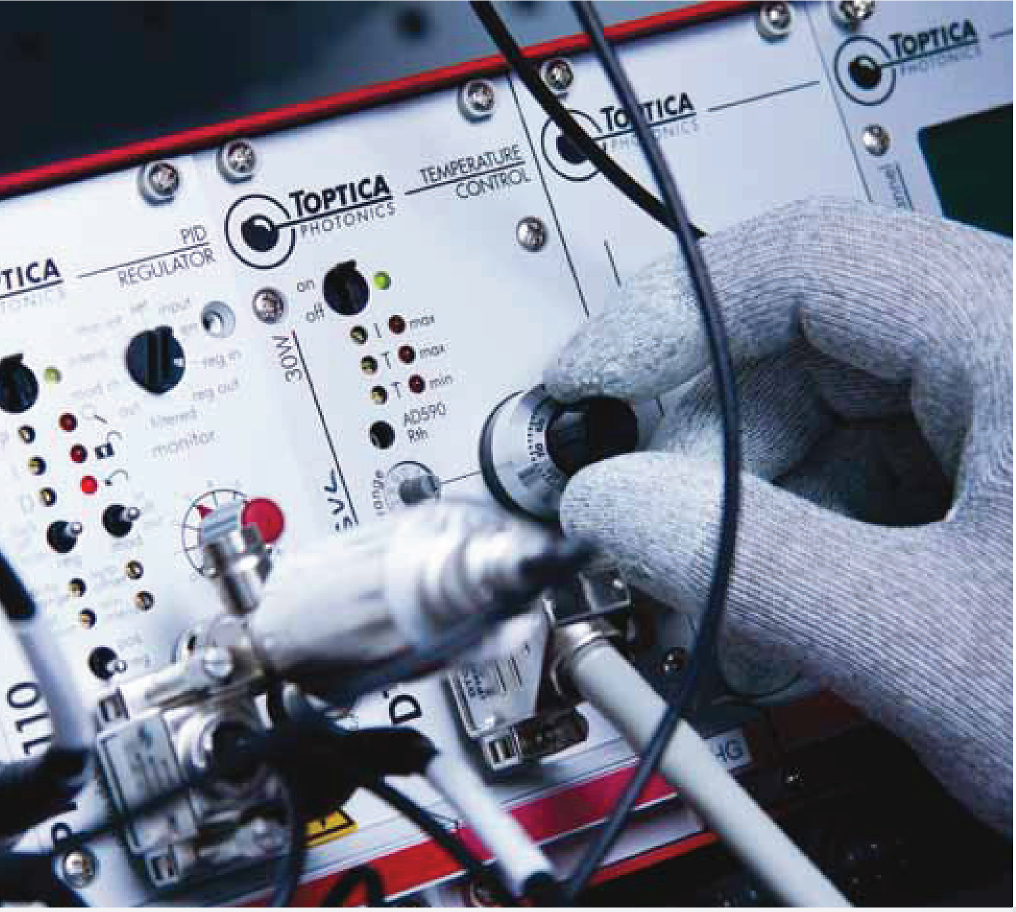


Photonicals™

Laboratory Electronics

TOPTICA offers a specialized system of electronics (SYS DC) for operating their scientific diode laser systems. It is a mostly analog, modular system that is optimized for lowest possible noise, yet providing a certain bandwidth for current regulation, modulation and scanning.
It can easily include additional modules for laser frequency stabilization and linewidth narrowing (see pages 48+).

Frequency stabilization
To actively stabilize the laser frequency, a reference is needed that serves as frequency discriminator. For absolute stabilization and drift compensation, atomic absorption lines (page 62), spectral lines of a locked frequency comb (page 74+), or wavelength meters (page 60) can be used. Relative frequency references include high-finesse optical resonators or quadrature interferometers (page 56). In a closed control loop, the measured frequency signal is compared with a set value, and a feedback circuit is applied to correct for deviations from this set value.
For a simple "side-of-fringe" lock, the difference between set and measured frequency is fed back to the laser through a PID controller. It can be used, for example, to stabilize the laser frequency to the slope of an absorption line.
For "top-of-fringe" locking, the original signal has a minimum or maximum at the desired frequency. A PID however needs a slope to lock to. Modulation/Demodulation techniques are used to create derivative error signals that show a slope with zero crossing. Such a signal can be ideally utilized to stabilize the laser via a PID regulator. The PID then acts on the laser's control parameters (e.g. current, temperature, grating angle) to keep the frequency at the extremum of the original signal.

Digital locking
Digital stabilization electronics offers a number of advantages. One advantage is, that parameters are entered as numbers. Numbers can be easily remembered, and after trying out other numbers for parameters, one can always go back to well proven configurations. No adjustment of trim pots or soldering of components is needed any more. In addition, digital amplifiers offer gain-independent signal delay times, and certain digital filters by far outmatch their analog alternatives.
The best digital laser stabilization solution on the market is TOPTICA's DigiLock 110. It extensively takes advantage of its digital nature, and in addition implements a multitude of functions and intelligence – for example for lock detection, relocking and to make locking easy and comfortable. See for yourself on pages 51–53 or try it on one of the trade shows and conferences that TOPTICA participates in.

