LASER LOCKING & LASER DRIVING

Electronic Control for Passive Stability and Active Locking

Apart from a well-engineered opto-mechanical design and the integrated laser diode, the most important part of a tunable diode laser system is its driving electronics, which is responsible for getting the most out of a laser system.

Wide mode-hop-free tuning with Littrow setups requires a well-defined interplay between piezo actuator and current driver. Drifts of the laser diode current, the temperature or the piezo voltage determine the drift of the laser frequency and the stability against mode-hopping.

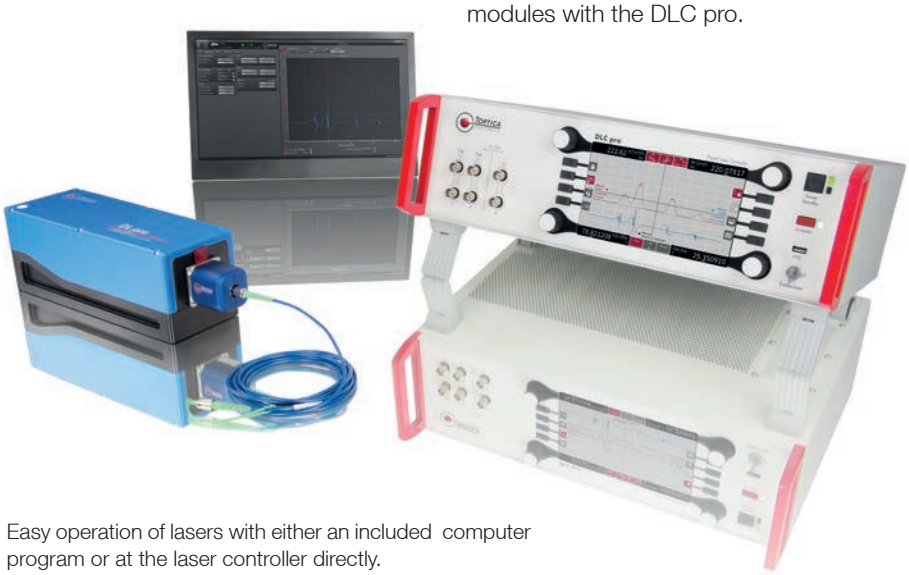
Noise on any of these outputs increases the laser linewidth. For laser frequency stabilization and linewidth narrowing, various locking schemes are used and require a variety of compatible options (see pages 10).

The digital DLC pro represents the latest stage of development of laser control electroncis. Its noise and drift properties are even better than the well established and widely used preceeding electronics SYS DC 110, which is still available as economic solution.

The DLC pro offers intuitive dial and multi-touch control on a 7" capacitive touch display. Remote control is possible via USB and Ethernet (TCP/IP), using either a graphical user interface on a standard PC, which is specifically developed for the DLC pro and included with the system, or through a vast set of software commands.

The DLC pro also offers laser-frequency locking enabled by a software license: A 30 day trail version is included. It has never been so easy to scan and lock a laser!

TOPTICA also provides a number of electronic modules for locking laser systems, e.g. DigiLock, the first digital laser locking solution or the analog FALC 110, the fastest locking electronic. The DLC ext allows to combine these electronic modules with the DLC pro.



Easy operation of lasers with either an included computer program or at the laser controller directly.

The DLC pro supports all lasers of TOPTICA's cw diode laser series: All laser systems in the lab may be operated via the same intuitive user interfaces or command language.

Features

- Current, temperature and piezo controller with lowest noise and drift
- No fans for cooling required: High reliability and low acoustic noise
- Signal display with hardware zoom (changes scan parameters to zoom into spectrum, etc.)
- Power Lock via control of current of laser diode or tapered amplifier current in kHz range
- Scan generator and X/Y, time- and frequency (FFT) display
- Side- and top-of-fringe locking*
- Two PIDs, lock-in signal generator*
- Lock detection and ReLock*
- Total remote control: PC GUI (included) and commands via TCP/IP and USB, e.g. for LabView or Python control programs
- Free software updates available on www.toptica.com

** These features are enabled with the DLC pro Lock software license.*

TOPTICA's DLC pro is a fully digital controller for tunable diode lasers, offering a new level of stability and lowest noise while allowing intuitive and comfortable control. Zooming into a Doppler-free line on a touch display and locking by tapping the desired peak opens up a completely new way of working with lasers.

A well-configured ReLock mechanism greatly increases an experiment's uptime, especially when it involves several lasers.

