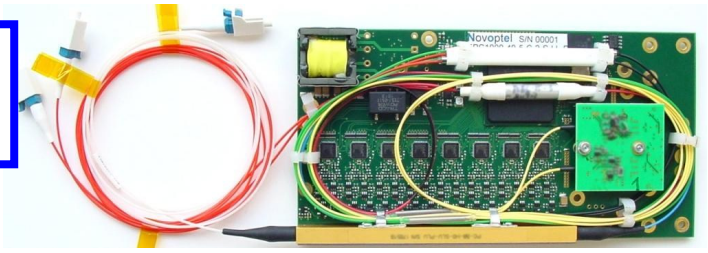
**Novel optics and electronics for telecommunication**

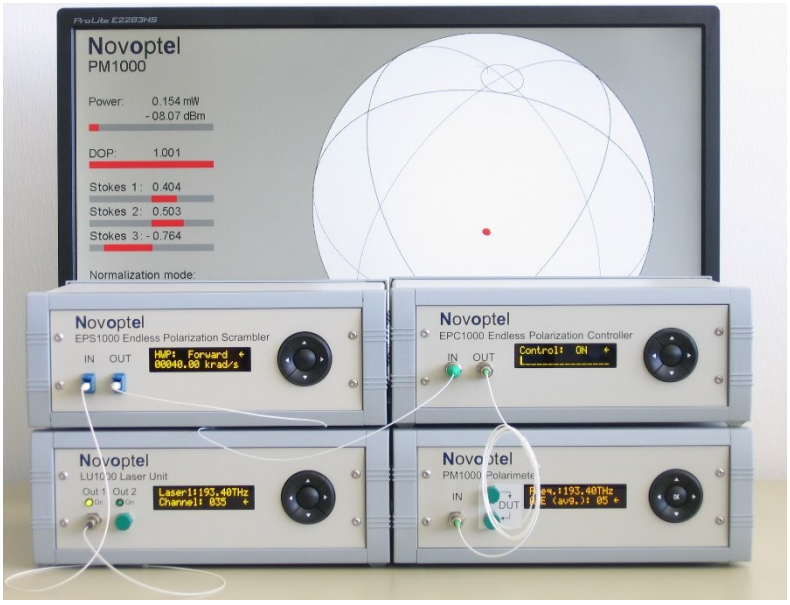
# Ultrafast polarization handling

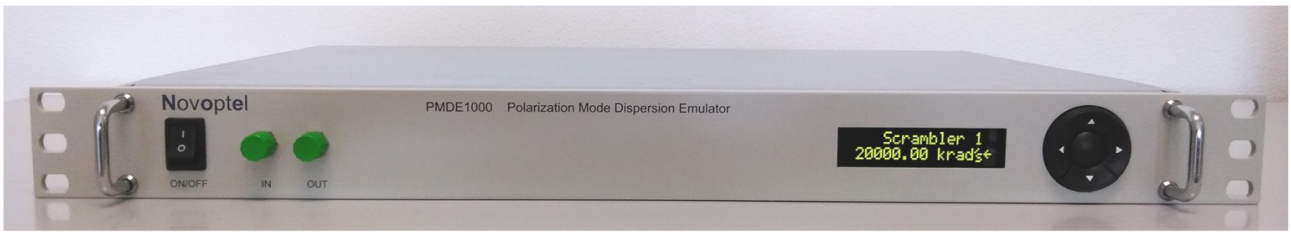


**OFC2025: Booth 5650**
**German Pavilion**



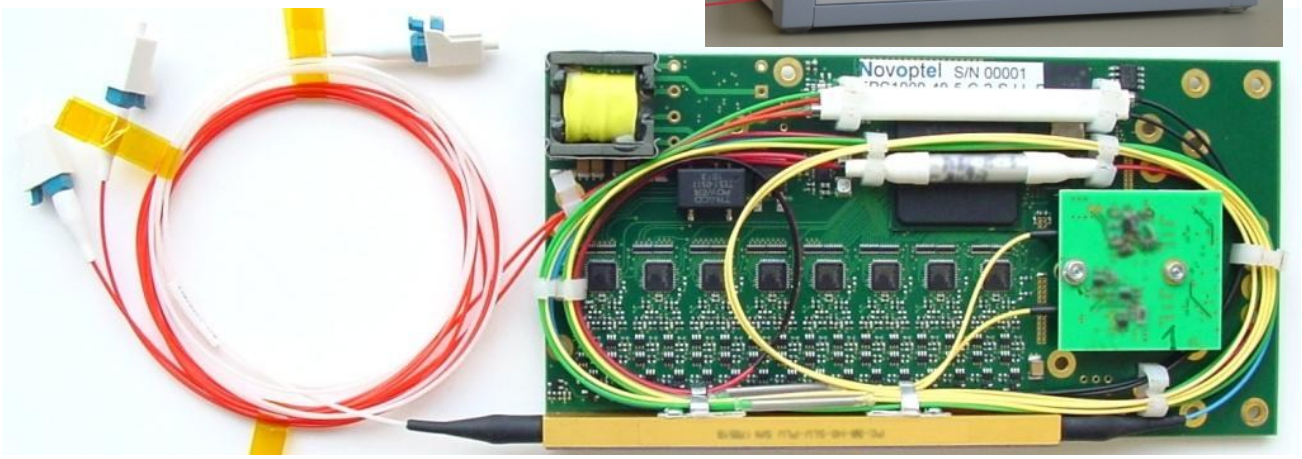
- Pictured: **Fastest or by far fastest polarization handling products** of their class
- **By far lowest cost per krad/s-Mrad/s-MS/s-MS-dB**
- Available as desktop units and PCBs
- Low power consumption, small PCB sizes, wide temperature range
- Operation stand-alone or via USB, LAN and Windows GUI, Matlab™, Labview™, Python
- Used by major telecom suppliers and carriers since 2010
- EPC1000 has achieved in 2010 a world record for highest symbol rate 50 Gbaud in realtime, polarization-agile (40 krad/s) 4 bit/symbol transmission (200 Gb/s PDM-QPSK, 430 km).



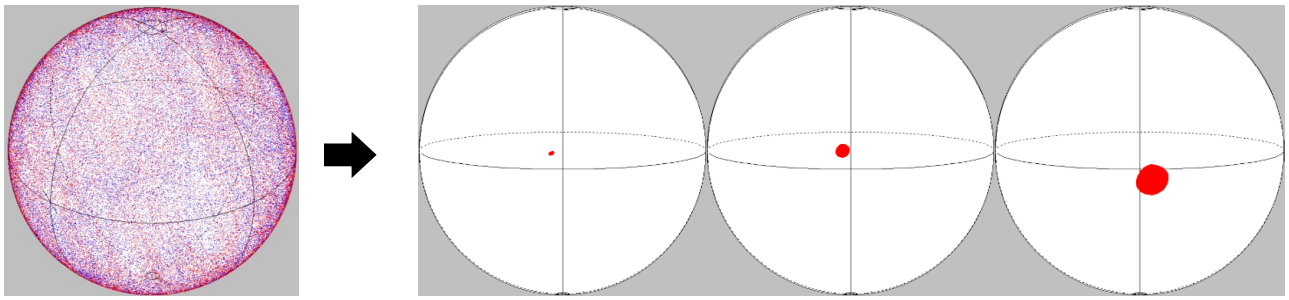




Novoptel GmbH, Paderborn, Germany (full info: page 12 bottom); info@novoptel.com (or info@novoptel.eu)

# EPC1000 Polarization Controller/Demultiplexer

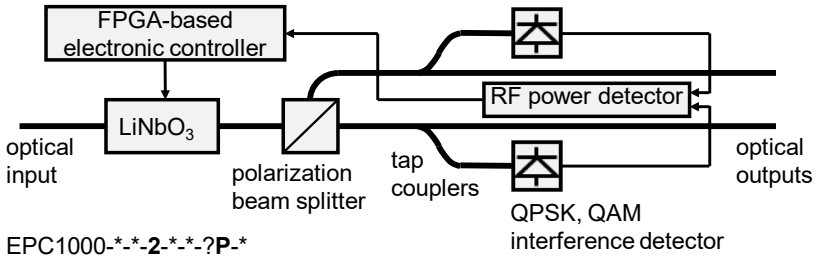




- **Guaranteed endless tracking (control) speed: 40**, **60** or **100 krad/s** on Poincaré sphere
- To our knowledge, **Novoptel's endless polarization tracking speed is at least 100 times as high as that of competitor products.** If you are aware of something better then please inform us so that we can correct this statement.
- Extremely reliable: More than **350 Gigarad** were tracked in several extended tests.



