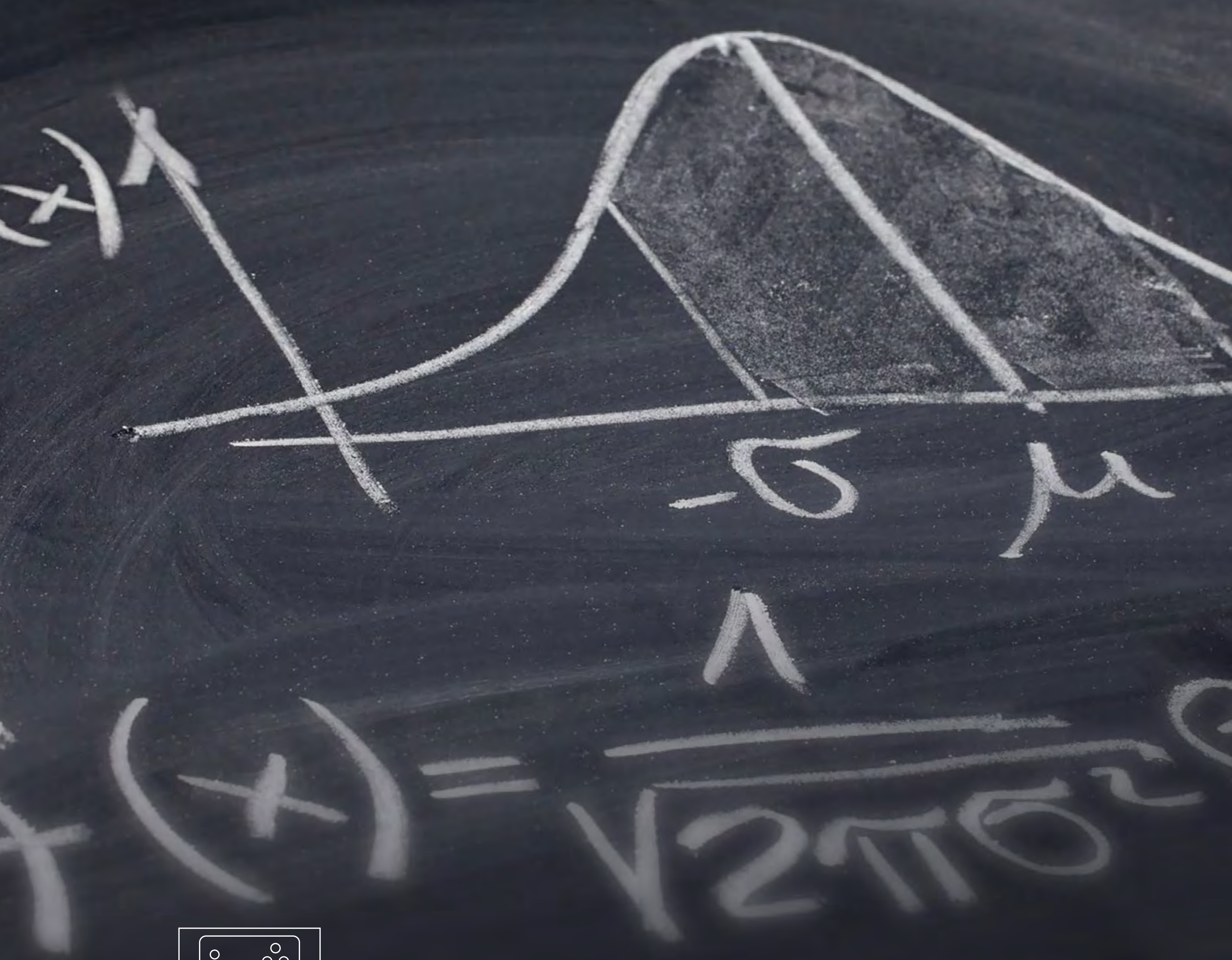
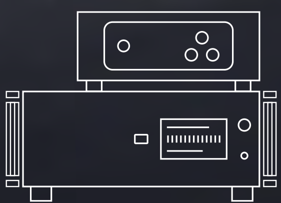
HighFinesse
The Standard of Accuracy





