Distributed Acoustic Sensing (DAS) for high resolution and high scale geophysical imaging

Fibre optical cables (FOC) & installation types

- Athena Chalari

IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-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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Outline

- Fibre types
- Connectors
- Cable types
- Cable installations & downhole components
- System architecture

Optical Fiber Handling Safety

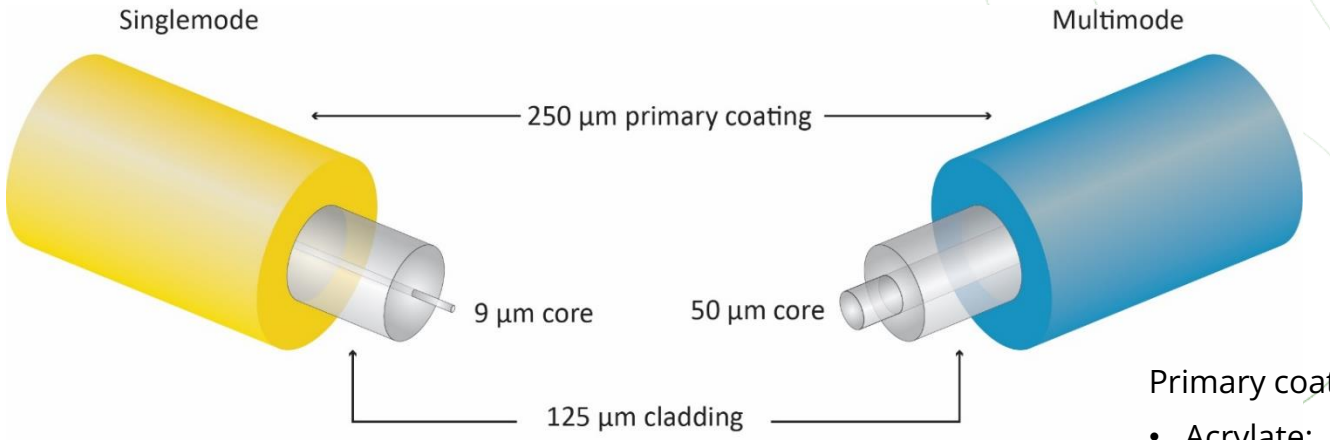
Hazards:

- ⚠ Optical fiber off-cuts can get embedded in the skin.
- ⚠ Optical fiber is brittle and breaks easily into small pieces.
- ⚠ Optical fiber is transparent which makes it difficult to spot.

Recommended best practices:

- ⚠ Account for all fiber off-cuts during splicing or termination process.
- ⚠ Use tweezers or tape to pick up fiber strands.
- ⚠ Sweep the entire fiber preparation area with tape to pick up any stray off-cuts before and after any splicing or termination work.
- ⚠ Dispose fiber off-cuts in appropriate sharps containers.
- ⚠ Keep food and drinks away from fiber preparation area.
- ⚠ Minimize skin contact with cleaning solvent, for example Isopropyl-alcohol (IPA), and be aware of any chemical safety requirements.

Optical Fibre: SMF vs MMF



Primary coating ambient temperature range

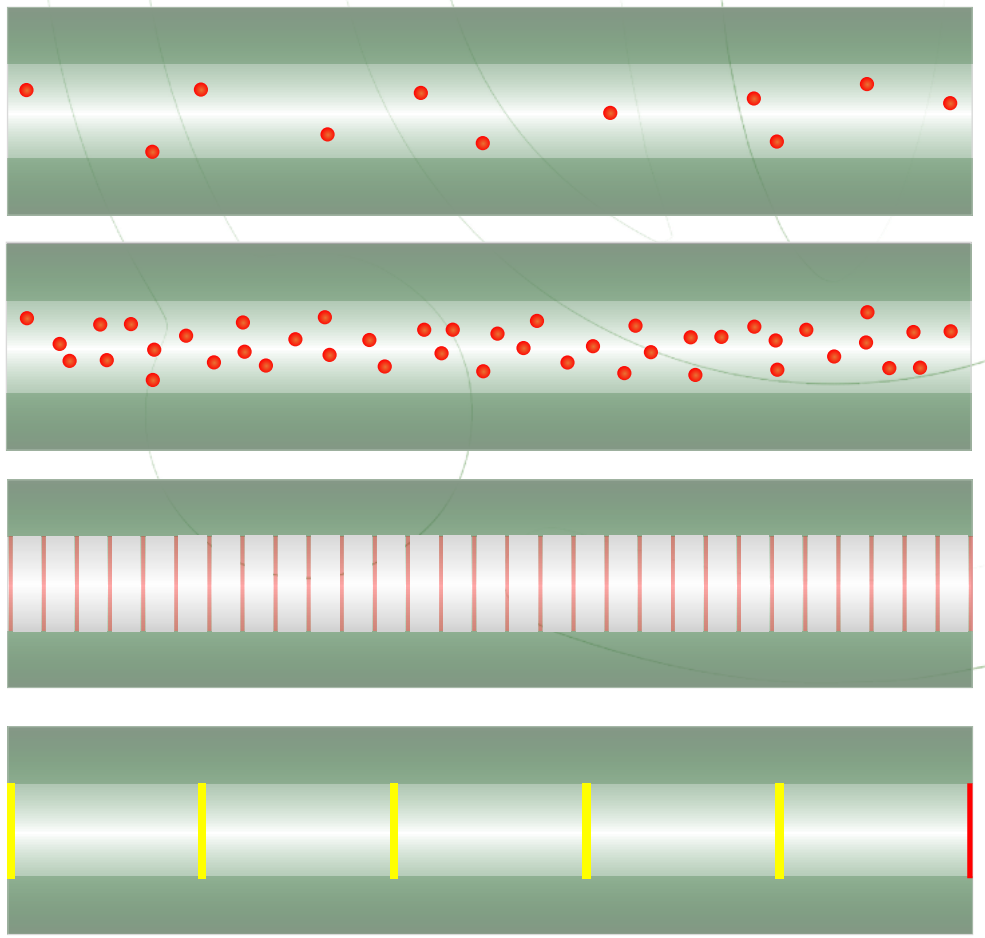
- Acrylate: -40°C to +85°C
- HT Acrylate: -40°C to +180°C
- Silicone PFA: -40°C to +200°C
- Polyimide: -180°C to +300°C
- Metal: -180°C to +650°C

Multimode typically used for DTS

- better system signal-to-noise ratio -> better temperature resolution.
- fibre connector losses are typically smaller.

