moglabs

External Cavity Diode Laser Controller

DLC102, DLC202, DLC252, DLC502

Revision 9.25

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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 mechanics and optics needed to turn a simple $10 120 mW AlGaAs diode laser into a research-quality narrow-linewidth tunable laser are fairly straightforward [1, 2, 3, 4], but the electronics is demanding – and, until now, not available commercially from a single supplier, let alone in a single unit.

The MOGLabs range of ECDL controllers change that. With each DLC unit, we provide everything you need to run your ECDL, and lock it to an atomic transition. In addition to current and temperature controllers, we provide piezo drivers, sweep ramp generator, modulator for AC locking, lock-in amplifier, feedback servo system, laser-head electronics protection board, even a high-speed low-noise balanced photodetector.

We would like to thank the many people that have contributed their hard work, ideas, and inspiration.

We hope that you enjoy using the DLC as much as we do. Please let us know if you have any suggestions for improvement in the DLC 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 DLC, 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.
- When the laser is switched on, there will be a short delay of two seconds before the emission of laser radiation, mandated by European laser safety regulations (IEC 60825-1).
- 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 the unit is configured for the correct voltage for your AC mains supply 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.

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 DLC is designed for use in scientific research laboratories. It should not be used for consumer or medical applications.

Protection Features

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

Softstart A time delay (3 s) followed by linearly ramping the diode current (3 s max).

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.

Current limit Sets a maximum possible diode injection current, for all operating modes. Note that current supplied through the RF connector on the laser headboard is not limited.

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 If the detected temperature is below −5°C or above 35°C, the temperature controller is disabled.

Internal supplies If any of the internal DC power supplies (+5, ±10, ±12 V) is 1 V or more below its nominal value, the respective components (temperature controller, diode current supply) are disabled.

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

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

Mains filter Protection against mains transients.

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 main unit and the laser head board have interlocks, to allow disabling of the laser via a remote switch, or a switch on the laser cover.

Contents

1. Introduction

The MOGLabs DLC 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 outline of some modes of operation, so that you can connect and go as quickly as possible. Details are provided in chapter 3.

1.1 Basic operation

In the simplest configuration, the MOGLabs DLC will be used to control the diode injection current, and temperature. All connections are via a single cable to the MOGLabs laser. If using with a non-MOGLabs laser, please see appendix G for information on connecting the diode, thermoelectric Peltier cooler (TEC), and temperature sensor via the laser head interface board which is provided. For operation with DBR/DFB diodes, please see appendix C.

The front-panel display and selector switch can be used to monitor the diode current, current limit, diode dropout voltage, temperature, temperature setpoint, and TEC current; see figure 1.1.

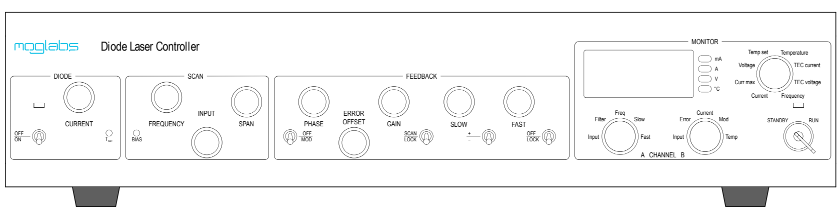


Figure 1.1: MOGLabs DLC front panel layout.

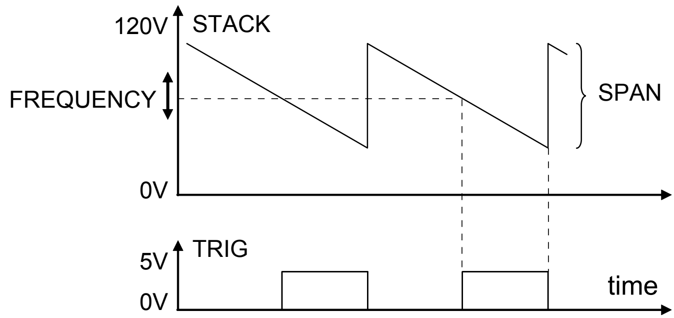


Figure 1.2: Stack (or current bias) output and trigger pulse, when scanning. Note that the ramp slope can be inverted. Details of the ramp behaviour are described in section A.2.

1.2 Passive frequency control

The MOGLabs DLC controls the laser frequency via the diode current, and piezo electric actuators to control the cavity length of an ECDL.

In normal (SCAN) mode, a sawtooth is supplied to the main (STACK) actuator to linearly sweep the laser frequency at a rate determined by the rear-panel trimpot, f_{sweep}, from 4 to 70 sweeps per second; see figure 1.2.

Critical DLC signals can be monitored using the CHANNEL A and CHANNEL B outputs on the rear panel, synchronised to the TRIG trigger output, which should be connected to the equivalent inputs on a two-channel oscilloscope. The particular signals are selected from the front-panel CHAN A and CHAN B selector switches. The signals are described in detail in the following chapter.

Figure 1.3 is an example of what is seen on the oscilloscope in a simple scanning configuration. The laser beam transmitted by an atomic vapour cell is detected on the photodetector provided with the controller, as the laser frequency sweeps through atomic resonances, thus showing the atomic absorption spectrum.

The FREQUENCY knob controls the offset to the piezo-electric actu-

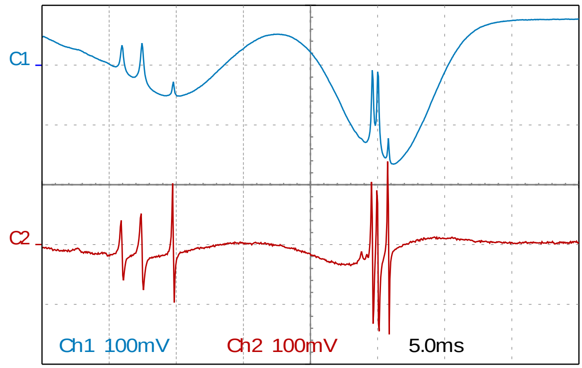


Figure 1.3: A simple absorption spectrum of rubidium with the controller in simple frequency scanning mode.

ator (STACK) and thus the mid-point frequency of the sweep. As the external cavity frequency changes, the laser may "mode-hop" due to competition between the external cavity and the internal cavity defined by the rear and front facets of the diode saemiconductor chip itself. The internal frequency of the diode can be adjusted by changing the diode current, either manually as the FREQUENCY offset is adjusted when modehops are observed. The current can also be automatically biased during the frequency sweep, if BIAS is enabled via the internal DIP switch 4. Note that adjusting the frequency offset (FREQUENCY knob) will affect the diode current if BIAS is enabled, but it may still be necessary to adjust the diode current as FREQUENCY is adjusted, to avoid modehops.

The extent of the frequency sweep is controlled with the SPAN control. The maximum range is typically $10 - 100\,\text{GHz}$. Depending on the offset, the span may be limited by the minimum and maximum voltage that can be applied to the actuator, as described in detail in section A.2.

1.3 DC locking to an atomic transition

Figure 1.4 shows one possible configuration in which a MOGLabs DLC is used to lock an ECDL to an atomic transition. Locking is to the side of an absorption peak in a vapour cell; see for example Demtröder [5] for more information on spectroscopy. The passive configuration of §1.2 is extended with the MOGLabs DLC photodetector (see appendix F), and an atomic vapour absorption cell. Alternately, a Fabry-Perot optical cavity or other reference could be used.

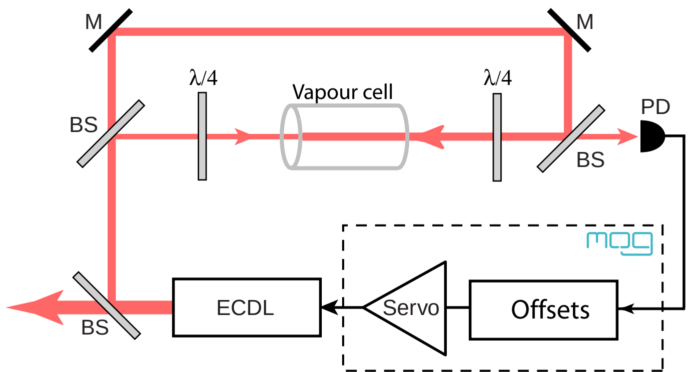


Figure 1.4: Schematic setup for DC locking to an atomic transition. PD is the DLC photodetector. BS beamsplitter, M mirror, $\lambda/4$ a quarter-wave retarder.

The schematic shows a saturated absorption spectroscopy arrangement, but often simply locking to the side of a Doppler-broadened absorption peak will be adequate. The photodetector can be used in single channel mode (default) or with balanced differential inputs, for example to subtract a Doppler background from a saturated absorption spectrum.

The lock frequency is determined by the zero-crossing point of the photosignal. The photosignal offset is adjusted via the INPUT OFFSET and ERROR OFFSET controls. Feedback can be via one or both piezo actuators, or the diode injection current, or all three.

1.4 AC locking to an atomic transition

With AC locking (FM demodulation or "lock-in amplifier" detection), the laser frequency can be locked to a peak centre. The AC approach offers the advantage of inherently lower detected noise 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 the reference frequency, is required. The MOGLabs DLC provides an internal 250 kHz oscillator which can directly dither the diode current, or drive an external modulator. In particular, it is designed to drive a Zeeman-shift modulation coil surrounding the atomic reference vapour cell; see appendix D.

Figures 1.5, 3.5, 3.6 show examples of AC locking arrangements, using a coil to Zeeman-modulate the atomic reference, or an acousto-optic modulator (AOM) for modulating the frequency of the beam passing through the vapour cell. If preferred, the modulator oscillator can be set to dither the diode current (see §2.4). Feedback can again be via one or both piezo actuators, the diode current, or all three.

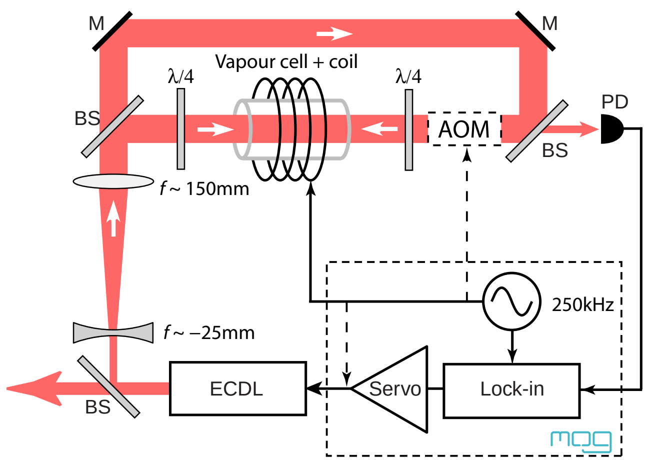
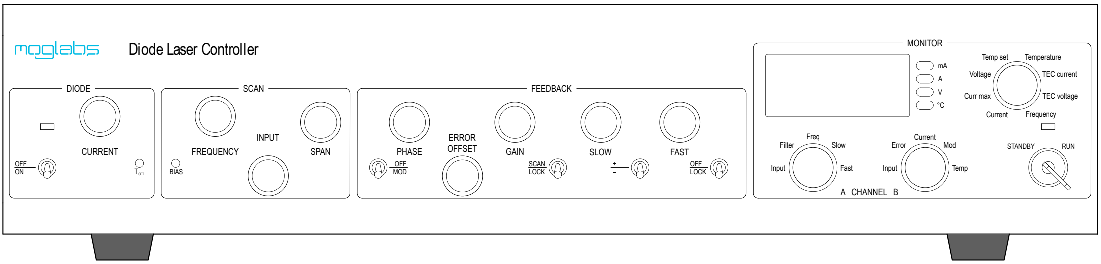


Figure 1.5: Setup for AC locking to an atomic transition. PD DLC photodetector, BS beamsplitter, M mirror, $\lambda/4$ quarter-wave retarder. See also Figs. 3.5, 3.6.

2. Connections and controls

2.1 Front panel controls



STANDBY/RUN In STANDBY mode, the DLC maintains the laser temperature, but powers down all other components including the high-voltage piezo power, and the main on-board low-voltage power.

In RUN mode, the DLC activates all circuits, including the laser current driver and piezo drivers. The diode current is disabled, and the STACK is on but not scanning, until the laser enable switch is ON.

On first power-up, the STANDBY indicator will be red; this is normal and indicates there has been a power failure since last switched to RUN. The unit should then be set to RUN to initiate temperature control, and back to STANDBY if further operation is not desired.

If the unit fails to switch to RUN mode (indicator does not show green), see appendix B.

OFF/ON Diode injection current enable. Also activates the STACK ramp and current bias (if DIP switch 4 in ON). The STANDBY/RUN key switch must first be on RUN and the associated indicator must be green.

If the unit fails to switch to RUN mode (indicator does not show green), see appendix B.

CURRENT Diode injection current, 0 to 100/200/250/500 mA (DLC102 to DLC502). The response is not linear; that is, the change in current varies for a given rotation of the knob. The mid-range sensitivity is reduced to allow greater precision at normal operating currents.

FREQUENCY The laser frequency will normally be controlled via a multilayer piezo-electric actuator (STACK). This knob controls the offset voltage applied to that actuator, 0 to 120 V (or 150 V; see LK2, p. 15). For DFB/DBR diodes, the frequency control feedback signal can control the diode current rather than the stack; see §2.4, DIP switch 16.

Note The FREQUENCY control will also affect the diode current, if BIAS (DIP switch 4) is enabled.

SPAN Frequency scan range, from 0 to 120 V (or 150 V; see LK2, p. 15). The span may be limited by the minimum and maximum voltage that can be applied to the actuator; see detailed description in section A.2.

PHASE When AC locking, the controller demodulates the error signal from the detected light intensity. PHASE adjusts the relative phase between the internal reference modulator and the detected signal, from 0 to 360°. When DC locking, the sign of the error signal can be flipped by rotating the PHASE control.

GAIN Overall error signal gain, 0 to 40 dB.

SLOW Gain for feedback to the slow (piezo) actuator, 0 to 40 dB.

FAST Gain for fast feedback to the diode current, 0 to 40 dB.

T_{set} Temperature set point, 0 – 30° standard; extended range optional.

BIAS Feed-forward bias current. If DIP switch 4 is ON, changes in laser frequency, usually via the STACK actuator, will simultaneously change the current. This trimpot controls the slope dI/df of current with frequency. It can be positive or negative, with a range of ±25 mA for the full frequency span.

