# Warranty

ppqSense S.r.l. guarantees its **QubeCL** system to be free of material and workmanship defects for one year from the date of the original shipment. This warranty is in lieu of all other guarantees expressed or implied, including any implied warranty of merchantability or fitness for any particular purpose. ppqSense S.r.l. shall not be liable for any special, incidental or consequential loss.

During the warranty period, ppqSense S.r.l. will repair or replace the unit or module, or issue credit, at our option, without charge. ppqSense's liability shall not in any case exceed the cost of correcting defects in the products as explained here., and this service is the sole remedy of the buyer.

This warranty does not apply to defects caused by abuse, accident, modifications, Acts of God, or the use of the product for which it was not intended. ppqSense S.r.l. shall not be liable for damages resulting from the use of the product, nor shall be responsible for any failure in the performance of other items to which the purchased product is connected or the operation of any system of the which the purchased product may be a part. The **QubeCL** system should not be used in the manner not specified by the manufacturer.

Information in this document is subject to change without notice.

# Table of contents

# Chapter 1: Introduction

This manual contains information for operating the modular QubeCL system. The QubeCL is a high-performance istrument that provides low-noise and high-ratings electric current and temperature control to drive optoelectronic devices. The QubeCL is particularly suited to drive state of the art semiconductor and Quantum Cascade (QCL) laser sources.

This chapter addresses pertinent safety issues and correct usage of this instrument, and defines all front panel connections, LED function indicators and its programmable control. Please carefully read this chapter before using the QubeCL. "Chapter 2: Getting started" on page 13 helps users to get started immediately using the QubeCL system to drive the optoelectronic device to be operated.

## Safety Considerations

The QubeCL is a versatile instrument that can be used in a variety of driving current and temperature conditions. However, the QubeCL is not intended for a fail-safe operation in hazardous environments or life-threatening situations. The user assumes full responsibility for correct and safe usage of the QubeCL in accordance with any applicable laws, codes and regulations, and standard pertaining to their specific application. ppqSense S.r.l. is not liable for any consequential damage due to misapplication or failure of the QubeCL system.

# Parts List

The QubeCL system is shipped in a package designed to provide excellent protection. The shipping box should be saved for future transportation or storage needs. Carefully remove and inspect the following items that are contained in the shipping box.

Modular QubeCL system including:

- **LH**: Laser Head module
- **TC**: Temperature Controller module
- **PLL**: Phase-lock module
- **CM10**: Current module 1 A
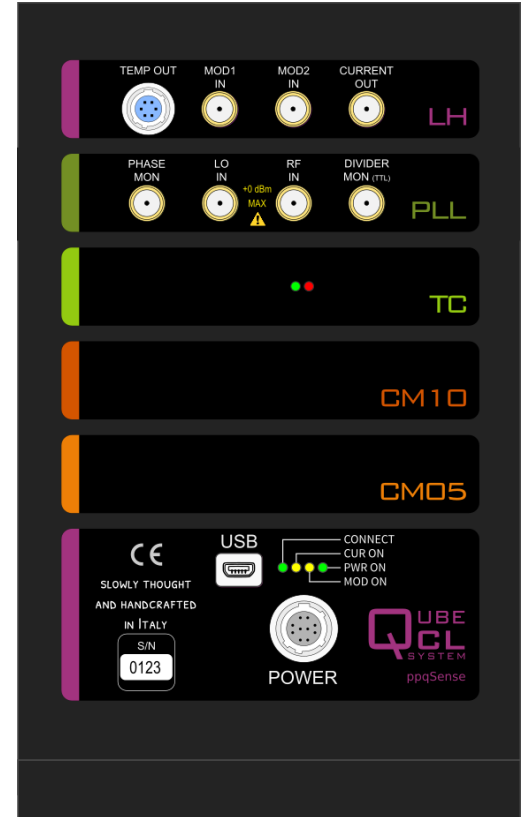- **CM05**: Current module 0.5 A



Power Supply Cable



TC Cable



USB Cable

# Electrical power supply

The QubeCL system must be powered by a **unipolar floating** DC power supply. A dual channel power supply or two different power supplies are necessary to drive independently CM and TC modules.

CM modules must be powered by a DC power supply providing at least 20V and 3A. A 24V and 3A power supply is recommended for a versatile usage and for a full compliance of the performances and dynamic range of the CM modules.

TC modules must be powered by a DC power supply providing at least 8V and 3A, but driving it with +12V and 3A is suggested for a versatile usage and to guarantee performances of the TC modules. As indicated in Table I, TC modules can be driven with higher DC voltage but this can lead to uncomfortable and dangerous temperatures of the QubeCl case.

The user must refer to Table I for minimum, typical and maximum voltages rates for LAS and TEC connections independently of any **floating** DC power supply configuration is used.

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 Caution: be sure to use a **FLOATING** DC power supply to electrically drive QubeCL system. The power supply terminals **must not be connected to ground**. Connecting any terminal to **ground** will **damage** the instrument 
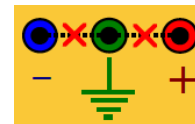
Table I: Electrical power supply DC voltage rates

| DC input | minimum | typical | maximum |
|----------|---------|---------|---------|
| LAS | +20V | +24V | +30V |
| TEC | +8V | +12V | +24V |

**Power Connector**

The QubeCL system provides a power supply cable with four connections: two for the Main Unit and the Current Modules (CM) and two for the Temperature Controller (TC). At the side of the connection to the QubeCL, the cable is ended with a 10 pin female connector as depicted in the figure. At the other end the cable is provided with four plug connectors:



| PS Las + | **Main Power Supply** |
| PS Las - | Suggested: **24V, 3A** |

| PS TEC + | **Temperature Controller** |
| PS TEC - | **Power Supply** Suggested: **12V, 3A** |

- two for CM power supply (green-labelled PS Las +, white-labelled PS Las –)
- two for TC power supply (red-labelled PS TEC +, yellow-labelled PS TEC –).
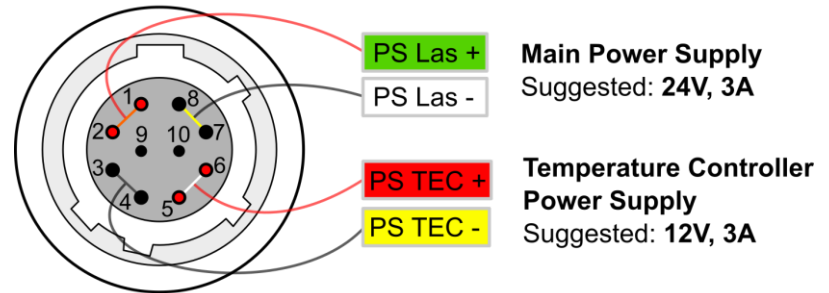
**TEC Connector (if present)**

If the QubeCL is equipped with the TEC module, a proper connection with the Peltier-based stage of the laser and with the NTC temperature sensor must be established. Please refer to the wires colors of the scheme on the right in order to properly connect the Peltier and the NTC to the provided TEC cable.

Inverting the connection to the TEC peltier + and – only affects the sign of the temperature stabilization settings (see pag. 19).

## TEC CONNECTOR


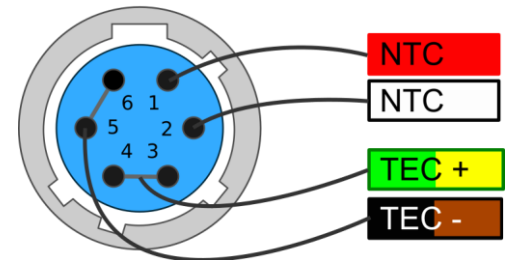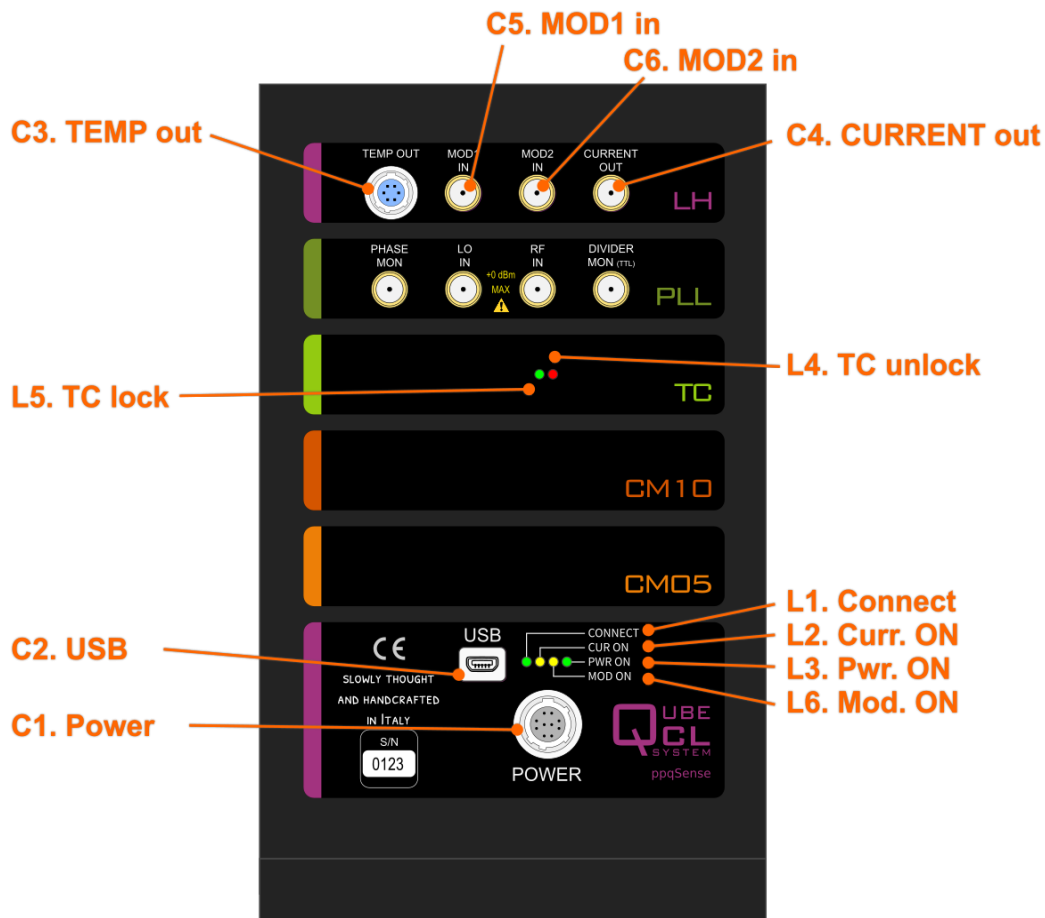
| NTC |
| NTC |

| TEC + |
| TEC - |

Figure 1: Front panel view: connections and LED indicators

# Front panel connections and LED function indicators

In Figure 1, the user can find a schematic view of the front panel with connectors and LED indicators.