Optical Fibre: Engineered

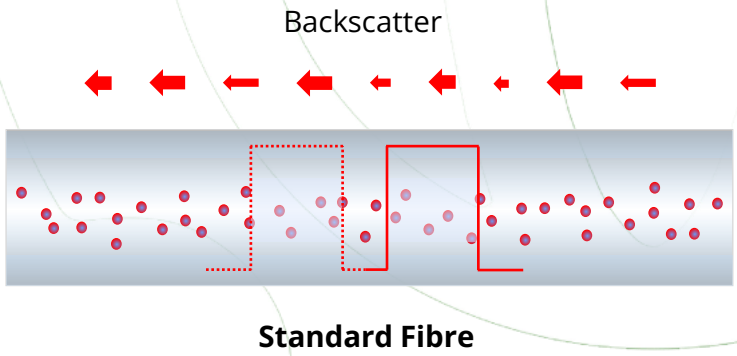
- **Standard fiber** – worst for signal, best for loss; uncontrolled phase relationship causes SNR variation (fading), which is an issue in some interrogator architectures
- **Highly doped fiber** – higher signal, but significantly higher loss increase
- **Continuous enhanced fiber** – much higher signal; reasonable losses but still uncontrolled phase relationship from multiple scatterers means there is a limit how the extra light can be effectively used
- **Engineered fiber** – much higher signal, reasonable losses and distinct scattering locations give control of the optical signal amplitude and phase: with the right interrogator, the extra light can be used to reduce the noise floor



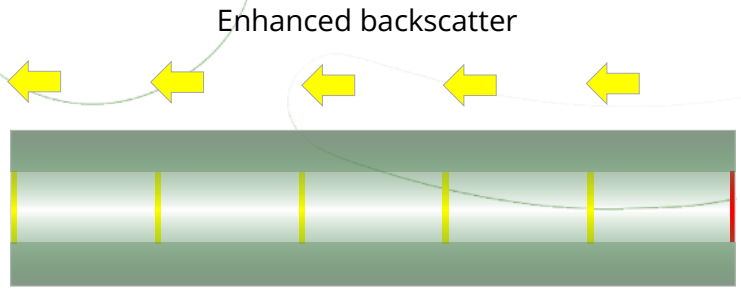
US Patent No. US 10,883,861 B2
EP Patent No. 3265757

Engineered Constellation Fibre

- 20 dB (100x) improvement in SNR when paired with Carina system
- Specifications can be tailored to the installation:
  - Engineered all along length, or just in region of interest
  - Increasing reflectivity to counteract losses
- Able to operate with multiple gauge lengths:
  - 2 m gauge length and above standard
  - 25 cm gauge length for specialist flow metering applications
- Multiple coating and core types:
  - Acrylate, silicone and polyimide coatings; carbon coating on the way
  - Germanium doped and pure silica cores
- Successfully tested for hydrogen resistance above 150ºC



Standard Fibre



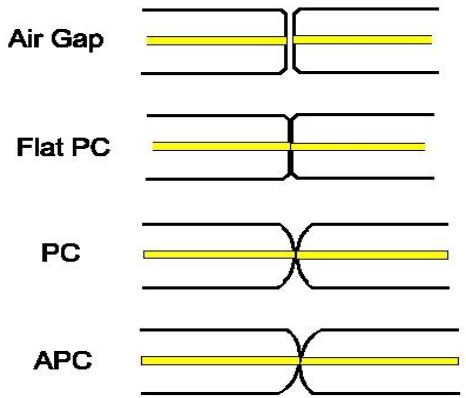
Engineered Fibre

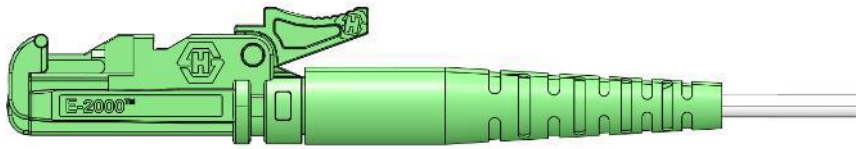
US Patent No. US 10,883,861 B2
EP Patent No. 3265757

Provides a **20 dB (100x) higher signal to noise ratio** than can be achieved on standard singlemode fibers.

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.

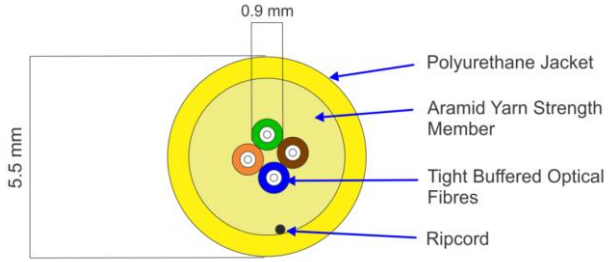
3. Plug the measurement cable into the XT-DTS front panel.

