the enclosure lid. If it is not the case, optimize the position of the lens holder appropriately.

#### 7.4.5. Grating alignment

Assemble the grating module. Attach the goniometer to the base plate with the four available M2.5 screws (see Fig. 7.25). Attach the adapter plate to the goniometer with the four available M2 screws (see Fig. 7.25). Attach the rotation stage to the adapter plate (see Fig. 7.25) and plug the cable. Turn the stage such that  $0^\circ$  on the fixed part is aligned with  $360^\circ$  on the moving part. Attach the grating holder to the stage with the four available M3 screws, Fig. 7.25.

A grating type suitable for the laser wavelength range is usually supplied with the laser chip. <sup>2</sup> There is an arrow drawn on the grating glass indicating the right orientation, see Fig. 7.21. Attach the grating holder by the two available M2 screws. The

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<sup>2</sup>If you have bought the chip and kit separately, contact Alpes Lasers to ensure you have a suitable grating or to procure a new one.

freedom in y-axis position does not have any impact on the further alignment.

Prealign the grating angle. Inverting the Bragg equation for the Littrow configuration, we can express the grating angle  $\theta_G$  as

$$\theta_G = \arcsin[\lambda/(2d)],$$

where  $\lambda$  is the wavelength of the laser in microns,  $d = 10^3/N$  is the period of the grating in microns, and  $N$  is the number of grooves per mm. The angle of the rotation stage  $\theta$  is then given as

$$\theta = 200 - \theta_G.$$

Where the value 200 comes from the approximate maximum angle of  $200^\circ$  between the grating and the beam in the kit.

Place the detector facing the front lens. Align the goniometer stage appropriately and find the signal. Optimize the rotation stage angle in order to maximize the signal.

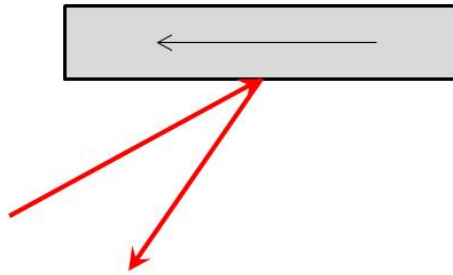


Figure 7.21.: Schematics of orientation of the grating in the setup. the laser beam is shown schematically by the red arrows.

## 7.5. Technical specifications

The CAD drawing of the system enclosure is shown in Fig. 7.22, including the output port positioning. The internal element are identified in the exploded view of Fig. 7.23.

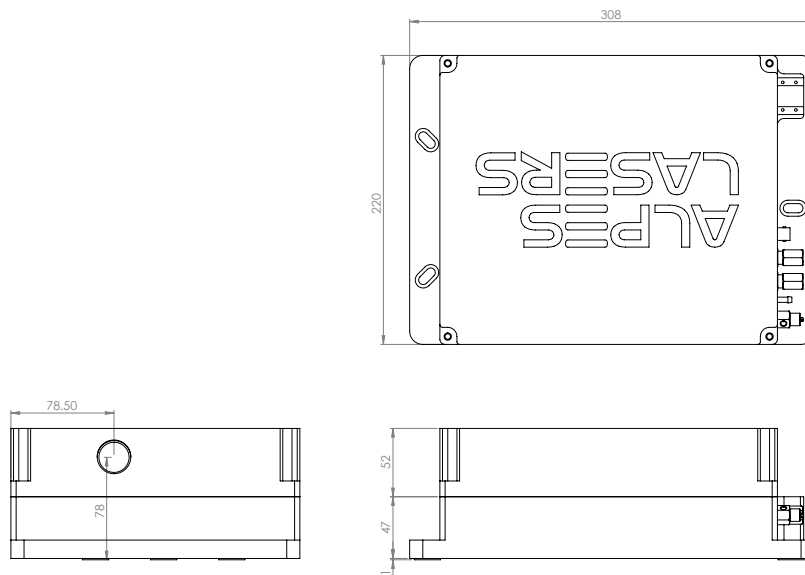


Figure 7.22.: Alpes Lasers External Cavity Laser Kit - closed view.

- (1) Enclosure base and (2) lid (same outer dimensions and compatible with Thorlabs TLK-E),
- (3) Base Module (same outer dimensions and compatible with Thorlabs TLK-BM),
- (4) Laser Module,
- (5) Drive Electronics (Alpes Lasers S-2 pulsed QCL driver),
- (6) Grating Module.

