PhaseLockManual

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Contents

1 Product description

1.1 General

PhaseLock is a general electronic device for the set-up of a phase-locked loop (PLL). It synchronizes the pulse train of a laser with an electronic reference clock or with another laser (see figure 1). *PhaseLock* comprises a phase comparator unit for two periodic RF (radio frequency) input signals and two PID controllers as well as a logic section that eases the locking and re-locking. High voltage amplifiers for PZT actuators and a micro stepping motor driver are available as add-ons.

PhaseLock well applies for:

- Stabilization of the repetition frequency and pulse timing of pulsed lasers
- Control of the pulse envelope phase (carrier offset frequency) of femtosecond lasers
- Stabilization of frequency or phase of electronic oscillators

Phase locking of the optical frequency of continuous-wave (cw) lasers was reportedly accomplished successfully.

1.2 Functional components

PhaseLock combines all components required or beneficial for this purpose in a user-friendly compact device:

- multi cycle phase comparator
- input section for signal conditioning
- independent PID regulators, adapted especially to resonant systems like piezo-driven optical components
- output amplifier, user-selectable as high-voltage amplifier for piezo actuators, or as low-voltage amplifier generating a control signal for external amplifier sections
- logic section for automatic recognition of successful locking

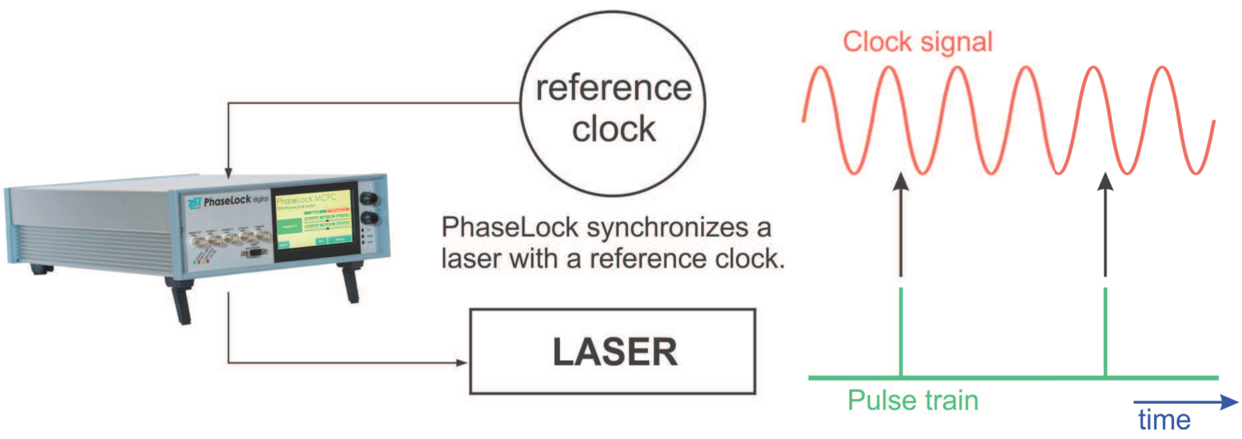


Figure 1: PhaseLock principle of operation.

The *PhaseLock* block diagram is shown in Figures 2 and 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 *PhaseLock*.

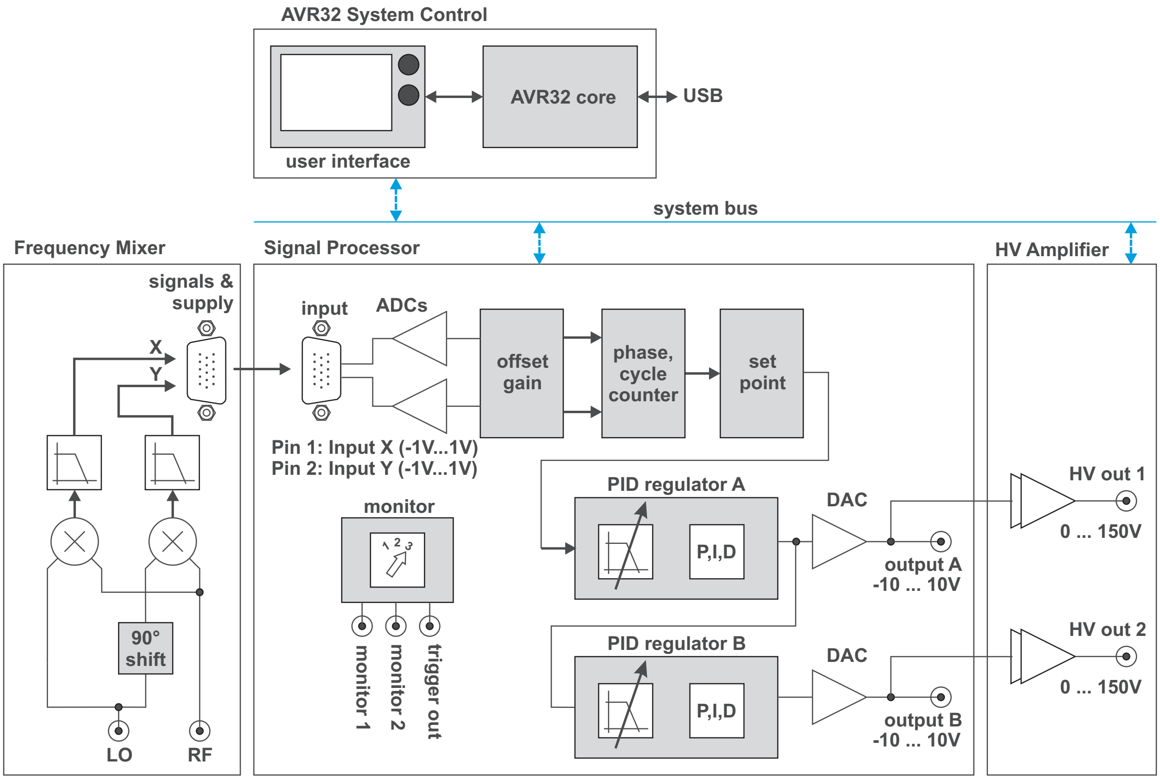


Figure 2: Schematic block diagram of *PhaseLock* digital device with MCPC option.

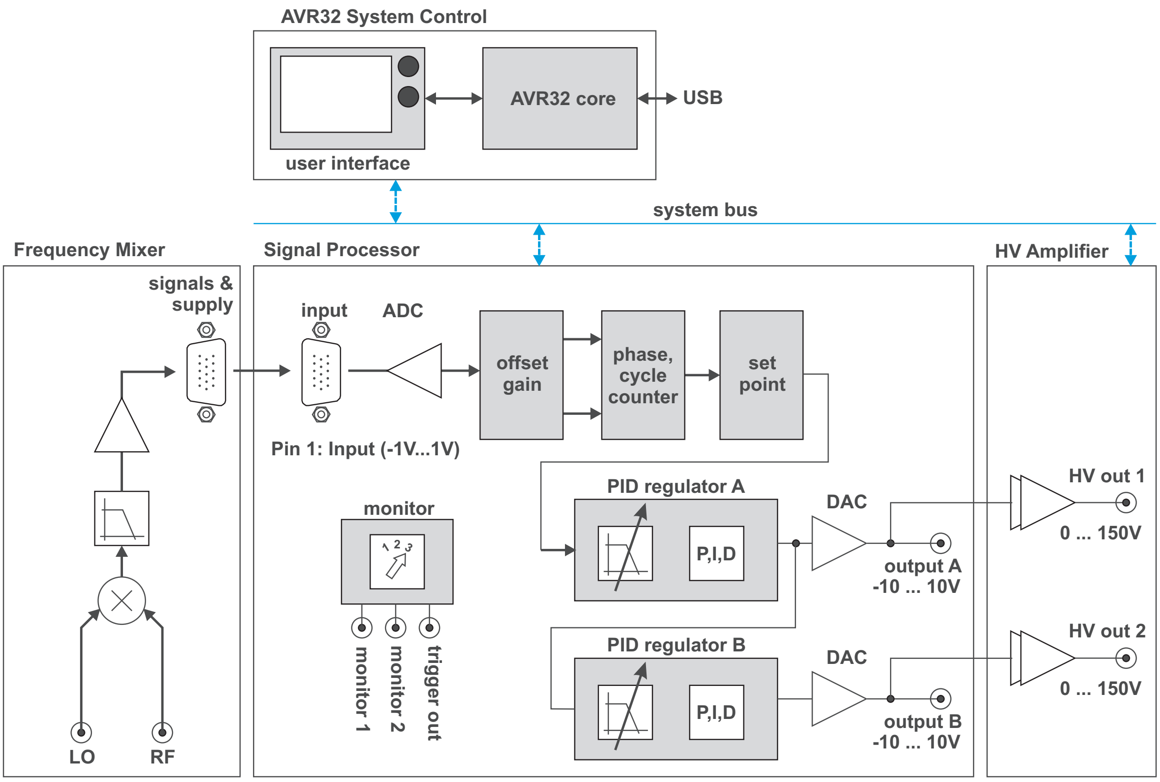


Figure 3: Schematic block diagram of *PhaseLock* digital device without MCPC option.

2 Safety Instructions

Before operating the *PhaseLock*, 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 *PhaseLock* device is intended for laboratory use only. The *PhaseLock* device should be operated by trained personnel.

CAUTION! The *PhaseLock* 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 "UnfallverhÃijtungsvorschrift 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 *PhaseLock* 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 *PhaseLock* 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 *PhaseLock* to third parties only with this manual.

3 Scope of delivery

Please check first of all if you obtained all the parts listed below. If not, please check your ordering form and refer to the manufacturer or distributor.

We recommend to keep the packaging material for future storage and transportation.

3.1 Mandatory components

- *PhaseLock* electronics in desktop or 19″ rack case
- Country specific power cord
- USB A – B cable
- USB memory stick containing PC software
- This manual

3.2 Components for standard (MCPC) configuration

The following parts come with the *PhaseLock* electronics for use with pulsed lasers (standard application). They are omitted for optical phase stabilization of cw lasers.

- RF mixer unit
- 15-pole cable with high density Sub-D connectors (male – female)

3.3 Optional parts

Upon explicit order, the following components are integral parts of the *PhaseLock* electronics

- High voltage amplifier for PZT actuators
- Driver for a stepping motor

3.4 Alternative parts

The low voltage supplied version of *PhaseLock* comes with an external AC-to-DC converter power supply (mains adapter) 12 W DC, min. 30 W.

4 Brief description of the control elements

4.1 Front panel elements

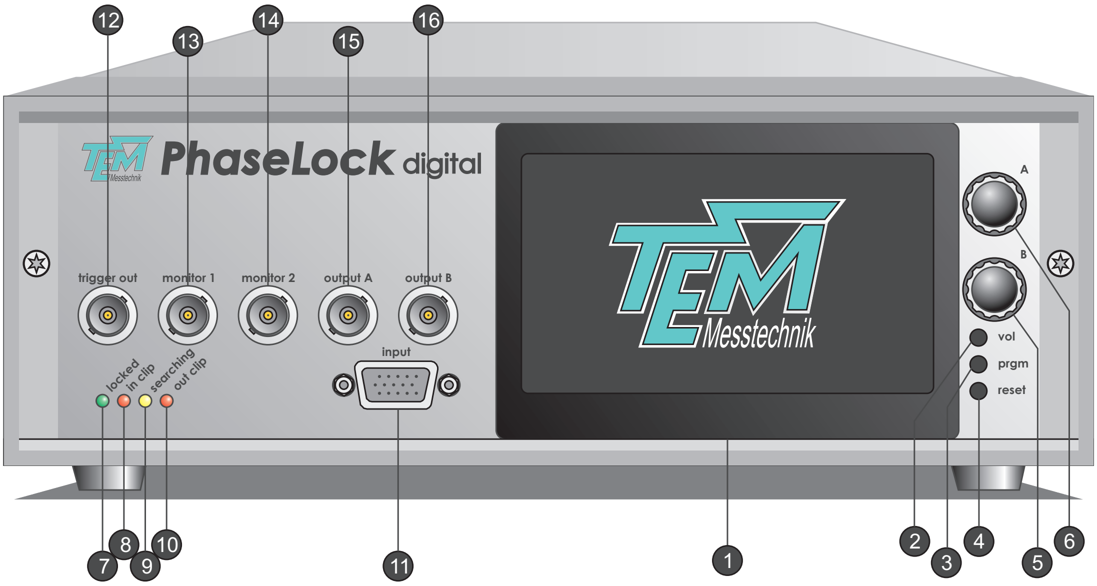


Figure 4: Front panel elements.

Nr.	Description
1	4.3″ TFT touch screen
2	Loudspeaker volume potentiometer
3	Programmer button. Only used for flashing firmware to the microcontroller.
4	Reset button. Resets the microcontroller.
5	Rotary knob B. To change the digital place when editing a numerical value, turn the wheel while keeping it pressed.
6	Rotary knob A. To change the digital place when editing a numerical value, turn the wheel while keeping it pressed.
7	LED "locked". Turns on whenever the error signal of all enabled regulators is within a small range
8	LED "input clip". Indicates a large input signal (above +0.9 V or below -0.9 V on input a, b or above +9 V or below -9 V on input c, d)
9	LED "searching". Turns on when one of the regulators is searching for a valid lock point
10	LED "out clip". Turns on when one of the regulators reaches the limit of its output range
11	"input" HD15 Socket. Feedback measurement input for the mixer product quadrature signal (not used if mixer is installed in device case)
12	"trigger out" BNC plug
13	"monitor 1" BNC plug. Can be used for observation of internal signals
14	"monitor 2" BNC plug. Can be used for observation of internal signals
15	"output A" BNC plug. Regulator output signal (low voltage: -10 V. . . +10 V). For HV amp output see rear side
16	"output B" BNC plug. Regulator output signal (low voltage: -10 V. . . +10 V). For HV amp output see rear side.

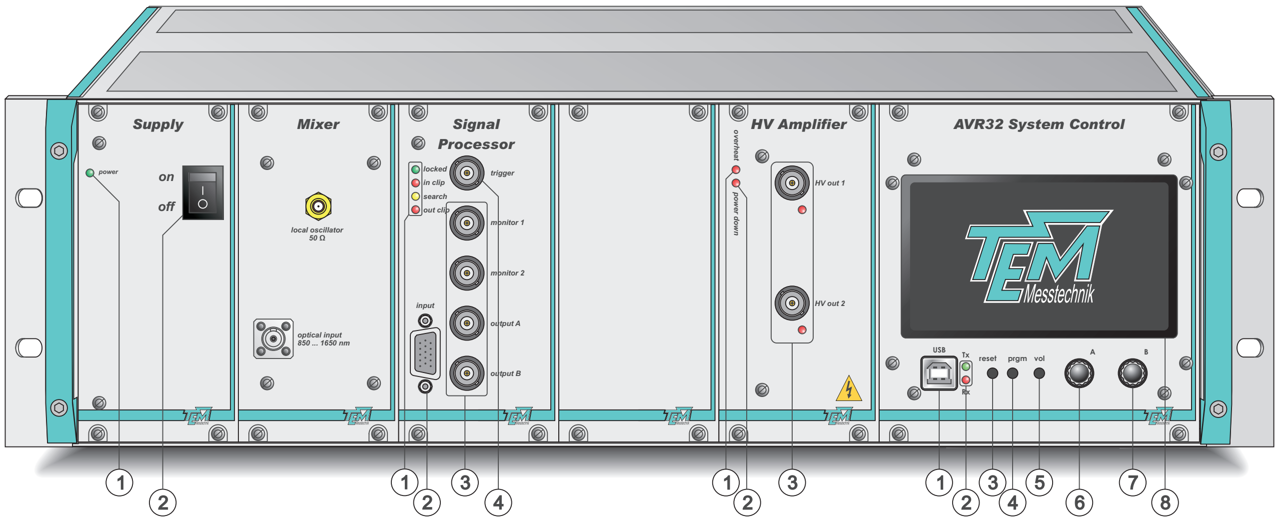


Figure 5: Front panel elements 19″ rack case.

