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a santec company

Mini Laser Controller

mLC/mCC/mTC

Revision 1.04

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Preface

The MOGLabs mLC Mini Laser Controller provides fully digital control of ECDL or DFB/DBR lasers in an ultra-miniature form factor. The board includes a temperature controller and current source with low noise, high current (up to 1 A), andhigh compliance (up to 8.5 V). It includes a high voltage (180 V) piezo driver as well as a fast ADC input. In addition to two analogue inputs for direct modulation of both piezo and current drivers, the mLC provides an internal lock-in amplifier for AC locking to an atomic transition or high finesse optical cavity. Electrical power input is through a USB-C connection, and the device is compatible with most USB-C power delivery adapters. It can be operated using a computer communications interface (TCP/IP or USB) with simple text-based commands.

We hope that the mLC meets and exceeds your expectations. Please let us know if you have any suggestions for improvement in the mLC or in this document, and check our website from time to time for updated information.

MOGLabs www.moglabs.com

Safety Precautions

Safe and effective use of this product is very important. Please read the following safety information before attempting to operate a laser using the MOGLabs mLC controller. Also please note several specific and unusual cautionary notes before use, in addition to the safety precautions that are standard for any electronic equipment or for laser-related instrumentation.

CAUTION – USE OF CONTROLS OR ADJUSTMENTS OR PERFORMANCE OF PROCEDURES OTHER THAN THOSE SPECIFIED HEREIN MAY RESULT IN HAZARDOUS RADIATION OR HIGH VOLTAGE EXPOSURE

Laser output can be dangerous. Please ensure that you implement the appropriate hazard minimisations for your environment, such as laser safety goggles, beam blocks, and door interlocks. MOGLabs takes no responsibility for safe configuration and use of your laser. Please:

- Avoid direct exposure to the beam.
- Avoid looking directly into the beam.
- Note the safety labels and heed their warnings.
- When the laser is switched on, there will be a short delay of three seconds before the emission of laser radiation, mandated by European laser safety regulations (IEC 60825-1).
- A STANDBY/RUN keyswitch must connected, and turned to RUN before the laser can be switched on. The laser will not operate

if the keyswitch is missing or in the STANDBY position. The key cannot be removed when it is in the RUN position.

- To completely shut off power to the unit, turn the keyswitch to STANDBY position, unplug the USB-C cable from the device and/or unplug the USB-C power adapter from the mains.
- When the STANDBY/RUN keyswitch is on STANDBY, there cannot be power to the laser diode, but power can still be supplied to the laser temperature controller and piezo driver.

CAUTION The device chassis must have a good ground connection.

CAUTION To ensure correct cooling airflow, the unit should not be operated with cover removed.

WARNING The internal circuit boards and many of the mounted components are at high voltage, with exposed conductors, in particular various sections of the HV power supply and piezo driver. The unit should not be operated with cover removed.

NOTE The MOGLabs mLC is designed for use in scientific research laboratories. It should not be used for consumer or medical applications.

Protection Features

The MOGLabs mLC includes a number of features to protect you and your laser.

Softstart A time delay (3 s) followed by linear ramp of the diode current (1 s/A).

Circuit shutdown Many areas of the circuitry are powered down when not in use. The diode current supplies may be without power when the unit is in standby mode, if an interlock is open, or a fault condition is detected.

Current limit Sets a maximum possible diode injection current, for all operating modes.

Cable continuity If the laser is disconnected, the system will switch to standby and disable all laser power supplies. If the laser diode, TEC or temperature sensor fail and become open-circuit, they will be disabled accordingly.

Short circuit If the laser diode, TEC or temperature sensor fail and become short-circuit, or if the TEC polarity is reversed, they will be disabled accordingly.

Temperature If the detected temperature is below −5°C or above the set limit, the temperature controller is disabled.

Internal supplies If the external USB-CDC power supply (+15 V) is 0.5 V or more below its nominal value, the system is disabled.

Protection relay When the power is off, or if the laser is off, the laser diode is shorted via a normally-opened MOS FET.

Emission indicator The MOGLabs mLC controller will illuminate the emission warning indicator LED immediately when the laser is switched on. There will then be a delay of at least 2 seconds before actual laser emission.

Key-operated The laser cannot be powered unless the key-operated STANDBY switch is in the RUN position, to enable protection against unauthorised or accidental use. The key cannot be removed from the controller when it is in the clockwise (RUN) position.

Interlocks The mLC controller has an external interlock to allow disabling of the laser via a remote switch, or a switch on the laser cover.

Extending laser diode and piezo lifetime

At night, switch to standby:

1. Switch the laser diode current and piezo driver off.

   Don't adjust the current, just press the on/off switch in the mLC control program to power off the diode and/or piezo driver.

2. Switch from RUN to STANDBY.

The temperature controller will continue to operate so that the laser is ready for quick startup the next day, but the laser diode current and piezo voltage will be zero, extending their operating life.

In the morning, switch back on:

1. Switch from STANDBY to RUN.

2. Switch the laser diode and/or piezo driver ON by pressing the on/off switch in the mLC control program.

   You don't need to adjust the current or piezo voltage, just wait a few minutes for the diode temperature to equilibrate.

You should switch your MOGLabs mLC into STANDBY mode at nights and weekends and whenever the laser is not being used for more than a few hours. Most lasers need to operate only 40 hours during a 168 hour week; thus switching to standby mode can extend the diode and piezo lifetime by a factor of four.

Contents

1. Quick start

The MOGLabs mLC can be used in various configurations, including simple current/temperature controller, passive laser frequency controller with internal or external sweep/scan, resonant cavity controller, and as a complete system for active frequency stabilisation (laser or resonant cavity) with AC, DC or external locking signal.

1.1 On-board connections

In the simplest configuration, the MOGLabs mLC will be used to control the diode injection current and laser temperature. The board has multiple connectors on both top and bottom sides (fig. 1.1). DFB/DBR lasers in a standard 14-pin butterfly package can be directly soldered onto the board. The board must be mounted on a heatsink to prevent potential overheating.

AUX MULT Auxiliary multifunctional input (UFL connector). Alternative connector for MULT IN.

AUX IMOD Auxiliary current modulation input (UFL connector). This connector provides a direct access to the high speed current modulation circuit bypassing the AUX MULT multiplexing circuitry.

EXP/TEST Expansion input/output (Hirose BK13 connector). Duplicates LD/TEC/PZT I/O and the input power lines required for expansion boards or internal device testing, and a standard 3.3 V USART interface for communication with the mLC board.

AUX ADC IN Auxiliary ADC input (UFL connector). Low bandwidth (-3 DB15 3 kHz) ADC input to be used with slowly changing signals. The input voltage should be from 0 to 5 V.