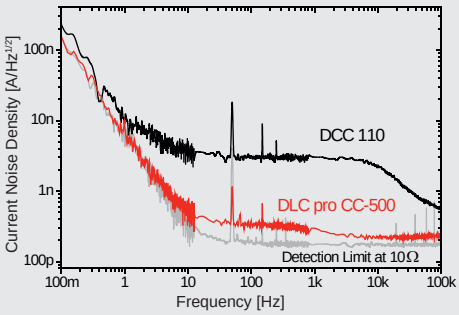
The advantages of using a digital control are starting to become available: A Power Lock allows for an active stabilization of the power, using an internal photodiode if available, to compensate for slow degradation of alignment or laser diode performance. Moreover, it is possible to use the included air pressure sensor to compensate for length changes in the laser cavity and hence improve the stability against mode-hopping even further.

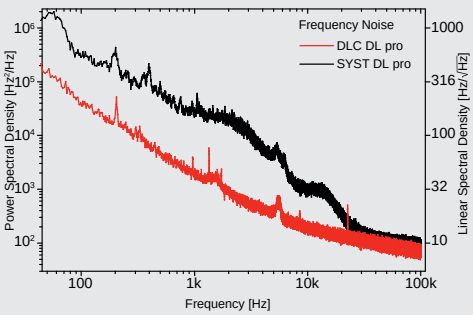
The DLC pro Lock is a software licence that enables the frequency lock of DLC pro controlled lasers at bandwidth of up to 30 kHz. Both, top-of-fringe and side-of-fringe locks are enabled - including the modulation of the laser frequency and the demodulation of the spectroscopic signal.

DLC pro — All-digital diode laser controller.

Options

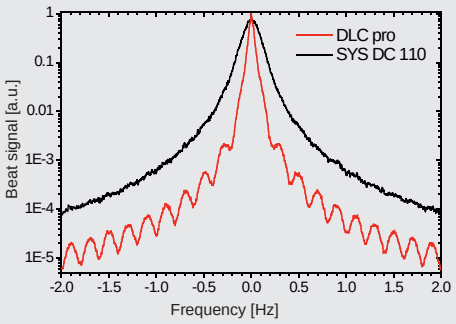
- The direct laser systems available with DLC pro control:
  - DLC DL pro
  - DLC DL pro HP
  - DLC DFB pro
  - DLC CTL
  - DLC TA pro
- Systems with frequency multiplexing available with DLC pro control:
  - DLC DL-SHG pro
  - DLC TA-SHG pro
  - DLC DL-FHG pro
  - DLC TA-FHG pro
- Break-out cable for digital lines
- DLC pro Lock: Enabling of frequency locking features via software key.

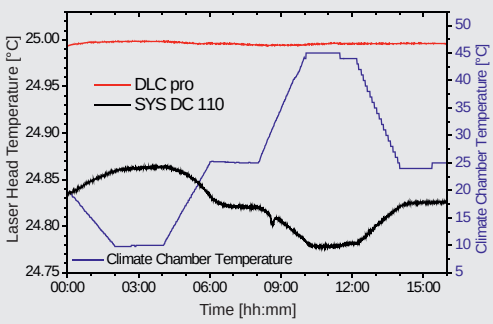




Left: Comparison of the current noise density of the current control modules.

Right: Frequency noise density of the laser light created with a DLC DL pro and a SYST DL pro.





Left: Delayed self-heterodyne linewidth measurement. Due to the long coherence length periodic modulation appears. The linewidth is obtained from the modulation depth (see page 9).

Right: Temperature of a DL pro laser head connected to a laser control electronics, which is located in a climate chamber and exposed to the temperature sequence shown by the blue line.

