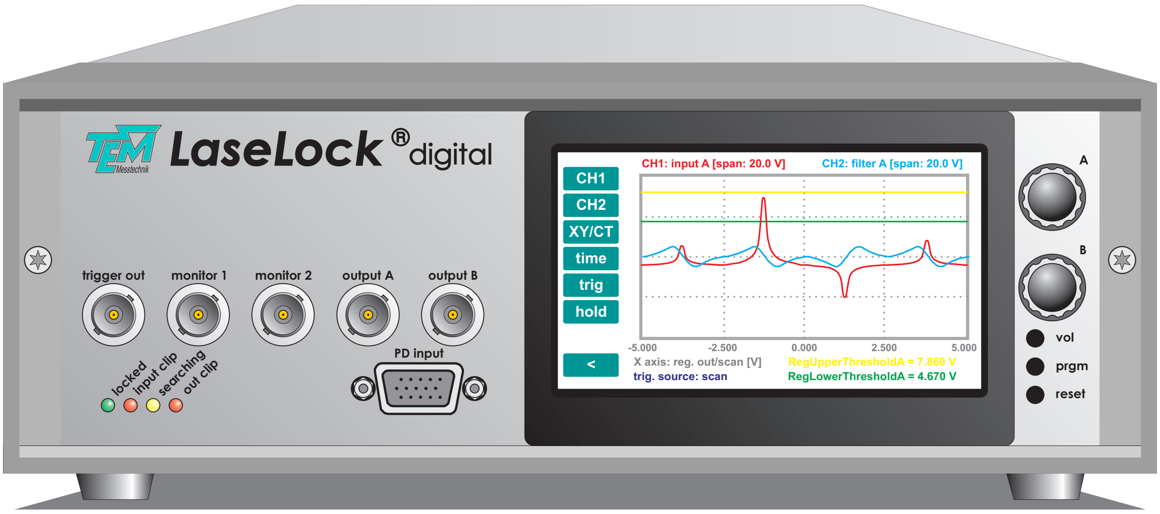
LaseLock Manual

TEM Messtechnik GmbH

April 27, 2023



TEM Messtechnik GmbH
Grosser Hillen 38
D-30559 Hannover
Tel: +49 (0)511 51 08 96 -31
Fax: +49 (0)511 51 08 96 -38
E-mail: `mailto:info@TEM-messtechnik.de`
URL: `http://www.TEM-Messtechnik.de`

Contents

1 Product description

1.1 Principle of operation

By the help of *LaseLock* electronics, tunable lasers (like diode lasers, dye lasers or Ti:Sapphire lasers) can be stabilized in their frequency. For this, particularly optical resonators (Fabry-Prot cavities) and atomic absorption or fluorescence lines serve as references. Vice versa, also optical resonators can be stabilized towards a given laser frequency by means of mechanical actuators (e.g. piezo actuators, stepping motors). Two different methods can be applied: Side-of-fringe stabilization or top-of-fringe stabilization. Moreover, *LaseLock* can be adapted to many other regulation tasks in the laboratory.

1.1.1 Side-of-fringe stabilization

Side-of-fringe stabilization is used if a discriminator signal can be derived directly from the measurement signal, e.g. by subtraction of a fixed set value.

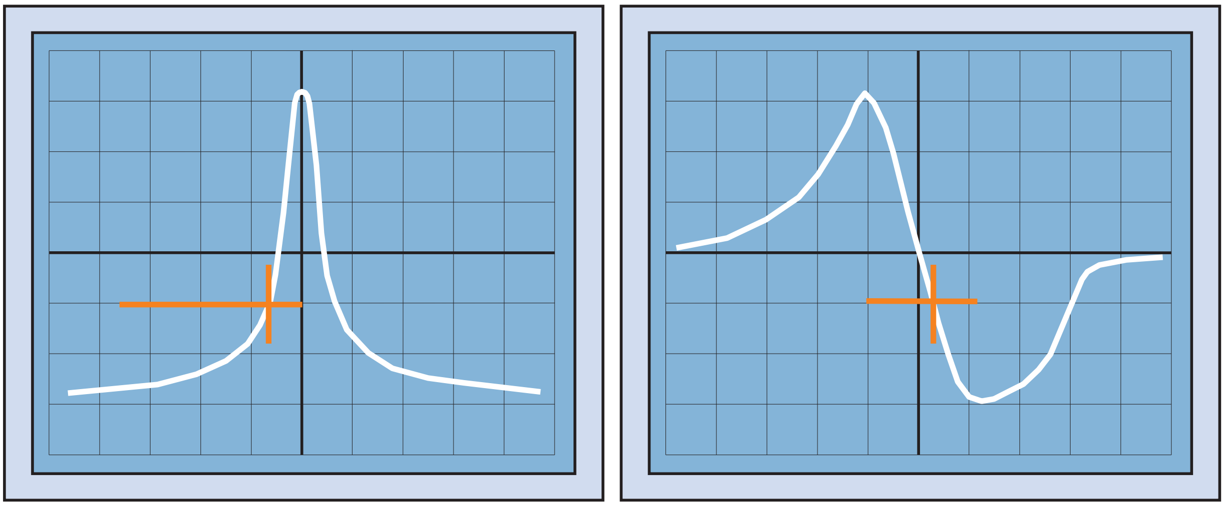


Figure 1: Side-of-fringe stabilization

1.1.2 Top-of-fringe stabilization

In contrast, top-of-fringe stabilization uses a modulation technique and phase-synchronous detection (PSD). For this, the laser frequency (or another physical dimension like the resonator length) is modulated ("dithered"), a detector signal is multiplied ("mixed") with the modulation signal, and the multiplied signal is averaged by a low pass filter. The resulting "lock-in" signal represents the first derivative of the measured signal with respect to the laser frequency (or the respective varied physical dimension). Even higher order derivatives can be generated by mixing with multiples of the modulation frequency. This can be used directly for physical examinations, because in most cases it contains less disturbing signal parts (noise, offsets) than the directly measured signal does. The zero-crossing of the derivative represents a maximum (or minimum) of the detected structure. For stabilization of a laser or resonator towards such an extremum, the "lock-in" signal is processed by a regulator, which generates a suitable control signal that is fed back (either directly, or for piezo actuators via a high-voltage amplifier) to the frequency-determining element of the laser (or resonator). In this way the control loop is closed and the laser (or resonator) is locked actively to the maximum (or minimum).

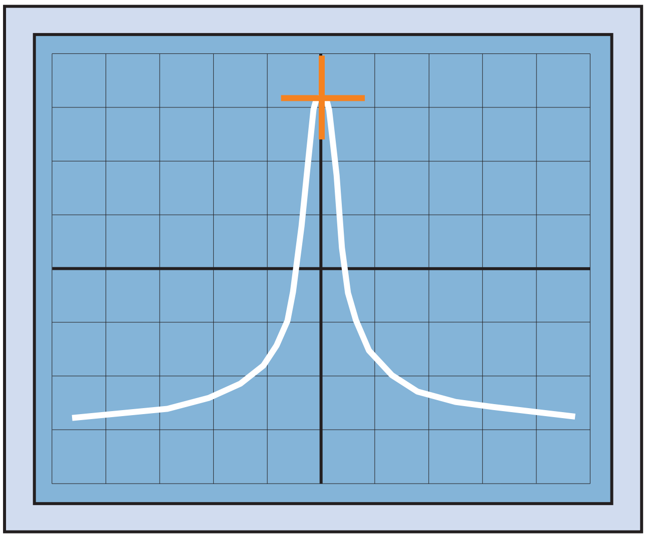


Figure 2: Top-of-fringe stabilization

1.2 Functional components

LaseLockcombines all components required or beneficial for this purpose in a user-friendly compact device. It contains the following sections (refer to Figure 3):

- Input section (linear combination of four input signals)
- sine generator (in addition cosine generator for quadrature detection)
- phase-synchronous detection, "lock-in" amplifier with adjustable phase and selectable low pass filter
- two independent PID regulators, adapted especially to resonant systems like piezo driven optical components
- scan generator, for adjustment or supervision of the physical system
- logic section for automatic recognition of valid or invalid lock points
- optional: drivers, on choice as high-voltage amplifier for piezo actuators, as power amplifier for magnetic or thermic actuators, current / temperature controllers for diode lasers, or stepping motor drivers

The *LaseLock* block diagram is shown in Figure 3, which gives a first overview on the function blocks, the relation of the function blocks to each other, the switching options, as well as the inputs and outputs of *LaseLock*.

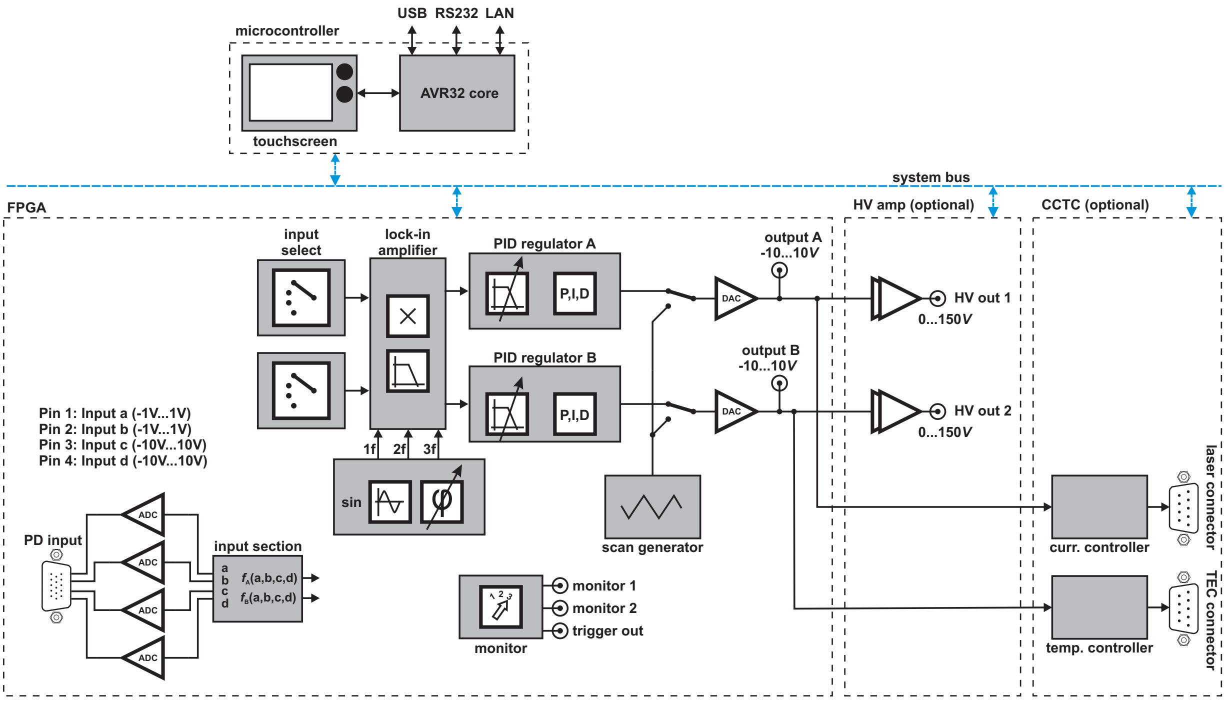


Figure 3: Schematic block diagram of *LaseLock* device

2 Safety Instructions

Before operating the *LaseLock*, please read this user guide carefully in order to avoid any damage of the device or connected equipment as well as any injury to persons.

CAUTION! The *LaseLock* device is intended for laboratory use only. The *LaseLock* device should be operated by trained personnel.

CAUTION! The *LaseLock* device is used with lasers emitting visible or invisible radiation. Do not stare into the laser beam! Take precautions to avoid exposure of direct or reflected laser radiation.

CAUTION! The user is responsible for keeping the legal rules concerning laser safety that apply in their country. In Germany, this is the "Unfallverhtungsvorschrift BGV B2" of the "Berufsgenossenschaft der Feinmechanik und Elektrotechnik".

CAUTION! Use only the supplied power adapter and plugs or the corresponding ones for your country, as only this guarantees safe operation and grounding of the device.

CAUTION! The *LaseLock* is intended for indoor operation with a temperature range of $+10°C$ to $+40°C$. Do not subject to heat, direct sunlight or the influence of other electric devices. Protect from humidity, dust, aggressive liquids and vapors.

CAUTION! The *LaseLock* should be opened by trained technical personnel only. Before opening the housing, the device must be disconnected from the supply voltage, for example by pulling the power plug.
Please keep this manual within easy reach to refer to if needed. Give your *LaseLock* to third parties only with this manual.

3 Brief description of the control elements

3.1 Front panel elements

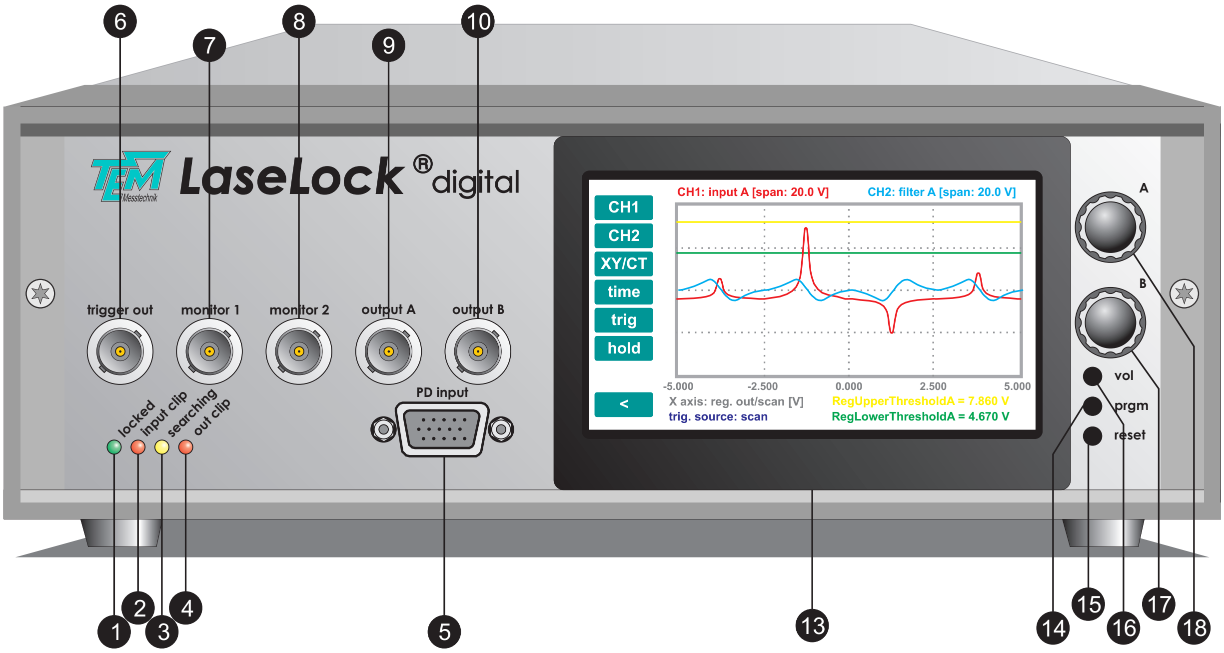


Figure 4: Front panel elements

Nr.	Description
1	LED “locked”. Turns on whenever the error signal of all enabled regulators is within a small range
2	LED “input clip”. Indicates a large input signal (above +0.9 V or below -0.9V on input a, b or above +9 V or below -9V on input c, d)
3	LED “searching”. Turns on when one of the regulators is searching for a valid lock point
4	LED “out clip”. Turns on when one of the regulators reaches the limit of the output range
5	“PD input” HD15 Socket. Feedback measurement input
6	“trigger out” BNC plug
7	“monitor 1” BNC plug. Can be used for observation of internal signals
8	“monitor 2” BNC plug. Can be used for observation of internal signals
9	“output A” BNC plug. Regulator output signal (low voltage: -10V...+10V). For HV amp output see rear side
10	output B BNC plug. Regulator output signal (low voltage: -10V...+10V). For HV amp output see rear side.
11	4.3” TFT touch screen
12	Programmer button. Only used for flashing firmware on the microcontroller.
13	Reset button. Resets the microcontroller.
14	Loudspeaker volume potentiometer
15	Rotary encoder B
16	Rotary encoder A

