Broadband High-Power Tm- and Ho-doped ASE Sources in the 2 µm Band

Wiktor Walasik, Alexandre Amavigan, Gustavo Rivas, Adrian Zepeda

Robert E. Tench, and Jean-Marc Delavaux

wiktor.walasik@cybel-llc.com

CYBEL LLC, Bethlehem, PA, USA

Talk Outline

- **Motivation and Objectives**
- **Tm-doped non-PM ASE source ($\lambda_{center} \approx 1880$ nm)**
  - Single-stage
  - Dual-stage
- **Ho-doped PM ASE source ($\lambda_{center} \approx 2060$ nm)**
  - Single-stage
  - Dual-stage
- **Applications**
- **Conclusions**

Motivation and Objectives

Applications:

- Fiber-optic gyroscopes
- Illumination for night vision scopes & Semiconductor wafer processing
- Testing Tm- and Ho-doped fibers
- **Testing of passive optical components**

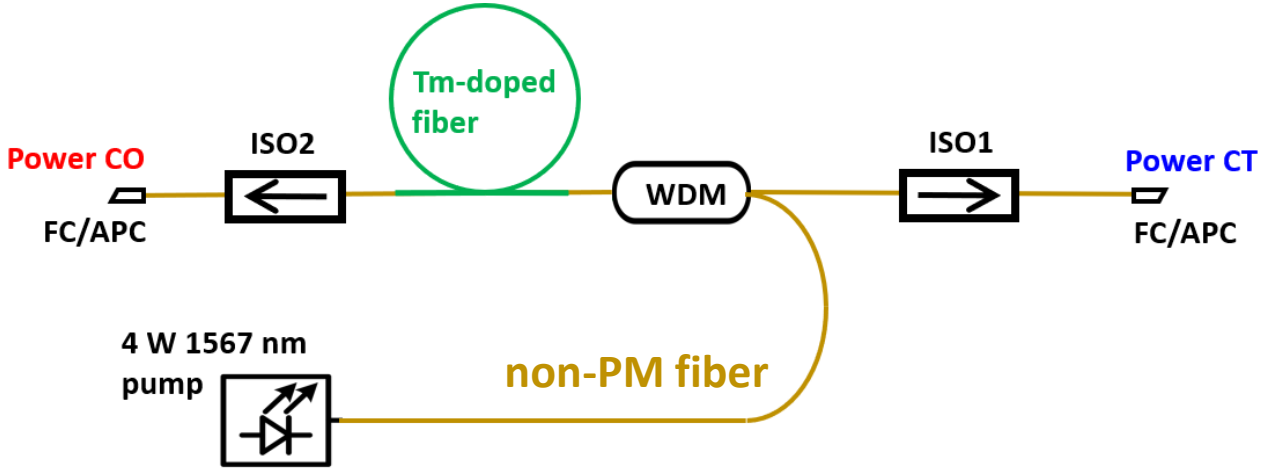
State of the art:

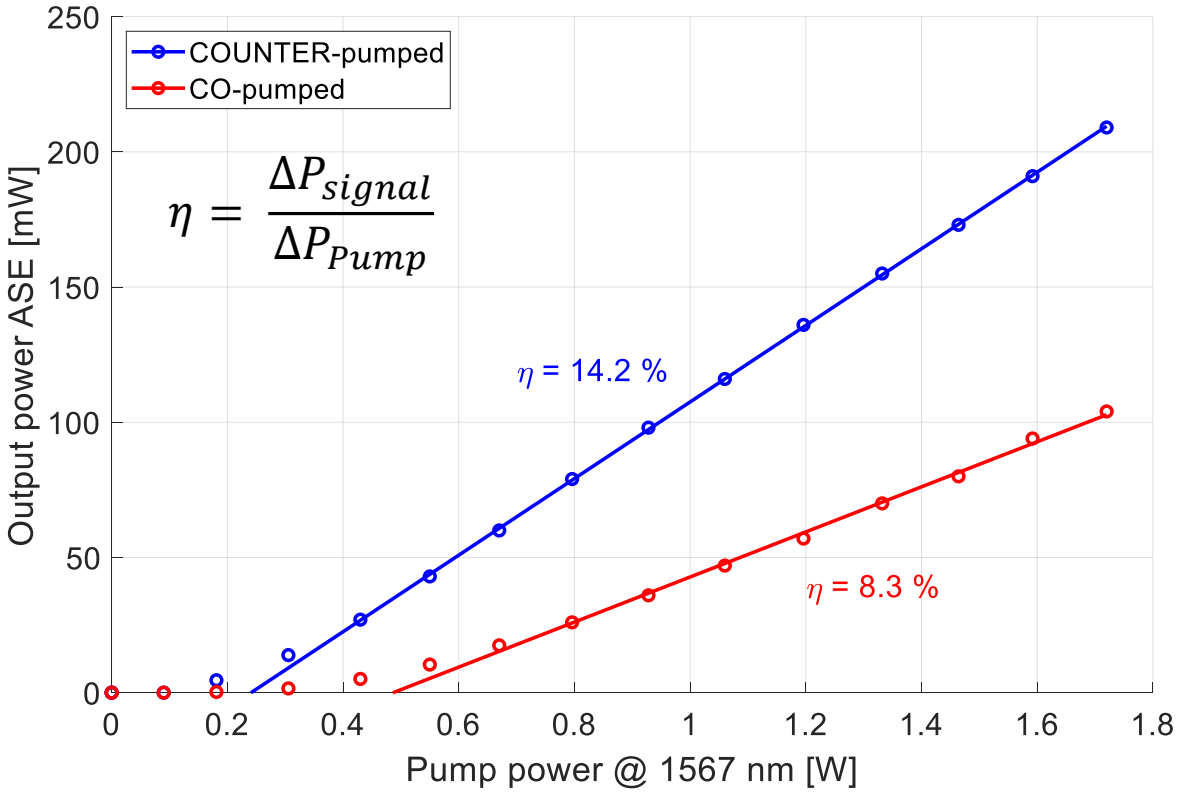
Low power ASE sources prone to self lasing

We deliver:

- High power (> 2 W) with no self lasing
- Center wavelength: 1800–2070 nm
- 20-dB bandwidth > 100 nm
- Compact, all-fiber PM or non-PM design

Single-stage Tm-doped ASE Source





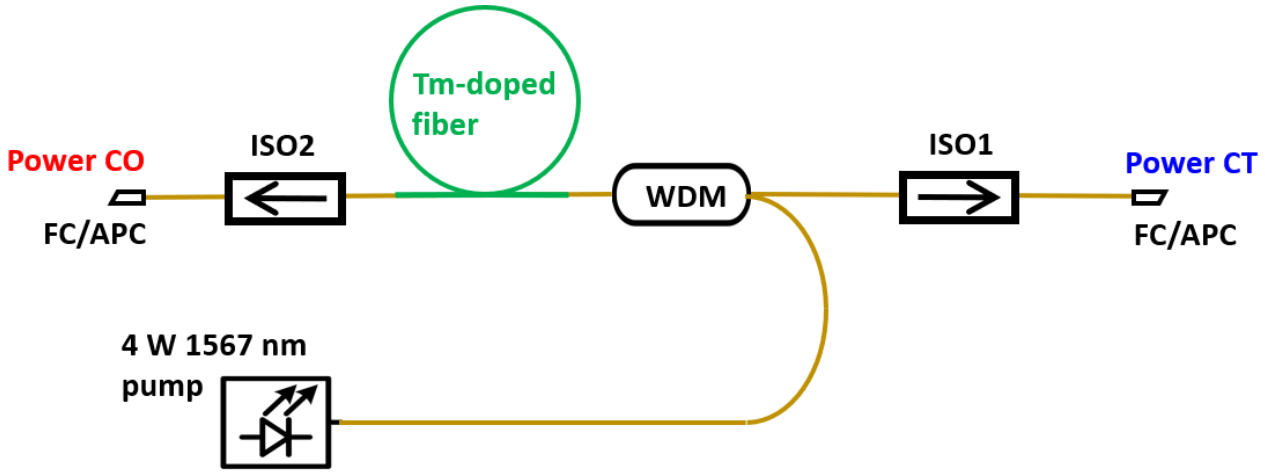
ASE source concept:

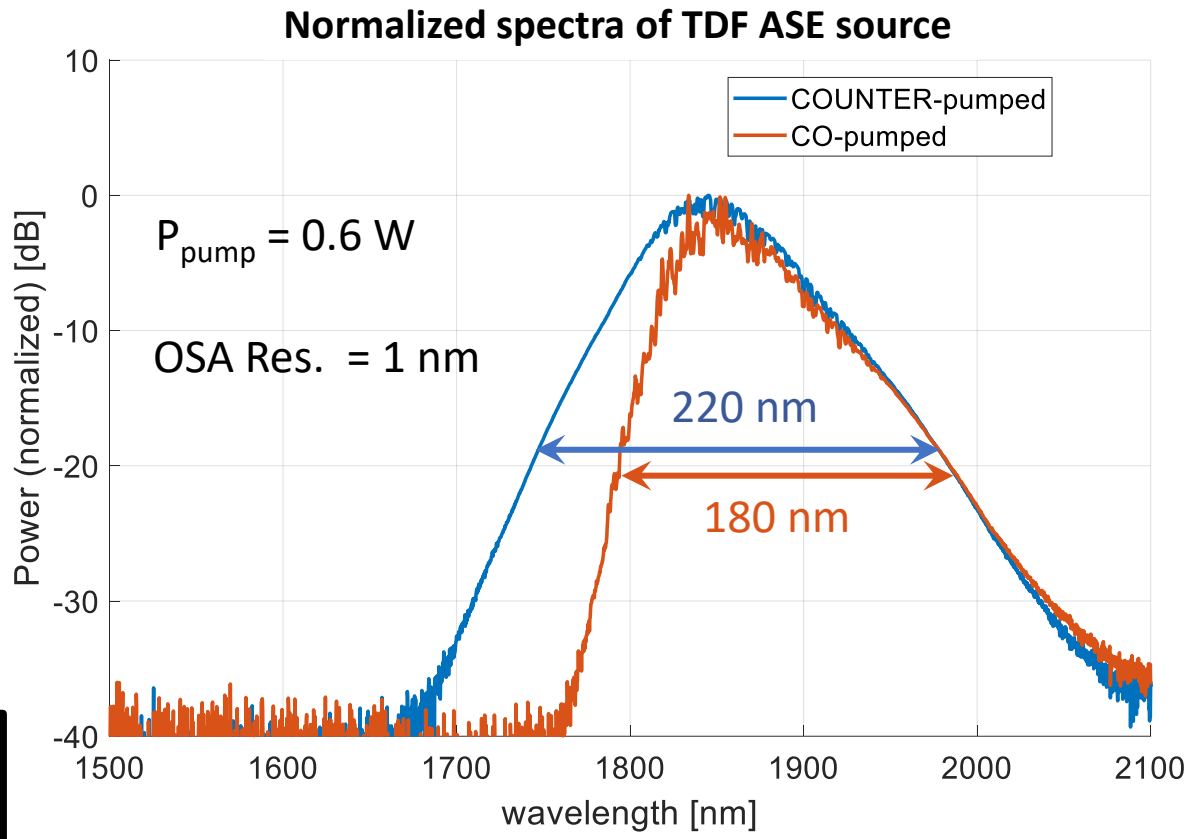
- Unseeded amplifier (typical fiber length <5 m)
- Tm-doped fiber pumped by a fiber laser at 1567 nm
- Commercially available non-PM fibers and components

