Opto-Electrical Measurements for Integrated & Silicon Photonics

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KEYSIGHT TECHNOLOGIES

Agenda

- Introduction
- Polarization Resolved Spectral Measurements
- High-Frequency Testing
- Summary / Q&A

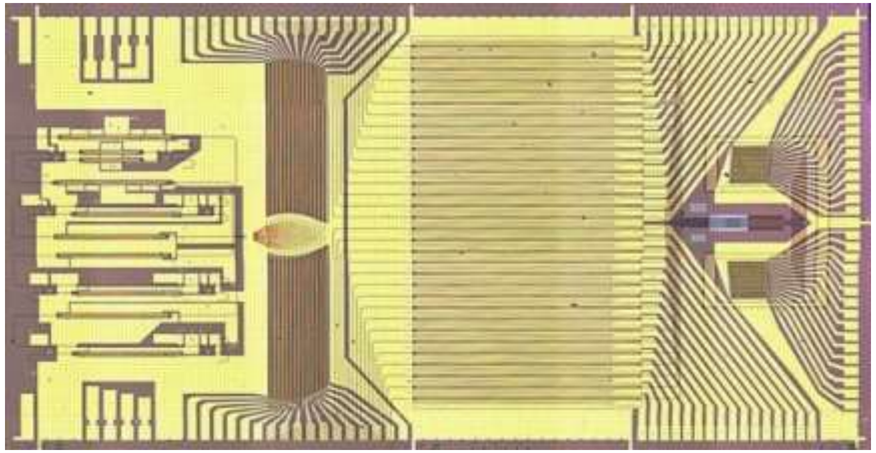
Introduction

INTEGRATED PHOTONICS

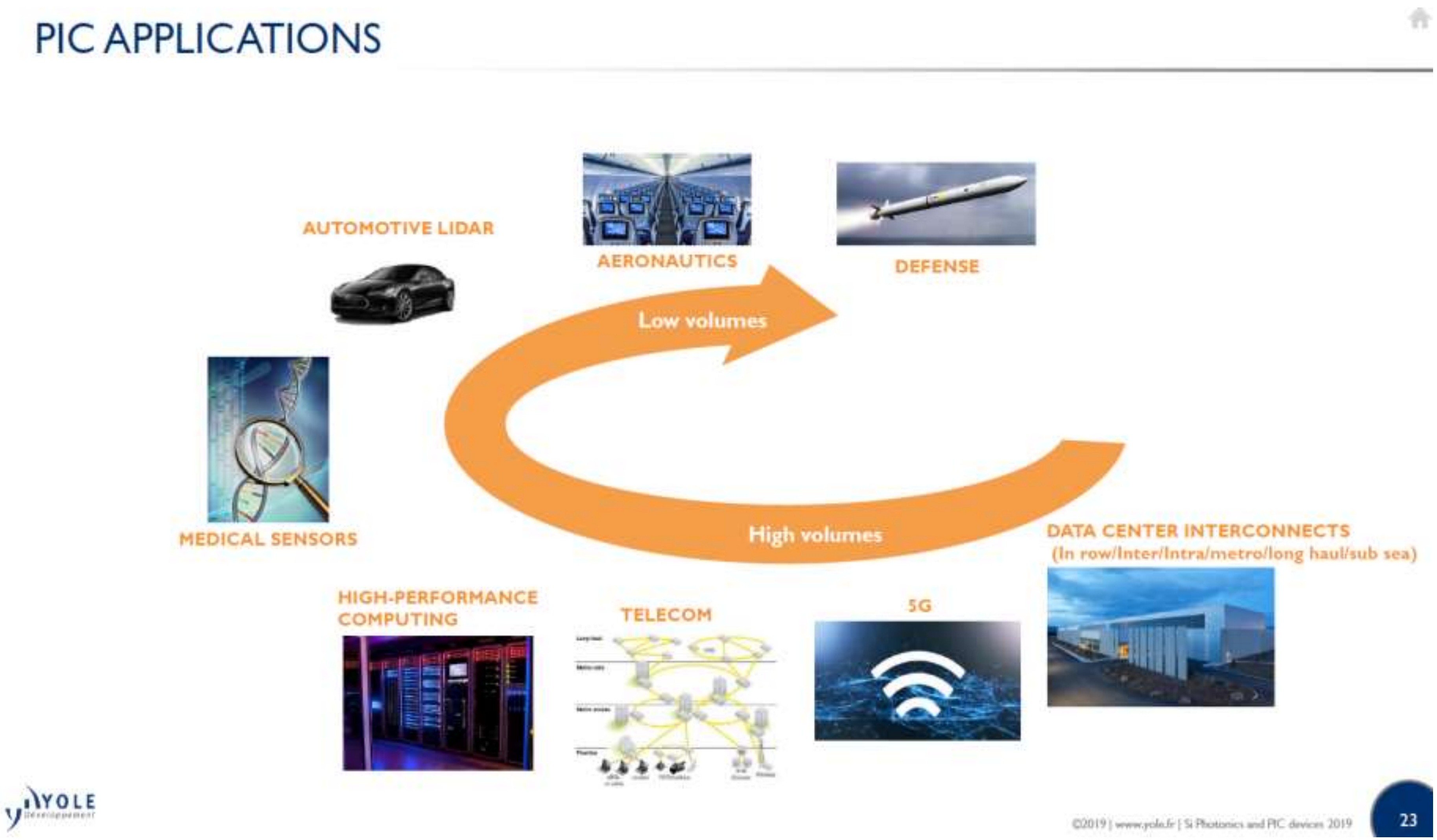
Motivation for Integrated Photonics

Motivations for photonic integrated circuits (PICs):

- Integration of different functions: waveguides, polarization components, lasers, modulators, switches, optical amplifiers, and detectors
- Higher data rates, lower power consumption, lower $/Gbps, high reliability
- Need PICs when:
  - VCSELs become limited in bandwidth and distance
  - WDM and single mode fiber transmission is required
  - The number of optical ports is increasing
  - Optics and electronics ICs are closer to each other
  - Data rates increase (400G, 800G, and more)
  - There is a need for embedded modules
  - Improved reliability is required



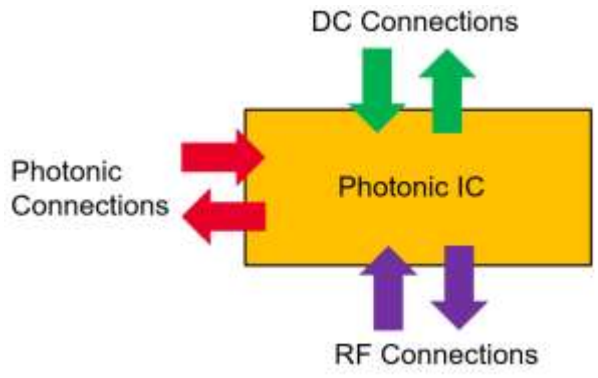
Integrated Photonic Circuit Applications



Optical & Optical-Electrical Test for Integrated Photonics

A new level of complexity:

- Photonic ICs are highly polarization dependent
- Photonic ICs can have a lot of electronic connections in addition to optics
- Probing can get busy, fast, and complex/error prone especially when RF comes into play



- Common questions:

1. What instruments should I use?
2. How to optimize for speed?
3. How to deal with polarization?
4. How to obtain dynamic range in filters with deep rejection?
5. What is the best approach for PDL measurements?
6. How to measure photodetectors and lasers?
   Both DC and high-frequency

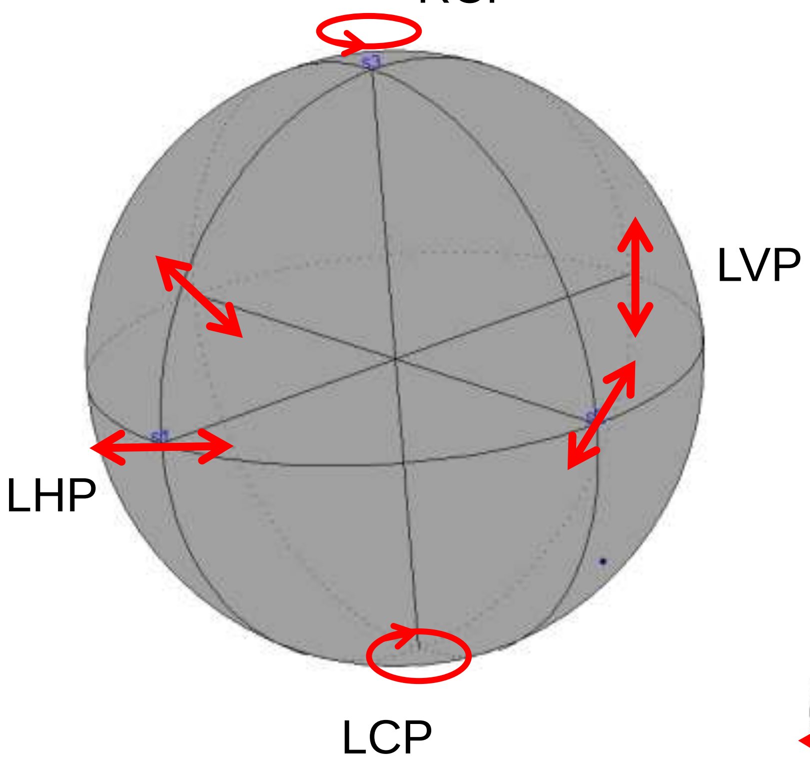
Polarization Resolved Spectral Measurements