INPUT OFFSET	Offset of input light intensity signal, 0 to −10 V. This can be adjusted to bring the photodetector light signal close to zero on the oscilloscope, and to shift the zero frequency lockpoint for DC locking.
OFF/MOD	Modulator enable, to switch on the coil driver, diode current dither, or external modulator.
ERROR OFFSET	Offset of the frequency error lock signal. The DLC will lock such that the error signal plus ERROR OFFSET is zero, allowing for small adjustment of the lock frequency.
SCAN/LOCK	Switch between scanning mode and lock mode. When switching from scan to lock, the controller will first reset the scanning actuator (usually STACK) to the offset voltage at the trigger point, and then lock to the nearest frequency at which the error signal is zero.
+/−	Sign of fast (current) feedback. The sign of the slow feedback can be changed with the PHASE control, for both AC and DC locking.
OFF/LOCK	Enable fast (current) feedback. The laser can be locked with slow (piezo) locking or fast (current) locking alone. Best performance is usually obtained with both channels of feedback; see chapter 4 for feedback optimisation.

2.2 Front panel display/monitor

Display selector

The MOGLabs DLC includes a high-precision 4.5 digit LED display with four unit annunciators and 8-channel selector switch.

Current	Diode current (mA) * *see note below*
Curr max	Current limit (mA) (−) sign indicates limit rather than actual current
Voltage	Diode voltage (V)
Temp set	Temperature set point (°C)
Temperature	Actual temperature (°C)
TEC current	Current to thermoelectric (Peltier) cooler (A)
TEC voltage	Voltage on thermoelectric (Peltier) cooler (V)
Frequency	Frequency actuator offset, usually slow piezo (normalised to a range of ±1)

Note

The current display shows the current set point, not the actual diode current. If BIAS is enabled, then during the scan the actual diode current will be higher or lower than that shown, depending on the adjusted value of the BIAS trimpot. The current limit circuit prevents the actual diode current from exceeding the limit set by I_{max} (see page 13), even if the current setting plus current modulation (internal, external, or BIAS) would exceed I_{max}.

Use CHAN B Current to see the actual diode current, and the effect of BIAS and current limit when scanning.

CHAN A

Several important signals can also be monitored externally with an oscilloscope via the rear connectors CHANNEL A, CHANNEL B and TRIG. The outputs to these can be selected with the CHAN A and CHAN B selectors.

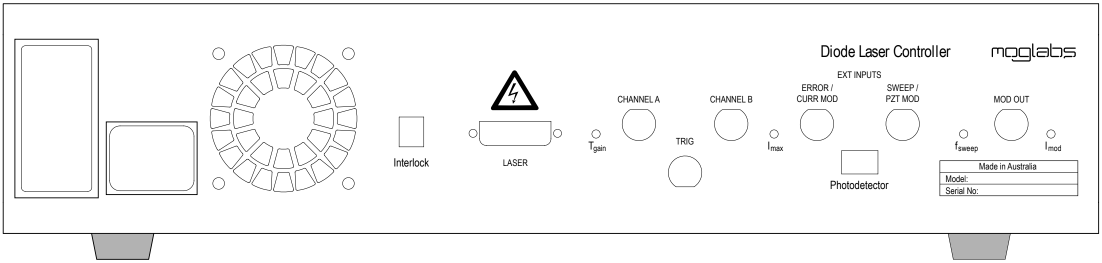
Input	Photodetector [30 mV/μW]
Filter	Filtered photodetector, 40 kHz low pass
Freq	Frequency-scanning actuator (STACK) [1 V/48 V]
Slow	Slow feedback STACK [1 V/0.24 V] DISC [1 V/4.8 V]
Fast	Current feedback [1 V/100 μA]

CHAN B

Input	Photodetector [30 mV/μW]
Error	Feedback error
Current	Diode current [2 V full scale*]
Mod	Modulator output current [1 V/A]
Temp	Temperature error [10 V/°C]

* Thus 20, 10, 8, 4 V/A for DLC102/202/252/502.

2.3 Rear panel controls and connections



IEC power in/out The unit should be preset for the appropriate voltage for your country. Please contact MOGLabs for instructions if you need to change the power supply voltage.

The output IEC connector is a direct connection to the input power, after the input mains filter. This outlet should be used only to power a monitoring oscilloscope. It is provided to minimise ground-loop noise problems.

Fan The fan speed is temperature-controlled.

Interlock The DLC will not power on the laser unless the pins on this connector are shorted. A standard 2.1 mm DC plug is provided.

LASER Connection to laser head. This connector provides diode current, two piezo drives, temperature sense, and TEC current. A DVI-D Dual cable is provided.

WARNING The piezo drive signals can be lethal. The high-voltage outputs, diode current and TEC current will be disabled if the cable is disconnected, or if the main or head interlocks are open-circuit, but these protection features should not be assumed.

Note Most computer display DVI cables will ***not*** work. See appendix I for further information.

T_{gain} Temperature control feedback gain. Increase this if the response time is too great or if the temperature error is large. Reduce this if the temperature oscillates.

CHANNEL A, B Monitor outputs; connect to oscilloscope, channels 1 and 2.

TRIG Oscilloscope trigger, TTL-level. Connect to external trigger input on oscilloscope. Set oscilloscope triggering for external, rising edge.

I_{max} Diode current limit. The current limit can be set with the display selector set to ***Curr max***. See page 10 for further information.

ERROR/CURR MOD Input for externally derived feedback error signal (DIP switch 5) or for current modulation (DIP switch 6). Impedance 5 kΩ. Signal normally $< \pm 1$ V; max ± 8 V. If used for external error, DIP switch 5 ON, applies in lock mode only.

If used for current modulation, DIP switch 6 ON, the sensitivity is controlled by the FAST gain control, from 0.25 mA/V to 25 mA/V.

Signal paths can be found in appendix H.

SWEEP/PZT MOD Input for externally generated frequency control (STACK, DIP switch 9 and/or DIP switch 13) or for piezo DISC modulation (DIP switch 14). This signal is *added* to the internal error signal if DIP switch 15 is on.

If DIP switch 9 is on, the internal sweep ramp is replaced with the external sweep input. In that case, the external sweep signal should be 0 to 2.5 V and *must* cross 1.25 V to generate triggering for the oscilloscope (TRIG) and locking. Impedance 5 kΩ. Sensitivity 48 V per volt (120 V max).

If the external sweep is less than 0 to 2.5 V then the current bias dI/df will be reduced in proportion.

It is possible to add the SWEEP signal to the internally generated STACK signal in all circumstances, for example to test actuator response while locked to a transition. To do this, add a resistor (approximately 5k0, size 0603) at R113.

Signal paths can be found in appendix H.

Photodetector Connection to photodetector unit. A standard 6-pin FireWire (IEEE-1394) cable is provided.

f_{sweep} Scan rate, 4 – 70 Hz. Note that the rapid return of the STACK sweep drive can excite mechanical oscillations in the laser. Slower sweeps are recommended; usually 10 or 20 Hz works well but if ringing is observed at the start of the sweep, reduce f_{sweep}.

MOD OUT Connection to external modulator, output is 0 to ±500 mA, ±8 V. Current sensing with 1 Ω sense resistor. It can be directly connected to a 50 Ω load, giving a voltage of ±5 V if I_{set} is adjusted to ±100 mA. See appendices D, E.

I_{mod} Modulation depth: the range of current modulation on MOD OUT and if DIP switch 3 is on, the diode current.

2.4 Internal switches and adjustments

See appendix H for schematic overviews of the piezo and diode current control signals, and the effect of the different DIP switches. See appendix J for the location of relevant internal components.

CAUTION The cover of the controller should be left on, even loosely, to ensure proper airflow and cooling.

Interlock Link LK1 (rear right of main board) can be shorted internally to avoid the requirement for an external interlock, if permitted by local safety regulations.

120 V Link LK2 (near LK1 and 160 V test point) can be shorted to limit the piezo stack voltage to 120 V, or removed to increase it to 150 V.

DIP switches

	OFF	ON
1	DISC fixed	DISC ON
2	STACK fixed	STACK ON
3	Current dither OFF	Current dither ON
4	Current bias OFF	Current bias ON
5	Internal error	External error
6	External current mod OFF	External current mod ON
7	AC lock	DC lock
8	Single photodiode	Dual photodiode
9	Internal sweep	External sweep
10	STACK feedback –	STACK feedback +
11	STACK sweep +	STACK sweep –
12	AC current feedback	DC current feedback
13	STACK internal	STACK external
14	DISC internal	DISC external
15	Default	External slow error
16	Current mod by SLOW control signal (for DBR/DFB)	

DIP 1, 2 Please refer to section 2.5 below for discussion of feedback configurations.

DIP 3 With DIP 3 ON, the 250 kHz modulator directly modulates the injection current to cause frequency modulation of the laser frequency. In conjunction with a frequency-dependent absorption on the photodetector signal, for example with an atomic vapour cell or etalon (see section 3.5). The modulation depth is adjusted via internal trimpot RT6 and the I_{mod} rear-panel trimpot. The modulation can be switched on and off via the front panel toggle switch OFF/MOD.

Caution Current dither (DIP 3 ON) inherently increases the effective linewidth of the laser. The modulation depth should be adjusted to the minimum which still provides a useful locking signal.

DIP 4 Enables injection current bias, sometimes called “feed-forward”. If this switch in ON, the injection current will be modulated in conjunction with changes to STACK, for example as the laser frequency is ramped, or due to frequency feedback locking. The depth of bias modulation is controlled with the BIAS front-panel trimpot. Appropriate adjustment can substantially extend the mode-hop-free scan range of the laser.

DIP 5 Externally derived locking signals can be used to control the laser current and piezo actuators. If DIP 5 is ON, the internally generated error signal is replaced with the signal from the rear-panel ERROR input, and then drives all feedback channels. The master gain adjustment, and both slow and fast gain adjustments, can be used.

DIP 6 If this switch is ON, the rear-panel ERROR/CURR MOD signal is added to other current feedback signals, and the gain of the combined signal is enhanced by a factor of 25. All internal servo shaping filters are bypassed by the external current modulation. The gain knobs affect the internally-generated error signals as usual. The FAST gain knob and +/− also affect the external current modulation. The state of DIP 5 does not affect ERROR.

DIP 6 and DIP 12 If both DIP 6,12 are on, internal slow feedback to STACK, and external current modulation to the diode current, are enabled.

DIP 7 Switch 7 determines whether AC (centre or top of peak) or DC (side of peak) locking is used. Generally AC is preferred because the noise at the modulation frequency of 250 kHz is much lower than at DC; thus AC locking is largely free of slow drifts. However, for many applications a DC reference is perfectly adequate and allows locking with wider bandwidth.

DIP 8 It can be convenient to subtract a background from the input signal, for example to remove a Doppler background from a saturated absorption reference. Switch 8 switches the photodetector to differential mode. The difference between the two photodiode signals is generated in the photodetector itself.

DIP 9, 13, 14, 15 These switches determine the function of the SWEEP input, for example to provide an external frequency ramp, or to use an external locking circuit (see section 3.7) or to allow measurement of the actuator response functions.

DIP 9 With DIP 9 ON, the laser frequency sweep will be driven from an external ramp. Note that the sweep, supplied via SWEEP, should be 0 to 2.5 V and *must* cross 1.25 V to generate triggering for the oscilloscope and locking. The TRIG signal will output at 1.25 V. The front-panel SPAN knob controls the amplitude.

DIP 10, 11 The sign of the response of the two piezo actuators can be reversed with switches 10, 11. For example, increasing the potential on STACK may increase or decrease the cavity length, while DISC may act in the same or the opposite sense. It is important for locking that both operate in the same sense. Also, it may be useful to reverse the scan for some applications. To reverse the sign of DISC, reverse the error signal first, and then adjust the sign of the STACK and current feedback.

Note The feedback to the STACK actuator reverses with DIP 1 and so DIP 10 should also be flipped when DIP 1 is flipped, or the PHASE adjusted to reverse the error signal. See section 2.5 below for further discussion.

DIP 12 Current feedback is normally AC coupled because slow feedback to STACK takes care of slow drifts. For lasers without piezo control, such as DBR and DFB diodes, DC feedback to current can be enabled by switching DIP 12 on. With external current modulation (see DIP 6 above), DIP 12 on enables slow piezo feedback and AC coupled external current modulation.

DIP 13 If DIP 13 is on, the internally generated STACK signal is replaced with the external SWEEP signal, independent of the state of SCAN/LOCK. The change occurs after the offset (FREQUENCY) and STACK polarity (DIP switch 11), before the SLOW gain adjust.

It is possible to *add* the SWEEP signal to the internally generated STACK signal in all circumstances, for example to test actuator response while locked to a transition. To do this, add a resistor (approximately 5k0, size 0603) at R113.

DIP 14 If DIP 14 is on, the internally generated DISC signal is replaced with the external SWEEP signal, independent of the state of SCAN/LOCK.

To measure an actuator response, connect an external variable-frequency oscillator to the SWEEP input, and sweep through the frequency range of interest. Measure the laser frequency modulation amplitude from the transmitted intensity at the side of a Fabry-Perot fringe or saturated absorption transmission peak (e.g. fig. 1.4), preferably with a lockin amplifier.

DIP 15 If DIP 15 is on, the external SWEEP input replaces the normal internally-generated slow (piezo) feedback error signal. The change occurs before the SLOW gain adjust. The fast (current) feedback is unaltered, except for the signal activated by DIP 16; see section 2.5 below. Sweep, offset (FREQUENCY) and stack polarity (DIP switch 11) are unaffected.

DIP 12, 16 Switches 4, 12, 16 allow operation of DFB/DBR lasers without external cavity feedback and thus with only current as an actuator. Please refer to section 2.5 below for discussion of feedback configurations.

Use switch DIP 4 (current feed-forward bias) to drive the current with the scanning ramp. Switch DIP 16 adds the fast DISC signal to the current. DIP 16 and DIP 4 can be active simultaneously. Switch 12 enables DC coupling of the current feedback, rather than the default AC coupling, to allow current-only feedback locking.

2.5 Feedback configurations

The DLC is designed to drive up to three feedback actuators with appropriate frequency bandwidths for each. The actuators are STACK, DISC and CURRENT. Suitable lasers include the MOGLabs ECDL which has CURRENT and STACK feedback but no DISC piezo; DFB/DBR lasers which only offer CURRENT feedback; and lasers with all three.

The nominal feedback bandwidths described below are defined by the unit gain bandwidth when all controls (MASTER, SLOW, FAST) are at their centre positions. The actual closed-loop unity gain frequencies will depend on the particular laser, diode, and piezos used and on the reference signal, so the frequencies are only a guide.

For CURRENT feedback, phase lead adjust can increase the bandwidth to 40 kHz.

Summary of configurations

DIP	16	10	2	1	Description
A	OFF	OFF	ON	ON	STACK slow DISC fast
B	ON	ON	ON	ON	STACK slow DISC fast
C	OFF	ON	ON	OFF	STACK fast DISC fixed
D	OFF	OFF	OFF	ON	STACK fixed DISC fast
E	ON	X	OFF	OFF	STACK fixed DISC fast

For the MOGLabs ECDL, use option C (default) or, to increase the range for slow drift, option B.

The configurations above assume that increasing the voltage on STACK increases the laser frequency (by reducing the cavity length). Reverse DIP 10 if the opposite is true.