Scrambled (example) Controlled @ 10 krad/s 40 krad/s 100 krad/s

- **Single (CW)** or **dual (DQPSK, QAM; also: DPSK, duobinary, ASK) polarization tracking**
- Wavelength range: **C band**, **extensible to L band**; also possible: S band, 1310 nm, ...
- Temperature range: **-10°C to +70°C**; extension is possible.
- Power consumption: About **5 W** from single **+5 V** source. Compatible with the needs of 40 Gb/s, 100 GbE, 2x100 GbE, 4x100 GbE and other transponders. Can be further reduced.
- Interfaces for computer (**USB**, **LAN**) or controller (**SPI**, **UART**, digital hardware lines)
- Functionality: **Channel swapping** (to exchange demultiplexed polarization channels, may for example be activated by a framer/mapper), **reset**, **control** (on/off), modification of important parameters (**control gain** and **speed**, **dither amplitude**, **delay time** of supplied error signal)
- **In-field upgradable firmware** and **remote access** possibility for diagnosis and troubleshooting
- **Desktop units (with GUI)**, **plug-in module cards**, **IP cores. Various configurations.**
- Options: User-supplied error signal, **arbitrary and endlessly variable output polarization**, ...
- APDs for smaller and variable optical input power




EPC1000-*-*-**2**-*-*-?**P**-*

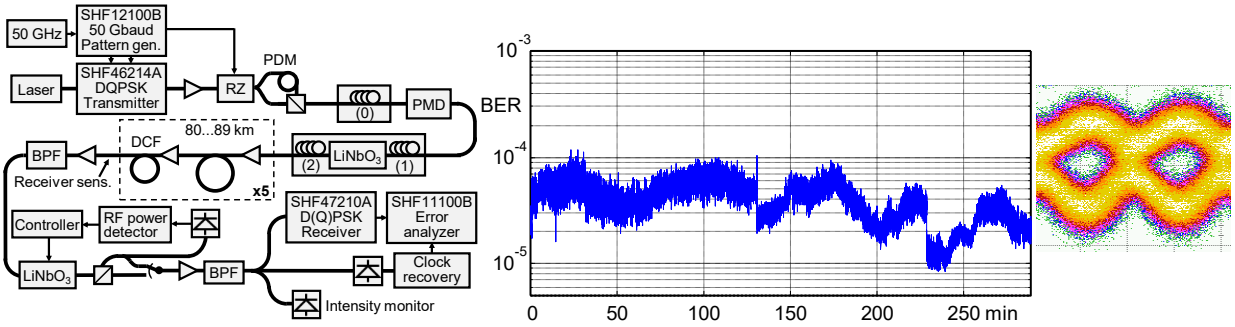
Configuration example:

EPC1000 with interference detection for **demultiplexing of polarization-multiplexed DQPSK or QAM signals**. Everything is mounted on controller card (see above).

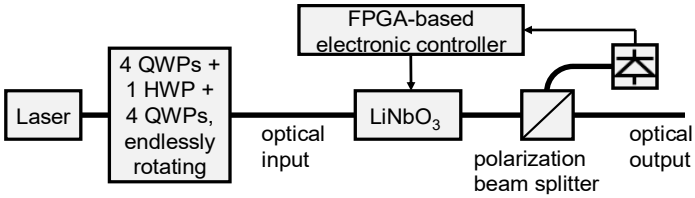
  

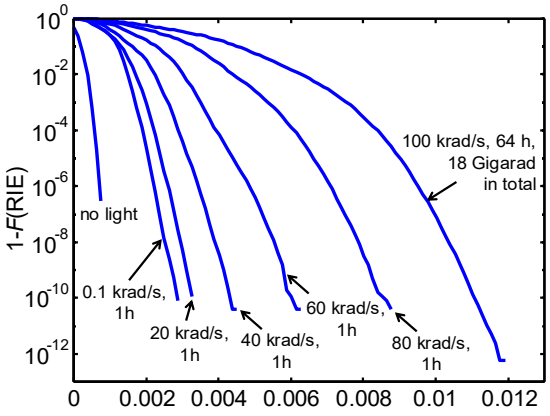
# Results obtained with EPC1000

**In 2010, world's highest symbol rate in polarization-agile realtime transmission with 4 bit/symbol: 50 Gbaud, 200 Gb/s, 430 km polarization-multiplexed DQPSK transmission with 40 krad/s polarization tracking** (IEEE PTL 22(2010)9, pp. 613-615)

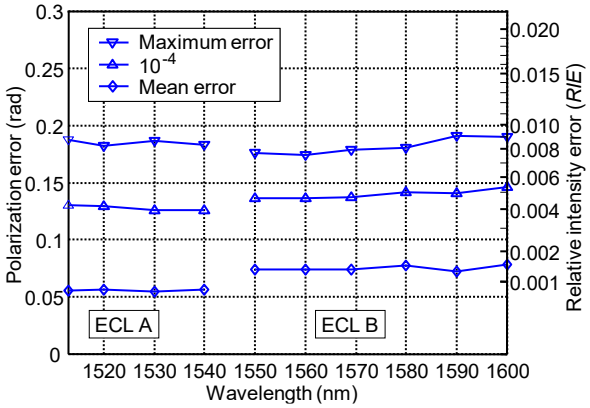



**World's fastest endless optical polarization control: 100 krad/s on Poincaré sphere tracked over 64 h** (Electron. Lett., Vol. 47, No. 14, 2011, pp. 813-814)




Complementary distribution function 1–*F*(*RIE*) of relative intensity error (*RIE*) for 1 hour at 0.1, 20, 40, 60, 80 krad/s, and for 64 hours at 100 krad/s scrambling speed (18 Gigarad in total). The zero point (*RIE* = 0) is determined without light.




Relative intensity error (*RIE*) and polarization errors which are surpassed only with the given probability, as a function of wavelength for 30-minute measurements at 50 krad/s scrambling speed.

**Widest endless optical polarization control bandwidth: 1 THz at 70 krad/s speed**
**Best extinction: 40 dB at 1 krad/s speed**
**Temperature-independent operation: -15°C...60°C (70°C testing if desired)**
**Two-sided endless polarization control: 15 krad/s at input, 200 rad/s at output**

Optics Express, Vol. 22, Issue 7, pp. 8259-8276, 2014; IEEE PTL 24(2012)22, pp. 2077-2079