Performance:

- 200 mW of ASE generated centered at 1850 nm
- Counter-pumping more efficient than co-pumping
- 14% or 8% optical-to-optical efficiencies

Single-stage TDF ASE: Spectrum

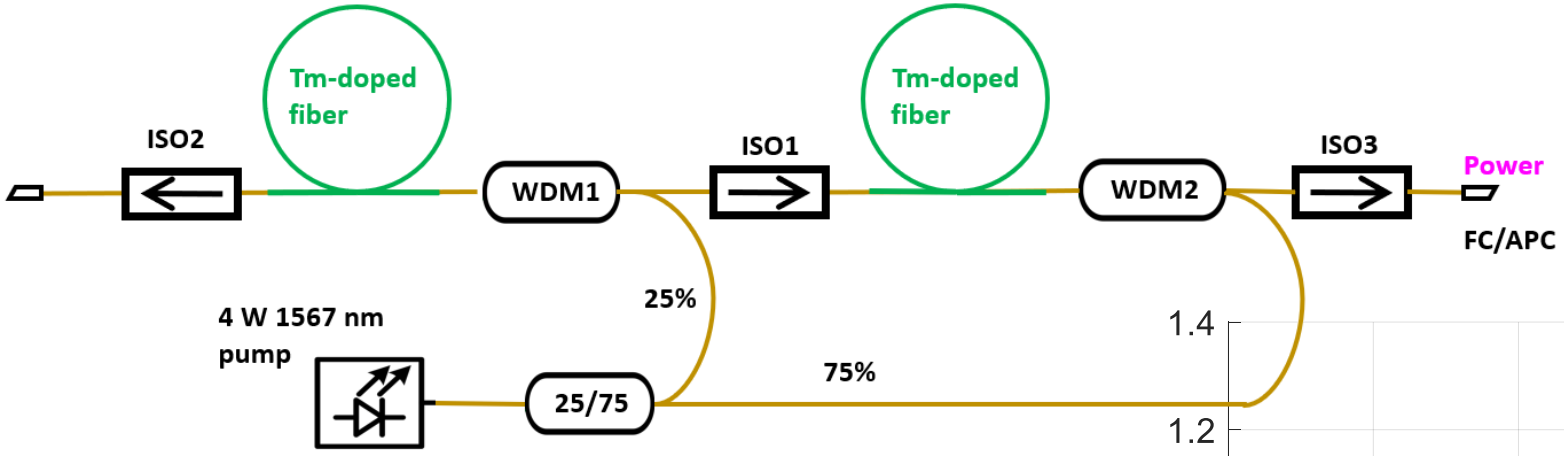




- No residual pump
- No self-lasing observed
- Co-pumped spectrum narrower due to re-absorption

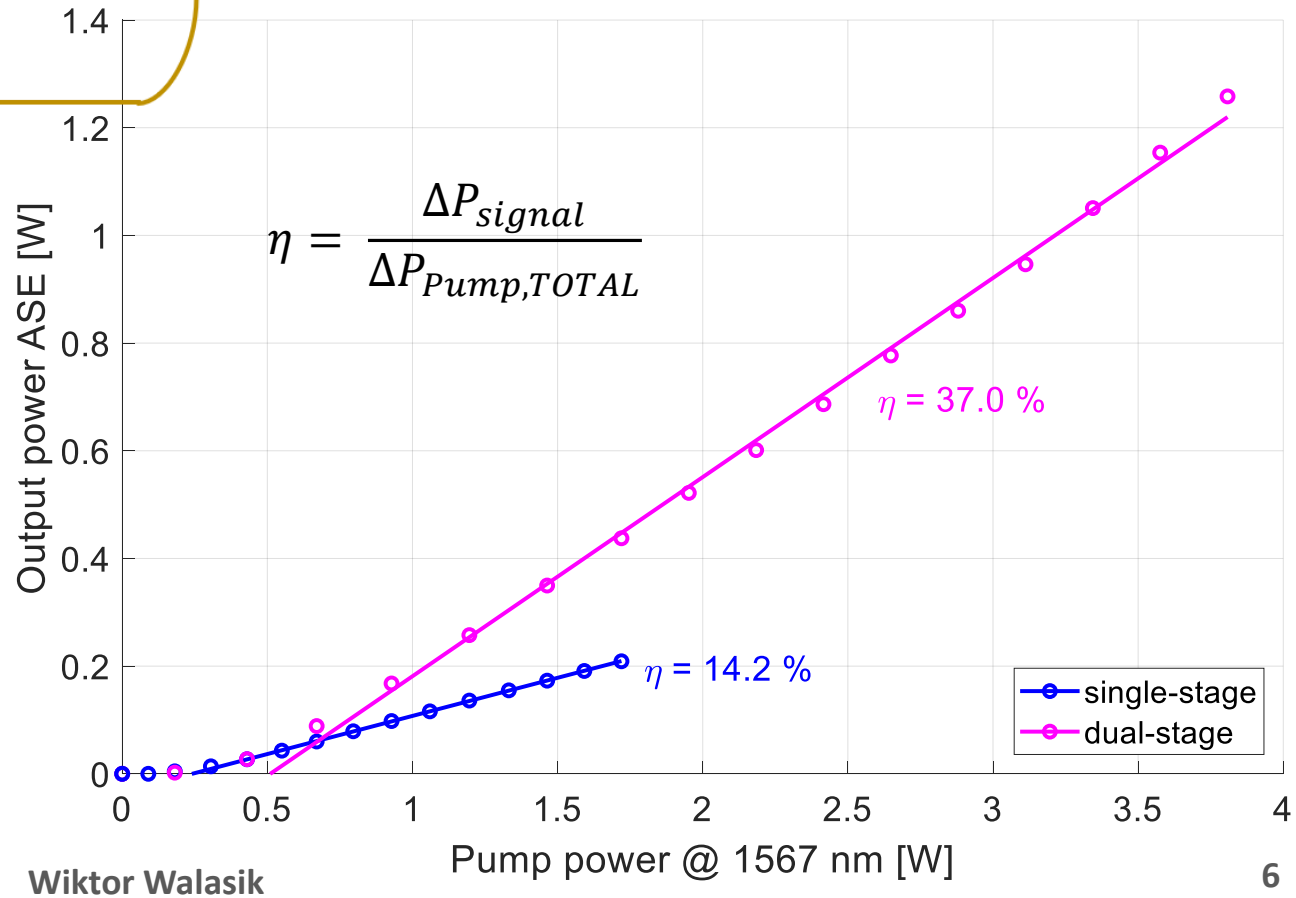
How to get more power?

Dual-stage TDF ASE Source

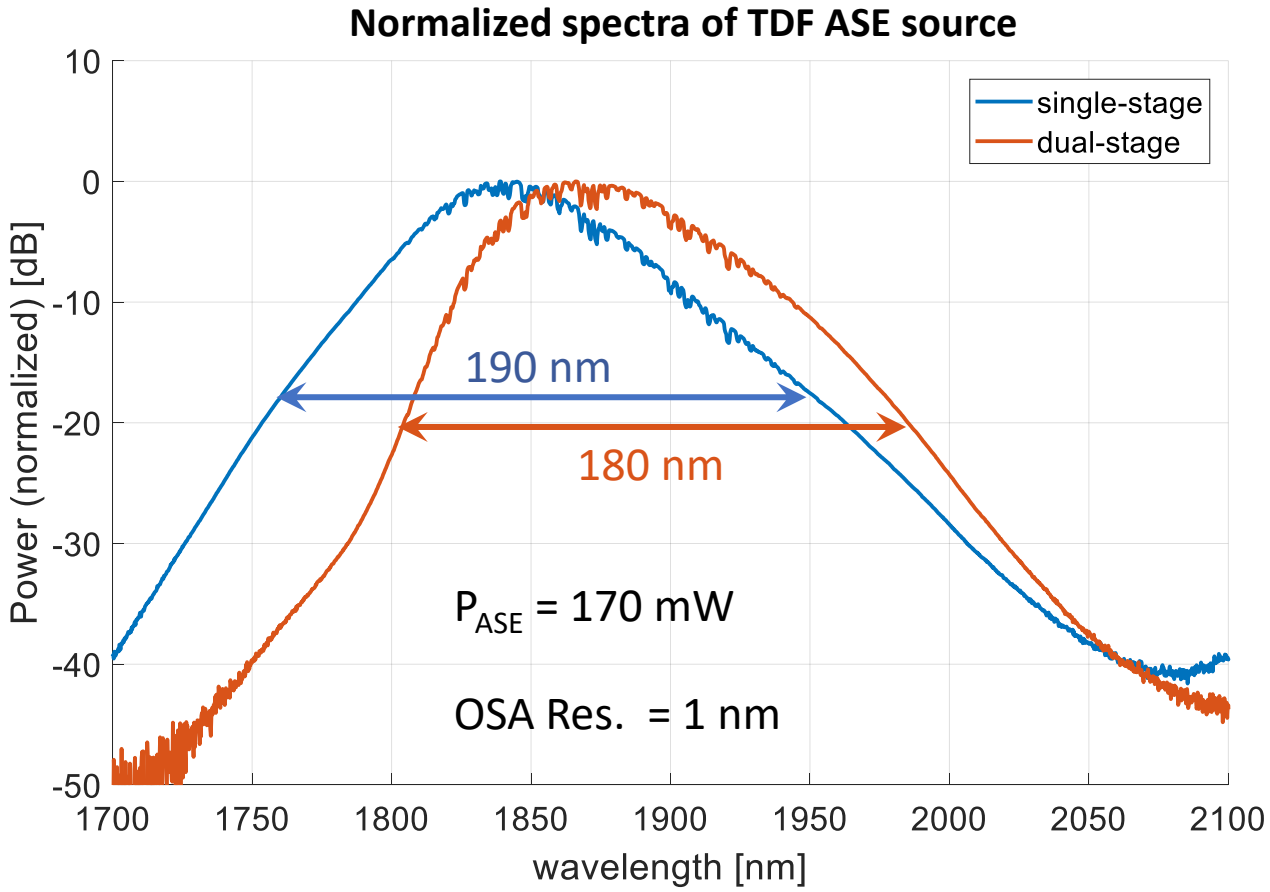


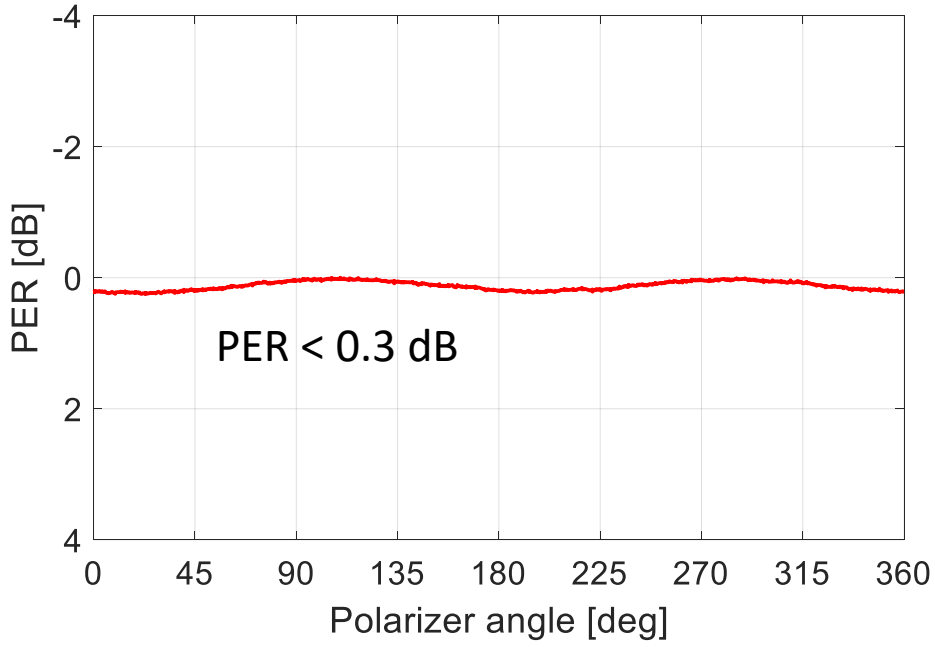
- More than 1.2 W of output power centered at 1880 nm
- Power limited by available pump power
- 37% optical-to-optical efficiency

