

Low Noise fiber laser systems for PDV applications

Jens Engholm Pedersen, Søren Løvgreen, Tony Pisano

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NKT Photonics A/S

Denmark

Introduction

- NKT Photonics has supplied low noise DFB fiber lasers for PDV applications for years:
 - *Low frequency noise, low RIN, narrow linewidth*
 - *High frequency stability*
 - *High reliability*
- Laser modules: integration in AcoustiK rack
- Modules with new functionalities have been added recently to:
 - Boost power
 - Perform non-linear frequency conversion
 - Apply various modulations schemes

Presentation describes functionality of laser and other modules & how they can be configured in the AcoustiK rack e.g. for PDV applications

All functionalities integrated in AcoustiK rack



Outline

- Laser source requirements for PDV & remote sensing
- AcoustiK platform & modules
- DFB fiber laser
- Other modules:
 - Amplifier module
 - Frequency conversion module
 - AOM & EOM modules
- Summary

Laser based remote sensing

Security	Seismic	Structural Health Monitoring	Vibrometry	Wind LIDAR / Ranging	PDV
					
Pipes Fences	Oil & Gas exploitation Navy	Water pipes Oil and gas pipes	Laser Doppler vibrometry	Wind turbines Airports Atmospheric sensing Aircraft monitoring	Shock wave analysis @ km/sec velocities

PDV requirements:

- Frequency stability
- Multi-channel systems
- High power (Watt level)
- VIS range for low speed sensitivity



- Laser modules
- Amplifier modules
- Frequency conversion modules
- Other functionality modules

All: detect low levels of change in phase, frequency or intensity →

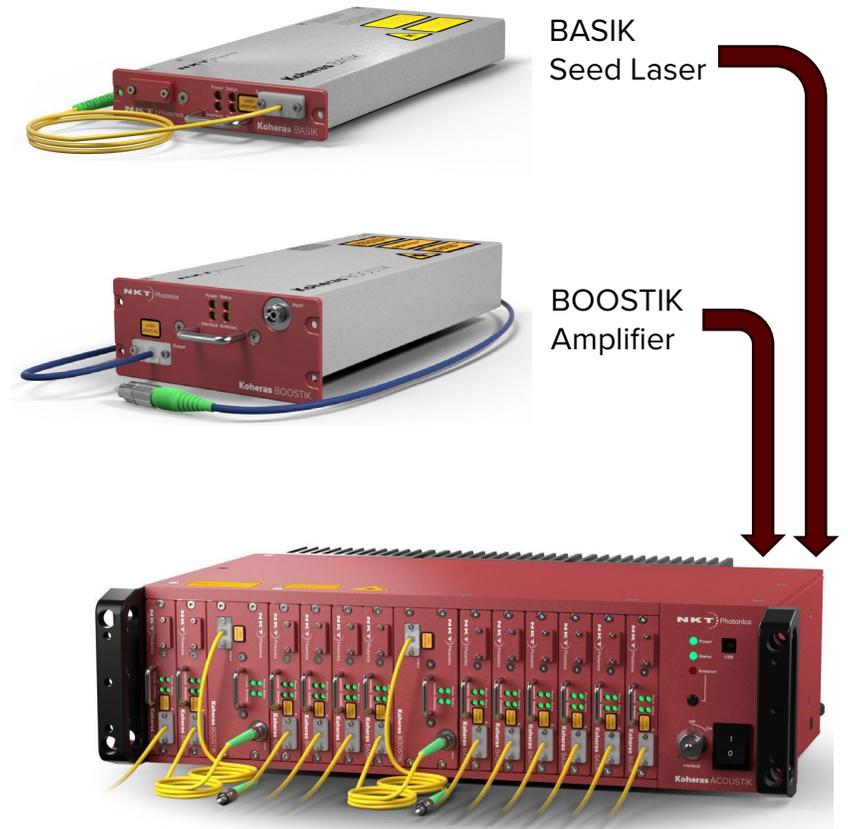
- low noise laser source (phase & amplitude)
- 'ease of use': compact, fiber coupled, maintenance free

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ACOUSTIK RACK & MODULES

- **Koheras ACOUSTIK**: platform designed to host line card modules containing lasers, amplifiers & other functionalities
- 3U height rack unit including power supply and control electronics
- Modular platform allows for highly customised outputs using standard building blocks
- **Standard modules:**
 - **BASIK**: DFB fiber laser module
 - **BOOSTIK**: amplifier module
- **New functionalities:**
 - Frequency conversion
 - Modulation, AOM & EOM based



