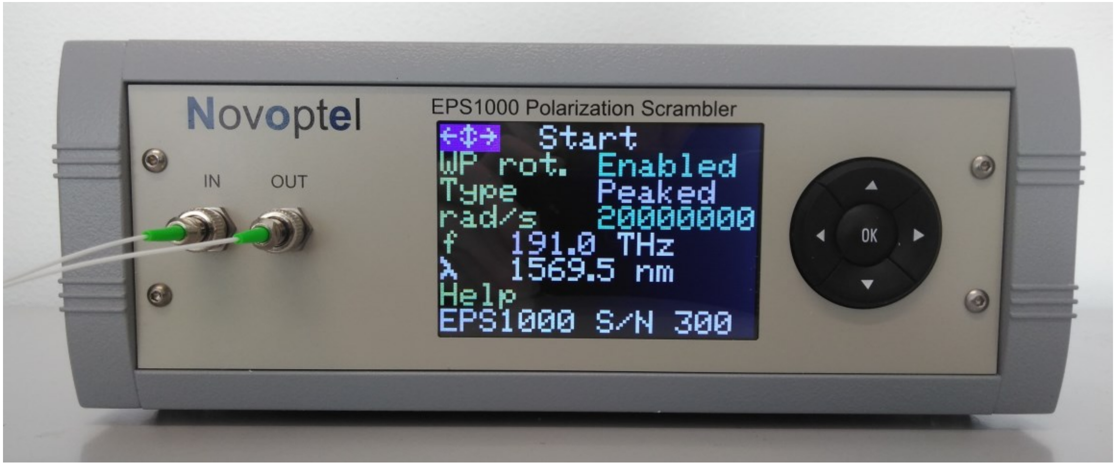
User Guide

Novoptel

EPS1000 Polarization Scrambler/Transformer



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Revision history

Version	**Date**	**Remarks**	Author
0.1.0	28.10.2011	Draft version	B. Koch
0.1.1	30.08.2012	Draft version	B. Koch
0.1.2	15.04.2013	Description of external voltage allocation (Registers 50…65)	B. Koch
0.1.3	23.07.2013	Support of multiple wavelength bands	B. Koch
0.1.4	07.05.2014	Description of PDL measurements	B. Koch
0.1.5	21.07.2014	Footnotes of USB register table added/corrected	B. Koch
0.1.6	26.06.2015	Updates due to GUI rev. 1.4.2.0	B. Koch
0.1.7	09.06.2016	For EPS Firmware>=1.1.0.0: Scrambling speed tables added	B. Koch
0.1.8	27.09.2016	Register description complemented	B. Koch
0.1.9	23.10.2017	LAN (TCP/IP) communication added	B. Koch
0.2.0	19.03.2018	Nominal scrambling speed explanation clarified, correction of table dwell time	R. Noe, B. Koch
0.2.1	20.04.2018	Rotation matrices and orientation angle of waveplates added	R. Noe
0.2.2	07.03.2019	Footnote (3) of Control Registers corrected (1828, not 1829)	B. Koch
0.3.0	22.06.2020	Description of firmware-embedded PDL measurement (firmware>=1.2.0.0)	B. Koch
0.3.1	15.11.2021	Description of scrambling type and target speed (firmware>=1.2.0.7)	R. Noe
0.3.2	18.08.2021	Description of optional SOP tracker	B. Koch
0.3.3	28.03.2022	Description of Retardation Scaling Factor Registers (firmware >=1.2.1.4) and Tracking Registers	B. Koch
0.3.4	04.06.2024	Description of PDL measurement with SOP tracking function (firmware >=1.2.2.7), and LCD screen menu	B. Koch, R. Noe

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Rear panel

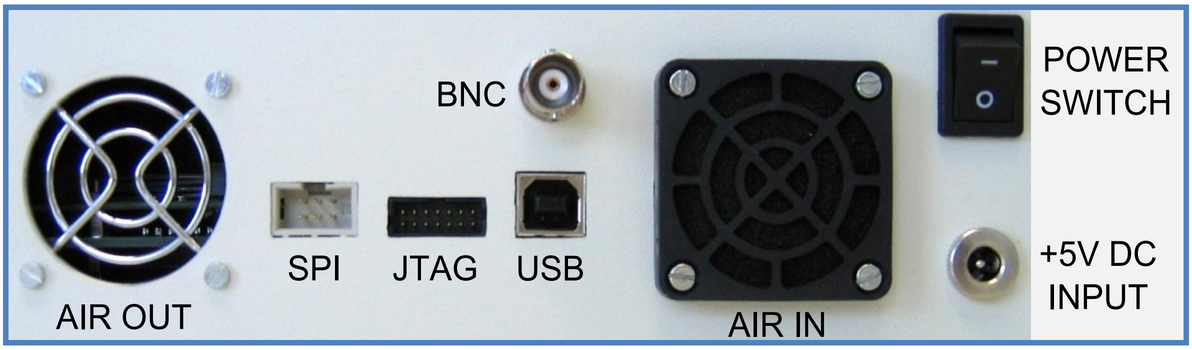


Fig. 1: EPS1000 rear panel

Operation of the instrument via front control panel

Power the instrument with the provided power supply and switch it on.

Legacy EPS1000 with OLED display

The scrambler firmware provides a cyclic menu. The menu structure is

WELCOME
Scrambling/PDL mode
QWP0
QWP1
QWP2
HWP
QWP3
QWP4
QWP5
Optical Frequency
Wavelength Band
LAN Configuration
Save Configuration

Menu items QWP0 and QWP5 are missing in scrambler configurations with only four quarter wave plates. Menu item *Wavelength Band* is missing if the scrambler supports only a single wavelength band. *LAN Configuration* is missing if the scrambler is not equipped with a LAN interface. *Scrambling/PDL mode* is missing if the scrambler is not equipped with an optical detector.

The control buttons *UP* and *DOWN* let you to navigate through the menu. The control buttons *LEFT* and *RIGHT* changes a selected setting or selects a decimal place, which can afterwards be changed with the buttons *UP* and *DOWN*.

For each waveplate, you can choose between *DISABLED*, *FORWARD* and *BACKWARD* operation of the wave plate and set the desired nominal scrambling speed. For the quarterwave plates (QWP), nominal scrambling speed is given in in rad/s between 0 and +999,999.99 rad/s. For the halfwave plate (HWP) it is given in krad/s between 0 und 20,000.00 krad/s. For actual scrambling speeds see p. 8.

The range for the optical frequency is at least C and L band, usually 182.9 THz (1639.1 nm) to 198.5 THz (1510.3 nm).

Current EPS1000 with LCD screen

A short usage introduction is given here:
https://www.youtube.com/watch?v=gcvqXdQE0ec

Meanwhile the cyclic menu has more items. The menu structure is very similar to the graphical user interface. If all options are ordered the current menu structure is:

Item	*Meaning*
Start	Quick setting of scrambling type and speed, optical band and frequency. Access to Help with >10 pages.
rad/s	Waveplate (WP) nominal scrambling speed setting. ATTENTION: Set speed sign to + or – to enable WP rotation. No speed sign means WP disabled.
rel. Pos. rad	Relative and absolute WP eigenmode orientations along equator of Poincaré sphere
rel. Ret. rad	Relative and absolute WP retardations
Voltages	Relative voltages at electrodes of 8 sections of polarization transformer
Sync/Trig.	Continuous/Synchronous/Triggered WP operation
Tracking	Maximum and minimum intensity or electrical signal or polarimetric tracking
PDL Extinct.	Measure device-under-test (DUT) PDL using extinction method (E); see https://www.novoptel.de/Control/Literature/PDL_measurement_2021_Noe&Koch.pdf or https://www.novoptel.eu/Control/Literature/PDL_measurement_2021_Noe&Koch.pdf
PDL Depol.	Measure DUT PDL using depolarization or sqrt(3) method (D); see link above.
Settings	LAN Configuration

Operation of the instrument via graphical user interface

The instrument communicates by a USB IC FT232R from FTDI (Future Technology Devices International Limited, http://www.ftdichip.com).

The Novoptel EPS1000 Graphical User Interface (= GUI) is compiled on a Microsoft Windows 10 64 Bit system. It is recommended to set the DPI scaling to 100%.

Installing the USB driver

Normally this driver is already provided by the Windows system. If this is not the case, one can install the newest driver from https://ftdichip.com/drivers/d2xx-drivers/

Connecting the instrument

After the driver is installed successfully, connect PC and instrument using the provided USB cable. Power the instrument with the provided power supply and switch it on. Wait until Windows has recognized the USB device and shown an acknowledgement message.

