moglabs

Digital Diode Laser Controller

dDLC

Revision 1.0.1, Firmware v1.13.3

Limitation of Liability

MOG Laboratories Pty Ltd (MOGLabs) does not assume any liability arising out of the use of the information contained within this manual. This document may contain or reference information and products protected by copyrights or patents and does not convey any license under the patent rights of MOGLabs, nor the rights of others. MOGLabs will not be liable for any defect in hardware or software or loss or inadequacy of data of any kind, or for any direct, indirect, incidental, or consequential damages in connections with or arising out of the performance or use of any of its products. The foregoing limitation of liability shall be equally applicable to any service provided by MOGLabs.

Copyright

Copyright © MOG Laboratories Pty Ltd (MOGLabs) 2007 – 2025. No part of this publication may be reproduced, stored in a retrieval system, or transmitted, in any form or by any means, electronic, mechanical, photocopying or otherwise, without the prior written permission of MOGLabs.

Contact

For further information, please contact:

MOG Laboratories P/L
49 University St
Carlton VIC 3053
AUSTRALIA
+61 3 9939 0677
info@moglabs.com

MOGLabs USA LLC
419 14th St
Huntingdon PA 16652
USA
+1 814 251 4363
www.moglabs.com

Preface

Diode lasers can be wonderful things: they are efficient, compact, low cost, high power, low noise, tunable, and cover a large range of wavelengths. They can also be obstreperous, sensitive, and temperamental, particularly external cavity diode lasers (ECDLs). The electronics needed to achieve research-quality performance must be sophisticated and precise, with careful adherence to ultra-low-noise design principles. Those demands are amplified when combining with the digital control systems required by modern complex quantum systems.

The MOGLabs dDLC laser controller provides everything needed to operate an ECDL, and lock it to an atomic transition, high finesse optical cavity, or beatnote offset lock to a femtosecond comb. In addition to current and temperature controllers, the dDLC provides piezo drivers, sweep ramp generator, modulator for AC locking, lock-in amplifier, feedback servo system, and Fourier-spectrum analysis.

We hope that the dDLC meets your expectations. Please let us know if you have any suggestions for improvement in the dDLC or in this document, so that we can make life in the laser lab easier for all, 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 your laser. Also please note several specific and unusual cautionary notes before using the MOGLabs dDLC, 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 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.
- The STANDBY/RUN keyswitch must be turned to RUN before the laser can be switched on. The laser will not operate if the keyswitch is in the STANDBY position. The key cannot be removed from the controller when it is in the clockwise (RUN) position.

- To completely shut off power to the unit, turn the keyswitch anti-clockwise (STANDBY position), switch the mains power switch at rear of unit to OFF, and unplug the unit.
- When the STANDBY/RUN keyswitch is on STANDBY, there cannot be power to the laser diode, but power is still being supplied to the laser head for temperature control.

CAUTION Please ensure that your AC mains supply voltage and frequency are within the specified limits (see appendix A) before connecting. The supply must include a good ground connection.

CAUTION To ensure correct cooling airflow, the unit should not be operated with cover removed and the side vents must be unobstructed.

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

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

Protection features

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

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 Both the dDLC and the laser head board have hardware interlocks, to permit integration with safety system requirements such as door interlocks or ensuring the laser cannot be operated without the laser cover.

Protection relay When the laser is turned off, the laser diode is shorted via a normally-closed solid-state relay at the laser head board.

Emission indicator The dDLC has LED indicators indicating the operational status of the laser, and the MOGLabs laser headboard will illuminate an emission warning indicator LED immediately when the laser is switched on.

Softstart Upon starting emission, the laser current is linearly ramped up to the setpoint current at 100 mA/sec.

Current limit Sets a maximum permitted diode injection current output by the dDLC in all operating modes[1]

---

[1] Note that this limit can be circumvented by current modulation into the SMA connector on the laser headboard when enabled.

Circuit shutdown	Many areas of the circuitry are powered down when not in use. The high voltage supply and piezo drivers, the diode current supplies, the coil driver, and others are without power when the unit is in standby mode, if an interlock is open, or a fault condition is detected.
Cable continuity	If the laser is disconnected, the system will switch to standby and disable all laser and piezo 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 limits	If the detected temperature is below 7°C or above 50°C, the temperature controller is disabled. User-adjustable limits are also provided to prevent accidental operation outside intended temperature ranges.
Internal supplies	If any of the internal DC power supply voltages are detected outside their prescribed range, the system will enter a fail-safe state.
Mains filter	Protection against mains transients.

Extending laser lifetime

MOGLabs strongly recommends setting your dDLC 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.

At night, switch to standby:

1. Switch the laser diode current off.

   Don't adjust the current, just press the on/off push-button to power off the diode.

2. Switch from RUN to STANDBY.

The temperature controller will continue to operate, ensuring the laser is ready for quick startup the next day, but the laser diode current and piezo voltage are powered down, extending their operating life.

In the morning, switch back on:

1. Switch from STANDBY to RUN.

2. Switch the laser diode on by pressing the push-button.

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

Contents

1. Quick start

The MOGLabs dDLC can be used in various configurations, including simple current/temperature controller, passive frequency controller with internal or external sweep/scan, and as a complete system for active frequency stabilisation with AC, DC or external locking signal. Here is a quick start so that you can connect and go rapidly. More details are provided in chapter 2.

1.1 Hardware connections

In the simplest configuration, the MOGLabs dDLC will be used to control the diode injection current and laser temperature. All connections are via the rear panel (Figure 1.1). Ensure that side vents and the rear fan vent are unobstructed.

An interchangeable connector plate can be used for different configurations; the standard setup is described below.

Do not hotplug the laser: Ensure that the dDLC is powered off when connecting or disconnecting the laser cable from either the dDLC or laser head.

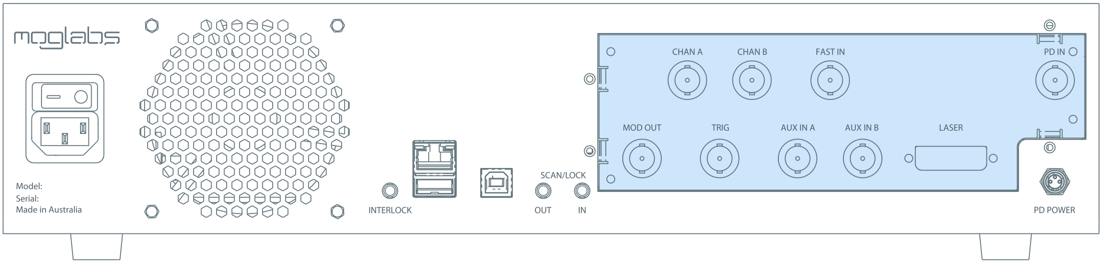
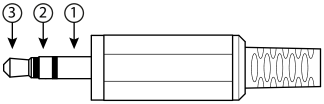
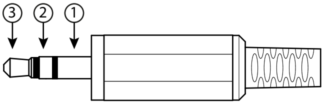


Figure 1.1: Rear-panel of the MOGLabs dDLC, including an interchangeable plate (shaded blue) which allows alternate connector arrangements for optional configurations.

IEC	Connector for mains power, 90 – 250 Vac, 43 – 63 Hz.
INTERLOCK	Standard stereo 3.5 mm headphone jack for connecting to an external interlocking system (see §2.1). Pins ① and ③ must be short-circuited to enable laser emission. *Do not supply any voltage to this input; use a relay if necessary to interface with logic levels.* 
LAN/USB	Twisted pair 10/100 ethernet (RJ45 connector) and USB type-B (printer-style) connections for communication to host computer. The USB type-A connector below the ethernet socket is reserved for external device connections.
LASER	DVI connector to connect the dDLC to a compatible laser head. Only high quality digital ***dual-link*** DVI-D DL cables should be used. **Ensure that the dDLC is powered off when connecting or disconnecting this cable.**
PD IN	BNC connector for photodetector signal input to monitor and lock laser.
AUX IN A/B	BNC connectors for auxiliary input signals, which can optionally be used for monitoring and locking.
MOD OUT	BNC connector for an external modulation coil to permit AC locking to an alkali cell using the Zeeman modulation technique (§3.2).
CHAN A/B	BNC connectors for configurable monitor analog outputs. The output signals can be selected via the control software or front-panel interface.
TRIG	BNC connector providing a *rising* TTL output trigger in the centre of the sweep.
PD POWER	Photodetector power (±15 V). Standard M8 connector pin-compatible with MOGLabs and THORLABS photodetectors.

SCAN/LOCK Stereo 3.5 mm headphone jack active-low TTL input/output for lock control. Providing an active low signal to the contacts of the IN jack will engage the associated lock, for interfacing with an external control system. Similarly the OUT jack outputs TTL low on pins ② and ③ respectively when the slow and fast locks are engaged, for monitoring or connecting to an external servo.



①: Common, ②: Slow lock, ③: Fast lock.

1.2 Front panel

This manual describes the standard dDLC with complete front panel (Figure 1.2), which allows operation via the on-device controls, or remotely from a host computer. An alternate version is available with a blank front panel for remote only operation.

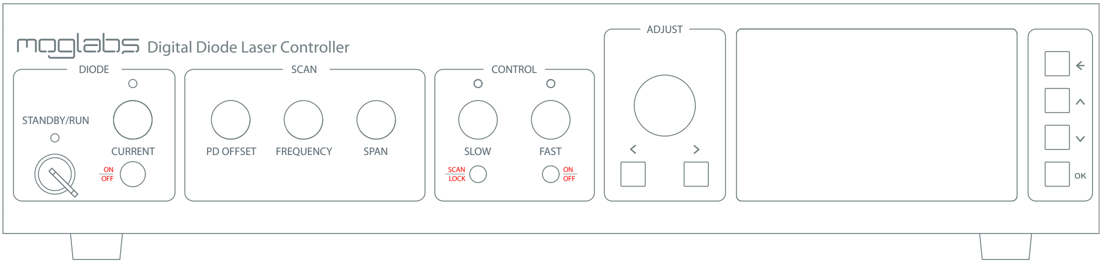


Figure 1.2: Fully-featured front-panel user-interface of the MOGLabs dDLC. The simplified “remote only” front-panel only contains the keyswitch.

DIODE Indicators for the operational state of the laser diode and controls to enable/disable the laser emission.

STANDBY/RUN Safety keyswitch and multicolour indicator LED. Must be set to the RUN position to permit laser emission, see §2.1.1.

		Turning to STANDBY will immediately power down the laser diode and piezo driver, but temperature control will continue. When the key is at STANDBY, it cannot be overridden remotely.
	ON/OFF	Laser emission control and status LED indicator. Pressing the ON/OFF pushbutton toggles laser emission.
	CURRENT	Adjustment for laser diode setpoint current.
SCAN		Photodetector offset adjust and piezo-electric actuator control. These controls are inactive when the laser is locked.
	PD OFFSET	DC offset of the photodetector signal.
	FREQUENCY	Laser frequency adjust: controls the average voltage applied to the piezoelectric transducer for selecting the lasing frequency. Also referred to as OFFSET.
	SPAN	Laser frequency sweep amplitude: controls the *height* of the sawtooth ramp driving the piezo, which sweeps the laser frequency (see §2.4).
CONTROL		Frequency stabilisation (locking) control. The dDLC has two servo controllers (SLOW and FAST) which can be operated independently or in combination (see chapter 3).
	SLOW, FAST	Gain adjust for slow (piezo) and fast (current) feedback.
	SCAN/LOCK	Pushbutton toggle between scanning (unlocked) and slow feedback enabled (locked).
	ON/OFF	Pushbutton toggle for slow/fast feedback locking. Engaging either lock will halt the voltage ramp to the piezo.
ADJUST		Pushbuttons and rotary encoder for stepping through on-screen menus and adjusting selected parameters. Note that the ADJUST encoder is also a pushbutton which is a context-dependent control to change the operation of the encoder.
LCD display		The display provides for detailed local operation of the device through a cascaded menu system, independent of a host computer. The adjacent buttons are used for navigating the menu system. The display also integrates a real-time oscilloscope function.

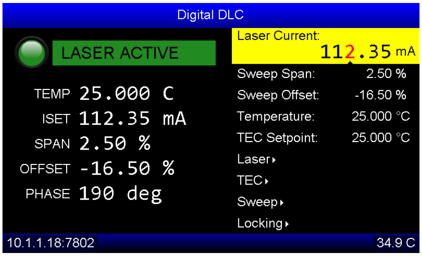
1.3 Powering up

1. Ensure all hardware is connected - namely power, interlock and laser. Do not connect or disconnect the LASER DVI cable while the device is powered on.
2. Turn on the unit's rear power switch (above the IEC power input).
3. The LCD display will show the device boot sequence is in progress.
4. Once boot is complete, the menu system will be shown on the display 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. Turn the keyswitch to RUN.
7. Verify that the measured laser temperature starts converging towards the setpoint temperature.
8. Set the laser diode current, initially slightly above the threshold current specified in the laser test report and definitely below the safe operating current without feedback, if specified.
9. Press the ON/OFF button to activate the laser diode.
10. Verify that emission is observed from the laser.
11. Increase the setpoint current to the intended operating current of the laser.
12. Control the laser using the front panel controls and menu system or the host computer interface described below.

1.4 Front panel control

The dDLC can operate as a standalone device using the front panel display for intuitive control of the laser and controller functions. The left-hand side of the display shows a readout of the current device status and the right-hand side provides an interactive menu system.



Digital DLC

LASER ACTIVE

TEMP 25.000 C
ISET 112.35 mA
SPAN 2.50 %
OFFSET -16.50 %
PHASE 190 deg

Laser Current: 112.35 mA
Sweep Span: 2.50 %
Sweep Offset: -16.50 %
Temperature: 25.000 °C
TEC Setpoint: 25.000 °C

10.1.1.18:7802
34.9 C

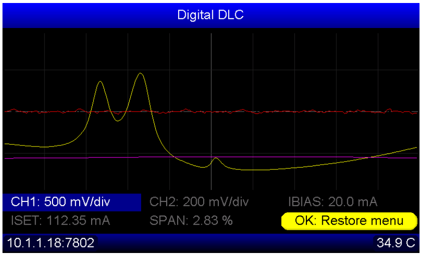
The up/down buttons select between menu items, OK enters a sub-menu and ← returns to the parent menu. Turning the ADJUST knob modifies the selected value, and the left/right buttons change the digit to be adjusted (shown in red).

1.4.1 Oscilloscope mode

The front panel includes a simple integrated oscilloscope function similar to the Windows® app. Pressing the ← button from the menu system root page will display the oscilloscope. The photodetector signal is shown in yellow and the error signal in red. When the laser is locked the last scan (yellow trace) is frozen and the active capture is shown in magenta for comparing against the expected lock point.

Several parameters can be adjusted while in oscilloscope mode without re-entering the menu system. Press the < or > buttons to select a parameter (highlighted with a blue background), and then turn the ADJUST knob to change it.

Turning any of the other front-panel knobs will display a yellow indicator box showing the value of the modified parameter.



CH1: 500 mV/div
CH2: 200 mV/div
IBIAS: 20.0 mA
ISET: 112.35 mA
SPAN: 2.83 %
10.1.1.18:7802
34.9 C

Figure 1.3: Example showing the integrated oscilloscope functionality

1.5 Remote PC operation

The dDLC is designed for remote operation from a PC, either from the provided standalone Windows® application or by integration into custom lab control software using a simple ASCII command interface. The command language is defined in Appendix B and requires no custom device drivers or specific software library[1].

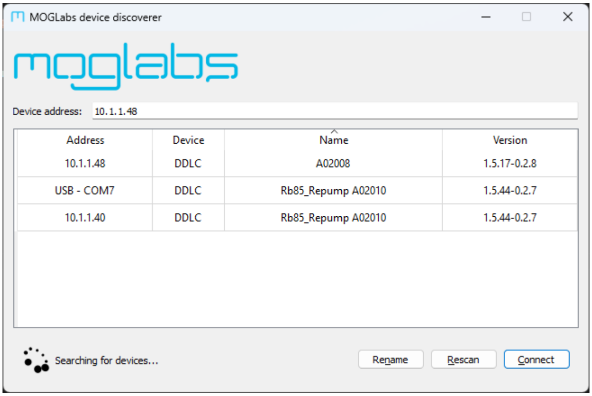
The dDLC app is available from our website. Install and start the app, which should then show the device discoverer (Figure 1.4) which searches for dDLC devices accessible over USB or the local network. MOGLabs recommends using the network interface rather than USB if possible. Select the intended device and click *Connect*.

Caution: When multiple dDLCs are available on your network, be sure to double-check the name and/or serial number of the device when connecting.

The dDLC app (Figure 1.5) provides control of the laser, and an integrated oscilloscope for adjusting the laser scan parameters and operating the feedback servos. The virtual controls on the left-hand side of the window duplicate the functionality on the device front-panel, and pressing the "…" button brings up associated settings. Detailed information about using the application is provided in §4.1.1.

---

[1] The OS's socket/serial port drivers can be used directly from any language.



Device address: 10.1.1.48

Address	Device	Name	Version
10.1.1.48	DDLC	A02008	1.5.17-0.2.8
USB - COM7	DDLC	Rb85_Repump A02010	1.5.44-0.2.7
10.1.1.40	DDLC	Rb85_Repump A02010	1.5.44-0.2.7

Figure 1.4: MOGLabs device discoverer which shows dDLC devices available via USB and network interfaces.

