Swept Wavelength Interferometry

OFC 2023 Hackathon

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Swept Wavelength Interferometry

Building an Optical Vector Network Analyzer

What is an optical vector network analyzer (OVNA)?

- How it works

What can you measure?

Breaking it down – what parts do you need?

Assembly

https://lunainc.com/product/ova-5100

Swept Wavelength Interferometry

Optical Vector Network Analyzer

What is an optical vector network analyzer (OVNA)?

- Device able to perform complete polarization-resolved characterization of optical components

What can an OVNA measure?

- Insertion loss
- Group delay
- Chromatic dispersion
- Polarization dependent loss and mode dispersion
- Min/Max loss
- Rayleigh backscatter

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Building an Optical Vector Network Analyzer (OVNA)

Breaking it down – what do we need to build it?

Polarization Multiplexer

Tunable Swept Laser

Polarization-diverse Receiver

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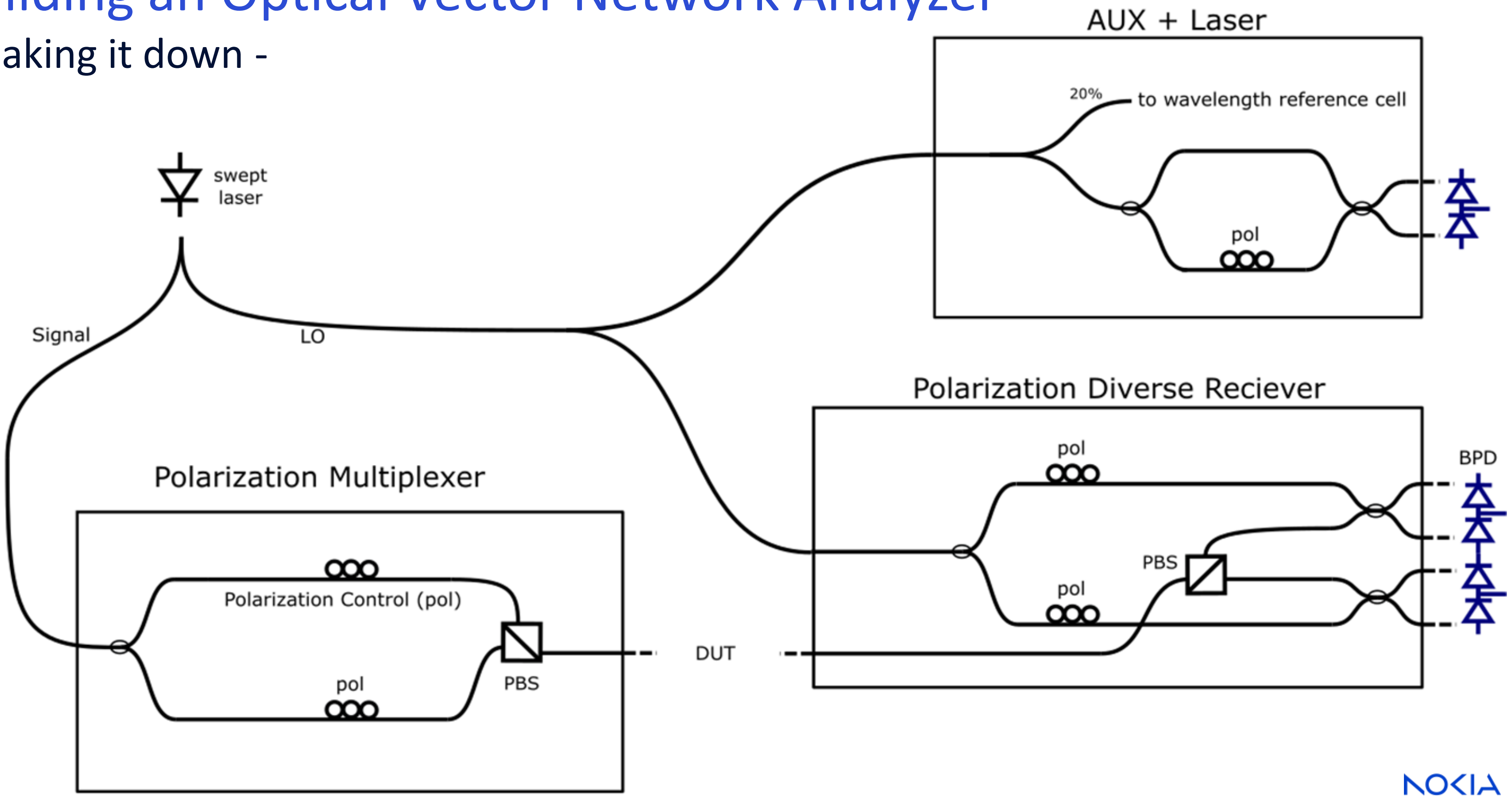
Building an Optical Vector Network Analyzer

Breaking it down -



Assembly

Gathering the Pieces

Optics

- Tunable laser source
- Polarization controllers
- Polarization beam splitters
- Couplers
- Wavelength reference cell

Electronics

- Digital to analog converter
- Digitizer
- Computer

Python Exercise

- Write a user interface
- Collect data and analyze!

