Sandia National Laboratories

S11A-02

Effects on Signal Propagation Across the Transition Between Dissimilar Optical Fibers for Distributed Acoustic Sensing Analysis

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Abstract

Distributed fiber optic sensing observations (acoustic, temperature, and strain) are increasingly used in studies including, but not limited to, climate change, natural hazards, and monitoring of natural and anthropogenic sources. A common subset of studies have utilized existing unused telecom fiber optic ("dark fiber") cables that were not designed for scientific research applications and often include multiple fiber types in different installation environments. Understanding signal propagation across dissimilar fibers is particularly important, especially when the fiber design parameters are unavailable. Preliminary results from the Cryosphere/Ocean Distributed Acoustic Sensing (CODAS) project reveal a change in signal attenuation and reflection when transitioning from a standard terrestrial fiber to an oceanic-type fiber designed for long-haul applications. We use a Silixa iDAS interrogator to test spliced fiber optic pairs to quantify the transitional effects on signal propagation for a range of fiber scenarios including terrestrial single-mode to oceanic single-mode fibers and oceanic to terrestrial fibers. Future work will include both DAS and DTS on standard, helically wound, and multi-mode type fibers, tests in variable temperature and pressure conditions, effects of amplifiers/splitters, and optimization of cable terminations solutions. These results have the potential to inform existing and future distributed fiber optic sensing applications. SNL is managed and operated by NTESS under DOE NNSA contract DE-NA0003525

Instrumentation

iDAS >> internal fiber 130m (520ch)
Corning SMF-28 >> terrestrial 96m (384ch)
Corning Vascade EX2000 >> oceanic 30m (120ch)
Test wavelength 1550 nm

Corning SMF-28
Nominal effective area = 82 μm²
Mode field diameter = 10.4 μm
Attenuation = 0.18 dB/km
Backscatter coefficient = -82 dB
Refractive index = 1.4682

Corning Vascade EX2000
Nominal effective area = 115 μm²
Mode field diameter = 11.9 μm
Attenuation = 0.15 dB/km
Backscatter coefficient = -85 dB
Refractive index = 1.4634

Connectors E2000/APC

Splicing
Sumitomo T56 Fusion Splicer
Splicer estimate < 0.01 dB loss

All fibers are terminated with a triple loop

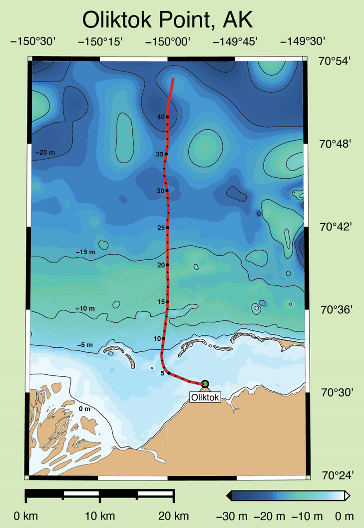


Fig 1. Oliktok fiber map

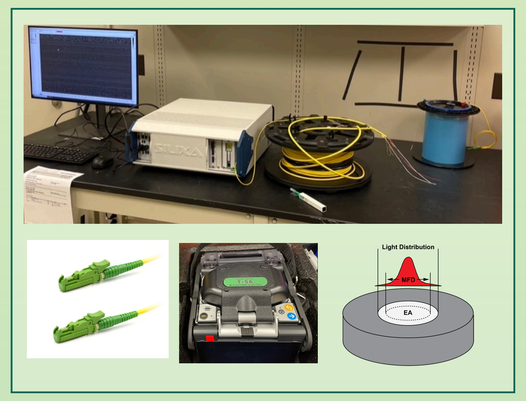


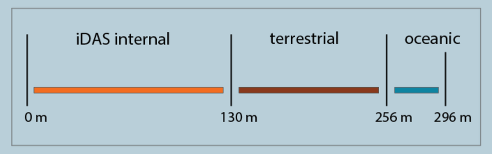
Fig 2. (Top) Experiments setup; (Bottom left) E2000/APC connector; (Bottom center) Fusion Splicer; (Bottom right) Light propagation in fiber