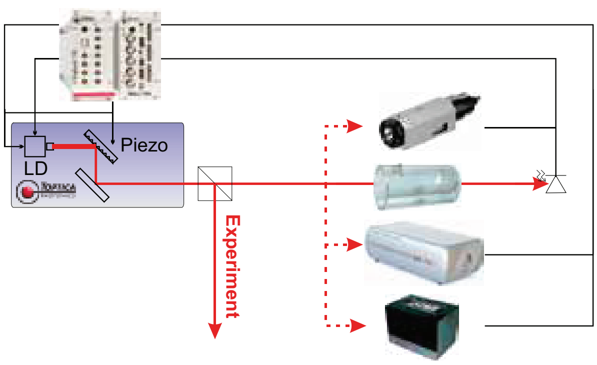
	PID 110	LIR 110	PDD 110/F	FALC 110	DigiLock 110	Lase-Lock	Wavelength Meter	iScan
Description / type	Analog PID	Analog lock-in regulator	Pound-Drever-Hall signal generation	Fast analog 2-channel PID	Versatile digital locking solution	Suited for third party lasers	Wavelength meter with PID option	Etalon-based frequency locking module
Side-of-fringe							Not applicable	
Top-of-fringe	With PDD			With PDD				
Locking bandwidth*	kHz .. MHz	kHz range		≈ 45 MHz	≈ 10 MHz	1 MHz	< 100 Hz	kHz range
Modulation frequency		0.6 Hz .. 14 kHz	12 .. 35 MHz **		17 Hz .. 25 MHz	33 Hz .. 1MHz	Not applicable	
Accuracy	Depends on reference (can be very good)						> 10 MHz	1 MHz (rel.)
Signal analysis								
Relock mechanisms								
Computer control								
High voltage output								
High bandwidth output								
Multiple output channels								
SYS DC 110 module								
Stand-alone								
Catalog page	48	48	49	50	51	55	60	56
	low budget		high end & preferrable					
*Estimated bandwidth depends on gain and PID settings **5 .. 70 MHz versions available								

Overview of TOPTICA's frequency stabilization electronics.

Linewidth narrowing
The laser linewidth can actually be reduced, when a locking circuit responds to frequency deviations faster than the frequency measurement. In this case high-bandwidth locking electronics together with a fast, low-noise frequency discriminator need to be employed.
TOPTICA's FALC 110 and DigiLock 110 are well suited for this task. Linewidths below 200 Hz (ms time scale) have been realized in TOPTICA's labs, using the FPI 100 as a relative frequency reference. Our customers have even achieved sub-Hz linewidths (8 seconds), combining the FALC 110 or DigiLock 110 and high-finesse, thermally stabilized reference cavities.

Linewidth broadening
On the other hand, certain tasks demand just the opposite: increasing the laser linewidth in a well-controlled way, in order to match the spectral shape e.g. to Doppler-broadened absorption profiles. TOPTICA's Laser Coherence Control unit LCC accomplishes just that: the output of a tunable diode laser is broadened via a dedicated current modulation scheme.

With TOPTICA's modules FALC 110 and DigiLock 110 on one side, and the LCC on the other side, the coherence length and linewidth of ECDL or DFB lasers can be tailored over more than nine orders of magnitude – from sub-Hertz levels to GHz ranges (coherence length 130 000 km .. 4 cm).



SYS DC 110 Series

Laser Driver and Frequency Stabilization Modules

DC 110 diode laser supply racks
The diode laser supply rack DC 110 serves as a general basis for all plug-in modules of the SYS DC 110 series. It provides the necessary supply and HV voltages via an integrated backplane. The backplane also enables the communication between the different modules, provides data lines for the monitor display, and – via the DCB 110 analog interface – allows for remote control of the modules by external devices.

The rack is available as 12", 19" and double-stage 19" version, housing 3, 5 and 10 units in addition to the DC 110 monitor, respectively. In its basic configuration, the 19" rack is equipped with a DC 110 Monitor Unit, Current Control module DCC 110, Temperature Control module DTC 110 Scan Control SC 110, and a DCB 110 analog interface board. Other modules can be flexibly added, depending on the number of lasers to be controlled, or for frequency stabilization tasks.

DC 110 monitor unit with LCD display
The monitor unit of the Diode Laser Controller DC 110 displays the most relevant laser parameters at a glance. Actual and preset values of current and temperature of up to three laser systems are indicated on a four-line LCD unit. Other important values, e.g. adjusted maximum current or operating temperature range, can also be shown.

The monitor unit features a power-up switch for the control rack, and an extra button to enable or disable laser operation. Internal safety circuits are included to prevent damage of the laser diode in case of power failure.

Specifications and safety features DC 110 supply rack

- Linearly regulated, low noise power supply, thermally protected
- Automatic mains voltage detection (100 – 120 or 220 – 240 VAC, 50 – 60 Hz)
- Very low noise transformers
- All supply voltages short circuit protected
- Interlock socket for external interlock circuit
- High power version available for use with DCC 110/5A

Specifications DC 110 monitor

- Four-line LCD dot matrix display
- Push buttons and rotary encoder for display selection of the operating parameters of up to 3 diode lasers
- Power supply ON/OFF safety key switch
- Monitor “sleep” function

DCC 110, DTC 110, SC 110, DCB 110

Premium Electronics for Diode Lasers

Driver electronics for TOPTICA's scientific diode lasers
Based on the rack and monitor, TOPTICA offers the perfect driving system for all scientific diode lasers. Besides the monitor unit, standard systems include the needed number of current, temperature and scan control modules (DCC 110, DTC 110, and SC 110).

