Fiber Sensing

GRP Workshop SCA25, Singapore

Marc Lyonnais, Director External Research, R&D

The Agenda

SMART CABLES OVERVIEW

DISTRIBUTED ACOUSTIC SENSING

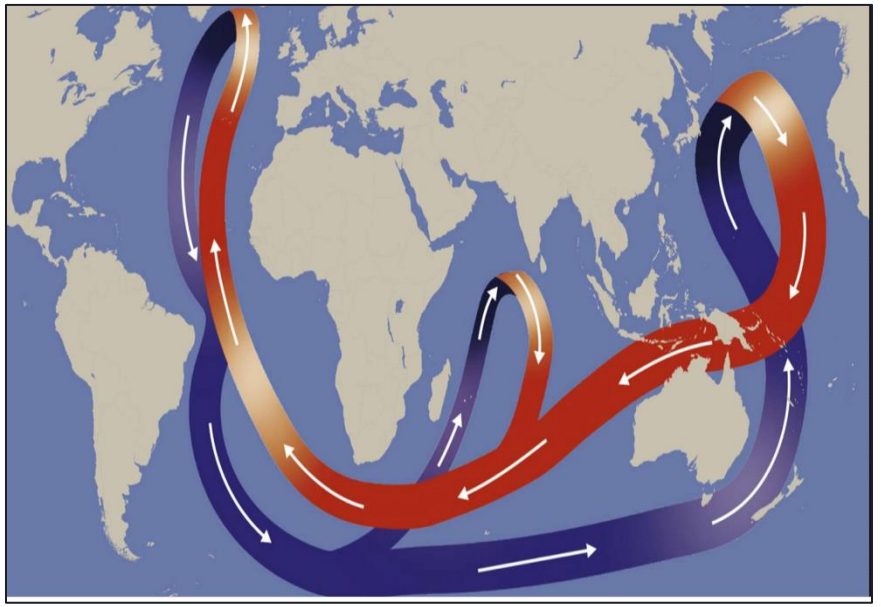
SOP CASE FOR CIENA

SMART Cables Overview

Who we are, our mandate

....a global initiative, with 300 volunteers and stakeholders from science and society, engineering, data management, business development, and legal and regulatory disciplines...

Earthquakes and Tsunamis



Climate Change, ocean heat, circulation and sea level rise

United Nations effort uniting science with the telecom industry to observe the oceans and Earth