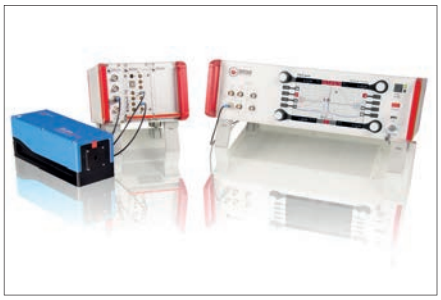
Specifications
DLC pro

DLC pro Specifications	
General / MC	
Operator controls	Touch display, 10 push buttons, 4 knobs, 1 key switch
Display	7 inch, 800 x 480 pixels, 262k colors
Touch panel	Projective capacitive (PCT) with multi-touch capability
Interfaces	Ethernet and USB
Inputs / Outputs	
Analog inputs (BNC)	2x (24 bit, DC .. 300 kHz) 2x (16 /10 bits, DC .. 300 kHz / 1.7 MHz)
Input range, impedance	-4 V .. + 4V, 10 kOhm
Analog outputs, BNC	2x (16 bit, DC .. 300 kHz)
Output range, impedance	-4 V .. + 4V (no load), 50 Ohm
Digital inputs**	4x TTL, 10 kOhm, Sub-HD 15-pin
Digital outputs**	4x TTL, 50 kOhm, Sub-HD 15-pin
Temperature Control TC	
Smallest set-temperature step	50 µK
Act. temperature noise (100 µHz ... 1 Hz)	< 300 µK p-p
Repeatability of actual temp.	< 0.001 K after >1h warm-up
Temperature coeff. of actual temperature	< 140 ppm K/K after >1h warm-up
Environment / Supply	
Voltage requirements	100 - 240 V~, 50/60 Hz
Power requirements	< 220 W, typ. 35 W, no active cooling fans
Size (H x W x D)	154 mm x 450 mm x 348 mm
Weight	8.0 kg (with MC, CC-500, PC, TC)

Specifications		
Current Control	**CC-500**	**CC-5000***
Max. laser current	2x 245 mA or 1x 490 mA (selectable)	5000 mA
Max. laser voltage	7 V @ 360 mA, 5 V @ 490 mA	3.5 V
Smallest current step	0.015 µA	5 µA
Current noise density	280 pA/√(Hz) @ 1 kHz	120 nA/√(Hz)
Low-frequency current noise (0.1 Hz ... 10 Hz)	< 50 nA p-p	10 µA p-p
Temperature coefficient of laser current	<3 ppm/K typ. after >1 h warm-up	100 Hz
Long-term stability of laser current	< 100 ppm/√(khrs) after >1 h warm-up	
Modulation bandwidth	DC to 15 kHz .. 30 kHz (depending on laser diode)	100 Hz
Piezo Control PC		
Piezo voltage range	-1 V .. +140 V	
Max. piezo current (charge/decharge)	25 mA	
Smallest piezo voltage step	0.01 mV	
Voltage noise density	140 nV/√(Hz) @ 1 kHz	
Temperature coeffi-cient of piezo voltage	< 40 ppm/K	
Small-signal bandwidth	3 kHz (0 load)	

*For TA pro systems. Two CC-5000 can be combined to drive one amplifier chip at up to 10 A.
**Optional break-out cable with 8 SMB connectors available.

DLC ext
Combination of DLC pro with fast locking modules



Laser system DLC DL pro extended by a DLC ext equipped with a DigiLock.

The DLC ext allows extending the DLC pro with TOPTICA's well-established fast locking modules. These modules DigiLock and FALC (see next page) provide high performance laser locking if a faster feedback than available with the DLC pro Lock option is needed.

Features

- Supports up to two modules, any two PDD 110, FALC 110, mFALC 110 and DigiLock 110
- 4 BNC signal outputs for access to backplane signals
- External power supply with automatic mains voltage detection

PDD 110/F, FALC 110 and mFALC 110

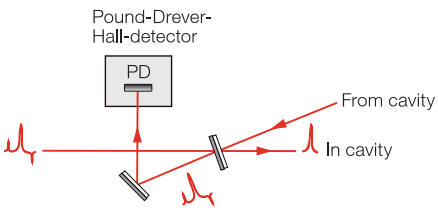
High-Bandwidth Linewidth Control with Optional Analog Mixer

PDD 110/F – fast Pound-Drever-Hall detector module

The Pound-Drever-Hall Detector PDD 110/F serves to lock a diode laser to the maximum of an absorption, reflection or transmission feature, such as an optical resonator or an atomic line. The module generates an HF modulation signal that acts either on the laser current, or on an electro- or acousto-optic modulator (EOM, AOM). A phase-sensitive detector unit demodulates the spectroscopic signal[1] and produces an error signal, which, in turn, serves as input for a PID regulator (e.g. FALC 110).

FALC 110 - highest bandwidth for frequency locking

The Fast Analog Linewidth Controller FALC 110, a high-speed control amplifier, performs advanced frequency stabilization tasks, such as laser linewidth reduction or high-bandwidth frequency locking. The module is compatible with any of TOPTICA's tunable diode lasers such as the DL pro, DL 100 and DL DFB.