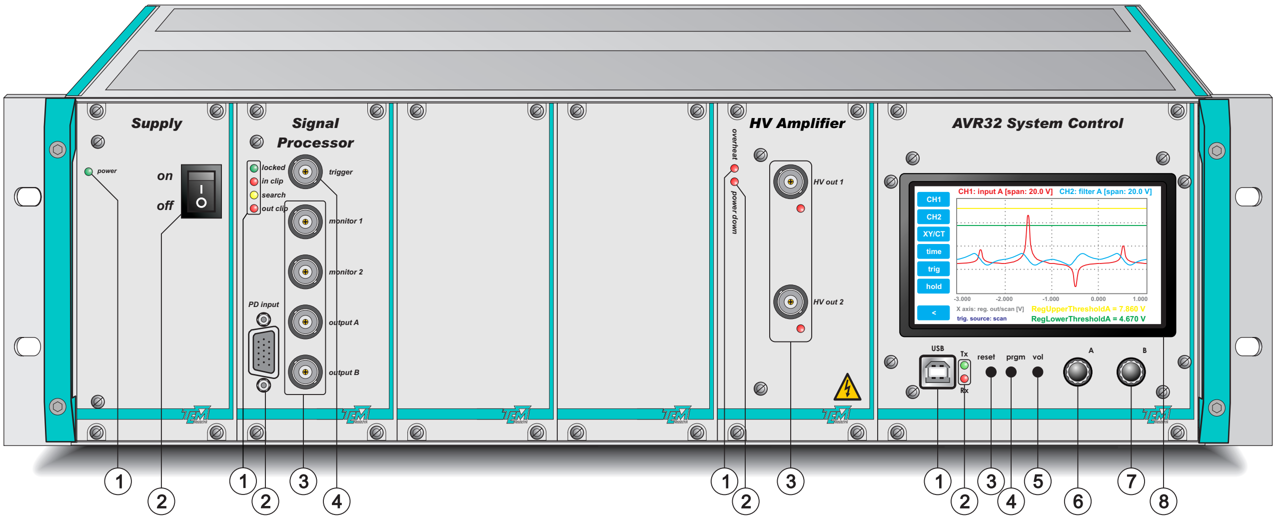


Figure 5: Front panel elements 19" rack case

Nr.	Description
Module: "Supply"	
-	Primary power switch and fuse holder (on the rear side)
1	Power on LED
2	Secondary power switch
Module: "Signal Processor"	
1	Status indicator LEDs: • LED "locked". Turns on whenever the error signal of all enabled regulators is within a small range • LED "input clip". Indicates a large input signal (above +0.9 V or below -0.9V on input a, b or above +9 V or below -9V on input c, d) • LED "searching". Turns on when one of the regulators is searching for a valid lock point • LED "out clip". Turns on when one of the regulators reaches the limit of the output range
2	"PD input" HD15 Socket. Feedback measurement input
3	Output BNC plugs: • "monitor 1" BNC plug. Can be used for observation of internal signals. • "monitor 2" BNC plug. Can be used for observation of internal signals. • "output A" BNC plug. Regulator output signal (low voltage: -10V...+10V). For HV amp output see module "HV Amplifier". • output B BNC plug. Regulator output signal (low voltage: -10V...+10V). For HV amp output see module "HV Amplifier".
4	"trigger out" BNC plug
Module: "HV Amplifier (optional)"	
1	"overheat" red LED: if the HV amp stage is overheated, this red LED is on, and the output voltage is switched off
2	"power down" red LED: this LED is on, when the amplifier voltage is disabled due to overheating or overcurrent
3	HV output BNC plugs (HV out 1 and HV out 2) for e.g. piezo actuators

Module: "AVR32 System Control"	
1	USB connector
2	USB data transmit (green) / USB data receive (red) LEDs
3	Reset button. Resets the microcontroller.
4	Programmer button. Only used for flashing firmware on the microcontroller.
5	Loudspeaker volume potentiometer
6	Rotary encoder A
7	Rotary encoder B
8	4.3" TFT touch screen

3.2 Rear panel elements

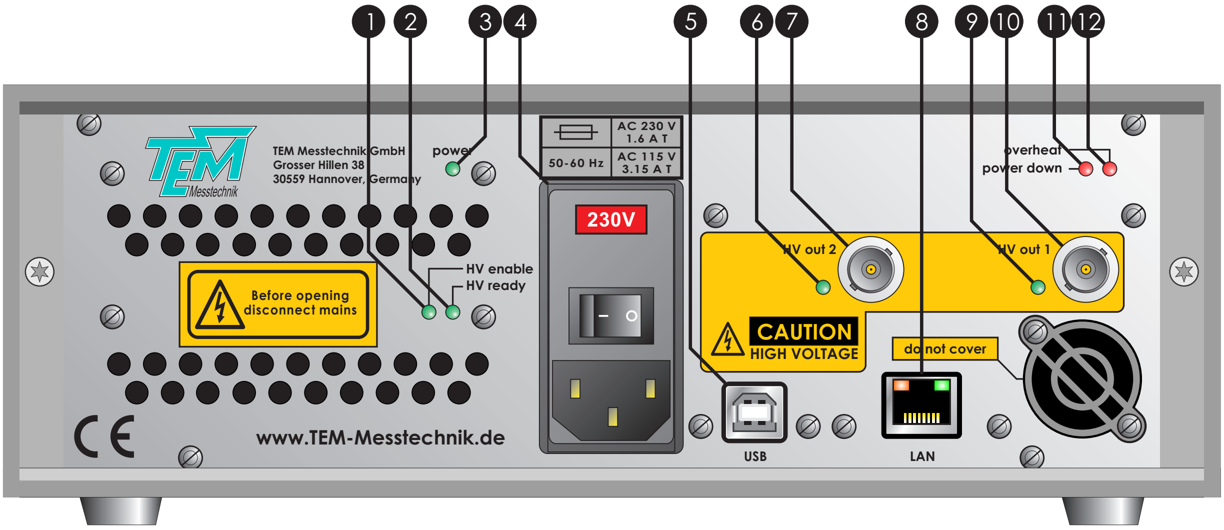


Figure 6: Rear panel elements (standard and HV version)

Nr.	Description
1	"HV enable" green LED: The voltage from the HV supply has been applied to the amplifier stage
2	"HV ready" green LED: HV supply module is powered on
3	"power" green LED: power on indicator
4	power supply plug with power switch and fuse holder
5	USB connector
6	(only with HV option) bicolor LED: output voltage indicator for HV out 2
7	(only with HV option) high voltage output channel 2 BNC jack (corresponding to output B signal)
8	(optional) LAN RJ-45 connector
9	(only with HV option) bicolor LED: output voltage indicator for HV out 1
10	(only with HV option) high voltage output channel 1 BNC jack (corresponding to output A signal)
11	"power down" red LED: this LED is on, when the amplifier voltage is disabled due to overheating or overcurrent
12	"overheat" red LED: if the HV amp stage is overheated, this red LED is on, and the output voltage is switched off

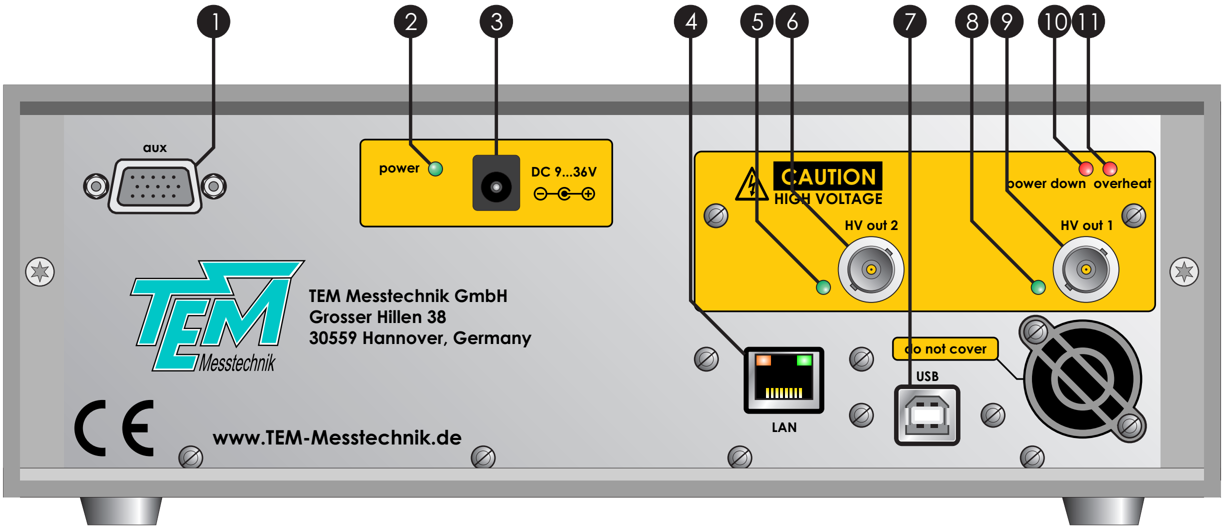


Figure 7: Rear panel elements (DC12V version)

Nr.	Description
1	"aux" HD15 Socket. Auxiliary connector for special functions.
2	"power" green LED: power on indicator
3	5.5 x 2.5 mm DC power supply plug (voltage range 9...36 V)
4	USB connector
5	(only with HV option) bicolor LED: output voltage indicator for HV out 2
6	(only with HV option) high voltage output channel 2 BNC jack (corresponding to output B signal)
7	(optional) LAN RJ-45 connector
8	(only with HV option) bicolor LED: output voltage indicator for HV out 1
9	(only with HV option) high voltage output channel 1 BNC jack (corresponding to output A signal)
10	"power down" red LED: this LED is on, when the amplifier voltage is disabled due to overheating or overcurrent
11	"overheat" red LED: if the HV amp stage is overheated, this red LED is on, and the output voltage is switched off

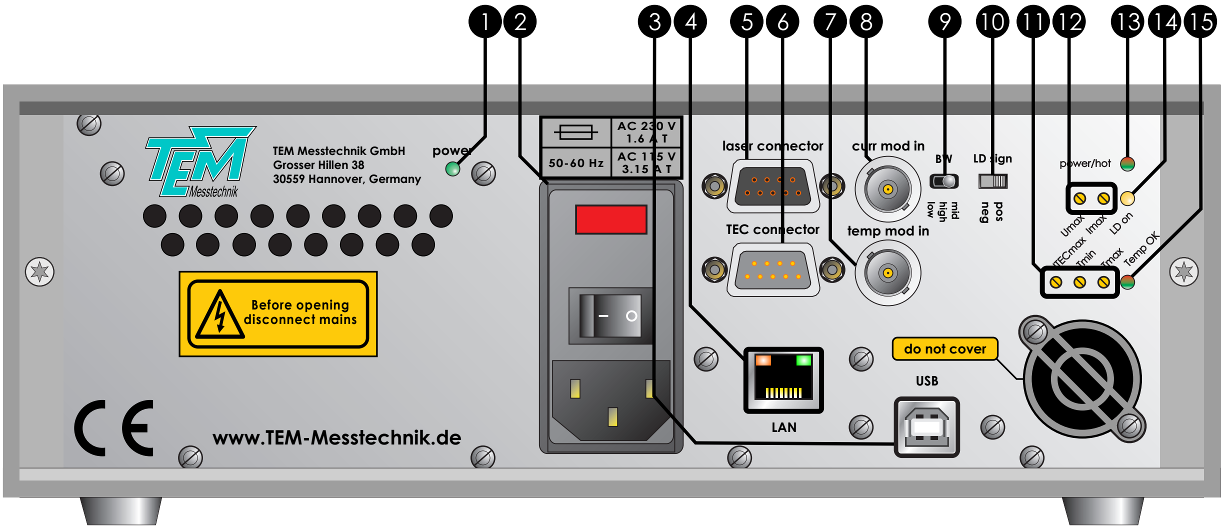


Figure 8: Rear panel elements (CCTC-DFB version)

Nr.	Description
1	"power" green LED: power on indicator
2	power supply plug with power switch and fuse holder
3	USB connector
4	(optional) LAN RJ-45 connector
5	connector for laser diode (compatible with the LasCon protection module)
6	connector for TEC (compatible with the TempCon sensor module)
7	temperature modulation input
8	current modulation input
9	setting of a low pass filter at the output of the current source
10	Polarity of the laser diode. The setting is accepted upon power-up. Changing this switch during operation will have no effect.
11	• "ITECmax:" Adjustment of the maximum TEC current • "Tmin:" Adjustment of the minimum laser temperature • "Tmax:" Adjustment of the maxmum laser temperature
12	• "Umax:" Adjustment of the maximum laser voltage • "Imax:" Adjustment of the maximum laser current
13	"power/hot" duo LED: is green module is ready (not in standby mode). LED is red if maximum heatsink temperature is exceeded. If so, both laser current and temperature control are disabled.
14	"LD on" yellow LED: is on when laser is swiched on
15	"Temp OK" duo LED: is green if set temperature is reached. LED is red if temperature is not reached.

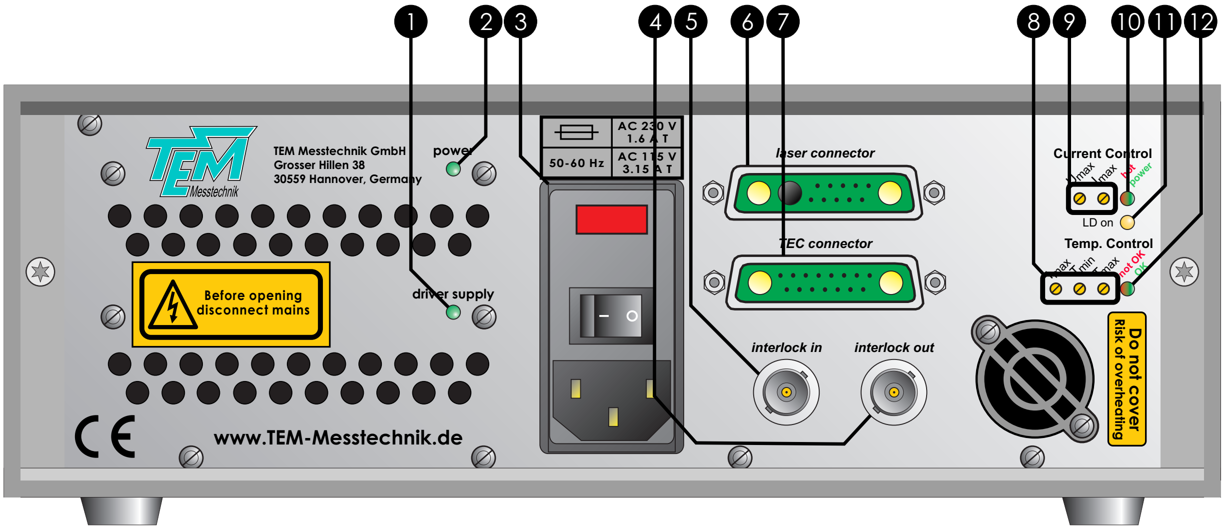


Figure 9: Rear panel elements (CCTC-12A version)

Nr.	Description
1	"driver supply" green LED: power on indicator for the driver supply module
2	"power" green LED: power on indicator
3	power supply plug with power switch and fuse holder
4	"interlock out" BNC plug: error output to further system components
5	"interlock in" BNC plug: error input for e.g. door contact
6	connector for laser diode (compatible with the LasCon protection module)
7	connector for TEC (compatible with the TempCon sensor module)
8	• "ITECmax:" Adjustment of the maximum TEC current • "Tmin:" Adjustment of the minimum laser temperature • "Tmax:" Adjustment of the maxmum laser temperature
9	• "Umax:" Adjustment of the maximum laser voltage • "Imax:" Adjustment of the maximum laser current
10	"power/hot" duo LED: is green module is ready (not in standby mode). LED is red if maximum heatsink temperature is exceeded. If so, both laser current and temperature control are disabled.
11	"LD on" yellow LED: is on when laser is swiched on
12	"Temp OK/not OK" duo LED: is green if set temperature is reached. LED is red if temperature is not reached.

3.3 Touch screen

3.3.1 Home screen

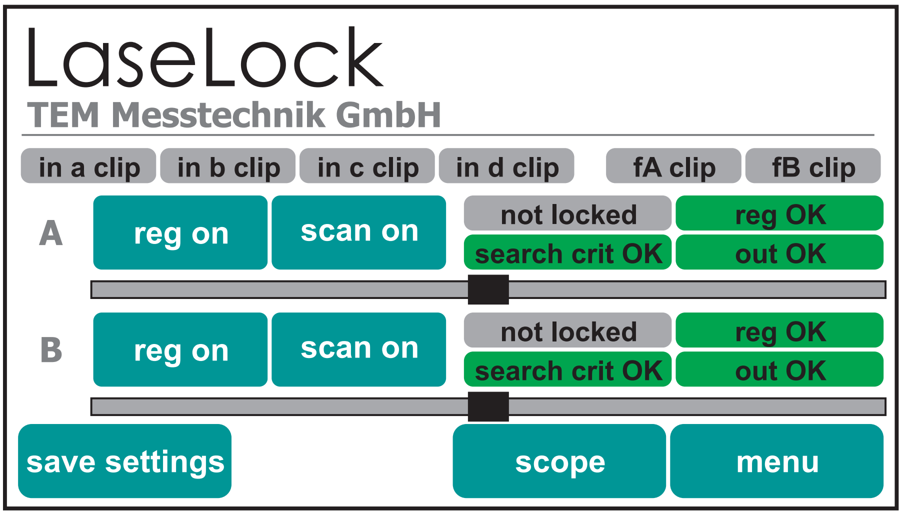


Figure 10: Home screen

The home screen of the device is shown in Figure 10 which allows quick access to important parameters and status flags.

- Six input status flags indicate the following internal states:
  - a clip, b clip, c clip, d clip - one of the input signals is out of range
  - fA clip, fB clip - one of the normalized input signals is out of range generator
- Four touch buttons (two for each regulator) allow access to following parameters:
  - reg on - enabling/disabling the regulator
  - scan on - coupling/decoupling the regulator output to the scan signal generator
- Eight status flags (four for each regulator) indicate the following internal states:
  - not locked / locked - the error signal is within small range around zero and the input signal is between the threshold values
  - reg OK / hold - the regulator was stopped because one of the criteria was not fulfilled
  - search crit OK / searching - B regulator is performing a search scan
  - out OK / out clip - regulator output voltage is at its limit
- two slide bars (one for each regulator) represents the actual position of the regulator output withing the output range
- "save settings" button allows quick saving of the parameters.
- "scope" button enters the scope screen.
- "menu" button enters the device menu and allows access to all parameters.