Laboratory DAS Data

Gauge length: 10 m, dx: 0.25 m
~5 dB amplitude change across all frequencies

[1] Hybrid fiber test: terrestrial to oceanic
[256 m > 1024 ch]

Channel spacing: 0.25m
iDas internal FO 0.....520
terrestrial FO 521.....904
transoceanic FO 905...1024



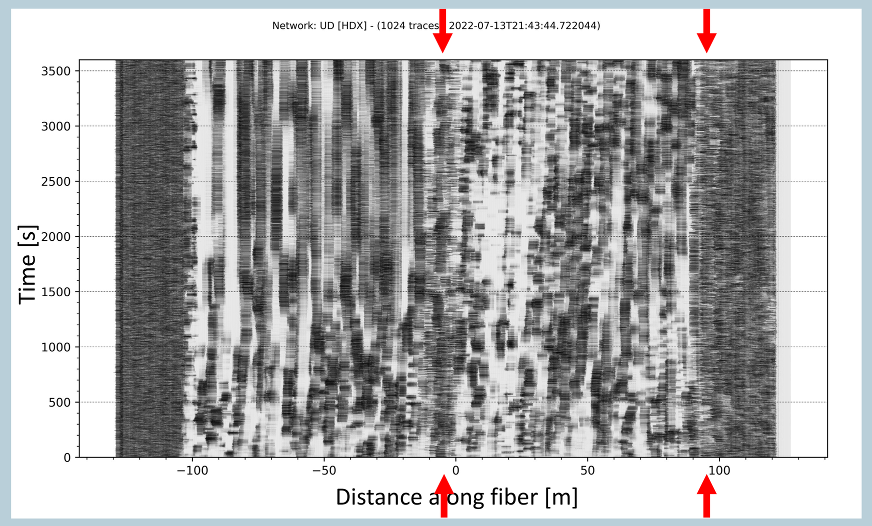


Fig 3. 1H raw data along the hybrid FO (terrestrial fiber spliced to oceanic fiber) plotted by distance. Negative distance corresponds to fiber within the iDAS interrogator. Amplitude is nanostrain-rate (x5).

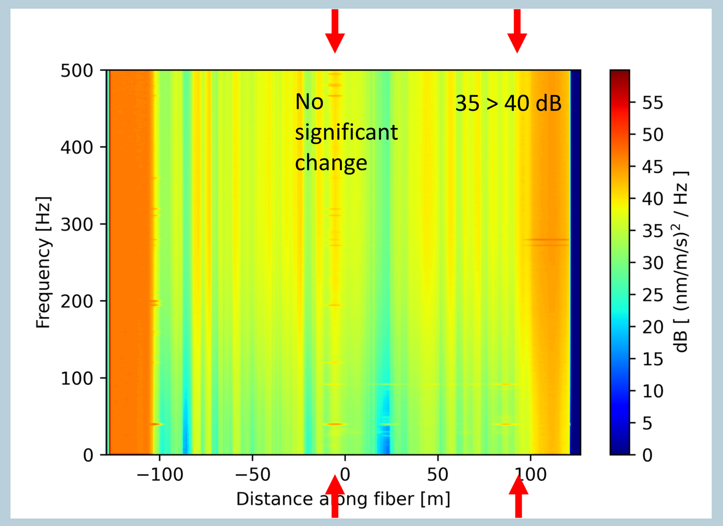
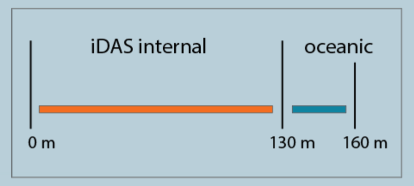


Fig 4. DAS power spectral density along hybrid fiber distance. Note the amplitude increase at ~100 dB where the terrestrial is spliced to oceanic type FO.