Installing the GUI

New GUI versions for EPS1000 with firmware version ≥ 1.1.0.0 will be published here:

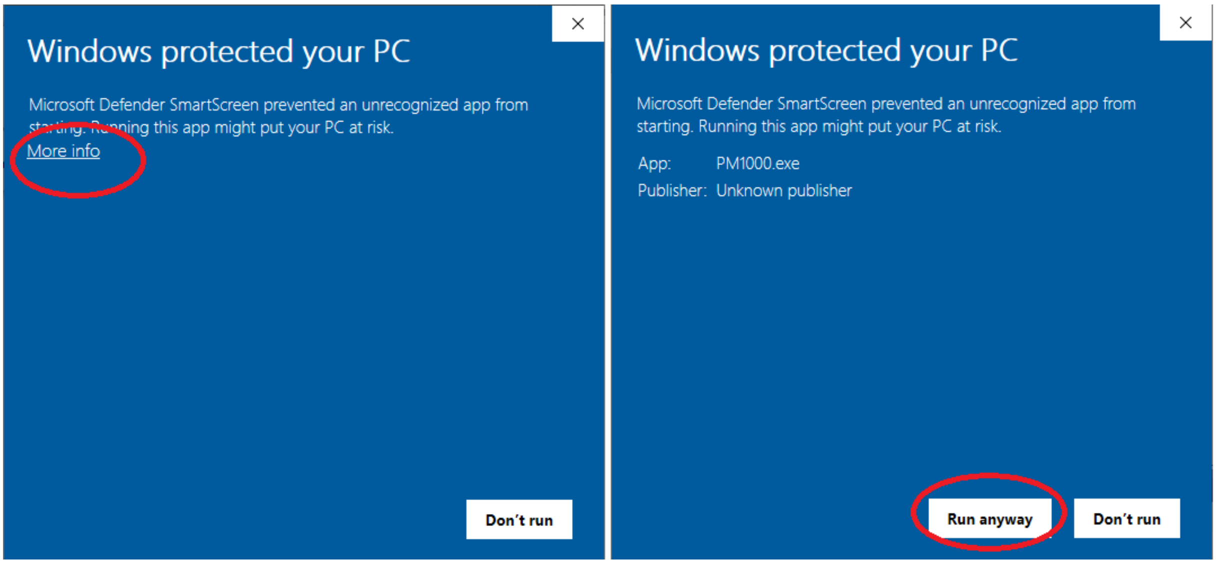
https://www.novoptel.de/Home/Downloads_en.php

The EPS1000_xxxx.exe can be executed without installation.

For EPS1000 with firmware version < 1.1.0.0, Novoptel provides earlier GUI versions that require installation. Any previous version of the GUI has to be uninstalled first. For installation, execute *setup.exe* in the folder *EPS1000_XXXX*, where *XXXX* refers to the GUI versions. Follow the instructions of the installation dialogue.

If not found on the PC, Microsoft .NET Framework 4.5 will be installed during installation of the GUI.

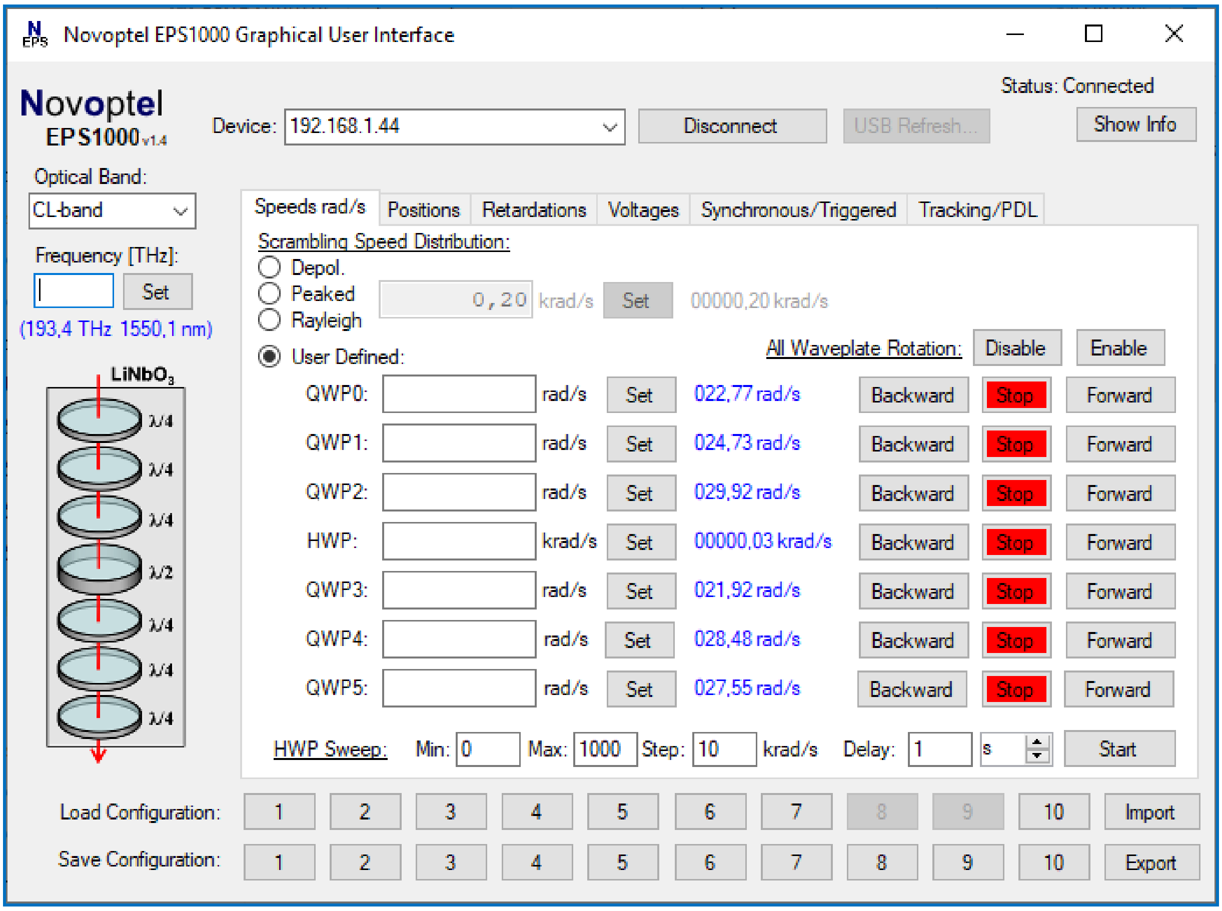
While installing a recently released GUI on Windows 10, you may receive a SmartScreen warning:



Microsoft Windows SmartScreen may flag newly uploaded files that have not built up a long enough history. You can install the GUI by clicking “More info” and then “Run anyway”.

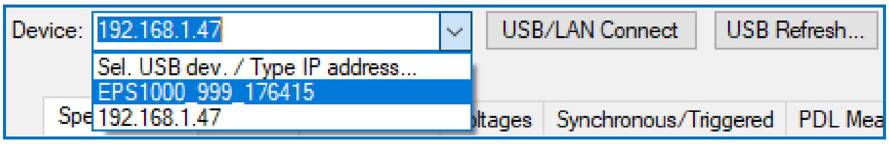
First steps with the GUI

The software launches automatically after installation. If you want to launch the software later manually, select *Programs\Novoptel\EPS1000* from the Windows Start Menu.



Selecting one of the instruments attached via USB or LAN

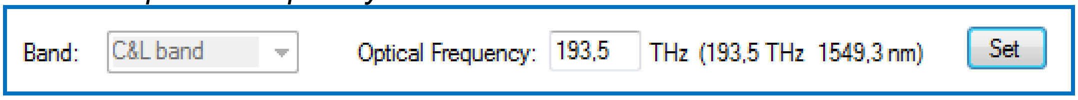
If you have attached only one Novoptel polarization scrambler/transformer, the GUI automatically selects this one. If you have attached more than one instrument, select the desired one from the drop-down list next to *Device* and click *USB/LAN Connect*.



If a connected instrument does not appear in the list, click the USB Refresh… button. Subsequently, you can launch further instances of the GUI and connect them to further instruments.
To connect with an instrument within the same LAN, type the instrument’s IP address into the field next to *Device* and click *USB/LAN Connect*. You can change the instrument’s network settings using the front buttons

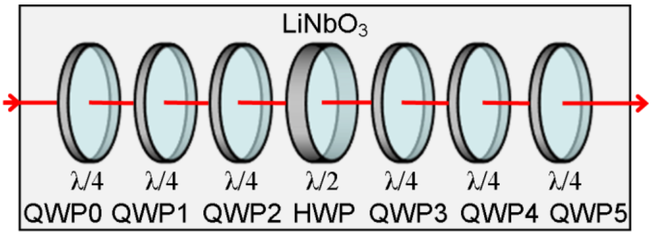
Setting optical frequency

Type the optical frequency in THz with up to one position after decimal point into the field besides *Optical Frequency*.



The valid range is at least C and L band, usually 182.9 THz (1639.1 nm) to 198.5 THz (1510.3 nm). Click the button *Set*. Retardations of the wave plates are fine-tuned to the given optical frequency.

Setting nominal scrambling speed and scrambling type



The $LiNbO_3$ polarization transformer inside the EPS1000 can be configured such that it contains cascaded electrooptic waveplates, 3 quarterwave plates (QWP0, QWP1, QWP2), 1 halfwave plate (HWP), 3 more quarterwave plates (QWP3, QWP4, QWP5). Each electrical period of waveplate voltages corresponds to half a mechanical turn of a waveplate. **As the nominal scrambling speed we define that speed on the Poincaré sphere which occurs if a waveplate generates rotating linear polarization.** This is the case with circular polarization at the input of a QWP or linear polarization at the input of the HWP.

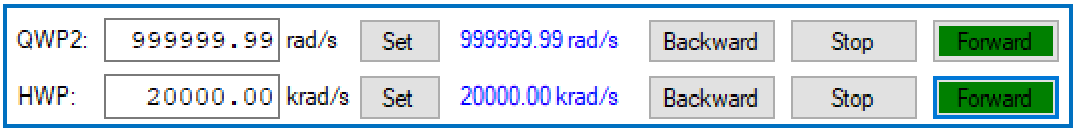
For the QWPs, nominal scrambling speed is given in in rad/s between 0 und 999,999.99 rad/s. The angular eigenmode rotation speed ($d\zeta/dt$) of a QWP equals its nominal scrambling speed. For input polarizations having ellipticity angle magnitudes <π/8 the polarization change speed of a QWP is up to sqrt(2) times the nominal scrambling speed, which is the achievable scrambling speed. For equidistributed input polarization the root-mean-square (rms) speed is 2/sqrt(3) = 1.15 times as large as for circular input polarization.