3.3.2 Scope screen

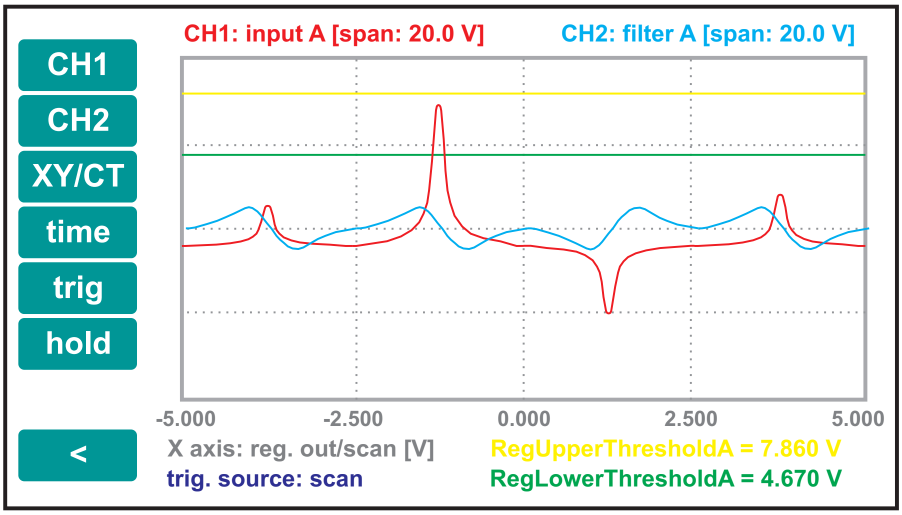


Figure 11: Scope screen

Figure 11 shows the scope screen. This function allows the observation of the input signal versus the scan signal or the time. By pressing inside the scope frame you enters the parameter menu where you can choose parameters which you want to adjust during the observation of the signal. The parameters are shown on the bottom of the screen. You can use both wheels to adjust the selected parameters (wheel A for the upper parameter; wheel B for the lower parameter). Following signals can be chosen as Y signal for the scope:

- fA(a,b,c,d) - normalized signal of input section A
- Filter A out - output signal from the first filter which enters the regulator section A
- Error A - error signal for regulator A
- fB(a,b,c,d) - (normalized signal of input section B)
- Filter B out - (output signal from the first filter which enters the regulator section B)
- Error B - error signal for regulator B

The buttons on the left side on the scope screen controls the scope parameters:

- CH1 - input signal and scale factor for channel 1
- CH2 - input signal and scale factor for channel 2
- XY/CT - switch between the XY and time based mode (in XY-mode the X signal always represents the regulator output (incl. scan) corresponding to the input signal on channel 1)
- time - time base in CT mode
- trig - trigger source and level adjustment
- hold - freezes the scope

3.3.3 Display settings

To adjust display settings like LED backlight brightness or screensaver settings go to (*menu* → *miscellaneous* → *display settings*)

Backlight brightness
The brightness of the LED backlight can be adjusted in 10 steps e.g. to avoid bright display illumination in dark rooms.

Screensaver
When displaying a static image for long periods of time the LCD displays can create a permanent ghost-like image. A static picture burns into the display and degrades the image quality. To prevent this burn-in effect the display becomes white after an adjustable delay time. You can return to the menu by touching the display.

4 Diode Laser Driver (DLD)

4.1 General

The DLD (Current Control and Temperature Control) series are universal laser driver modules for use with TEM Messtechnik's laser control systems. They provide a constant current source and a temperature regulator with remote control of their operational parameters.

4.2 Versions

DLD-DFB
The DFB version of the DLD has been optimized for use with distributed feedback laser diodes. Given a high stability of laser temperature and current, as ensured by use of the DLD-DFB module, the optical frequency of the DFB laser diode is arbitrarily tunable in a large range, which is usually between some hundreds up to 1500 GHz. Thus, the DLD-DFB applies well for:

- High resolution spectroscopy
- Frequency scanning or phase shifting interferometry
- Generation of continuous-wave terahertz radiation by mixing of two laser fields.

4.3 Laser protection system

The DLD is equipped with an elaborated laser protection system, which prevents damage in case of operating error or malfunction of the optical set-up. This is especially helpful under experimental laboratory conditions.

4.4 Getting started

4.4.1 Set-up

The DLD module is integrated in the *LaseLock* device. For set-up of the control unit, please refer to the corresponding chapter.

4.4.2 Adjustment of maximum/minimum ratings

Before connecting the laser for the first time, check all min/max parameters: Switch on the mains power of the *LaseLock* device. When the uC module is ready, read out the following parameters: Imax, Umax, Tmax, Tmin, ITECmax. Make sure that the values comply with the maximum ratings of your laser diode. You may alter these values by turning the corresponding trim pots on the rear panel (desktop case) or front panel (19" rack case with front monted modules), resp..

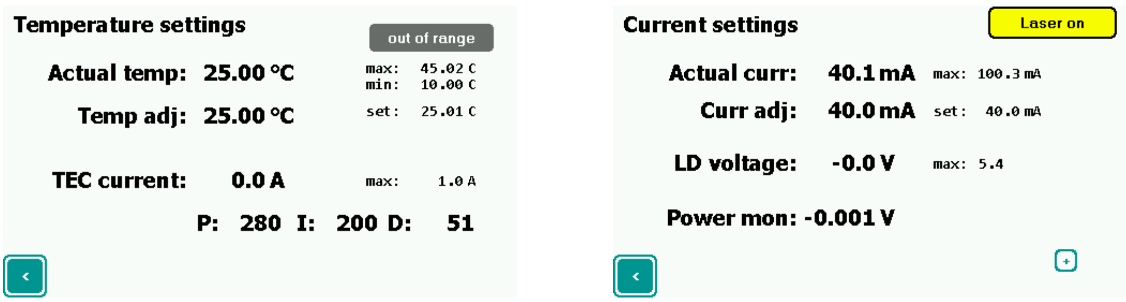


Figure 12: DLD menu on the TFT touch panel

You may also preset the values for temperature and/or laser current by changing the parameters Tset or Iset, respectively. However, please note that these values are added to signals applied to the external and internal modulation lines. As a result, the final values for temperature/ current may differ from Tset/Iset. In any case, the trim pot min/max values will never be exceeded.

4.4.3 Connections

Before connecting the laser, switch off the *LaseLock* device. Then connect the Sub-D connectors laser diode and TEC with the corresponding connectors of the laser according to the following pinouts. Please note that in this case the laser operation is disabled unless at least 1mA is drawn from the +/-8V supply. An interruption of the current drawn from the +/-8 V supply will switch off the laser immediately.

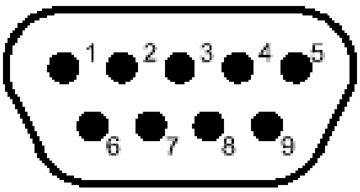


Figure 13: Sub-D-9 "TEC connector" pinout

1	+15V supply
2	reference ground (optional: NTC-)
3	reference voltage, +10V (optional: NTC +)
4, 6	TEC +
5, 8	TEC -
7	- 15V supply
9	temperature sensor voltage

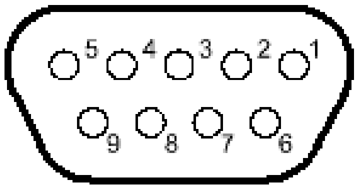


Figure 14: Sub-D-9 "laser connector" pinout

1	+8 V, 100 mA supply
2	photo diode cathode
3	laser diode ground
4	photo diode anode
5	-8 V, 100 mA supply
6	laser diode voltage sensing (cathode)
7, 8	laser diode anode/cathode
9	laser diode voltage sensing (anode)

LasCon open PCBs
The DLD is prepared for use with the LasCon laser protection circuit. The latter is to be located inside the laser case. As long as it is not connected to the DLD driver, a relais on the LasCon board short-circuits the laser diode, thus preventing damage by electrostatic discharge. The relais contact is opened by the +/-8 V supply voltage on the Sub-D laser plug, as soon as the *LaseLock* device is powered up. It is therefore essential to switch off the *LaseLock* device before connecting the laser diode!

When using the circuit boards LasCon and TempCon follow 16 and 15 for wiring the laser diode. Then connect the Sub-D connectors laser diode and TEC with the corresponding connectors of the laser.

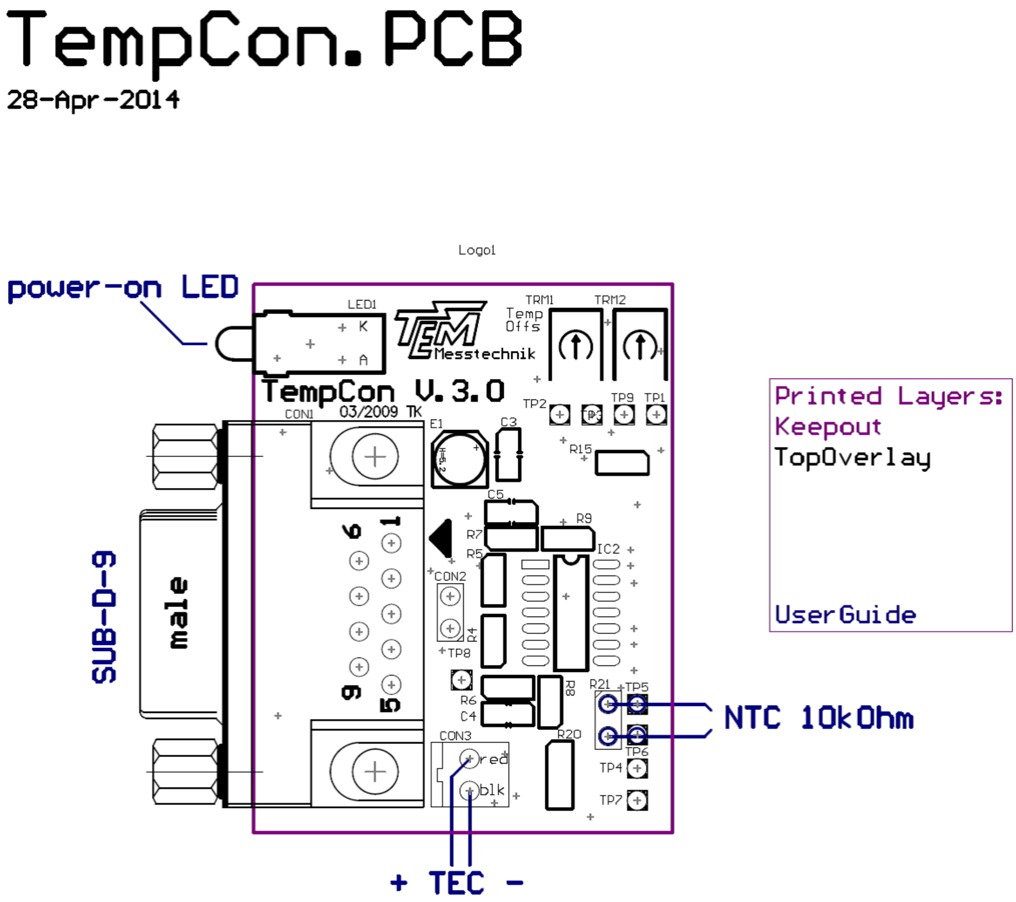


Figure 15: Temperature sensor amplifier board

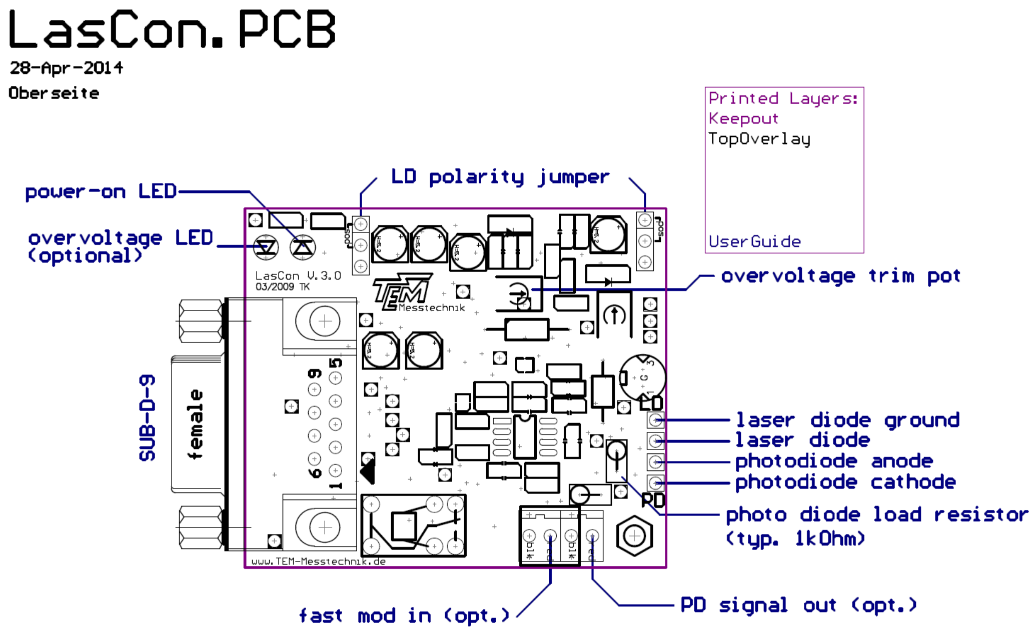


Figure 16: Laser modulation board

CAUTION! Always fasten the screws of the Sub-D connectors.

4.4.4 Power-up

Finally, switch on the *LaseLock* device again. In general, the DLD will startup with the temperature controller switched on but with the laser switched off.

However, customer specific firmware versions may switch on the laser automatically after the uC boot procedure! Before switching the laser on, we recommend to carefully read the following chapters concerning the software and hardware protection scheme.

4.5 "Laser on" procedure and current adjustment

4.5.1 Power-up check

For powering-up the laser diode, the corresponding microcontroller variable LaserOnOff must be set to a value of 1. This is done either by pressing the corresponding button on the uC front panel, or by remote control. I.e. sending the phrase "LaserOnOff= 1" via the interface. If the laser is not yet on, the uC will check several preconditions, among these:

- Laser connected? At least 1mA must be drawn from the +/-8V supply to fulfill this condition.
- Door contact closed, error input at TTL low level? The door contact at the rear side of the case must be closed. No other module in the system may send an error signal to this module via the backplane.

The laser diode be powered up only if these conditions are met. Otherwise, the variable LaserOnOff is reset to 0, and the uC will send an ERROR message to the PC.

4.5.2 Laser current adjustment

The laser current is adjusted by the parameter Ioffset. Please note that this value is altered by modulation signals, which may be applied via front panel connectors or via the backplane. In any case, the final laser current is limited to the maximum (adjustable via the trim pot on the front panel) within the driver hardware.

4.6 Hardware laser protection (interlock) circuit

4.6.1 Temperature surveillance

In order to prevent damage to the laser diode due to over-/undertemperature, one can enable a temperature-dependent shut-down. For this purpose, the jumper JP503 on the DLD module must set (closed). Then, if the actual temperature (variable Tact) exceeds either the Tmax or the Tmin limit, the laser diode is switched off immediately.

4.6.2 Module overtemperature protection

The temperature of the heatsink on the CCTC module is controlled. If a fan is installed, the fan speed is controlled by the heatsink temperature. The heatsink temperature can be read out through the LCD or by a remote PC, sending the phrase "Theatsink=". If the heatsink temperature exceeds $90°C$, the module is set to its stand-by mode, i.e. disabling both laser diode temperature and current control.

5 LaseLock Getting started

5.1 Overview of Getting started

The following sections describe how to take *LaseLock* into operation from the beginning, step by step. These chapters can be used for becoming acquainted with *LaseLock*, as well as for function testing of the device. It is strongly recommended to read through chapter 3 on page 9 first. A detailed description will follow later in this manual. Please start with the device disconnected and switched off.

5.2 Installation of the PC visualization software “Kangoo”

Even though the *LaseLock* device can work completely as a stand-alone device, it is very helpful and strongly recommended to use “Kangoo” for visualization and set up of parameters.

Please refer to the separate chapter on installation of the Kangoo software to your computer.

5.3 Connection of the device to main power supply

Use the cables which came with the device. If you want to use cable extenders, please contact TEM about which cables can be used.

All TEM cases and racks have an IEC power socket at the rear. Use the delivered power cord (European, German, US) for connection to the main power supply. If country-specific cables are required use high quality power cords, fitting to the local power supply outlets.

IMPORTANT! Do not use dimmed or switching power supply lines (used in UPS [Uninterrupted Power Supply] units.) They may damage the transformers or the power supply circuits.

NOTE! The power supply automatically adapts to local main power supplies of 100...120 VAC, 220...240 VAC.

5.4 Switch the device on

1. Turn on the main switch on the rear side.
2. (19” rack case version only) Turn on the secondary power switch on the front side (module: “Supply”)
3. The device will be ready to use after a short acoustical signal.

5.5 Connection to PC

Please refer to the separate chapter on installation of the USB driver to your computer.

Connect the *LaseLock* to the PC by means of a standard USB (A-B) cable. (Please avoid cables longer than three meters, especially if strong electromagnetic fields are present in your environment). The device will appear as “TEM uC Virtual Com Port” in the device manager of your computer.