Cable types

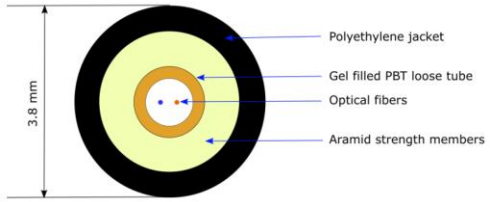
Durability

Low-temp **High-temp**

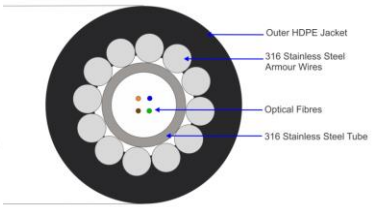
Tactical



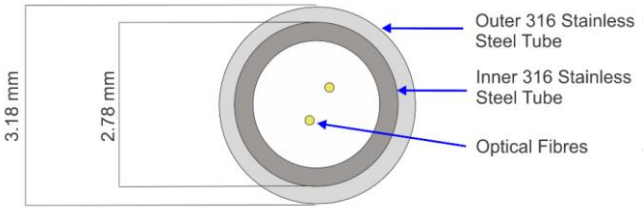
Loose Tube



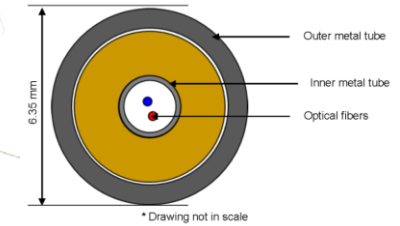
Armored FIMT



1/8” or 4mm Double-Tube



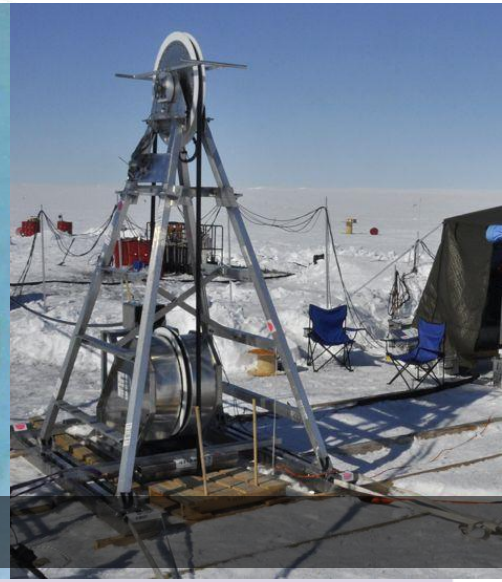
1/4” Downhole



....Or just use dark fibres in telecom networks

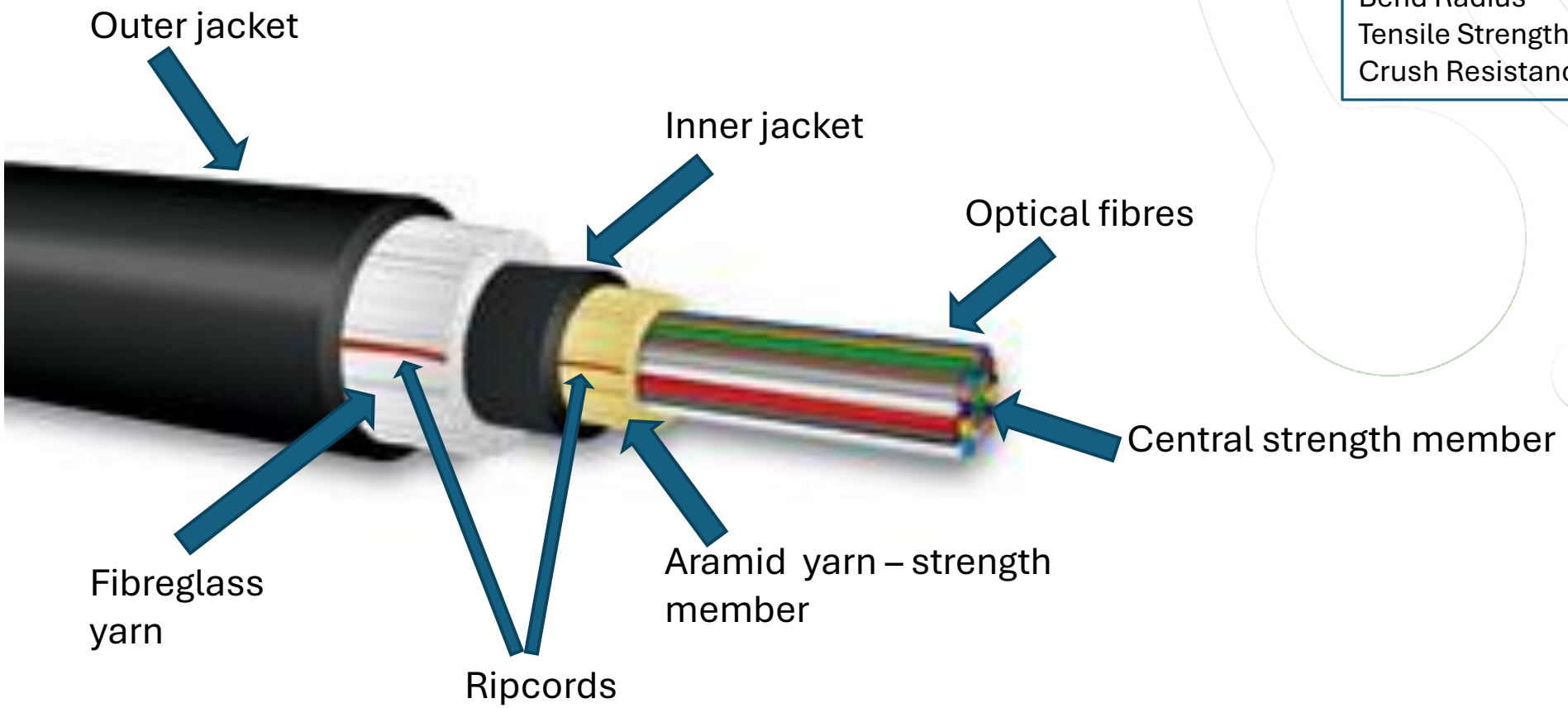
Surface

Downhole



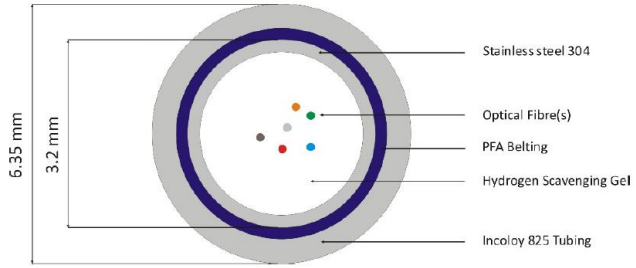
Fibre Optic Cable – Tight Buffered

Typical properties	
OD:	11mm
Bend Radius	11 cm
Tensile Strength	2,100N
Crush Resistance	1,800 N/cm



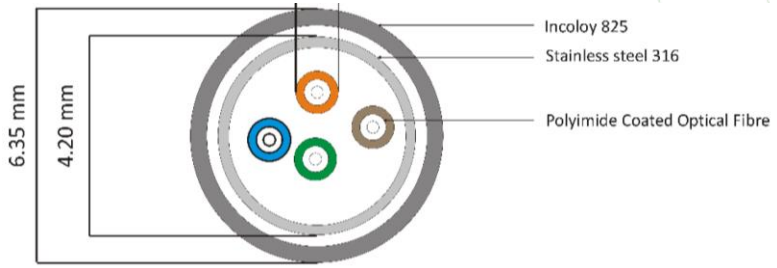
Downhole cables

High-temp – 260º C



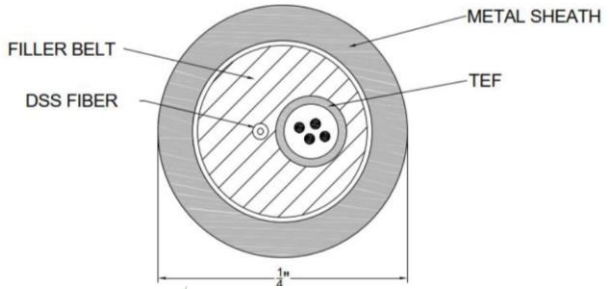
	ENTIRE ARMOURED CABLE
Nominal overall Diameter	6.35 mm
Approximate Weight	156.0 kg/km
Tensile Strength	10,904 N
Yield Strength	8,481 N
Strain at Yield	0.320%
Coefficient of thermal expansion	1.44E-05 m/m°C
Hydrostatic Pressure	121.1 MPa
Working Pressure	104.1 MPa
Dynamic Bend Radius	635 mm
Static Bend Radius	159 mm
Temperature rating	-40°C to +260°C
	METAL TUBING
Material	Stainless steel 304
Thickness tubing	0.2 mm
OD	3.2 mm
Material	Incoloy 825
Thickness tubing	0.89 mm
OD	6.35 mm

High-temp – 300º C



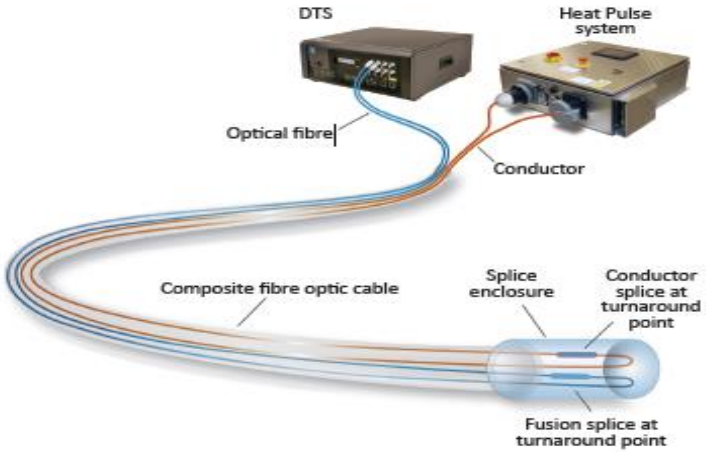
	ENTIRE ARMOURED CABLE
Nominal overall Diameter	6.35 mm
Approximate Weight	144.7 kg/km
Tensile Strength	10,904 N
Yield Strength	8,481 N
Strain at Yield	0.320%
Coefficient of thermal expansion	1.45E-05 m/m°C
Hydrostatic Pressure	121.1 MPa
Working Pressure	104.1 MPa
Dynamic Bend Radius	635 mm
Static Bend Radius	159 mm
Temperature rating	-40°C to +300°C
	METAL TUBING
Material	Stainless steel 316
Thickness tubing	0.2 mm
OD	4.2 mm
Material	Incoloy 825
Thickness tubing	0.89 mm
OD	6.35 mm