A: STACK slow, DISC fast

STACK: −20 dB/decade, BW 50 Hz
DISC: −40 dB/decade, BW 1.5 kHz
CURRENT: −20 dB/decade, BW 15 kHz

B: STACK slow, DISC fast, extra CURRENT

STACK: −20 dB/decade, BW 50 Hz
DISC: −40 dB/decade, BW 1.5 kHz
CURRENT: −20 dB/decade BW 15 kHz + flat response

Additional CURRENT feedback with flat response (no integrator) to boost low-frequency feedback. The combined current feedback gain is reduced 25×. In this configuration, the error signal must be reversed; that is, the error signal should have a positive slope at the lock point, the +/- current feedback polarity toggle switch should be down (−). Note DIP 10 is ON.

C: STACK fast, DISC fixed

STACK: −40 dB/decade, BW 750 Hz
DISC: fixed
CURRENT: −20 dB/decade, BW 15 kHz

High gain (fast) output to STACK reduces range of STACK to ±1 GHz before internal signal saturates.

D: STACK fixed, DISC fast

STACK: fixed
DISC: −40 dB/decade, BW 1.5 kHz
CURRENT: −20 dB/decade, BW 15 kHz

E: CURRENT only

STACK: fixed
DISC: fixed
CURRENT: flat, BW 15 kHz
DIP 12 should be ON for DC CURRENT feedback.
DIP 4 ON to drive the current with the scanning ramp.

For DBR and DFB lasers and ECDLs when it is desirable to operate without piezo actuators.

2.6 Digital control

HD12 is a 10-pin header which provides access to several control signals for locking and for sample-and-hold of the lock-point. HD12 is located near the DIP switches, slightly towards the front and left-hand side of the unit (see appendix J). The pinout of the header is described in section I.4. The signals are standard TTL-compatible, $> 2.4\,\text{V}$ HIGH and $< 0.8\,\text{V}$ LOW. The inputs are ORed with the front toggle switches, such that the signal is activated if either the digital input is active (i.e. HIGH) or the toggle switch is on (down).

Laser ON HIGH to switch the laser diode current on, regardless of the state of the front-panel switch.

LOCK HIGH to SLOW lock, regardless of the state of the front-panel switch. LOW to sweep, if the front-panel switch is up.

FAST HIGH to FAST lock.

HOLD HIGH to freeze STACK. With HOLD active, the feedback to the slow piezo will be fixed by a sample-and-hold circuit. The diode current can then be modulated via the rear-panel CURR MOD input (with DIP switch 6 ON), to jump the laser frequency quickly, without the error feedback circuit competing with the external modulation. External current modulation is independent of the FAST lock status.

FAST lock is asynchronous with HOLD active; that is, the FAST lock will activate immediately, rather than the normal delay until the scan ramp reaches the sweep centre.

To relock, restore the CURR MOD input voltage, and return the HOLD input LOW; the locking feedback will then be reactivated. FAST lock can then be reactivated.

This ability can be used for auto-locking under computer control, and also for atom trapping experiments involving sequences with different detunings for polarisation gradient cooling and for compression.

2.7 Internal trimpots

RT6	Current dither amplitude limit
RT12	Phase lead
RT13	Ambient temp for active sensors (AD590, AD592)
RT15	TEC current limit

RT6 For AC locking, either the laser frequency or the external reference must be modulated at the DLC dither frequency, 250 kHz. An external modulator (see appendix E) is normally used, but the laser injection current can be modulated directly. The modulation depth is then controlled by the rear-panel I_{mod} trimpot. The limit to the current modulation is factory set via RT6.

RT12 A phase-lead circuit is included on the current feedback channel, to boost the output at higher frequencies (tens of kHz). RT12 controls the phase lead and can be adjusted for different diodes; see appendix 4.

RT13 Offset adjustment for active temperature sensors (AD590, AD592), so that temperature reads in °C.

RT15 Current limit for TEC output. To set, change the set temperature suddenly, and adjust RT15 while reading the TEC current.

3. Operation

3.1 Simplest configuration

In the simplest application, the MOGLabs DLC will be used to control just the diode injection current and temperature. All connections are via a single cable to the MOGLabs laser. If using with a non-MOGLabs laser, please see appendix G for information on connecting the diode, thermoelectric Peltier cooler (TEC), and temperature sensor via the laser head interface board. For operation with DBR/DFB diodes, please see appendix C.

To operate in passive configuration:

1. Ensure the power is on, and the STANDBY/RUN switch is on STANDBY. In this mode, most circuits will be switched off, including much of the main internal board, low and high voltage DC supplies, photodetector, piezo and diode outputs. On first power-up, the STANDBY indicator will be red; this is normal. The switch should be set to RUN to initiate temperature control, and then may be returned to STANDBY.
2. Switch from STANDBY to RUN. The indicator should change from red (if just powered up), or orange, to green. If the indicator is not green, the TEC or sensor is not correctly wired. In RUN mode, all electronics will be powered up, except for the diode injection current supply and piezo drivers.
3. If the controller is switched back to STANDBY, all electronics will be powered down, *except for the temperature controller*, which will continue to operate normally.
4. Adjust the temperature setpoint: first select **Temp set** on the display selector, then adjust T_{set} via the front-panel trimpot.
5. Temperature control can be optimised by adjustment of the integrator gain, rear-panel trimpot T_{gain}. Adjust to minimise

the time to equilibrate the temperature (CHANNEL B output, front panel CHAN B set to **Temp**) after a sudden change in T_{set}.

6. Adjust the current control knob to minimum (fully anti-clockwise).
7. Set the diode maximum current: select **Curr max** on the display selector, then adjust the maximum allowed diode injection current via the rear panel I_{gain} trimpot. Note that with the display set to **Curr max**, a negative sign (−) provides a visual reminder that the limit is being displayed rather than the actual current.
8. Switch the laser on. The indicator on the laser head board should illuminate, and the front-panel indicator above the switch should turn green.

Note that the SCAN/LOCK and fast-channel OFF/LOCK switches must be set to SCAN and OFF respectively. Other protection features will prevent current to the diode, including main cable disconnect, and open circuit on the rear-panel or laser head interlocks.

3.2 Laser frequency control

In normal (SCAN) mode, a sawtooth ramp is supplied to the the stack, at frequency of $f_{sweep} = 4$ to $70\,\text{Hz}$; see fig. 3.1. Depending on the frequency offset (FREQUENCY) and the width of the scan (SPAN), the STACK can saturate either at the low or high frequency end of the sweep. The spectrum may then be constant, although if current bias is enabled the laser frequency may still scan in that range, but at a smaller slope (see section A.2 for details).

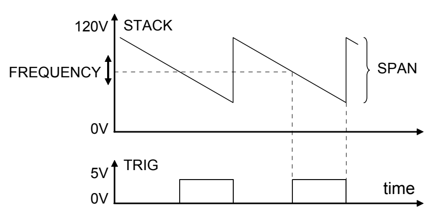


Figure 3.1: Stack output voltage and trigger signal, when scanning.

Several adjustments of the frequency sweep are possible:

SCAN/LOCK	The SCAN/LOCK switch should be on SCAN.
FREQUENCY	Offset; i.e. mid-point voltage of the ramp.
SPAN	Sets the height of the ramp; see fig. 3.1.
BIAS	The BIAS front-panel trimpot controls the feed-forward bias injection current which follows the ramp, to enable wider mode-hop-free scans. The bias can be adjusted in a trial-and-error manner to achieve the widest possible scans. BIAS is disabled unless internal DIP switch 4 is ON.
f_{sweep}	The rear-panel f_{sweep} trimpot adjusts the ramp rate from 4 to 70 Hz.

Note The rapid return of the STACK sweep drive can excite mechanical oscillations in the laser. Slower sweeps are recommended; usually 20 Hz works well but if ringing is observed at the start of the sweep, reduce f_{sweep}.

Figure 3.2 is an example of an absorption spectrum acquired with the simple scanning configuration, using a standard (uncoated) diode and BIAS current feed-forward. The transmission of the laser through a rubidium vapour cell was detected on the DLC photodetector, as the laser frequency was scanned through the $5^2S_{1/2} \rightarrow 5^2P_{3/2}$ levels.

3.3 External scan control

An external source can be used to control the laser frequency while in SCAN mode.

1. Connect the external frequency control (ramp, or DC) signal to the rear-panel SWEEP external input.
2. Select external signal by setting DIP switch 9 to ON.
3. Set DIP switch 4 on if current bias is required.

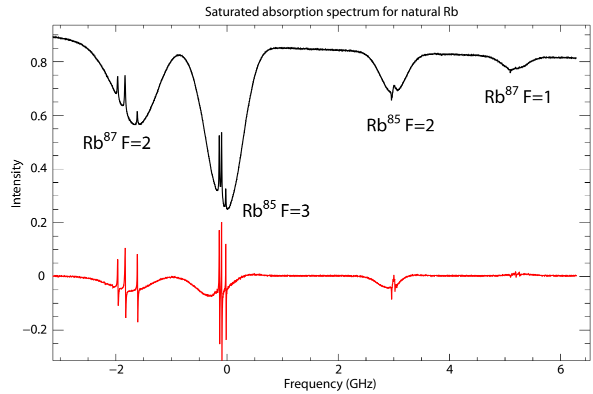


Figure 3.2: A saturated absorption spectrum of rubidium using a standard uncoated laser diode and low diffraction efficiency grating in Littrow configuration (upper trace). The lower trace shows the AC-modulation error signal (see §3.5).

4. Toggle DIP switch 11 (external sweep has reverse polarity to internal).
5. Set SCAN/LOCK to SCAN. The front-panel SPAN knob controls the amplitude.

Note The frequency control supplied to SWEEP should be between 0 and 2.5 V and *must* cross 1.25 V to generate essential internal triggering. The TRIG signal will output at 1.25 V.

3.4 Locking to an atomic transition: DC

Figure 3.3 shows how an ECDL can be locked to an atomic transition as determined from absorption in a vapour cell. The basic configuration described in §3.2 is extended with the DLC photodetector, and an atomic vapour absorption cell. A Fabry-Perot optical cavity or other frequency reference could also be used.

The photodetector can be used in single channel mode (default) or with balanced differential inputs, for example to subtract a Doppler

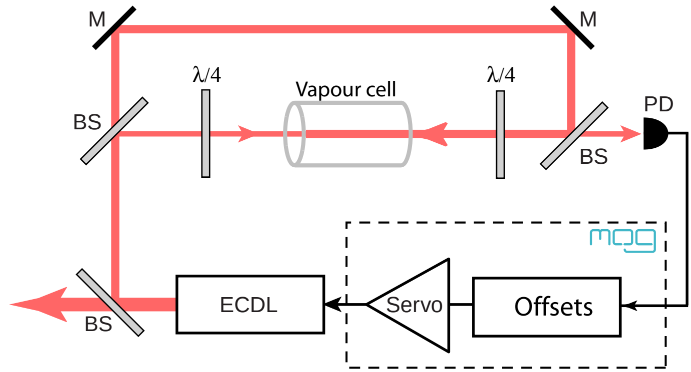


Figure 3.3: Schematic setup for DC locking to an atomic transition. PD is the DLC photodetector. BS beamsplitter, M mirror, $\lambda/4$ retarder.

background from a saturated absorption spectrum.

Sample oscilloscope traces obtained in DC locking ("side of fringe") mode are shown below, for wide and narrow spans. These traces were obtained with an 8 cm long Rb vapour cell at room temperature.

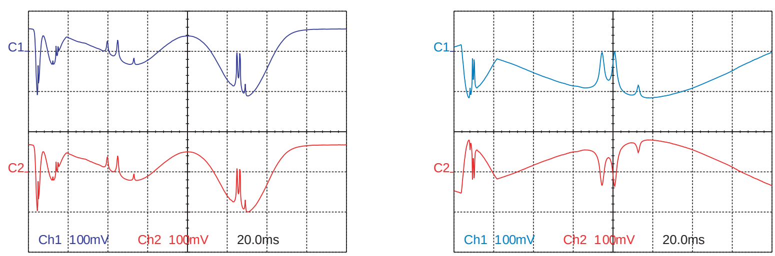


Figure 3.4: Examples of spectra for DC locking, for wide and narrow spans (upper traces) and error signals (lower traces).

To operate in DC locking configuration:

1. Select DC locking by setting internal DIP switch 7 to ON.
2. If using differential inputs, set internal DIP switch 8 to ON.
3. Using an optical beamsplitter, a stray reflection, or by other

means, deflect a fraction of the laser output through the vapour cell. The MOGLabs DLC is designed to operate best with about 250 μW incident on each of the Si-PIN photodiodes. Lensed and filtered photodiodes are standard, to minimise the influence of background light, but best results will be obtained if light from incandescent or fluorescent lamps is eliminated.

4. If using balanced inputs, the second light beam should illuminate the second photodiode.
5. Find an appropriate spectral feature.
6. Adjust front-panel INPUT OFFSET and ERROR OFFSET to obtain a zero-crossing ERROR signal at the desired frequency. The slope should normally be negative (depending on DIP switches **10, 11**). The ERROR signal can be inverted by coarsely adjusting the PHASE control.
7. Set SLOW and FAST gains to minimum (fully anti-clockwise).
8. Switch SCAN/LOCK to LOCK.
9. Switch OFF/LOCK to LOCK. It may be necessary to invert the sign of the fast lock with the ± switch.
10. Increase SLOW and FAST gains to minimise the error signal, ideally using an external audio spectrum analyser. The gains should be increased until the onset of oscillation, and then reduced. See chapter 4 for additional discussion of feedback optimisation.

Note that it is not necessary to “zoom in” on the desired lock point. The controller will automatically lock to the zero-crossing closest to the trigger point, i.e. to the centre of the oscilloscope trace.

When the laser is locked (step 8 above), the photodetector (INPUT) signal should be fixed at the value corresponding to the lock frequency – in this case zero since for DC locking, the controller locks to the zero-crossing.

3.5 Locking to an atomic transition: AC

Figures 3.5 and 3.6 show two alternate saturated absorption spectroscopy arrangements, useful for AC ("top of fringe") locking. The laser frequency can be directly modulated via the diode current (see §2.4, DIP switch 3), or using an external modulator. The controller includes a modulator driver with sufficient power to drive a coil directly for Zeeman modulation, or an external modulator such as an acousto-optic modulator can be used; see appendix D.

Sample oscilloscope traces obtained in AC locking mode are shown below, for wide and narrow spans. These traces were obtained with an 8 cm long Rb vapour cell at room temperature, using a Zeeman modulation coil as described in appendix D.