[2] Submarine fiber test: iDas internal to oceanic
[160 m > 640 ch]

Channel spacing: 0.25m
iDas internal FO 0...520
transoceanic FO 521...640



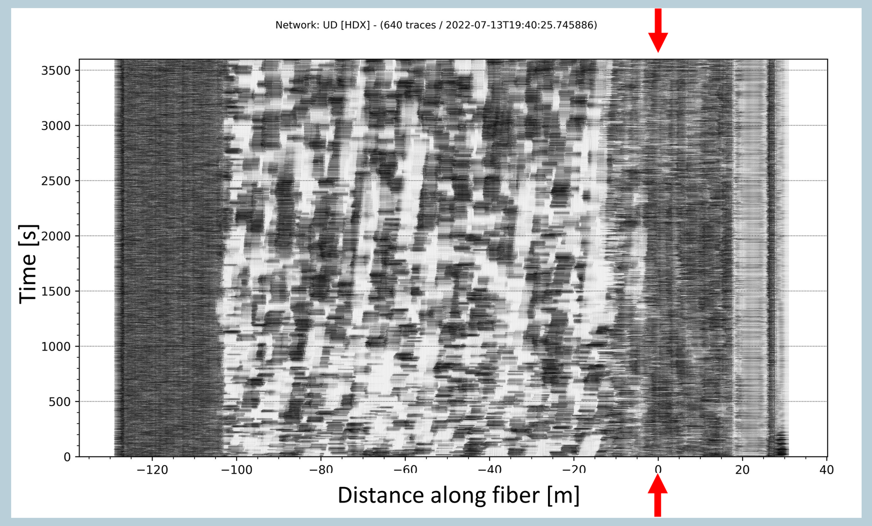


Fig 5. 1H raw data along the SM oceanic FO plotted by distance. Negative distance corresponds to fiber within the iDAS interrogator. Amplitude is nanostrain-rate (x5)

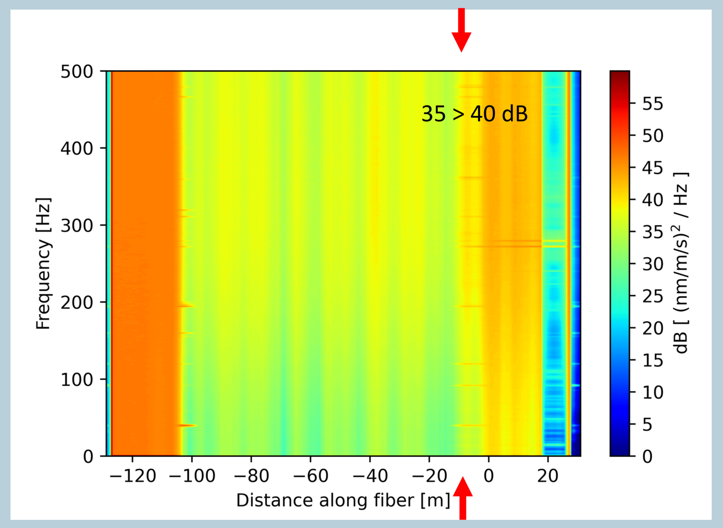
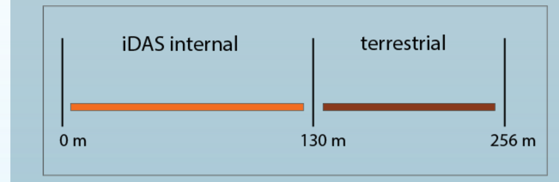


Fig 6. DAS power spectral density along oceanic fiber distance. Note the ~5 dB amplitude change from DAS internal FO to oceanic type FO.

[3] Terrestrial fiber test: iDas internal to terrestrial
[226 m > 904 ch]