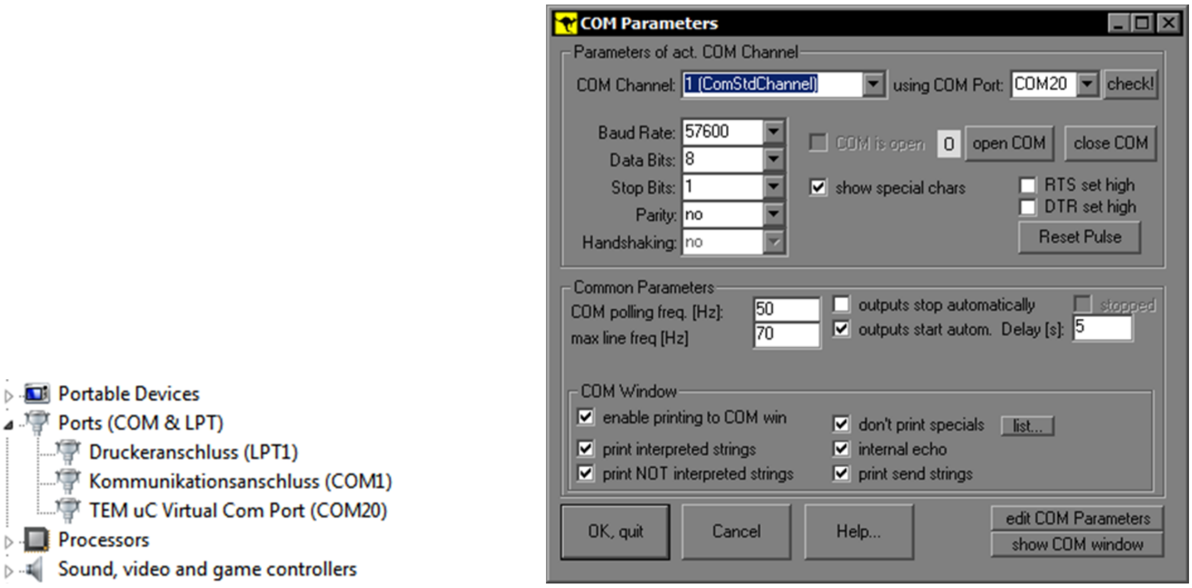


Figure 17: COM Port in the device manager (left) and corresponding COM port settings in Kangoo (right)

Start the Kangoo software and type F5 (or go to Communication → COM parameters) to open the interface dialog (compare fig. 32). Click to “check!” in the COM Parameters windows to search for available COM ports. The COM number of *LaseLock* should appear in the drop down list next to the button. The port settings like baud rate, data bits und parity settings are important for “real” COM ports e.g. RS-232. They will be ignored for USB connections.
To test the communication click ”show COM window” in the dialog. Click into the window named ”COM-Terminal” and press ‘ENTER‘. The device should answer with ”no command. . . ” (compare fig. 33).

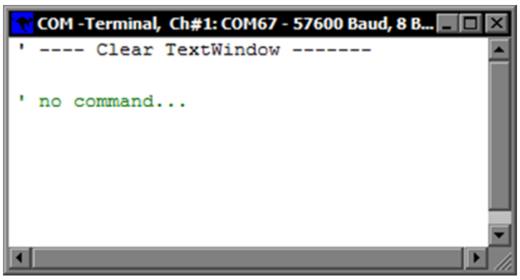


Figure 18: COM Terminal window

Later on, you may use this terminal window to learn how to control your device by simple ASCII commands. Just try and enter ”hello” followed by the ’ENTER’ key . . .

5.6 Taking the input section into operation (simple mode)

In the following sections, the setup of a simple control loop is described, using input a for measurement and output A for system control. If you are not sure about the initial settings of your *LaseLock*, just type the command "vardefault" in the PC terminal window or enter *menu* → *miscellaneous* → *restore factory settings*. This will reset all internal parameters to factory settings.

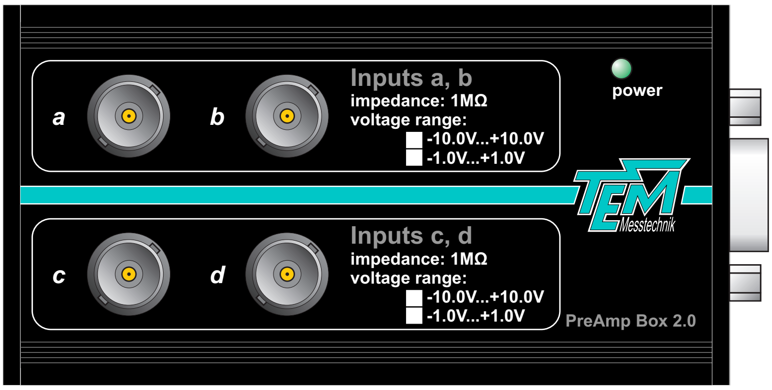


Figure 19: PreAmp Box for input signals

1. Connect the signal sources (e.g. Photo Diode Receiver) to the BNC connectors "input a...d" of the PreAmp Box shown in the Figure 19. The amplitude of the signals a and b should be in the range of one volt (-0.9...0.9V). The amplitude of the signals c and d should be in the range of ten volt (-9...9V). Signal amplitudes up to +/-15V will not damage the device. Unused inputs must be short-circuited to the shield or closed with a 50Ω resistor. All inputs have an input impedance of 1MΩ.

2. Connect an oscilloscope to the BNC jacks "monitor 1, 2" on the front panel. For convenience, you may connect the trigger input of your oscilloscope with the BNC jack "trigger out".

3. Choose the input signal for monitor line nr. 1 either by PC control (Kangoo) or by the touch panel menu: *menu* → *monitor* → *monitor1* → *input a raw*. Leave this menu by pressing "<".

4. Choose the and the output signal for monitor line nr. 2 in a similar way: *menu* → *monitor* → *monitor2* → *output A*.

5.7 Taking the output section and scan generator into operation

1. Connect your system (laser, Fabry-Pérot cavity, SHG ring cavity, ...) to the output BNC jack of the *LaseLock*. When using the HV amp option, you will find the amplified signals provided on separate BNC jacks on the rear side of *LaseLock*. Please check that your system complies with the output voltage range of *LaseLock*!

2. Choose an appropriate scan frequency for your system: *menu* → *scan settings* → *frequency*, then turn the knob. Remark: Turning the knob whilst keeping it pressed will change the decimal place. Leave this menu by pressing "<".

3. Switch on the scan generator for output A by pressing "couple to reg. A" in the scan settings screen. A triangular signal will now show up on the oscilloscope, representing the scanned output signal. Please note that the trigger signal is synchronous with the scan ramp.

4. The monitor channel 1 on the scope should now show the reaction of the scanned system (i.e. fringes from a Fabry-Pérot cavity). Please note that the signals on input a or b are displayed with a 10x amplification. If the input signal appears with to low amplitude, it should be amplified externally (i. e. before sent to the *LaseLock*).

5. Enter the *menu* → *scan settings* → *offset A* to adjust the output offset. This will shift up and down the scan ramp. By turning the wheel while it is pressed you can select the digit you want to change. The curser marks the actual digit which can be changed by the help of the wheel.

6. Enter the *menu* → *scan settings* → *width A* to adjust the output range. This will influence the scan amplitude. Please note that the scan range also defines the output voltage range that later on can be addressed by the regulator. It is displayed as percentage of the full output voltage range.

7. Check that the LED "input clip" on the front panel is not lit, i. e. all input signals are within their allowed range.

8. Now change the oscilloscope display to normalized signals: Set the monitor channel 1 to the combined and normalized input signal: *menu* → *monitor* → *monitor1* → *fA(a,b,c,d)*. Later in this manual we describe how to configure complicated arithmetic operations on the 4 input signals. Here, fA(a,b,c,d) is simply equal to input signal a: fA(a,b,c,d) = a. Set the monitor channel 2 to "Reg out A": *menu* → *monitor* → *monitor 2* → *Reg out A*. This will scale the output range to +/-10V on the oscilloscope, independent from the true output range. It is recommended to switch your scope to XY-Mode, as this will display the output signal in X and the input signal in Y direction.
   It will help you to play with "offset A" and "width A" as in 5. and 6., in order to get familiar with the display.

5.8 Taking the lock-in amplifier into operation

You may skip this section if you plan a side-of-fringe lock.

1. Set the monitor 1 to "Input filter A".

2. Check that the input signal on the oscilloscope is not distorted. Otherwise reduce the scan frequency or increase the cut-off frequency of the low pass filter in the input section: *menu* → *regulator A* → *input filter* → *cut off*.

3. Choose an appropriate dither (modulation) frequency for your system (*menu* → *regulator A* → *lock-in* → *dither. frequency*).

4. Increase the dither amplitude (*menu* → *regulator A* → *lock-in* → *dither. ampl.*), until the fringes on the oscilloscope broaden.

5. Switch to the demodulated signal (derivative) by choosing first harmonic demodulation (*menu → regulator A → lock-in → harmonic*, then adjust the parameter to "1").

6. Now, the derivative signal should show up as filtered signal on the oscilloscope. Please note that the time constant of the lock-in amplifier is determined by the cut off frequency of the input filter (see 2.).

7. Adjust the demodulation phase (*menu → regulator A → lock-in → lock-in phase*) then adjust the phase in a way that the lock-in signal gets its maximum amplitude.

8. Increase the input filter gain (*menu → regulator A → input filter → filter gain*) to get the derivative in the same voltage range as the input signal.

5.9 Taking the PID regulator into operation

1. Choose the error signal for display on the oscilloscope, i. e. set the monitor 1 to "Error A".

2. Adjust the parameter "Set Point" (*menu → regulator A → set point*) to the required regulation value. This value should be as near as possible to the middle of the scan/regulating area, i.e. in the center of the scan ramp.

3. Select the appropriate regulator sign (*menu → regulator A → sign → positive or negative*). When set to "positive" *LaseLock* will regulate to a positive edge of the error signal.

4. Stop the scan by pressing "scan" on the home screen or *menu → regulator A → scan on/off*. The scan will stop at the middle of the output range (0V on the oscilloscope).

5. Switch on the PID loop by pressing "reg A" on the home screen or *menu → regulator A → reg on/off*. However, the regulator will not do anything yet!

6. As a final step, increase the I coefficient (and after that, the P and the D), until you get a stable lock. Details for a good PID adjustment are given later in this manual: *menu → regulator A → PID settings → I gain (P gain, D gain)*.

5.10 Saving the settings

In order to keep the new settings you made, press "save settings" on the home screen before power down.

6 Detailed Description

6.1 Description of the functional blocks

6.1.1 Overview

The *LaseLock* block diagram is shown in Figure 20 which gives a first overview of the inputs and outputs of *LaseLock*.

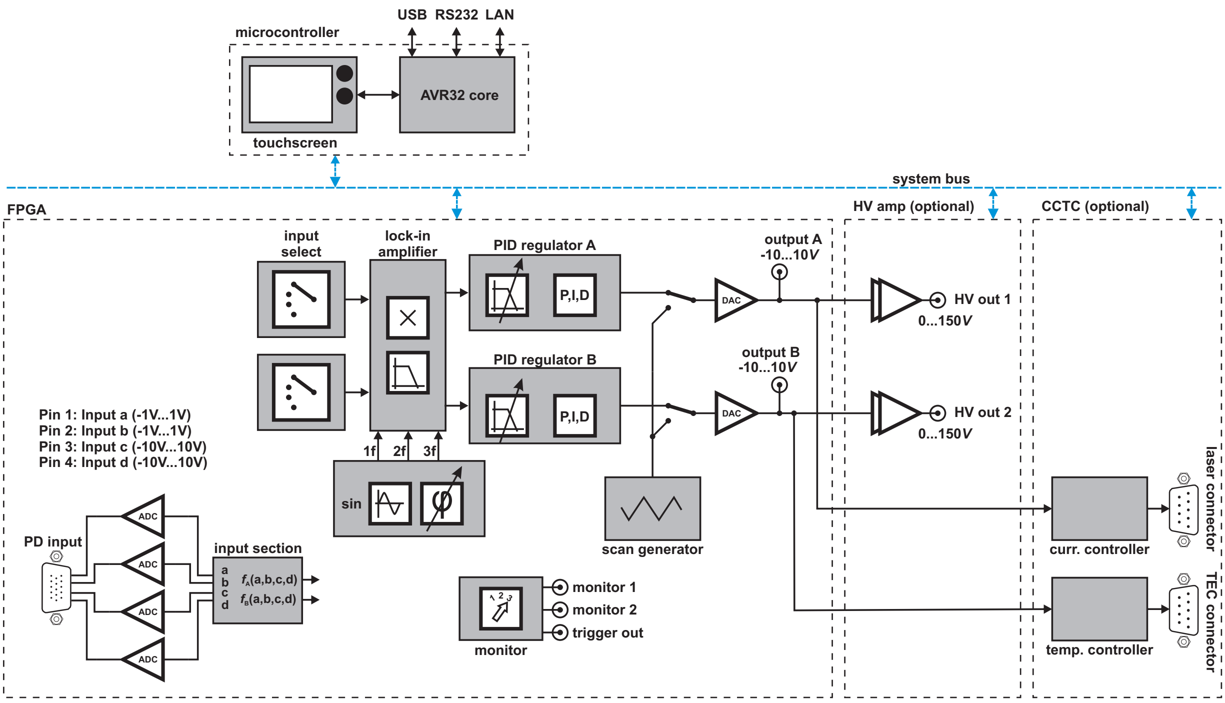


Figure 20: Schematic block diagram of *LaseLock* device

6.1.2 FPGA

The device contains an FPGA chip (field programmable gate array) connected to several ADCs and DACs for input and output of analog signals. The FPGA handles the entire signal processing, like:

- Input trimming and normalization
- Lock-in amplifier (phase-sensitive detection)
- Filtering
- PID control loop
- Monitor signal selection
- Logic operations
- Other arithmetical operations

6.1.3 Microcontroller

The 32-bit AVR microcontroller acts as an arbitrator between the user (PC or user interface) and the FPGA. The main purpose of the microcontroller is to receive the user defined data and, if required, convert it and send it to the FPGA over the system bus.

The microcontroller can communicate to a PC via USB. The configuration and control of the microcontroller is done from a PC by sending simple commands via the communication interface. For a description of the commands see chapter 8. The commands can be sent to the microcontroller either line-based with a universal communication tool (like HyperTerminal) or more user-friendly and application-oriented with the help of the *LaseLock* digital application software Kangoo running on a PC.

The microcontroller also manages the user interface with colored touchscreen on the front panel. All important parameters can be controlled using menu navigation.

6.1.4 Power switch and fuse holder

LaseLock is equipped with primary power switch on the rear side. Turning off this switch disconnects the device from the lines on the primary side. This ensures zero power consumption and is recommended when the *LaseLock* is out of use. Before connecting *LaseLock* to the mains, we recommend to switch off the device.

After making the connections, turn on the main switch on the rear side. Last, take your individual settings for the system parameters.

6.1.5 Input section

There are four input signals at the "PD input" HD15 connector input a (pin 1), input b (pin 2), input c (pin 3) and input d (pin 4). In the following, these signals are referred to as "raw" signals.

The offset value for each raw input signal can be trimmed independently by the parameters "InputOffsetA, ...B, ...C, ...D". In order to create a smoother input signal, a simple moving average can be applied to the raw input signals. The average degree is defined by the parameter "InputAverageA, ...B, ...C, ...D".

The actual regulator input signals are obtained from the raw signals by linear combination and/or division. This process is referred to as normalization. The normalization of the signals can be defined in two modes: simple mode and expert mode.

The user can define the combination by the help of following parameters:

- "InputNumModeA" (a, -a, a-b) sign and/or difference of the input signals
- "InputDenomModeA" (1, b, a+b, c) denominator for the normalization
- "InputBalanceA" (-0.8...0.8) balance value between input a and input b
- "InputNumModeB" (b, -b, c-d) sign and/or difference of the input signals

- "InputDenomModeB" (1, c, c+d, d) denominator for the normalization
- "InputBalanceB" (-0.8...0.8) balance value between input c and input d

To use the input section in the simple mode make sure that the parameter "InputSimpleModeA, ...B" is enabled.

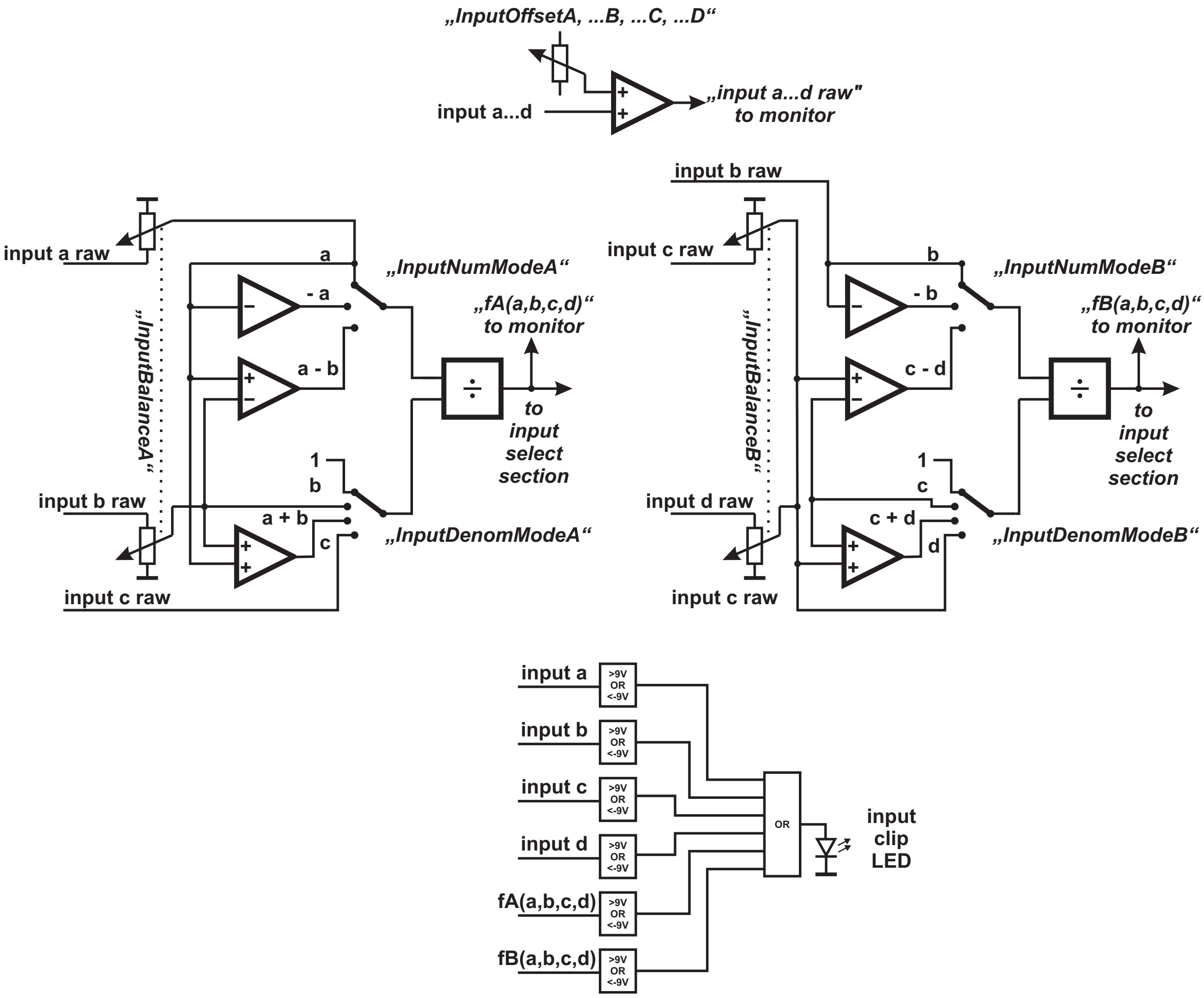


Figure 21: Block diagram of the input section (simple mode)

In the expert mode, the user can define the arbitrary combination of the four inputs by the following equation:

$$f(a,b,c,d) = G_{binary} \cdot \frac{G_{1N} \cdot a + G_{2N} \cdot b + G_{3N} \cdot c + G_{4N} \cdot d}{G_{0D} \cdot 1 + G_{1D} \cdot a + G_{2D} \cdot b + G_{3D} \cdot c + G_{4D} \cdot d} \tag{1}$$

The factors $G_{1...4N}$ ("InputCoeffNumA1...A4, B1...B4") for the numerator and $G_{1...4D}$ ("InputCoeffDenomA0...A4, B0...B4") for the denominator define the ratios for each input signal in the combination.

