Beyond DAS: Advances in Distributed Rayleigh Sensing

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Fiber Optic Sensing Association
Connect and protect

Presentation Overview

Introduction

- AP Sensing
- Products and Services

Technology

- DAS Concept
- DAS Terminology
- Phase vs Amplitude

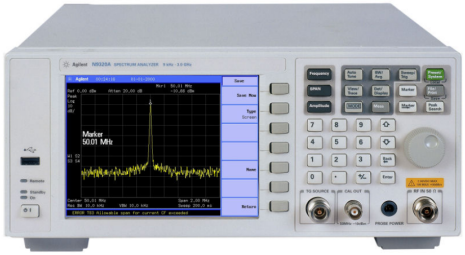
Case Study

- Enhanced DTS

Company History

1939 Hewlett-Packard (HP) started as a test and measurement company.

1959 HP establishes its first production site outside of the US in Boeblingen, Germany.



1999 The measurement business from HP is spun off into Agilent Technologies.

2007 The fiber optic monitoring business is spun off to create AP Sensing.

Global Presence

Established Markets

Power Cable Monitoring

LNG Monitoring

Fire Detection

Pipeline Monitoring

Established Markets

Well & Reservoir Monitoring

Train & Rail Monitoring

Geo- and Hydrological

Perimeter Security

Innovative Technology Company

R&D	% of Revenue
Intel	20%
AP Sensing	**17%**
Google	13%
Siemens	6%
Samsung	6%
Apple	3.5%

Code Correlation
Low power
Single receiver
8 km
Outdoor
8 & 12 channel
12 km
VdS
Configurator
ATEX
Dual-Ended
DDW
GeoDTS
Modbus
RTTR
IEC-104
UL521
SmartVision 1.0
4x speed
-40°C
OPC / DNP3
MultiSensorBoard
24 channel
Hibernation Mode
HD relays
Integrated Modbus
DAS A
DVS
10x speed
Safety tester
SIL 2
DAS B
30km SM
50km MM
40km MM
SmartVision 3.x
50km SM
70km MM
RTTR 7.0
RTTR 10.0
DAS C
70km SM

2004 **2006** **2008** **2010** **2012** **2014** **2016** **2018**

AP Sensing Solutions

Instruments

DTS

DAS

Enclosure

Wall Mount

ATEX

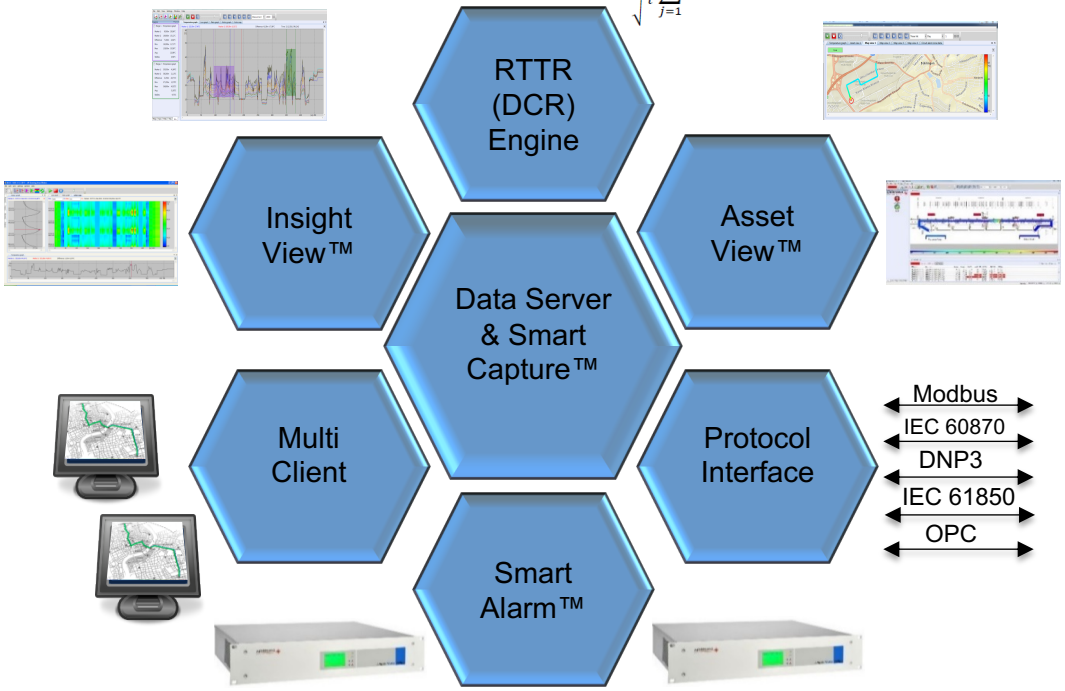
Low Temperature

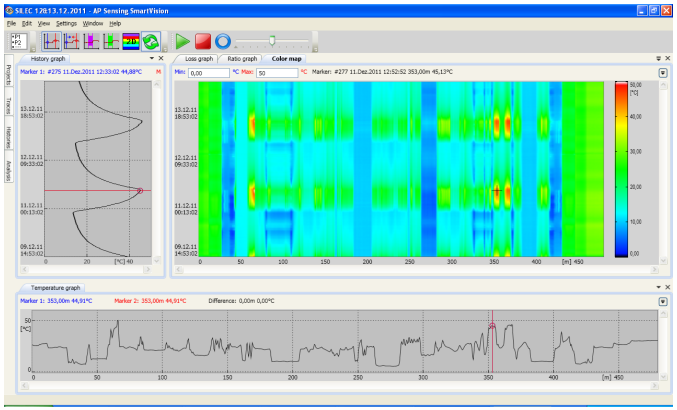
Rack Solutions

- Redundant Systems
- Networking
- UPS
- Backup Solutions
- Operator Displays

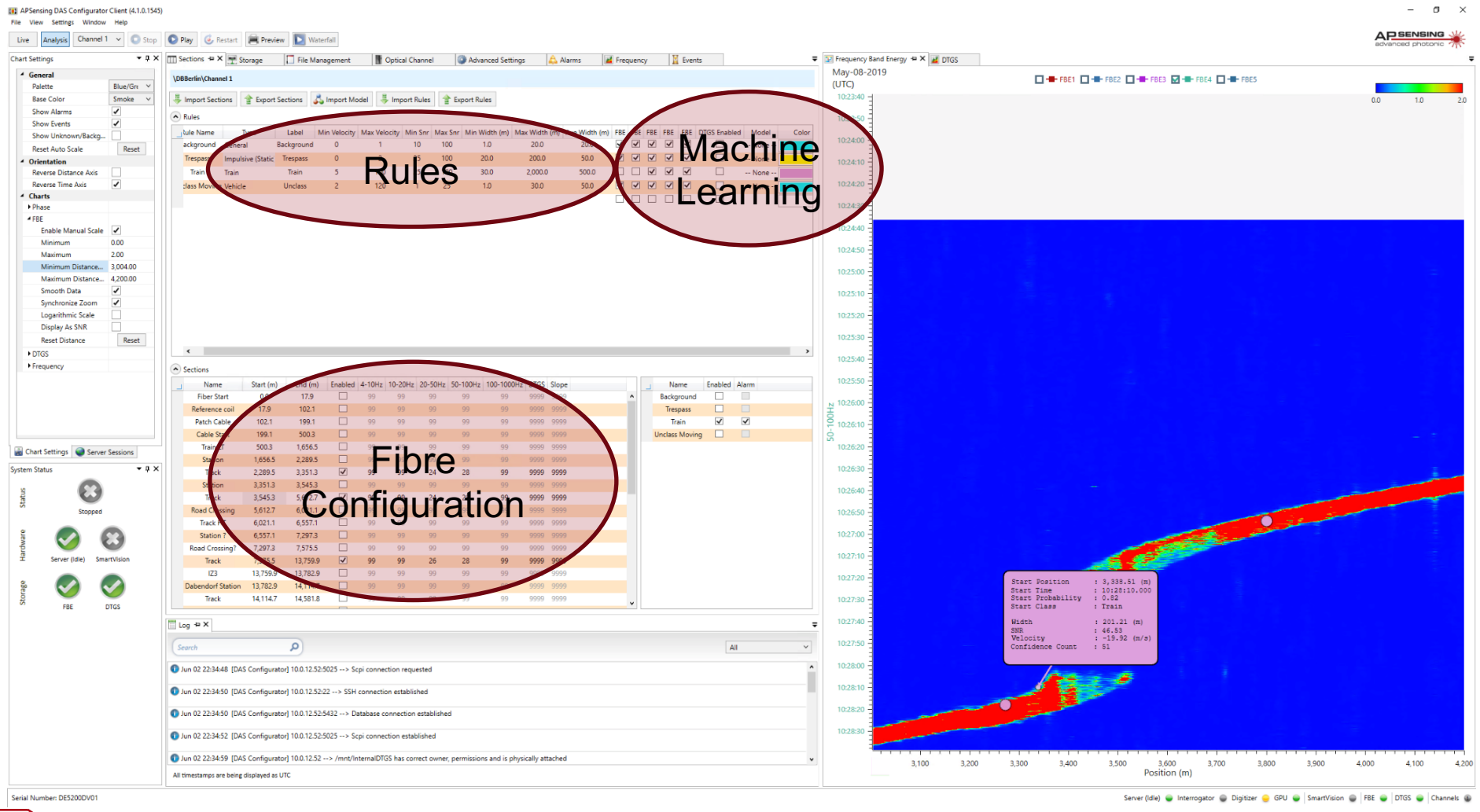
AP Sensing Solutions

$$F = \sqrt{\frac{1}{T}\sum_{j=1}^{N}[\vartheta_{est}(j\Delta t, \rho_{soil}, \vartheta_{amb}) - \vartheta_{measured}(j\Delta t)]^2 \Delta t}$$



