Sensorfusion energieautarker Punktsensoren mit Distributed Acoustic Sensing Systemen entlang der Sensorfaser

ÖVG-Forum

Lichtwellenleitersensorik im Eisenbahnwesen

Anwendung, Forschung und Entwicklung

21. Oktober 2020

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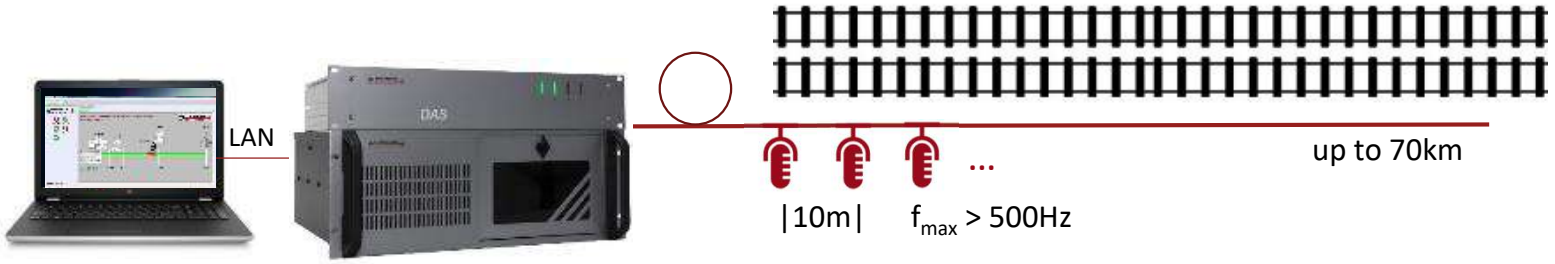
- Distributed Acoustic Sensing
  - Amplitude DAS
  - Phase sensitive DAS
- SpectRail
  - Concept and Architecture
  - Components
  - Field test
- Conclusion

What is DAS (Distributed Acoustic Sensing)?

DAS systems work like an up to 70 km long chain of highly sensitive microphones, which can be interrogated typically every 10 meters. Acoustic events can be detected, localized, classified and can be used to generate alarms.

A DAS system consists of:

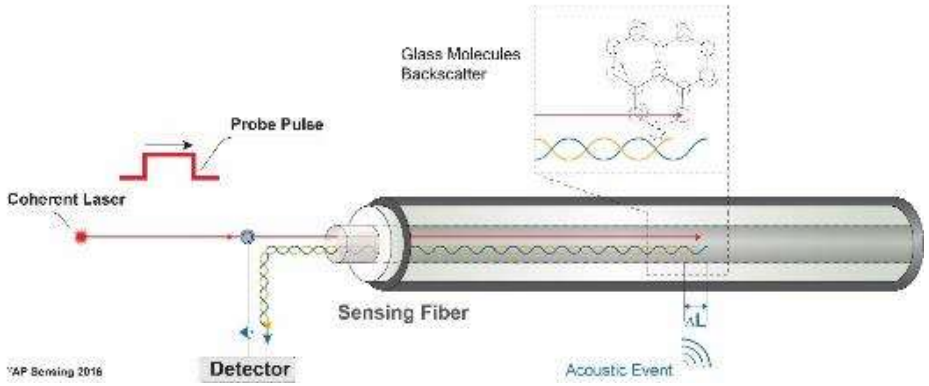
- Optical interrogator & Processing unit
- Standard telecom single mode fiber
- Interface to application management software