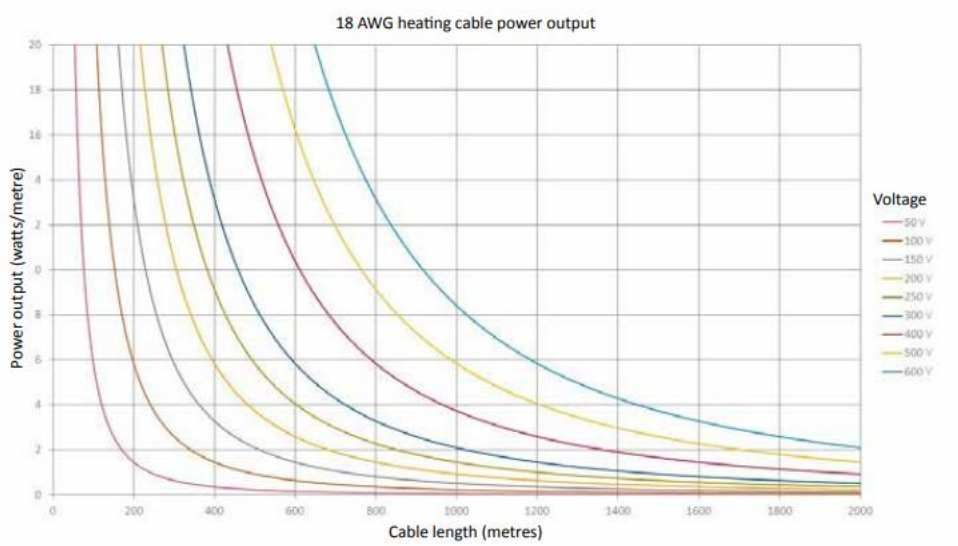
Special construction including DSS – 260º C



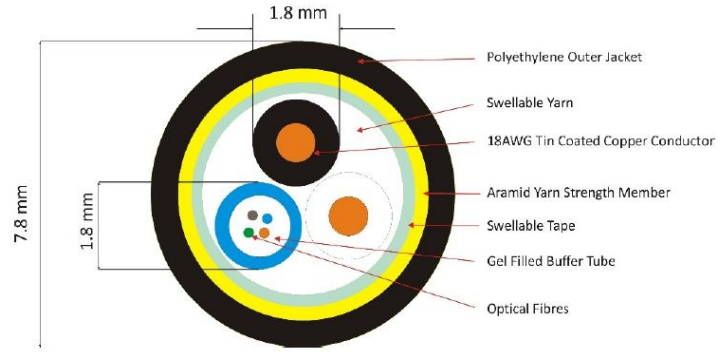
External Collapse Pressure	40,000 psi		
Temperature Rating	260 °C		
Fiber Type	Singlemode Carbon Polyimide		Silixa Constellation™ Pure Silica Core Polyimide
Fiber Count	4		1
Core Diameter	9 µm		9 µm
Cladding Diameter	125 µm		125 µm
Wavelength	1310 nm	1550 nm	NA
Maximum Attenuation	<1.0 dB/Km	<1.0 dB/Km	NA
Inner tube material	SS 316L		
Belting material	PP		
Outer tube material	SS 316L		
Nominal Diameter	6.4 mm (0.250")		

Composite Cables





Typical values:
1-2 W/m for atmospheric measurements such as wind speed
0-20 W/m for geothermal wells and shallow soil monitoring



Typical characteristics

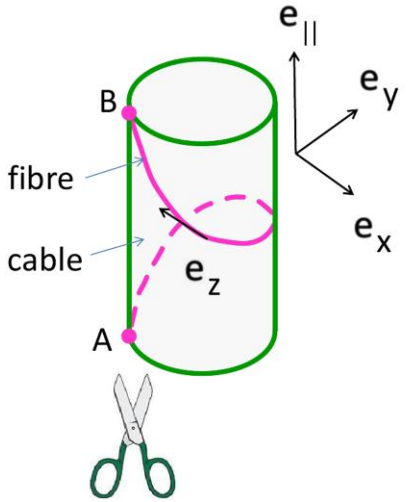
Fibre Code/Type	Multimode/OM3		Singlemode / ITU-T G.652.A2	
Fibre Count	2		2	
Core Diameter	50 µm		9 µm	
Cladding Diameter	125 µm		125 µm	
Wavelength	850 nm	1300 nm	1310 nm	1550 nm
Maximum Attenuation	3.5 dB/km	1.5 dB/km	0.5 dB/km	0.5 dB/mm

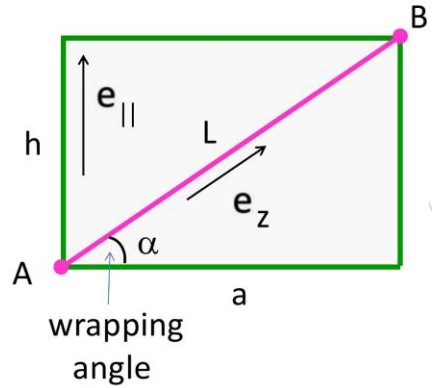
Mechanical Properties

Cable Diameter	7.8 mm
Total Cable Weight	60 kg/km
Installation:	
Max. Tensile Load	1,780 N
Min. Bend Radius	15.6 cm
Operating:	
Max Tensile Load	400 N
Min Bend Radius	2.8 cm
DC Resistance at 20°C	23.3 ohms/km
Voltage Rating	500 volts d.c
Operating Temperature	-40°C to +80°C
Storage Temperature	-40°C to +80°C

Power output cable with 2x18 AWG (American Wire Gauge)
Electrical resistance of 21.4 Ohms/ km for different voltages as a function of cable length.