**Connectors:**

C1. Power:   used to connect the supplied power cable to provide electrical power to the QubeCL system.

C2. USB:   used to connect the supplied USB cable for programmable control of the QubeCL system.

C3. TEMP out:   used to connect the supplied TC cable for the temperature control of the driven device. It provides NTC (10 kΩ) temperature sensor input and TEC output (2.7A maximum).

C4. CURRENT out:   Output SMA connector. Used to supply the low-noise driving current of the CM modules to the controlled device. A proper SMA cable must be provided by the user. The output provides a maximum current corresponding to the limits of the installed CM modules of the QubeCL (for example 1.5A for a QubeCL with one CM10 and one CM05 modules), with a maximum output voltage compliance of 18 V.

C5/C6. MOD1/2 in:   Input SMA connectors. Used to finely control the laser by adding to the C4 Current out a current component proportional to a controlling voltage: $Imod = Vin * G_{1,2}$ with $G_1=0.2$ mA/V and $G_2=1$ mA/V for MOD1 and MOD2, respectively. The accepted range for Vin is ±2.5V. The frequency bandwidth is $fc_{-3dB} = 2$MHz.

**LED function indicators:**

L1. Pwr. ON:    Green illuminated when the QubeCL main unit is powered on. Not illuminated otherwise.

L2. Curr. ON:    Yellow illuminated when the current of the CM modules is supplied from      C4 Current out connector. Not illuminated otherwise.

L3. Connect:    Green illuminated when the QubeCL main unit is connected to a computer USB port. Not illuminated otherwise.

L6. Mod. ON:    Yellow illuminated when the modulation signals are enabled by software. Not illuminated otherwise.

L4. TC unlock: Red illuminated when the temperature of the controlled device is unlocked from the temperature set-point value. Not illuminated otherwise.

L5. TC lock:    Green illuminated when the temperature of the controlled device is locked to the temperature set-point value. Not illuminated otherwise.

## QubeCL control software installation

The operation of the QubeCL system can be controlled by communicating with the internal microcontroller. The communication constists if a set of read/write commands sent to the microcontroller via Serial-USB protocol. In Table II at the end of this guide, a list of commands and their meaning is provided. The user can develop his/her own Serial communication software for sending the commands and control the QubeCL instrument.

Alternatively, ppqSense S.r.l. provides the "QubeCL_Control" software which is an intuitive graphical user interface for LabView Runtime Environment. In the following, the installation procedure and main features of this software are described.

### Installation

For installation on Windows OS, please follow these steps with the software provided in the USB key:

1. Run the library installation application to install the following needed libraries/drivers:
    ● Microcontroller USB-driver (CDM21228_Setup)
    ● LabVIEW 2014 Runtime Engine (LVRTE2014f2std)
    ● LabVIEW NI-VISA Utilities (NIVISA1600full)

2. Copy the directory "/QubeCL_CONTROL:vX.X" and its content to your computer.

# Chapter 2: Basic Operation: current and temperature controls

## Overview

This chapter explains the typical set-up and operation of the QubeCL system composed by a CM module (or a stack of several of them) and a TC module. The chapter should help less experienced users to rapidly adapt the QubeCL system to drive their specific optoelectronic devices. Keep in mind that not all the possible operations of the QubeCL system with a specific controlled device can be adequately addressed in this manual: these are general guidelines for operating a QubeCL system with specific illustrative examples. Adequate parameter values must be considered by the users when controlling their specific device.

The primary functions of the QubeCL system described in this manual are:

- to provide a very low-noise and high-level (up to 1.5A) DC current to drive the connected optoelectronic device
- to provide device temperature stabilization at a few mK level.

In particular, operating instructions are provided to drive and control a laser device.

## Set-up

The typical set-up for operation of the QubeCL system is composed by the used modules, the laser device to be controlled, a DC power supply, and a PC.

With his se-up, the correct operation is achieved by following these steps:

1. Set the voltage values of the **floating** DC power supply following the indications of the section *Electrical Power Supply* of chapter 1 of this manual.
2. Connect the provided power supply cable to the **floating** DC power supply instrument by using the plug connectors:

connect TEC+ and TEC- to the +/- poles of the power supply selected channel for electrical supply of the TC module, respectively.

connect LAS+ and LAS- to the +/- poles of the power supply selected channel for electrical supply of the CM module(s), respectively.

_____

Caution: be sure to **RESPECT THE POLARITY POSITIVE** of the power supply cable. **REVERSE** voltages will **damage** the instrument.

If the external power supplies are turned ON after the cable has been connected to the QubeCL, please **turn ON the TC BEFORE the CM**.

_____

3. Connect the provided power supply cable to the C1 connection of the main unit module of the QubeCL system
4. Connect the provided USB cable to the C2 connection of the main unit module of the QubeCL system and to a USB port of the PC computer

5. Select the Laser ouput polarity and grounding configuration (only with "opening lid" Option)

If the "Opening lid" Option is present, the polarity of the current output SMA connector can be selected:

Open the magnetic lid of the QubeCL.

Locate the red-highlighted jumpers on the laser-head board.

Select the polarity by changing the jumpers orientation according to the scheme at right.

Add/remove the green-highlighted jumper for setting the grounding of the SMA connector*.

**Close the lid** before powering on.

External Grounded
Central Negative

External not Grounded
Central Positive

Current Out SMA

6. If present, connect the provided TC cable, properly wired to the laser (see pag. 6), to the C3 connection of the LC module of the QubeCL system.
7. Connect the user provided laser device current cable to the SMA C4 connector of the LC module of the QubeCL system.
8. Optional: connect a modulation generator or control signals to one or two of the SMA C5-C6 connectors of the LC module of the QubeCL system.

Now the QubeCL is ready to be operated.

* When operating in "Central Positive" configuration, removing the grounding jumper ensure a safer operation, since preventing eventual external electrical noise to be coupled to the laser.
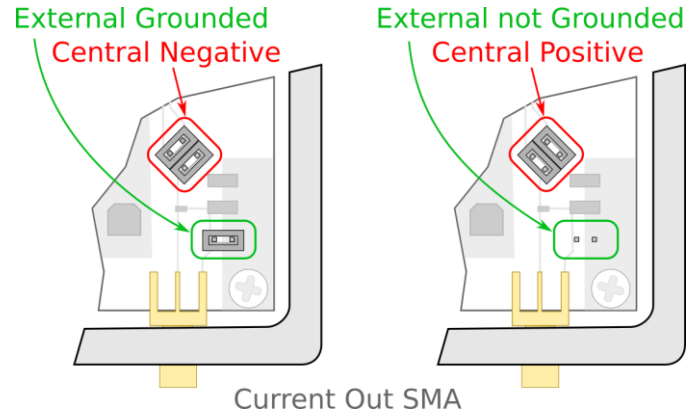
# Software control panel

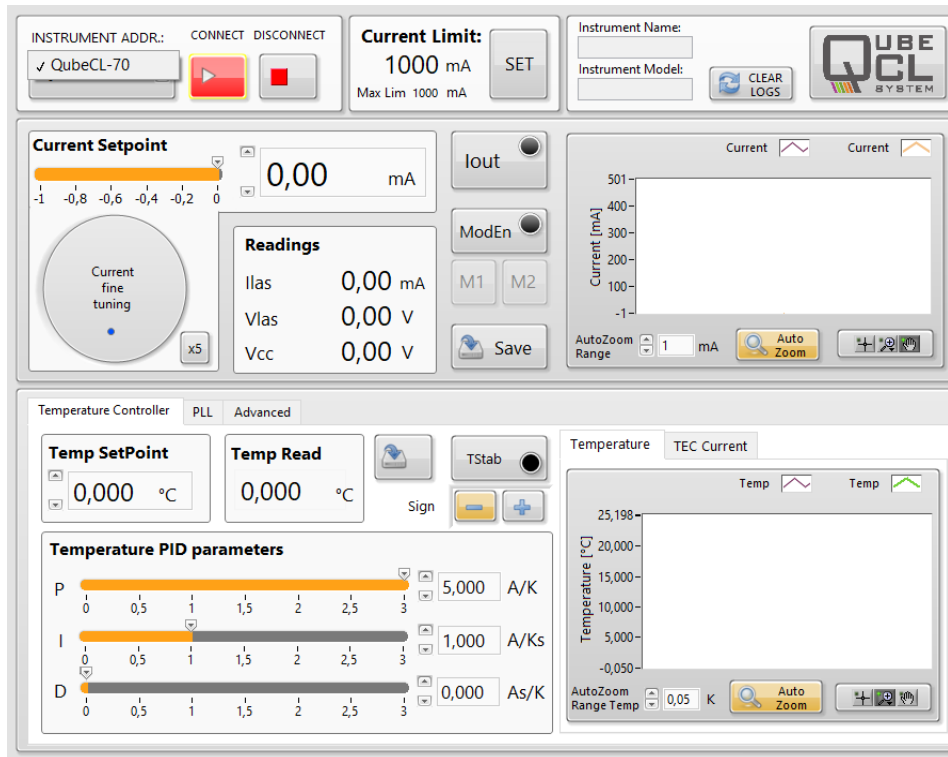In this section the control software of the QubeCL system is described in details.



*Figure 2:* Graphical view of the QubeCL control software: instrument selection

From the folder "QubeCL_CONTROL:vX.X" that you have copied into your computer (see Section "QubeCL control software installation") you can launch the executable program "QubeCL_Control_vX.X.exe". A graphical interface will appear, as shown in Figure 2.

It is organized in three horizontal panels:

1. *Configuration panel* at the top, where:
    • **INSTRUMENT** menu: selects the QubeCL system to control
    • **CONNECT** and **DISCONNECT** buttons: connects/disconnects to the selected QubeCL instrument and switches on/off the software control.
    • **CURRENT LIMIT** menu: sets the maximum current provided by the QubeCL at the Current output connector (C4)
    • **System configuration** menu: shows the modules configuration of the connected QubeCL instrument and allows to change it.


2. *Current driver panel* in the middle, where:
    • **Current setpoint**: three different controls are provided to set the operating BIAS current at the Current out connector (C4). First, a numerical value in mA can be set by direct typing; second, a horizontal slider increments or decrements the current setpoint in a coarse way; Third, the circular knob increments or decrements the current setpoint in fine way of 1mA/turn or 5mA/turn if the "x5" button is pressed.
    • **Iout** button: enables/disables the BIAS current output (C4).
    • **Mod En** button: enables/disables the possibility of adding to the bias current one ore more among the following signals: *Mod1 in* (C5) *Mod2 in* (C6), PLL correction.
    • **M1** and **M2** buttons: enable/disable the modulation input *Mod1 in* (C5) *Mod2 in* (C6), respectively. These switches are enabled by the main *Mod En* switch and, if ON, are automatically switched off if the *Mod En* switch is turned off.
    • **Save** button: permanently stores in the QubeCL memory the current setpoint value. The saved value is restored as default value every time the QubeCL is turned on.