The **DCC 110** modules are ultra low noise, analog current control modules that deliver currents up to 100 mA, 500 mA, 3000 mA, or 5000 mA. BNC input and output connectors are provided for external modulation of the laser current, and for monitoring the internal photodiode signal of a laser diode. The DCC 110/5A requires a special high power SYS DC 110 supply rack.

The **DTC 110** is a low-noise temperature control module that regulates the laser diode temperature with a precision of approx. 1 mK. It can be used to sweep the emission wavelength of DFB diodes. Its bipolar control allows for fast and stable regulation. Special versions are available for DFB diodes and for regulating the temperature of nonlinear crystals.

The **SC 110** is optimized for driving external cavity diode lasers, DFBs or scanning Fabry-Perot interferometers (FPI 100). It can be configured for HV (150 V) or LV (±12 V) output. The feed forward feature controls the diode current during a piezo scan to maximize the mode hop free tuning range of external cavity lasers.

The **DCB 110** is an analog interface board that provides access to the backplane of the rack. It enables the user to monitor and control important parameters of the modules in the rack.

Standard configurations can easily be extended with TOPTICA's sophisticated locking electronics (see pages 48–53).

Specifications DCC 110	**Specifications DTC 110**	**Specifications SC 110**	**Specifications DCB 110**
Output current range: 0 .. ±100 mA (DCC 110/100 mA) 0 .. ±500 mA (DCC 110/500 mA) 0 .. ±3 A (DCC 110/3A) 0 .. −5 A (DCC 110/5A)	Output current: 0 .. 5 A, maximum output power: 30 W	Frequency 0.01 Hz to 10 kHz, coarse frequency range switch and continuous fine tuning	Sub-D25 connector to access all relevant backplane parameters
Laser stabilization to constant operating current or constant light power	Temperature selection range: 0 °C to 50 °C or DTC/SVL for non-linear crystals: 25 °C to 75 °C	High voltage mode: maximum amplitude 150 V up to 10 kHz, adjustable offset -5 .. +150 V	BNC-connector for additional access to selected backplane lines (e.g. remote scan control)
Fine tuning of output current or laser power via precision trimmers	Limits of operating temperature adjustable via precision trimmers	Low voltage mode: maximum amplitude 24 V up to 10 kHz, adjustable offset -12 .. +12 V	Depending on the signal, a line is buffered or used as read/write line
External modulation of output current up to 7 kHz (-3 dB)	Typical long-term stability with TOPTICA laser heads: 1 .. 2 mK (RMS)	Sawtooth signals with symmetric or asymmetric ramp, variable degree of symmetry	DCB 110 AUX: additional supply port for auxiliary DC supply voltages (-12 V, -5 V, GND, +5 V, +12 V)
Numerous protection circuits for the laser diode, including excess voltage clip	Remote control of set temperature possible via backplane and DCB 110 interface	TTL trigger synchronization output, adjustable trigger time delay	
RMS wideband noise and ripple, 5 Hz .. 1 MHz: 200 nA (DCC 110/100 mA), 1 µA (DCC 110/500 mA), 10 µA (DCC 110/3 A) 40 µA (DCC 110/5 A)	Relevant parameters available at DC 110 monitor	Adjustable feed forward for simultaneous control of laser current and grating angle	

PID 110

PID Regulator

PID 110 –
flexible Proportional Integral Differential regulator module

The PID 110 is a proportional integral differential regulator for frequency stabilization of tunable diode lasers (DL 100, DL DFB, DLX, etc.). It accomplishes **side-of-fringe locking** e.g. to the edge of an atomic resonance, or to the slope of a cavity transmission peak. Side-of-fringe stabilization is employed in case a discriminator signal can be directly derived from the measurement signature.

The PID 110 module offers flexible handling of all relevant control parameters and can be utilized both for HV (piezo actuators) and LV (laser current) control tasks. Common applications are active length control of the frequency doubling cavity of the SHG 110 system (see pages 32–43), or RF sideband locking to narrow absorption signatures in conjunction with the Pound-Drever-Hall Detector PDD 110/F (see page 49).

LIR 110

Lock-In Regulator

LIR 110 –
Lock-In Regulator module

The lock-in regulator LIR 110 accomplishes **top-of-fringe frequency stabilization** to an absorption signature (e.g. an atomic resonance or interferometer transmission peak), utilizing a modulation technique with phase-synchronous detection. Here, the laser frequency is modulated, the detector signal is multiplied with the modulation input signal, and the resulting product signal ("lock-in signal") represents the derivative of the detector signal with respect to the laser frequency. The zero-crossing of the derivative corresponds to the maximum or minimum of the detected signal structure.

The LIR 110 module comprises the modulation source (sine or sawtooth), an input signal amplifier, the phase-sensitive detection unit and a PID regulator. The unit can be used with any of TOPTICA's tunable diode lasers.