Helically wound cables



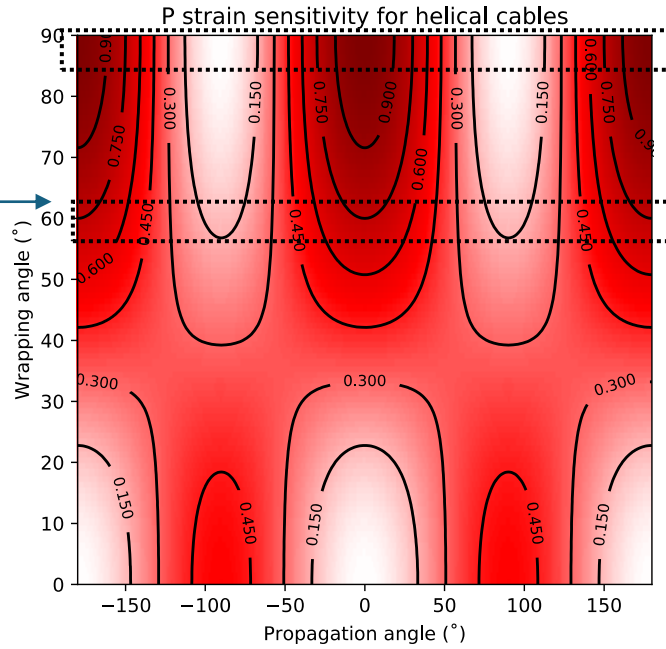


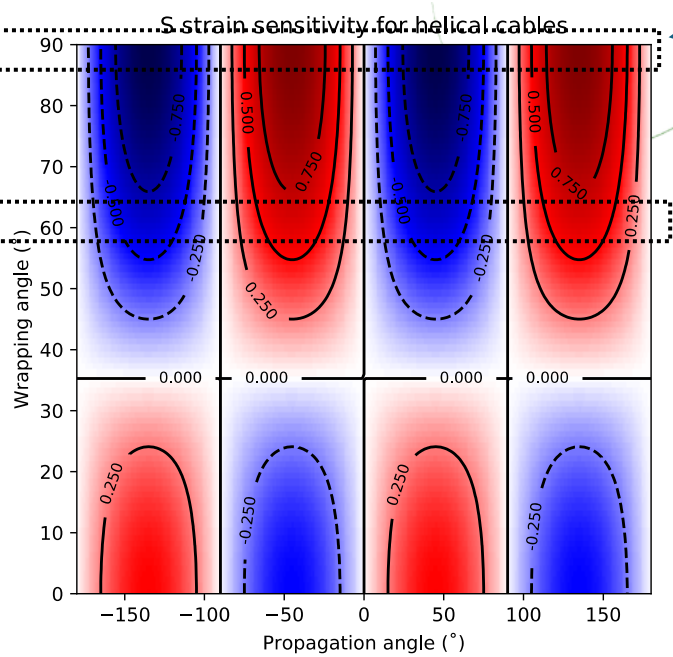
Linear fibre

HWC

S-wave
Lower response than linear

P-wave
More even response



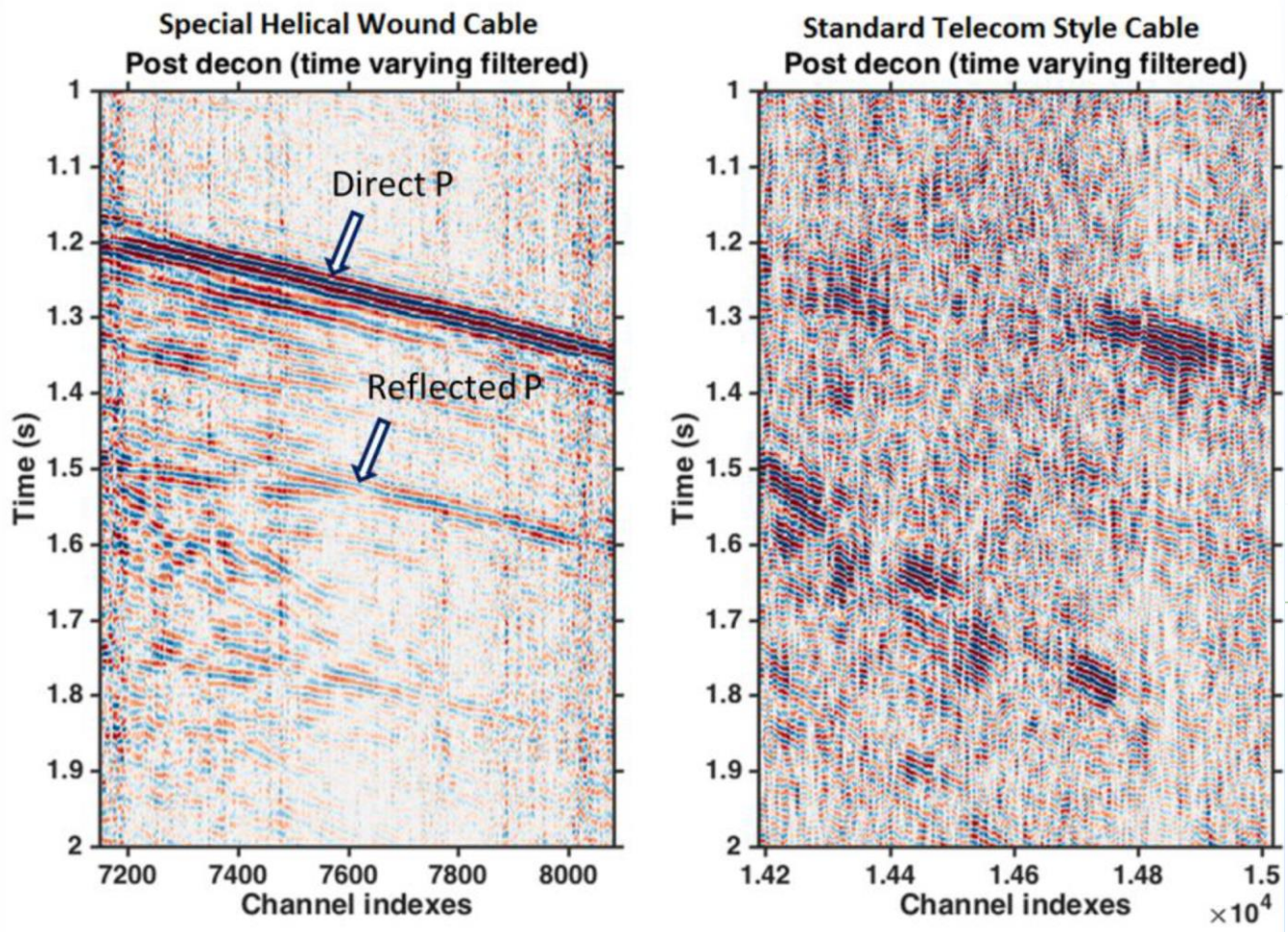


Baird, 2020

HWC case study: Archer Daniels Midland CCS (USA)