- **Readings** window: shows the values of the output current (Ilas) and voltage (Vlas) as well as the supply voltage (Vcc)
- **Current** plot: shows the temporal behaviors of the set current (orange trace) and the output current (purple trace)

3. Temperature control panel at the bottom, where:
   - **Temp. SetPoint**: sets the operating temperature (in °C) of the laser.
   - **Temp. Read**: gives the value of the measured laser temperature in °C (i.e. NTC temperature)
   - **TStab** button: turn on/off the temperature stabilization loop.
   - **Loop sign +/-** buttons: set the proper sign sign of the TEC transducer for effective temperature stabilization
   - **Temperature PID parameters** window: sets the proportional (P), Integral (I) and Derivative (D) gain of the digital loop for the temperature stabilization. Horizontal sliders are used to independently increment or decrement the gains.
   - **Save** button: permanently stores in the QubeCL memory the following temperature control parameters: *setpoint*, *loop sign*, *PID digital gains* and *TStab* status. The saved values are restored as default values every time the QubeCL is turned on. In particular, if the Save button is pressed when the temperature stabilization is ON, the QubeCL will automatically start to stabilize the temperature when turned ON.
   - **Temperature** plot: shows temporal behaviors of the set temperature (green trace) and the read temperature (purple trace).

## Operation

Once the QubeCL is set-up according to the indications in Chapter 1, for a correct operation please follow the steps listed below:

1    Turn on the **floating** DC power supply instrument:
   ◦    LED L1 becomes lighting green
   ◦    LED L4 becomes lighting red. If the saved status of TStab button was "ON" and all the TEC parameters are correct, after a while the L4 led switches off and L5 led becomes lightning green, indicating that the laser temperature has already been stabilized.

---



Warning: At POWER supply switch on, the TC module is restored to the saved temperature control parameters, including the **TStab STATUS**

2    Turn on the PC:
   ◦    LED L3 becomes lighting green, indicating proper USB connection of the QubeCL to the PC computer
3    Run the QubeCL_control program:
   ◦    A Control Panel as the one shown in Figure 2 appears
   ◦    A search for the connected QubeCL instruments automatically starts: select one from the list of **INSTRUMENT** menu
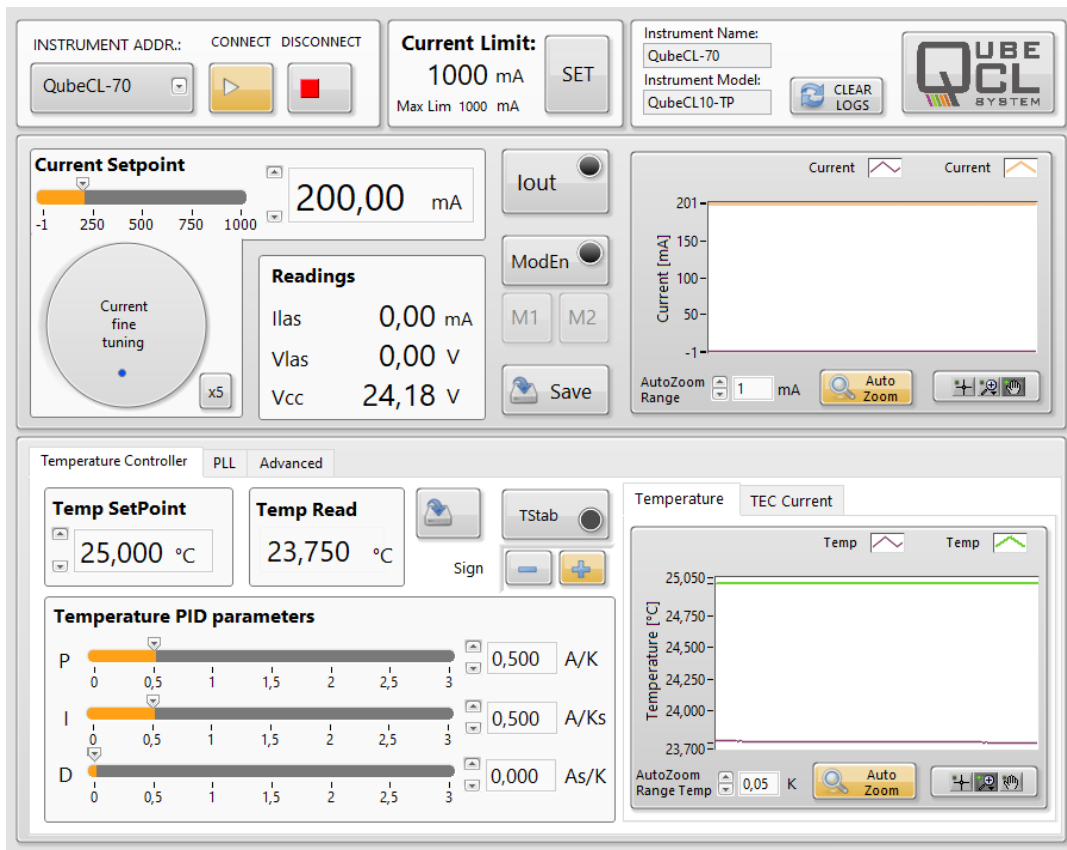   ◦    The **CONNECT** button blinks

*Figure 3:* Graphical view of the QubeCL control software: connected instrument

4  Press the blinking **CONNECT** button to start the remote control:

- ◦ The **CONNECT** button becomes orange
- ◦ A screen as the one shown in Figure 3 appears
- ◦ If it was not made before, use the *System Configuration* menu to set the correct modules configuration of the connected QubeCL INSTRUMENT. Use the *Current limit* menu to set the maximum current limit (default 1500 mA for a system with a CM10 and CM05 modules)
- ◦ The current set-point and temperature parameters stored in the QubeCL main module are read and shown in the screen as well as the power supply voltage for CM modules (Vcc), the laser device current (Ilas), voltage (Vlas) and temperature (Temp Read)
- ◦ The current and temperature graphs show the time behavior of the read parameters

At this point, laser device temperature, drive current and current modulation can be controlled by software, according to the following instructions:

***Temperature control operation*** (If present, refer to Figures 4 and 5)

1  Set the temperature at which the laser device must be stabilized: a numerical value with a precision of 0.01 °C is accepted in the Temp SetPoint window
2  Set I and D gains of the PID to the minimum, and P to a middle value
3  Switch the TStab button on:
- ◦ TStab button becomes orange and the L4 LED becomes red indicating that stabilization has not been reached yet
- ◦ If read temperature (purple trace on temperature graph) becomes to drift:
  - ▪ Towards Temp set point: correct Loop Sign ⯈ continue procedure at step 4.
  - ▪ Away from Temp set point: incorrect Loop Sign ⯈ change loop sign switch.

4   Increase I gain:
  ◦   Oscillation of the read temperature around set temperature must be observed as shown in temperature graph of Figure 4
  ◦   The red ligth on TStab button becomes green when the read temperature matches the set temperature within ±10mK. Similarly, on the TC module of the QubeCL, L4 LED turns off and L5 LED lights green according to the same criteria
5   Play with P and I gains in order to achieve a minimum number of oscillations before reaching a stable temperature as the one shown in Figure 5:
  ◦   The light on Tstab button and L5 LED's remain lighting green as indication of proper temperature stabilization
  ◦   The Temp Read and Temp SetPoint values are equal and purple and green traces in the temperature graph are coincident.

The PID parameters are expressed in their natural units: A/K for P, A/Ks for I and As/K for D.

_____

INFO: If the temperature control situation as, for example, the one shown in Figure 5 is saved in the main unit of the QubeCL system by using the save button in the program, the same situation is recovered in the successive POWER on switching of the QubeCL instrument. Otherwise the unsaved temperature parameters must be set again by following the above procedure
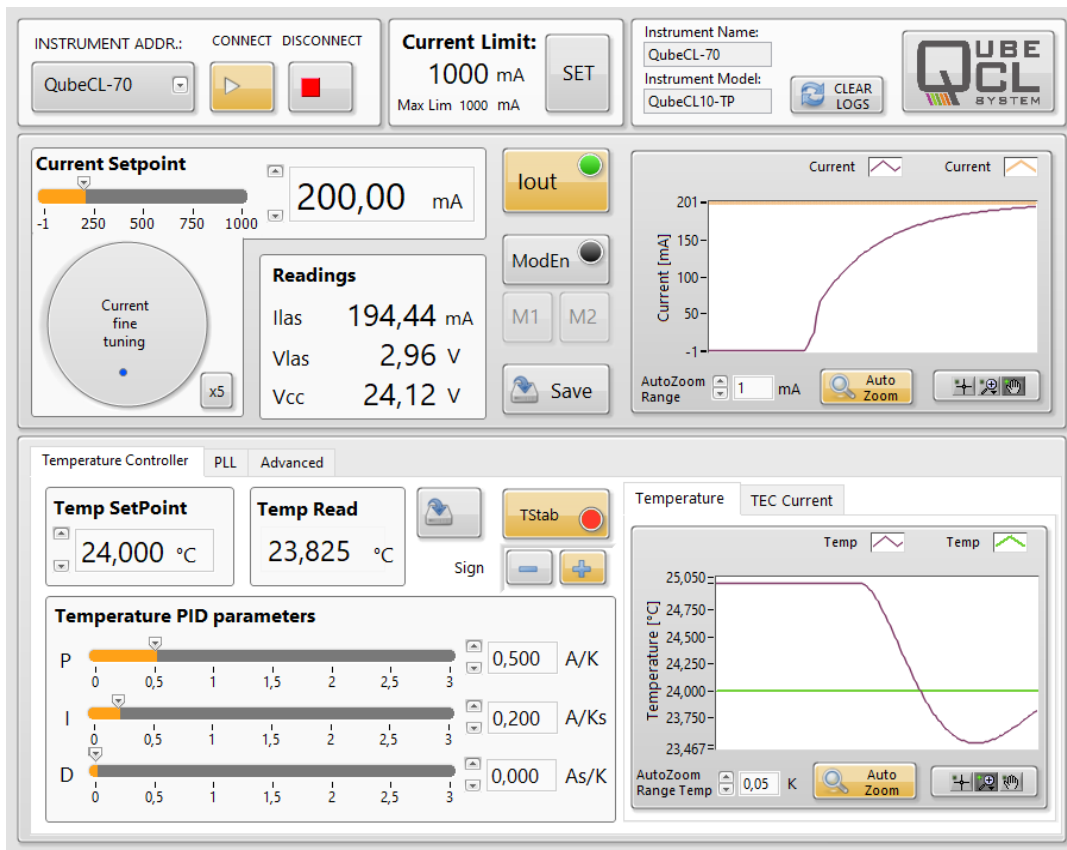
*Figure 4:* Graphical view of the QubeCL control software: Temperature and current control
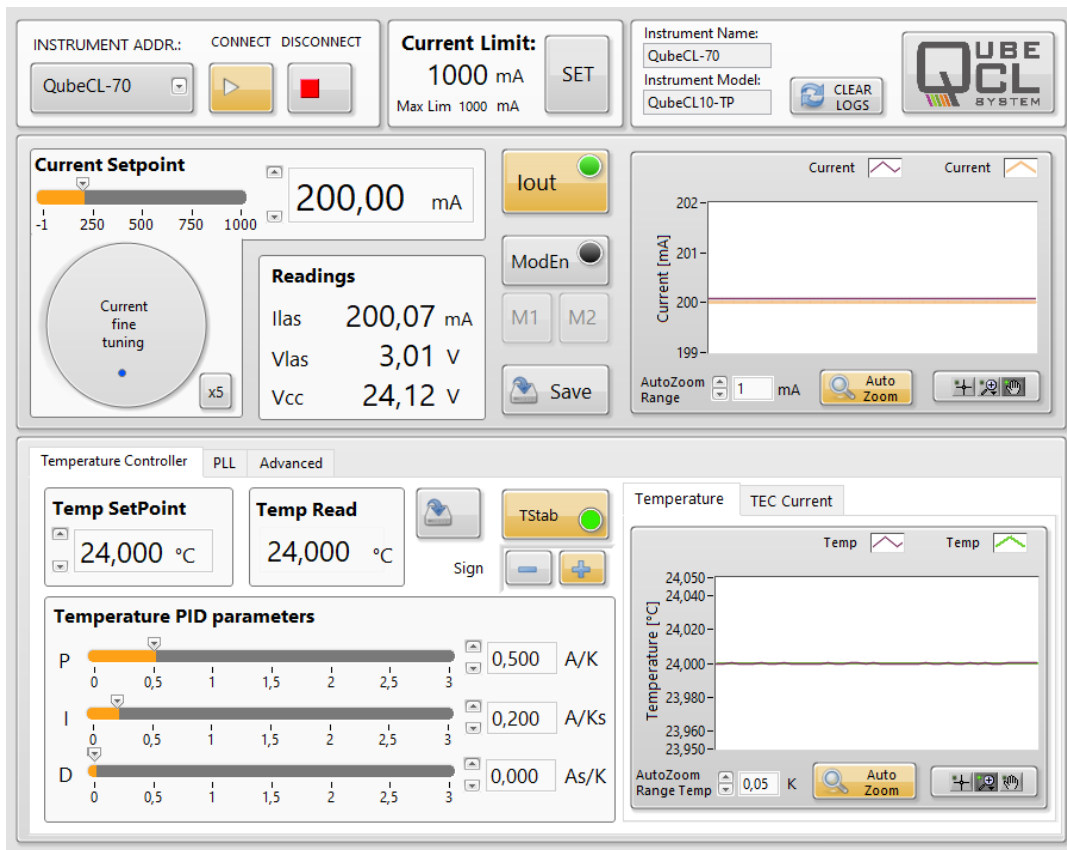
*Figure 5:* Graphical view of the QubeCL control software: Temperature and current control

