

Distributed Temperature Sensing (DTS)

DTS Configuration/ Calibration/ Best Practices

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Mission 4 “Education and Research” - Component 2: “From research to business” - Investment
3.1: “Fund for the realisation of an integrated system of research and innovation infrastructures”



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OVERVIEW

-  DTS Hardware
-  DTS Configuration
-  Data acquisition
-  Mapping zones

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 **ITINERIS**

ULTIMA & XT-DTS

ULTIMA

- Standalone unit with on-board PC
- Industrial, rack mount
- Min. 1s measurement time



- 2/5/10km variable range model M. 65cm spatial resolution. 25/50cm sampling interval.
- 10/20/35 km variable range model L. 2.1m spatial resolution. 1/2m sampling interval.
- 30km range singlemode model L-SM. 2.1m spatial resolution. 1/2m sampling interval.
- Enhanced data storage capacity
- Fanless and low power consumption

SILIXA
A LUNA company

ITINERIS

XT-DTS

- Ruggedized for field deployments
- Designed for remote configuration
- Min. 5s measurement time



- 2/5/10km variable range model M. 65cm-spatial resolution. 25/50cm sampling interval.
- 10/20/35 km variable range model L. 2.1m spatial resolution. 1/2m sampling interval.
- 4 or 8 channels
- Fanless and ultra-low power consumption mode (2mW)

Setup Considerations

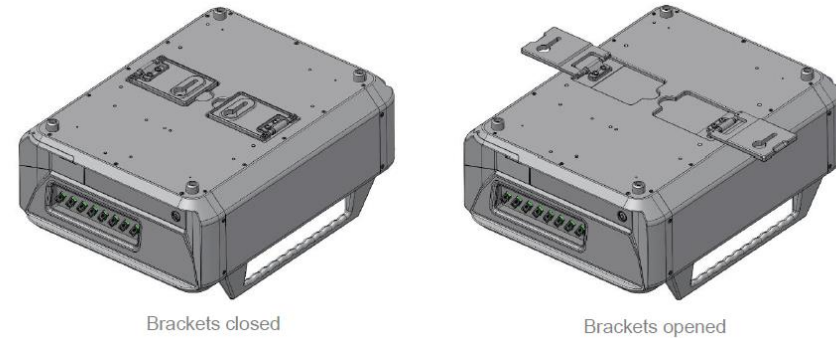
Environmental

- Operating temperature: **-40 - +65 °C** (-40 – +149 °F)
- Storage temperature: **-40 - +85 °C** (-40 – +185 °F)
- Relative humidity: **10 – 85 % non-condensing**

Electrical

- Input frequency: **DC only**
- Nominal voltage range: **12 - 24 VDC**
- Absolute min & max voltages: **11 - 36 VDC**
- Measuring power: **≤43 W**
- Idle power: **11 W**
- Hibernating power: **2 mW**
- Over current protection: **internal fuse**
- Ground connection on rear of chassis.

Can be mounted either vertically or horizontally



Never open the chassis
(this will invalidate the warranty)

Key Components

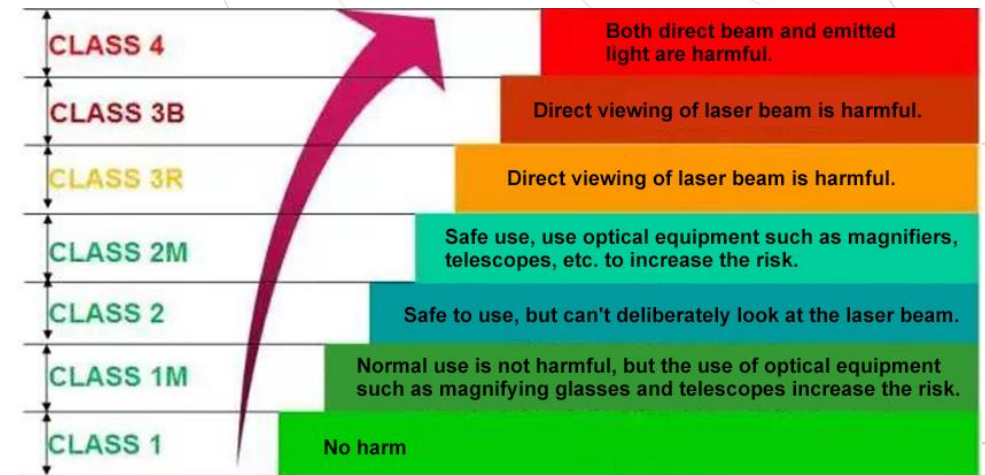
- A pulsed laser
- Optoelectronic detectors
 - Gain and bandwidth optimized for target SNR and spatial resolution
- DAQ card
 - Capability to spatially distribute measured backscatter signal by accounting for time of flight; sampling frequency set by target spatial resolution
- Optical fiber

Laser Safety

Silixa DTS units are safe under all reasonably foreseeable circumstances.

- Class 3R internal laser module
- Class 1 laser product
- Radiation is infrared (not visible)

Laser	Output
Wavelength	1064 nm
Pulse duration	1.25 – 2.5 ns
Pulse Repetition Rate	≤ 36 kHz
Maximum Average Output Power	≤2.3 mW



Peripherals

- Laptop
- Ethernet cable
- Fiber optic cleaner
- Power source (e.g., 12 V battery)
- Temperature probes (optional)
- Network modem (optional)



We do not recommend using off-brand cleaners

*Connect laptop to the XT-DTS via Ethernet
and connect fiber before powering up the unit.*

Pt100 temperature probes



- Temperature measurement range -50°C to $+250^{\circ}\text{C}$
- Accuracy better than $\pm 0.1^{\circ}\text{C}$

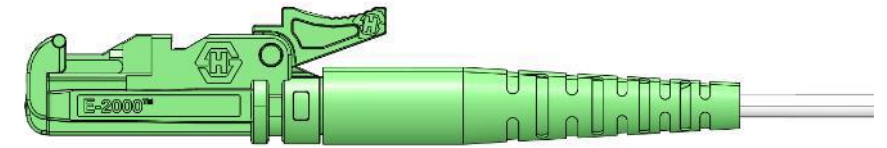
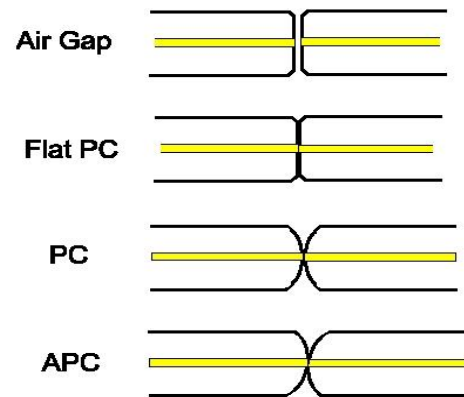
Host PC

Host PC hardware and operating system requirements

	Minimum Requirements	Recommended
Operating System	Windows 7, Windows 10	Windows 7, Windows 10
CPU	1GHz Single Core	1GHz or above Multi-Core
RAM	1GB	4GB or above
Graphics	1366x768	1366x768 or above
Free Storage	5GB for Software only	10GB+ for Software and measurement files
Connectivity	Ethernet (TCP/IP)	Ethernet (TCP/IP)

E2000 Connector

Fiber optic cabling comes with several connectors and can have several different ferrule shapes or finishes.



Fibre Connection

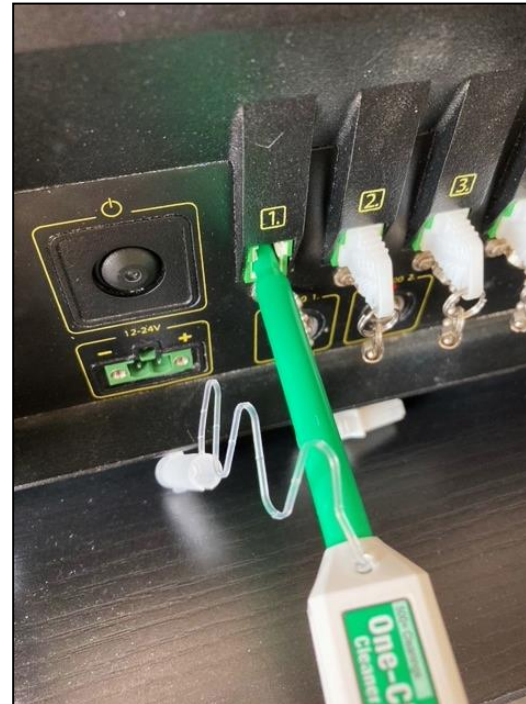
Clean connectors every time.

1. Use the fiber optic cleaner to clean the connector attached to the measurement cable.



With the cleaner inserted in the connector, push cleaner in until it clicks and releases.

2. Remove the dust protection cap and use the fiber optic cleaner to clean the connector on the XT-DTS front panel.

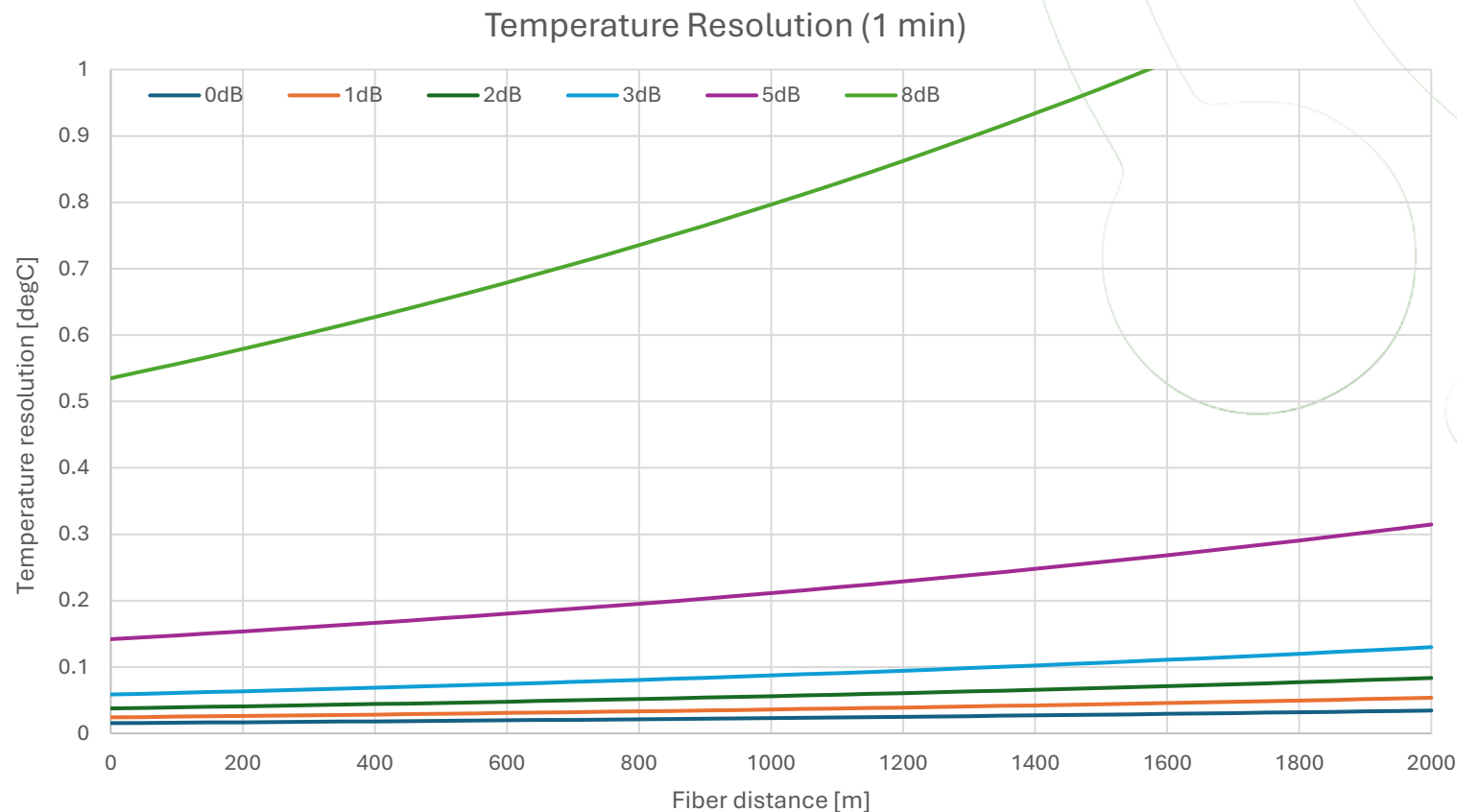


3. Plug the measurement cable into the XT-DTS front panel.



Temperature Resolution: impact of connectors

Connectors and splices have associated optical losses.