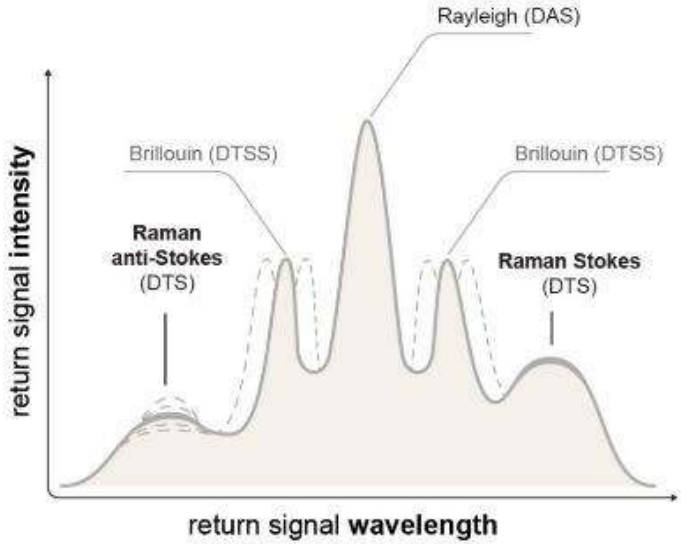


Coherent Rayleigh OTDR

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

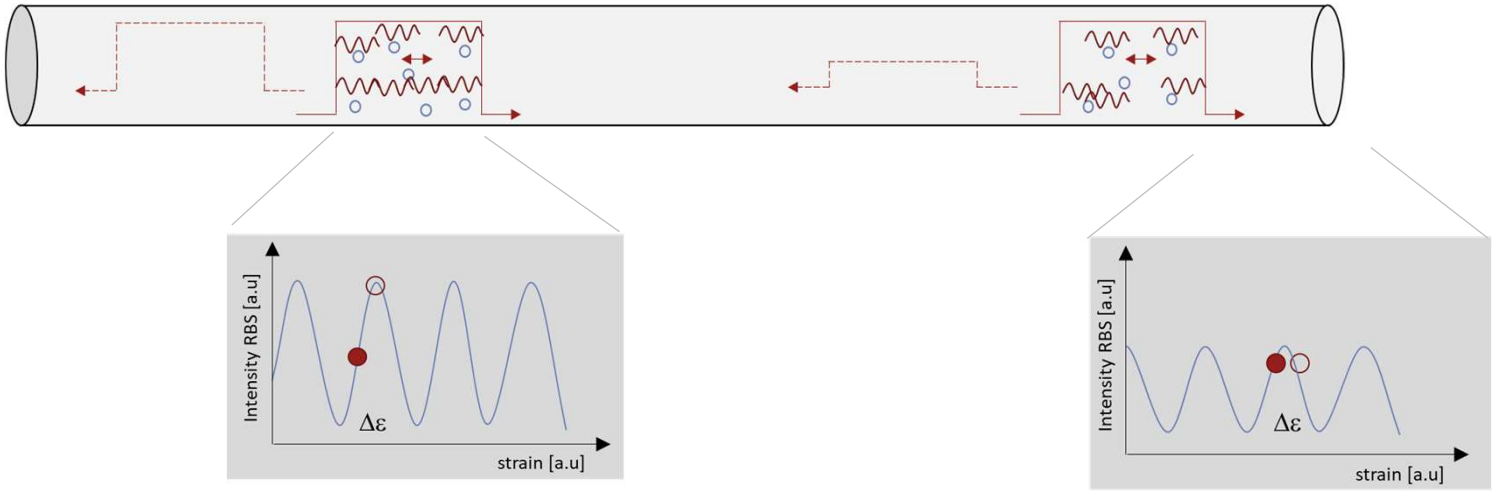
The ***position*** of the acoustic/ vibration event is determined by measuring the arrival time of the returning light pulse, similar to a radar echo.



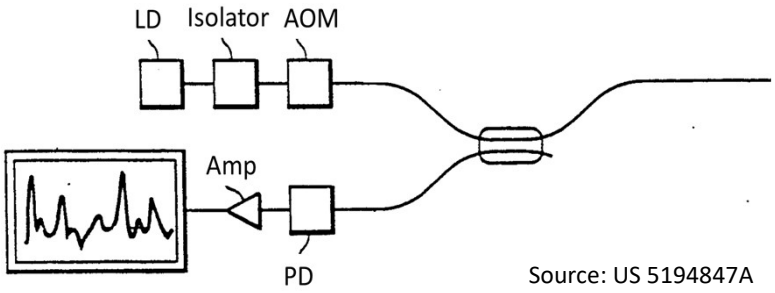


Amplitude DAS

Working principle



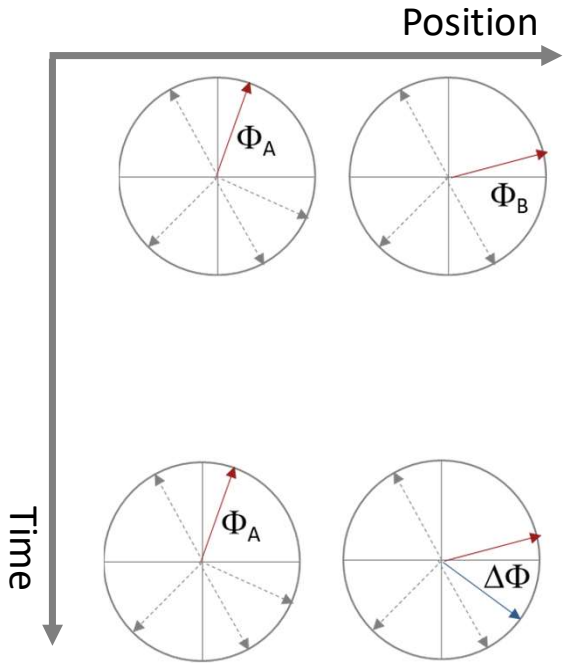
- Easy to realise
- Non-linear relationship between strain and backscattered intensity
- Different relations at different positions along the sensor fibre
- Fading issues