$$\eta = \frac{\Delta P_{signal}}{\Delta P_{Pump,TOTAL}}$$



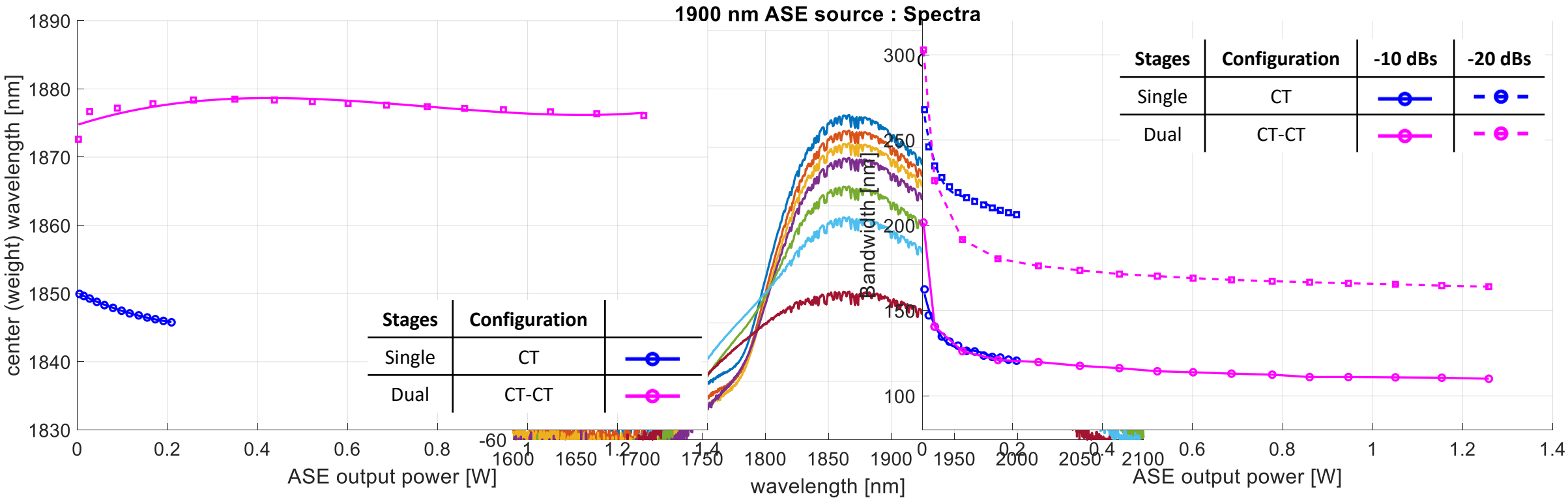
Dual-stage TDF ASE: Spectrum & PER





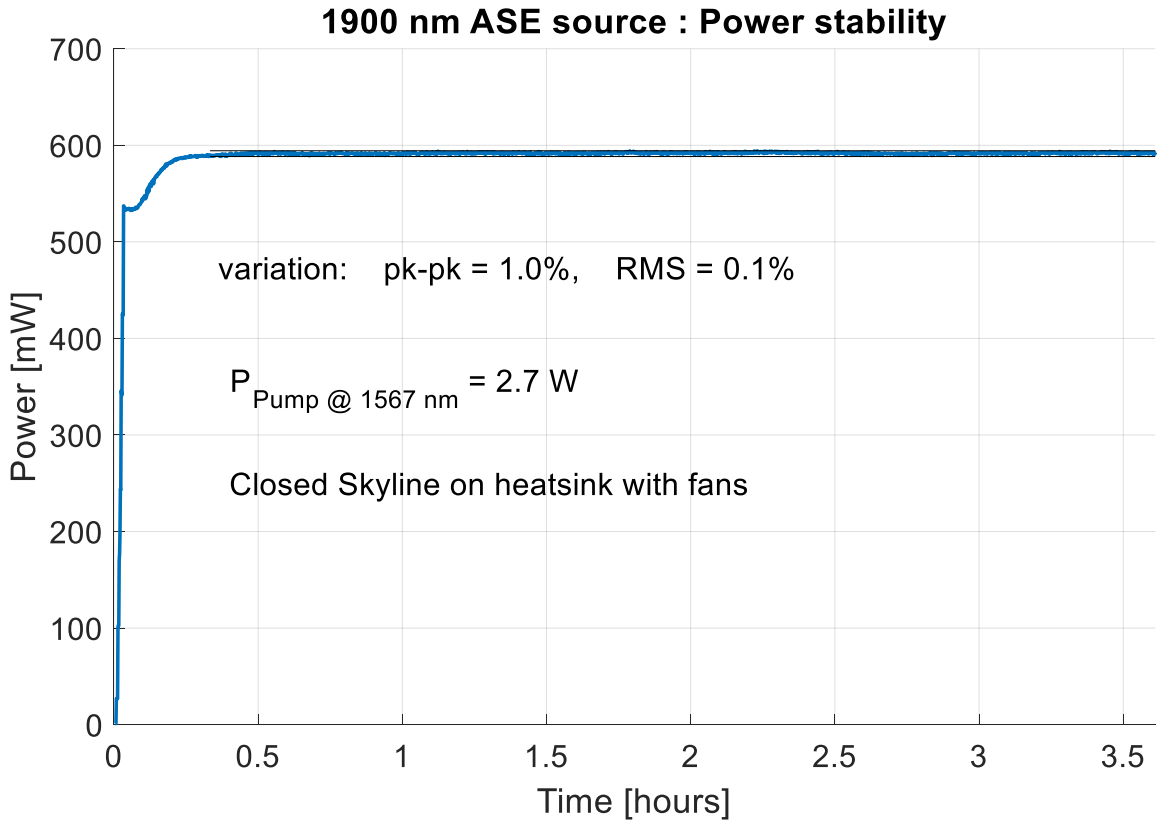
- Dual-stage spectrum red-shifted by 30 nm
- No self-lasing observed
- H_2O vapor absorption lines
- Random polarization state of the output

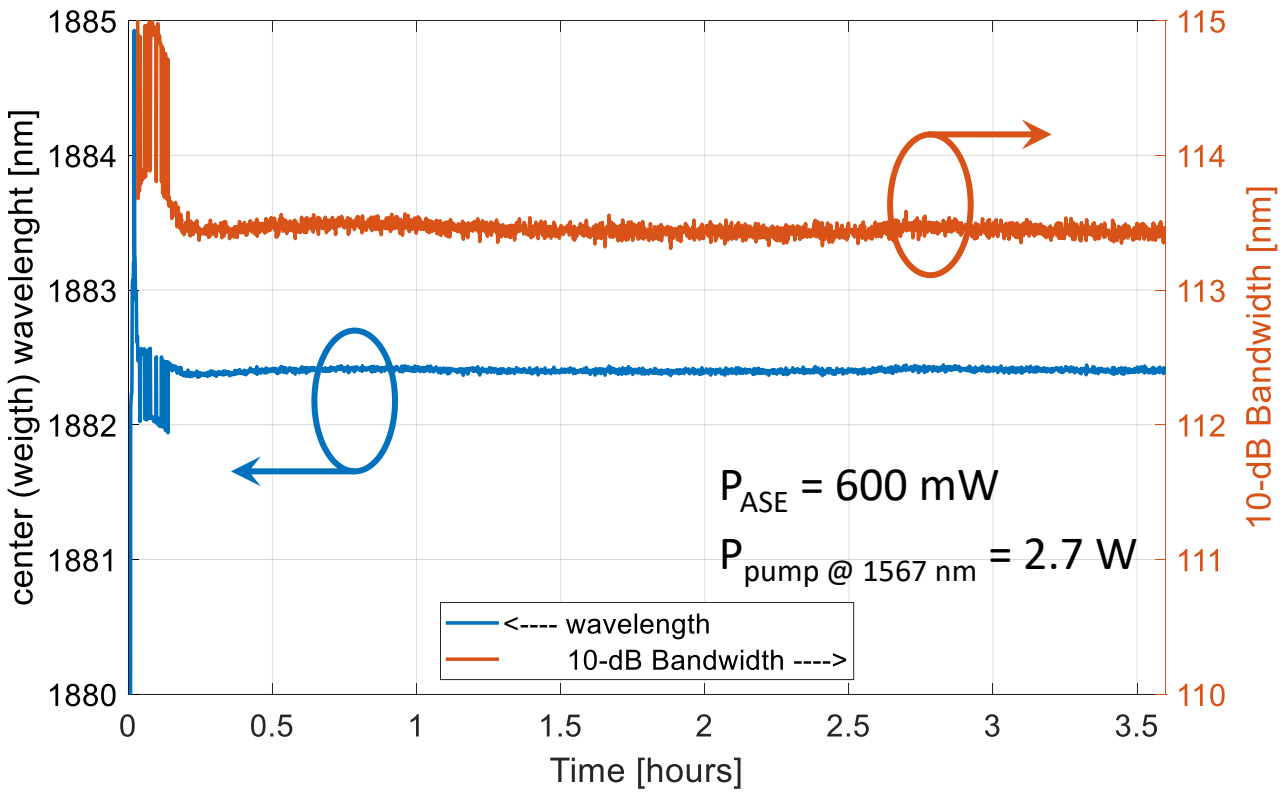
Dual-stage TDF ASE: Bandwidth



- Bandwidth decreases with increasing pump power
- Dual-stage ASE Source spectrum slightly narrower than single-stage
- -20 dBs bandwidth > 170 nm
- Center wavelength largely independent of pump power (Δλ < 10 nm)