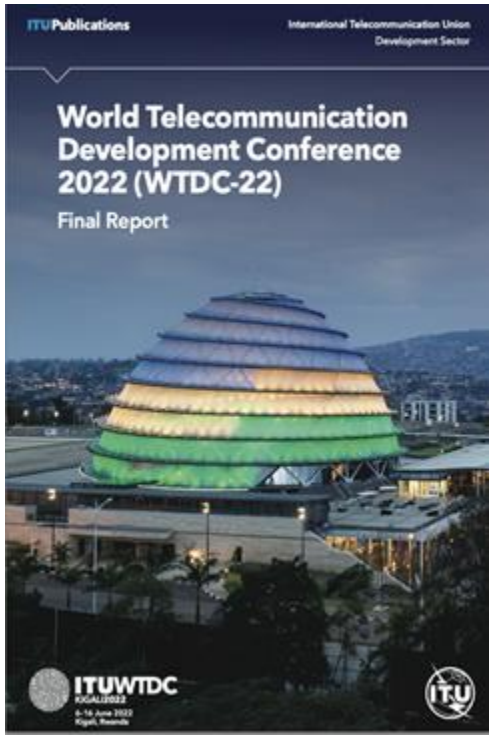
Source: SMART CABLE, Bruce Howe

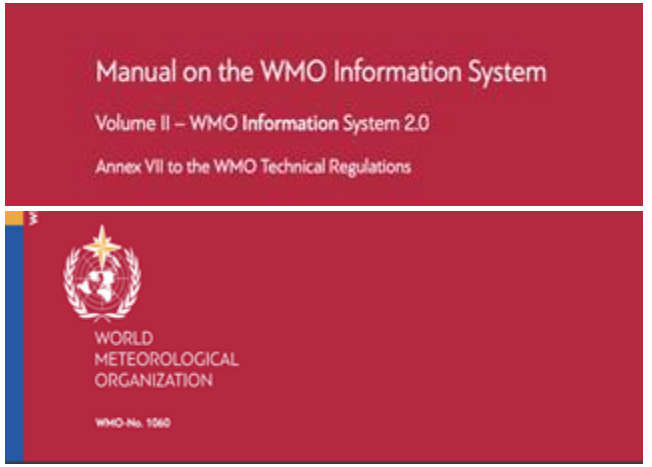
JTF Sponsors

- JTF Secretariat
- Resolutions on climate change Disaster Risk Reduction (DDR) includes SMART
- Recommendations SG15/Q8 G.dsssc/9730.1 and G.SMART/9730.2

- Integrates SMART into WMO Information platform

- Global Ocean Observing System (GOOS)
- Tsunami Programme
- UN Ocean Decade: endorsed Project
- Emerging Observing Network of GOOS





