A new method to determine Loss, PDL, GD, and DGD of passive optical components

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NFOEC, Dallas 2002
Outline

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Optical Network Evolution

Next Generation optical network facts:
- 40 Gb/s and beyond
- ultra dense WDM (≤10 Gb/s)
- transparent

Network performance strongly depends on both:

- amplitude (loss) and
- phase (dispersion)

characteristics of optical components
Complex component designs require an adequate all-parameter test method

Example: TFF-Design

Advanced components require high resolution and high accuracy for both loss and dispersion test

(G.Lenz et al., IEEE J. Quant. Electr., 1,390 (1998))
Experimental Setup

Swept homodyne interferometry
Loss & PDL Determination

• Application of four well-known polarization states to the DUT

• Transmission data are used to calculate the 1st row - Mueller matrix coefficients

• PDL is obtained from the Mueller matrix coefficients

accuracy comparable with polarization scanning method
GD & DGD Determination

Interferometric principle

\[ P_{i,j}(\omega) = E_{LO}^2(\omega) + E_{dut}^2(\omega) + 2 E_{LO}(\omega) E_{dut}(\omega) \cos \varphi_{i,j}(\omega) \]

Polarization resolved measurement based on two orthogonal sweeps \( i \) and detections \( j \).
Calculation from Jones matrix

Transformation of the eigenvectors $\vec{x}_{1/2}$ of the DUT Jones matrix

$$\vec{y}_{1/2}(\omega) = \sigma_{1/2}(\omega) e^{i\delta_{1/2}(\omega)} \cdot \vec{x}_{1/2}(\omega) = U(\omega) \cdot \vec{x}_{1/2}(\omega)$$

$$\vec{x}_{1/2} = \left( \frac{1}{\sigma_{1/2}(\omega)} e^{-i\delta_{1/2}(\omega)} U(\omega) \right) \cdot \vec{x}_{1/2}$$

Eigenvectors do not depend on the wavelength

$$\frac{d\vec{x}_{1/2}}{d\omega} = 0 = \left( \frac{-\sigma_{1/2}'}{\sigma_{1/2}^2} e^{-i\delta_{1/2}} U - \frac{1}{\sigma_{1/2}} i\tau_{1/2} e^{-i\delta_{1/2}} U + \frac{1}{\sigma_{1/2}} e^{-i\delta_{1/2}} U' \right) \cdot \vec{x}_{1/2} .$$

Simplification to an eigenvalue relation

$$(\gamma_{1/2} U - U') \cdot \vec{x}_{1/2} = 0 \quad \text{, with } \gamma_{1/2} = \frac{\sigma'}{\sigma} + i \tau_{1/2}$$

Calculation of GD and DGD from the eigenvalues

$$DGD(\omega) = |\text{Im}(\gamma_1) - \text{Im}(\gamma_2)|$$

$$GD(\omega) = \frac{1}{2} \left( \text{Im}(\gamma_1) + \text{Im}(\gamma_2) \right)$$
Comparison of measured and theoretical GD curve of HCN gas cell peak

Theoretical curve reconstructed with Kramers-Kronig relation from amplitude response.

deviation below 1%
Comparison of DGD measurement with NIST

Averaged DGD results on NIST SRM 2518 / 029

NIST device consist of coupled waveplates.

DGD value is averaged over wavelength interval (PMD 1st order).
Measured DGD repeatability (i.e. TFF)
**Noise contribution of setup**

- **GD**

![Graph showing GD noise variation with averages and sliding window width]

- **DGD**

![Graph showing DGD noise variation with averages and sliding window width]

Number of averages and width of sliding window have to be set properly for required SNR and spectral resolution.
Measurement of Dispersion Compensator (FBG)

- Reflection

- Transmission
Measurement of Thin-Film Filter

- IL [dB]
- GD [ps]
- DGD [ps]

Wavelength [nm]

IL:
- 0 dB
- -10 dB
- -20 dB
- -30 dB
- -40 dB
- -50 dB

GD:
- -50 ps
- -40 ps
- -30 ps
- -20 ps
- -10 ps
- 0 ps

DGD:
- 1 ps
- 2 ps
- 3 ps
- 4 ps
- 5 ps
Measurement of AWG

- IL [dB]:
  - 0 dB
  - -10 dB
  - -20 dB
  - -30 dB
  - -40 dB
  - -50 dB
  - -60 dB

- GD [ps]:
  - -30 ps
  - -20 ps
  - -10 ps
  - 0 ps
  - 10 ps
  - 20 ps
  - 30 ps
  - 40 ps
  - 50 ps
  - 60 ps
  - 70 ps

- PDL [dB]:
  - 0 dB
  - 2 dB
  - 4 dB
  - 6 dB
  - 8 dB
  - 10 dB
  - 12 dB

- DGD [ps]:
  - 0 ps
  - 10 ps
  - 20 ps
  - 30 ps
  - 40 ps
  - 50 ps
  - 60 ps
  - 70 ps

- Wavelength [nm]:
  - 1552.8
  - 1553.2
  - 1553.6
  - 1554.0
  - 1554.4

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Measurement of EDFA

- **IL (dB)**: A plot showing insertion loss at various wavelengths.
- **GD (ps)**: A plot showing group delay as a function of wavelength, with a red line indicating data.
- **DGD (ps)**: A plot showing differential group delay with a blue line indicating data.

The diagrams cover a wavelength range from 1530 nm to 1570 nm.
Summary

• In this presentation we reported on a new measurement method for testing passive components for spectral loss, PDL, GD, and DGD.

• When moving to advanced networks (beyond 10G or ultra-dense) requirements to test all-parameters can be expected for many components.

• All-parameter test combines the state-of-the-art technique for Loss and PDL with a new high potential interferometric GD and DGD measurement.

• The new measurement method demonstrates its potential particularly when characterizing advanced network components.