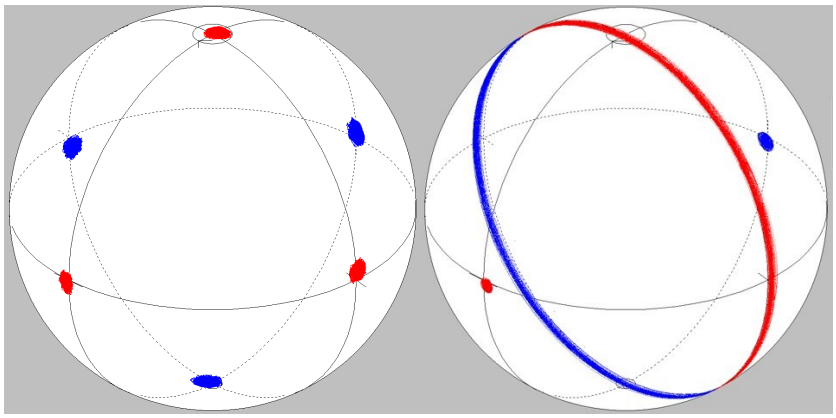
## Customer feedback

"Novoptel's polarization tracking device EPC1000 is probably the only commercially available equipment that is capable of demultiplexing two orthogonal states of polarization with a tremendously high tracking speed (≈60 krad/s). We have evaluated extensively the EPC1000 module and have confirmed its performance to be fully satisfactory and just as claimed. Prof. Reinhold Noe and Dr.-Ing. Benjamin Koch are the well-known pioneers and leaders in this field. With their team they have achieved remarkable progress and tracking speed records over the years. I am so happy to see Novoptel offer these polarization controllers to the lightwave communication community as affordable subsystems for coherent detection."
*Dr. David Tzeng, Measurement Analysis Corporation, USA*

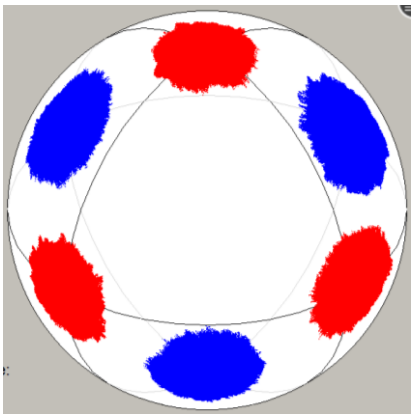
# Polarization and phase control, usable for QKD

- **Worldwide unique product: Endless optical polarization and phase (difference) control**
- Not only an unknown variable incoming polarization is transformed into a fixed output polarization (2 degrees-of-freedom), but also the phase difference (3rd degree-of-freedom) between this polarization and its orthogonal is controlled, endlessly (without any interruption).
- **Indispensable** for any application where optical polarization and phase control are needed: General retarder with 3 and not just 2 deterministically controlled degrees-of-freedom, optical phased array, self-homodyne receiver with polarization beamsplitter for recovery of modulated signal and unmodulated LO with orthogonal polarizations and defined phase relation, coherent optical receivers with simplified electronic signal processing and ...
- **for fiberoptic quantum key distribution (QKD) based on BB84 or similar protocol implemented in the polarization domain**
- Pilot signals (0°, 45°)
  - in the frequency/wavelength domain (WDM) or
  - in the time domain (TDM), with complete pilot laser extinction and with clock recovery for QKD window timing. Very PMD-tolerant! Very advantageous.
- **Whole normalized Stokes space of the probe signal is stabilized.**
- **Endless tracking speed 20 krad/s** (typically)
- Speed scalable for TDM QKD where scattering has completely decayed

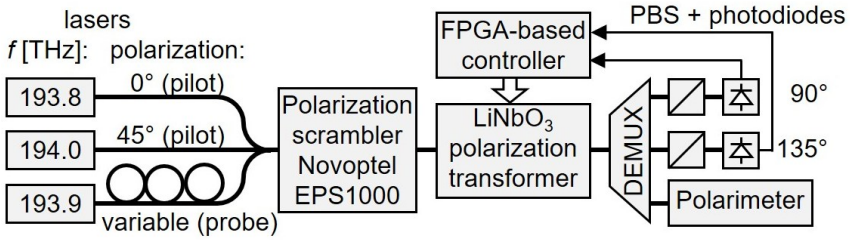


Stabilization of normalized Stokes space of the probe signal, under 20 krad/s polarization scrambling. Perfect for QKD with BB84

Traditional polarization control, does not work for QKD with BB84

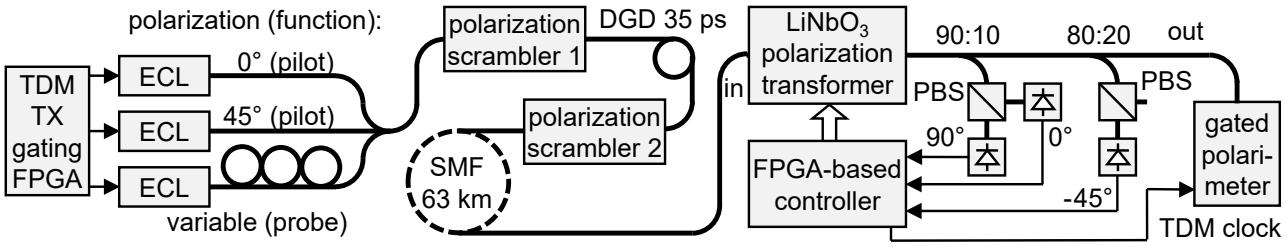


Stabilization of normalized Stokes space of the probe signal, under 20 krad/s polarization scrambling, with 35 ps of PMD. Time divsion multiplex (TDM) version.




Corresponding setup for polarization and phase control with WDM pilot signals, see Electronics Letters, Vol. 49, No. 7, pp. 483-485, 2013

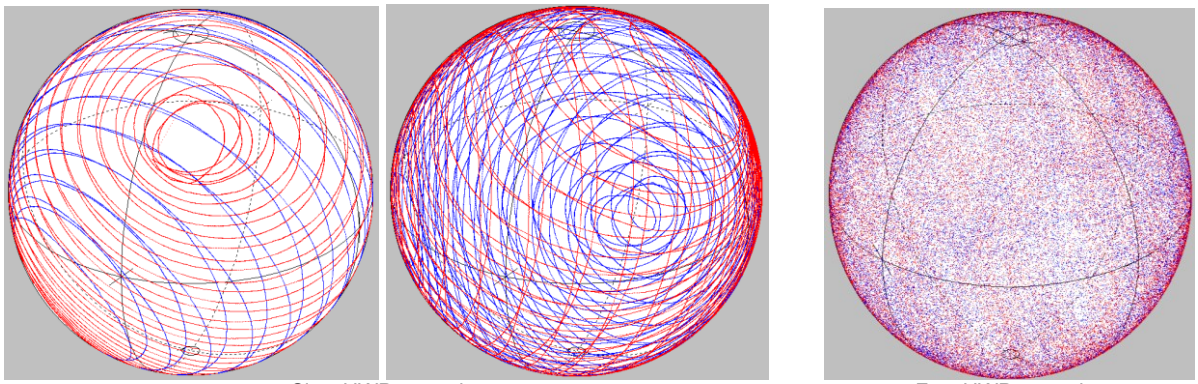
Below: PMD-tolerant setup with TDM pilot signals. Includes laser control PCBs for fast modulation with extreme extinction.



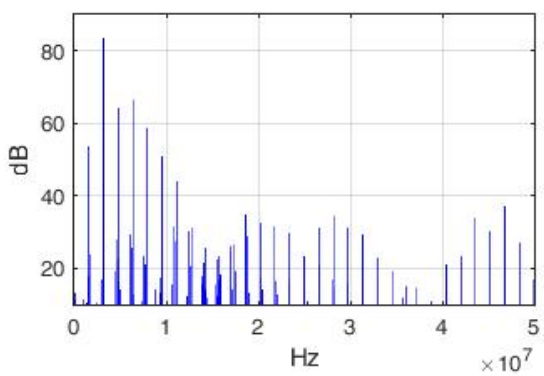
# EPS1000 Polarization Scrambler/Transformer