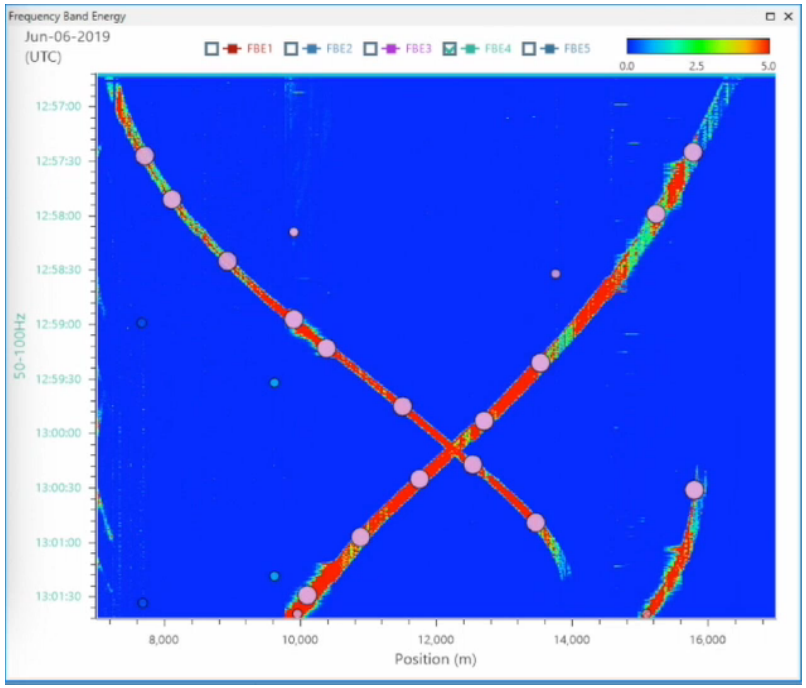


Powerful Analysis and Configuration Tools



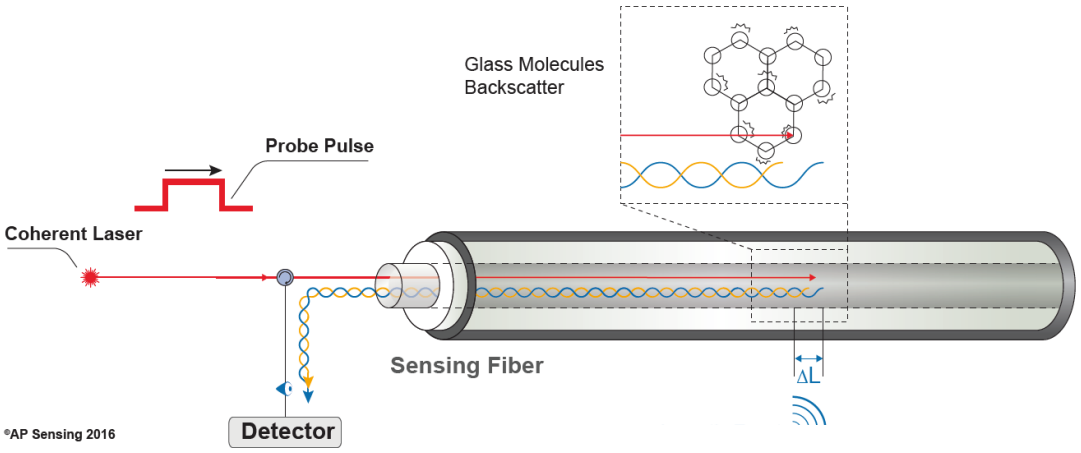
SmartVision MapView

- Live data can be displayed either on satellite image or conventional schematic representation
- Train data including position, velocity and length can be displayed
- Cars at road crossings and pedestrians can also be monitored and displayed

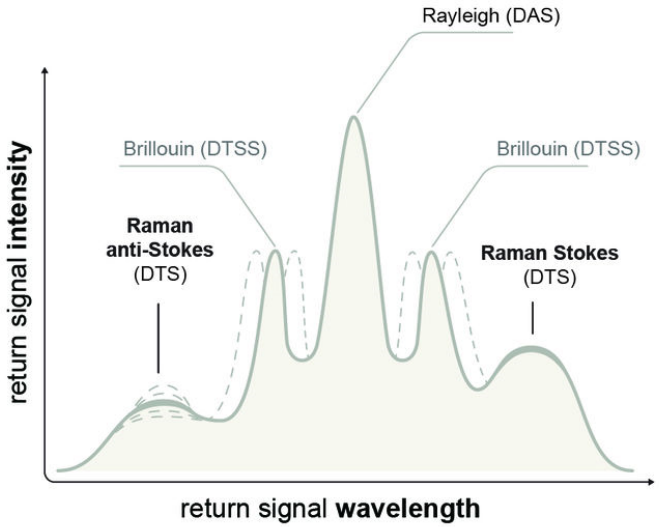


Technology
DAS Measurement

DAS is an OTDR based technology. The ***position*** of the acoustic/vibration event is determined by measuring the arrival time of the returning light pulse, similar to a radar echo.



The ***coherent Rayleigh effect*** is stimulated by minute strain changes in the fiber as a consequence of **thermal**, **acoustic, vibration or strain effects**. The returned signals are analyzed and presented in the form of **frequency and amplitude of disturbance**.