Current control operation (Refer to Figures 4 and 5)

1. Set the Current Setpoint to the desired value: a numerical value in the Current SetPoint or an increment of the horizontal slider are accepted
2. Switch on the Iout button:
   - The Iout switch becomes orange and its light becomes green. Similarly, L2 LED in the QubeCL main module becomes lighting yellow
   - The current Ilas and Voltage Vlas of the laser device are shown in the Readings window and graphically in the Current/time graph.
3. If a current modulation is needed:
   - Apply a modulating voltage to the MOD1 in (C5) and/or MOD2 in (C6) inputs of the LC module (input signal range: ± 2.5 V; MOD1 gain: 0.2 mA/V; MOD2 gain: 1mA/V)
   - Turn on the general modulation switch by pressing the *MOD En* button.
   - Enable the specific input by pressing the *M1* and/or *M2* button.

---

INFO: MOD En, M1 and M2 buttons are disabled when Iout is OFF and in the first 10s after Iout is turned ON. If Iout it switched off, MOD En, M1 and M2 automatically switch off.

INFO: If the current control situation is, for example, the one shown in Figure 5 is saved in the main unit of the QubeCL system by using the save button in the program, the current set point is recovered in the successive POWER on switching of the QubeCL instrument.

**Automatic protections**

The QubeCL continuously monitors the voltage, current and temperature parameters in order to detect anomalous events and to prevent any damage to the laser.

Current Protections

***Open-circuit protection***: if the connection to the laser is lost during operation, the QubeCL automatically switches-off the current and grounds the current terminal. At the same time, a warning appears in the "Readings" panel of the software interface: a square warning box appears next to "Vlas" and blinks yellow/red until the Iout button is pressed again (see Figure at right).

| Readings | | |
|---|---|---|
| Ilas | | 0.00 V |
| Vlas | ! | 0.00 V |
| Vcc | | 24.11 V |

***Compliance limit***: The same warning described above occurs if the voltage drop across the laser reaches the compliance limit corresponding to the chosen supply voltage. The compliance limit (CL, Volts) is automatically calculated from $V_{cc}$ according to the following equation: CL = (Vcc * 0.77) − 1.

***Low supply voltage protection***: if the supply voltage (PS Las) gets below 18.5 V, the QubeCL automatically switches-off the current and grounds the current terminal. At the same time, a warning appears in the "Readings" panel of the software interface: a square warning box appears next to "Vcc" and blinks yellow/red until the Iout button is pressed again (see Figure at right).

| Readings | | |
|---|---|---|
| Ilas | | 0.00 mA |
| Vlas | | 0.00 V |
| Vcc | ! | 15.48 V |

Temperature Protections

***TEC module communication fault****:* if some problem occurs to the communication with the TEC module (i.e. when the module is not properly powered) the *Temp Read* value becomes -273 °C, and a square warning box appears next to it (see Figure at right). The warning disappears as soon as the communication with the TEC is re-established.

***Temperature sensor reading fault****:* if the temperature sensor is not properly detected (i.e. when the sensor is not connected) the *Temp Read* value becomes -63 °C, and a square warning box appears next to it (see Figure at right). The warning disappears as soon as the temperature sensor is properly detected.

If one of the above events occurs during temperature stabilization (*Tstab* button activated), the stabilization loop is automatically disabled, and an additional warning box appears next to *Temp Read*. In case the current output was enabled in the current section (*Iout* button activated), also the current output is automatically disabled.

***Temperature error active control****:* during temperature stabilization, if the *Temp Read* value can not be stabilized around the *Temp Setpoint* for any reason, the QubeCL enters in protection mode, the current output and temperature stabilization are disabled and a warning box appears next to *Temp Read.*

The threshold of the temperature error control can be set in the advanced section of the Control Software (see Chapter 4).
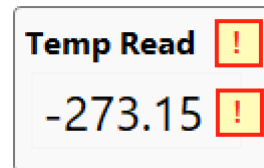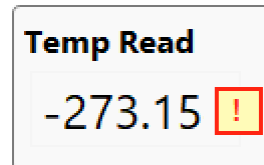
# Chapter 3: The PLL module

## PLL module overview

The PLL module gives to the QubeCL instrument the capability of easily perform a complex task such as the phase-lock of the controlled laser frequency to a reference source. The PLL module requires two input signals: the radio-frequency (RF) signal generated by the beatnote between the controlled laser and the reference laser and the signal from a Local Oscillator (LO) used for the stabilization of the RF signal. When the PLL is activated, a current proportional to the phase error signal is processed by a Proportional-Integral (PI) stage and internally added to the bias current in order to close the phase-stabilization loop.

For a proper operation both the RF and LO signals are processed by a frequency divider. The RF and LO frequencies can be divided by an integer value, in order to obtain two signal at a similar frequency at the input of the internal phase-detector. Each divider can be independently set by software, while the two divided signals can be monitored on the *DIVIDER MON* output (C9). When the loop is activated, the *PHASE mon* output (C10) provides a real-time replica of the phase-error signal after the PI stage.

### Module connectors



**C7. RF in**: signal level: -30 dBm – 0 dBm
bandwidth: 10 MHz – 300 MHz

**C8. LO in**: optimal level: 0 dBm (600 mVpp)
bandwidth: 10 MHz – 100 MHz

**C9. DIVIDER mon:** requires 50 Ohm load, AC coupled

**C10. PHASE mon:** requires High-Z load, range: -5 V – 0 V, DC coupled

# PLL software control panel
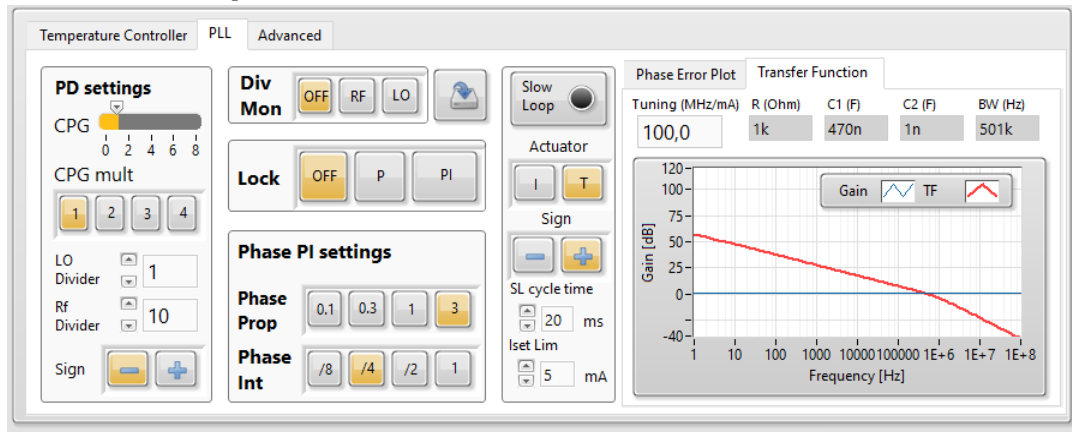


*Figure 6:* PLL panel in the QubeCL control software

The PLL panel can be selected by clicking on the "PLL" Tab in the bottom panel.

The PLL panel shows:

On the left, the settings of the Phase Detector, of the Divider Monitor and of the PI stage, and the control switches of the phase-lock loop.