For the HWP, the nominal scrambling speed is in given krad/s between 0 und 20,000.00 krad/s (20M version). The angular eigenmode rotation speed ($d\zeta/dt$) of the HWP equals half its nominal scrambling speed. The maximum achievable scrambling speed of the HWP equals its nominal scrambling speed. For equidistributed input polarization the rms speed is √2/3 = 0.816 times as large.

The waveplates are depicted among each other in the sequence in which they are traversed by the light. Type the desired speed with up to two positions after decimal point into the box beside the wave plates. To obtain a uniform distribution of the polarization states on the Poincaré sphere, the nominal scrambling speeds of the waveplates should be incommensurate with each other. See Section III. of http://ieeexplore.ieee.org/document/7507007/ for application examples. Bipolar nominal scrambling speeds (forward and backward, in the following marked by the sign) generally yield broader polarization speed distributions on the Poincaré sphere than unipolar speeds.

A Rayleigh-like speed distribution is for example obtained by setting QWP0, QWP1, QWP2, HWP, QWP3, QWP4, QWP5 to nominal scrambling speeds of 8387, −3766.8, 13363, 9840, −7062.6, 14800, −11677 rad/s, respectively. The observed rms scrambling speed is 37.3 krad/s.

A peaked speed distribution, useful for accelerated performance or outing testing, is for instance obtained by the nominal speeds 119.28, −53.57, 190.04, 70000, −100.45, 210.5, −166.07 rad/s, respectively. It is peaked around 70 krad/s. Given the dominance of the HWP speed it is useful to say: QWP0 to QWP2 scramble the unknown input polarization. Dependent on this, the HWP generates circles in parallel planes of the Poincaré sphere with radii between 0 and 1. QWP3 to QWP5 reorient these circles arbitrarily.

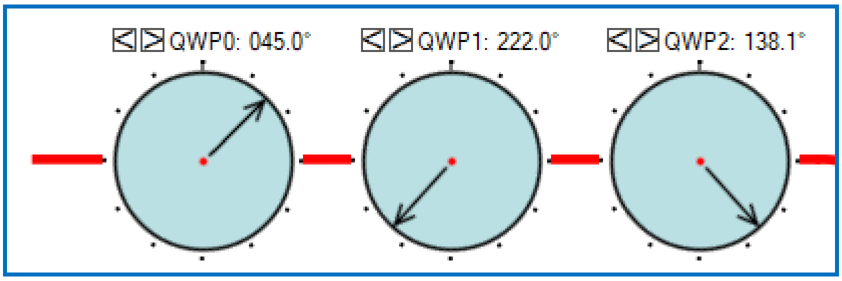


Click the button *Set*. This will transfer the entered value to the value in blue. Only the blue value is the actually applied rotation speed. Select the rotation direction by clicking "*Forward*" or "*Backward*" (or "*Stop*", to stop the waveplate).

Scrambling type Depolarizer generates exemplary time-periodic polarization transformations for an input polarization independent depolarizer. HWP, QWP3, QWP4 speeds are configured to realize a depolarizer described in https://arxiv.org/abs/1901.08838. The other QWPs have speeds which decrease by powers-of-4. If desired the slowest ones may be disabled to reduce depolarization time. Depolarization time = 2*pi/(speed of slowest enabled QWP). Depolarization speed can be varied to meet a specific depolarization time, which may be needed due to a finite-time integration in a measurement device.

Setting certain state of polarization

This function allows setting a fixed state of polarization or adjusting the input- and output polarization of a rotating wave plate. Select the tab *Position Control*. Each waveplate is depicted as a rotary knob. An arrow marks the eigenmode orientation angle ζ of the waveplate on the equator of the Poincaré sphere. The eigenmode orientation angle is shown above the waveplate in degrees.



To rotate the waveplate, click on one knob and move the mouse with pressed mouse button around the center of the knob. In case that the wave plate was configured to

rotate with a given speed, it will be halted automatically. You can start the rotation again using the tab *Rotation Control*.
Physically, waveplates can be described by their rotation matrices **G** of the normalized Stokes vector. These are

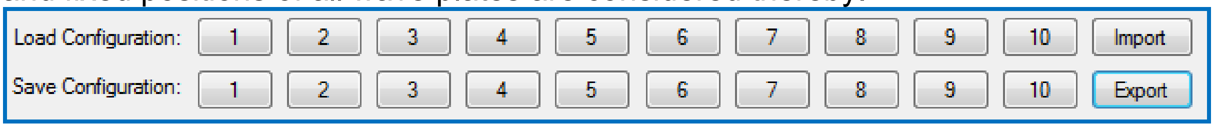
$$\mathbf{G}=\begin{bmatrix}(1+\cos(2\zeta))/2 & \sin(2\zeta)/2 & \sin\zeta \\ \sin(2\zeta)/2 & (1-\cos(2\zeta))/2 & -\cos\zeta \\ -\sin\zeta & \cos\zeta & \cos\delta\end{bmatrix}$$ for the QWPs,

$$\mathbf{G}=\begin{bmatrix}\cos(2\zeta) & \sin(2\zeta) & 0 \\ \sin(2\zeta) & -\cos(2\zeta) & 0 \\ 0 & 0 & -1\end{bmatrix}$$ for the HWP.

The eigenmode orientation angle ζ on the equator of the Poincare sphere is also the physical electrostatic field orientation angle inside the waveguide. It equals twice the orientation angle of a mechanical waveplate. The angular eigenmode rotation speed in the foregoing subchapter is $d\zeta/dt$.
The total normalized Stokes vector rotation matrix or polarization transformation of the EPS1000 is obtained by cascading (multiplying) the rotation matrices of the 7 waveplates.

__Store and load configurations__

You can save and recall up to ten configurations. Both nominal scrambling speeds and fixed positions of all wave plates are considered thereby.



Click on a numbered button beside *Save Configuration* to save the configuration to one of the memory locations. Click on a button beside *Load Configuration* to recall a configuration from a memory location. Unused memory locations are faded out. Instances of the Software which are launched in parallel share the memory locations.

The configuration can also be imported from and exported to text files (*.dat). The files consist of 66 lines, for register addresses 65 down to 0 (in this order). Each line of the text file simply contains the register address and the corresponding 16 Bit register value, separated by a space character (blank). The register addresses cover configuration of electrode voltages, waveplate positions, rotation speeds and rotation directions of the waveplates (see section *Control Registers*).

Operation of the instrument using register access

The polarization scrambler is controlled by reading from and writing to internal control registers. The register address line is 12 bits wide, while each register stores 16 bits. The connection host, e.g. the program running on the connected PC, initiates all communication.

Access the USB driver

The USB driver (FTDI D2XX) has to be installed on your system and the scrambler needs to be connected using a USB cable.

Support for Matlab

Novoptel provides a Matlab class (EPS1000.m) with functions for EPS1000 as well as precompiled MEX files for register operations via USB or LAN. The archive Matlab_Support_Files.zip is available at the top of page https://www.novoptel.de/Home/Downloads_en.php.

Support for Python

Novoptel provides a Python class (PyEps.py or EPS.py) with functions for EPS1000 via USB or LAN. The archive EPS_Python_Example.zip is available at the top of page https://www.novoptel.de/Home/Downloads_en.php.

Operation of the instrument using other programs

The USB vendor FTDI provides examples for USB access using other programs, for example LabVIEW® here:
https://ftdichip.com/software-examples/code-examples/
A rudimental example of a LabVIEW-VI (virtual instrument) is available from Novoptel upon request.

USB Settings

The following settings have to be applied to enable USB communication:

Baud Rate	230400 baud
Word Length	8 Bits
Stop Bits	0 Bit
Parity	0 Bit

To speed up sequential read and write operations, we recommend setting:

USB Latency Timer	2 ms

USB Transfer protocol

Writing to a register requires a 9 byte data packet. Each byte represents an ASCII-coded character. The packet starts with the ASCII-code 0x57 (for “W”) and ends with the ASCII-code 0x0D for *carriage return*.

Send *write data* packet

„W“	A(2)	A(1)	A(0)	D(3)	D(2)	D(1)	D(0)	^CR

The 12 bit register address A is sent using 3 bytes, each containing the ASCII-character of the hexadecimal numbers 0 to F which represents the 4 bit nibble. The character of the most significant nibble is sent first. The 16 bit data, which should be written into the register, is sent with 4 bytes using the same coding as the register address.

Reading data from a register requires the host to send a *request data* packet to the instrument. The packet starts with the ASCII-code 0x52 (for “R”), followed by the register address coded the same way as in *write data* packets.

Send *request data* packet

„R“	A(2)	A(1)	A(0)	„0“	„0“	„0“	„0“	^CR

After receiving the *request data* packet, the instrument sends the requested data packet to the host:

D(3)	D(2)	D(1)	D(0)	CR

TCP/IP (LAN) Communication

The user can set the IP address, gateway and subnet mask via the front buttons. After the next power-up, the EPS1000 will open a TCP/IP socket using the entered settings and wait for a connection.

TCP/IP Settings

Port	5025
Input buffer	8192 Bytes

TCP/IP Transfer protocol

write data **packet**

In contrast to USB communication, writing to a register via TCP/IP requires only a 5 byte data packet. The packet starts with the ASCII-code 0x57 (for "W").