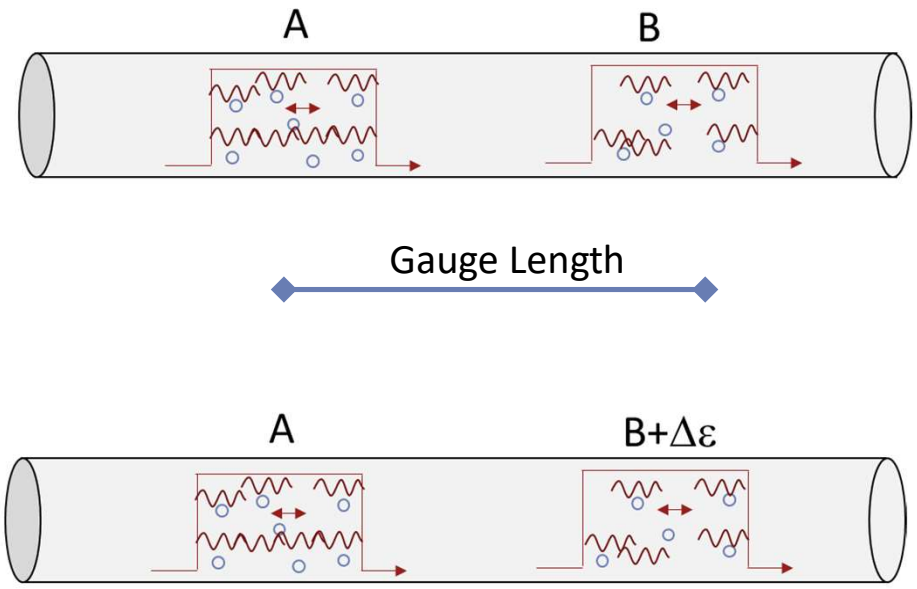


Source: US 5194847A

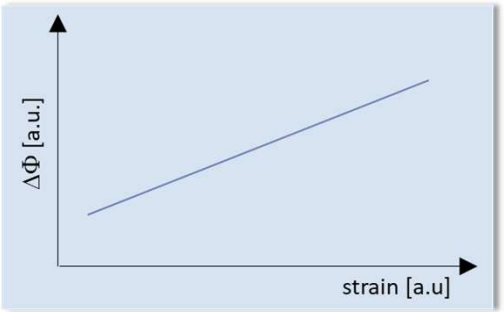
Phase DAS

Working Principle





- Need for a Gauge Length (2 positions)
- Complex optical architecture
- The phase Φ is a random parameter
- $\Delta\Phi$ responses linearly to $\Delta\varepsilon$



DAS Technology

DAS technology can be split broadly into two types

Distributed Acoustic

- Amplitude
- Phase

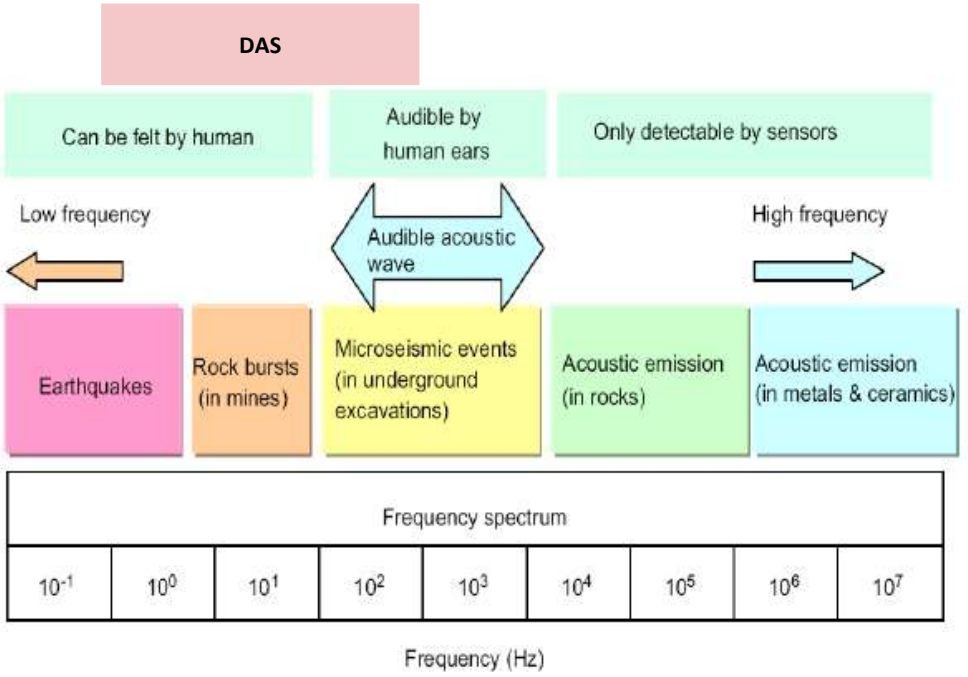
Quasi-Distributed Acoustic

- FBG arrays

Distributed Temperature Gradient (DTGS)