Pound-Drever-Hall detection scheme.

Researchers using the FALC 110 highly benefit from a fast circuit layout. At 10 MHz there is a phase delay of less than 45 degrees, and the bandwidth of the fastest signal path reaches 100 MHz.

In a typical setup, the fast output of the FALC 110 controls the current of an ECDL or DFB laser. Additionally, a slow integrator cancels out long-term frequency drifts, by acting either on the grating piezo of an ECDL, or on the temperature of a DFB laser.

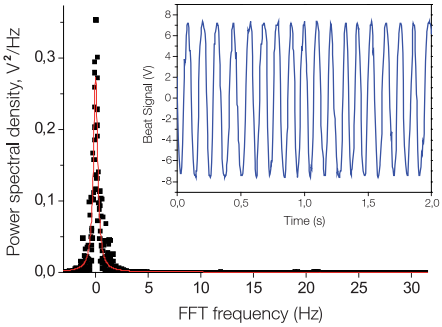
mFALC 110 – the solution for phase locking

The mixing FALC (mFALC 110) extends the functionality of the FALC 110 by integrating an additional analog mixer. The module accomplishes fast phase-locking of two diode lasers to a local RF oscillator: The beat signal of the two lasers is mixed with and phase-stabilized to the external RF source.

Sub-Hertz linewidths

The design works: Researchers at MPQ Garching locked two diode lasers to two high-finesse cavities with a resulting beat width of less than 0.5 Hz[1]. Sub-Hertz frequency stabilization of a DL pro with FALC was shown at the MPL Erlangen[2]. And scientists at the University of Frankfurt used the mFALC to maintain a stable phase lock of two DL DFB lasers to a local RF oscillator, and employed this setup for coherent terahertz imaging[3].

PDD 110/F — Pound-Drever-Hall detectors.
FALC 110 — Fast Analog Linewidth Controller.
mFALC 110 — FALC with integrated mixer.



Beat measurement of two independent ECDLs locked to two high-finesse ULE cavities, one of them using FALC 110. The beat width was less than 0.5 Hz over 8 s. The inset shows the phase stability of the beat note filtered with a 100 Hz low-pass filter (J. Alnis, MPQ Garching).

PDD 100/F	
Input section	
Error signal generated	Dispersive error signal for top-of-fringe locking
Modulation frequency	20 MHz (default), adjustable from 12 .. 35 MHz
Output section	
HF output amplitude	1 V pp (+4 dBm) @ 50 Ω
Second-harmonic suppression	> 30 dB typ.
General specifications	
Adjustable LO phase at mixer	0° - 190°, inversion +/- 180°
Total signal delay	< 12 ns (100 MHz bandwidth)
Number of detection channels	1 (2 possible with PDD 110/F DUAL)

FALC 110, mFALC 110	
Input section	
Inputs	Two high-speed differential inputs, adjustable input offset
Fast circuit branch	
PID regulator	Signal delay < 15 ns, Phase delay < 45° @ 10 MHz
DC gain	15 dB .. 80 dB
Output voltage range	Max. ± 2 V @ 50 Ω
Slow integrator	
Bandwidth	10 kHz, for grating piezo or laser temperature control
DC gain	Typ. 110 dB
Output voltage range	Max. ± 5 V, high-impedance load
RF input (beat signal of two lasers, mFALC only)	
Frequency range	10 MHz .. 200 MHz
Max. input voltage	5 V DC, 4.5 V pp AC
LO input (local oscillator, to be mixed with RF input, mFALC only)	
Frequency range	10 MHz .. 200 MHz, sine wave preferred
Max. input voltage	2 V DC, 2.8 V pp AC

[1] J. Alnis et al., Phys. Rev. A 77, 53809, (2008). [2] Y. N. Zhao et al., Opt. Commun. 283, 4696, (2010). [3] F. Friederich et al., Opt. Express 18:8, 8621, (2010).

DigiLock 110

Digital Feedback Controlyzer for Laser Locking and Analysis

DigiLock 110 — A versatile, digital locking module for DLC ext or SYS DC 110 electronics.

Features

- Scan generator
- Laser control
- Multi-channel Oscilloscope
- Controller Design
- Dual PID + P
- Click & Lock
- Pound-Drever-Hall
- AutoLock & ReLock
- Lock-in
- Computer control
- Spectrum analysis
- Network analysis

Laser stabilization easier than ever
Selfmade solutions for stabilization tasks often involved a heap of electronics, soldering, trial and error, and frustration. The DigiLock 110 is TOPTICA's versatile solution: a digital locking module, flexible to solve locking tasks with perfection, and yet easy to use thanks to intelligent software control with a clear and comfortable graphical user interface.