Nr.	Description
Module: "Supply"	
1	Power on LED
2	Primary power switch (another primary power switch and the fuse holder are located on the rear side!)
Module: "Mixer"	
	This module contains the mixer electronics. The contruction and the front panel elements may vary depending on the mixer architecture and application requirements. For more details, please refer to chapter "Mixer". In standard configuration, the mixer electronics are located in a separate case.
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 95%) • 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 knob A
7	Rotary knob B
8	4.3″ TFT touch screen

4.2 Rear panel elements

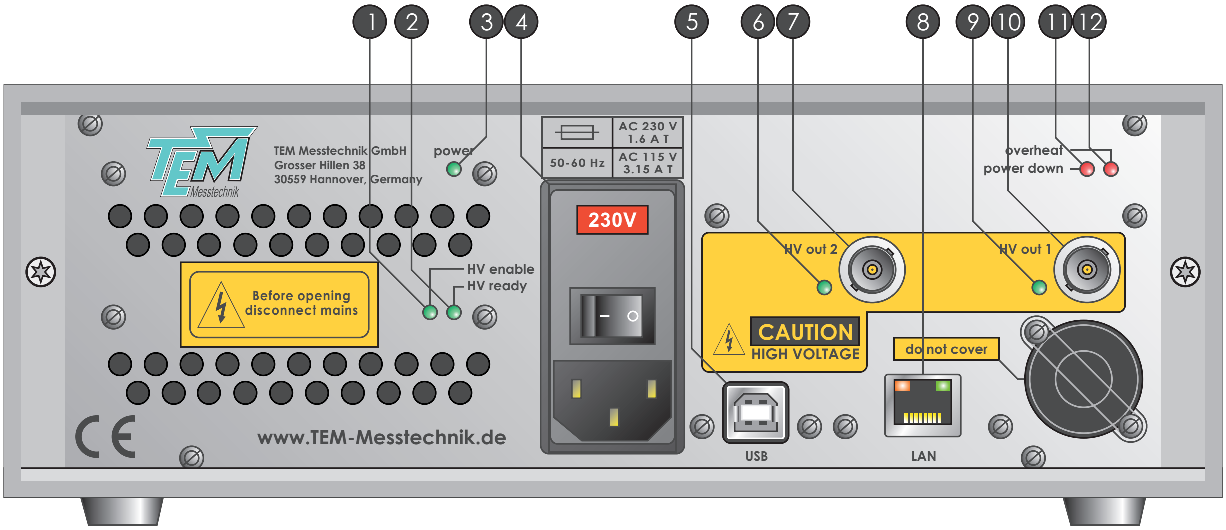


Figure 6: Rear panel elements (standard and HV version).

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

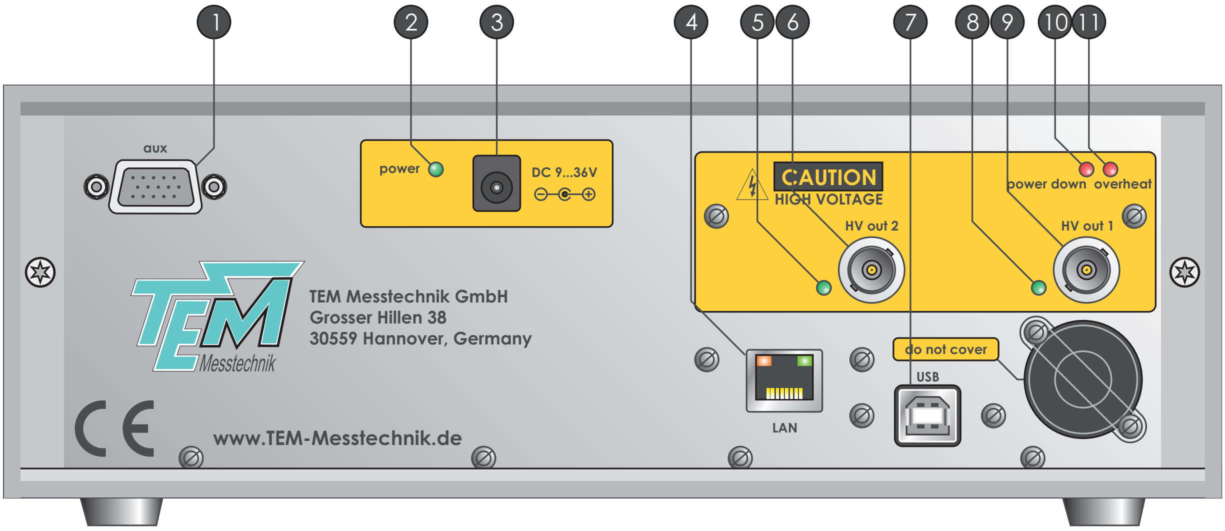


Figure 7: Rear panel elements (DC12V version).

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 (green: actual output voltage high, red: actual output voltage low)
6	(only with HV option) high voltage output channel 2 BNC jack (corresponding to output B signal)
7	(optional) Ethernet LAN connector (RJ-45)
8	(only with HV option) bicolor LED: output voltage indicator for HV out 1(green: actual output voltage high, red: actual output voltage low)
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 lit when the amplifier voltage is disabled due to overheating or overcurrent
11	"overheat" red LED: Lit, if the HV amp stage is overheated and the output voltage is switched off.

4.3 Touch screen

4.3.1 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.

5 Installation

5.1 Placement

Place *PhaseLock* suitably, taking into account the safety warnings in chapter 2.

5.2 Mains Connection

PhaseLock has an IEC power socket at the rear side (unless otherwise ordered, see section 5.3). Use the delivered power cord for connection to the AC mains. If country-specific cables are required use high quality power cords, fitting to the local power supply outlets. *PhaseLock* accepts AC power supply in a wide voltage range (100. . . 240 V AC). The primary mains switch and the fuse holder are located next to the IEC socket at the rear side. For fuse rating, see label next to the holder.

5.3 Alternative DC power supply

Upon special order, *PhaseLock* may be equipped with a DC supply socket instead of the AC power supply. In that case, use the AC-to-DC converter power supply ("mains adapter") delivered with the *PhaseLock*. Alternatively, any other standard DC power supply with voltage from 12. . . 24 V and minimum 30 W power rating may be used. The connector must have 5.5 mm outer and 2.5 mm inner diameter, plus pole at the inner contact. Please note that no primary switch nor a fuse holder are present for the DC supply. The device will start up right after the connection has been made.

5.4 Connection to PC

PhaseLock can work completely as a stand-alone device. However, you might find it helpful to use the "Kangoo" software for visualization and set up of parameters. If you wish to connect *PhaseLock* to a PC, use the delivered USB cable. For software and driver installation refer to section 11.

6 Getting started

6.1 Overview

The following sections describe how to take *PhaseLock* into operation from the beginning, step by step. These chapters can be used for becoming acquainted with *PhaseLock*, as well as for function testing of the device. It is strongly recommended to read through chapter 4 on page 10 first. A detailed description will follow later in this manual. Please have a 2-channel oscilloscope with at least 10 MHz input bandwidth at hand. An analog oscilloscope is a good choice, but if you use a digital one, make sure the sampling rate is at least 10 MHz to avoid aliasing effects. Start with the *PhaseLock* installed according to section 5 and switched *off*.

6.2 Using the PC visualization software "Kangoo"

Even though the *PhaseLock* 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. If you wish to operate *PhaseLock* by the frontpanel touch screen, just proceed with section 6.3. All explanations will be given for software and front panel operation, as far as both are available.

If "Kangoo" has not yet been installed on your computer, please follow the instructions in chapter 11 on software and driver installation.
Connect the *PhaseLock* 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.

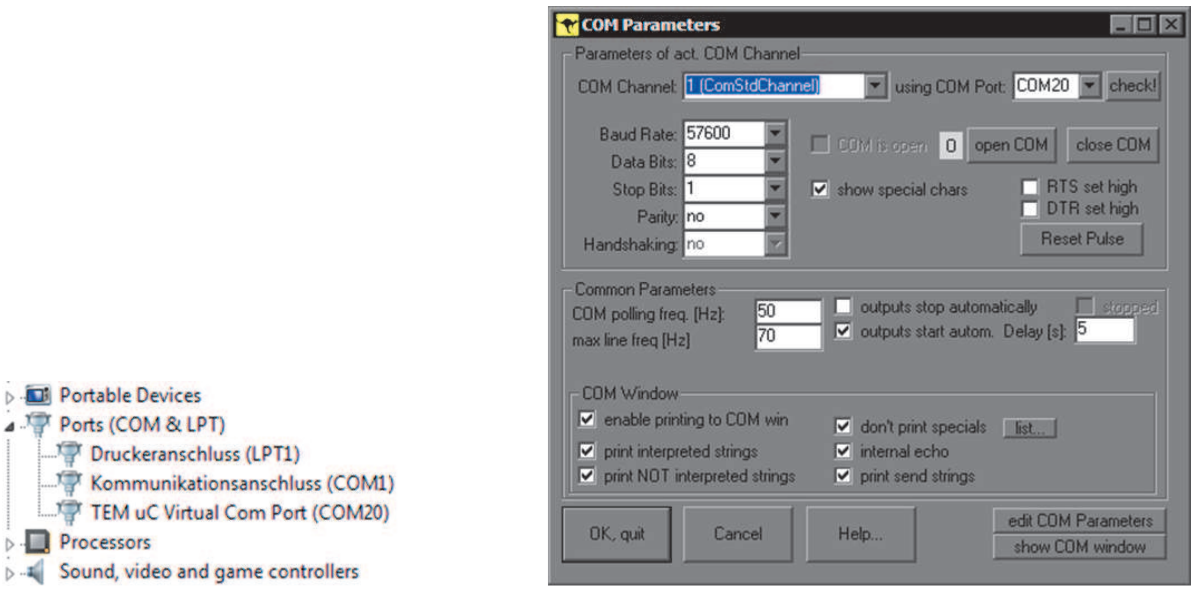


Figure 8: COM Port in the device manager (left) and corresponding COM port settings in Kangoo (right).

Start the "Kangoo" software and type F5 (or go to Communication → COM parameters) to open the interface dialog (compare figure 8). Click to "check!" in the COM Parameters windows to search for available COM ports. The COM number of *PhaseLock* 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 figure 9).

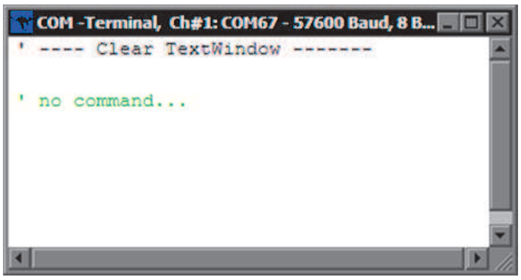


Figure 9: COM Terminal window.

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 ....

6.3 Input signal connections

PhaseLock requires two high-frequency input signals: First, the photo diode signal representing the laser's pulse train (preferably bandpass filtered). Second, a sinusoidal reference frequency signal (named "LO" = local oscillator). This may be a synchrotron clock, an RF signal from a synthesizer or another laser, e.g.. The mixer unit converts the high frequency input signals into a low-frequency signal (so-called intermediate signal) containing the information about the frequency and phase difference of the input signals. Operation of the *PhaseLock* requires the LO frequency to equal the repetition frequency of the laser or an integer multiple thereof (a harmonic of the pulse signal):

$$f_{\mathrm{LO}} = n \cdot f_{\mathrm{rep}}, n = 1, 2, 3, \ldots \tag{1}$$

Example: If the laser repetition frequency can be adjusted in the range 80.00...80.10 MHz, the LO frequency should be chosen $f_{\mathrm{LO}} = 80.05$ MHz or $f_{\mathrm{LO}} = 160.1$ MHz or $f_{\mathrm{LO}} = 240.15$ MHz and so on. Set the LO signal to an amplitude of approximately 1 V_{pp}. (The mixer circuit accepts LO signals in a power range of 0...7 dBm at 50 Ω, corresponding to 0.3...1.5 V_{pp}.) Connect the LO signal to the SMA connector "LO in" located at the face side of the mixer, see figure 10.

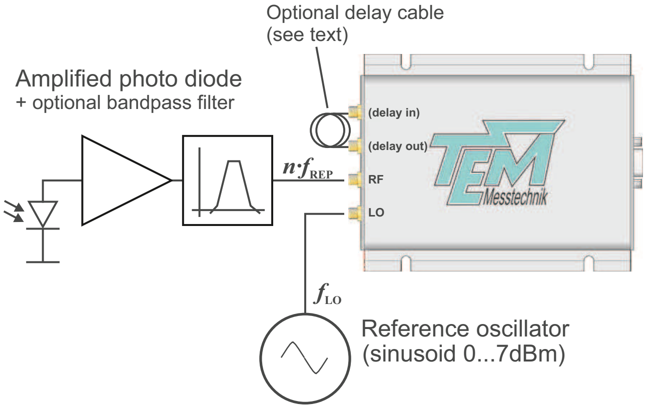


Figure 10: Frequency mixer module and its RF connections.

Connect the photodiode signal to the SMA connector "RF" located at the face side of the mixer, see figure 10. Please make sure that the bandwidth of the photodiode is at least as high as the chosen LO frequency. If higher harmonics are used ($n >= 2$), we recommend to insert a suitable bandpass filter between the photodiode and the mixer. The purpose of the filter is to suppress all but the nth harmonic in photodiode signal.

All SMA connectors have an impedance of 50 Ω. Please make sure that both signal sources (photodiode and local oscillator) as well as the interconnecting cables are matched to this impedance.

Note that the MCPC version of the mixer contains a delay cable the length of which is matched to a certain LO frequency that was defined upon order. That frequency value is noted on the face side of the mixer. (If you ordered a mixer for a wide frequency range, the delay cable must be chosen according to the LO frequency. In this case connect the appropriate cable to the SMA connectors "delay in" and "delay out" located at the face side of the mixer, see figure 10. Please refer to chapter 10.1 for details on this topic.)

The intermediate signal is transferred to the signal processor via the 15-pole Sub-D connector. Connect the frequency mixer to the 15-pole "input" connector of the *PhaseLock* device (see figure 11). Please note that the amplitude of the signals inside the mixer is adjusted remotely by the *PhaseLock* 's signal processor. Therefore, this connection must be made before power up.

During the installation process, several signals in the signal path must be checked for their shape and size. For this end, connect an oscilloscope to the BNC jacks "monitor 1, 2" on the front panel - see figure 11). (The location of the monitor BNC connectors on 19″ rack case are shown in figure 5.) Set the input sensitivity of the oscilloscope channels to 2 V/div and remove / switch off any 50 Ω matching resistor!
MCPC option only: If possible, switch the oscilloscope to the X–Y display mode.

6.4 Output signal connections

PhaseLock has up to three outputs to control the laser: two voltage outputs ("output A" and "output B" on the front panel) and one optional motor driver accessible from the rear side. If a high voltage amplifier is installed, amplified copies of the output A and output B voltages are available

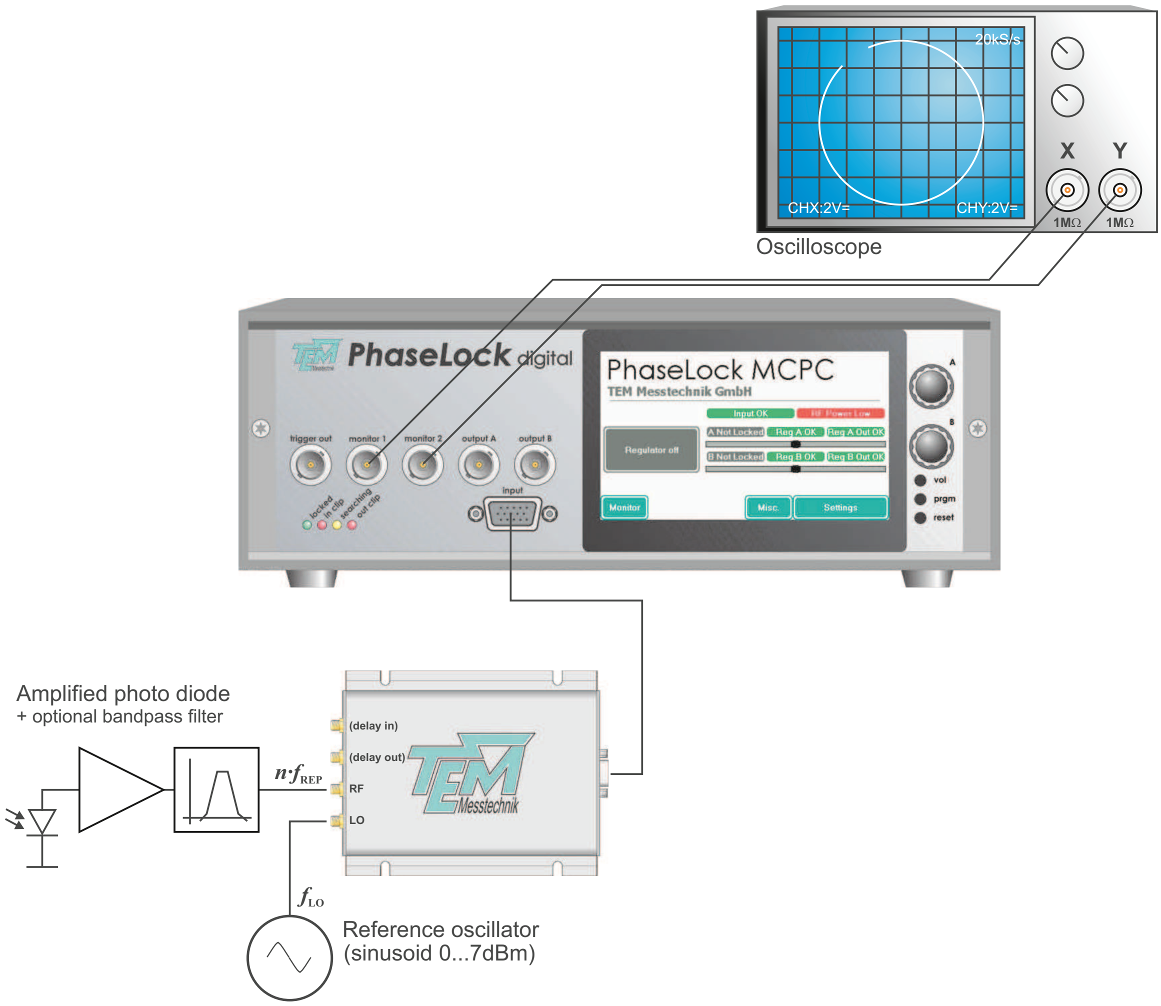


Figure 11: PhaseLock input and monitor wiring scheme.