Specifications PID 110

- P, I, D parameters of the control loop individually adjustable by precision trimmers
- Adjustable regulator set point for side-of-fringe stabilization
- Automatic relock feature
- External modulation input or internal synchronization with Scan Control SC 110 possible
- SubD9-connector for photo detector signal input
- BNC-connectors for signal monitor, regulator output (-5 V .. +150 V, max. 30 mA) and external modulation input (-5 V .. +5 V)

Specifications LIR 110

- For top-of-fringe frequency stabilization
- Modulation frequency 0.6 Hz .. 14 kHz
- Modulation amplitude: maximum ±5 V
- Adjustable lock-in bandwidth (16 mHz .. 16 kHz)
- Variable input amplifier gain (1 .. 3000)
- Various BNC connectors, e.g. for signal input, signal monitor, regulator output (max. ±13 V), modulation output etc.
- Potentiometer for continuous phase adjustment
- Proportional, integral and differential distribution continuously adjustable (separately or combined)

PDD 110 / F

Pound-Drever-Hall Detector

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

The Pound-Drever-Hall Detector PDD 110/F is used to generate a low noise error signal that can be used to lock the laser frequency to absorption lines or cavity resonances. The error signal is obtained by fast modulation of the laser frequency and phase sensitive demodulation of the spectroscopy signal. The PDD 110/F features an internal HF modulation source with variable output amplitude. The modulation signal is fed to the DL-Mod input of TOPTICA's tunable diode lasers or to electro- or acousto-optic modulators (EOMs, AOMs). The PDD 110/F also comprises a detector section with a low-noise mixer and adjustable phase offset.

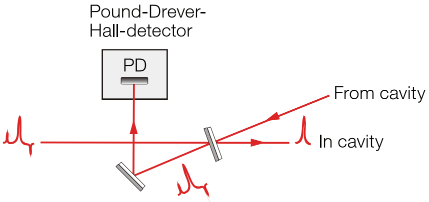
Typical applications of the PDD 110/F are Pound-Drever-Hall frequency stabilization (R.W.P. Drever, J.L. Hall, F.V. Kowalsky et al., Appl. Phys. B 31 (1983) 97) and linewidth reduction of lasers using an external resonator as a reference, as well as frequency modulation spectroscopy or modulation transfer spectroscopy. For locking, the derived error signal serves as input for a PID regulator, e.g. PID 110 or FALC 110.

In TOPTICA's frequency converted laser systems (see pages 32–43), the PDD 110/F module can be used to keep the frequency doubling cavity resonant (correctly adjusted cavity length) with the fundamental laser. The modulation is applied directly to the AC coupled modulation input of the laser head. The reflection of the cavity is detected with a fast photo diode and demodulated in the PDD 110/F. The resulting error signal is fed into the PID 110 controller, and the PID's HV output is used to control the doubling cavity's length via a piezo-mounted mirror. The resonantly enhanced light in the doubling cavity can then be effectively frequency converted.

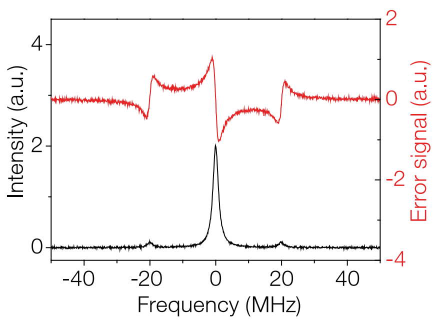
PDD 110/F and PDD 110/F/Dual

Specifications PDD 110/F

Internal oscillator adjustable 12 .. 35 MHz, (customized frequencies between 5 and 70 MHz on request)	
HF output amplitude ±1.2 V (11.6 dBm) @ 50 Ω	
Second harmonics suppression typ. > 30 dB	
Phase adjustment via front panel potentiometer, 0° .. 300°	
Phase error signal bandwidth > 20 MHz, Total signal delay < 12 ns	
Also available in a two-channel version as PDD 110/F/Dual	



Pound-Drever-Hall detection scheme.



Pound-Drever-Hall error signal.

FALC 110 and mFALC 110

High-Bandwidth Linewidth Control with Optional Analog Mixer

FALC 110 – Fast Analog Linewidth Controller.

mFALC 110 – FALC with integrated mixer for phase-locked loops.

FALC 110 – highest bandwidth for frequency locking

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

The design of the FALC 110 was optimized with respect to a fast circuit layout: At 10 MHz there are less than 45 degrees of excess phase delay, and the -3 dB bandwidth of the fastest signal path reaches 100 MHz.

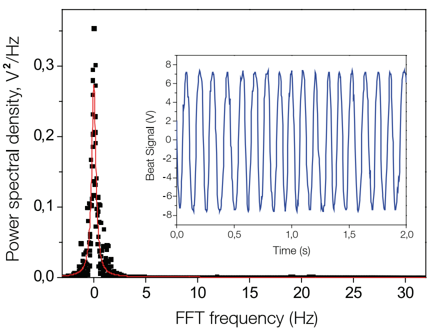
In a typical setup, the fast PID regulator output of the FALC 110 controls the driver current of an external-cavity or DFB diode laser. Additionally, a slow integrator serves to cancel out long-term drifts of the laser frequency, by acting either on the grating piezo of an ECDL, or on the current or 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 is designed for 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: At the MPQ Garching, two diode lasers were locked to two high finesse cavities with a resulting beat width of less than 0.5 Hz (J. Alnis et al., Phys. Rev. A 77, 53809, 2008). Sub-Hertz frequency stabilization of a DL pro with FALC was shown at the MPL Erlangen (Y. N. Zhao et al., Opt. Commun. 283, 4696, 2010). 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 (F. Friederich et al., Opt. Express 18:8, 8621, 2010).



