All Fiber Polarization Scrambler

Your Solution for Polarization related Problems

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1. Introduction:
   - Why PS?
2. Polarization scrambling:
   - Principle and Methods
   - Features of FiberPro's PS
3. Applications
4. Conclusions
To solve the polarization-related problems in,

- Communications
- Measurements
- Sensors
Limiting Factors in Amplified systems Cumulative Signal distortions

Polarization effects

- Polarization mode dispersion (PMD)
- Polarization Dependent Loss (PDL)
- Polarization Dependent Gain (PDG)

- Temporal pulse broadening
- SNR fluctuations
- SNR average penalty

1000km span, Including CD, Nonlinear effect

J. Chesnoy, Alcatel, ECOC'97
Polarization effect in long haul systems

- Simulation parameters:
  - PDG = 0.14 dB/EDFA
  - PDL = 0.06 dB/EDFA
  - PMD = 0.13 ps/√km

- Experimental parameters:
  - 1 kHz scrambling speed
  - Single source (1558.6 nm)
  - 5 Gbps, NRZ
  - with 181 EDFA, 4000 km link

Mean penalty on the Q factor in a 4000 km link

Mean penalty on the SNR in a 4000 km link

Improvement in the mean Q due to polarization scrambling vs. link length at DOP < 10%

Polarization Problems in Measurement

- **Example 1.**
  In long-haul DWDM system, **Gain-Wavelength characteristics** need to be tested **precisely up to 0.005 - 0.01 dB**
  For equalization and etc.
  - Input Light Power fluctuation by PDL
  - Output Power fluctuation by PDG (~0.1dB)
  - PDL in measurement equipment (0.03-0.1dB)

- **Example 2.**
  **Filters** for telecommunications requires to set accurately less than 10G Hz(0.08nm). PDL can give wrong value of **center wavelength** during interrogation.
Polarization-Induced Phase Noise in Fiber Interferometric Sensors

- Polarization Perturbations of Input Fiber
  - Visibility fluctuation
  - Phase Noise
solve the polarization-related problems in,

**Communications**
- PDG in long EDFA chain

**Measurement**
- Error caused by PDL of DUT & Measuring equipment

**Sensors**
- Polarization induced phase noise
What is polarization scrambling?

A. Depolarizer:
   Removing correlation between polarization states
   (Broadband Source)
   e.g.: Lyot depolarizer

B. Polarization Scrambler:
   Modulate polarization state
   (over Poincare sphere)
   (Monochromatic Source)
How to make polarization scrambling?

Concept: Apply time varying phase delay between the two orthogonal polarization modes.
Principle of Polarization Scrambling

Monochromatic light

\[
\begin{align*}
E_x(t) &= a_1 \exp \left[ i \phi_1(t) \right] \\
E_y(t) &= a_2 \exp \left[ i \phi_2(t) \right]
\end{align*}
\]

\[\delta = \phi_1 - \phi_2\]

General Stokes Parameters

\[
\begin{align*}
S_0 &= \langle a_1^2 \rangle + \langle a_2^2 \rangle \\
S_1 &= \langle a_1^2 \rangle - \langle a_2^2 \rangle \\
S_2 &= 2 \langle a_1 a_2 \cos \delta \rangle \\
S_3 &= 2 \langle a_1 a_2 \sin \delta \rangle 
\end{align*}
\]

Effective Degree of Polarization

\[
P_{\text{eff.}} = \frac{I_{\text{pol.}}}{I_{\text{tot.}}} = \frac{\sqrt{S_1^2 + S_2^2 + S_3^2}}{S_0} \quad (0 < P_{\text{eff}} < 1)
\]

Effectively Depolarized Light (Perfectly Scrambled Light)

\[P_{\text{eff.}} = 0\]
Electro-Optic Polarization Scramblers

- Fast Speed.
- Relatively small
- Phase chirp
- High PMD: ~ 17 ps
- Complex driving circuit
- High loss: > 5 dB
- Input Pol. Dependent

\[ \Delta \phi (t) = \Gamma_y \left( \frac{2 \pi}{\lambda_0} \right) n_0^3 r_{12} L \left( \frac{V(t)}{G} \right) \propto \frac{1}{\lambda^2} \]
Mechanical/PM fiber Polarization scramblers

- Pseudo Random Pol. generation
- Slow speed: ~100 rev./sec MAX
- Not for DOP zero applications
- High PMD (PM fiber type)

Rotating waveplate

PM fiber

Trace for 2 second

Poincare Sphere
Polarization scrambling at PS

Poincare Sphere

Input polarization independent
Polarization scrambling

Sinusoidal Modulation of Birefringence

For orthogonal polarization
Poincare Sphere representation of Output SOP

Trace for 200 µsec
Polarization Scrambler Output

Input Polarization Independent

PS is OFF

PS is ON
Output DOP vs. Measurement Bandwidth

- PS makes Zero DOP on time average.
- Measurement bandwidth is important parameter when using PS.
FIBERPRO S All Fiber Optic Polarization Scrambler
PS for Rack mount (custom made)
Why FiberPro’s PS?

- All Single Mode Fiber configuration
- Low Loss < 1.5dB (with connectors)
- Super Low PMD < 0.2 psec
- High Speed
- Wide operating Wavelength Range: > 60nm
- Plug & Play
Typical applications of PS

• Improving SNR from PDG, Pump Pol. Dep. in long-haul systems

• PDL independent measurement. Filter, DFA, and etc.

• Removing error from equipment. DDS, PDL
BER Improvement in Long-haul Transmission: Single channel

Set-up ~9000 km transmission

BER after transmission

F. Heismann, et al., PTL, Vol. 6, No. 9, 1156 (1994)
SNR Improvement in Long-haul Transmission: Multi channel

Reduce accumulated ASE noise

-after 9000km transmission

w/o PS
w/ PS

Optical power (dBm)

Optical spectrum

SNR improvement

-w/o PS same SOP
-w/o PS orthogonal SOP
-with PS

Accumulated PDG/PDL in long EDFA chain

LD: Laser Diode
VA: Variable Attenuator
AOM: Acousto-Optic Modulator
PC: Polarization Controller
GFF: Gain Flattening Filter

IL Interrogation of DUT with PDL

PDL in the DUT can make erroneous values in measuring IL and etc.
Polarization Induced Phase noise

- Polarization induced noise
- Interferometer output
- Noise floor when scrambler Off
- Noise floor when scrambler ON

A. D. Kersey, et. Al., JLT, Vol. 8, No. 6, 838 (1990)
other applications...

- Pump Polarization Dependent Gain in EDFA
  1480 nm, 980nm version is available
  other wavelengths are also available.

- Polarization modulator applications
  sensors, lasers, and etc.

- Polarization Dependent Loss measurement
  PDL Multimeter under development
Conclusions

All Fiber Polarization Scrambler

- **Solves PDG/PHB** in long-haul systems.
- **Component characterization** without polarization dependence.
- **Manufacturing** filters or WDM component.
- **Removes Polarization induced phase noise or errors** in Fiber Interferometers
- **Polarization Simulation**.

Future works

Fast PDL measurement