„W“	A(11..8)	A(7..0)	D(15..8)	D(7..0)

The 12 bit register address is sent first in two bytes, followed by the 16 bit register data in another two bytes.

Reading data over TCP/IP requires the program to send a *request data* packet of 3 bytes to the instrument. The packet starts with the ASCII-code 0x52 (for "R"), followed by the register address coded the same way as in *write data* packets.

Send *request data* packet

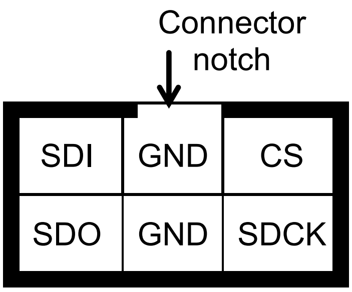
„R“	A(11..8)	A(7..0)

After receiving the *request data* packet, the instrument sends the requested data packet to the host:

D(1)	D(0)

Operation of the instrument using SPI

The EPS1000 starts operation without serial peripheral interface SPI. The user doesn't have to use the SPI at all. While the module starts operation without SPI, this serial interface can be used to control function, modify parameters, read back these commands as well as debug register contents. All control registers can (also) be accessed by SPI. The SPI allows communication with a simpler protocol and shorter delays than USB. The SPI connector at the backside of the device provides the following connection:



Transmission starts with falling edge of CS and ends with rising edge of CS. After falling edge of CS, the command is transmitted. SDI is sampled with rising edge of SCK. Maximum SCK frequency is 500 kHz. Command and data word length is 16 bit each. MSB of command and data word is sent first, LSB last. If a valid *register read* (RDREG) command is received, the SDO output register shifts with falling edge of SCK to transmit the requested data word. Otherwise SDO remains in high impedance state. Data transfer to the device continues directly after transmitting a *register write* (WRREG) command.

Serial interface (SPI) commands

Each SPI register has 16 bit. Upon power-on, all registers are reset to default. The upper 4 bit can be 0h (read) or 1h (write). The lower 12 bits are the control register address.

Command	**Code**	**Data**	**Function**
RDREG	0XXXh	OUT	Read control register XXXh (for definition see below)
WRREG	1XXXh	IN	Write control register XXXh (for definition see below)

Serial interface (SPI) timing

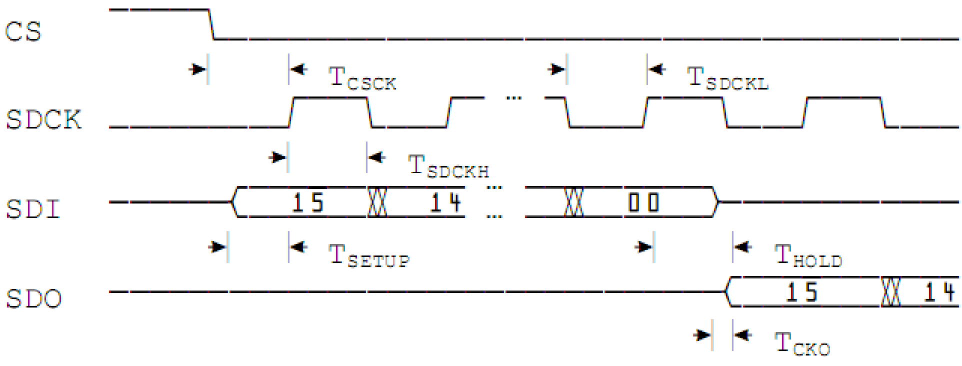


Fig. 2: Timing of SPI port.

Symbol	Description	Min	Max	Units
T_{CSCK}	CS low to SDCK high	120	–	ns
T_{CKCS}	SDCK low to CS high	120	–	ns
T_{SDCKL}	SDCKL low time	1	–	µs
T_{SDCKH}	SDCKL high time	1	–	µs
T_{SETUP}	SDI egde to SDCK high (setup time)	30	–	ns
T_{HOLD}	SDCK to SDI edge (hold time)	30	–	ns
T_{CKO}	SDCK edge to stable SDO	–	100	ns

Control registers

The following table describes all control register used to operate the scrambler. They can be accessed via USB, TCP/IP (LAN) and SPI.

All registers in the 12-bit address space that are not defined below are reserved, and should not be written into! For a possible remote debugging, content of all defined registers needs to be read and sent to Novoptel.

Register address	Bit(s)	Read/ Write	Function
0	0	R/W	HWP rotation enable(1) or disable (0)
	1	R/W	HWP direction backward(1) or forward(0)
1	0	R/W	QWP0 rotation enable(1) or disable (0)
	1	R/W	QWP0 rotation direction backward(1) or forward(0)
2	0	R/W	QWP1 rotation enable(1) or disable (0)
	1	R/W	QWP1 rotation direction backward(1) or forward(0)
3	0	R/W	QWP2 rotation enable(1) or disable (0)
	1	R/W	QWP2 rotation direction backward(1) or forward(0)
4	0	R/W	QWP3 rotation enable(1) or disable (0)
	1	R/W	QWP3 rotation direction backward(1) or forward(0)
5	0	R/W	QWP4 rotation enable(1) or disable (0)
	1	R/W	QWP4 rotation direction backward(1) or forward(0)
6	0	R/W	QWP5 rotation enable(1) or disable (0)
	1	R/W	QWP5 rotation direction backward(1) or forward(0)

9	15..0	R/W	HWP nominal scrambling speed Bits 15..0(1)
10	15..0	R/W	HWP nominal scrambling speed Bits 31..16(1)
11	15..0	R/W	QWP0 nominal scrambling speed Bits 15..0(2)
12	15..0	R/W	QWP0 nominal scrambling speed Bits 31..16(2)
13	15..0	R/W	QWP1 nominal scrambling speed Bits 15..0(2)
14	15..0	R/W	QWP1 nominal scrambling speed Bits 31..16(2)
15	15..0	R/W	QWP2 nominal scrambling speed Bits 15..0(2)
16	15..0	R/W	QWP2 nominal scrambling speed Bits 31..16(2)
17	15..0	R/W	QWP3 nominal scrambling speed Bits 15..0(2)
18	15..0	R/W	QWP3 nominal scrambling speed Bits 31..16(2)
19	15..0	R/W	QWP4 nominal scrambling speed Bits 15..0(2)
20	15..0	R/W	QWP4 nominal scrambling speed Bits 31..16(2)
21	15..0	R/W	QWP5 nominal scrambling speed Bits 15..0(2)
22	15..0	R/W	QWP5 nominal scrambling speed Bits 31..16(2)
23	15..0	R/W	Target speed of distribution in multiples of 10 rad/s; Bits 15..0(8)
24	15..0	R/W	Scrambling type; Bits 31..30 3 = Rayleigh 2 = Peaked 0, 1 = User Target speed of distribution in multiples of 10 rad/s; Bits 29..16(8) Target speed (Bits 29..0) is limited to 1000000 (Rayleigh, 10 Mrad/s) or 2000000 (Peaked, 20 Mrad/s). Limiting takes place when register 24 is written and scrambling type is Rayleigh or Peaked. To avoid accidental target speed truncation, write register 23 first, then write register 24.
25	15..0	R/W	Optical Frequency Index I(3)
26	2..0	R/W	Index of optical band as unsigned decimal. The value "0" is the first available band (usually C&L-band), "1" is the second available band (usually O-band) and so on.
30..37	15..0	R/W	Waveplate Retardation Scaling Factors for $LiNbO_3$ sections 1 (QWP0) to 8 (QWP5), including sections 4 and 5 that form the HWP, as 16 bit unsigned integer. A value of 2^{15} refers to a factor of 1. Maximum factors are 1.25 for the QWP sections and 1 for the HWP sections.(9)
40	15..0	R/W	HWP position Index I(4)
41	15..0	R/W	QWP0 position index I(4)
42	15..0	R/W	QWP1 position index I(4)
43	15..0	R/W	QWP2 position index I(4)
44	15..0	R/W	QWP3 position index I(4)
45	15..0	R/W	QWP4 position index I(4)
46	15..0	R/W	QWP5 position index I(4)
47	15..0	R	Table Dwell Time (multiples of 40 ns) as stored in the table, Bits 15..0