PD Power Photodetector power (±12 V). Standard 1.27 mm pitch header. This

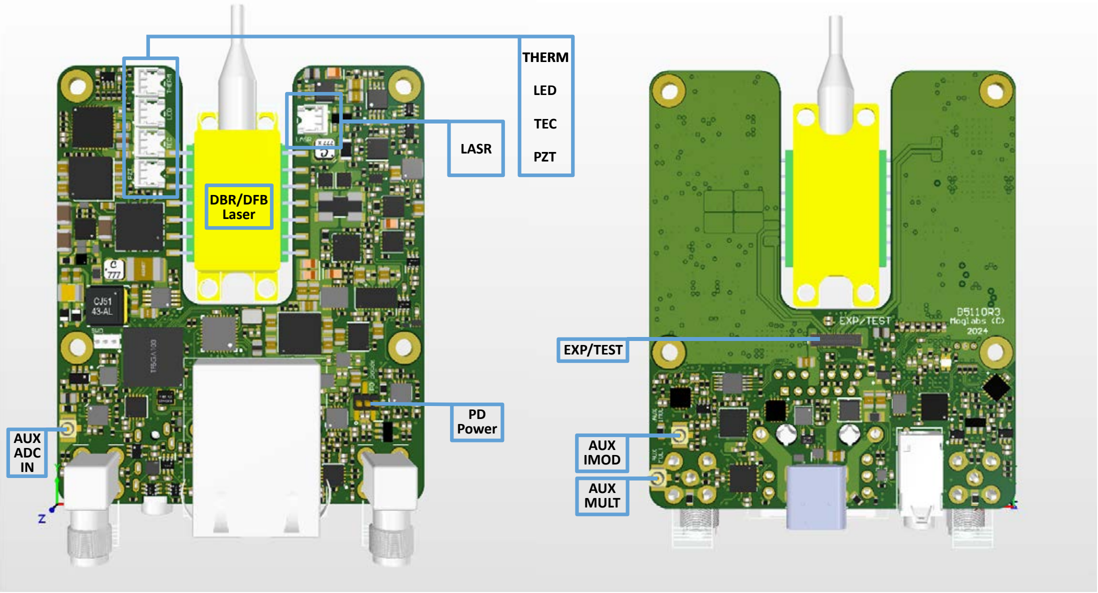


Figure 1.1: Top and bottom views of the MOGLabs mLC board.

connector provides power for an external photodetector amplifier board such as the MOGLabs B1131.

THERM NTC thermistor input (MOLEX EZmate connector).

LED Indicator LED output (MOLEX EZmate connector).

TEC TEC module output (MOLEX EZmate connector).

PZT Piezoelectric stack output (MOLEX EZmate connector).

LASR Laser diode output (MOLEX EZmate connector).

DFB/DBR The mLC board can accommodate direct mounting of a standard 14-pin butterfly laser package. The laser should be soldered directly to the PCB to ensure a good connection.

1.2 Front panel connections

This manual describes the standard mLC with complete front panel (fig. 1.2), which allows operation remotely from a host computer. Other variants of the mLC board may have a different connector set.

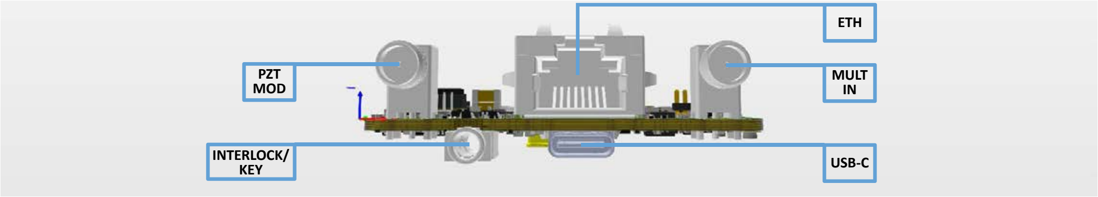


Figure 1.2: Front view of the MOGLabs mLC board.

USB-C — Power input. The USB-C power delivery adapter must be able to provide 15 V, 1 A to power the mLC board.

ETH — Twisted pair 10/100 ethernet (RJ45 connector) connection for communication to host computer.

INTERLOCK/KEY — Standard 3.5 mm headphone style connector for both interlock and keyswitch. The pins must be externally short-circuited to enable laser emission. The safety keyswitch must be set to the RUN position to permit laser emission, including for remote operation. Turning to STANDBY will immediately disable power to the laser diode, but the piezo driver and temperature control will continue. *Do not supply any voltage to this input; use a relay if necessary.*

PZT MOD — Piezo driver modulation input (SMA connector). The input provides direct analogue control of the piezo driver. The input voltage should be from 0 to 2.5 V.

MULT IN — Multifunction input (SMA connector). This input can be used for direct laser current modulation (standard ±1 mA) or AC/DC coupled high speed ADC input. The function of this input is set through the `mogmlc` software. Use this input for a photodetector signal.

1.3 Powering up

1. Ensure all hardware is connected: ethernet, interlock, piezo driver, TEC and laser diode. Do not connect or disconnect the laser while the device is powered on.

2. Connect the USB-C power adapter to the mLC board via a proper USB-C cable that supports USB-C PD; that is, the USB-C power delivery protocol. The USB-C connector is located at the front of the unit.

3. If using ethernet, connect to your local subnet. See appendix C for assistance with configurating the network parameters.

4. Once the booting sequence is complete, the device will appear on the device discoverer in the `mogmlc` software and the device will now accept connection from a host computer.

5. Set and/or verify both the laser current limit (in the *Laser* submenu) and the TEC setpoint temperature as necessary to prevent accidentally damaging the laser diode. The maximum safe current is specified in the MOGLabs laser factory test report.

6. Enable the TEC controller and piezo driver. Verify that the measured laser temperature starts converging towards the setpoint temperature.

7. Turn the keyswitch to RUN.

8. Set the laser diode current, initially slightly above the threshold current specified in the laser test report.

9. Activate the laser diode controller. Verify that the laser diode current is ramping and reaches the set value.

10. Control the laser using the host computer interface described below.

1.4 Remote operation

The `mLC` is designed for remote operation only, either from the provided standalone Windows$^{\text{TM}}$ application or by integration into custom lab control software using a simple command interface. The command language is defined in appendix B. The `mLC` app is discussed in detail in the following chapter.

2. MOGMLC computer software

The host software program `mogmlc` provides a graphical user interface that allows remote control of the mLC controller. `mogmlc` is available from the MOGLabs website.

It may be necessary to install a firmware update (section 2.8) before being able to use the `mogmlc` software. If the software detects an incompatibility it will offer to install the update, which can also be obtained from the MOGLabs website.

2.1 Device discovery

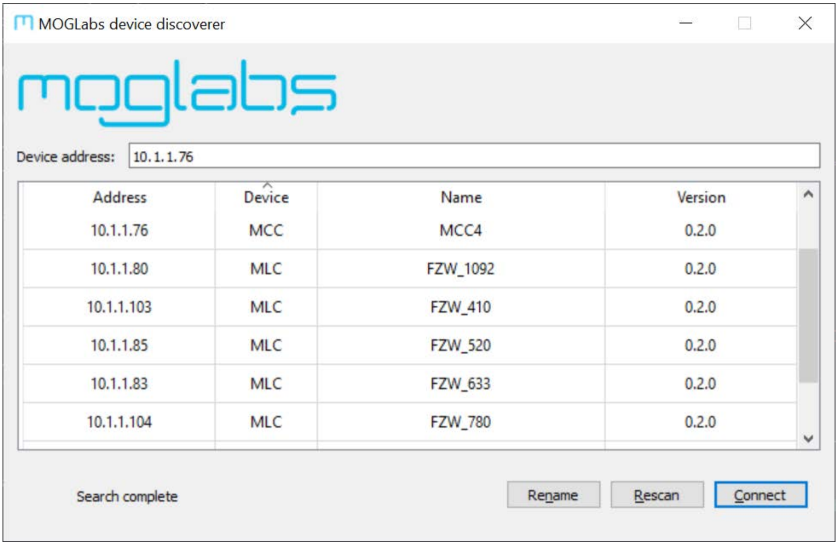
Install and start the app, which should then show the device discoverer (see fig. 2.1) which searches for mLC devices accessible over USB or the local network. Use the network interface rather than USB if possible. See chapter C for information on communications.

Select the intended device and click *Connect*. When multiple mLCs are available, be sure to double-check the name and/or serial number of the device when connecting. If the network does not permit device discovery and/or your mLC does not appear in the list, you can type the IP address in the *Device address* box, or use USB connection instead.