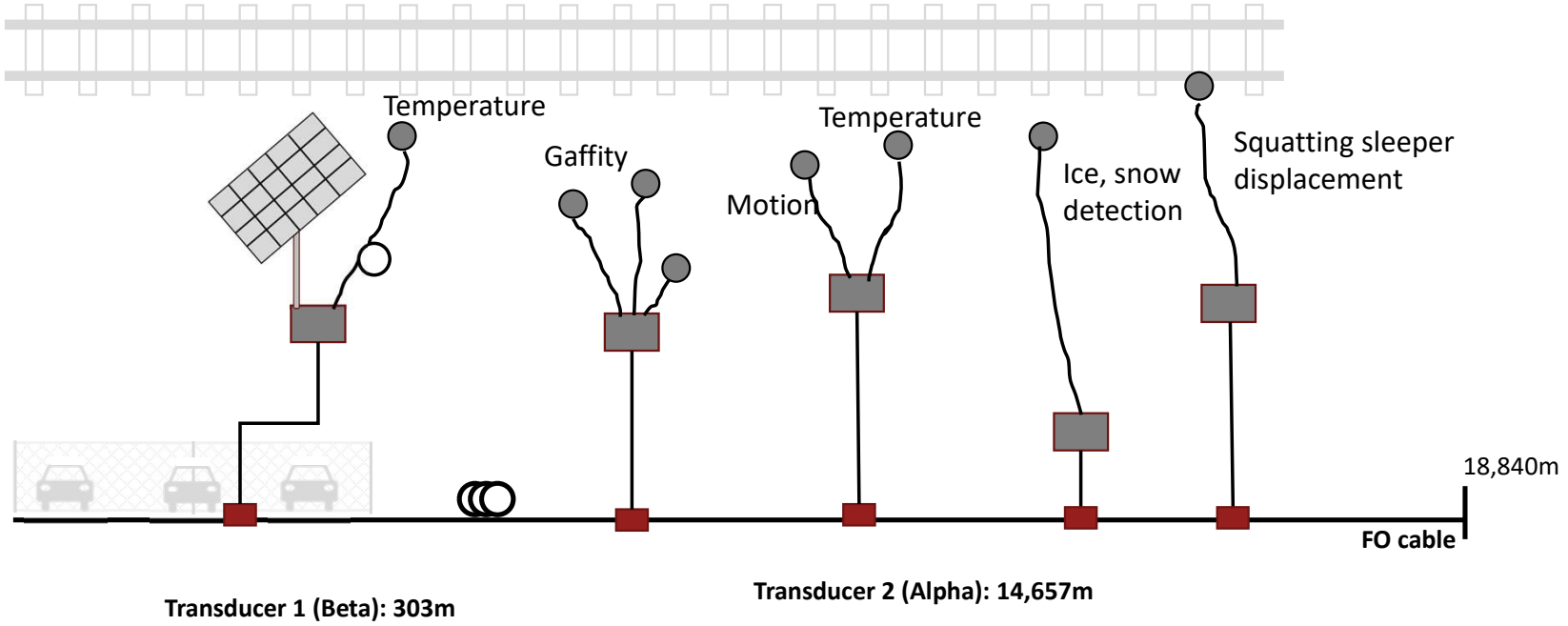
Very sensitive to temperature

Target 50mrad rms noise floor (0.5pStr) which is 1.2mK sensitivity to temperature over a 10m gauge length



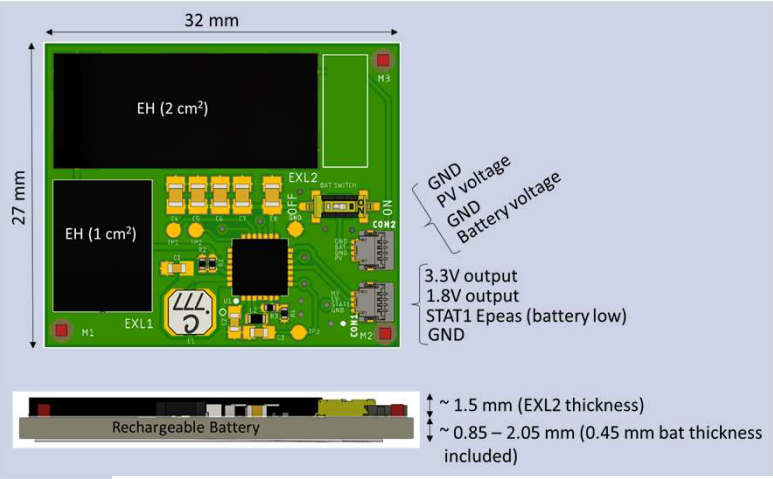
The SpectRail concept:

DAS + external IoT sensors + energy harvesting

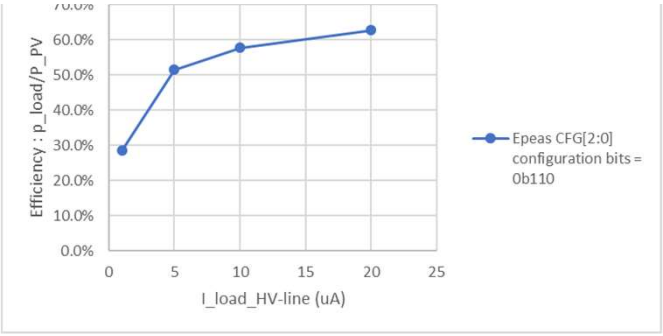


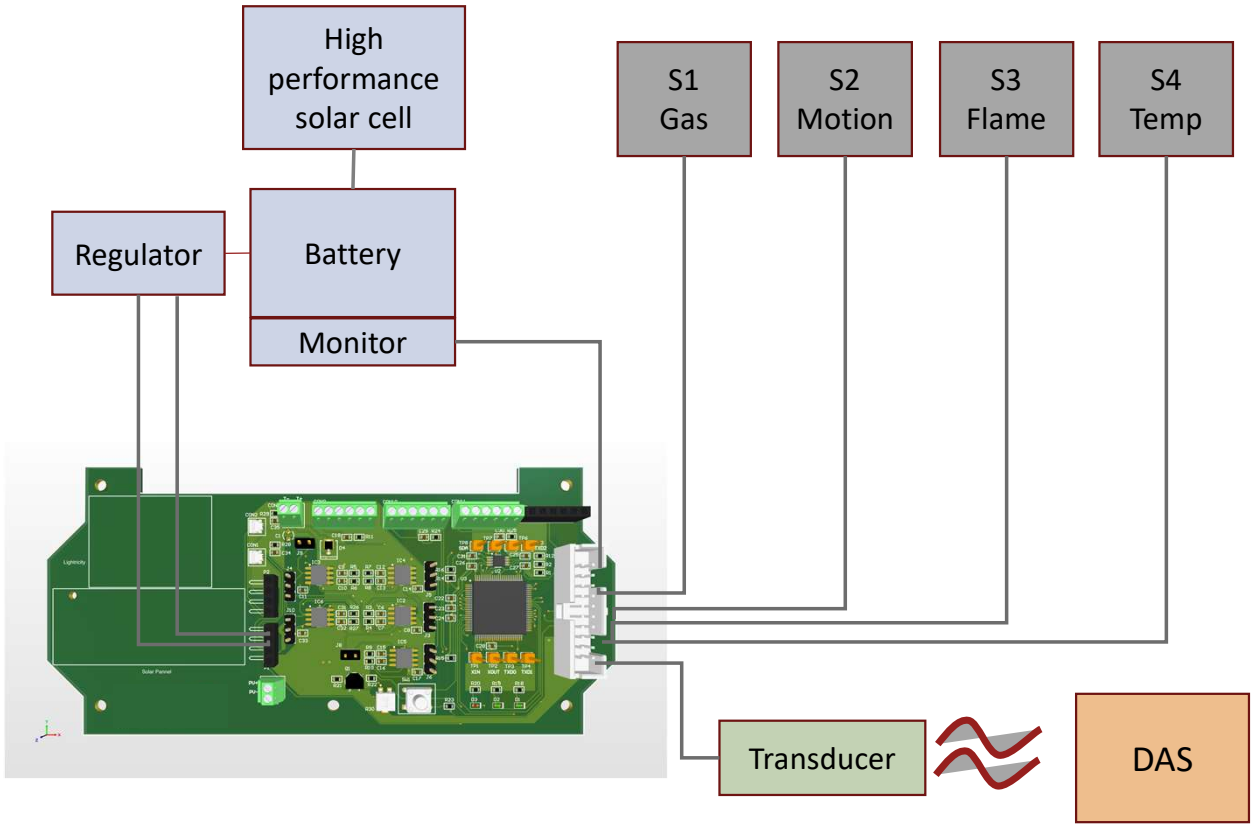
- ***Single or multiple – even different types of – sensors are connected the FO cable via a sensor node***
- ***SpectRail is self-powered***