To operate in AC locking configuration:

1. Select AC locking by setting internal DIP switch 7 to OFF.
2. Connect the photodetector module and optimise the photosig-

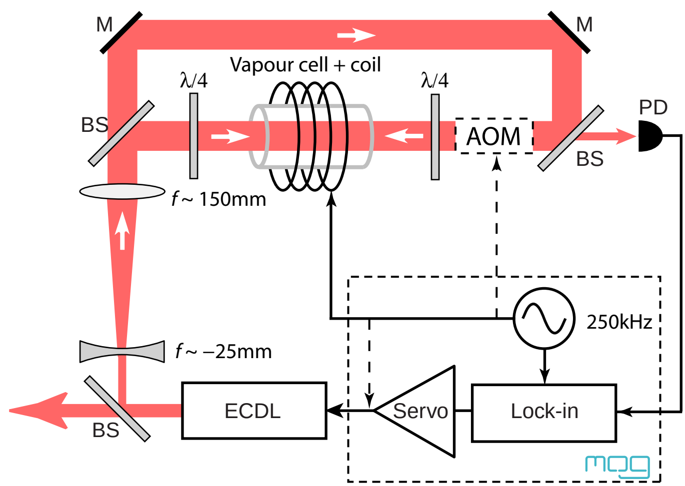


Figure 3.5: Schematic setup for AC locking to an atomic transition. PD is the DLC photodetector. BS beamsplitter, M mirror, $\lambda/4$ retarder. Beam expanding lenses increase signal power without power broadening.

nal on CHANNEL A. The MOGLabs DLC is designed to operate best with about 250 μW incident on the Si-PIN photodiode. Lensed and filtered photodiodes are standard, to remove most background light, and when AC locking at 250 kHz modulation frequency, any remaining photocurrent from background lighting should not be a problem.

3. Adjust the INPUT OFFSET such that saturated absorption trace is near zero.
4. Switch the modulation on with OFF/MOD.
5. Find an appropriate spectral peak and observe the dispersive error signal with CHAN B set to ERROR.
6. Optimise the error signal (usually for maximum slope) by adjusting the front panel PHASE. The error signal slope should normally be negative (depending on DIP switches **10, 11**) at the desired frequency.
7. Adjust the GAIN such that the error peaks are roughly 250 – 500 mV peak-to-peak. Note that larger signals are *not* recom-

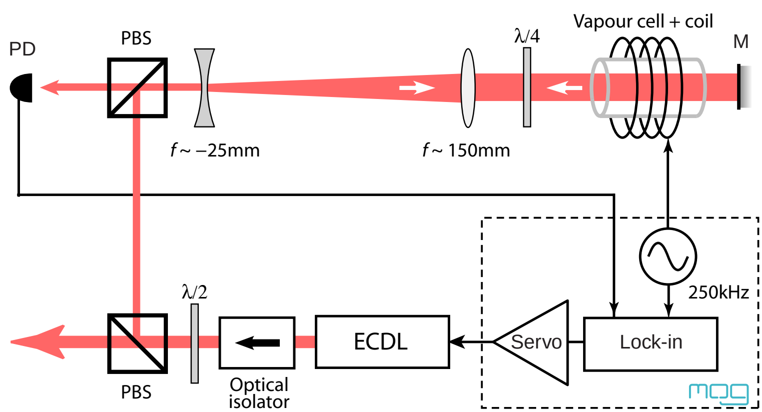


Figure 3.6: Schematic setup for a more compact and more easily aligned saturated absorption arrangement. PD is the DLC photodetector. PBS polarising beamsplitter, M mirror, $\lambda/4$ and $\lambda/2$ retarders. Beam expanding lenses increase the signal power while minimising saturation broadening.

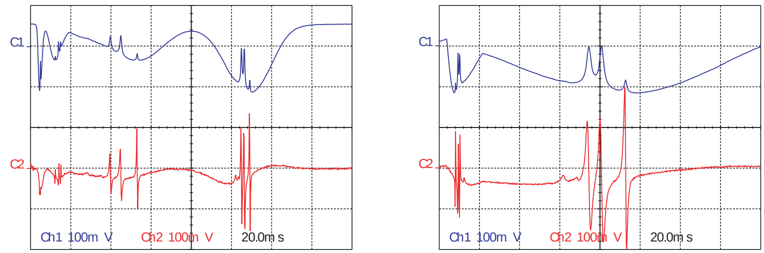


Figure 3.7: Examples of spectra for AC locking, for wide and narrow spans (upper traces), with error signals (lower traces).

mended; although the signal-to-noise may look better on an oscilloscope, that is a reflection of the noise of the oscilloscope and is not the case inside the DLC controller.

8. Adjust front-panel ERROR OFFSET such that the error signal is crossing zero at the desired frequency.
9. Set SLOW and FAST gains to minimum (fully anti-clockwise).
10. Switch SCAN/LOCK to LOCK.
11. Switch OFF/LOCK to LOCK. It may be necessary to invert the sign of the fast lock with the ± switch.
12. Increase SLOW and FAST gains to minimise the error signal, ideally using an external audio spectrum analyser (see chapter 4). The gains should be increased until the onset of oscillation, and then reduced. See chapter 4 for additional discussion.

Note again that it is not necessary to "zoom in" on the desired lock point. The controller will automatically lock to the zero-crossing of the error signal (in this case the peak of a spectral feature) closest to the trigger point, at the centre of the oscilloscope trace.

When the laser is locked (step 10 above), the photodetector (INPUT) signal should be fixed at the value corresponding to the lock frequency. In contrast to the DC locking case, this should be the INPUT signal at the peak of the spectral feature, *not* zero.

3.6 External sweep

An external ramp can be used to control the frequency sweep, for example if very slow sweeps are required, or for computer-controlled sweeps.

To operate with external sweep:

1. The external sweep signal *MUST* have 1.25 V offset. That is, it must transition through 1.25 V at some time during the sweep.
2. The external sweep signal should be within 0 to 2.5 V range.
3. Connect the external sweep signal to the rear-panel SWEEP external input.
4. Select the external sweep signal by setting internal DIP switch 9 to ON.
5. Normally DIP switch 4 should be on so that current bias (feed-forward) is enabled.
6. The front panel knobs FREQUENCY and SPAN will then apply offset and attenuation to the external ramp. It is recommended to set FREQUENCY to its midpoint (0 V on the front-panel display, with Frequency selected) and set SPAN to fully clockwise. The ramp amplitude and offset can then be controlled externally, or via the SPAN and FREQUENCY controls.

Note: if you have a Rev. 8 controller, you will probably need to remove resistor R113. See figure below, and contact MOGLabs for assistance if you have any doubts.

3.7 Locking using an external signal

The MOGLabs DLC can be used with a wide variety of externally generated dispersive signals; see appendix E for examples, and appendix H for block diagrams of the control circuitry.

Note that this section refers to *error* and *control* signals. An error signal is a dispersive signal with a potential that depends on laser frequency. A control signal is a feedback servo signal generated from an error signal, usually with PID (proportional-integral-differential) or PIID (PID with a double integrator) response.

When using an external error or control signal, it will normally be advisable to switch off the modulator (DIP switch 3).

3.7.1 External error signal

To operate with externally generated *error* signal, but using the internal DLC servo PIID feedback control:

1. Connect the external error signal to the rear-panel ERROR external input.
2. Select the external locking signal by setting internal DIP switch 5 to ON. DIP switch 6 should be OFF.
3. Follow the procedure above for DC locking.

The bandwidth limit will be the same as for a DLC-generated error signal; that is, about 25 kHz on the fast (current) channel.

3.7.2 External slow control signal to piezo

To drive the piezo from an external control signal, for example from the PID output of a wavemeter. This option is preferable to external sweep (section 3.6 above) if you want to use the internal DLC ramp to find your lockpoint, and then switch to the external control signal to lock.

1. Connect a 5k resistor to R113 (see figure 3.8).
2. Connect the external control signal to the rear-panel SWEEP input.
3. Select the external locking signal by setting internal DIP switch 5 to ON. DIP switch 9 should be OFF.
4. Follow the procedure above for DC locking.

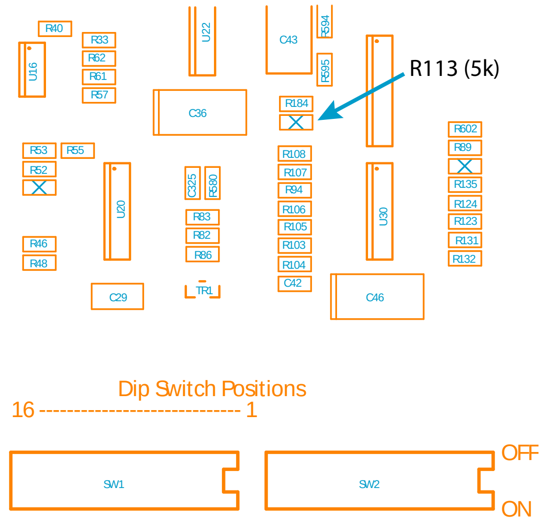


Figure 3.8: R113 is connected so that signals on the SWEEP input always affect the piezo. Remove if using external sweep, or add if using external *control* signal to drive the piezo.

3.7.3 External fast (current) control for higher bandwidth

For higher bandwidth feedback, a fast *control* signal can be input on ERROR and enabled via DIP switch 6. The fast signal will then control current directly, *without* DLC feedback control.

The external feedback circuit must include appropriate response. If using current-only control, without piezo control, then PID or PIID is probably appropriate.

If the DLC is still controlling the piezo (with SLOW lock turned on) then the current control should be AC coupled, and include gain reduction at high frequencies to avoid servo loop oscillation.

3.7.4 External fast and slow

To control both current (fast) and piezo (slow) with external signals:

1. Connect fast *control* signal to ERROR.
2. Enable fast current control with DIP switch 6.
3. Connect slow *error* signal to SWEEP.
4. Enable slow piezo control with DIP switch 15.

The piezo will be controlled by the DLC if SCAN/LOCK is on SCAN, and by the external slow signal when switched to LOCK.

The slow signal should be a dispersive error signal without PID or other servo response function. The fast signal should be AC coupled, and include gain reduction at high frequencies to avoid servo loop oscillation.

3.8 External control of lock frequency setpoint

It is often useful to have external control of the lock frequency setpoint, for example to suddenly change the detuning of a laser. See section 2.6 for discussion of such external control.

4. Optimisation

Laser frequency stabilisation is a complex and ongoing research topic. A thorough treatment would require extensive discussion of control theory, actuator response, mechanical design, laser-atom interactions and electronics. Here we consider the problem from a pragmatic perspective.

The laser is assumed to be moderately stable, operating close to the desired frequency, with a linewidth of a few MHz averaged over a typical measurement time of about one second. The very short-term linewidth is determined by the Schawlow-Townes (S-T) limit, which is typically less than 100 kHz. The MOGLabs DLC will stabilise the laser frequency to an external reference, usually an atomic absorption feature, and reduce the effective linewidth as close as possible to the S-T limit.

Achieving the best frequency locking stability requires careful optimisation of the signal-to-noise ratio (SNR) of the frequency discrimination signal obtained from the saturated absorption or other reference. Then the phase and gain settings must be optimised, preferably by measuring the feedback error signal spectrum.

4.1 Frequency reference

The frequency reference is critical to the performance of the MOGLabs DLC: the controller cannot reduce the laser frequency noise without an appropriate frequency-dependent reference signal.

The DLC has been designed to work with a saturated absorption reference, as shown in figures 3.5 and 3.7. Users should familiarise themselves with saturated absorption spectroscopy, for example as described in Demtröder [5].

The frequency discriminator ("ERROR") SNR should be optimised to produce clear (low-noise) dispersive error signals as shown in the upper trace of fig. 3.7. Note that the error signal should be about 0.5 V p-p. While the signal looks cleaner at larger amplitude relative to background oscilloscope noise, in fact the overall performance will deteriorate. Other important factors to consider:

Probe power The probe power should be about 250 μW. Higher power will increase the photosignal, but the detector saturates at about 500 μW.

Probe intensity The probe intensity should be low to reduce power-broadening. Thus, the probe beam should be expanded to 5 or 10 mm diameter, to allow high power and low intensity, as discussed in section 3.5.

Polarisation The frequency discriminator (ERROR) signal is sensitive to the pump and probe polarisations. Good polarisers and careful alignment can be very helpful.

Coil design See appendix D.

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 main unit and from the laser, 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.

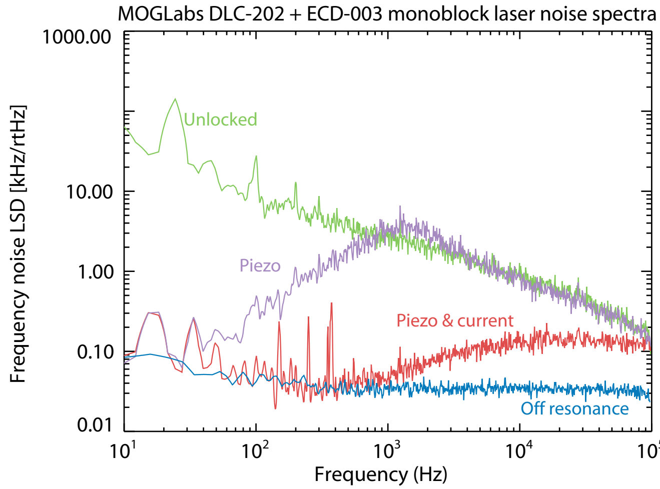


Figure 4.1: Error signal spectra, with laser unlocked, locked with SLOW (piezo) feedback only, and with SLOW and FAST (piezo+current) feedback. The off-resonance spectrum provides information on the effective noise floor.

4.2 Noise spectra

The master, slow and fast gains can be set as described in chapter 3, increasing them until the onset of oscillation, and then reducing slightly. If possible, an audio frequency spectrum analyser can be used to provide better guidance. A generic computer sound card with spectrum analysis software gives reasonable results up to 20 kHz. A good sound card (24-bit 200 kHz, e.g. Lynx L22 or E-Mu 1212m) provides noise analysis up to 100 kHz with 140 dB dynamic range, surpassing most standalone audio spectrum analysers, at very low cost. Connect the spectrum analyser to the CHANNEL B output, and set the CHAN B selector to ERROR.

You should see curves similar to those shown in fig. 4.1. The noise spectrum with laser unlocked was obtained in scan mode, but with zero span, and the frequency carefully set to an atomic resonance (the highest saturated absorption dip in fig. 3.7). Similarly for the *Off resonance* curve, but with the laser tuned far away from all resonances, outside a Doppler absorption peak. The *Off resonance* spectrum gives the frequency discriminator noise floor: it is meaningless to try to reduce the laser frequency noise below this level.

With SLOW feedback enabled, the noise for low Fourier frequencies is drastically reduced. A double-integrator is used for slow feedback, such that the suppression is 40 dB/decade. The SLOW gain adjusts the 0 dB gain point; in the figure, this reaches approximately 5 kHz. Higher gains result in oscillation at a frequency corresponding to a pole in the piezo actuator response (i.e. a mechanical resonance).