2.2 Main window

The mLC is designed for remote operation only, either from the provided standalone Windows^{TM} application or by integration into custom lab control software using a simple command interface. The command language is defined in Section B.

The mLC app (see fig. 2.2) provides control of the laser, and logging of TEC temperature and current, and laser diode current and voltage. An integrated oscilloscope displays the measured photode-



Device address: 10.1.1.76

Address	Device	Name	Version
10.1.1.76	MCC	MCC4	0.2.0
10.1.1.80	MLC	FZW_1092	0.2.0
10.1.1.103	MLC	FZW_410	0.2.0
10.1.1.85	MLC	FZW_520	0.2.0
10.1.1.83	MLC	FZW_633	0.2.0
10.1.1.104	MLC	FZW_780	0.2.0

Search complete

Figure 2.1: MOGLabs device discoverer which shows mLC devices available via USB and network interfaces.

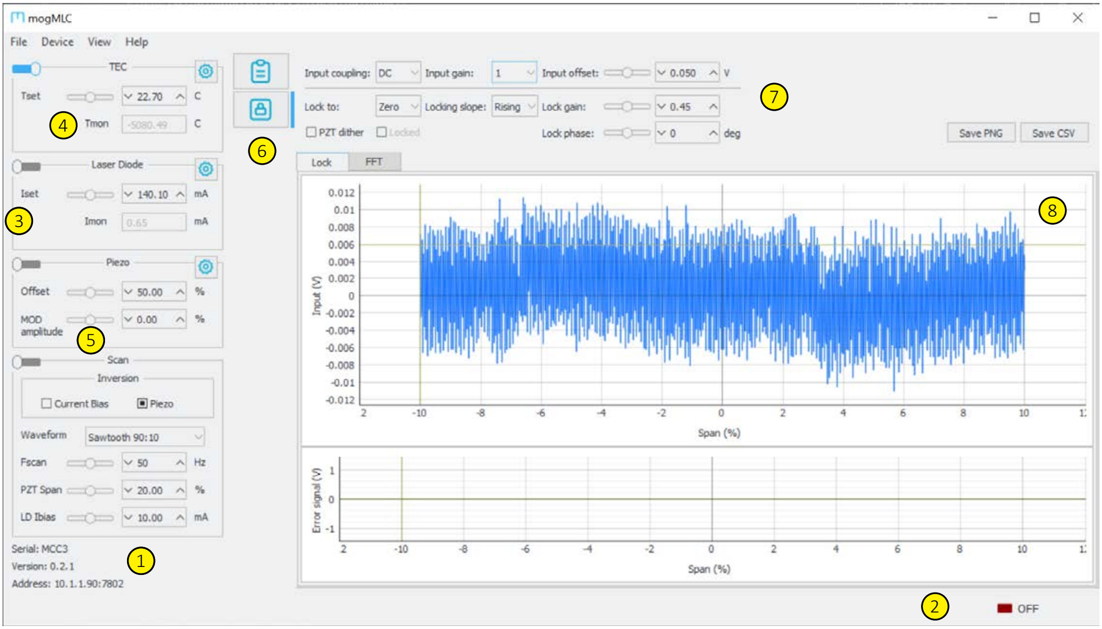
tector voltage and the error signal against piezo scanning position, to assist with adjusting the laser scan parameters and operating the feedback servos and for identifying and locking to features of interest. One full laser sweep is displayed.

2.3 Main features

1. Device identification, the serial number by default but can be assigned by double-clicking. Also shows the current IP address and firmware version.

2. System status indicator, for example whether the laser is active or if a problem has been detected.

3. Primary function controls, permitting enabling or disabling of core functionality such as TEC, piezo, laser diode current and scanning. Click the “gear” button adjacent to each switch for



TEC

Tset 22.70 C

Tmon -5080.49 C

Laser Diode

Iset 140.10 mA

Imon 0.65 mA

Piezo

Offset 50.00 %

MOD amplitude 0.00 %

Scan

Inversion

☐ Current Bias ☒ Piezo

Waveform Sawtooth 90:10

Fscan 50 Hz

PZT Span 20.00 %

LD Ibias 10.00 mA

Serial: MCC3
Version: 0.2.1
Address: 10.1.1.90:7802

Input coupling: DC Input gain: 1 Input offset: 0.050 V

Lock to: Zero Locking slope: Rising Lock gain: 0.45

☐ PZT dither ☐ Locked Lock phase: 0 deg

🟥 OFF

Figure 2.2: MOGLabs mLC Windows^{TM} application for control and monitoring mLC devices.

additional settings.

4. Laser temperature indicator.

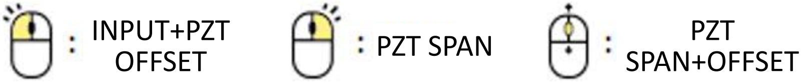
5. Virtual encoders provide a mechanism for smoothly adjusting parameters. Click and drag the dials to adjust the values with fine control, or type a number in the associated box.

6. Tabs for accessing different application functionality, such as logging, oscilloscope or noise spectrum analysis.

7. Drop-down boxes for controlling the input signal and internal lock-in amplifier.

8. Oscilloscope feature, showing the input and demodulated error signals for a complete piezo span.

The oscilloscope supports mouse interactions and gestures. Left-clicking and dragging adjusts the input (vertical movement) and piezo (horisontal movement) offsets respectively. Right-clicking adjusts the piezo span.



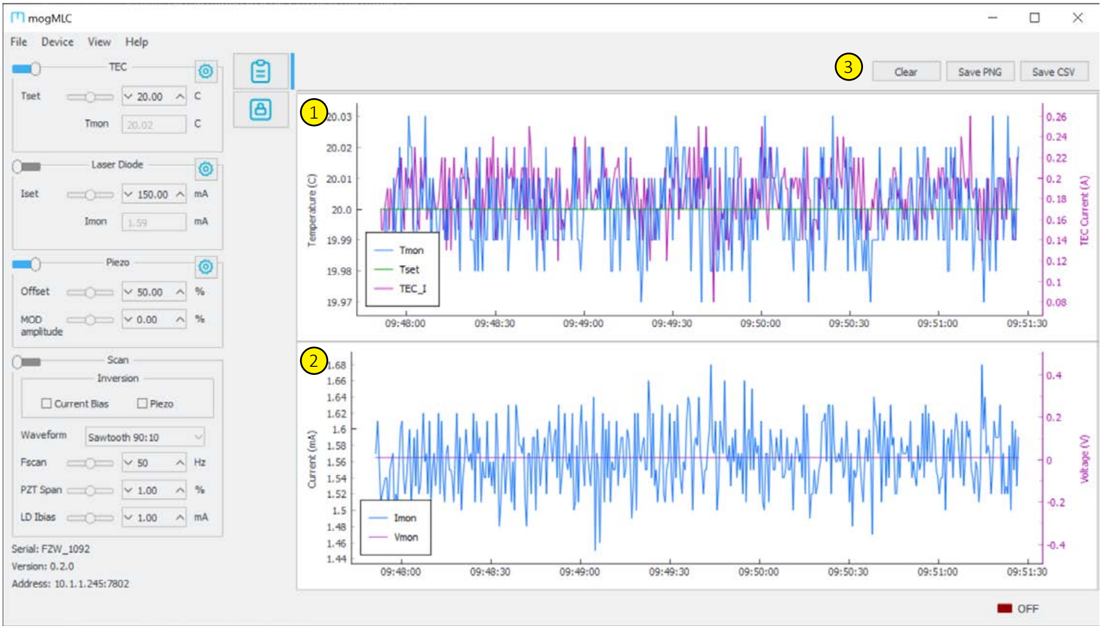
Using the mouse wheel adjusts vertical and horizontal simultaneously to zoom in or zoom out from the position of the mouse cursor.