Terminology

Coherent Fading Noise 1984

Coher

Coher

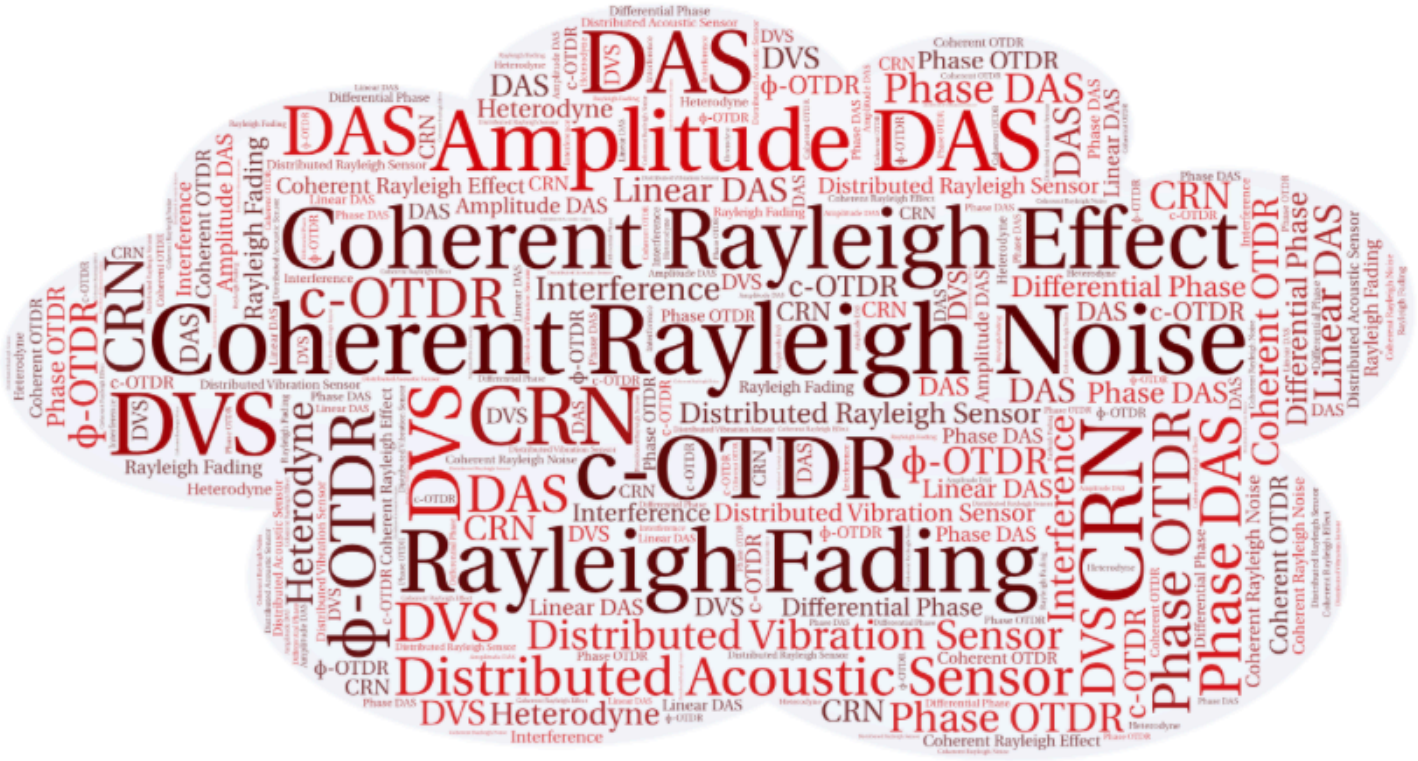
ϕ-OTD

Distrib

Distrib

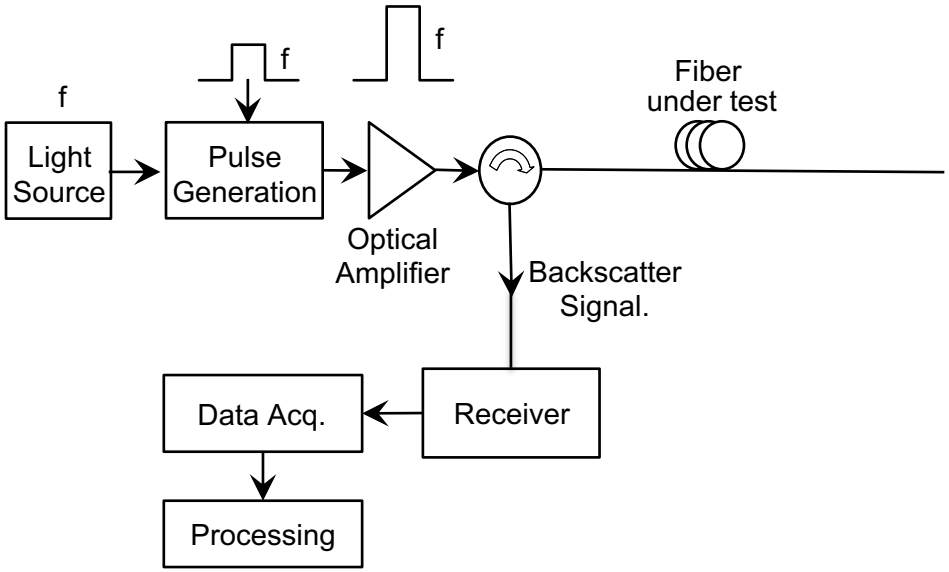
Ampli

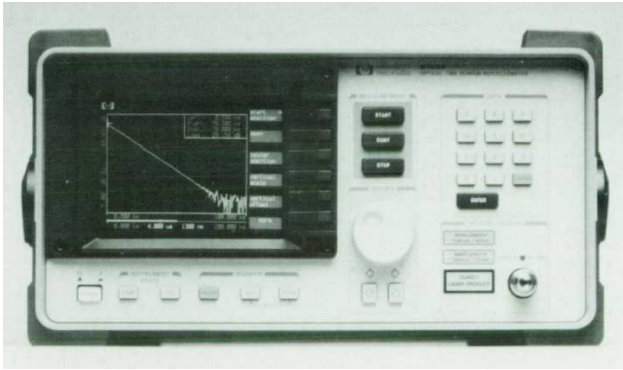
Phase



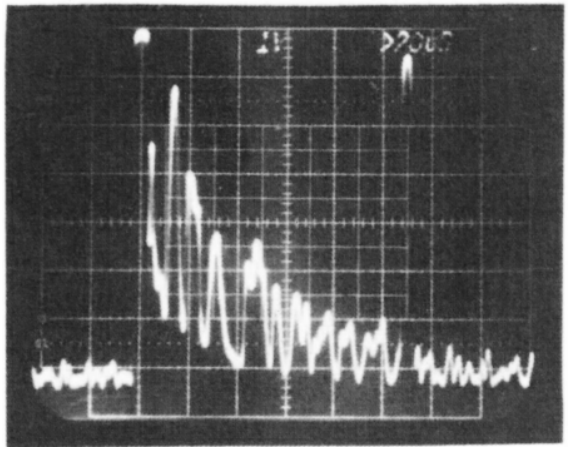
Distributed Rayleigh Sensor

Technology





Fleischer-Reumann, M., and Sischka, F. “A High-Speed Optical Time-Domain Reflectometer with Improved Dynamic Range.” *Hewlett-Packard Journal*. 1988

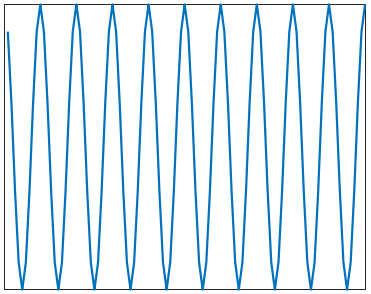


P. Healey, “Fading in heterodyne OTDR,” Electron. Lett., vol. 20, no. 1, p. 30, 1984.

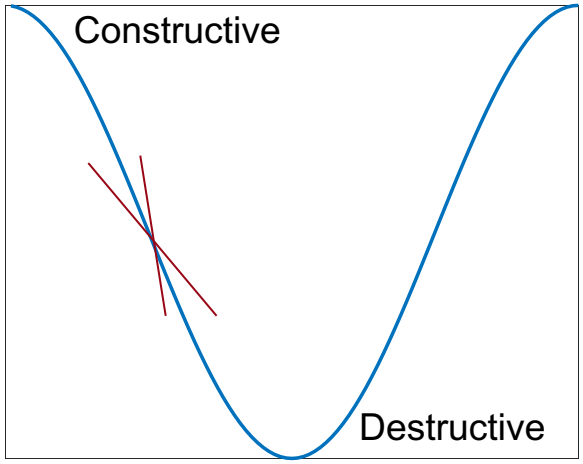
AP Sensing N5000 (2015).

Technology

Input Signal

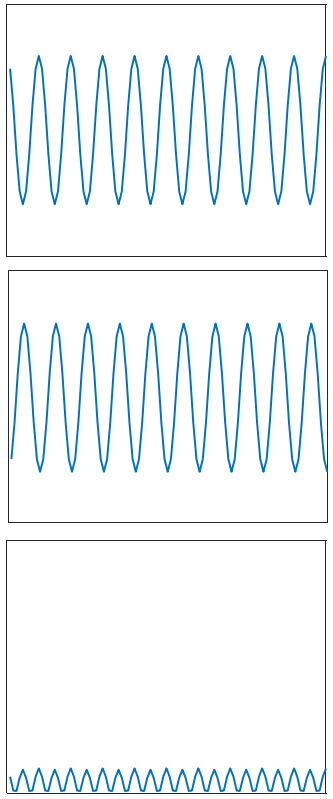


Interference
Transfer Function



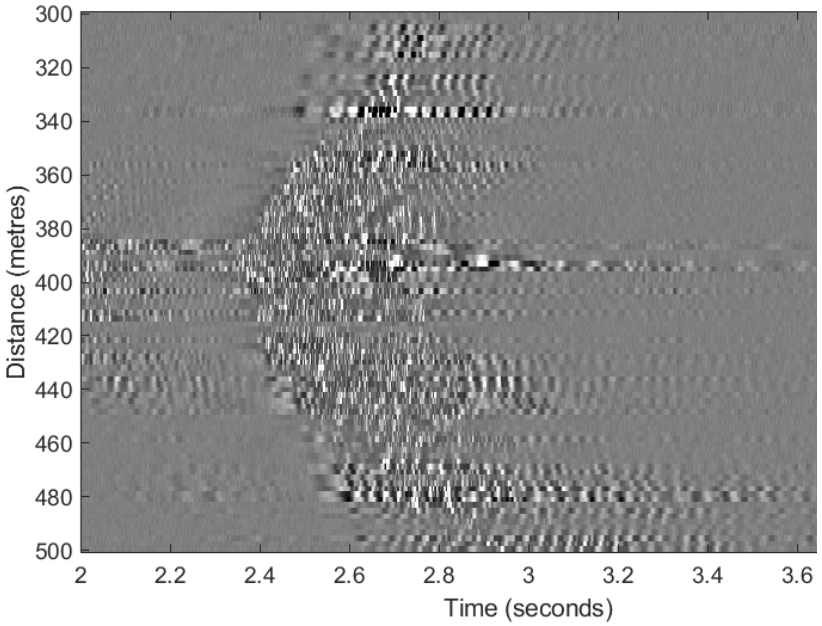
The transfer function is actually varying depending on the local scattering