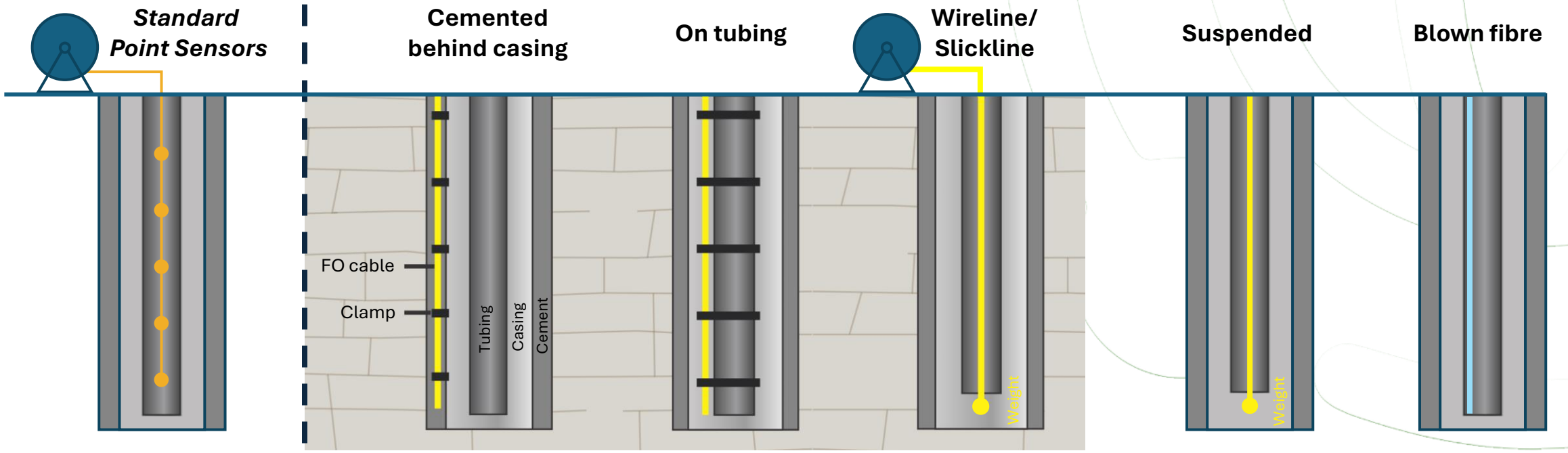
SOV – Surface Orbital Vibrator

Broadside sensitive cable



McDonald (2017), US Dept. of Energy data repository.

Downhole installation options



- Low coverage/ density
- High cost for higher temp
- High failure rate
- Need service