48	15..0	R	Table Dwell Time (multiples of 40 ns) as stored in the table, Bits 31..16
50	13..0	R/W	$LiNbO_3$ section 1 electrode 1 voltage(5)
51	13..0	R/W	$LiNbO_3$ section 1 electrode 2 voltage(5)
52	13..0	R/W	$LiNbO_3$ section 2 electrode 1 voltage(5)
53	13..0	R/W	$LiNbO_3$ section 2 electrode 2 voltage(5)
54	13..0	R/W	$LiNbO_3$ section 3 electrode 1 voltage(5)
55	13..0	R/W	$LiNbO_3$ section 3 electrode 2 voltage(5)
56	13..0	R/W	$LiNbO_3$ section 4 electrode 1 voltage(5)
57	13..0	R/W	$LiNbO_3$ section 4 electrode 2 voltage(5)
58	13..0	R/W	$LiNbO_3$ section 5 electrode 1 voltage(5)
59	13..0	R/W	$LiNbO_3$ section 5 electrode 2 voltage(5)
60	13..0	R/W	$LiNbO_3$ section 6 electrode 1 voltage(5)
61	13..0	R/W	$LiNbO_3$ section 6 electrode 2 voltage(5)
62	13..0	R/W	$LiNbO_3$ section 7 electrode 1 voltage(5)
63	13..0	R/W	$LiNbO_3$ section 7 electrode 2 voltage(5)
64	13..0	R/W	$LiNbO_3$ section 8 electrode 1 voltage(5)
65	13..0	R/W	$LiNbO_3$ section 8 electrode 2 voltage(5)
78	6	R/W	Ext. gating of QWP5 rotation en-/disable(7)
	5	R/W	Ext. gating of QWP4 rotation en-/disable(7)
	4	R/W	Ext. gating of QWP3 rotation en-/disable(7)
	3	R/W	Ext. gating of HWP rotation en-/disable(7)
	2	R/W	Ext. gating of QWP2 rotation en-/disable(7)
	1	R/W	Ext. gating of QWP1 rotation en-/disable(7)
	0	R/W	Ext. gating of QWP0 rotation en-/disable(7)
79	6	R/W	Ext. gating of QWP5 active high (1) or low (0) (7)
	5	R/W	Ext. gating of QWP4 active high (1) or low (0) (7)
	4	R/W	Ext. gating of QWP3 active high (1) or low (0) (7)
	3	R/W	Ext. gating of HWP active high (1) or low (0) (7)
	2	R/W	Ext. gating of QWP2 active high (1) or low (0) (7)
	1	R/W	Ext. gating of QWP1 active high (1) or low (0) (7)
	0	R/W	Ext. gating of QWP0 active high (1) or low (0) (7)
84	15..0	R	Firmware version
91	15..0	R	Serial Number
123	15..0	R	Dark current of ADC sample (optional photodetector)
124	15..0	R	Optical power at upper ADC range limit in µW
126	1	R/W	(1) automatic or (0) manual switching between two optional photodetectors
	0	R/W	Manual switch position or polarity of automatic switching according to Bit 1
128	15..0	R	Integer part of ADC sample
129	9..0	R/W	Averaging Time Exponent (ATE) for ADC sampling
130	15..0	R/W	Address of internal sampling memory
131	15..0	R	Data-Out of internal sampling memory
132	0	R/W	Triggered WP rotation enable (1) or disable (0)
133	15..0	R	Fractional part of ADC sample, frozen at each reading of register 128
134	15..0	R/W	Memory stop-address for measurements (max.2^{16}-1)

135	15..0	R	Next sampling memory address bits 15..0
136	15..0	R/W	Measurement delay in multiples of 20 ns(6)
137	15..0	R/W	Memory Averaging Time Exponent (MEMATE) for memory trigger(6)
138	2..0	R/W	Control of optional electrical switches(6)
139	0	R	Next sampling memory address bit 16(6)
140	15..0	R/W	Number of cycles to be skipped during measurements(6)
141	3..0	R/W	With a value A in this register, 2^A samples will be stored per waveplate position(6)
150	0	R/W	(0): Define WP rotation by registers 9...22 (1): Define WP rotation by registers 151...157
151	15..0	R/W	HWP eigenmode rotations per 10.7 s
152	15..0	R/W	QWP0 eigenmode rotations per 10.7 s
153	15..0	R/W	QWP1 eigenmode rotations per 10.7 s
154	15..0	R/W	QWP2 eigenmode rotations per 10.7 s
155	15..0	R/W	QWP3 eigenmode rotations per 10.7 s
156	15..0	R/W	QWP4 eigenmode rotations per 10.7 s
157	15..0	R/W	QWP5 eigenmode rotations per 10.7 s
218	0	R/W	Table execution in row (1) or table (0) mode
219	9..0	R/W	Table memory input address
220	0	R/W	Enable (1) or disable (0) continuous table execution
221	15..0	W	Table memory write trigger. Must be reset to “0” in firmware<1.0.7.0! Bit 0: Write table memory vector 00, 01, and 02 Bit 1: Write table memory vector 03 Bit 2: Write table memory vector 04 .. Bit 15: Write table memory vector 17 In firmware <1.0.7.0, Bit 0 writes all table memory vectors.
222	15..0	R/W	Int. trigger period in mult. of 40 ns, Bits 15..0
223	15..0	R/W	Int. trigger period in mult. of 40 ns, Bits 31..16
224	0	R/W	External trigger input enabled (1) or disabled (0)
225	1	R/W	Enable (1) or disable (0) trigger by ATE counter
	0	R/W	Enable (1) or disable (0) internal trigger counter
226	1	R/W	Configure BNC port as output (1) or input (0)
	0	R/W	1: Enable BNC trigger signal output
227	1..0	W	Bit 0: “1” will launch a trigger event (manual trigger) Bit 1: “1” will reset the table to the first entry
228	9..0	R/W	Length of current table in table memory
229	6..0	R/W	Fixed waveplate positions are defined by registers (0) or by table memory (1) Bit 6: QWP0 Bit 5: QWP1 Bit 4: QWP2 Bit 3: HWP Bit 2: QWP3 Bit 1: QWP4

			Bit 0: QWP5 Note: In firmware < 1.0.7.0, Bit 0 defines the status for all waveplates.
239	2..0	R/W	Table mode. "000": No table mode "001": Waveplate positions "010": Waveplate nominal scrambling speeds "011": Electrode voltages "1XX": Depolarization voltage tables (optional). For depolarization mode to be active, also the number >0 of a specific provided depolarization table must be written in Bits 7..0 of Reg. 240. Note: This and all table memory registers are described for firmware >=1.1.0.0. For earlier firmwares please refer to User Guide rev. 0.1.6.
240	15..8	R	Number of provided depolarization tables (optional), usually 10 or 15 (see test report of your EPS1000).
	7..0	R/W	Selected depolarization table (optional). Lowest valid number is "1".
241	15..0	R	Period of selected depolarization table (optional) in multiples of 10 ns. For example "24" refers to a depolarization time of 240 ns.
250..267	15..0	R/W	Table memory input elements 00 to 17. See section "Table memory".
270..287	15..0	R	Table memory output elements 00 to 17
330(10)	13..0	W	Read address of intensity recording memory.
	15..0	R	Intensity of DUT receiver memory at read address.
331(10)	15..0	R	Intensity of REF receiver memory at read address.
332(10)	15..8	R	Number of fractional bits of REF receiver memory (reg. 331)
	7..0	R	Number of fractional bits of DUT receiver memory (reg. 330)
333(10)	14..0	R	Current address of intensity recording memory. Can be read during PDL sweep for progress checking.
334(10)	3	R	Status of BNC input in PDL by extinction mode
	2..0	R/W	Configuration of PDL measurement during sweep: "000": Normal operation (automatic switching between minimum and maximum tracking). Intensities memory address is reset. "001": Only Minimum or only maximum tracking, defined by Bit 0 of register 342. "011": BNC input is used as trigger input for storing intensities during tracking. Requires external trigger input to be enabled (reg. 224) "111": Internal trigger signal, gated by BNC input, stores intensities during tracking.
335(10)	15..11	R/W	Measurement time exponent (MTE) for PDL by extinction method. Measurement in minimum or maximum transmission state is 20 ns * 2^{MTE}.

	7..0	R/W	Number of tracking iterations in PDL by extinction method
340(10)	3..0	R/W	Configuration of tracking and PDL measurement. Requires optional error detector or digital error signal interface. “0000”: SOP Tracking mode disabled (default) “0001”: SOP Tracking mode enabled, but tracking disabled. “0011”: SOP Tracking enabled. “0101”: PDL measurement by Extinction method enabled. “1000”: PDL measurement by Depolarization method enabled.
341	15..0	R/W	Control gain (100 by default)
342	0	R/W	Error signal minimization (“0”) or maximization (“1”). Maximization is only recommended for checking the error signal range, not for enduring control
343	3..0	R/W	Averaging time exponent (ATE). Although function is more complicated than this one may define an equivalent averaging time which is roughly 80 ns * 2^{ATE}. Fundamental control speed changes like 1 / (80 ns * 2^{ATE} + 100 ns). High ATE (= low control speed) tolerates higher time constant of error signal and is good for averaging of noisy error signal. Low ATE (= high control speed) requires low time constant of error signal. Permissible time constant of control signal is roughly 40 ns * 2^{ATE}. When using digital feedback interface to the PM1000, minimum ATE is 2. 0000h = least averaging, highest speed 0001h = more averaging, reduced speed ... 000Fh = most averaging ($2^{000Fh} = 2^{15}$), lowest speed
344	12..0	R/W	Error signal delay (deadtime, risetime), given as multiples of 20 ns. Default value for digital feedback interface to PM1000 is 41.
345	2..0	R/W	Dither amplitude. Small dither is recommended if error signal is of good quality. Large dither is needed if error signal is noisy. Register determines percentage of nominal dither amplitude. Default value is 0002h = 50%. 0000h = 0% 0001h = 25% 0002h = 50% 0003h = 75% 0004h = 100% 0005h = 125% 0006h = 150% 0007h = 175%
346	3..0	R/W	Strength with which voltages are pulled back to zero during tracking. Default = 1. Tracking fast, endless trajectories may require higher values.
347	6..0	R/W	Settings for tracking mode. Bit 6: APD control enabled (1) or disabled (0) Bit 5: REF path: Sensitive mode enabled (1) or disabled (0)