The factor G_{binary} ("InputDivisionGainA, ...B") defines the binary gain of the division, which determines the dynamic range of the division. It is necessary to adjust this correctly, because the signals are digitally processed and are therefore subject to a limited numerical resolution. Make sure to adjust G binary in a way that the normalized signal $f(a, b, c, d)$ is as large as possible without clipping.

To use the input section in the expert mode make sure that the parameter "InputSimpleModeA, ...B" is disabled.

6.1.6 Sample and hold

NOTE! The sample and hold is not a standard functionality and is only available on requenst. Please contact TEM for futher informations and upgrade.

To allow the regulator section to work with signals from pulsed lasers, a sample and hold stage can be applied. This stage detects the peak of the signal an holds it until the next pulse occurs.

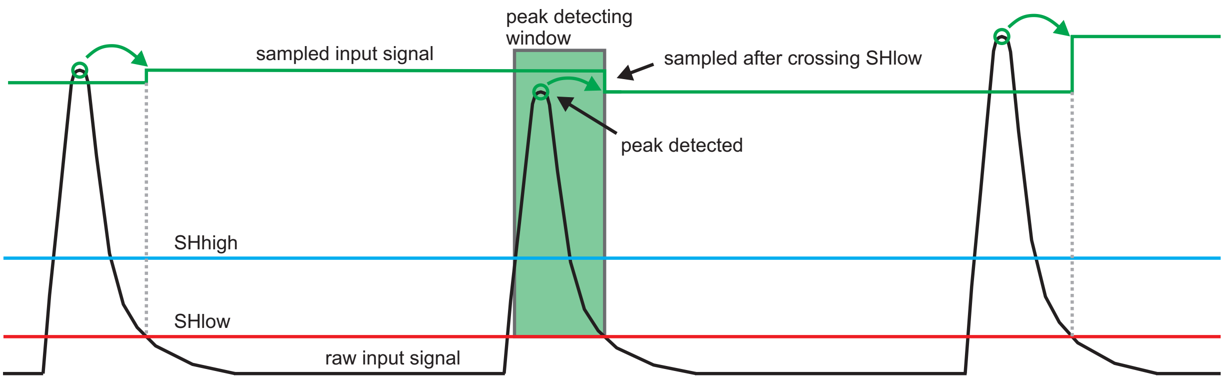


Figure 22: Principle of sample and hold stage

The peak detection starts when the input signal crosses the "SHhighA, ...B" threshold. The detected peak value will be adopted after crossing the "SHlowA, ...B" threshold. To avoid faulty peak detections, it is recommended to keep a small hysteresis windows between "SHhighA, ...B" and "SHlowA, ...B".

To provide a validity check of the sampled signal, the sample and hold stage generates a trigger status signal. This signal goes low, when no threshold value has been crossed for a time period defined by the parameter "SHTriggerTimeOut". In this case the servo loop is opened while regulator output is "frozen" at the current integrator value without starting a search scan.

6.1.7 Input select section

This section allows a selection of the input signal for the following processing path. You can choose between following signals:

- raw signal a...b
- fA,B(a,b,c,d)
- regulator output

The last choise allows the regulators to operate in serial mode.

6.1.8 Lock-in amplifier section

The lock-in amplifier section allows a phase-sensitive detection of the input signal and thus its differentiation with respect to a dithered parameter. This section consists of a quadrature (sine and cosine) signal generator for the dither signal, and two independent product mixers that perform the amplitude and phase detection.

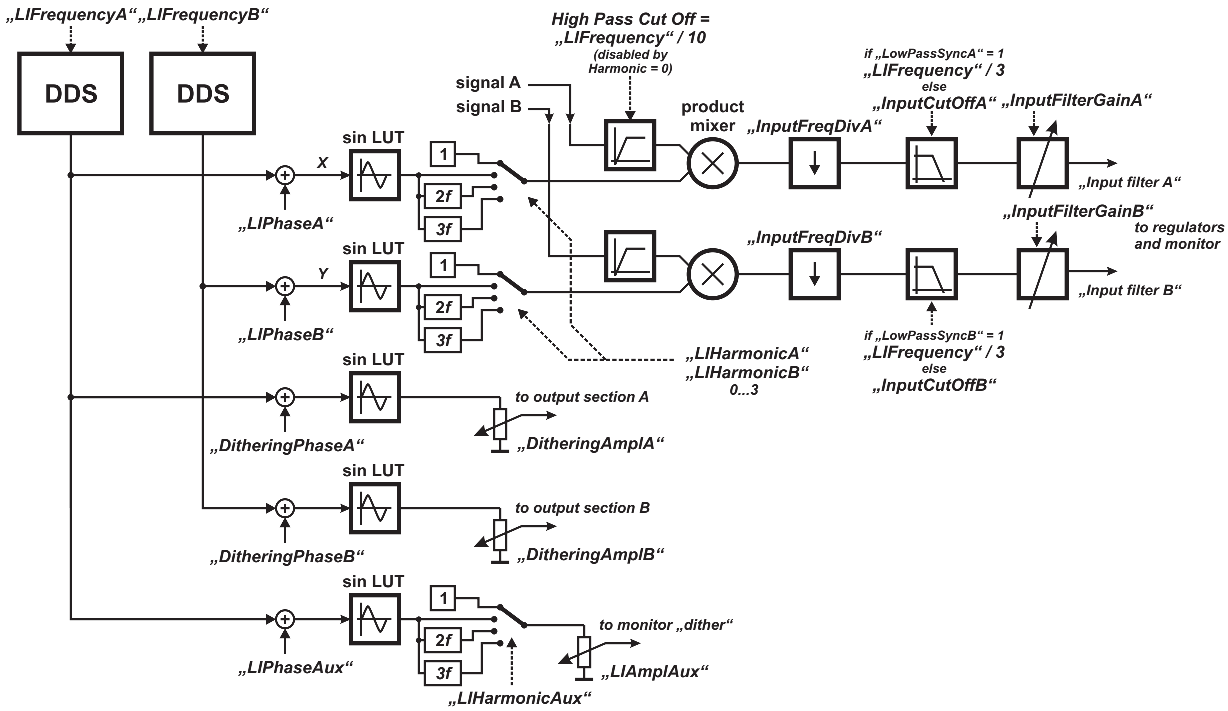


Figure 23: Block diagram of the lock-in amplifier section

The quadrature signal generators in combination with a pair of mixers offers the advantage that the phase shift of the input signal can be detected directly, so that the phase can be adjusted easier. Alternatively, the second mixer can calculate the derivative of an independent input signal.

In usual phase-sensitive detection, the high pass filtered input signal is multiplied with the dither signal and then low-pass filtered. However, *LaseLock* offers the possibility to multiply with the frequency-doubled or frequency-tripled dither signal by selecting the “LIHarmonicA, ...B” parameter. Setting this parameter to 0 disables the phase-sensitive detection, thus forwarding the unchanged input signal to the low-pass filter.

The parameter “DitheringAmplA, ...B” defines the amplitude of the dither signal that appears at the output.

The frequency of the dither signal generator can be adjusted by the help of the parameter “LIFrequency” for regulator A and “LIFrequency2” for regulator B. By setting the frequency to the same value the dither signals will be synchronized to each other.

The cut-off frequency of the low pass filters at the mixer output can be adjusted by the parameter

"InputCutOffA, ..B". This filter can be used for demodulation or bandwidth reduction. The parameter "InputFilterQualityA, ..B" defines the quality of the filter. If the parameter "LowPassSyncA, ...B" is enabled, the low pass cut off frequency will beadjusted automatically to a third of the dither frequency. Following low pass qualities can be selected:

- Bessel
- Butterworth
- Chebyshev with 0.5 dB Vripple
- Chebyshev with 1.0 dB Vripple
- Chebyshev with 2.0 dB Vripple
- Chebyshev with 3.0 dB Vripple

The parameters "InputFreqDivA, ...B" allow to reduce the sampling frequency by dividing the standard sampling rate of 2.5 MSPS. Reducing the sampling frequency allows lower cut-off frequencies. Please make sure that the sampling frequency is chosen in accordance with the Nyquist theorem in order to prevent aliasing effects. Note that the filter settings are found in the menu "input filter" rather than in the lock-in menu, as thealso apply for the undemodulated (direct) input signal (with "harmonic" set to 0).

When working with pulsed laser it make sence to syncronize the dither frequency to the repetition rate. This can be done by the help of the parameter "LISyncToPulse". If this parameter is enabled, the dither generator shifts the phase by $90°C$ after every detected pulse on the input.

6.1.9 Set point

The difference of the actual regulator input signal to an arbitrarily chosen "set point" value serves as "error signal" for the regulator loop. The set point is given by the parameter "RegSetPointA, ...B". The parameter "RegSignA, ...B" selects the sign of the error signal.

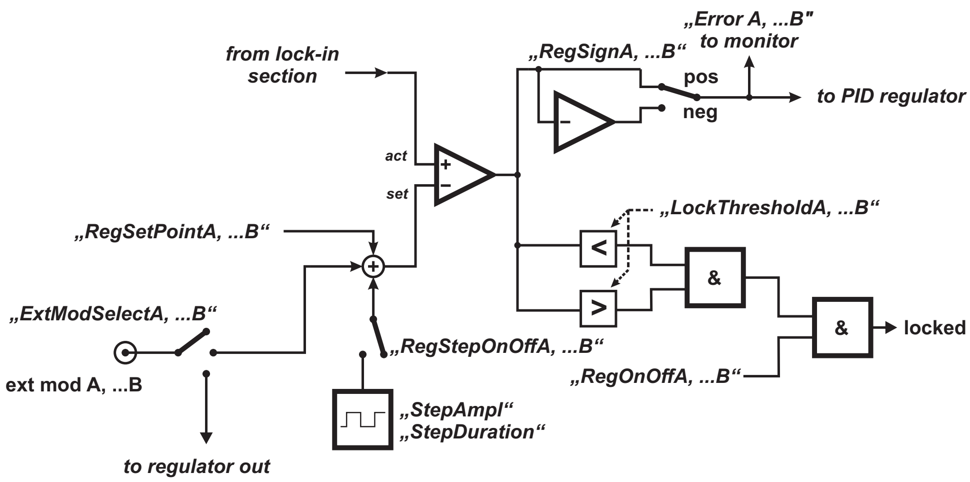


Figure 24: Block diagram of the set point section

The green LED “locked” indicates that the error signal of the activated regulator is within a small range around zero (defined by the parameter “LockThresholdA, ...B”).
In addition, the internal set point value can be modulated. By setting the parameter “ExtModSelectA, ...B” to “set point” the voltage at the BNC plug “ext mod A, ...B” will be added.

To observe the “step response” of the regulator and set up the regulator gains, a square signal can be added to the set point value by enabling “RegStepOnOffA, ...B” parameter. The amplitude and the cycle time of the square signal can be defined by the following parameters:

- “StepAmpl”: the peek-to-peek amplitude of the signal.
- “StepDuration”: cycle duration of the signal in milliseconds.

Please refer to chapter 6 for a description how to adjust the PID values. Do not forget to disable “RegStepOnOffA, ...B” once you have finished the PID adjustment.

6.1.10 Regulator section

The block diagram shown in Figure 25 gives a first overview of the whole regulator section. The regulator section includes two independent regulators and controls the main servo loop functionality.

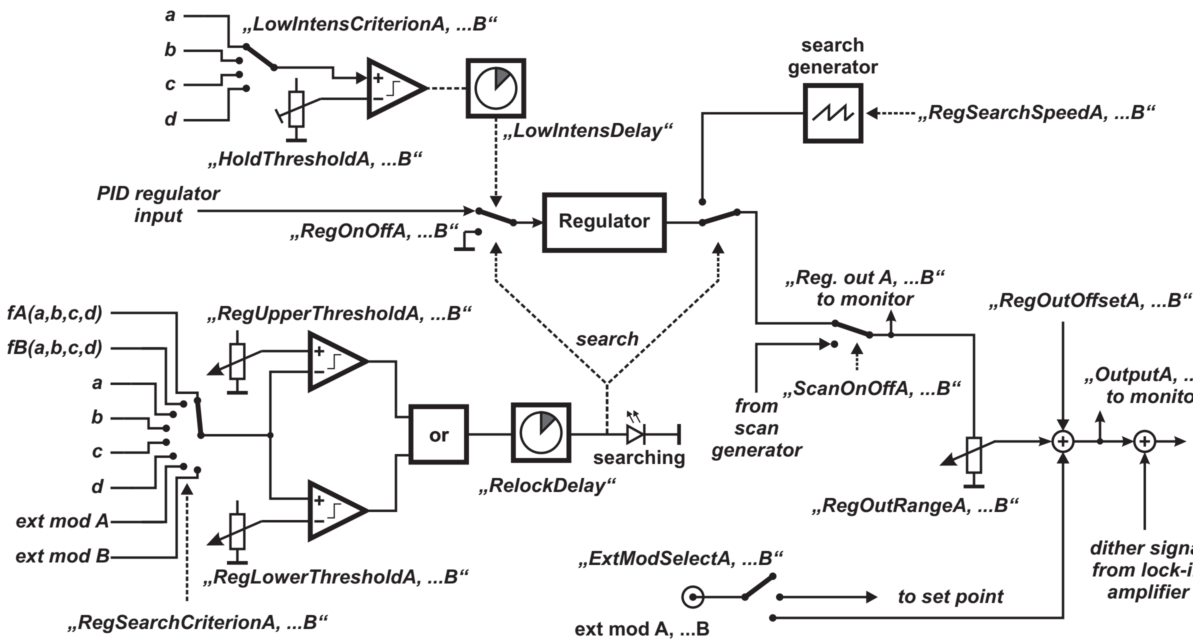


Figure 25: Block diagram of the regulator section

Output range

The parameters “RegOutOffsetA, ...B” and “RegOutRangeA, ...B” define the operating range of the regulator, i .e. the voltage range of the output that can be addressed by the regulator output.

Reset

The parameter “RegOffModeA, ...B” defines the behavior of the regulator output after disabling. You can choose the following modes:

- Hold: regulator holds the last output value
- Reset: regulator jumps to the user defined reset value defined by “RegResetValueA, ...B”

Relock

If the regulator output is driven to either limit of the operating range, the control logic will take a user-programmable action, which is selected by the parameter “RegRelockModeA, ...B”.
You can choose following relock modes:

- Stop: regulator holds the output value (search logic will reverce direction)
- Relock: regulator jumps to the opposite relock value
- Left relock: regulator jumps always to the left relock value
- Right relock: regulator jumps always to the right relock value

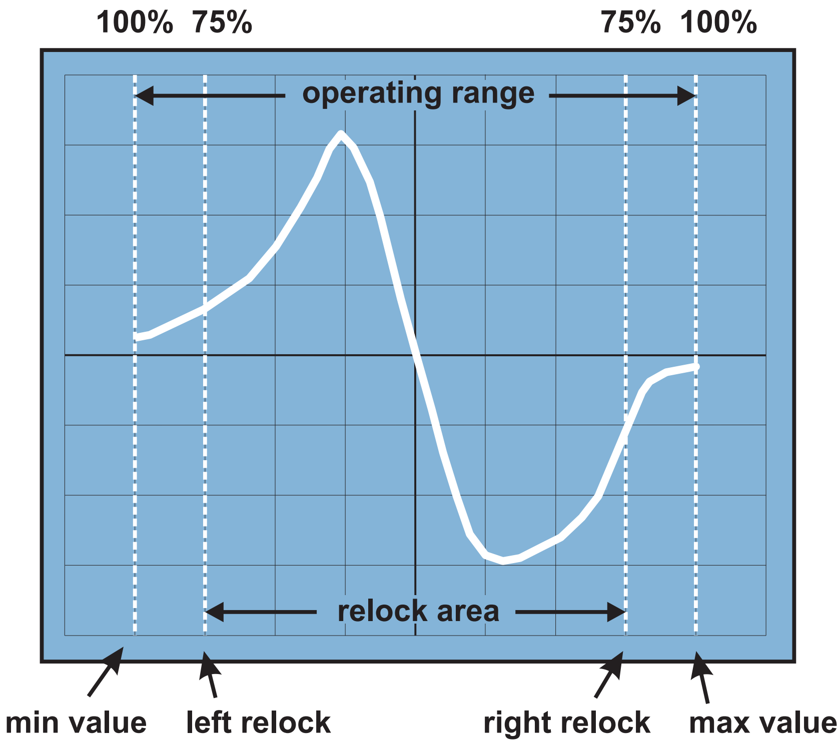


Figure 26: Display of the input signal vs. the output signal, which is applied to the controlled system. Explanation of the operating range and the relock range (example: relock = 75%)

"RegRelockValueA, ..B" defines the relock range as a percentage of the operating range.