- Ultrafast endless optical polarization scrambling at up to **20 Mrad/s** (or **50 Mrad/s** with less waveplates)
- **10 ns clock cycles** (= updating intervals) assure continuous, quasi steady polarization changes even at high scrambling speeds (e.g., in **0.01 rad steps at 1 Mrad/s**) and minimize deviations from desired smooth time-dependence of trajectory, for meaningful assessment of polarization/PMD tracking/trackers.
- 3 electrooptic quarterwave plates (QWPs) + 1 halfwave plate (HWP) + 3 QWPs with adjustable rotation speeds (QWP: −2000000.00 ... +2000000.00 rad/s; HWP: −20000.00 ... +20000.00 krad/s)
- **NEW** Optional **O-E-S-C-L-U** band operation **≤182...241 THz / 1240...≥1650 nm**
- Insertion loss ~1.8...2.5 dB. Power consumption ~12 W (+5 V power supply 100-240 V included)
- Differential group delay (DGD) sections consisting of polarization-maintaining fibers (PMF) available for highly realistic PMD emulation, using several EPS1000 and DGD sections.
- Available as a desktop unit, module or intellectual property core
- Interfaces for computer (**USB**, **LAN**) or controller (**SPI**, **UART**, digital hardware lines)
- Standalone operation of desktop unit via control buttons. Several units can be controlled simultaneously by graphical user interface (GUI; see next page), Matlab™, Labview™ or similar. Speeds of rotating and positions of stopped waveplates and electrode voltages can be set, saved and loaded.
- Serial Peripheral Interface (SPI) permits realtime operation; e.g., direct setting of waveplate voltages.
- In synchronous scrambling mode, user-generated tables with sets of waveplate positions or speeds can be loaded. Following an external trigger event (3.3 V LVCMOS signal applied at BNC connector, or SPI command) the sets are executed sequentially at specified instants (granularity: 40 ns; minimum delay until next execution instant: 200 ns). For **recirculating loop experiments** and **emulation of lightning strikes**.
- In triggered scrambling mode, the sets are executed cyclically one by one upon external trigger events or USB commands (minimum delay until next execution instant: 200 ns). Application examples: polarization-dependent loss (PDL) and Mueller/Jones matrix measurements.
- Optional photodetectors enable accurate PDL and loss measurements and **polarization tracking**.
- **Depolarization in 960...240 ns interval**, based on 50 Mrad/s version with 3 rotating waveplates
- EPX1000 = cost-saving desktop unit with combined functionalities of EPS1000 and 40...100 krad/s polarization controller/demultiplexer EPC1000
- PMS1000 = combination of EPS1000 with ultrafast (100 MHz) polarimeter PM1000

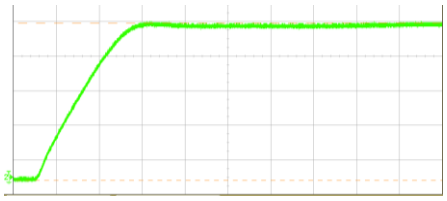


Slow HWP operation — Fast HWP operation

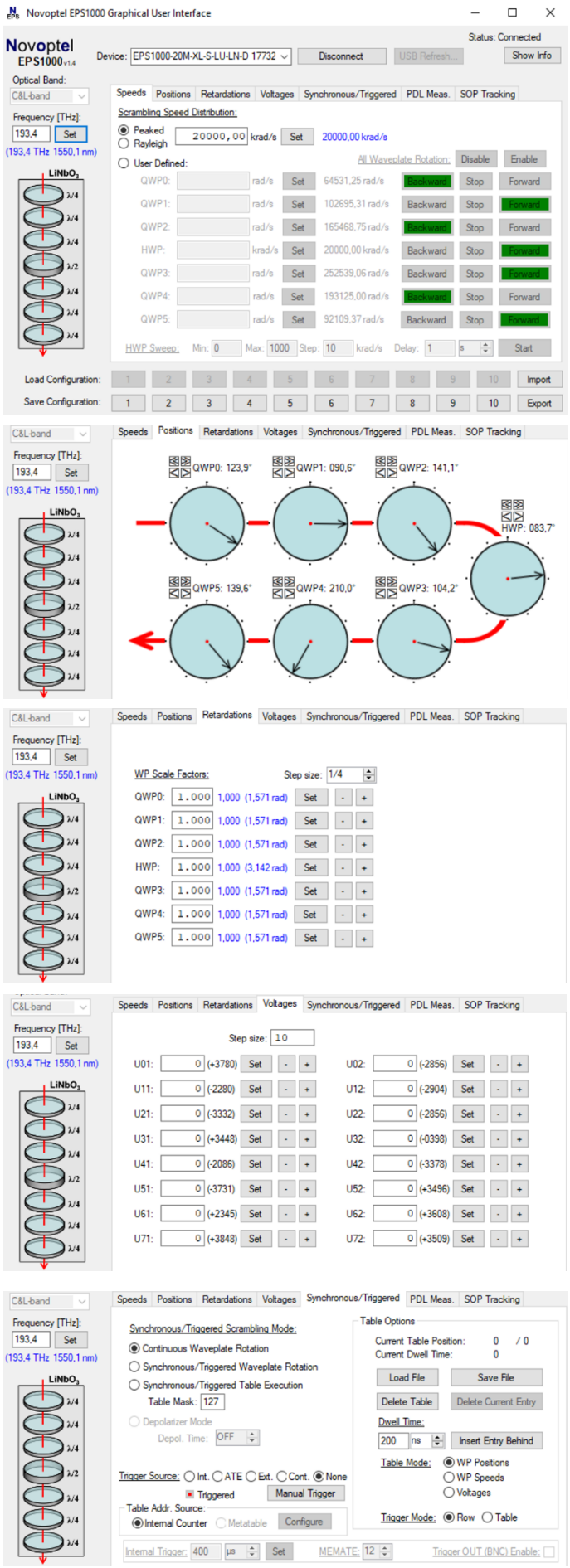
Exemplary output trajectories on Poincaré sphere




Electrical scrambling spectrum. Only HWP scrambles at 20 Mrad/s. Recorded with PM1000 polarimeter



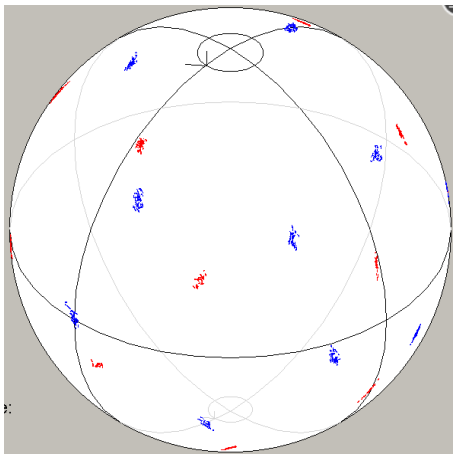
60-V step at HWP settles completely within 50 ns (20 ns/div). Small-signal response is a lot faster.




**Left:** Frequently used operation modes of USB- or LAN-operated graphical user interface. Other operation modes are:

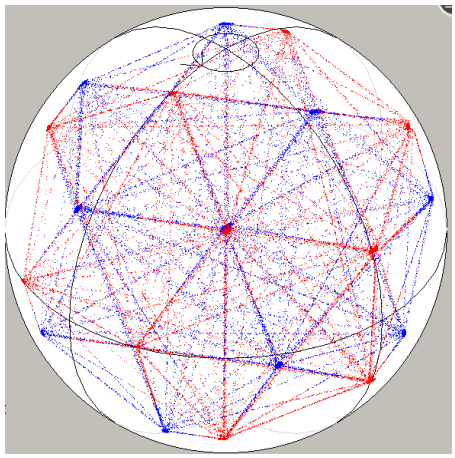
- Device Testing (optional): Intensity recording for PDL and loss measurement
- SOP Tracking (optional): Tracks SOP as defined by PM1000, also during optical frequency sweep and according to table

## Pseudorandom state generation



Above: 20 vertices of dodecahedron, measured at the ends of 640 ns symbols.