→ DFOS

- Permanent
- Good Coupling

- Semi-permanent
- Brown field development

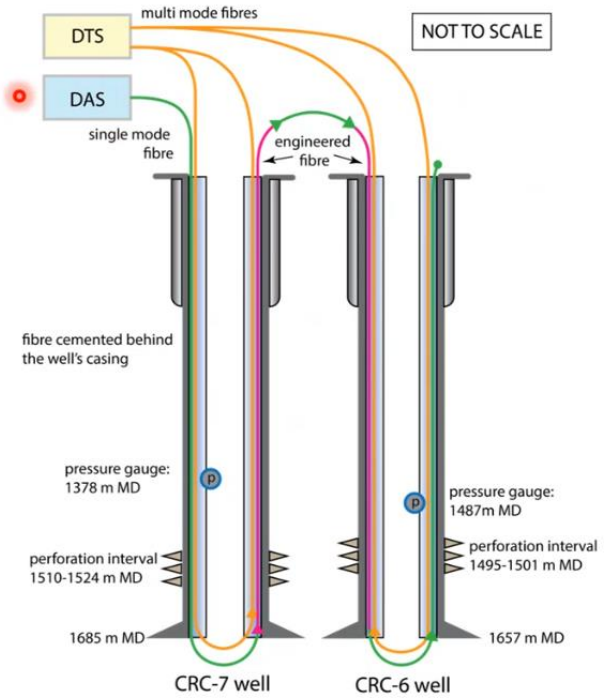
- Intervention
- Time-lapse surveys

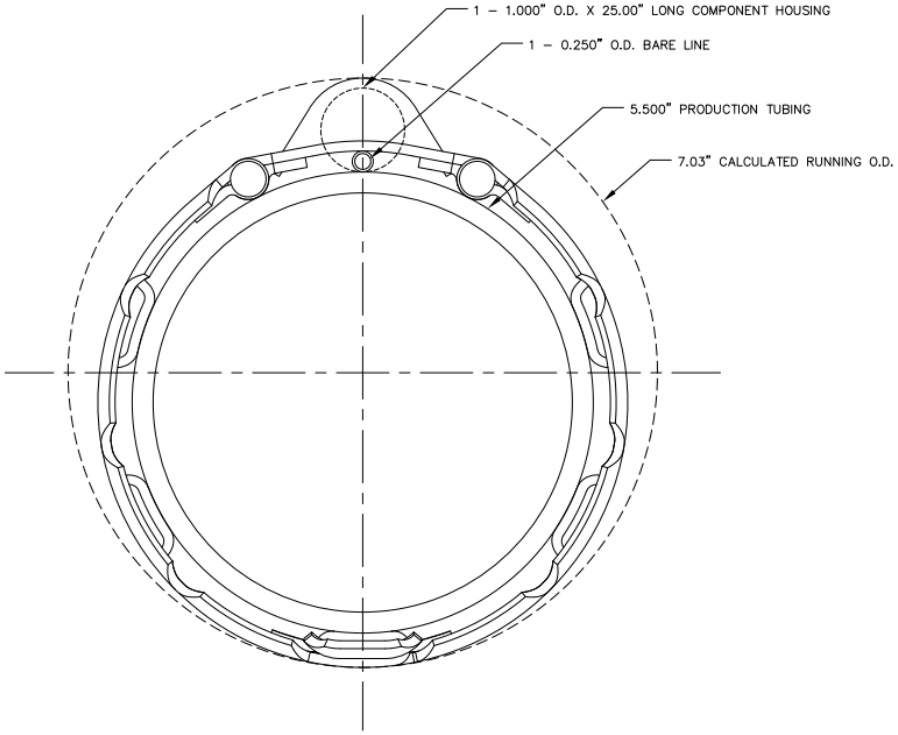
- Semi-permanent
- Time Lapse Surveys

- Corrosive & H_2-rich environments
- Fibre can be replaced

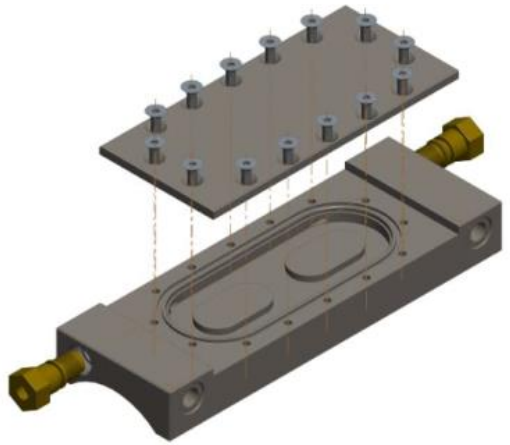
Downhole components

High Pressure Bottom Hole Assembly





High Pressure Downhole Splice Housing

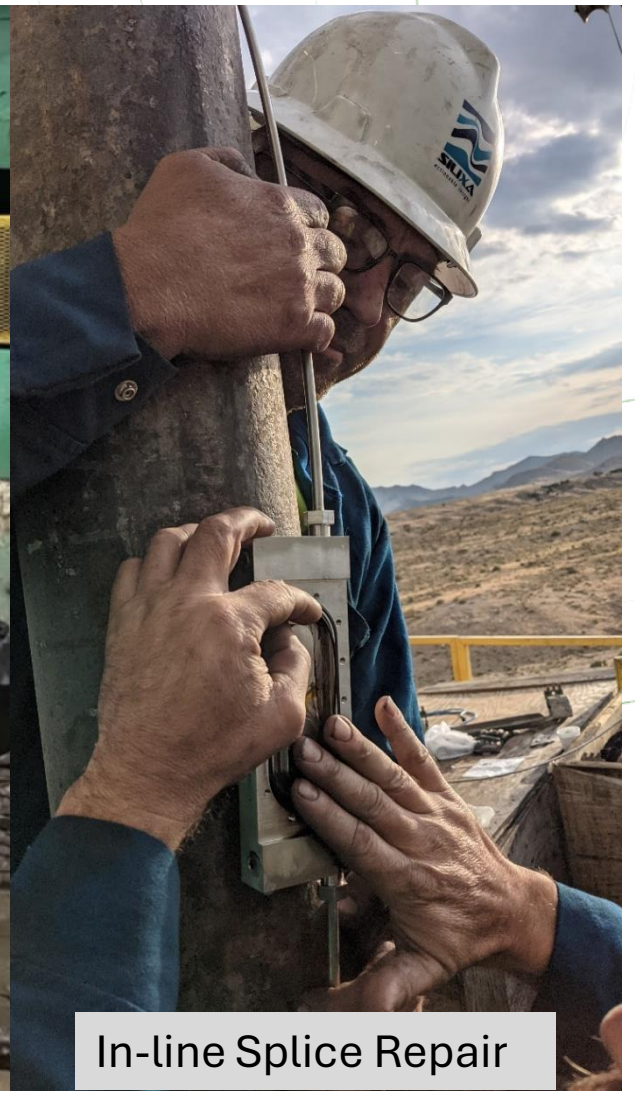


Cable Installation

Cable Installation

Bottom Hole Assembly Clamp

Welded Bar Centralizers and FOC

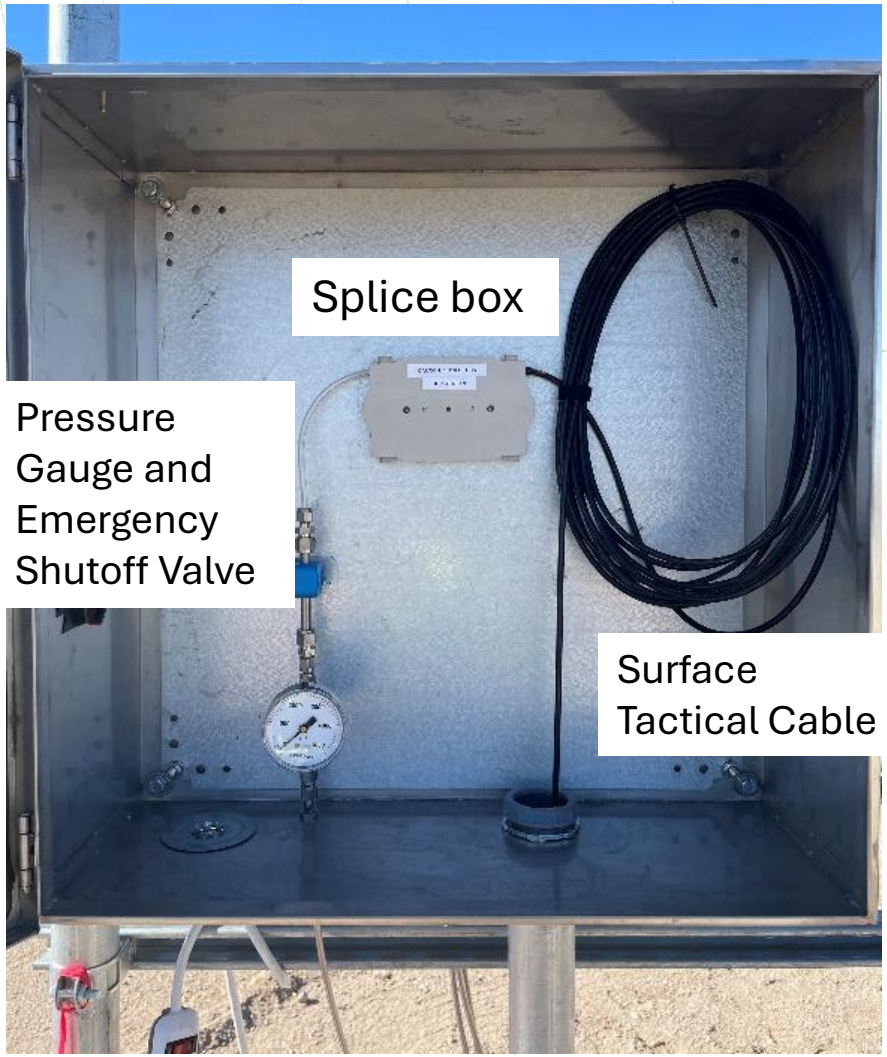


In-line Splice Repair

Example Fiber Optic Cable Surface Enclosure

Example Cable Trenching from Wellhead to Surface Enclosure

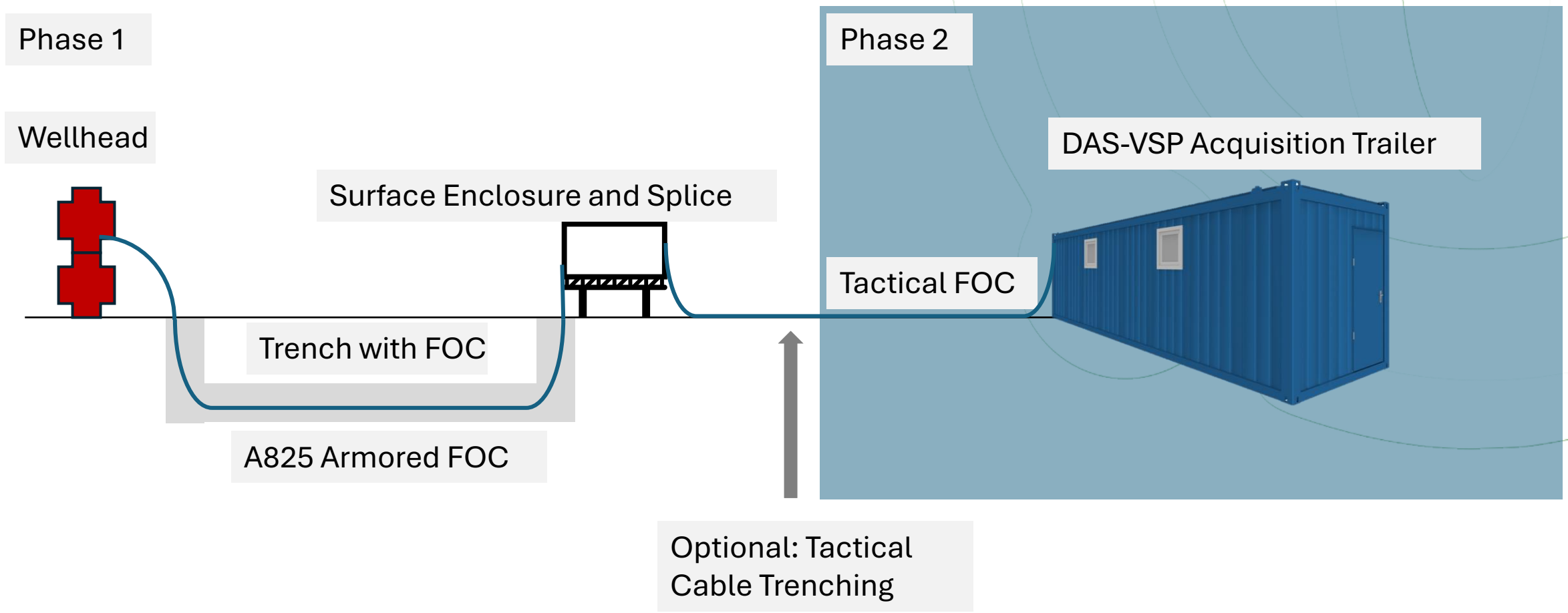
Example Cable Termination in Surface Enclosure with Spare Surface Cable