Dual-stage TDF ASE: Stability

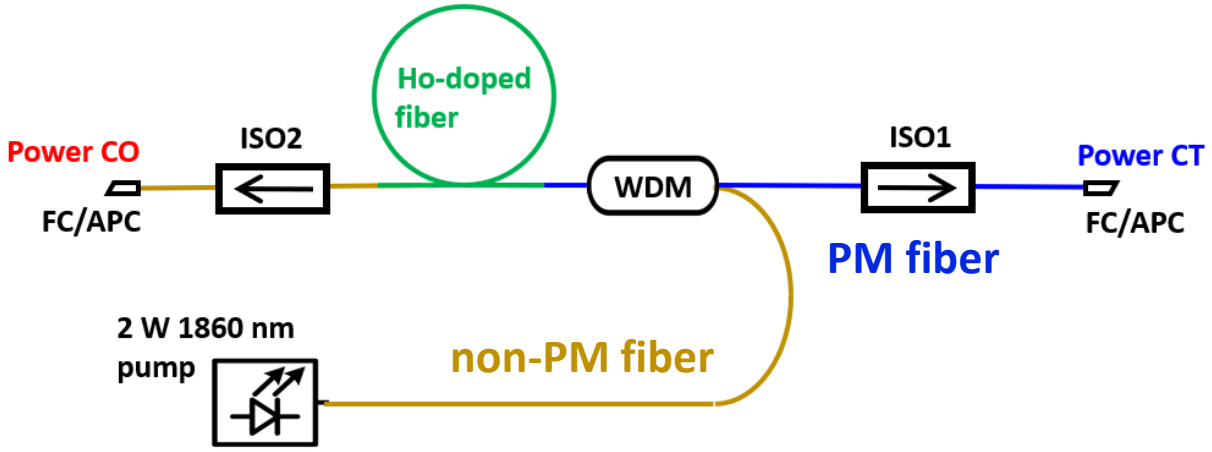


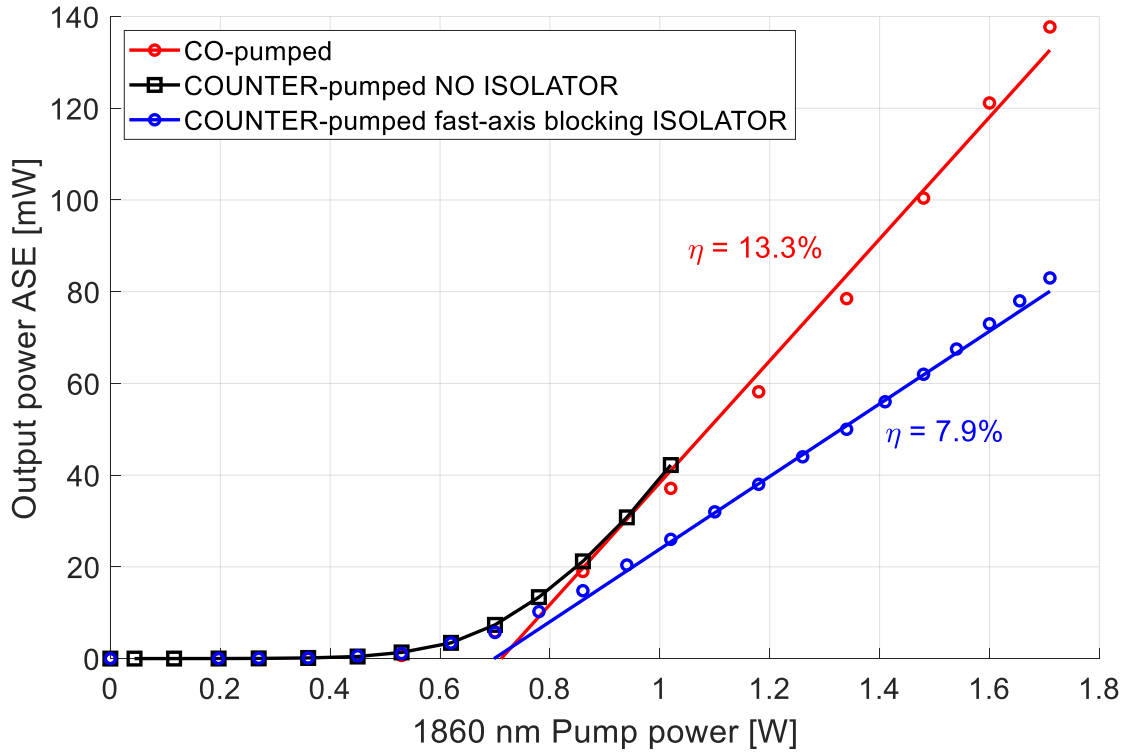


Within 3.5 hours:

- **< 1% power variation**
- **< 0.5 nm change in both center wavelength and bandwidth**

Single-stage Ho-doped ASE Source





ASE source concept:

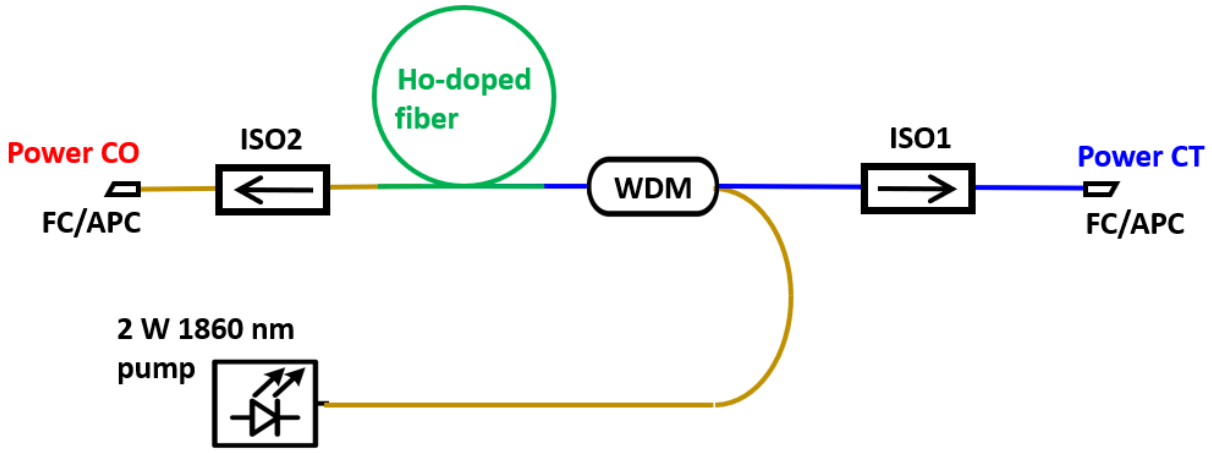
- Unseeded amplifier (typical fiber length <5 m)
- Ho-doped fiber pumped by a fiber laser at 1860 nm
- Commercially available PM fibers and components

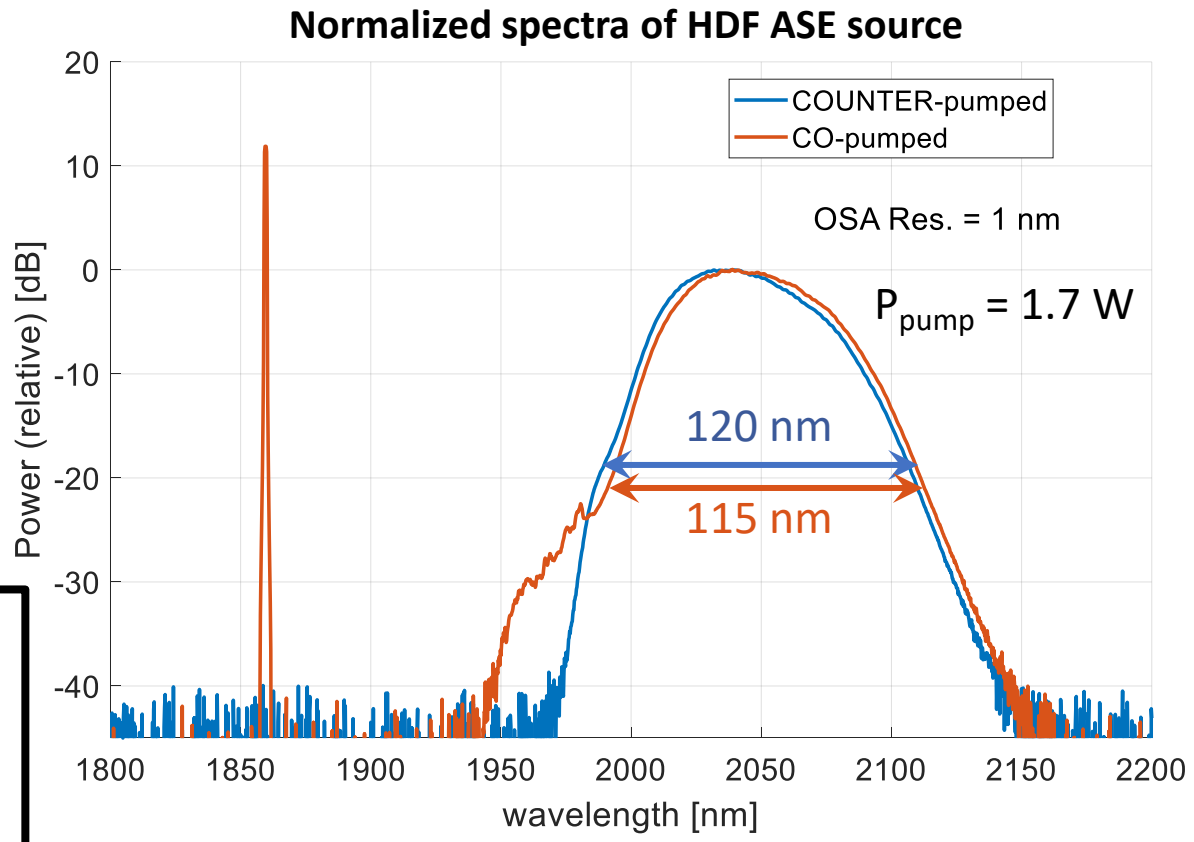
More on 1860 nm pumping efficiency:
R. E. Tench, W. Walasik, and J.-M. Delavaux
Journal of Lightwave Technology, 39, 3546 (2021)

Performance:

- 80 mW of polarized ASE generated centered at 2045 nm
- Counter- and co-pumping show similar efficiency (13%)
- 8% optical-to-optical efficiencies after PM isolator