The SpectRail architecture:



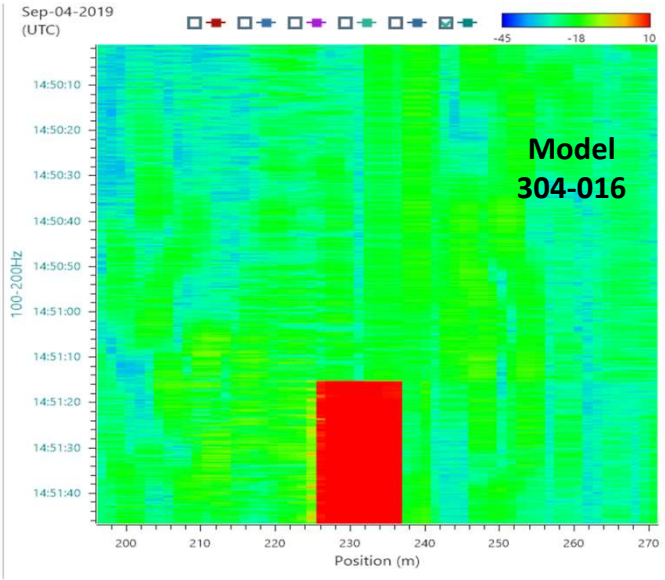
Performance as a function of light level
(from low indoor light to cloudy outdoor conditions, <100 - 1000 lux):



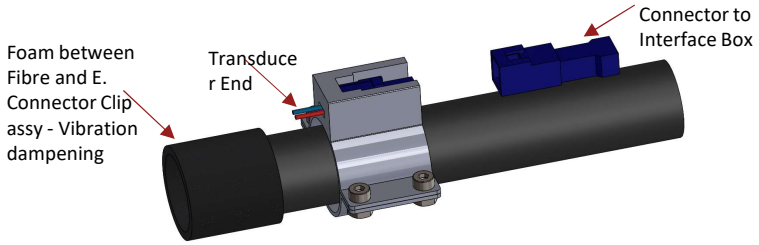


Different transducers were tested

Model	Orientation	Voltage	Current (mA)	Detected Signal (SNR)	Detected Frequency (Hz)
304-016	parallel	1.5 V	18	18	102-200
310-003	Straight on the top	1.5	55	20	145
307-103	parallel	2	130		no peak frequency Multiple peaks
C10-100	Straight on the top	2 Vrms	50 mA rms	17	175 Hz

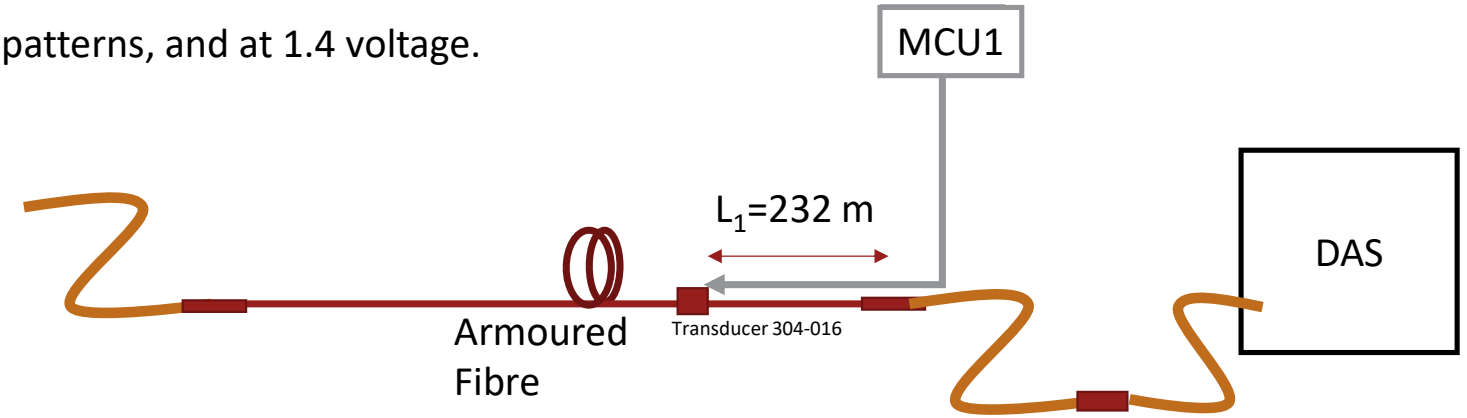


- 4 Transducers were tested by applying the DC rated voltage.
- Frequency response and the SNR were measured.
- Model 307-103 generates multiple peaks at different frequency bands, which is not suitable to use it as an indicator at this frequency band (100-200 Hz).