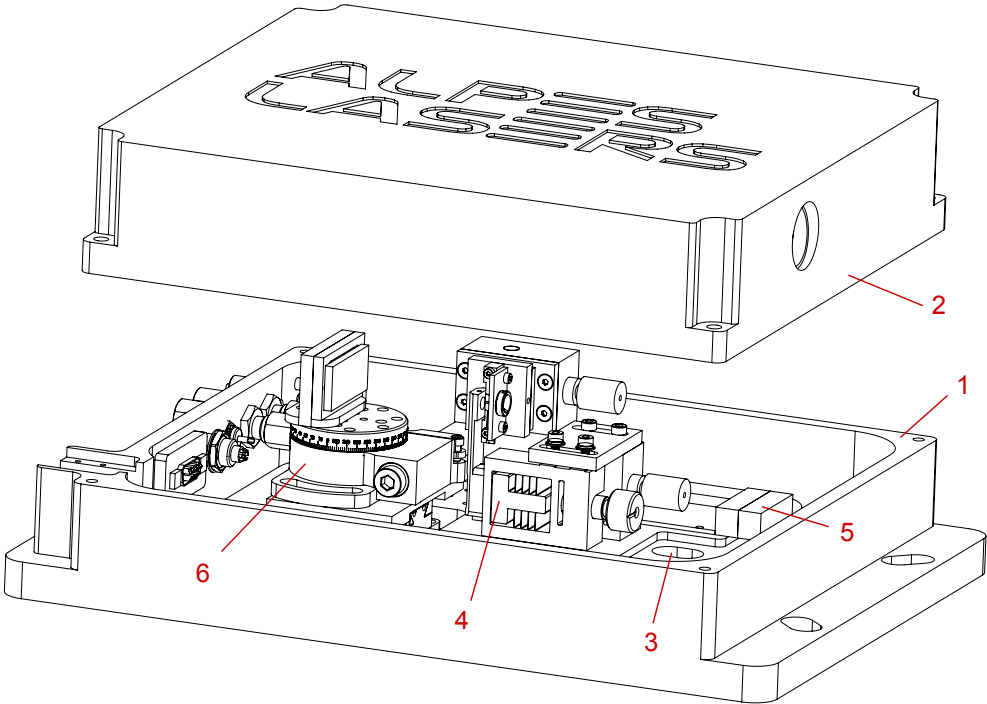


Figure 7.23.: Alpes Lasers External Cavity Laser Kit - open view.

## Laser module

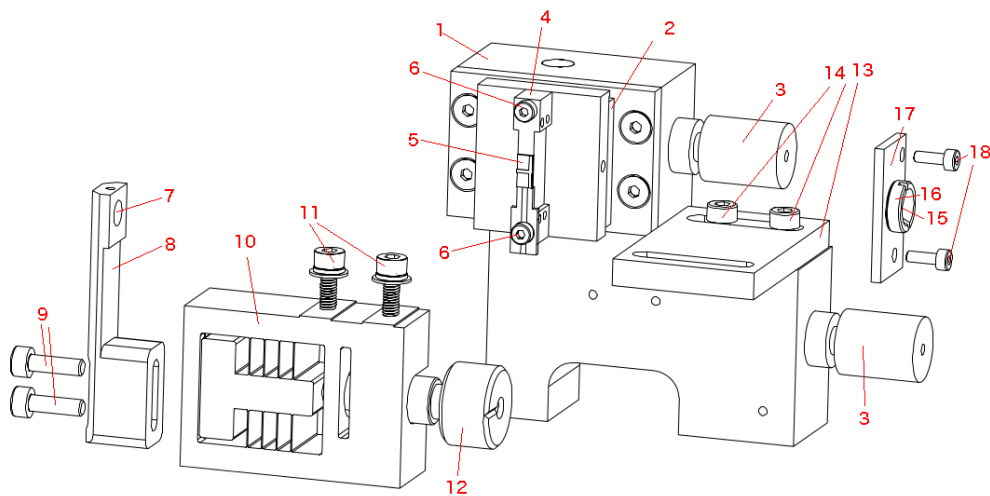


Figure 7.24.: Laser module.