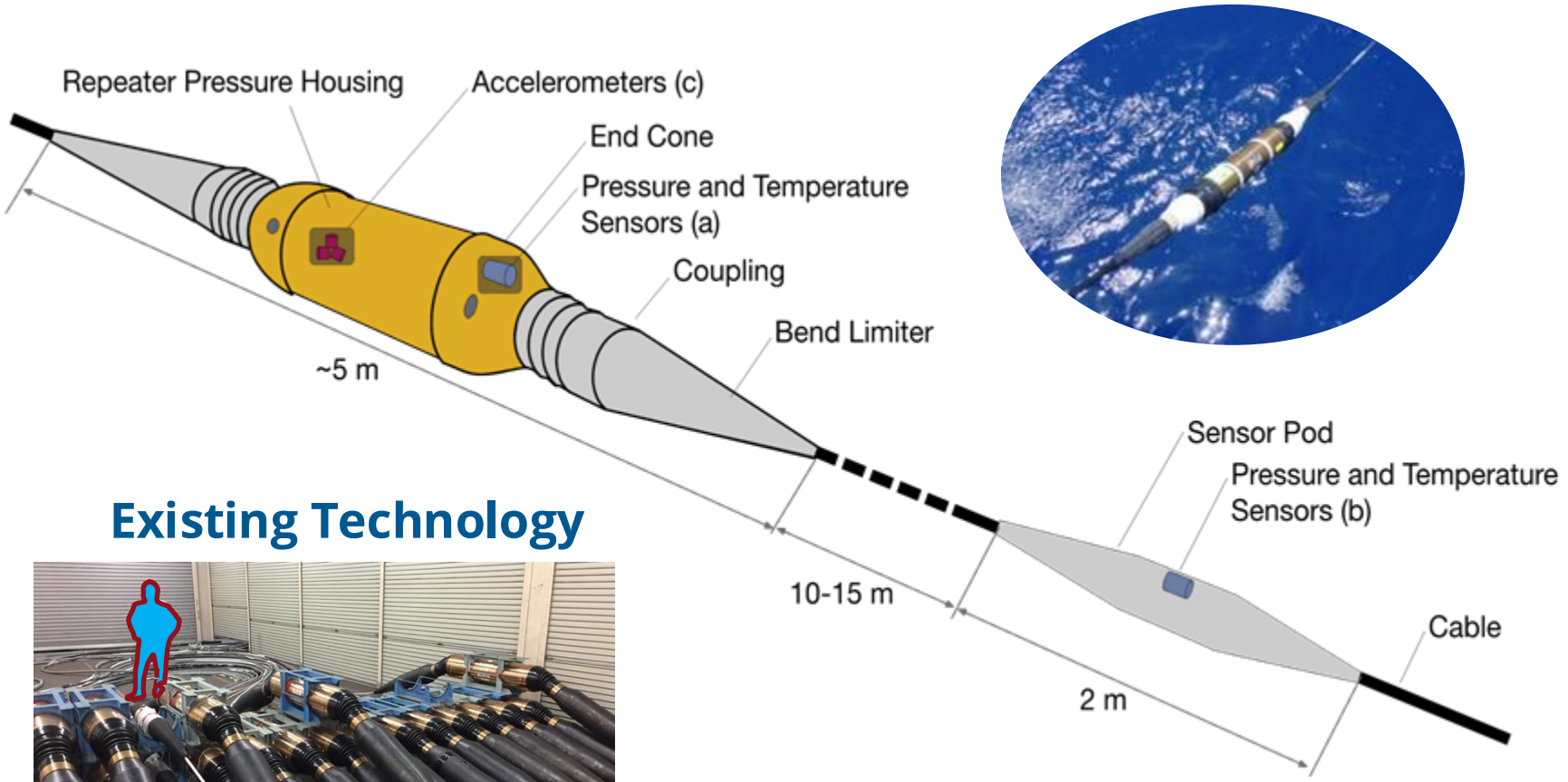
The Global Ocean Observing System

UN World Conference on Disaster Risk Reduction 2015 Sendai Japan

Source: SMART CABLE, Bruce Howe

SMART Technical Solution

Shared Cable Infrastructure: Telecom + Science



Existing Technology

Sensors:

- Temperature
- Pressure
- Seismic

Key points:

- Spacing ~100 km
- Essential Ocean Variables, Global Ocean Observing System

No Interference

Source: SMART CABLE, Bruce Howe

Distributed Acoustic Sensing

Optical Fiber Sensing Categories

Backscatter:

- DAS – Distributed acoustic sensing (Rayleigh)
- DSS – Distributed strain sensing (Brillouin)
- DTS – Distributed temperature sensing (Raman)

} Short range – kms

} Set aside for now

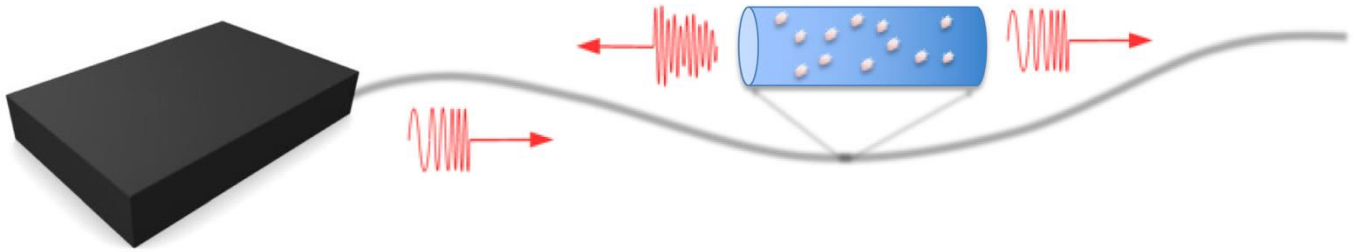
Forward Propagation

- SOP – State of polarization
- USLI – Ultra-stable laser interferometry

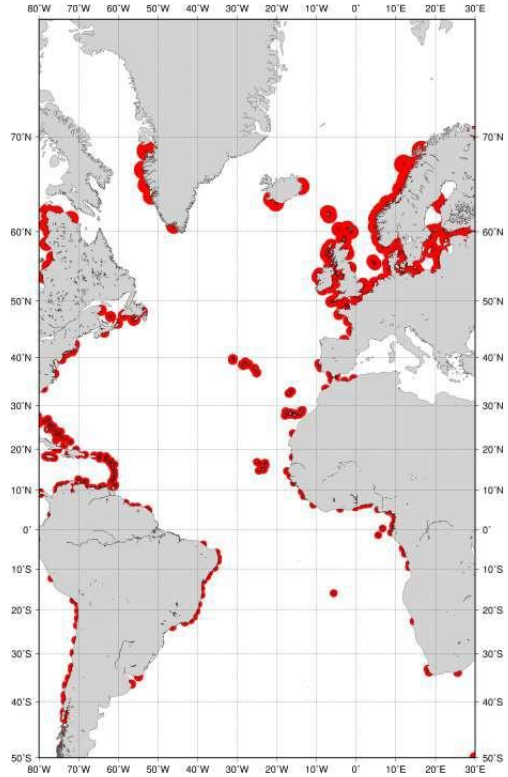
} Exponential growth of scientific publications