Output Signal



Hartog, A. (2017). An Introduction to Distributed Optical Fibre Sensors (First). CRC Press. P.237

Technology

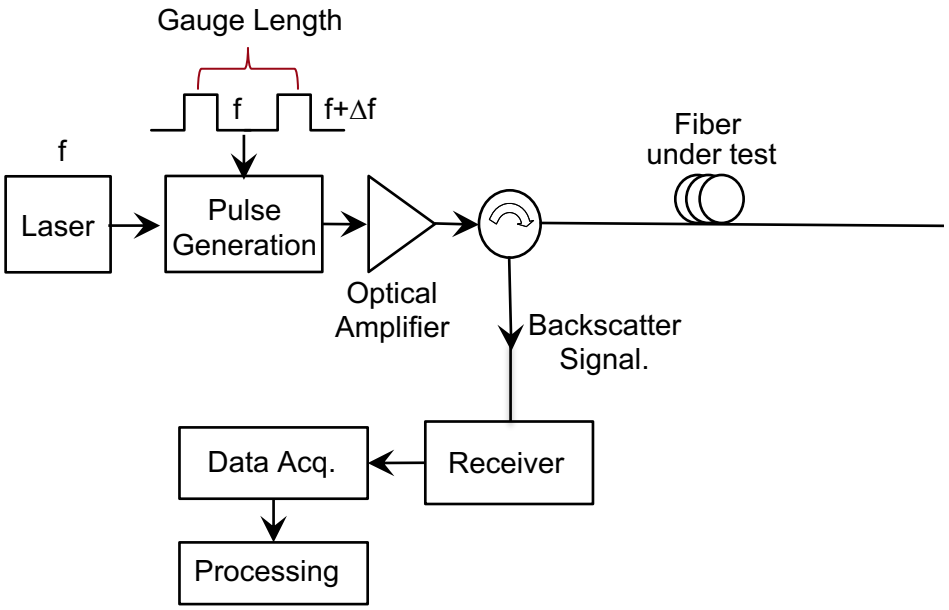


Amplitude Measurement

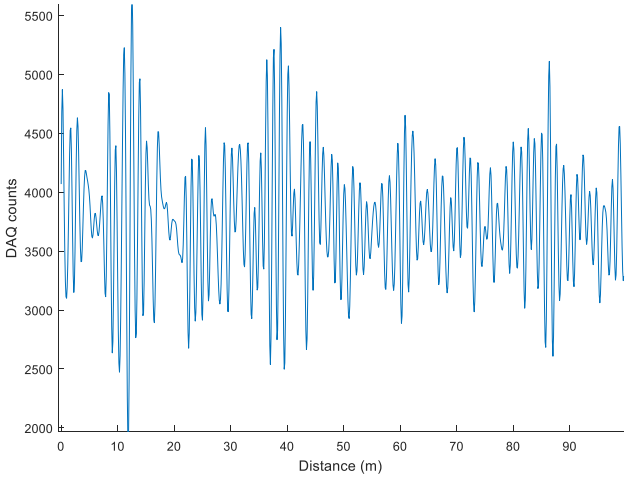
- Acoustic signal generates a disturbance in the 1D speckle
- Disturbance has a random sensitivity and direction
- Good for locating events but not suitable for reproducing applied signal