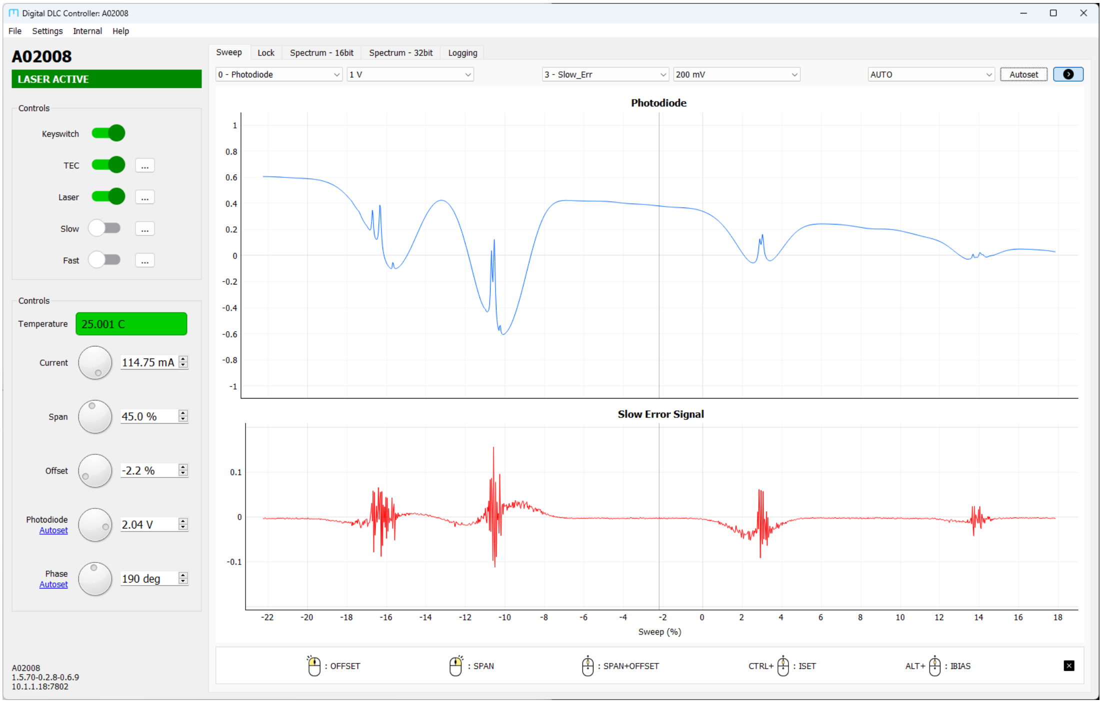
The scope automatically displays the measured photodetector voltage and the error signal against time, for identifying and locking to features of interest. The oscilloscope supports mouse interactions and gestures (see §4.2.1) including dragging to adjust the sweep offset and mouse-wheel to adjust the span.

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

1.6 Locking with internal error

The dDLC can frequency-stabilise the laser using a number of techniques, as detailed in chapter 3. One of the most common use-cases is to lock to an alkali atomic absorption resonance, for example with the MOGLabs MGSA saturated absorption reference device.

Here is a quick outline of how to use the PC app in this scenario, although the front-panel controls can also be used.



0 - Photodiode
1 V
3 - Slow_Err
200 mV
AUTO

Temperature 25.001 C
Current 114.75 mA
Span 45.0 %
Offset -2.2 %
Photodiode 2.04 V
Phase 190 deg

A02008
1.5.70-0.2.8-0.6.9
10.1.1.18:7802

Figure 1.5: MOGLabs dDLC Windows® application for control and monitoring dDLC devices.

1. Adjust diode current to achieve a stable operating mode at the required optical power.
2. Ensure the temperature of the laser has stabilised at the operating diode current (as shown in the *Logging* tab).
3. Increase the SPAN (e.g. to 25%) to see the spectral features of interest. Adjust the diode setpoint and bias currents to achieve continuous scans without mode-hops (see also §2.5).

   The error signal may appear noisy at large span, as shown in Figure 1.6(A). This is expected behaviour.
4. Reduce SPAN to zoom in on the desired locking feature.

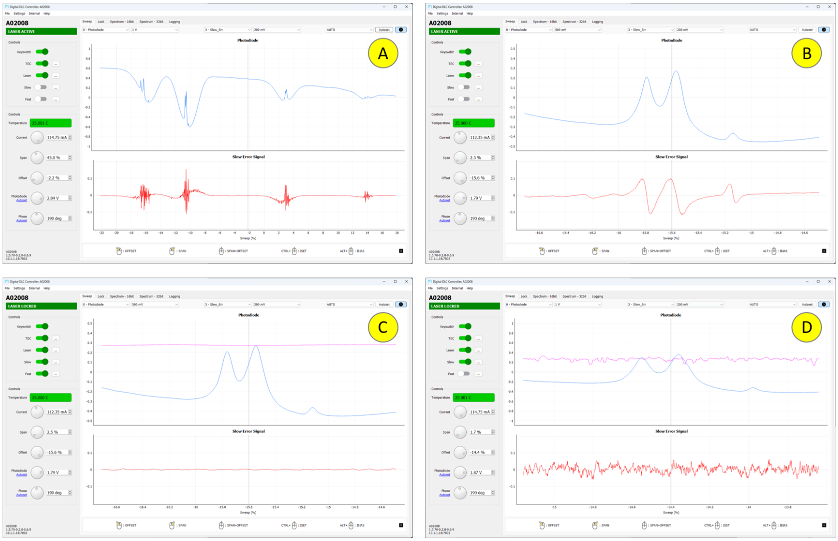


Figure 1.6: Typical saturated absorption spectra at wide span (A) and narrow span (B) with optimised phase. Engaging the lock stabilises to the peak (C) and increasing the gain too far leads to oscillation (D).

5. Increase the dither current in the *Laser Settings* until an error signal can be seen.

6. Adjust phase to optimise the error signal for largest *negative* slope at the locking point.

7. Adjust the dither current and/or master gain so that error signal amplitude is about 100 mV. Where possible the master gain should be kept close to unity.

8. Adjust the error offset to adjust the zero-crossing. The error signal should be smoothly varying and cross zero at the intended lock point, such as Figure 1.6(B).

9. Press the SLOW slider button to engage the lock. As shown in Figure 1.6(C), the unlocked photodetector signal trace (blue) maintains the last photodetector trace before the piezo is set

to the lock point, enabling comparison against the locked photodetector signal (magenta).

If the DC value does not match the intended setpoint, follow the lock troubleshooting guide in §3.8.

10. Increase the slow gain K_p until the error signal amplitude starts to destabilise such as Figure 1.6(D), then reduce K_p by approximately 10% until the residual fluctuations are minimised.

11. Engage the FAST lock and verify the DC photodetector signal (magenta) does not jump. The PD level changing significantly indicates it has jumped out of lock, so check the servo polarity and/or fast master gain.

12. Increase the fast gain K_p until the error signal amplitude is minimised.

13. If required, further optimisation can be achieved using the spectrum analyser mode as described in §3.6.

2. Laser operation

The dDLC performs five critical functions for laser operation: safety interlocking, temperature stabilisation, injection current control, frequency sweep, and frequency locking.

2.1 Safety interlocking

It is a legislative safety requirement in many jurisdictions that safety protocols be guaranteed in hardware when operating class-3B+ lasers. These protocols prevent potential harm to operators by ensuring the laser cannot be accidentally activated and that a clear mechanism is provided for disabling the laser in hardware.

To satisfy these requirements, the following preconditions must be met to permit laser emission. Violating any of these conditions will cause immediate cessation of the laser emission and show an error message on the display.

1. The laser headboard must be connected at power-on.

   Hotplugging the laser headboard is not supported, and the system must be powered down before attaching/detaching the headboard.

2. The external hardware interlock on the dDLC back-panel must be *short-circuited* (see §1.1).

   This is intended to integrate with laboratory interlocking systems[1] (such as door interlocks or emergency-stop). MOGLabs supplies a short-circuit plug which should only be used to bypass this requirement where external interlock systems are not required by local safety legislation.

---

[1] The external interlock input may be damaged by logic-level inputs and a relay is recommended for interfacing with logic-level systems. Confirm the details of your interlock system before connecting it to the dDLC.

3. The hardware interlock on the laser headboard must be *short-circuited*.

   Generally this is not required on class-3B lasers such as MOGLabs ECDLs, but is often connected to a case-switch on class-4 lasers to ensure the laser is switched off when the laser case is removed.

4. The hardware keyswitch on the dDLC front-panel must be turned to the *Run* (“on“) position.

   The keyswitch can be disabled remotely by software to guarantee the system is disabled, but it is not possible to override the keyswitch from the *Standby* position.

5. Any critical error must be cleared by toggling the keyswitch to *Standby* and back to *Run* again.

   Toggling the keyswitch can be done remotely, but only when the physical keyswitch is in the *Run* position.

Any unmet requirements will be displayed on the front-panel OSD, or can be interrogated using the `STATUS` command.

2.1.1 Keyswitch behaviour

Upon powering-up the dDLC, it is necessary to toggle the keyswitch[2] before the system becomes active. Turning the keyswitch from the *Standby* to *Run* position activates the TEC immediately to begin temperature stabilisation. Laser emission will only begin when the *Laser* button is pressed.

Turning the keyswitch to the *Standby* position will power down the laser and ensure it cannot be activated until returned to the *Run* position. In this case the TEC will remain in operation while in *Standby* mode to keep the temperature stable, as this does not negatively affect the lifetime of the product.

---

[2] The toggle can be performed in software provided the physical keyswitch is in the *Run* position.

2.2 Temperature control

Diode lasers typically have very high sensitivity to changes in temperature, shifting their peak emission frequency in the order of 10 GHz/K. It is therefore very important to stabilise the temperature of the diode laser down to the 1 mK level, as even small drifts in the ambient environment can perturb the laser frequency at the 100 MHz level.

Most laser systems control the temperature of the laser using a thermoelectric cooler (TEC), also known as a Peltier device. Passive thermal stability is achieved by heatsinking the laser diode to the laser body, and active thermal stability uses a PID algorithm to adjust the current running in the TEC to maintain the temperature as measured by a thermistor near the laser diode.

The dDLC is capable of driving 2 A into the TEC to settle at a desired setpoint temperature, but typically the steady-state operating current is in the order of 100 mA to maintain a fixed temperature within a few degrees of ambient.

The relatively large heat capacity of the laser head means that the TEC exhibits significant control lag in normal operation. Reaching the setpoint temperature therefore often results in an overshoot of the desired temperature that is corrected over the course of a few minutes (Figure 2.1).

MOGLabs strongly recommends that the laser head be placed in thermal contact with an optical table (or similar) to provide a heatsink for the heat rejected from the TEC, as increased baseplate temperature reduces the operational efficiency of the TEC. We also recommend the laser head be isolated from strong air currents, particularly drafts from doors and air conditioning (HVAC) systems.

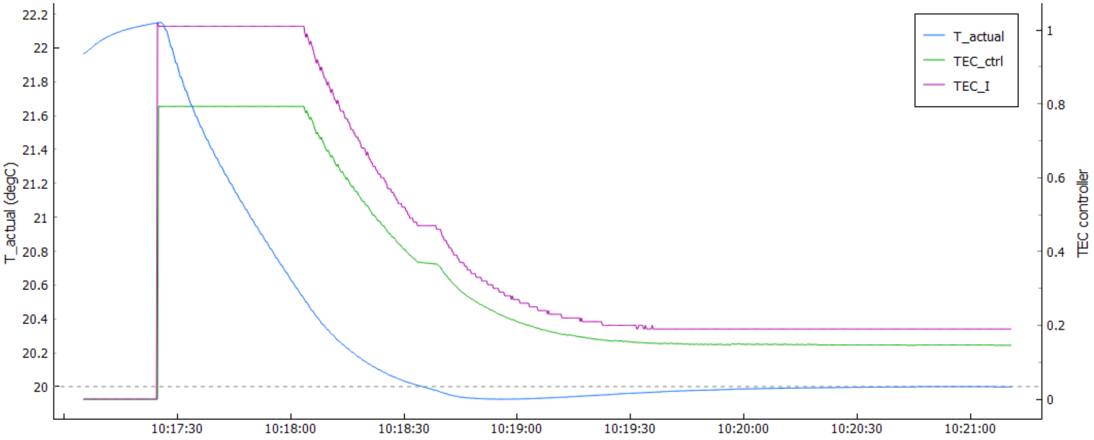


Figure 2.1: Example of temperature overshoot and stabilisation to setpoint temperature (dashed line) to 50 mK within 3 minutes. Exact performance depends on ambient conditions, drive current, and laser chassis.

2.3 TEC optimisation

Thermoelectric devices are manufactured with a wide variety of package sizes and performance characteristics. Common TEC packages used for ECDL laser-head stabilisation might achieve cooling rates in the order of 1°C/min, whereas a TEC integrated within a small butterfly package might achieve rates of 100°C/min.

The dDLC has user-adjustable TEC controller gain which can be adjusted on a per-laser basis from within the *TEC settings* (§4.3.1), to compensate for the TEC performance. This is substantially simpler than adjusting the individual PID gains of the controller and typically achieves near optimum performance with far fewer steps.

The recommended procedure is to induce a 1°C step-change in the setpoint temperature and measure the approach time, the degree of overshoot, and the damping time of any oscillations. Typically a clear optimum will be observed where the controller converges rapidly within 0.1°C and then settles without oscillation (Figure 2.2).

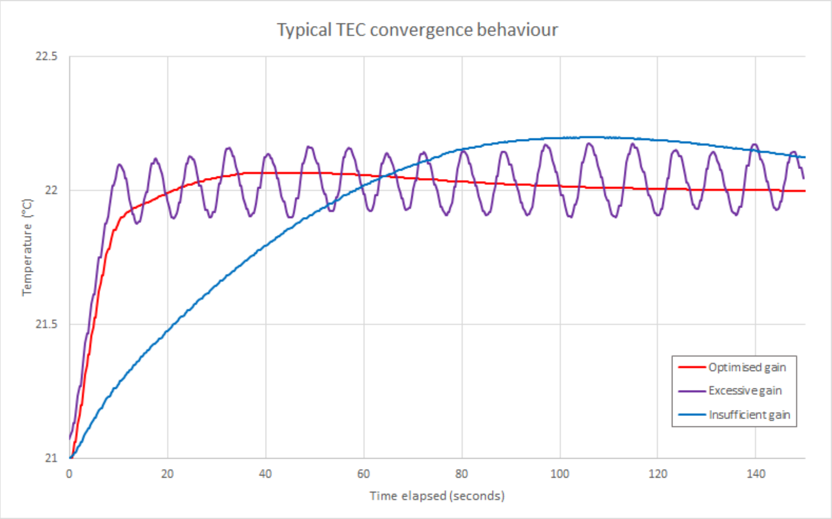


Figure 2.2: When the TEC control gain is too low, the temperature takes a long time to converge to the setpoint (blue), whereas when the gain is too high the controller oscillates without damping (purple). Optimising the gain yields rapid convergence with minimal overshoot (red).

Troubleshooting advice for common temperature control problems is provided in §2.9. If required, advanced users can adjust the individual PID feedback coefficients using specific commands (see §B.6).

2.3.1 Automatic gain reduction

If the dDLC detects that the TEC is unstable because the rate of temperature change is significantly higher than expected, it will automatically reduce the control gain by 3 dB until stable performance is obtained. Typically this will be achieved within 30 seconds.

This mechanism is intended as a fallback to prevent rapid oscillation when the TEC control gain substantially exceeds the stability threshold. The automatically-adjusted gain is unlikely to provide optimal performance and will likely require manual optimisation, but gives an indication of the stability region.

2.4 Frequency sweep

The wavelength output by an external cavity diode laser depends on the diode temperature, injection current and length of the external cavity. Typically these parameters need to be tuned in order to reach the emission wavelength of interest.

The simplest way to adjust the laser frequency is by tuning the external cavity length by sweeping the piezo voltage. This gives an approximately linear shift in frequency with a large degree of tunability (typically tens of GHz).

In normal (SCAN) mode, a sawtooth is supplied to the laser piezo actuator to linearly sweep the laser frequency (Figure 2.3). The amplitude of the wave is called the SPAN and the midpoint is called the OFFSET or FREQUENCY in reference to the lasing frequency.

The sweep rate is adjustable, and it may be preferential to sweep slowly for spectroscopy purposes, or rapidly to identify and narrow down on individual spectroscopic features for locking.

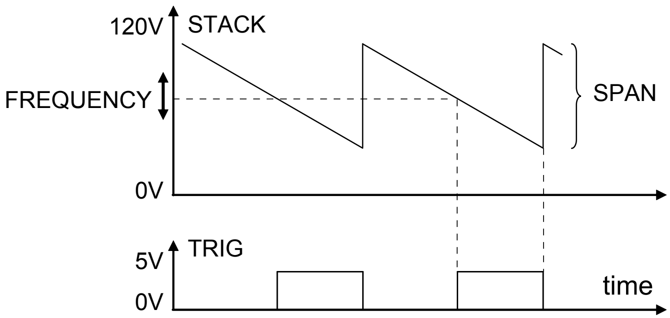


Figure 2.3: Example piezo output voltage (top) and trigger signal (bottom) when scanning. The rising trigger transition occurs when the piezo voltage is at the midpoint of the sweep. Note that the ramp slope can be inverted to sweep in the opposite direction.

2.5 Mode-hops and bias current

A more detailed understanding of the behaviour of the laser as a function of the actuator parameters is achieved by considering the frequency-dependent elements of the laser cavity. These elements include the external cavity controlled by the piezo, the laser diode internal cavity between the rear and front facets of the diode, the filter transmission or grating dispersion function, and the gain bandwidth of the laser diode.

The net gain is the combined product of semiconductor gain, filter or grating function, internal and external cavity interference, as shown schematically in Figure 2.4. Ignoring hysteresis, the lasing frequency corresponds to the peak of this gain spectrum. Sweeping the voltage on the piezo changes the length of the external cavity, which causes very small changes to the spacing of the external cavity gain curve peaks, effectively shifting the position of the peak gain.

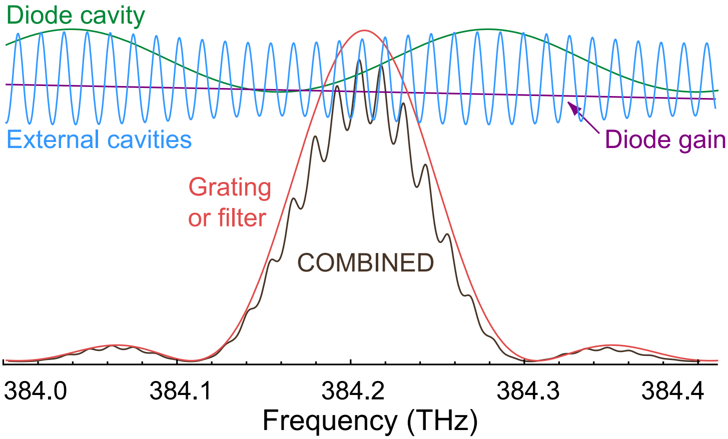


Figure 2.4: Schematic representation for the various frequency-dependent factors of an ECDL[3]. In this case the diode gain is so broad, variation cannot be seen on this scale.

---

[3] Adapted from S. D. Saliba et al. Mode stability of external cavity diode lasers. *Appl. Opt.*, 48(35):6692, 2009

However, the combined gain profile contains many local maxima, and in some circumstances the net gain can be very similar at adjacent external cavity modes (Figure 2.5).