} Transition research - applied

Distributed Acoustic Sensing



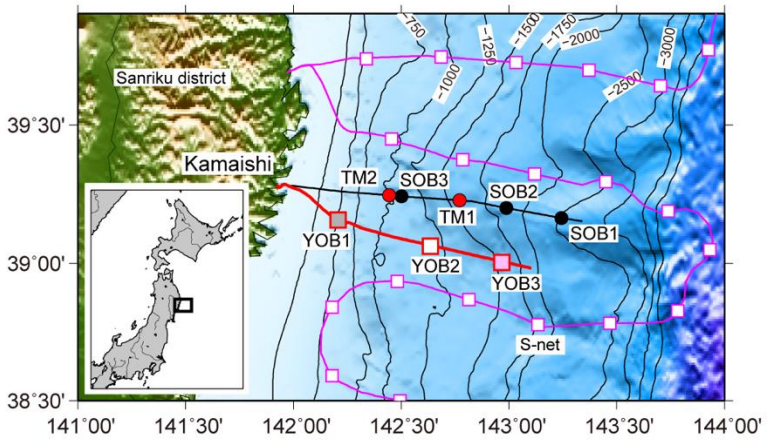
- **Backscatter:**
- DAS – Distributed acoustic sensing (Rayleigh)
- Scatters off natural inhomogeneities / index of refraction / impedance
- Typical range 50-170 km (present)
- One interrogator on one end (shore)
- Strain and temperature