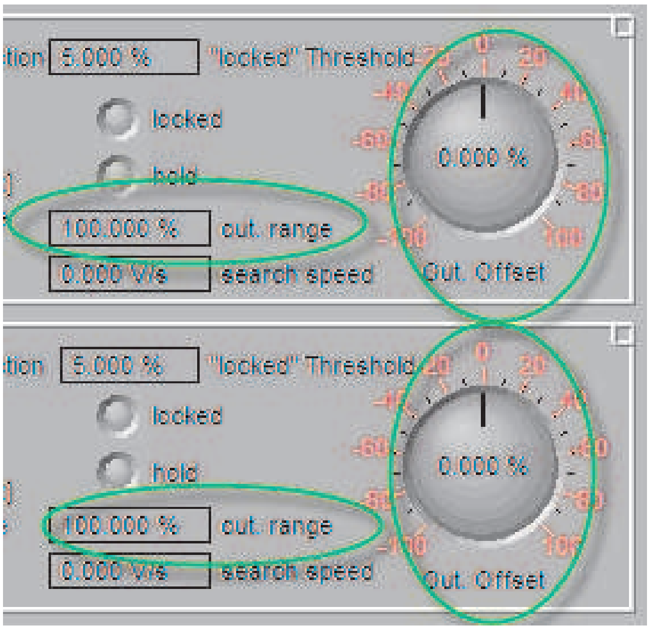


Figure 12: Settings in the Kangoo GUI that define the voltage ranges of output A and B. Be aware that faulty operation may cause damage to your laser!

at the "HV out 1 " and "HV out 2" BNC connectors at the rear side. Before connecting PZTs, please check that they comply with the output voltage range of *PhaseLock* (standard: 0. . . 150 V)! However, see section 6.5 for a software reduction of the output voltage range.

If your laser is equipped with *one* PZT actuator to control the pulse repetition frequency (rep rate), connect it to the "output A" or "HV out 1", respectively.

If your laser is equipped with *two* PZT actuators (one for fast and the other one for slow but large-range control), connect the fast PZT to the "output A" or "HV out 1", respectively. Then connect the slow, large-stroke PZT to the "output B" or "HV out 2", respectively.

If your laser is equipped with a motorized stage to coarsely adjust the pulse repetition frequency, connect it to the "Motor" connector at the rear side.

6.5 Output signal range

The voltage range of "output A" and "output B" on the front panel is ± 10 V. For the high voltage outputs "HV out 1 " and "HV out 2" it is 0. . . 150 V. You can reduce this range by software settings. In order to adjust the range, localize the corresponding GUI elements "out range" and "out offset" in the Kangoo (see figure 12). For "out range", 100% corresponds to the said voltage range, while for "out offset" $\pm$100% corresponds to the full range. Therefore the standard values are 100% and 0%, respectively.

NOTE: Faulty operation on the range / offset settings may cause damage to the laser!

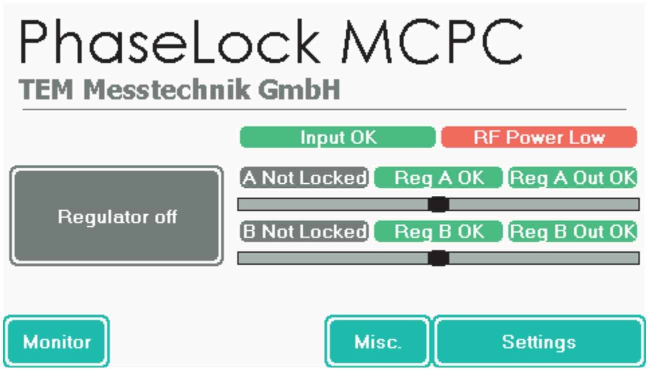


Figure 13: Home screen on the TFT display after power–up.

For example, a range of 66% and an offset of –33% would reduce the high voltage output to 0. . . 100 V.

Do not forget to click the "save to disc" button to store the recent settings to the non–volatile memory of the *PhaseLock*.

6.6 Switch the device on

Turn on the main switch on the rear side. (19″ rack case version only: Turn on the power switch on the front side, too — see figure 5.) Given a few seconds for booting, the device will be ready for use after a short acoustical signal. The display will show the home screen as shown in figure 13.

In the following sections, the setup of a simple control loop is described, using a PZT inside the laser to stabilize the pulse timing relative to a reference oscillation.

6.7 Input Signal Monitor

The mixer unit contains amplifiers the gain of which needs to be adjusted depending on the level of the photodiode signal, so that the intermediate signal reaches an amplitude of about 8. . . 16 V peak-to-peak. In order to find the best gain setting, the intermediate signal has to be displayed on the oscilloscope (see 10.2 for details). For this end, choose the "input" signal for monitor output 1. For the MCPC option, choose "input X" for monitor output 1 and "input Y" for monitor output 2: When operating the *PhaseLock* by PC control ("Kangoo" software), click to the selector "monitor 1" and choose "norm X", then click to the selector "monitor 2" and choose "norm Y". When operating the *PhaseLock* by the touch panel, press the button "Monitor". In the subsequent menu list (compare figure 14), press "Monitor 1". This opens up a list of options through which you can scroll either by the up and down buttons on the right hand side or by turning the rotary knob B. Select "Input X normalized" by clicking the corresponding button. Leave this menu by pressing "<" once. For the MCPC option, press "Monitor 2" and select "Input Y normalized" from the list. Leave this menu by pressing "<" twice to return to the home screen.

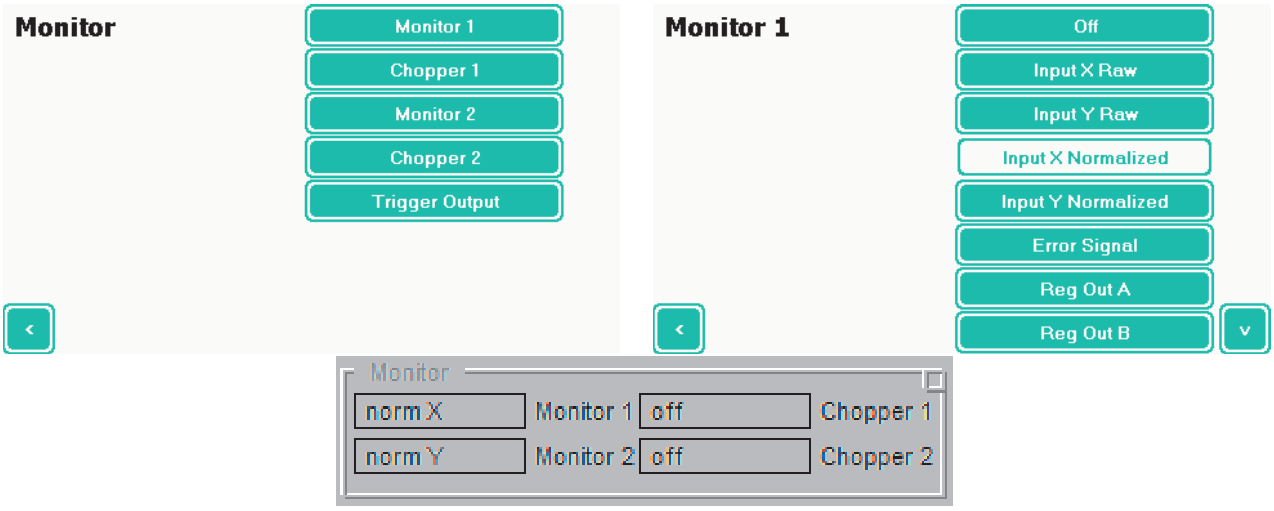


Figure 14: Monitor menu (top left) and selection list (top right), and the corresponding GUI elements (bottom).

The oscilloscope now displays the mixer output signal (intermediate signal) as it is received and digitized by the *PhaseLock* electronics. The signal shape should be a sinusoidal (MCPC: a cosine (x) and a sine (y) signal – a Lissajous figure) with an amplitude of several volts peak-to-peak), like shown in figure 15.

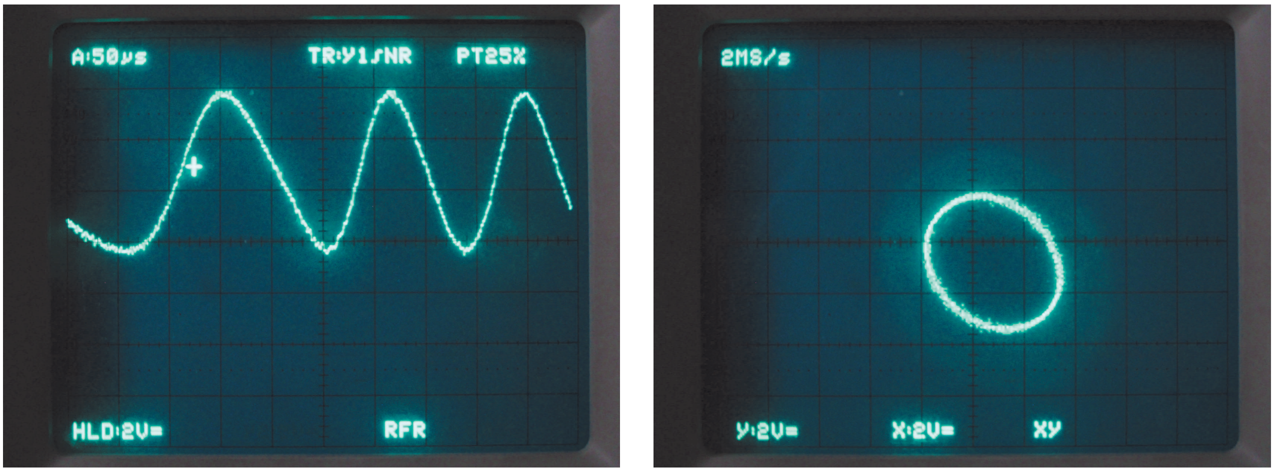


Figure 15: Intermediate signal (monitor signals "Input X normalized" and "Input Y normalized") displayed on an oscilloscope in Y–T mode (left) or X–Y mode (right, MCPC version only). Please note that these signals still need to be adjusted in terms of offset, amplitude and phase - see section 6.8.

However, the amplitude of the signal(s) on the oscilloscope may be low (even almost zero) for either of the following reasons:

1. The frequency difference between the mixer input signals (the photodiode and the reference signal) may be too large, resulting in an intermediate frequency exceeding the bandwidth of the *PhaseLock* electronics. During the adjustment, the frequency difference should be below 100 kHz.

2. The signal level on the photodiode may be rather low, resulting in a low amplitude of the intermediate signal.

So if the signal on the oscilloscope has a low amplitude you may proceed and increase the mixer gain according to next section 6.8. Alternatively, you can try to coarsely change the either the reference frequency or the laser rep rate and see if the signal reappears. For this end, proceed with section 6.9 and return to this paragraph afterwards.

6.8 Input Signal Adjustment

The aim of this section is to adjust the input signals in terms of offset and amplitude so that they cover a range from -6 V to +6 V like shown in figure 16.

First of all, adjust the laser or the reference oscillator so that the difference between the reference frequency and the pulse frequency (or the chosen harmonic of the latter) does not exceed 100 kHz. If you do not know how to do that straight forward, you may arbitrarily change either frequency and thus try to minimize the frequency of the signals on the oscilloscope. You may jump to section 6.9 and return to this paragraph afterwards. Remark: If your laser is extremely stable, you may find a setting were the rep rate equals the LO frequency on a sub-Hz level. This results in the intermediate signal to move very slowly or even stop moving. If this is the case, adjust the difference to at least some tens of Hz, otherwise it takes too much time to recognize the signal shape.

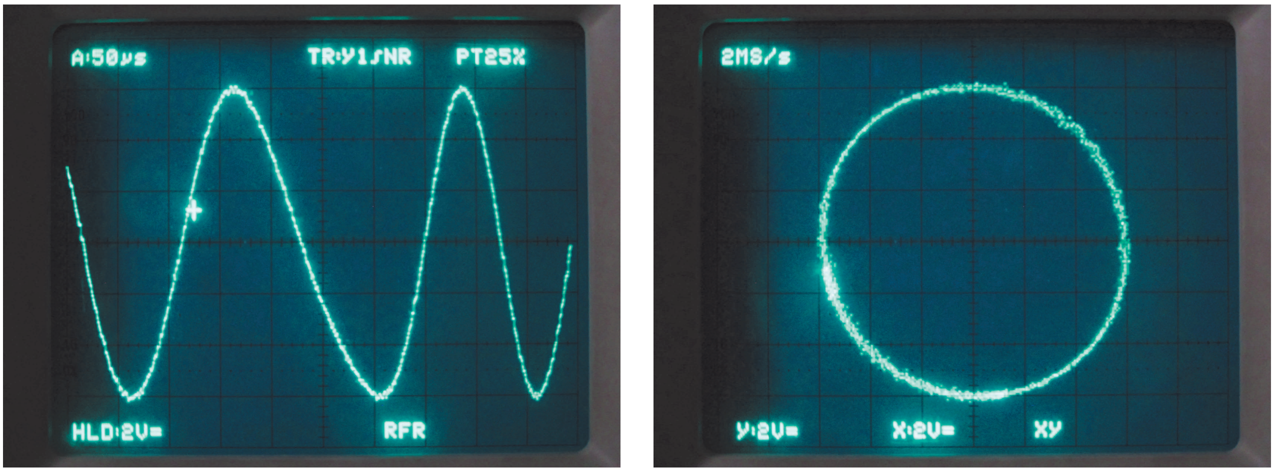


Figure 16: Intermediate signals properly adjusted in terms of offset, amplitude and phase, displayed in Y–T mode (left) or X–Y mode (right, MCPC version only).

When operating the *PhaseLock* by touch panel, navigate to the "Input settings" menu (see figure 17) by pressing *menu* → *Input settings*. When using the Kangoo software, locate the respective GUI elements on the screen.

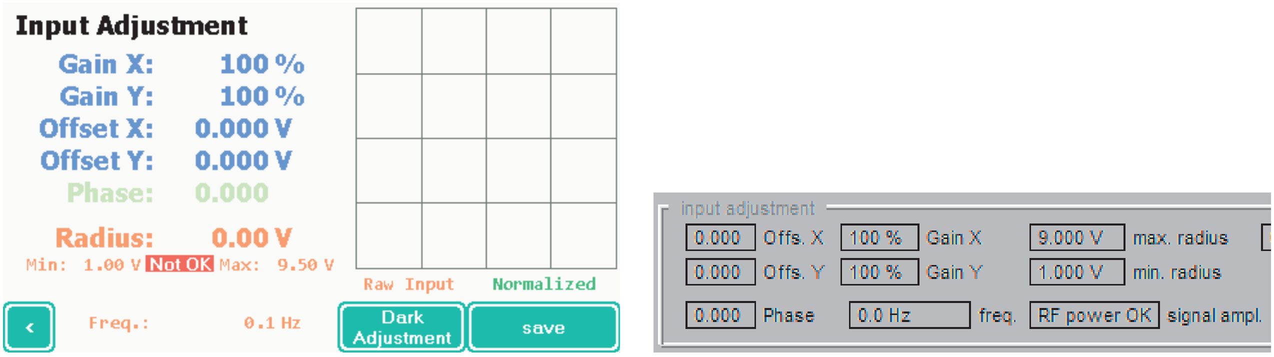


Figure 17: Input adjustment screen and GUI.