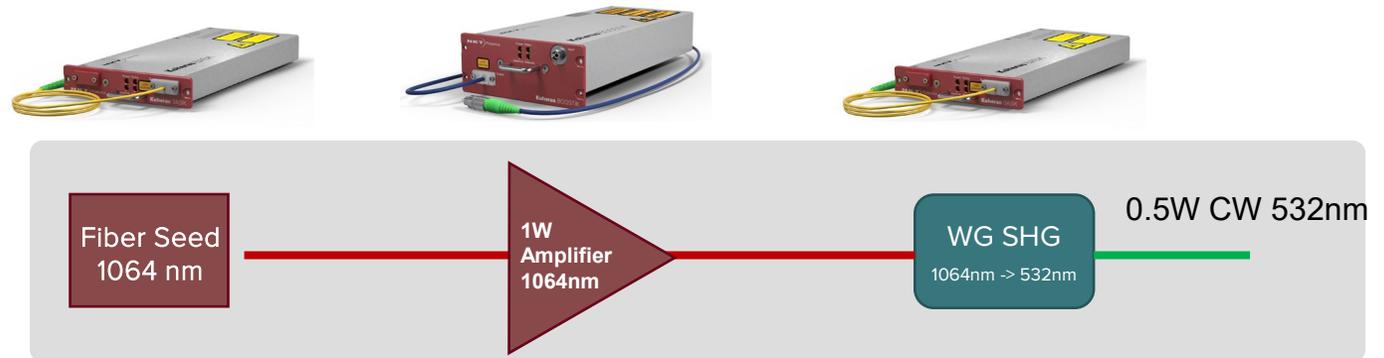
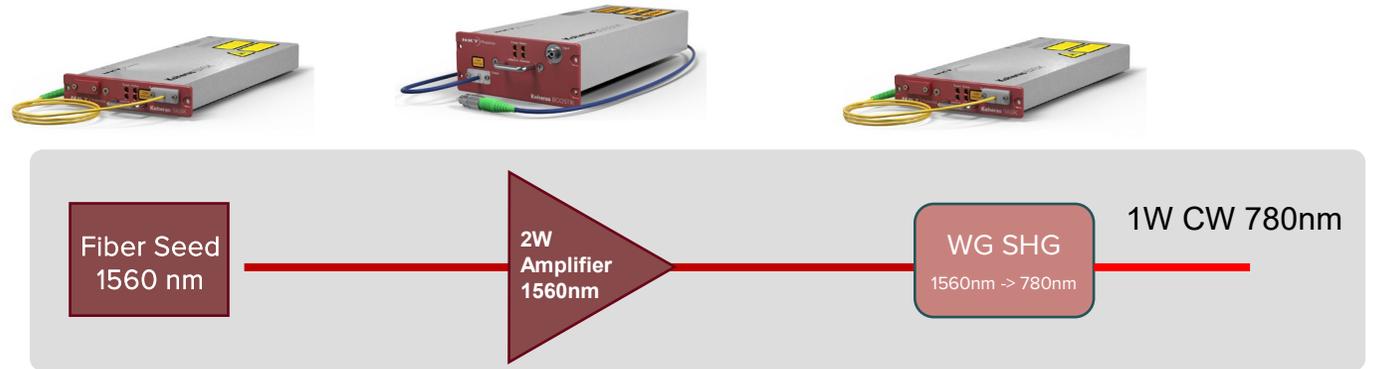
Fully populated ACOUSTIK rack

ACOUSTIK example: SHG 532/780nm

- Frequency converted systems
- 1W of CW output power in **red**, 0.5W in **green**
- The full chain of modules utilizes 4 ACOUSTIK slots
 - seed laser (1 slot)
 - amp (2 slots)
 - SHG (1 slot)
- Fibre coupled output
- All controlled via ACOUSTIK user interface
- Preserves low noise performance of Koheras seed lasers



ACOUSTIK Platform

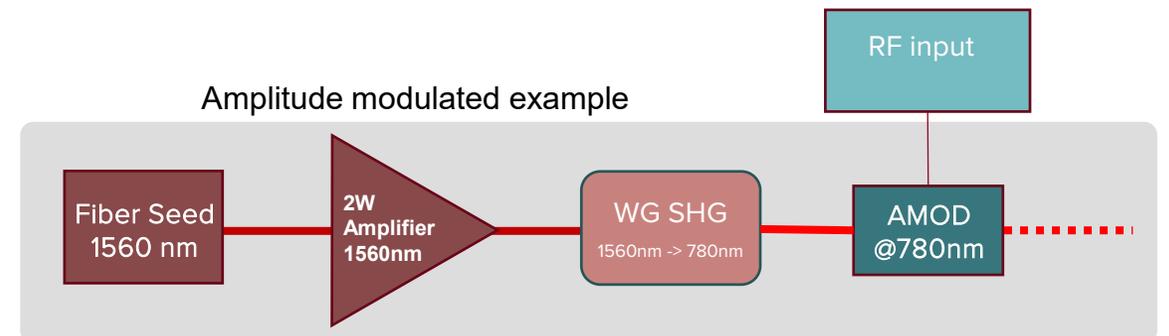
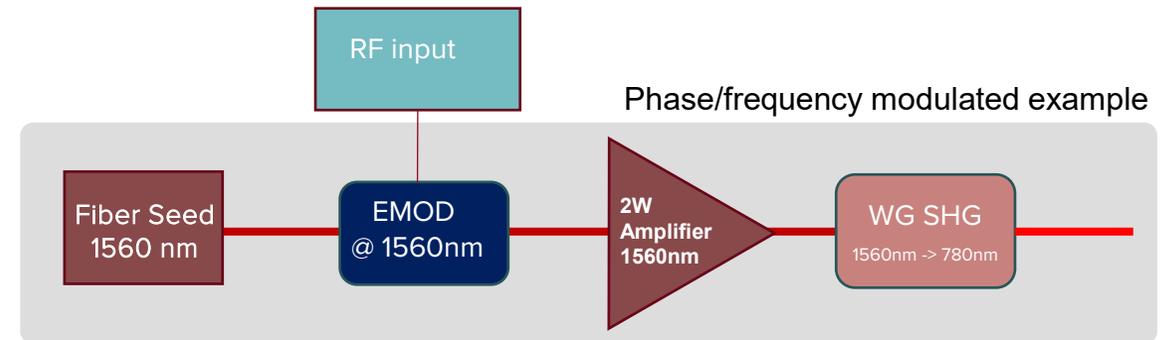


ACOUSTIK example: Modulation Functionality

- Acousto- (AMOD) or Electro- (EMOD) Optic Modulation can be supplied as card modules
- Phase, frequency and amplitude modulation possible and combinable
- Modulators can be used with function generators or to lock laser systems to external reference
- Wide range of modulation type, speed, range and wavelength