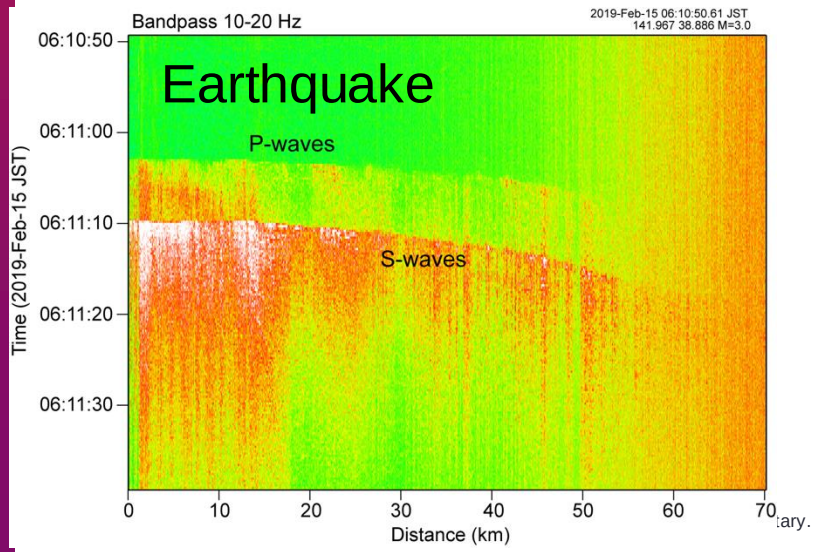
100 km shore

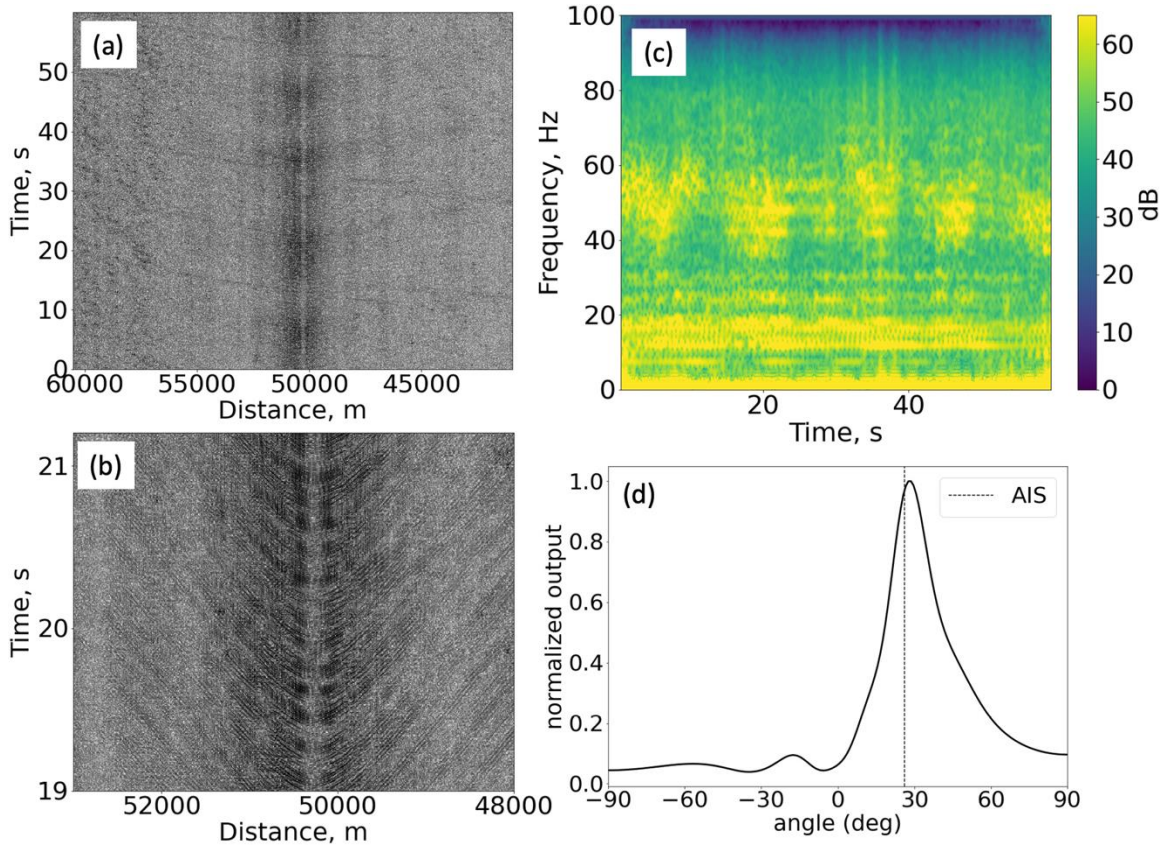
Source: SMART CABLE, Bruce Howe

Examples of DAS



DAS using Sanriku seafloor cable observation system. Shinhoara et al, 2019)