Below: Transients visualized, 1 ms symbols

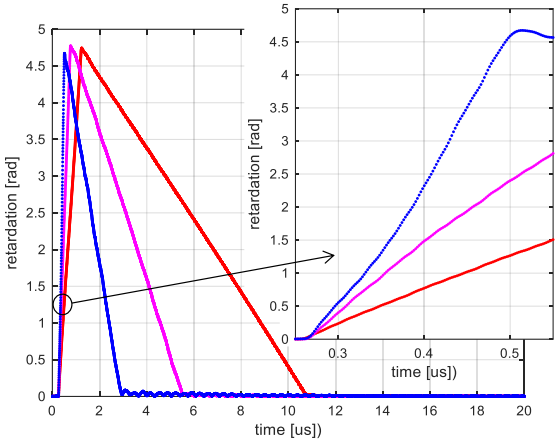


## Customer feedback

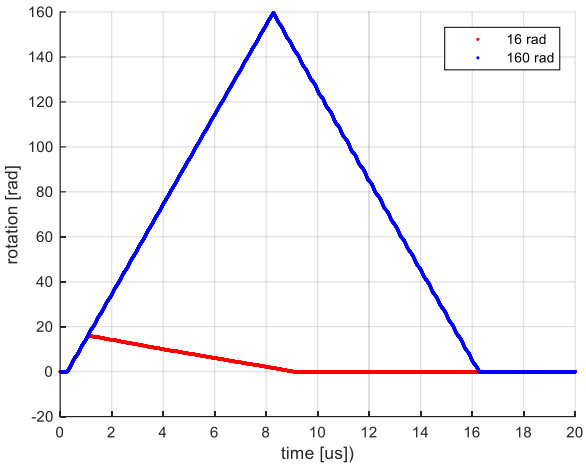
"We have used the EPS1000 endless polarization scrambler in our record-breaking coherent transmission experiments (see our site www.optcom.polito.it) and it has performed flawlessly. We have particularly appreciated its very low insertion loss and its flexibility. Thanks to the EPS1000 endless polarization scrambler our recirculating-loop experimental results have become stable, repeatable and reliable."

*Prof. Dr. Pierluigi Poggiolini, Politecnico di Torino, Italy*

### Emulation of lightning strikes in fiber with EPS1000-20M



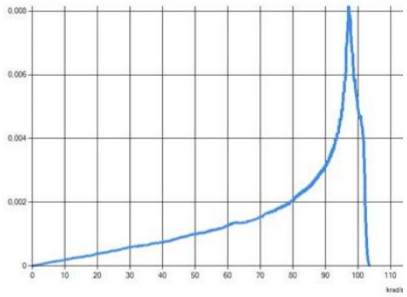

Circular retardation vs. time with 2 ns temporal resolution for scrambling 3 different speed profiles, all having the same peak retardation of 4.8 rad.



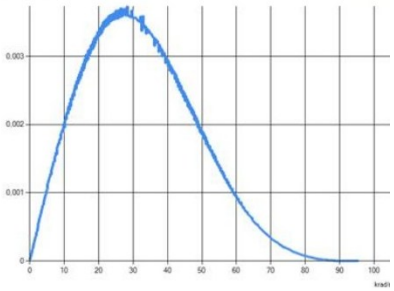

Polarization rotation for 800 ns / 8000 ns @ 20 Mrad/s, and return in 8000 ns.

The polarization scrambler EPS1000 has been used to demonstrate lightning protection https://www.infinera.com/ice5-innovation/ of coherent optical data transmission at the OFC2018 exhibition.

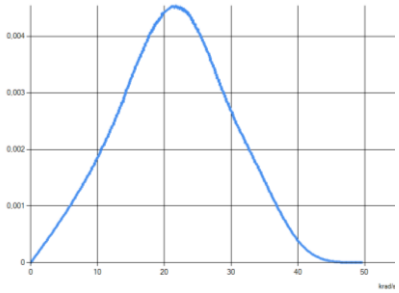
### Exemplary polarization speed distributions obtained with EPS1000



Peaked (for fastest assessment of coherent RX)



Quasi-Rayleigh

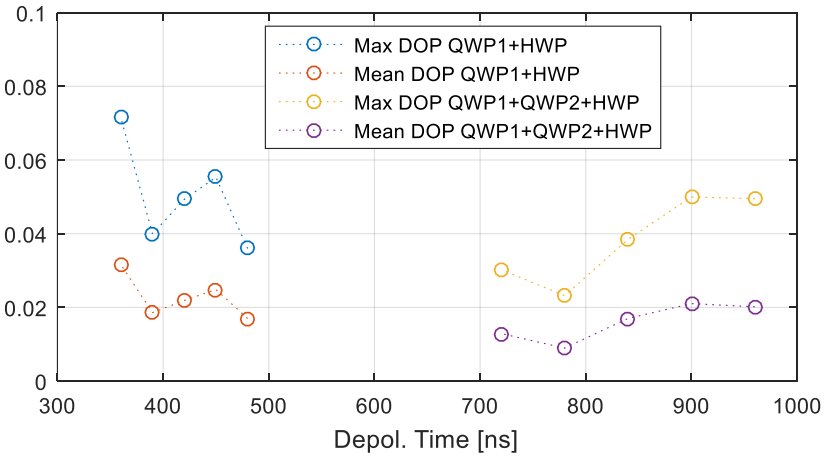


Triangular

Scalable software examples (Python, Matlab) available for speed setting. Many other choices

## EPS1000-50M Depolarizer

- **50 Mrad/s** version with 2 QWPs (8 Mrad/s) + 1 HWP (40 Mrad/s)
- Sets of periodic electrode voltages with integer relative driving frequencies, for instance [2, 3, –2]
- Depolarization in **960...240 ns** interval
- Independent of input polarization

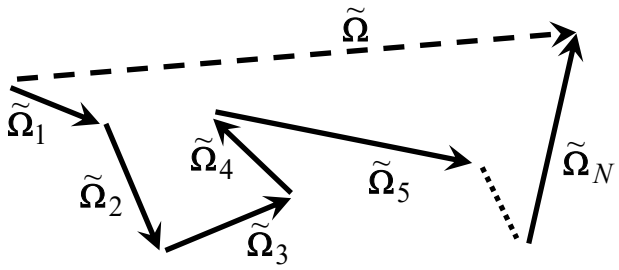



Mean and maximum degree-of-polarization (DOP) obtained with 1000 random input polarizations

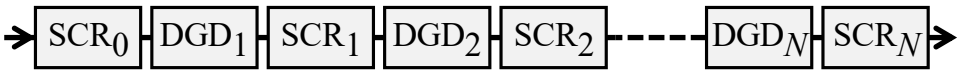
  

# PMDE1000 Polarization Mode Dispersion Emulator

- *N*+1 polarization scrambler modules (boards) EPS1000 with speeds up to 20 Mrad/s (or 50 Mrad/s) and *N* differential group delay (DGD) sections are integrated into one case. (Standard: 19 inch rack-mount)
- Section DGDs can be switched.
- Typical configuration: 3 EPS1000, 2 DGD sections (switchable, e.g., 15 ps, 50 ps, ..., or external)
- Applications: Polarization mode dispersion (PMD) emulator for coherent fiber links (400 Gb/s 80 km ZR, transoceanic links, Tb/s links, ...). PMD equalization (with user-supplied control signals).




Exemplary differential group delay profile, with overall first-order PMD being equal to sum of individual DGD or PMD vectors



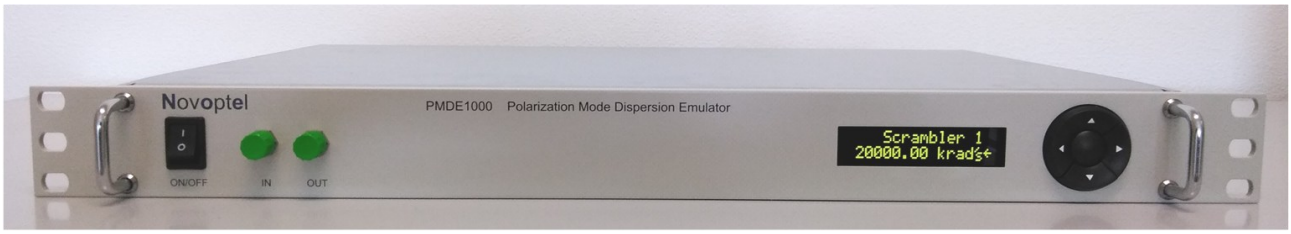

PMD emulator with *N* DGD sections (indices 1...*N*) placed between *N*+1 retarders/scramblers SCR (indices 0...*N*)


Example: PMDE1000 with 3 EPS1000 and 2 switchable DGD sections

Reasoning:

See our contribution to PMD emulator standardization http://www.ieee802.org/3/ct/public/adhoc/19_0328/noe_3ct_01a_190328.pdf and underlying arguments in https://arxiv.org/abs/1903.05248 [eess.SP].