Adjust the parameters "Gain" and "Offset" (MCPC option: "Gain X", "Gain Y", " Offset X" and "Offset Y") so that the signal(s) on the oscilloscope are symmetric about zero and have an amplitude of about ± 6 V (± 12 V_{pp}). To change a parameter, touch the respective number on the display so that it is marked up. Then turn the knob B to edit the underlined digit. **REMARK:** In order to select the digit for editing, turn the knob while keeping it pressed.
The signals should not exceed the range of ± 8 V to avoid distortion. The red LED "in clip" will be lit if the signal approaches the limits of ± 10 V.
Please note that the amplifier bandwidth decreases when increasing the gain, possibly affecting the feedback quality. It is recommended to operate the *PhaseLock* at a gain setting around 100%. If the required intermediate signal level cannot be reached at this gain, it is often better to increase the optical power on the photodiode or insert an RF amplifier between the photodiode (or bandpass filter, if present) and the mixer input, than to increase the mixer gain.
MCPC option only: Adjust "Phase" so that the phase difference between the signals is $90°$. If your oscilloscope is set to X–Y display mode, you can recognize the optimal setting by the signal shape becoming a circle centered about the origin and having a radius of 6 V, see right hand side of figure 16.

MCPC option only: The *PhaseLock* can detect the presence of the RF input signal from the radius of the Lissajous figure. To enable this feature, set the "Min. Radius" value to 4 V which is well below the actual value of about 6 V. Absence of the input signal (or the intermediate leaving the mixer bandwidth) will be signalized by the green LED "OK" turning red.
Finally click to "save" on the TFT or on "Save to ÂțC" on the GUI to store the parameters to the non-volatile memory of the *PhaseLock* device.

6.9 Output signal check

If your laser is equipped with *one* PZT actuator to control the pulse repetition frequency (rep rate), skip the following paragraphs and continue with section 6.9.2.

If your laser is equipped with *two* PZT actuators (one for fast and the other one for slow but large-range control), proceed with the following section to adjust the large-stroke actuator.

6.9.1 Check and adjustment of the actuator at output B (HV out 2)

When operating the *PhaseLock* by touch panel, navigate to the "Regulator B" menu (see figure 18) by pressing *menu* → *Regulator B*. When using the Kangoo software, locate the respective GUI elements on the screen.

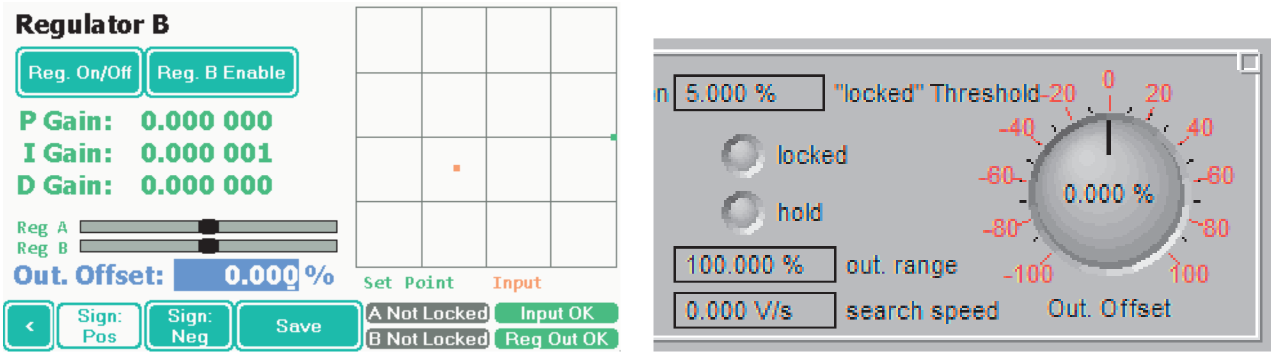


Figure 18: Output and regulator B adjustment screen and GUI.

In order to check the effect of the large-stroke actuator on the laser's repetition frequency, change the "Out. Offset" value and observe the effect on the frequency of the intermediate signal. For this end, touch the respective number on the display so that it is marked up as shown in figure 18. Then turn the knob B to edit the underlined digit. **REMARK:** In order to select the digit for editing, turn the knob while keeping it pressed. The avaliable range of ±100% corresponds to a voltage range of ±10 V on "output B" and 0...150 V at the high voltage output "HV out 2".

Please be aware that the signal on the oscilloscope may disappear and reappear if the intermediate frequency leaves or enters the bandwidth of the mixer output. The aim is to coarsely adjust the frequency so that the amplitude reaches its maximimum and then fine-tune it so that the frequency comes close to 0.

If the intermediate frequency does not reach 0 within the adjustment range of the large-stroke PZT, a coarse adjustment by other means is required. If a motor is available for coarse adjustment, proceed with the corresponding section in this manual. Otherwise refer to the laser's manual for coarse adjustment. Alternatively, you can change the reference oscillator's (LO) frequency to minimize the intermediate frequency.

Finally cross-check that the input signals cover a range from -6 V to +6 V like shown in figure 16. If this is not the case, return to section 6.8

Before leaving the "Regulator B" menu, check that regulator B is *not* enabled.

6.9.2 Check of the actuator at output A (HV out 1)

When operating the *PhaseLock* by touch panel, navigate to the "Regulator A" menu (see figure 19) by pressing *menu* → *Regulator A*. When using the Kangoo software, locate the respective GUI elements on the screen.

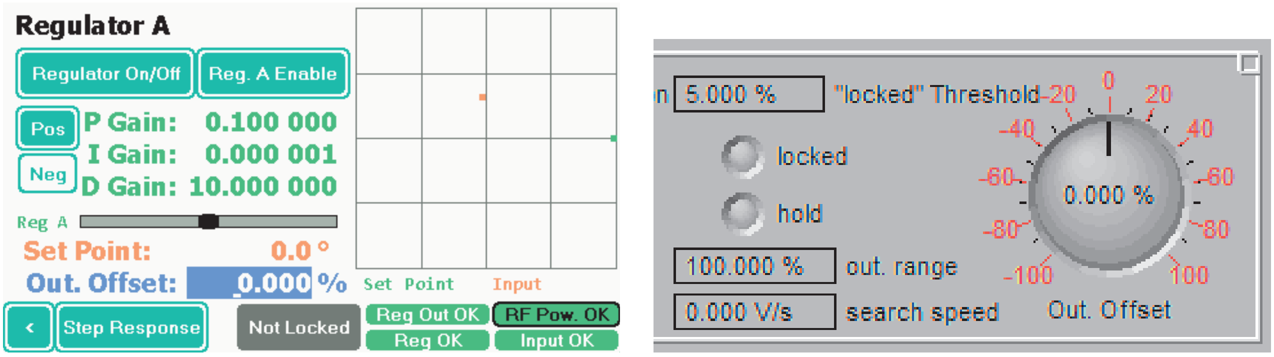


Figure 19: Output and regulator A adjustment screen and GUI.

In order to check the effect of the actuator on the laser's repetition frequency, change the "Out. Offset" value and observe the effect on the frequency of the intermediate signal. For this end, touch the respective number on the display so that it is marked up as shown in figure 19. Then turn the knob B to edit the underlined digit. **REMARK:** In order to select the digit for editing, turn the knob while keeping it pressed. The avaliable range of $\pm 100\%$ corresponds to a voltage range of $\pm 10\,\mathrm{V}$ on "output A" and $0\ldots 150\,\mathrm{V}$ at the high voltage output "HV out 1".

If the intermediate frequency reaches its minimum at an output offset far away from 0%, a coarse adjustment by other means is required. If your laser has a second PZT with larger stroke, jump to section 6.9.1. If a motor is available for coarse adjustment, proceed with the corresponding section in this manual. Otherwise refer to the laser's manual for coarse adjustment. Alternatively, you can change the reference oscillator's (LO) frequency to minimize the intermediate frequency.
MCPC option only: Notice the direction of the frequency change. This will be important for regulator sign selection. If you increase the output offset and the frequency increases too, you will need a *positive* regulator sign. (The Regulator sign is irrelevant without MCPC option.)

6.10 Taking the PID regulator A into operation

The purpose of the *PhaseLock* is to adjust the laser in a way that

1. its repetition frequency (or a multiple thereof) equals the reference frequency, and
2. the relative phase of both oscillations stabilizes at a preset value. For a pulsed laser, the "phase" corresponds to the time at which the pulse occurs with respect to the period of the reference oscillation (see figure 1).

Once the phase is stabilized (locked), you can adjust it arbitrarily between 0 and 2π and beyond (i.e., adjust the timing of the laser pulses to arbitrary values within one period of the reference signal — or even shift it by multiples thereof).
When setting up the regulator, keep in mind that the phase of the intermediate signal (mixer output signal) serves as "error signal". The regulator continuously determines its value and drives the output (and thus the laser) in a way that the error signal approaches a user-defined set (target) value (zero, e.g.). As a result, the phase difference between the RF input signal (photodiode signal) and the LO input (reference signal) becomes constant, meaning that the laser pulses appear always at the same time relative to the period of the reference oscillation (see figure 1).

For this reason, it is necessary to monitor the error signal and the regulator output signal simultaneously on the oscilloscope. For this end, set "Monitor 1" to "Error signal" and "Monitor 2" to "Reg out A" (compare figure 20).

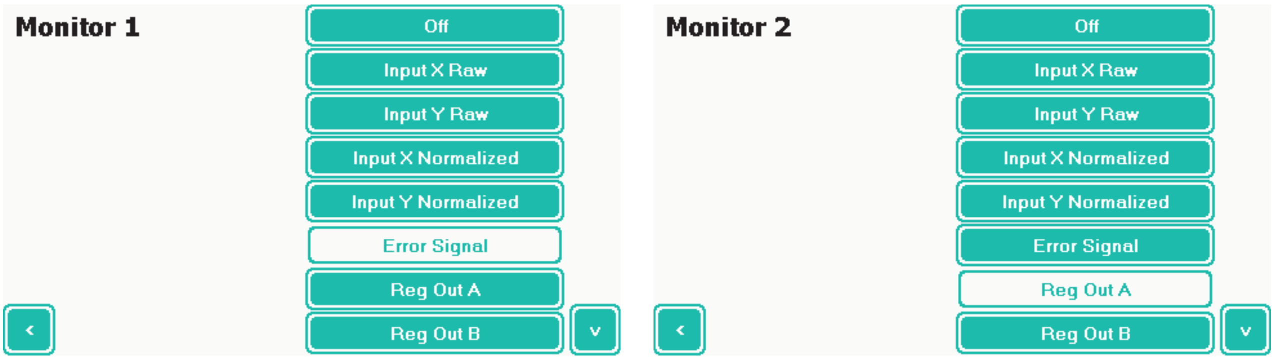


Figure 20: Monitor 1 and 2 set to "Error signal" and "Reg out A", respectively.

(If you are using a good analog oscilloscope in XY mode, you can these signals simultaneously to the previously selected input signals using "Chopper 1" and "Chopper 2" instead of monitor 1/2.)

Before the regulator is active, the RF (photodiode signal) frequency typically differs somewhat from the LO (reference signal) frequency. This means the relative phase (and thus the error signal) continuously increases or decreases. The error signal will therefore be displayed at either end of its voltage range (+10 V) or (-10 V), while the regulator output is at (0 V).
When operating the *PhaseLock* by touch panel, navigate to the "Regulator A" menu (see figure 21) by pressing *menu* → *Regulator A*. When using the Kangoo software, locate the respective GUI elements on the screen.

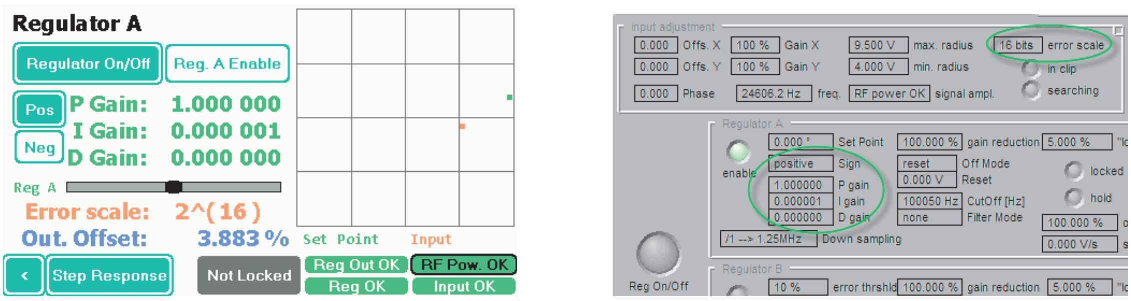


Figure 21: Regulator A adjustment screen and GUI (default settings).

Check the PID gain settings (P=1.0, I=0.000001, D=0.0; 'Error scale" = 2^{16}) and set the sign according to the direction of the actuator attached to output A: If the rep rate increases with increasing voltage, choose "positive" and otherwise "negative". (The latter case is the typical situation where a resonator end mirror is glued to a PZT.) Check that regulator A is enabled while regulator B is *not*.

Now watch the signal on the oscilloscope while clicking "Reg On/Off" and compare the observation with figure 22:
When the regulator is switched on, the phase detection counter is reset so that the error signal jumps back to zero (1). Due to the frequency difference between the laser and the reference, the phase

starts to increase (or decrease) again (2). However, this time the regulator output voltage starts to increase (or decrease), too. As this voltage controls the laser repetition frequency, it decelerates the phase slope and even reverses its direction so that it converges to zero (3), and the regulator output voltage comes to rest at a finite level (4). Congratulations! Your laser is phase–locked! You may now proceed with section 6.11 to optimize the lock. (This only works if the sign is correct — otherwise it will accelerate the phase slope (5) so that both voltages diverge towards $\pm\infty$ (6) until they come to stop at (+10 V) or (-10 V). This is of course not intended. If you observe this, switch the regulator off, reverse the regulator sign and try switching on again.)

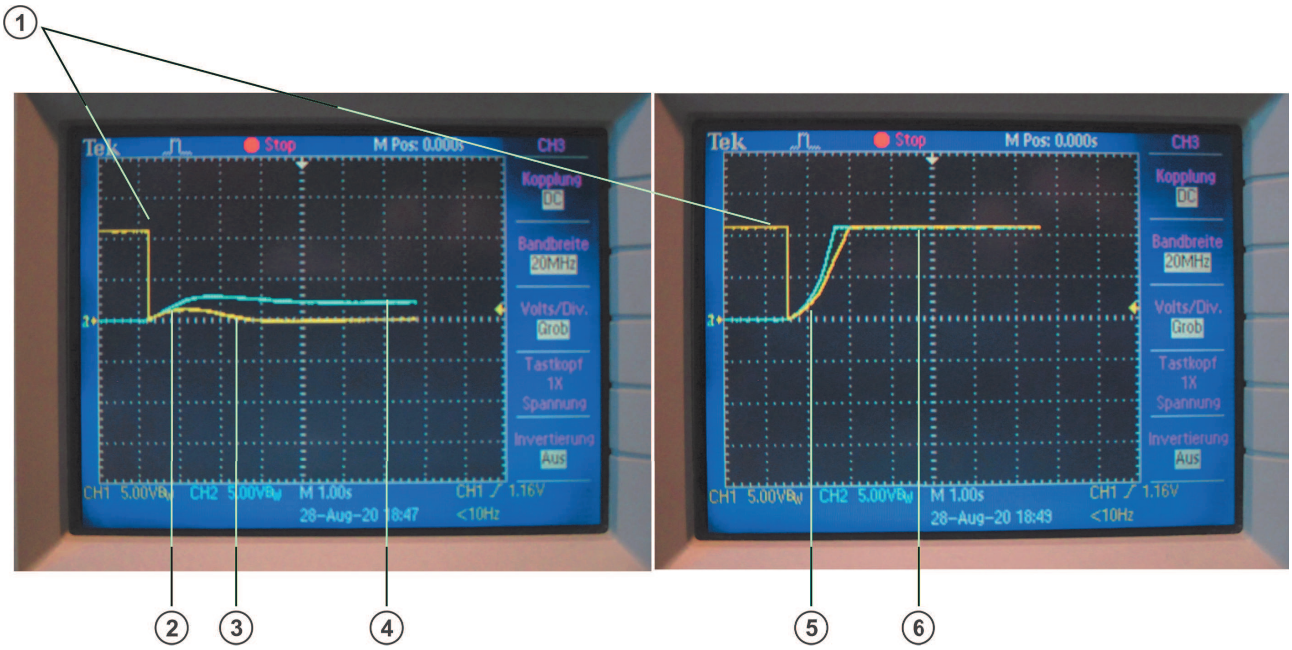


Figure 22: "Error signal" and "Reg out A" signal when the regulator is switched on, with correct setting of the regulator sign (left) and false setting (right).