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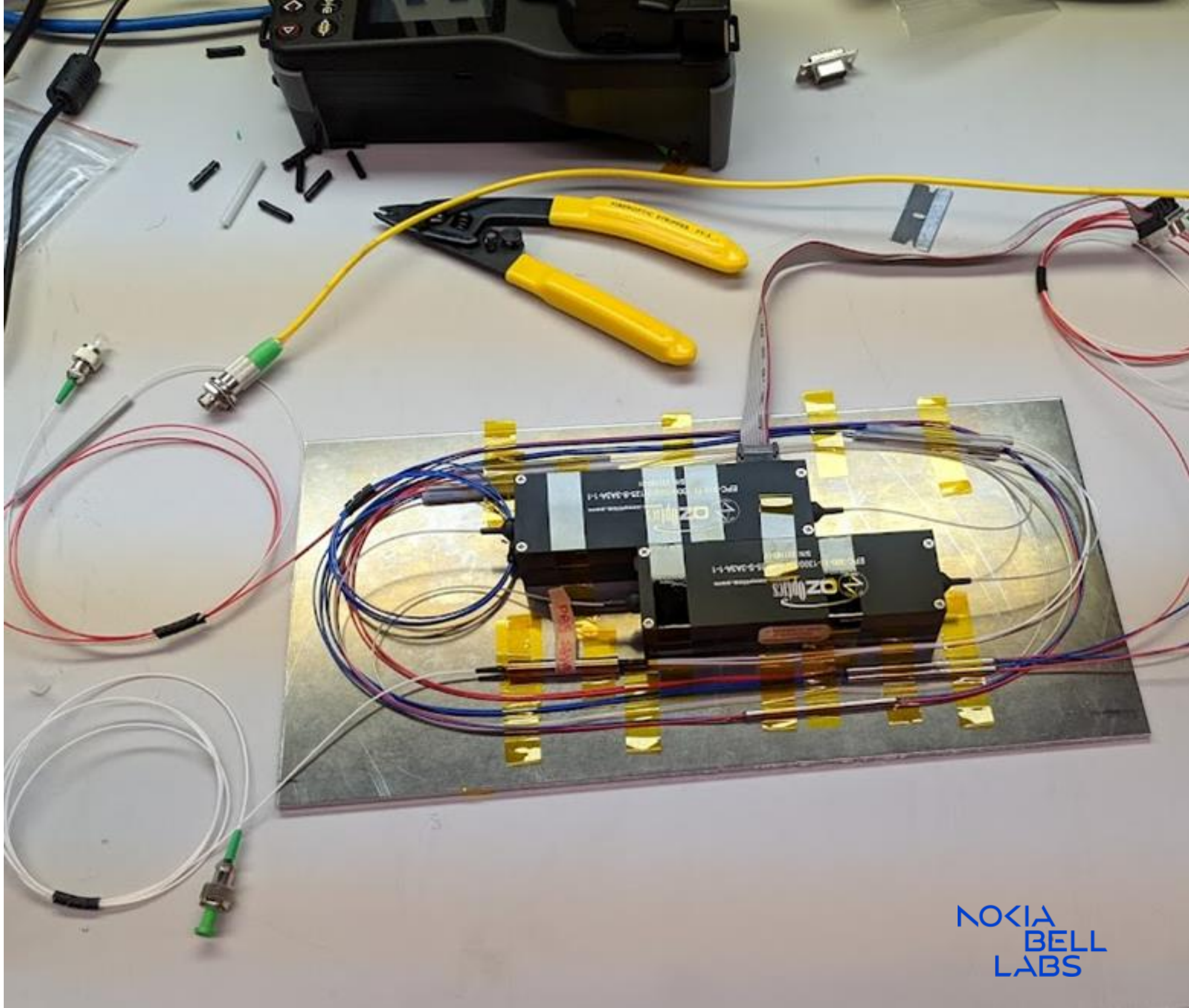
Assembly

- Put everything together

SPLICE!