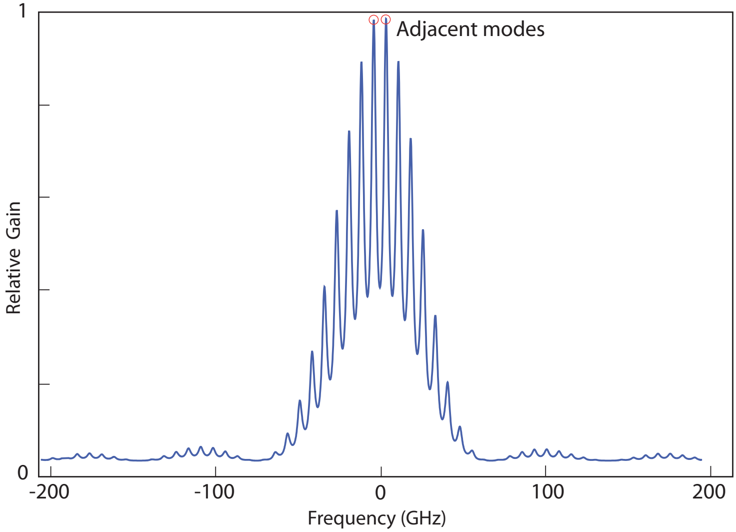


Figure 2.5: Combined gain for an external cavity diode laser, including the internal and external modes, the diode laser gain, and the filter or grating response. A small relative shift of the external cavity mode relative to the other contributions will cause the laser to jump to another external cavity mode where the net gain is higher.

Therefore despite smoothly adjusting the piezo voltage as part of the sweep, the lasing frequency can experience stepwise changes called ***mode hops*** because the net gain is higher at a different frequency. This prevents achieving a smooth linear sweep at arbitrary SPAN, which is quantified in terms of the *mode-hop-free scan range (MHFR)* of the laser mode. Figure 2.6 compares the measured frequency of a continuous sweep to one with a mode-hop at one edge of the scan.

Since the mode-hop behaviour depends on competition between all the contributions to the gain curve, the MHFR depends on temperature, diode injection current, piezo voltage and grating/filter angle.

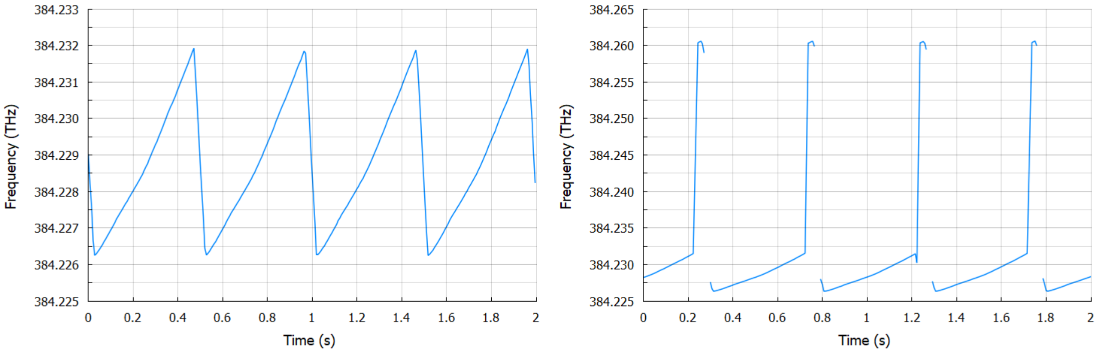


Figure 2.6: Frequency of a scanning laser measured with a MOGLabs FZW wavemeter showing stable sweep (left) and with a mode-hop at one edge of the scan (right). The mode-hop is about 30 GHz corresponding to one diode cavity mode in this laser.

In practice the injection current is carefully adjusted to optimise for the most *stable mode*.

This gives rise to a feed-forward technique of applying a *bias current* to the diode during the sweep which is proportional to the piezo voltage. This change in current perturbs the laser diode contributions to the gain curve, shifting the gain curve envelope to match the shift in the external cavity contribution, ensuring that the position of the overall peak wavelength is smoothly varying.

2.5.1 Bias optimisation

As mode-hops arise from competition between the resonant modes of the lasing cavity, scanning the laser typically demonstrates strong hysteresis as the gain of the actively lasing mode must be significantly suppressed before a competing mode overtakes it. This makes optimisation of the bias current an iterative process, as it is sensitive to a number of parameters.

Although mode-hops can sometimes be identified directly by observing step-changes in the optical power measured on a photodiode,

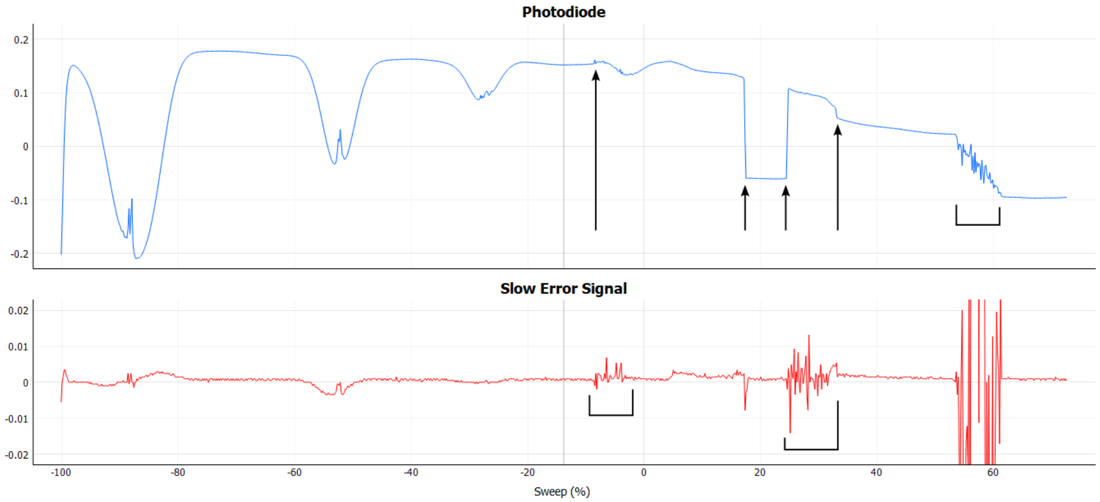


Figure 2.7: Mode-hops can sometimes be identified in a photodiode signal as step-changes in the optical power (arrows), or areas of high noise where the mode competition is unstable (marked sections). However, not all mode-hops are as easily identified in the photodiode signal.

it is strongly recommended to use a direct frequency discriminator such as a wavemeter or scanning Fabry-Perot cavity.

The following procedure is recommended for optimising the bias current to achieve the best MHFR.

1. Initially set the OFFSET and SPAN to zero.
2. Adjust the *Setpoint Current* to achieve a stable mode near the desired wavelength and required optical power. Refer to the laser manual and/or factory test report as a guide for expected parameters and performance.
3. Open the *Laser Settings* and set the *Bias Current* to zero.
4. If the wavelength is more than a few GHz away from your target frequency, make small adjustments to the injection current,

operating temperature and/or mechanical filter/grating alignment per the laser manual to achieve the operating wavelength.

5. Increase the SPAN while observing the wavemeter *Long Term* measurement to observe the sweeping behaviour (or equivalently the transmission of a scanning Fabry-Perot cavity), such as in Figure 2.6.

6. As the SPAN is increased, a mode-hop will become apparent where the wavelength suddenly changes.

   The mode hop often appears at one edge of the scan; if so, adjust the OFFSET so that the scan is free of mode hops, and continue adjusting in the same direction until a mode hop is observed on the other edge of the scan.

7. Adjust the OFFSET to the mid-point between the two extremes.

8. Increase SPAN further, until a mode hop is again apparent, and readjust the OFFSET to the mid-point.

9. Repeat until mode hops are observed at both edges of the scan.

10. Adjust the diode CURRENT by small amounts to try to remove at least one of these mode hops, then attempt to increase the SPAN further.

11. If the mode hops are at both edges of the scan and cannot be removed by OFFSET or CURRENT adjustments, attempt increasing or decreasing the *Laser Bias* to remove one or both of the mode hops. If increasing the bias only makes the mode hops worse then try decreasing the bias, and vice versa. If both mode hops are removed, repeat the steps above (increasing SPAN) until no further improvements can be made to the MHFR.

12. If the MHFR is substantially less than expected (refer to the factory test report), it may be advisable to change mode by

increasing or decreasing the CURRENT to find a nearby single-mode current, or to rotate the filter or grating slightly to alter the net gain so that one cavity mode has higher gain than those adjacent.

13. Iterate OFFSET/SPAN/CURRENT/BIAS adjustments until no further improvement in MHFR can be achieved.

Note that non-linearity in the sweep behaviour (primarily due to non-linearity in the response of the piezo transducer) means that the optimal bias current can depend on SPAN, and even after optimising the bias current for maximum MHFR the laser may mode-hop when changing from large to small SPAN.

2.6 Compliance voltage

The constant-current source that drives the laser diode is powered by an adjustable DC power supply. The *compliance voltage* is the highest voltage the supply can output, which must maintain a small headroom above the diode voltage to compensate for cable drop and ensure normal operation of the control circuitry.

An adjustable upper-limit is applied to the compliance voltage, to prevent accidentally destroying the laser diode from over-voltage due to damage or bad cable continuity, and to limit thermal power dissipation in the control system.

As different laser diodes have different compliance requirements, the maximum compliance should be set to around 1 V above the voltage drop in the diode datasheet, to accommodate for losses. This option should be preconfigured as part of the laser build process, but it may be necessary to change the compliance limit when changing laser diodes.

2.7 System error messages

Toggle keyswitch The keyswitch must be toggled to resume normal operation, either after power-on or to clear a critical error (see §2.1.1).

Laser disabled by interlock The system is disabled as a safety requirement because one of the preconditions related to the hardware interlock is not met (see §2.1). Check the events log for more information.

TEC short/open circuit The effective resistance of the TEC was measured to be outside permitted bounds. This implies that the connections from the headboard to the TEC are damaged, or that the TEC itself is damaged.

Laser short/open circuit The measured voltage across the diode indicates a short or open-circuit condition. Check the connections from the headboard to the laser diode and confirm operation at a lower current.

Insufficient compliance voltage The dDLC was unable to drive the requested injection current within the specified maximum compliance limit (see §2.6). It is recommended to set the compliance limit to approximately 1 V above the voltage listed in the laser diode datasheet.

2.8 Troubleshooting current and sweep

Cannot set laser current to 0mA The minimum supported laser current in normal operation is 20 mA; the laser should be disabled instead of setting the current to zero. If it is important that the laser current is guaranteed to be zero, use the keyswitch (or the `KEYSW` command) to hardware-disable the laser current.

Cannot set current to ILIM When a nonzero bias curret is specified, the maximum supported current is `ILIM`−|`IBIAS`| to ensure the current does not exceed the limit at the edge of the sweep.

Laser current has increased noise near ILIM The hardware current limiter guarantees that the laser drive current **does not exceed** the limit current. This means that the current limiter is more likely to activate slightly below the limit current, which may present as increased noise in the drive current. It is recommended to maintain a headroom of at least 10 mA on the limit circuit, i.e. $\texttt{ILIM} > \texttt{ISET} + |\texttt{IBIAS}| + 10\,\text{mA}$

Increasing SPAN changes OFFSET The sweep waveform is a sawtooth wave with average `OFFSET` and peak-to-peak `SPAN`, which requires the following inequality to be true

$$\texttt{SPAN} + \tfrac{1}{2}|\texttt{OFFSET}| \leq 100\%.$$

If increasing `SPAN` would break this inequality, then `OFFSET` is adjusted appropriately.

Cannot increase OFFSET Similar to the above, the inequality defines bounds on `OFFSET`. When hitting a limit, the value in the dDLC app is shown with a red background colour.

Changing SPAN causes a mode-hop When a large bias current is used, the laser is only in quasi-thermal equilibrium because the thermal load is changing across the sweep. Changing the SPAN therefore changes the thermal load slightly, which can induce a mode-hop in the laser.

Capture timeout Check the sweep rate. Although dDLC supports very slow sweep rates, this can cause timeout issues when waiting for the trigger to occur. In particular, the lock is engaged in the middle of the sweep (on the rising trigger) which might require up to one full sweep period. MOGLabs recommends sweep rates at least 5 Hz and discourages sweep rates slower than 1 Hz.

2.9 Troubleshooting TEC operation

Measured temperature is always 6°C Indicates a problem measuring the thermistor on the laser head. Power-off the dDLC and reconnect the DVI cable. If the issue persists, verify the thermistor connection to the laser headboard and continuity through the DVI cable.

TEC diverged setpoint This error occurs if the difference between the setpoint and measured temperature increases over time. Most commonly due to the TEC polarity being incorrect, but may also occur if the TEC limit current is too high and the controller greatly overshoots the setpoint temperature.

TEC settles at wrong temperature Indicates that the TEC limit current is too low and the controller cannot achieve the desired tempreature. Check the measured TEC current and increase the limit current if the drive current is approaching the limit.

If the *steady-state* current is 0.5 A or higher, it is likely necessary to water-cool the laser head to adequately heat-sink the thermal base and prevent the TEC efficiency from decreasing.

TEC oscillates rapidly This indicates that the overall closed loop gain of the TEC controller is too high, causing it to become unstable. This can occur for TEC configurations that achieve a very high heating/cooling rate, and requires the TEC controller gain to be reduced (§2.3). It is recommended to reduce the gain to -10 dB to ensure stability, then increase the gain until the required convergence rate is achieved.

TEC oscillates slowly over several minutes The slow response of the TEC and the thermal mass of the laser head caused potential thermal oscillations over long timescales in early firmware. Improvements to the TEC control algorithm exponentially damp these oscillations and this issue should be resolved by installing the latest firmware update.

Temperature unstable at 20mK level In normal operation, the TEC is expected to converge to within 20mK of the setpoint temperature in a few minutes. However, at this level of precision the laser head is vulnerable to air currents inducing thermal fluctuations that perturbs the laser frequency. MOGLabs recommends isolating the laser head from the environment using a acrylic box or similar, in particular to block any drafts from HVAC systems.

3. Laser locking

Laser frequency stabilisation ("locking") refers to continuously adjusting the properties of a laser so that the optical frequency matches a reference; typically an atomic absorption line, an optical cavity resonance, or a wavemeter.

The reference behaves like a frequency discriminator, measuring the laser frequency and outputting an *error signal* that describes how far the laser is above or below the desired frequency. A servo controller then induces *control action* on an actuator to bring the laser back to the reference frequency, correcting for perturbations induced by ambient environment changes and acoustic disturbances.

The dDLC has separately configurable SLOW and FAST controllers for responding to perturbations on different timescales (Figure 3.1). The SLOW controller corrects for slow drift by adjusting the piezoelectric transducer, which has a large control range but has limited modulation bandwidth. The FAST controller corrects rapid perturbations by adjusting the laser current, since that provides rapid modulation but is vulnerable to inducing mode-hops when correcting for long-term drift.

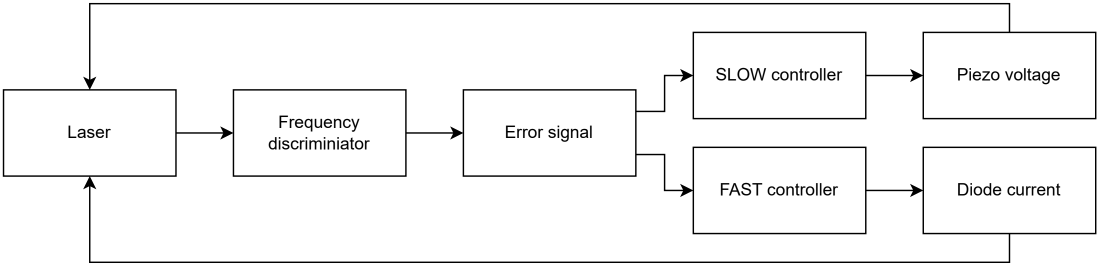


Figure 3.1: Simple schematic overview of dDLC laser locking. The frequency discriminator is typically an atomic reference or a wavemeter.

There are a wide number of techniques for generating error signals from different references, here we will outline how to configure the dDLC for the most common use-cases.

3.1 DC locking to an atomic transition

Often referred to as *side-of-peak* locking, the DC locking method adjusts the laser to maintain a specific DC value on the error signal, such as a photodiode voltage.

This approach is simple to implement but cannot be used to lock to the peak of a signal, and is vulnerable to drifts in optical power as the servo controller will incorrectly adjust the laser frequency for any change in photodiode voltage.

A common way to lock to an atomic reference is the "saturated absorption spectroscopy" ("satabs" or SAS) configuration[1] which helps eliminate Doppler broadening of the atomic resonance (Figure 3.2). The counter-propagating beam yields narrow resonances which can be used to lock much closer to the transition resonance than the side of the associated Doppler curve.

The following steps are recommended to configure the dDLC for use with DC locking

1. Configure the laser to sweep across the desired lock point.
2. Adjust the INPUT OFFSET to coarsely remove the DC offset from the PD signal at the desired lock point as seen on the PD monitor signal. The dDLC has an *Auto-Offset* feature to automatically set INPUT OFFSET for the current sweep.
3. Open the lock settings and set the *Lock mode* to *External error* using the *PD* input.

---

[1] See for example W. Demtröder. *Laser Spectroscopy, Basic Concepts and Instrumentation*. Springer, Berlin, 2e edition, 1996

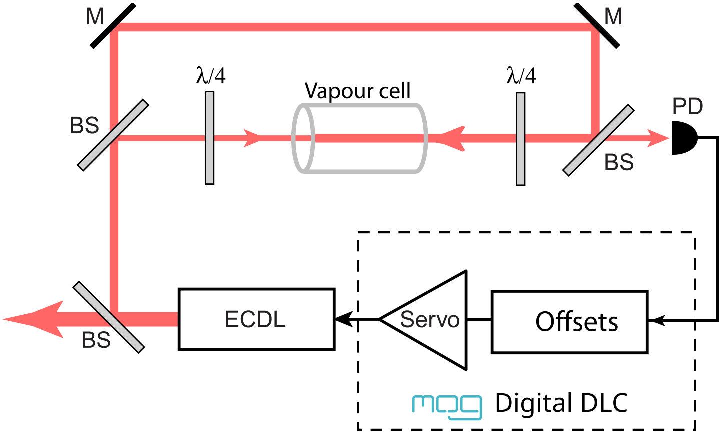


Figure 3.2: Schematic setup for DC satabs locking to an atomic transition. PD is a photodetector, BS beamsplitter, M mirror, $\lambda/4$ a quarter-wave waveplate.