- (1) Laser heatsink assembly,
- (2) Thermoelectric cooler,
- (3) Sockets for water cooling,
- (4) Laser carrier attached by its (6) screws,
- (5) Laser submount,
- (7) Back aspheric collimating lens in (8) a holder and (9) its screws  
(Thorlabs 390037; EFL = 1.873 mm, WD = 0.723 mm),
- (10) Focus adjuster and its (11) screws and (12) adjusting knob  
(Thorlabs TLK-FM1; moving dist. 0.3 mm),
- (13) Contact plate and its (14) screws,
- (15) Front aspheric collimating lens (Thorlabs C037TME; EFL = 1.863 mm, WD = 0.34 mm),
- (16) Thread mount,
- (17) Front lens holder attached by its (18) screws,
- (19) Temperature sensor socket.

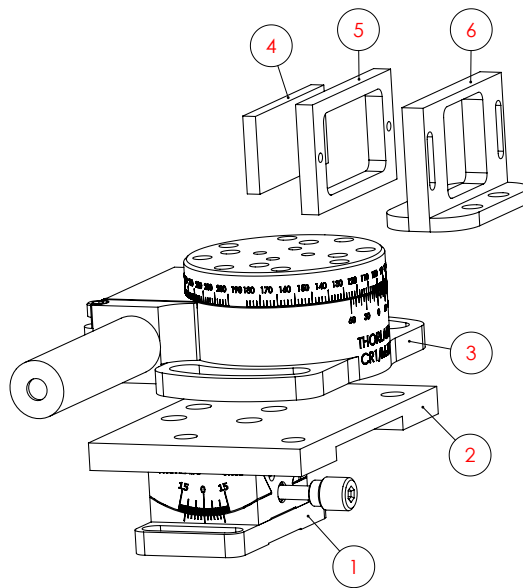


Figure 7.25.: Grating module.

### Grating module

- (1) Goniometer (Thorlabs GN05/M),
- (2) Adapter plate,
- (3) Motorized continuous rotation stage with motor controller (Xeryon XRT-U 30),
- (4) Blazed diffraction grating attached to its (5) frame,
- (6) Grating holder.

# A. QCL theory and application notes

## A.1. QCL wavelength range

Unlike standard bipolar semiconductor lasers (e.g.  $1.55\mu\text{m}$  telecom devices), for which the emission wavelength is closely related to the band gap energy, the QCL transition consists in the transition of an electron inside sub-bands, from one upper quantum well level to a lower quantum well level.

A series of potential wells and barriers for the electrons are built by using two different semiconductor materials (InGaAs and AlInAs). These wells and barriers are so thin that the electrons are allowed only a discrete set of energy levels, similar to the orbitals of an atom. The positions of the allowed energy levels are determined by the thicknesses of the wells and barrier. This makes it possible to define a wide range of laser transitions by using only one material system (InGaAs/AlInAs grown on InP). This range is limited by the intrinsic absorption of the material and the potential difference between the wells and barriers.

All QCLs are created using the same materials, but with layers of specific thicknesses and compositions to obtain a given emission wavelength. The wavelength is determined by the geometry of the semiconductor layers that make up the laser crystal.

## A.2. QCL electrical response

The QCL can be modeled with a combination of one resistor and two capacitors. R1 increases from a higher resistance at low biases to 1-4 Ohms at the operating point. The resistance at low bias varies from 10-20  $\Omega$  to  $10^2$  k $\Omega$  for 10  $\mu\text{m}$  and 4  $\mu\text{m}$  wavelength QCLs respectively. C1 is a 100 pF capacitor (essentially bias independent) between the cathode and the anode comes from the bonding pads. C2 depends on the laser mounting; typically, C1 < 100 pF in the LLH.

As an example, the values given below apply for a 10  $\mu\text{m}$  laser wavelength. *Note:* Voltage and resistor values may vary according to the type of laser.