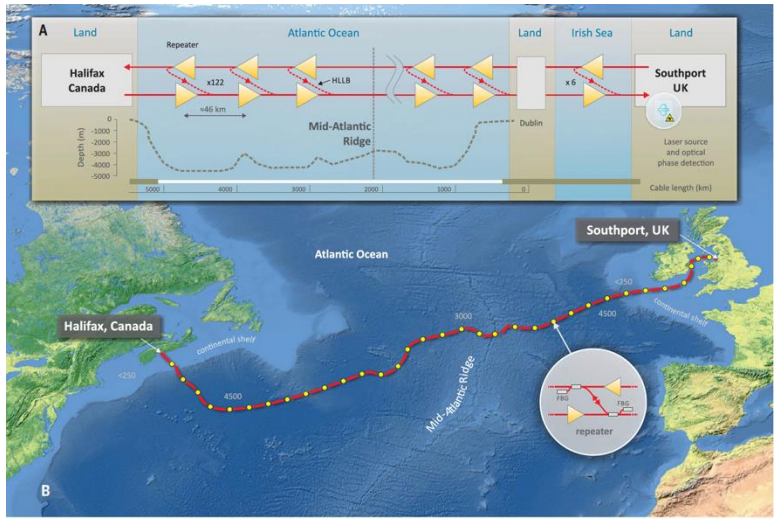


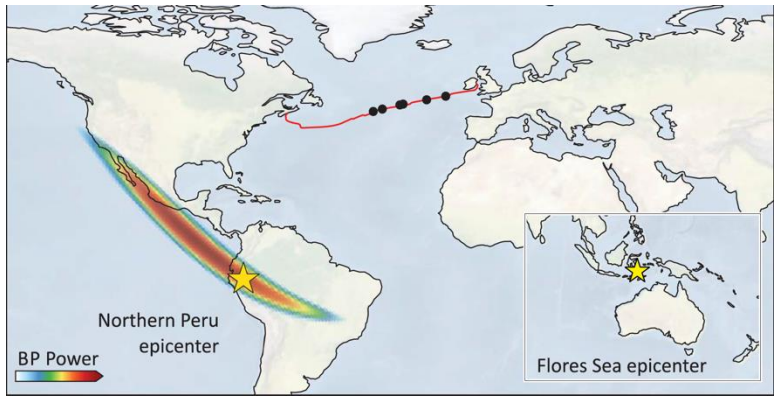
180 m–long cargo ship, 50 km to cable, 13 kt. At 26 deg. Detection range interval 5 km. (Wilcock et al., 2023)

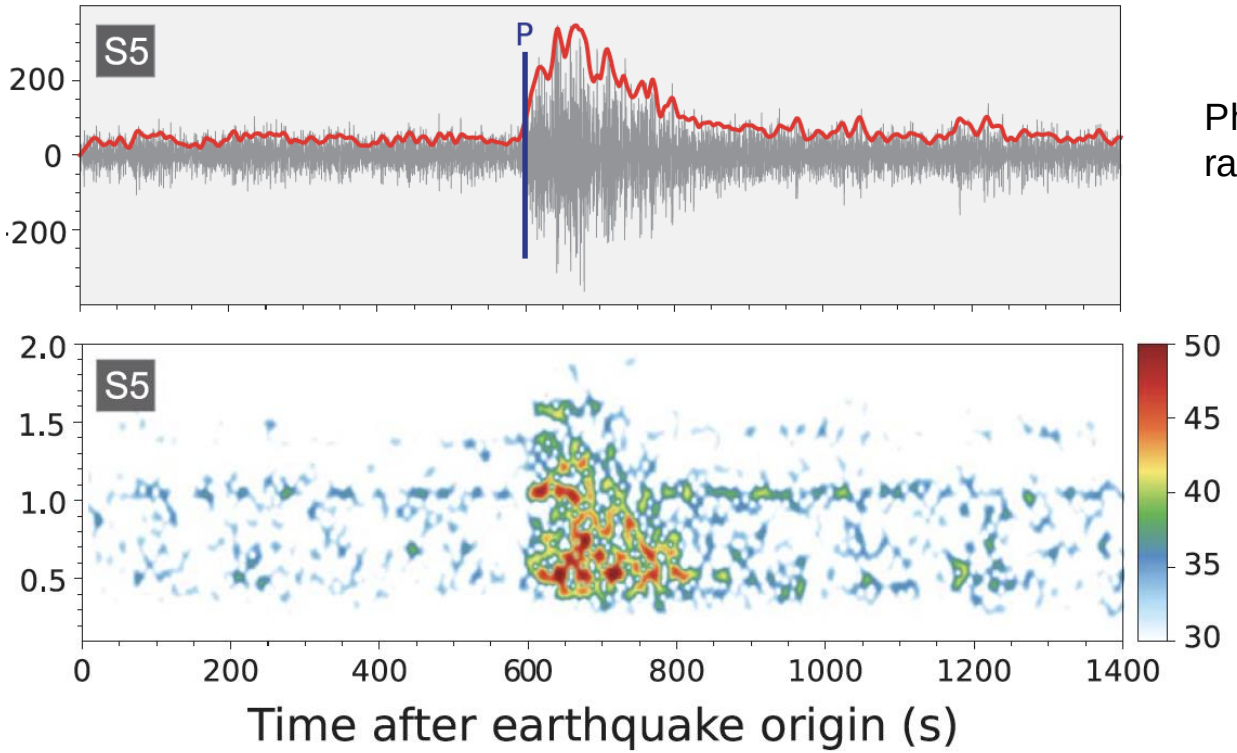
Source: SMART CABLE, Bruce Howe

USLI – Ultra-stable laser interferometry

- Strain and temperature – change in optical phase
- First in 2018 – between shore stations – now Marra et al., 2022:
- Round-trip (loop-back) accumulated optical phase changes in the fiber between the transmitter end of the cable and repeater n
- Then difference - Phase changes between respective repeaters
- An earthquake off South America, use 6 repeater spans