4. Confirm that the error signal shows the same features as the PD signal and adjust the master gains to give approx 100 mVpp across the feature.
5. Adjust the ERROR OFFSET for fine control of the location of the lock point.

3.2 AC locking to an atomic transition

Also known as FM demodulation or "lock-in amplifier" detection, AC locking permits the laser frequency to be locked to a peak centre. This approach offers inherently lower detected noise and reduced sensitivity to environmental perturbations, and thus the potential for improved laser frequency stability.

The setup is similar to that for DC locking, but modulation of the laser frequency (or equivalently the reference frequency) is required. The MOGLabs dDLC has an integrated 250 kHz oscillator which can directly dither the diode current or drive an external modulator via the MOD OUT backpanel connector.

Figure 3.3 shows an example of AC locking to an atomic reference in the saturated absorption configuration, where modulation is applied directly to one of the diode current, an acousto-optic modulator (AOM), or symmetrically a resonant coil that modulates the Zeeman levels of the atomic reference instead. See §3.9 for more details.

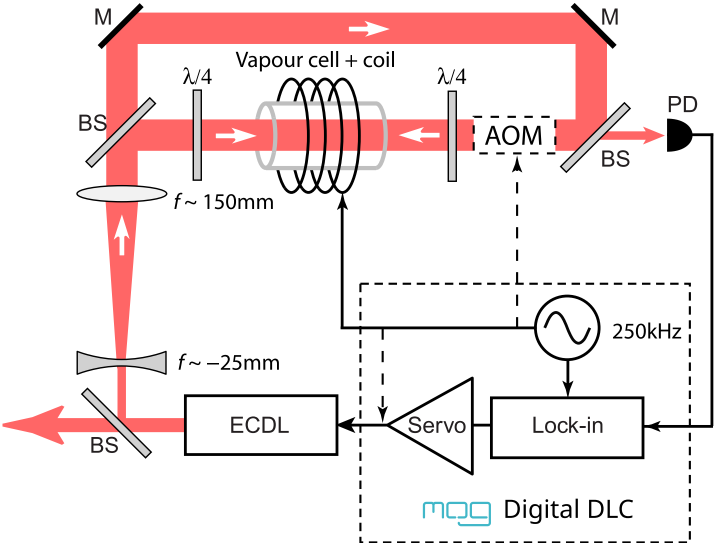


Figure 3.3: Example setup for AC locking to an atomic vapour transition. PD photodetector, BS beamsplitter, M mirror, $\lambda/4$ quarter-wave waveplate. Modulation is performed using one of the diode current, the magnetic coil, or an optional AOM. The optional beam-shaping lenses reduce power-broadening of the transition.

Note: The following instructions only apply to AC locking where the demodulation is performed by the dDLC. External demodulators are covered in §3.3.

1. Configure the laser to sweep across the desired lock point with optimised modehop-free scan-range.
2. In *Lock Settings*, set the *Lock mode* to *Internal error*.
3. In *Laser Settings*, set the *Current dither* or *External dither* in the laser settings as required. It is recommended to start with 50% modulation depth and adjust later as required.
4. Adjust the demodulation phase to maximise the amplitude of the feature at the lock point, ensuring it has negative slope.

   Alternatively, use the *Autoset Phase* feature of the dDLC to automatically optimise the phase.
5. Reduce the dither strength if required to reduce the influence of higher-order perturbations.

   In general the dither should be as weak as possible to achieve the required error signal strength. Too much dither increases higher-order components that can decrease the lock performance and change the shape of the error signal.
6. Adjust the ERROR OFFSET to correct any residual offset in the error signal at the desired lock point, and set the master gains to give approx 100 mVpp across the feature.

3.3 External error signal locking

There are many other techniques for generating an error signal external to the dDLC, such as modulation-transfer spectroscopy (MTS), Pound-Drever-Hall locking, or beatnote-offset locking.

To lock to an externally generated error signal it should be connected to the PD input, and any photodiode signal (if required) should be connected to one of the AUX channels instead to permit monitoring using the oscilloscope function.

1. Configure the laser to sweep across the desired lock point.
2. Open the lock settings and set the *Lock mode* to *External error* using the *PD* input.
3. Set the master gains to 1.0. Where the gain of the external signal processing can be adjusted, it is recommended to keep the master gain near unity to reduce the amplification of input noise.
4. Adjust the properties of the external error generation system to optimise for the strongest *negative slope* at the desired lock point.
5. Adjust the ERROR OFFSET for fine control of the location of the lock point.

It should be noted that any group delay in the error signal generation will reduce the lock bandwidth. The overall group delay of the system needs to be taken into account when quantifying lock performance.

In particular, the finite measurement rate of wavemeters makes them unsuitable for this type of lock, as even though many types of wavemeter can output an analog error signal, the measurement rate tends to be well below 1 kHz and the control servo will overreact to the step changes in the signal even at minimum gain. Locking in such a scenario should be done with a servo integrated into the wavemeter as discussed in the next section.

3.4 External low-bandwidth (wavemeter) locking

Many wavemeters, including the MOGLabs FZW and MWM offerings, have an integrated PID servo for holding the laser at an arbitrary frequency without the need for a specific reference. Typically these servos are only intended to correct for slow drift in environmental conditions as the wavemeter measurement is limited in absolute accuracy, measurement rate, and shot-to-shot measurement variation.

The following steps are recommended to configure the dDLC for locking to a MOGLabs FZW or MWM wavemeter, although analogous steps should apply to other wavemeter brands.

1. Connect the PID output SMA connector from the wavemeter to the AUX A BNC input on the dDLC.
2. Configure the wavemeter for the desired lock setpoint.
3. Adjust the wavemeter error signal gain – typically in the order of 1 V/GHz.
4. Configure the wavemeter output to be symmetric about zero. For MOGLabs wavemeters this means setting the offset voltage to 0 V and the min/max voltages to ±2.5 V.
5. Open the lock settings and set the *Lock Mode* to *External Slow Servo* using the AUX A input.
6. Set the dDLC master gains to unity and the error offsets to zero. The other gain settings are ignored in this configuration.
7. Set the wavemeter PID proportional gain to 1.0 and integral gain to zero.
8. Enable the PID on the wavemeter.
9. Confirm that the error signal on the dDLC shows a discretised ramp across zero as the laser sweeps across the lock point.

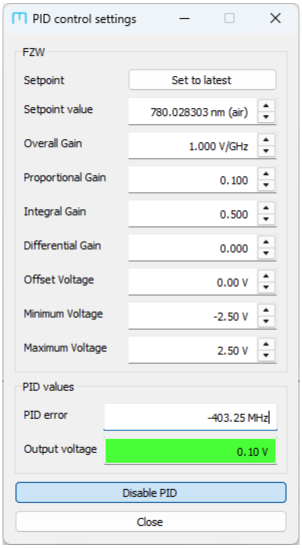
   This confirms the PID is configured and connected correctly.

10. Engage the SLOW lock on the dDLC. Note that the FAST controller is disabled in this configuration.

    Activating the locks in this order prevents mode-hops from integrator wind-up.

11. Set the integral gain on the wavemeter to 0.5 and confirm the laser wavelength converges towards the intended setpoint. If not, invert the SLOW controller action.

12. Adjust the wavemeter PID gains until the laser converges to the target wavelength without oscillating due to measurement noise.



Setpoint	Set to latest
Setpoint value	780.028303 nm (air)
Overall Gain	1.000 V/GHz
Proportional Gain	0.100
Integral Gain	0.500
Differential Gain	0.000
Offset Voltage	0.00 V
Minimum Voltage	-2.50 V
Maximum Voltage	2.50 V
PID error	-403.25 MHz
Output voltage	0.10 V

Figure 3.4: Screenshot showing typical PID settings for a MOGLabs FZW wavemeter to lock with a dDLC.

3.5 External high-bandwidth (PDH) locking

Some frequency discriminators are extremely sensitive to laser frequency and have resonances narrower than the natural laser line-width. The most common example of such a system is a stabilised high-finesse optical cavity with cavity line-width 1 kHz or lower.

These discriminators can be used for *line-width narrowing* by feeding back directly into the laser current with the smallest possible group delay. Typically this is achieved by connecting an external *Fast Servo Controller* with lag-optimised analog feedback path (such as the MOGLabs FSC) directly to the laser headboard, bypassing the laser controller entirely.

In this arrangement, we still recommend using the SLOW servo of the dDLC to correct for long-term drift, rather than controlling the SLOW actuator from an external servo. Using the dDLC provides the most flexibility for remote control and monitoring, and avoids potential issues related to saturation of the SLOW controller. Furthermore, the dDLC provides TTL outputs for triggering the external controller to provide remote operation even if the servo is fully analogue.

The following steps are recommended to configure the dDLC for locking to a PDH apparatus with the MOGLabs FSC, although analogous steps should apply to other brands of fast servo controller. For additional instructions on setting up and optimising the PDH error signal, please refer to the Application Note on our website.

1. Connect FAST OUT of the FSC to the SMA connector on the laser headboard (Figure 3.5).

2. Ensure that the headboard modulation is enabled – typically it is disabled by default.

   The B1140-series of MOGLabs laser headboards can be configured remotely for DC modulation via the *Laser Settings* in the dDLC app or menu system.

   If this option is not available, the modulation must be configured using jumper switches on the headboard itself. Consult the laser manual for more information.

3. Connect the MON A output from the FSC to the PD IN on the dDLC and set the FSC to output FAST ERROR.
4. Connect TRIG OUT from the dDLC to the SWEEP IN on the FSC and configure the FSC for *External Sweep* mode.
5. Open the *Lock Settings* dialog and select *External Fast Servo* using PD IN.
6. Connect the LOCK OUT stereo jack of the dDLC to the LOCK IN jack on the FSC. This allows the FSC to be controlled remotely via the dDLC using TTL signals.
7. Set the dDLC master gains to unity and the error offsets to zero.
8. Adjust the laser to sweep across the PDH resonance. Note that it may be difficult to directly observe the error signal while sweeping across the PDH resonance as the sample rate may

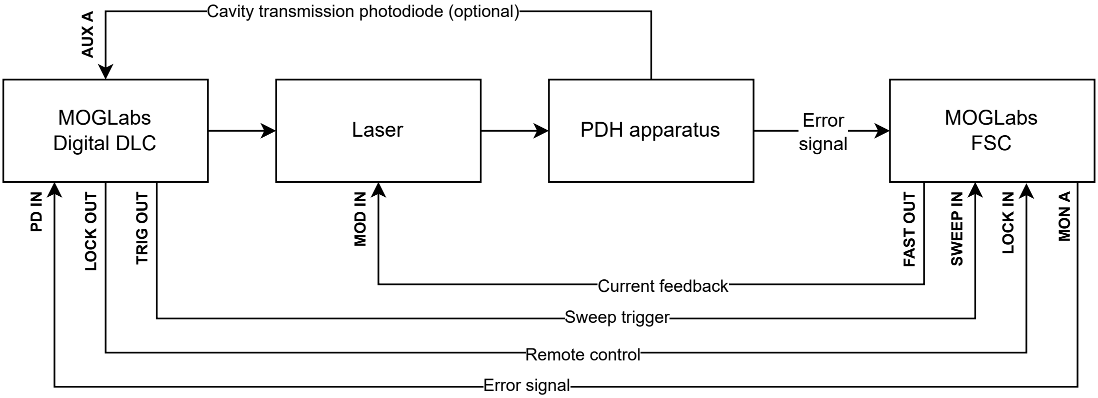


Figure 3.5: Recommended connections for a high-finesse PDH lock with the MOGLabs dDLC and FSC.

be insufficient to see the sharp features. It may be necessary in some circumstances to use an external oscilloscope until the PDH error signal is optimised.

9. If available, connect the cavity transmission photodiode to the AUX A input for monitoring purposes.
10. Set the FSC to SCAN+P mode and optimise the FSC fast gain to "stretch" the error signal as described in the *Application Note*. The error signal should now be clearly visible on the dDLC integrated oscilloscope mode.
11. Adjust the OFFSET to put the PDH resonance in the centre of the sweep and reduce the SPAN as far as possible.
12. Engage the SLOW lock on the dDLC. This "quasi-locks" the laser to the cavity, where the proportional-only feedback of the FSC is sufficient to correct the laser fluctuations and the SLOW controller compensates any slow drift.
13. Engage the FAST lock on the dDLC. Although the integrated FAST controller is disabled in this mode, it triggers the FSC to lock via the TTL output.
14. Optimise the fast servo settings on the FSC to maximise the cavity transmission.
15. Optimise the slow servo settings on the dDLC to remove any slow fluctuations in the FAST controller output of the FSC.
16. Perform further optimisation by measuring the laser line-width, if necessary.

3.6 Noise spectrum optimisation

A simple heuristic method for optimising the lock performance as described in §1.6 is to increase the gains until the onset of oscillation and then reduce slightly. However, achieving the optimum gains is better achieved by looking at the power spectrum of the error signal.

The dDLC app contains an integrated spectrum analyser for looking at the noise power up to 100 kHz. This can be useful for checking the behaviour of the control loop and identifying the limiting factor on increasing the servo action.

Figure 3.6 shows typical performance of an optimised AC-lock to a saturated absorption spectroscopy apparatus, as described in §3.2.

The **Laser unlocked** noise spectrum was obtained in *Scan Mode* with zero span manually centred on the atomic resonance. The **Off resonance** curve was similarly obtained with the laser unlocked but

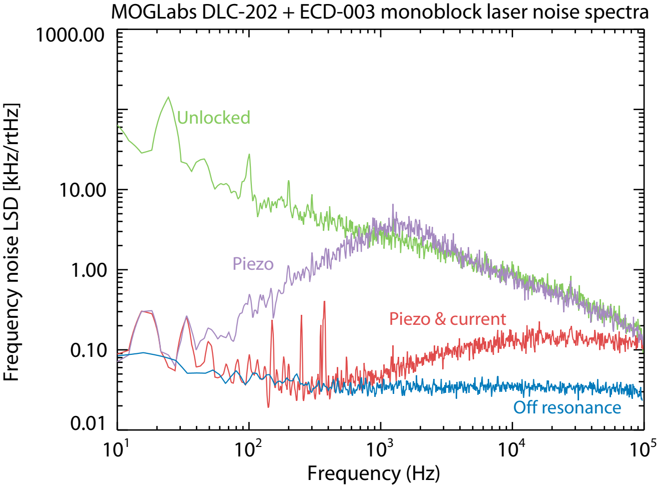


Figure 3.6: Error signal spectra, with laser unlocked, locked with SLOW (piezo) feedback only, and with SLOW and FAST (piezo+current) feedback. The off-resonance spectrum provides information on the effective noise floor.

tuned far away from any resonances. This represents the overall noise floor of the frequency discriminator: it is meaningless to try to reduce the laser frequency noise below this level.

When SLOW feedback is enabled, the noise for low Fourier frequencies is drastically reduced. The SLOW gain adjusts the 0 dB gain point of the controller, which in this figure is approximately 5 kHz. Higher gains can result in oscillation at a frequency corresponding to a pole in the piezo actuator response, which can be seen as a sudden increase in the measured noise.

Additionally engaging the FAST feedback results in further suppression, with 0 dB gain beyond 20 kHz. Typically we find that the laser diode itself has a 90° phase lag at 15 to 100 kHz.

Ideally, the SLOW and FAST gains should be adjusted to minimise the total integrated noise (the area under the error spectrum). The **Piezo** curve in this example shows a weak “Bode bump” around 1 kHz where it weakly exceeds the **Unlocked** noise. Generally it is preferable to minimise the excess noise contained in the Bode bump, but often there is a trade-off that still yields overall lower integrated noise. In this case no bump can be seen in the **Piezo & current** curve.

The signal-to-noise ratio (SNR) of the frequency discriminator (represented by the difference between the *Unlocked* and the *Off resonance* spectra) is critical to the performance of the servo controller. Improvements to the reference, for example using a high-finesse PDH apparatus rather than saturated absorption spectroscopy, can provide much greater SNR and correspondingly greater laser frequency noise suppression.

3.7 Troubleshooting error signal generation

Error signal is zero Check the *Lock Mode* and *Lock Source* in the *Lock Settings*. Confirm that dither is enabled when using AC-locking, and when using external dither (such as a coil) connect MOD OUT to an oscilloscope set to 50 Ω termination to confirm the signal. When using DC-locking, ensure that the error signal is not saturating the input.

Error signal has unexpected shape When using an AC-locking technique, ensure that the demodulation phase is optimal to eliminate the residual shape in the photodiode signal. It is recommended to sweep the PHASE control through 90° to ensure the largest slope has been identified.

Error signal shape is incorrect despite optimising phase This implies saturation of the signal-processing pipeline, usually as a result of the error signal amplitude being too high. First check that the phase is adjusted to eliminate as much of the residual background absorption profile as possible. Reduce the master gain to the range 0.5-1.0, reduce the dither strength if applicable, and/or decrease the optical power until the expected shape is regained.

Error signal contains flat sections This implies saturation of the AC-coupled ADC, usually as a result of a strong Doppler absorption profile. This can occur even if the DC-coupled PD measurement does not show saturation. Decrease the amplitude of the PD signal by decreasing the optical power and then compensate with increased master gain if required.

Error signal is noisy at large values of SPAN When span is large (> 10%) the sweep rate of the laser frequency across the features of the error signal causes higher-order contributions to pass through the digital-signal processing chain, causing an apparent increase in noise. The noise should disappear as the span is reduced. Alternatively the sweep rate can be reduced.

Error signal is noisy when using dither When the dither is too strong it couples higher-order contributions into the error signal that pass through the signal processing filters. We recommend using the smallest dither strength that yields the desired error signal shape.

Error signal shifts over time One advantage of AC-locking techniques is that they are first-order insensitive to changes in optical power, making the error signal less sensitive to environmental drift. However, when the demodulation phase is suboptimal the error signal contains a component that depends on the optical power which can drift over time, especially when using fiber-coupled beams. Adjust the phase to reduce sensitivity to changes in optical power.

This can also occur when using polarisation-maintaining (PM) fibers where the polarisation axis does not match the fiber axis, resulting in a polarisation rotation that varies with ambient temperature.

Similarly, very strong Zeeman modulation (coil dither) increases the residual Doppler component, which drifts with optical power. Reduce the amplitude of the dither to remove more of the Doppler background and compensate with increased master gain if required.

3.8 Troubleshooting lock stability

When encountering difficulties related to engaging the frequency lock, we recommend using the “Lock diagnostics” tab in the dDLC PC app (see §4.4) to identify what behaviour is occurring upon activating the locks.