Beat measurement of two independent ECDLs locked to two high finesse ULE cavities, one of them using FALC 110. The beat width was measured to be 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 (Janis Alnis, MPQ Garching).

Input section	
Inputs	Two high-speed differential inputs, adjustable input offset (mFALC see below)
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

DigiLock 110

Digital Feedback Controlyzer for Laser Locking and Analysis

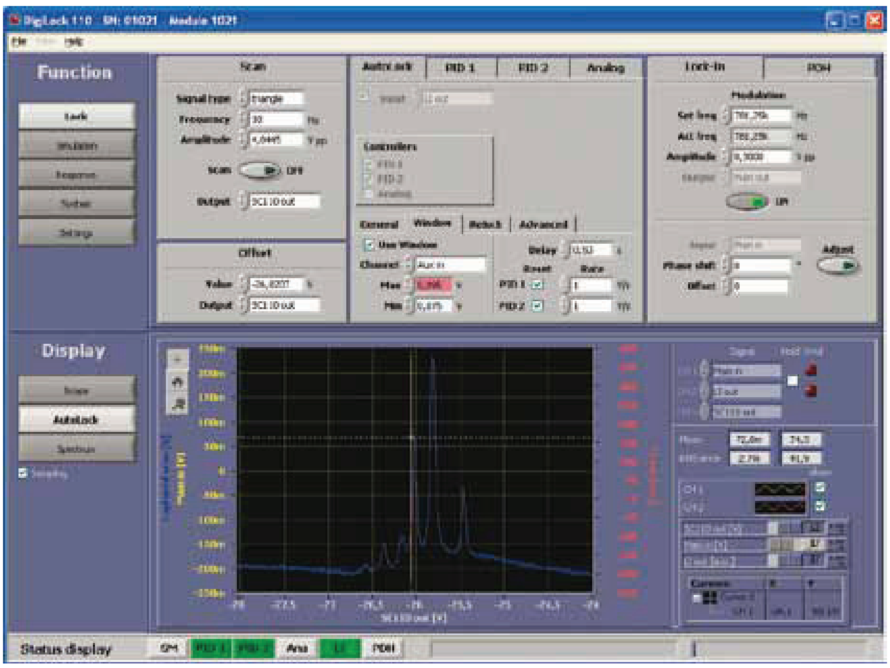
Laser stabilization easier than ever
Selfmade solutions for stabilization tasks often involved a heap of electronics, soldering, try and error, and frustration. DigiLock 110 is TOPTICA's versatile solution: a digital locking module, that is flexible to solve locking tasks with perfection, and yet easy 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 auto lock 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.

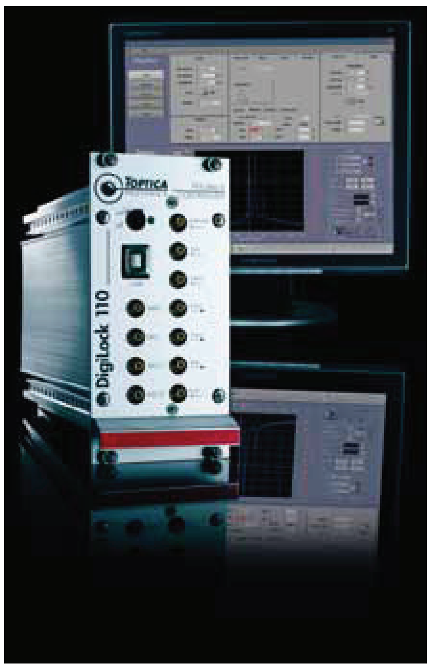
DigiLock 110 – flexibility & perfection
Flexibility and perfection both originate from the underlying technology: the hardware is based on a fast FPGA (Field Programmable Gate Array). Together with numerous high speed and high precision AD and DA converters, the FPGA provides the needed flexibility with sufficient bandwidth. The large bandwidth, in fact, allows one to substantially reduce 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. And as was previously 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. Once out of lock, the DigiLock can start searching, at preset 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.



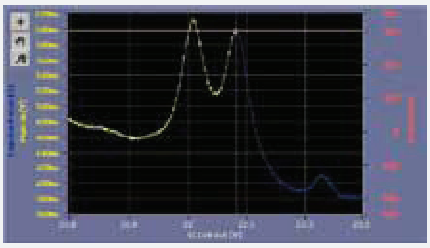
DigiLock 110 – Digital Feedback Controlyzer

DigiLock 110

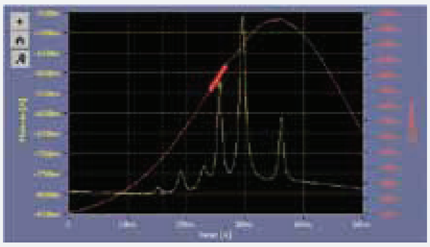
Digital Feedback Controlyzer for Laser Locking and Analysis

- Scan Generator
- Multi Channel ‘Oscilloscope’
- Dual PID + P
- Pound-Drever-Hall
- Lock-In
- Spectrum Analysis

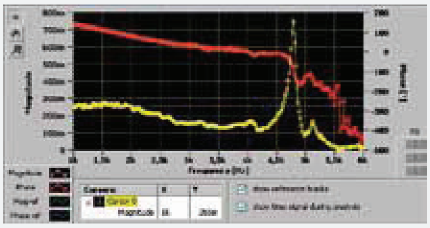
- Laser Control
- Controller Design
- Click & Lock
- AutoLock & ReLock
- Computer Control
- Network Analysis



Example feature “Click & Lock”:
The user can click on the slope position or on any peak or valley, the laser scans to this position, and the DigiLock activates the lock.