R1 : ..... 10 to 20  $\Omega$  when a voltage of less than 4 to 6 Volts is applied

R1 : ..... 1 to 4  $\Omega$  up to 10 - 12 Volts

R1 : ..... 10 to 20  $\Omega$  over 12 Volts, after which the laser no longer operates

C1 : ..... 100pF, capacitor between the anode and the cathode

C2 : ..... <100pF, depending on your mounting of the laser

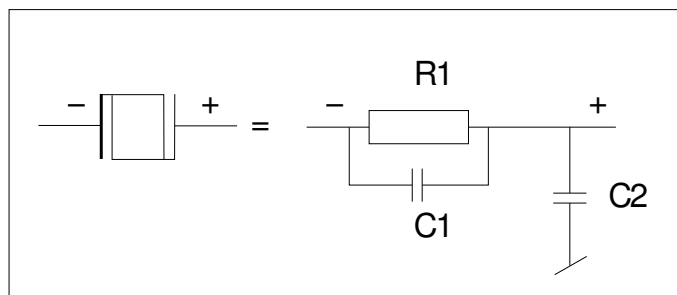


Figure A.1.: Electrical model for QCL.

## B. Operations for advanced users

In this section, tips for advanced users are provided for specific application. It is not recommended to perform these procedures under normal operation conditions.

**IMPORTANT:**

The operation instructions contained in this section must be performed by expert users only, as permanent damage to the laser may occur if not manipulated correctly.

### B.1. Direct QCL voltage

The LLH housing includes two LEMO connectors which are not used in the standard configuration. These connections give direct access to the voltage of the laser. This direct measurement is not necessary to get the correct optical output and is not typically performed outside of the factory.

**IMPORTANT:**

Direct voltage measurement of the QCL must be performed by experts only and agreed upon with ALPES LASERS.

The "L" connection connects the AC coupled to the cathode of the laser through a divider by ten. The end of cable must be  $50\Omega$  terminated for accurate measurement. The "B" is connected the same to the anode of the laser (Base Receptacle).

By using the math trace of an oscilloscope showing the "L" channel minus the "B", one can get the voltage on the laser. This measurement is more accurate than the information obtained from the LDD or S-2.

*Note:* the cables are not included in the Starter Kit but can be supplied by ALPES LASERS.

## B.2. CW modulation

This section gives some advice and rule of thumbs if you need to design your own electrical circuit to drive a CW laser.

To operate a laser in CW mode, an AC signal is added to the DC current. It is recommended to modulate the external power supply directly, within the parameter range specified in the ALPES LASERS datasheet. If this is not possible, an additional modulated source must be used, like a waveform (ramp) generator for example.

### Interface circuit

To reduce cross-talk with other system components and to improve mechanical stability, this interface circuit should be installed into a small metal box with only the connectors accessible. Do so as shown in figure B.1.

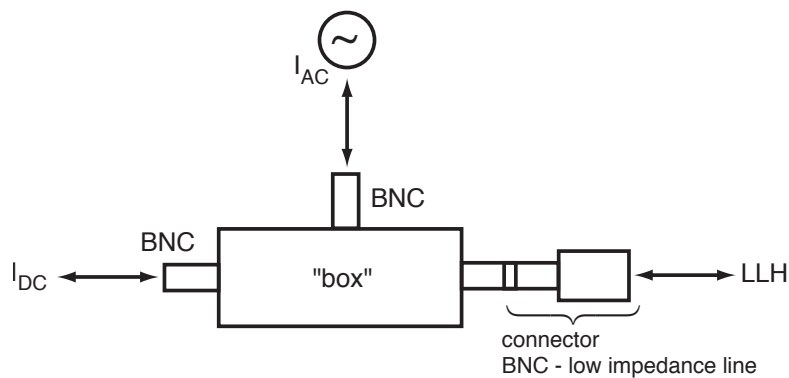


Figure B.1.: Interface circuit for CW laser modulation.

Connectors for the LLH with a BNC plug are available for CW laser operation, ALPES LASERS provides the C-LDX-LLH cable pinout, the adaptor must be made by the user. It is center positive, shield negative, and can directly be connected to a stabilized DC supply. Make sure the polarity is correct and limits as specified in the datasheet are set.

### B.2.1. External power supply protection

To prevent the current modulating and going back to the external power supply, an RLC circuit needs to be added (see figure B.2). The values of  $R_{AC}$ ,  $L$ ,  $C$  depend on the modulation frequency, the AC source and (to some extent) on the QCL.