Servo does not lock to zero-crossing Try inverting the polarity of the servo controller to confirm the action is correct. Also check whether there is a mode instability near the locking point causing the laser to mode-hop after engaging the servo.

Cannot lock FAST and SLOW controllers simultaneously Check that FAST has DC-block enabled otherwise small differences can integrate up to destabilise the controllers. If the controllers lock individually, reduce the gain of the SLOW controller to minimum and slowly increase.

Display shows LOCK WARNING A sudden perturbation was detected in the controller output (at least 20% output change in 10ms). Usually this represents a significant perturbation that likely destabilised the lock. For example, after a mode-hop the laser may lock to a different resonance.

FAST controller gives LOCK ERROR The FAST controller has reached saturation of its output. Generally, the SLOW controller should compensate for any long-term drift, so saturating the FAST output implies the gain is too high.

SLOW controller gives LOCK ERROR The SLOW controller has reached saturation of its output. Check the environmental stability (especially ambient air temperature and pressure). If the controller saturates in response to a perturbation (particularly acoustic) reduce the servo gain.

Lock is unstable when locking to an adjacent resonance The overall control action depends on the slope of the error signal, so the optimum gains depend on the transition being locked to. For example, gains optimised for a resonant satabs transition may be unstable when locking to the adjacent (stronger) cross-over transition because the slope of the error signal is much steeper at that resonance.

3.9 Saturated-absorption recommendations

MOGLabs recommends the following considerations when locking a laser to an atomic reference using the saturated-absorption spectroscopy technique.

Probe power The probe power should be about 250 μW. Higher power will increase the photosignal, but the detector saturates at about 500 μW. Too much optical power can result in clipping of the error signal resulting in unexpected structure.

Probe intensity The probe intensity should be low to reduce power-broadening of the atomic resonance. We recommend the probe beam be expanded to 10+ mm diameter to allow increased optical power at low intensity.

Polarisation

The demodulated error signal is sensitive to the pump and probe polarisations due to optical-pumping considerations. Good polarisers and careful alignment can be very helpful. The light should be circularly-polarised as it passes through the atoms.

Coil design

In many cases it is preferable to modulate the atomic resonance itself to avoid dither sidebands on the laser light. This can be done with a matched coil ("tank circuit") which is resonant at the modulation frequency (250 kHz). Such a coil can be wound and tuned manually, or purchased from MOGLabs as a bare component or integrated apparatus (Figure 3.7).

Figure 3.7: Example vapour-cell Zeeman coil (left) and integrated into the fiber-coupled MGSA apparatus (right).

Shielding

The Zeeman coil produces substantial magnetic fields, oscillating at 250 kHz. These fields can readily induce problematic potentials and currents in the laser head and/or main circuit board. In particular, it is quite possible to produce a larger frequency modulation from induced currents in the laser diode than from the Zeeman modulation of the reference.

It is vital that the coil be located far from the dDLC and from the laser head, or that it be shielded. A layer of high-permeability material (soft iron or mu-metal) is probably adequate. To test this, simply reverse the polarity of the coil connection. If the error signal is also reversed, but otherwise similar, then the shielding is probably adequate.

4. Software control

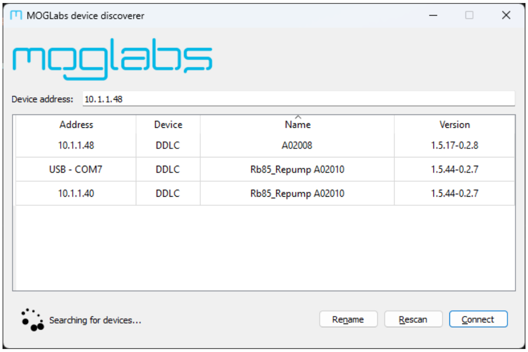
4.1 Overview

The MOGLabs dDLC is designed for both local and remote operation, will fully-featured access to all of its functionality over USB and Ethernet. A complete software application for remote operation of the dDLC from a Windows® PC is available from our website.

Alternatively, the dDLC can be integrated into any custom control system using the command language (Appendix B), providing access to the same functionality that is used by the application without requiring any specific device drivers, DLLs, or software libraries.

4.1.1 Device discovery

The PC control application is recommended for normal operation of the dDLC in most applications. Starting the application will display the discoverer (Figure 4.1) which scans your PC and local network for dDLC devices. Select the desired device and click *Connect* to start the application.



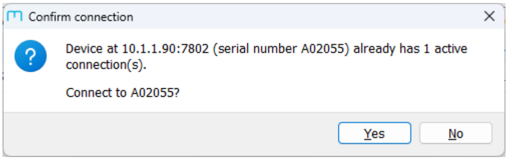
Device address: 10.1.1.48

Address	Device	Name	Version
10.1.1.48	DDLC	A02008	1.5.17-0.2.8
USB - COM7	DDLC	Rb85_Repump A02010	1.5.44-0.2.7
10.1.1.40	DDLC	Rb85_Repump A02010	1.5.44-0.2.7

Searching for devices...

Figure 4.1: MOGLabs device discoverer which shows dDLC devices available via USB and network interfaces.

The application will remember the address of the last connected device and automatically attempt to reconnect when restarted. When connecting to a device that is actively being operated from another connection, a confirmation dialog will be shown to prevent accidentally clicking on the wrong item (Figure 4.2).



Device at 10.1.1.90:7802 (serial number A02055) already has 1 active connection(s).

Connect to A02055?

Figure 4.2: Confirmation dialog box shown when connecting to a device already in use.

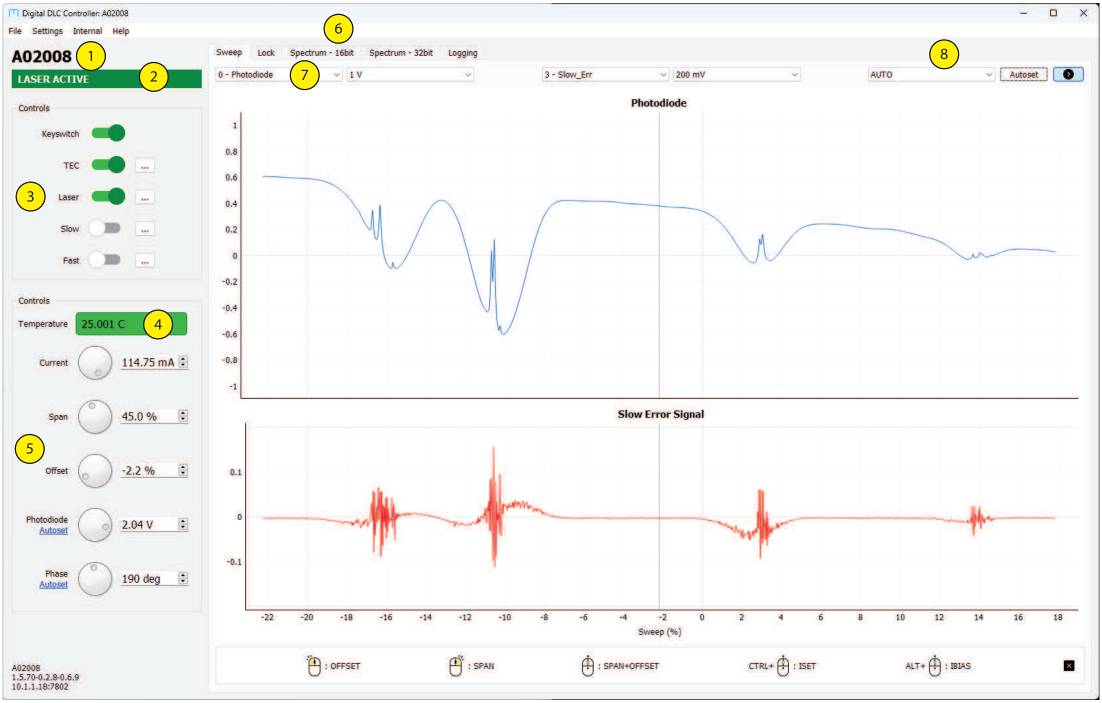
In environments that contain more than one dDLC device, MOGLabs recommends assigning a name to each to more easily identify the desired connection. Clicking the *Rename* button in the discoverer allows a user-specified ASCII string to be assigned to each unit.

4.1.2 Control application

The main interface of the dDLC control application comprises a virtual front-panel and oscilloscope display. This provides convenient access to the most-commonly used functionality of the device, with additional settings available in pop-up dialog boxes.

The layout of the application is shown in Figure 4.3 with identified features as listed below:

1. Device identification string. By default this is the serial number, but can be replaced with a user-specified ASCII string by double-clicking the label.
2. Laser status indicator, displaying the overall status of the system and laser state. Hover the mouse for a tooltip with a brief explanation of the status text. Normal operation is displayed



Digital DLC Controller: A02008

A02008

LASER ACTIVE

Temperature 25.001 C

Current 114.75 mA

Span 45.0 %

Offset -2.2 %

Photodiode 2.04 V

Phase 190 deg

0 - Photodiode

1 V

3 - Slow_Err

200 mV

AUTO

A02008
1.5.70-0.2.8-0.6.9
10.1.1.18:7802

Figure 4.3: MOGLabs dDLC Windows® application for control and monitoring dDLC devices.

with a green background, warning states are shown in orange, and error states in red.

3. Primary function on/off controls, permitting enabling or disabling of core functionality. Click the "…" button adjacent to each switch to display a popup dialog with additional settings (also accessible from the *Settings* menu).

4. Laser temperature indicator. Red indicates the temperature is greater than 1°C from the setpoint, and green is within 0.1°C.

5. Virtual encoders provide a mechanism for smoothly adjusting or step-changing parameters. Some parameters have an *Au-*

toset option which measures the scope capture and automatically sets the parameter.

6. Tabs for accessing different application functionality, such as spectrum analysis or logging.
7. Drop-down boxes for selecting the channels and graph scaling of the oscilloscope feature.
8. Timebase for the oscilloscope feature. Setting to AUTO will display one sweep of the scan. Clicking the arrow button toggles the acquisition between being active or paused.

4.1.3 Virtual encoders

In the course of normal operation, the parameters of the laser typically need to alternate between small smooth changes and large step changes.

The virtual encoders provide a mechanism for making small adjustments with click+drag on the encoder dials, or making a step change by typing a value in the adjacent spinbox.

Where there are limits on the min/max acceptable values, the background colour of the spinbox will change to indicate the value is near the limit (orange) or at the limit (red).

116.50 mA

116.50 mA

120.00 mA

Figure 4.4: Virtual encoders can be smoothly adjusted by mouse-dragging horizontally on the dial (left), scrolling the mouse-wheel, or changed to a new value by typing in the box (middle). When the parameter hits a limit on its permitted range, the background colour changes to red (right).

4.1.4 Multiple devices

The application supports connecting to multiple dDLC units simultaneously for monitoring purposes. Select *File* → *Add Device* from the menu bar to display the discoverer and select a second unit for connection. When connected to multiple devices the application shows a tab bar to select the active device.

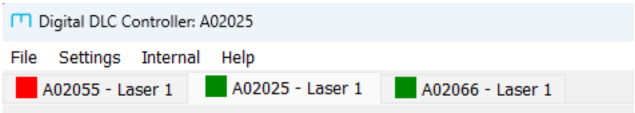


Figure 4.5: A tab bar appears when connecting to multiple devices. The coloured indicator next to the unit identifier represents the device state at a glance.

A device can be removed from the application by selecting *File* → *Remove Device* from the menu, or right-clicking the device tab and selecting *Disconnect*.

When operating the app with multiple connected devices, it is important to ensure that adjustments are being made to the intended device. The settings dialog boxes (e.g. *Laser Settings*) display the customised device name (or serial number) in the window title bar to clarify the unit they control.

Note that dDLC devices connected to a network will accept simultaneous connections from multiple computers, whereas USB only supports one single connection at a time. This generally makes Ethernet more desirable for remote operation and logging, but raises the possibility of simultaneous access from multiple locations[1].

---

[1] At this stage the dDLC does not provide “local lockout” or similar functionality.

4.2 Oscilloscope mode

The oscilloscope feature displays two channels simultaneously which can be selected from the drop-down menus. By default the capture is set to AUTO timebase which captures one duration of the laser sweep, but other options are available. The capture is triggered such that the middle of the sweep is always in the middle of the capture.

The oscilloscope capture runs continuously by default, but can be paused by using the capture control button Figure 4.6. Left-clicking the button will toggle between active and paused mode, and right-clicking the button will trigger “single shot” mode which captures one acquisition and then pauses automatically.

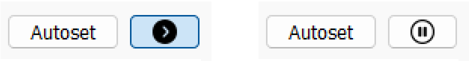


Figure 4.6: Capture indicator showing active (left) and paused (right).

A right-click menu provides additional options like *Export CSV* to save the captured data in human-readable format, and *View All* which autosets the y-range to fit the displayed data.

4.2.1 Mouse interactions

The oscilloscope supports mouse interactions and gestures (including pinch-zoom on appropriate devices). Clicking and dragging horizontally within the graph area adjusts the OFFSET and SPAN of the sweep depending on the mouse button (Figure 4.7).

Dragging vertically adjusts the PD OFFSET or the ERROR OFFSET as appropriate depending on the selected channel.

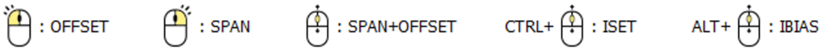


Figure 4.7: Mouse interactions supported within the oscilloscope widget.

Similarly, scrolling the mouse wheel adjusts both OFFSET and SPAN simultaneously to zoom in or zoom out from the position of the mouse cursor. Combining the mouse wheel with the CTRL or ALT keys allows directly adjusting the setpoint current or scan bias while looking at the sweep, which is convenient for finding a stable operating mode and optimising the scan-range there (see §2.5.1).

4.3 Device settings

Additional settings for device operation are available by clicking the "..." button in the main window, or selecting from the *Settings* menu. The user-assigned name (or serial number) of the associated unit is displayed in the window title to clarify when multiple units are connected simultaneously.

4.3.1 TEC settings

Setpoint temperature Desired operating temperature of the laser diode. Refer to the laser's factory test report for the intended operating temperature.

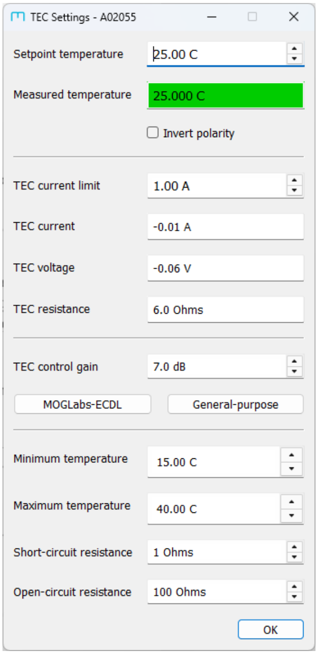
Measured temperature Temperature measured by the thermistor in the laser head.

Displayed in red when the temperature is more than 1°C from the setpoint, and green when within 0.1°C of the setpoint.

Invert polarity The TEC controller assumes that positive drive current induces cooling in the laser head and negative drive current induces heating. The polarity needs to be inverted if the TEC is wired in the opposite polarity.

Current limit Limit current to enforce on the TEC. The limit current is generally only relevant when approaching the setpoint temperature and can be increased to improve the approach rate at the expense of increased overshoot.

Typically 1 A is more than sufficient for most operation, and at least 200 mA is required to maintain temperature in common operating conditions.



Setpoint temperature	25.00 C
Measured temperature	25.000 C
	☐ Invert polarity
TEC current limit	1.00 A
TEC current	-0.01 A
TEC voltage	-0.06 V
TEC resistance	6.0 Ohms
TEC control gain	7.0 dB
Minimum temperature	15.00 C
Maximum temperature	40.00 C
Short-circuit resistance	1 Ohms
Open-circuit resistance	100 Ohms

Figure 4.8: Screenshot of typical TEC settings dialog box.

TEC current	Instantaneous measured current through the TEC.
TEC voltage	Measured voltage across the TEC. Sign indicates when the current is being sourced or sunk.
TEC resistance	Inferred resistance of the TEC. Typically the TEC resistance is a few ohms in normal operating conditions; anomalously high or low resistance indicates a poor connection to the TEC, or damage within the TEC. Note that the resistance is not a meaningful measure at low TEC current, or across the transition between heating and cooling modes.
TEC control gain	Adjustment for the overall gain of the TEC control loop (§2.3). Increasing the gain achieves more rapid convergence at the potential expense of instability and temperature oscillation. If necessary, the

gain should optimised by measuring the step-response of the controller.

The *MOGLabs-ECDL* button restores the factory-default indented for use with MOGLabs ECDL lasers, which may cause oscillation in custom lasers. The *General-purpose* button reduces the gain to provide stable action for most systems at the expense of slow convergence.

Minimum temperature Lower limit temperature for the TEC controller, to protect the laser from thermal runaway. Should be set above the dew point of the operating environment to prevent condensation on the laser diode, which can cause damage.

Maximum temperature Upper limit temperature for the TEC controller, to protect the laser from thermal runaway. Should be set a few degrees above the intended maximum operating temperature to prevent thermal expansion causing strain within the laser diode barrel.

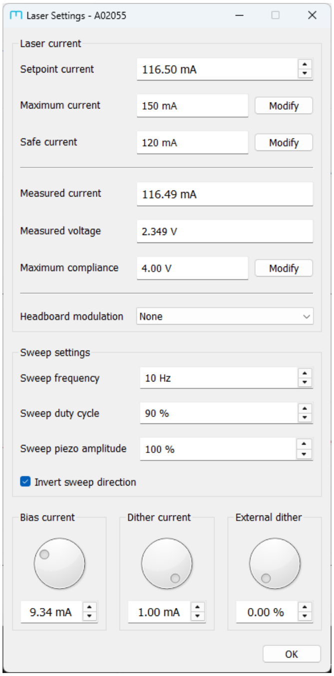
Short-circuit resistance Critical resistance below which the short-circuit alarm will be triggered when running at least 100 mA.

Open-circuit resistance Critical resistance above which the open-circuit alarm will be triggered when running at least 100 mA.

4.3.2 Laser settings

Setpoint current Desired injection current through the laser diode. Changes to setpoint current are smoothly interpolated by the laser driver to prevent step-changes. Cannot be set higher than the limit current.

Limit current Hardware limit on the current injected into the laser diode, before any modulation is applied. Prevents accidental damage to the laser diode by increasing the drive current beyond its damage threshold. To protect the load, the hardware limit starts to shunt away the injection current within a few milliamps of the limit, so the limit current should be set at least 10 mA above the highest intended operating current.



