MenloSystems

TIMING DISTRIBUTION AND SYNCHRONIZATION

COMPLETE SOLUTIONS FROM ONE SINGLE SOURCE

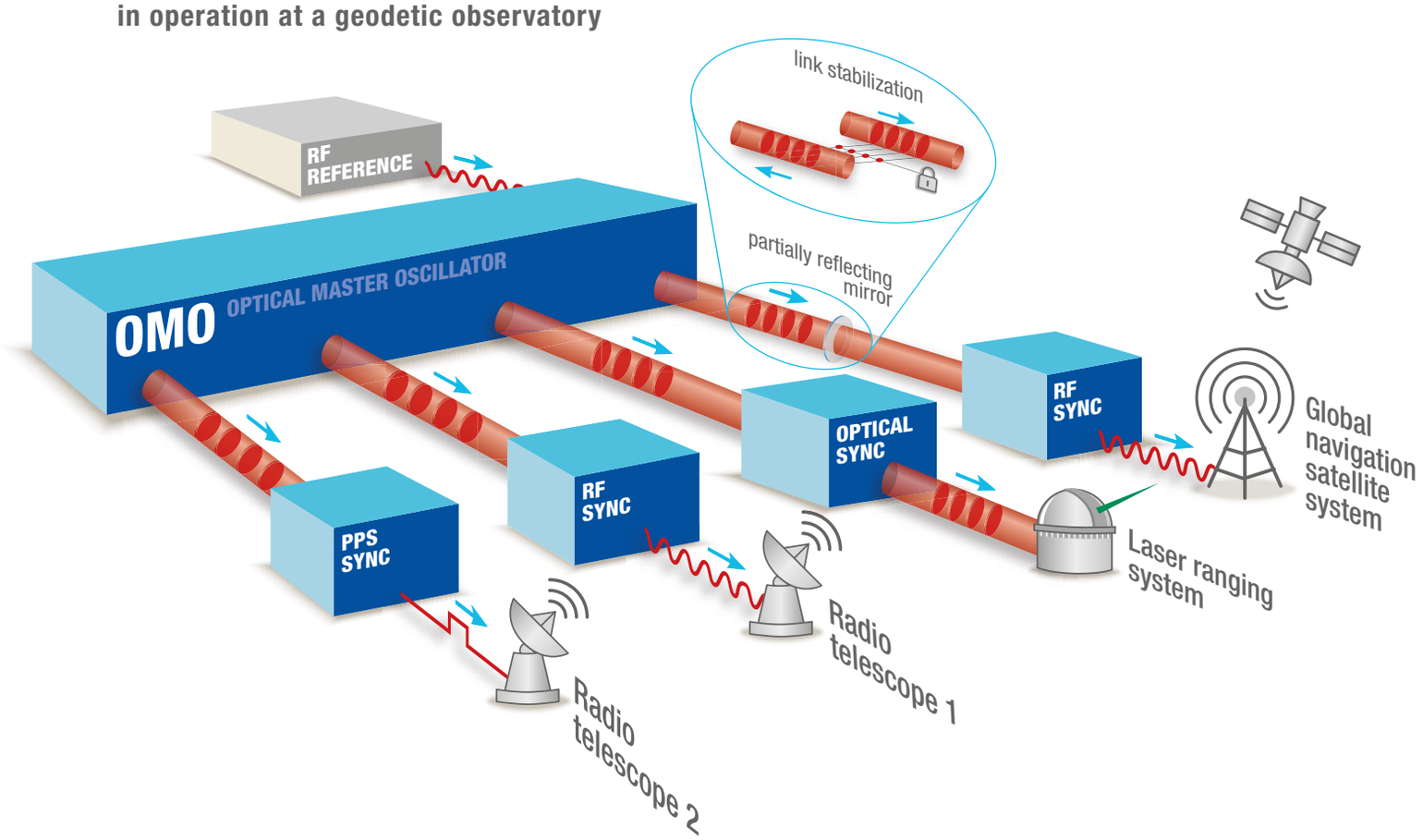
FEMTOSECOND SYNCHRONIZATION FOR LARGE-SCALE FACILITIES

TAILOR-MADE FULLY INTEGRATED SOLUTIONS

The Timing Distribution System (TDS) is our answer to the need of disseminating the most precise timing signal from the master clock throughout a large-scale research facility. Due to the all-optical technology the distributed signals suffer minimal added phase noise and drift and thus ensure synchronization of the clients on the femtosecond time scale over long distances. Our system is based on modular devices, all designed and fabricated in-house. The result is a fully integrated customized turn-key system according to the site specific requirements. All system components are also available for individual stand-alone applications. The Timing Distribution System is ideally suited for fourth-generation accelerator facilities, laser amplifier chains, or geodetic observatories.

The main building blocks of the Timing Distribution System are an ultra low noise optical master oscillator that is synchronized to the master RF clock, a splitting and amplification unit to provide multiple optical signals to be distributed to the various clients, dispersion compensated fiber links, and detection and stabilization electronics to provide the error signals and the stabilization thereof.