Search logic

The search logic distinguishes valid from invalid regulation ranges: A user-selected normalized input signal is compared to a voltage window given by the parameters "RegUpperThresholdA, ...B" and "RegLowerThresholdA, ...B". If the input signal is outside the window bounds for a time greater than "RelockDelay", a user-programmable action is taken, depending on the parameter "RegSearch-ModeA, ...B". You can choose the following search modes:

- "off": The servo loop remains closed if the signal is out of window
- "search": The servo loop is opened and a search scan starts at the present regulator output voltage
- "left relock & search": The servo loop is opened and the regulator output is set to the left relock value and then starts searching
- "right relock & search": The servo loop is opened and the regulator output is set to the right relock value and then starts searching

During a search scan, a sawtooth voltage is passed to the regulator output in order to "search" for a valid region. The yellow LED "search" indicates the search mode. The rise time of the output voltage during the search scan is adjustable by the parameter "RegSearchSpeedA, ...B". As soon as the input signal enters the window again, *LaseLock* closes the loop.

Push back

Using the search functionality may simplify the relock and improve the automation of the application. However, in some scenarios it can result in unexpected behaviour. This can have different causes:

- inert actuator (e.g. heavy mirror)
- delayed search criterion signal (e.g. slow photo diode signal)
- further signal delays in the loop

These issues can cause a permanent regulator "overshoot" of the valid regulating area.

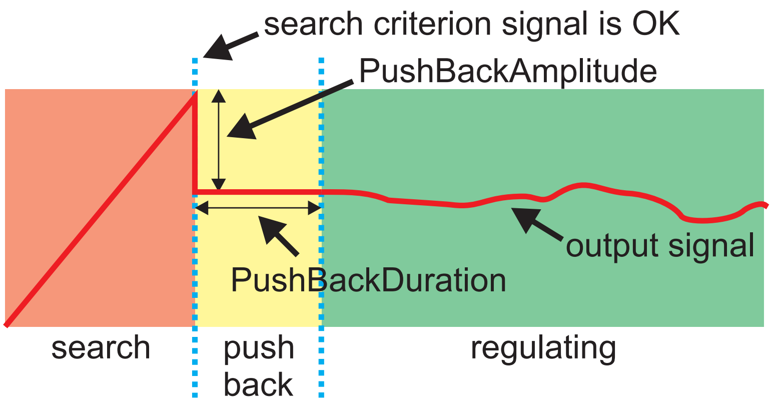


Figure 27: Search push back

Using the push back feature a defined "kick" can be appended to the regulator output after fullfilling the search criterion to counteract the inertance or the delay in the loop. The heigth und the duration of this kick can be defined with parameters "RegSearchPushBackAmplitudeA, ...B" and "RegSearchPushBackDurationA, ...B".

Total gain reduction

Tight adjusted regulator gains can also cause unexpected behavior. Best possible gain values may provide excellent regulating results in normal operation. However, enabling the regulator or scenarios like relock can make the regulator get "nervous" and cause overshoots due to large error signal. This can make the system unable to lock, even though the best possible PID gains are set.

To avoid this behaviour the total gain of the loop can be reduced to a defined starting value ("RegGainReductionA, ...B") and slowly increased to 100%.

Hold

In order to prevent irregular loop behavior upon loss of laser power, a user-selectable input signal is compared to a threshold value "HoldThresholdA, ...B". For criterion, you can choose any of the four raw input signals, by setting the parameter "LowIntensCriterionA, ...B". If the selected signal is below the threshold, the servo loop is opened while regulator output is "frozen" at the current integrator value without starting a search scan. This function can be used to stop the regulator when the laser intensity drops.

The same behavior occurs when the trigger status signal from the sample and hold stage goes low.

If the criterion signal becomes greater than the threshold value for a time defined by the parameter "LowIntensDelay", the servo loop is closed again.

Regulator
The regulator is represented by the filter and the PID elements. The second order Butterworth filter (selectable as a low pass or a high pass) limits the bandwidth of the servo loop if necessary. This is important when regulating systems that tend to resonate (e.g. piezo-mechanical set-ups). It is therefore recommended to set the cutoff frequency to a value well below the resonance frequency of the set-up. This in turn allows increasing the D coefficient of the regulator, which is required for tightly locking inert actuators. The filtered error signal is amplified (P-coefficient), integrated (I-coefficient) and differentiated (D-coefficient), adjustable by the parameters "RegP-, I-, D-GainA, ...B". An additional integrator (Parameter "RegI2GainA, ...B") can be added to the regulating circuit. The parameter "RegFSampleA, ...B" defines the work period of the regulator.

To keep a constant loop gain the regulator input is multiplied with the inverse value of the output range. The parameter "RegFSampleA, ...B" defines the sampling frequency of the regulator input signal.

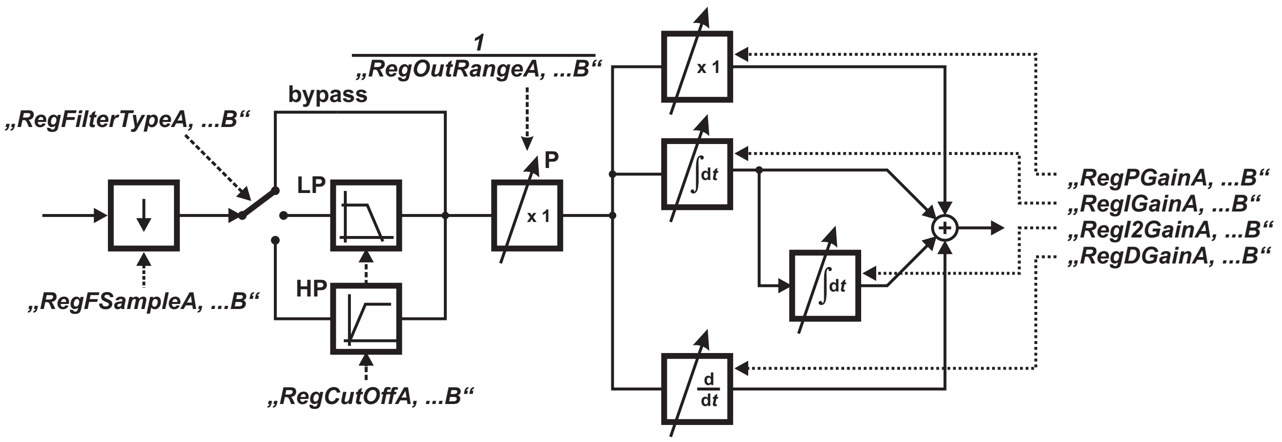


Figure 28: PID regulator with filter

Crosslink

Some technical setup, especially diode laser control loops, need a simultaneous movement of two actuators (e.g. laser current and temperature) to achieve a single mode and mode hop free operating range. The crosslink function allows adding a defined part of one regulator output signal to the other. The parameter "CrosslinkGainA" defines the part of Output B which will be added to Output A. The parameter "CrosslinkGainB" defines the part of Output A which will be added to Output B.

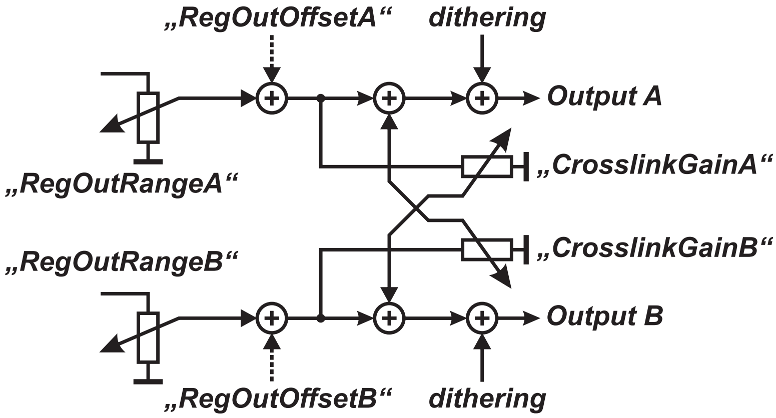


Figure 29: Crosslink

6.1.11 Scan generator

The built-in scan generator generates a signal with triangular or saw tooth waveform. The scan signal can be used e.g. for identifying the search area for atomic resonances, or for system alignment.

Each regulator output can be individually coupled to the scan generator by enabling the parameter "ScanOnOffA, ...B". To avoid jumps the scan generator will be coupled first when the scan signal crosses regulator output.

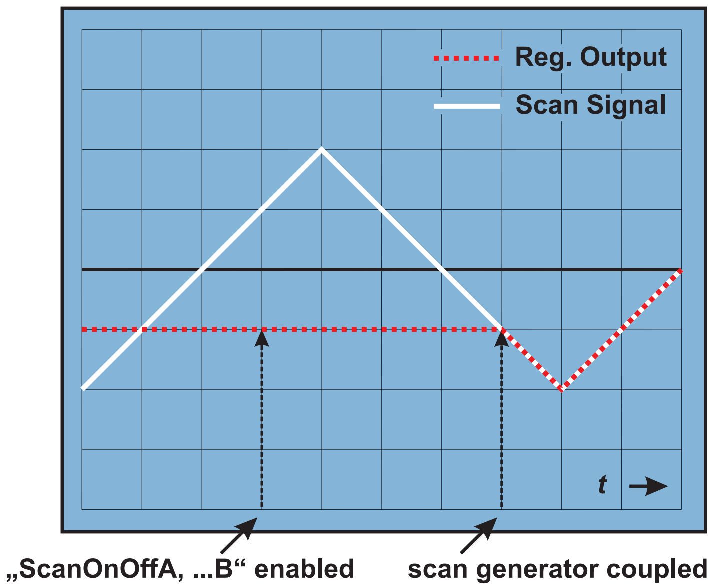


Figure 30: Scan on behavior

After disabling of the parameter “ScanOnOffA, ...B” the scan generator will remain coupled until it reaches the user defined “ScanStopA, ...B” value.

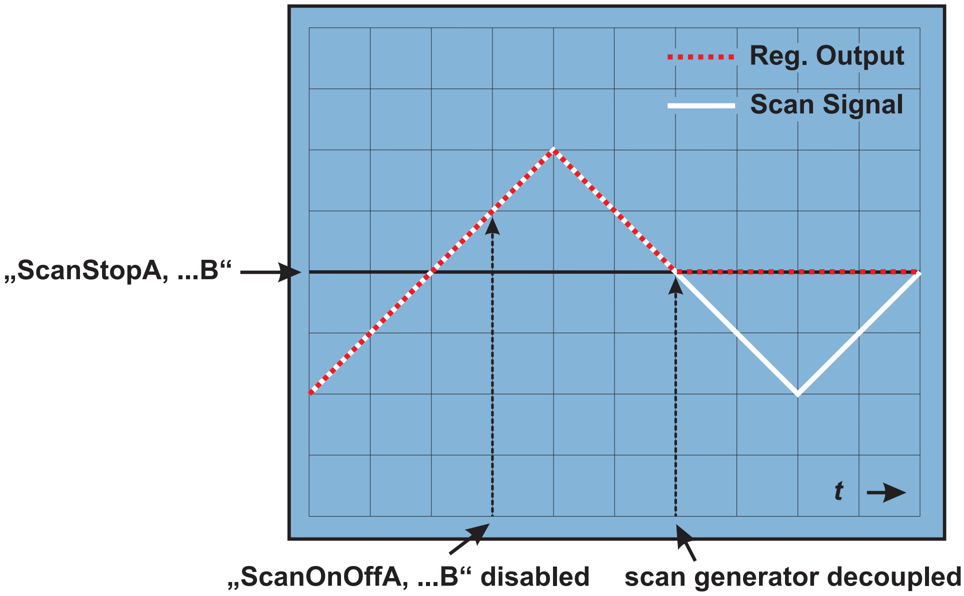


Figure 31: Scan off behavior

The frequency of the scan signal can be defined using the “ScanFrequency” parameter in a range of 0.1...20000 Hz. The parameter “ScanShape” selects between triangular and saw tooth waveform.

6.1.12 Monitor section

Optionally: connect an oscilloscope to the monitor outputs “monitor 1” and “monitor 2” for observation of several internal signals depending on the selection in the menu section “MonitorSelect1” and “MonitorSelect2”. Use the setting menu or Kangoo to select the monitor signals. You can choose between the following signals:

- Input a raw (raw signal on input a, incl. offset)
- Input b raw (raw signal on input b, incl. offset)
- Input c raw (raw signal on input c, incl. offset)
- Input d raw (raw signal on input d, incl. offset)
- fA(a,b,c,d) (linear combination of the input signals, i. e. normalized signal A)
- fB(a,b,c,d) (linear combination of the input signals, i. e. normalized signal B)
- Input filter A (output of low pass filter for demodulation and bandwidth limitation on the input of the regulator A section)
- Input filter B (output of low pass filter for demodulation and bandwidth limitation on the input of the regulator A section)
- Error A (difference between the set point and the regulator A input signal)
- Error B (difference between the set point and the regulator B input signal)
- Reg filter A (filtered error signal A)

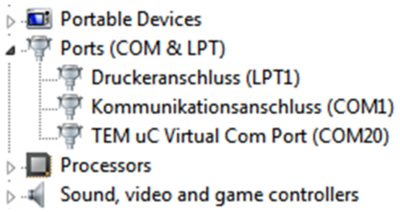
- Reg filter B (filtered error signal B)
- Reg output A (output signal of the PID regulator A)
- Reg output B (output signal of the PID regulator B)
- Output A (output signal A without modulation)
- Output B (output signal B without modulation)
- Scan out (signal from the signal generator)
- Dither (additional dither signal from the dither generator)
- Ext mod A (external modulation signal A)
- Ext mod B (external modulation signal B)

The connector "trigger out" gives a digital trigger signal (0...5V) for synchronizing the scope with the scan signal, step signal or dithering (Parameter: "TriggerOutSelect") in the XY-mode. This signal can be inverted by selecting the parameter "ScanTriggerInvert".

6.2 Connection to PC

Please refer to the separate chapter on installation of the USB driver to your computer.

Connect the *LaseLock* to the PC by means of a standard USB (A-B) cable. (Please avoid cables longer than three meters, especially if strong electromagnetic fields are present in your environment). The device will appear as "TEM uC Virtual Com Port" in the device manager of your computer.



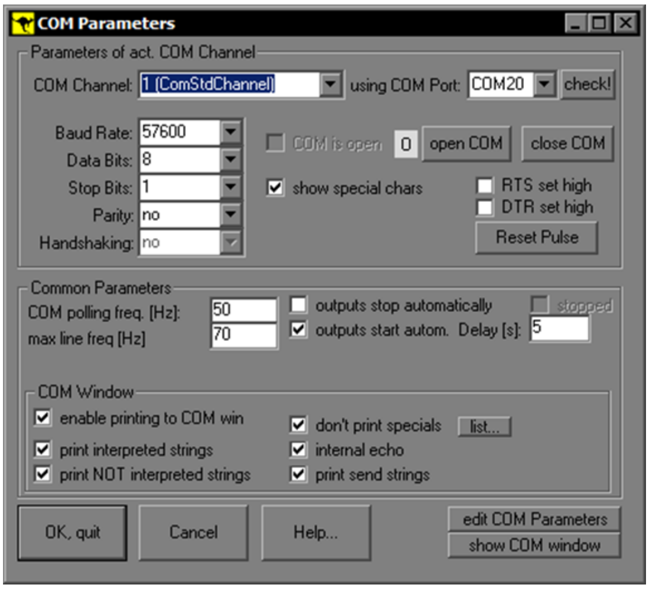


Figure 32: COM Port in the device manager (left) and corresponding COM port settings in Kangoo (right)

Start the Kangoo software and type F5 (or go to Communication → COM parameters) to open the interface dialog (compare fig. 32). Click to "check!" in the COM Parameters windows to search for available COM ports. The COM number of *LaseLock* should appear in the drop down list next to the button. The port settings like baud rate, data bits und parity settings are important for "real" COM ports e.g. RS-232. They will be ignored for USB connections.
To test the communication click "show COM window" in the dialog. Click into the window named "COM-Terminal" and press 'ENTER'. The device should answer with "no command…" (compare fig. 33).

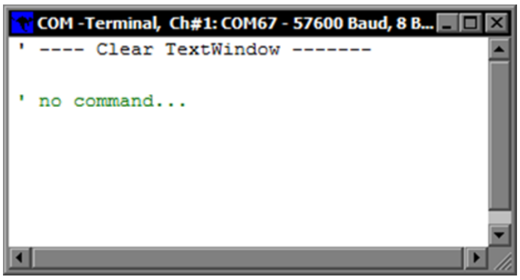


Figure 33: COM Terminal window

Later on, you may use this terminal window to learn how to control your device by simple ASCII commands. Just try and enter "hello" followed by the 'ENTER' key …

6.2.1 Using Kangoo "LaseLock digital: standard configuration"

When you have installed and started the Kangoo Software, you will be greeted by a welcome screen which lets you choose the *Main Menu Configuration* (the Kangoo software can handle a large variety of different hardware modules). Please choose *LaseLock* digital → *LaseLock* standard configuration.