Technology

Dual Pulse Technique

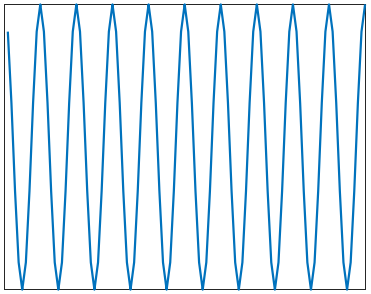


Carrier Frequency Δf

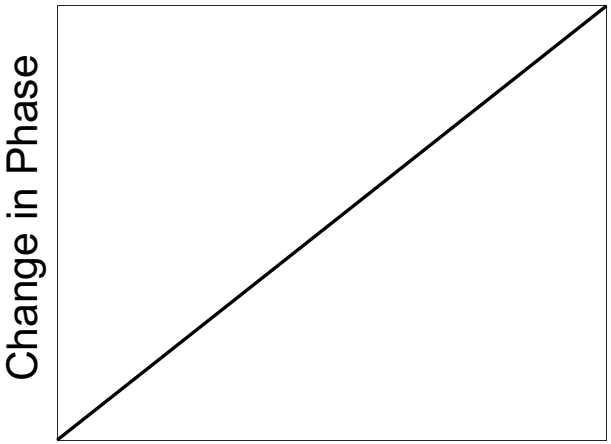


Technology

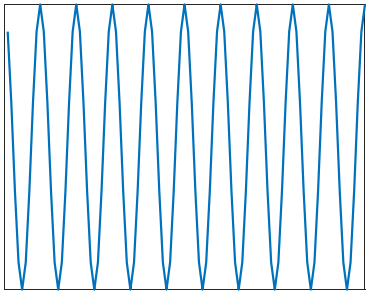
Input Signal



Transfer Function

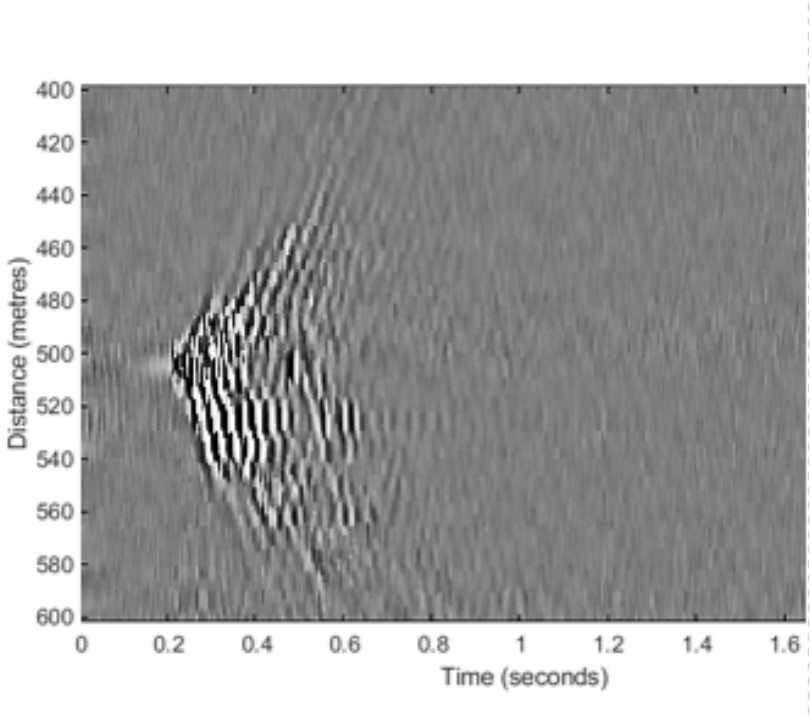


Output Signal



The output is proportional to the input

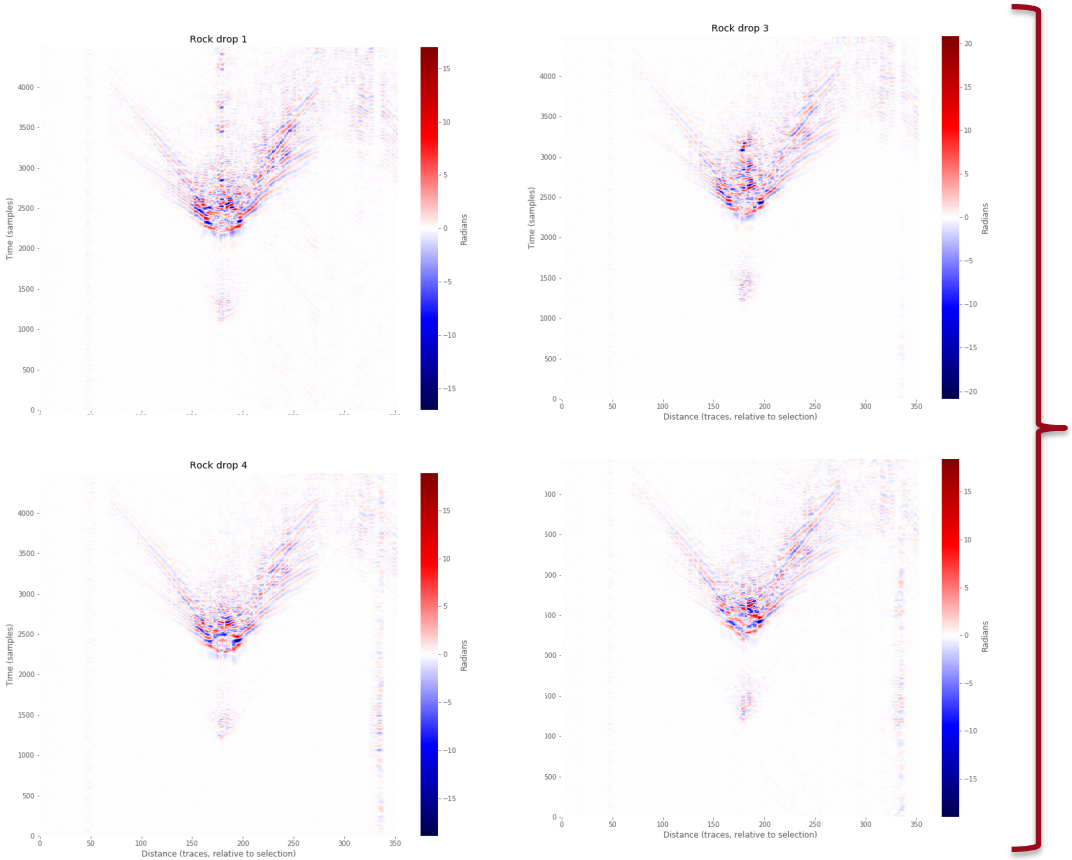
Technology

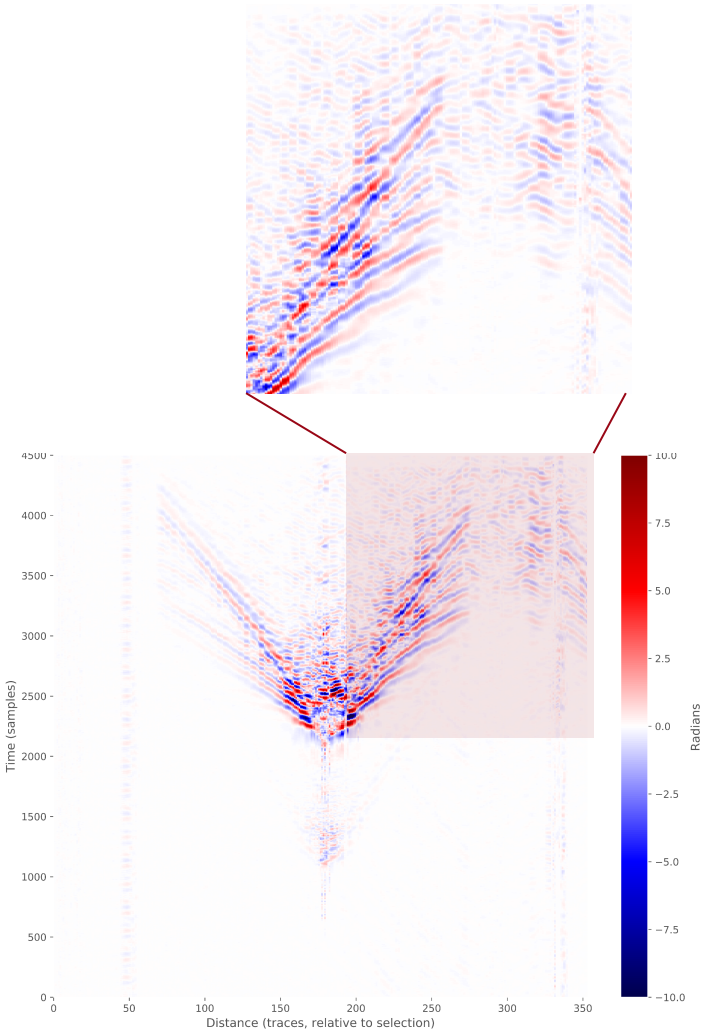


Phase Measurement
Differential Phase Measurement

- Acoustic signal generates a disturbance in the 1D speckle
- Disturbance has a known and repeatable sensitivity and polarity

Signal Repeatability

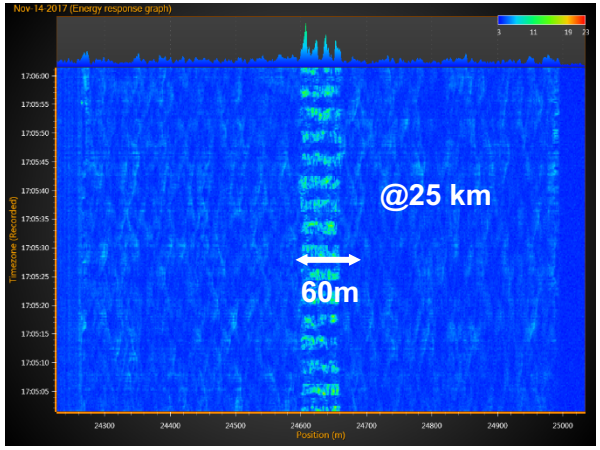




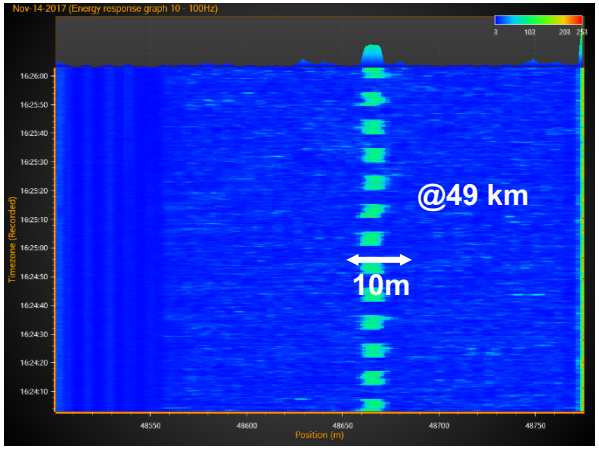
Leading the Way with Passion.

DAS Performance Comparison

Amplitude DAS



Differential Phase DAS

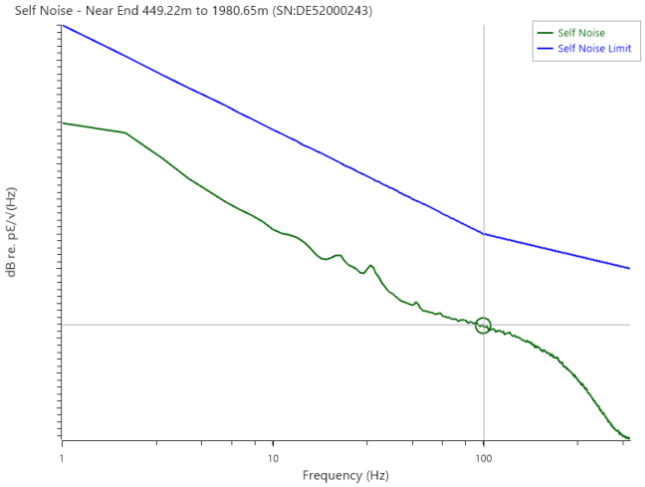


- **Conventional DAS Technology**
  - Non-linear signal response over distance and acoustic intensity
  - Can suffer from fading
- **2P Squared DAS**
  - High SNR over 70 km measurement range
  - Linear response over distance & signal strength
  - Reduced Fading

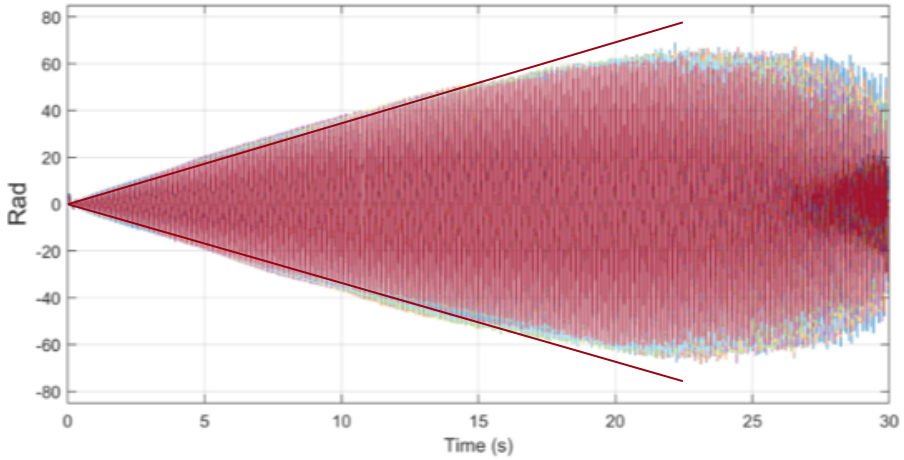
Signal Linearity

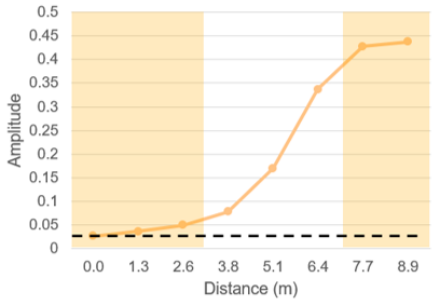
SEAFOM - DAS Parameter Definitions and Tests (August 2018)