6.11 Optimizing the PID regulator

The aim of this section is to trim the PID regulator A to achieve the best possible phase stability with the given laser. In order to assess the performance of the PID loop, increase the sensitivity of the oscilloscope so that the error signal is displayed with 100 mV/div. If available, activate the oscilloscope's RMS measurement for the respective channel.

Decrease the "Error scale" value until you observe a considerable amount of noise on the error signal (up to about $\pm$100 mV; each step will increase the loop gain by a factor of 2.)
If the error signal begins to oscillate, the error scale is too low – better increase it by one or two steps. If this does not help, switch the regulator off, reset the error scale to 2^{16} and try to switch it on again.
If you reach an error scale of 2^0=1 with the error signal still showing low noise, your laser is already very stable. Nevertheless, continue this optimization procedure to get the most out of the system.

Repeatedly alter the PID settings in the following order, each time adjusting them so that the noise on the error signal (RMS value) minimizes (if necessary, further increase the sensitivity of the oscilloscope so that the noise on the error signal can be seen clearly):

1. P Gain
2. D Gain
3. I Gain

If you loose the lock due to oscillations, restart the PID regulator as described above, with temporarily higher error scale if necessary.
Congratulations! Your laser is now phase-locked with high quality!
PhaseLock can indicate this success via the LED "locked". The criterion for the LED to turn from grey to green is that the regulator is active ("Regulator A enabled" and "Regulator On") *and* that the error signal does not fluctuate but in a small range around zero. The thresholds that define the "locked" range are somewhat arbitrary and have to be adjusted individually to the laser. For some lasers, the error signal fluctuates more than ±10% (of the available range of ±10 V), while other lasers are so stable that they cannot be considered "locked" when the error signal exceeds ±1%. Therefore, simply set the value of " 'locked'-Threshold" to the smallest possible value that lets the LED appear continuously green when the PID regulator A is on and the lock seems stable to you. (You may gently knock on the table or on the laser case to see if the LED flickers due to the increased disturbance.)

Do not forget to click to "save" on the TFT or on "Save to ÂţC" on the GUI to store the parameters to the non-volatile memory of the *PhaseLock* device.

If your laser is equipped with only one actuator, installation and set–up are now finished. You may wish to proceed with chapter 7 to learn more about the daily work with your *PhaseLock*.

6.12 Taking the PID regulator B into operation

If your laser is equipped with *two* PZT actuators for the control of the repetition frequency, typically one of them has a fast response but small stroke, while the other one is slower but has large stroke (large control range).
The following explanation is based on the assumption that the actuators are connected to the *PhaseLock* and that the PID loop for output A has already been optimized as described in the previous sections.
When the PID for output A is working, it keeps the error signal at its target (phase setpoint) value by applying the appropriate output voltage to the actuator. Therefore, if the setpoint is zero, the error signal will be zero, too, while the output voltage will be stable at a certain value that is typically different from zero. In contrast, if the laser drifts over time, the regulator will have to compensate for that by a continually increasing output voltage. However, if the latter reaches either limit at (+10 V) or (-10 V), the regulator looses the lock. In order to prevent this, the large-stroke actuator can be used to support the fast actuator. For this end, a second PID regulator is used that takes the actual output A voltage as error signal and drives its own output voltage (and thus the connected large-stroke actuator) in way that the error signal (and thus the fast actuator) can return to the center of its operating range.
For the set-up and optimization of regulator B it is necessary to monitor its error signal and the regulator output signal simultaneously on the oscilloscope. For this end, set "Monitor 1" to "Reg

out A" (as this is the error signal for regulator B) and "Monitor 2" to "Reg out B". (Refer to the previous sections to learn how to select monitor signals.)
When operating the *PhaseLock* by touch panel, navigate to the "Regulator B" menu (see figure 23) by pressing *menu* → *Regulator B*. When using the Kangoo software, locate the respective GUI elements on the screen.

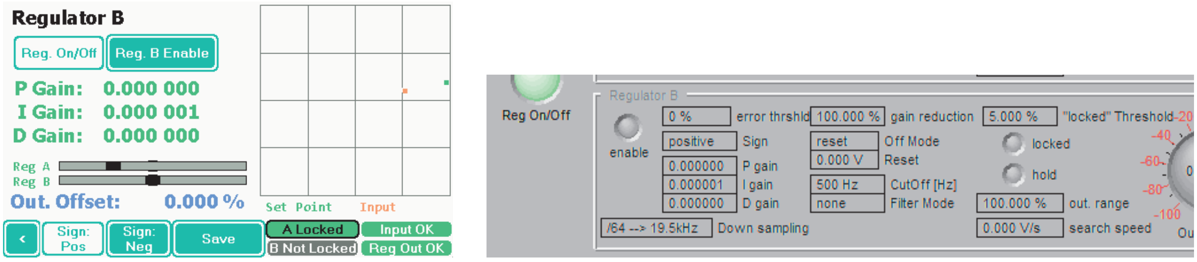


Figure 23: Regulator B adjustment screen and GUI (default settings). Note that the LED "A locked" is green as a prerequisite for the operation of regulator B.

As regulator B is supposed to work very slowly (only for drift compensation), we recommend to reduce its sampling rate by some factor (64, e.g., see figure 23). The gains for P and D can remain at zero while the I gain must be set to the smallest possible value 0.000001.
If both actuators work in the same direction, the "Sign" must be set positive. This is typically the case if the actuators consist of resonator end mirrors glued on top of a PZT, because then a positive voltage will result in a smaller resonator length (and thus higher rep rate) for both PZTs. If the effective direction is opposite for both actuatuors, the sign must be set "negative".
It is furthermore necessary that the regulator A is enabled and "on", and that its error signal is stably close to zero. This condition is indication by the LED "A locked" being lit green.
Now watch the signal on the oscilloscope while clicking "Reg On/Off" and compare the observation with figure 24:
At the beginning the "Reg out A" signal is at a certain voltage as described before, while "Reg out B" is at zero. When the regulator is switched on, "Reg out B" starts to increase (or decrease) (2). "Reg out A" in turn converges to zero, and the regulator B output voltage comes to rest at a finite level (4). This only works if the sign is correct — otherwise it will accelerate the phase slope so that both voltages diverge towards $\pm\infty$ (6) until they come to stop at (+10 V) or (-10 V). This is of course not intended. If you observe this, switch the regulator off, reverse the regulator B sign and try switching on again.
From now on, every movement of actuator A will be counteracted by a slow movement of actuator B, so that in the time average, the output A voltage stays at zero (meaning that the actuator A stays in the center of its range). Thus, fast fluctuations of the repetition frequency and pulse phase will be compensated for bei actuator A, the long term drift by actuator B.
If for any reason, regulator A unlocks, regulator B will be set on "hold" state, that is suspend working until regulator A signalizes "locked" again. It may also happen that the movement of the slow actuator changes the frequency so much that it exceeds the mixer bandwith and thus the error signal for regulator A disappears. If this happens, the feedback system hangs up, because regulator A signalizes "unlocked" and regulator B remains in that disadvantegous position. In this case, switch the "regulator off" (this applies to both regulators), adjust the "out. offset" of regulator B to minimize the intermediate frequency (as you already did in section 6.12), and try switching on again. Also if regulator B is too slow so that regulator A reaches either limit of its output range,

regulator B will hold on. If this happens, the speed of regulator B should be increased, either by choosing a higher "I gain" or by selecting a lower "Downsampling" factor.

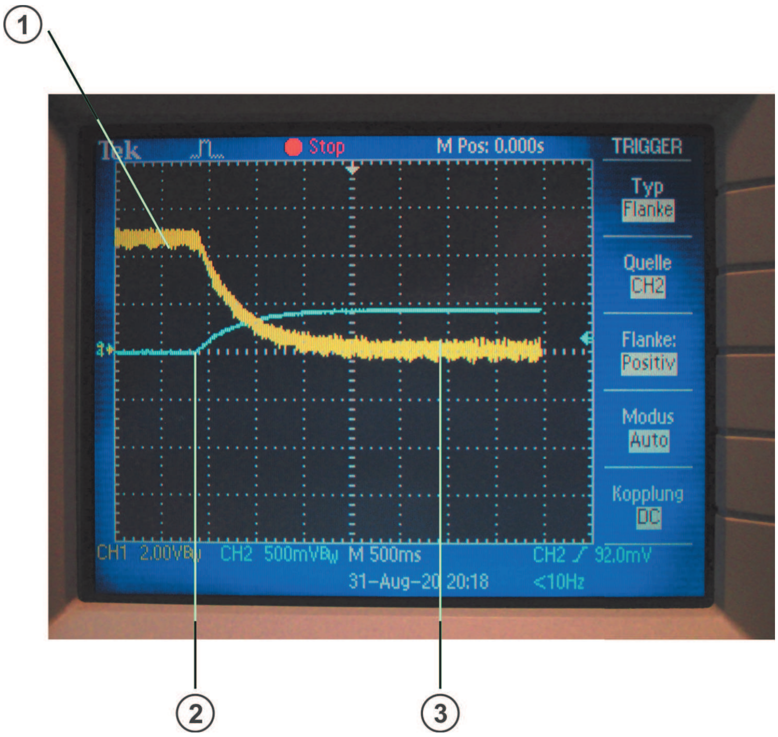


Figure 24: "Reg out A" and "Reg out B" signal when the regulator is switched on.

6.13 Loss of input signal and hold mode

The phase detector requires a minimum amplitude (radius) of the quadrature signal for proper operation. If one of the actuators in the laser has a large stroke, it might shift the laser repetition frequency so much that the difference to the reference frequency (thus the mixer output intermediate frequency) exceeds the bandwidth of the mixer. In this case the regulator input signal disappears. To prevent unexpected actions of the regulators, the level of the input signal is constantly surveilled: If the radius of the quadrature signal drops below the (user-defined) threshold "MinRadius", the regulator is put in a "hold" state, where the integration is stopped and the output remains constant. In such a case, some action is required to bring the laser back in a frequency range that can be covered by the mixer so that the PID can continue working. This can be done manually by the user or automatically by "search mode" of the *PhaseLock* — see following section

6.14 Automatic search mode

If the system falls into a hold state because of signal loss (see previous section), you may wish the output voltage to scan automatically for a range where the rep rate is close enough to the refeence frequency that the intermediate frequency re-enters the bandwidth of the input section. The search mode should be activated to that actuator that has the largest stroke. For activation, select "Radius" and "Reg out A" or "Reg out B", respectively. Check that the "Min. Radius" value is set to 4 V as described at the end of section 6.8. Then locate the "search speed" GUI element on the "Kangoo" software for regulator A or B resp., and set it to 1 V/s while the regulator is off. Then compare the signals with figure 25 and turn regulator on (1): the regulator output will be scanned slowly up or down (2) as long as the radius of the intermediate signal is below the min radius threshold (3). If it rises above AND the intermediate frequency is below a user-defined maximum "MaxFrequenc", the search scan is stopped and the PID is activated to lock the laser at the next zero-corssing of the error signal (4). Details of the signals and conditions can be seen in figure 26.

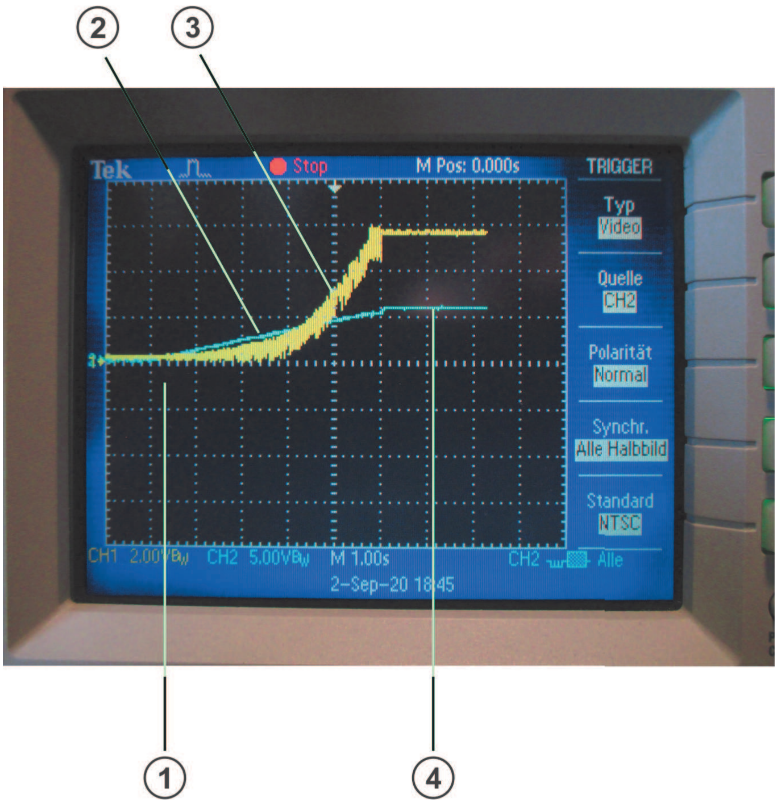


Figure 25: "Radius" and "Reg out" signal when the regulator is switched (1) on and the radius is below threshold: The search scan is started (2) and does not stop until the radius (3) is above threshold (4).

Do not forget to click to "save" on the TFT or on "Save to ÂţC" on the GUI to store the parameters to the non-volatile memory of the *PhaseLock* device.

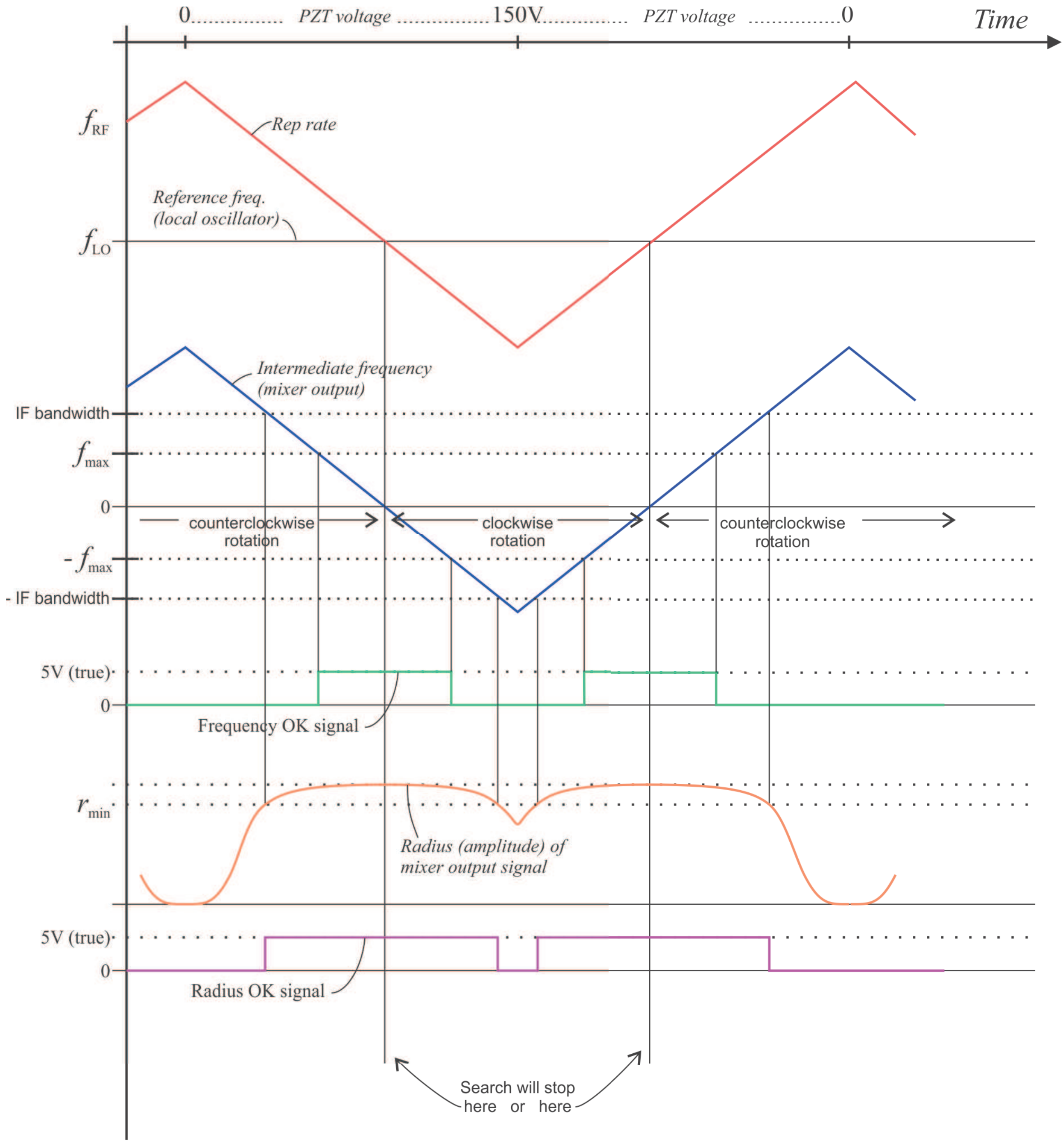


Figure 26: Timing and condition diagram for the automatic search scan.