Scheme of a femtosecond synchronization system in operation at a geodetic observatory



TIMING DISTRIBUTION SYSTEM (TDS)

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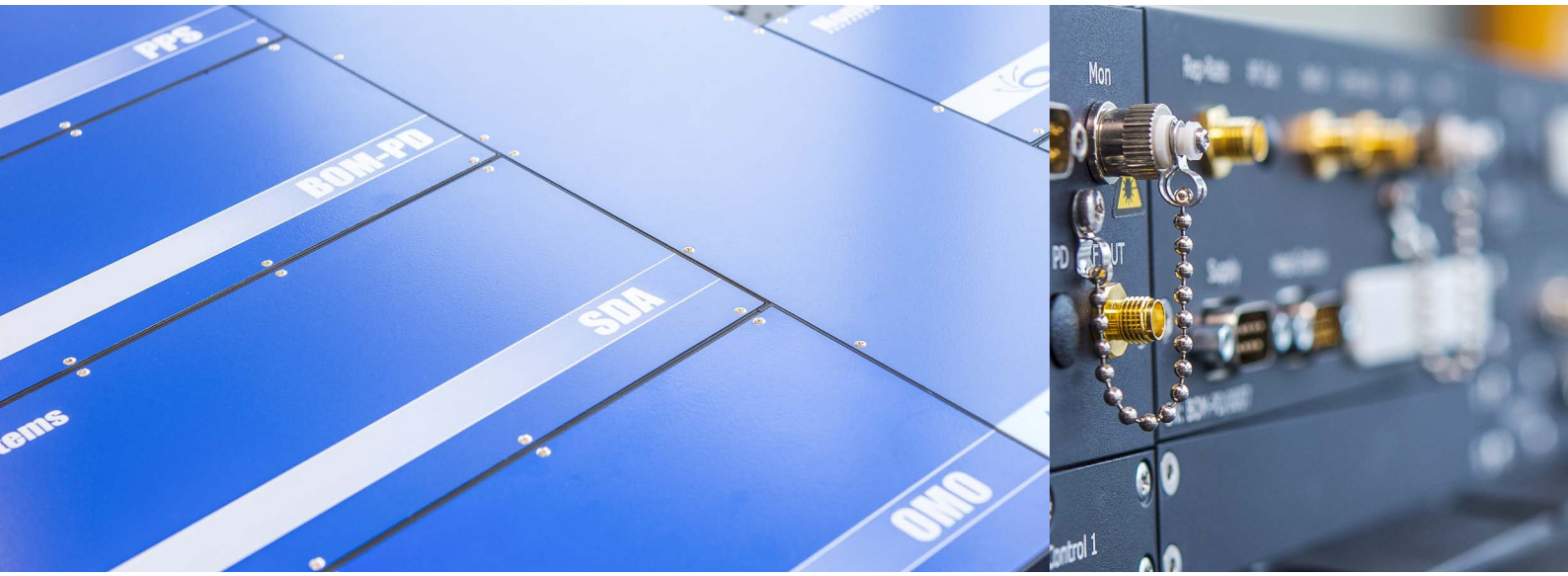
Menlo Systems' Timing Distribution and Synchronization System (TDS) is a solution for the distribution of stable optical frequencies and for the maintenance of synchronization and timing in large scale facilities.

The system is fully integrated and remote controllable. A mode locked laser is used as the Optical Master Oscillator (OMO) which is synchronized to a low-noise RF oscillator or a cavity stabilized CW laser, to obtain optimum phase noise performance both close to and far away from the carrier. The signal from the laser is amplified using our Source Distribution Amplifier (SDA), and split up using our fully in-fiber design Splitter Box (SPBox) into the required number of ports. The pulsed, stable laser signal is then distributed across the facility using our Stabilized Fiber Links (SFL) to remotely synchronize lasers or RF systems with unprecedented overall precision and stability. Optionally, a drift-free a Pulse-Per-Second (PPS) signal is offered at each system backend with programmable frequency and delay. With all components such as the laser system, optics parts, electronics, and RF generation manufactured by Menlo Systems the TDS is an all-from-one solution allowing close interaction between user and manufacturer for fast and efficient system integration.

APPLICATIONS

Timing distribution for

- free electron lasers
- synchrotron beam lines
- radio telescope arrays
- particle accelerators
- laser research centers
- laser amplifier chains



TIMING DISTRIBUTION SYSTEM (TDS)

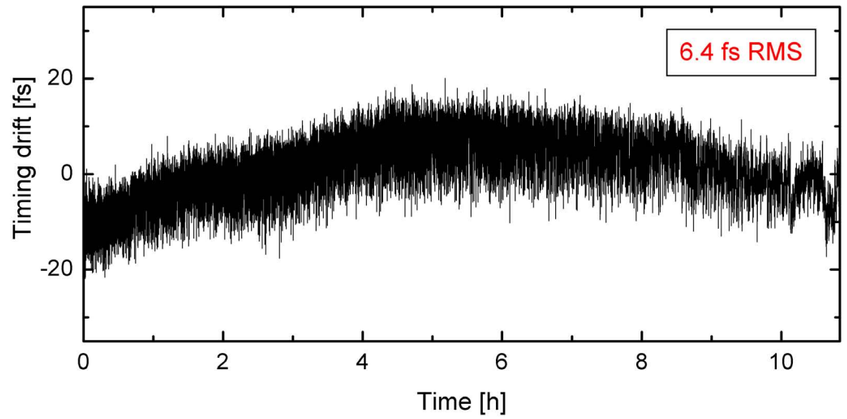
SPECIFICATIONS:

Parameter	Value	Comment
OPTICAL UNIT		
Added timing jitter (short term)*	<4 fs	integrated, [0.1 Hz, 500 kHz]
Added timing drift*	<10 fs	RMS over 8 hours
Fiber link length	<400 m	
Fiber links per TDS platform	up to 7	upgradable anytime to 14
Output type at backend	optical and RF	
Optical power per client	>10 mW	
Optical wavelength	1560 nm	
Design pulse repetition rate	50 - 250 MHz	to be specified prior to system order
Dimensions of one TDS platform enclosure	1156 x 986 x 182 mm^3	
Drift-free pulse-per-second (PPS) distribution	optional	PPS output at system´s backend with programmable frequency and delay; two independent channels
RF signal outputs at backend**	optional	low-noise RF signals at 5, 10 and 100 MHz; phase coherent to the optical pulses
GHz-signal extraction at backend**	optional	low-noise, low-drift RF signal with frequency in the range of 1 - 6 GHz
Ambient temperature requirement	20 – 25 °C	
Ambient temperature variation requirement	±1 °C	for full specifications
SYSTEM ELECTRONICS		
System control electronics	included	19" rack housing
Length of connector cables to optical units	max. 6 m	
Integrated feedback	included	SYNCRO-RRE for locking of the OMO to the RF reference
Control system interfaces	USB/RS232	
Auto lock	included	
Ambient temperature requirement	15 – 25 °C	
Ambient temperature variation requirement	±1 °C	for full specifications