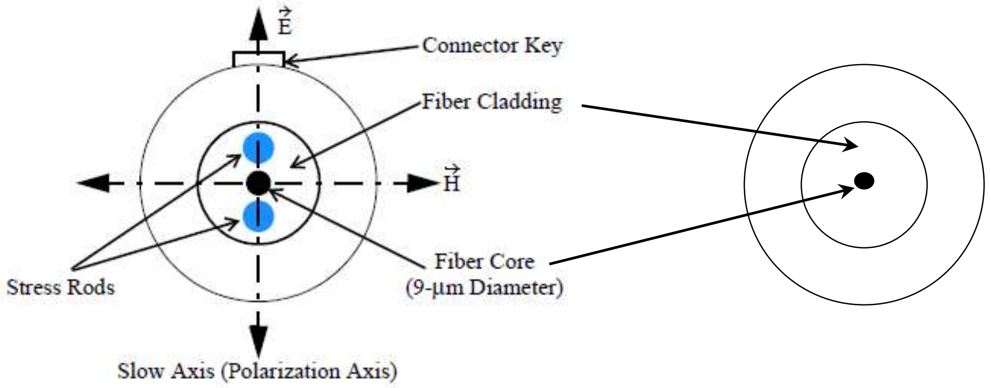
CHALLENGES AND SOLUTIONS

Polarization Background

LIGHT TRANSMISSION IN OPTICAL FIBER

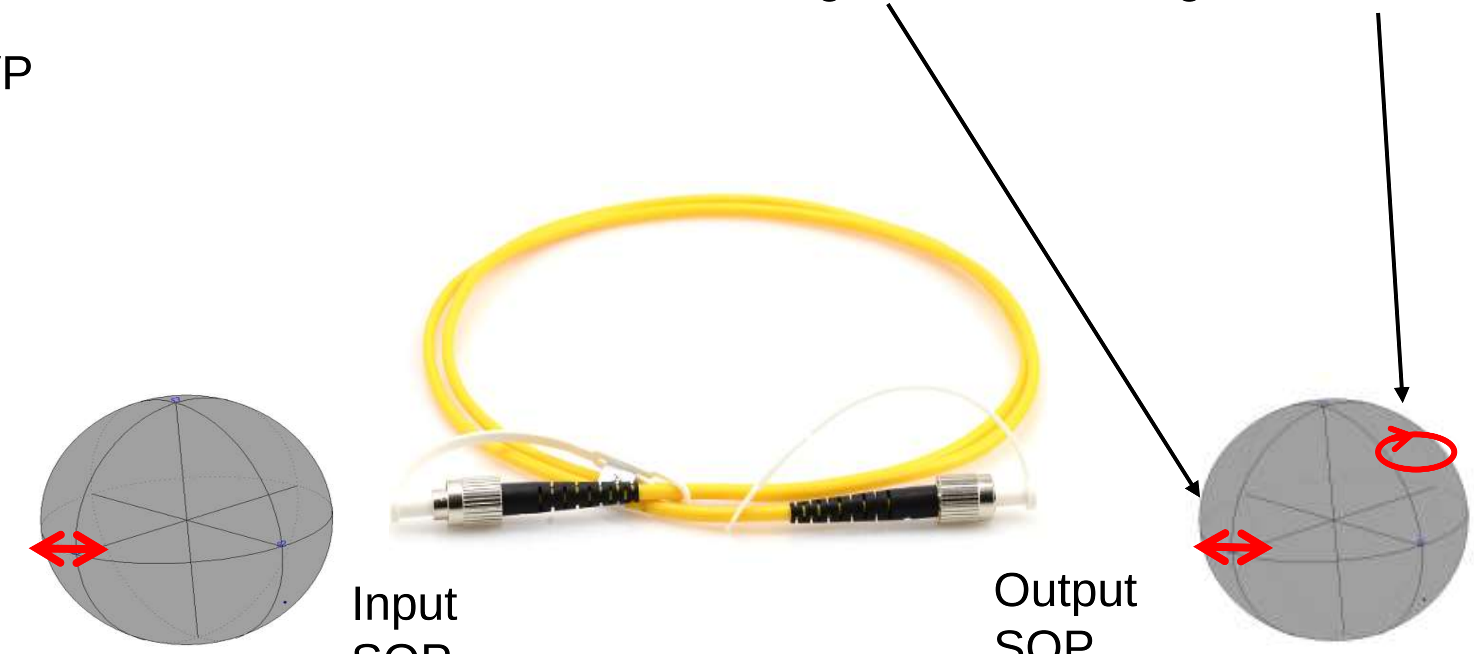
Poincare Sphere





Polarization Maintaining Fiber

Single Mode Fiber



Input SOP

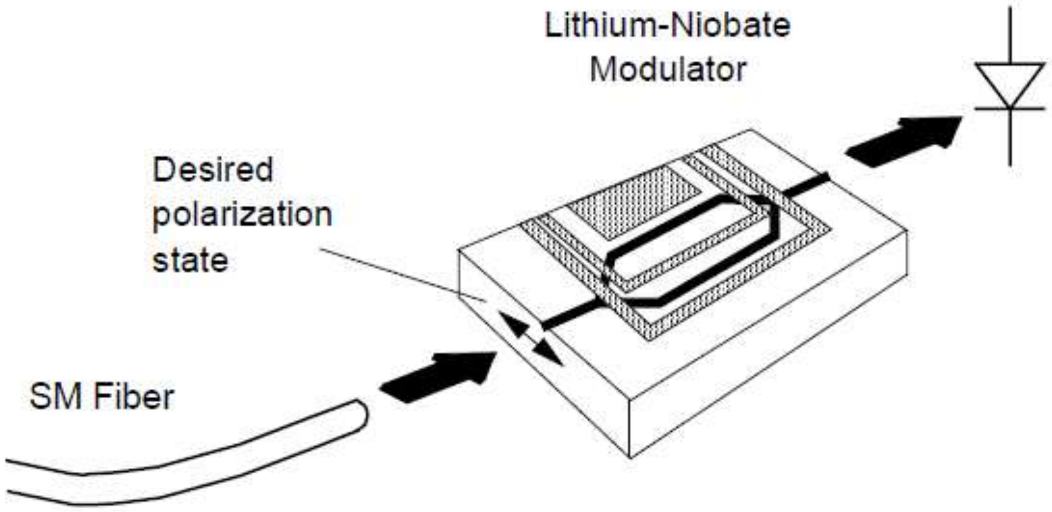
Output SOP

Testing Integrated Photonics

TE/TM ANALYSIS WITH IL/PDL SOLUTION

Keywords: “**integrated photonics**”, “**silicon photonics**”, “**planar lightwave circuits (PLC)**”, “**photonic integrated circuits (PIC)**”

- Planar devices on wafers, bars, and chips
- Often desired or undesired difference for E-field polarization in-plane TE or out-of-plane TM
- Measurement is often still made by aligning polarization in a search and optimize process and then measuring
  - Slow and the polarization changes as the wavelength is swept

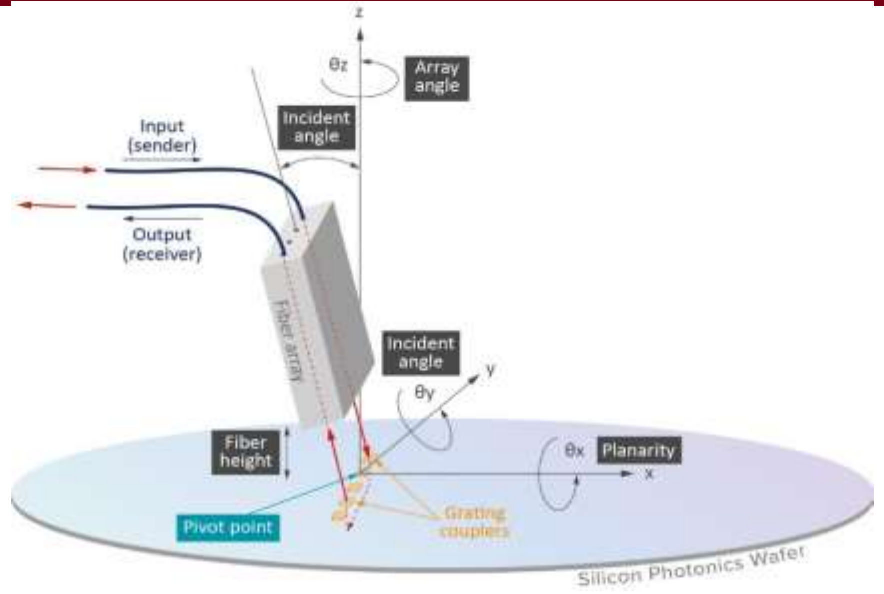


Measurement Challenges

- Probe station alignment
- Polarization resolved measurements
- Wavelength resolved measurements
- Fast measurement throughput

On Wafer Measurement Solutions

FORMFACTOR CM300XI-SIPH AUTOMATED WAFER LEVEL SOLUTION FOR PHOTONICS



Exclusive Automated Calibration of Positioning Solution to the Probe Station

Automated High Speed Optical Alignments/Optimizations

Verifiable Coupled Power Repeatability of <0.3dB

Photonic Measurement Solutions

INSTRUMENT BUILDING BLOCKS FOR OPTICAL AND DC ELECTRICAL TEST

Tunable Lasers O S C L Band

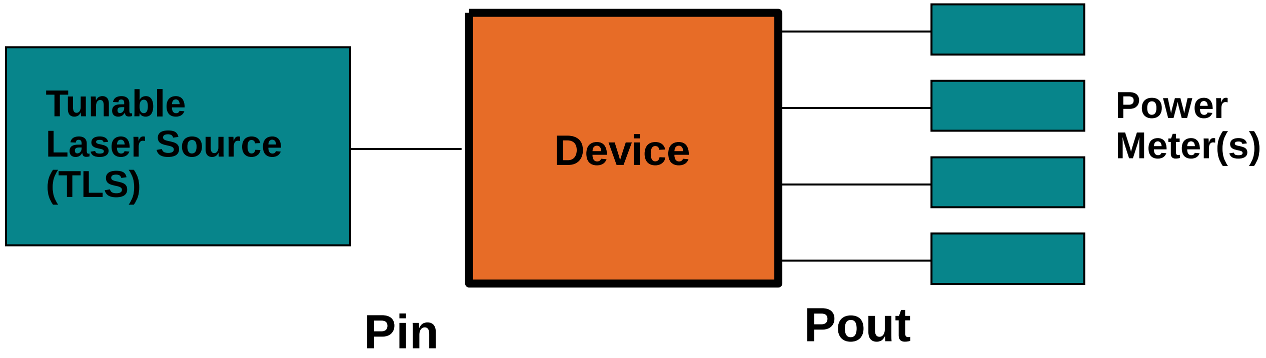
Optical Power Meters

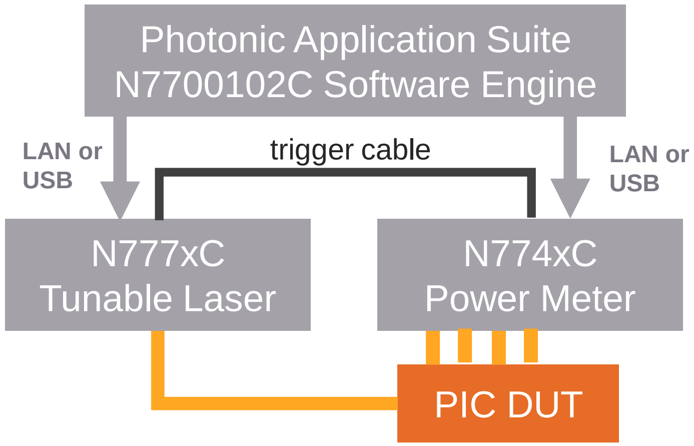
Polarization Control / Polarization Analysis

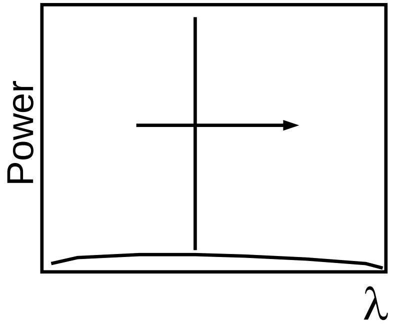
Source Measurement Unit

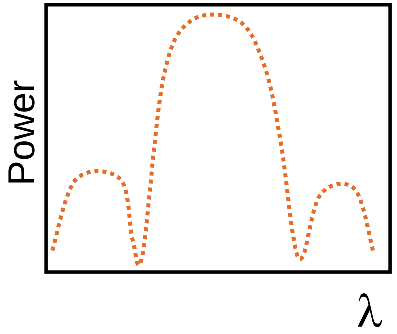
Photonic Measurement Solutions

TUNABLE LASER AND POWER METER – SWEPT INSERTION LOSS (IL)









Insertion Loss (dB)

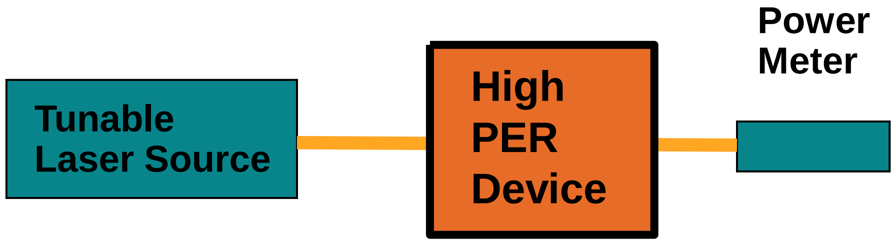
10*log(Pin/Pout)

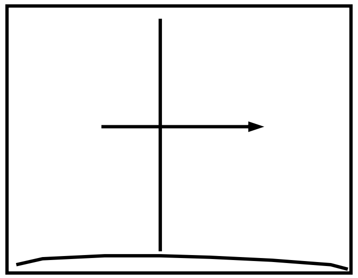
TLS performs a continuous sweep
at constant velocity (i.e. 40 nm/s)

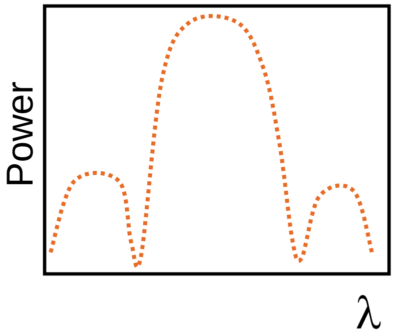
PM’s take samples at regular intervals
(i.e. every 0.001 nm = 40,000 samples/s)

Photonic Measurement Solutions – Polarization Alignment

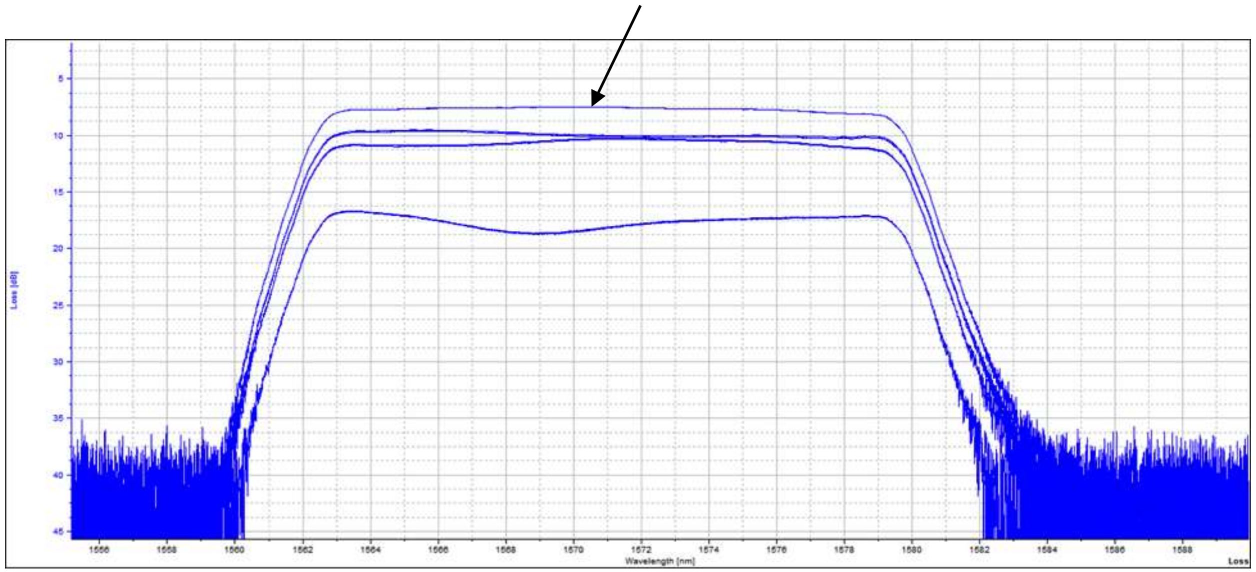
THE NEED FOR POLARIZATION ALIGNMENT







Min Loss vs. Wavelength @ various input SOP



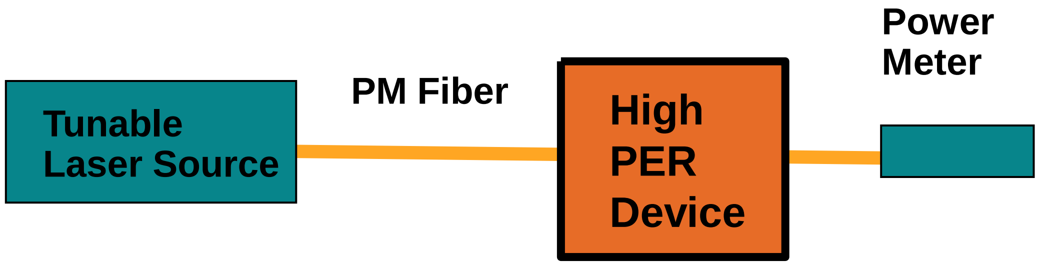
TLS performs a continuous sweep at constant velocity (i.e. 10nm/s)