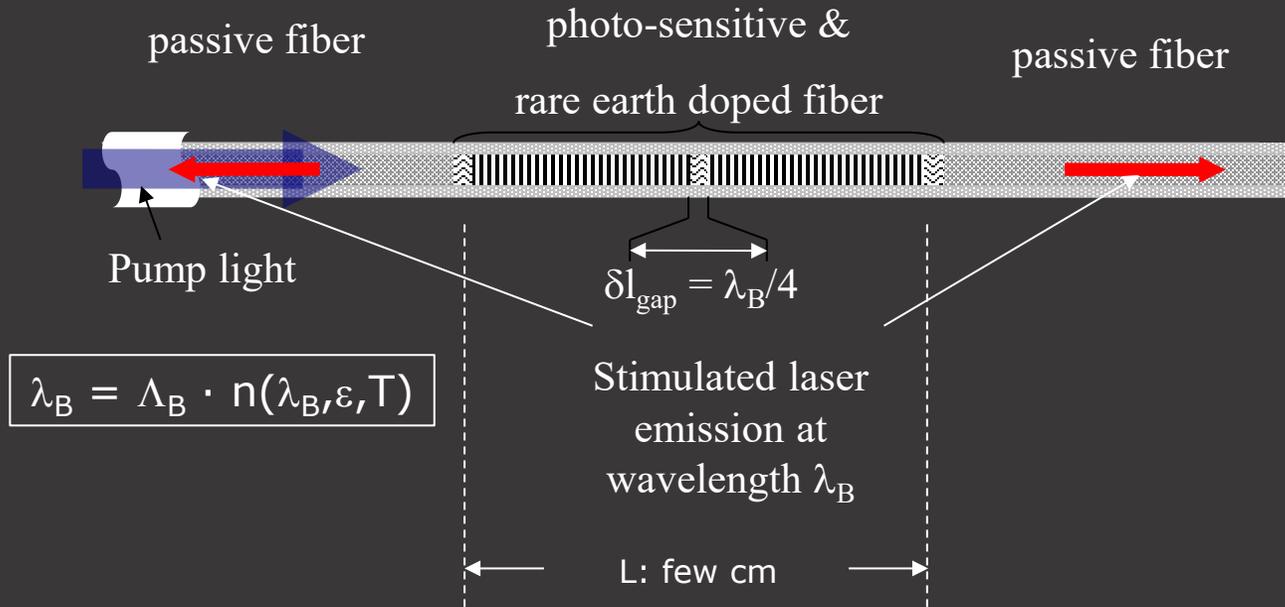
ACOUSTIK Platform



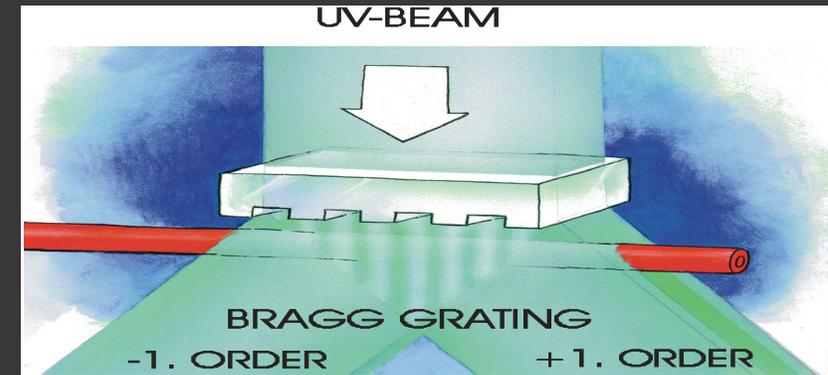
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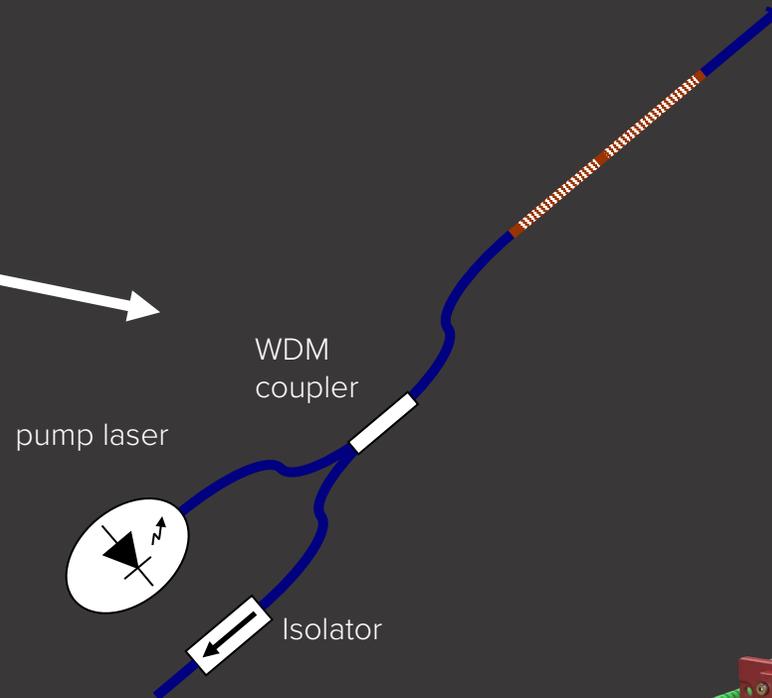
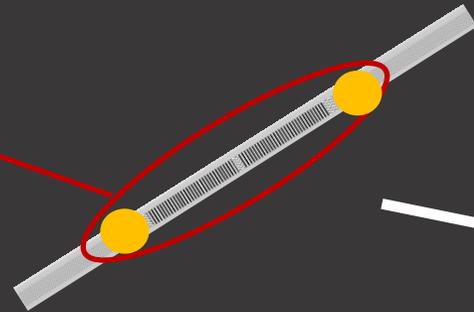
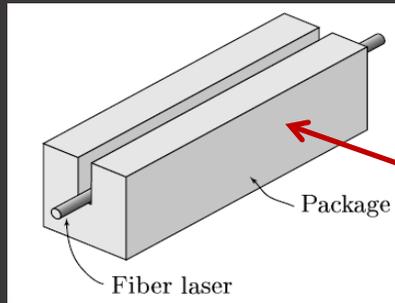
DFB Fiber Laser: fundamentals



RE dopant	Wavelength range
Yb	1030-1120 nm
Er	1530-1600 nm
Tm	1730-2100 nm



DFB Fiber Laser - packaging



Fiber laser grating mounted under tension on substrate.