The basic configuration will look as follows:

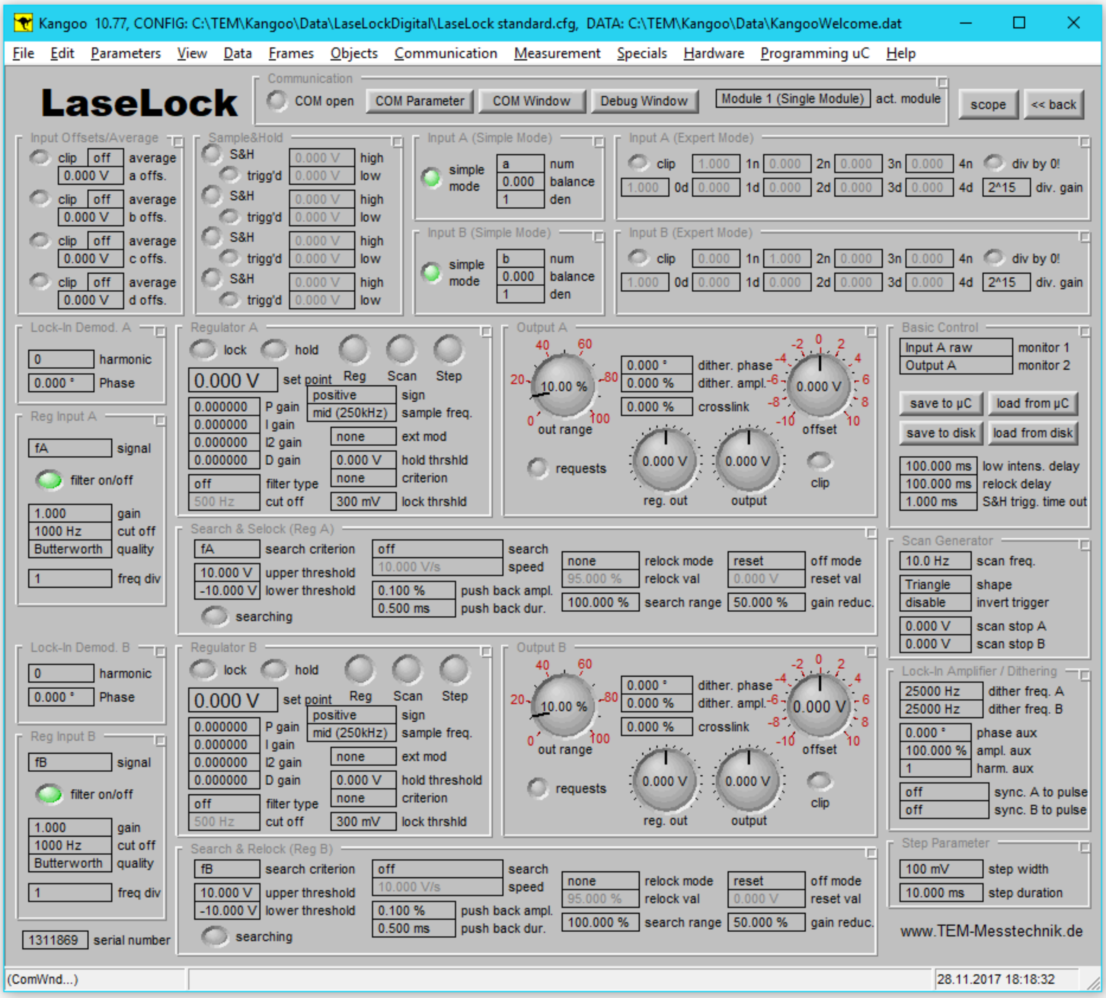


Figure 34: *LaseLock* digital standard configuration

Several objects ("devices", buttons, lamps, etc.) allow visualization and control of the microcontroller based device.

In the following table, the items of the *LaseLock* standard configuration are described:

Section: "Basic Control"	
Monitor 1 / 2	Monitor signal selection
save to μC / load from μC	These two buttons save or load all current settings in the microcontrollers non-volatile memory. These saved values are loaded automatically at startup.

save to disk / load from disk	These two buttons save or load all current settings in the hard disk of your computer.
low intens. delay	Defines the time the chosen criterion signal should be above the threshold value to reactivate the regulator
relock delay	Defines the time the input signal should be outside the window defined by the upper and the low threshold to hold the regulator start to search for valid lock point
S&H trigg. time out	Defines the trigger time out value for sample and hold section
Section: "Communication"	
open COM port	Opens / closes the active communication port
COM parameter	Displays the COM port parameter window
COM window	Displays the communication window. The user can watch the communication between Kangoo and the microcontroller. Additionally, commands and requests can be typed manually at the COM window.
debug window	Displays the debug window. The user is provided with feedback about all processes of the Kangoo software.
Section: "Scan Parameters"	
frequency	Defines the frequency of the scan signal
shape	Scan signal shape selection
invert trigger	Inverts the trigger signal an the "trigger out" BNC plug
scan stop A, B	Defines the stop value after decoupling the scan generator for each regulator
Section: "Lock-in amplifier / Dithering"	
dither freq. A	Defines the dither frequency for regulator A
dither freq. B	Defines the dither frequency for regulator B
phase aux	Defines the phase shift of the monitor dither signal
ampl. aux	Defines the amplitude of the monitor dither signal
harm. aux	Defines the harmonic of the monitor dither signal
sync. to pulse	Enables / disables the synchronization with a pulsed input signal
Section: "Step Parameters"	
step Duration	Defines the cycle duration of the square signal
step Ampl.	Defines the peek-to-peek amplitude of the square signal
Section: "Input Offsets"	
a offs., b offs., c offs., d offs.	Defines the offset value for each input signal
average	Defines the average grade for the raw input signals
clip	Input signal clips
Section "sample and hold"	
SH	Enables / disables the sample and hold stage
trigg'd	Sample and hold trigger status
high	Sample and hold high trigger threshold
low	Sample and hold low trigger threshold
Sections "Input A, B (simple mode)"	
numerator	Mode selection for the numerator
balance	Defines the gain ratio of the input signal
denominator	Mode selection for the denominator
Section "Input A, B (expert mode)"	
1n, 2n, 3n, 4n	Define the coefficients for the values in the numerator
0d, 1d, 2d, 3d, 4d	Define the coefficients for the values in the denominator
division gain	Defines the binary gain value for the division
clip	Normalized Input signal clips
Sections "Lock-In demod. A" and "Lock-In demod. B"	
harmonic	Selects the harmonic of the lock-in signal which will be mixed with the input signal
phase	Defines the phase shift of the signal which will be mixed with the input signal
Sections "Reg. Input A" and "Reg. Input B"	
signal	Selects the regulator input signal
filter on/off	Enables / disables the input filter
gain	Defines the gain value of the input filter
cut off	Defines the cut off frequency of the input filter
quality	Defines the quality of the input filter

freq. div	Defines the sampling frequency division value
Sections "Regulator A" and "Regulator B"	
lock	Regulator is locked
hold	Regulator holds
reg	Enables / disables the regulator
scan	Couples / decouples the scan generator to the regulator output
step	Enables / disables the addition of the step signal to the set point value
SetPoint	Defines the internal set point value in V
Hold threshold	Defines the minimum value for the hold criterion
criterion	Selects the hold criterion signal
ext. mod.	Selects the use of the signal at the "ext mod A" or "ext mod B" BNC plug
sign	Regulator input sign selection
P, I, I2, D gain	Define the gain values of the regulator
CutOff	Defines the cutoff frequency of the low pass filter
filter type	Selects the filter type between low pass and high pass
F sample	Defines the sampling frequency of the regulator in kHz
Sections "Output A" and "Output B"	
out range	Defines the output range value in %
offset	Defines the output offset value in V
dither. Ampl.	Defines the amplitude of the dithering
dither. Ampl.	Defines the phase shift of the dithering
crosslink	Defines the crosslink amplitude
clip	Regulator output clips
reg. out.	Actual regulator output value (use "requests" button to activate)
output	Actual output value (use "requests" button to activate)
requests	Activates / deactivated the requests of reg- out. and output
Sections "Search & Relock (Reg. A)" and "Search & Relock (Reg. B)"	
search criterion	Defines the signal for search criterion
upper threshold	Defines the upper threshold for the input value
lower threshold	Defines the lower threshold for the input value
search	Selects the search mode
speed	defines the search speed and the direction
searching	Regulator is searching
relock Mode	Mode selection by crossing the limits of the operating area
reset Mode	Mode selection by disabling the regulator
relock	Defines the relock value in %
reset	Defines the reset value in V
push back ampl.	Defines push back amplitude in % of search speed
push back dur.	Defines push back duration in ms
search range.	Defines the search range around zero in % of output range
gain reduc.	Defines the total gain value at which the regulator will start working

7 Empirical adjustment of the PID regulator

7.1 Introduction control techniques

What is a regulator? A regulator is a means to drive some actuator in such a way that some relevant physical measure ("control variable") equals (or comes close to) an arbitrary value ("set value"). In other words, the difference between the set value and the actual value of the control variable (the "error value") is to be minimized. To this end, the regulator mainly consists of a means to calculate (digitally) the difference between the input signal and the user-selected set value, and one or more amplifiers with different characteristics. In case of the PID regulator, three amplifiers are present:

- The output signal of the proportional (P) amplifier is proportional to the error signal.
- The output of the integrating (I) amplifier is the integral of the error signal over the time.
- The output of the differentiating (D) amplifier is the derivative of the error signal with respect to the time.

The output signal of the regulator (the "actuating value") is the weighted sum of the three amplifier output signals. Optimizing the regulator means to adjust the weights of the three contributions in a manner that the error resulting from an external disturbance is as small as possible. As the regulator, the actuator (here: the laser) and the sensor (here: an FPI, a spectroscopy setup or similar) form a loop ("servo loop"), the system might be excited to stable oscillations of the signals. The condition for this unwanted effect is that the total loop gain is greater than 1 for frequencies, for which the loop delay equals a phase shift of 180°. Thus, the optimization of the PID-contributions remains a trade-off between low gains in the critical frequency ranges (leading to large residuals error values) and high gains (leading to unstable or oscillating states).

7.2 Finding the operation point

Before switching the regulator on, make sure that there is at least one operating point within the output voltage range of the regulator. (The operating point is a value of the regulator output for which the error signal crosses zero. This can be found by help of the scan function: Watch the error signal whilst scanning the laser, and adjust the output offset and the output range so that at least on zero-crossing is well within the scan range.) Then switch the scan off. Turn the trim pots for P-, I- and D-Gain to their minimum. Then switch on the regulator on ("RegOnOff") while watching the error signal on the oscilloscope. Increase the P-Gain until the error signal converges (slowly) to zero. (If it diverges away from zero, the feedback sign is wrong change it). When the error signal is about zero, the system has reached the operating point.

7.3 Optimization of the step response

In order to appraise the regulation quality, a reproducible disturbance needs to be induced. (It can be superimposed either to the set value (set point modulation) or to the output voltage (output modulation).) Enable the "RegStepOnOff" parameter. *LaseLock* then adds a rectangular voltage with user defined amplitude and cycle duration to the set point.

The error signal exhibits step-shaped disturbances that creep towards zero after each step. (The creeping is an effect of the integrating amplifier.) Increase the P contribution. The steps will turn into impulses (needles). Increase either P or the total gain until you observe an overshoot of the error signal by about 30% of the step size. Increase I until the error signal reaches the zero as soon as possible after each step.

7.4 Adjusting the differential (D) contribution

When regulating inert systems (as are present in most cases), a D contribution helps to damp the overshoot of the error signal that occurs with PI regulation. The D contribution can be explained as a measure for the amount of energy that needs to be placed in the system in order to compensate the disturbance. Care has to be taken when regulating resonant systems (e.g. spring-mass-systems, such as piezo-mounted mirrors): The differentiation provide frequency proportional gain (i.e. high gain for high frequencies) with a 90° phase shift for all frequencies. As the resonance of the system also provides high gain at a phase shift of 90°, the oscillation condition is easily met. To avoid this, a low-pass filter is required, that reduces the gain at the critical frequency, thus allowing a large D contribution in the low-frequency range.

The adjustment of the filter cut-off frequency and the D contribution is a trade-off again: Choosing cutoff frequency low (compared to the resonance frequency), thus reducing the regulation bandwidth, allows to increase the gain, thus leading to better regulation in the remaining frequency range.

If you work with a non-resonant system (as is the case e.g. with temperature regulation of a thermal mass), just increase the D gain until the overshoot disappears (or at least reaches a minimum value).

If you work with a resonant system, increase the D contribution, until you observe a large overshoot or even oscillations. Decrease cut-off frequency of the low-pass filter at the PID input (parameter "RegCutOff"), until the overshoot or oscillation disappears. Repeat the last two steps until further decreasing of the cutoff frequency has no significant effect. Decrease the D gain until the overshoot disappears (or at least reaches a minimum value).

7.5 Fine adjustment

The regulator is now adjusted very close to its optimum. You can now play with the P, I and D gain as well as the overall gain, and see if the step response gets somewhat better. But keep in mind that an overshoot indicates potential instability.

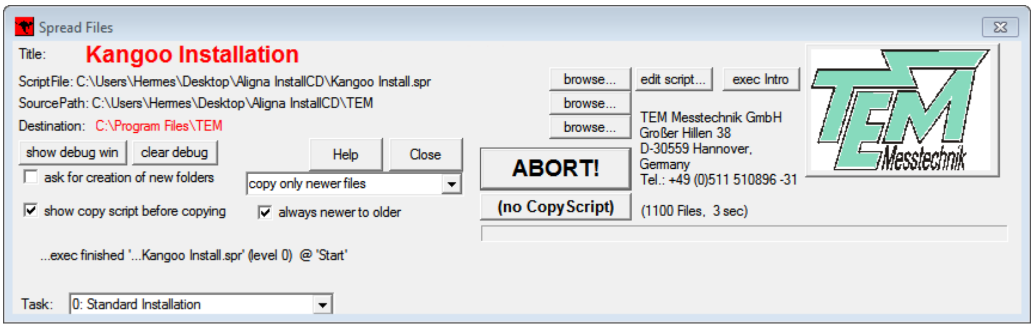
Do not allow more than few percent overshoot.

8 Software Installation

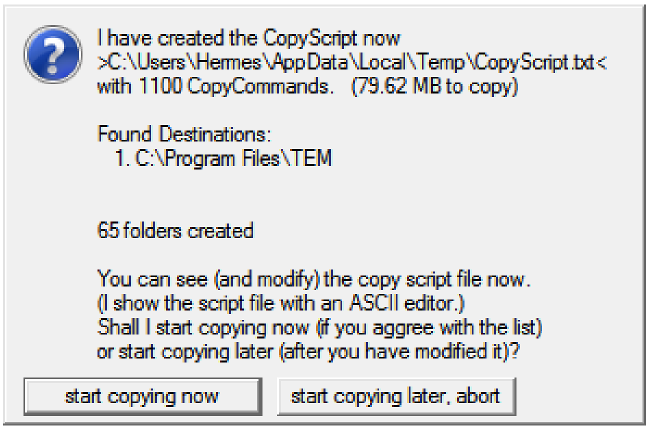
8.1 Installation of the Kangoo Software

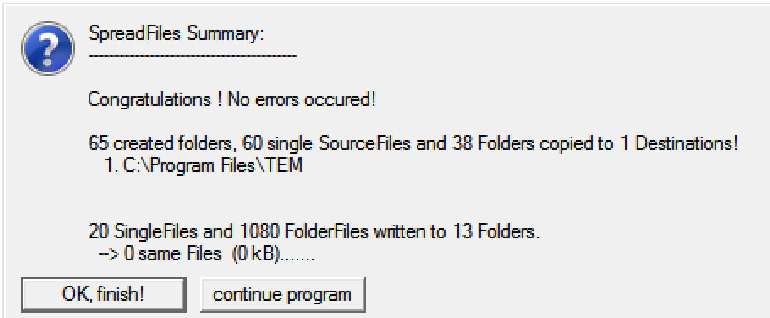
To install the Kangoo software, start the program Install.exe in the root directory of the installation CD or USB memory stick, resp.. The installer will show a welcome screen with several options.

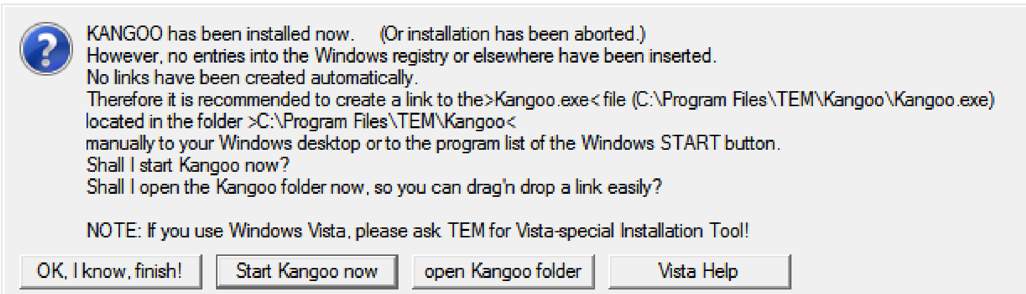
The default options should work fine, with the possible exception of the section "Destination Path", where the destination directory is specified. The standard directory is "TEM" in the "Program Files" folder. On Windows Visa or Windows 7 systems, please avoid the "Program Files" folder and choose and a different path, for example "C:/TEM". The button "OK, install now!" starts copying all required files from the source path to the destination path. During the installation procedure, the installation program checks all required files.



The program then creates a list of file copy commands. When this list is complete, you can check the list and start the copy procedure.







8.2 Installation of LabView Drivers

To install LabView demo VIs and their Sub-VIs, simply copy the content of the folder /TEM/LabView of the installation CD or USB memory stick, resp.., to your local LabView folder.
Please note that the NI-VISA package is required, which can be downloaded from the National Instruments web site.