If configured to work with the stack actuator only (see §2.4), then the SLOW feedback will suppress noise only to a few tens of Hz.

FAST feedback adds an additional 20 dB/decade suppression, with 0 dB gain beyond 20 kHz, even as high as 40 kHz, depending on the diode, optical feedback, the frequency discriminator noise floor and other details. Typically we find that the laser diode itself has a 90° phase lag at 15 to 100 kHz. Some compensation for that phase lag is provided by a phase lead compensator (see RT12, page 24).

Ideally, the SLOW and FAST gains should be adjusted to minimise the integrated noise (the area under the error spectrum). The data in fig. 4.1 show a small "Bode bump" at around 30 kHz, indicating excessive current gain, leaving the laser marginally stable. For lower FAST gain, the Bode bump will be reduced, at the expense of reduced suppression of the mechanical resonance noise peaks around 2 kHz.

The frequency discriminator SNR – that is, the difference between the *Unlocked* and the *Off resonance* spectra (in the data shown above, about 10 dB for high frequencies) – is critical. Improvements to the reference, for example using a Fabry-Perot etalon rather than saturated absorption spectroscopy, can provide much greater SNR and correspondingly greater laser frequency noise suppression. See §E.2, page 66, for one approach.

A. Specifications

Parameter	Specification
Current regulator	
Output current	0 to 100/200/250/500 mA
Max diode voltage	3.2 V at full current; 6 V at half current /HC models up to 6.5 V at full current
Display resolution	±0.01 mA
Noise	< 10 nA rms (10 Hz – 1 MHz)
Stability	Warmup time: 15 minutes
CURR MOD	5 kΩ, ±8 V max, sensitivity 100 μA/V, 1.5 MHz bandwidth
RF modulation	SMA 50 Ω, 160 kHz – 2.5 GHz, see below
BIAS	±25 mA over full sweep
Temperature controller	
TEC current max	±2.5 A
TEC voltage max	±9 V
TEC power max	22 W
Stability	±5 mK/°C
Sensor	NTC 10 kΩ, AD590, AD592
Range	0–30° standard; extended range optional
Display resolution	±0.01°

Note

The TEC is controlled with a linear regulator, which will overheat if the current load is high and the TEC voltage is low. Choose a TEC with resistance of 4 to 5 ohms to optimise power to the device.

Parameter	Specification
Piezos	
STACK	0 to 120 V for FREQUENCY (default) 0 to 150 V optional (LK2 removed)
DISC	100 ± 16.4 V feedback
Scan rate	4 to 70 Hz

Note The default maximum piezo voltage is 120 V but can be increased to 150 V by removing jumper LK2; see page 15.

Note The maximum piezo drive current is 10 mA, which limits the scan rates for piezos with high capacitance. For exmaple, for a 250 nF piezo, the rate should not be greater than 25 Hz.

Parameter	Specification
Photodetector	
Photodiodes	Si-PIN, IR filtered 740 nm – 1100 nm, 1×1 mm^2 sensor, ±10° field of view See appendix F for spectral response. Options: • unfiltered 400 nm – 1100 nm • ± 20°, ±70°
Coupling	AC and DC, single or differential
Diode separation	10 mm
Bandwidth	720 kHz
Dimensions	$25 \times 25 \times 60$ mm

Feedback system	
MOD OUT	250 kHz, ±8 V, ±500 mA Current output (1 Ω sense) Control via I_{mod} rear-panel trimpot
PHASE	0 to 360° (min)
INPUT OFFSET	−10 V to +10 V
ERROR OFFSET	±0.5 V
GAIN	MASTER ±20 dB SLOW MASTER ±20 dB FAST MASTER ±20 dB
Bandwidth (gains at midpoint)	SLOW 0 dB at 700 Hz FAST 0 dB at 80 kHz

Protection and status	
External interlock	2.1 mm DC power plug (provided)
Laser head enclosure interlock	2-pin MOLEX connector (provided)
Key switch interlock	STANDBY/RUN
Delayed soft-start	3 s delay + 3 s ramp
Open circuit detect	Laser cable, TEC, temperature sensor
Diode current limit	Rear panel trimpot I_{max}

STANDBY/RUN LED	DARK	AC mains off, or fault condition detected (TEC failure, polarity reversed, open-circuit, cable unplugged, missing sensor, temperature out of range)
	RED	AC mains power on
	ORANGE	Standby (temperature controller on)
	GREEN	Fully operational (piezo, current, ramp)
STATUS LED	RED	Start sequence error or fault (Either LOCK switch ON, interlock open, head cable disconnected, temperature controller fault detected)
	ORANGE	Ready
	GREEN	Diode running

Mechanical & power	
Display	4.5 digit LED; standard colour red
Fan	12 V DC ball-bearing Temperature controlled
IEC input	110 to 130 V 60Hz or 220 to 260 V 50Hz Fuse: 5x20mm, anti-surge (slo-blo) ceramic, 250V/2.5A
IEC output	Common ground with power input Intended for oscilloscope; 1 A max
Dimensions	19” 2U, WxHxD = 422 × 84 × 200 mm
Weight	4.3 kg (excluding cables, laser head board, photodetector). 8 kg shipping
Power	35 W to 70 W (low/high TEC load)

A.1 RF response

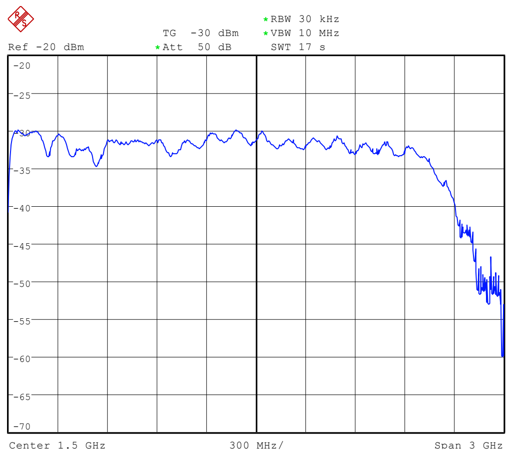


Figure A.1: RF response, SMA input on laser headboard to diode SMA output.

A.2 Sweep saturation and trigger

In normal scanning mode, a sawtooth is supplied to the stack piezo (or other laser frequency actuator), at a frequency of 1 to 70 Hz; see fig. A.2. At the nominal midpoint of the sweep, a trigger (low to high) signal is output via the rear panel TRIG connection, for synchronising to an oscilloscope or external experiment.

The span may be limited by the minimum and maximum voltage that can be applied to the actuator, 0 and 120 V [150 V optional]. That is, the ramp may "saturate", as shown in fig. A.2. The period remains fixed, and the trigger remains at the centre of the period, but the laser frequency will not scan for the entire period. Thus the spectrum will appear to shift to the left or right of centre and will be "flat" for part of the span. For situations where complete linear spectra are needed, the actual ramp output should be monitored using the *Freq* selection of the CHAN A output.

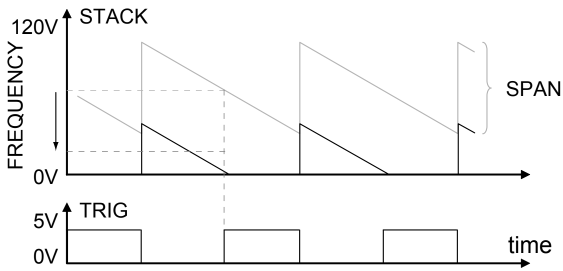


Figure A.2: STACK output voltage and trigger pulse, when FREQUENCY is set near the midpoint (upper) or moved closer to 0 V (lower), where the output voltage exceeds the maximum range.

B. Troubleshooting

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

B.1 STANDBY/RUN indicator

Colour	Status
DARK	Temperature controller off. Reset via keyswitch, RUN → STANDBY → RUN Possible faults: • AC mains off • Interlock(s) disconnected • TEC open or short-circuit • TEC polarity reversed • Cable disconnected • Temperature sensor disconnected • Active temperature sensor connected to thermistor pins • Thermistor connected to active sensor pins • Temperature out of range (< -5°C or > 35°C) • External sweep selected (DIP switch 9) but no external sweep supplied • Wrong AC mains voltage
RED	AC mains power failure (temperature controller off)
ORANGE	Standby (temperature controller on)
GREEN	Fully operational (piezo, current, ramp)

B.2 Diode OFF/ON indicator

Colour	Status
RED	Fault Reset via OFF/ON switch ON → OFF → ON Possible faults: • SCAN/LOCK switch not up (SCAN) • OFF/LOCK switch not up (OFF) • Rear interlock disconnected • Laser head interlock disconnected • Laser head cable disconnected • TEC disabled (temperature out of range) • Any one of $+5, \pm 12(aux), \pm 12\,\mathrm{V}$ internal supplies below nominal by more than 1 V • External sweep selected (DIP switch 9) but no external sweep supplied
ORANGE	Standby: above conditions satisfied, diode ready to start
GREEN	Diode fully operational, piezos active

If the indicator remains ORANGE after switching the diode ON, check the possible faults listed above, in particular the lack of a clock sync provided from internal or external sweep (see 2.4).

B.3 250 kHz modulation

The 250 kHz sine-wave oscillator relies on critical non-linear behaviour of an electronic component. Due to component drift, the oscillator may cease, and the AC error signal is then lost. A few small adjustments of trimpots will restore the oscillator.

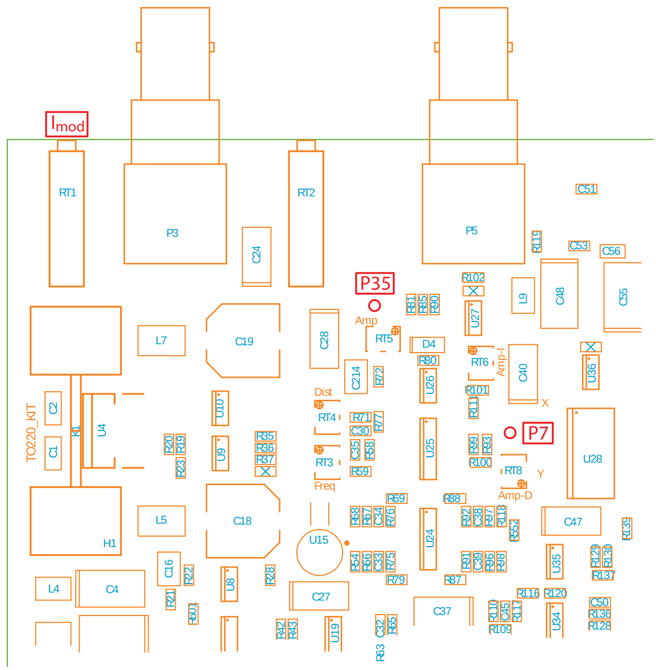


Figure B.1: 250 kHz oscillator trimpots and testpoints.

1. Measure test point P35 (with a multimeter) and adjust RT5 (labelled `Amp`) for −1.15 volts. P35 is near RT5 `Amp` trimpot. On older units that don't have P35, you can instead use the anode (left hand side) of diode D4, just to the right of RT5.
2. Probe U25, Pin14 (top pin on right-hand side of U25), and adjust RT4 `Dist` and RT3 `Freq` to obtain 2.6 V peak-peak, 250 kHz sine wave. RT4 is used to bring the oscillator to life, and adjust the voltage gain. RT3 is used to adjust the

frequency, only. Adjust RT4 first, and once the sine wave appears, adjust RT3 for 250 kHz, then finally adjust RT4 for the 2.6 V p-p. If the oscillator is not stable, try 2.7 V p-p.

3. Probe test point P7 (near RT8 `Amp-D` and U28), and adjust RT8 to obtain a 1.0 V peak-peak sine wave. On older units that don't have P7, use pin 8 of U25.
4. With the rear-panel I_{mod} trimpot set to maximum (fully clockwise), probe test point P36 (just to the right of U59) and adjust RT6 `Amp-I` to obtain a 1.0 V peak-peak sine wave. For older controllers (serial numbers with a 7 or smaller number in the 6th digit, e.g. A12027...), P36 does not exist; instead, measure pin 15 of U59.
5. Finally adjust I_{mod} to the required modulation depth, typically about half way (6 turns anti-clockwise).

B.4 Locking

The MOGLabs controller provides feedback via three channels each with a complex servo loop function. A few common problems are addressed here; for more difficult problems, MOGLabs will be happy to work with you to find the best possible solution.

B.4.1 SLOW does not lock

- Try locking with STACK only, DISC only, or both (see DIP switches 1,2).

  It can be very useful to watch the SLOW output (via CHAN A) when locking.

- Try locking with FAST channel only. If FAST locking works but not SLOW, then there is a gain or polarity problem, or a disconnect on one of the slow actuators (STACK, DISC).

- STACK feedback has wrong polarity. See DIP switch 10.

- Lock signal zero-crossing too far from trigger point.

- Gain too high. Try smaller and smaller gain, but be careful to ensure that the lock error signal is crossing zero.

- Loop response too fast for actuator. The controller is normally shipped with slow-channel response gain of 1 (0dB) around 700 Hz. Please contact the factory for instructions on changing this for slower actuators.

B.4.2 SLOW locks only briefly

Usually this is because the STACK feedback has the wrong polarity. Again, it can be very useful to watch the SLOW output (via CHAN A) when locking. Try flipping DIP switch 10. Ensure the laser frequency is scanning properly, i.e. that the STACK is properly connected and working.

B.4.3 FAST does not lock

- FAST feedback has wrong polarity. Try reversing the polarity with the front-panel switch.
- If the laser frequency is close to a mode hop (i.e. intrinsic diode cavity resonance is half way between two external-cavity longitudnal modes), the current response can be opposite to normal. Try adjusting the diode current very slightly.
- Lock signal zero-crossing too far from trigger point.
- Gain too high. Try smaller and smaller gain, but be careful to ensure that the lock error signal is crossing zero.

B.4.4 FAST locks only briefly

The FAST channel is normally AC-coupled (see DIP switch 12), with a time constant of 0.1 s. Thus with FAST feedback only, the laser will drift off resonance. Normally the SLOW channel is used to compensate for very slow drift, but the laser can be locked by current feedback only with DIP switch 10 ON. With DC current feedback, the feedback saturates at ± 10 mA.

B.5 External sweep

Please remember when using external piezo signal (DIP 9 on), your signal must cross 1.25 V. It can be 1.2 to 1.3 V or 0.5 to 1.5 V but not 1.1 to 1.2 V or 1.5 to 2.0 V.

When the signal crosses through 1.25 V, a signal is generated which triggers the control circuits, for example to read the state of the front-panel toggle switches. You can see if that control signal is generated by observing the TRIG output which should transition from low to high periodically. If the TRIG output isn't changing, then the toggle-switch settings are not being updated.