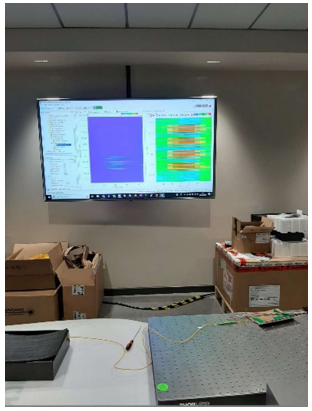
Different frequency encoded data patterns were tested

- Test performed at different bit period from 2 sec down to 50msec
- 5 different data patterns, and at 1.4 voltage.



Tested Data patterns

10101010
11111111
11000011
10110100
10010010



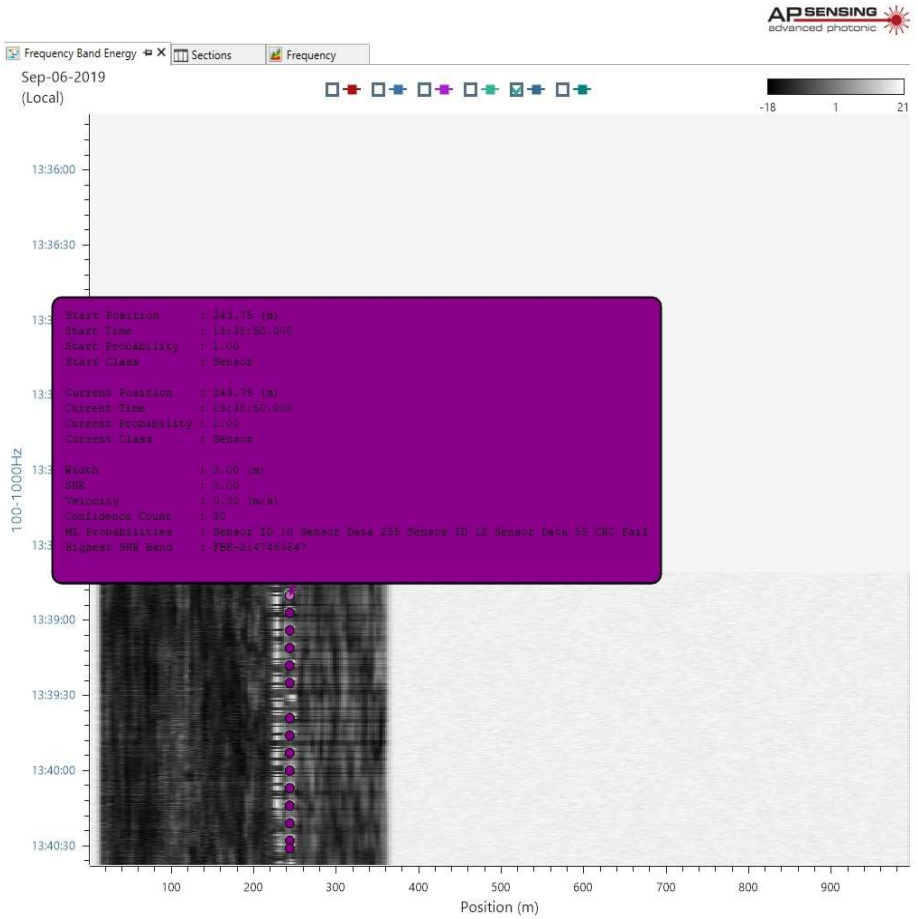
The signal can be detected and decoded

Transducer

Scheme to encode of 2 different sensors

START BYTE (0xC)	SENSOR ID (1-14)	SENSOR DATA	SENSOR ID (1-14)	SENSOR DATA	STOP BYTE (0x4)
4 bits	4 bits	1 BYTE	4 bits	1 BYTE	4 bits
1011	0100	10111110	0110	01001111	0100

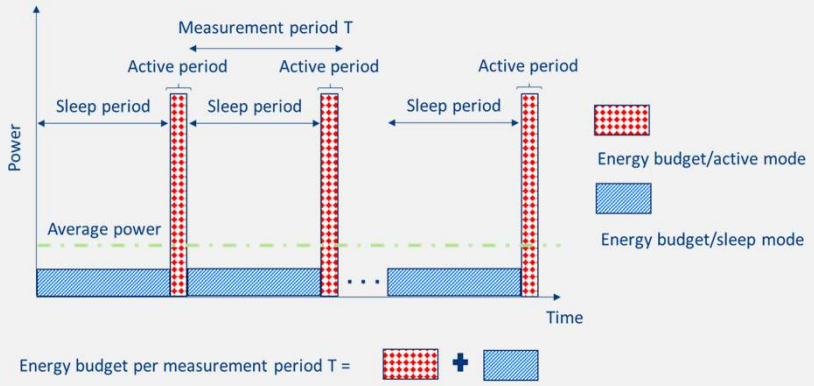
- 32 Bit encoding of the sensor signals is used
- START and STOP bytes are different
- Carrier frequency : 100 – 200 Hz
- The minimum bit period requirement is 200ms to ensure that the data will be successfully detected