Laser Settings - A02055

Laser current

Setpoint current: 116.50 mA

Maximum current: 150 mA

Safe current: 120 mA

Measured current: 116.49 mA

Measured voltage: 2.349 V

Maximum compliance: 4.00 V

Headboard modulation: None

Sweep settings

Sweep frequency: 10 Hz

Sweep duty cycle: 90 %

Sweep piezo amplitude: 100 %

☑ Invert sweep direction

Bias current: 9.34 mA

Dither current: 1.00 mA

External dither: 0.00 %

Figure 4.9: Screenshot of typical laser settings dialog box.

Safe current	As part of the laser build process, a *safe operating current* will be specified for checking the health of the diode laser. It is strongly recommended to check the output power of the laser at the safe current to check for damage after shipping or relocating the laser. Increasing the current beyond the safe current may result in damage to the diode laser if the cavity is misaligned sufficiently to prevent stable optical feedback. Provided for diagnostic purposes; not intended to be modified by customers.
Measured current	Measured current through the laser diode. Large discrepancies between setpoint and measured current indicates the driver is artificially limited, typically implicating the compliance voltage.
Measured voltage	Measured voltage across the laser diode and cable, as measured at

the controller output.

Maximum compliance The maximum permitted voltage of the DC power supply that drives the laser current (see §2.6). This prevents accidental over-voltage damage to the laser diode and typically only needs adjusting when changing laser diodes.

Headboard modulation Laser headboards that support software-configurable direct modulation will display a selector for the modulation coupling. The headboard has an SMA connector that provides low-latency high-bandwidth current modulation, which can be AC or DC coupled. Headboards that do not support this option must be set using hardware jumpers per the laser manual.

Sweep frequency Frequency of the sweep generator. Changing the sweep frequency will also change the oscilloscope capture timebase when set to AUTO.

Sweep duty cycle Duty cycle of the sweep generator. It is strongly recommended to maintain a duty-cycle in the range 50-90% to prevent excessive acceleration of the piezoelectric transducer at the end of the sweep, which can reduce its lifetime. Duty-cycle below 50% should use the *Invert sweep direction* instead.

Sweep piezo amplitude Some lasers have very large piezo transducers which may benefit from bias currents beyond what can normally be generated by the dDLC. This parameter controls the amplitude of the sweep fed to the piezoelectric transducer, which effectively increases the relative bias current at the expense of ramp voltage.

Typically this is set during the laser build process, and should be set to 100% in normal operation for most lasers.

Invert sweep direction Reverse the direction of the sweep, which may be preferable for spectroscopic purposes depending on whether the action of the piezoelectric transducer is to increase or decrease the laser output frequency. Note that laser mode hysteresis and nonlinear piezo characteristics mean the behaviour is typically not perfectly symmetrical.

Bias current Proportional change in laser diode injection current to apply simultaneously with the piezoelectric sweep to help prevent mode-hops (see §2.5). The stated quantity is the *amplitude* of the change in injection current at 100% span and the sign represents whether the correction is inverted with respect to the piezo voltage.

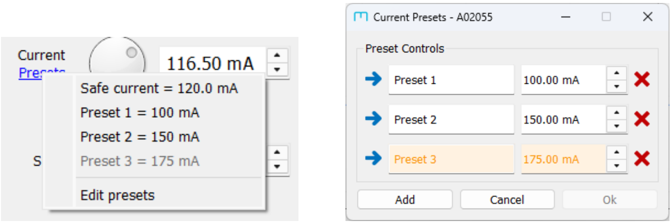
Typically the bias current is optimised in-situ by adjusting while observing the modehop-free scan-range, or using an iterative process (e.g. §2.5.1)

Dither current Strength of modulation applied to the laser current for AC-locking during internal demodulation (§3.2). This results in 250 kHz sidebands on the laser light, which may be undesirable for some applications where external dither may be preferable.

External dither Amplitude of the 250 kHz modulation dither output on the MOD OUT BNC connector on the rear-panel of the dDLC. Intended for driving a frequency-matched Zeeman coil for AC-locking purposes, such as the MOGLabs MGSA integrated sat-abs apparatus (§3.9).

4.3.3 Current presets

Often there are a number of useful laser currents relevant to different diagnostic or operating conditions (such as low power/high power operating modes). *Current presets* provide a mechanism for storing named settings for later reference.



Current 116.50 mA

Safe current = 120.0 mA
Preset 1 = 100 mA
Preset 2 = 150 mA
Preset 3 = 175 mA
Edit presets

Current Presets - A02055

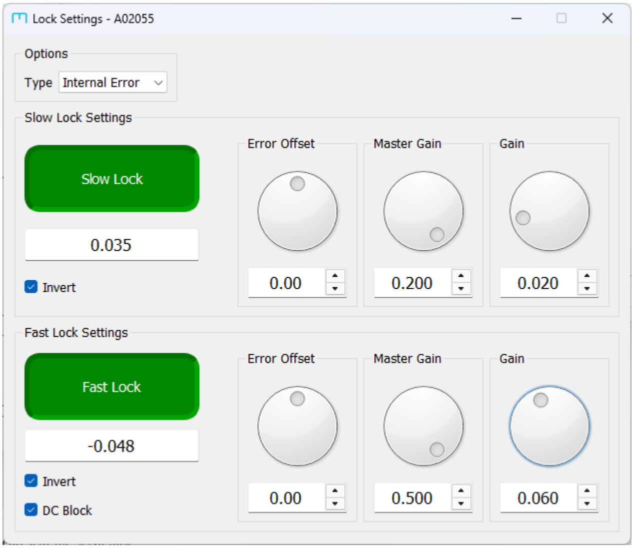
Preset Controls

Preset 1 100.00 mA
Preset 2 150.00 mA
Preset 3 175.00 mA

Figure 4.10: Screenshot of current presets popup menu (left) and associated settings dialog (right). `Preset 3` is shown as disabled because the stored value exceeds the limit current.

The *Add* button defines a new preset entry, the right-arrow button replaces the associated preset entry with the setpoint current, and the cross button removes the preset entry. Pressing *OK* stores the preset table on the PC and *Cancel* reverts any changes.

4.3.4 Lock settings



Type: Internal Error

Slow Lock Settings: 0.035; ☑ Invert; Error Offset 0.00; Master Gain 0.200; Gain 0.020

Fast Lock Settings: -0.048; ☑ Invert; ☑ DC Block; Error Offset 0.00; Master Gain 0.500; Gain 0.060

Figure 4.11: Screenshot of typical lock settings dialog box for a locked laser. The *Slow Lock* and *Fast Lock* buttons both represent the servo lock status, and can be clicked to toggle the lock state.

Lock type Selects the desired locking method, which is one of the following:

Internal Error	AC-locking technique generating an error signal by internally demodulating the dither current or external dither.
External Error	DC-locking technique where the error signal is derived externally and connected to the specified input.
Aux Slow Lock	Internal servo controllers are bypassed and the specified input is fed directly to the SLOW controller output. The FAST servo is disabled in this mode.

Used for low-bandwidth locking to an external servo such as a wavemeter (§3.4).

FSC Mode An external fast servo controller (such as the MOGLabs FSC) is used instead of the internal FAST controller (§3.5).

The SLOW controller operates normally using the specified input as a DC-coupled error signal, but the FAST lock button only toggles the LOCK OUT TTL output to enable remote operation of the FSC.

Lock source Specifies which BNC input connector should be used to obtain the error signal, where applicable. Defaults to the PD-input when not displayed.

Lock button Click to toggle whether the associated servo is active or inactive. If neither servo is active then the laser is scanning. The button is colour-coded according to the following:

GREY Servo is inactive.

GREEN Servo is running and considered locked.

ORANGE Servo is running but a warning condition was identified (check the logging tab). Does not necessarily mean the laser is unlocked, but should be checked.

RED An error was detected and the lock needs to be reset.

BLACK Servo is not available for the specified *Lock type*.

Lock value The indicator box below the lock button shows the instantaneous output value of the servo controller, normalised to the range $[-1, 1]$. When the control output reaches ± 1 the controller is "saturated" and cannot correct for any additional fluctuations, typically representing controller failure.

Invert The default controller assumption is that increasing the actuator parameter will push the laser frequency in the direction of the sweep. Depending on the sweep direction and actuator geometry this may require inverting to achieve a stable lock.

DC block	The DC block is strongly recommended to prevent competition between the FAST and SLOW controllers from integrating small differences in their responses at low frequencies. Disable if the SLOW controller is not intended to be used at all (e.g. no piezo transducer).
Error offset	DC offset to apply to the associated error signal. Should be zero for most AC-locking configurations, or used for fine adjustment of the locking frequency for DC-locking.
Master gain	Overall gain applied to the error signal before passing to the servo controller, and therefore affects the captured noise spectra. Should be kept at 1.0 for most applications, and should be used to compensate for the amplitude of the error signal being too low or too high for stable servo action.
Gain	Controls the corner frequency of the integrator of the associated PI-servo, which is used to adjust the controller performance. From a control-theory perspective this simultaneously adjusts the gains KP and KI to simplify operation.

4.3.5 Monitor outputs

On dDLC units with a rear-panel supporting monitor output BNC connectors, the signals output on the MON-A and MON-B connectors can be specified from the *Settings* menu bar (Figure 4.12).

4.3.6 Dark mode

"Dark mode" (Figure 4.13) can be selected from the *Settings* menu. This setting is persistent and will apply automatically the next time the application is started.

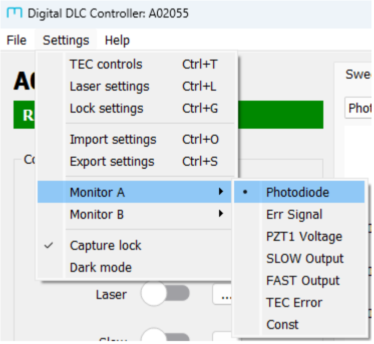
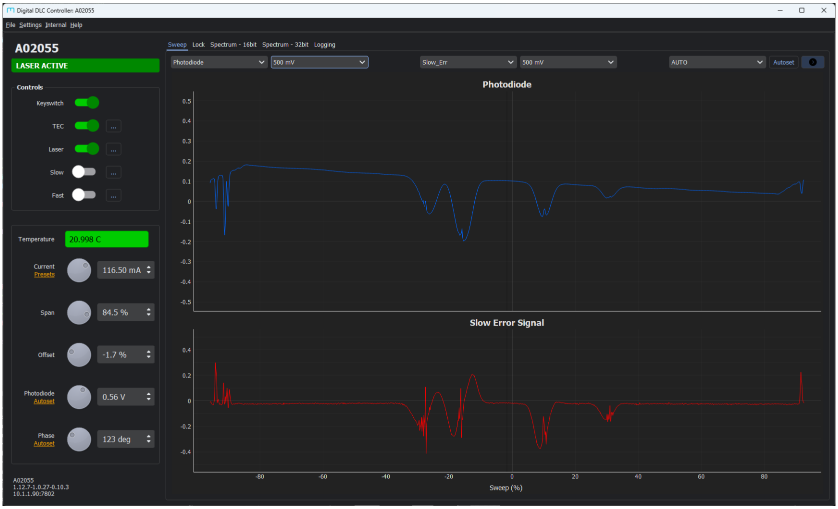


Figure 4.12: Screenshot showing monitor signals available for the rear-panel monitor outputs.



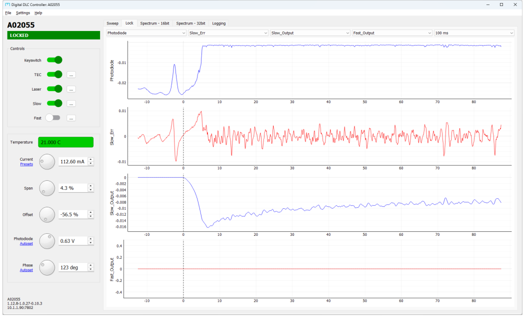
Temperature 20.998 C
Current 116.50 mA
Span 84.5 %
Offset -1.7 %
Photodiode 0.56 V
Phase 123 deg

A02055
1.12.7-1.0.27-0.10.3
10.1.1.90:7802

Figure 4.13: Screenshot showing application running in dark mode.

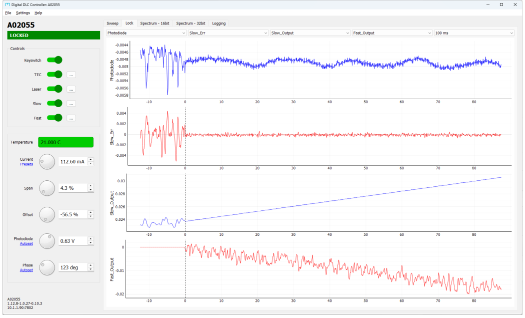
4.4 Lock diagnostics

The *Lock Diagnostics* mode is a special acquisition mode that captures up to four channels simultaneously, triggering the acquisition to start when the laser is switched from scanning mode to locked mode. This allows the behaviour of the servo(s) to be inspected and easily identify whether the servos are configured correctly.



Temperature 21.000 C
Current 112.60 mA
Span 4.3 %
Offset -56.5 %
Photodiode 0.63 V
Phase 123 deg

Figure 4.14: Lock diagnostic showing expected behaviour of the SLOW servo upon being engaged. Upon engagin the controller (dashed line), the action integrates the error signal to reach the lock point and stabilise within the first 10ms.



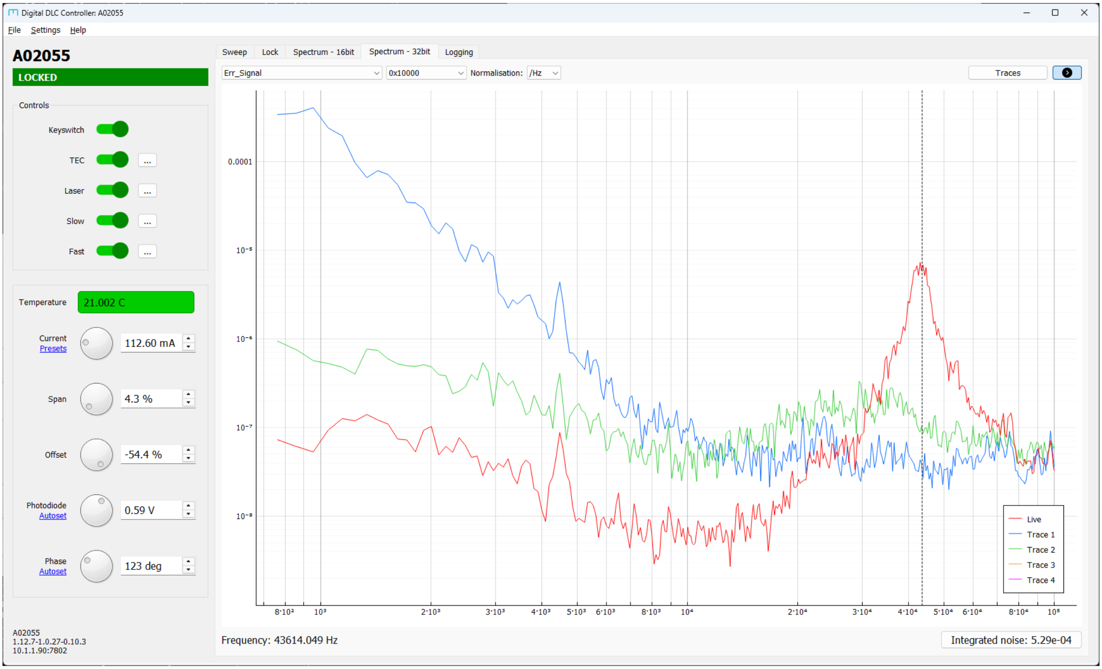
Temperature 21.000 C
Current 112.60 mA
Span 4.3 %
Offset -56.5 %
Photodiode 0.63 V
Phase 123 deg

Figure 4.15: Lock diagnostic showing the FAST controller opposing the SLOW controller because both integrate in opposite directions. In this case the DC-block needed to be enabled on the FAST servo.

4.5 Spectrum analyser mode

The data capture feature can also be used as the basis of a simple spectrum analyser to measure the performance of the locking servos and assist in optimisation. Note that the noise spectrum presented by the application is not calibrated, and should be used for feature identification and relative comparison only.

Even with these limitations it is a convenient way to identify noise sources, estimate the closed-loop bandwidth and compare servo performance at different gain settings (Figure 4.16).



Err_Signal
0x10000
Normalisation: /Hz

Temperature: 21.002 C
Current: 112.60 mA
Span: 4.3 %
Offset: -54.4 %
Photodiode: 0.59 V
Phase: 123 deg

A02055
1.12.7-1.0.27-0.10.3
10.1.1.90:7802

Frequency: 43614.049 Hz

Integrated noise: 5.29e-04

Figure 4.16: Spectrum analyser mode comparing the noise spectrum in several scenarios. The dashed line is moved by double-clicking in the graph area, with associated frequency displayed in the bottom left. In this case the red trace shows ringing at 44 kHz because the servo gain is too high.

There are two modes of operation for the spectrum analyser: **16-bit** and **32-bit** modes. The 16-bit measurement represents the raw measurements from the analog-to-digital (ADC) converters, and the 32-bit measurements contain internal recordings from the digital signal processing (DSP) pipeline.

The 32-bit measurements have better resolution and longer capture windows, which can result in clearer spectra that reach down to lower frequencies, but have fewer available channels and a much slower acquisition time.

The spectrum viewer can store multiple traces to aid in comparison of different scenarios. Click on the *Traces* button in the top-right corner to reveal the options (Figure 4.17). Traces can also be toggled by clicking their entry in the plot legend.

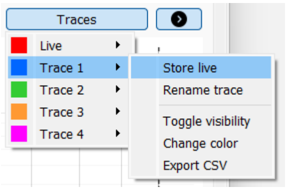
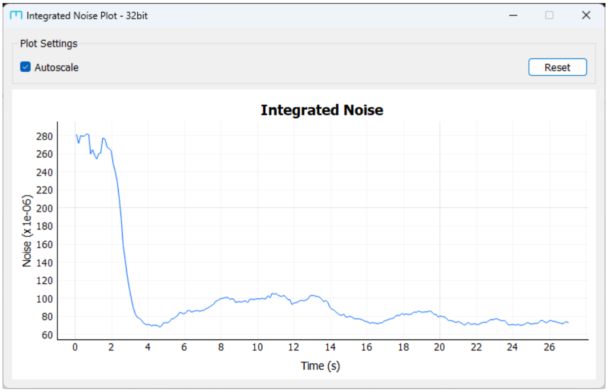


Figure 4.17: Screenshot of trace options in spectrum analyser mode. Select the *Store live* option to record the most recent spectrum to the stored trace.