#### Rule of thumb for L

As the impedance  $X_L = 2\pi fL$  of the inductivity should be much higher than the dynamic resistance  $X_Q$  of the laser to block the AC component from the DC supply,

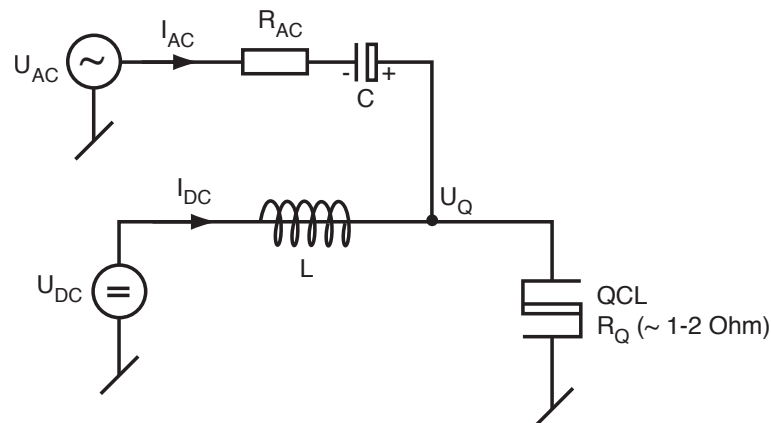


Figure B.2.: RLC circuit for external power supply protection.

applying  $X_L > 100X_Q$  leads to roughly  $L > 16X_Q/f$ .

In general,  $X_Q$  is of the order of 1..2  $\Omega$ . For a modulation frequency of 10kHz,  $L$  should therefore be of the order of 3mH or larger.

### rules of thumb for R and C

To prevent the AC source from dominating or reverse biasing the current through the QCL,  $U_{AC} < U_Q$  must always be given (in absolute values). Furthermore, as the AC voltage source together with  $R_{AC}$ ,  $C$  is forming a current source, to prevent variations of QCL dynamic resistance  $X_Q$  to influence the AC current,  $R_{AC} + X_C \gg X_Q$  must be guaranteed. As the generator for  $U_{AC}$  will have an impedance  $Z_{AC}$ , impedance matching demands for  $R_{AC} + X_C + X_Q = Z_{AC}$ . Putting these constraints together leads to  $I_{AC} < U_Q/Z_{AC}$ .

For the capacitor  $C$  to let pass the AC current,  $2\pi R_{AC}C > 1/f$  must be true, and with  $X_C = R_{AC}/100$  or smaller to make sure that the impedance of the AC current source does not vary too much with frequency, it follows that roughly  $C > 8/Z_{AC}/f$ .

For a 50  $\Omega$  generator at 10kHz,  $C$  should therefore be of the order of 16uF or larger.

Please keep in mind that such high capacity components may have a remarkably high inductivity, so it may be useful to put a second capacitor of small value (some nF, Tantalum or similar non-polarized type) in parallel to the one calculated before.

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## C. Cryogenic operation of QCLs

Alpes Lasers can deliver lasers with cooling solutions that can reach cryogenic temperatures.

### C.1. LN2 Dewar

The **LN2 Dewar** is a modified Kadel dewar that serves as housing for a QCL. As it lacks a temperature control, it is typically used for lasers which do not tune appreciably with temperature, such as THz lasers or other Fabry-Perot lasers.



Figure C.1.: A LN2 dewar. The light output is seen on the left, the LBI connector on the right.

The LN2 Dewar is only available with the laser pre-assembled and no user servicing is available. The laser is installed on a cold finger in an empty enclosure.

The laser output is through a transparent window which can be of ZnSe or TPX depending on the wavelength. The light is uncollimated.

The laser is connected to a series of pins which is identical to the pins found on a LLH (see §5.3.1).

### **C.1.1. Usage**

To cool down the dewar, simply fill it with liquid nitrogen from its top. A filled dewar should last for up to 6 hours when not in use, and typically 3-4 hours when in use (the actual cold time will depend highly on the energy dissipation of the laser).

Connect the pulser or CW driver to the pins as if it was a LLH housing.

### **C.1.2. Maintenance**

The laser sits in a vacuum. Over the course of normal operation the housing is air-tight. In case of a leak, the dewar can be sent back to Alpes Lasers to be re-sealed.

## **C.2. Others**

Two other cryostats are offered by Alpes Lasers; a LN2/liquid helium cryostat and a Stirling cooler. The manuals for these devices is not yet available.