Double-clicking within the oscilloscope display will toggle whether the laser or cavity is locked. Double-clicking to activate the lock will engage the lock at the mouse position, allowing a transition of interest to be selected.

Bright and dark colour schemes can be accessed via *View* → *Theme* menu.

2.4 Logging

The mLC software logs the temperature and laser diode current controller operations (see fig. 2.3). The information can be useful for long-term testing of system behaviour and for adjusting locking PID coefficients (see Section 2.5) to improve system stability. Logging graphs can be accessed at any time by clicking on the appropriate tab. The appearance of the logging tab will depend on the hardware variant of the mLC controller. In the default configuration the tab will show the TEC temperature and laser diode current and voltage monitor graphs, but mCC and mTC variants will only show the diode or TEC values.



mogMLC

File Device View Help

TEC
Tset 20.00 C
Tmon 20.02 C

Laser Diode
Iset 150.00 mA
Imon 1.59 mA

Piezo
Offset 50.00 %
MOD amplitude 0.00 %

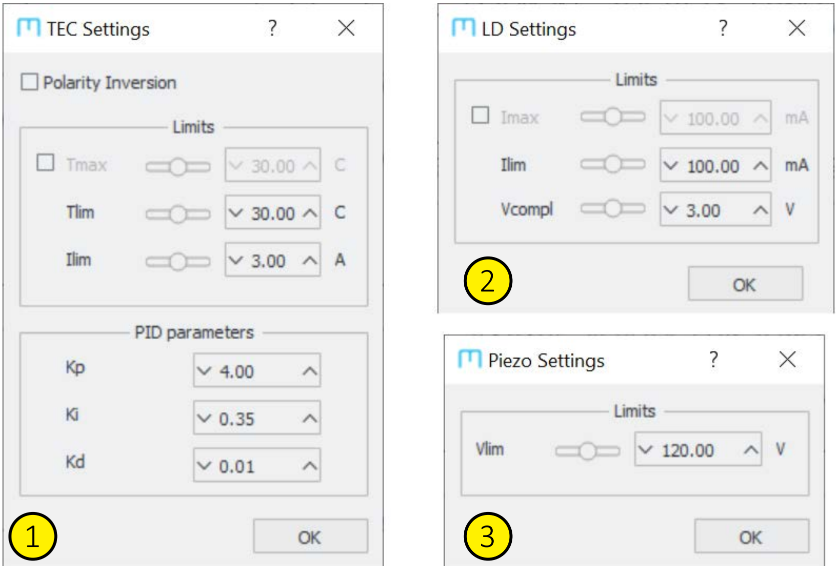
Scan
Inversion
☐ Current Bias ☐ Piezo
Waveform Sawtooth 90:10
Fscan 50 Hz
PZT Span 1.00 %
LD Ibias 1.00 mA

Serial: FZW_1092
Version: 0.2.0
Address: 10.1.1.245:7802

Figure 2.3: Logging tab shows the temperature convergence of the TEC controller (1) and laser diode current and voltage monitoring (2) graphs respectively. The buttons above (3) can be used to save or clear the data at any time.

2.5 Settings

Each of the mLC subcomponents (TEC, piezo, laser diode) has additional parameters that can be accessed by clicking the "gear" icon (see fig. 2.4). Usually these parameters do not require a continuous adjustment and only need to be set once. The values are usually preset by MOGLabs manufacturing team during system testing with a dedicated laser or cavity or waveguide doubler but can be further adjusted by the user. The piezo servo controller PID parameters (see fig. 2.5) can be accessed via *Device* → *Settings* → *Piezolock* menu. In most cases only the integral PID coefficient will require some adjustment. Note that overall servo gain is adjusted through the main window (see fig. 2.2).



TEC Settings

□ Polarity Inversion

Limits

□ Tmax 30.00 C

Tlim 30.00 C

Ilim 3.00 A

PID parameters

Kp 4.00

Ki 0.35

Kd 0.01

LD Settings

Limits

□ Imax 100.00 mA

Ilim 100.00 mA

Vcompl 3.00 V

Piezo Settings

Limits

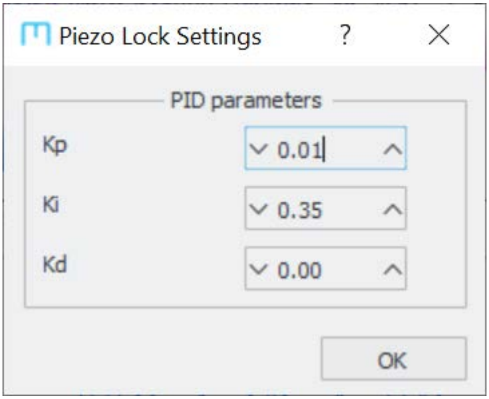
Vlim 120.00 V

Figure 2.4: Pop-up settings windows be called by clicking the "gear" button at the top right corner of a particular group box (TEC/LD/Piezo).

2.6 Locking

The mLC can frequency-stabilise the laser using an external error signal, wavemeter, or an internally-generated error signal based on the photodetector input. It is commonly used to lock to an alkali atom, for example with the MOGLabs MGSA saturated absorption reference device. It is also possible to use mLC to lock a resonant doubling cavity to a particular laser frequency to ensure operation on resonance. Below is an outline of how to use the mLC app for laser frequency locking; refer to the relevant laser manual for detailed information about adjusting bias current to achieve a wide modehop-free scan-range.

1. Set the piezo offset to 50%.
2. Adjust diode current to achieve required optical power.



Piezo Lock Settings

PID parameters

Kp 0.01

Ki 0.35

Kd 0.00

Figure 2.5: Piezo servo controller settings window.

3. Make sure that the diode frequency is correct by using a wavemeter or spectrometer.

4. Increase the piezo Span (e.g. to 25%) to see spectral features of interest, adjusting the diode current (I_{set}) and/or current bias (LD I_{bias}) to achieve continuous scans without mode-hops.

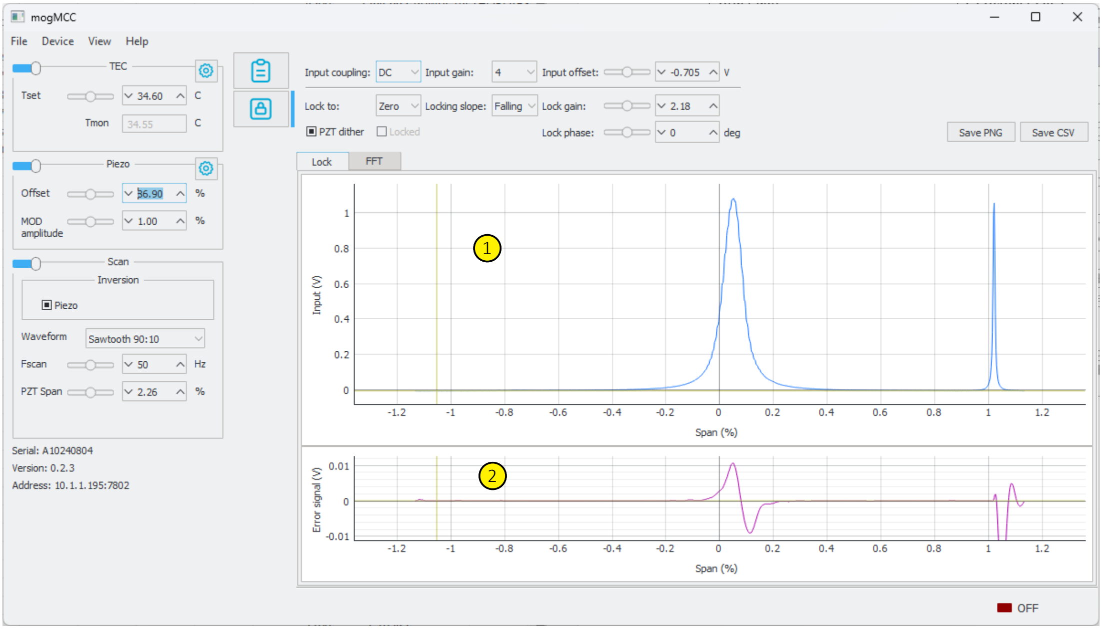
5. Adjust the piezo offset to ensure the desired locking feature is centred and reduce the piezo Span to zoom in on it.