A metric of interest for optimising the performance of the servo controllers is the *total integrated noise*, which is displayed in the bottom right of the screen in arbitrary units. In some situations this metric can be used as a simple proxy for laser line-width.

It can be difficult to intuit when the total noise is minimised because the control action can act to shift noise power at low frequency to high frequency, changing the shape of the noise profile without decreasing the total noise. To assist in minimising the total noise, clicking on the *Integrated Noise* button in the bottom right corner raises a pop-up dialog that shows the measured integrated noise over time (Figure 4.18).


Plot Settings

☑ Autoscale

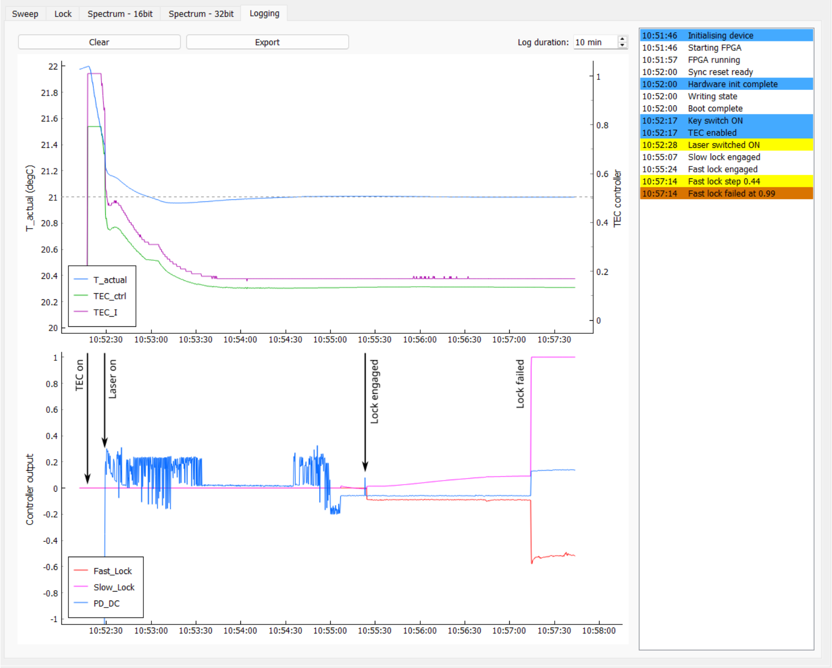
Figure 4.18: Screenshot of total integrated noise measurement over time as servo gain is varied, assisting identification of the gain where the total integrated noise is at a minimum.

4.6 Logging

The logging tab shows the temperature stability and locking servo outputs over long timescales, as well as an event log of timestamped debug information about device operation. In the event of unexpected device behaviour or error condition, check the event log for additional diagnostic information.

The top graph shows the temperature stability of the laser, and can be used to identify residual thermal fluctuations or sensitivity to environmental changes. In particular it can help identify thermal fluctuations that correlate with laboratory air-conditioning cycles.

The bottom graph shows the output of the servo controllers and the photodiode level over long timeframes. This helps tracking long-term drift, identify when the controllers are close to saturating, check for competition between the FAST and SLOW controllers, and identify step-changes corresponding to the laser undergoing a mode-hop (Figure 4.19).



Log duration: 10 min

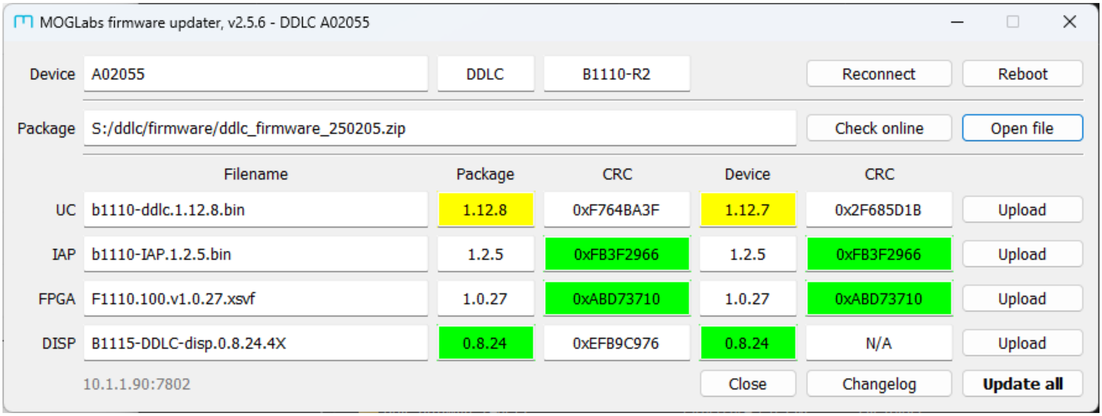
```
10:51:46  Initialising device
10:51:46  Starting FPGA
10:51:57  FPGA running
10:52:00  Sync reset ready
10:52:00  Hardware init complete
10:52:00  Writing state
10:52:00  Boot complete
10:52:17  Key switch ON
10:52:17  TEC enabled
10:52:28  Laser switched ON
10:55:07  Slow lock engaged
10:55:24  Fast lock engaged
10:57:14  Fast lock step 0.44
10:57:14  Fast lock failed at 0.99
```

Figure 4.19: Screenshot showing logging tab with temperature log (top left), servo log (bottom left) and timestamped event log (right). The events in the log can be correlated to measurements in the plots to identify behaviour like lock failure due to laser mode-hop.

4.7 Firmware update

MOGLabs will release new versions of the firmware running on the dDLC to provide new functionality and address issues identified in previous versions. MOGLabs strongly recommends updating to the latest firmware whenever possible to achieve the best performance.

The recommended way to install the firmware is through the PC application. Connect to the unit and from the menu bar select *Help → Firmware Update*. Select the relevant ZIP file downloaded from the website and the interface will show which components need updating (Figure 4.20).



MOGLabs firmware updater, v2.5.6 - DDLC A02055

Device: A02055 | DDLC | B1110-R2

Package: S:/ddlc/firmware/ddlc_firmware_250205.zip

	Filename	Package	CRC	Device	CRC
UC	b1110-ddlc.1.12.8.bin	1.12.8	0xF764BA3F	1.12.7	0x2F685D1B
IAP	b1110-IAP.1.2.5.bin	1.2.5	0xFB3F2966	1.2.5	0xFB3F2966
FPGA	F1110.100.v1.0.27.xsvf	1.0.27	0xABD73710	1.0.27	0xABD73710
DISP	B1115-DDLC-disp.0.8.24.4X	0.8.24	0xEFB9C976	0.8.24	N/A

10.1.1.90:7802

Figure 4.20: Screenshot of the firmware update window. Items that do not require updating are shown in green, and items that should be updated are shown in yellow.

Click *Update All* to begin the update process. **Do not interact with the dDLC while the firmware update is in progress** as the results may be unpredictable. The PC application is disabled while the firmware update dialog is shown, or if a firmware update is detected to have been initiated. A progress bar will be shown in the OSD to indicate when the device is busy with the update.

Warning: The process may take several minutes to complete, during which time the device may reboot several times. It is important that the process not be interrupted once begun otherwise the device memory may be wiped.

4.8 Diagnostic capture

In the event of an unexpected issue, please send device diagnostic information to MOGLabs to assist in troubleshooting. This is generated by selecting the *Capture debug ZIP* item from the *Help* menu.

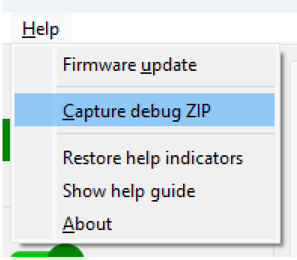


Figure 4.21: Menu item to capture diagnostic information about the dDLC.

A. Specifications

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

Parameter	Specification
Current regulator (B5110 single-channel driver)	
Output current	0 to 800 mA ±5 μA, control ±8 nA
Noise*	240 pA/$\sqrt{\text{Hz}}$ @ 1 kHz 250 nA rms (1 Hz – 1 MHz)
Accuracy	±0.2 ppm/°C and 0.1% from setpoint
Max diode voltage	8 V at 400 mA, 4 V at 800 mA
Current mod	±25 mA: analogue, sweep ±1 mA: analogue, dither, DAC1, DAC2 ±250 μA: dither, DAC2 DAC1, DAC2: 16 bits at 3.125 MHz
Bandwidth	Direct analogue mode: 1.2 MHz (−3 dB) DAC control (fast): 3.2 MHz (28-bit depth)
Temperature (B1180 single-channel driver)	
Range	7.5°C to 49.5°C, ±1mK resolution
Stability	Better than ±1 mK/°C
TEC power	±2 A, ±12 V (24 W)
Sensor	NTC 10 kΩ
Control	PID with variable sample rate Bandwidth 50 Hz
Protection	PCB over-temp, TEC over-current, open/short circuit

Parameter	Specification

Piezo (B1190 dual-channel driver)	
Piezo output	Two independent channels 0–150 V, ±10 mA
Sweep/control	16-bit unipolar sweep DAC 16-bit bipolar control DAC
Resolution	Sweep: 2.5 mV at maximum range Control: variable gain 240 µV to 16 µV per LSB
Noise*	$80\,\text{nV}/\sqrt{\text{Hz}}$
Sweep	Internal 0.1 Hz to 62.5 Hz
Monitoring	Voltage and current measurement for each channel
Protection	Leakage, PCB over-temp

Frequency stabilisation	
Bandwidth	3.2 MHz
Dither	0 to 2.5 MHz ±0.058 Hz 250kHz default Diode current mod ±250 µA or ±1 mA or external mod ±150 mA or ±4 V
Phase	$0 - 360^\circ \pm 0.022^\circ$
Error signal	32-bit signed, sampling 6.25 MHz
Post demod filter	5-stage IIR and user-adjustable response Bypass option
Servo controls	Slow (piezo) and Fast (current)
Gain controls	±18 dB master + ±18 dB on slow, fast
Slow inputs	Slow error (after offset and master gain) AUX A, AUX B Photodetector DC Fast controller out
Slow action	PI with 20 dB/dec gain with user-adjustable response
Fast inputs	Fast error (after offset and master gain) DC block output (AC coupled error)

Fast action	PI with 20 dB/dec gain with user-adjustable response

Signal input/output (B1120 rear panel)	
Signal in/out	8 BNC connectors 4 analogue in (PD IN, AUX A, AUX B, DIRECT) 2 analogue out (CHAN A, CHAN B monitors) MOD OUT, TRIG out 1 MOGLabs LASER (DVI-D DL socket)
Analogue in (4)	Signal range ±4.096 V protected to ±15 V *Photodetector* AC: 12.5 MHz $>$ 150 dB dynamic range DC: 1 MHz $>$ 110 dB dynamic range *AUX A, AUX B:* DC 1 MHz $>$ 110 dB dynamic range *Direct:* analogue direct to diode current mod
Analogue out (2)	CHAN A, CHAN B: 16 user-selectable signals Signal range ±4 V Sampling up to 3.25 MHz @ 16 bits, BW 1 MHz Dither voltage/current driver (user-selectable): ±4.096 V ±150 mA BW 1 MHz
Digital in	TTL compatible, active low $<$ 0.8 V $0 - 6.5$ V tolerant and protected a) 3.5 mm stereo jack (external Fast/Slow Lock inputs) b) 3.5mm stereo jack (External Laser1/Laser2 interlocks)
Digital out	TTL compatible, active high $>$ 2.4 V $0 - 6.5$ V tolerant and protected a) Trigger (sweep mid-point) b) 3.5mm stereo jack (Fast/Slow Lock out)

Front panel (B1118)	
Operator controls	1 key switch STANDBY/RUN 6 dedicated rotary encoders: diode current, input offset, frequency, span, slow gain, fast gain, each with press-function 3 dedicated pushbuttons: diode on/off, slow lock, fast lock 1 menu adjust encoder 2 menu step pushbuttons
LED indicators	Four 3-colour LEDs: standby/run, laser diode, slow lock, fast lock
Display	127mm, 800x480 pixels, full colour

Connectivity	
Communications	TP 10/100 ethernet; USB 2.0 Type B
Laser	Standard: MOGLabs DVI-D DL socket Option: Toptica DLPro
Power out	±15 V photodetector supply (M8-3 Thorlabs compatible)

Power & dimensions	
IEC input	90 to 264 Vac 47 – 63 Hz
Power	28 W (laser off)
Dimensions	19″ 2U, WxHxD = 422 × 88 × 270 mm
Weight	3.5 kg (excluding cables), 8 kg shipping
Operating temperature	10 – 35°C

B. Command language

The MOGLabs dDLC acts as a simple USB-CDC device and TCP socket server, so no specific device drivers or DLLs are required to communicate with it. Therefore the dDLC is cross-platform and language-agnostic, since most languages have built-in support for serial port and socket-based protocols.

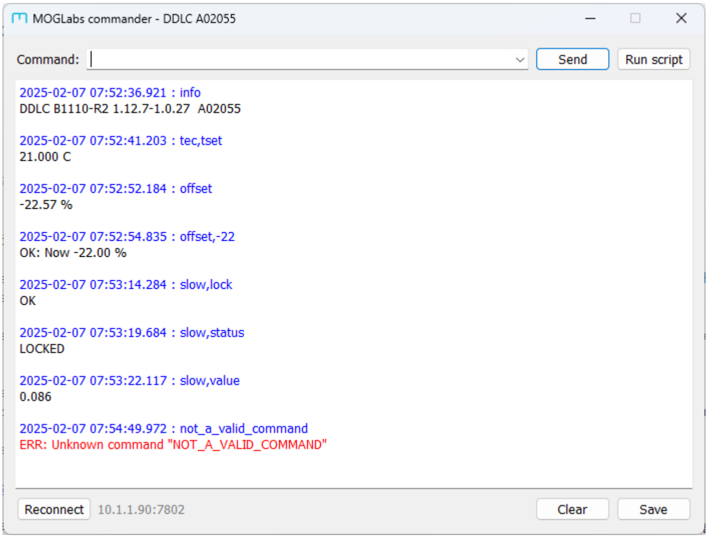
The communications protocol follows a text-based request-reply pattern, where every request is guaranteed to have a response. The syntax is case-insensitive with messages delimited by CRLF. Failed queries are replied to with the string "ERR" followed by an explanation of the issue. It is **strongly recommended** to check for the response before sending the next command.

The protocol is consistent across the MOGLabs range of products, and examples showing how to communicate in several programming languages are available from the MOGLabs website.

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

B.1 Example behaviour

All MOGLabs products include an integrated *Device Commander* which can be used to issue commands and check responses. This is also available as a standalone application for diagnostic purposes. Figure B.1 demonstrates both "query" behaviour (retrieving a value) and "command" behaviour (causing an action).



```
2025-02-07 07:52:36.921 : info
DDLC B1110-R2 1.12.7-1.0.27  A02055

2025-02-07 07:52:41.203 : tec,tset
21.000 C

2025-02-07 07:52:52.184 : offset
-22.57 %

2025-02-07 07:52:54.835 : offset,-22
OK: Now -22.00 %

2025-02-07 07:53:14.284 : slow,lock
OK

2025-02-07 07:53:19.684 : slow,status
LOCKED

2025-02-07 07:53:22.117 : slow,value
0.086

2025-02-07 07:54:49.972 : not_a_valid_command
ERR: Unknown command "NOT_A_VALID_COMMAND"
```

Figure B.1: Demonstration of interacting with the dDLC using the *Device Commander*. Outbound transmissions are timestamped and shown in blue, errors are shown in red. Commands that perform an action always respond with a string prefixed by `OK` or `ERR`.

B.2 Python library

Although the communications interface is language-agnostic, the most requested language binding is `python`. MOGLabs provides a helper class `MOGDevice` which wraps the request-reply interaction and raises errors as python exceptions. It also provides simple mutex locking to prevent comms desynchronisation in multi-threaded environments.

We recommend using such an interface over using `socket` or `serial` classes directly to simplify error handling. The driver is available on the *Python Package Index (PyPI)* at `https://pypi.org/project/mogdevice/`.

This section provides a simple overview of the class, please refer to the docstrings in the code for more specific API details.

B.2.1 MOGDevice class

The `MOGDevice` represents a single connection over USB or TCP and provides two main mechanisms for interaction: `ask` and `cmd`. Both functions are blocking and wait for a `CRLF`-terminated response. If the response string has the prefix `ERR`, an instance of `DeviceError` is raised with details of the failed query.

Primary Methods

`ask(query)`	Send the provided query string and return the response as a string. If `query` is `bytes`, the return value is also `bytes`.
`ask_val(query)`	Calls `ask(query)` but performs type conversion on the response string; to `float` by default. Also performs simple SI-units conversion of the response, when units are provided. Recommended for querying measured values from the device, instead of casting the response string directly.
`ask_dict(query)`	Calls `ask(query)` and parses the response string into a python dictionary. Intended for parsing compound responses such as `VER` and `REPORT`. Does not perform type conversion of the values.
`cmd(command)`	Send the provided command string to the device and wait for a response. Raises a `DeviceError` if the response string does not contain the prefix `OK`.
`reconnect()`	Close the connection (if applicable) and reconnect with the same parameters. Recommended for handling disconnection or reboot events.

Item Properties

The `INFO` query is common across MOGLabs devices to help identify the product at a glance. The `MOGDevice` parses this query at connection and stores the results as keys which can be accessed directly by indexing the device instance via `__getitem__()`.

`"type"`	Product name string (e.g. dDLC).
`"code"`	PCB identification string.
`"rev"`	Mainboard PCB revision to identify firmware compatibility.
`"ver"`	Primary version numbers for the UC and FPGA. See also the `VER` query for additional information.
`"serial"`	Serial number of the unit.
`"name"`	User-defined name for the unit (see `DEVNAME`), or serial number where custom name is not set.
`"iap"`	Identifies that the devices is in firmware-update (IAP) mode.

B.2.2 DeviceError class

The `DeviceError` class is used to distinguish between errors raised by the dDLC compared to errors communicating with the dDLC. Instances of this class are raised in response to receiving an `ERR` message from the device, indicating the query was *successfully received and processed* but is not valid.

Casting to a string with `str()` returns the error message received from the device, whereas the `repr()` representation also contains the device connection, and the query string that was submitted.