Phase
radians

Freq Hz left
dB right

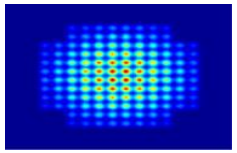
Source: SMART CABLE, Bruce Howe

SOP Case for Ciena

Opportunities for Neural Nets with Machine Learning using Modem Data

- Modern DWDM systems can now produce vast amounts of data
- Coherent modems by their very nature can generate a number of different optical parameters which historically were difficult to measure in real-time
- Combining traditional system parameters like power levels, loss, distance with coherent modem parameters like CD, PMD, SOP, SNR, etc yields a rich area for analysis

Higher Baud/Higher order modulation



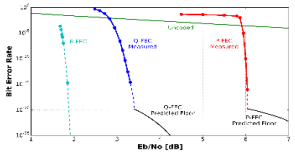
- Selectable baud- up to 95 Gbaud
- Optimize capacity for a given photonic layer

Link Monitoring Enhancements

$$SNR_{ASE} = \frac{S(\Delta f)}{N(\Delta f)}$$

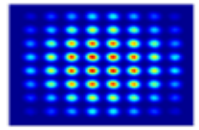
- Link monitoring derived from machine learning
- Ability to optimize network designs

Enhanced coding gain



- Longer distance
- More capacity/wave
- Higher spectral efficiency

Probabilistic Constellation Shaping



- Granular capacity increments, from 200G-800G to optimize capacity to avail. margin

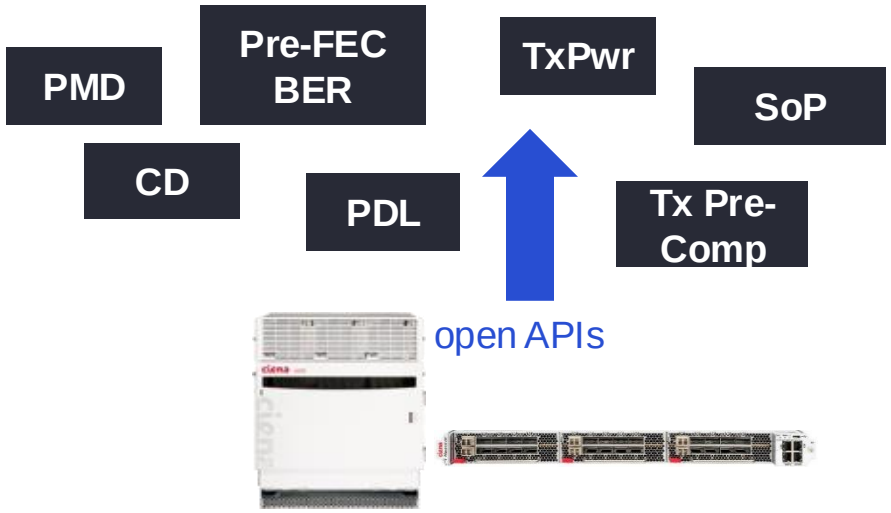
Non-Linear Compensation

- Improved reach for a given capacity and vice versa

Real-time access to unprecedented levels of network performance data

Using Coherent Modem as a Sensor

Access real-time link parameters through streaming telemetry



New Parameters

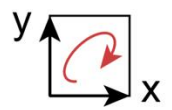
ESNR	OSNR
• Effective Signal-to-Noise Ratio • Total noise experienced by Rx: internal, linear and nonlinear noise	• Optical Signal-to-Noise Ratio • Optical linear noise derived using machine learning

Visibility into real-time link parameters allows for optimal link engineering and diagnostics