Example feature “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.



Example feature “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.

For detailed video turorials, please visit our website http://www.toptica.com/digilock

Specifications DigiLock 110

Functionality	Value	Unit	Comment
Scan function			
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	12 – 781 x 10^3	Hz	
Pound-Drever-Hall function			
Modulation frequency	1.56, 3.13, 6.25, 12.5, 25	MHz	

General	Value
Supply voltage	±15 V
Supply current +15 V (typ)	700 mA
Supply current -15 V (typ)	200 mA

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 at <Main in> has to be between ±3.5V; <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 out	14	100 M	19 M	±1.0	Yes	Sum of <Sum in> and Analog P branch
Aux out	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 SC110
DCC Iset	21	100 k	18 k	±6.5	No	SYS DC 110 backplane
DTC Tset	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
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	

LCC

Laser Coherence Control

LCC – laser modulation source for controlled linewidth broadening

Key features
· Modulation source for ECDL and DFB lasers · Controlled linewidth broadening/ coherence length reduction over more than three decades · Adjustable linewidth up to GHz values · For spectroscopy of Doppler-broadened lines and fiber ampilfier seeding

Stand-alone unit for linewidth broadening

The Laser Coherence Control unit LCC serves to broaden the spectral line profile of an ECDL or DFB laser in a well-controlled way, maintaining both frequency control and tuning properties of the laser. The module allows the user to match the laser linewidth e.g. to Doppler-broadened absorption lines of gaseous molecules or atoms, whilst the laser remains tuned to the respective resonance frequency.

The compact stand-alone unit comprises a broadband modulation source with up to 28 dBm (0.6 W) output, which can be attenuated in steps of 1 dB (0 .. -61 dB). The output is fed to an AC-coupled modulation port of a DL 100, DL DFB or DL pro based laser head ("DL MOD" option, see page 21). Varying the modulation output allows the researcher to tailor the laser's coherence length to the needs of the individual experiment.

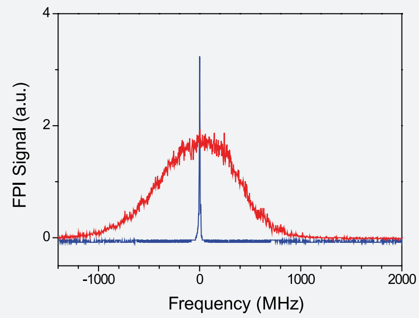
Nine decades of coherence control

Applications of the LCC include optical pumping of metastable Helium-3 (1083 nm, linewidth 2 GHz), or seeding of high-power fiber amplifiers whilst avoiding unwanted nonlinear effects. Using the LCC in conjunction with an 855 nm DL DFB laser, spectral widths up to 3 GHz were realized, corresponding to a minimum coherence length of only 4 cm. This represents a linewidth increase of more than 3 orders of magnitude, compared to regular laser operation.

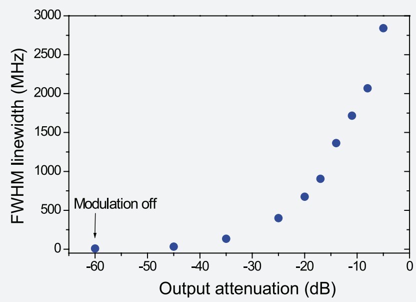
Considering that, on the other side, TOPTICA's high-bandwidth locking modules FALC 110 and DigiLock 110 have been shown to achieve sub-Hertz linewidth values, the range of laser coherence control even extends over more than nine orders of magnitude (coherence length 130000 km .. 4 cm).

Specifications LCC

Stand-alone module with separate power supply
Maximum power: 0.6 Watt @ 50 Ω (= 28 dBm)
Attenuation: 0 .. -61 dB, via dip switch board
Output spectral bandwidth: 10 MHz .. 200 MHz
Allowed voltage standing wave ratio at output (VSWR): 1 .. ∞
Connector type: SMA



Mode spectrum of a TOPTICA DL DFB laser.
Blue: 1 MHz linewidth without modulation,
red: linewidth broadening to 900 MHz using the LCC.



Linewidth of an 855 nm DL DFB,
for different LCC output amplitudes.