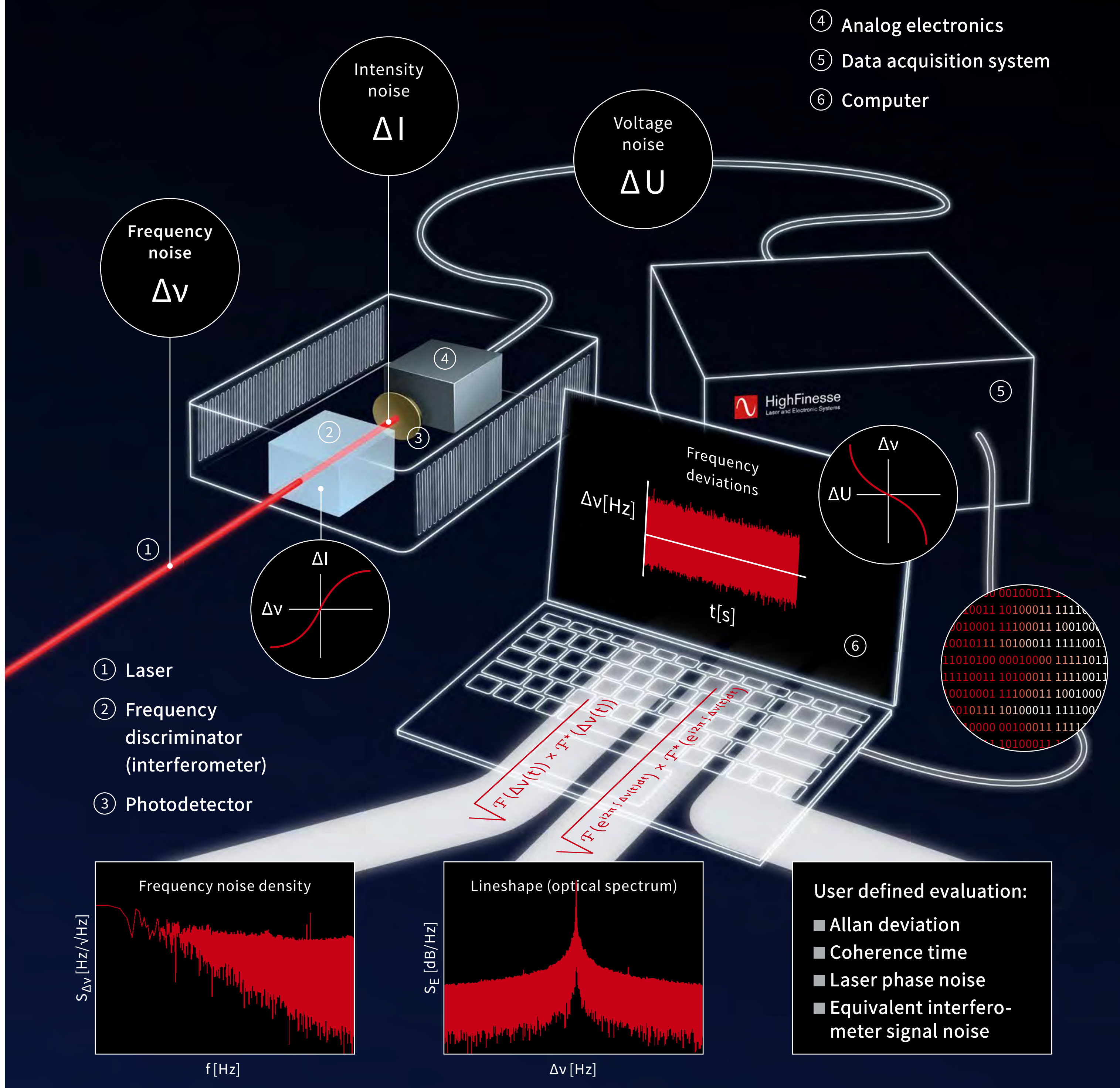
Linewidth Analyzer

High resolution lineshape spectra and ultra sensitive noise analyzers for narrowband lasers

The HighFinesse Linewidth Analyzers are the ultimate high-end instruments for measuring, analyzing and controlling frequency of lasers. The superb sensitivity of these instruments is achieved by combining an interferometric working principle with high-end optical and electronic components.