- Minimize bending

- Tape everything down



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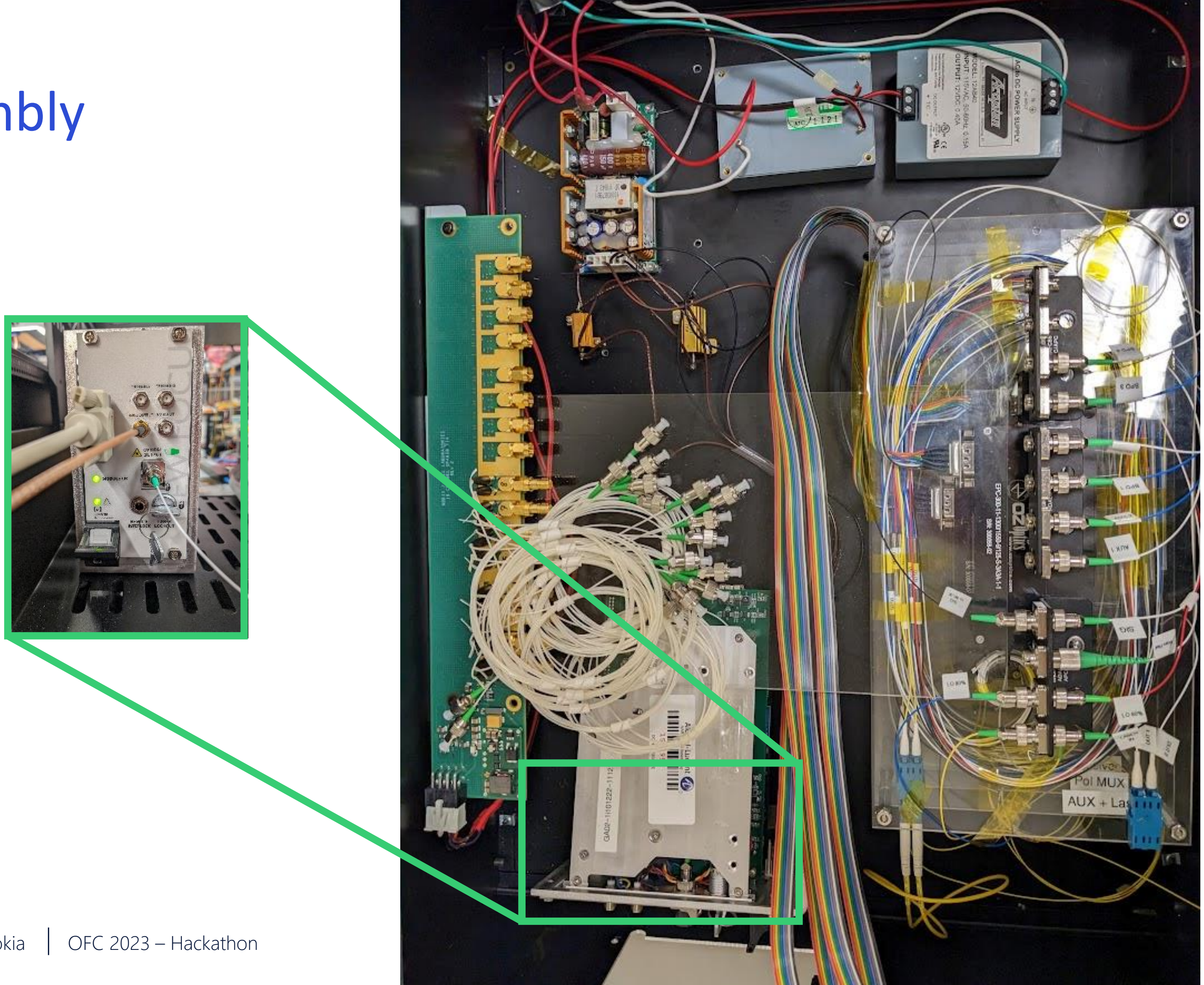
Assembly



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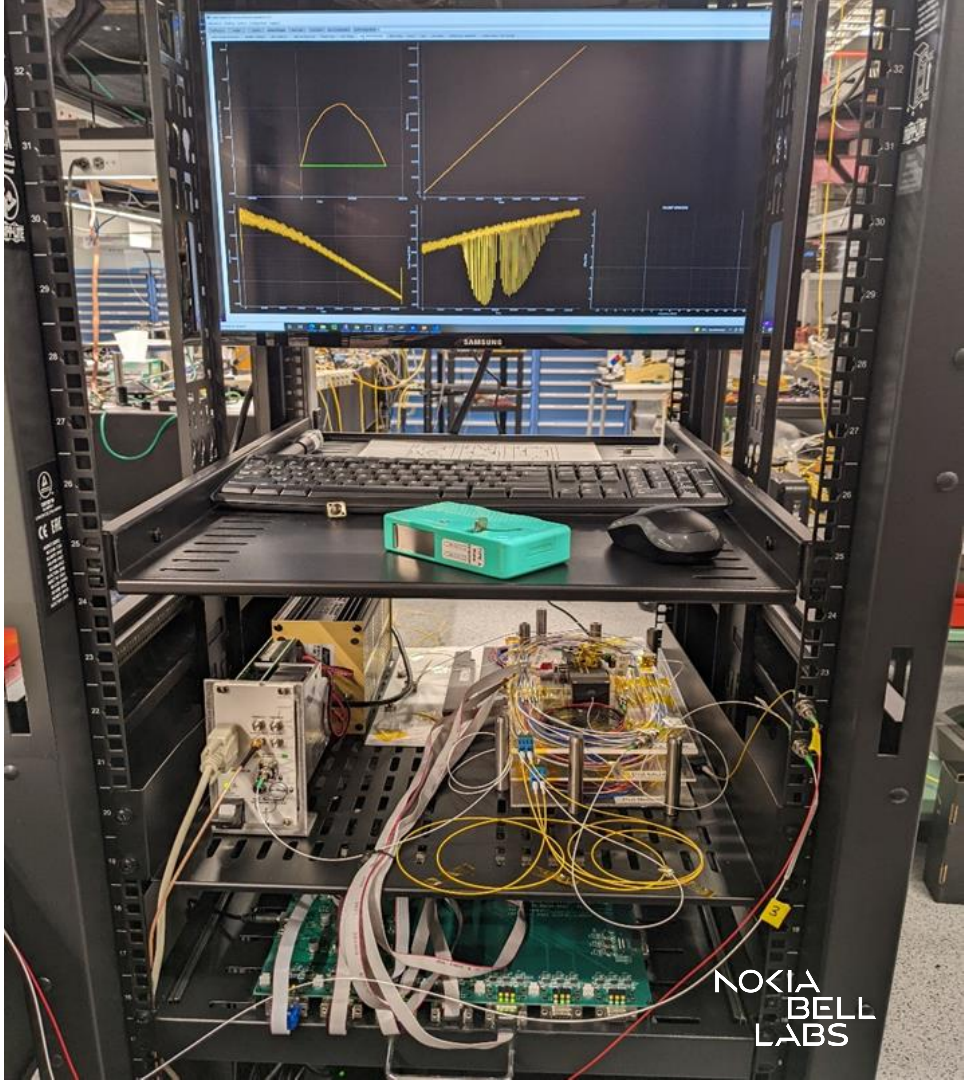
Optical Vector Network Analyzer

Measures the transfer function:

- Jones matrix represents the complete mathematical description of the propagation of light through the device.