C. Using DBR/DFB diodes

DBR (Distributed Bragg Reflector) and DFB (Distributed Feed-Back) diodes offer a compact and robust alternative to ECDLs. The linewidth of DBR and DFB diodes is typically 2 to 3 MHz, and they are very susceptible to external optical feedback, necessitating two or even three stages of Faraday isolator to prevent frequency instability. Their frequency of operation is controlled by temperature and current only, and the DLC must be reconfigured for optimum use without the usual piezo actuator control. The issues are discussed below.

C.1 Fine current control

Without piezo control of frequency, very find control of the current is required. The coarse CURRENT knob can be used to set the current to within a milliamp or two, and the FREQUENCY knob must then be used. The FREQUENCY knob is normally used to adjust the piezo actuator offset, but it also couples to the current via the current feed-forward (bias). The BIAS trimpot can be adjusted such that the FREQUENCY knob varies the current by up to ±25 mA. For finer control, the BIAS can be reduced arbitrarily, from fully anti-clockwise (−25 mA range) to fully clockwise (+25 mA range). Note that DIP switch 4 must be ON.

C.2 DC current feedback

For locking, the current feedback is normally AC coupled because slow drifts are compensated by the STACK actuator. Change to DC current feedback by turning DIP switch 12 ON.

C.3 Slow current feedback

The feedback signal that normally drives the DISC actuator can be coupled to the current feedback, by turning DIP switch 16 ON.

C.4 Lock saturation

Slow drift is normally compensated by the STACK actuator, and hence the DISC and current feedback signals only have small range, and with DBR/DFB diodes this is easily saturated. Use feedback configuration B (see section 2.5) to maximise the lock range. Dip switch 1 should be ON.

C.5 Special options

Modifications can be made to the controller, including:

1. External control of temperature set-point, for example to enable slow frequency scans via the diode temperature.
2. Very slow locking feedback to the diode current.
3. Very slow locking feedback to the temperature set-point.

Contact MOGLabs for details.

D. Modulation coils

The MOGLabs DLC is designed to lock to an atomic transition, particularly using AC locking. The frequency of the laser light can be modulated (e.g. using internal current modulation or an external modulator), or the reference can be modulated. In the latter case, an atomic reference can be modulated at low cost using a solenoid coil wrapped around an atomic vapour cell, as shown below.

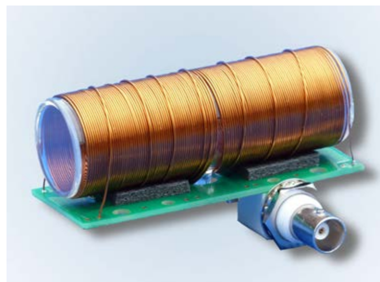


Figure D.1: Vapour cell, Zeeman coil, and primary excitation coil, mounted on PCB (available from MOGLabs).

D.1 Field requirements

Ideally the Zeeman dither coil should produce a frequency shift of about half the peak width, typically a few MHz. Atomic "stretched" state transitions will be Zeeman shifted by

$$\mu_B = \frac{e\hbar}{2m_e} = 1.4\,\text{MHz/Gauss} \tag{D.1.1}$$

so we need fields of around one Gauss (10^{-4} Tesla). The magnetic field inside a long solenoid is

$$B = \mu_0 n i \tag{D.1.2}$$

where n is the number of turns per unit length and i the current. For wire diameter 0.4 mm, $n = 2500\,\mathrm{m}^{-1}$, and the current requirement is only 22 mA/MHz.

D.2 Coil impedance

However, driving an oscillating current through a coil is problematic because the impedance grows with the frequency. The impedance is given by $X_L = \omega L$ where ω is the radial frequency and L the inductance. The inductance for a long solenoid is

$$L = \mu_0 n^2 A l \tag{D.2.3}$$

where A is the cross-section area of the coil (πr^2 for a circular cross-section) and l is the coil length. In practice, the inductance will be less (e.g. see Wheeler [9]):

$$L_{\mathrm{Wheeler}} = \frac{N^2 r^2}{228r + 254l} \qquad \text{(mH)} \tag{D.2.4}$$

where N is the total number of turns, r is the coil radius in metres, and l is the length in metres ($l > 0.8r$). We have found that for dimensions typical of coils wound around vapour cells, these two formulae agree within a factor of two.

Note that the inductance increases with n^2 whereas the magnetic field and hence modulation depth grows with n; thus for our purposes, we generally prefer small n and large currents. On the other hand, the driving voltage requirement (the "back emf") is given by

$$\epsilon = -L\frac{di}{dt} \qquad \epsilon_{\mathrm{max}} = L i_0 \omega \tag{D.2.5}$$

for a sinusoidal current of amplitude i_0. The required output slew rate is

$$dV/dt = -L\frac{d^2 i}{dt^2} \qquad \mathrm{Max} \equiv L i_0 \omega^2. \tag{D.2.6}$$

The MOGLabs DLC operates at $\omega = 250\,\text{kHz}$. For a cell of length 8 cm, 0.4 mm wire, and 20 mA, we find $L_{\text{Wheeler}} \approx 650\,\mu\text{H}$, and $\epsilon_{\text{m}ax} = 20\,\text{V}$, and the maximum slew rate is $32\,\text{V}/\mu\text{s}$.

The MOGLabs DLC does not have that direct output capability. Reducing n helps: inductance, and thus ϵ and dV/dt fall with n^2 while the frequency modulation depth falls with n. Thus a coil of about 40 turns ($500\,\text{m}^{-1}$) and current amplitude of 150 mA should result in a modulation depth of 1.3 MHz. However, we prefer to use a two-coil impedance matching arrangement to increase the modulation depth at smaller currents.

D.3 Impedance matching

The DLC can drive up to $\pm 0.5\,\text{A}$ and $\pm 8\,\text{V}$, with a slew rate of $6\,\text{V}/\mu\text{s}$. This can be impedance-matched to a high current coil using a transformer, or quite effectively by directly winding a primary on the main Zeeman coil, as shown in the photo above.

For the main Zeeman coil, 0.4 mm to 0.6 mm diameter wire wound around the vapour cell, about 120 to 200 turns, works well. The coil is "balanced" for the standard modulation frequency of $\omega = 250\,\text{kHz}$ using a capacitor. The coil is excited inductively by a primary, about five to ten turns, connected directly to the DLC modulator output (see figure). The cell, coils, and balancing capacitor can be conveniently mounted on a PCB, as shown in the image above, available from MOGLabs.

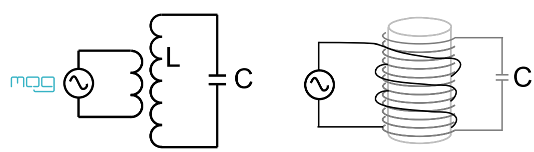


Figure D.2: Circuit diagram for Zeeman coil and excitation coil. Typically the primary is 5 to 10 turns, and the secondary 120 to 200 turns.

The capacitor should be chosen such that the capacitive impedance equals the inductive impedance. That is,

$$\omega L = \frac{1}{\omega C} \qquad\qquad C = \frac{1}{\omega^2 L}. \tag{D.3.7}$$

Using the long-solenoid equation for inductance,

$$C = \frac{1}{\omega^2 \mu_0 n^2 A l} \tag{D.3.8}$$

although in practice we find that the inductance is about half the long-solenoid prediction and hence the capacitance should be doubled, typically about 1 to 5 nF. With this arrangement, energy is stored in the inductor-capacitor "tank", and the DLC need only drive a small current (e.g. 50 mA peak-to-peak) to compensate for losses.

WARNING! The potential across the secondary Zeeman coil can easily be hundreds of volts! Please ensure that your coil and capacitor do not have exposed connections! Also be sure to use capacitors with adequate voltage rating.

D.4 Tuning

To maximise the current in the secondary, the capacitor should be chosen to tune the circuit to the DLC modulation frequency. A spectrum analyser with tracking generator is particularly helpful: connect the coil to the TG output, and to the SA input, and sweep through the resonance (see figure). Alternately, drive the coil with a function generator and measure the magnetic field with another independent coil (e.g. 20 turns of fine wire on a 1 cm diameter former) connected to an oscilloscope. Adjust the capacitor by adding or removing small capacitors in parallel, until the detected field is maximum at 250 kHz. Again, be sure to use capacitors with sufficient voltage rating.

In some cases the Q of the circuit may be *too* high, such that a series resistor of about 0.5 ohm can result in increased current at 250 kHz, and reduced sensitivity to frequency drifts.

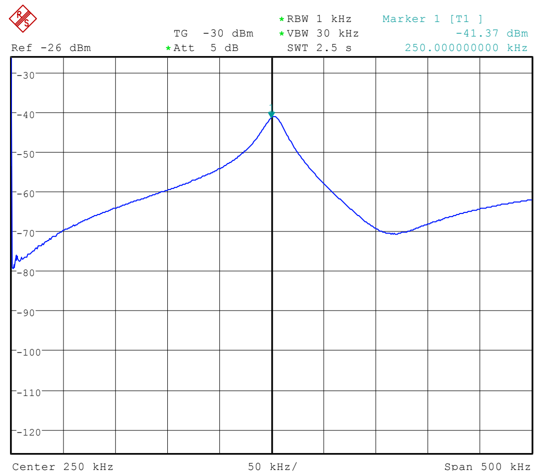


Figure D.3: Coil response acquired using a spectrum analyser with tracking generator. The response shows a strong resonance near 250 kHz.

D.5 Shielding

Large magnetic fields oscillating at 250 kHz can readily cause problematic electromagnetic interference (EMI). Induction in the laser head or the cable to the laser head can easily produce substantial diode current modulation. The coil (and vapour cell) should be located far from the laser and from the controller, or shielded with soft iron or a high permeability alloy such as mu-metal or Conetic. We find that a tube made from thin (0.25 mm) sheet mu-metal, about 50% longer than the cell and coil, is adequate.

E. External modulators and injection current modulation

The MOGLabs DLC is designed for AC locking a laser to an external reference such as an atomic resonance or an optical cavity. In many cases it is convenient to use the internal modulator driver, and Zeeman modulation of an atomic transition, as described in appendix D. Zeeman modulation is not always possible (e.g. if the reference is an optical cavity), or desirable (e.g. due to magnetic interference). The MOGLabs DLC can dither the laser diode injection current (DIP switch 3), or drive an external modulator, such as an electro-optic modulator (EOM) or acousto-optic modulator (AOM).

E.1 Coupling circuit

The DLC provides a current-controlled modulation output, with 1 Ω sense resistor. It can be directly connected to a 50 Ω load, producing a voltage of ±5 V with I_{set} adjusted to ±100 mA.

Impedance-matching and a DC level shift may be needed to drive an external modulator, as in the schematic below, designed for the D323B RF amplifier from ISOMET.

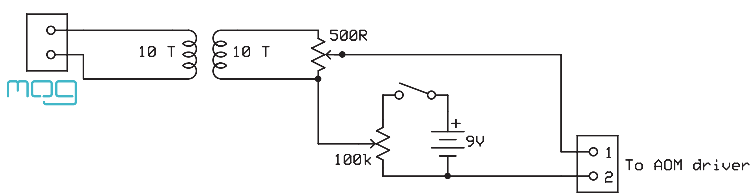


Figure E.1: Coupling from MOD OUT to an external modulator.

The ISOMET D323B RF driver has a frequency control input with 4 to 17 V range. We AC couple using a simple 10T:10T ferrite bead transformer. Primary and secondary were wound with 10 turns of PVC-insulated hookup wire around a ferrite bead approximately 15 mm diameter. A 500 Ω potentiometer allows control of the modulation amplitude, and a 9 V battery and 100 kΩ potentiometer provide a DC shift to set the centre modulator frequency. The latter allows frequency offset control of the modulated light beam.

E.2 Injection current modulation

The MOGLabs DLC can dither the laser diode injection current (set by DIP switch 3), at the standard 250 kHz, or with high frequency modulation (e.g. 10 MHz) via the SMA RF input on the laser head-board. Very narrow linewidths can be achieved with suitably high bandwidth frequency discrimination, for example by phase locking two lasers. The diagram below shows an arrangement to lock two lasers to an EIT (electromagnetically induced transparency) resonance, which obtained a beatnote linewidth below 1 kHz [10].

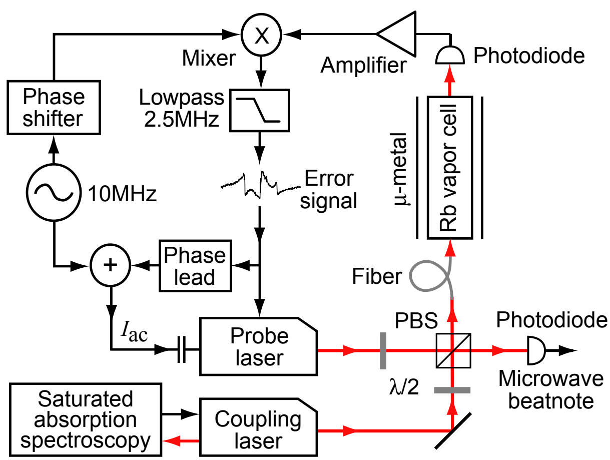


Figure E.2: High bandwidth locking based on FM sideband demodulation [11, 6]. The probe laser is locked with high bandwidth, relative to the coupling laser, using electromagnetically induced transparency as a dispersive reference.

The coupling laser was locked to the $5^2S_{1/2}F = 2 \rightarrow 5^2P_{3/2}F = 2$ transition of ^{87}Rb using the Zeeman modulation technique, as in section 3.5. The probe laser was tuned to the $F = 1 \rightarrow F = 2$ transition and modulated at 10 MHz. The two lasers copropagated through a Rb vapour cell and onto a photodiode. An electromagnetically induced transparency provided a dispersive reference. A frequency error signal was obtained by FM demodulation [11, 6]. The error signal is returned to the external error input on the probe laser MOGLabs DLC, which locked the laser with bandwidth up to about 40 kHz. The error signal was also coupled through a single stage passive phase-lead (high-pass) filter, and then combined with the 10 MHz modulation using a passive bias tee, and injected into the SMA modulation input, to provide feedback bandwidth of about 600 kHz.

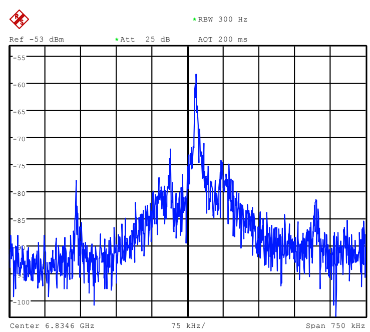


Figure E.3: RF beatnote from two MOGLabs DLC-locked lasers. The −3 dB peak width was 750 Hz with a spectrum analyser RBW setting of 300 Hz. For a 20 s average, the width was about 4 kHz.

F. Photodetector

The MOGLabs photodetector, shown below, can be used as a single detector, or as a differential pair (internal DIP switch 8). The photodetector is connected via the rear socket and cable provided. A number of M4 and 8-32 threaded holes allow mounting in different configurations to minimise the footprint on an optical bench (see figure F.2).