Channel spacing: 0.25m
iDas internal FO 0.....520
terrestrial FO 521.....904



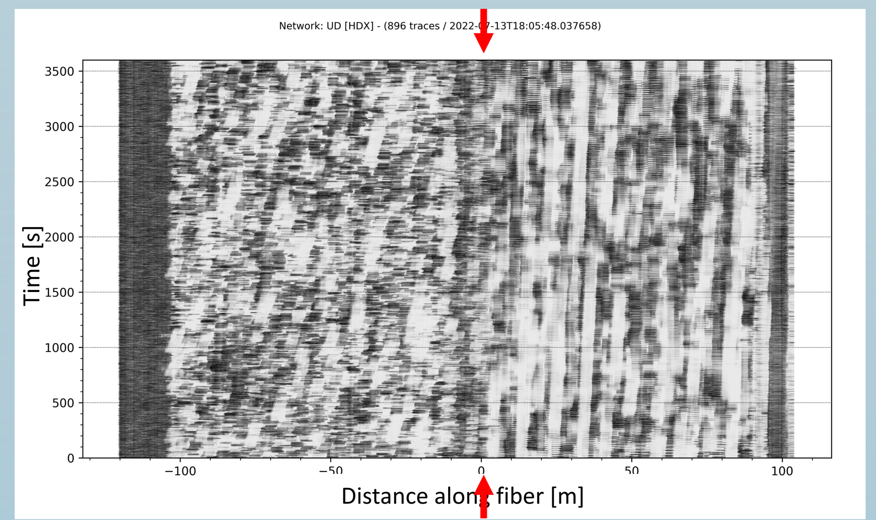


Fig 7. 1H raw data along the SM oceanic FO plotted by distance. Negative distance corresponds to fiber within the iDAS interrogator. Amplitude is nanostrain-rate (x5)

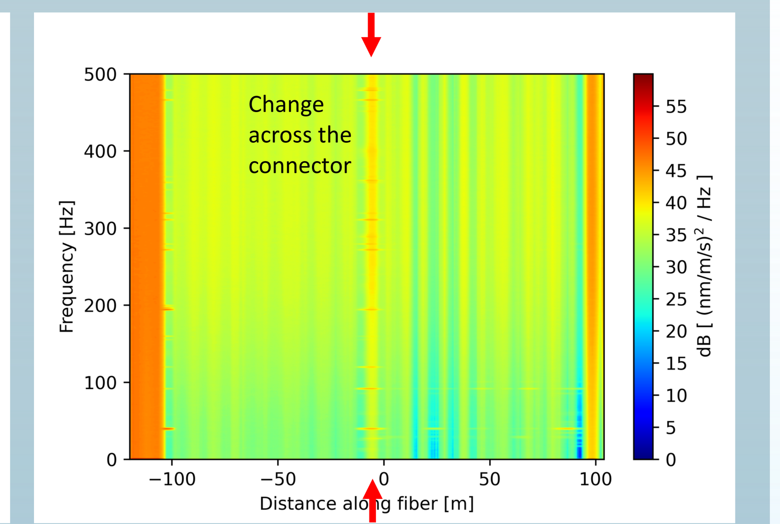


Fig 8. DAS power spectral density along terrestrial fiber distance. There is not a significant change across the terrestrial type FO, except at the connector location.

Oliktok DAS Data

Gauge length: 10m, dx = 2 m
Amplitude change across different FOs and environments

Feb 08 2021, 11:00 – 12:00, Ice bound

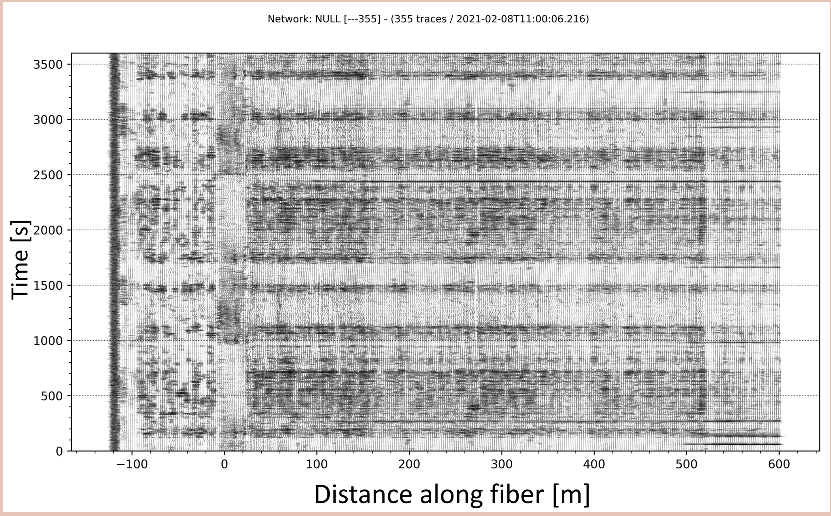


Fig 9. 1H raw data along the Oliktok FO during ice bound season. Amplitude is nanostrain-rate (x5). Note the change in amplitude at 17 m, 166 m, and 517 m.