$$\lambda_B = \Lambda_B(\epsilon, T) \cdot n(\lambda_B, \epsilon, T)$$

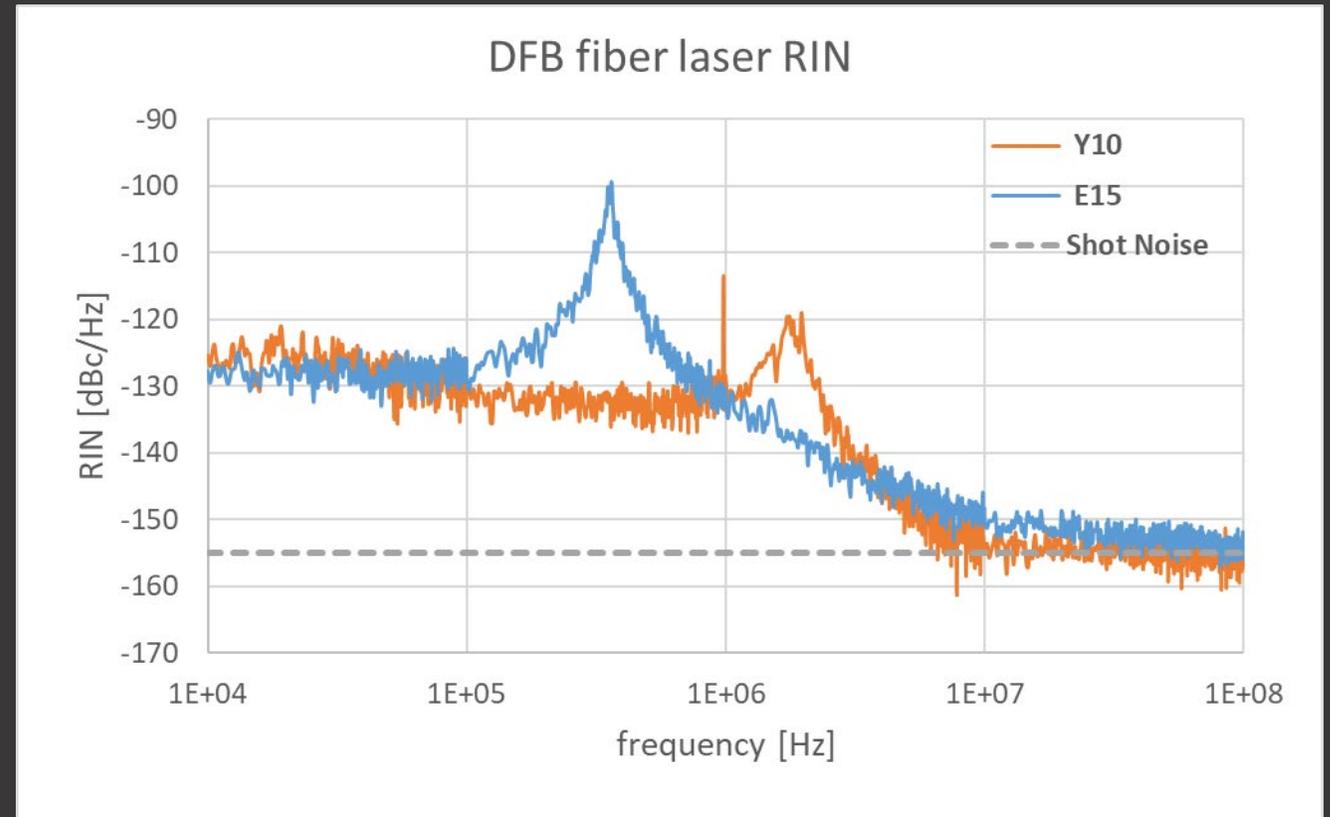
Fiber laser **wavelength** determined by grating pitch (Λ_B), tension (ϵ), temperature (T)

- *piezo tuning of wavelength through strain (10 GHz)*
- *temperature wavelength tuning (1 nm)*

RIN

Rare Earth doped fiber laser RIN:

- Laser cavity dynamics / relaxation oscillations: dominates in the MHz region
- Quantum noise: shot noise or signal-ASE beat noise. Dominates at higher frequencies (several MHz & beyond)
- Electronic noise: $1/f$ & noise spikes propagate via pump drive current onto fiber laser. Low frequencies < 100 kHz - 1 MHz