  - Insertion loss
  - Group delay
  - Chromatic dispersion
  - Polarization dependent loss
  - Polarization mode dispersion
  - Min/Max loss
  - Rayleigh backscatter
  - Etc.



Operating as Optical Frequency Domain Reflectometer (OFDR)

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OVNA can operate as an Optical Frequency Domain Reflectometer

Optical Frequency Domain Reflectometer (OFDR)

- Rayleigh backscatter of components and fibers

Optical Time Domain Reflectometer (OTDR)

- OVNA has higher resolution capabilities compared to generic OTDR operating based off a laser pulse

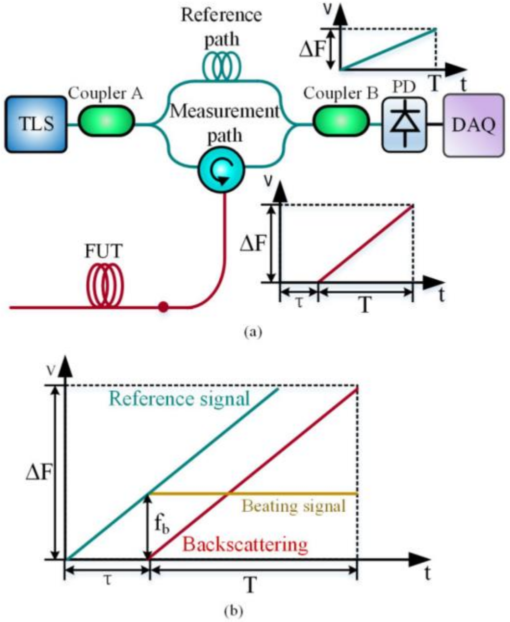


FIGURE 1. (a) OFDR system configuration, (b) beating signal between reference and backscattering signals under linearly optical frequency tuning condition.

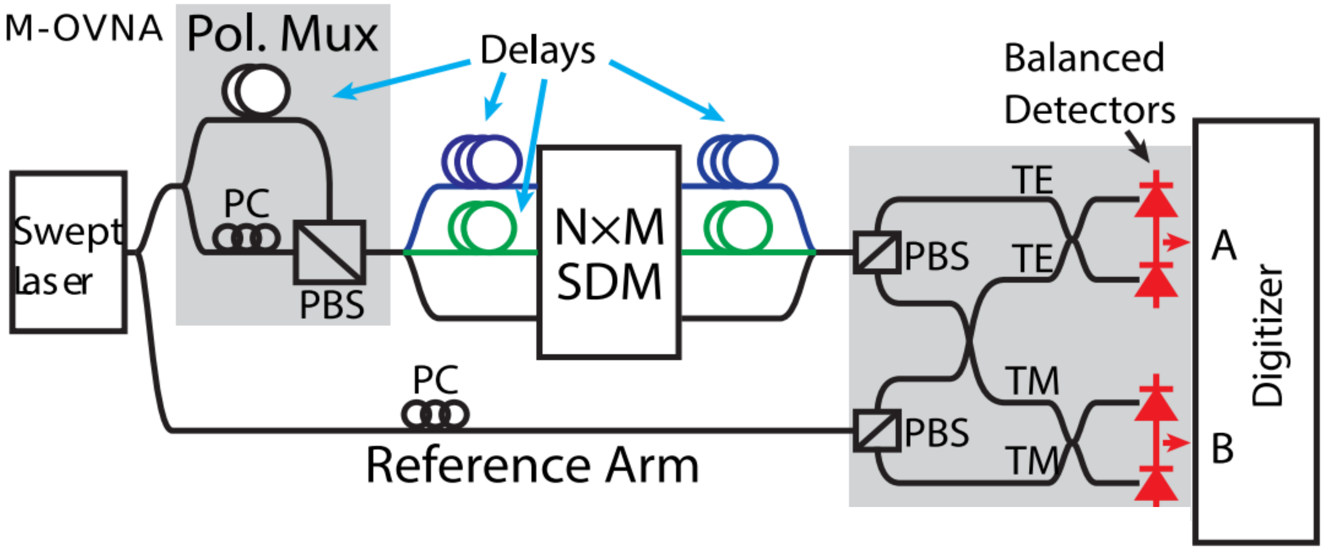
C. Liang, Q. Bai, M. Yan, Y. Wang, H. Zhang and B. Jin, "A Comprehensive Study of Optical Frequency Domain Reflectometry," in *IEEE Access*, vol. 9, pp. 41647-41668, 2021, doi: 10.1109/ACCESS.2021.3061250.