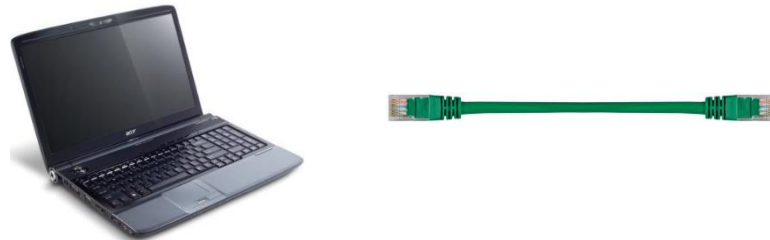
XT-DTS setup

All communications work over TCP/IP.

There are two modes:

1. **Laptop-DTS direct connection.** Only an Ethernet cable is needed.
2. **Laptop-DTS network connection.** The DTS must be connected to an access point with an Ethernet cable. The laptop can use Ethernet cable or Wi-Fi.

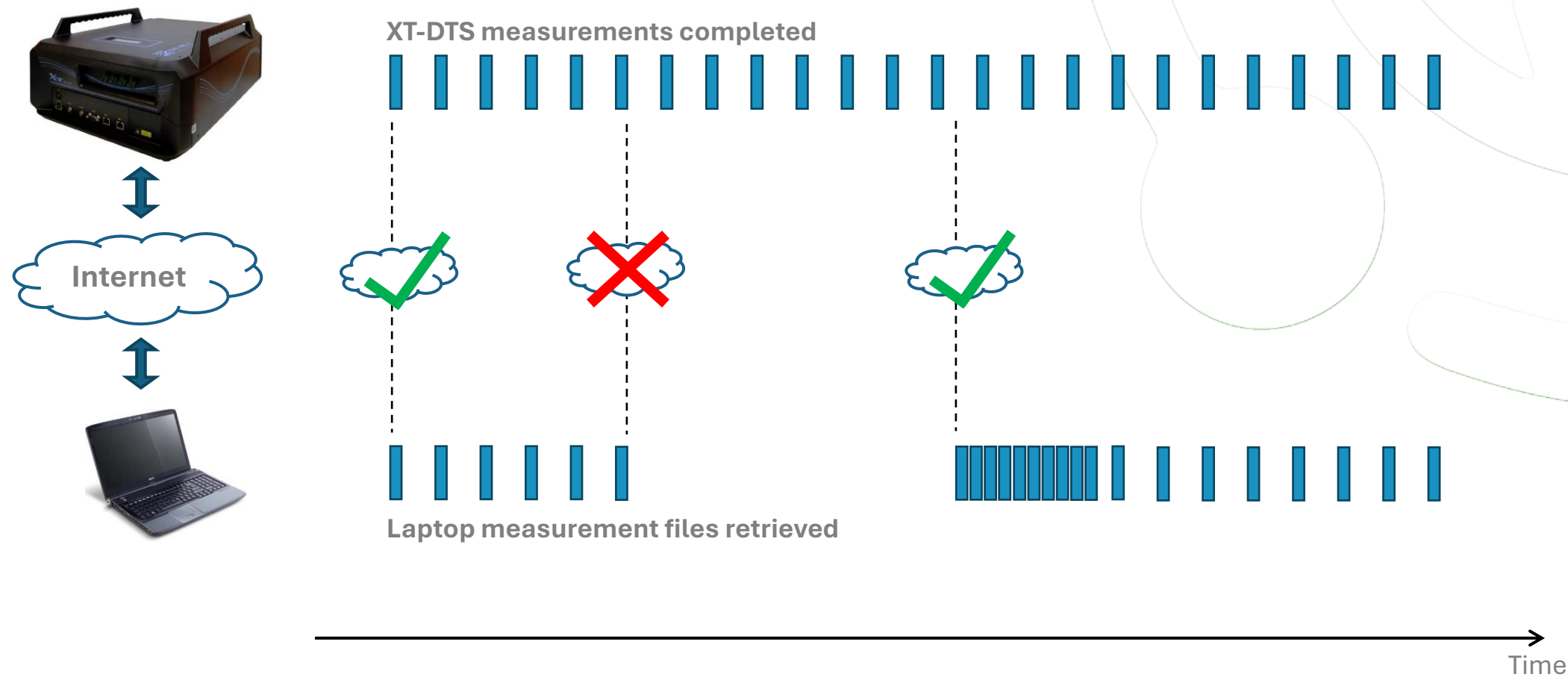
(1)



(2)



Communications



Data Retention

25 cm sampling

Cycle Time	Data Retention Time (time before measurements start to be removed)		
	2km	5km	10km
5 seconds	230 Hours	92 Hours	46 Hours
10 seconds	460 Hours	184 Hours	92 Hours
60 seconds	115 Days	46 Days	23 Days
5 minutes	575 Days	230 Days	115 Days
10 minutes	1150 Days	460 Days	230 Days

DTS system configuration

DTS system configuration: Single-ended vs Double-ended

Single-ended

Launches light into one end of the fiber only.

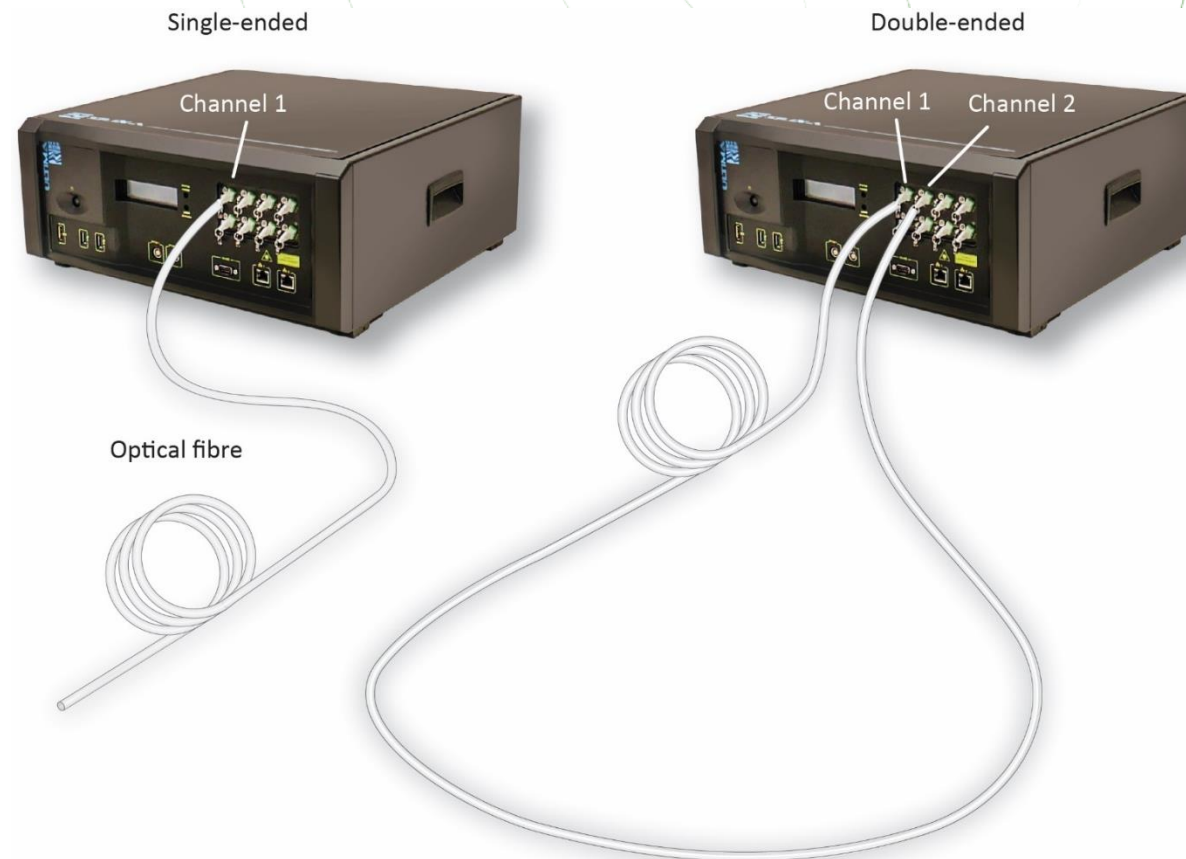
Two calibration parameters: **temperature offset** & **differential loss**