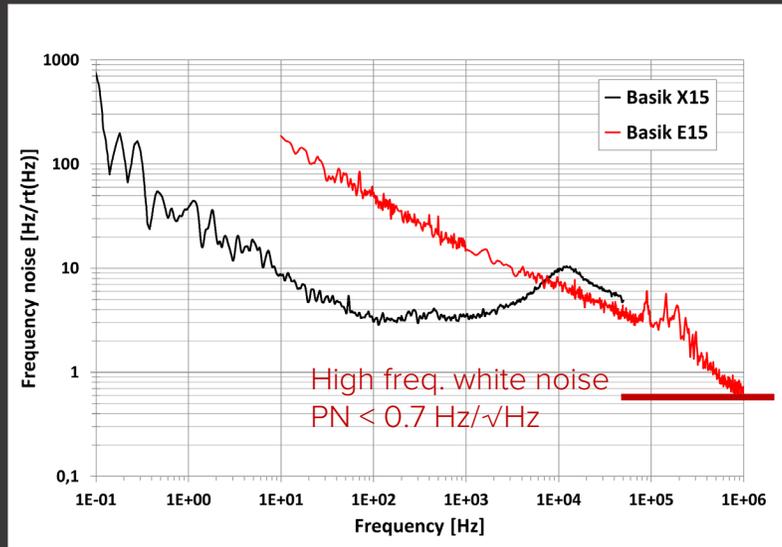


Frequency noise & spectral linewidth

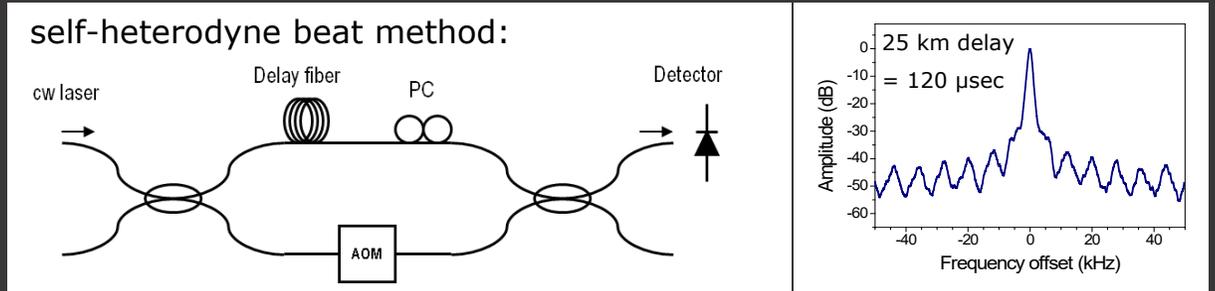
- Low loss fiber waveguide
- High finesse FBG cavity
- Long radiative lifetimes (msec's)



- Hz level intrinsic spectral linewidth
- Low HF phase noise (Shawlow-Townes)
- Low freq. PN determined by technical noise (frequency jitter)



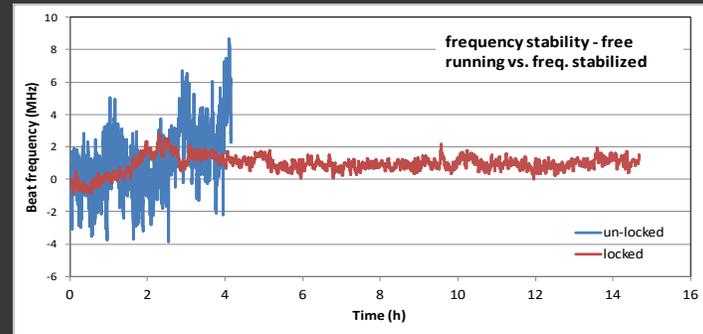
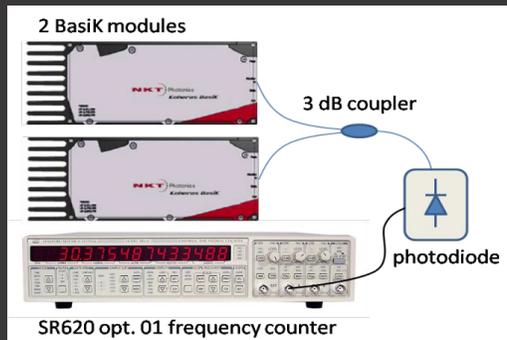
High freq. Phase noise < 0.7 Hz/rt(Hz) → Hz level intrinsic linewidth



Spectral linewidth:

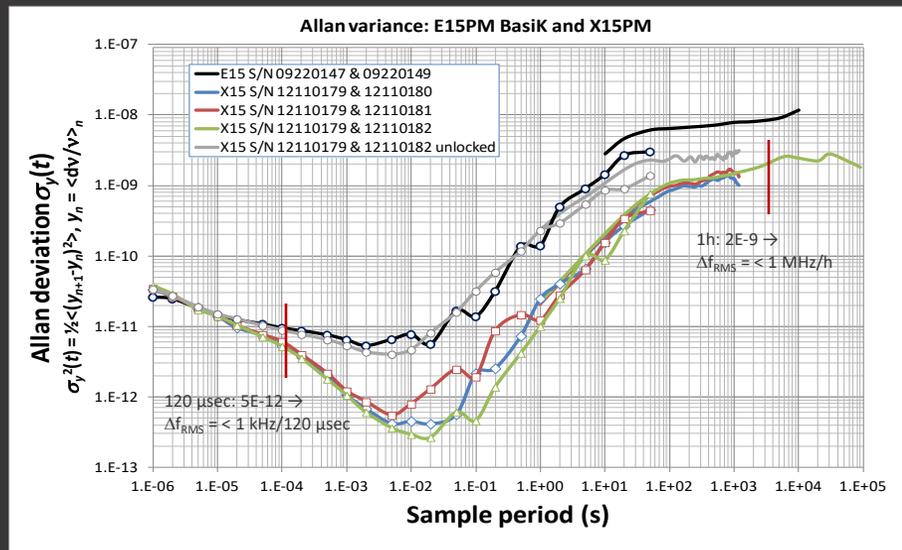
- Self-Heterodyne beat method: 25 km delay → kHz LW
- Indicates that coherence length > 25 km
- Combination of Gaussian (technical) & Lorentzian ("intrinsic" LW) noise sources

Frequency stability over time



Frequency stability over time:

- Locked laser (X15): < 1 MHz/10 hours
- High frequency stability useful e.g. for PDV



Allan variance analysis of frequency stability data:

X15:

- < 0.5 MHz/h
- < 1 kHz/120 μ sec (self-heterodyne LW @ 25 km delay)

E15:

- < 2 MHz/h
- < 2 kHz/120 μ sec (self-heterodyne LW @ 25 km delay)

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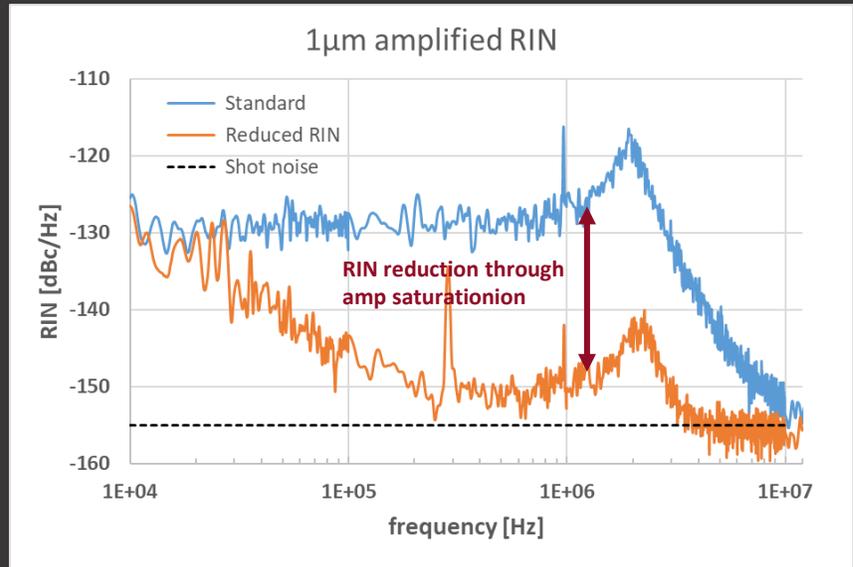
Linecard Amplifier module