Multiport Measurement Example

Characterizing Multi-Port Devices

Time-Delay Multiplexing Measurement Technique

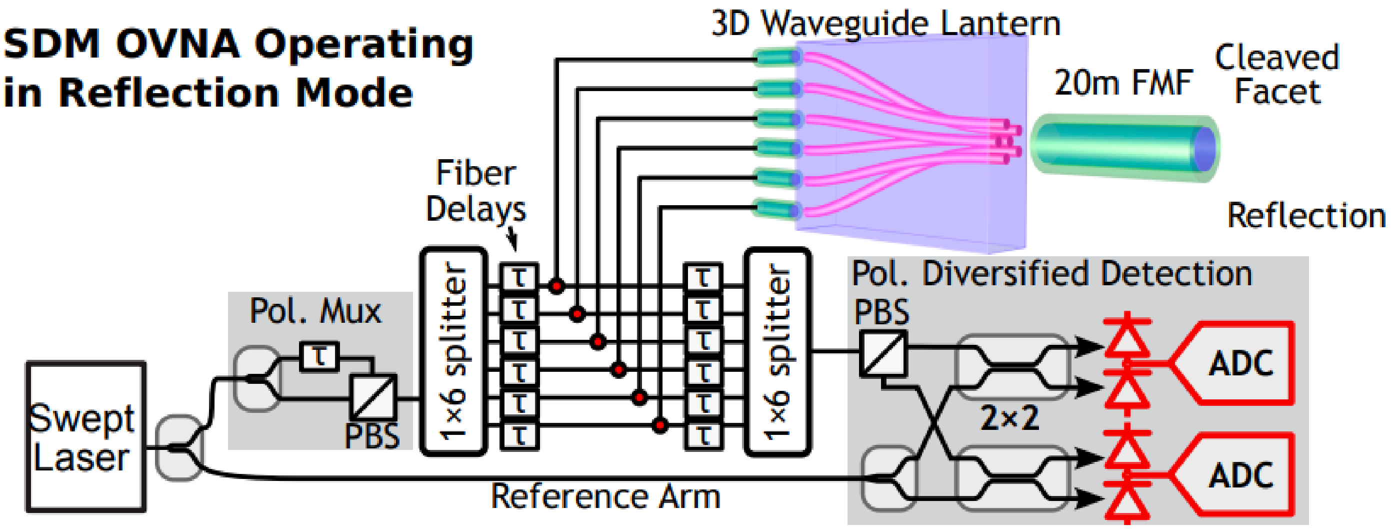
Measure multiple impulse responses in a single scan



N. K. Fontaine, R. Ryf, M. A. Mestre, B. Guan, X. Palou, S. Randel, Y. Sun, L. Grüner-Nielsen, R. V. Jensen, and R. Lingle, "Characterization of Space-Division Multiplexing Systems using a Swept-Wavelength Interferometer," in Optical Fiber Communication Conference/National Fiber Optic Engineers Conference 2013, OSA Technical Digest (online) (Optica Publishing Group, 2013), paper OW1K.2.

Characterizing Multi-Port Devices

Example: Characterizing Photonic Lantern



N. K. Fontaine and R. Ryf, "Characterization of Mode-Dependent Loss of Laser Inscribed Photonic Lanterns for Space Division Multiplexing Systems," in *2013 18th OptoElectronics and Communications Conference held jointly with 2013 International Conference on Photonics in Switching*, (Optica Publishing Group, 2013), paper MR2_2.

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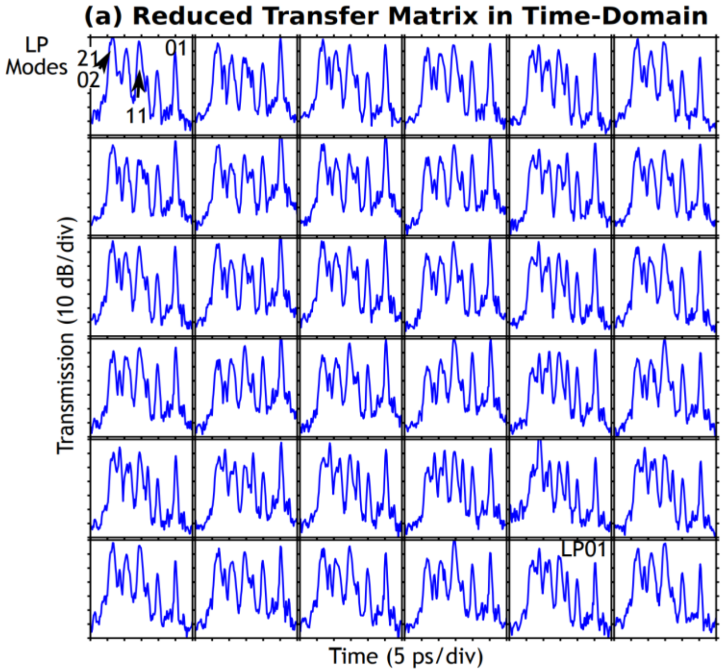
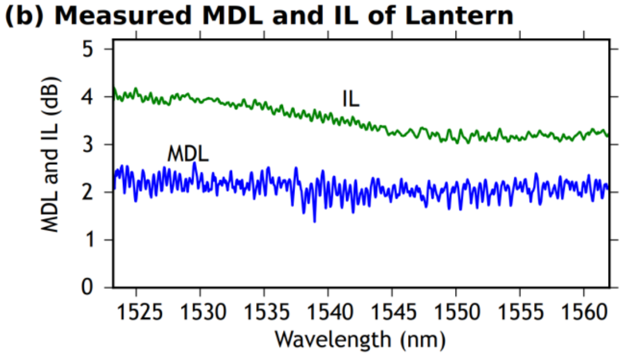
Characterizing Multi-Port Devices

Example: Characterizing Photonic Lantern

- 12×12 frequency-dependent transfer matrix, H(ω), of a 6-port photonic lantern spatial multiplexer using a swept-wavelength interferometer. Eigenvalue analysis of H(ω) provides of the mode-dependent loss and insertion loss.



N. K. Fontaine and R. Ryf, "Characterization of Mode-Dependent Loss of Laser Inscribed Photonic Lanterns for Space Division Multiplexing Systems," in *2013 18th OptoElectronics and Communications Conference held jointly with 2013 International Conference on Photonics in Switching*, (Optica Publishing Group, 2013), paper MR2_2.