On the right, two plots can be selected by a tab control: the plot of the total transfer function of the loop, that provides a visual help in properly setting the correct loop parameters, and the Phase Error plot, that shows the temporal evolution of the phase error signal.
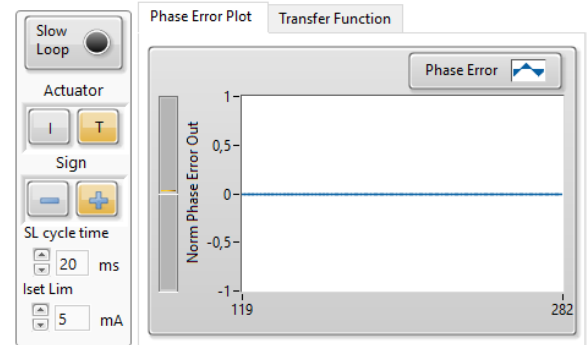
**Phase Detector settings:**

- CPG:  Sets the output gain of the Phase detector can be set in the range 1-8.
- CPG mult:    It is an additional multiplier for CP gain. Total CP gain = CPG x CPG mult.
- LO Divider:    Sets the integer division factor of the Local Oscillator frequency.
- RF Divider:    Sets the integer division factor of the RF Beatnote frequency.
- Sign:  Sets the sign of the phase-lock loop.

***Divider Monitor:***    Selects the signal to be output from the Divider MON connector (C9). The output LO and Rf signals are taken after the dividers, so that a change in the Divider controls can be directly monitored on these signals.

***Lock:*** 3-way switch that controls the phase-lock loop.

- OFF:    The phase-lock loop is off.
- P:    The phase-lock loop is enabled only with the proportional gain.
- PI:    The phase-lock loop is fully enabled (proportional and integral gains)

***Phase PI settings:***

- Phase Prop:    Sets the proportional gain of the PI stage
- Phase Int:    Sets the integral gain and of the PI stage and the high-frequency cut-off of the loop.

***Transfer Function plot:*** Automatically updates when any of the above parameters is changed, and shows the overall transfer function of the system. For a correct calculation the tuning range of the controlled laser has to be given in the "Laser Tuning" input box. A proper locking is achieved when the Transfer Function trace crosses the unity gain level with the smaller slope.

**Phase Error plot:** Shows the temporal evolution of the phase error. It is slowly updated but gives a long history of the phase error drift during locking. It includes also a control panel for the active compensation of slow drifts. (see pag. 28)

## PLL Operation

For a proper set-up and operation of the phase-lock loop, follow the steps listed below:

1. Check that the beatnote (RF) signal has a level between -30 and 0 dBm and a frequency between 0 and 300 MHz. Connect this signal to the **RF IN** (C7) connector.
2. Generate a Local Oscilllator signal with a level close to 0 dBm (600mV$_{pp}$) and a frequency between 10 and 100 MHz. Connect this signal to the **LO IN** (C8) connector.
3. Set the values of *LO divider* and *RF divider* to 1.
4. Connect the **DIVIDER MON** out (C9) to an oscilloscope (50 Ohm termination), act on the *Div Mon* switch to display the desired signal and check that it is properly counted. A good signal appears as a sharp and stable square wave at the frequency of the input signals. If this check fails, improve the level or the filtering of the signal that is not properly counted.
5. Set the values of *LO divider* and RF *divider* in order to have the counted signals at the same frequency. For example, if $f_{RF}$=100 MHz and $f_{LO}$=10 MHz, set *LO div* = 1 and *RF div*=10.
6. Put the correct value for the laser tuning coefficient in the *Laser Tuning* input box in the *Transfer Function plot* tab, and sets the values for *CPG, CPG mult, Phase Prop* and *Phase Int* in order to have the Transfer Function curve properly crosses the unity gain level.
7. Check that the phase detector is properly working on the *Phase Error Plot*: tune the current with the software knob in order to sweep the RF frequency across the LO frequency and check that the Phase error switches from positive values to negative ones (or vice-versa).
8. Tune the current in order to approach the lock position and enable the *Proportional Lock* loop (P button of the Lock multi-switch). If the RF signal frequency goes apart from the LO frequency change the *Loop Sign*. If the RF signal frequency sticks to the LO frequency the system is locking.
9. Enable the *PI Lock* (PI button of the Lock multi-switch).
10. Tune the *CPG*, *Phase Prop* and *Phase Int* settings in order to optimize the locking. Several locking positions can be found, with different bandwidths and gains.

# Automatic compensation of slow phase-error drifts

During the locking, a number of environmental factors (temperature, mechanical vibrations or strains, optical feedbacks, etc.) may often induce slow drifts of the locking point, that can be easily monitored by observing, in the **Phase Error Plot**, a slow drift the phase error. If the phase error reaches an edge of the capture range (level 1 or -1 in the Phase Error plot, corresponding to levels 5 V or 0 V of the PHASE MON signal, (C10)), the loop can not lock properly anymore.

The control software allows for automatically compensate the drifts by acting on current or on temperature. Such a *Slow Loop* can be enabled and configured from the menu to the right of the Phase Error plot.

**Slow Loop switch:** Enables/Disables the automatic compensation.

**Actuator:**    Selects the actuator to be used (Current/Temperature)

**Sign:** Sets the sign of the correction.

**SL cycle time:**    Sets the temporal rate of the correction in ms.

**Iset Limit:**   Sets the maximum variation allowed for the current with respect to the original Current Setpoint.

Operation

1. Set-up and activate the phase-lock loop (see Pag. 28)
2. Enable the automatic correction by pressing the **Slow Loop** button.
3. Look at the **Phase Error Plot:** if the Phase error progressively goes back to zero, the correction is working. If it diverges, then change the correction **Sign**
4. Change the **SL cycle time** in order to make the compensation faster or slower.
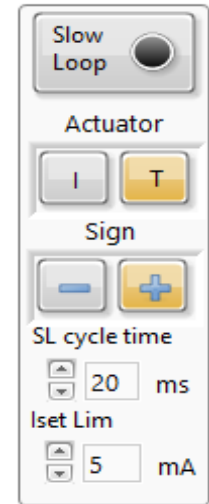
# Chapter 4: The PDH module

## PDH module overview

The PDH module gives to the QubeCL instrument the capability of easily perform a complex task such as the lock of the controlled laser frequency to an optical cavity.

The PDH module requires two input signals: the radio-frequency (SIGNAL IN) signal generated by the frequency-modulated laser beam reflected back from the cavity and the Local Oscillator (REF IN) signal used for demodulating RF signal. The LO is usually generated by the same function generator used for the frequency modulation, after a careful tuning of the relative phase.

When the PDH is activated, a current proportional to the error signal is processed by a Proportional-Integral (PI) stage and internally added to the bias current closing the frequency-stabilization loop.

## Module connectors
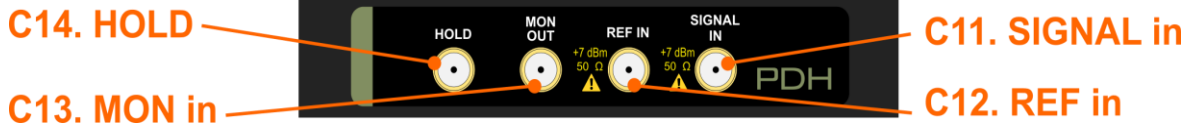


**C11.SIGNAL in**: signal level: -30 dBm - 20 dBm
Bandwidth: 300 kHz - 100 MHz

**C12.REF in**: signal level: 7dBmBandwidth:
300 kHz - 100 MHz

**C13.MON OUT**: requires High-Z load
Range: -5 V - 0 V, DC coupled*

**C14.HOLD**: signal level: TTL
Bandwidth 10 MHz

*the monitor signal is correctly provided only if the QubeCL is properly grounded. This can be obtained either by the ground hole on the right side of the case or by properly grounding the laser.

# PDH software control panel
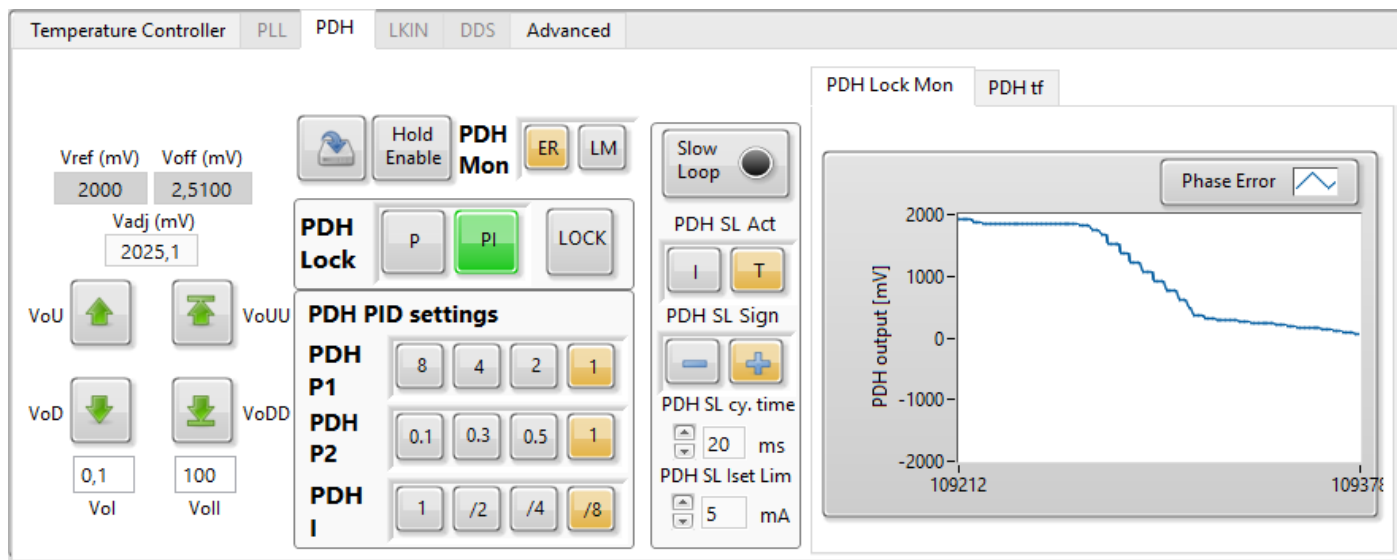


Figura 7: PDH panel in the QubeCL control software

The PDH panel can be selected by clicking on the "PDH" tab in the bottom panel.

The PDH panel shows:

On the left, the controls for adjusting the PI input offset voltage, the settings for the output monitor signal, the settings for the PI loop.

On the right, two plots can be selected by a tab control: the plot of the total transfer function of the loop, that provides a visual help in properly setting the correct loop parameters, and the PDH Lock Mon plot, that shows the temporal evolution of the PI loop output signal.

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***Input offset Adj.***: The four arrows allow to change the Vadj value, which modifies the PI loop input offset. An offset value equal to 0 corresponds to a Vadj value of 2000 mV. The Vadj variation steps produced by acting on the arrows can be modified by writing the desired step value into the two boxes. Vadj accepts values between 0 mV and 4000 mV.

***PDH Mon***: Selects the signal to be output from the MON OUT connector (C13). Error Signal (ER) is the signal produced by the mixer, with only some filtering, the same signal used to drive the PI loop. Lock Monitor (LM) is the PI loop output signal, used to correct the laser current.