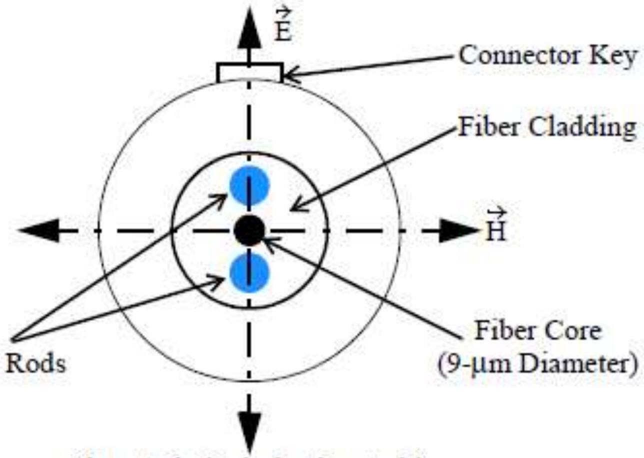
PM's take samples at regular intervals (i.e. every 0.002nm = 5000 samples/s)

PER = Polarization Extinction Ratio

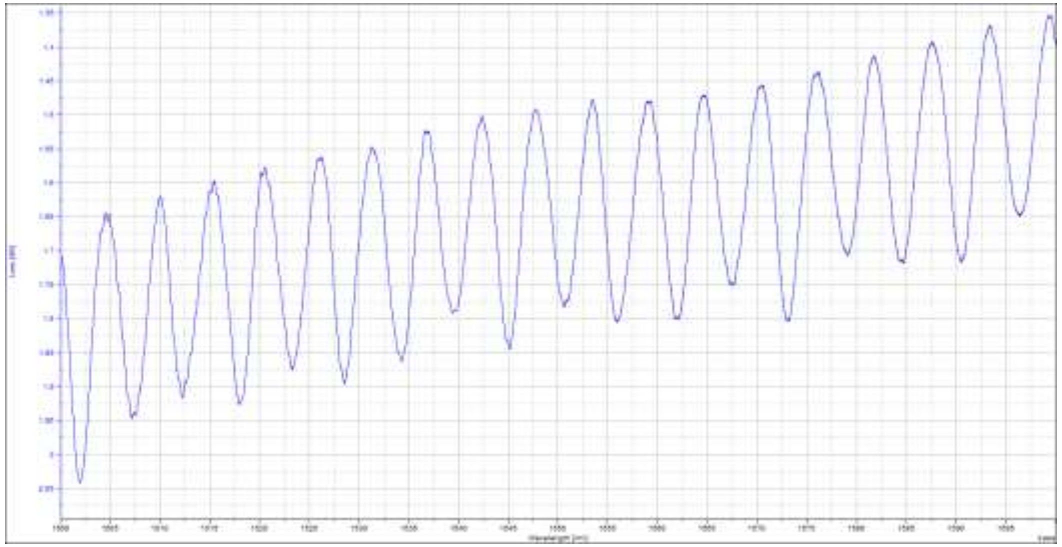
Photonic Measurement Solutions – Polarization Alignment

POLARIZATION MAINTAINING (PM) FIBER





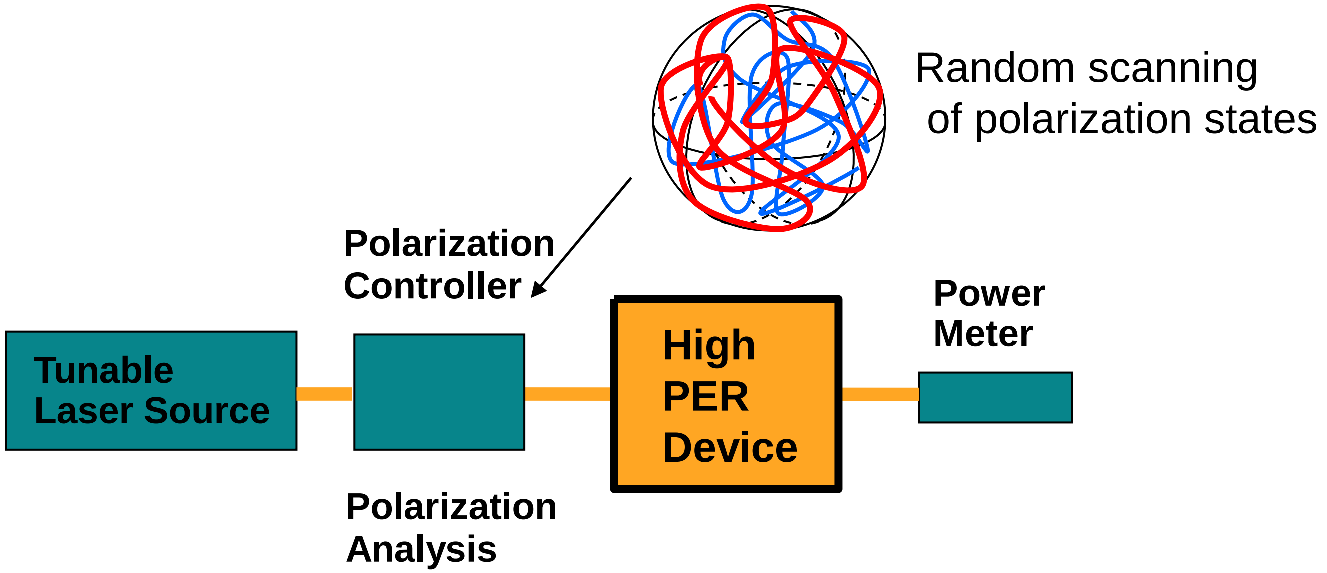
PM fiber slow axis aligned to polarizer



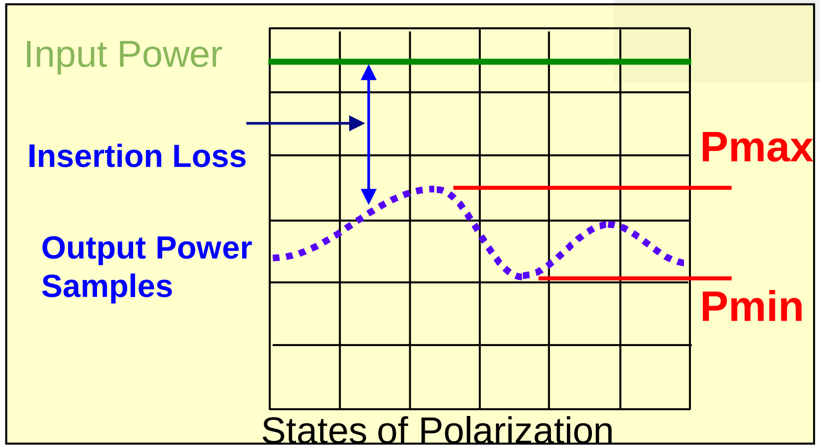
Limited extinction between fast and slow axis causes ripple

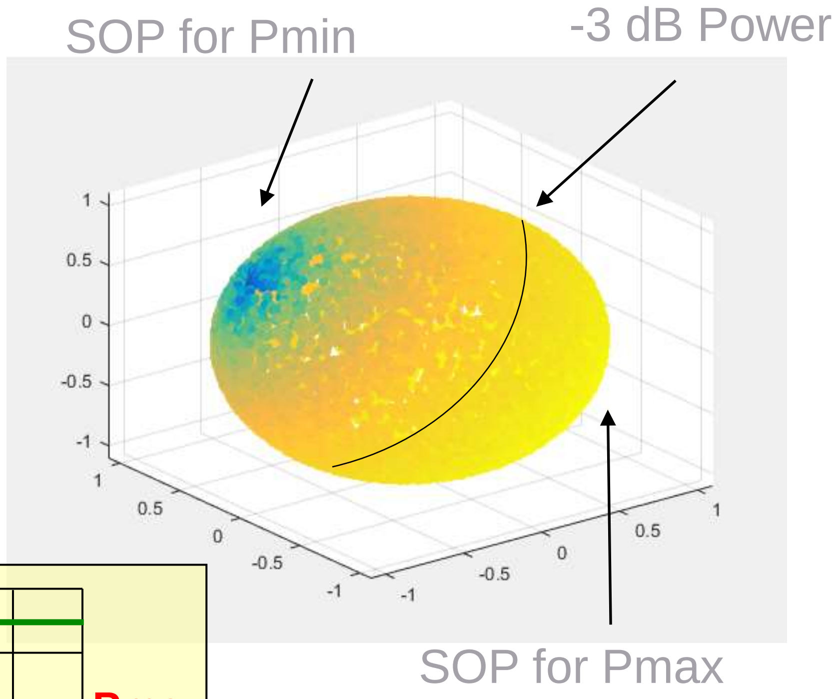
Photonic Measurement Solutions – Polarization Alignment

POLARIZATION SCANNING – SEARCH FOR PMAX AT λ



- ~ 2 to 5 seconds measurement time per λ
- Best for single / few λs
- High accuracy
- Simple to implement

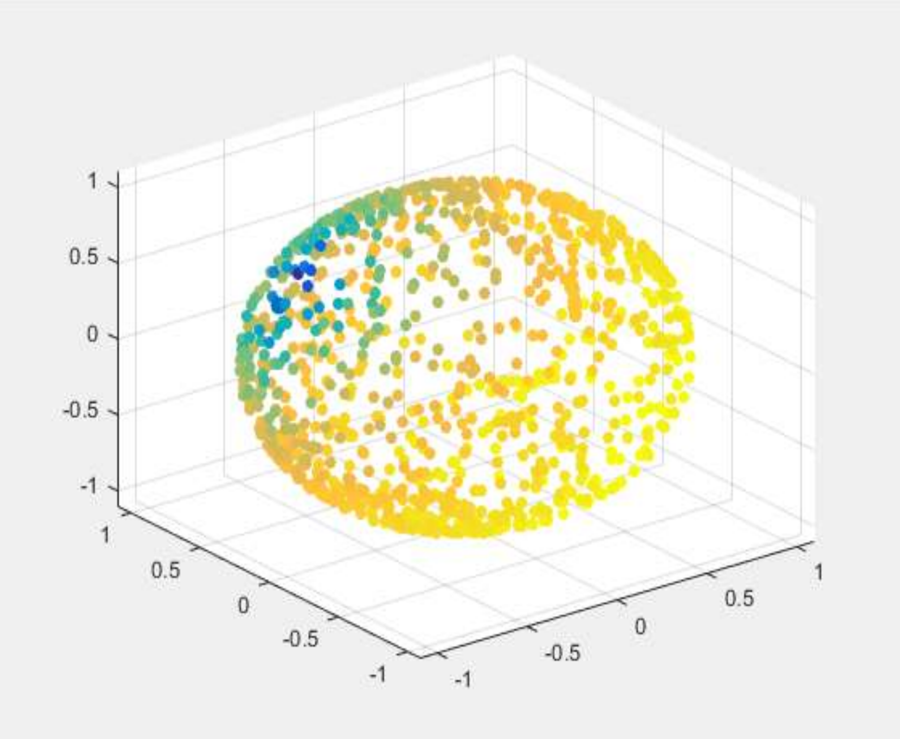




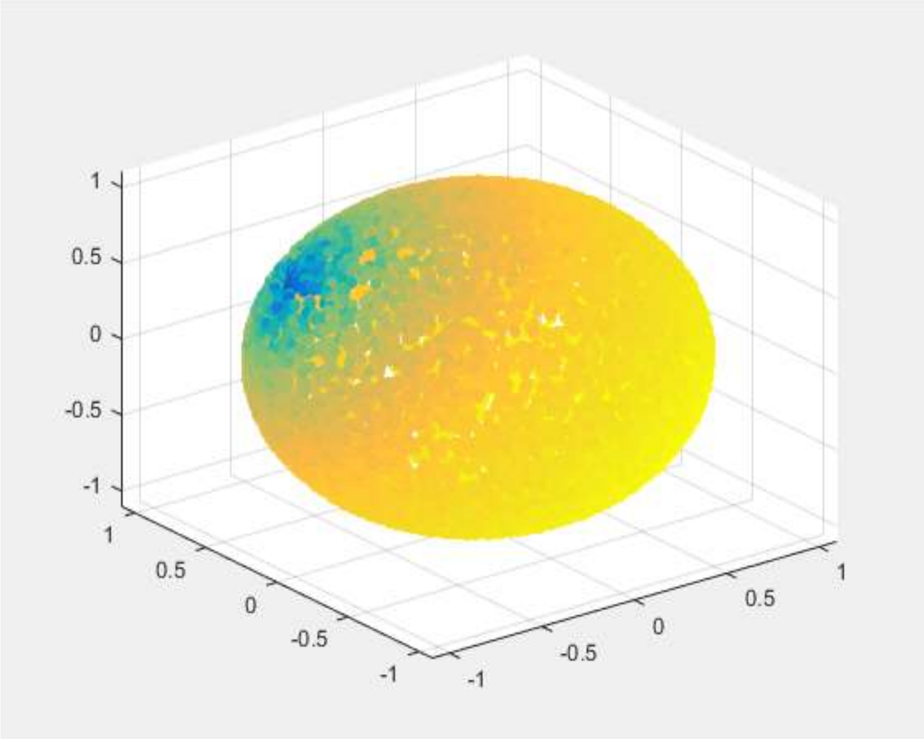
Photonic Measurement Solutions – Polarization Alignment