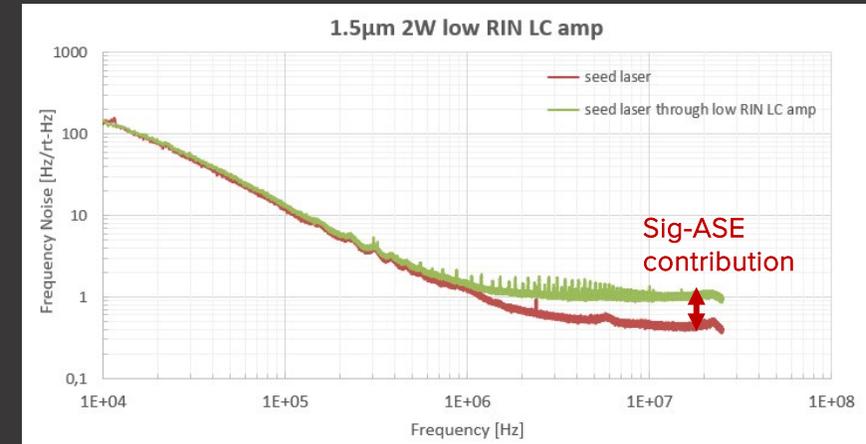
Linecard amp module:

- Integration with other modules in Acoustik
- 2W @ 1.5 μ m
- Wavelength range: 1545 – 1565 nm
- RIN reduction option
- Maintains / improves seed laser low noise quality
- Maintains high frequency stability of DFB fiber laser
- 1 μ m: coming up....

RIN:



Frequency Noise:



HARMONIK FREQUENCY CONVERSION LINECARD

Second Harmonik Generation Module

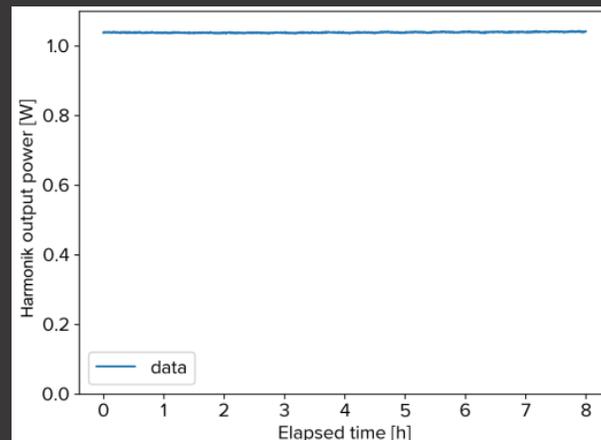


Linecard SHG module:

- Waveguide frequency doubler
- 1560nm → 780nm: 2W in → 1W out
- 1064nm → 532nm: 1W in → 0.7W out
- Lower power versions available
- Integration with other modules in AcoustiK
- Maintains seed laser low noise quality
- High frequency stability of DFB fiber laser maintained

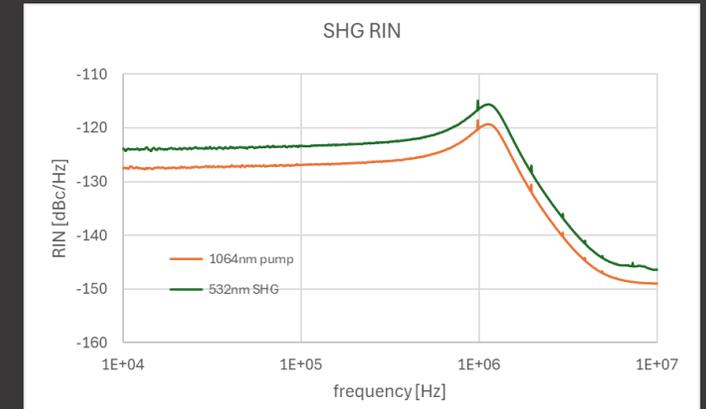


Power conversion

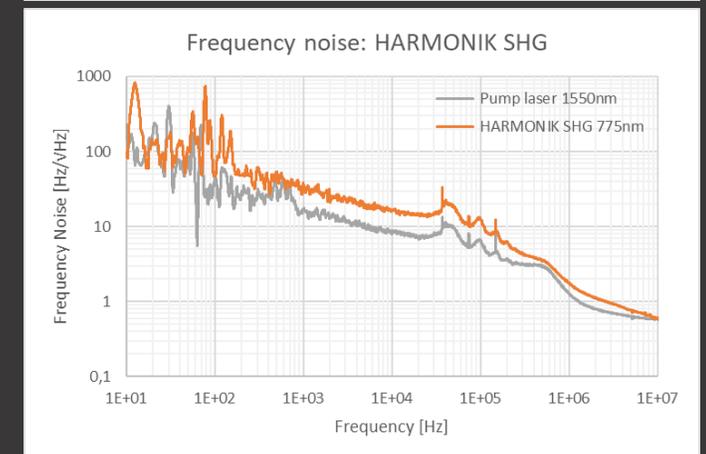


Power stability

RIN:

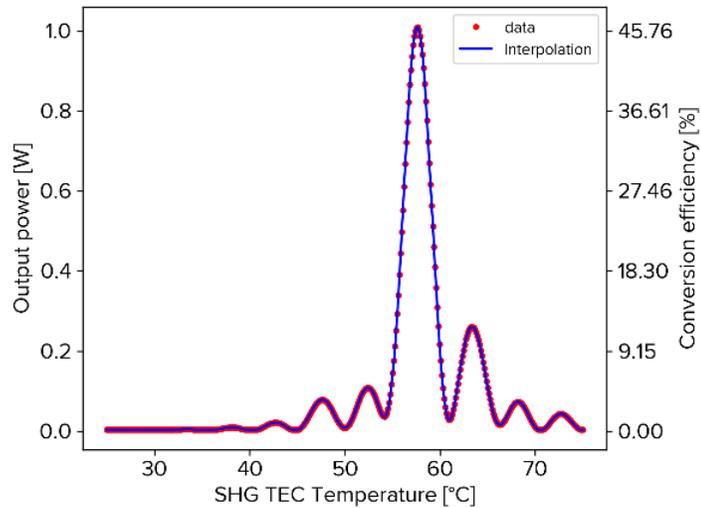


Frequency
Noise:

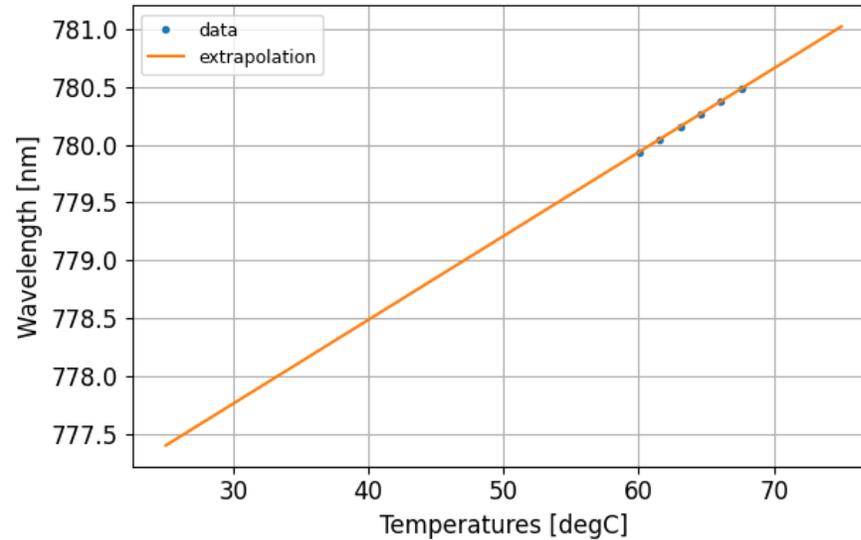


FREQUENCY CONVERSION LINECARD

Temperature tuning:



PPLN temperature response



1560 → 780nm:
Temperature tuning 25 – 75 °C:
bandwidth 3.6 nm
(777.4 to 781 nm)

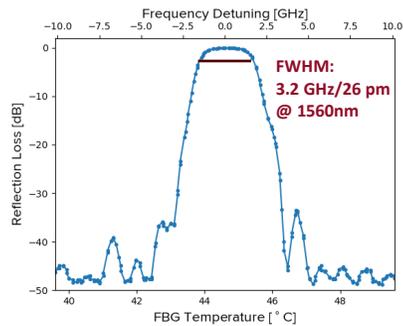
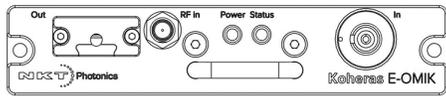
EMOD: EOM LINECARD MODULE

EMOD: EOM optical phase modulator w. internal RF driver in a linecard module:

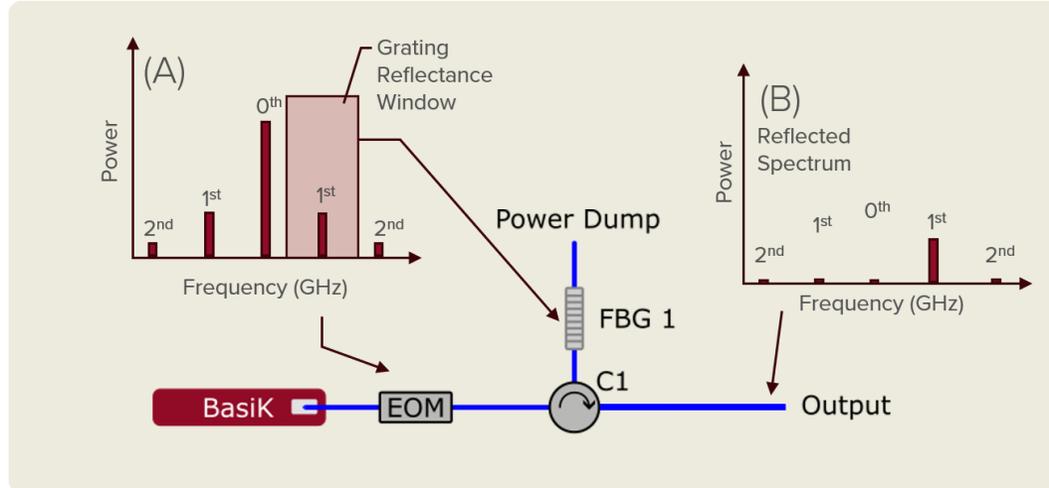
- generate optical sidebands in GHz range
- Transmit fundamental + sidebands

fEMOD: additional FBG filter to transmit only sideband:

- Frequency Tuning: optical sideband can be created and shifted within the reflectance bandwidth of the FBG
- Amplitude Tuning: amplitude modulation of the electronic RF frequency → optical amplitude variation / switching



Reflective FBG filter



Spectral: 1.5 μ m range (1 μ m range on demand)