The main features are:

- Frequency noise density, laser phase noise density, optical lineshape analysis with evaluation of intrinsic (Lorentzian) and effective (optical) linewidth
- Intrinsic (Lorentzian) linewidth measurements down to 350 Hz
- Effective (optical) linewidth measurement range down to 1 kHz
- Frequency noise density floor down to 5 Hz/√Hz with a dynamic range of 60 dB between 10 Hz and 10 MHz
- Laser phase noise density floor down to 3.2 µrad/√Hz
- Robust against acoustic noise
- Error signal generator for further linewidth, frequency noise reduction
- Powerful tool for a detailed analysis of noise sources like servo bumps, frequency drifts, power supply noise and acoustics
- Extremely fast analysis: up to real time measurements and evaluation

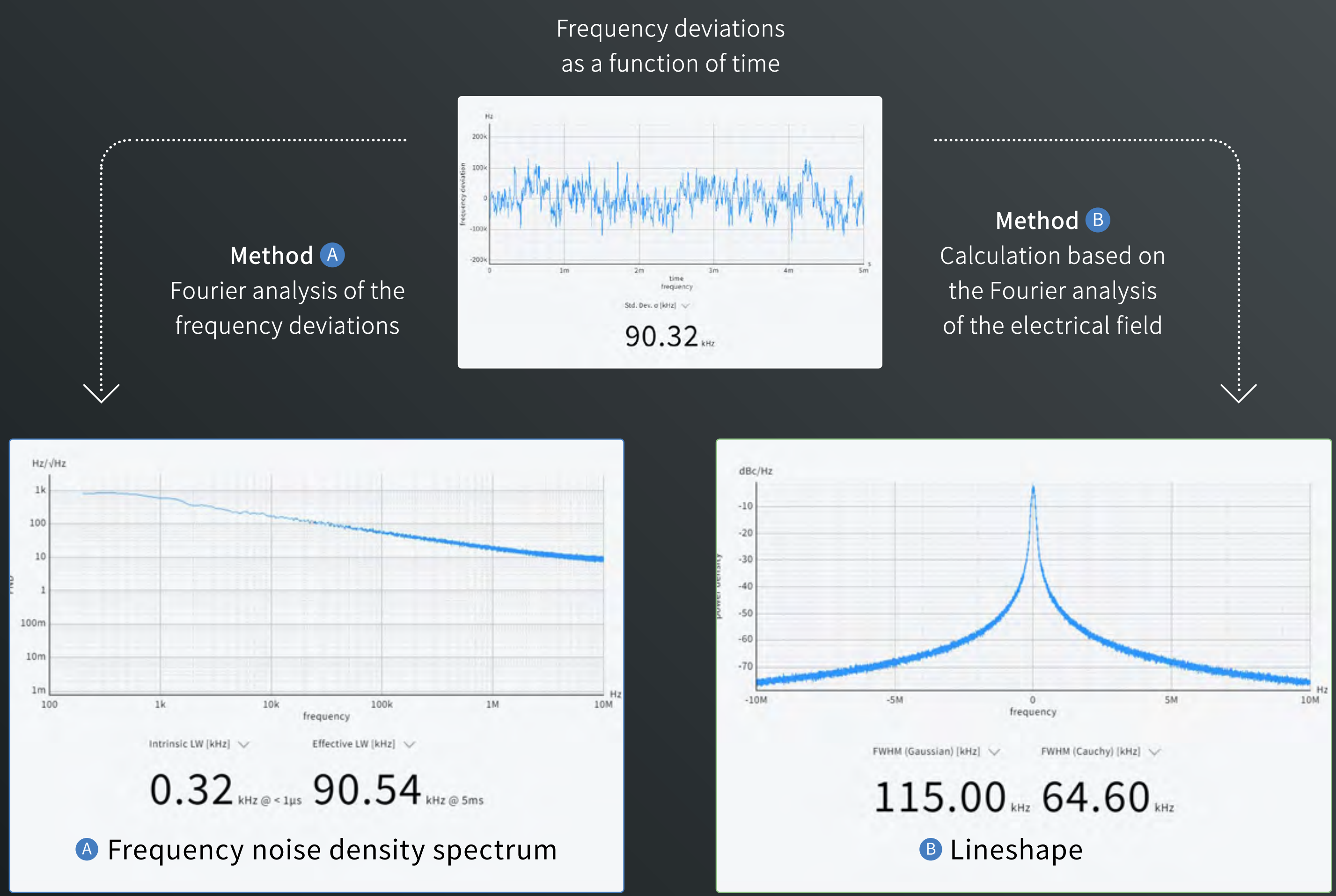


The laser light ① is coupled to the input fiber and lead through an interferometer ② acting as a frequency discriminator. The transmitted intensity, which is directly proportional to the variations of the input frequency, is converted by a photodetector ③ and our analog electronics ④ into a voltage signal.