POLARIZATION SCANNING – SEARCH FOR PMAX AT λ

1k point sequence
~ 1.5 seconds

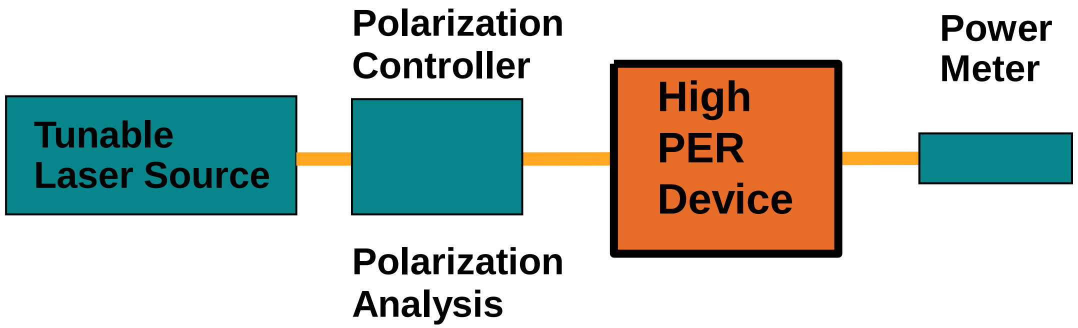


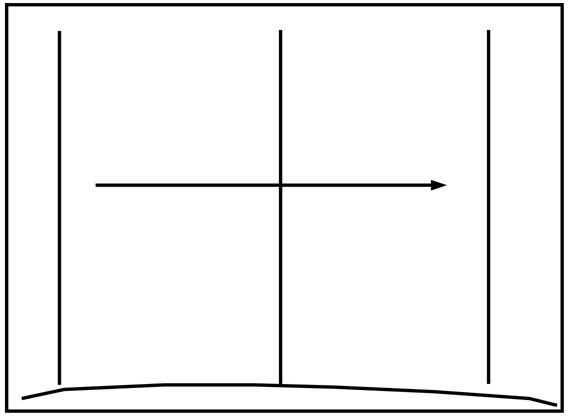
10k point sequence
~ 4.5 seconds

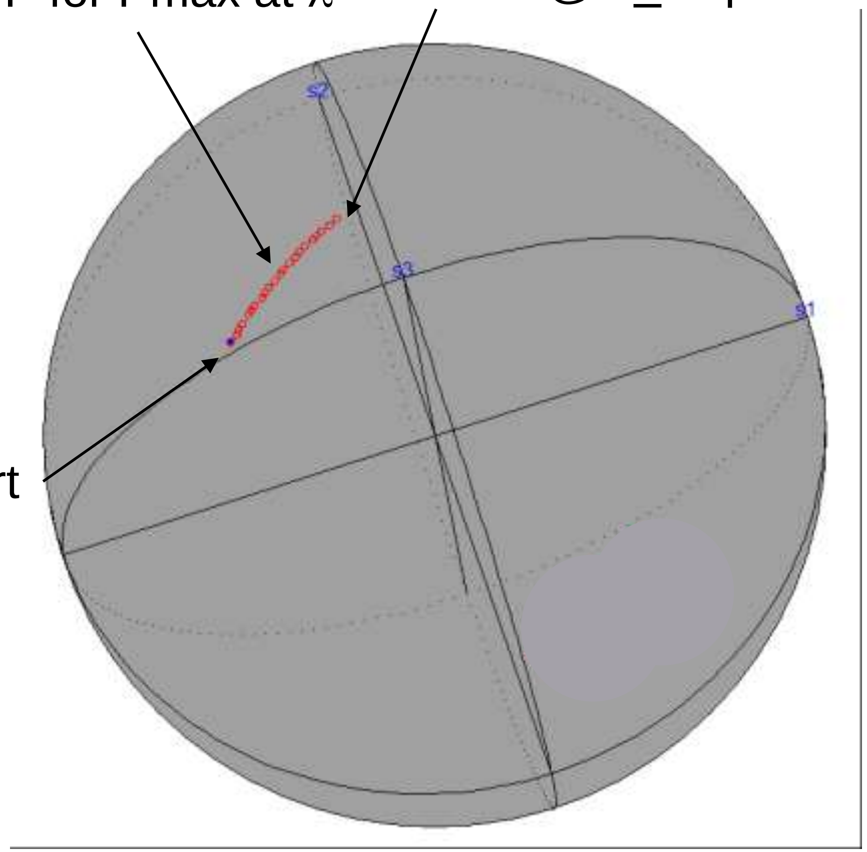


Photonic Measurement Solutions – Polarization Alignment

POLARIZATION SCANNING – SET SOP FOR PMAX AT λ

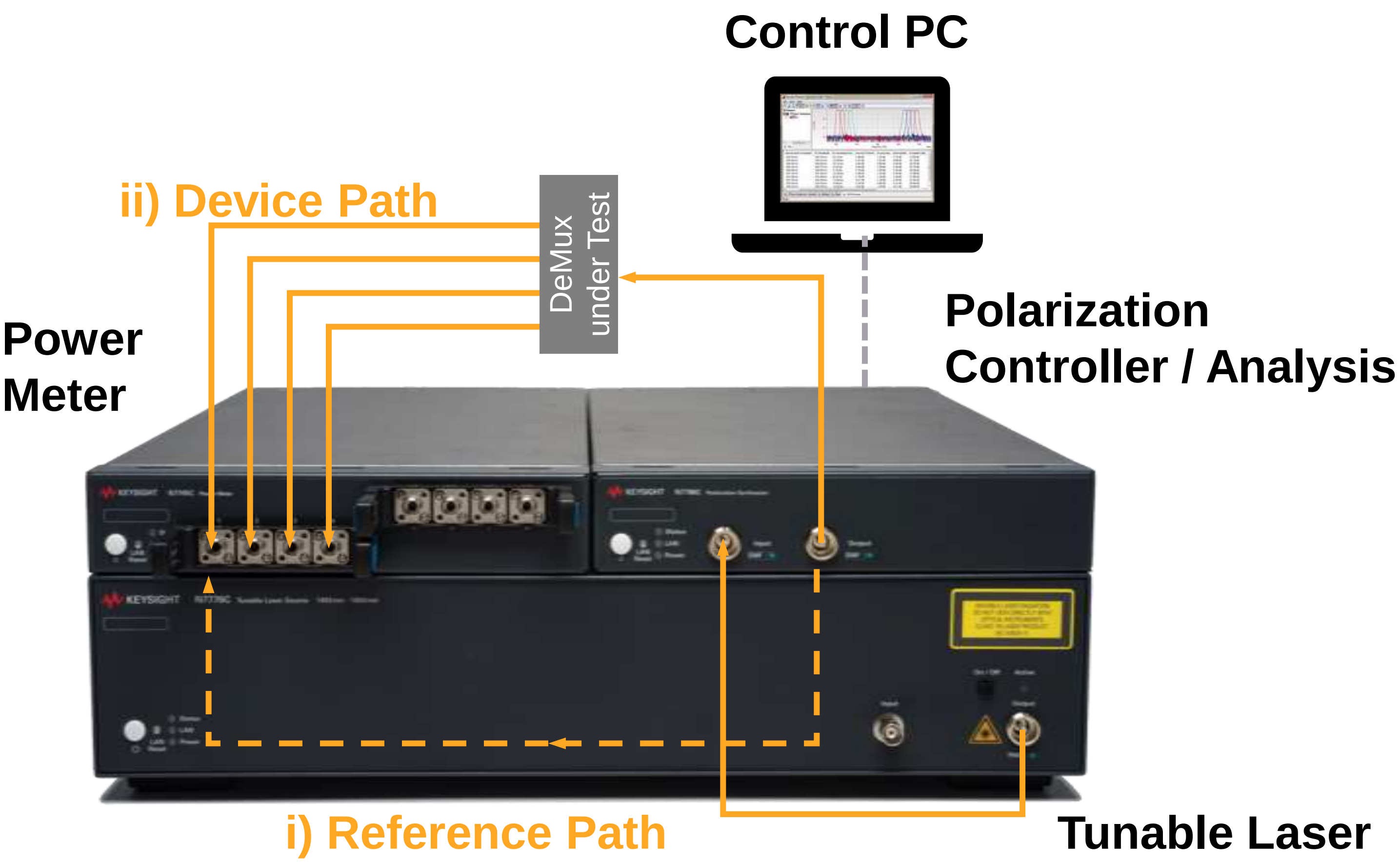


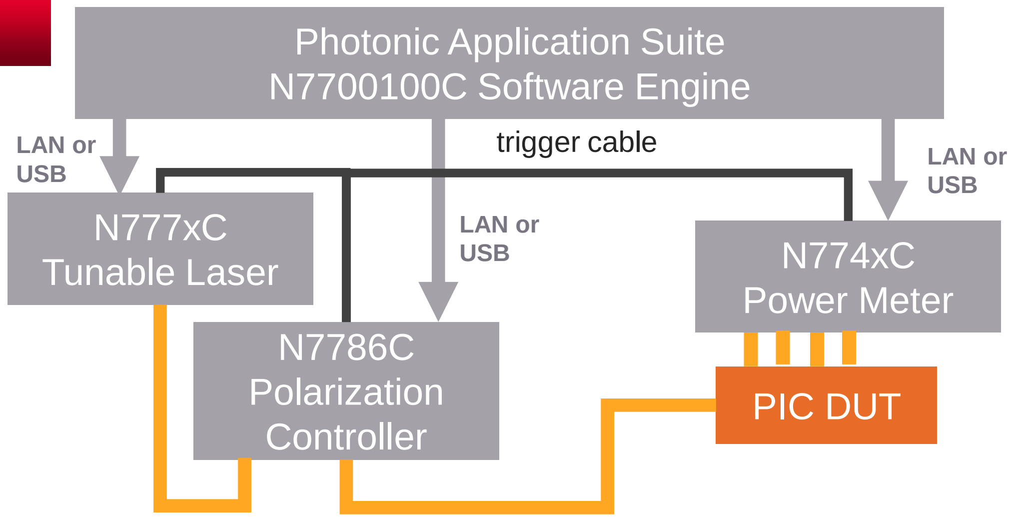


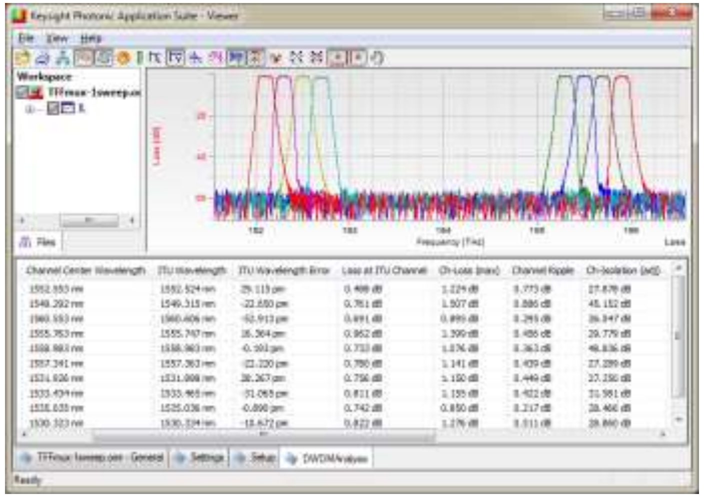


Photonic Measurement Solutions

MUELLER MATRIX - SWEPT IL / PDL



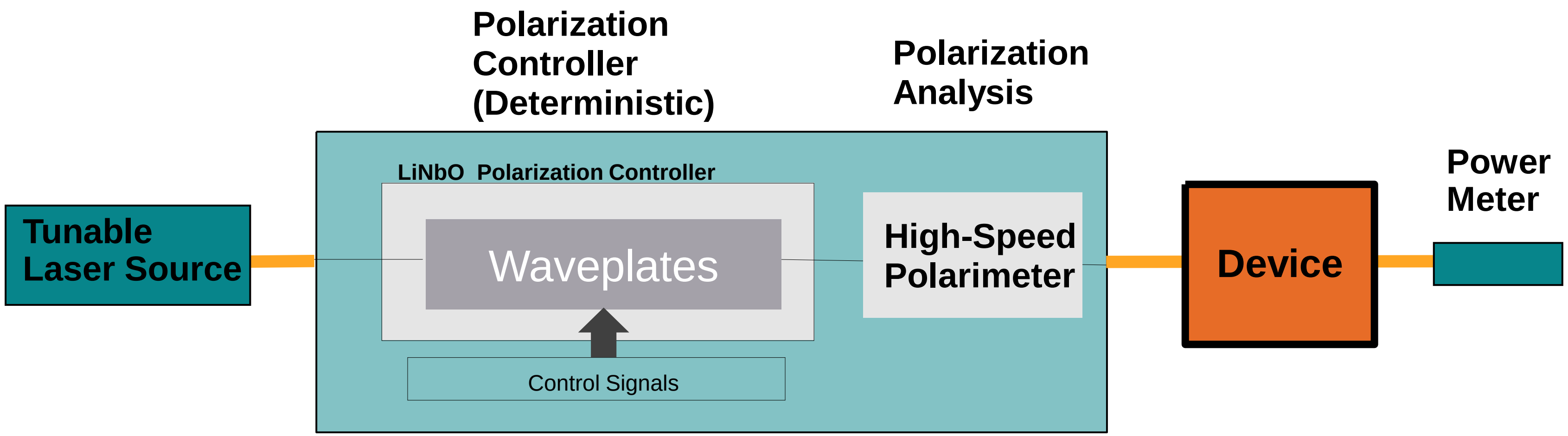




Insertion Loss / Polarization Dependent Loss / TE – TM Loss

Photonic Measurement Solutions

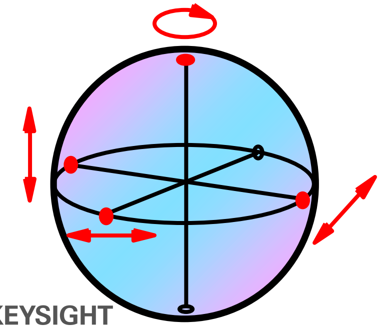
SWEPT IL / PDL – MULTI VS. SINGLE SWEEP MUELLER MATRIX