B.2.3 USBError class

The `pyserial` module is used to interface with the dDLC via the virtual serial port over USB. The design behaviour of this module is that errors from the operating-system level are translated to `serial.SerialException` exceptions. However, these descriptions on Windows® are often opaque and confusing to the user – such as

"Something went wrong". When using USB connections, `MOGDevice` translates the `pyserial` exceptions into `USBError` and attempts to clarify the error description.

B.2.4 Example code

The following example demonstrates simple interaction with the dDLC, including separation of device errors from communications errors.

Demonstration of the `MOGDevice` class

```python
import logging, time
# Import the device classes
from mogdevice import MOGDevice, DeviceError

# Connect to the device by its IP address
dev = MOGDevice("10.1.1.90")
# Sanity-check the expected serial number
assert dev["serial"] == "A02055"

# Log information about the device state
logging.info("%s", dev.ask_dict("REPORT"))

# Change the setpoint temperature
tset = 21  # degC
dev.cmd(f"TEC,TSET,{tset}")

# Track the temperature changing
tvals = []
for i in range(50):
    tvals.append(dev.ask_val("TEC,TEMP", "C"))
    time.sleep(1)

# Attempt to turn the laser ON
try:
    dev.cmd("LD1,ON")
except DeviceError:
    logger.exception("Failed␣to␣turn␣laser␣ON")
except Exception:
    logger.exception("Communications␣error")
```

B.3 System overview

INFO	Returns the model, serial number, firmware versions, and any user-assigned name associated with the dDLC. Similar to the `*IDN?` query standardised across SCPI devices.
VER	Returns the version numbers of the component firmwares on the device as a comma-separated list.
DEVNAME	Get/set the user-facing name of the dDLC to assist in identifying the device in the discoverer. Considered distinct from the user-facing name of the *laser*. Wrap the string in double-quotes to preserve the case of the string.
UPTIME	Get the current uptime of the system, which is returned in seconds, minutes or hours as appropriate.
TEMP	Return the measured system temperatures, in °C. Up to three measurements are returned, corresponding to different internal temperature sensors.
CLIENTS	Return the number of other active connections serviced by the dDLC. This can be used to warn the operator about connecting to a unit being actively used by another connection.
STATUS	String indicator describing the state of the system, in particular if there is a boot error or some other system-level issue preventing normal operation of the dDLC. See §C.4 for a list of response strings.
KEYSW	Query the status of the interlock keyswitch, returning one of `ON`, `OFF` or `TOGGLE`. Optionally specifying the `state` as one of these options will apply a software override to the keyswitch which can be used as a remote toggle (§2.1.1).

B.4 Laser control

REPORT

Returns string containing most standard setpoints and readings, providing a simple mechanism to snapshot device state with reduced communications overhead compared to making multiple separate queries.

The key-value pairs are delimited with a colon (ASCII code 0x3a) and separated with a line-feed (ASCII code 0xa). The specific items included in the `REPORT` response may vary between firmware versions.

Example output of the `REPORT` query

```
KEYSW: ON
TEC: ON
TEMP: 21.000 C
TSET: 21.000 C
LASER: ON
ISET: 139.81 mA
ILD: 139.65 mA
VLD: 2.476 V
ILIM: 160 mA
IBIAS: 9.20 mA
SPAN: 26.48 %
OFFSET: -32.82 %
PDOFFSET: 0.758 V
PHASE: 116.0 deg
```

LD1,ON

Turn ON the laser driver. Returns an error message if not permitted, does not return an error if the laser is already ON.

LD1,OFF

Turn OFF the laser driver. Does not return an error if the laser is already OFF.

LD1,ONOFF

Get/set the operational state of the laser. If a precondition preventing the laser from being enabled (such as interlock requirements), an error message describing the requirement is returned.

LD1,ISET

Get/set the laser setpoint current, in mA. This is the modulation-free current injected into the laser diode.

LD1,ILIM	Get/set the limit current value, in mA. Prevents accidentally damaging the laser diode by injecting a current above its damage threshold. The limiter circuit is applied in hardware, ensuring that the drive current cannot exceed the desired limit.

> **Note:** The limit current should be set with headroom above the highest intended current to prevent the hardware limiter prematurely restricting the current (see §2.8).

LD1,IBIAS	Get/set the signed bias current as measured for 100% span, in mA. The bias current is used to improve the modehop-free scan-range, as described in §2.5.
LD1,IDITHER	Get/set the amplitude of the current dither applied to the injection current, in mA. Used for AC-locking to an atomic transition by generating optical sidebands (§3.2).
ICOIL	Get/set the amplitude of the dither output to the MOD OUT external coil driver, in percent. Used for AC-locking to an atomic transition using Zeeman modulation (§3.2).
LD1,ILD	Returns the measured diode injection current, before modulation is applied.
LD1,VLD	Returns the measured voltage across the laser diode, measured at the driver output.
LD1,HBMOD	Get/set the headboard modulation coupling on laser headboards supporting this feature. Options are `NONE`, `AC` or `DC`. Returns an error when not supported by the laser headboard, which otherwise require adjusting jumper settings on the PCB.
PDOFFSET	Get/set the DC photodiode offset voltage, in volts. This voltage is removed from the PD input signal at the input to the dDLC. Also accepts the optional argument `AUTO` which automatically measures the DC offset from the current input.
PHASE	Get/set the demodulation phase of the modulator, in degrees. Also accepts the special keywords `INV` to swap sign of phase, `Q` to change

phase by 90°, and `OPT` to run the optimisation algorithm using the error signal amplitude.

B.5 Sweep

SPAN	Get/set the sweep span (amplitude), in percentage full-scale.
OFFSET	Get/set the offset of the sweep in percentage full-scale. Automatically limited by the chosen SPAN to prevent truncation of the sweep.
SWEEP,FREQ	Get/set the frequency of the sweep, in Hz. Permitted values are 0.1–62.5 Hz, although sweep rates above 20 Hz may be limited by the responsivity of the piezo transducer.
SWEEP,DUTY	Get/set the duty cycle of the sweep, in percent. The duty cycle should be limited to the range 5–95% to avoid driving the piezo actuator too rapidly on the return part of the sweep.
SWEEP,INV	Get/set the sweep inversion bit to change the direction of the sweep, which may be desirable for spectroscopy applications. Also swaps the sign of the bias current.

B.6 Temperature controller

TEC,REPORT	Query string that replies with a summary of TEC-related setpoints and readings.
TEC,ONOFF	Get/set the state of the temperature controller.
TEC,TSET	Get/set the TEC setpoint temperature, in °C.
TEC,TEMP	Query the actual thermistor temperature, in °C. Returns error if thermistor cannot be read.
TEC,DERIV	Report the measured rate of change of temperature, in °C/min.

TEC,ILIM	Get/set the limit current of the TEC, in amps. Increasing the limit current can improve the convergence rate to the setpoint temperature, but may increase the overshoot upon reaching the setpoint. Must be set to prevent damage to the TEC.
TEC,I	Report the measured current through the TEC, in amps.
TEC,V	Report the measured voltage across the TEC, in volts.
TEC,INV	Get/set the TEC polarity inversion state. Should only be changed if the temperature diverges from the setpoint upon enabling the controller.
TEC,⟨TMIN/TMAX⟩	Get/set the acceptable temperature range. Used as safeguard to prevent operation with the wrong TEC polarity.
TEC,⟨RMIN/RMAX⟩	Get/set the permitted range of TEC resistance, in ohms. Used as safeguard to detect open/closed circuit.
TEC,VAL	Query the dimensionless output value of the TEC controller as a float in the range [-1,1], intended for monitoring of TEC behaviour.
TEC,KM	Get/set the master gain associated with the TEC controller, in dB (see §2.3). The gain can be increased for improved convergence time or reduced to prevent oscillation.
TEC,⟨KP/KI/KD⟩	Get/set the individual PID component gains for the TEC controller, in dB, to allow further optimisation of the TEC control action. Provided for power-users who are experienced with PID optimisation methods. The value -50 dB represents the associated component being disabled. Note that the interpretation of these coefficients may change between versions of the firmware, and the values may need to be re-optimised after applying a firmware update.

B.7 Locking

Accesses a list of sub-commands to control the frequency stabilisation servos. Most options are individually adjustable for the `type=FAST` and `type=SLOW` servos; ensure to substitute ⟨type⟩ in the relevant commands below.

LOCK,STATUS Returns string indicator of overall lock status.

UNLOCKED	Neither servo is locked, sweep is active.
LOCKED	One or more of the servos is active, so the system is locked.
WARNING	Lock detect algorithm has measured a performance metric outside of expected ranges, indicating the operator should physically verify lock status.
FAILED	Lock detect algorithm has identified that one of the servo outputs has railed, indicating the lock has almost certainly failed and is unlikely to recover.

LOCK,MODE Get/set the operational mode of the lock.

INT	Internal error signal generation by demodulating the photodiode input (§3.2).
EXT	External error mode where the error signal is supplied directly to the specified input, also used for DC locking (§3.1).
SLOW	External SLOW servo mode, used for wavemeter locking (§3.4). The input signal is fed directly to the SLOW controller output, and the FAST controller is disabled in this mode.
FAST	External high-bandwidth FAST servo mode (§3.5). The SLOW controller operates normally using the specified error signal input, and the internal FAST controller is disabled.

LOCK,SRC Get/set which backpanel input is used to provide the error signal for the locking servos.

AC	AC-coupled PD input. Required for INT mode, not compatible with other modes.
DC	DC-coupled PD input.
AUX_A	DC-coupled AUX A input.
AUX_B	DC-coupled AUX B input.

⟨type⟩,STATUS	Same as `LOCK,STATUS` but for individually querying the specified servo (SLOW or FAST).
⟨type⟩,KM	Get/set the master gain associated with the specified servo. This gain is applied to the error signal *before* processing, affecting the monitoring outputs and spectrum analysis.
⟨type⟩,KP	Get/set the proportional gain associated with the specified servo. The servo controller is a PI-type controller, and the integral gain is adjusted automatically.
⟨type⟩,OFFSET	Get/set the DC offset which is subtracted from the error signal.
⟨type⟩,INV	Get/set inversion status for the associated servo. Corrects for whether the actuator increases or decreases the laser frequency in response to a change.
⟨type⟩,LOCK	Activate the lock for the associated servo. The lock will then be engaged at the midpoint of the sweep to prevent inducing a mode-hop.
⟨type⟩,UNLOCK	Disable lock for the associated feedback channel; that is, switch to scanning mode.
⟨type⟩,VAL	Query the dimensionless output of the servo controller, in the range $[-1, +1]$. This may be useful for long-term monitoring.
FAST,BLOCK	Get/set whether the DC-block is enabled for the fast servo. The DC block is strongly recommended to prevent competition between the FAST and SLOW controllers from integrating small differences in their responses at low frequencies. Disable if the SLOW controller is not intended to be used at all (e.g. no piezo transducer).

C. Error indicators

The MOGLabs dDLC detects a wide range of fault conditions and deactivates related circuitry accordingly. The front-panel LEDs and LCD display provide indication of the state of these functions.

C.1 Keyswitch STANDBY/RUN

Colour	Status
GREEN	Keyswitch is set to RUN and no error detected
ORANGE	System is in STANDBY mode
RED	Error state: check display message
BLUE	System disabled, e.g. during firmware update

C.2 Diode OFF/ON

Colour	Status
OFF	Laser disabled in hardware
ORANGE	Laser inactive but TEC is running
GREEN	Laser active, laser emission expected
RED	Error state: check display message
BLUE	System disabled e.g. during firmware update

C.3 Locking

Colour	Status
OFF	Control servo disabled
GREEN	Locked
ORANGE	Anomalous servo state detected
RED	Error detected: check laser state

C.4 System states and error messages

This section defines the status messages that are displayed on the OSD interface and are provided in response to the `STATUS` command.

When encountering an unexpected issue, please send device diagnostic information to MOGLabs to assist in troubleshooting. This is generated by selecting the *Capture debug ZIP* item from the *Help* menu.

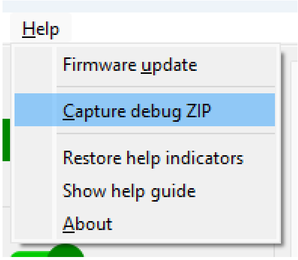


Figure C.1: Menu item to capture diagnostic information about the dDLC.

C.4.1 Normal operation

`STANDBY`	System is disabled by user input, generally because the keyswitch is in the *STANDBY* state.
`READY`	Keyswitch is in the *RUN* state, ready for the laser to be turned on by pressing the *Laser On/Off* button.
`LASER ACTIVE`	The laser is enabled and injection current is being supplied. Emission should be expected from the laser head.
`LASER LOCKED`	Sweep is disabled and FAST and/or SLOW feedback servos are engaged. SPAN and OFFSET controls are disabled while lock is active.
`RELOCKING`	Where available, indicates dDLC is attempting to automatically relock to the desired transition in response to detecting the laser has become unlocked.

C.4.2 Error states

`INTERLOCK`	One of the interlock preconditions is not being met, see §2.1.
`TOGGLE KEYSW`	Hardware or software toggle of the keyswitch is required to resume normal operation, see §2.1.1.
`KEYSW OVERRIDE`	System is disabled because the keyswitch was overridden by software. Cleared by either releasing the keyswitch override in software (with the `KEYSW` command) or toggling the keyswitch in hardware.
`HARDWARE FAULT`	System was shut down because a hardware fault condition was detected. Please contact MOGLabs with the debug information ZIP (Figure C.1) to assist in further diagnostics.
`TEC ERROR`	Laser was disabled because an issue was identified with the TEC, see §2.9.
`LASER ERROR`	Laser was disabled because an issue was identified with the laser driver or headboard, see §2.8.
`LOCK WARNING`	A diagnostic metric indicated that the laser might no longer be locked, see §3.8. This does not mean the laser has become unlocked, but it should be checked when convenient.
`LOCK ERROR`	An error was identified with one of the locking servos, implying that the laser is no longer locked. The most common cause is saturation of the control output in response to large ambient changes, or acoustic perturbation to the lasing cavity.

D. Connectors and cables

D.1 LASER

WARNING: The LASER connector should only be connected to a MOGLabs laser or laser head board. High voltages are present on some pins. The supplies will be disabled if the cable is disconnected, but considerable care should be taken.

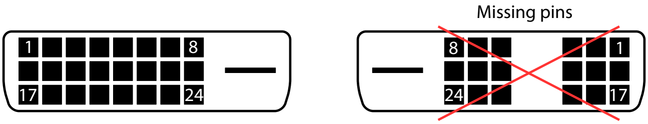
Note Most computer display DVI cables will ***not*** work. They are missing important pins; see diagram below. Only high quality digital ***dual-link*** DVI-D DL cables should be used.

NOTE: The pinout of the DVI connector is similar but not identical to the MOGLabs legacy DLC. Please confirm with MOGLabs before connecting a legacy laser product.

A nominal 10 kΩ thermistor should be connected between NTC+ and NTC–. Relay GND (pin 14) is grounded when the laser diode is activated from the dDLC, which opens the relay that otherwise short-circuits the laser diode. The headboard should supply +5 V to pin 16 (Interlock) from pin 15, to signal that the headboard interlock requirements are satisfied.

The pinout is similar to legacy MOGLabs laser products but **does not support alternative temperature sensors or dual-piezo laser configurations**. Please contact MOGLabs support if you intend to use the dDLC to operate a laser that contains multiple piezoelectric transducers (e.g. “dual-stack” geometry).

Pin	Signal	Pin	Signal	Pin	Signal
1	TEC –	9	DIODE –	17	Comms
2	TEC +	10	DIODE +	18	Comms
3	Shield	11	Shield	19	Shield
4	TEC –	12	DIODE –	20	PIEZO +
5	TEC +	13	DIODE +	21	PIEZO –
6	+15V out	14	Relay GND	22	
7	-15V out	15	+5V out	23	NTC –
8		16	Interlock in	24	NTC +



LASER Socket: DVI-D DL (Dual Link)

Plug: DVI-D SL (Single Link)
Do not use SL cables

Figure D.1: LASER connector on rear panel of dDLC, and plug of common display cable, unsuitable for use with dDLC due to missing connections.

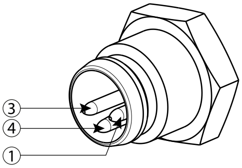
D.2 Photodetector

The photodetector signal is connected via a standard BNC connector.

Low-noise DC power for photodetectors, ±15 V, 125 mA, is supplied through an M8 connector (TE Connectivity part number 2-2172067-2, Digikey A121939-ND, 3-way male).

These are compatible with MOGLabs PDA and THORLABS photodetectors, and should be used with standard M8 cables, for example Digikey 277-4264-ND.

Ensure that any photodetector is switched off when being connected to the power supplies to prevent the output from being latched at the voltage rail.



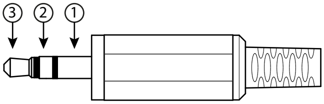
1	+15 V
3	−15 V
4	0 V

Figure D.2: M8 connector pinout for PD POWER.

D.3 Remote interlock

Remote interlock for integration with laboratory interlock systems (§2.1) via standard 3.5 mm cylindrical stereo headphone jack. The two signal pins (for two lasers) are connected to ground via 10 kΩ resistor. The corresponding laser is enabled by shorting the respective signal pin to the outer conductor.

For logic-level interlock systems, it is recommended to use a relay to interface with the remote interlock. Do not connect the signal pins to logic-level outputs. Digikey cable CP-2207-ND provides a 3.5 mm plug with wire ends; red for laser 1, thin black for laser 2, and thick black for ground.



1	+5 V
2	Laser 2
3	Laser 1

Figure D.3: INTERLOCK 3.5 mm stereo connector on rear panel.

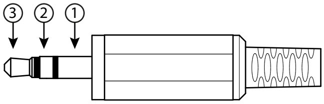
MOGLabs supplies a short-circuit plug which should only be used to bypass the remote interlock requirement where external interlock systems are not required by local safety legislation.

D.4 Remote lock control

The LOCK IN/OUT stereo 3.5 mm headphone jacks are active-low TTL input/output for lock control.

Providing an active low signal to the contacts of the LOCK IN jack will engage the associated lock, for directly interfacing with an external control system.

Similarly the LOCK OUT jack provides TTL low on pins ② and ③ respectively when the slow and fast locks are engaged, for monitoring or connecting to an external servo.



1	Common
2	Slow lock
3	Fast lock

Figure D.4: Remote LOCK IN/OUT 3.5 mm stereo connectors on rear panel.

MOG Laboratories Pty Ltd
49 University St, Carlton VIC 3053, Australia
Tel: +61 3 9939 0677 info@moglabs.com

© 2007 – 2025
Product specifications and descriptions in this document are subject to change without notice.