Single-stage HDF ASE: Spectrum

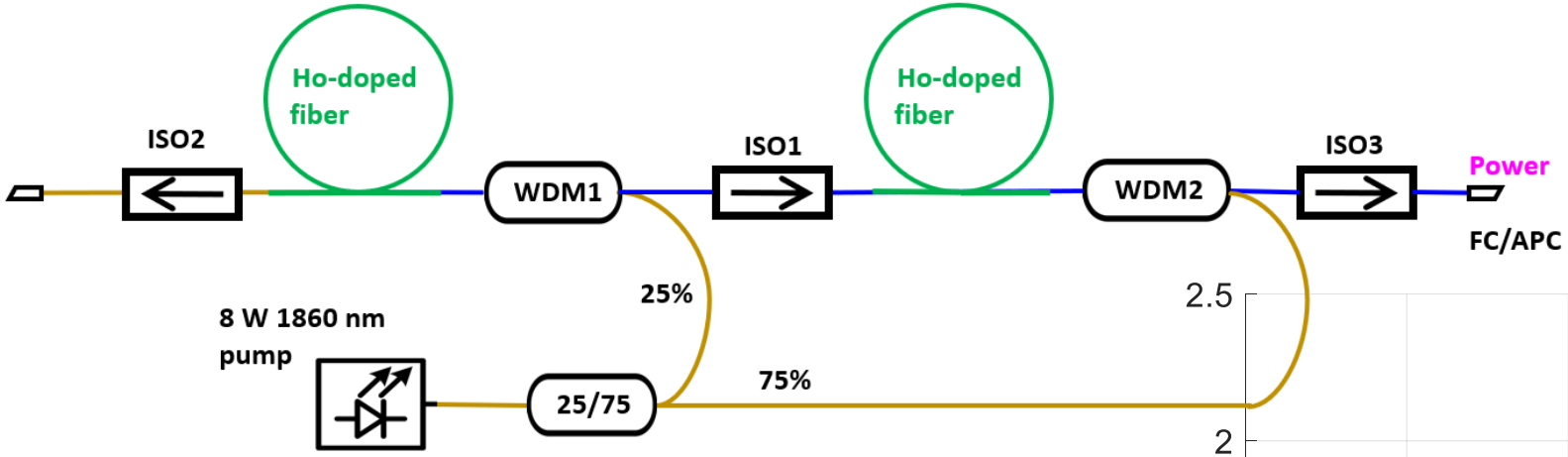




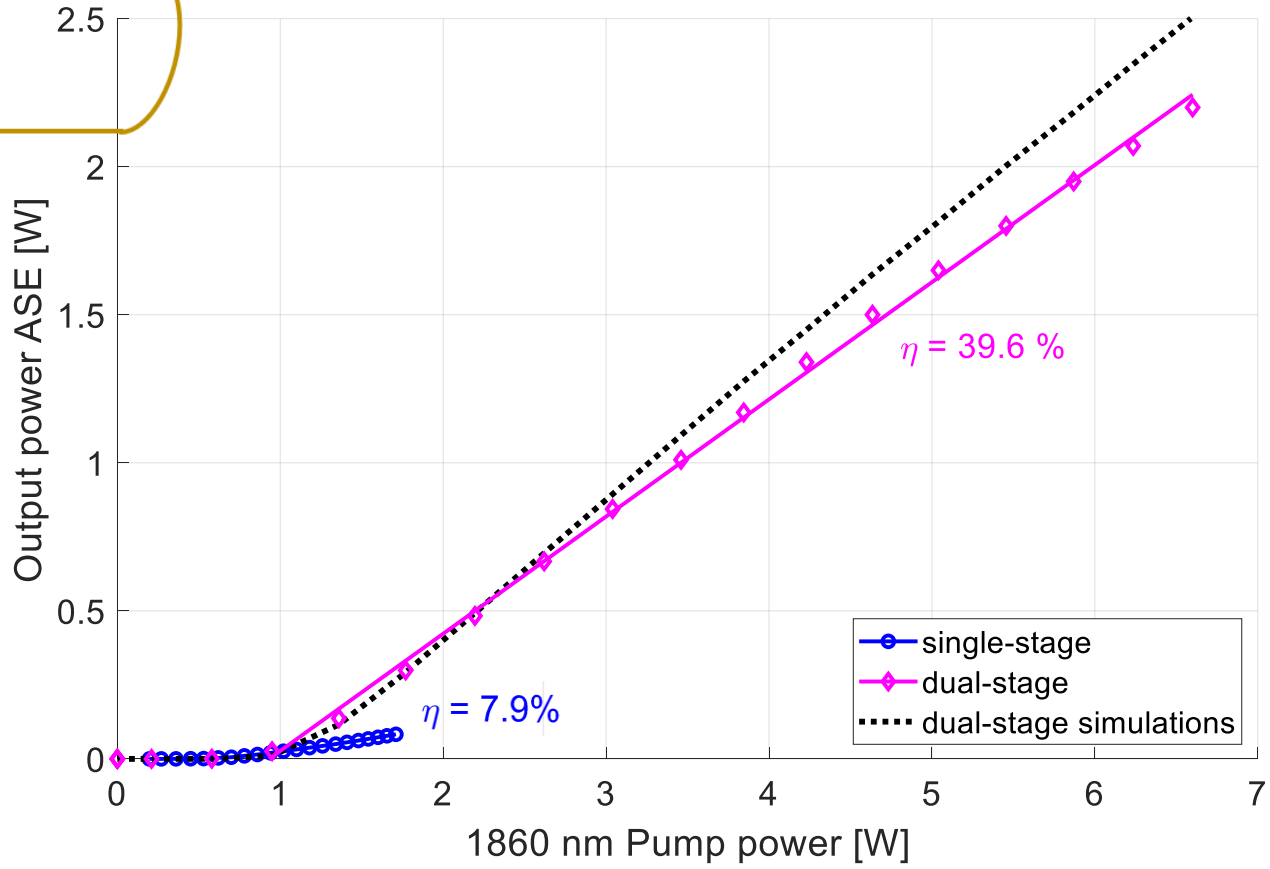
- Residual pump (≈ 20%) can be removed with a filter
- No self-lasing observed
- Similar co- and counter-pumped spectra
- Counter-pumped spectrum trimmed by filter-type WDM
- Both un-polarized and polarized outputs available

How to get more power?

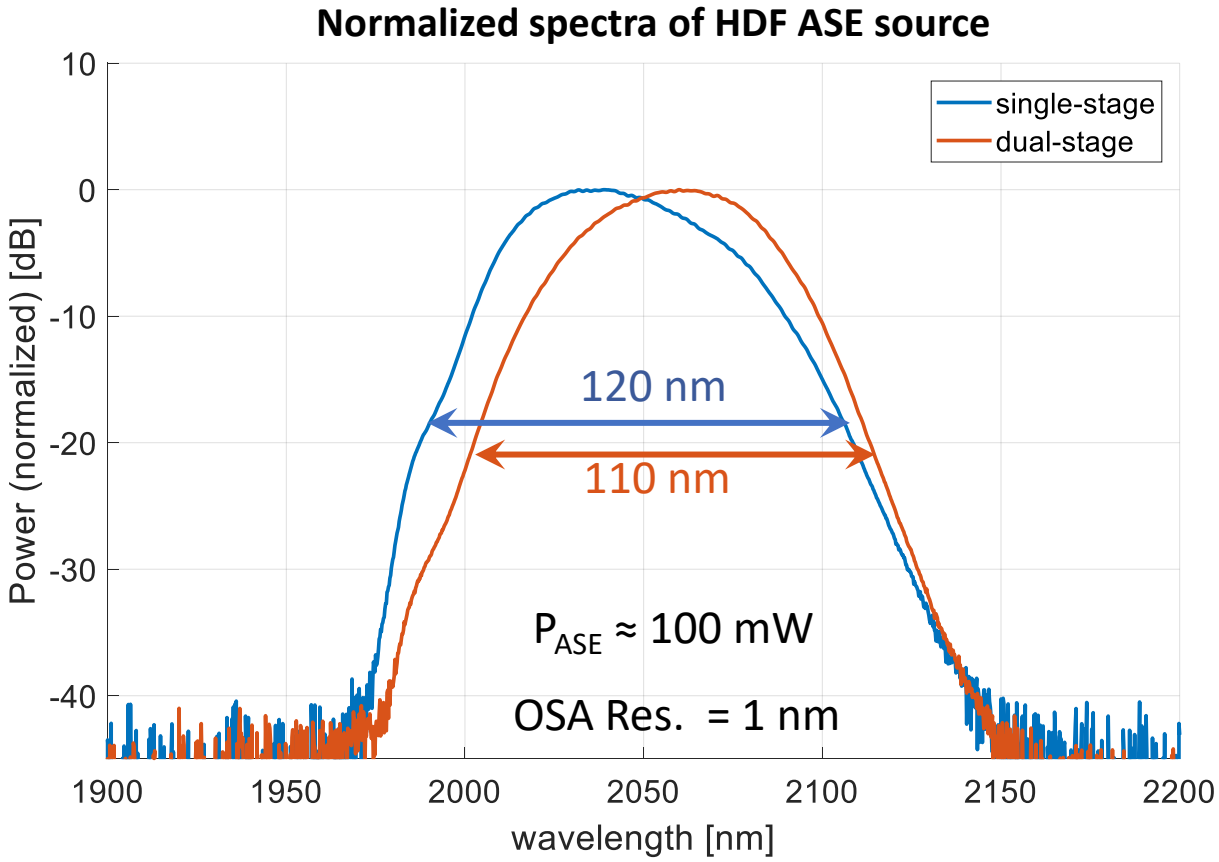
Dual-stage HDF ASE Source

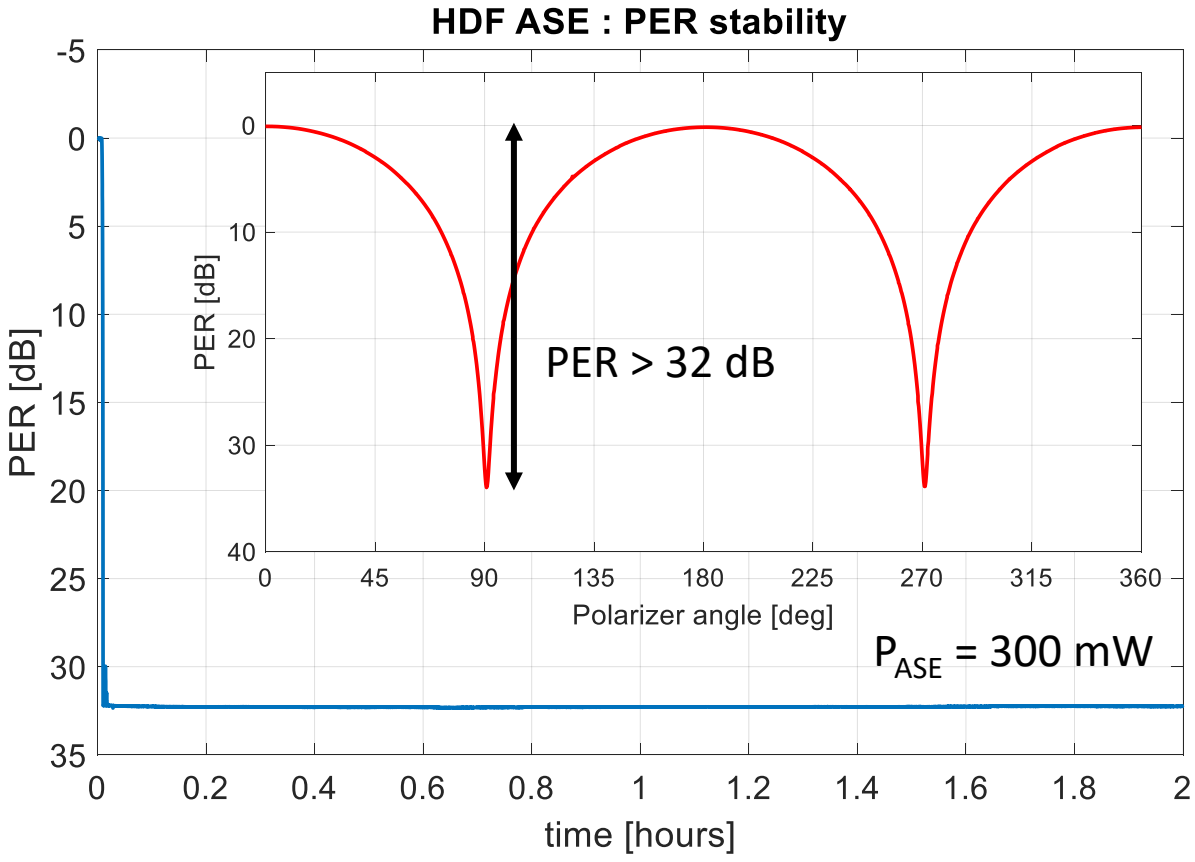


- More than 2.2 W of output power centered at 2060 nm
- 39% optical-to-optical efficiency
- Linearly polarized ASE output
- Good agreement with simulations (δP < 10%)