6. When the piezo span is $\sim$ 2 to 5% activate the piezo dither by selecting the dither checkbox. Dithering can be activated earlier; it will not affect scanning.

7. Increase the MOD amplitude by 0.5 to 1% until the error signal is clean and stable.

8. Adjust *Lock phase* to optimise error signal for largest negative or positive slope at the locking point.

9. Double-click (with the left mouse button) on the feature you would like to lock to. The unlocked photodetector signal trace (magenta) maintains the last photodetector trace before the piezo is set to the lock point, enabling comparison against the



mogMCC

TEC
Tset 34.60 C
Tmon 34.55 C

Piezo
Offset 36.90 %
MOD amplitude 1.00 %

Scan
Inversion
☒ Piezo
Waveform Sawtooth 90:10
Fscan 50 Hz
PZT Span 2.26 %

Serial: A10240804
Version: 0.2.3
Address: 10.1.1.195:7802

Input coupling: DC Input gain: 4 Input offset: -0.705 V
Lock to: Zero Locking slope: Falling Lock gain: 2.18
☒ PZT dither ☐ Locked Lock phase: 0 deg

Figure 2.6: Typical resonant cavity transmission spectra (1) and error signal (2) with optimised phase.

locked photodetector signal (blue). If the DC value does not match the intended setpoint, try inverting the *Locking slope polarity* and/or decreasing the *Lock gain*.

10. Increase *Lock gain* until the error signal amplitude begins to increase, then reduce it by 10%.

11. If required, further optimisation can be achieved using the spectrum analyser mode (FFT tab).

2.7 Spectrum analysis

The mLC application includes a spectral noise analysis tool for optimising the performance of feedback servos. The goal of the servos is to suppress noise in the error signal, which is a measure of the laser frequency stability. In general, increasing the gain of the controllers suppresses noise at low frequencies at the expense of increasing noise at high frequencies. Increasing the gain too far will destabilise the controller, which can be detected as a rising peak (known as a “Bode bump”) in the noise spectrum. Figure 2.7 shows the desired behaviour with the servo activated at the optimal gain, and with excessive gain leading to oscillations at the Bode

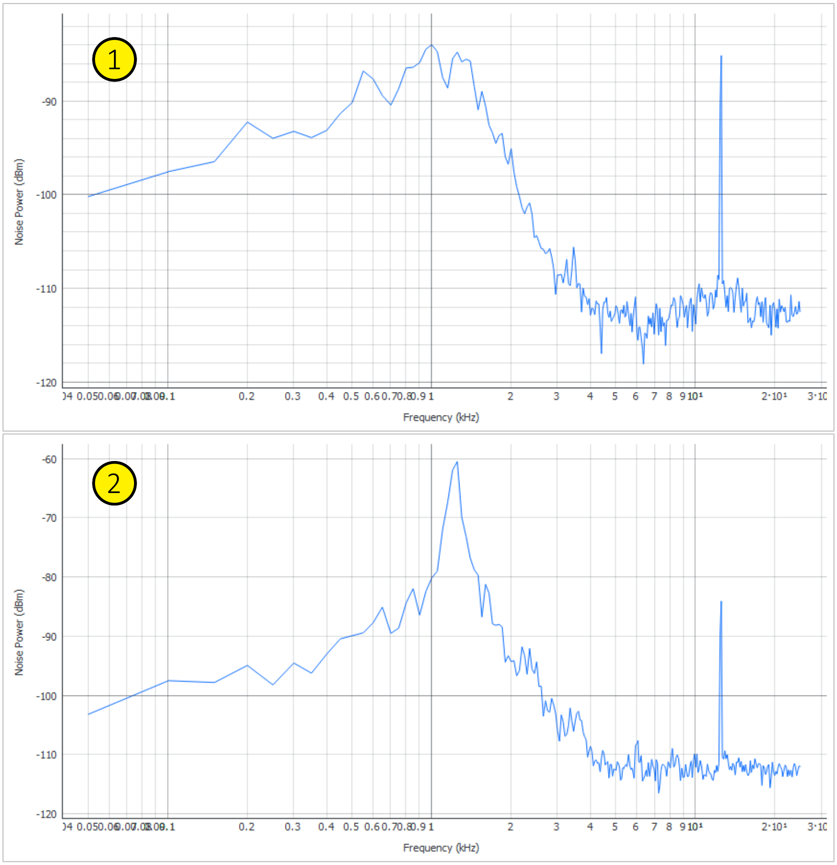


Figure 2.7: The noise spectra for optimal (1) and excessive (2) PID gains respectively.

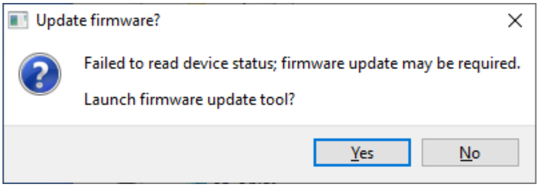
bump. The frequency of the Bode bump is the servo bandwidth for the combination of frequency discriminator, controller, and control actuator.

Changing the master gain affects the error signal used for the spectrum analysis, and should be kept constant while considering the spectrum. In most cases the integrator gain K_i can be left at the default value; adjusting it is recommended only for advanced users familiar with PID optimisation.

2.8 Firmware update

Firmware updates will be available from the MOGLabs website and should be installed on the device using the `mogmlc` application.

The firmware update procedure will be activated automatically if the mLC app detects incompatibility (see fig. 2.8). It is recommended to update firmware using a network connection, but USB can be used. When using USB it may be necessary to unplug the USB cable to reboot the system. The mLC should not be in use while applying a firmware update. The mLC must not be powered off or interrupted during the firmware update or the firmware could become corrupted.


Update firmware?

Failed to read device status; firmware update may be required.

Launch firmware update tool?

Figure 2.8: If `mogmlc` detects a version incompatibility it will offer to install a firmware update.

Firmware is distributed as a ZIP file that contains different firmware components. Upon opening the firmware update tool, click the *Select* button and browse for the firmware ZIP file. The tool will identify the components that need upgrading, which will by installed by clicking the *Update all* button.

The firmware update process typically requires the device to reboot several times. A prompt is displayed once the process is complete. Closing the firmware update tool will then allow `mogmlc` to be used.

A. Specifications

Values for parameters marked with an asterisk $*$ are calculated from detailed simulations. Experimental verifications are in progress.