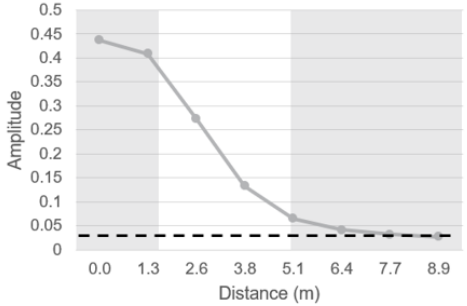
Self-phase Noise



Dynamic Range / Linearity





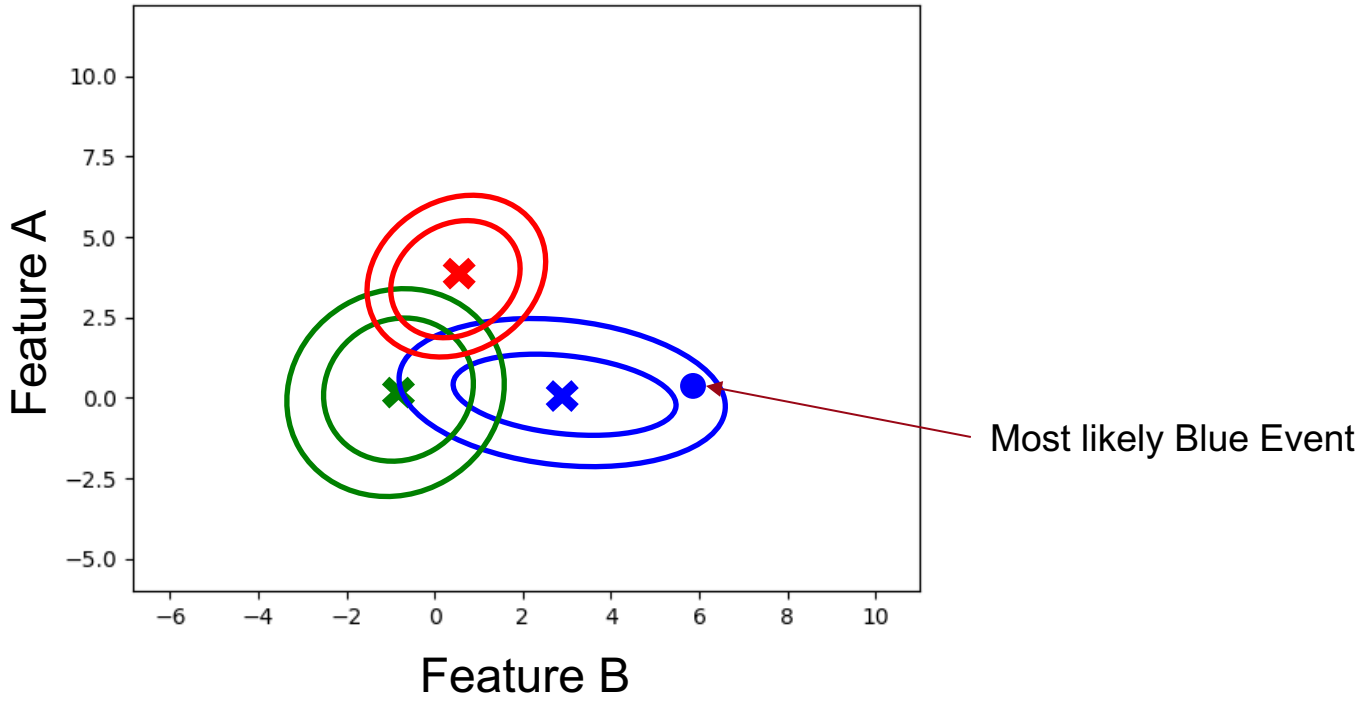


Spatial Resolution

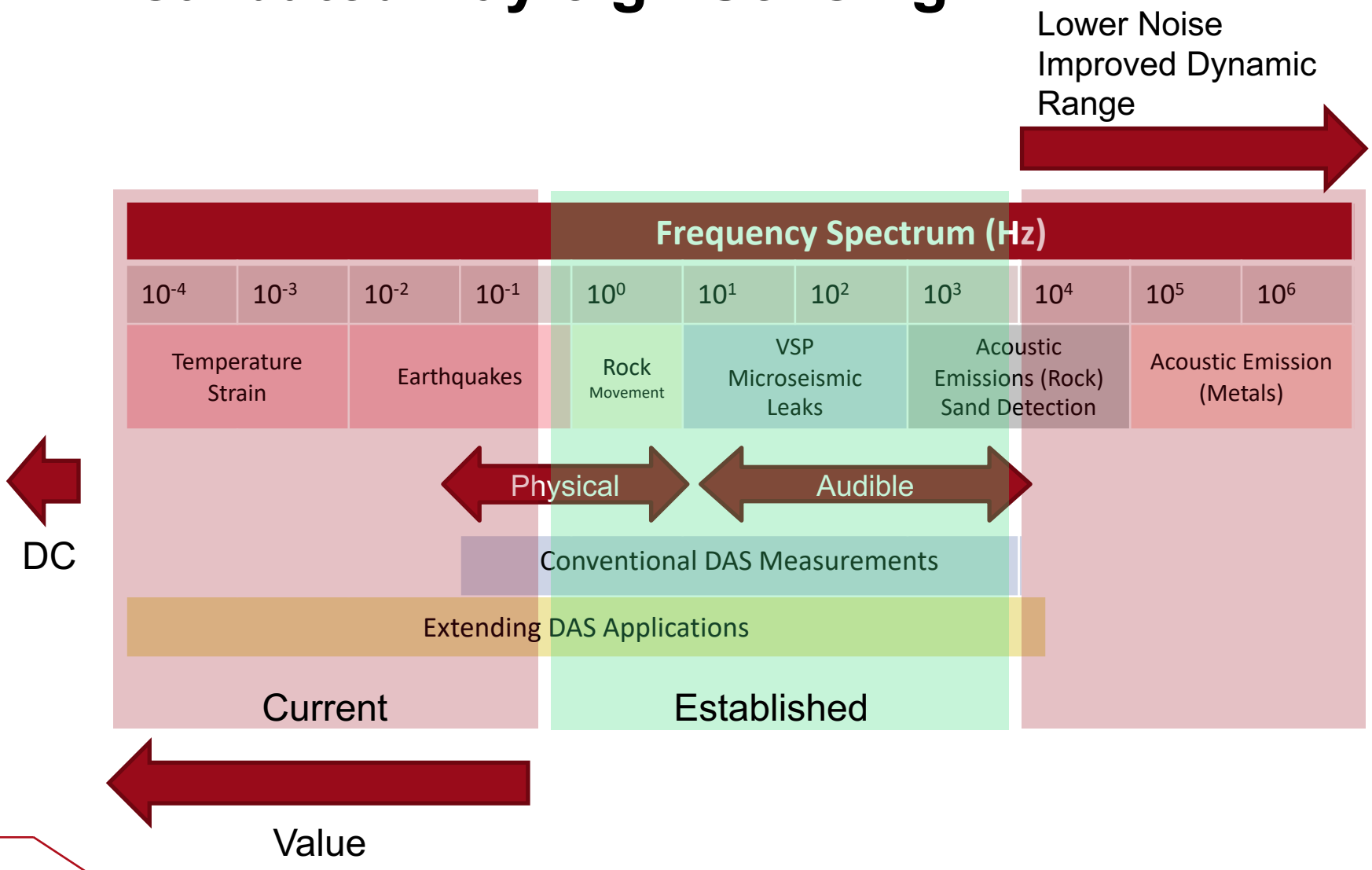
Advanced Signal Processing

The linear transfer between applied signal and the instrument output provides a much more robust prediction of events.