			Bit 4: DUT path: Sensitive mode enabled (1) or disabled (0) Bit 3: Reference path enabled (1) or disabled (0) Bit 2: Gradient type fast (0) or power-independent (1) Bits 1..0: Detector mode
349	2..0	R	Sensitive mode of REF receiver (Bit 0) and DUT receiver (Bits 1..0)
350	15..0	R	Feedback signal of detector 1 (unsigned 16 bit vector)
351	15..0	R	Feedback signal of detector 2 (unsigned 16 bit vector)
352	15..8	R	Only for firmware >= 1.2.2.5: Number of fractional bits of detector 2 feedback value (reg. 351) when in sensitive mode
	7..0	R	Only for firmware >= 1.2.2.5: Number of fractional bits of detector 1 feedback value (reg. 350) when in sensitive mode
360	15..0	R	Power limit in Microwatt of DUT receiver
361	15..0	R	Power limit in Microwatt of REF receiver
362(10)	15..0	R	PDL result of depolarization method. Bits 15..10: Integer part. Bits 9..0: fractional part
363(10)	15..0	R	Mean value of DUT path during PDL measurement with depolarizing method
365(10)	15..0	R	Mean value of REF path during PDL measurement with depolarizing method
370(10)	15..0	R	Maximum value of DUT path during PDL measurement with extinction method
371(10)	15..0	R	Maximum value of REF path during PDL measurement with extinction method
372(10)	15..8	R	Number of fractional bits of Max. value of REF (reg. 371)
	7..0	R	Number of fractional bits of Max. value of DUT (reg. 370)
373(10)	15..0	R	Minimum value of DUT path during PDL measurement with extinction method
374(10)	15..0	R	Minimum value of REF path during PDL measurement with extinction method
375(10)	15..8	R	Number of fractional bits of Min. value of REF (reg. 374)
	7..0	R	Number of fractional bits of Min. value of DUT (reg. 373)

(1) The HWP speed index I (32 bit integer) is calculated from the nominal HWP scrambling speed SHWP (in krad/s) by I = round(SHWP·100).
(2) The QWP speed index I (32 bit integer) is calculated from the nominal QWP scrambling speed SQWP (in rad/s) by I = round(SQWP·100).
(3) The optical frequency index I is calculated from the optical frequency F (in THz) by I=round(F·10-1828).
(4) The position index I is calculated from Position P (in degrees) by I=round(P·65536/360).
(5) Only applicable since firmware 1.0.2.0.
(6) Only applicable since firmware 1.0.6.0.
(7) Only applicable since firmware 1.0.8.1.
(8) Only applicable since firmware 1.2.0.7. In older firmwares the individual WP speeds must be set. To find possible settings, activate Peaked or Rayleigh

distribution in the GUI, set a target speed and read individual WP speeds and rotation directions.
(9) Only applicable since firmware 1.2.1.4.
(10) Only applicable since firmware 1.2.2.7.

Table memory

The table memory registers are described for firmware >=1.1.0.0. For earlier firmware versions please refer to User Guide rev. 0.1.6.
The elements 00 to 17 are described in the following. They are contained in each row/entry of a table. A table may consist of up to 1024 rows/entries which are active at different times.

The first two vectors of a table define the dwell time of the table row/entry:

Element	Meaning
00	Table dwell time in multiples of 40 ns, minus 1, Bits 15..0
01	Table dwell time in multiples of 40 ns, minus 1, Bits 31..16

For a dwell time of 200 ns, a value of 4 must be written into element 00, since (4+1)*40ns=200ns.

The meaning of all other elements depends on the table mode:

Waveplate positions:
The waveplate positions are given in integer numbers between 0 and 2^{16}-1, where 2^{16} means a full revolution.

02	Position of HWP
03	Position of QWP0
04	Position of QWP1
05	Position of QWP2
06	Position of QWP3
07	Position of QWP4
08	Position of QWP5
09..17	reserved

Waveplate nominal scrambling speeds:
The nominal scrambling speeds are given in rad/s/100 for the quarterwave plates and in krad/s/100 for the halfwave plate.

02	HWP nominal scrambling speed Bits 15..0
03	Bits 4..0: HWP nominal scrambling speed speed Bits 20..16 Bit 14: Enable (1) or disable (0) HWP rotation Bit 15: HWP rotation direction backward (1) or forward (0)
04	QWP0 nominal scrambling speed Bits 15..0
05	Bits 10..0: QWP0 nominal scrambling speed Bits 26..16 Bit 14: Enable (1) or disable (0) QWP0 rotation Bit 15: QWP0 rotation direction backward (1) or forward (0)
…	…
14	QWP5 nominal scrambling speed Bits 15..0
15	Bits 10..0: QWP5 nominal scrambling speed Bits 26..16 Bit 14: Enable (1) or disable (0) QWP5 rotation

	Bit 15: QWP5 rotation direction backward (1) or forward (0)
16..17	reserved

Electrode voltages:
The 16 electrode voltages (8 sections, 2 voltages per section) are given as integer number between 2^{15}-6000 and 2^{15}+6000.

02	Voltage 1 of section 1
03	Voltage 2 of section 1
04	Voltage 1 of section 2
05	Voltage 2 of section 2
…	…
16	Voltage 1 of section 8
17	Voltage 2 of section 8

Firmware upgrade

Via the JTAG port the user can upgrade the firmware, if ever needed. Note that the upgrading firmware must be obtained from Novoptel to avoid incompatibilities. An application note for firmware upgrading is available at the bottom of page https://www.novoptel.de/Home/Downloads_en.php.

Synchronous/Triggered Waveplate Rotation

In normal scrambling mode, waveplates are rotated continuously. Quasi-steady polarization changes are thereby achieved. For some applications, the polarization should be fixed for a defined time interval to allow accurate SOP sampling within it. This can be done with the synchronous/triggered waveplate rotation function: The waveplates will be kept rotating internally, but the corresponding electrode voltages will be updated only upon a trigger event.

Trigger Source

Several different trigger sources are available:

Manual: Trigger events can be manually released by pushing the *Manual Trigger* button.

Internal: The scrambler is triggered by an internal clock. The *Internal Trigger Period* can be adjusted in multiples of 40 ns. Minimum *Internal Trigger Period* is 200 ns

ATE: Internal trigger synchronous to the averaging time of the optional photodetector. The trigger event will be launched every 80 ns · 2^{MEMATE}.

External: Triggering by a LVCMOS33 (0 V / +3.3 V) signal that is applied to the BNC connector at the rear panel of the device.

Continuous: Only applicable for synchronous/triggered table execution: The scrambling table is executed continuously.

The internal triggers can optionally be fed out to the BNC connector at the rear panel of the device if the box *Trigger (OUT) BNC* is activated.

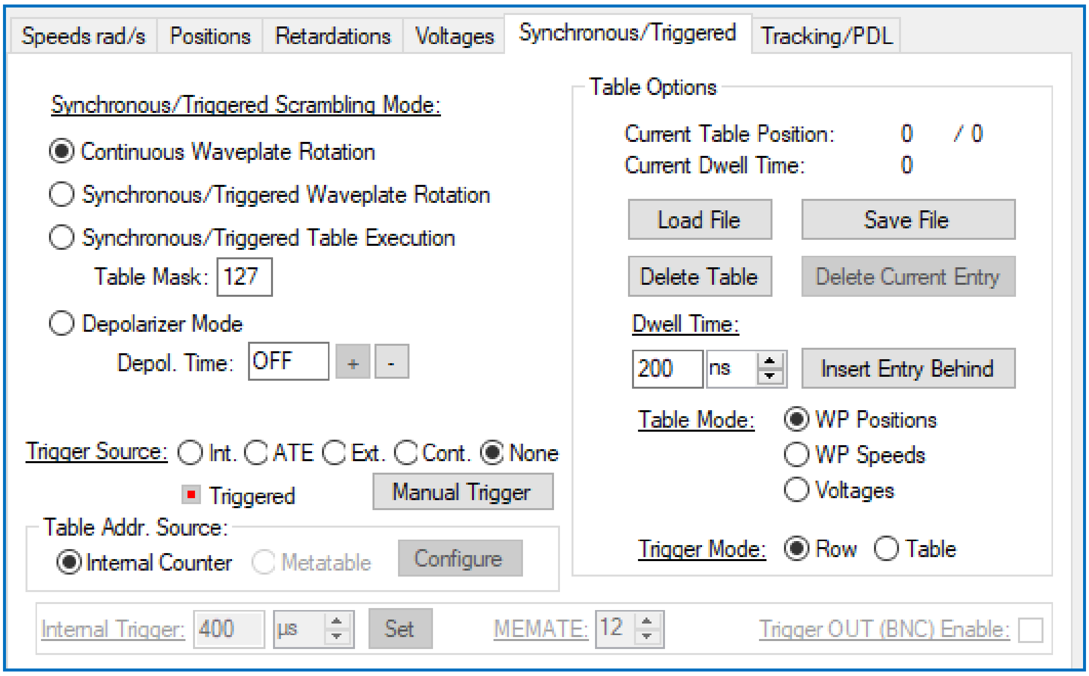


Fig. 3: “Synchronous/Triggered“ tab

Synchronous/Triggered Table Execution

The scrambler can put all waveplates to specified positions or even put all electrode voltages to specified values which are stored in a table. Each row of the table contains the positions of the 7 waveplates, followed by the 16 corresponding electrode voltages and a dwell time (= subsequent delay) in nanoseconds. The dwell time must be a multiple of 40 ns. Minimum dwell time is 200 ns.

Tables can be created using the GUI. They can be stored to and loaded from a file. This way, tables can also be generated by an external program and, afterwards, loaded into the scrambler. For a better understanding of the corresponding registers, please also refer to Application Note 2.

Since firmware 1.1.0.0 of the scrambler, three separate table modes exist for waveplate positions, nominal scrambling speeds and electrode voltages. The first row of a text file defines the table mode using the syntax *table_mode='mode'*, where *'mode'* is one of *'position'*, *'speed'* and *'voltage'*.