Parameter	Specification

Current regulator	
Output current	0 to 1024 mA ±15 μA
Noise*	1.4 nA/rtHz @ 1 kHz 880 nA rms (1 Hz – 1 MHz)
Accuracy	±0.2 ppm/°C and 0.1% from setpoint
Max diode voltage	8 V at 500 mA, 7.5 V at 1024 mA
Current mod	±25 mA sweep, ±1 mA analogue in
Bandwidth	12 MHz (−3 dB) analogue

Temperature	
Range	7.5°C to 70°C ±0.01°C resolution
Stability	Better than ±10 mK/°C
TEC power	±3 A, ±4.5 V (13.5 W)
Sensor	NTC 10 kΩ
Control	PID with variable sample rate Bandwidth 20 Hz
Protection	TEC over-current, open/short circuit

Piezo	
Piezo output	0 to 180 V, 15 mA (charge and discharge)
Sweep/control	Direct analogue, and 16-bit digital
Resolution	2.7 mV at maximum range
Noise*	790 nV/rtHz @ 1 kHz
Sweep	1 Hz to 50 Hz
Bandwidth	Internal 16 kHz; external 100 kHz

Parameter	Specification
Protection	PCB over-temp
Frequency stabilisation	
Bandwidth	10 kHz
Dither	262.5 kHz
Phase	0 – 360°
Error signal	16-bit signed, sampling 50 kHz
Post demod filter	4-stage IIR with bypass option
Servo controls	Slow (piezo)
Gain controls	x16/8/4/2/1/0.5/0.25 master
Slow inputs	Slow error (after offset and master gain) Photodetector AC/DC Fast controller out
Slow action	PI or PI^2
Signal input/output	
Signal in	2 SMA connectors
Analogue in (2)	Signal range ±4.096 V protected to ±12 V *Photodetector* AC/DC: 3.1 MHz > 110 dB dynamic range *Piezo mod:* analogue direct to piezo *Current mod:* analogue direct to diode current
Front panel	
Interlock & Key	3.5 mm headphone jack 3-pin connector
Communications	TP 10/100 ethernet (RJ-45); USB-C
Connectivity	
Laser/piezo/TEC	14-pin butterfly PCB footprint 5 MOLEX Pico-Emate connectors 1 Hirose BK13 32-pin connector

Parameter	Specification
Power & dimensions	
Input	USB-C power delivery adapter
Power	4 W standby, 30 W peak

Dimensions	WxLxH = 56 × 67 × 17.6 mm (board)
	WxLxH = 125 × 87 × 33 mm (enclosure)

Weight	32 g
Operating temp	10 – 35°C

B. Command language

The mLC can be controlled over USB via a virtual serial port, or over Ethernet using TCP/IP. The syntax follows a text-based request/reply architecture with messages delimited by CRLF. Commands are comma-separated, and respond with a string that begins with either "OK:" or "ERR:" to indicate success or failure. It is strongly recommended that the response is checked before sending a subsequent command.

Please note: The command language is being continuously updated across firmware releases to improve functionality and add features. When upgrading firmware, please refer to the most recent version of the manual available at `http://www.moglabs.com`

B.1 Arguments

Some commands accept values with units. Units can be specified for values associated with frequency, power, phase and time.

Frequency Hz (default), kHz, MHz

Power dBm (default), dB, mW, W

Phase deg (default)

Time ns, us, ms (default), s

Temperature queries report in °C; do not use units for setting

Calibrations are used to convert parameters to internal discretised values. Most commands will return a message that includes the *actual* value, which may differ from the *requested* value because of discretisation and/or parameter limits.

B.2 System overview

INFO `info`

Report device identification, including running firmware version and serial number. Please include this information in all correspondence with technical support.

DEVNAME `devname`

Set or query the user-facing name of the mLC. Considered distinct from the user-facing name of the *laser*.

UPTIME `uptime`

Query the current uptime of the system, which might be in seconds, minutes or hours as appropriate.

B.3 ADC and SMA input

MLC `mlc`

Access a list of sub-commands for querying and adjusting the mLC high speed ADC and SMA input.

REPORT `mlc,report`

Report device user-defined name, global flags, mLC board settings register, gain and the offset of the photodetector input. Please refer to section E.1.1 for more information about the global flags.

Use `mlc,report,1` to return as a python-compatible dict.

SETTINGS `mlc,settings`

Set or query the mLC settings register.

SMA `mlc,sma`

Access a list of sub-commands for querying and adjusting the mLC SMA input.

ENABLE `mlc,sma,enable`

Enables the ADC/laser mod SMA input.

DISABLE `mlc,sma,disable`

Disables the ADC/laser mod SMA input. When disabled the input is in a high-impedance state.

INPUT `mlc,sma,input`

Connects the SMA port to high speed ADC (AC or DC coupled) input or to laser direct current modulation. Please refer to section D.3 for more information about the options.

HSADC `mlc,hsadc`

Access a list of sub-commands for querying and adjusting the mLC high speed ADC.

ENABLE `mlc,hsadc,enable`

Enables the high speed ADC.

DISABLE `mlc,hsadc,disable`

Disables the high speed ADC, reducing power consumption drops by 300 W.

GAIN `mlc,hsadc,gain`

Set or query the ADC gain setting. The gain is discreet and can be 16, 8, 4, 2, 1, 0.5 or 0.25.

OFFSET `mlc,hsadc,offset`

Set or query the ADC input offset setting. The offset can be −4.096V to 4.096 V.

CAPTURE `mlc,hsadc,capture`

Returns an ADC captured vector. The output is a binary array of 2000 bytes, every two bytes represent a two's complement signed `int16` value giving a total vector length of 1000 points. The time discretisation is equal to `pzt,period` value divided by 1000.

ERRSIG `mlc,hsadc,errsig`

Returns an error signal vector with format as above.

B.4 Temperature controller

TEC `tec`

Access a list of sub-commands for querying and adjusting the mLC temperature controller.

REPORT `tec,report`

Report the state of the TEC controller, flags, V_{TEC}, T_{TEC}, I_{TEC}, current limit, T_{SET}, T_{MAX}, T_{LIM}, PID coefficients K_P, K_I, K_D, enabled/disabled state and TEC polarity. Please refer to section E.1.2 for more information about the TEC flags.

Use `tec,report,1` to return as a python-compatible dict.

TSET `tec,tset[,val]`

Set or query the required set temperature. $T_{SET} \leq T_{LIM}$.
`val` $\in [-10, 70]$ in °C.

TMAX `tec,tmax[,val]`

Set or query the absolute maximum temperature.
`val` $\in [-10, 70]$ in °C.

TLIM `tec,tlim[,val]`

Set or query the temperature limit. $T_{LIM} \leq T_{MAX}$.
`val` $\in [-10, 70]$ in °C.

POLINV `tec,polinv[,val]`

Set or query the TEC polarity inversion.
`val` $\in [0, 1]$ where 1 is true (invert).

ONOFF `tec,onoff[,val]`

Turns the TEC controller on/off.
`val` $\in [0, 1]$ where 1 is on.
`tec,onoff,toggle` toggles the controller state.

PID `tec,pid`

Sub-commands for querying and adjusting the TEC PID coefficients.

KP `tec,pid,kp`

Set or query the TEC PID proportional coefficient. $kp \in [0..10]$

KI `tec,pid,ki`
Set or query the TEC PID integral coefficient. $ki \in [0..1]$

KD `tec,pid,kd`
Set or query the TEC PID differential coefficient. $kd \in [0..1]$

B.5 Piezo controller

PZT `pzt`

Sub-commands for querying and adjusting the mLC piezo controller.

REPORT `pzt,report`

Report the state of the piezo controller, flags, scanning waveform type, ramp up/down rate, V_{LIM}, V_{SET}, V_{SWEEP}, scanning inversion, scanning period, external modulation maximum resistance R_{MAX}, external modulation set resistance R_{SET}, enabled/disabled state, piezo PID controller locking slope, overall PID gain coefficient K, K_P, K_I, K_D, dither enabled/disabled state and dither phase. Please refer to section E.1.3 and E.2 for more information about the piezo flags and waveform types.

Use `pzt,report,1` to return as a python-compatible dict.

VLIM `pzt,vlim[,val]`

Set or query the manual voltage limit. $V_{LIM} \leq 180$V.
`val` $\in [0, 180]$ in volts.