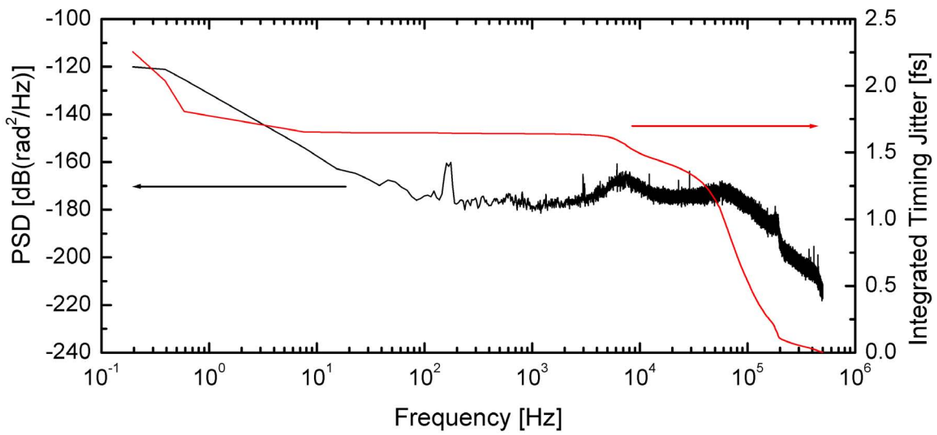
*Stability and drift determination in-house and on user site
** Please contact us for further details

MEASUREMENT DATA:

Out-of-loop long term timing drift between two stabilized fiber links, measured below 1 Hz:



Out-of-loop timing jitter power spectral density (PSD) and integrated timing jitter between two stabilized fiber links, measured from 0.5 MHz to 0.2 Hz:



TIMING OPTICAL MASTER OSCILLATOR (TIMING-OMO)

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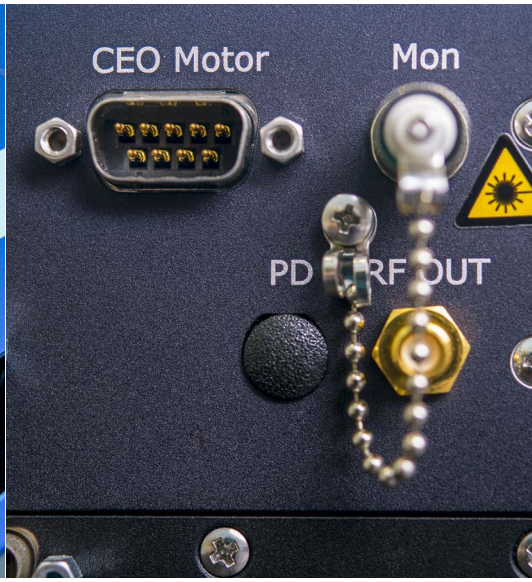
The Timing Optical Master Oscillator (Timing-OMO) is the source delivering optical pulses for the timing distribution system. The laser system is based on an optical femtosecond oscillator using an Er-doped fiber in Menlo Systems' figure 9® design. Subsequent amplification of the oscillator output in a Source Distribution Amplifier (SDA) unit provides sufficient optical power for the required client links. The repetition rate of the laser is synchronized to an external Radiofrequency Master Oscillator (RMO), the master timing reference of the facility.

Due to active stabilization and control of each fiber link all output pulses at the backend are almost drift-free and thus a reliable copy of the OMO pulses. The femtosecond oscillator provides an additional optical output for the extension of the timing system to up to 14 independent stabilized fiber links.

APPLICATIONS

Low-phase noise optical pulses for

- timing distribution through fiber links
- PPS synchronization and distribution



TIMING OPTICAL MASTER OSCILLATOR (TIMING-OMO)

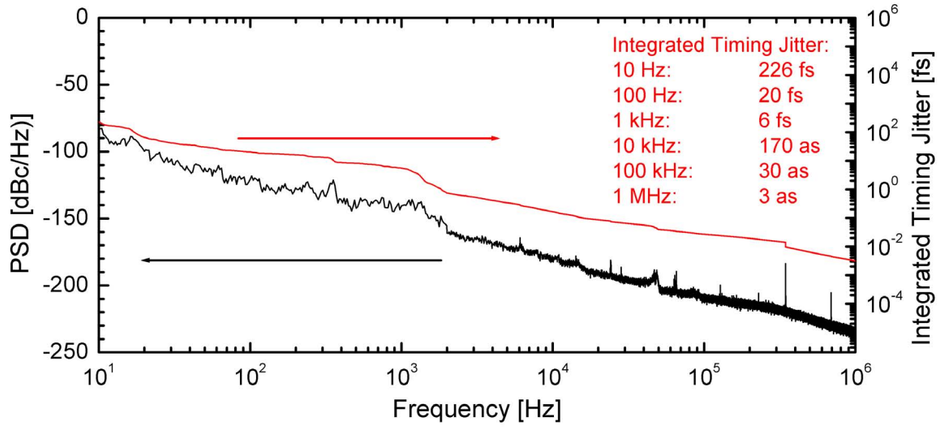
SPECIFICATIONS:

Parameter	Value	Comment
GENERAL SPECIFICATIONS		
Laser architecture		Er-doped fiber laser, PM, figure 9®
Active temperature stabilization	<10 mK	RMS over 8 hours
Repetition rate	50 - 250 MHz	to be specified prior to system order
Tuning range of repetition rate	>210 kHz*	available with stepper motor
OPTICAL OUTPUT		
Number of outputs	2	for later system extension to up to 14 links
Output wavelength	1560 nm	
Output wavelength tolerance	±20 nm	factory-set
Optical pulse duration	N/A	output not dispersion compensated, spectral bandwidth supports 100 - 250 fs FWHM
Monitor port output power	~1 mW	fiber coupled (FC/APC), suitable to measure the optical spectrum of the laser by an external OSA
Optical amplitude stability	<0.1 %	RMS, [1 kHz, 10 MHz]
Integrated timing jitter (free-running)	<10 fs	RMS, [1 kHz, 10 MHz]
ELECTRICAL OUTPUTS		
RF monitor port	1 GHz	3-dB bandwidth, electrical signal synchronous to laser pulses; SMA connector
REMOTE CONTROL		
Interface on 19" control unit	USB/RS232	documentation of the communication protocol included
ENVIRONMENTAL REQUIREMENTS		
Ambient temperature	20 – 25 °C	
Ambient temperature variation	±1 °C	for full specifications

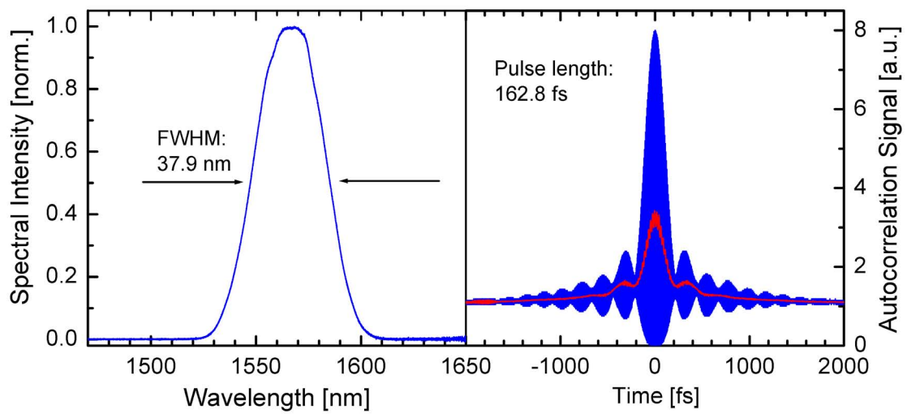
*Valid for lasers with repetition rate of 100 MHz. Tuning range can be smaller for lower repetition rates.

MEASUREMENT DATA:

Single side band phase noise PSD of a free-running 100 MHz erbium oscillator, normalized to the fundamental repetition rate:



Optical spectrum and autocorrelation trace of a 100 MHz erbium oscillator after SDA and Splitterbox (SPBox):



STABILIZED FIBER LINK (SFL)

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The Stabilized Fiber Link (SFL) is a length-stabilized, dispersion-compensated optical link for the timing distribution system, comprising the subunits Fiber Link Stabilization Unit (FLS) and Link Fiber Connection-Receiver (LFC-Receiver). With an attosecond precision phase detector, actuators, and SYNCRO locking electronics, the FLS unit on the system reference side includes all necessary components to stabilize the length of the optical fiber link. The LFC-Receiver on the client side consists of a dispersion compensation module and a bi-directional optical amplifier. The amplifier at the end of the link ensures the level of output power as required for the clients. Part of the signal is reflected back through the link to provide feedback on any length changes.

APPLICATIONS

- Low-drift and low-jitter distribution of optical signals over larger distances

STABILIZED FIBER LINK (SFL)

SPECIFICATIONS:

Optical link stabilization unit:

Parameter	Value	Comment
GENERAL SPECIFICATIONS		
Fundamental design frequency	50 – 250 MHz	to be specified prior to system order
Added timing jitter	<10 fs*	RMS [3 Hz, 10 MHz]
Added timing drift	<10 fs	RMS over eight hours, measured with balanced cross correlator, out-of-loop measurement
Timing resolution	<300 as	detection noise floor of integrated timing jitter [1Hz,10MHz]
OPTICAL INPUT		
Optical power	>20 mW	
Pulse duration	<200 fs	FWHM, Gaussian, interferometric autocorrelation
Input connector	SC/APC	
OPTICAL OUTPUT AT CLIENT SIDE		
Wavelength	1560 nm	
Central wavelength tolerance	±20 nm	
Average power	>10 mW	
Pulse duration	<300 fs	FWHM, Gaussian, interferometric autocorrelation
Output port type	Free space or fiber coupled	
ELECTRICAL OUTPUT		
High sensitivity error signal	>100 mV	SMA connector
UTILITY AND ENVIRONMENTAL REQUIREMENTS		
Ambient temperature	20 – 25 °C	
Temperature variation	±100 mK	for full specifications; pertains to FLS unit **only**
Length of connecting cable	10 m	Between FLS unit and SYNCRO-FLS
Integrated feedback	SYNCRO-FLS	Menlo SYNCRO Platform, optimized for fiber link stabilization
Auto lock	yes	Automatic (re-)lock algorithm in SYNCRO-FLS
REMOTE CONTROL		
Control system interfaces front-end	USB/RS232	Interface to SYNCRO-FLS
Control system interfaces back-end	USB/RS232/Ethernet	Interface to LFC-receiver

*full specifications only if the temperature stability of the environment is within specified range

Optical fiber link:

Parameter	Value	Comment
GENERAL SPECIFICATIONS		
Input/output connectors	SC/APC	
Fiber optic specifications	ITU-T G.652.D compliant	SMF28+
Effective link length	<400 m	
Dispersion compensation	DCF spool	matched lengths of DCF and SMF**
DCF spool connectors	SC/APC	
In-loop link amplifier		Er-doped amplifier to compensate for link losses
Monitor output port	<1 mW	fiber-coupled (SC/APC), suitable to measure the optical spectrum of the laser by an external OSA
UTILITY AND ENVIRONMENTAL REQUIREMENTS		
Ambient temperature	20 – 25 °C	
Temperature variation	±2 °C	for full specifications; pertains to all link components **except** the FLS unit

** The compensation of the optical links has to be done “in the field“. The length of the DCF spools will be prepared based on link length measurement data to be provided.

Optical fiber link output on client side:

Parameter	Value	Comment
GENERAL		
Link end point		partially reflective Faraday rotating mirror
VERSION 1: OPTICAL FREE SPACE OUTPUT* **		
Pulse length	<300 fs	FWHM
Average output power	>10 mW	
Optical amplitude stability	<0.1 %	RMS [1kHz-10 MHz]
Optical bandwidth	>10 nm	
Central wavelength	1560 nm	
Central wavelength tolerance	±20 nm	
Beam diameter	>1 mm	
VERSION 2: OPTICAL OUTPUT FIBER COUPLED* **		
Pulse length	<300 fs	FWHM; the real value has to be the same for all lines
Average output power	>10 mW	
Optical amplitude stability	<0.1 %	RMS [1 kHz, 10 MHz]
Optical bandwidth	>10 nm	
Central wavelength	1560 nm	
Central wavelength tolerance	±20 nm	
Output connector	SC/APC	

***Decision on either Version 1 or 2 for each of the links has to be made eight weeks prior to the start of manufacturing

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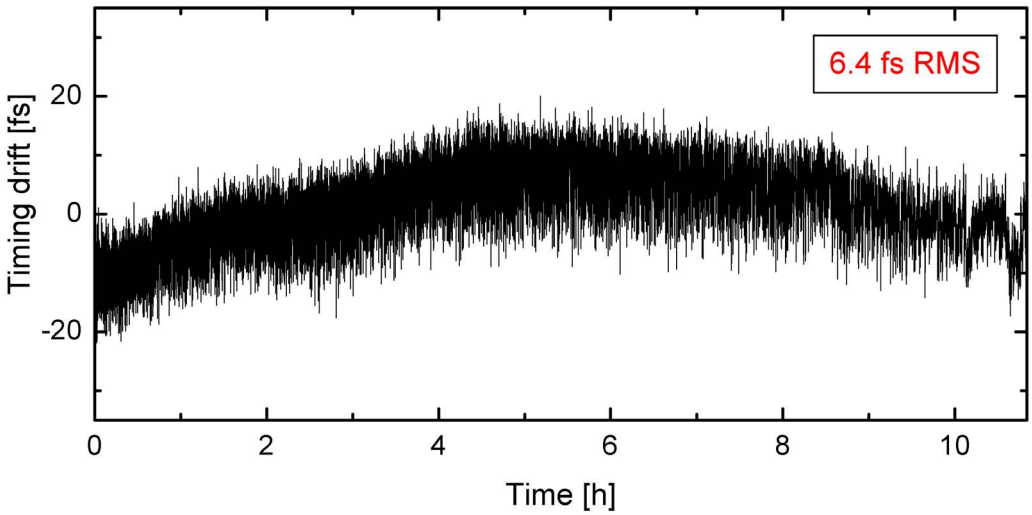
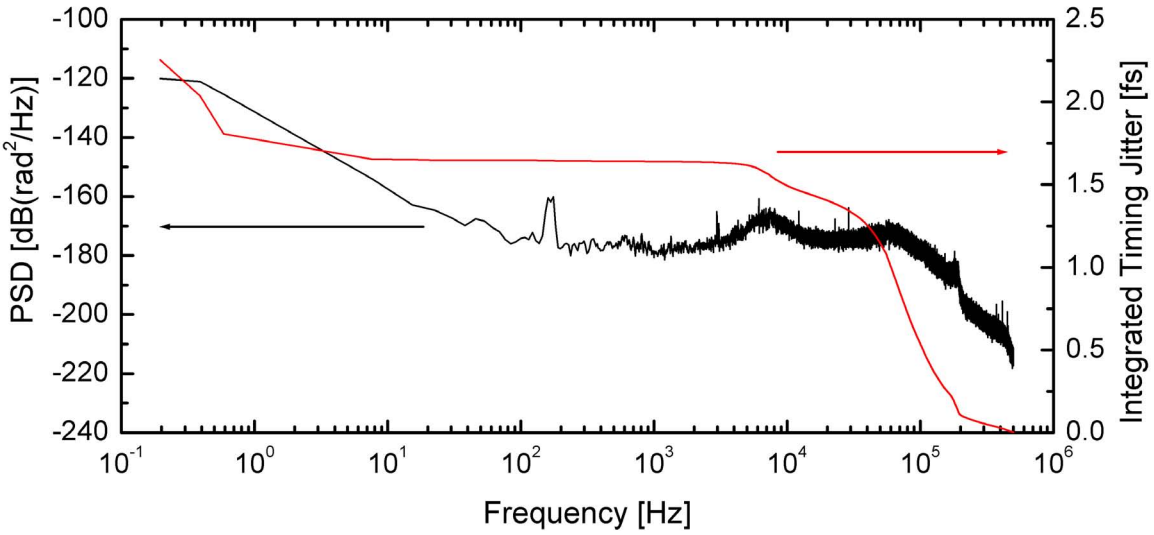
MEASUREMENT DATA:

Out-of-loop long term timing drift between two stabilized fiber links:



Out-of-loop power spectral density (PSD) (black line) and integrated timing jitter (red line) between two stabilized fiber links:



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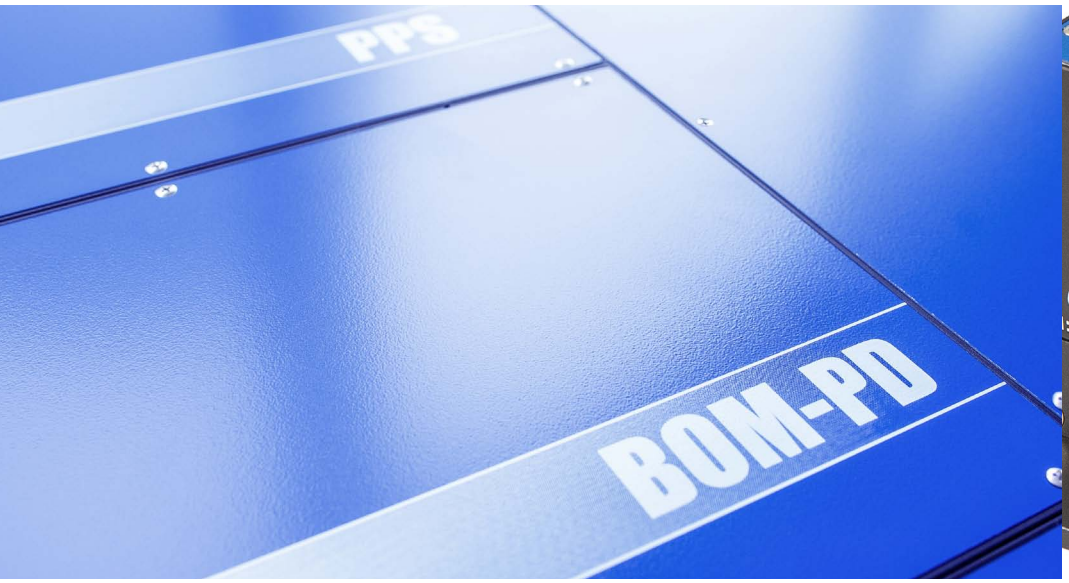
BALANCED OPTICAL TO MICROWAVE PHASE DETECTOR (BOM-PD)

MenloSystems

The Balanced Optical Microwave Phase Detector (BOM-PD) is a high resolution stand-alone external phase detector engineered for ultra-low noise detection of the phase between optical and RF signals. Due to its improved balanced Sagnac-interferometer technology this device is intrinsically low drifting while having large detection sensitivity. The BOM-PD does not only allow an outstanding synchronization of a laser source to a custom reference frequency, it can also be used to synchronize a low noise voltage controlled oscillator (VCO) to the laser source for a radio frequency synthesis.

APPLICATION

- Synchronization of ultrafast lasers to RF signals in a timing distribution system
- Synchronization of RF signals to ultrafast lasers in a timing distribution system
- Synchronization of RF signals to the output of stabilized fiber links
- Synchronization of voltage controlled oscillators (VCO) to an ultrafast laser for low noise RF-extraction



BALANCED OPTICAL TO MICROWAVE PHASE DETECTOR (BOM-PD)

SPECIFICATIONS:

	BOM-PD 800 NM	BOM-PD 1060 NM	BOM-PD 1560 NM
GENERAL SPECIFICATIONS			
Timing resolution*	<10 fs	<10 fs	<10 fs
Relative jitter [3Hz-1MHz]	<30 fs	<30 fs	<10 fs
Relative drift (RMS over 8 hours; ambient temperature stability ± 1°C)	<30 fs	<30 fs	<10 fs
Locking bandwidth**	≥6 kHz	≥6 kHz	≥6 kHz
Temperature drift (RMS over 8 hours)***	<10 mK	<10 mK	<10 mK
Control system interfaces	no active control of the BOM-PD is necessary		
Auto lock	optional, can be implemented only when using Menlo Systems SYNCRO platform		
OPTICAL INPUT			
Spectral range	745 – 825 nm	1000 – 1100 nm	1530 – 1590 nm
Max. incident power	100 mW	100 mW	100 mW
Fundamental design frequency****	50 – 250 MHz	50 – 250 MHz	50 – 250 MHz
Optical input type	Fiber (Nufern PM780-HP) or free space	Fiber (PM980XP) or free space	Fiber (SMF28 or PM Panda) or free space
ELECTRICAL INPUT			
RF input frequency range	1 - 6 GHz	1 - 6 GHz	1 - 6 GHz
RF input power (50 Ω impedance)	10 - 15 dBm	10 - 15 dBm	10 - 15 dBm
RF stability (RMS)	<0.1 %	<0.1 %	<0.1 %
RF connector	SMA	SMA	SMA
ELECTRICAL OUTPUT			
Error signal amplitude (PP, sine wave)	>400 mV	>400 mV	>400 mV
Output impedance	50 Ω	50 Ω	50 Ω
Detection sensitivity @ 3 GHz reference, 10 dBm	> 0.3 V/rad (80 mW optical input)	> 0.3 V/rad (80 mW optical input)	> 1 V/rad (20 mW optical input)
Error signal shape	square	square	square
Error signal output connector	SMA	SMA	SMA

*relative timing jitter between two lasers stabilized using the BOM-PD
**or same as actuator resonances whichever applies first
***when using Menlo Systems SYNCRO platform for the temperature controller
****repetition rate of the laser, design frequency to be specified prior to system order