Polarization Synthesizer

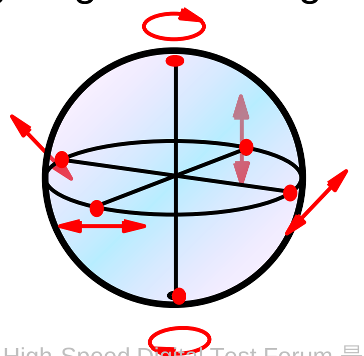
Traditional Mueller Method:

- Generate only 4 discrete states
- 4 consecutive wavelength sweeps



Advanced Mueller Method:

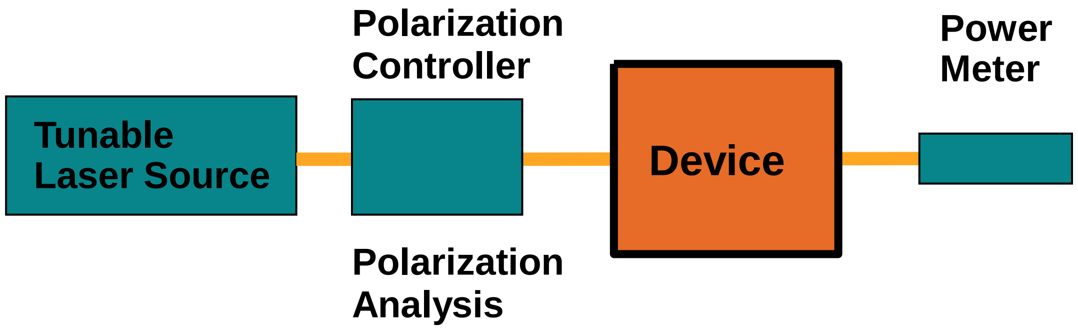
- Generate 6 discrete states !
- Fast switching between states during single wavelength sweep

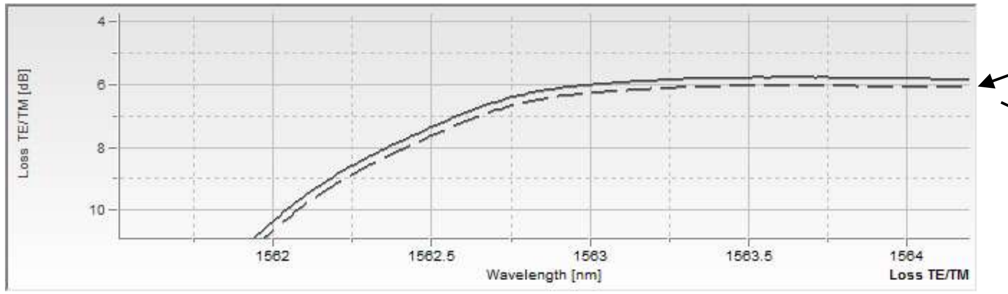


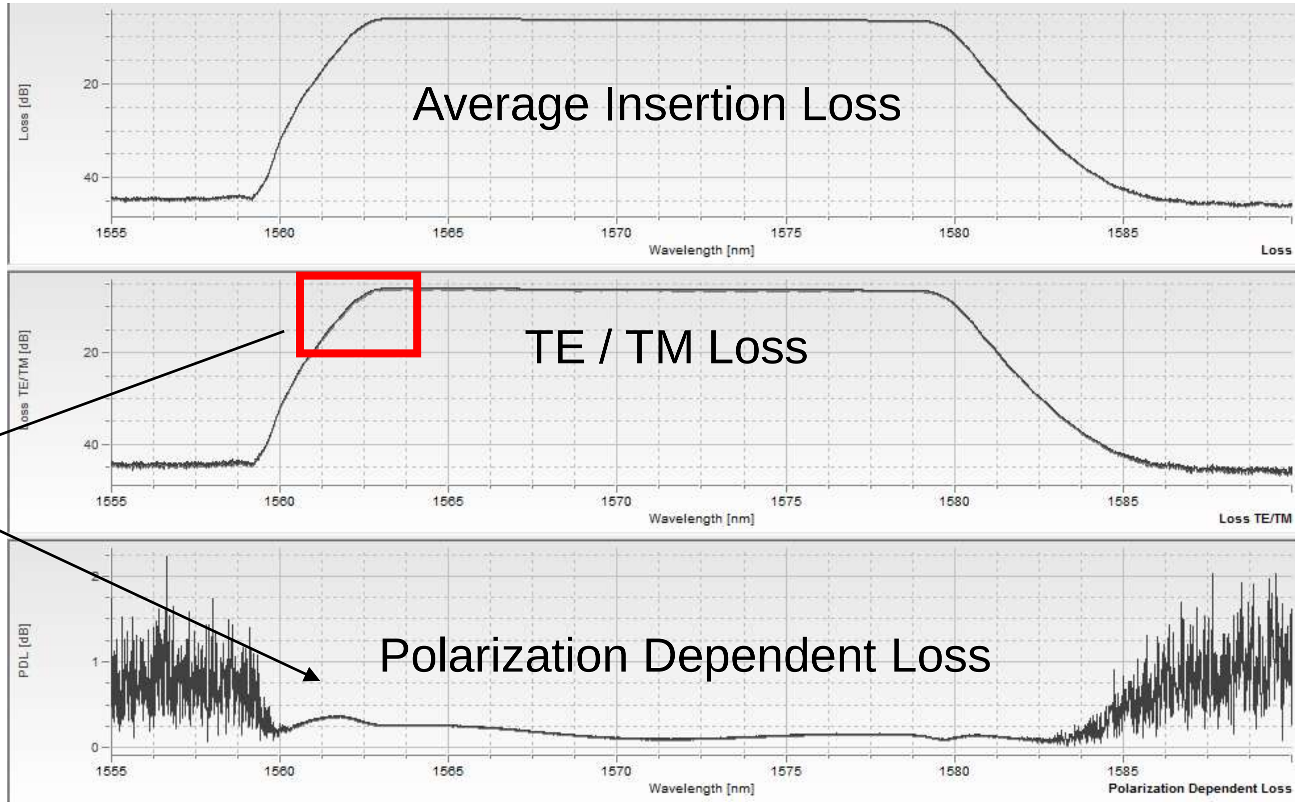
- More precision by using measured SOPs in PDL calculation
- Best method for PDL vs wavelength
- TE Loss vs. Wavelength