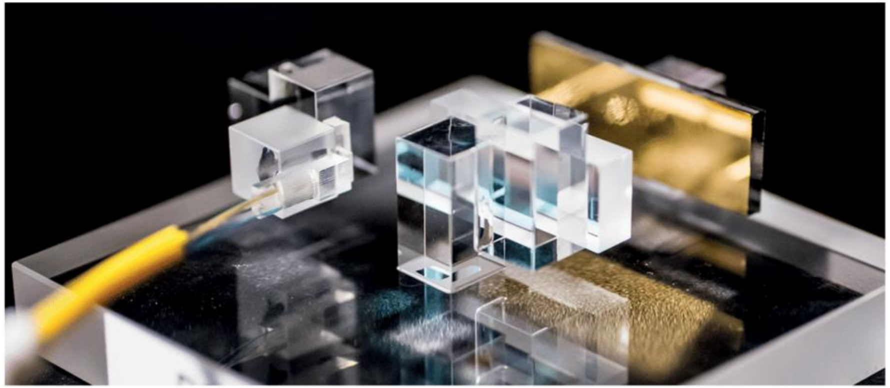


Multiport Measurement Demo

The Device Shown in this Demo

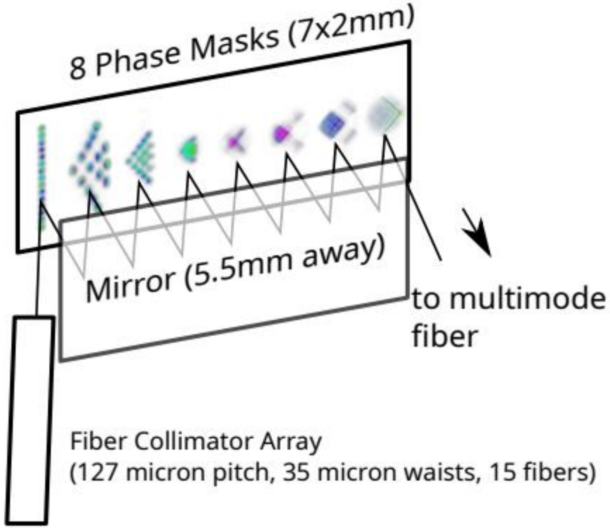
15 – Mode Multi-plane Light Converter

Example of a commercial 15-mode MPLC



P. Sillard et al., "Few-Mode Fiber Technology, Deployments, and Systems," in Proceedings of the IEEE, vol. 110, no. 11, pp. 1804-1820, Nov. 2022, doi: 10.1109/JPROC.2022.3207012.

Design of MPLC shown in this demo:



N. K. Fontaine, "Broadband 15-Mode Multiplexers based on Multi-Plane Light Conversion with 8 Planes in Unwrapped Phase Space," (ECOC) 2022, paper We3A.2.

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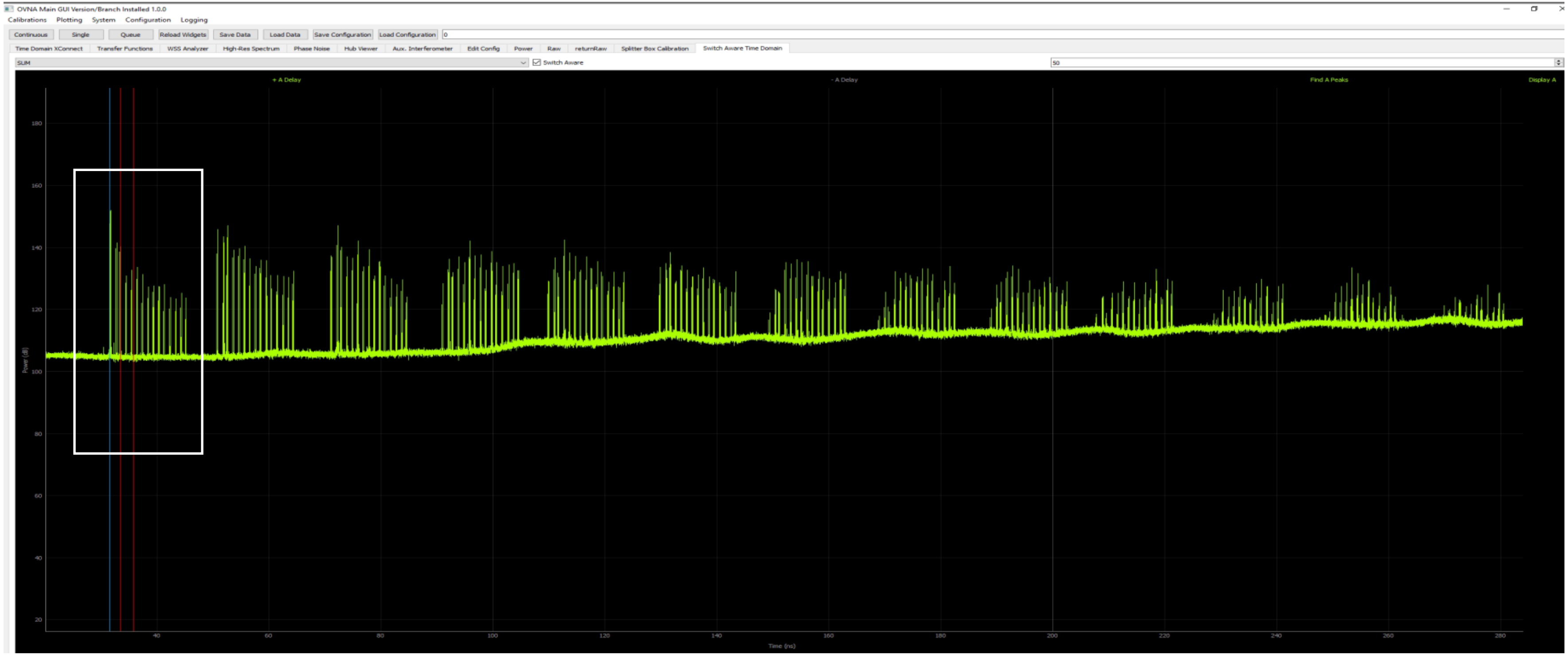
OVNA Demo – Multiport Device Characterization