Oct 01 2021, 03:00 – 04:00, open water

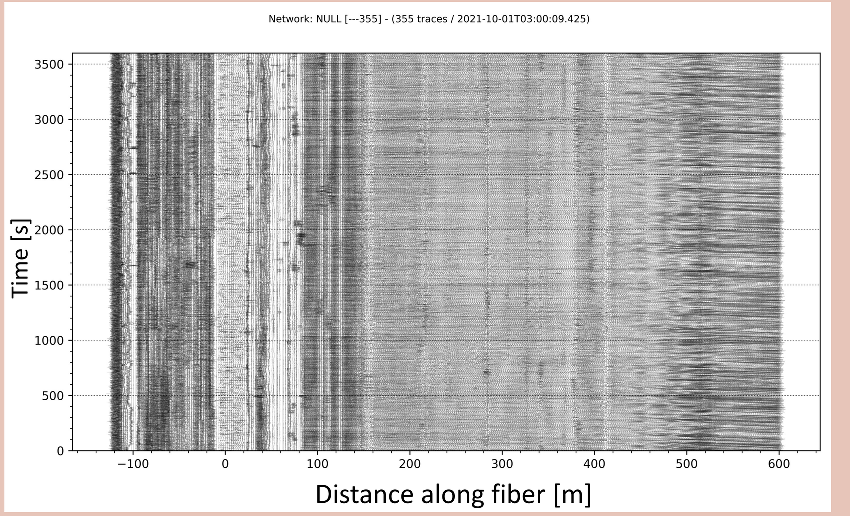


Fig 12. 1H raw data along the Oliktok FO during open water season. Amplitude is nanostrain-rate (x5). Note the change in amplitude at 17 m, 166 m, and 517 m.

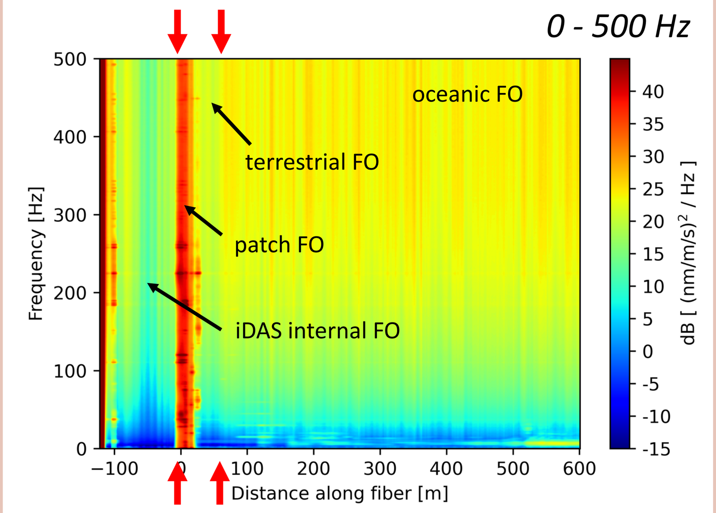


Fig 10. 0-500 Hz PSD (ice bound). Note the amplitude change across the patch cable (~0-17 m, increased local noise) and the transition to oceanic type FO (~50 m) >> changes occur across all frequencies.

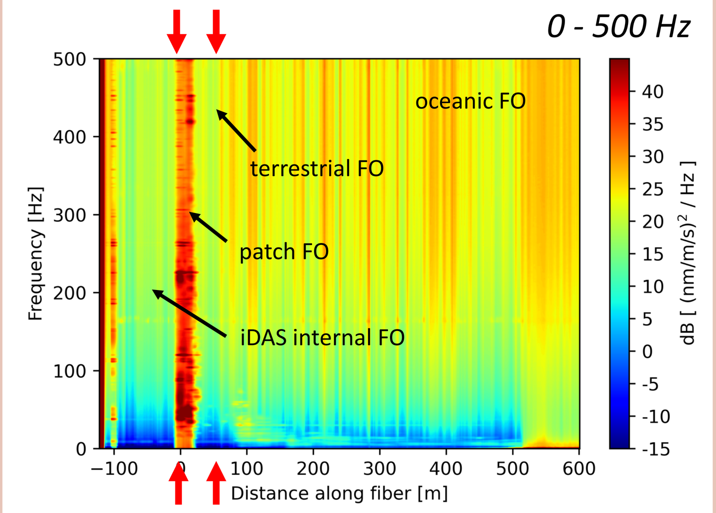


Fig 13. 0-500 Hz PSD (open water). Note the amplitude change across the patch cable and the transition to oceanic type FO >> changes occur across all frequencies.