In the positions table, the positions of the 7 waveplates are given as integer numbers between 0 and 2^{16}-1, followed by the dwell time as described above. In the speeds table, the first 7 numbers define the status (on/off, Bit 0) and the direction (forward/backward, Bit 1) of the waveplates, followed by the 7 nominal scrambling speeds and the dwell time. The nominal scrambling speeds are given in rad/s/100 for the quarterwave plates and in krad/s/100 for the halfwave plate. In the voltages table, the 16 electrode voltages are given as integer number between 2^{15}-6000 and 2^{15}+6000, followed by the dwell time.

The trigger sources are the same as described in the previous section "Synchronous/Triggered Waveplate Rotation". There are two basic trigger modes, row or table:

Row Trigger Mode

In row trigger mode, the rows of the stored table are executed one-by-one upon a trigger event. After the last table row, the counter starts over from the first table row.

Table Trigger Mode

In table trigger mode, the scrambler starts over from the first table entry upon every trigger. Subsequent rows are executed after the dwell time delay specified in each row. After the last table row, the row counter is halted until the next trigger event occurs.

In *Row Trigger Mode* the *Internal Trigger Period* must be chosen at least as long as the longest *Dwell Time*. In *Table Trigger Mode* the *Internal Trigger Period* must be chosen at least as long as the sum of all *Dwell Times*.

Table Mask

With the table mask, selected wavepates can be excluded from the table execution. The mask is given as an integer number that represents a 7 Bit vector. The most significant bit corresponds to the first waveplate (QWP0) and so on. Position and nominal scrambling speeds of waveplates excluded from table execution can be used as in normal operation mode.

Depolarization Tables

As an option, EPS1000-50M can be equipped with internal tables for fast depolarization, independent of input SOP. After selecting *Depolarizer Mode* in the *Synchronous/Triggered* tab, one can switch through the tables for different depolarization times by pressing the "+" and "-" buttons. For the available number of depolarization tables (usually 10 or 15), refer to the EPS1000 test report.

External electrode voltage allocation

Since firmware 1.0.2.0 (release 15.04.2013), the EPS1000 allows external allocation of the 16 $LiNbO_3$ electrode voltages via USB, LAN or SPI. This increases flexibility when searching for a defined polarization state: 16 instead of 7 degrees of freedom are thereby provided. The external voltage setting overwrites any nominal speed or position setting of the corresponding waveplate when writing to one of the registers 50 to 65, see register description. The voltage value is given as an unsigned integer with an offset of 8192. Positive integers generate positive voltages. The register value is limited to 8192±6000, referring to a voltage range from -48V to +48V. In the GUI, the offset is not shown.

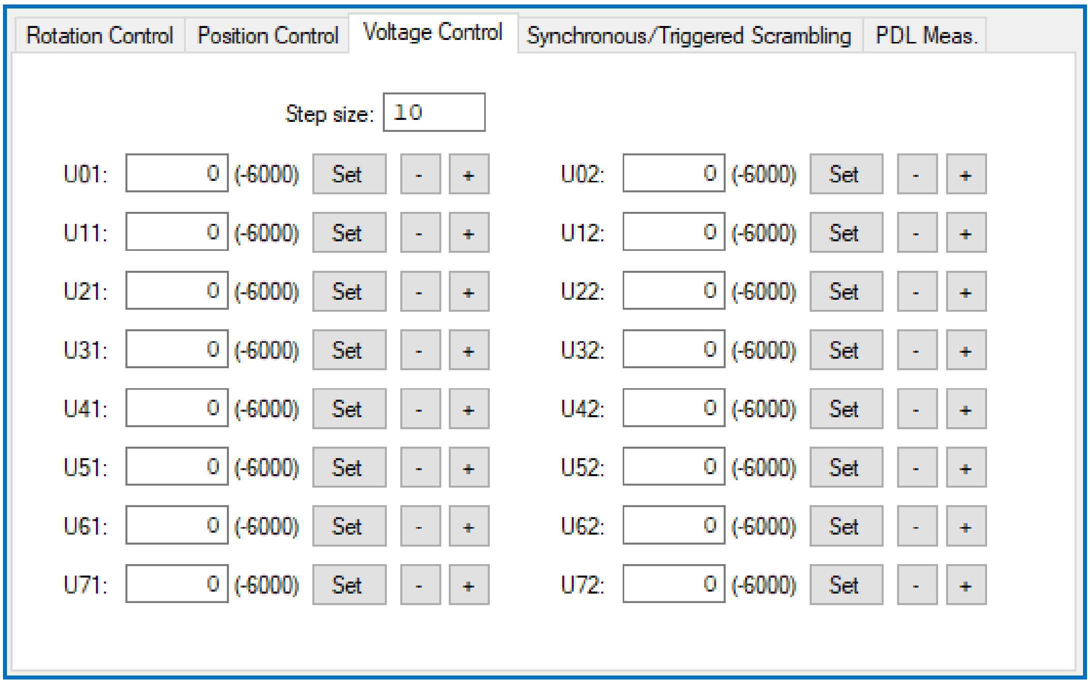


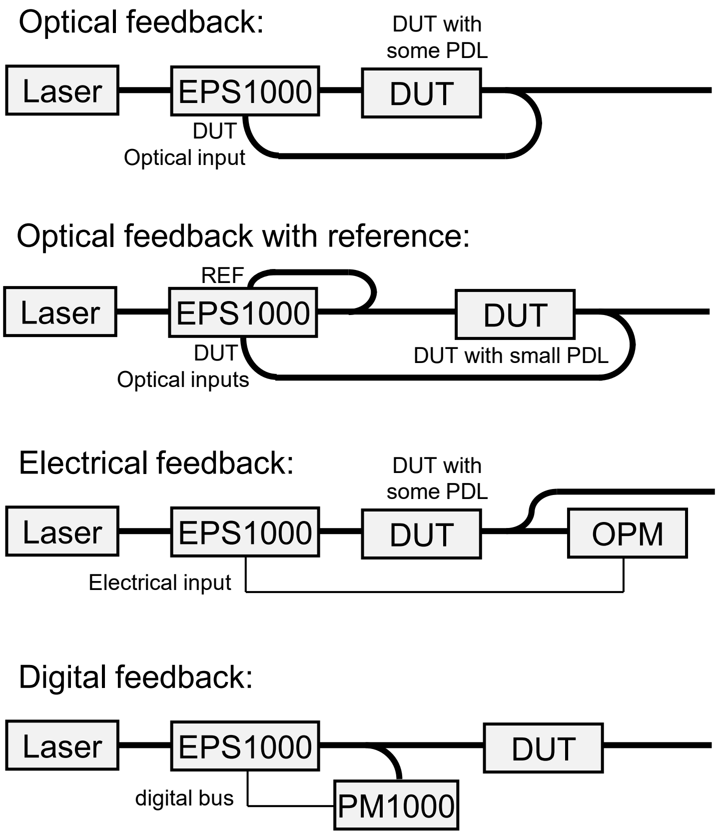
Fig. 4: Allocation of registers corresponding to 16 electrode voltages.

The given value is written into the digital-to-analog converter (DAC) directly after it appears in the register. When using SPI, the delay between the last SPI command bit and the internal DAC complete output flag is <100 ns. Initial electrooptic response is typically obtained in <100 ns more.

SOP tracking

The EPS1000 can optionally be equipped with an error detector or digital error feedback interface to a polarimeter PM1000 that allow polarization tracking.

Possible setups



Optical feedback: The signal is fed through a DUT with some PDL. Behind the DUT, a part of the signal is tapped and fed back to the EPS1000. The EPS1000 can either minimize or maximize the optical feedback signal, thereby adjusting the polarization to either the minimum or maximum transmission path of the DUT.

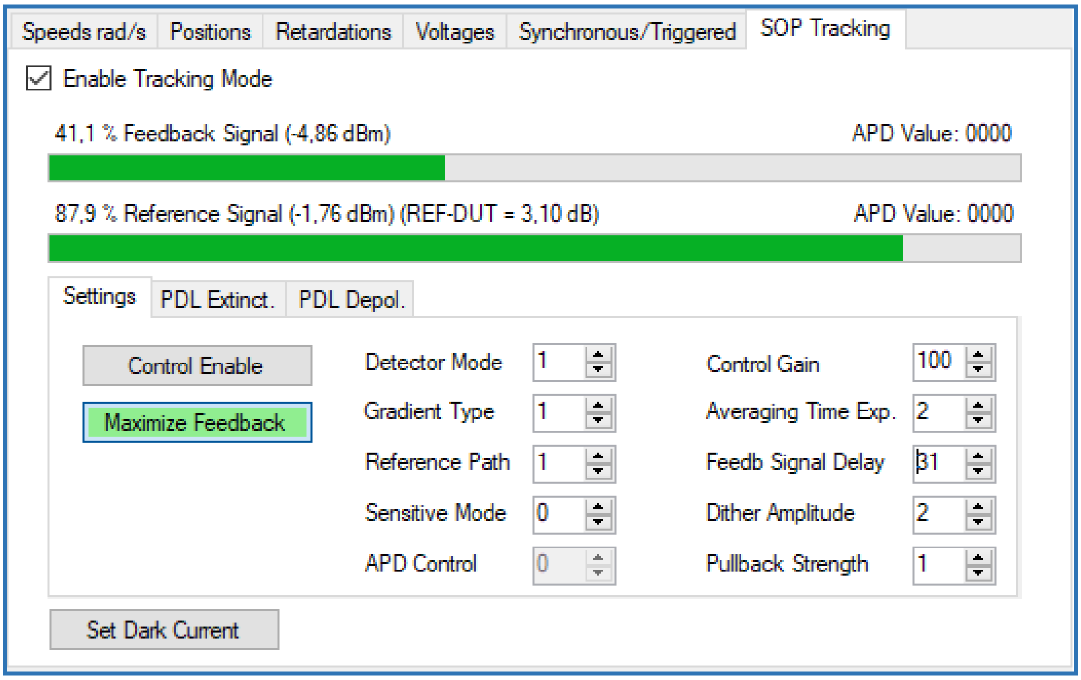
Optical feedback with reference: If PDL of the DUT is small, also the feedback signal's intensity gradient becomes small. Power fluctuations and residual PDL of the EPS1000 can decrease tracking accuracy. This can be improved by a reference measurement of the signal tapped out in front of the DUT.