15 Mode Multiplane Light Conversion Device



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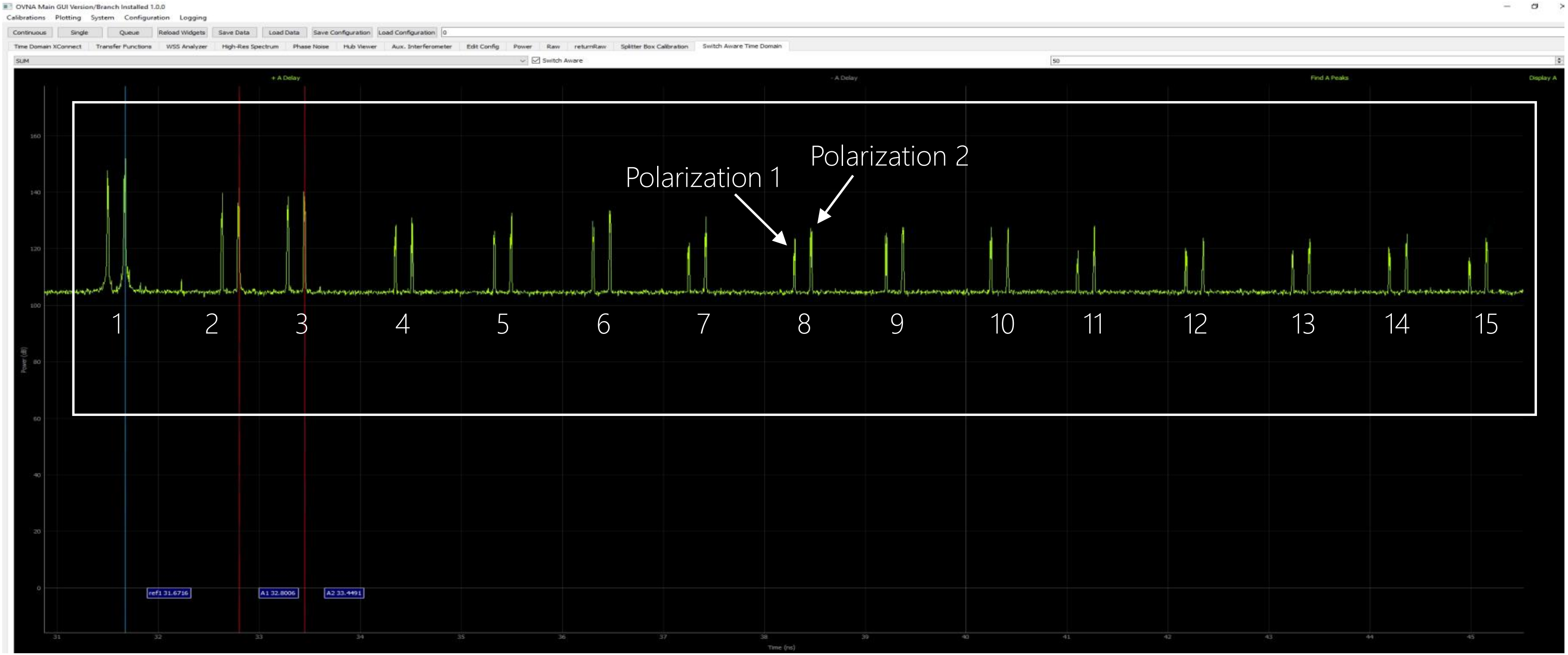
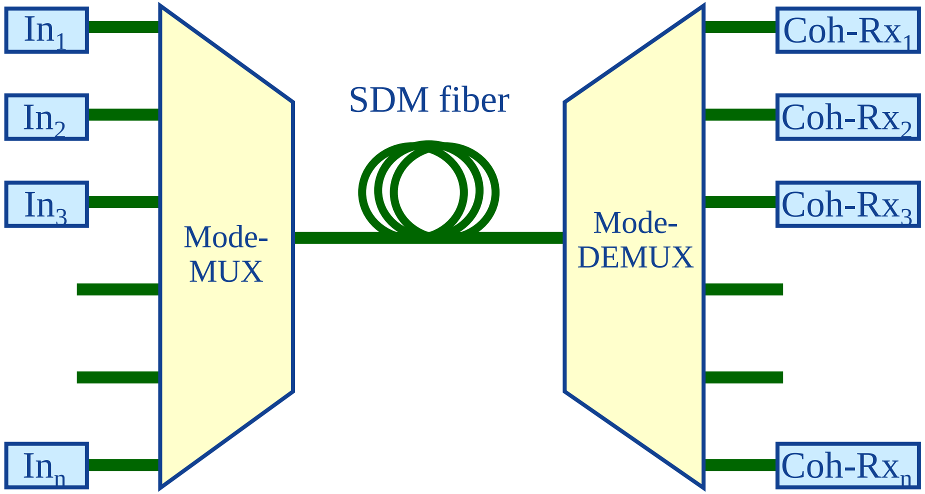
OVNA Demo – Multiport Device Characterization