Prediction of class is based on proximity to the centroid of each class in different hyperplanes



Distributed Rayleigh Sensing



Case Study
Enhanced DTS (eDTS)

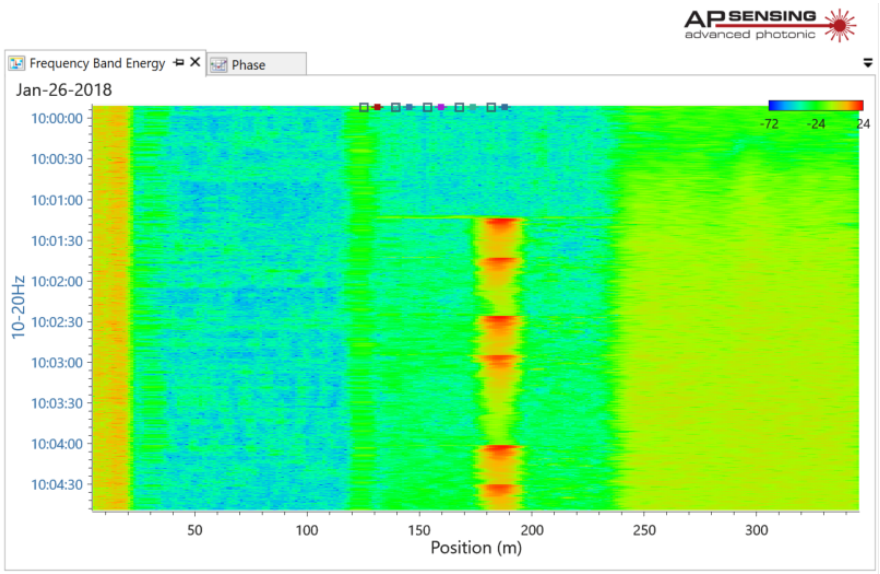
Distributed Temperature Sensors based on Raman scattering provide reliable, robust measures of the absolute temperature of the optical fiber

Distributed Rayleigh Sensors can provide a measure of the changes in temperature of the fiber in short periods of time

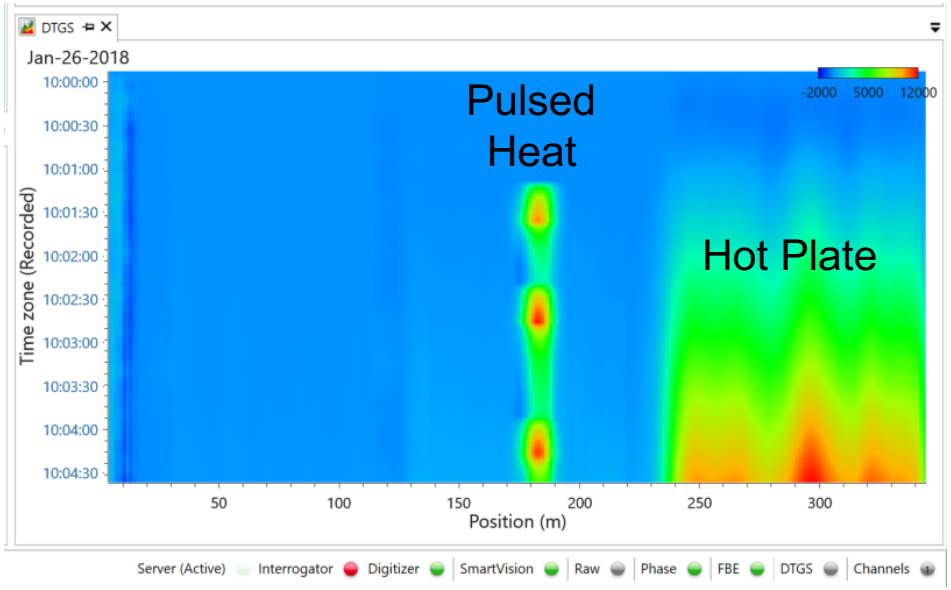
Combination of Raman DTS and DAS produces a system with improved performance both in response time and in temperature resolution

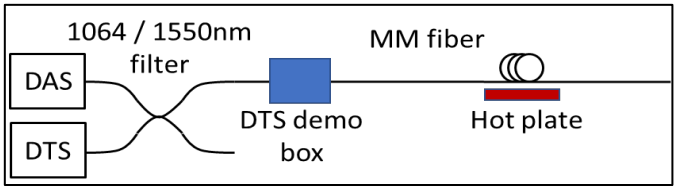
Visualisation .. DAS Configurator

Standard FBE Output



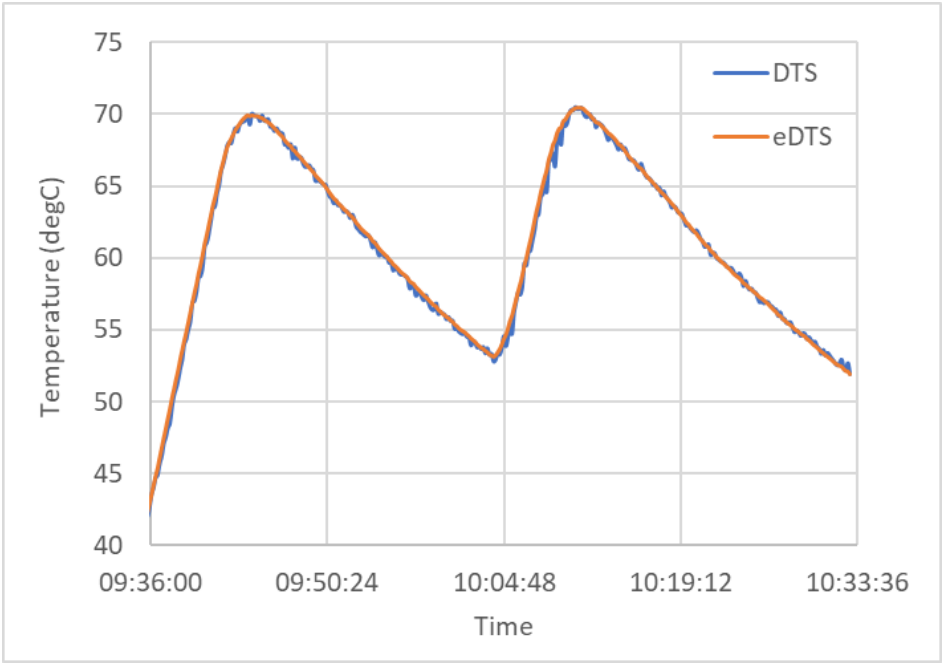
DTGS Temperature Output





Test set up – with one fiber

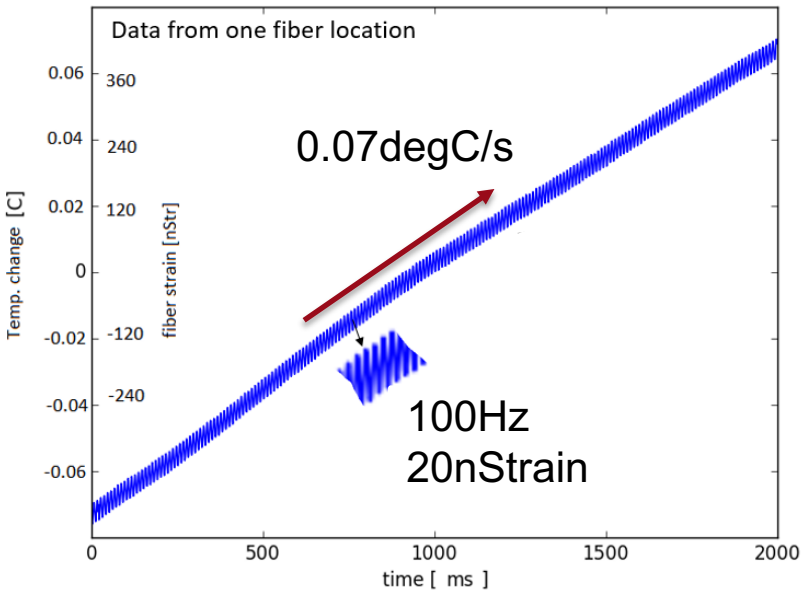
Integration .. Enhanced DTS Measurement

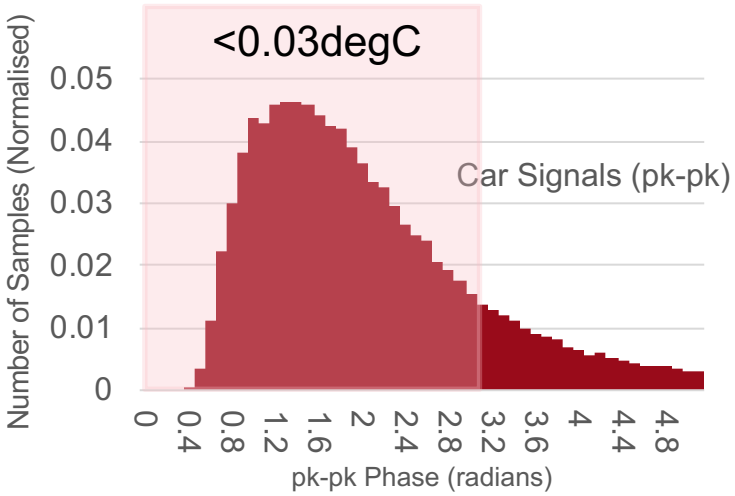


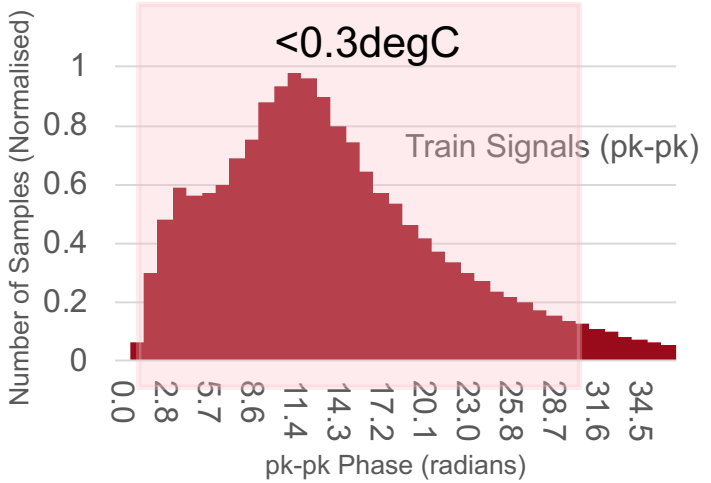
Acoustic vs Temperature .. Amplitude

Two key factors

- Temperature changes are slow
- Phase changes due to temperature are large – generally much larger than acoustic signals