Dual-stage HDF ASE: Spectrum & PER

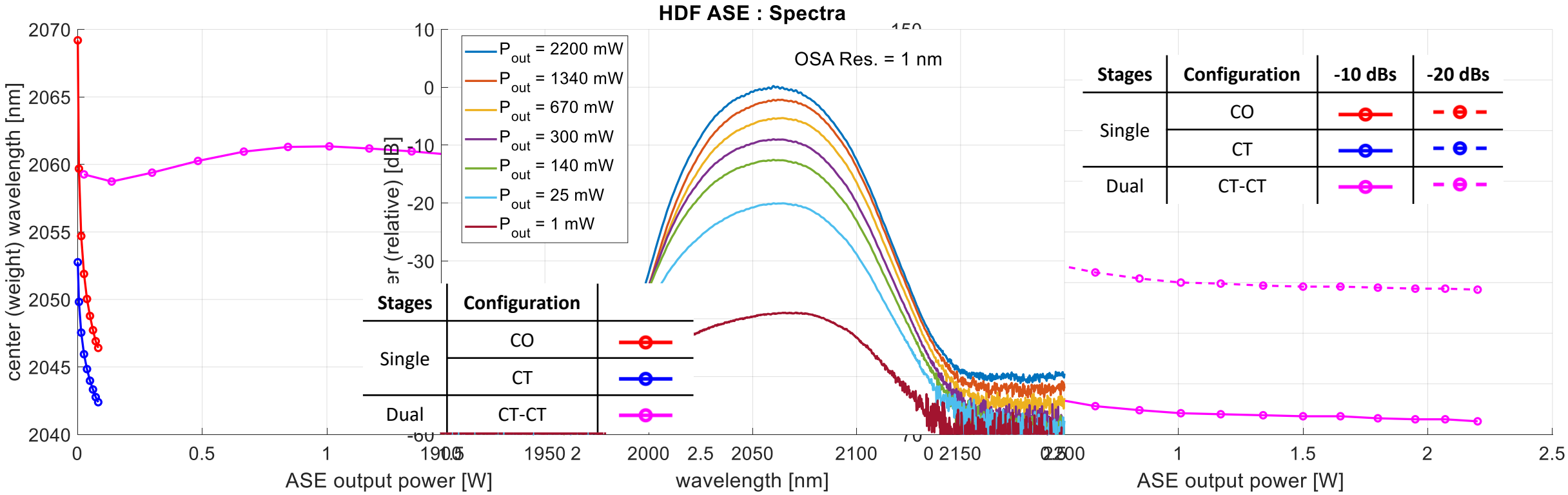




Dual-stage spectrum red-shifted by 20 nm

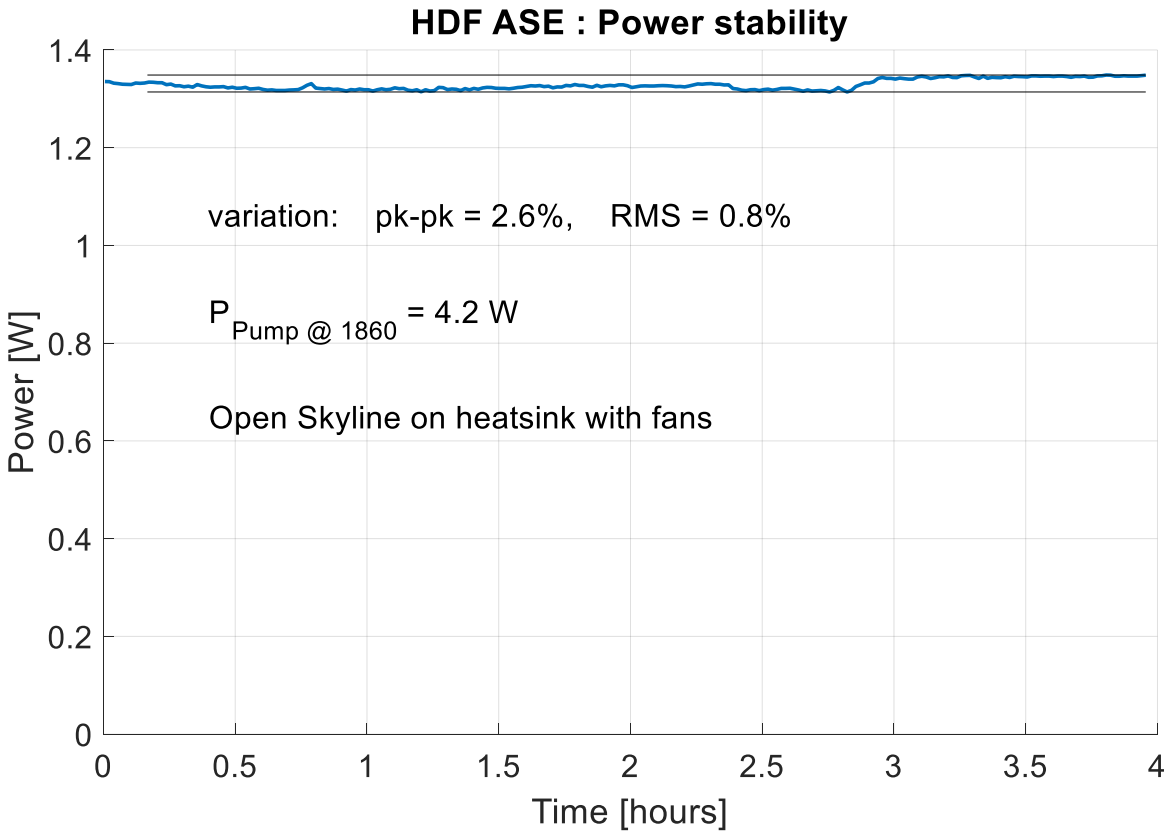
Excellent PER > 32 dB with ultimate stability

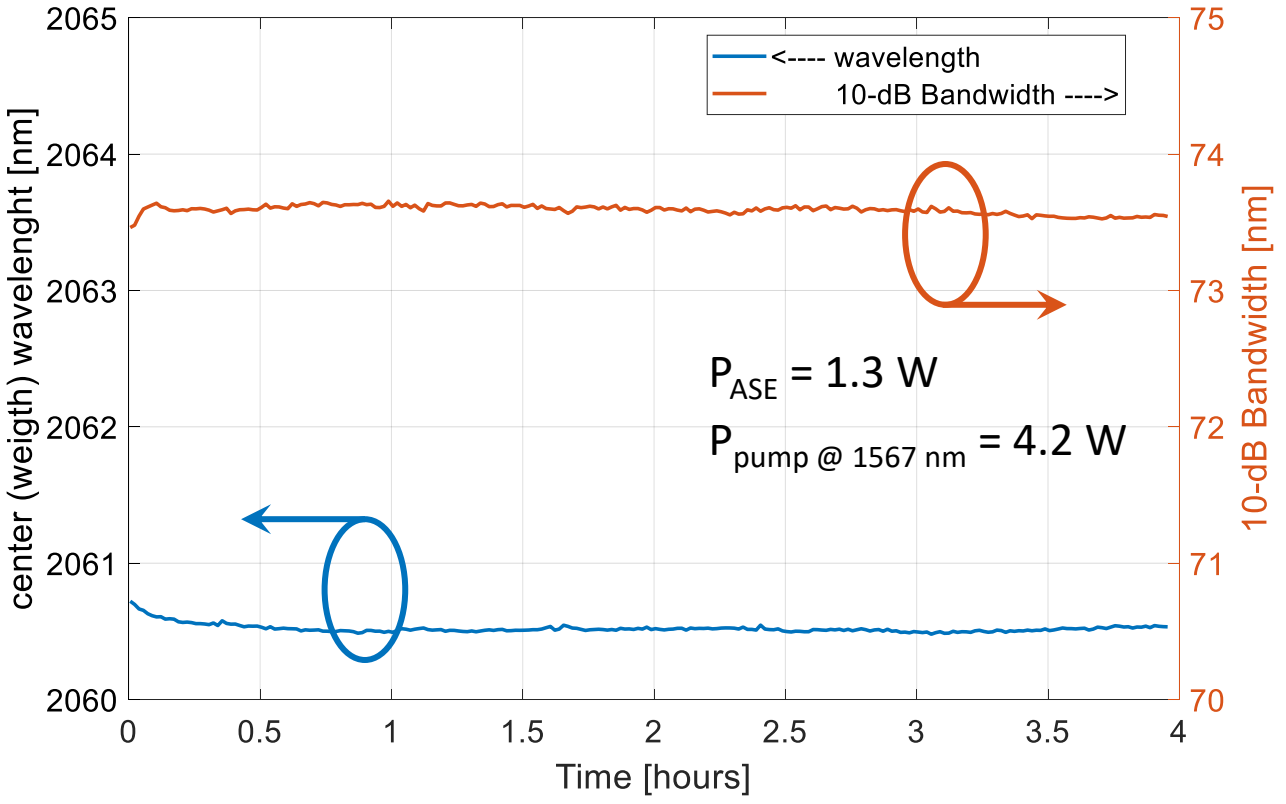
Dual-stage HDF ASE: Bandwidth



- **Bandwidth decreases with increasing pump power**
- **Dual-stage ASE Source spectrum narrower than single-stage**
- **-20 dBs bandwidth ≈ 100 nm**
- **Dual-stage center wavelength largely independent of pump power (Δλ < 5 nm)**