Example Completed Surface Enclosure

Silixa Surface Enclosure and Instrumentation

Example Completed Surface Enclosure



DAS-VSP Data Collection

Edge Monitoring Platform: System Architecture

Assembled

Instrumentation Cabinet

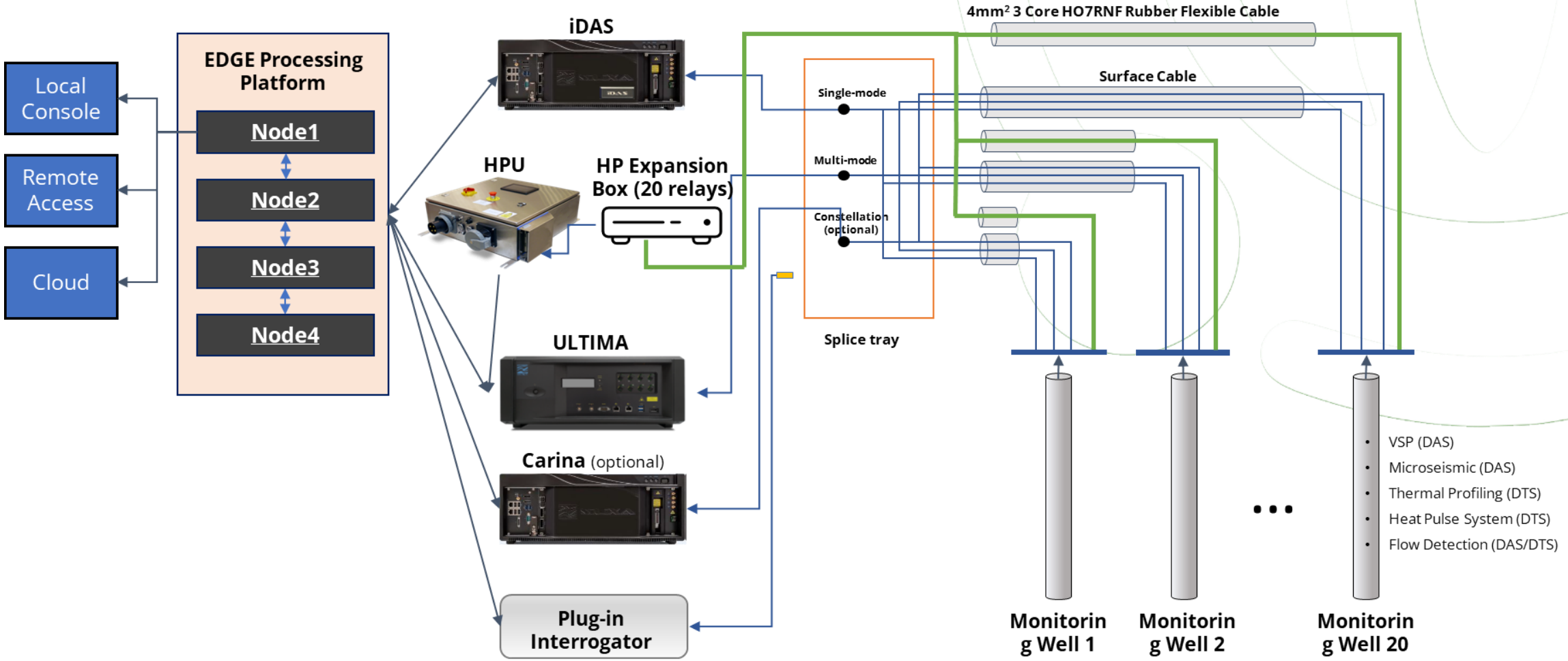
Processing Cabinet

On-Site Example

Front of Cabinet

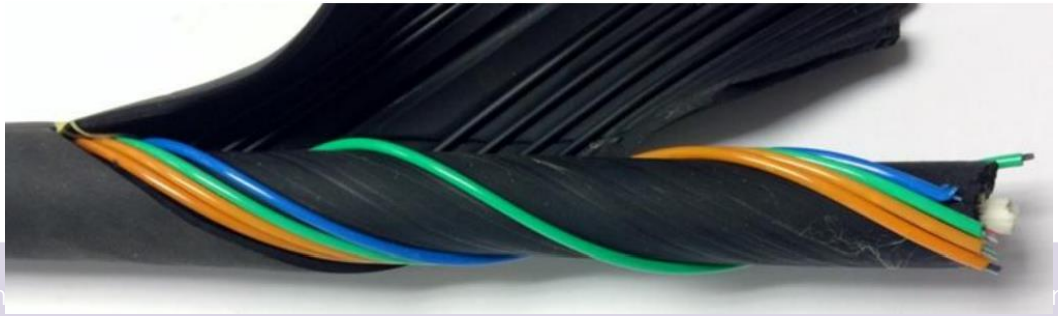
Cable Routing

System design & test



Surface Installations

(HWC) – Improve broadside P-wave sensitivity

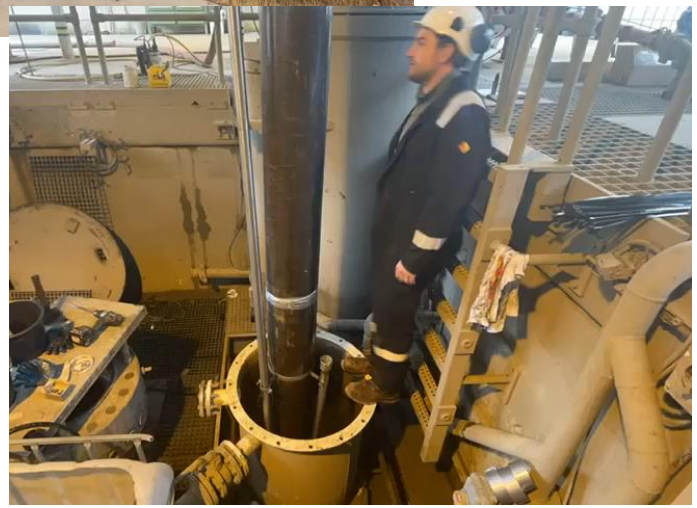


Surface Installations

Installation during Construction

Retrofit - Trenching

More Installation Types



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