We have shown in https://www.novoptel.de/Control/Literature/getPDF4_annot.pdf (Section V.) that the physical DGD section model (distributed or discrete) of PMD displayed above is the only one which makes sense because it approximates natural PMD best. (Higher-order PMD modeling based on a finite Taylor expansion of the PMD vector is unphysical because it inevitably predicts infinite PMD far off the optical reference frequency.) In https://www.novoptel.de/Control/Literature/70EF9388d01_annot.pdf (Section II.A) is described why this is much more reasonable than the usage of variable DGD sections. PMD is emulated highly realistically by the usage of several EPS1000 and DGD sections in the PMDE1000

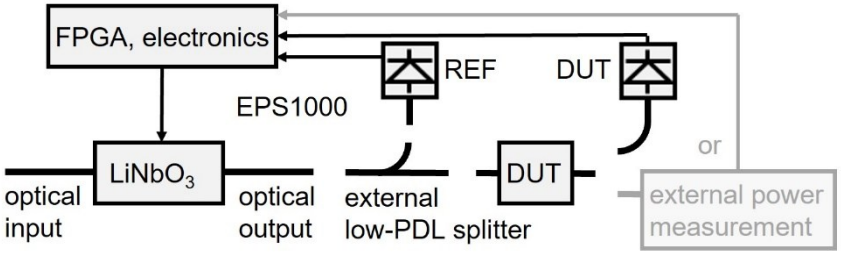



PMDE1000 with up to 4 EPS1000 and 3 switchable DGD sections in 19'' rackmount

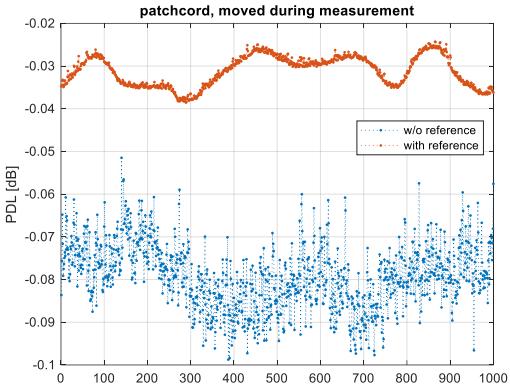
# Polarization Tracking & PDL Measurement with EPS1000

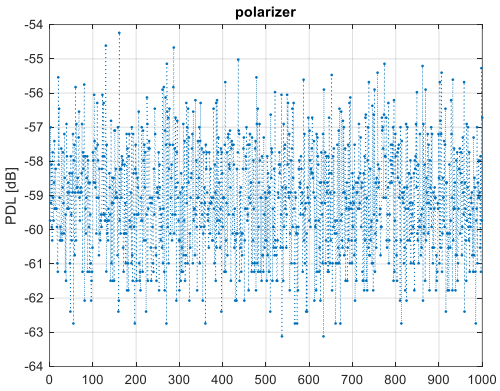
- Polarization tracking for maximum and minimum transmission and polarization-dependent loss (PDL) measurement are added to EPS1000 polarization scrambler. Suitable for laser frequency sweeps.
- **2 built-in photodetectors** (DUT, REF), external low-PDL splitter (1570 nm, 1310 nm, …)
- **Analog voltage input** supports third-party external power measurement.
- **Polarimetric feedback** from PM1000 is possible via direct digital feedback interface.
- **PDL ~0.05...>50 dB** and mean loss are calculated in firmware. Measurement interval <100 ms.
- Extinction method (superb especially for large PDL) and depolarization/sqrt(3) method
- Ideally suited for PIC testing **1240...≥1650 nm**. Fully programmable.




Left: Polarization tracking for maximum or minimum transmission. Reference measurement eliminates PDL of $LiNbO_3$ component

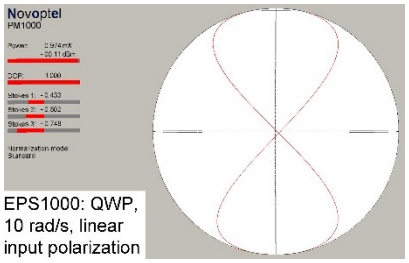
Below: 1000 PDL measurements (extinction mode) of patchcord (left) and polarizer (right)



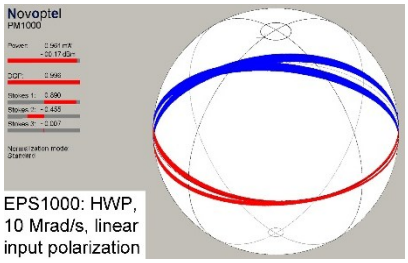




# PM1000 Polarimeter

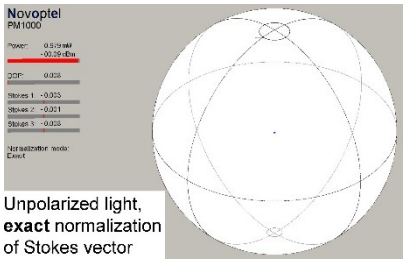
- Measurement of all 4 Stokes parameters, display on **Poincaré sphere** and in **oscilloscope mode**. Also available: Normalized Stokes vector, degree-of-polarization (DOP)
- Three choices for the normalization of Stokes parameters/vectors:
  - Standard: Normalized Stokes vectors are normalized to unit length. Regardless of power and DOP, they appear at the surface of the Poincaré sphere.
  - Exact: Normalized Stokes vectors are normalized only with respect to optical power. For DOP < 1 (or DOP = 0) they appear inside (or in the center of) the Poincaré sphere.
  - Non-normalized: Display of the non-normalized Stokes parameters. This means, DOP and optical power determine the length of the displayed $S_1$-$S_2$-$S_3$ Stokes vector.
- **100 MHz polarization state sampling frequency. 64 M polarization states can be recorded.**
- **30 MHz analog bandwidth.** Averaging (10 ns, 20 ns, 40 ns, ... 2.68 s), triggering, gating
- **Internal triggering on SOP or intensity events.** Selectable pre-trigger data ratio. Perfectly suited for **automated long-term assessment of polarization transients**. **Download while recording** next events!
- **Realtime Poincaré sphere display up to 100 MHz** in graphical user interface (GUI) or 50 MHz on connected monitor (HDMI; 720p60). **Not a single sample is lost!**
- 100 MHz memory view, zoom in oscilloscope mode, screenshots, numeric display
- Speed histogram, intensity histogram, software examples for Matlab™ and Labview™
- Hardware option: 2 sensitivity ranges extend usability to +4...–40 dBm.
- With EPS1000 or EPX1000: **Mueller & Jones matrix (≥ 5.12 us), PDL (<0.005...>60 dB), PMD measurement**. Optional lock-in detection. EPS1000 card can be plugged onto PM1000 card.
- Power consumption: ~5 W (+5 V from included power supply 100-240 V)
- Available as a standalone desktop unit, as a module card, and as an intellectual property (IP) core
- Realtime operation with Serial Peripheral Interface (SPI), trigger/gating input/output (BNC)
- Operation via control buttons of desktop unit, **USB**, **LAN**, **SPI** or graphical user interface (GUI)
- **NEW** Optional **O-E-S-C-L-U** band operation **≤182...241 THz / 1241...≥1647 nm**
- Tunable C&L band laser modules can be built in.
- Can define SOP tracking by EPS1000, also during optical frequency sweep and according to table