Dual-stage HDF ASE: Stability



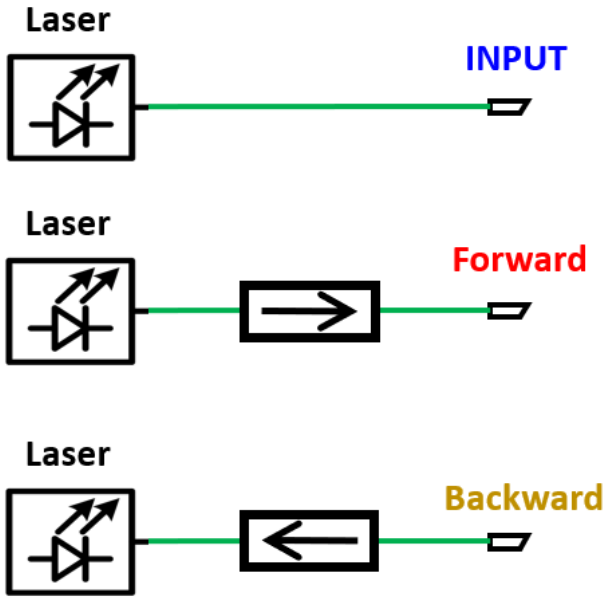


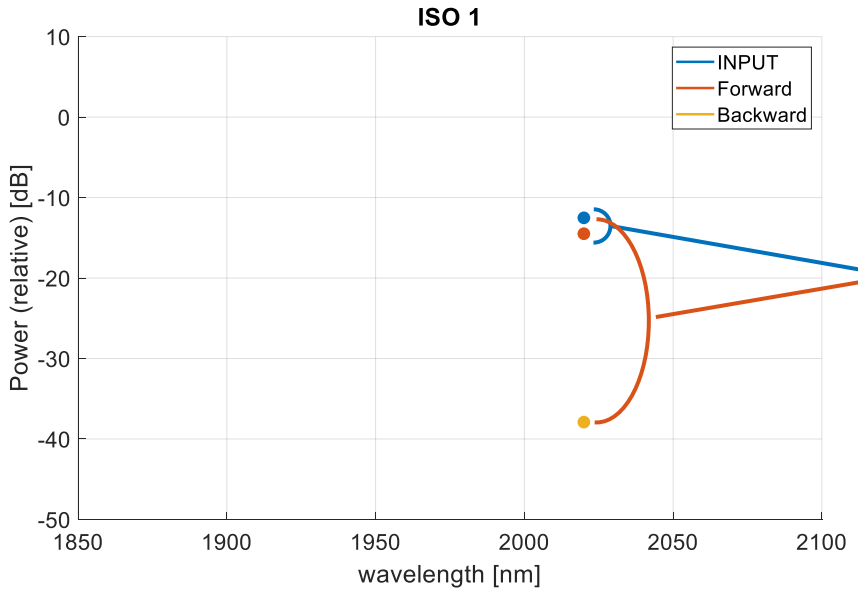
Within 4 hours:

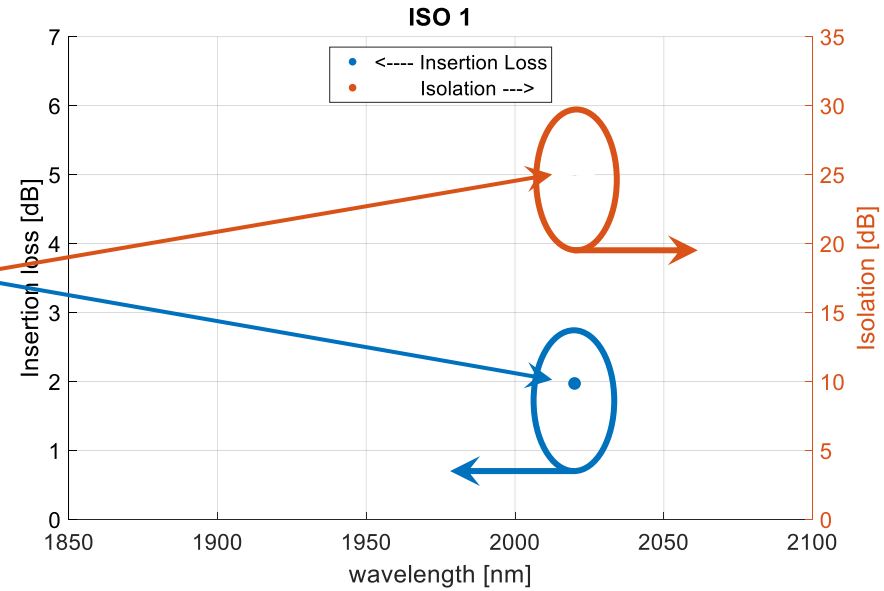
- **< 3% power variation**
- **< 0.5 nm change in both center wavelength and bandwidth**

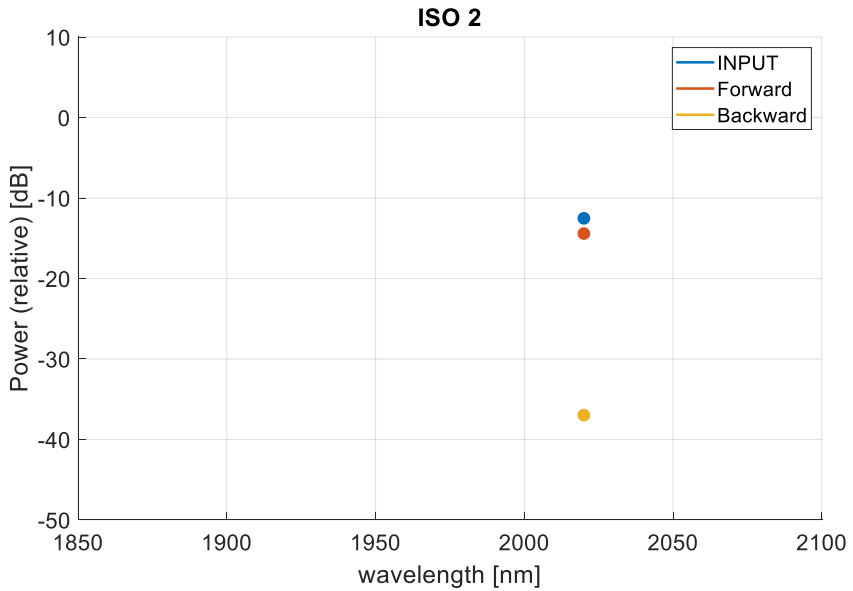
Component qualification: monochromatic source