	BOM-PD 800 NM	BOM-PD 1060 NM	BOM-PD 1560 NM
UTILITY AND ENVIRONMENTAL REQUIREMENTS			
Ambient temperature	20 – 25 °C	20 – 25 °C	20 – 25 °C
Ambient temperature variation	±1 °C	±1 °C	±1 °C
Supply voltages	-15 VDC, GND, +15 VDC	-15 VDC, GND, +15 VDC	-15 VDC, GND, +15 VDC
Current consumption	<1 A @ ± 15 V	<1 A @ ± 15 V	<1 A @ ± 15 V
Length of connecting cable to SYNCRO-RRE	4 m	4 m	4 m
Device dimensions	413 x 178 x 120 mm^3	413 x 178 x 120 mm^3	413 x 178 x 120 mm^3

Parameter	Value	Comment
RF EXTRACTION OPTION FOR BOM-PD @ 800/1060/1560 NM		
VCO	included	frequency to be defined prior to system order
Integrated PID loop	included	
Relative timing jitter	<15 fs	
RF output frequency range	1 - 6 GHz	
RF output power	>3 dBm	
RF output stability	<1 %	RMS in 1 day continuous operation

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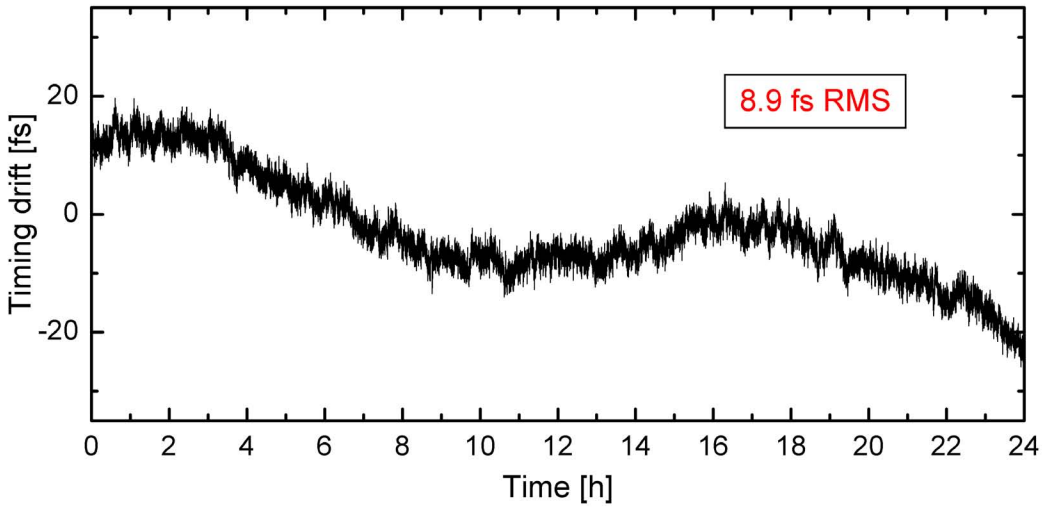
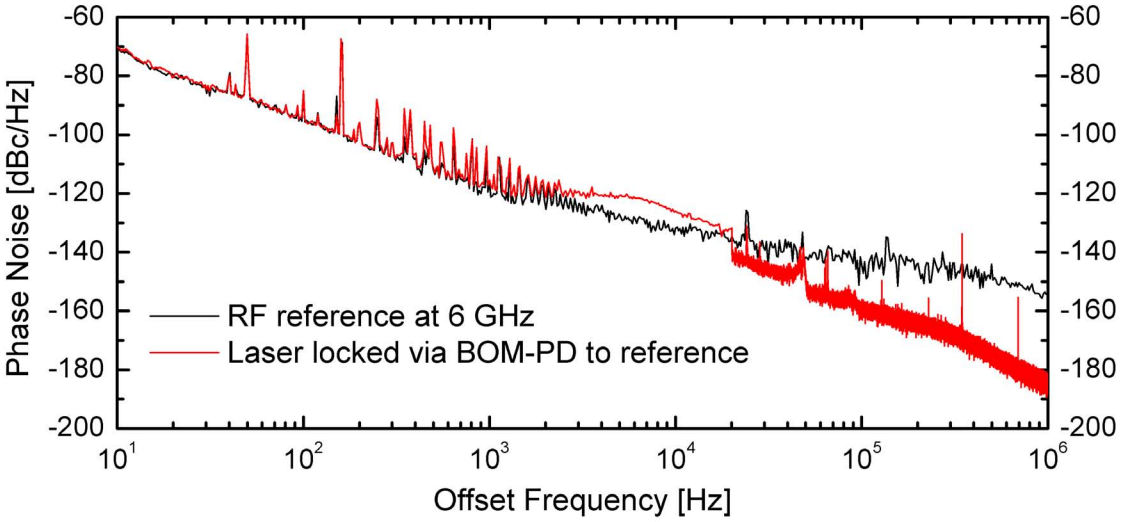
MEASUREMENT DATA:

Out-of-loop timing drift between optical pulses and RF-Reference:



Out-of-loop timing jitter spectral density: comparison between reference at 6 GHz and laser locked to reference:



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BALANCED CROSS CORRELATOR PHOTODETECTION (BCC-PD)

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The high resolution optical balanced cross correlator is optimized for detecting the timing error between the reference pulse train and a laser client system with ultra-high sensitivity. The balanced detection makes the system more robust reducing the phase deviation from unintentional amplitude variations (AM-PM conversion). The BCC-PD is required for high level synchronization of femtosecond laser systems to a reference pulse train.