Photonic Measurement Solutions

MUELLER MATRIX – STANDARD PASSIVE OPTICAL COMPONENT W/ LOW PDL

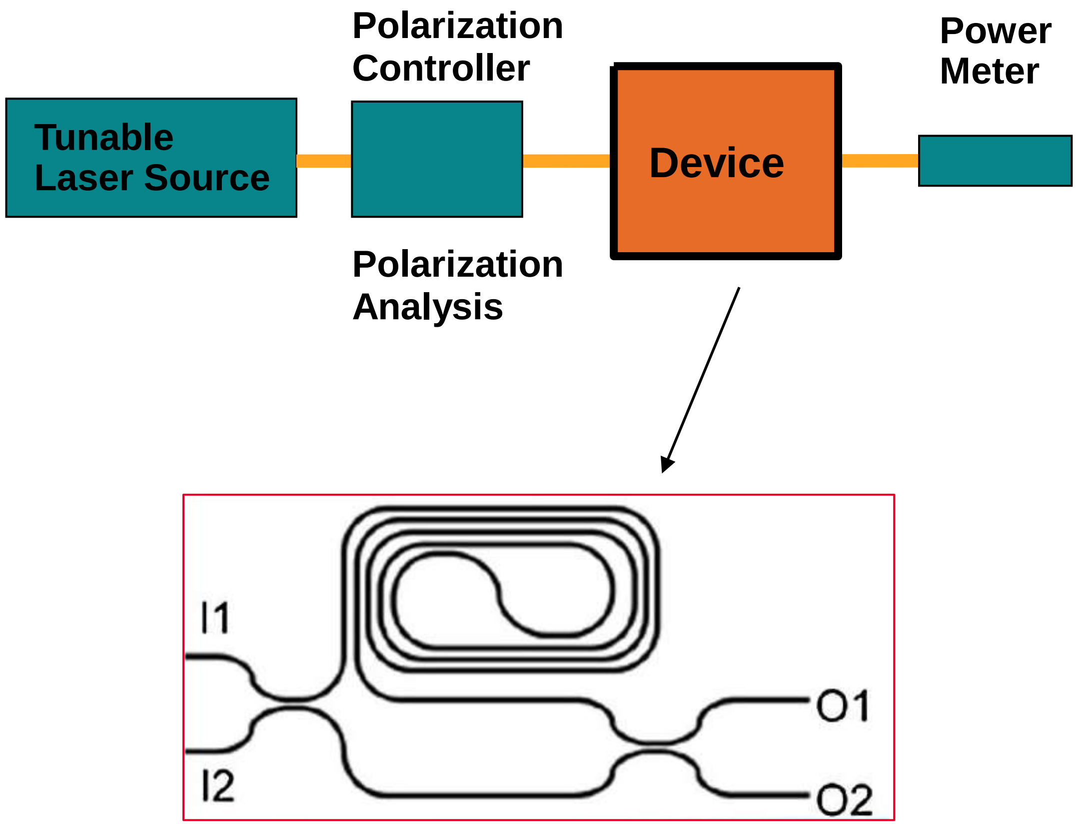




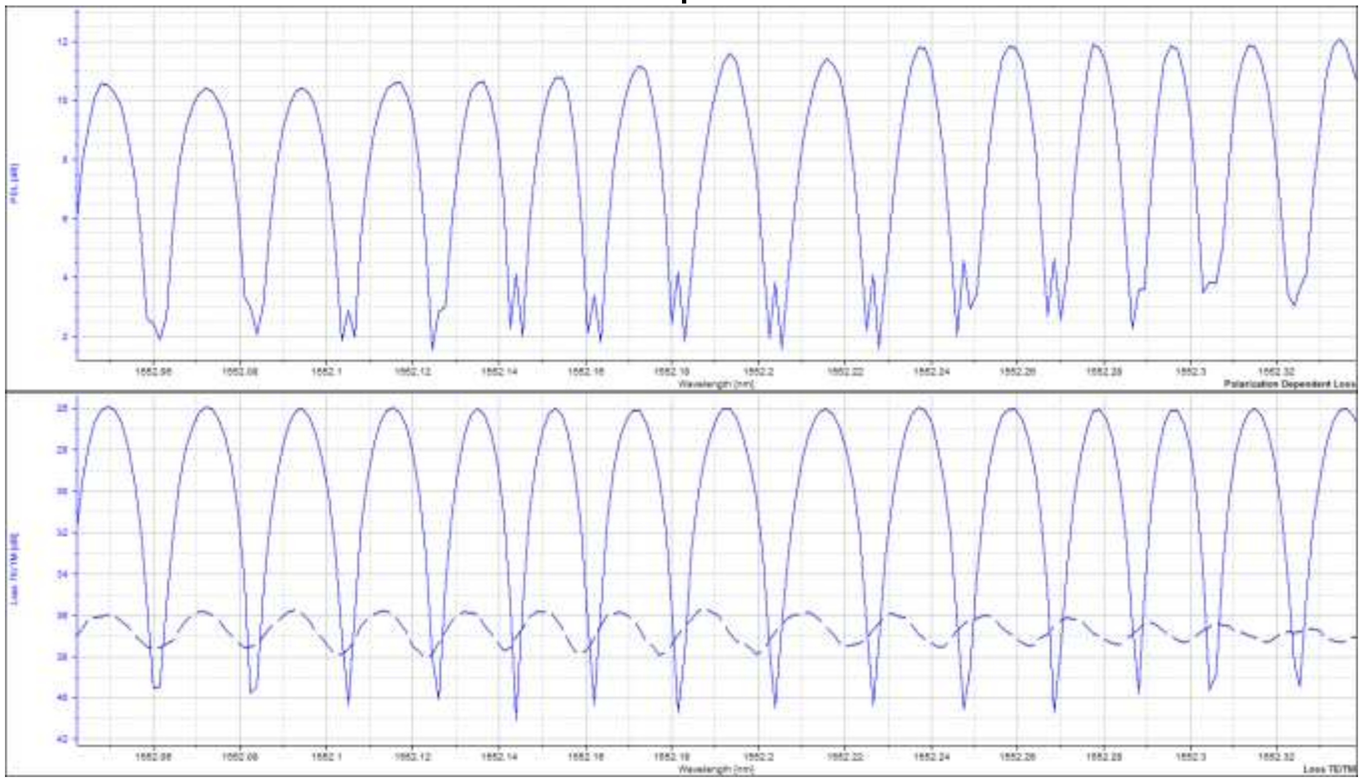


Photonic Measurement Solutions

MUELLER MATRIX – PASSIVE OPTICAL COMPONENT W/ MEDIUM PDL



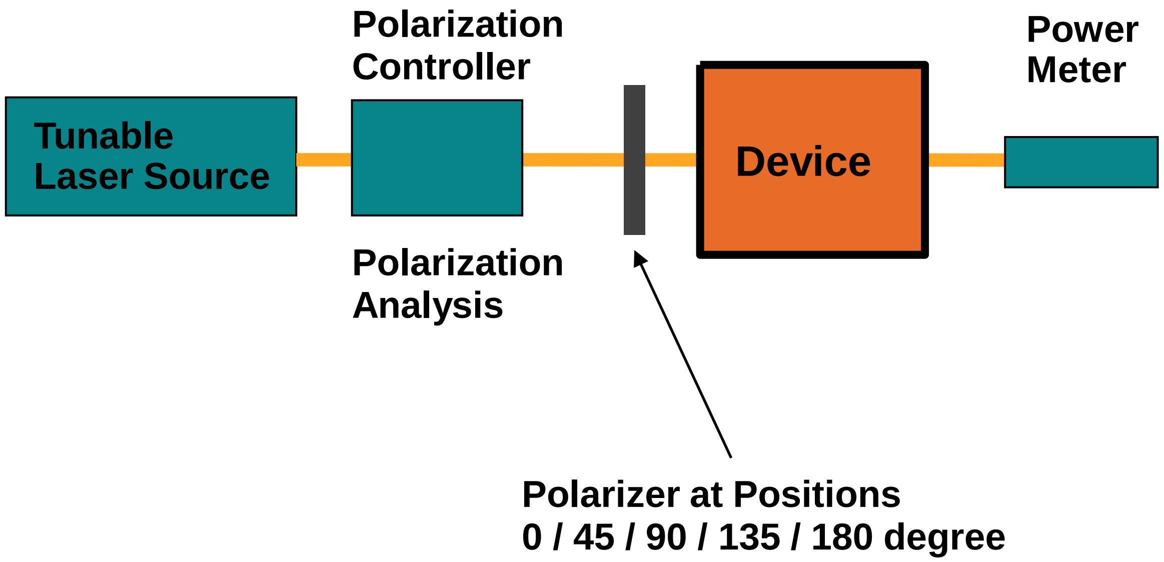
Polarization Dependent Loss

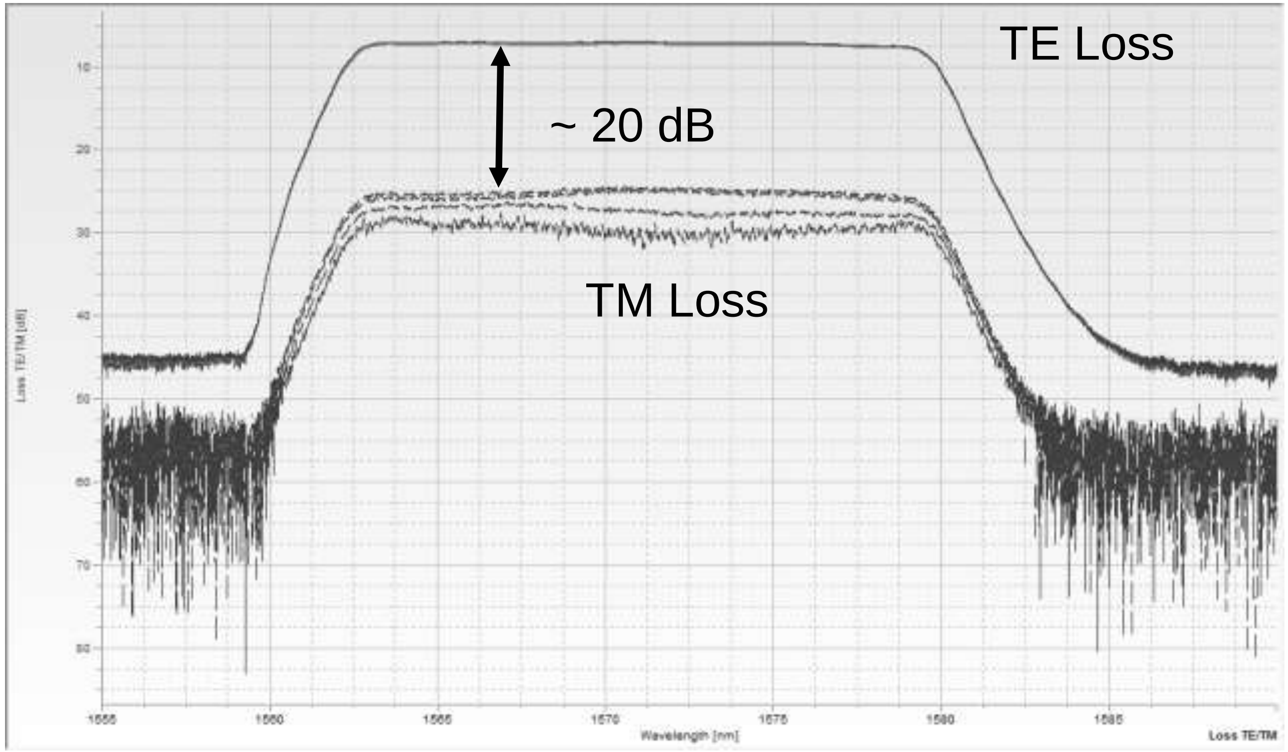


TE / TM Loss

Photonic Measurement Solutions

MUELLER MATRIX – HIGH PER PASSIVE OPTICAL COMPONENT

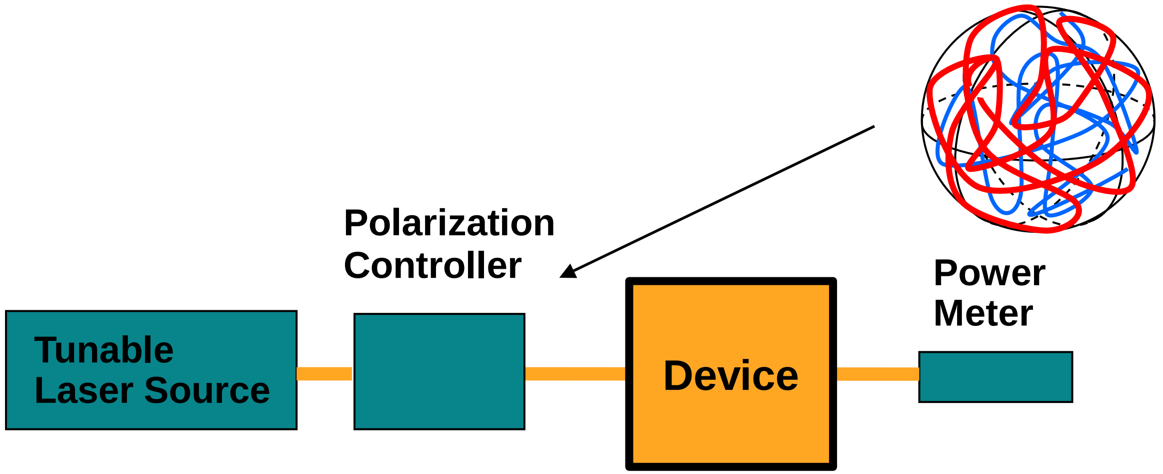




- Matrix analysis for IL in principle axes (TE Loss)
- No Polarization Alignment steps
- Mueller Matrix only able to resolve < 20 dB PDL

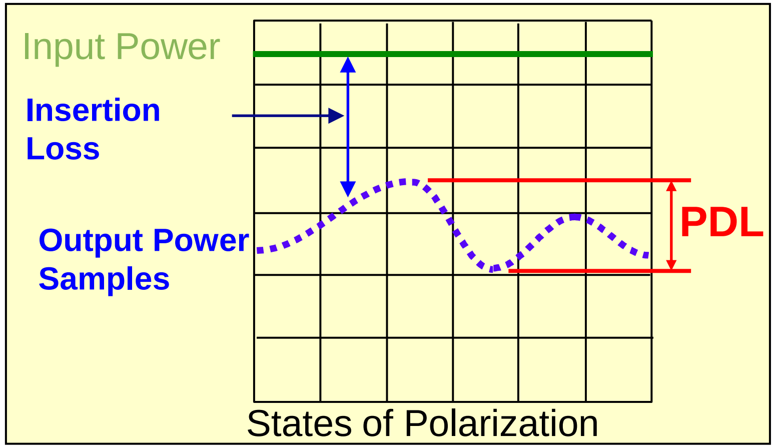
Photonic Measurement Solutions

ALL STATES – WAVELENGTH SELECTIVE PER MEASUREMENTS



Polarization Dependent Loss

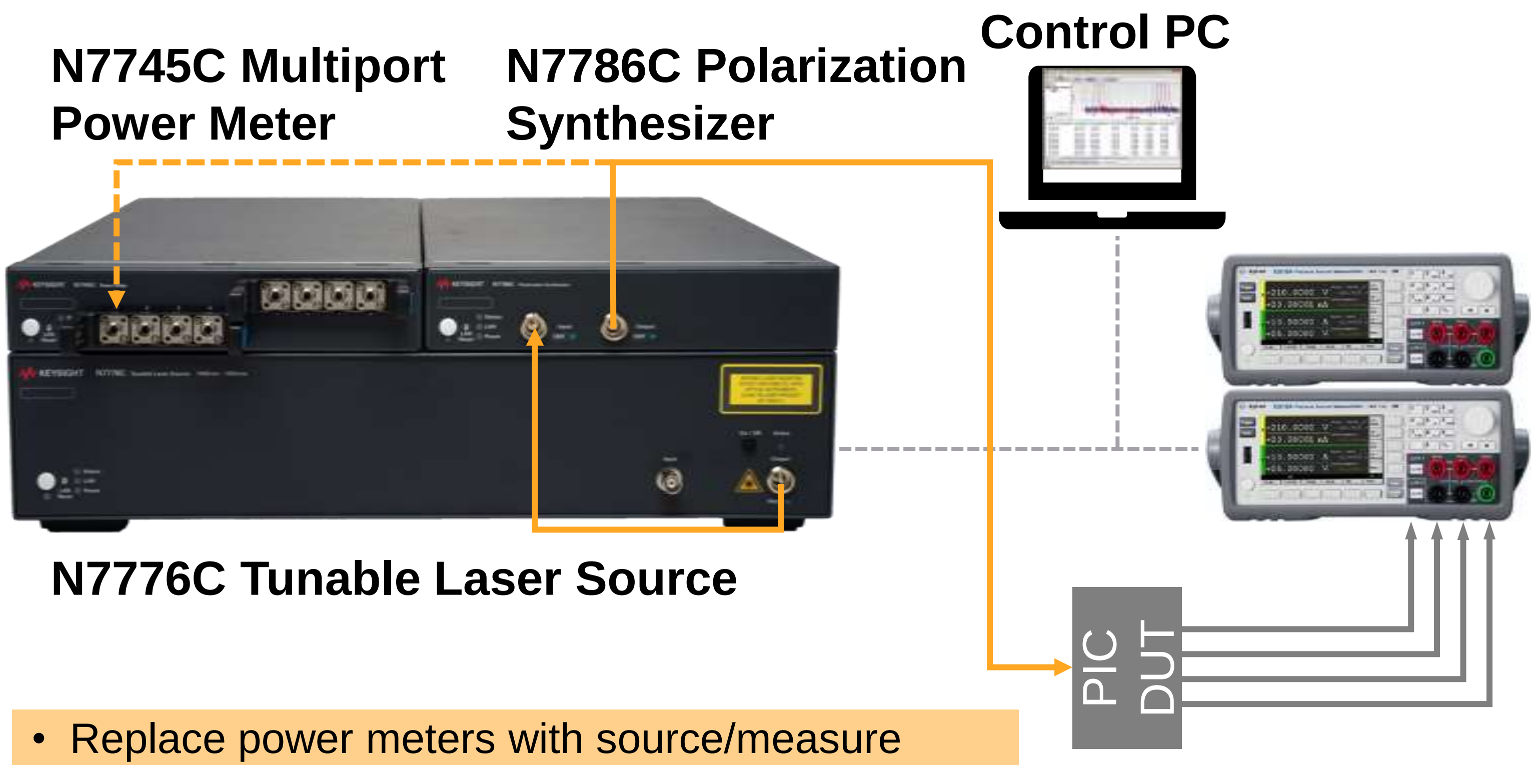
PDL = 10*log(Pout_max/Pout_min)