2020 nm monochromatic laser source



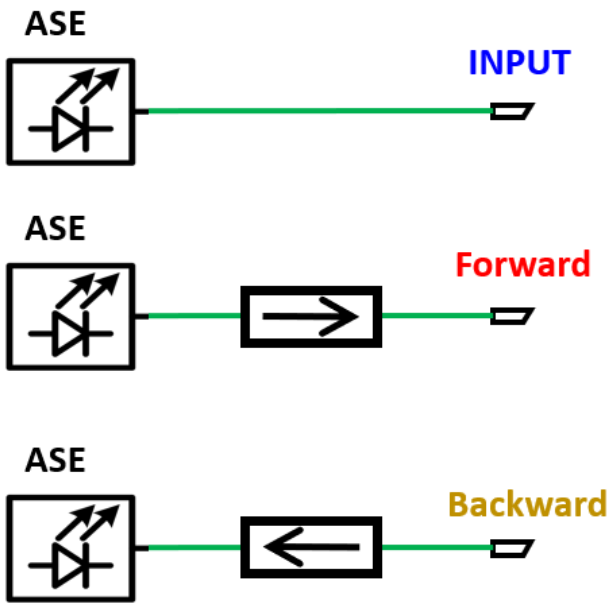


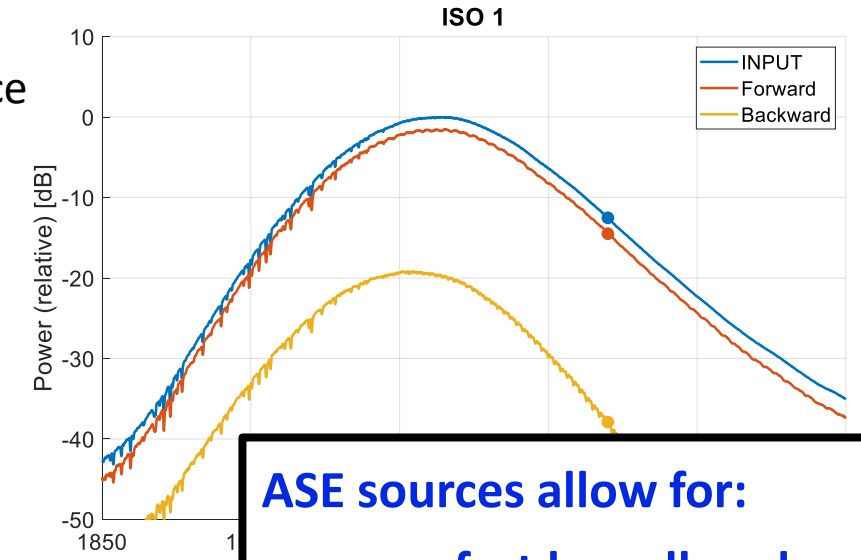


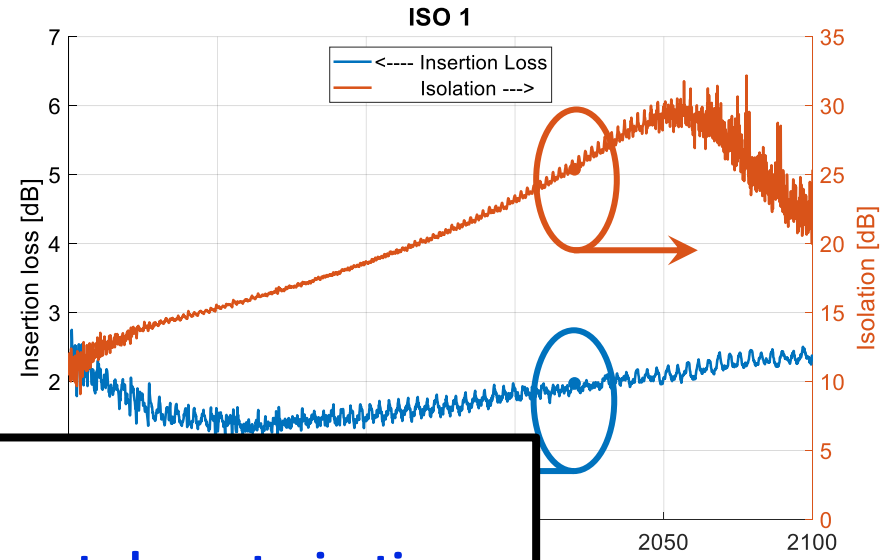


Component qualification: ASE

Low power, single stage ASE source
5m DC THF pumped at 793 nm

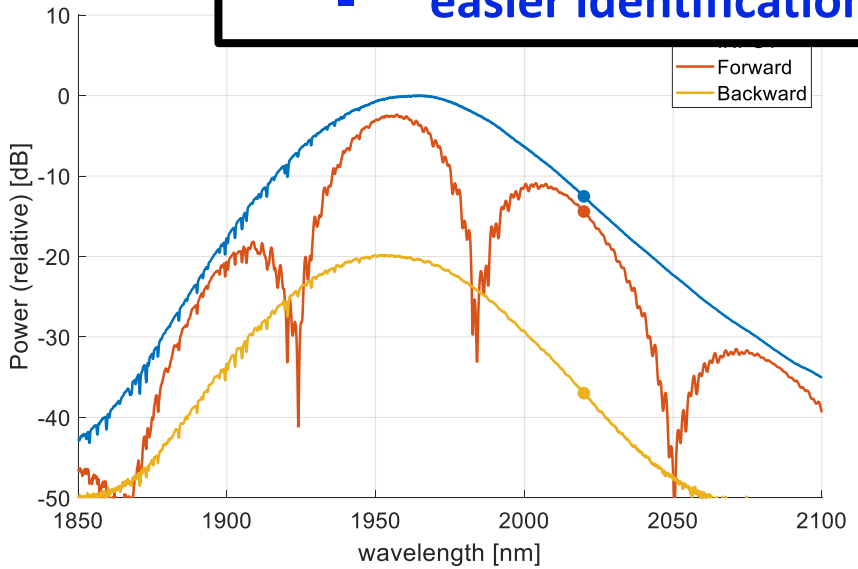


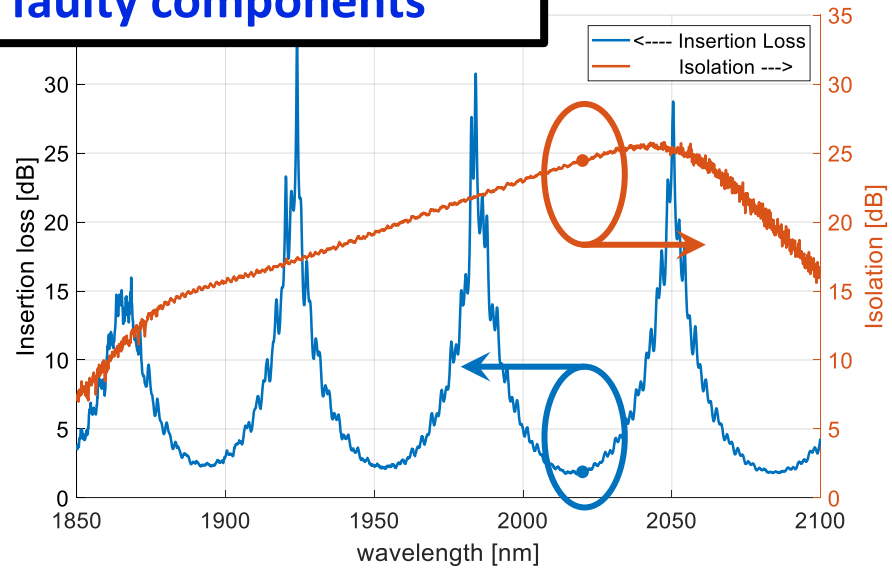




ASE sources allow for:

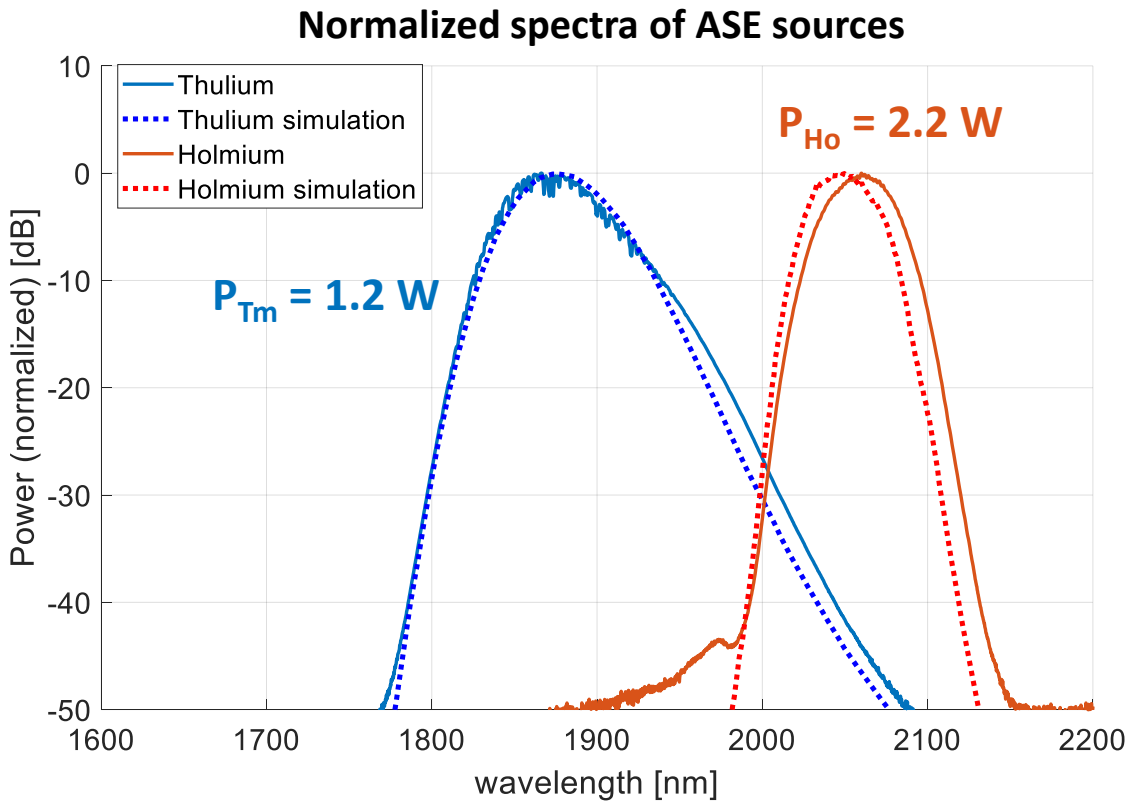
- fast broadband component characterization
- easier identification of faulty components





Conclusions

Fiber	Topology	Power [W]	λ_{center} [nm]	BW_{-20dBs} [nm]
Thulium	CO	0.10	1865	180
	CT	0.20	1850	220
	CT-CT	**1.20**	1880	**170**
Holmium	CO	0.14	2050	115
	CT (PM)	0.08	2045	120
	CT-CT (PM)	**2.20**	2060	**100**



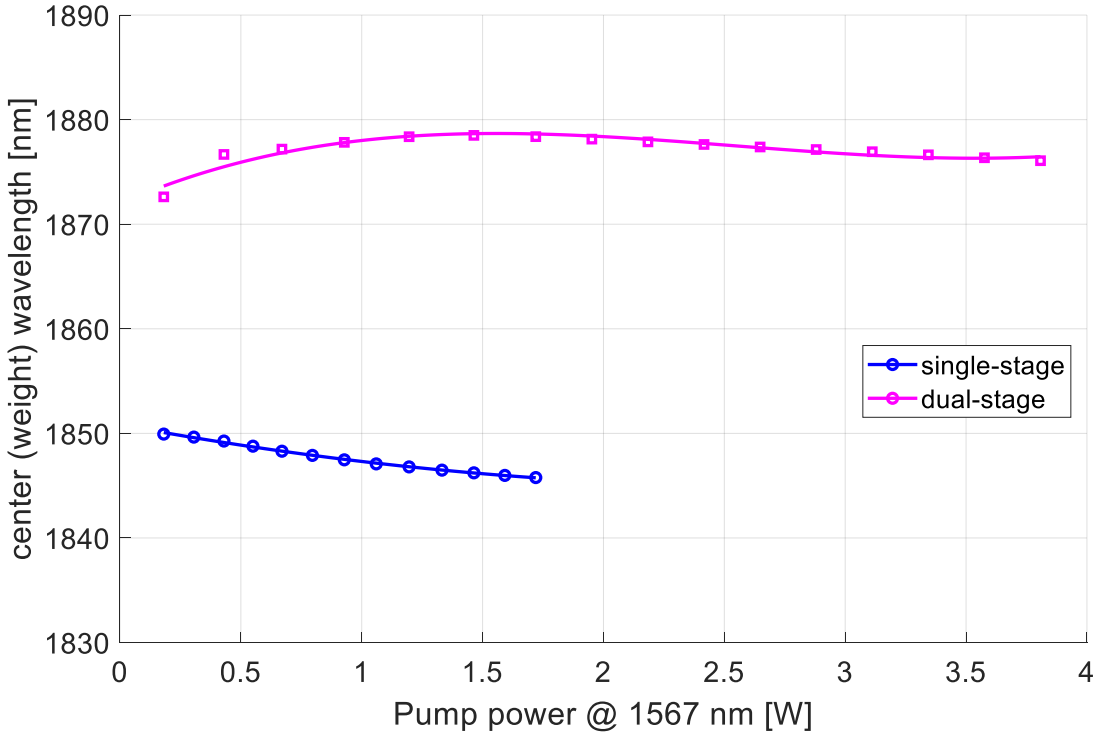
ASE sources for 2 µm band:

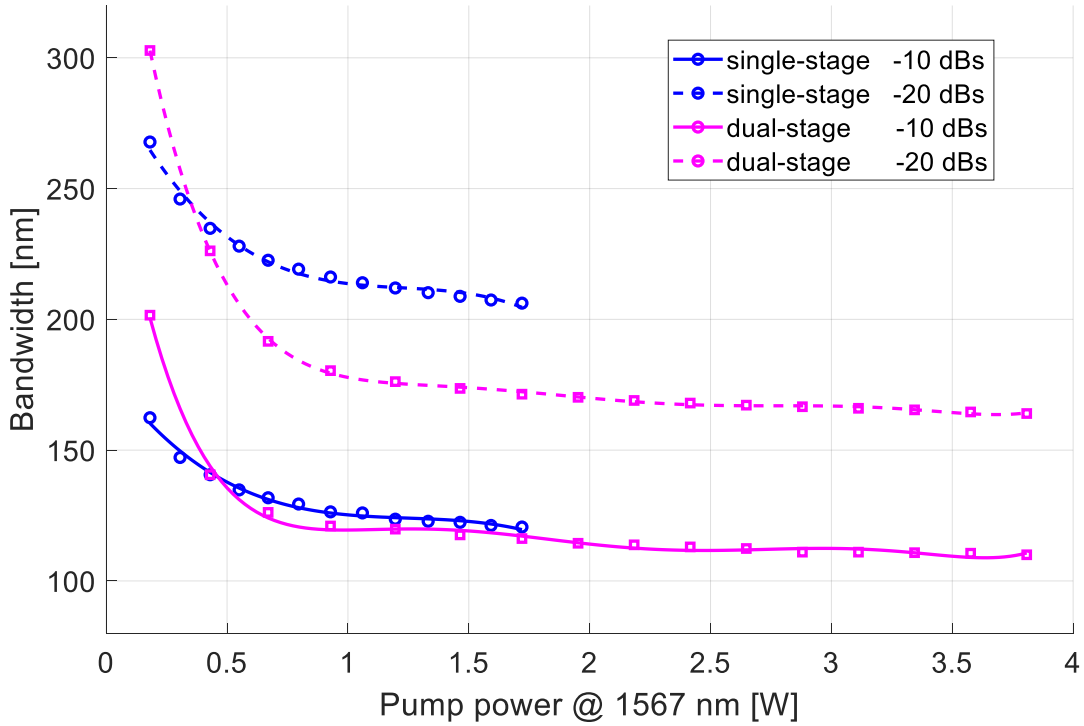
- More than 1 W of broadband output power
- Great power and spectral stability
- Available with random or linear polarization
- Power and spectrum optimized by simulations

CYBEL offers NIR- and MID-IR ASE sources centered between 1800 and 2070 nm

Thank you for your attention

Dual-stage TDF ASE: Bandwidth





Dual-stage HDF ASE: Bandwidth