This voltage is finally digitized by the Digitizer ⑤ to provide the data for evaluation on a computer ⑥. The software suite recovers the original frequency noise using the precisely known interferometer function. Based on that the software provides the user with the exact frequency noise density, laser phase noise density, and lineshape. From this, the exact frequency noise density, laser phase noise density and line shape are calculated.

The user can also export the timeseries data in order to perform custom evaluation methods such as Allan deviation or coherence time analysis.

Let the Software Suite do the math for you. The LWA Software Suite is delivered with all LWA products.



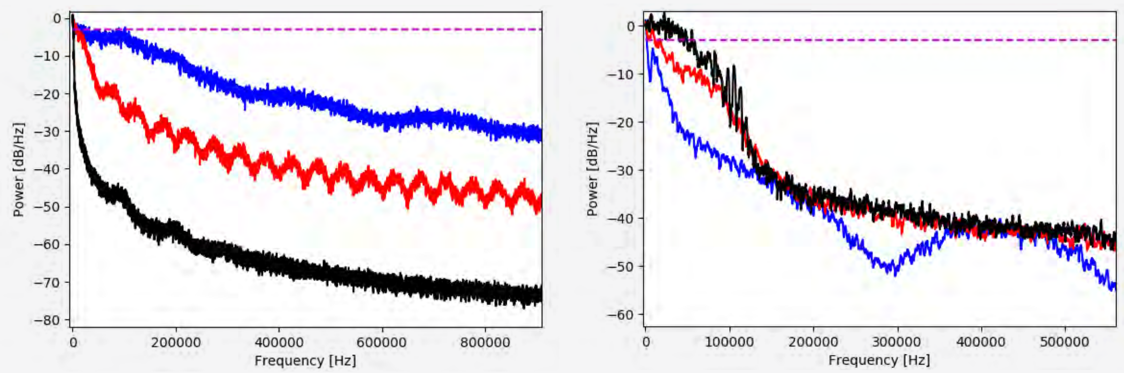
- Real-Time Analysis of laser frequency noise
- Automatic calculation of:
  - frequency noise density.
  - laser phase noise density.
  - intrinsic and effective laser linewidth based on the β-separation approach [DiDomenico Appl. Opt. 49 (2010)].
  - optical lineshape for various observation times.
  - linewidth parameters by fitting Voigt, Lorentzian or Gaussian models to the observed lineshape.
- Simple data export to compute: Allan deviation, coherence time, equivalent interferometer signal noise, etc.
- Including programming examples for evaluation of:
  - linewidth parameters by fitting Voigt, Lorentzian or Gaussian models to exported data.
  - Conversion tools.