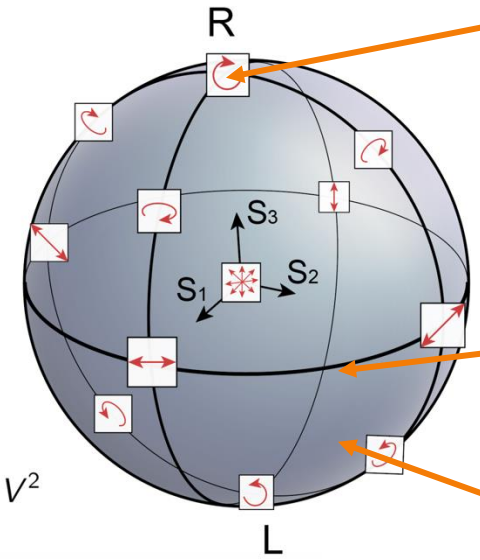
Poincare sphere

Poincare sphere and stokes vectors are tools developed by physicist and used to describe all possible state of polarization:

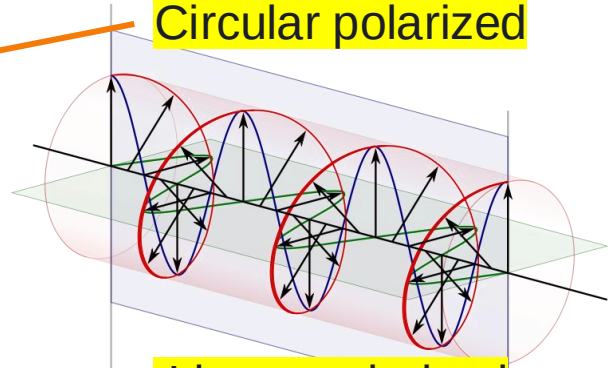
$$S_0 = I = E_x^2 + E_y^2$$
$$S_1 = Q = E_x^2 - E_y^2$$
$$S_2 = U = 2E_xE_y\cos\delta$$
$$S_3 = V = 2E_xE_y\sin\delta$$



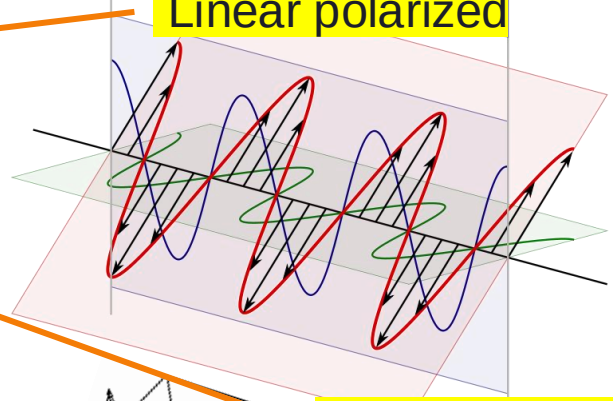
$$radius = I^2 \geq Q^2 + U^2 + V^2$$



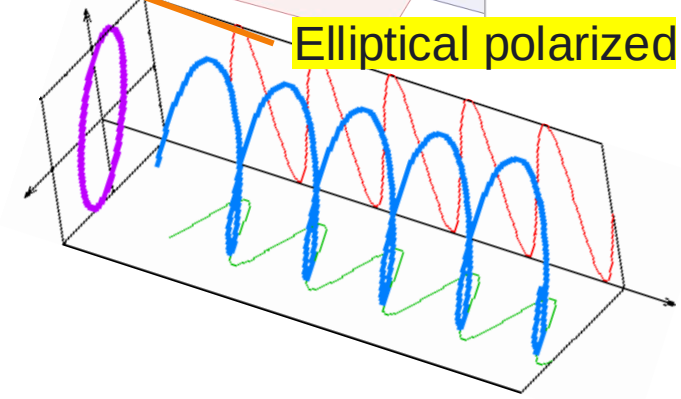
Circular polarized



Linear polarized



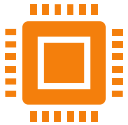
Elliptical polarized



Poles on the sphere represent right and left circular polarized light and circle of S1,S2 plane represent linear polarized light. Other points on the sphere represent elliptical polarized light.

Take-aways…

Take-aways



There are many ways to look at fiber sensing. A lot of options are available

There is a lot of Scientific papers about SOP and DAS, lots of research going on on real cables.

Ciena is more looking at the SOP fiber sensing right now,