APPLICATION

- Timing synchronization of two optical pulse trains at different wavelengths
- Timing synchronization of an ultrafast laser to the output of a stabilized fiber link
- Timing synchronization of an ultrafast laser to an optical master oscillator
- Timing synchronization within a laser amplifier chain or between different setups

BALANCED CROSS CORRELATOR PHOTODETECTION (BCC-PD)

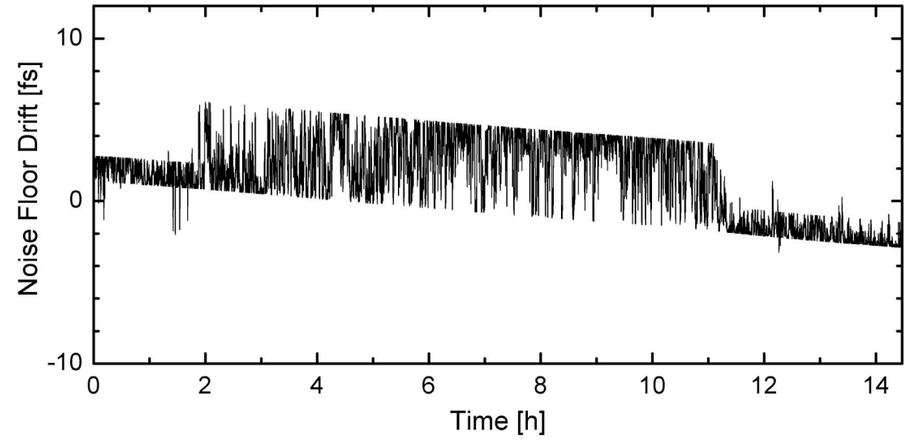
SPECIFICATIONS:

	BCC-PD 800 NM	BCC-PD 1060 NM	BCC-PD 1560 NM
Optical input 1	1560 nm fiber coupled (SMF28 or PM Panda)	1560 nm fiber coupled (SMF28 or PM Panda)	1560 nm fiber coupled (SMF28 or PM Panda)
Spectral range input 1	1530 – 1590 nm	1530 – 1590 nm	1530 – 1590 nm
Optical input 2	Fiber (Nufern PM780-HP) or free space	Fiber (PM980XP) or free space	Fiber (Nufern PM780-HP) or free space
Spectral range input 2	745 – 825 nm	1000 – 1100 nm	1530 – 1590 nm
Max. incident power	100 mW	100 mW	100 mW
Output impedance	50 Ω	50 Ω	50 Ω
Error signal amplitude	1 Vpp	1 Vpp	1 Vpp
Error signal shape	Dispersive S	Dispersive S	Dispersive S
Error signal output connector	SMA	SMA	SMA
Sensitivity @ 100 MHz lasers	>15000 V/rad (50 mW optical input)	>15000 V/rad (50 mW optical input)	>15000 V/rad (50 mW optical input)
Supply voltages	-15 VDC, GND, +15 VDC	-15 VDC, GND, +15 VDC	-15 VDC, GND, +15 VDC
Current consumption	<1 A @ ±15 V	<1 A @ ±15 V	<1 A @ ±15 V
Operating temperature	10 - 40 °C	10 - 40 °C	10 - 40 °C
Device dimensions (stand-alone)	413 x 178 x 90 mm^3	413 x 178 x 90 mm^3	413 x 178 x 90 mm^3

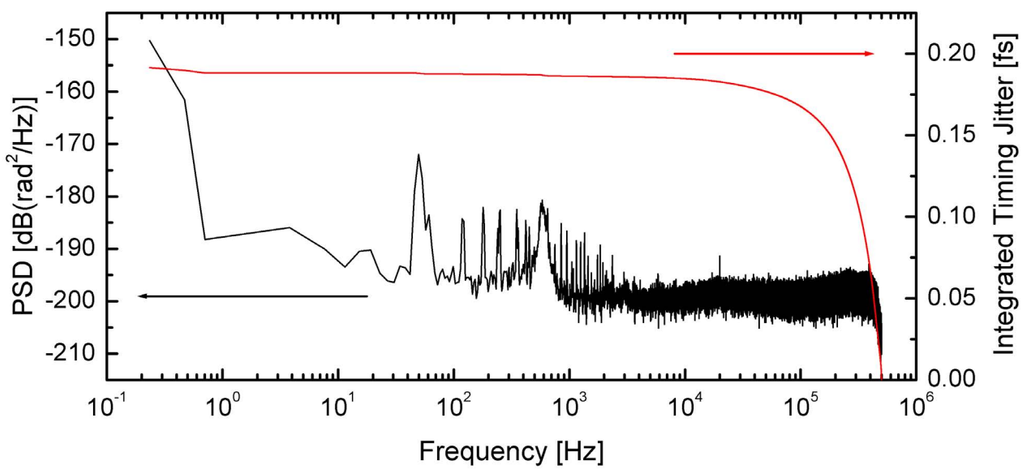
MEASUREMENT DATA:

Detection noise floor when seeding the BCC-PD with two identical signals from laser:

1) Long-term stability over 10 hours:



2) Short-term stability:



» The design and integration of the Timing Distribution System into the control system of the facility is an intensive process of close collaboration between Menlo Systems and our customer. We build on a strong relationship and offer reliable support at all times. «

Dr. Pablo Dominguez
Product Manager
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MenloSystems

Menlo Systems GmbH is a leading developer and global supplier of instrumentation for high-precision metrology. The company with headquarters in Martinsried near Munich is known for its Nobel Prize winning optical frequency comb technology. With subsidiaries in the US and China and a global distributor network, Menlo Systems is closely connected to its customers from science and industry. The main product lines are optical frequency combs, time and frequency distribution, Terahertz systems, ultrafast and ultrastable lasers, and corresponding control electronics. Besides standard production, Menlo Systems develops and manufactures custom made solutions for laser-based precision measurements.

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