Frequency shift: 2+ GHz

Rise/Fall time: 800 ps

Tuning range (3 dB): approx. +/- 2 GHz

Insertion loss: approx. 9 dB

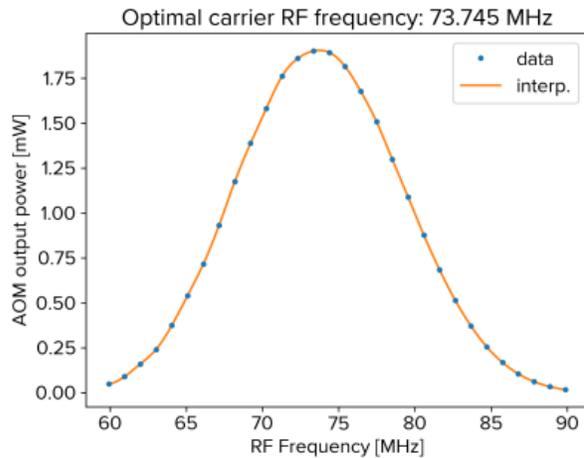
Extinction ratio: approx. 40 dB

AMOD: AOM LINECARD MODULE

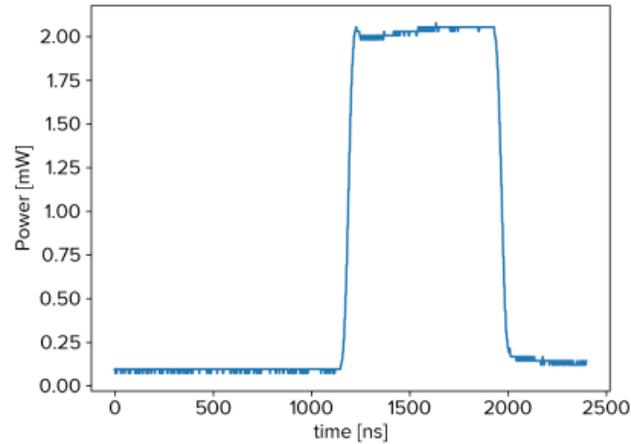


AMOD: AOM with internal RF driver in linecard module intended for modulation/control of optical power & frequency – standard AOM, but integrated in linecard module:

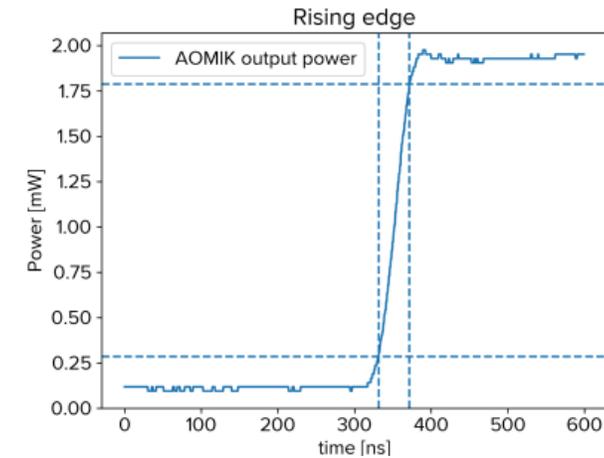
- Insertion loss: 2 dB
- Drive frequency: 70 MHz (typical – other frequencies available)
- Frequency tuning depth: 13 MHz
- Rise/fall time: 40 nsec
- Power consumption: 15-30W



Frequency response



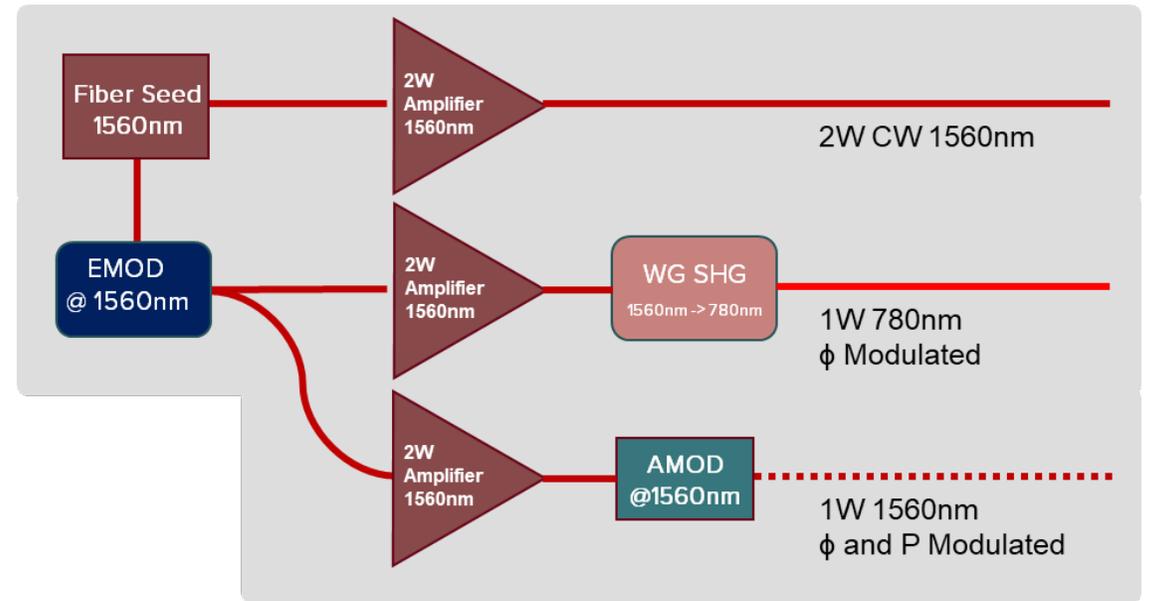
Amplitude modulation



Rise time

Summary

- DFB fiber laser: high frequency stability and other properties suited for PDV applications
- Combining ACOUSTIK card modules allows for the creation of complex, highly customised laser systems
- Compatible with BOOSTIK HP high power amplifiers
- Flexible system that can be expanded and enhanced as needed over time
- Proven high reliability
- Visit NKT Photonics booth for more info



1560nm/780nm multi-channel system example

SOLUTIONS FOR INNOVATORS