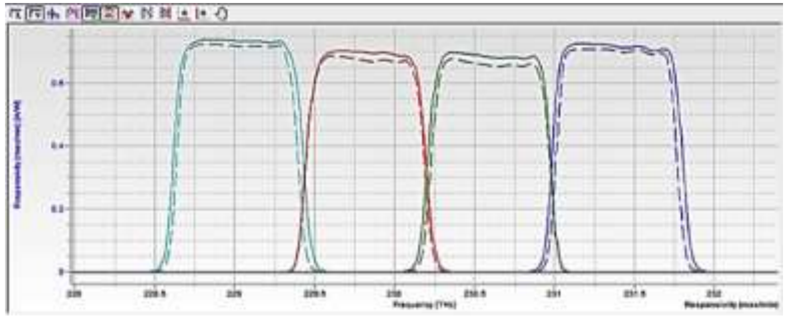


- ~ 2 to 5 seconds measurement time per λ
- Best for single / few λ's
- High accuracy
- Simple to implement
- Large Dynamic Range ~ 35 dB

Photonic Measurement Solutions

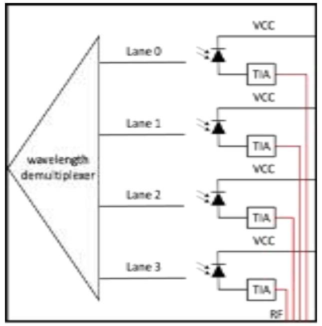
COMPONENTS WITH INTEGRATED OPTICAL DETECTORS





B2900A Series Source/ Measure Units

- Replace power meters with source/measure units to detect photocurrent for responsivity test
- Spectra for IL and pol.-averaged IL
- Matrix analysis for IL in principal axes (TE/TM) without polarization alignment steps
- CMRR for balanced ports



CWDM receiver

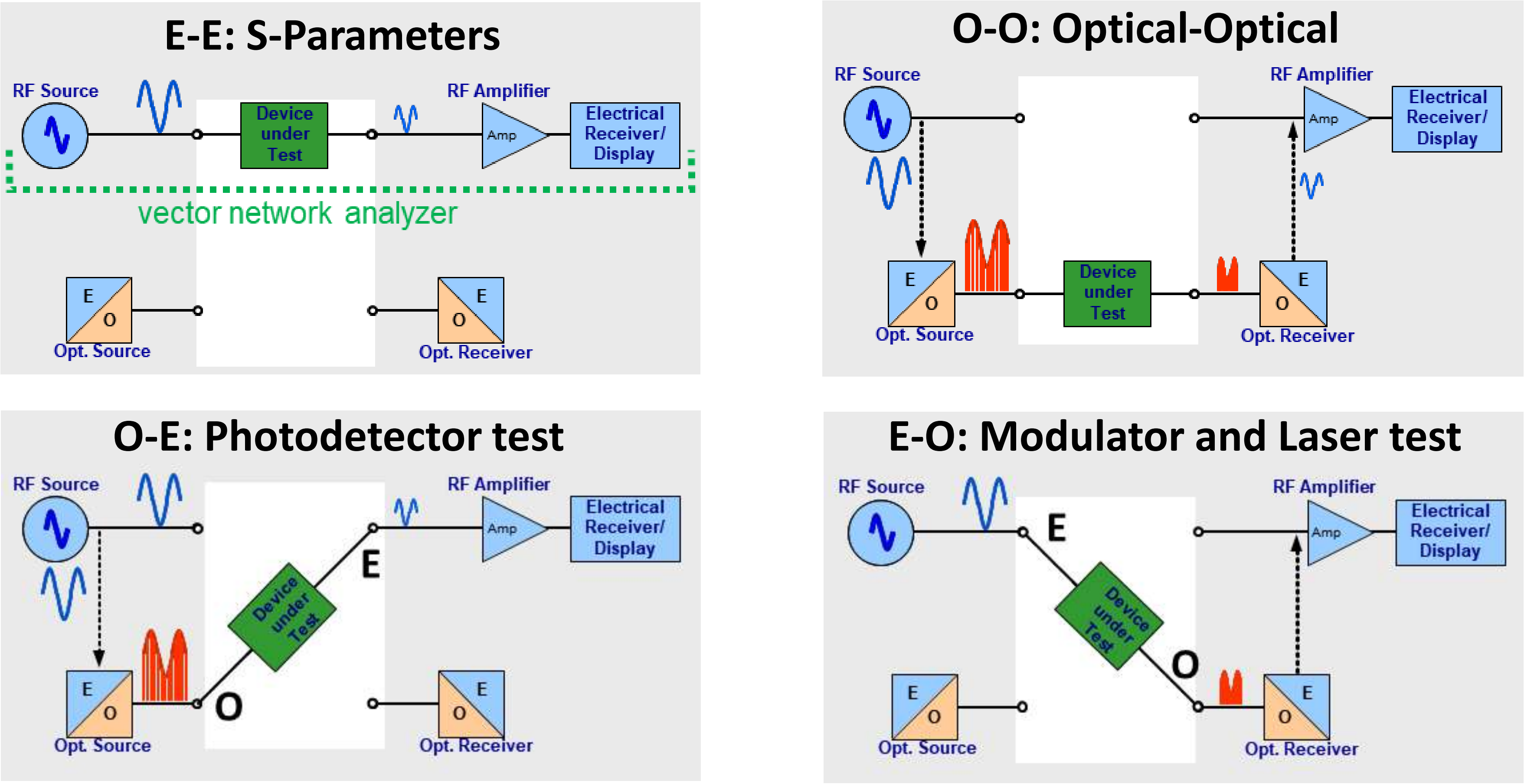
High-Frequency Testing

MODULATORS AND DETECTORS ON-WAFER

High Frequency Testing

LCA = VNA + CALIBRATED OPTICAL FRONT END

Lightwave Component Analyzer (LCA) Modes of Operation

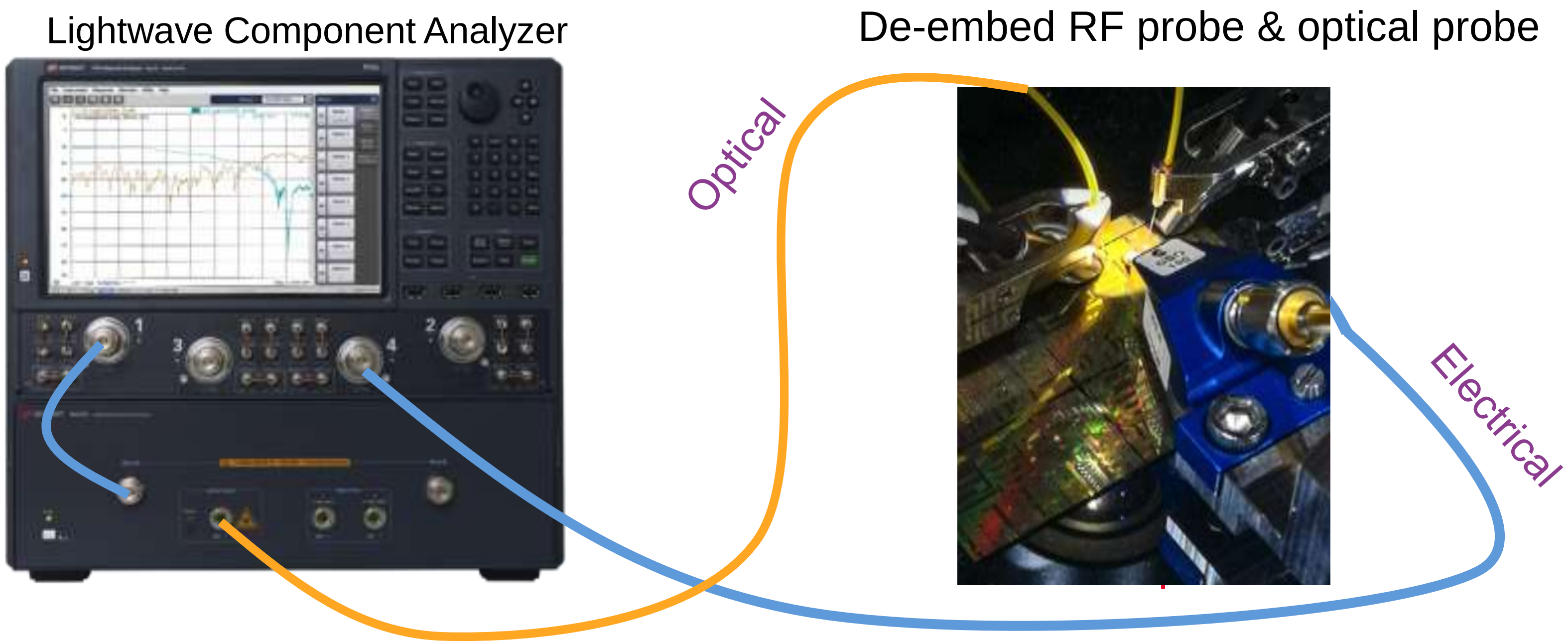


Mixed stimulus-response:
Wavelength: 0.85, 1.3, 1.5 μm

LCA measures photodetectors/ receivers and lasers/modulators

Example: LCA Wafer Level Test

PHOTODIODE ON WAFER/CHIP LEVEL



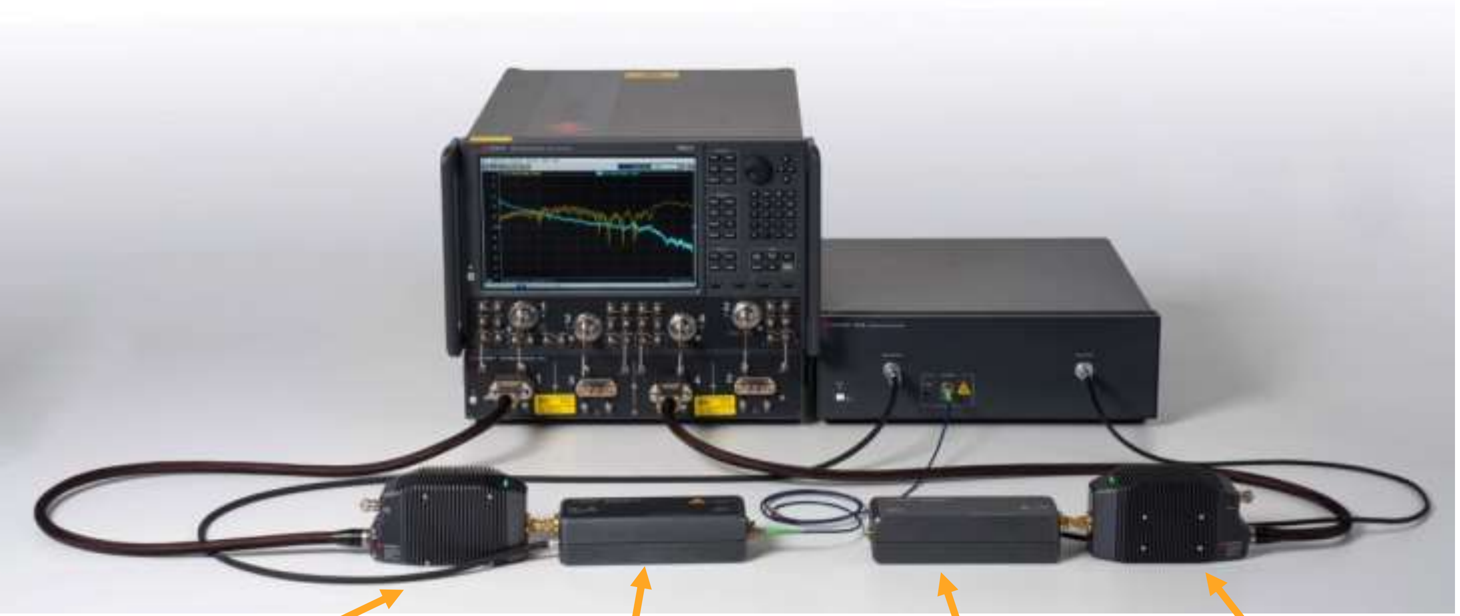
- Four LCA measurement modes:
  - OO, OE, EO and EE with one instrument
- 1310/1550 nm or 1290 to 1610 nm with external laser, 850 nm with MMF
- Balanced port measurements with 4-port network analyzer options

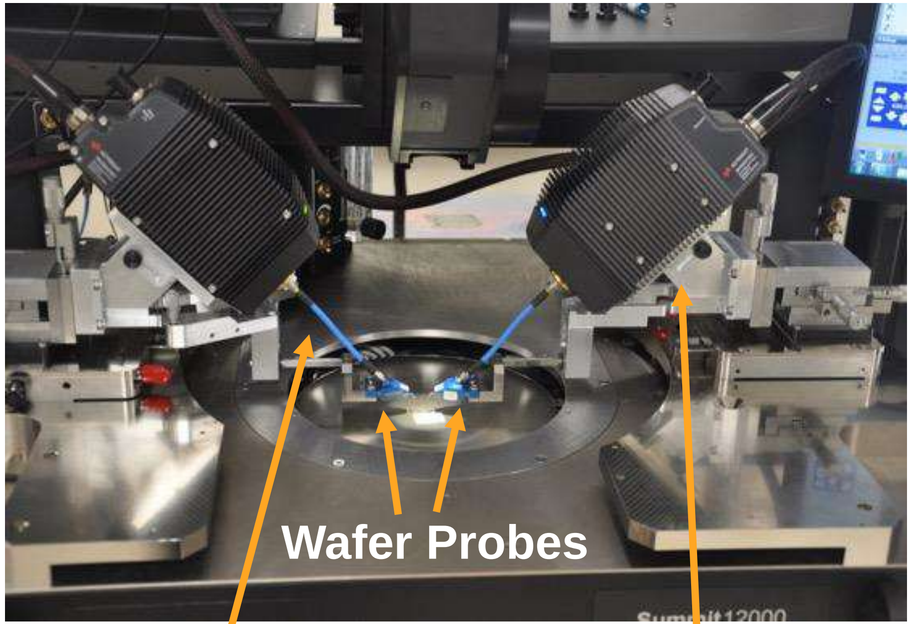
Polarization alignment of LCA stimulus signal to DUT needed:

- Done in combination with the IL/PDL setup and static mode or using PMF to DUT.