***PDH Lock***: Switch to select the PI loop status:

- P: Activates only the proportional gain of the loop;
- PI: Activates both the proportional and integral action of the loop;

P and PI are mutually exclusive. The loop output signal is always visible on the monitor connector or on the display graph

- LOCK: enables the correction to be added to the laser current.

PDH PI settings:

- PDH P1: Sets the overall gain of the PI loop;
- PDH P2: Sets the proportional gain of the loop, also affecting the integrator corner frequency when the loop is in PI mode;
- PDH I: Sets the integral gain of the PI loop;

***Transfer Function plot***: Automatically updates when any of the above parameters is changed, and shows the overall transfer function of the system. For a correct calculation the tuning range of the controlled laser has to be given in the "Laser Tuning" input box. A proper locking is achieved when the Transfer Function trace crosses the unity gain level with the smaller slope.

**PDH Lock Mon plot**: Shows the temporal evolution of the PI loop output. It is slowly updated but gives a long history of the signal drift during locking. It also includes a control panel for the active compensation of slow drifts.

## PDH Operations

For a proper set-up and operation of the PDH module, follow the steps listed below:

1. Verify that the signal reflected from the cavity has a level between -40 dBm and 20 dBm, with a frequency between 300 kHz and 100 MHz. Connect this signal to the **SIGNAL in** (C11) connector.
2. Use a function generator to generate a proper demodulation signal, with 7 dBm magnitude and a frequency between 300 kHz and 100 MHz. Connect this signal to the **REF in** (C12) connector.
3. With LOCK and Hold Enable deactivated, compensate the PI input offset with the following method: put the PI loop in **PI mode**, P1 = 1, P2 = 1, I = /8; while monitoring the PI output signal, which should be saturated, use the Input offset Adj. to find a value for which the PI output inverts its saturation polarity; once found, gradually reduce the Adj step size, and with some successive approximation reach the value that keeps the PI loop output as stable as possible, away from the saturation levels.
4. Activate the modulation signal to the laser, monitoring the **ER** signal you'll be able to find the characteristic PDH signal. Adjust the modulation signal phase until you find the value that minimizes the carrier contribution to the signal, leaving only the sidebands contributions. At that point, the right phase to obtain a good lock is that value ±90°. Try one of those two values and **LOCK** the loop in **P** mode, if only the sidebands contributions are magnified try the other phase value, otherwise this is the right one.
5. While locked and in **P** mode, try the **P1** and **P2** values until you find the combination that produces the best effects on the signal transmitted by the cavity. Reduce the amplitude of the ramp signal used to scan the laser's frequency searching for the one that matches the cavity while adjusting its offset to keep the laser's frequency close to the resonance.
6. Activate the **PI mode** and search for the best PI parameters combination, which guarantees the best locking performance.

## Automatic compensation of slow phase-error drifts

During the locking, a number of environmental factors (temperature, mechanical vibrations or strains, optical feedbacks, etc.), or even some voluntary modification of the system (cavity length variation, etc.) may often induce slow drifts of the locking point, that can be easily monitored by observing, in the PDH Lock Mon Plot, a slow drift of the locking signal. If the locking signal reaches an edge of the capture range (+2 V or -2 V), the loop can not properly lock anymore.

The control software allows for automatic compensation of the drifts by acting on laser current or on laser temperature. Such a Slow Loop can be enabled and configured from the menu to the left of the PDH Lock Mon plot. This function is analogous to the one previously presented for the PLL module, so you can refer to that section (pag. 31) for more details.

# Chapter 5: The Lock-In Amplifier module

## LIA module overview

The LIA module gives the QubeCL instrument the capability of performing lock of the controlled laser frequency to the first or second derivative of a molecular absorption line profile.

The LIA module requires two input signals: one square demodulating signal for the LIA, and the signal from the detector used to retrieve the absorption signal from the reference molecular sample. The reference signal must be synchronous with the modulating signal used to perform the LIA operation, hence the two are usually generated with the same function generator.

The modulation-demodulation action performed by a QubeCL equipped with a LIA module allows the instrument to obtain a signal proportional to the first or second derivative of the absorption line signal retrieved by the detector. The error signal is processed by an internal Proportional-Integral (PI) stage in order to obtain a correction current which can be directly fed to the laser in addition to its bias current, closing the frequency-locking loop over the reference absorption line.

## Module connectors
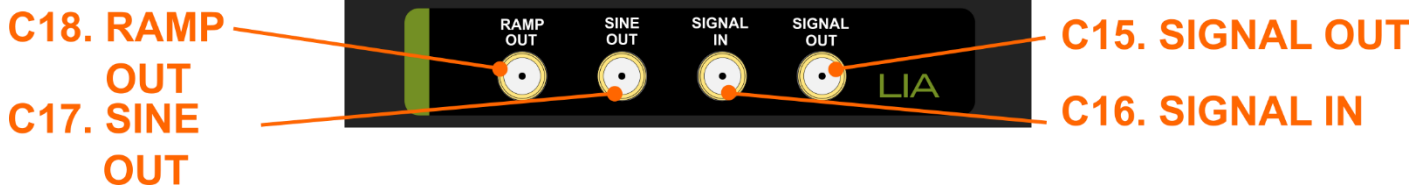


**C15.SIGNAL out**: Monitor signal, < 2 Vpp     **C17.SINE OUT**:  sine modulating signal monitor

**C16.SIGNAL in**:   Signal level: < 10 mV     **C18.RAMP OUT**: ramp modulating signal monitor*

*Ramp out must be used as demodulating signal input connector when the QubeCL is not equipped with a DDS module.

# LIA software control panel
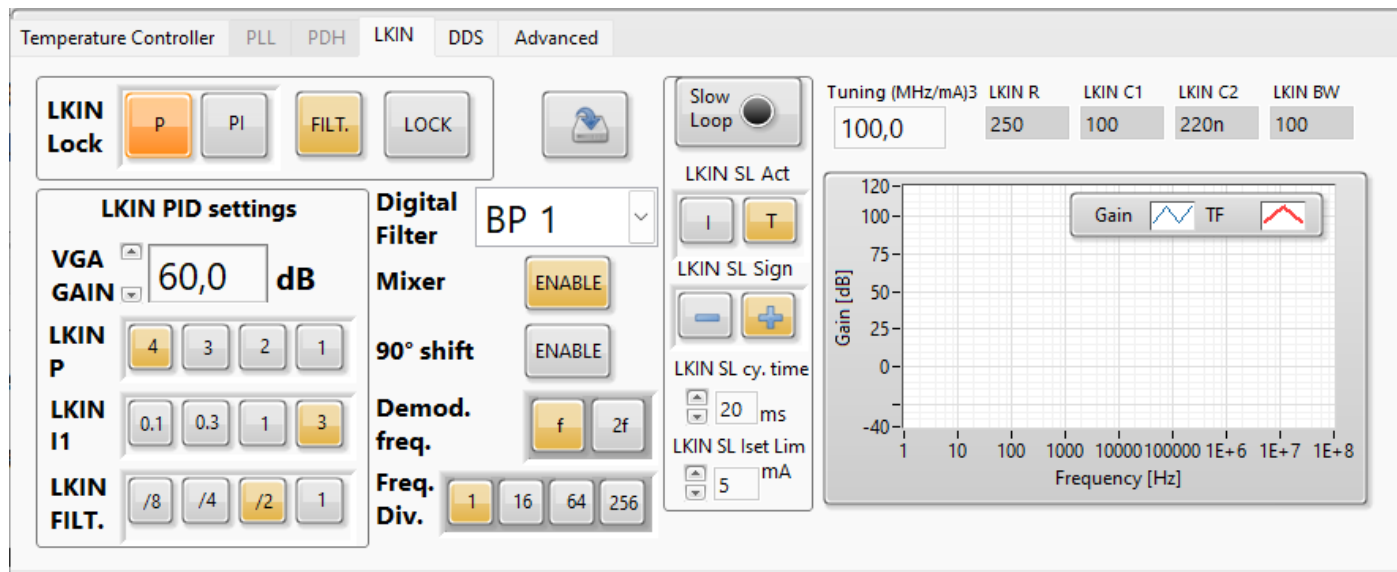


The LIA control panel can be selected by clicking on the "LKIN" tab on the bottom half of the GUI.

On the left part of the LIA panel, the controls for adjusting the PI loop parameters can be found, along with the commands to define the active functionality of the loop. The central portion of the panel houses the controls specific for the Lock-In Amplifier. On the rightmost section there is a plot showing the transfer function of the feedback-loop.

**LKIN Lock**: this control allows the user to choose the functional mode of the PI feedback loop:

- P: sets the loop to work in a pure Proportional mode;
- PI: sets the loop to work in a Proportional-Integrative mode.

**FILT.**: This button enables a Low Pass Filtering stage built in with the PI feedback loop. The cut frequency of the filter can be chosen with the LKIN FILT. selector.

**LOCK**: This button activates the correction action of the LIA module, injecting the correction current to the laser (if the overall MOD. EN. is active).

**VGA GAIN**: This control allows the user to choose the amplifying factor of the LIA pre-amplifier. It ranges from 0 to 80 dB.

**LKIN P**: This control allows the user to choose the magnitude of the Proportional action of the PI feedback loop. Four values are available.

**LKIN I**: This control allows the user to choose the time constant of the Integral action of the PI feedback loop. Four values are available. This control has any effect only when the PI mode is activated.

**LKIN FILT.**: This control allows the user to choose the corner frequency of the Low Pass filter that can be activated with the FILT. button.

**SAVE BUTTON**: When pressed, the button with the Save icon saves the LIA module configuration in the QubeCL EEPROM, so that this configuration will be recalled at next power-up of the device.

**Digital Filter**: The LIA has a built in digital filter for which more information can be retrieved below. This control allows the user to choose the desired behavior for the filter.

**Mixer**: This button activates the internal mixer of the LIA, enabling its functionality.

**90° shift**: This button activates the internal 90° shift applied to the demodulating signal of the LIA. Once the worst condition for the reciprocal phase of the modulating and demodulating signals is found, this command can be used to immediately find the optimal condition.

**Demod. Freq**: This button allows the user to choose the demodulating frequency of the LIA. The demodulating frequency can assume only two values: 16384 Hz and 32768 Hz.

**Freq. Div.**: This control defines the divisor factor applied to the demodulating signal fed to the LIA. The optimal functionality can be obtained with a demodulating signal with a frequency of 1024 kHz and a divisor factor of 1.