Double-ended

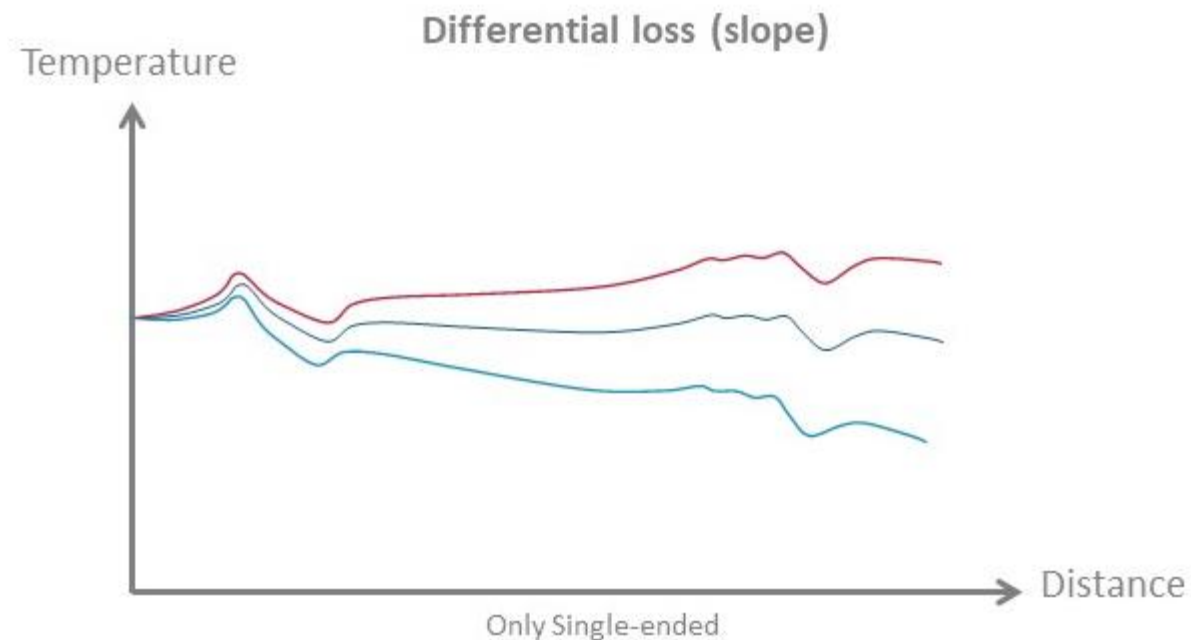
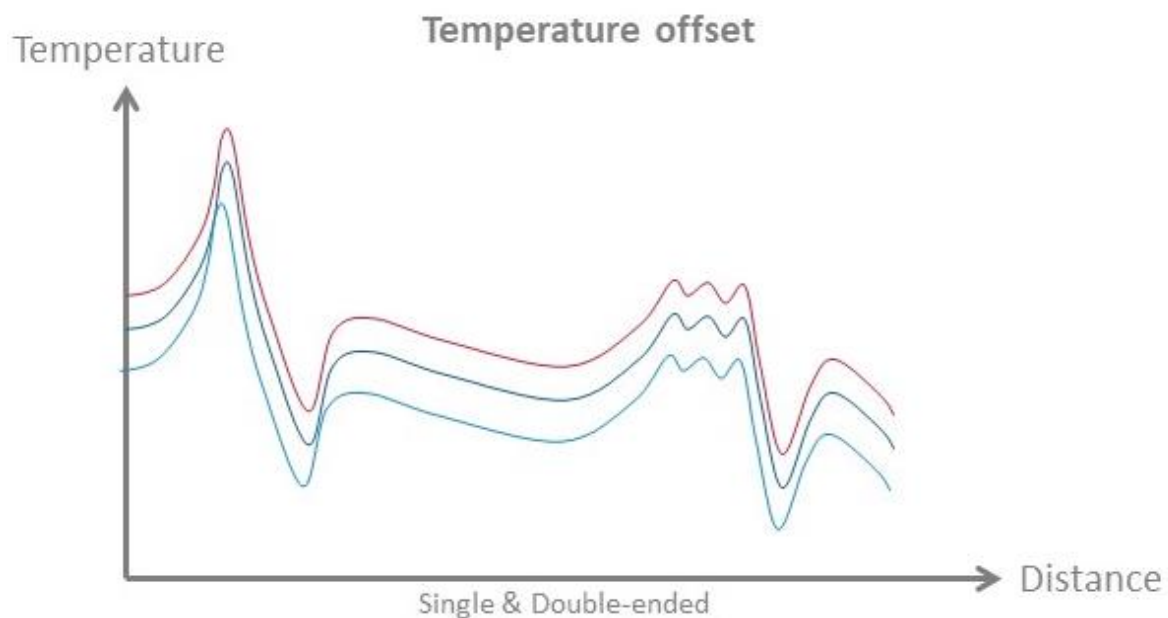
Launches light to both ends of the fiber.

One calibration parameter: **temperature offset**.

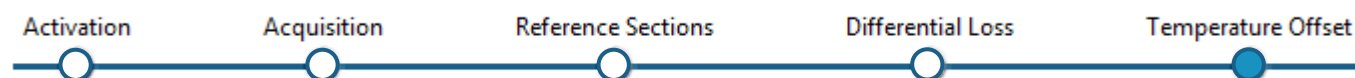
Differential loss is dynamically worked out by combining the forward and reverse signals.



DTS System Configuration: Temp offset and differential loss



Temperature Offset calibration options



Temperature Offset Correction None

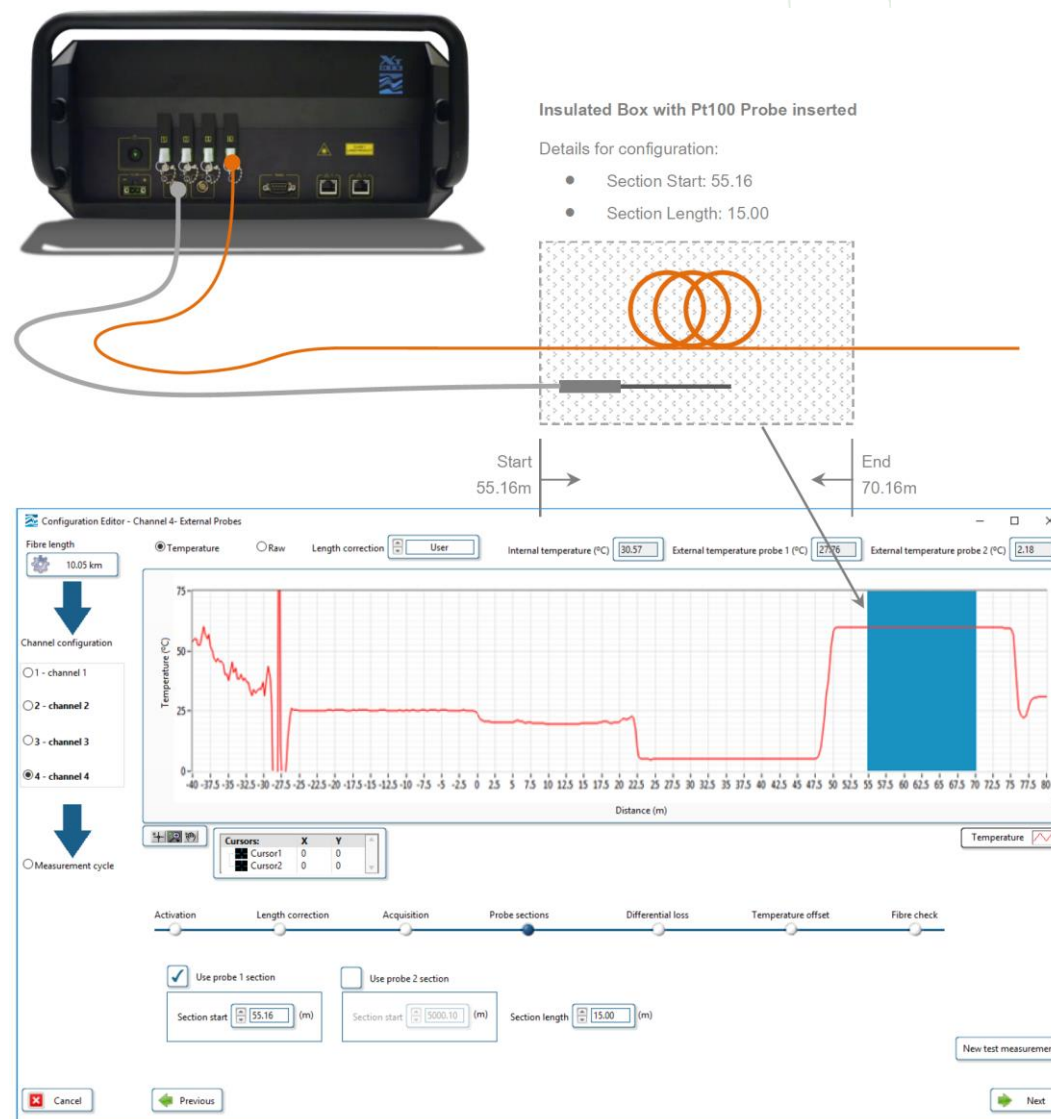
Temperature Offset Correction Constant Offset

Temperature Offset 0.20 (°C)

Temperature Offset Correction External Probe

Probe Section Temperature Probe 1

Temperature offset: external probe



Calibration baths

- Sufficient length of fiber optic cable in bath (~30-50 m if possible)
- Use a thermally insulated container
- Try to eliminate temperature gradients by mixing with a pump
- Cable should not touch bottom, or sides; no sharp bends or kinks
- Different options for bath fluid and cold/hot temperature source depending on setup location (lab vs field)



Differential loss calibration options

1.

Differential Loss Correction

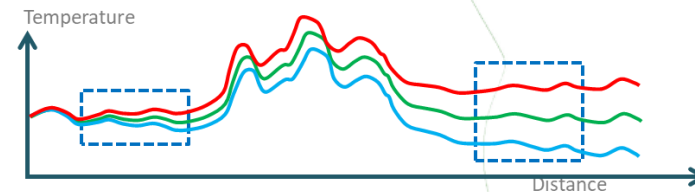
Fixed Differential Loss dB/km

2.

Differential Loss Correction

Section 1 start (m) Section Length (m)

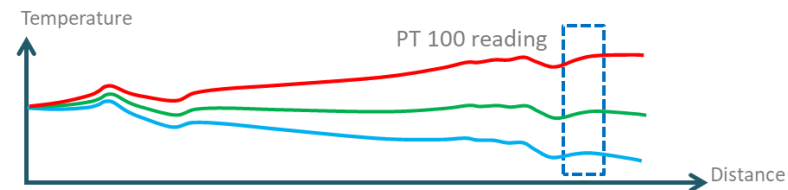
Section 2 start (m)



3.

Differential Loss Correction

Probe Section



4.

Differential Loss Correction

Paired Channel

Adjust reverse signal

- The differential loss value is different for each fiber as it corresponds to the intrinsic optical loss difference between the Stokes and anti-Stokes signals.
- It can also be affected when operating in harsh environments (high temperature, high pressure, mechanical stress, hydrogen ingress, etc...).
- The correct differential loss value will deliver a flat trace when the fiber is at constant temperature.

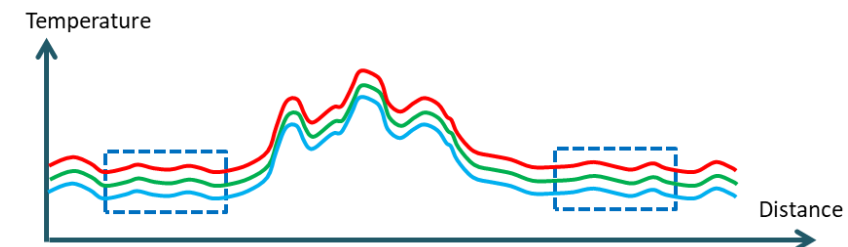
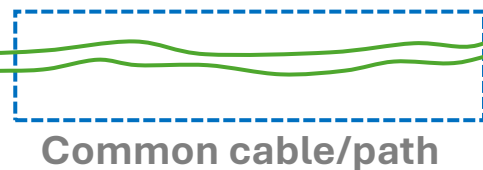
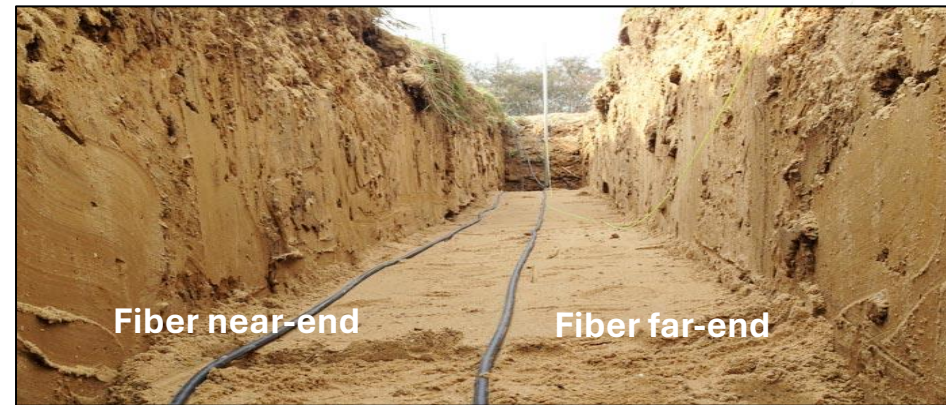
Differential loss calibration options:

Fixed values

- 🌐 The fixed value differential loss correction term is the difference in attenuation between the Stokes and anti-Stokes signals expressed in [dB/km]
- 🌐 Optimum setting determined by ensuring points/zones at the near and far end of the trace known to have equal temperature reported by the DTS
- 🌐 Typical differential loss ranges from 0.250 to 0.260 dB/km for 1064nm DTS units
- 🌐 Typical differential loss ranges from 0.020 to 0.08 dB/km for 1550nm DTS units

Differential loss calibration options: temperature matching

- The option “**matched sections**” can be used if no thermally isolated box is available and the near-end/far-end of the fiber share a long common physical path. The assumption is that both fiber ends experience the same ambient temperature.
- Sections should be at least 500 m long and as far apart as possible.
- Differential loss is re-calibrated each time a measurement is taken.