7 Operation

This chapter describes the daily work with your *PhaseLock*. A correct installation and complete adjustment of all parameters according to 6 is assumed.

All newly adjusted parameters should be saved to the non-volatile memory of the *PhaseLock* device for switching the power off. (For this end, click to "save" on the TFT or on "Save to µC" on the GUI.)

The *PhaseLock* is built for continuous, uninterrupted operation. Once the laser has been locked, no unlocking or relocking will take place unless any external event kicks the laser out of the lock.

Anyway, if you prefer to switch the *PhaseLock* off over night, e.g., simply toggle the mains switch at the rear side (desk top case) or on the front panel (19″ rack case) of the device.

For power-up, turn on the mains switch at the rear side (desk top case) or on the front panel (19″ rack case). Given a few seconds for booting, the device will be ready for use after a short acoustical signal. The display will show the home screen as shown in figure 13.

Before locking the laser, check that "RF power OK" is displayed in green, rather than "RF power low" in red. If the RF power is low, a coarse adjustement of the frequency may be required according to chapter 6.

The simply press the "Regulator on/off" button to lock the laser. After some time, the gray LED "A not locked" should turn green. If, instead, the LED "Reg A OK" turns yellow and says "Reg A hold" the input amplitude (radius) is probably insufficient. This is also indicated by the LED "RF power OK" turning red to "RF power low". If the LED "Reg A out OK" turns red and says "Reg A out clip", the output voltage has reach its limit. This may be due to an insufficient control range of the actuator or due to a false regulator sign. In either of these cases follow the advice in chapter 6 to find the right lock point and sign.

If the regulator output appears to be stable, with LEDs "Reg A OK" and "Reg A out OK" being both green, and the laser appears to be phase locked, but the LED "A not locked" remains gray, it might simply be a matter of noise on the error signal that exceeds the (somewhat arbitrary) level of "locked threshold". If you are happy with the stability of your locked laser, you may increase this level until the LED reflects your happiness.

If both regulators are enabled, the respective advice is valid for regulator B, too.

If you have enabled the automatic search (see section 6.13 and 6.14), turning the regulator on may result in an immediate search if the signal amplitude is low. If the control range of the actuators is large enough and the laser is in a condition for successful locking, the search should end up in the LEDs turning green and the laser being locked. If this is not the case, follow the advice in chapter 6 to readjust the signal conditioning and/or the laser.

In order to observe the phase stability, it makes sense to display the intermediate signal on the oscilloscope (see section 6.7). While the unlocked laser created a circle in the XY plane (because the phase difference between the laser and the reference oscillation was continuously increasing or decreasing), the stable phase of the locked laser is now represented by a small section of the circle - see figure 27.

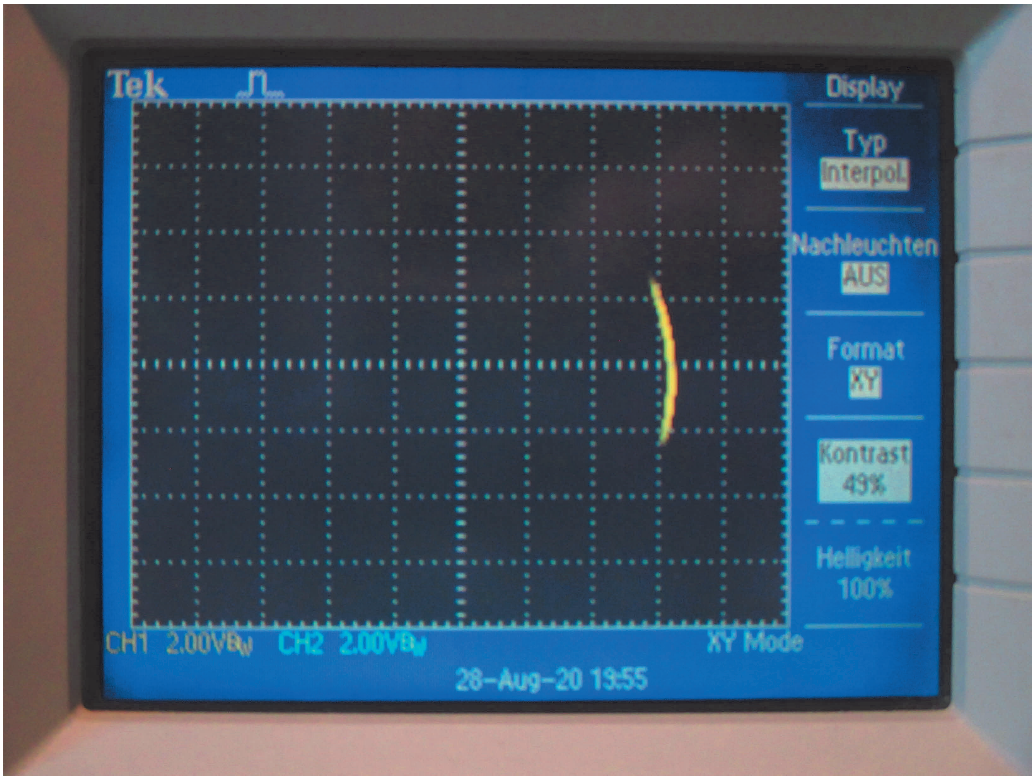


Figure 27: Intermediate signal (monitor signals "Input X normalized" and "Input Y normalized") displayed on an oscilloscope in Y–T mode when the laser is locked.

The actual angular distribution of this "cloud" depends on the laser's stability. If it is very stable, the signal may appear merely as a dot rather than a sickle. In contrast, if the phase fluctuations are very large, the phase may vary by more than $\pm 2\pi$ and therefore draw a full circle on the screen. This is typically the case when phase-locking the lightwaves of cw lasers. However, the phase can still be considered "locked" because the average difference is about zero.

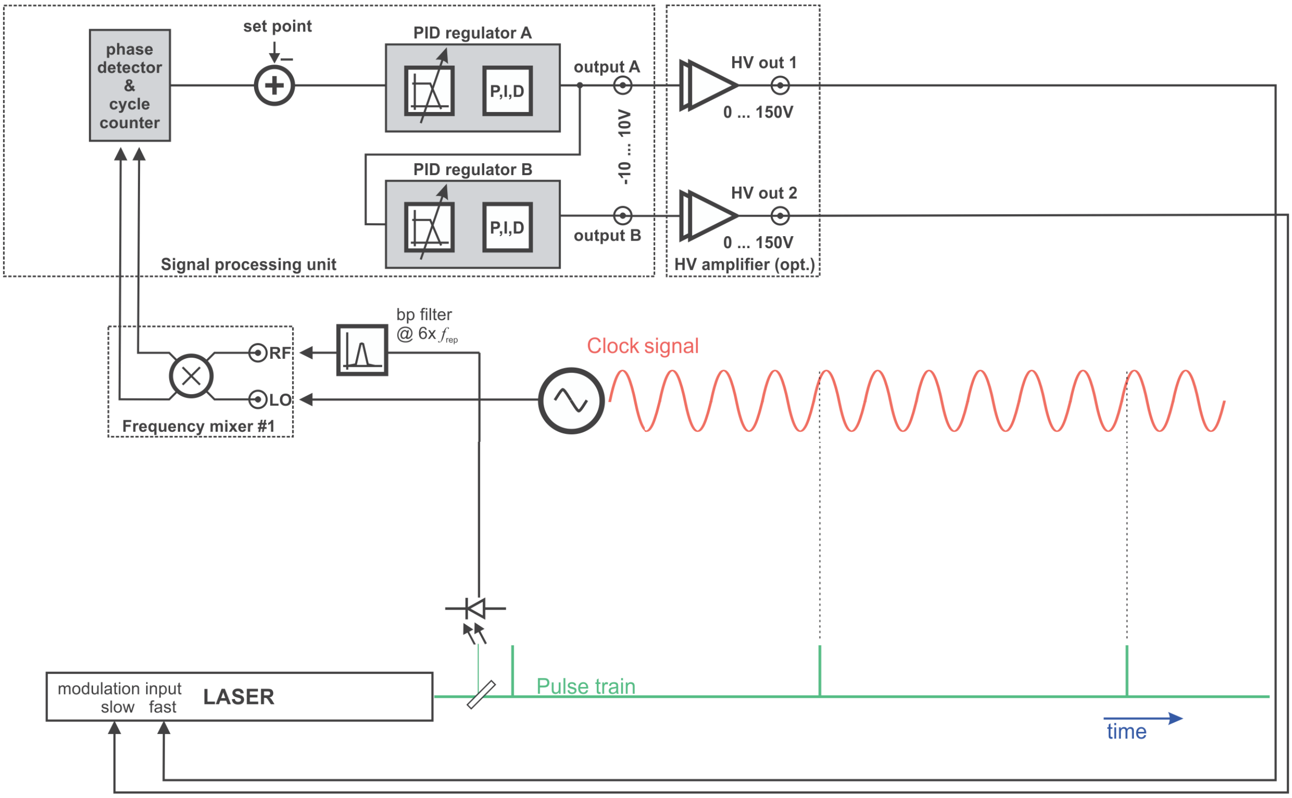


Figure 28: PhaseLock and a laser form a phase-locked loop.

8 "Bucket Skipping" (add-on, optional)

8.1 Locking to higher harmonics

Oftentimes the frequency of the reference signal is much high than the repetition rate of the laser. (For example, typical clock signals in synchrotrons and accelerator plants range from 500 MHz to 2.6 GHz, while typical laser repetition rates range from 30 MHz to 100 MHz. There are only few lasers with GHz rep rate on the market.) However, this is not a problem for the PhaseLock electronics:
As the photodiode signal obtained from the laser is a train of short pulses, one can understand this as a spectral superposition of sinusoidal signals whose frequencies are integer multiples (overtones) of the repetition rate (which is the fundamental frequency). Therefore a bandpass filter can extract a harmonic from the signal. In this case PhaseLock will control the VCO in a way that an integer multiple of the repetition rate is equal to the reference frequency. This is sketched in figure 28, where the laser is locked to the 6th harmonic.

Choosing the n-th harmonic rather than the fundamental frequency for locking is beneficial for the performance of the PLL, because the sensitivity to phase deviations is increased by a factor of n. Thus the signal-to-noise ratio at the output of the phase detector is improved by a factor of n, too.

8.2 Finding the "right" cycle

Locking to a higher harmonic might be a challenge if the laser has to be synchronized to other processes in the lab that also repeat with integer fractions of the clock frequency. This is because the laser will initially be locked to any period of the reference signal, and so will be the other processes. As a result, the laser pulses will be timed exactly synchroneous with the reference clock, but they will miss other events by multiples of the reference period time.

If this is the case, the phase between the laser and the reference can be adjusted manually by altering the regulator's set point, which can be accessed via the "scan" menu. By the way, the set point can also be scanned periodically, for a pump-probe scan, e.g.. As the phase can be shifted by multiples of 360° (2π), one can move the laser pulses in time across several "hills and valleys" of the reference signal. Therefore, some people coined the word "bucket skipping" for this type of adjustment.

However, the bucket skipping will have to be repeated after every relock, because once the lock is lost, the laser might relock to a different period of the reference signal.

8.3 Automatic synchronization

With the respective add-on, the PhaseLock can adjust the set point adjustment (or do the "bucket skipping") automatically, if a signal is available at the fundamental frequency. (This may be derived from the reference clock by a frequency divider, e.g.). In this case, a second mixer unit can detect the phase of the laser pulses with respect to that oscillation and determine the time shift (see figure 29).
The actual time shift is compared to some user-defined "set point 2".

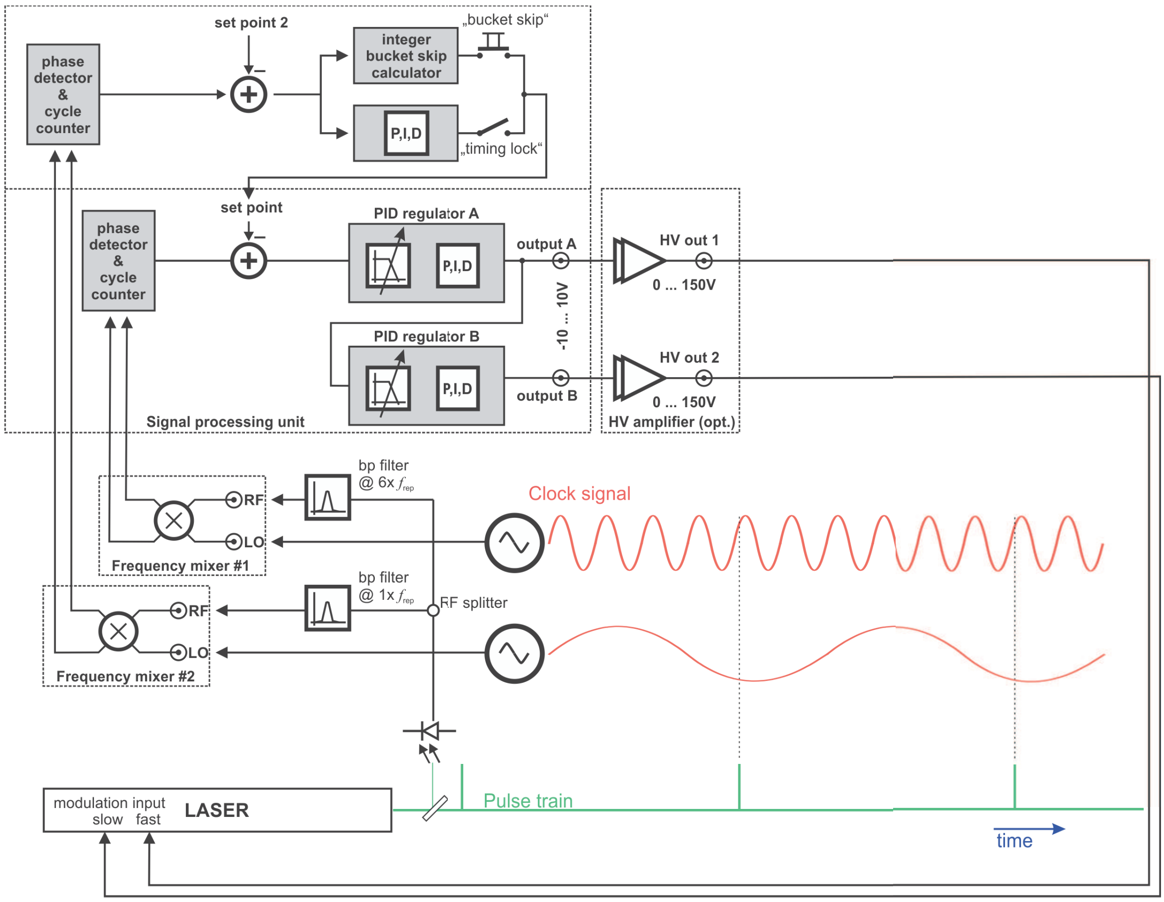


Figure 29: Determination of the time shift using a second phase detector at the fundamental frequency.

There are two options to compensate for the time shift mismatch:

a) An algorithm determines the nearest integer multiple of the reference period to the time shift mismatch. This value is added to the locking set point upon explicit command (indicated as a key "bucket skip" in figure 29).

b) A PID loop continuously alters the locking set point so that the time shift approaches the set point 2 (indicated as switch "timing lock" in figure 29).

Both options can be found on the start (home) screen as well as in the sub-menu "Skip menu", see figure 30.
The main difference between both methods is the following:
The bucket skipping is only done once (either by manual command or automatically, see below) after the lock has been established. It ensures that the phase relative to the higher harmonic remains the same before and after every bucket skipping. Furthermore, this phase will not change afterwards (unless the phase is lost anyway due to an unlock event). This method should be preferred if the high-harmonics reference provides a better phase reference than the fundamental reference.