EPS1000: QWP, 10 rad/s, linear input polarization

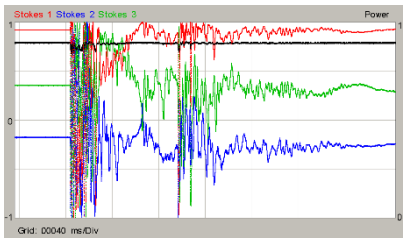



EPS1000: HWP, 10 Mrad/s, linear input polarization

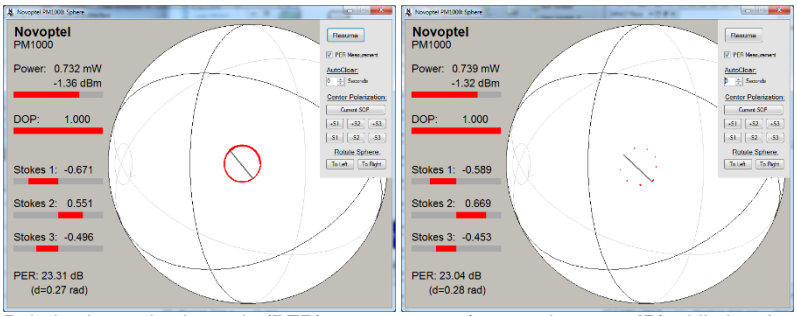



Unpolarized light, **exact** normalization of Stokes vector

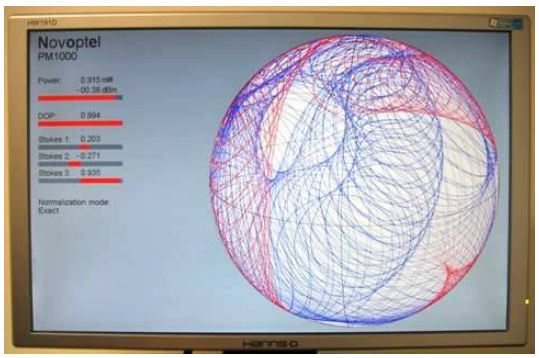
EPS1000 polarization scrambler, characterized with various settings and PM1000 averaging times



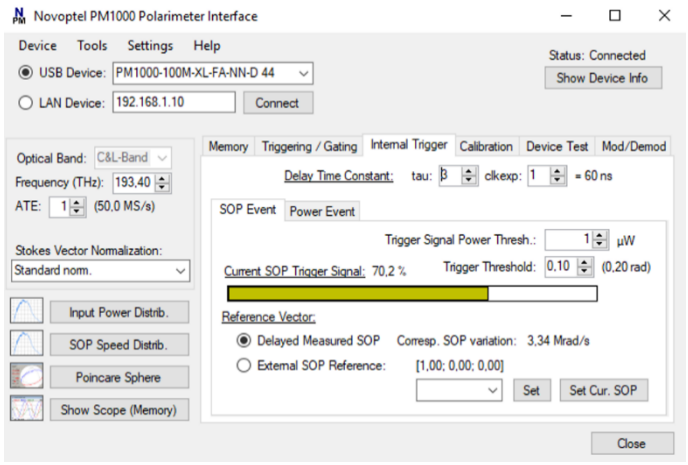

Configurable (1 rad/s ... >100 Mrad/s) internal trigger is used to record the polarization fluctuations caused by hitting a DCM cassette. Oscilloscope mode.



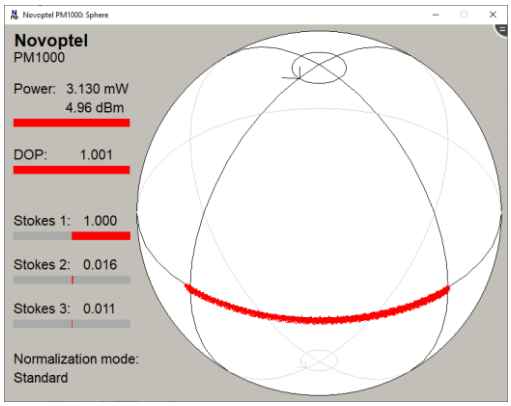

Polarization extinction ratio (**PER**) measurement (up to at least **44 dB**) while heating PMF (left) or tuning an ITLA (right). Tuning-induced polarization transients are cut by intensity threshold.




PM1000 desktop unit comes with Windows GUI. Can be connected to monitor (HDMI; 720p60) and used without extra computer!


Rich internal and external triggering possibilities




Tracking (by EPS1000, aided by PM1000) of time/ frequency/wavelength-dependent predefined polarizations. **Very helpful for PIC characterization.**

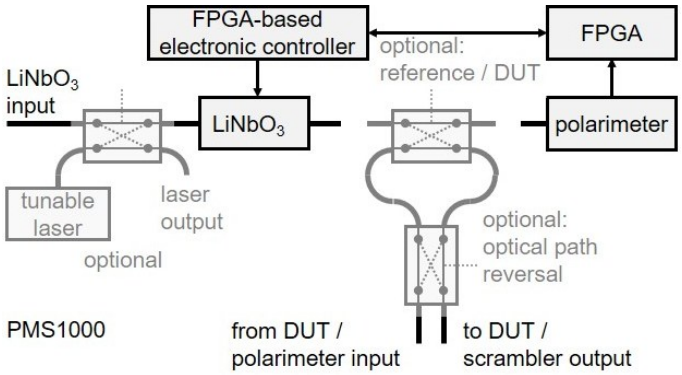
Predecessors PM500 of the polarimeter PM1000 have been used by D. Charlton et al. for field measurements of state of polarization transients in optical ground wire, with time and location correlation to lightning strikes: https://www.osapublishing.org/oe/abstract.cfm?uri=oe-25-9-9689

The polarimeter https://www.novoptel.de/Polarimeter/Polarimeter_PM1000_en.php has also been used by F. Pittala et al. for "Laboratory Measurements of SOP Transients due to Lightning Strikes on OPGW Cables" https://doi.org/10.1364/OFC.2018.M4B.5.

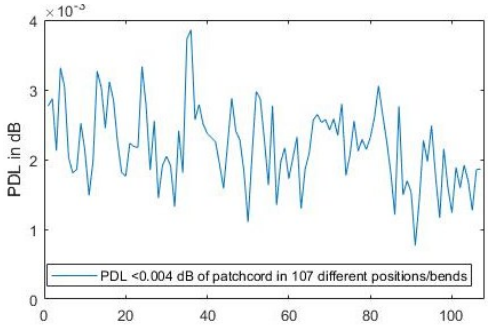
  

# PMS1000 Polarimeter and Polarization Scrambler/Transformer

- Combination of the PM1000 polarimeter with the EPS1000 polarization scrambler/transformer
- All properties of PM1000 and EPS1000. Perfect for **PIC characterization in O-E-S-C-L-U bands**.
- Ideal for **synthesis of desired polarization states** and **device under test (DUT) polarimetry**
- Opto-mechanical or MEMS 2x2 switch can connect output of $LiNbO_3$ polarization transformer directly to input of polarimeter. Insertion loss of each path is thereby increased by ~0.5 dB (<1 dB).
- Another 2x2 switch can reverse propagation direction, to determine DUT reciprocity.
- **Tracking function** with feedback: optical (–2...–50 dBm), electrical (analog; also third-party), polarimetric
- **Wide support of lasers** (LU1000 + all other manufacturers) and software (Matlab, Octave, Python)
- Desktop units (separate EPS1000 & PM1000 or combined PMS1000) or module cards

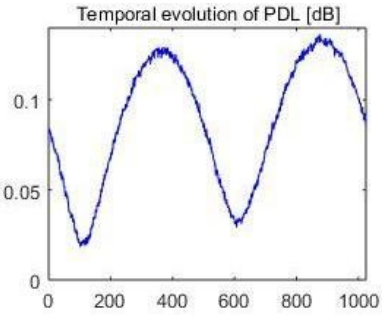



Mueller/Jones and PMD measurement. Optional components shaded. O/E/S/C/L band tunable lasers (such as LU1000).