VSET `pzt,vset[,val]`

Set or query the required output voltage. $V_{SET} \leq V_{LIM}$.
`val` $\in [0, V_{LIM}]$ in volts.

VSWP `pzt,vswp`

Set or query the piezo scanning amplitude. $V_{SWP} \leq V_{LIM}$.
`val` $\in [0, V_{LIM}]$ in volts.

SWPINV `pzt,swpinv`

Set or query the piezo scanning polarity inversion.
`val` $\in [0, 1]$ where 1 is true.

SWEEP `pzt,sweep[,wave][,duty]`

Start piezo scanning.
`duty` is the duty cycle percentage between 1 and 99.
`wave` refer to wavetype (section E.2).

PERIOD `pzt,period[,val]`

Set or query the piezo scanning period.
`val` is time in milliseconds.

HOLD `pzt,hold`
Stop piezo scanning and set the output voltage to V_{SET}.

ENABLE `pzt,enable`
Enables the piezo controller.

DISABLE `pzt,disable`
Disables the piezo controller.

ONOFF `pzt,onoff[,val]`
Turns the piezo controller on/off.
`val` $\in [0,1]$ where 1 is on.
`pzt,onoff,toggle` toggles the controller state.

DITHER `pzt,dither[,val]`
Enable/disable the piezo dithering. The default dithering frequency is 262.5 kHz.
`val` $\in [??]$.

DITHPHASE `pzt,dithphase[,val]`
Set or query the piezo dithering phase.
`val` $\in [-180, 180]$ degrees.

EXTMODR `pzt,extmodr[,val]`
Set or query the piezo external modulation amplitude potentiometer value.
`val` $\in [??]$.

LOCK `pzt,lock,{index},{locking type}`
Enables the servo controller and locks it to either a particular ADC input value or 0 V. The *locking type* parameter can be either 0 or 1 which corresponds to lock to 0 V or to a particular input value respectively. The *index* parameter is the index in the ADC input vector array which the servo should be locked to. For example if the index points to the value of 1.5 V then the servo controller will

be locked to 1.5 V. If the *locking type* is set to 0 then the *index* parameter is ignored.

PID `pzt,pid`
Sub-commands for querying and adjusting the piezo PID parameters.

SLOPE `pzt,pid,slope`
Set or query the piezo PID locking slope which can be either rising (1) or falling (−1).

K `pzt,pid,k`
Set or query the piezo PID overall gain.
$k \in [0..2]$

KP `pzt,pid,kp`
Set or query the piezo PID proportional coefficient.
$kp \in [0..1]$

KI `pzt,pid,ki`
Set or query the piezo PID integral coefficient.
$ki \in [0..1]$

KD `pzt,pid,kd`
Set or query the piezo PID differential coefficient.
$kd \in [0..1]$

B.6 Laser diode controller

LD `ld`

Sub-commands for querying and adjusting the mLC laser diode controller.

REPORT `ld,report`

Report the state of the laser diode controller, flags, scanning waveform type, ramp up/down rate, V_{COMPL}, I_{MAX}, I_{LIM}, I_{BIAS}, scanning inversion, scanning period, I_{SET}, I_{MON}, V_{MON} and the enabled/disabled state of the controller. Please refer to section E.1.4 and E.2 for more information about the laser diode controller flags and waveform types.

Use `ld,report,1` to return as a python-compatible dict.

VCOMPL `ld,vcompl`

Set or query the compliance voltage. $V_{COMPL} \leq 8.5\,\mathrm{V}$.

ISET `ld,iset`

Set or query the required laser diode current. $I_{SET} \leq I_{LIM}$.

IMAX `ld,imax`

Set or query the absolute maximum laser diode current. This current should not exceed the maximum operating current of the laser diode.

ILIM `ld,ilim`

Set or query the manual limit of the laser diode current. $I_{LIM} \leq I_{MAX}$.

ISWP `ld,iswp`

Set or query the laser diode current scanning amplitude. $I_{SWP} \leq I_{LIM}$.

SWPINV `ld,swpinv`

Set or query the laser diode scanning polarity inversion.

SWEEP `ld,sweep[,wave][,duty]`

Start laser diode current scanning.
`duty` is the duty cycle percentage between 1 and 99.
`wave` refer to wavetype (section E.2).

PERIOD `ld,period[,val]`
Set or query the laser diode current scanning period. `val` is time in milliseconds.

HOLD `ld,hold`
Stop laser diode scanning and set the output current to I_{SET}.

ENABLE `ld,enable`
Enables the laser diode current controller.

DISABLE `ld,disable`
Disables the laser diode current controller.

ONOFF `ld,onoff[,val]`
Turns the laser diode current controller on/off.
`val` $\in [0, 1]$ where 1 is on.
`ld,onoff,toggle` toggles between on and off.

B.7 Ethernet configuration

The default ethernet configuration is DHCP enabled. If DHCP negotiation fails, the fall-back static IP address is 10.1.1.190 with port 7802. TCP/IP parameters can be reconfigured using the commands below. For the following, if the argument is absent, the command will return the current value or status.

static `ETH,static,"xxx.xxx.xxx.xxx"`
Set static IP address based on decimal dotted-quad string (e.g. "10.1.1.190"). Note that the double-quotes are part of the syntax and must be included to delimit the IP address string.

mask `ETH,mask,"xxx.xxx.xxx.xxx"`
Set IP mask based on dotted-quad string (e.g. "255.255.255.0").

gw `ETH,gw,"xxx.xxx.xxx.xxx"` or `ETH,gate,"xxx.xxx.xxx.xxx"`
Set the IP gateway based on dotted-quad string (e.g. "10.1.1.1").

mac `ETH,mac,"xx:xx:xx:xx:xx:xx"`
Set the MAC address.

port `ETH,port,portnumber`
Set the TCP/IP port number (default 7802) for device communication.

dhcp `ETH,dhcp,[off,on]`

web `ETH,web,[off,on]`
Enable or disable DHCP or the integrated web server; both default to enabled. The argument can be `0, 1, off, on, dis, en` where `dis, en` are for disable or enable.

status `ETH,stat` or `ETH,ipaddr` or `ETH,ip`
Connection status.

info `ETH,info`
Extended connection information.

restart `ETH,res`
Restart the ethernet interface.

C. Communications

The mLC can be connected to a computer by USB or ethernet (TCP/IP) for use with the provided mogmlc app or integrated into existing control software. If you are experiencing difficulty in connecting to your device, please review the detailed instructions available at www.moglabs.com/support/software/connection.

C.1 Protocol

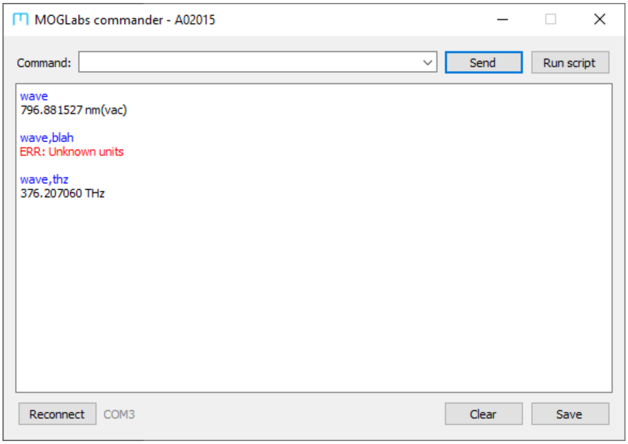
Communication follows a query/response protocol, where the user sends a text string to the unit, and the unit returns a text response.

Messages are CRLF-terminated; that is, all commands must end with ASCII code 0x0D 0x0A. The C syntax is \r\l. Most terminal applications automatically append these characters. Responses from the unit should be buffered until CRLF is received. It is strongly recommended to check command responses to ensure correct operation.