The continuous method shifts the timing and thus the phase of the high-harmonics all the time as long as "Timing lock" is activated. (However, the timing lock will pause as long as the high-harmonics lock signalizes "unlock" because during such events a correction its set point makes no

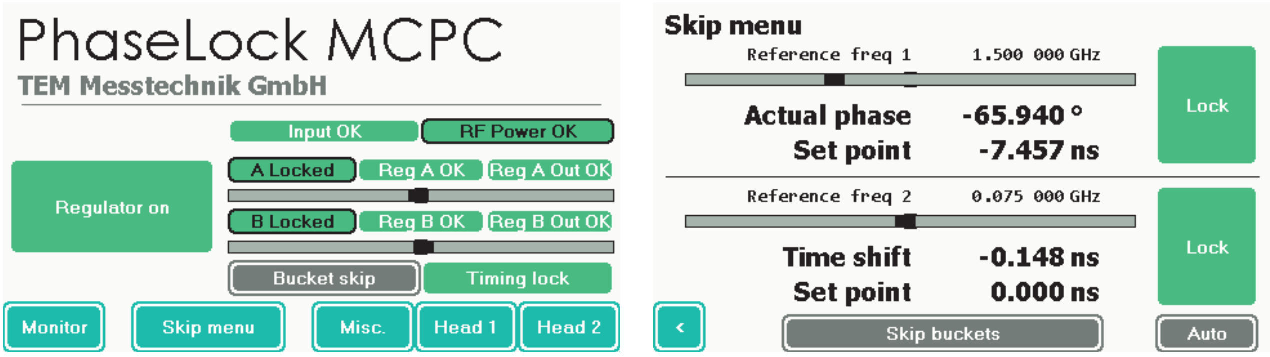


Figure 30: Buttons for timing lock and bucket skipping on the touch screen.

sense. This method should be preferred if the phase of the high harmonics reference oscillation is not stable with respect to the fundamental reference oscillation.

The "bucket skipping" can be executed automatically after any relock so that no user interaction is need when the lock is lost for any reason. For this end, simply activate "auto" in the skip menu.

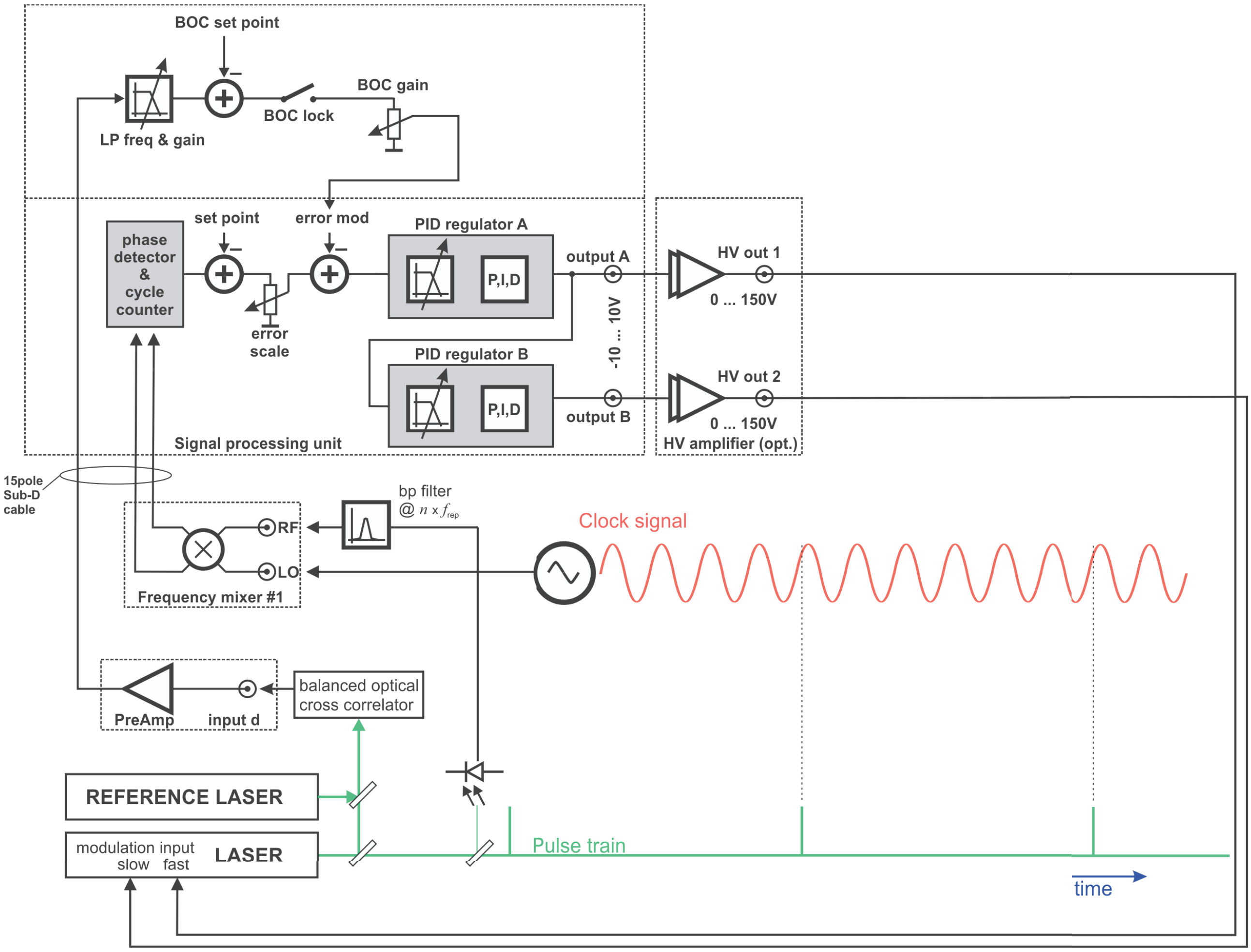


Figure 31: The electronic phase-locked loop can be enhanced by an optical cross-correlator.

9 Input for balanced optical cross-correlator (BOC, optional)

The RF mixer in combination with the FPGA signal processor has a maximum numerical resolution of approximately $1/(n \times f_{rep})/(\pi \times 2^{16})$, where n is the order of harmonic used (see section 8). Typical values are 60 fs for an 80 MHz rep rate laser locked at 80 MHz, or 1.6 fs if the same laser ist locked at the 37th harmonic (2.960 GHz). However, due to noise on the signals, this precision will in most cases not be reached by the feedback loop. In order to enhance the resolution, one can use a "Balanced Optical Cross Correlator" (BOC) that provides a differential signal for high-resolution determination of the actual pulse overlap. Its signal can be fed into the signal processing path via the "input d" of the Sub-HD-15 connector (see fig 31). It is recommended to use the "LaseLock PreAmp" module in parallel to the mixer. (When ordered for this purpose, the the PreAmp has its lines a and b not connected and thus does not interfere with the X/Y signals of the mixer.)

The settings are accessible from the front panel or via the Kangoo GUI (see fig. 32).

If the corresponding switch "BOC lock on" is activated, the input signal is added to the phase error signal with a weighting factor "BOC gain" between 0 and 10 and a positive or negative sign. In turn, the scaling of the phase error signal may be reduced in steps of x2. Note that a high value of

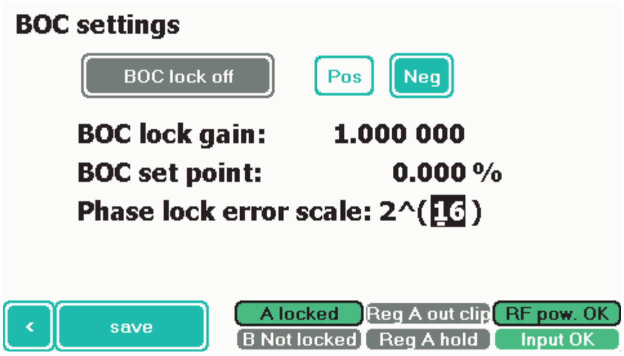


Figure 32: Buttons for locking to an optical feedback signal on the GUI and on the touch screen.

"Phase lock error scale" means a low weighting factor.

10 Detailed description

10.1 Frequency Mixer

The PhaseLock device is a system to control the pulse timing of pulsed lasers. It controls the repetition rate of pulsed lasers and adjusts this rate in a way that the pulses are generated with at fixed times relative to a reference clock. The reference clock is often an electronic sinusoidal signal (e.g. from a synchrotron or a quartz oscillator).

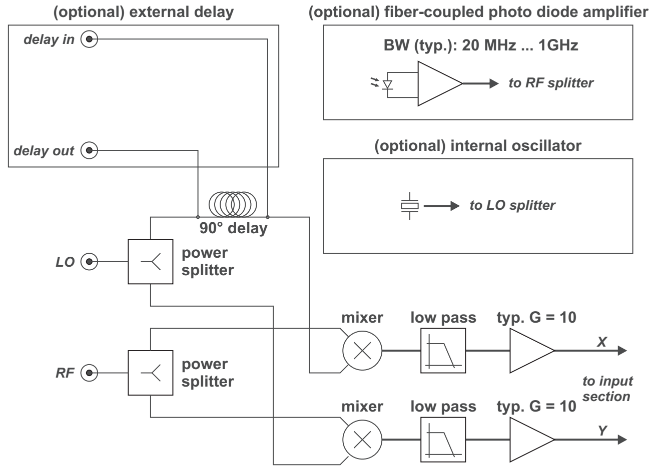


Figure 33: Block diagram mixer electronics.

Usually the mixer unit operates with a specific frequency value (on customer requirement) for the following reason: the mixer unit internally generates a 90° shifted copy of the reference signal (LO, local oscillator) e.g. by the help of a longer signal path or a phase shifting splitter. The reference signal pair (sine and cosine) allows the multi cycle phase comparison functionality. This works with one specific frequency value and a small range around it.

In order to provide a wide frequency range, the mixer unit can be equipped with additional SMA plugs (delay out, delay in) for an external delay path. Here the SMA cables with different lengths can be used as delay path to generate a 90° phase-shifted copy of the reference signal. In the following table you will find the frequency ranges and the appropriate delay cable lengths:

Frequency range	Cable length
8...12 MHz	500 cm
10...40 MHz	200 cm
30...70 MHz	111 cm
60...90 MHz	78 cm
80...120 MHz	56 cm
100...400 MHz	26 cm
300...700 MHz	15 cm
600...900 MHz	13 cm
800...1200 MHz	11 cm

If you are able to generate a 90° shifted copy of the reference signal (e.g. with a 2 channel DDS), you can connect it to the "delay in" SMA plug. Please make sure you use 10cm longer cable for the shifted reference in order to compensate the internal signal path.

10.2 Signal monitor

10.2.1 Analog monitor signals

PhaseLock provide access to several internal signals. Although the signal processing is purely numerical, the monitor picks intermediate calculation results and reconverts them into analog signals by means of D/A converters so that the user can probe them with an oscilloscope just as if he was checking an analog circuit.
The following signals can be selected for probing through the "Monitor X" and "Monitor Y" outputs. The numbers correspond to the value of the parameter "Monitor1Select" or "Monitor2Select", resp..

Value	Name	Description
0	off	Monitor output voltage = 0 V const.
1	Raw x	Copy of mixer output (x component of the quadrature signal, pin 1 of the HD15 connector)
2	Raw y	Copy of mixer output (y component of the quadrature signal, pin 2 of the HD15 connector)
3		(Optional: RF power measurement, pin 3 of the HD15 connector)
4		(Optional: pin 4 of the HD15 connector)
5, 6	Norm X, Y	X, Y component of the normalized (size adjusted) quadrature signal
7	Error	Deviation of the measured phase (of the input quadrature signal) from the set point.
8	Reg out A	Output signal of PID regulator A N. B.: This signal covers a range of -10 V to +10 V, independent of the actual setting of the regulator output range (parameter RegOutRangeA)
9	Reg out B	Output signal of PID regulator B N. B.: This signal covers a range of -10 V to +10 V, independent of the actual setting of the regulator output range (parameter RegOutRangeB)
10	Output A	Copy of the signal on the "Output A" BNC connector. When using a high voltage (piezo) amplifier, the voltage range of -10 V to +10 V corresponds to 0 to 150 V at the amplifier output.
11	Output B	Copy of the signal on the "Output B" BNC connector. When using a high voltage (piezo) amplifier, the voltage range of -10 V to +10 V corresponds to 0 to 150V at the amplifier output.
12. . . 15	Measurement input a. . . d	(Optional: Copy of the signals applied to measurement inputs (pin11 to 14 of the HD15 connector))
16	Normalized scan	Signal proportional to the scan. The voltage range -10 V to 10 V alwaysc orresponds to the full scan range, independent on the actual setting of the parameter "ScanWidth".

17, 18	Set point X, Y	Quadrature signal generated from the phase set point. The purpose of this signal is only visualization of the phase scan.
19	Radius	Actual radius of the normalized (size adjusted) input quadrature signal
20	Phase	Actual phase of the normalized (size adjusted) input quadrature signal. The signal voltage range -10V to +10V corresponds to -180° to +180°, unless the parameters NormPhaseOffset and NormPhaseGain are changed.
21...29	(reserved)	
30	Frequency	Period of the input signal (reciprocal of the frequency). The value can have negative sign if the RF signal has a lower frequency than the LO. ±10 V corresponds to 26.2 ms (32768/1.25 MHz)

Note: Values from 33 to 52 are available in twin systems, i. e. systems that handle two *PhaseLock* RF mixers.
Note: The monitor is capable of displaying two signals virtually simultaneously by quickly switching between two values. To activate this, set the parameters *Monitor1Chopper* or *Monitor2Chopper* to a value according to the above table. (A value of 0 for the chopper will put the switching off.)

10.2.2 TTL output

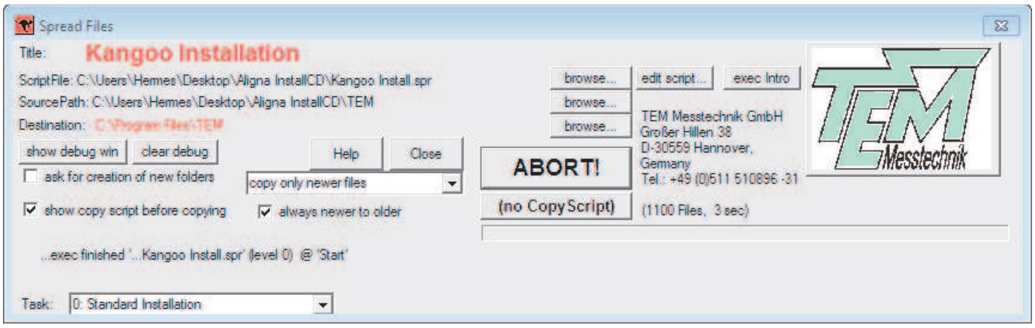
The "Trigger" BNC connector provides a digital TTL (0 to 5 V) square signal that synchronizes the oscilloscope display with the processes inside the *PhaseLock*, such as scan, step response and others. It is therefore recommended to connect the trigger output of the device to the trigger input of the oscilloscope.

11 Software Installation

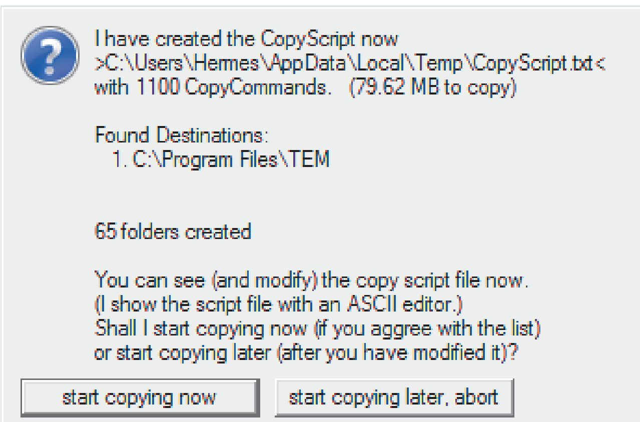
11.1 Installation of the "Kangoo" Software

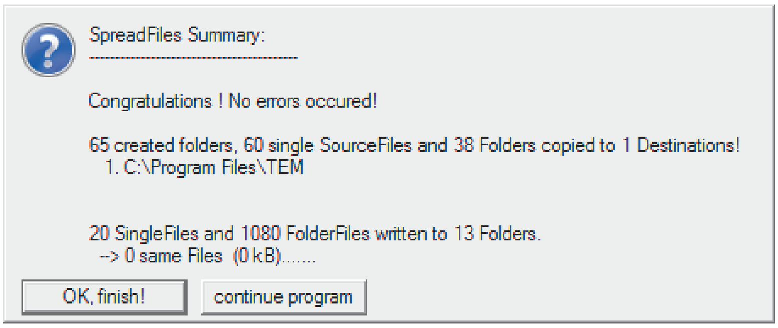
To install the "Kangoo" software, start the program "Install.exe" in the root directory of the installation CD or USB memory stick, respectively. The installer will show a welcome screen with several options.