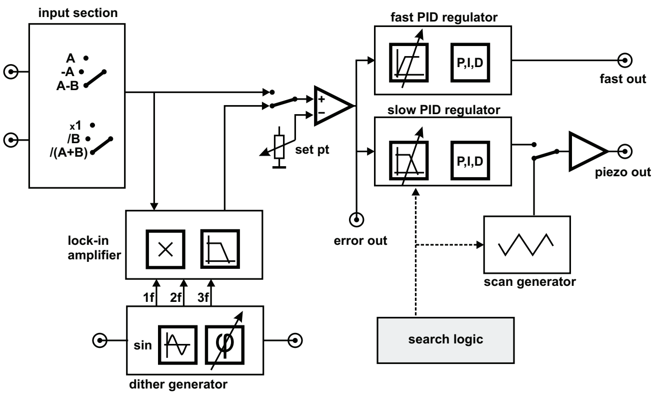
LaseLock

Stand-Alone Lock-Box for Laser Frequency Stabilization

Frequency locking of any tunable laser

The LaseLock has been designed for precise frequency stabilization of any tunable laser source. It can be used both with TOPTICA's diode lasers and with third party lasers. Optical resonators or atomic absorption signatures may serve as frequency references. Vice versa, optical resonators also can be stabilized to a given laser frequency. The unit comprises a pair of PID regulators for side-of-fringe stabilization, as well as a lock-in regulator (frequency modulation with phase-synchronous detection) for top-of-fringe locking tasks.

Applications include laser frequency stabilization to an atomic resonance line, e.g. in combination with TOPTICA's spectroscopy module CoSy (see page 62), or stabilization of an optical cavity (Fabry-Perot resonator or ring cavity) to the emission frequency of a laser source.



LaseLock block diagramm.

Universal stand-alone lock-box.

Specifications LaseLock

Signal input	User-selectable impedance (Standard 10 kΩ) Amplifier gain 1 .. 3000 Bandwidth 5 MHz 2 separate inputs: generation of signal difference or ratio
Outputs	HV output: 150 V, 100 mA, BNC HF output: 1 MHz, 50 Ω, BNC Scan trigger output: TTL Scan monitor output: ±10 V @ 1 kΩ Multichannel monitor: ±10 V @ 1 kΩ, ±5 V @ 50 Ω
Lock-In amplifier	Modulation frequency: 33 Hz .. 1 MHz (sine) 2f / 3f demodulation, user selectable Phase adjustment: 0 .. 360° Filter cut-off frequency 33 Hz .. 100 kHz
Twin PID regulator	2 independent PID regulators (e.g. for piezo & current control) P, I, D coefficients individually adjustable Bandwidth: 1 MHz Second order low-pass filter (e.g. for mechanical resonance suppression)
Scan generator	Output frequency, triangular shape: 10 mHz ..10 kHz
Operating voltage	100 .. 120 V / 220 .. 240 V AC, 50 .. 60 Hz (auto detect), low noise linear power supply
Housing dimensions	88 mm x 260 mm x 373 mm (H x W x D)
Search logic	Discriminator logic for identification of valid search ranges Automatic relock upon loss of input signal

Key features

- Compact, stand-alone locking electronics for diode lasers, dye lasers, Ti:Sa lasers, or optical resonators
- Side-of-fringe and top-of-fringe stabilization
- Two independent PID regulators
- High-voltage output
- Automatic relock feature with "search" function and lock point validity detection
- Multi-channel monitor for display of regulator signals

iScan

Mode Monitoring and Frequency Control

iScan measurement head.

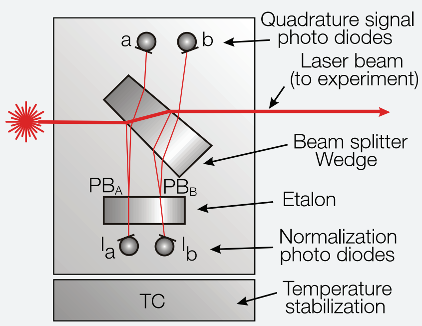
Key features

- Fast and precise scanning of tunable lasers
- Scan linearization
- Stepping and stabilization to arbitrary wavelengths
- Static and dynamic mode surveillance
- For diode lasers, fiber lasers, dye lasers, solid state lasers
- Upgrade of existing laser systems possible

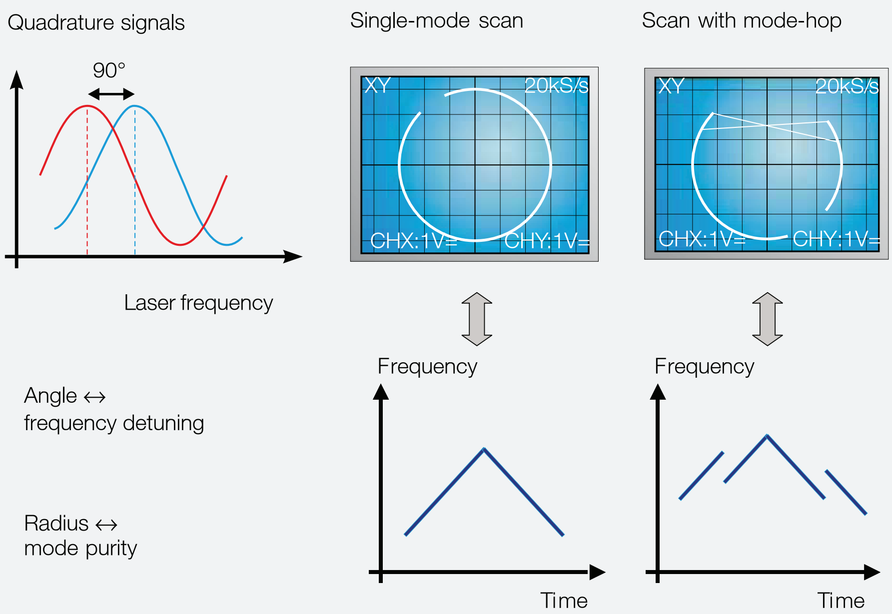
Continuous frequency reference
TOPTICA's iScan comprises a patented interferometer for fast and precise frequency control of tunable lasers. The laser frequency can be scanned in any desired manner, or stabilized to any frequency within the laser's tuning range.