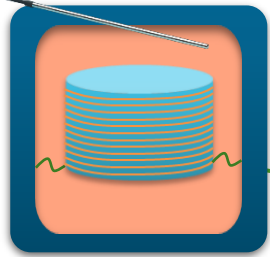


Differential loss calibration options: external probe

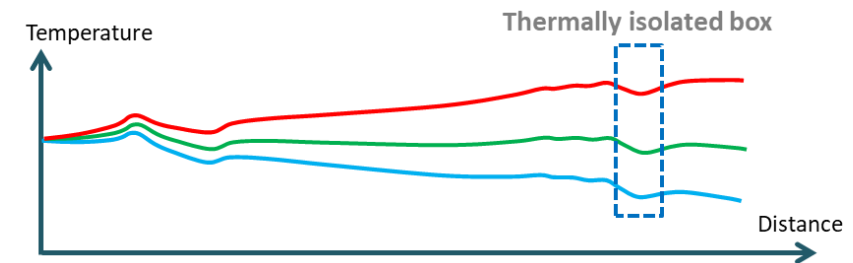
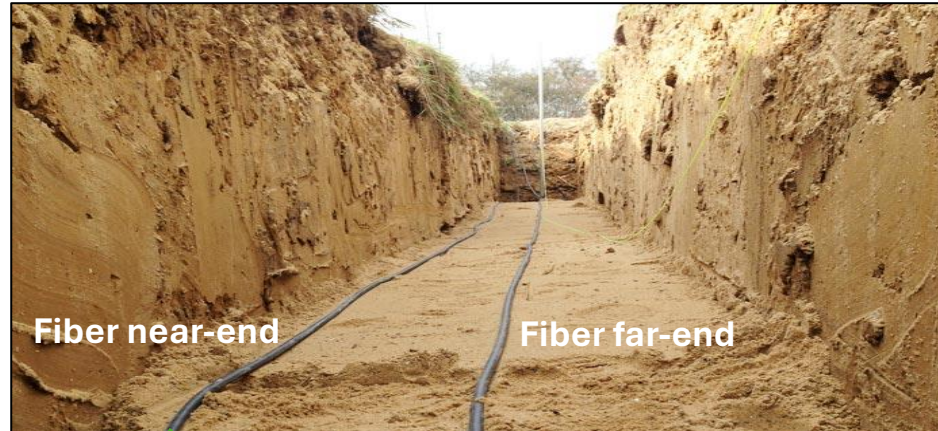
- The differential loss can be calibrated in the field in real time **using the external Pt100 probes**.
- The reference section must be located at the far-end of the fiber to optimize the slope estimation. The section must be long enough so that the residual noise doesn't impact the calibration.



PT-100
probe



Thermally isolated box
("calibration bath")

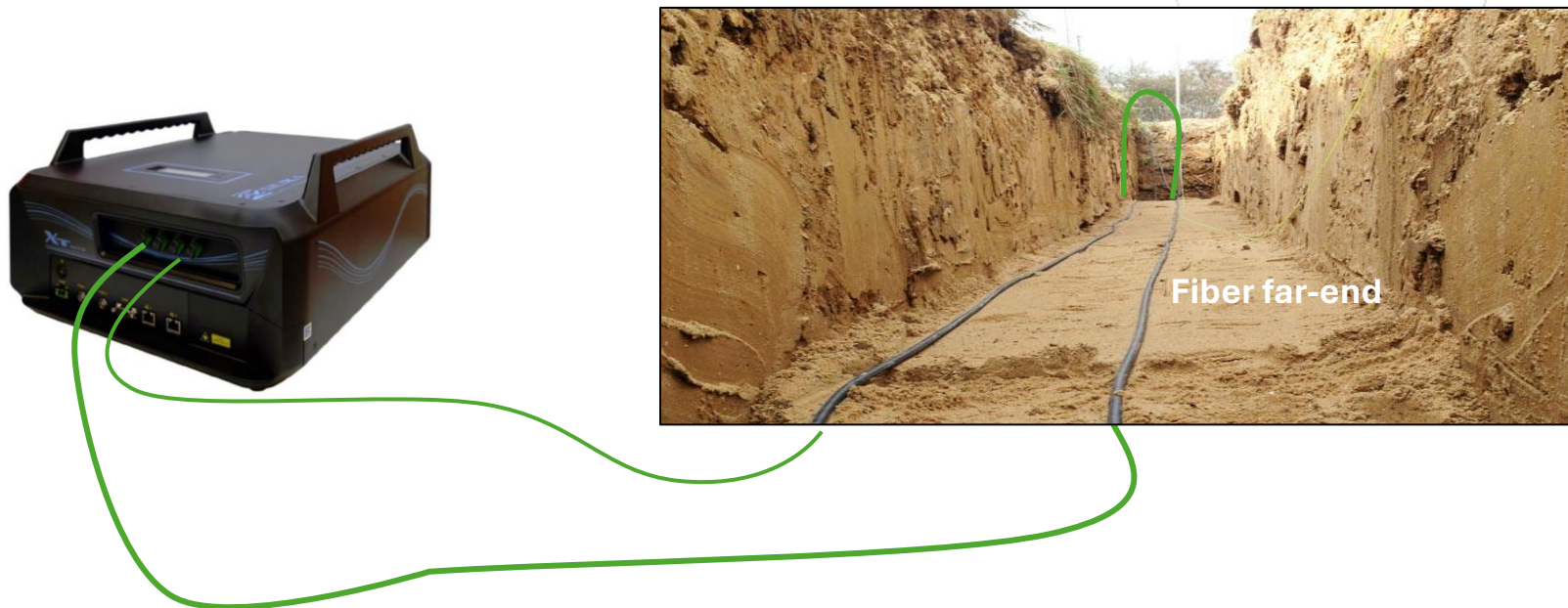


Differential loss calibration options: double-ended

Double-ended calibration can correct differential light loss that varies over the length of the fiber.

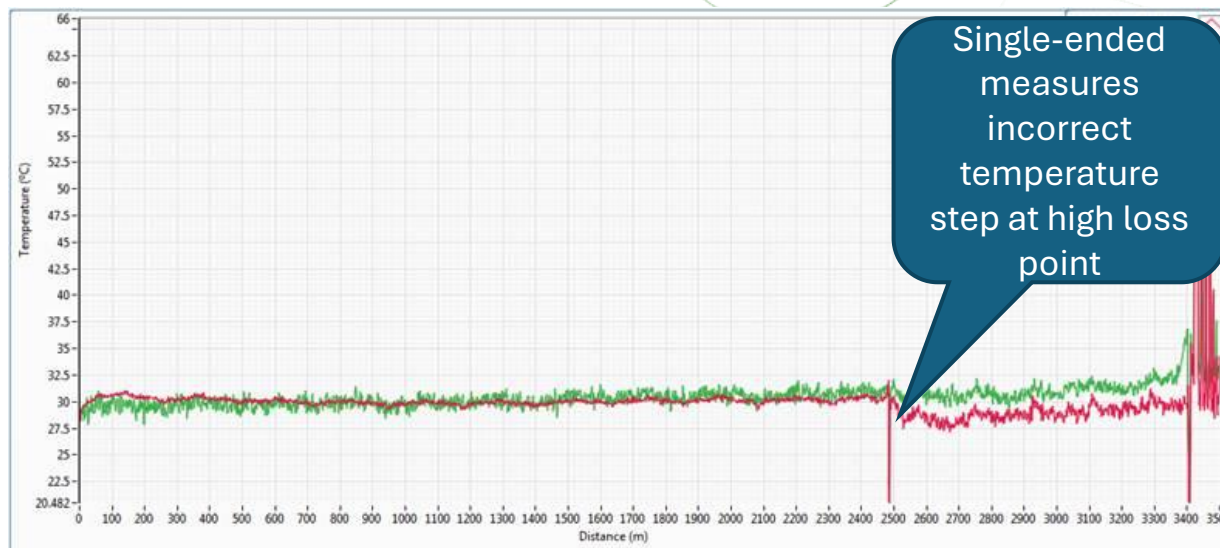
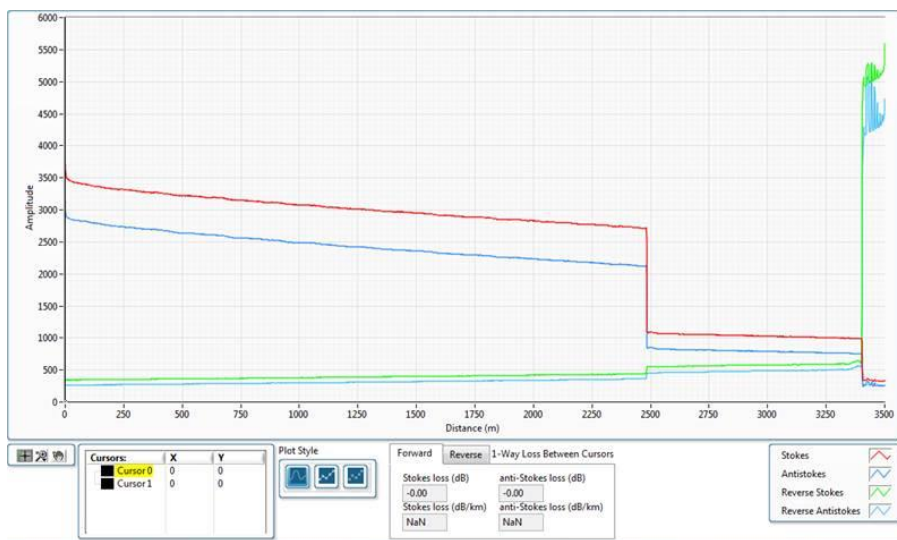
- Fiber must be in loop (length doubled & 2 channels used).
- Laser pulses launched from alternating ends of the fiber (forward and reverse directions).
- Requires precise alignment of the forward and reverse signals.
- Differential loss value is dynamically determined by combining the forward and reverse signals.
- Measurements are noisiest closest to the sensor and have the least noise at the midpoint of the fiber.