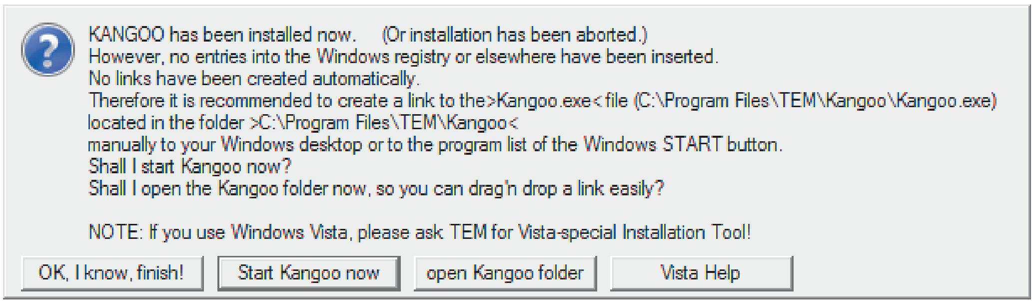
The default options should work fine, with the possible exception of the section "Destination Path", where the destination directory is specified. The standard directory is "TEM" in the "Program Files" folder. On Windows Visa or Windows 7 systems, please avoid the "Program Files" folder and choose and 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.







11.2 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.

11.3 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 34).

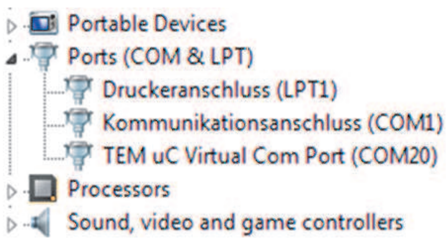


Figure 34: TEM COM Port in the device manager

11.4 Upgrading the Firmware

Please contact TEM Messtechnik for details about firmware upgrades.

12 Communication interface

12.1 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

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

12.2 Variables

The following tables lists the most important operational parameters (stored as "variables" in the microcontroller). A complete list of variables and their values can be obtained using the command "vardump" (see section 12.1).

12.3 Input settings

Parameter name	Default value	Description	Access mode
DetectorX1Gain	10000	Adjusts sensitivity of IF signal component x	
DetectorY1Gain	10000	Adjusts sensitivity of IF signal component y	
DarkAdjustA	0	Constant offset subtracted from input x ADC value.	
		Adjust this value only in absence of an input signal (laser off, e.g.).	
DarkAdjustB	0	Constant offset subtracted from input y ADC value.	
InClip	0	Flag = 1 if any input signal out of range	Read-only
InputPhase	0	Shape adjust of the normalized (size-adjusted) quadrature IF signal	

12.4 Quadrature signal analysis

Parameter name	Default value	Description	Access mode
Circle	0	Integer part of phase value (multiples of 360°).	Read-only
Frequency	1	Revolution frequency of the input quadrature signal. Clockwise revolution will result in negative frequency values.	Read-only
MaxFrequency	100 000	Search will not stop if frequency exceeds this value ("FreqOK" false)	
FreqOK	0	Flag = 1 if Frequency < MaxFrequency	Read-only
Radius	0	Momentary radius of quadrature signal	Read-only
MinRadius	1000	Regulators are put to "hold" whenever the radius drops below this value ("RF level low")	
MaxRadius	9500	Regulators are put to "hold" whenever the radius exceeds this value ("RF level too high")	
RadiusOK	0	Flag = 1 if MinRadius < Radius < MaxRadius	Read-only

12.5 Monitor settings

Parameter name	Default value	Description	Access mode
Monitor1Select	5	Selection of probe signal for "Monitor X" output. See monitor description	
Monitor1Chopper	0	Second probe signal for "Monitor X" output. If not "off", the monitor output quickly switches between the signal selected here and by "Monitor1Select", thus virtually displaying both signal simultaneously on the oscilloscope.	
Monitor2Select	6	Selection of probe signal for "Monitor Y" output âĂŞ see above.	
Monitor2Chopper	0	Second probe signal for "Monitor Y" output âĂŞ see above.	
NormPhaseOffset	0	Shifts the phase signal probed by the monitor (when set to signal no.20)	
NormPhaseGain	1	Scales the phase signal probed by the monitor (when set to signal no.20)	
AutoNormPhase	0	If set to 1, the parameters NormPhaseOffset and NormPhaseGain are adjusted automatically to ensure +/-10V correspond to +/-180Âř	
RawX	0	Direct access to monitor values.	Read-only
RawY	0	Direct access to monitor values.	Read-only
NormX	0	Direct access to monitor values.	Read-only
NormY	0	Direct access to monitor values.	Read-only
Radius	0	Direct access to monitor values.	Read-only
Phase	0	Direct access to monitor values.	Read-only
SetPointPhase	0	Direct access to monitor values.	Read-only
Error	0	Direct access to monitor values.	Read-only
RegOutA	0	Direct access to monitor values.	Read-only
RegOutB	0	Direct access to monitor values.	Read-only
OutputA	0	Direct access to monitor values.	Read-only
OutputB	0	Direct access to monitor values.	Read-only
CircleState	0		Read-only

12.6 Regulator (servo loop) settings

Parameter name	Default value	Description	Access mode
RegOnOff	0	General enabling of all regulators	
ErrorScale	0	Attenutation of the error signal (in powers of 2). Set to 0 to cover $\pm 10\,V$ range with $\pm 180°$ of signal phase	
RegOnOffA	1	Setting this value to 0 makes servo loop A inactive.	
RegOnOffB	0	Setting this value to 0 makes servo loop B inactive.	
RegSignA, RegSignB	0	Sign of regulator loops A, B.	
RegPgainA, B	0	Regulator A, B: P gain	
RegIgainA, B	1	Regulator A, B: I gain	
RegDgainA, B	0	Regulator A, B: D gain	
RegGainReductionA, RegGainReductionB	100000	Softstart percentage of regulator A, B (100 000 = no soft start)	
RegOutRangeA, B	100000	Voltage range that can be addressed by regulator A, B (before high voltage amplifier, if this is present)	
RegOutputOffsetA, B	0	Center of regulator A, B output range	
RegResetModeA, B	1	Behavior of the regulator output voltage when the regulator is off (0: hold, 1: go to RegResetValueA, B)	
RegResetValueA, B	0	Value of the regulator's output voltage when the regulator is off.	
RegLockThresholdA, B	5000	Threshold for qualifying a lock "stable", see LockedA, Locked B	
RegErrorThresholdA, B	0	Regulator remains on hold if the error signal is within ±RegErrorThreshold.	
ErrorMeansA,B	0	RMS of the error signal, averaged over one period of the step response signal	Read-only
RegMeansThresholdA, B	0	See above: RegLockThresholdA, B	
MeansOKA, B	0	Flag set to 1 if error RMS (parameter ErrorMeansA, B) < RegMeansThresholdA, B	Read-only
LockedA, B	0	Flag is set to 1 if the corresponding regulator is active and its error signal is within the range ±ReLockThreshold AND ErrorMeans is within the range ±RegMeansThreshold.	Read-only

12.7 Output settings

Parameter name	Default value	Description	Access mode
RegOutRangeA, RegOutRangeB	100000	Voltage range that can be addressed by regulators A, B (before high voltage amplifier, if this is present)	
RegResetValueA, RegResetValueB	0	Value of the regulators A, B output voltage when the regulator is off.	
TEOffsetA, TEOffsetB	0	Output A, B voltages at ScanOffset = 0 (added to RegOutOffsetA, B and RegResetValueA, B, resp.)	

12.8 "Search for signal" settings

Parameter name	Default value	Description	Access mode
Searching	0	Flag indicating that the output is scanned in order to obtain a valid input signal (radius OK and frequency OK)	Read-only
RegSearchSpeedA, B	0	Search speed of regulator A, B. (Regulator starts a search scan if RegSearchSpeed>0 and RF power is low (radius<minRadius)	

12.9 Step response settings

Parameter name	Default value	Description	Access mode
SPStepWidth	10000	Amplitude of square signal (for step response measurement)	
SPStepDuration	419430	Period of square signal (for step response measurement), read only	
SPStepRate	16	Sets frequency of square signal (for step response measurement) as fraction of the regulator sampling rate	
CoupleStep	0	Set to 1 to apply square signal to regulator input (serves to measure the step response of the servo loop).	

12.10 Scan settings

Parameter name	Default value	Description	Access mode
Scan (timing shift) settings			
ScanEnable	0	General on/off for the scan generator	
ScanWidth	1000	Total scan width (max âĂŞ min value)	
ScanOffset	0	Center value of bipolar scan; start value for unipolar scan	
ScanReady	0		
ScanNmbOfSteps	10	Number of steps in a stepwise scan.	
ScanContStep	0	Set to 0 for a linear (continuous) and to 1 for a stepwise scan.	
ScanUniBipolar	1	Set to 0 for scan that addresses only positive (or only negative) output values. Set to 1 for a scan that covers both output polarities.	
ScanStepDuration	10	Time to wait for the next scan step	
ScanFrequency	100	Scan frequency	
ScanStopValue	0	Output value of the scan generator when the scan is off. This parameter can be used for a "manual" scan.	
ScanStepSize	100	Scan step size	
QIActive	1	Set to 1 to apply the scan settings to the phase set point.	
QIGain	1000000	Conversion factor from scan generator to phase set point.	
QIOffset	0	Phase set point at ScanOffset = 0	

12.11 Trigger settings

Parameter name	Default value	Description	Access mode
PointTriggerMode	0	Defines event upon which a new scan step is made.	
PointTriggerEdge	0	Sign of optional point trigger TTL input.	
ScanTriggerMode	0	Defines event upon which a new scan is started.	
ScanTriggerEdge	0	Sign/behavior of optional scan trigger TTL input.	
ScanFromMemory	0	Set to 1 in order to generate the scan from values previously written into the FPGA RAM. To be used for arbitrary waveform scans only	
SelectTTLout1	0	Selects the use of the "Trigger" output BNC connector.	
InvertTTLout1	0	Sets polarity of the "Trigger" output BNC connector.	

12.12 Motor driver settings

Parameter name	Default value	Description	Access mode
MEnable	0	Enables the motor control.	
MReady	0	Flag indicating that the stepping motor has reached the target position	
MRangeClip	0	Flag indicating that the stepping motor has reached the limit of its range	
MPosition	0	Actual motor position	Read-only
MRegOnOff	0	Switch Motor regulator on / off.	
MRegSign	0	Motor regulator sign.	
MSearchSign	0	Direction of search when using the motor.	
MInputSelect	0	Selection of the input signal for the motor control regulator.	
MWaitForLock	0	Determines whether the motor regulator remains on hold as long as regulator A and B are not "locked".	
MSpeedMax	512	Speed limit for motor.	
MSpeedMin	1	Minimum speed for motor.	
MAccel	1	Acceleration limit for motor.	
MCurrentDrive	50000	Drive current of motor.	
MCurrentSndBy	5000	Rest current of motor.	
MRegErrorThres	20000	Minimum error signal level for the motor regulator to react on.	
MSearchSpeed	0	Motor speed during search.	
MRegPGain	0	Motor regulator P gain.	
MRegIGain	0	Motor regulator I gain.	
MPosMax	2^{30}-1	Motor range (maximum)	
MPosMin	-2^{30}+1	Motor range (minimum)	
MOffset	0	Motor position at ScanOffset=0	

12.13 Dither lock settings

Parameter name	Default value	Description	Access mode
ScanModAmplitude	0	Amplitude of sinusoidal modulation on scan generator (for dither lock, e.g.)	
LockInFrequencyA	20000	Dither frequency of dither generator A	
LockInInputSelectA	0	Signal selected a input to demodulation for dither lock.	
LockInHarmonicA	0	Order of derivative generated by demodulation for dither lock (0: direct lock, 1: first derivative âĂŞ demodulation with 1 x f, 2: demodulation with 2f, 3: demodulation with 3f)	
LockInPhaseA	0	Demodulation phase (relative to dither generator)	
LockInLPGainA	1000	Gain of demodulation low pass filter.	
LockInLPFreqA	1000	Cut-off frequency of demodulation low pass filter.	
LockInRegEnableA	0	Setting this value to 1 acitvates the dither lock.	
LockInRegSetPointA	0	Setpoint for dither lock.	
LockInRegSignA	0	Sign of dither lock.	
LockInRegPGainA	0	P gain of dither lock	
LockInRegIGainA	0	I gain of dither lock	
LockInRegDGainA	0	D gain of dither lock	
LockInRegOutSelA	0	Output signal to which the dither lock output is added	
LockInRegOutRangeA	10000	Voltage range that the dither lock output can address.	
LockInDitherAmplA	0	Dither generator output amplitude	
LockInDitherPhaseA	0	Dither generator output phase	
LockInRegLocked	0		
LockInRegHold	0		
LockInRegOutClip	0		

12.14 Measurement settings

Parameter name	Default value	Description	Access mode
MeasClockDivision	0	Used to slow down the reading of measurement values during a scan.	
DatasetNumber	0	Number of measurement being performed.	
NumberOfFrames	0	Number of data frames recorded at each scan point.	
NumberOfPoints	0	Number of measurement points (typically = ScanNmbOfSteps)	
DataSendDelay	100	Time to wait between data packages during transmission to PC	
DataFormat	0	Format used for data transmission to PC	
DataReady	0	=1 if data is available to PC	Read-only
MeasSingleCont	2	Single or continuous measurement.	
MeasAddrOffset	0	Determines memory layout for measurement data.	
MeasChannel1...8	0	Selection of signal to record during a measurement.	
MeasOffset1...8	0	Offset added to measured value before scaling.	
MeasShift1...8	-8	Bit shift applied to measured value before storing to memory.	
MeasMask1...8	255	Bit assignment for storage of measurement value.	
MeasAvrg1...8	0	Number of averages applied to each data point.	

12.15 System information

Parameter name	Default value	Description	Access mode
SerialNumber	9999999		Read-only
Build	1257	Firmware build number	Read-only
Mute	0	Set to 1 to suppress echos and spontaneous outputs to the PC.	
FPGAFirmware	0	FPGA firmware version	Read-only
LCDBrightness	100	LCD brightness	
ScreenSaverEnable	1	Set to 1 to enable white screen.	
ScreenSaverDelay	120	Time in minutes after which the TFT screen turns white.	

13 Electrical Specifications

13.1 Technical Data

Mixer / Input stage	
Input Impedance	50 Ω
required LO power	+4 ... +7 dBm
RF sensitivity	-20 ... -15 dBm
Bandwidth	1 MHz ... 1 GHz (standard configuration)
Sampling rate	1.25 MSps
Outputs	
Voltage range LV (front)	-10.0... 10.0 V at 1 kΩ load
Bandwidth LV	200 kHz
Voltage range HV (rear)	0... 150 V 120 mA continuous, 240 mA peak (each channel)
Bandwidth HV	100 kHz (small signal bandwidth)
Sampling rate	2.5 MSps
Supply	
Voltage range	100... 240 V AC, 50... 60 Hz
Voltage range (DC12V option only)	DC 9... 36 V; 5.5x2.5 mm 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	100 mm x 260 mm x 377 mm
Housing (19 inch rack case)	
Dimensions H x W x D	150 mm x 450 mm x 340 mm
Display	
Size	4.3″ (11 cm) TFT display
Resolution	480 x 272 pixels, 16-bit color
Technology	resistive touchscreen, LED backlight

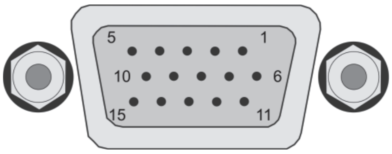
13.2 Mains Power Cable

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 V AC, 220. . . 240 V AC.

13.3 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.



1	input X
2	input Y
3	(optional normalization input)
4	(optional input)
5	analog ground
6	+15 V
7	-15 V
8	system ground
9	I^2C clock
10	I^2C and SPI data
11	(optional input)
12	(optional input)
13	(optional input)
14	(optional input)
15	SPI clock

14 Delivery Content

(see section 3)

15 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`

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