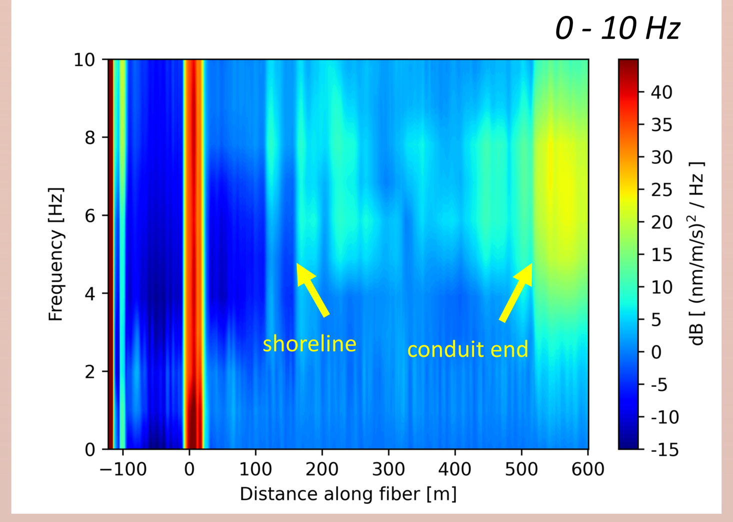


Fig 11. 0-10 Hz PSD (ice bound). Note the amplitude across the shore line (166 m) and the location where the fiber exits the conduit (517 m).

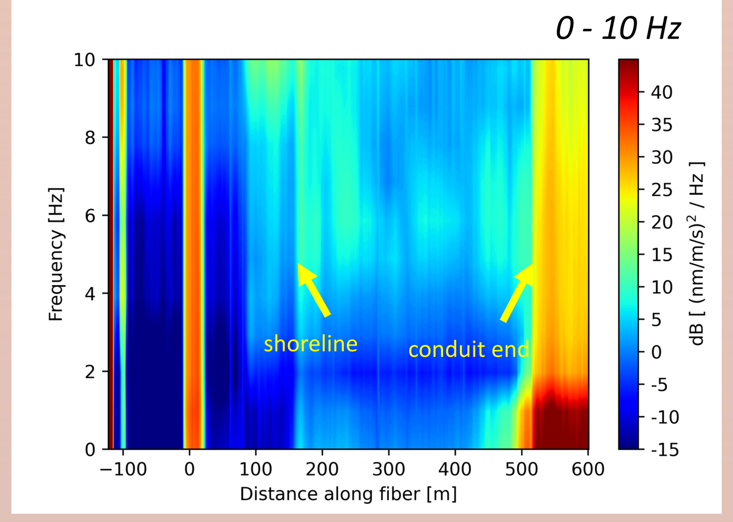


Fig 14. 0-10 Hz PSD (open water). Larger amplitude across the 166 m and 517 m likely due to increase acoustic noise during the open water season.

Conclusions

- The laboratory raw data and the PSD plots show increased amplitude and power starting at the transition from terrestrial to oceanic fiber (~35 dB to ~40 dB). However, since data was acquired under "quiet" conditions the elevated amplitudes/power (relative to Oliktok data) would express larger noise levels. Since this is a differential measurement, less signal into the interferometer looks like louder noise.
- Less backscatter intensity can be driven by core diameter mismatch, change in scattering density, or a change in core cross-section.
- For Oliktok data, uncoupled fiber (17 m between iDAS and the fiber port) is characterized by high frequency noise.
- Elevated levels of lower and higher frequencies during the open water season highlight the shoreline (166m) and conduit end (517 m).

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CODAS Cryosphere/Ocean Distributed Acoustic Sensing

PEMDATS

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