U-bend



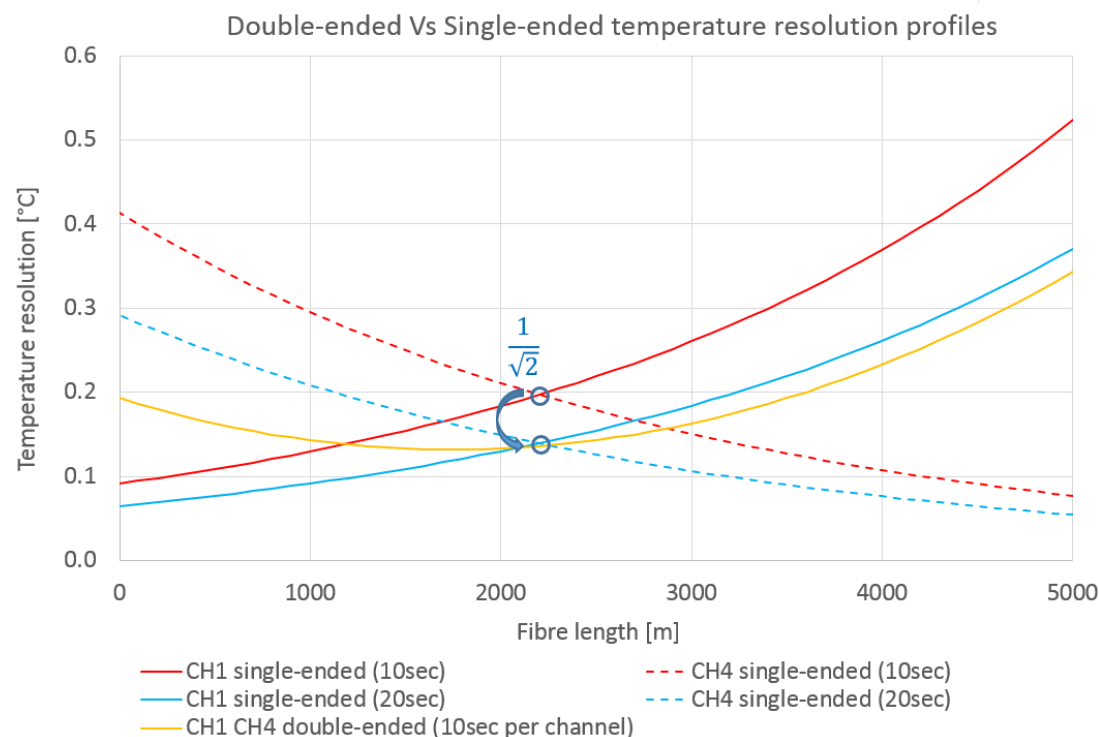
DTS System Configuration: Double-ended configuration

- There is no requirement for the fiber to follow the same path or fiber at given distances to experience the same temperature signals
- Mostly recommended in harsh environments
- Not advised otherwise due to relative complexity of configuration
- Example of single-ended and double-ended measurement through a high loss (and differential loss) point
- Double-ended gives a better calibration but worse SNR towards the beginning of the fiber



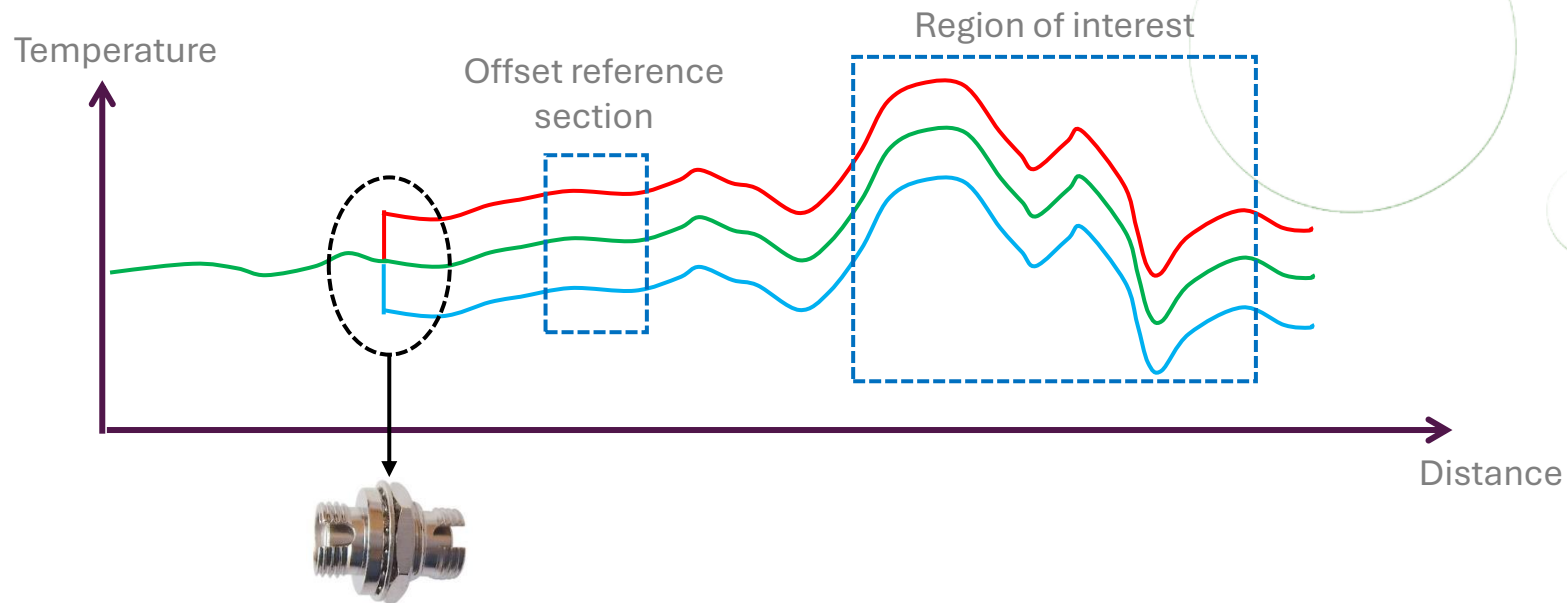
Double-ended measurements

- The differential loss is automatically calibrated in real time. Non-constant differential losses along the fiber are automatically accounted for.
- Only the offset must be calibrated. Internal or external Pt100 reference sensors can be used.
- The temperature resolution profile is U-shaped rather than an exponential function.



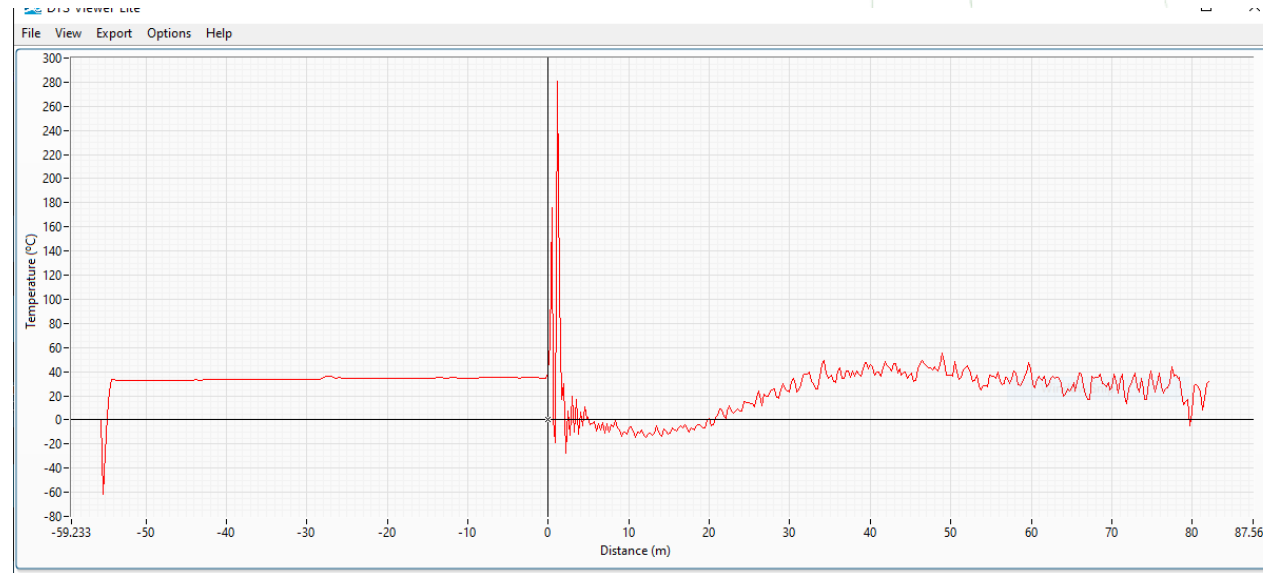
Impact of connectors and splices

- Connectors and splices have associated optical losses. In general, the Stokes loss and the anti-Stokes loss will be different. This causes an artificial step in the temperature trace. The height of the step can change with ambient temperature.
- If a real-time offset calibration is needed, then the reference section should be located after all external splices and connectors.