Beside the frequency discrimination approach, homo- and heterodyne delay-line techniques are commonly used for linewidth determination. However, using optical delay lines can lead to complex spectra with non-trivial evaluation needs due to the technique inherent loss of information.

Lineshape of two lasers investigated by the LWA and a homodyne delay line detector

Fiber laser@1550 nm

Ti:Sapphire@813 nm



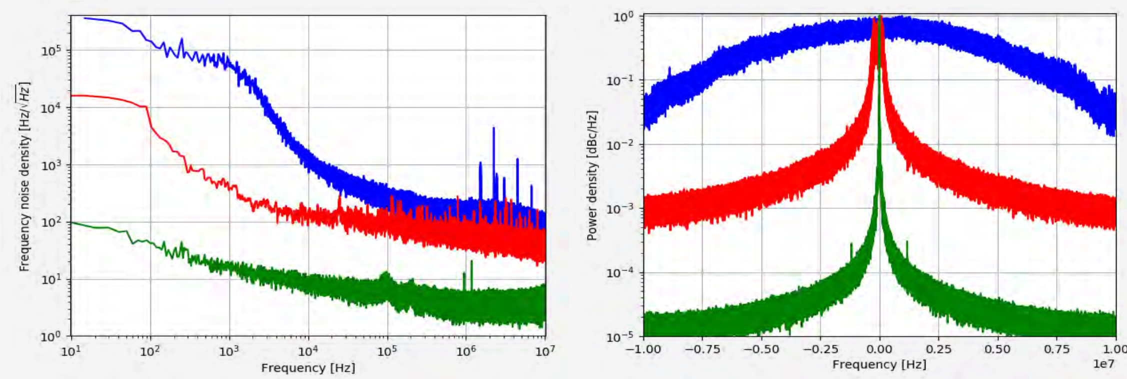
The distorted measurement results of a homodyne delay line detector can be simulated using the time-frequency deviation data of the LWA.

The simulations are shown for a short delay line (■ 3.5 µs) and a long delay line ■ 20 µs). As a comparison the undistorted lineshape observed by an ■ LWA-1k is shown.

Versatality of the LWA and examplary measurements

LWA-1k 1550
Typical frequency noise density spectra

LWA-1k 1550
Typical lineshape spectra



■ DBR laser
■ ECDL @ 1550 nm
■ Fiber laser

The LWA does not only yield the linewidth information but also offers the full lineshape and frequency noise density spectrum of the laser.

Advantages of the HighFinesse LWA	HighFinesse LWA	Delay-line approach
Principle	Direct frequency noise to intensity conversion	Optical delayed superposition by different path lengths
Limits	Steepness of discriminator-function	Length of delay path
Basic data	Frequency deviations in time	Spectrum of beat note (convolution of original spectrum)
Frequency noise density	By a Fourier analysis of the frequency deviations	Not possible without additional methods
Lineshape	By a Fourier analysis of the calculated electric fields	Lorentzian part (intrinsic linewidth) of the lineshape
Linewidth evaluation	Effective (optical) and intrinsic (Lorentzian) linewidths directly accessible via frequenvy density noise spectrum or lineshape spectrum	Only the Lorentzian part of the linewidth is accessible, because the frequency noise is high-passed by the delay line
Laser phase noise spectrum	By performing a Fourier analysis of the integrated frequency fluctuations	Not possible without additional methods
Interferometer signal noise spectrum	By performing a Fourier analysis of the calculated interferometer phase signal 1)	Not possible without additional methods