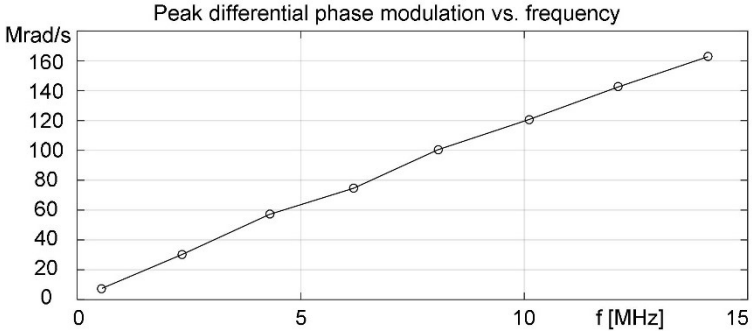

PDL measurement repeatability <0.004 dB

- ≥4 polarization states are generated for DUT and yield **Mueller matrix**, **Mueller-Jones matrix** (= Mueller matrix made non-depolarizing) and **Jones matrix**
- **Measurement time** can be **5.12 us** or even less.
- **Eigenmodes**, **retardation**, **mean loss**, **PDL** (**<0.005...>60 dB**) ⟶
- Decomposition of Mueller/Jones matrices into sequences SBA + PPPS + SBA. Definitions: PPPS = horizontal **p**artial **p**olarizer and **p**hase **s**hifter. SBA = **S**oleil-**B**abinet **a**nalog = retarder with retardation 0...π and eigenmodes on $S_2$-$S_3$ great circle. An SBA does to 0°/90° polarizations the same as a Soleil-Babinet compensator to circular polarizations: mode conversion with adjustable phase shift.
- **10 ns temporal resolution** of all time-variable component properties (Mueller matrix etc.) ⟶
- **PMD measurement <10 fs ... 10 ps with standard deviation ≤3 fs**
- With LU1000 or other tunable laser, Mueller/Jones matrices can be measured vs. optical frequency, and **PMD** is determined. Inverse scattering allows generating a **DGD profile** (= differential group delay profile; JLT **21**(2003)5, p. 1198, JLT **33**(2015)10, pp. 2127-2138, 2015).

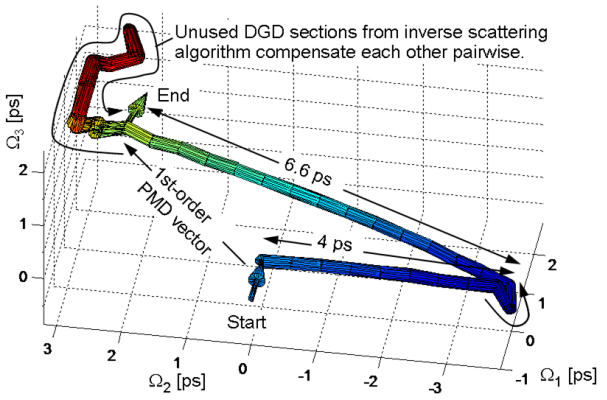



Time-resolved PDL of a rotating electrooptic halfwave plate (EPS1000) as a DUT, extracted from 1024 Mueller matrices recorded with **320 ns** temporal spacing.

Peak differential phase modulation vs. frequency



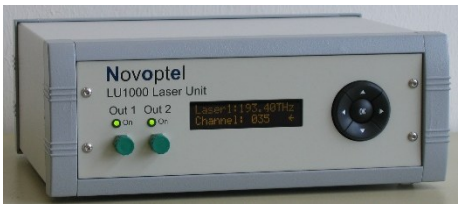

$LiNbO_3$ phase modulator is investigated as another DUT. From measured time-resolved Mueller matrices differential phase modulation is extracted.




Measured DGD profile in the PMD vector space of two concatenated, arbitrarily oriented PMFs, with DGDs of 4 and 6.6 ps. Not only the total 1st-order PMD vector but also the structure of the DUT becomes apparent.

# LU1000 Laser Unit



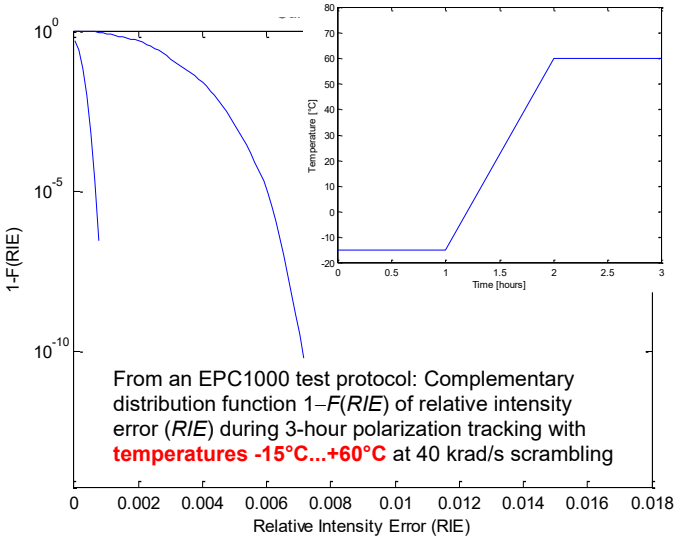

- Up to 4 lasers, continuously tunable according to nano/micro ITLA MSA. Ultra-narrow linewidth (or tbd)
- Up to 17 dBm output power, adjustable
- C band, L band, optional AM, FM
- O band (or any other available) laser module, comprises pulsing with extreme extinction and usable for **QKD**, also available as PCB with USB control.
- Operation via control buttons or SPI, USB, LAN using Graphical User Interface, Matlab, Labview or similar
- Desktop unit. **Fully compatible with EPS1000 and PM1000 for device characterization**

# All Novoptel products

- Temperature tested
- Available as module cards, desktop units, 19'' 1U rackmounts
- USB, LAN, SPI available
- Fully programmable (USB, LAN, GUI, Matlab, Octave, Python, Labview, C, ...)

# Novoptel fulfills your needs

- Delivered items come with test protocols. ⟶
- Customer feedback and requests are taken into account during development and after purchase through free software updates. This has led to new features.
- Special developments upon customer request




From an EPC1000 test protocol: Complementary distribution function 1−*F*(*RIE*) of relative intensity error (*RIE*) during 3-hour polarization tracking with **temperatures -15°C...+60°C** at 40 krad/s scrambling

# About Novoptel

Novoptel GmbH was founded by Dr.-Ing. Benjamin Koch and Prof. Dr.-Ing. Reinhold Noé in 2010 as a spin-off of the University of Paderborn, Germany, with the aim of developing and delivering novel optics and electronics for telecommunication. Leveraging decades of pioneer experience in optical polarization control plus knowledge about needs of the telecom industry, Novoptel has brought this technology to unprecedented maturity and has developed ultrafast optical endless polarization controllers, polarization scramblers, polarimeters and other products.

Deutschland Land der Ideen

In 2011, Novoptel and Univ. Paderborn were selected as one of the "365 Landmarks in" Germany, "the Land of Ideas, under the auspices of the German Federal President Christian Wulff. In 2012, Novoptel's ultrafast endless polarization controller EPC1000 was integrated into the category Technology/Innovation of "Germany at its best", a marketing campaign of the Land North Rhine-Westphalia.

GERMANY AT ITS BEST NORDRHEIN-WESTFALEN

Prior to founding Novoptel, Reinhold Noé co-received the Innovation Award 2008 of the Land North Rhine-Westphalia in the category Innovation, for the first submitted/published synchronous QPSK transmission with DFB lasers (2006) and with polarization multiplex (2007). He has (co-)authored about 300 peer-reviewed journal and conference papers and 160 patent applications and patents.

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