The principle of the iScan is based on quadrature signal generation within a low-finesse Fabry-Perot etalon. A wedge-shaped beamsplitter generates two low intensity probe beams (PB_A and PB_B), which enter the etalon under slightly different angles. The etalon produces a pair of interference signals with a relative phase of $\pi/2$ (90°). These signals are detected by two photodiodes (a and b) and combined into a quadrature signal, the phase of which is a linear function of the optical frequency. Two additional photodiodes (I_a and I_b) behind the etalon provide normalization values.

Quadrature signals represent mode properties
The normalized quadrature signal can be visualized on an oscilloscope operating in XY-mode: when the laser frequency is scanned, each of the photodiodes a and b detects an oscillating, near-sinusoidal signal. The XY-display yields a circle, where the momentary phase angle mirrors the laser frequency. The completed circumference of the circle represents the range of the frequency scan, and a full circle corresponds to the FSR of the interferometer. The circle radius additionally reveals information on the mode properties of the laser. A mode-hop free scan yields a smooth curve, whereas a mode-hop within the scan range causes a sudden jump across the circle. Multi-mode operation and coherence reduction due to optical feedback are also recognized by their distinct signatures.



Design of the optical interferometer within the iScan head. A precision temperature controller (TC) serves to maintain the optical path lengths constant.



Quadrature signals and corresponding mode signatures (see text for explanations).

Scan linearization and frequency locking

For frequency regulation, the interferometrically measured frequency is compared to a user-selected target frequency. Analog electronics generate an error signal, which is processed by a PID regulator and fed back to the laser (e.g. piezo and current of an ECDL, or temperature and current of a DFB laser).

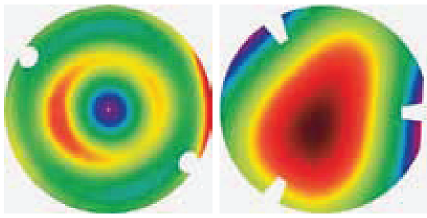
The iScan not only accomplishes a precise frequency “lock” but also compensates for perturbations which would influence the laser frequency otherwise, e.g. temperature changes, mechanical drifts or vibrations. And last not least, the laser frequency remains regulated even during a wavelength scan.

iScan applications

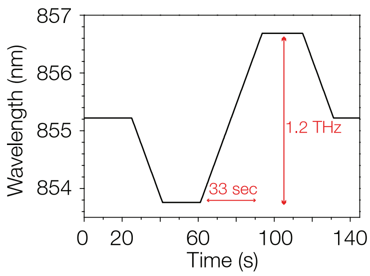
The iScan lends itself to frequency control of semiconductor lasers, as well as fiber lasers, solid state lasers and dye lasers. The unit is conveniently controlled from a standard PC via USB or RS 232.

Applications include wavelength drift surveillance, laser ageing control and tuning optimization, phase-shifting interferometry, LIDAR seeding, and high-resolution spectroscopy in cw-terahertz experiments.

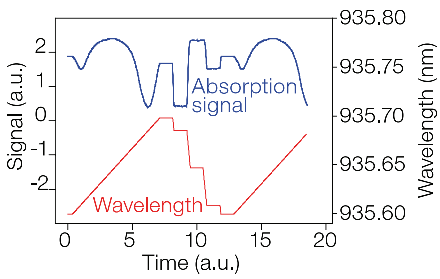
In combination with absolute frequency standards such as atomic absorption lines (CoSy, page 62), the iScan becomes a unique system for absolute laser stabilization at arbitrary frequencies – throughout the optical spectrum.



Wavefront of a lens (left) and a wafer (right), recorded with phase-shifting interferometry.



Tuning curve of a DFB laser with iScan control. A linear scan of +0.6 THz is followed by a scan of –1.2 THz, before the frequency returns to its initial value.



Water absorption spectrum, recorded with a DL 100 + iScan. The lower trace shows the wavelength, the upper trace the corresponding absorption signal. A linear scan sweeps the laser wavelength across two absorption lines. Thereafter, the wavelength is tuned in discrete steps to the first resonance, an “off-line” value, the second resonance and to the start of the scan range.

Specifications	
Design wavelength	400 .. 1100 nm (standard version), 1100 .. 1700 nm (IR version)
Useable wavelength range	approx. +/-50 nm around design wavelength
Input beam	SM/PM fiber, minimum power 20 .. 100 µW (wavelength dependent)
Error signal generation	Up to 1 MHz bandwidth
Relative frequency resolution	1 MHz typ., customized version with higher resolution on request
Long-term frequency stability	Better than 20 MHz (3 hours, laboratory environment)
Arbitrary wavelength locking	Possible, precision typ. 1 MHz, no grid!
Computer interfaces	RS 232 and USB 2.0
Housing dimensions	iScan head 80 x 80 x 114 mm³ (H x W x D), control rack 134 x 300 x 445 mm³
Patented technology	US 6,178,002

*In a laboratory environment. Can be significantly improved with reference spectra, e.g. using the CoSy module (see page 62).