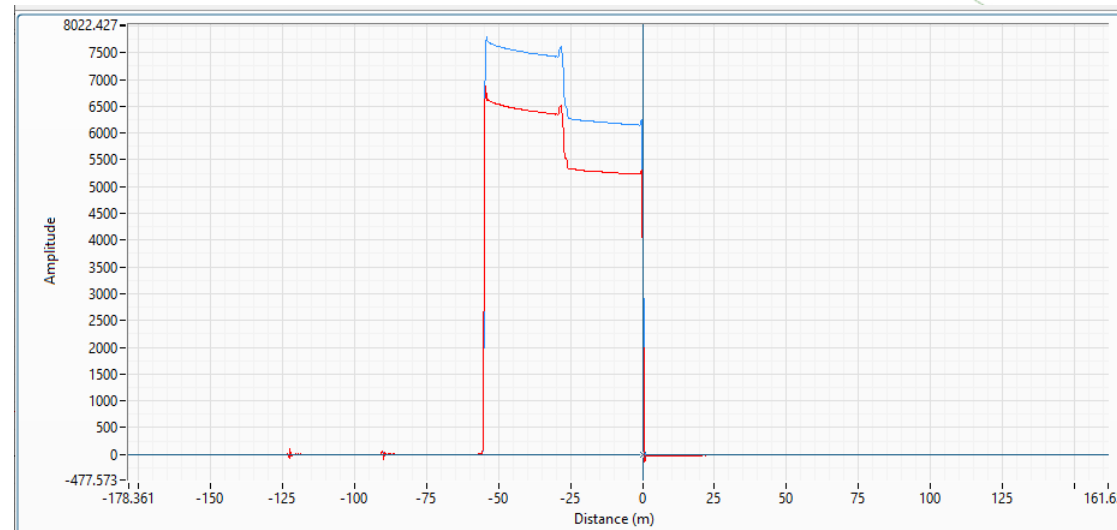


View raw: check losses at connectors or splicers

Temperature



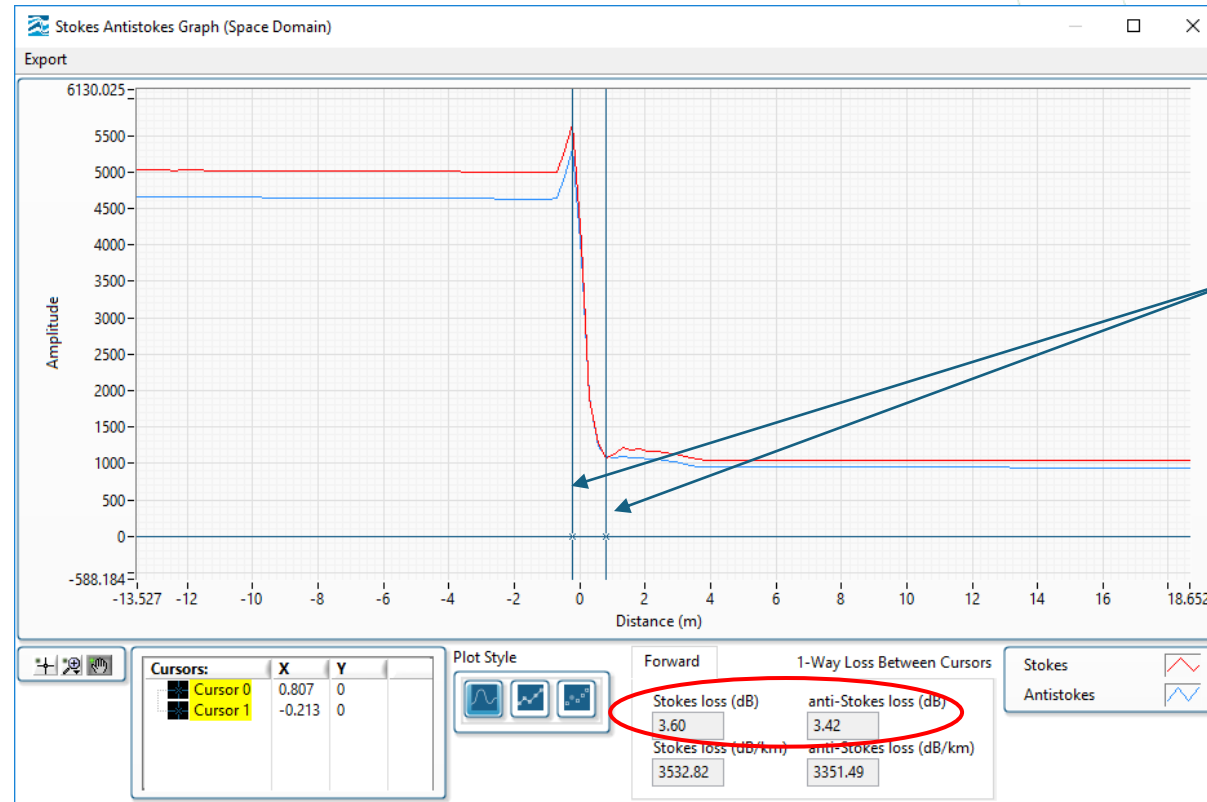
Raw Stokes & anti-Stokes



Signal loss at 0m usually indicates connector not plugged in

Raw signal: check losses

View raw signal and check optical losses.

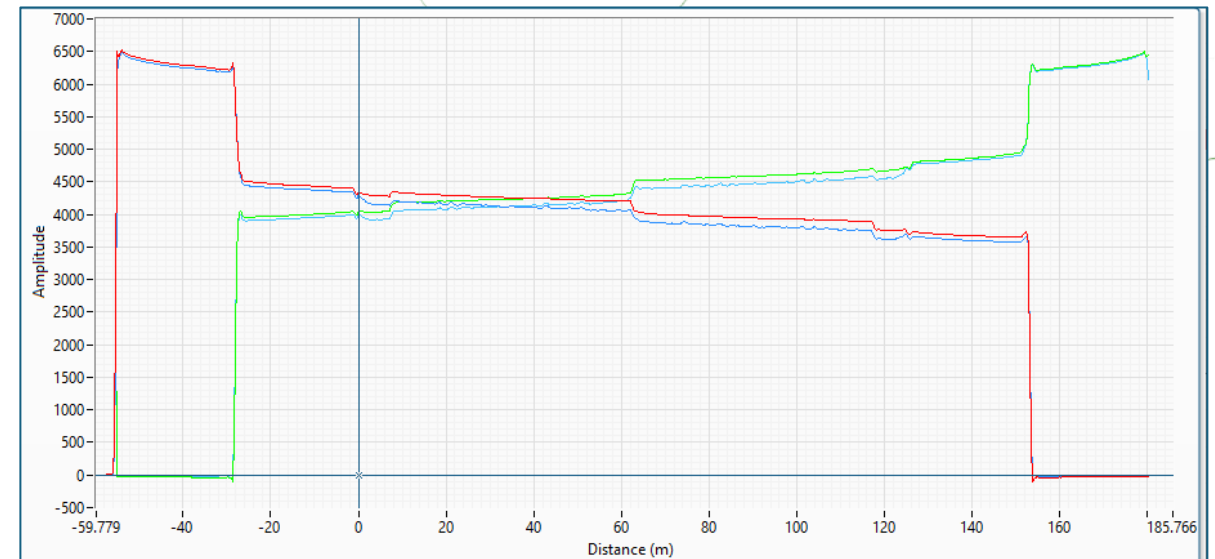
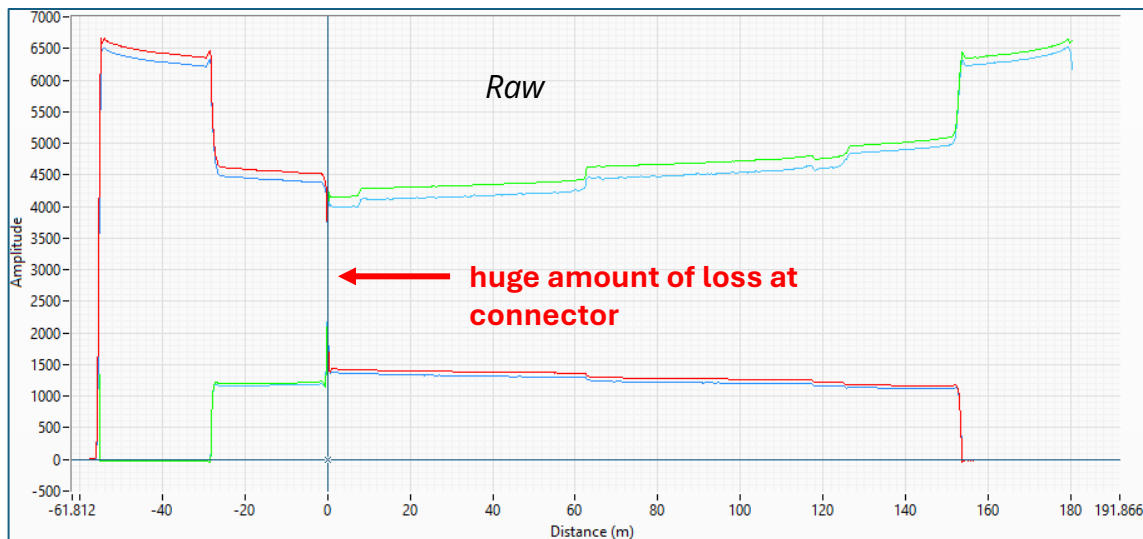
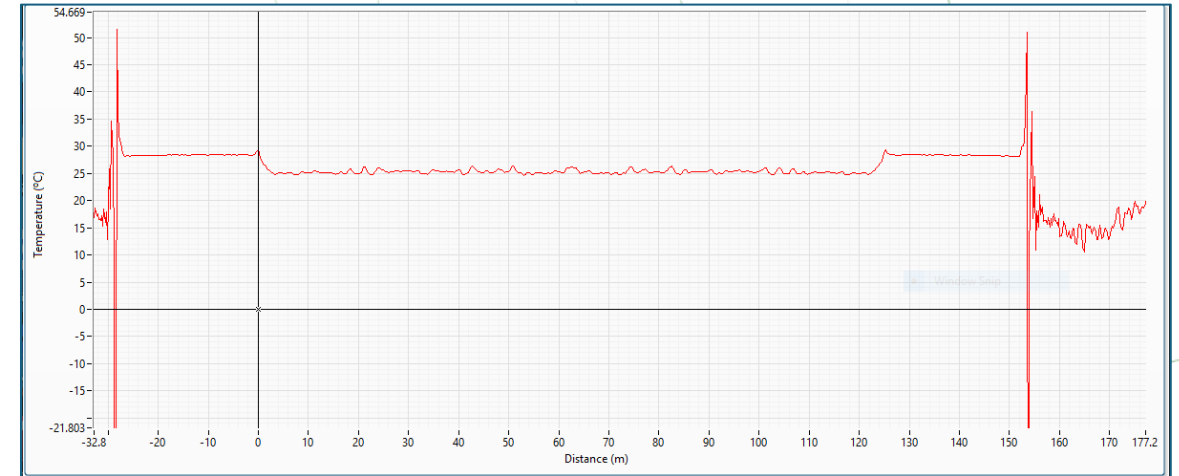
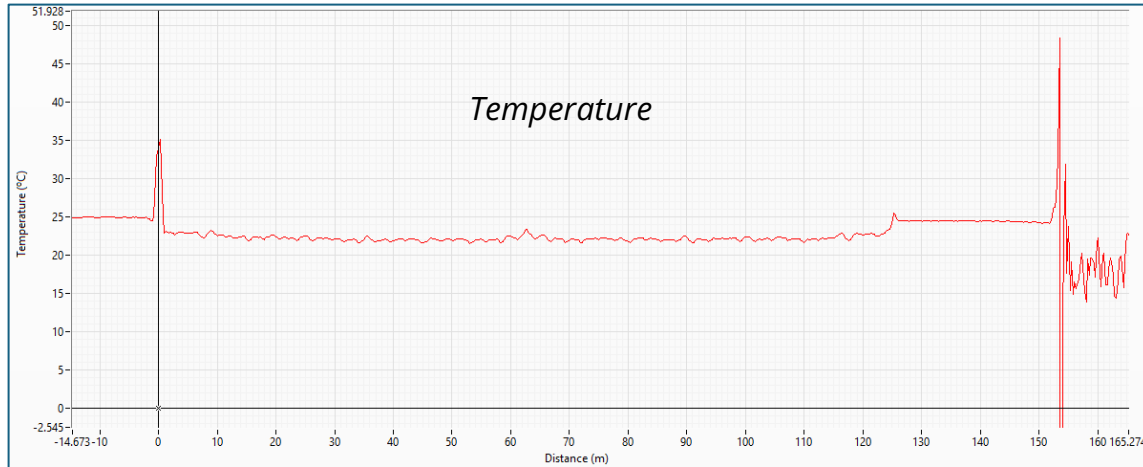


Place cursors at start and end of section showing loss to display the loss in dB

Typical 'good' connector losses are between ~0.1 – 0.3 dB

Effect of dirty connector

Connector not cleaned



Final step: Measurement Cycle

Finite number of measurements if “fixed number” has been selected in **Measurement Method**

Name of the user configuration

Settings Graph

Configuration Name

Comments

Measurement Method Continuous

Number Of Measurements

Measurement Interval Seconds

Measurement Cycle (seconds)