Figure F.1: MOGLabs DLC balanced differential photodetector.

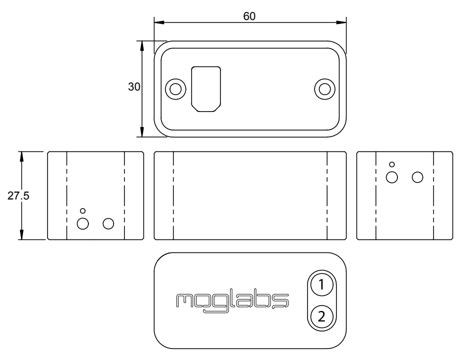


Figure F.2: M4 mounting holes are marked with a dimple; others are 8-32. Single channel photodiode 1, differential signal $1 - 2$.

F.1 Photodiodes

The standard photodetector uses Si-PIN photodiodes encapsulated in a coloured plastic which transmits in the near-infrared and blocks most room light. The diodes include a lens to reduce the acceptance angle to ±10°. Unfiltered diodes, and wider acceptance angles, are also available.

Photodiode Specifications		
Parameter	Standard	Options
Spectral range(10% of max)	750 – 1100 nm	400 – 1100 nm
Peak sensitivity	900 nm	850 nm
Half angle	±10°	±20° ; ±75°
Sensitive area	$1 \times 1\,mm^2$	
Max incident power	500 μW	
Apparent sensitivity (CHAN A)	30 mV/μW	

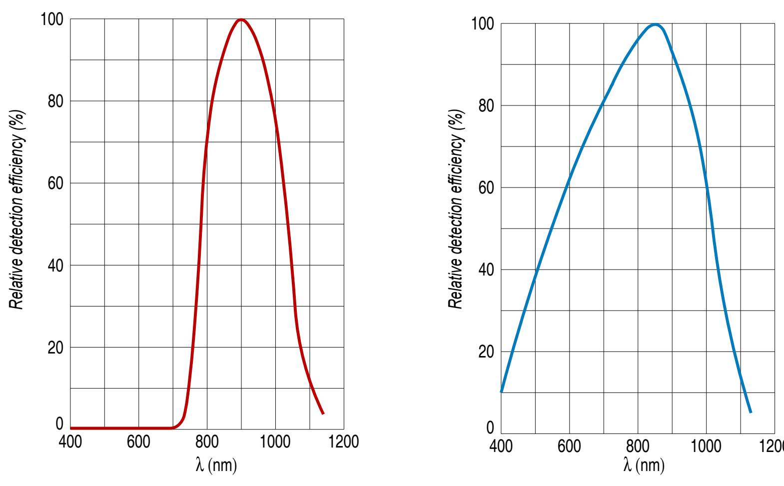


Figure F.3: Photodiode spectral response, standard filtered and unfiltered.

G. Laser head board

A laser head interface board is provided to allow convenient connection breakout to the laser diode, TEC, temperature sensor, piezo actuators, and laser head interlock. It also includes a protection relay and passive protection filters, a laser-on LED indicator, and an SMA connection for direct diode current modulation. A mounting plate is provided, either a generic format or one compatible with older Toptica DL-100 laser mechanics.

Several versions of the laser headboard are available. Recent lasers have shipped with the B1047 headboard which provides high bandwidth active current modulation for wide bandwidth frequency stabilisation and linewidth narrowing, for example using a high finesse optical cavity or polarisation spectroscopy. Higher bandwidth is provided by the B1240 headboard which increases bandwidth and reduces phase delay, easily achieving sub-Hz linewidth narrowing. For RF modulation, a B1045 is available.

The default headboard provided with DLC controllers purchased without a laser is the B1040, which includes an RF bias tee allowing modulation up to 2.5 GHz, for example to add sidebands for repumping, or to add noise for coherence control. For high bandwidth RF modulation the diode can be directly soldered to a special interconnect assembly available from MOGLabs.

In all cases, there is no provision for the internal photodiode in many consumer-grade laser diodes.

G.1 B1040 headboard

The B1040 is a small rectangular board using Molex KK100 connectors, most suitable for home-built lasers. It provides connection to one or two piezos (slow high-range multi-layer stack and fast disc), and either passive NTC thermistor or active AD590/592 active temperature sensor. Note only one temperature sensor should be connected, not both.

For high bandwidth RF modulation (see below), the diode should be connected to the SMA connector (P3) rather than to the MOLEX HD1. Another very small circuit board, to connect directly to the diode, is also available from MOGLabs, with SMA and MOLEX connectors. The MOGLabs DLC does not provide a mechanism for optical power control or measurement for diodes with an internal photodiode.

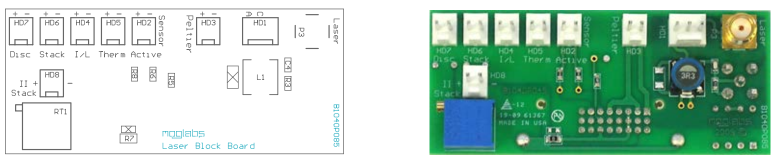


Figure G.1: MOGLabs DLC laser head board showing headers for connection of laser diode, piezo actuators, temperature sensor, TEC and head enclosure interlock.

P1	Microwave RF modulation input (SMA)
P3	Diode (SMA, high bandwidth)
HD1	Diode (MOLEX, low bandwidth)
HD2	Active temperature sensor (AD590 or AD592)
HD3	Peltier TEC
HD4	Interlock; laser disabled unless short-circuited
HD5	Thermistor temperature sensor, 10 kΩ
HD6	Primary piezo STACK
HD7	Piezo DISC
HD8	Secondary piezo STACK

G.2 B1045 headboard

The B1045 is essentially the same as the B1040 but shaped to fit inside MOGLabs lasers.

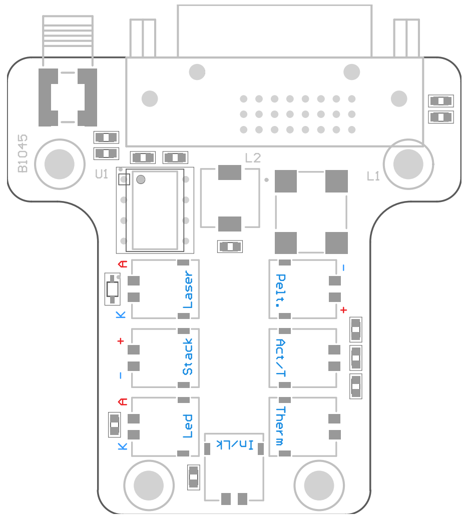


Figure G.2: MOGLabs B1045 laser head board showing connectors for laser diode, piezo actuator, temperature sensors, TEC and head enclosure interlock.

G.3 B1047/B1240 headboards

The B1047 and B1240 provide high-speed active modulation of the diode current. They use 500 MHz opamps and very low latency circuitry to reduce phase delay to around 12 ns for the B1240. The B1047 allows for closed-loop bandwidth of about 1.2 MHz while the B1240 can achieve about 4 MHz (in both cases, without phase advance). The latter makes it particularly easy to achieve sub-Hz linewidth reduction by locking to a high-finesse optical cavity. The B1240 also allows direct-ground connection or buffered; the latter is about 10% slower but reduces problems with ground-loop noise. The B1240 is not suitable for diodes with high compliance voltage, those with wavelength below 600 nm.

Note that connection to the SMA input will reduce the diode current, even if the input voltage is at zero.

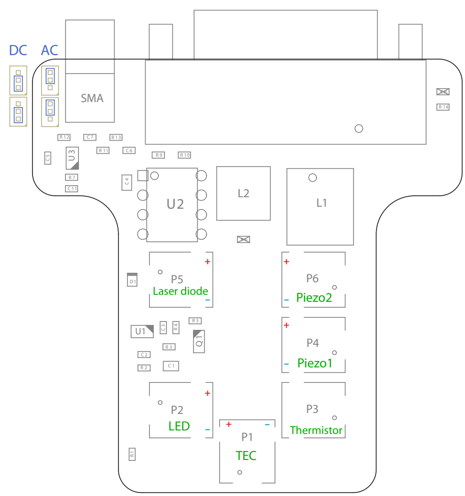


Figure G.3: B1047 enhanced laser head board. Jumpers at top left can be configured for AC or DC coupling. Modulation input via SMA connector, sensitivity 2.5 mA/V. The B1240 is almost identical but has an additional jumper for direct or differential ground coupling adjacent to U2.

G.4 Dual piezo operation

The DLC provides outputs to two piezo elements. They can be configured as:

Single Typically, only a single "stack" actuator, such as the Tokin AE0203D04 (available from Thorlabs, `www.thorlabs.com`), will be required. The single stack actuator allows frequency scanning and frequency offset selection, and active slow feedback (up to ≈ 100 Hz). Connect STACK to **HD6** (sometimes labelled Stk_1 on the headboard).

Two channel The DLC feedback servos include a second channel for high-speed piezo feedback, typically to a disc actuator. This would be connected to **HD7** (Stk_2 or Piezo 2).

Since DLC revision 9.01, this second feedback channel is disconnected and instead both piezo outputs are driven in parallel, with a variable relative gain adjusted by RT7 (near the DIP switches). If there is a failure of the STACK electronic driver, it is possible to use the DISC driver; simply connect the STACK to **HD7** (Stk_2).

Alternate single channel For older controllers, to change to the alternate high voltage driver, make the following modifications on the DLC main board, referring to appendix J for component locations:

- Insert a 0R0 resistor, size 0603, for R602
- Remove R601 (nominally 10R0)
- Change R372 from 30k0 (size 1206) to 270k (STACK at 120 V) or 390k (STACK at 150 V) (see LK2, p.15).
- Adjust RT7 fully clockwise.

On the laser headboard, connect the STACK piezo actuator to **HD7** (Stk_2 or Piezo 2).

Parallel The DISC channel can instead be used to drive a second STACK actuator, for example to allow simultaneous translation and tilt of a diffraction grating, to increase the mode-hop free tuning range. Connect the second piezo to **HD7** and adjust RT7 to vary the relationship of the potential to the second piezo from 0.3 to 1.0 times the potential on the main STACK.

G.5 RF coupling

For the B1040 and B1045 headboards, the SMA connector allows high-frequency current modulation via a bias-tee. The RF input is AC coupled, with low- and high- frequency limits of about 30 kHz and 2.5 GHz (see fig. A.1). Capacitor C4, either 47 nF or 100 pF, can be changed to adjust the low-frequency cutoff. For higher bandwidths, use an external bias-tee such as the Mini-Circuits ZFBT-4R2GW-FT between the head board and the diode.

The input impedance is 10 k. The sensitivity depends on the diode impedance but is now typically around 1 mA/V.

WARNING: The RF input is a direct connection to the laser diode. Excessive power can destroy the diode. It is separated from the head board relay by an inductor, and thus the relay does *not* provide protection from high frequency signals.

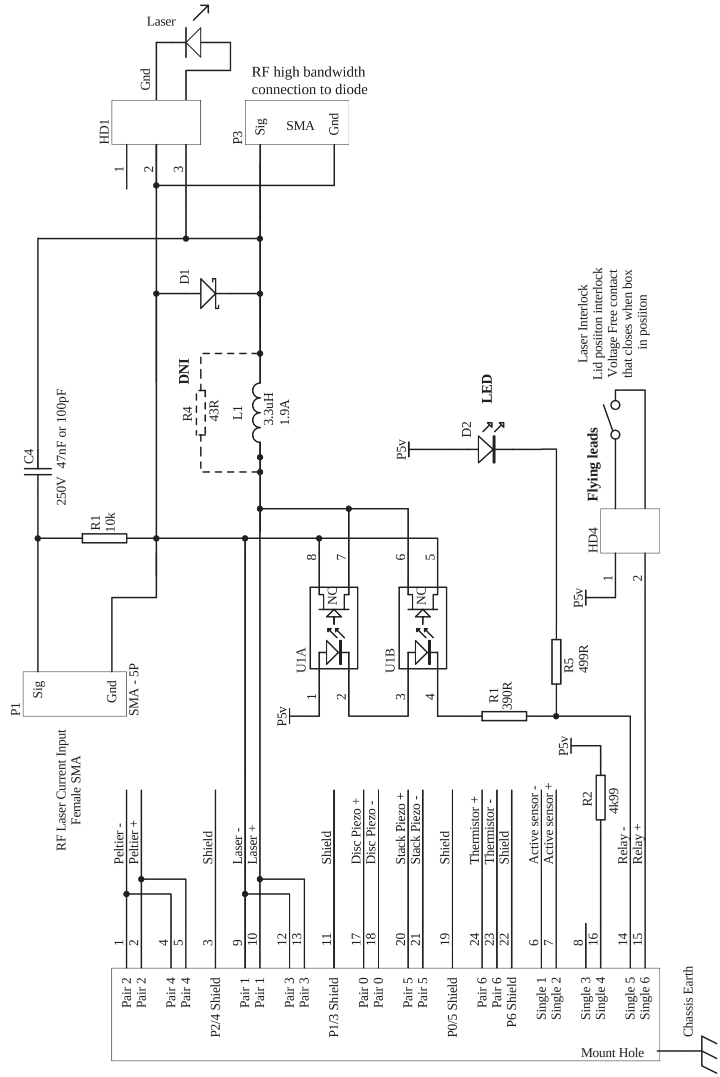


Figure G.4: MOGLabs DLC laser head board schematic (B1040/1045). The RF modulation low-pass cutoff frequency is determined by C4 and the diode impedance ($\sim 50\Omega$).

H. Feedback overview

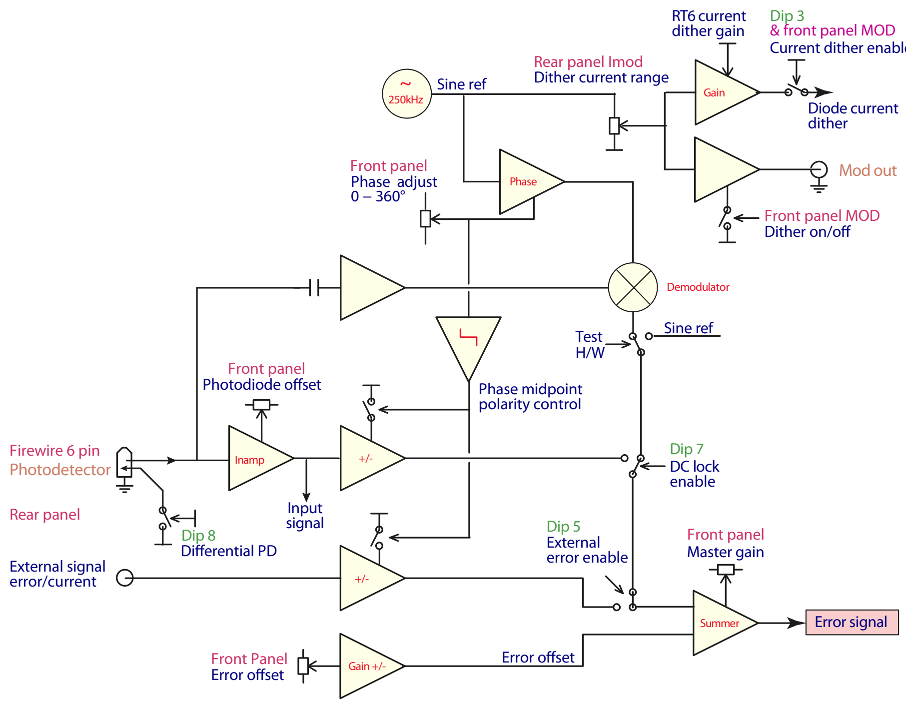


Figure H.1: Overview of error signal.