LCA Measurements Up to 110 GHz

GETTING RF TO DUT AS CLOSE AS POSSIBLE

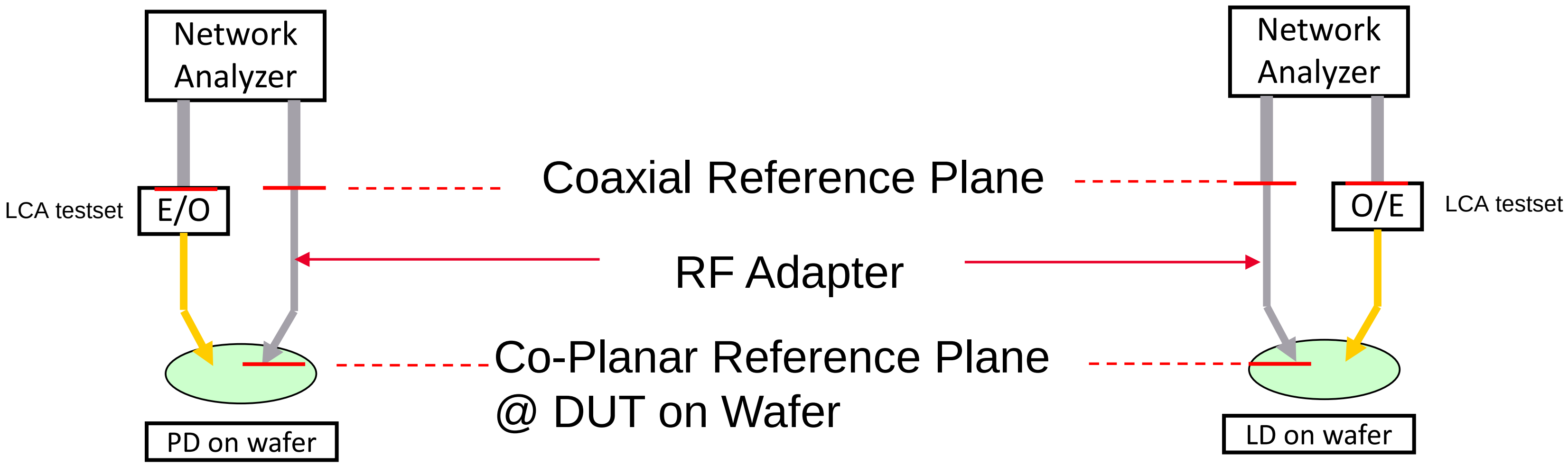




Calibration

TRANSFERRING CALIBRATION PLANE FROM COAXIAL TO CO-PLANAR

OE Measurement: EO Measurement:

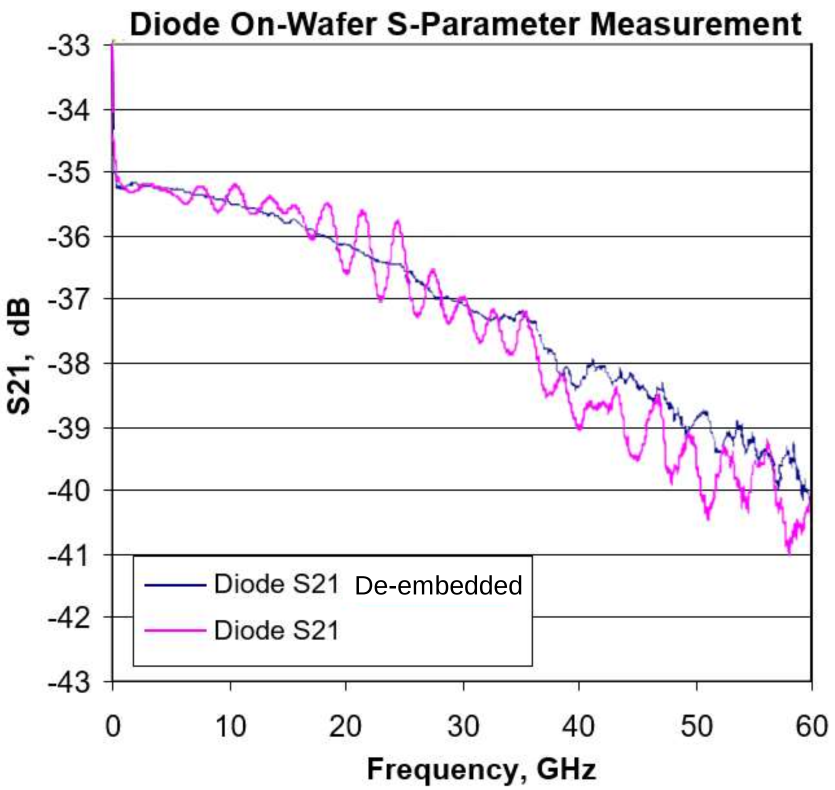


Steps:
1. Coaxial calibration 2-port
2. Connecting wafer probe
3. Co-planar calibration 1-port
4. Adapter characterization and de-embedding in VNA

RF adapter: RF cable + wafer probe

Photodetector Frequency Response

LCA MEASUREMENT ON WAFER LEVEL



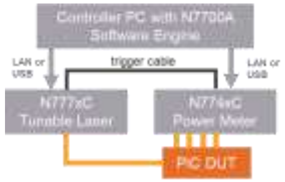
De-embedding as part of the calibration process provides a more accurate measurement

Summary

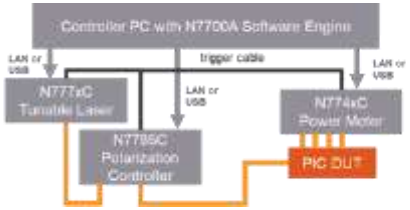
Summary of Photonic IC Test Solutions

WAVELENGTH AND FREQUENCY RESOLVED

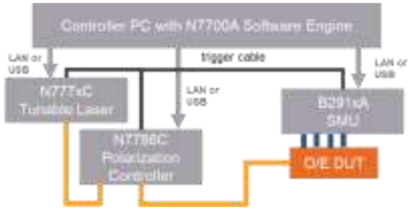
- ☑ **Simple insertion loss (IL) vs. wavelength**



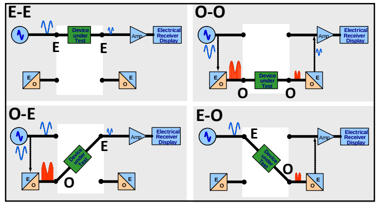
- ☑ **Polarization – dependent IL vs. wavelength**



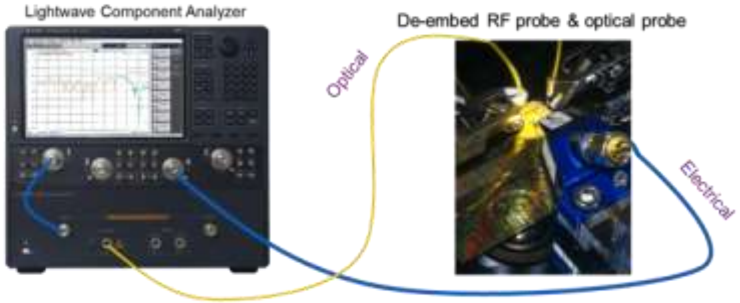
- ☑ **Polarization – dependent responsivity vs. wavelength**



- ☑ **E/O, O/E and S-Parameters vs. frequency, 4.5/26.5/67/110 GHz**



LCA: N437X



- ☑ **Test Automation**

Keysight References – Additional Information

[1] Keysight P/N 5964-9937E: “Polarization Dependent Loss (PDL) Measurement”
https://www.keysight.com/us/en/assets/7018-06776/application-notes/5964-9937.pdf

[2] Keysight P/N 5990-3281EN: “Measure Polarization Dependent Loss of Optical Components”
https://www.keysight.com/us/en/assets/7018-02006/application-notes/5990-3281.pdf

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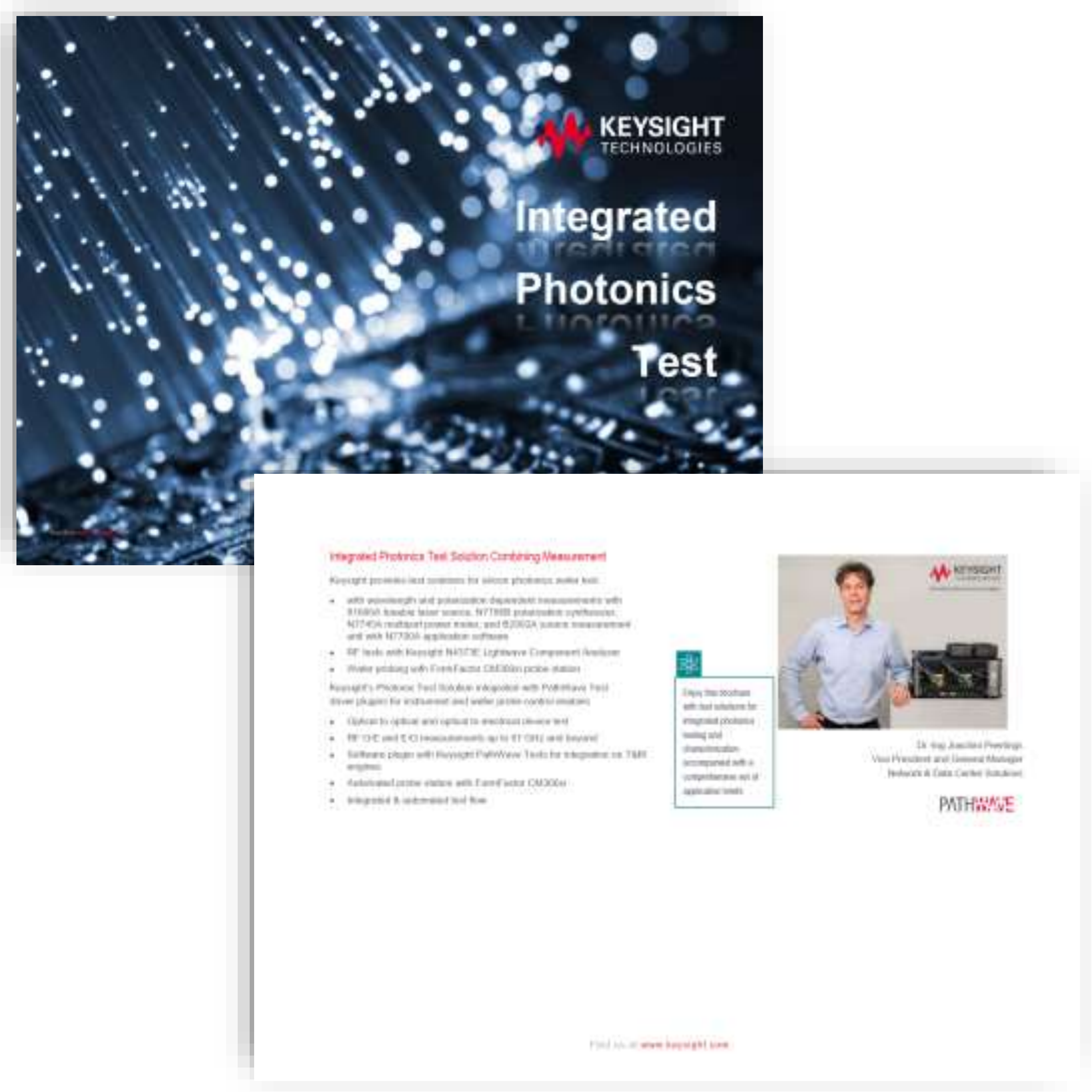

Integrated Photonics Test Solution Brochure

- 82 pages
- 62 pages with detailed product and solution description
- 20 pages with application briefs and technology insights
- Tables for an easy product selection
- Product & solution categories
- Specification Tables