## LIA operations

For a proper set-up and operation of the PDH module, follow the steps listed below:

1. Verify that the signal produced by the detector has a magnitude lower than 10 mVpp, connect this signal to the SIGNAL IN connector of the LIA module.
2. The modulation signal for the laser must be generated with the onboard DDS module. It must be generated by the DDS module because the same module is deputed to the generation of the demodulating signal, and the two signals have to be perfectly synchronous. The modulating frequency must be 32.768 kHz. Instructions on the use of the DDS module may be found in the dedicated chapter of this manual.
3. Connect the SIGNAL OUT connector to an oscilloscope in order to have a monitor signal to be used as a reference during the locking operation. The oscilloscope must have a high impedance input ( $\geq 1$ MHΩ).
4. On the DDS panel, activate the INT. SYNC. button, in order to switch on the demodulating signal produced by the DDS module. Then enable the Mixer button to make the LIA start demodulating. Pay attention to set Freq. Div. at 1.
5. Chose the desired Digital Filter and demodulating frequency.
6. By adjusting the modulating signal phase, search for the worst condition (lowest signal on the monitor). Once achieved, change the modulating frequency phase by 90° to obtain the optimum phase condition.
7. Adjust the PID settings to obtain the laser locking.

# Digital filters

The LIA module is equipped with a mixed signal Lock-In Amplifier which includes a variety of built-in digital filters. The digital filters show a frequency behavior which is dependent on the clock frequency used to drive the filter. In the LIA module, the clock signal used for the digital filter is generated by the DDS daughter board (described below) and has a fixed frequency which is:

$$f_{CLK} = 2^{20} = 1.048576 \, MHz$$

The clock signal pass through a series of frequency divider before reaching the programmable digital filter. The division factor has a fixed component which is set to be 8, and a variable component, which is controllable by the GUI with the command Freq. Div. By changing this parameter, the entire frequency behavior of the LIA module changes, hence we recommend to leave it at the standard position of 1. If so, the clock frequency for the digital filter is:

$$f_{SO} = 2^{17} = 131.072 \, kHz$$

The available filters, selectable by the mean of the dedicated scroll-down menu, are the following:

- BP0: Band Pass filter, centered on $\frac{f_{SO}}{8} = 16.384 \, kHz$
- BP1: Band Pass filter, centered on $\frac{f_{SO}}{4} = 32.768 \, kHz$, 2nd order, Q=8.4
- BP2: Band Pass filter, centered on $\frac{f_{SO}}{4} = 32.768 \, kHz$, 2nd order, Q=4.3
- LP1: Low Pass filter, corner frequency $\frac{f_{SO}}{5} = 26.2144 \, kHz$, 4th order
- LP2: Low Pass filter, corner frequency $\frac{f_{SO}}{8} = 16.384 \, kHz$, 4th order
- Notch: centered on $\frac{f_{SO}}{4} = 32.768 \, kHz$, 1st order
- All pass

# Chapter 6: The DDS daughter board

## DDS daughter board overview

The DDS daughter board enables the QubeCL instrument to generate its own modulation signals. The on-board generated signals are arbitrary, being controllable both in amplitude, frequency and phase by the mean of an easy user interface integrated in the QubeCL GUI.

Moreover, the DDS board is built to interact with the locking modules, sourcing both modulating and demodulating signals, in order to make the QubeCL capable of performing locking operations without the need of any other external equipment.

## Module connectors
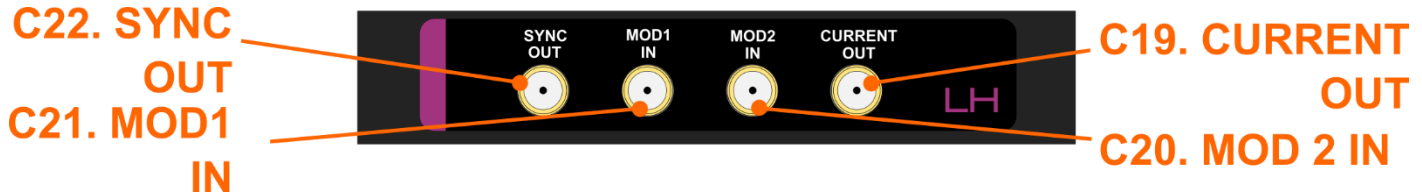


**C19.CURRENT out**: Current output of the QubeCL system

**C20.MOD 2 in**: High-gain modulation input Rin = 5 kΩ

**C21.MOD 1 in**: Low-gain modulation input Rin = 5 kΩ

**C22.SYNC out**: Sync signal output, TTL

The presence of the DDS board inside the LH module leaves it mostly unaltered, save the addition of a fourth output connector from which the synchronization signal produced by the DDS can be retrieved.

## DDS software control panel



The DDS control panel can be accessed by clicking on the "DDS" tab in the lower half of the GUI.

The panel is subdivided into three zones: the leftmost one is dedicated to the settings of the clocking and synchronization signals, while the other two are identical and are deputed to the management of the two DDS channels.

The two DDSs are connected respectively to the two modulation channels, meaning that each modulation input must be activated with the respective button, as indicated in this manual, prior to use the DDSs generated modulation signal.

The function of each command is listed below:

**Save param.:** This button can be used to save the current parameters of the DDS tab so that they will be reloaded as default at the switch-on of the QubeCL.

*Clock & Sync. section*

**DDS CLOCK:** This button enables the clock signal for the two DDSs. If this button is disabled, both of the DDS circuit are inactive, while deactivating it when the DDSs are unnecessary may bring a little noise reduction on the current output. We recommend to leave it enabled during all the operations. This signal has no user-controllable parameters.

**INT. SYNC:** This button enables the internal synchronization signal. This clock signal runs through the internal QubeCL bus and can be used as demodulating signal by the PDH or LIA modules, if present. This signal has no user-controllable parameters.

**EXT. SYNC:** This button enables the external synchronization signal. When activated, a synchronization signal is present on the SYNC out connector of the LH module. The signal is a 5 V square wave.

**Ext. Sync. Freq.:** This control can be used to set the frequency of the synchronization signal.

**Ext. Sync. Phase:** This control can be used to change the phase of the synchronization signal.

*DDS section*

The commands are listed only once for both the sections, since they are identical but each one referred to a different channel.

**ENABLE:** This button enables the corresponding DDS channel, making it start synthetizing the chosen signal. This control has effect only if the respective MOD enable button has already been pressed.

**SYNC:** This button sets the frequency of the External Synchronization signal at the same value of the respective DDS generated signal.

**WAVEFORM:** This control allows the user to choose the type of waveform synthesized by the DDS. The two available options are sinusoidal wave and triangular wave.

**AMPLITUDE:** This control can be used to set the amplitude of the DDS generated modulating signal. The amplitude is expressed in mA peak-to-peak.

**FREQUENCY:** This control gives the user the ability to change the frequency of the DDS generated modulation signal. The frequency value is expressed in Hz.

**PHASE:** This control allows the user to change the phase of the DDS generated modulating signal. The phase value is expressed in degrees.

## DDS Operations

To properly operate with the DDS module, follow the steps listed below:

1. Prior to start using the DDS, make sure to activate the DDS clock button;
2. Activate the current on the laser with the dedicated interface and wait until the GUI gives you the ability to use the modulation controls;
3. Activate the overall modulation control and the control for the desired channel;
4. Set the desired signal parameters (amplitude, frequency, phase, waveform) and activate the respective DDS to make it start sourcing the generated signal;
5. The signal parameters can be changed at any time during the operations;
6. Disable the DDS generated signals using the respective Enable controls when they are not needed anymore;
7. Use the External Synchronization signal as a synchronous trigger signal for an oscilloscope if needed, after enabling it with the respective button;
8. If one between PDH and LIA module is present, it needs a demodulating signal for its operation. Such signal is sourced by the DDS board and has to be activated to make the operation possible by the use of the Internal Synchronization signal enable button.

# Chapter 7: Advanced settings
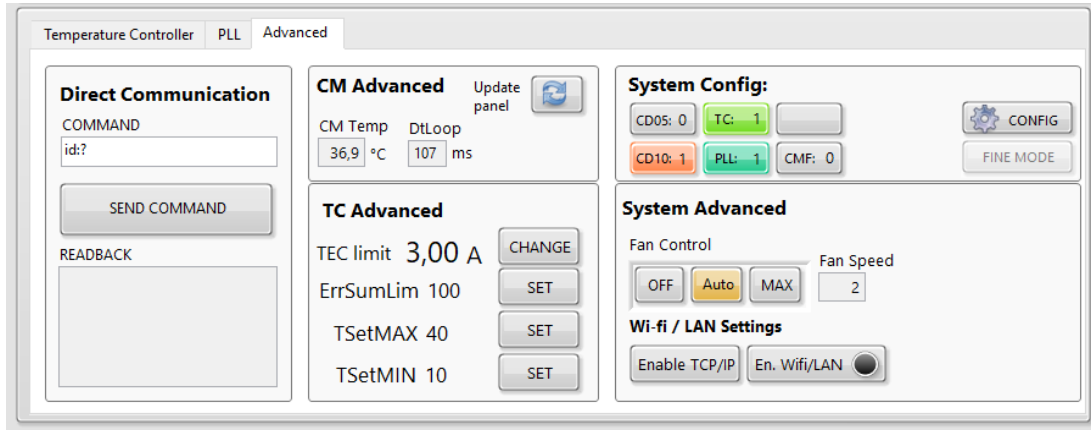


The *Advanced* Tab contains less frequent settings that may be useful in some case. Please change them carefully only if strictly necessary.

**Direct communication.** This console allows to send a serial command to the QubeCL. The termination character is automatically added, so that it is not necessary to add it at the end of the command string. The command is sent to the instrument by clicking on the *SEND COMMAND* button. In case the command is a query, the answer from the QubeCL is displayed in the *READBACK* box.

**CM Advanced.** This section, at present, displays the internal temperature of the CM module and the refresh time of the Software Interface (in ms).

**System Advanced.** "*Panel Update*" forces the update of all the indicators of the Control Panel. "*Fan Control*" buttons allow to control the internal fan, whose speed is displayed in a scale 0-20. In "*Wi-Fi / LAN Settings*" the "*Enable Wi-Fi/LAN*" button enables the choice of TCP/IP connection instead of USB connection when the software is started. If the Wi-Fi option is installed, the Wi-Fi connection will

be enabled, ad can be eventually disabled by clicking on the "*Wi-Fi*" button. If the Ethernet option is installed, the LAN connection will be enabled.

**TC Advanced.** "*TEC Limit*" control allows to set the maximum current that the QubeCL can provide to the Peltier cell. Change this according to the specifications of your Peltier, the maximum value is 3.9A.

"*T Error Limit*" sets the threshold used for the automatic detection of temperature stabilization problems. As an example, the default value of 100 K*s makes the instrument shut off if the temperature error keeps larger than 10 K for at least 10 s or 1 K for at least 100 s. In general, if the temperature stabilization of your laser as fast as few seconds, you can reduce this value by one order of magnitude. On the other hand, if the stabilization of your laser is slow (tens of seconds) you may need to increase these value.

"*T Set MAX*" and "*T Set MIN*" define the allowed range for the temperature setpoint (Tset).