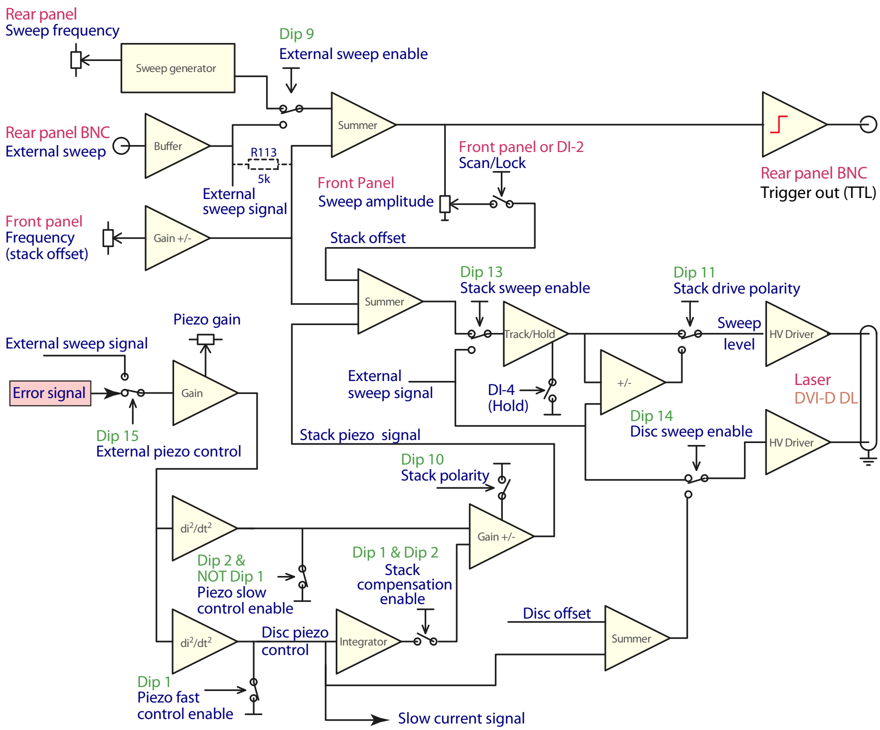


Figure H.2: Overview of slow feedback and piezo signals. Note that resistor R113 is not installed by default.

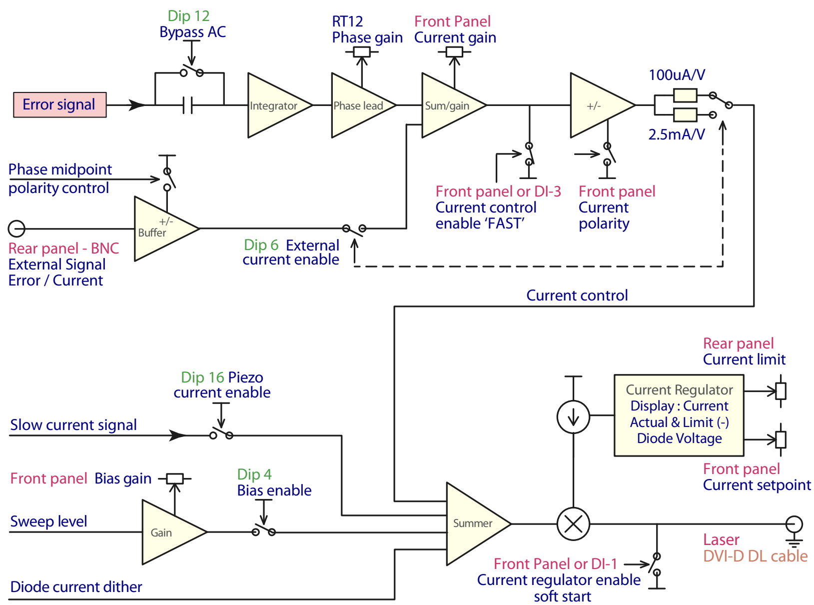


Figure H.3: Overview of fast feedback and diode current signals.

I. Connectors and cables

I.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 nevertheless considerable care should be taken to ensure non-MOGLabs devices are not connected.

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.

Pin	Signal	Pin	Signal	Pin	Signal
1	TEC –	9	DIODE –	17	DISC +
2	TEC +	10	DIODE +	18	DISC –
3	Shield	11	Shield	19	Shield
4	TEC –	12	DIODE –	20	STACK +
5	TEC +	13	DIODE +	21	STACK –
6	AD590/592 –	14	Relay GND	22	
7	AD590/592 +	15	Relay +5V	23	NTC –
8		16	Interlock +5V	24	NTC +

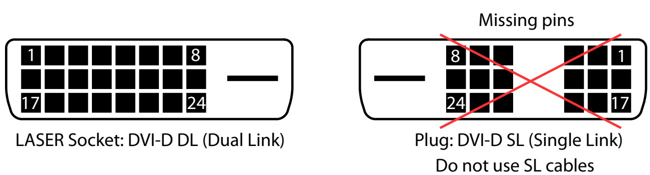


Figure I.1: LASER connector on rear panel, and plug of common display cable, unsuitable for use with DLC due to missing pins.

I.2 Photodetector

The photodetector is connected via standard 6-pin IEEE-1394 (FireWire) connectors. Note that firewire cables swap pins 3,4 with pins 5,6 so the pinout on the photodetector connector is different to that on the controller.

Pin	Controller	Detector
1	Ground	
2	Differential if GND	
3	+12 V	Signal –
4	−12 V	Signal +
5	Signal –	+12 V
6	Signal +	−12 V

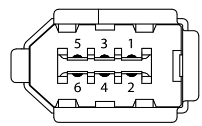


Figure I.2: PHOTODETECTOR connector on rear panel of DLC and corresponding connector on photodetector. Differential output is enabled if pin 2 is grounded (0 V). Single-ended is open-circuit or high (+12 V). Note that firewire cables swap pins 3,4 with 5,6.

I.3 Interlock

The rear-panel interlock socket is a standard 2.1 mm cylindrical DC power jack. The outer conductor is supplied with 5 V via a 5 k resistor. The inner pin is connected to ground via a 10 k resistor. The laser should be enabled by shorting the two contacts.

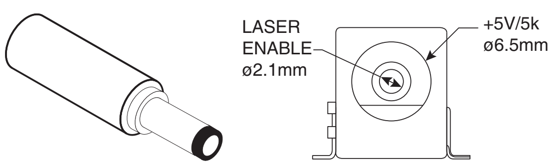


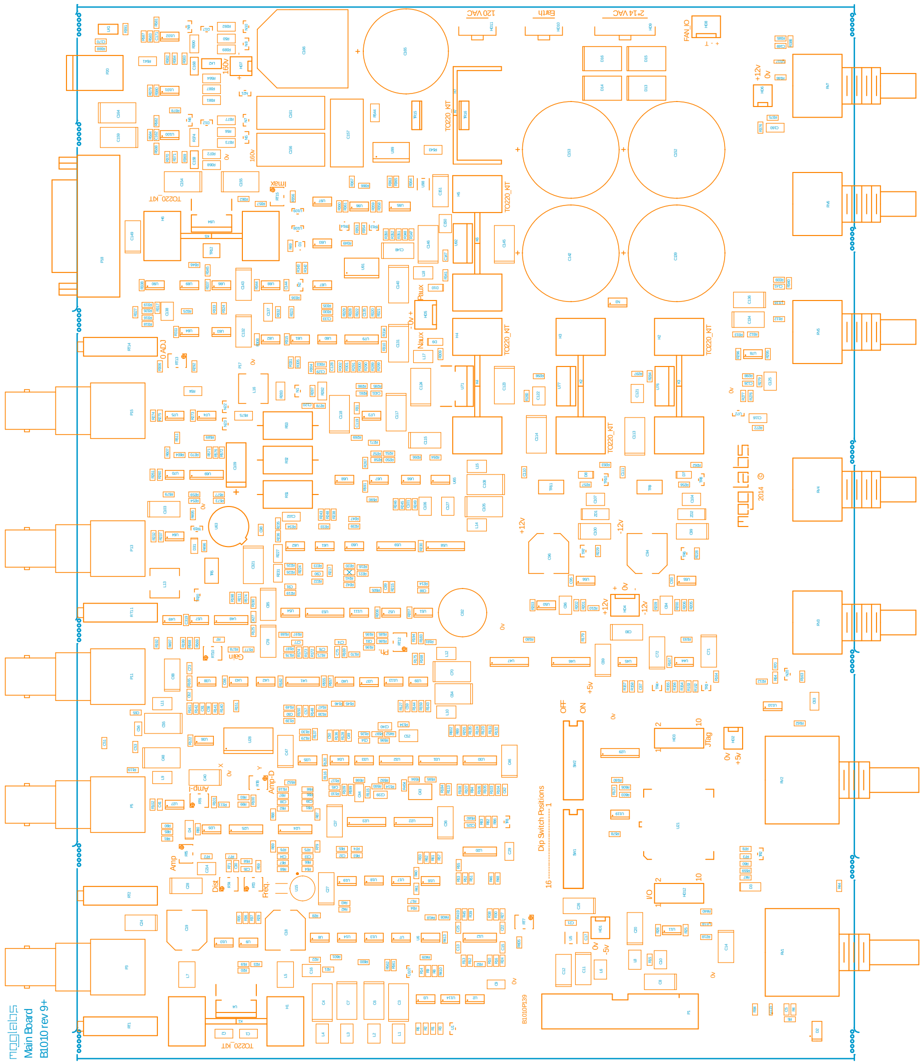
Figure I.3: INTERLOCK connector on rear panel.

I.4 Digital control

HD12 is a 10-pin header which provides access to several important control signals for locking and for sample-and-hold of the lock-point, as described in section 2.6. The signals are standard TTL-compatible, > 2.4 V HIGH and < 0.8 V LOW. The inputs are ORed with the front toggle-switches, such that the signal is activated if either the digital input is active (i.e. HIGH) or the toggle switch is on (down).

Pin	Signal	Pin	
1	Laser ON/OFF	2	GND
3	Lock/Sweep	4	GND
5	Fast Lock	6	GND
7	Hold	8	GND
9	+5 V	10	GND

J. PCB layout



K. 115/230 V conversion

K.1 Fuse

The fuse is a ceramic antisurge, 2.5A, 5x20mm, for example Littlefuse 021502.5MXP. The fuse holder is a red cartridge just above the IEC power inlet and main switch on the rear of the unit (Fig. K.1).

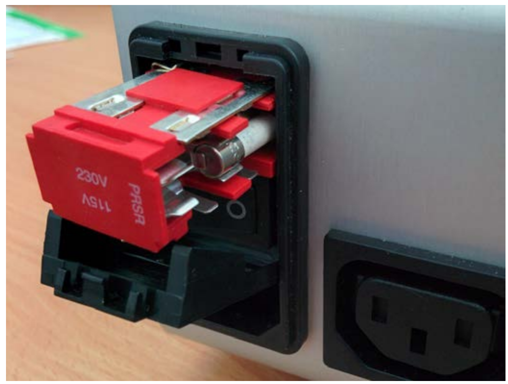


Figure K.1: Fuse catridge, showing fuse placement for operation at 230 Vac.

K.2 120/240 V conversion

The controller can be powered from AC 50 to 60 Hz, 110 to 120 V (100 V in Japan), or 220 to 240 V. To convert between 115 V and 230 V, the fuse cartridge should be removed, and re-inserted such that the correct voltage shows through the cover window.

Figure K.2: To change fuse or voltage, open the fuse cartridge cover with a screwdriver inserted into a small slot at the top of the cover, just above the red voltage indicator.

When removing the fuse catridge, insert a screwdriver into the recess at the *top* of the cartridge; do not try to extract using a screwdriver at the sides of the fuseholder (see figures).

Figure K.3: To extract the fuse cartridge, insert a screwdriver into a recess at the *top* of the cartridge.

When changing the voltage, the fuse and a bridging clip must be swapped from one side to the other, so that the bridging clip is always on the left and the fuse always on the right; see figures below.

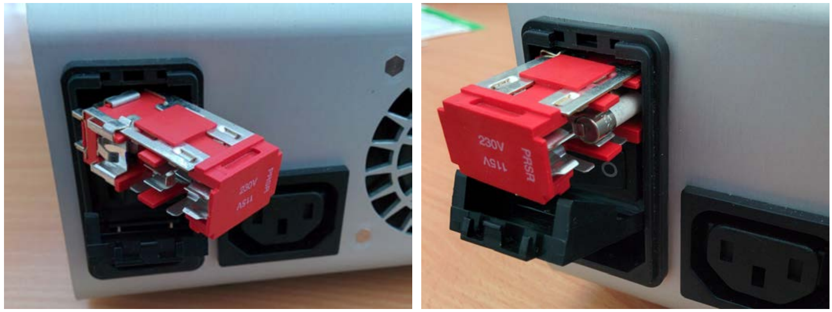


Figure K.4: Bridge (left) and fuse (right) for 230 V. Swap the bridge and fuse when changing voltage, so that the fuse remains on the right-hand side (see below).

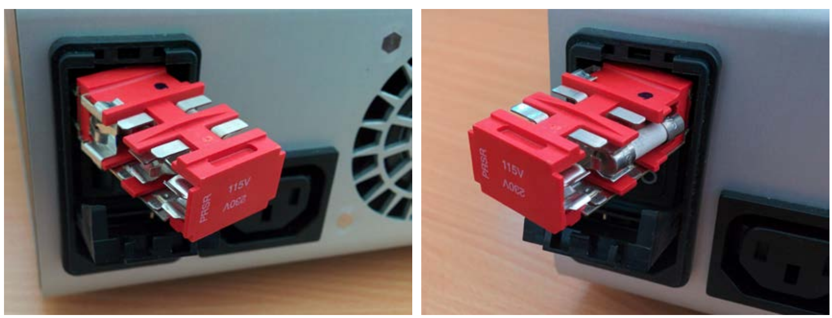


Figure K.5: Bridge (left) and fuse (right) for 115 V.

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