In addition to standard functions like side-of-fringe and top-of-fringe locking, the DigiLock 110 offers computer control over the laser, signal visualization, and signal analysis. In AutoLock mode, the user can modify the scan parameters of the laser by dragging the mouse, and zoom into a feature of a spectrum on the software oscilloscope screen.

With the feature displayed on the screen, one can then simply "Click & Lock" to any peak or slope. For optimizing lock parameters, spectral analysis of error signals can be performed, as well as measurements of actuator transfer functions.

DigiLock 110 – flexibility and perfection
Flexibility and perfection both originate from the underlying technology: The hardware is based on a fast FPGA (Field Programmable Gate Array). Together with numerous high-speed and high-precision AD and DA converters, the FPGA provides the needed flexibility with sufficient bandwidth. The large bandwidth, in fact, allows for substantially reducing diode laser linewidths: using two DigiLocks 110 to lock two DL pro to one FPI 100, a beat width of less than 300 Hz was measured.

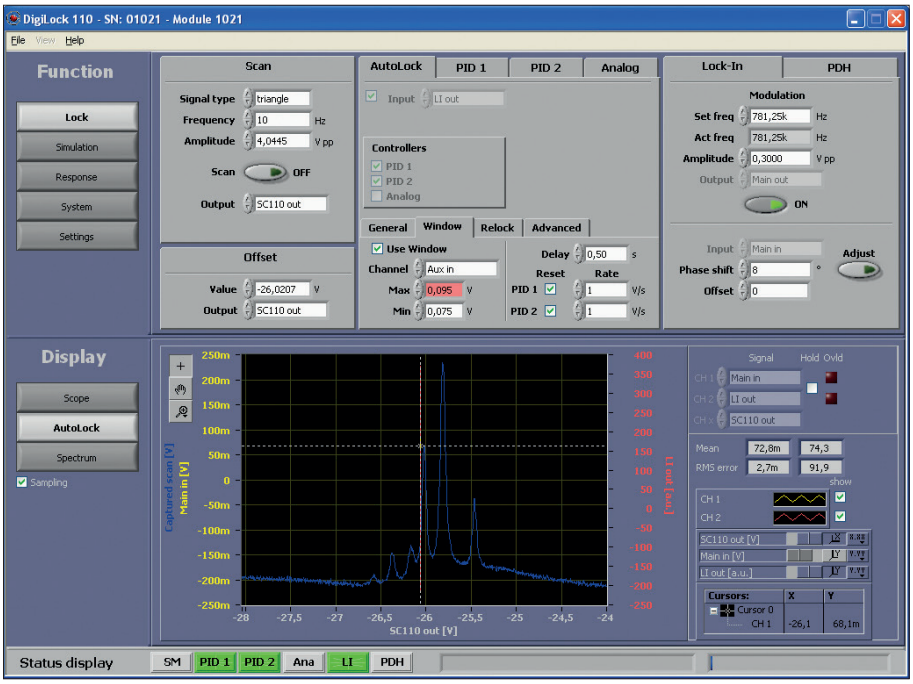
As shown with FALC 110, it was possible to also achieve sub-Hz linewidths with the DigiLock 110, utilizing the high-bandwidth analog bypass.

Intelligence in laser stabilization
The DigiLock 110 tries to support the laser user wherever possible. In addition to the aforementioned features, the DigiLock can be configured to detect whether the frequency is locked – locked in general – or even whether the laser is locked to the right position.

It is for example possible to define a voltage window in a Doppler-broadened spectroscopy signal, that contains only one transition of the corresponding Doppler-free signal, thus allowing the laser to only lock to this particular peak (see AutoLock & ReLock example, page 43).

Once out of lock, the DigiLock can start searching, at pre-set speed, over a configurable width, until the voltage lies within the locking window again and the laser is tightly locked. The automatic relock makes frequent manual readjustments obsolete.

Multiple DigiLocks and remote control
The latest software version of the DigiLock 110 offers control of up to four DigiLocks from one computer. Also, remote control via TCP/IP is now available, so the DigiLock can be integrated in automated experiments and controlled by other hard- and software.