0 2.5 5 7.5 10 12.5 15

1 idle

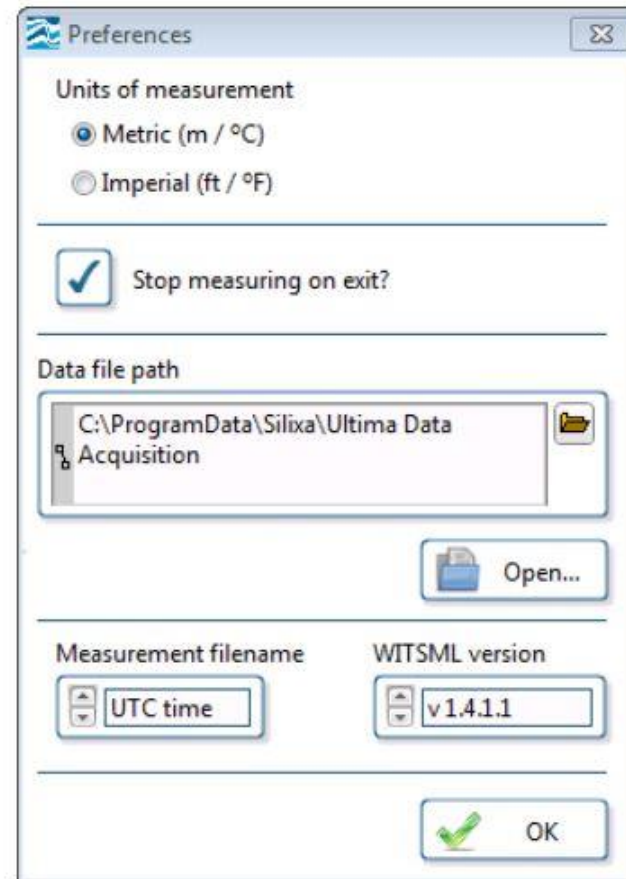
Controls total time taken for each measurement cycle.

Sums acquisition times set for each channel + idle time.

Can be set to acquire **continuously** (the measurement cycle repeats indefinitely) or **fixed number**

(graph below shows the timeline)

Preference editor



Final Checks

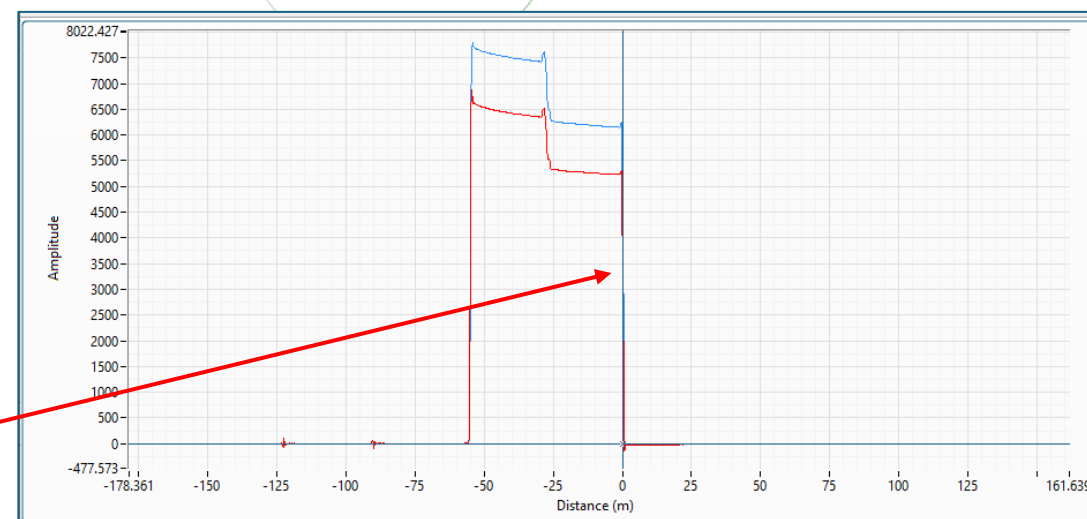
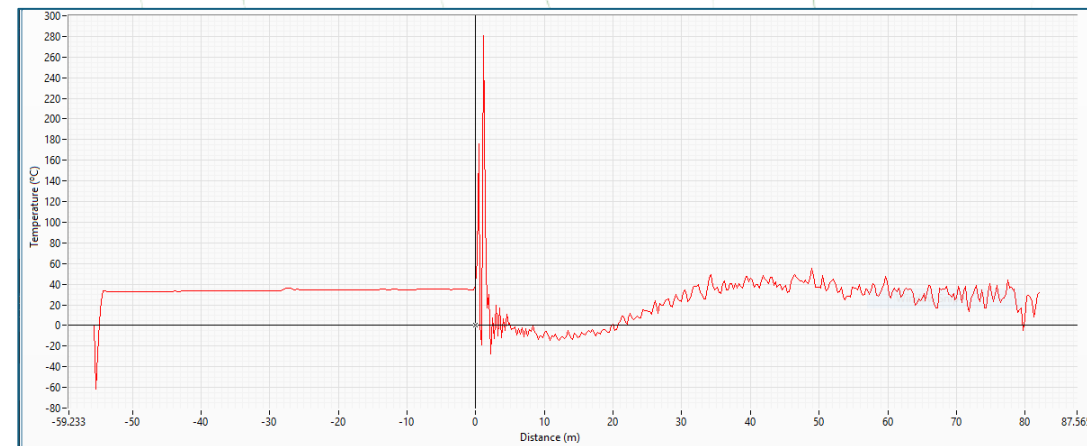
Data files

Name	Date modified	Type	Size
channel 3_20190725150608671	7/26/2019 12:33 PM	XML Document	1,049 KB
channel 3_20190725160608812	7/26/2019 12:33 PM	XML Document	1,049 KB
channel 3_20190725170609265	7/26/2019 12:33 PM	XML Document	1,049 KB
channel 3_20190725180609109	7/26/2019 12:33 PM	XML Document	1,049 KB
channel 3_20190725190609484	7/26/2019 12:33 PM	XML Document	1,049 KB
channel 3_20190725200609562	7/26/2019 12:33 PM	XML Document	1,049 KB
channel 3_20190725210608500	7/26/2019 12:33 PM	XML Document	1,049 KB
channel 3_20190725220608921	7/26/2019 12:33 PM	XML Document	1,049 KB
channel 3_20190725230610234	7/26/2019 12:33 PM	XML Document	1,049 KB
channel 3_20190726000609765	7/26/2019 12:33 PM	XML Document	1,049 KB
channel 3_20190726010610984	7/26/2019 12:33 PM	XML Document	1,049 KB

Check:

- File path
- File sizes
- Timestamps

Temperature

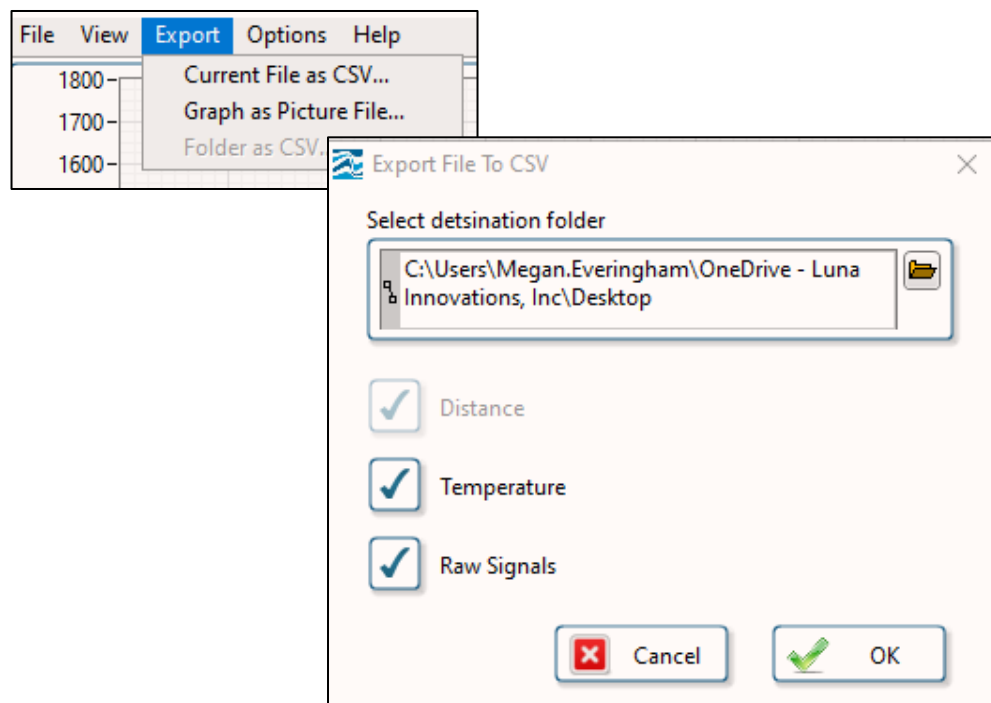


Signal loss at 0 m indicates connector not plugged in

Raw Stokes & anti-Stokes

DTS Viewer: export to CSV

Data can be exported within client software to CSV file format



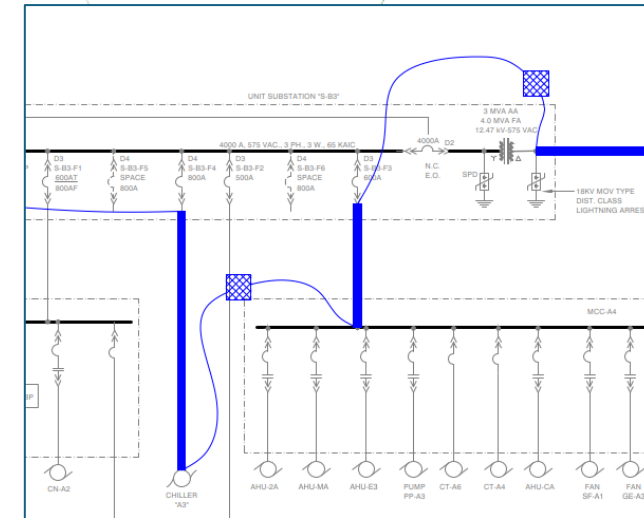
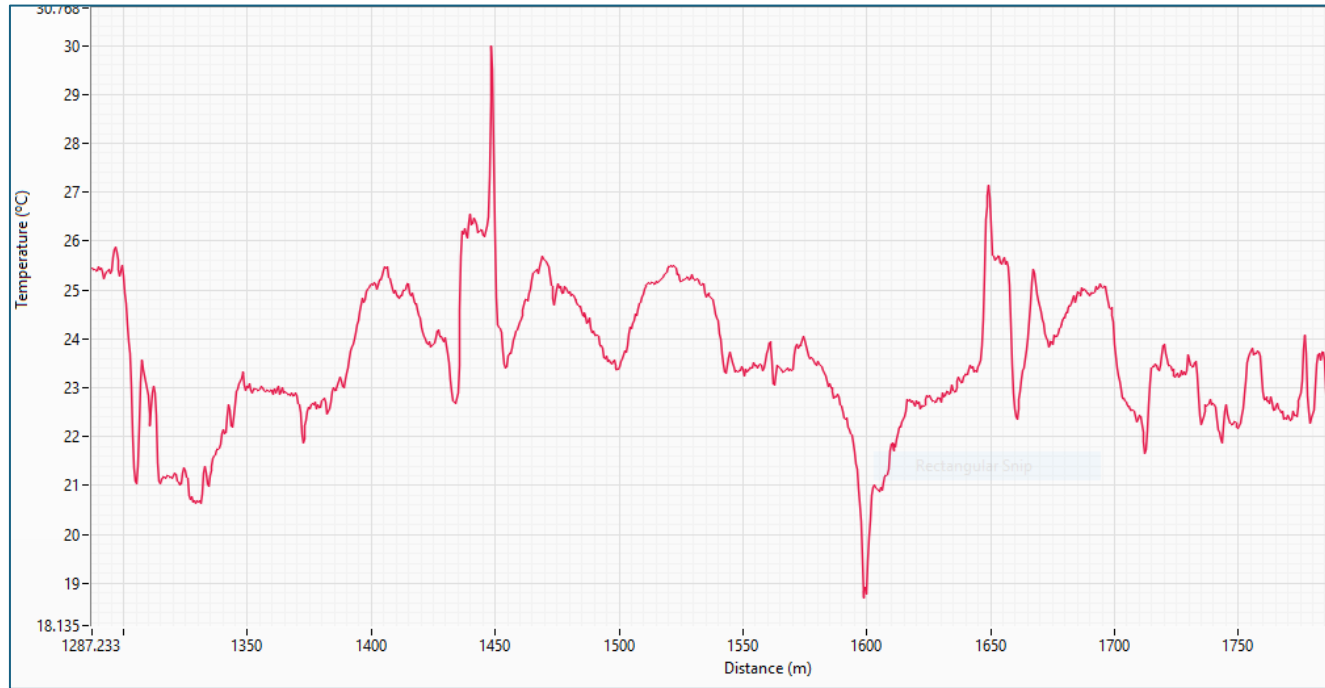
File	Home	Insert	Page Layout	Formulas	Data	Review	View	Automate	Developer	Help	Acrobat
<div>Clipboard: Paste, Copy, Format Painter</div> <div>Font: Aptos Narrow, 11, Bold, Italic, Underline, Color, Background Color</div> <div>Alignment: Left, Center, Right, Justify, Merge & Center</div>											
	A	B	C	D	E	F	G	H			
1	INT=27.20°C PT1=-998.72°C PT2=-998.97°C										
2	distance	temperature	forward stokes	forward antistokes	reverse stokes	reverse antistokes					
3	-220.989	78.648	0.282	-0.223	-0.14	0.326					
4	-220.735	180.863	0.204	0.402	-0.191	0.329					
5	-220.481	38.926	-0.287	0.794	-0.025	-0.012					
6	-220.226	65.684	-0.326	0.14	-0.096	-0.371					
7	-219.972	1037.418	-0.115	-0.28	0.026	-0.146					
8	-219.718	111.513	-0.164	0.284	0.259	0.346					
9	-219.464	362.904	0.057	0.2	-0.058	0.103					
10	-219.21	-91.392	0.127	-0.005	-0.073	-0.292					
11	-218.955	-146.703	0.11	0.01	0.461	-0.073					
12	-218.701	-53.499	-0.109	0.063	0.786	0.484					
13	-218.447	-49.504	-0.34	0.153	0.47	0.402					
14	-218.193	149.417	-0.307	0.01	0.001	0.099					
15	-217.939	1288.362	-0.195	-0.858	0.056	-0.195					
16	-217.684	0	-0.097	-0.744	-0.08	-0.534					
17	-217.43	81.564	0.403	-0.256	-0.157	-0.464					
18	-217.176	-5.542	0.153	-0.191	-0.157	0.098					
19	-216.922	1035.504	-0.273	-0.41	-0.072	0.641					
20	-216.668	-148.728	-0.273	-0.013	-0.162	-0.043					
21	-216.413	0	-0.238	0.585	-0.042	-0.555					
22	-216.159	112.871	-0.109	0.639	-0.355	-0.141					
23	-215.905	-95.3	0.304	0.213	-0.313	-0.057					
24	-215.651	4.716	0.512	-0.201	0.076	-0.172					
25	-215.397	208.708	0.07	-0.207	-0.137	-0.177					
26	-215.142	-56.162	-0.054	0.097	0.237	0.044					
27	-214.888	-120.65	-0.071	0.072	0.694	-0.035					
28	-214.634	-29.945	-0.003	0.063	0.241	-0.007					
29	-214.38	905.27	0.005	0.106	-0.164	0.094					
30	-214.126	-87.89	-0.034	-0.008	0.096	0.064					
31	-213.871	15.038	0.053	-0.426	0.37	0.046					
32	-213.617	-90.194	-0.265	-0.385	0.292	-0.03					
33	-213.363	100.536	0.015	0.093	0.186	-0.065					
34	-213.109	-66.426	0.552	-0.179	-0.052	-0.043					
35	-212.855	139.499	0.527	-0.232	0.057	0.353					

Which differential loss correction option should be used?

- Double-ended is the best choice in the common case of non-uniform attenuation, however:
 - Fiber must be in loop beginning and ending at unit; 2 channels used
 - No requirement for fiber to follow same path
 - Tradeoffs due to longer measurement length
 - Forward and reverse signals must be very accurately aligned when measurement configured
- For single-ended measurement configuration:
 - Fixed value
 - Reasonable if attenuation is uniform
 - External probe
 - Only accurate if section referenced to probe is in the distant $2/3^{\text{rd}}$ of the fiber and can be accurately defined
 - Thermally stable reference bath/chamber; length of fiber and probe need to be able to be placed in bath
 - Matched sections
 - Usually only chosen when there is symmetry in fiber path
 - Sections must be as long as possible and accurately defined
 - Sections in first and last quarter of fiber length

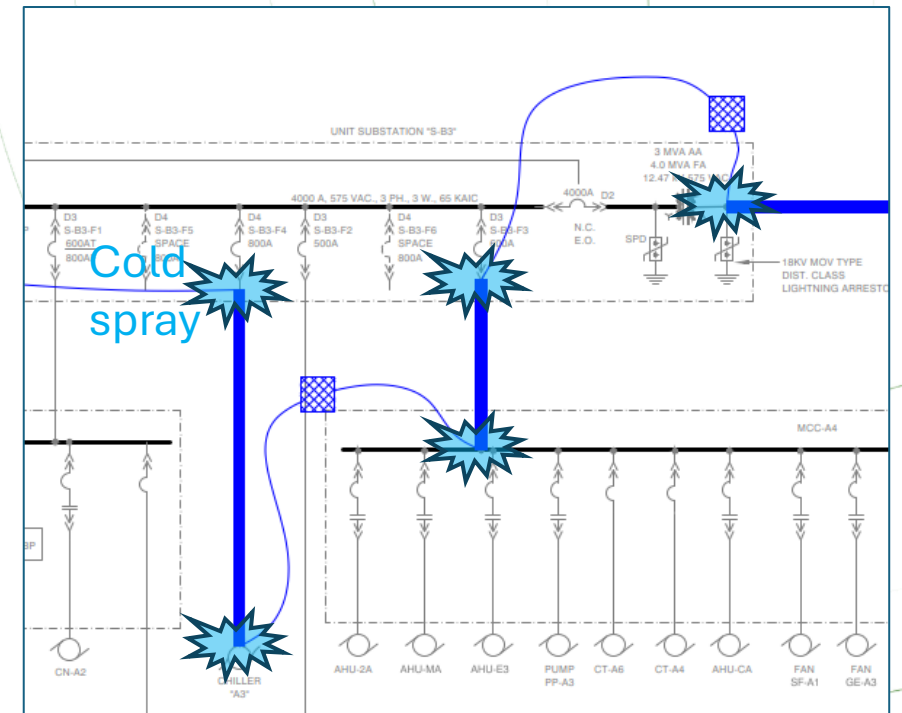
Mapping zones

Mapping zones in DTS data



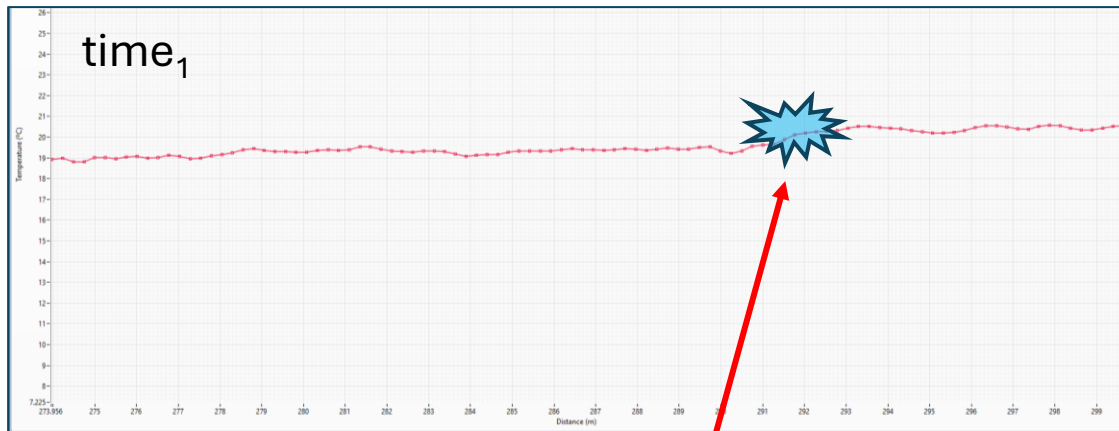
Map zones/location

- Configure measurements to capture applied temperature signal in space and time.
- Smallest sampling interval -> improve spatial resolution
- Apply a strong temperature signal when mapping

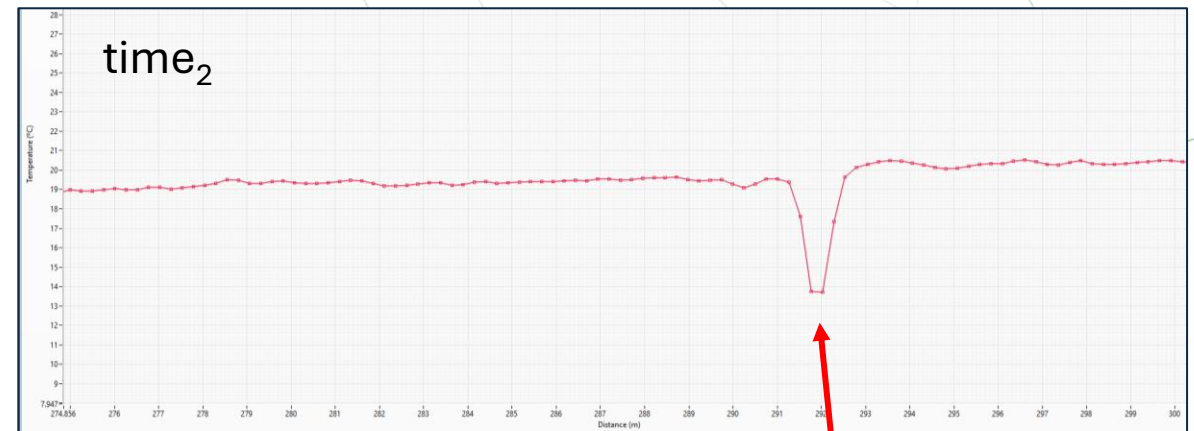


Cold spray for mapping

Apply spray to a length of cable approximately equal to the sampling interval (~25 cm in most cases)



cold spray applied



signal should appear as a deep spike in temperature



THANKS!

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3.1: "Fund for the realisation of an integrated system of research and innovation infrastructures"



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