Electrical feedback: The electrical, analogue output of an external optical power meter (OPM) serves as feedback for EPS1000. The signal range of the EPS1000 input port is 0 V to 2 V. This and other properties can be adjusted during production so that 0 V to 5 V is also possible.

Digital feedback: A polarimeter PM1000 calculates a feedback signal from the distance between measured SOP and a target SOP. This way, the signal can be stabilized at any given SOP, not just minimum and maximum transmission of the DUT. The target SOP is written into the control registers of PM1000. PM1000 also supports target SOP tables of up to 512 SOPs that are applied consecutively.

SOP tracking parameters

The *Tracking/PDL* tab of the GUI allows enabling the tracking mode and changing the tracking parameters of the EPS1000:



Control Enable: Enables (button becomes green) or disables (button becomes grey) the control

Maximize Feedback: Maximizes (button becomes green) or minimizes (button becomes grey) the feedback signal. Usually minimization provides better tracking accuracy. With digital feedback from PM1000, set the opposite target SOP instead of using maximization.

Set Dark Current: Calibrates the offsets of the ADCs for optical DUT and REF inputs.

Detector Mode: Switches feedback between supported sources:

0: digital feedback from PM1000
1: optical feedback from tracking input port(s) at the front panel
2: electrical feedback from analogue input at the rear panel

Gradient Type: Selects between

0: Fast, intensity sensitive mode. In this mode, the value "Control gain" should reflect the inverse of the ADC range that is covered by the feedback signal. If the whole range is covered set a value of 100. If half of the range is covered, set a value of 200.

1: Slower, intensity insensitive mode. The value "Control gain" does not matter here.

Reference Path: Only with optical feedback to EPS1000 and with intensity insensitive gradient type: Enables the reference measurement.

Sensitive Mode: Only with optical feedback to EPS1000 and with intensity insensitive gradient type: Automatic switching between normal and more sensitive input ranges. Selected value 0 to 3 enables this function in

0: None of the paths
1: The DUT feedback path only
2: The REF feedback path only
3: Both the DUT and REF feedback path

APD control: Depending on configuration, the internal optical detector may be equipped with photodiode(s) of avalanche type (APD) This setting enables the automatic adjustment the APD voltage(s)

Control Gain: Adjusts the gradient step amplification (only for gradient type “0”).

Averaging Time Exp. (ATE): Adjusts the control speed inversely. Recommended values are

Digital Feedback (PM1000): Minimum 2
Optical Feedback: 0 (may need to be increased if DUT PDL or optical power is low)
Electrical Feedback: Depends on signal bandwidth. Recommendation: (80 ns $*2^{ATE}$) > (4*integration time of OPM)

Important: When using the digital feedback interface between EPS1000 and PM1000 it must be ensured that ATE of PM1000 exceeds ATE of EPS1000 only by a maximum of 1. For example, if ATE of EPS1000 is 2, ATE of PM1000 must be ≤3.

Error Signal Delay: Adjusts the internal error signal delay (deadtime). One step refers to 20 ns. Recommended value is 31 for a DUT (and OPM) with negligible delay.

Dither Amplitude: Adjusts the dither (modulation) amplitude. Recommended value is 2. If optical or electrical feedback is used and DUT has only low PDL, a higher value, e.g. 4 may be advantageous.

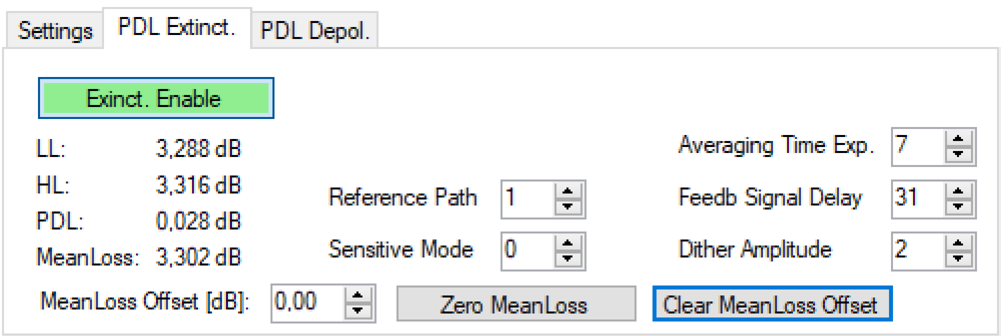
Pull Back Strength: Ensures limitation of control voltages. Recommended value is 1.

PDL measurement

Polarization-dependent loss (PDL) can be measured by Mueller matrix evaluation with Novoptel's polarimeter PM1000 and the EPS1000. In contrast, **non-polarimetric** methods for PDL (and loss) measurement are covered here.

We recommend
- either the **extinction method**, i.e. the searching of polarizations with maximum and minimum transmission,
- or the **depolarizing method**. This requires a sequence of polarizations states, whose correlation matrix of normalized Stokes vectors is 1/3 times the identity matrix. Such a sequence is applied to the device under test (DUT) and the output power P is measured for each applied polarization state. Maximum and minimum output power are given by $\langle P\rangle \pm \sqrt{3}\sigma_P$. The PDL in dB is given by $10\log_{10}\left(\left(\langle P\rangle+\sqrt{3}\sigma_P\right)/\left(\langle P\rangle-\sqrt{3}\sigma_P\right)\right)$. Here $\langle P\rangle$ is the mean output power and σ_P is the standard deviation of P. Examples for suitable polarization state sequences are the corners of diamond, cube and other polyhedrons, or simply equidistributed polarizations. The latter will automatically be applied and analyzed when using the *Depolarizing Mode* of the PDL measurement feature.
For more details see
https://www.novoptel.de/Control/Literature/PDL_measurement_2021_Noe&Koch.pdf
or
https://www.novoptel.eu/Control/Literature/PDL_measurement_2021_Noe&Koch.pdf.

Only if the EPS1000 is equipped with one or two photodetectors, the tabs *PDL Extinct.* and *PDL Depol.* will be enabled:



Recalibration of the photodetector's dark currents can improve measurement accuracy, especially at high PDL. This can be done by the button *Set Dark Current*. The new dark current values will be stored permanently.

PDL measurement using extinction method

When the extinction measurement is activated by pressing the *Extinct. Enable* button in the *PDL Extinct.* tab, the EPS1000 will measure the powers in the DUT channel after alternately adjusting the SOP to minimum and maximum transmission. Minimum loss (LL), highest loss (HL), PDL and mean loss are calculated and displayed in dB. If the source is sufficiently monochromatic, extinctions up to at least 50 dB can be measured. PDL of the LiNbO3 component in the EPS1000 is compensated by simultaneous measurements in the reference path. The settings

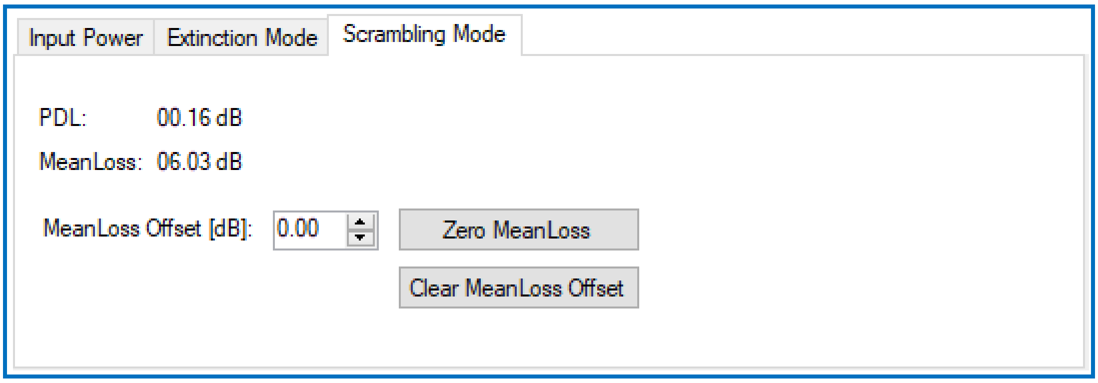
- Reference Path,
- Sensitive Mode,
- Averaging Time Exp.,
- Feedb. Signal Delay and
- Dither Amplitude

can be adjusted and have the same effects as during SOP tracking.

For calibration or comparison of different DUTs, the displayed mean loss value can be adjusted (by entering a value in the numerical box) or set to zero (buttons *Zero MeanLoss* and *Clear MeanLoss Offset*).

PDL measurement using depolarization method

When the *Scrambling Mode* tab is active, the EPS1000 will apply equidistributed polarizations to the DUT and calculate PDL as described above.



The offset for the mean loss value can be adjusted the same way as in the *Extinction Mode*.

An advantage of the depolarization (or scrambling or sqrt(3)) method is that no timing is needed between transmitter and receiver, if the reference path is not used. This way even PDL of amplified transoceanic fiber links can be measured.