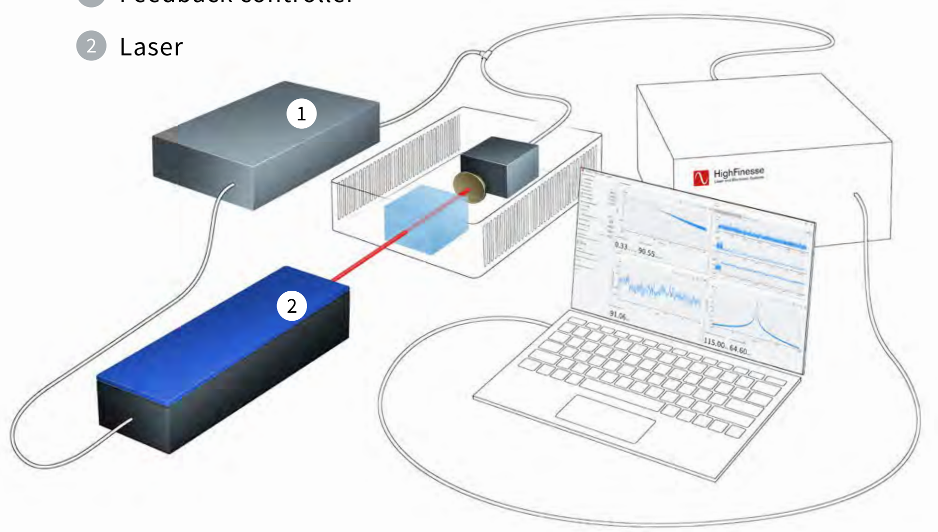
1) Assuming the interferometer working purely as a frequency discriminator and the interferometer phase signal being proportional to the frequency deviation signal.

Due to the design of the LWAs, the output voltage can be directly used as an error signal for a feedback controller allowing to reduce the frequency noise of the test laser.

Depending on the used feedback controller and the laser system the optical linewidth can be reduced by more than two orders of magnitude offering a vast amount of new opportunities.

1 Feedback controller

2 Laser



Active laser noise reduction

- Connect the Analyzer output signal A as input signal to a fast feedback controller.
- Connect the feedback controller to the laser's fast DC modulation input (e.g. laser diode current). B
- Adjust the feedback to minimize the output signal of the Analyzer (e.g. PID parameters, gain)

Typical application

- Laser module quality control
- Laser design optimization
- Metrology and quantum technology
- Linewidth control for spectroscopy
- Modulation surveillance

Technical Data

Technical Data	Unit	LWA-1k 780 [1] min	typ	max	LWA-10k VIS [1] min	typ	max	LWA-1k 1550 min	typ	max	LWA-10k NIR min	typ	max	LWA-100k NIR min	typ	max
Wavelength range	nm	760	780	1064	450	780	1064	1530	1550	1625	1064	1550	1625	1064	1550	1625
Input power range (@typical wavelength)	mW	1	10	15	0.5	5	8	0.5	5	8	0.5	5	8	0.5	5	8

Parameter	Unit	LWA-1k 780 [1]	LWA-10k VIS [1]	LWA-1k 1550	LWA-10k NIR	LWA-100k NIR
Required input power stability	%	±5				
Laser type		Laser type CW, single mode				
Input fiber type		PM-FC/APC	PM, FC/APC	PM-FC/APC	PM, FC/APC	PM, FC/APC
Maximum frequency stroke (@ f > 10Hz)	MHz	30	40	30	40	100

Frequency Noise Specification

LWA-1k 780 [1]

Parameter	Unit	10	100	1k	10k	100k	> 1M
Noise floor $N_{\Delta\nu}$ @ typ. input power and wavelength [6]	Hz/√Hz	200	75	30	30	25	15
Laser phase noise floor @typ. input power and wavelength [2] [7]	rad/√Hz	20	750 m	30 m	3 m	250 µ	15 µ
	dBrad/√Hz	26	–2.5	–30	–50	–72	–96
Equivalent interferometer signal noise @typ. input power and wavelength [2] [4]	rad/√Hz/m	6.2 µ	2.3 µ	920 n	920 n	770 n	460 n
	dBrad/√Hz/m	–104	–112	–120	–120	–122	–126

LWA-10k VIS [1]