**PLL Advanced.** Reserved section

Table II: Serial command list for QubeCL control

**NB:** Send commads with *\n* termination, receive strings with *\r\n* termination.

| Command | Value | R/W | Action | Ouput Format | Units |
|---|---|---|---|---|---|
| id: | ? | R | Returns the identification string of the instrument | QubeCL-#### | |
| ilas: | ? | R | Returns the output current value | ####.## | mA |
| iset: | ? | R | Returns the current setpoint | ####.## | mA |
| | ####.## | W | Sets the current setpoint | | mA |
| iout: | on | W | Switches the current ON | | |
| | off | W | Switches the current OFF (if ON, also modulation inputs are switched OFF) | | |
| imax: | ? | R | Returns the output current limit set by the user | ####.## | mA |
| | ####.## | W | Sets the output current limit | | mA |

| vlas: | ? | R | Returns the voltage drop across the laser | ####.## | V |
|-------|---|---|------------------------------------------|---------|---|
| mod: | on, off | W | Enables/disables the general switch for modulations, active from 10 sec. after iout:on | | |
| mod1: | on, off | W | Enables/disables input modulation Mod1 | | |
| mod2: | on, off | W | Enables/disables input modulations Mod2 | | |
| tlas: | ? | R | Returns the laser temperature | ####.## | °C |
| tstab: | on | W | Switches the temperature stabilization ON | ####.## | °C |
| | off | W | Switches the temperature stabilization OFF | | °C |
| tset: | ? | R | Returns the laser temperature setpoint | ####.## | °C |
| | ####.## | W | Sets the laser temperature setpoint | | °C |
| kp: | #### | W | Sets the proportional gain of the digital PID for the temperature stabilization | | |

| ki: | #### | W | Sets the integral gain of the digital PID for the temperature stabilization | | |
|---|---|---|---|---|---|
| kd: | #### | W | Sets the derivative gain of the digital PID for the temperature stabilization | | |
| pid: | ? | R | Returns the gain values of the digital PID for the temp. stabilization:<br><br>   kp<br><br>   ki<br><br>   kd | #####:<br><br>#####:<br><br>##### | |
| tecsign: | ? | R | Returns the sign of the PID for the temp. stabilization (0:reverse, 1:direct) | # | bool |
| | dir, rev | W | Sets the sign of the digital PID for the temp. stabilization (direct, reverse) | | |
| tlimax: | ? | R | Returns the maximum settable temperature for tset | ##.## | K |
| | ##.## | W | Sets the maximum settable temperature for tset | | K |
| tlimin: | ? | R | Returns the minimum settable temperature for tset | ##.## | K |

| | | | | | |
|---|---|---|---|---|---|
| | ##.## | W | Sets the minimum settable temperature for tset | | K |
| teclim: | ? | R | Returns the maximum current output of the TEC module | #.# | A |
| | #.# | W | Sets the maximum current output of the TEC module | | A |
| teslim: | ? | R | Returms the threshold for the Active Temperature Error control | #### | K*s |
| | #### | W | Sets the threshold for the Active Temperature Error control | | K*s |
| vcc: | ? | R | Returns the supply voltage | ####.## | V |
| tsense: | ? | R | Returns the internal temperature of the instrument. | ####.## | °C |
| qpar: | ? | R | Returns the main operational parameter:<br>    ilas<br>    vlas<br>    tlas<br>    tsense<br>    Peltier current<br>    vcc | ####.##:<br>####.##:<br>####.##:<br>####.##: | mA<br>V<br>°C<br>°C<br>mA<br>V |

| | | | | | |
|---|---|---|---|---|---|
| | | | LasOnFlag: status of the iout command (0:OFF, 1:ON) | ####.##: | bool. |
| | | | StabOnFlag: status of the tec command (0:OFF, 1:ON) | | bool. |
| | | | TripFlag: switches to 1 if an "open circuit" event occurs | ####.##: | bool. |
| | | | Vcc_low_flag: switches to 1 if vcc goes below 18 V | #: | bool. |
| | | | ModOnFlag: status of the mod command (0,OFF, 1:ON) | #: | bool. |
| | | | ReLasOnFlag: status of the relay switch on the curr. out. (1: gnd, 0:open) | #: | bool. |
| | | | | #: | |
| | | | | #: | |
| | | | | #: | |
| | | | | # | |
| qst: | ? | R | Returns the main status parameters: | | |
| | | | iset | ####.##: | mA |
| | | | tset | | °C |
| | | | imax | ####.##: | mA |
| | | | MaxImax: maximum settable current, according to the modules config. | ####.##: | mA |
| | | | | | bool |
| | | | LasOnFlag: status of the iout command (0,OFF, 1:ON) | ####.##: | bool |
| | | | StabOnFlag: status of the tec command (0,OFF, 1:ON) | #: | bool |
| | | | | | bool |

| | | | | | |
|---|---|---|---|---|---|
| | | | ModOnFlag: status of the mod command (0,OFF, 1:ON) | #: | bool |
| | | | Mod1OnFlag: status of the M1 command (0,OFF, 1:ON) | #: #: | bool |
| | | | Mod2OnFlag: status of the M2 command (0,OFF, 1:ON) | #: # | |
| | | | tecsign: correction sign of the digital PID for the temp. stabilization | | |
| cp: | 0-7 | W | Sets the prop. gain (CPG) of the phase-detector (0:1 … 7:8)) | | |
| hg: | 0-3 | W | Sets the CPG multiplier (0:3; 1:2, 2:1, 3:0) | | |
| mux: | 0, 2, 4 | W | Selects the signal to be sent out from the "Div Mon" output connector.<br><br>0: output disabled (this position is required during locking)<br><br>2: RF signal after division by ndiv parameter<br><br>4: LO signal after division by rdiv parameter | | |
| sig: | 0, 1 | W | Sets the sign of the phase-locking loop (0: negative, 1: positive) | | |

| | | | |
|---|---|---|---|
| ndiv: | # | W | Sets the integer number to be used ad divider of the RF signal frequency |
| rdiv: | # | W | Sets the integer number to be used as divider of the LO signal frequency |
| pll | on, off | W | Sets the status of the phase-detector inputs (on: enabled, off: disabled) <br><br> This must be set to on for counting and locking |
| cp: | on, off | W | Sets the status of the phase-detector output (on: enabled, off: disabled) <br><br> This must be set to on for locking |
| lk: | on, off | W | Controls the error correction to the laser (on: enabled, off: disabled) |
| pby: | on, off | W | Enable/Disable the integral part of the PLL (on: enabled, off: disabled) |
| tp: | 0 - 3 | W | Sets the time constant of the PLL PI loop (from 0:slow to 3:fast) |

| | | | | | |
|---|---|---|---|---|---|
| tz: | 0 - 3 | W | Sets the proportional gain of the PLL PI loop (from 0:large to 3:small) | | |
| lm: | ? | R | Returns the value in mV of the error signal, in the range 0-5 V and with an offset of 2.5 V. A the value 2500 corresponds to an error = 0. | # | mV |
| pg: | ? | R | Returns the PLL PI status parameters:<br><br>  lk: lock status (0, unlocked, 1:locked)<br><br>  pby: integrator enable status (0, disabled, 1:enabled)<br><br>  tp: selected time constant of the PI loop (0-3, from slow to fast)<br><br>  tz: selected proportional gain of the PI loop (0-3, from large to small) | #:<br>#:<br>#:<br># | bool<br>bool<br>int<br>int |
| re: | ? | R | Returns the status of the internal 24bit registers (R: N: F) of the phase-detector chip. The position of the parameters into the registers is shown in the table below.<br><br>| Parameter to read | Register R, N, F | Position into register | Bit length |<br>|---|---|---|---|<br>| | | | | | 0x#:<br>0x#:<br>0x# | hex<br>hex<br>hex |

|  |  |  |  |  | 0-23 |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
|  |  |  | pll | F | 3 | 1 |  |  |
|  |  |  | mux | F | 4 | 3 |  |  |
|  |  |  | sig | F | 7 | 1 |  |  |
|  |  |  | cp | F | 8 | 1 |  |  |
|  |  |  | cpg | F | 15 | 3 |  |  |
|  |  |  | ndiv | N | 8 | 13 |  |  |
|  |  |  | rdiv | R | 2 | 14 |  |  |
| pllock: | ? | R | Returns the status of the "Slow Loop" for PLL error compensation. (0:OFF, 1:ON) |  |  |  |  | # | bool |
|  | on, off | W | Enable/Disable the "Slow Loop" for the PLL error compensation. |  |  |  |  |  |

| pllocka: | ? | R | Sets the actuator of the "Slow Loop" for the PLL error compensation. (0: current, 1: temperature) | # | bool |
|---|---|---|---|---|---|
| | curr,temp | W | Sets the actuator of the "Slow Loop" for the PLL error compensation. | | |
| pllocks: | ? | R | Returns the sign of the "Slow Loop" for the PLL error compensation. | # | bool |
| | 0,1 | W | Sets the sign of the "Slow Loop" for the PLL error compensation. | | |
| pllockt: | ? | R | Returns the rate of the "Slow Loop" for the PLL error compensation. | #### | ms |
| | #### | W | Sets the rate (in ms) of the "Slow Loop" for the PLL error compensation | | ms |
| pllocki: | ? | R | Returns the max current excursion (in mA) of the "Slow Loop" for the PLL error compensation, when the current is used as actuator. | ## | mA |
| | ## | W | | | |

| | | | |
|---|---|---|---|
| | | | Sets the max current excursion (in mA) of the "Slow Loop" for the PLL error compensation, when the current is used as actuator. |
| pdhlock: | on, off | W | Enable/Disable the PDH PI loop output signal. |
| pdhhold: | on, off | W | Enable/Disable the PDH PI loop hold state. |
| pdhint: | on, off | W | Enable/Disable the integrative action of the PDH PI loop. |
| pdhrint: | 0,1,2,3 | W | Sets the overall proportional gain of the PDH PI loop (from 0: large to 3: small). |
| pdhtz: | 0,1,2,3 | W | Sets the proportional gain of the PDH PI loop, also affects the time constant (from 0: small, faster to 3: large, slower). |
| pdhtp: | 0,1,2,3 | W | Sets the time constant of the PDH PI loop (from 0: fast to 3:slow). |
| pdhmon: | 0,1 | W | Selects the output signal on the PDH module monitor connector: 0: error        1: PI loop output |

| pdhmoni nt: | ? | R | Returns the values of input and output signals to the PI loop: | | |
|---|---|---|---|---|---|
| | | | PI loop output | ####.## | mV |
| | | | Error signal | : | mV |
| | | | | ####.## | |
| pdhvoff: | ? | R | Returns the input offset signal to the PI loop. | ####.## | mV |
| | ##.## | W | Sets the input offset signal to the PI loop. The effective offset applied to the loop is equal to (2000 - Voff)/10. | | |
| saveall | | W | Save all the parameters that can be saved in Eprom. | | |