8.3 Installing the USB Drivers

Typically, when the USB connection between the micro-controller and a PC is first made, Windows will open the Found New Hardware Wizard. Here, choose to install drivers from a user-specified location. The necessary driver file is located in the directory “TEM/Service/USB Driver” in the Kangoo installation directory (or on the install CD or memory stick). The Hardware Wizard will now finish the installation and no further configuration will be necessary.
Once the installation is complete, Windows will assign a COM-port. To find out which COM-port has been assigned, check for a new entry in the section “Ports (COM & LPT)” of the device

manager. The device will appear as "TEM uC Virtual Com Port" in the device manager of your computer (see figure 35).

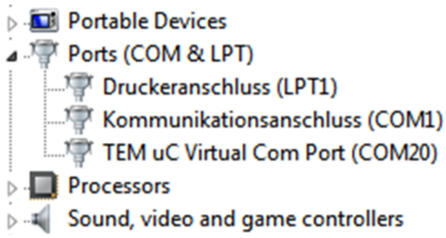


Figure 35: TEM COM Port in the device manager

8.4 Upgrading the Firmware

Please contact TEM Messtechnik for details about firmware upgrades.

9 Communication interface

9.1 Communication syntax

The communication between PC and microcontroller is carried by an ASCII-encoded stream of characters. (Exceptions are sometimes made in order to achieve fast binary data transfer.) The stream is structured in lines, the ends of which are marked by ASCII 13 (carriage return), followed by ASCII 10 (line feed).

Lines can be sent to the microcontroller (and in turn received from the μ)C by:

- entering them literally in the COM window of *Kangoo* or another terminal such as Microsoft HyperTerminal
- application programs such as *Kangoo* or LabView "Virtual Instruments"
- user-written programs, using languages like VB (Microsoft Visual Basic), C/C++, Delphi, etc. with help of COM procedures.

Both the microcontroller and the PC may send lines at any time. Please note that the microcontroller sometimes sends information without "being asked for". This means that the line received by the PC right after a query does not necessarily contain the answer to the query. Therefore a communication routine has to be programmed to catch all incoming lines and to parse them for the information of interest: Every single line has to be interpreted by the respective receiver.

An ASCII 39 (apostroph) character denotes a comment: the apostroph and all subsequent characters are deleted before the evaluation of the line.

The microcontroller distinguishes between "commands" and "variable assignments".

If the line does *not* contain an equal sign, the microcontroller interpretes it as a "command line". Tokens within the command line have to be separated by ASCII 32 (space) characters. The first token is taken for the command name, all further tokens are parameters to the command.

Example: If the microcontroller receives
`help`$\langle CR\rangle$
it will send a list of available commands to the PC.

Example: If the microcontroller receives
`help hello`$\langle CR\rangle$
it will send information about the command "hello", if available. In this case the token "hello" is a parameter that is handed over to the command "help".

If the line contains an equal sign (not preceeded by a space!), followed by a value, it is interpreted as a variable assignment.

Example: If the microcontroller receives
`CutOff= 1000`$\langle CR\rangle$

it will set the value of "CutOff" to 1000 and echo the value:

`CutOff= 1000`$\langle CR \rangle$

An ASCII 92 (backslash) at the beginning of the line suppresses the echo.
Example: If the microcontroller receives

`\CutOff= 1000`$\langle CR \rangle$

it will set the value of "CutOff" to 1000 and *not* echo the value, unless the value was not accepted. (In that case the echo will tell the actual value.)

If the rest of the line (after the equal sign) does not contain a value, the microcontroller responds telling the actual value. (This is a query for a value.)

Example: If the microcontroller receives

`CutOff=`$\langle CR \rangle$

it will send back

`CutOff= 1000`$\langle CR \rangle$

A complete list of variables and their values can be obtained by sending the command "vardump":
If the microcontroller receives

`vardump`$\langle CR \rangle$

it will echo one line for each available variable, in the style

$\langle variablename \rangle$`=` $\langle value \rangle\langle CR \rangle$

9.2 List of firmware variables

The actually defined variables can be requested by means of the interface command "VarDump".

Variable	Default	Min	Max	Unit / Scale	Comment
SerialNumber	-	-	-	-	Serial number of the device
LCDBrightness	100	0	100	%	Brightness of the LCD screen
InputSimpleModeA, B	0	0	1	-	Enabling, disabling the simple mode for input signal adjustment
InputCoeffNumA1, InputCoeffNumB1	0	-1000	1000	10^{-3}	Coefficient for input a in the numerator (expert mode)
InputCoeffNumA2, InputCoeffNumB2	0	-1000	1000	10^{-3}	Coefficient for input b in the numerator (expert mode)
InputCoeffNumA3, InputCoeffNumB3	0	-1000	1000	10^{-3}	Coefficient for input c in the numerator (expert mode)
InputCoeffNumA4, InputCoeffNumB4	0	-1000	1000	10^{-3}	Coefficient for input d in the numerator (expert mode)
InputCoeffDenomA0, InputCoeffDenomB0	0	-1000	1000	10^{-3}	Coefficient for one in the denominator (expert mode)
InputCoeffDenomA1, InputCoeffDenomB1	0	-1000	1000	10^{-3}	Coefficient for input a in the denominator (expert mode)
InputCoeffDenomA2, InputCoeffDenomB2	0	-1000	1000	10^{-3}	Coefficient for input b in the denominator (expert mode)
InputCoeffDenomA3, InputCoeffDenomB3	0	-1000	1000	10^{-3}	Coefficient for input c in the denominator (expert mode)
InputCoeffDenomA4, InputCoeffDenomB4	0	-1000	1000	10^{-3}	Coefficient for input d in the denominator (expert mode)
InputNumModeA, B	0	0	1	-	Numerator mode (simple mode) [0: a, 1: -a, 2: a-b]
InputDenomModeA, B	0	0	1	-	Denominator mode (simple mode) [0: 1, 1: b, 2: a+b]
InputBalanceA, B	0	-800	+800	10^{-3}	Input gain ratio
InputDivisionGainA, B	215	20	215	-	Binary division gain [21520]
InputFreqDivA, B	1	1	250000	-	Input sample frequency division value
InputCutOffA, B	1000	100	850k	Hz	Cut off frequency for the input low pass filter
InputFilterGainA, B	1000	0	100000	10^{-3}	Gain value for the input low pass filter
LIPhaseA, B	0	0	360000	'	Phase shift of the lock-in signal
RegSignA, B	0	0	1	-	Sign of the error signal
RegSetPointA, B	0	-1000	1000	mV	Set point value
RegFSampleA, B	20000	10	1.25M	Hz	Regulator/filter sampling frequency
RegCutOffA, B	500	1	250k	Hz	Filter cut off frequency
RegFilterTypeA, B	0	0	1	-	Filter type [0: off, 1: low pass, 2: high pass]
RegPgainA, B	0	0	10^7	10^{-6}	Gain value of the proportional (P) amplifier
RegIgainA, B	0	0	10^6	10^{-6}	Gain value of the integrating (I) amplifier
RegI2gainA, B	0	0	10^6	10^{-6}	Gain value of the second integrating (I2) amplifier
RegDgainA, B	0	0	10^7	10^{-6}	Gain value of the differentiating (D) amplifier
RegOnOffA, B	0	0	1	-	Regulator enabling/disabling [0: disable, 1: enable]
RegOutOffsetA, B	0	-10000	10000	mV	Output offset value
RegOutRangeA, B	10000	1000	100000	‰	Output range value
RegOffModeA, B	0	0	1	-	Regulator reset mode selection [0: hold, 1: reset]
RegResetValueA, B	0	-10000	10000	mV	Regulator reset value
RegRelockModeA, B	1	0	3	-	Regulator relock mode selection [0: none, 1: relock, 2: left relock, 3: right relock]
RegRelockValueA, B	95000	0	95000	‰	Regulator relock value
ScanOnOffA, B	0	0	1	-	Coupling the regulator output to scan generator [0: disabled, 1: enabled]

RegStepOnOffA, B	0	0	1	-	Adding a square signal to the set point [0: disabled, 1: enabled]
LIHarmonicA, B	0	0	3	-	Lock-in harmonic selection
RegUpperThresholdA, B	1000	-1000	1000	mV	Upper threshold for the input signal
RegLowerThresholdA, B	-1000	-1000	1000	mV	Lower threshold for the input signal
RegSearchSpeedA, B	10^4	0	10^6	mV/s	Search speed
RegSearchRangeA, B	100000	0	100000	‰	Search range
RegGainReductionA, B	50000	0	100000	‰	Regulator total gain reduction
RegSearchPushBackAmplitudeA, B	100	0	100000	‰	Push back amplitude
RegSearchPushBackDurationA, B	0	0	1000000	μs	Push back duration
RegSearchModeA, B	0	0	3	-	Search mode [0: off, 1: search, 2: left relock & search, 3: right relock & search]
RegSearchCriterionA, B	0	0	7	-	Search criterion signal selection [0: fA, 1: fB, 2: input a, 3: input b, 4: input c, 5: input d, 6: ext mod A, 7: ext mod B]
InputFilterQualityA, B	1	0	5	-	Quality of the input filter [0: Bessel, 1: Butterworth, 2: Chebyshev with 0.5dB Vripple, 3: Chebyshev with 1dB Vripple, 4: Chebyshev with 2dB Vripple, 5: Chebyshev with 3dB Vripple,]
DitheringAmplA, B	0	0	100000	‰	Output dithering amplitude
DitheringPhaseA, B	0	0	360000	‘	Output dithering phase shift
LowIntensCriterionA, B	0	0	4	-	Input signal for low intensity criterion [0: none, 1: input a, 2: input b, 3: input c, 4: input d]
HoldThresholdA, B	0	-10000	10000	mV	Minimum value for criterion signal
CrosslinkGainA, B	0	-1000	1000	-	Crosslink value
ExtModSelectA, B	0	0	2	-	Use selection for the signal at the “ext mod A” or “ext mod B” BNC plug [0: off, 1: set point, 2: output]
MonitorSelect1, MonitorSelect2	0, 14	0	24	-	Signal selection at the “monitor 1” and “monitor 2” BNC plug [0: Input A raw, 1: Input B raw, 2: Input C raw, 3: Input D raw, 4: fA(a,b,c,d), 5: fB(a,b,c,d), 6: Input filter A, 7: Input filter B, 8: Error A, 9: Error B, 10: Reg filter A, 11: Reg filter B, 12: Reg out A, 13: Reg out B, 14: Output A, 15: Output B, 16: Scan out, 17: dither, 18: ext mod A, 19: ext mod B]
LIFrequency	20k	1	1M	Hz	Frequency of the modulation signal
LIHarmonicAux	1	0	3	-	Harmonic of the modulation signal on the monitor
LIAmplAux	100000	0	100000	‰	Amplitude of the modulation signal on the monitor
LIPhaseAux	0	0	360000	’	Phase shift of the modulation signal on the monitor
RelockDelay	100ms	0	1s	μs	Defines the time the input signal should be outside the window defined by the upper and the low threshold to hold the regulator start to search for valid lock point
LowIntensDelay	100ms	0	1s	μs	Defines the time the chosen criterion signal should be above the threshold value to reactivate the regulator
ScanFrequency	100	1	200000	1/10Hz	Frequency of the scan signal
ScanShape	0	0	1	-	Shape of the scan signal
ScanTriggerInvert	0	0	1	-	Inverts the trigger signal at the “trigger out” BNC plug
TriggerOutSelect	0	0	2	-	Selects the trigger signal at the “trigger out” BNC plug [0: scan, 1: step, 2: dither]
StepAmpl	1000	0	10000	mV	peek-to-peek amplitude of the square signal
StepDuration	20ms	10	1s	μs	cycle duration of the square signal
InputOffsetA	0	-1000	1000	mV	offset value for input a

InputOffsetB	0	-1000	1000	mV	offset value for input b
InputOffsetC	0	-10000	10000	mV	offset value for input c
InputOffsetD	0	-10000	10000	mV	offset value for input d
LockedA	0	0	1	-	Regulator A is locked
LockedB	0	0	1	-	Regulator B is locked
SearchA	0	0	1	-	Regulator A is searching
SearchB	0	0	1	-	Regulator B is searching
RegClipA	0	0	1	-	Regulator A output clipped
RegClipB	0	0	1	-	Regulator B output clipped
HoldA	0	0	1	-	Regulator A holds
HoldB	0	0	1	-	Regulator B holds
InClipA	0	0	1	-	Input signal A to large
InClipB	0	0	1	-	Input signal B to large
DivByZeroA	0	0	1	-	Denominator A equals zero
DivByZeroB	0	0	1	-	Denominator B equals zero

9.3 List of commands

Entering a command with a parameter value sets the value of the parameter to the corresponding value. A blank separator (‘space‘) has to be used between command and the parameter:

Example: `SendToFPGA 120 1024`$\langle CR \rangle$

A typical command set of the LaseLock digital is listed in the following table:

command	**arg. 1**	**arg. 2**	**comment**
GetFromFPGA	address	-	requests a value from FPGA
SendToFPGA	address	data	sends a value to FPGA
FPGAtest	-	-	testing communication with the FPGA module
VarSave	-	-	saves all parameters to the microcontroller‘s non-volatile memory
VarLoad	-	-	loads all parameters from the microcontroller‘s non-volatile memory
VarDefault	-	-	loads default parameters
VarDump	-	-	prints all parameters
Hello	-	-	testing communication. Microcontroller answers with “Here I am”
uCtype	-	-	prints the used microcontroller type
Sound	-	-	plays a short peep tone
Mute	-	-	activates/deactivates sounds

10 Electrical Specifications

10.1 Technical Data

Signal Input	
Impedance	1 MΩ
Voltage range	-1.0...1.0 V (fast inputs) -10.0...10.0 V (slow inputs)
Bandwidth	300 kHz
Sampling rate	2.5 MSps (fast inputs) 500 kSps (slow inputs)
Outputs	
Voltage range LV	-10.0...10.0 V at 1 kΩ load
Bandwidth LV	200 kHz
Voltage range HV	0...150 V 120mA continuous, 240mA peak (each channel)
Bandwidth HV	100 kHz (small signal bandwidth)
Sampling rate	2.5 MSps
Lock-In amplifier	
Modulation frequency	0.1 Hz...1 MHz
Phase adjustment	0...360° (≈0.005° phase tuning resolution)
Cut-off frequency	25 Hz...850 kHz
Twin PID regulator	
Combinations	independent / parallel / series (selectable input signal)
Over-all delay	1.8...2.5 µs for fast path (best case: raw input signal, all filter deactivated; worst case: normalized input signal, all filters activated); approx. 5 µs for slow path (using input c or d as input)
Scan generator	
Output frequency	0.1...20000 Hz (triangular shape, TTL trigger output)
Supply	
Voltage range	100...240 V AC, 50...60 Hz (auto detect)
Voltage range (DC12V)	DC 9...36V; 5.5x2.5mm plug; positive polarity
Power consumption	Typ. ≈ 10 W, 20 W with HV option, max. 50 W at full load
Housing (desktop case)	
Dimensions H x W x D	100mm x 260mm x 377mm
Housing (19 inch rack case)	
Dimensions H x W x D	150mm x 450mm x 340mm
Display	
Size	4.3 inch (11 cm) TFT display
Resolution	480 x 272, 16-bit color
Technology	resistive touchscreen, LED backlight

CCTC-DFB	
Laser current range	0...200mA
Laser current polarity	positive or negative fixed on manufacturing level
Coarse current adjustment resolution	61μA
Laser voltage range	0...4V
Temperature range	$0...50°C$
Coarse temperature adjustment resolution	50mK
Max. TEC current	2A
Current modulation input	+/-10V for +/-250mA
Modulation bandwidth	1kHz / 10kHz / 100kHz switchable
Temperature modulation input	+/-10V for +/-10K
Laser diode protection values	Maximum current, maximum voltage, maximum temperature, minimum temperature (all adjustable)
CCTC-12A	
Laser current range	0...12A
Laser current polarity	positive only
Coarse current adjustment resolution	3mA
Fine current adjustment resolution	120μA
Laser voltage range	0...4V
Temperature range	$13...56°C$
Coarse temperature adjustment resolution	10mK
Max. TEC current	8A
Minimum seed level threshold	0...2.5V adjustable
Laser diode protection values	Maximum current, maximum voltage, maximum temperature, minimum temperature, minimum seed level, maximum output power or maximum reflected power (all adjustable)

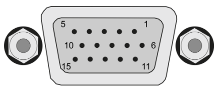
10.2 Mains Power Cable

Use the included power supply cable that provides proper grounding contact. The system may be delivered with country-specific mains power cables.

The power supply automatically adapts to local main power supplies of 100...120 VAC, 220...240 VAC.

10.3 HD-15 Connector

NOTICE: Only use the cable delivered with your system. Using standard cables like those that are used for personal computers can lead to malfunction or damage of electronic components. Many available cables have internal connections (common shielding of R, G, B) or some pins are not connected.



Hd15 Socket

1	input a
2	input b
3	input c
4	input d
5	analog ground
6	+15V
7	-15V
8	system ground
9	n.c.
10	n.c.
11	n.c.
12	n.c.
13	n.c.
14	n.c.
15	n.c.

11 Delivery Content

Your *LaseLock* system consists of the following components:

- *LaseLock* control unit
- *LaseLock* user manual
- 1x PreAmp Box
- Kangoo Software USB drive
- 1x HD-15 cable
- USB cable
- Country specific power supply cable
- External power supply (DC12V version only)

It is recommended to keep the packaging material for future storage and transportation. Please check the contents of your delivery for completeness.

12 Customer Service

In case of service needs, general questions, need of repair or warranty claims you will get quick and effective support at:

TEM Messtechnik GmbH
Grosser Hillen 38
D-30559 Hannover
Germany

Tel: +49 (0)511 51 08 96 -30
Fax: +49 (0)511 51 08 96 -38

E-mail: `mailto:info@TEM-messtechnik.de`
URL: `http://www.TEM-Messtechnik.de`

Notes

Notes

Notes