Parameter	Unit	10	100	1k	10k	100k	> 1M
Noise floor $N_{\Delta\nu}$ @ typ. input power and wavelength [6]	Hz/√Hz	500	150	60	60	50	30
Laser phase noise floor @typ. input power and wavelength [2] [7]	rad/√Hz	5	1.5	60 m	6 m	500 µ	30 µ
	dBrad/√Hz	24	3.5	–24	–44	–66	–90
Equivalent interferometer signal noise @typ. input power and wavelength [2] [4]	rad/√Hz/m	16 µ	4.6 µ	1.8 µ	1.8 µ	1.6 µ	920 n
	dBrad/√Hz/m	–96	–106	–114	–114	–116	–120

LWA-1k 1550

Parameter	Unit	10	100	1k	10k	100k	> 1M
Noise floor $N_{\Delta\nu}$ @ typ. input power and wavelength [6]	Hz/√Hz	80	40	15	10	8	5
Laser phase noise floor @typ. input power and wavelength [2] [7]	rad/√Hz	8	400 m	15 m	1 m	80 µ	5 µ
	dBrad/√Hz	18	–8	–36	–60	–82	–106
Equivalent interferometer signal noise @typ. input power and wavelength [2] [4]	rad/√Hz/m	2.5 µ	1.3 µ	460 n	310 n	250 n	160 n
	dBrad/√Hz/m	–112	–118	–126	–130	–132	–136

LWA-10k NIR

Parameter	Unit	10	100	1k	10k	100k	> 1M
Noise floor $N_{\Delta\nu}$ @ typ. input power and wavelength [6]	Hz/√Hz	200	100	30	20	15	10
Laser phase noise floor @typ. input power and wavelength [2] [7]	rad/√Hz	20	1	30 m	2 m	150 µ	10 µ
	dBrad/√Hz	26	0	–30	–54	–76	–100
Equivalent interferometer signal noise @typ. input power and wavelength [2] [4]	rad/√Hz/m	6.2 µ	3.1 µ	920 n	620 n	460 n	310 n
	dBrad/√Hz/m	–104	–110	–120	–124	–126	–130

LWA-100k NIR

Parameter	Unit	10	100	1k	10k	100k	> 1M
Noise floor $N_{\Delta\nu}$ @ typ. input power and wavelength [6]	Hz/√Hz	1k	200	60	50	40	25
Laser phase noise floor @typ. input power and wavelength [2] [7]	rad/√Hz	100	2	60 m	5 m	400 µ	25 µ
	dBrad/√Hz	40	6	–24	–46	–68	–92
Equivalent interferometer signal noise @typ. input power and wavelength [2] [4]	rad/√Hz/m	31 µ	7 µ	2 µ	2 µ	2 µ	765 n
	dBrad/√Hz/m	–90	–104	–115	–116	–118	–122

Parameter	Unit	LWA-1k 780 [1]	LWA-10k VIS [1]	LWA-1k 1550	LWA-10k NIR	LWA-100k NIR
Frequency noise bandwidth [4]	Hz	10 – 10 M				
Minimum measurable intrinsic linewidth (lorentzian linewidth @ 1 µs)	Hz	< 3 k	< 12 k	< 350	< 2 k	< 10 k
Effective linewidth range (optical linewidth @ 100 ms) [β-separation method]	Hz	< 10 k – 20 M	< 20 k – 30 M	< 1 k – 20 M	< 5 k – 30 M	< 15 k – 100 M
Relative intensity noise limit (lorentzian linewidth)	dB/Hz	–	–	On request only	–	–
Dynamic range	dB	60				

Lineshape Specifications

Parameter	Unit	LWA-1k 780 [1]	LWA-10k VIS [1]	LWA-1k 1550	LWA-10k NIR	LWA-100k NIR
Effective linewidth range (optical linewidth)	Hz	< 10 k – 10 M	< 20 k – 10 M	< 1 k – 10 M	< 5 k – 10 M	< 15 k – 10 M
Dynamic range	dB	60				