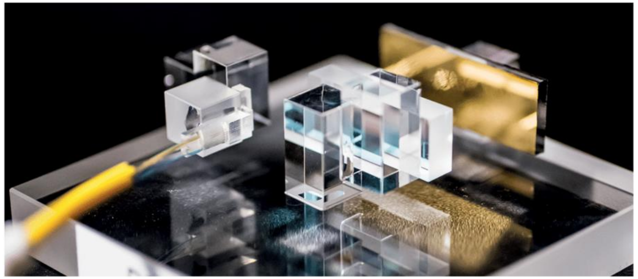
15 Mode Multiplane Light Conversion Device



Coupling into and out of Few-mode fiber

- Multiplane Light Converter (MPLC) to mode multiplex (MUX) or de-multiplex (DEMUX)
  - Transforms N spatial modes to N other spatial modes via reflecting off phase plates
  - Use it to convert from array single mode inputs to spatial fiber modes and back





P. Sillard et al., "Few-Mode Fiber Technology, Deployments, and Systems," in Proceedings of the IEEE, vol. 110, no. 11, pp. 1804-1820, Nov. 2022, doi: 10.1109/JPROC.2022.3207012.

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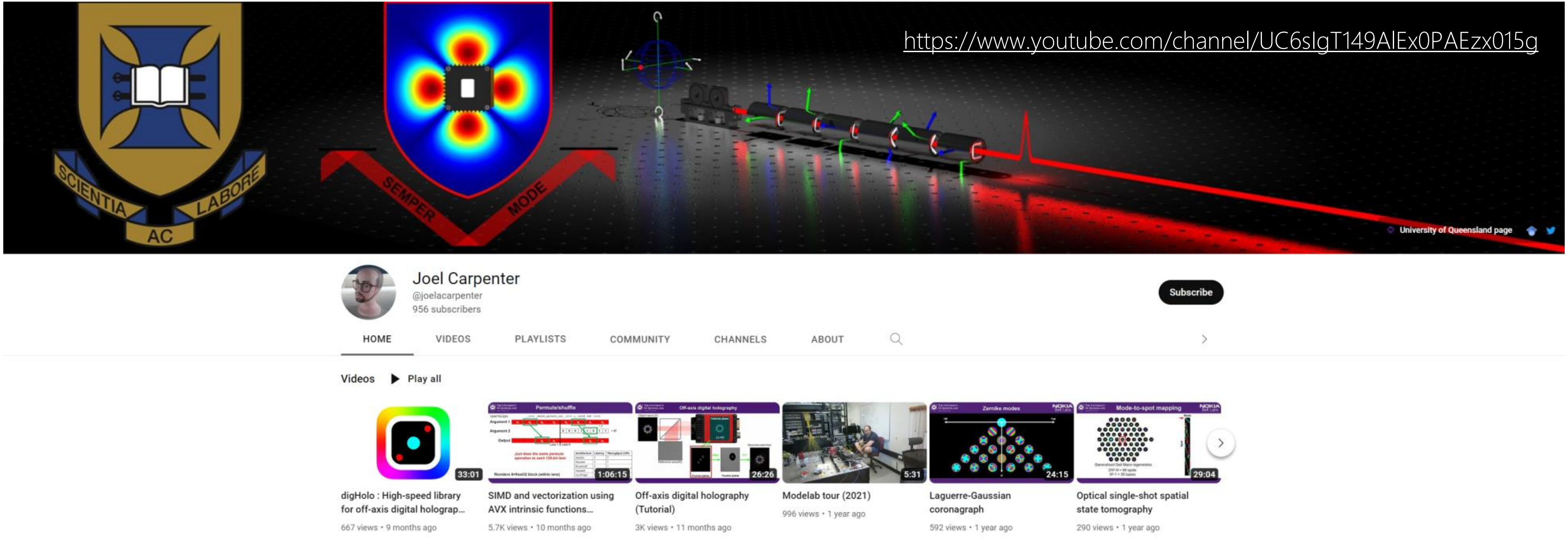
Highly Recommended YouTube Channel

For learning about fiber modes, mode multiplexers, etc.



More about Optical Vector Network Analyzer Development and Swept Wavelength Interferometry Techniques

- G. D. VanWiggeren, A. R. Motamedi and D. M. Barley, "Single-scan interferometric component analyzer," in IEEE Photonics Technology Letters, vol. 15, no. 2, pp. 263-265, Feb. 2003, doi: 10.1109/LPT.2002.806100.

- M. Froggatt, B. Soller, D. Gifford, and M. Wolfe, "Vibration Tolerant Swept Wavelength Interferometry," in Optical Fiber Communication Conference and Exposition and The National Fiber Optic Engineers Conference, Technical Digest (CD) (Optica Publishing Group, 2005), paper PDP8.

- N. K. Fontaine, R. Ryf, M. A. Mestre, B. Guan, X. Palou, S. Randel, Y. Sun, L. Grüner-Nielsen, R. V. Jensen, and R. Lingle, "Characterization of Space-Division Multiplexing Systems using a Swept-Wavelength Interferometer," in Optical Fiber Communication Conference/National Fiber Optic Engineers Conference 2013, OSA Technical Digest (online) (Optica Publishing Group, 2013), paper OW1K.2.

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