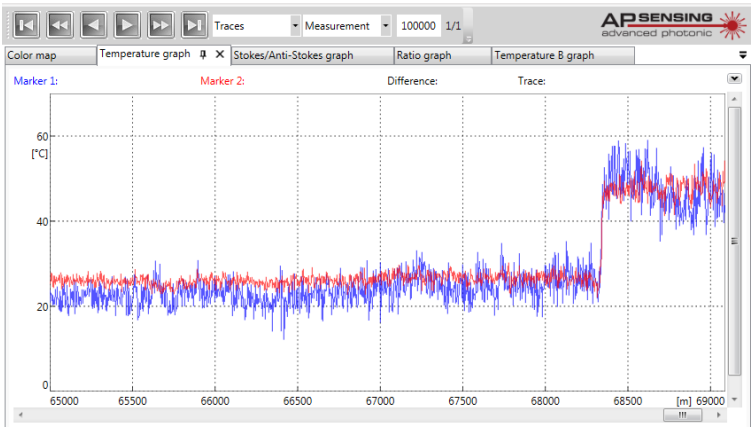




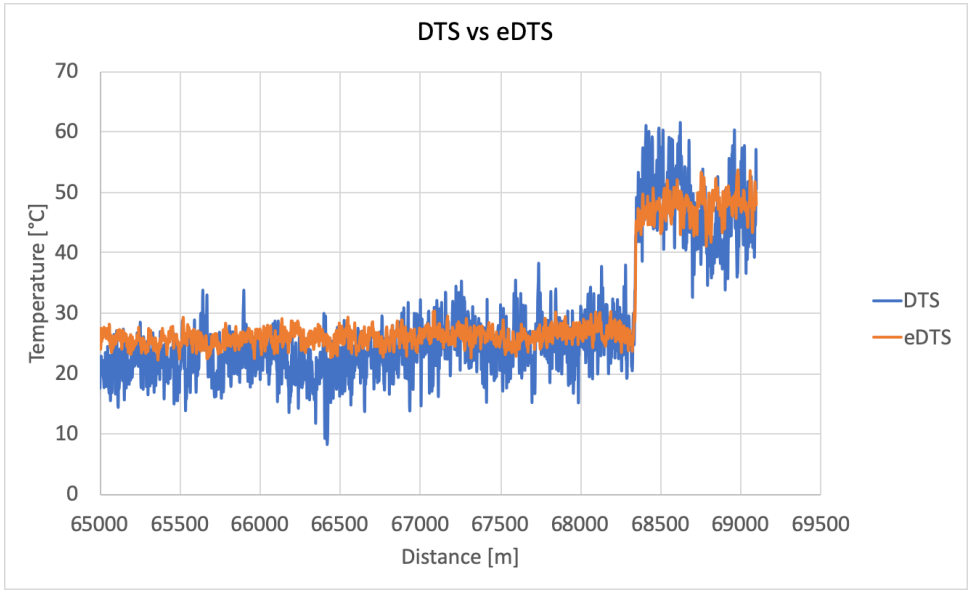
Examples of signal magnitudes from Machine Learning Library Data

Enhanced DTS Temperature Resolution

Improved temperature resolution and reduced measurement time at 69km

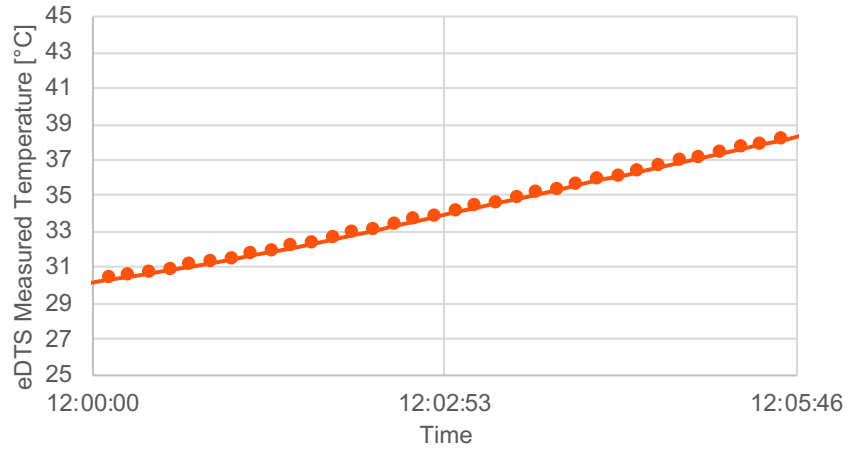


SmartVision

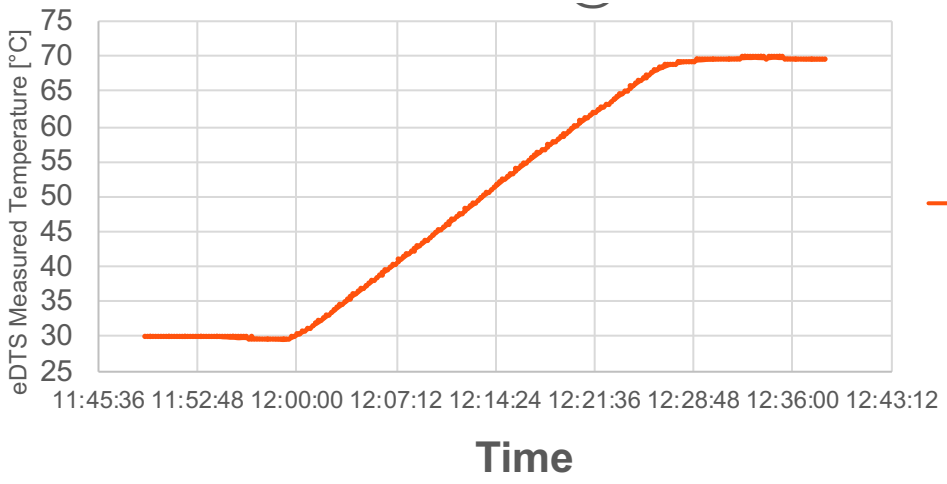


Spatial Resolution	2degC
Measurement Time	30mins
Range	69km

Enhanced DTS Measurement Time



DAS provides fast response
Each data point is 10seconds



Summary

- DAS terminology can be very confusing
- Not all DAS systems are the same
- Performance of a DAS where the output is **linear** and **repeatable** with the input offers significant advantages
- The low frequency output of the DAS is predominantly temperature and can be used to enhance the Raman DTS measurement to provide either an improved temperature resolution or a faster measurement output

- Exciting and evolving field with many advances to come

Questions?

References

[1] Muanenda, Y.; Oton, C.; Faralli, S.; Nannipieri, T.; Signorini, A.; Pasquale, F. Hybrid distributed acoustic and temperature sensor using a commercial off-the-shelf DFB laser and direct detection. *Opt. Lett*. 2016, 41, 587–590.

[2] Y. Koyamada, Y. Eda, S. Hirose, S. Nakamura, and K. Hogari, “Novel Fiber-Optic Distributed Strain and Temperature Sensor with Very High Resolution,” *IEICE Trans. Commun.*, vol. E89–B, no. 5, pp. 1722–1725, 2006.

[3] K. Miah and K. D. Potter, “A Review of Hybrid Fiber-Optic Distributed Simultaneous Vibration and Temperature Sensing Technology and Its Geophysical Applications,” *Sensors*, vol. 17, no. 11, pp. 1–25, 2017.

[4] M. Karrenbach *et al.*, “DAS Microseismic Monitoring and Integration With Strain Measurements in Hydraulic Fracture Profiling,” in *Proceedings of the 5th Unconventional Resources Technology Conference*, 2017.

[5] M. M. Molenaar, D. J. Hill, P. Webster, E. Fidan, and B. Birch, “First Downhole Application of Distributed Acoustic Sensing (DAS) for Hydraulic Fracturing Monitoring and Diagnostics,” in *SPE Hydraulic Fracturing Technology Conference*, 2011, pp. 1–9.

[6] Taylor, H. F., & Lee, C. E. (1991). *Patent No. US 5194847*. https://doi.org/10.1145/634067.634234.

[7] Dakin, J., & Lamb, C. (1988). *Patent No. GB2222247A*. United Kingdom.

[8] Hartog, A. (2017). *An Introduction to Distributed Optical Fibre Sensors* (First). CRC Press.