Miscellaneous

Parameter	Unit	LWA-1k 780 [1]	LWA-10k VIS [1]	LWA-1k 1550	LWA-10k NIR	LWA-100k NIR
Interface		USB 2.0 Type B	Ethernet	USB 2.0 Type B	Ethernet	Ethernet
Analog Output		BNC ± 7.5 (50 Ω) ± 15 (high impedance) V, single ended				
Cutoff (highpass filter)	Hz	10, 1k, 10k, 100k	10	10, 1k, 10k, 100k	10	10
Dimensions	mm	220 × 334 × 96	440 × 340 × 155	220 × 334 × 96	440 × 340 × 155	440 × 340 × 155
Weight	kg	8.0	12	8.0	12	12

Digitizer Module

Parameter	Unit	Value
Sample rate	Sa/s	62.5 M (max.)
Resolution	bits	16
Acquisition time (time series)	s	1 m – 100 m
Evaluation time [5]	s	10 m – 1 (typ.)
Communication		USB 3.0 Type B
Dimensions	mm	210 × 200 × 74
Weight	kg	2.0

1) Frequency noise and lineshape specifications are derived from measurements at 780 nm.

2) Not included in the software, can be calculated by the user from exported data.

3) According to a –3 dB criterion.

4) This is the calculated noise of the interferometer phase of a two path interferometer with length imbalance L (in meters). The calculation is performed for a given frequency noise density floor by $2\pi nL/c \times N_{\Delta\nu}$ with n being the refractive index of the reference fiber interferometer material and c being the speed of light in vacuum. Values in the table are given for an refractive index of n = 1.46 and a reference length of 1 meter.

5) Windows 10 or newer, Intel i5 8600/AMD Ryzen 5 2600 or better, 16GB RAM or more.

6) $N_{\Delta\nu}$ is the noise floor of the instrument in terms of the square root of the power spectral density of the frequency noise.

7) The phase noise floor corresponds to the noise floor of the square root of the power spectral density of the phase. It is calculated from $N_{\Delta\nu}$ by the formula $1/f \times N_{\Delta\nu}$. Additionally, phase noise is often specified in terms of $\mathcal{L}(f)$ which can be calculated with the formula $\mathcal{L}(f) = 1/f^2 \times N^2_{\Delta\nu}/2$.

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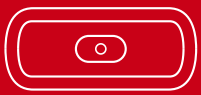
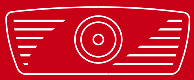


Wavelength Meter

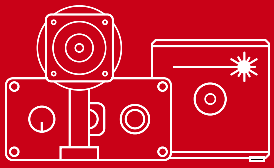
HighFinesse/Ångstrom offers sensitive and compact wavelength meters with a large spectral range for high speed measurement of lasers. The optical unit consists of temperature-controlled Fizeau-based interferometers that are read out by photodiode arrays. The high absolute accuracy is achieved by use of solid state, non-moving optics. The optical unit and associated electronics are housed in a compact, thermal casing. The connection to a computer or notebook is realized via a highspeed USB 2.0 port, which allows a high data read-out rate. The analyzing software displays all the interferometer information.



Spectrometer

The grating based HighFinesse/Ångstrom Laser Spectrum Analyzers offer the capability for a very accurate simultaneous measurement of both the center wavelength and the linewidth of a laser source with a compact and versatile instrument.

The product series covers the ranges from 192 nm to 2250 nm. The grating based technology allows the analysis of laser sources over a large linewidth range. Utilizing the principle of non-moving parts just like the well-known HighFinesse WS-series wavemeters, the LSA offers the time-tested robustness and ability to measure both pulsed and cw lasers.



Calibration Sources

HighFinesse offers a variety of frequency stabilized, narrow linewidth laser sources for the calibration of all wavelength meters and applications down to ± 0.5 MHz absolute accuracy. These are user friendly, plug and play devices that can be connected to the wavelength meter. Different technologies, accuracies and wavelengths are available to suit your application.

HighFinesse stabilized frequency references yield extremely accurate frequency stabilizations, ideal for calibration of our wavelength meters in the visible and infrared wavelength regimes.

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