Statements are either **commands** or **queries**. A command is a statement that causes some action to occur, and the unit will respond with either "OK" or "ERR" as appropriate. It is strongly recommended that all software should wait for this response and check for success before continuing. The python and LabVIEW bindings available on the MOGLabs website take care of buffering and error checking automatically. The *MOGLabs Commander* application (mogcmd), available from the mLC app or as a separate tool from our website, provides a convenient interface for sending commands and receiving responses (Figure C.1).

C.2 TCP/IP

The mLC can be accessed over ethernet via the IPv4 protocol. When ethernet is connected, the mLC will attempt to obtain an IP ad-



```
wave
796.881527 nm(vac)

wave,blah
ERR: Unknown units

wave,thz
376.207060 THz
```

Figure C.1: The `mogcmd` application, showing successful and unsuccessful commands and queries.

dress by DHCP. If DHCP fails, an internally defined address (default `10.1.1.190`) will be used. In both cases, the address will be shown on the device display (e.g. `10.1.1.190:7802`), showing the address and port number for communicating with the device.

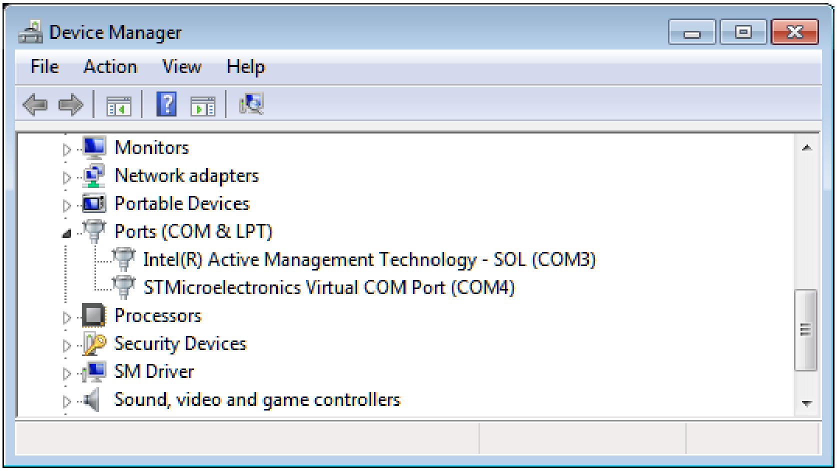
C.2.1 Changing IP address

If your network does not use a DHCP server, you may need to manually change the IP address. This can be done with the *MOGLabs Commander* (see above), first allowing the device to revert to the static IP address (usually `10.1.1.90`) and then using the ethernet configuration commands in section B.7. Note that in this case, the host computer must have an IP address different to that of the mLC but within the same network subnet. Please refer to our website, `https://www.moglabs.com/support/software/connection` for more information.

C.3 USB

The mLC can be directly connected to a host computer using a USB cable (type A-male). The correct USB device driver is packaged with the mogmfe software package or can be downloaded from www.moglabs.com/support/software/connection.

Connecting the mLC will install a new COM port on the machine. To determine the port number of the device, go to Device Manager (Start, then type Device Manager into the Search box). You should see a list of devices including "Ports" (Figure C.2).



Monitors
Network adapters
Portable Devices
Ports (COM & LPT)
Intel(R) Active Management Technology - SOL (COM3)
STMicroelectronics Virtual COM Port (COM4)
Processors
Security Devices
SM Driver
Sound, video and game controllers

Figure C.2: Screenshot of Device Manager, showing that the mLC can be communicated with using COM4. The port number might change when plugging into a different USB port, or after applying a firmware update.

The mLC can be identified as a COM port with the following name,

```
STMicroelectronics Virtual COM Port (COMxx)
```

where xx is a number (typically between 4 and 15).

If the port appears in Device Manager with a different name, then the driver was not successfully installed. If this occurs, disconnect the mLC from the host computer and reinstall the device driver.

Please refer to our website, `https://www.moglabs.com/support/software/connection` for more information on connecting.

D. Connector pinouts

D.1 Power

Power is provided by the USB-C connection. Only high quality USB-C (USB 3.0–3.2) cables with a power delivery capacity of at least 60 W should be used.

D.2 Interlock/key

The front-panel interlock socket is a standard 3.5 mm cylindrical stereo headphone jack. The outer conductor is supplied with 3.3 V via a 1 k resistor. The mLC board will be enabled by shorting the respective signal pin to the outer conductor.

Digikey cable CP-2207-ND provides a 3.5 mm plug with wire ends.

1	+3.3 V via 1 kΩ
2	Key input
3	Interlock input

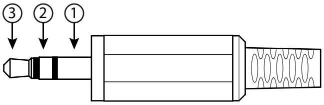


Figure D.1: Interlock/key 3.5 mm stereo connector on front panel.

Note: Do not apply a voltage across the interlock pins, or the mLC may be irreversibly damaged!

D.3 SMA signal input

The input signal SMA connector can be multiplexed to different internal circuits, depending on required application. The following table shows the options.

NC	Not connected
AC	High speed ADC AC-coupled input
DC	High speed ADC DC-coupled input
Imod	Direct diode current modulation

E. Troubleshooting

E.1 State flags

Flags are used to monitor the states of every mLC control component (TEC, laser diode, piezo) as well as the overall state of the controller itself and can be very helpful in troubleshooting. The flags are constantly updated and can be accessed via report commands (see Chapter B). The flags are reported in hexadecimal format.

The mLC flags provide information about global triggers (interlock, power good etc.). The submodule flags provide information about the internal monitors and abnormal conditions. Some bits in the flags are constantly updated showing the current state of the signal. Other bits are showing if a certain signal has been triggered, which helps to determine what signal caused the shutdown. The trigger signals can only be reset by re-enabling the interlock.

A detailed description of each flag is given below.

E.1.1 Global (MLC) flags

Flag name	HEX	Description
FLAG_GLOB_INTRLK_ENABLED	0x01	Interlock enabled
FLAG_GLOB_POWERGOOD	0x02	Power good
FLAG_GLOB_KEYSW	0x04	Keyswitch enabled
FLAG_GLOB_INTRLK	0x08	Interlock input

E.1.2 Temperature controller flags

Flag name	HEX	Description
FLAG_TEC_PGOOD	0x01	Power good
FLAG_TEC_SHORT_CIRCUIT	0x02	TEC short-circuit
FLAG_TEC_OPEN_CIRCUIT	0x04	TEC open-circuit
FLAG_TEC_NTC_DISCONNECTED	0x08	Thermistor disconnected
FLAG_TEC_TEMPERATURE_OVERRUN	0x10	Temperature overrun

E.1.3 Piezo controller flags

Flag name	HEX	Description
FLAG_PZT_PGOOD	0x01	Power good

E.1.4 Laser diode controller flags

Flag name	HEX	Description
FLAG_LD_ILIM_TRIG	0x01	Current limit triggered
FLAG_LD_SHORT_CIRCUIT	0x02	Laser diode short-circuit
FLAG_LD_OPEN_CIRCUIT	0x04	Laser diode open-circuit
FLAG_LD_LOW_COMPLIANCE	0x08	Current source compliance voltage too low

E.2 Scanning waveforms

The mLC controller supports scanning the piezo voltage (0 to V_{LIM}V) and laser diode current (0 to 25mA). The scanning waveform can be one of the following.

Wave name	Value	Description
TYPE_NONE	0	None (DC)
TYPE_SAWTOOTH	1	Sawtooth shape
TYPE_SINE	2	Sine shape
TYPE_TRIANGLE	3	Triangular shape

For additional assistance please contact MOGLabs. Please include the device serial number and firmware versions.

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