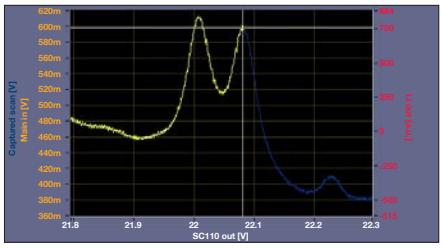


DigiLock's graphical user interface.

Functionality	Value	Unit	Comment
Scan frequency	0.1 - 33 x 10^6	Hz	Bandwidth limited on some channels
Waveform types	Sine, triangle, square, sawtooth		
PID function 1			
Signal latency	200	ns	ADC and DAC latency included
Parameters	P, I, D, I cut-off		
PID function 2			
Signal latency	200	ns	ADC and DAC latency included
Parameters	P, I, D		
Analog P function			
Bandwidth	21 MHz (-3 dB, 200° phase)		
Lock-In function			
Modulation frequency	0.012 – 781	kHz	
Pound-Drever-Hall function			
Modulation frequency	1.56, 3.13, 6.25, 12.5, 25	MHz	

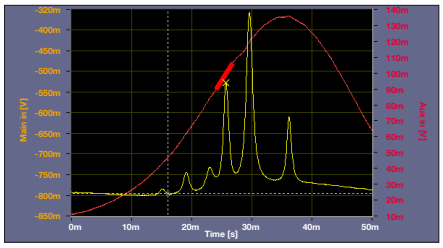
Input channels	Resolution (bit)	Sample rate (Hz)	Bandwidth (-3 dB) (Hz)	Range (V)	Impedance (Ohm)	Comment
Main in	14	100 M	14 M	± 2.1	50	Input signal <Main in> has to be between ± 3.5 V, <Input Offset> and amplification can be controlled from DigiLock Software
Aux in	14	100 M	15 M	± 2.1	50	
Precise in	16	200 k	50 k	± 2.0	10 k	
DCC I_{act}	16	100 k	15 k	± 13.1	40 k	SYS DC 110 backplane
DTC T_{act}	16	100 k	15 k	± 13.1	40 k	SYS DC 110 backplane
AIO 1 in	16	100 k	15 k	± 12.5	47 k	Normally used as output
AIO 2 in	16	100 k	15 k	± 12.5	47 k	
Sum in			27 M	± 1.0	50	Bandwidth between <Sum in> and <Main out>

Output channels	Resolution (bit)	Sample rate (Hz)	Bandwidth (-3 dB) (Hz)	Range (V)	50 Ohm driver	Comment
Main in	14	100 M	19 M	± 1.0	Yes	Sum of <Sum in> and analog P branch
Aux in	14	100 M	19 M	± 1.0	Yes	
SC 110 out	21	100 k	18 k	± 6.5	No	SYS DC 110 backplane; amplification by 15 with SC 110
DCC Iset	21	100 k	18 k	± 6.5	No	SYS DC 110 backplane
DTC Iset	16	100 k	18 k	± 6.5	No	SYS DC 110 backplane
AIO 1 out	16	100 k	16 k	± 6.5	No	
AIO 2 out	16	100 k	16 k	± 6.5	No	Normally used as input
Sum in			27 M	± 1.0	50	Bandwidth between <Sum in> and <Main out>
Error out			20 M	± 1.7	Yes	Error out = (<Main in> + <Input Offset>) x Gain/2; bandwidth between <Main in> and <Error out>
TRIG				0, 2.6	Yes	



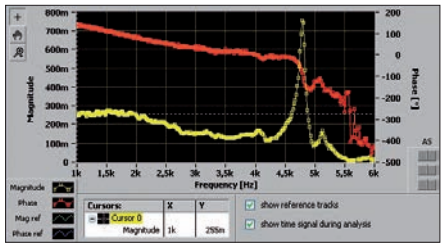
“Click & Lock”:

The user can click on the slope position or on any maximum or minumum. The laser scans to this position, and the DigiLock activates the lock.



“AutoLock & ReLock”:

The DigiLock enables/disables multiple PIDs and an analog P component simultaneously. Once in lock, the error signal is plotted against the scan voltage for monitoring. The user can define voltage windows to allow the DigiLock to lock to certain features only, and initiate a search if the voltage lies outside the window.



“Spectrum and Network analysis”:

The DigiLock can show the spectrum of an error signal, for example to reveal oscillations. Actuator transfer functions and bandwidth can be measured by sweeping a modulation to an actuator and measuring the response in amplitude and phase. The picture shows a measurement of the DL pro piezo resonance frequency.