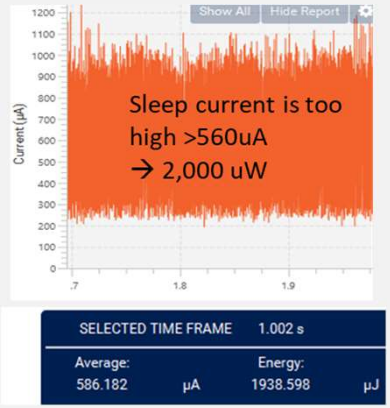
Energy Harvesting had a constrained energy budget

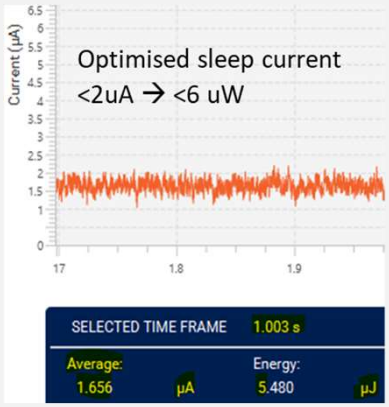
Solutions to reduce power consumption

a) Wake-up by chip select



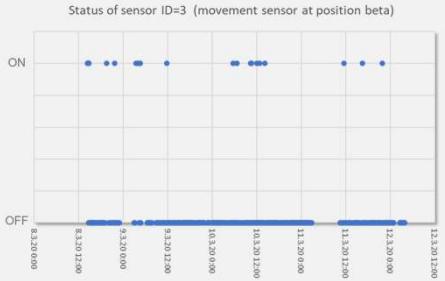
b) Hard- and Firmware optimisation





c) Wake-up by signal

The sensor‘s wake-up packet is looking for a changing IR event

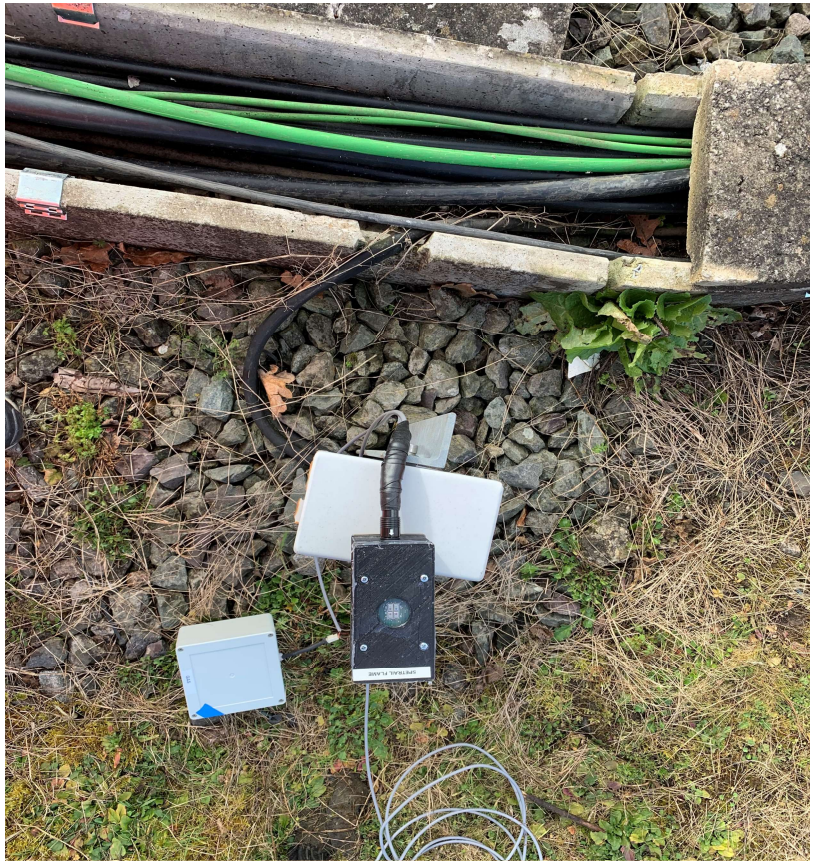


SpectRail was tested at two locations in the field

Installation at km 0.303 was cross-checked and runs

SpectRail was tested at two locations in the field

Installation at km 14.6



SpectRail‘s sensor node is operational with different sensors

Temperature sensor reading 10-12C ambient temperature

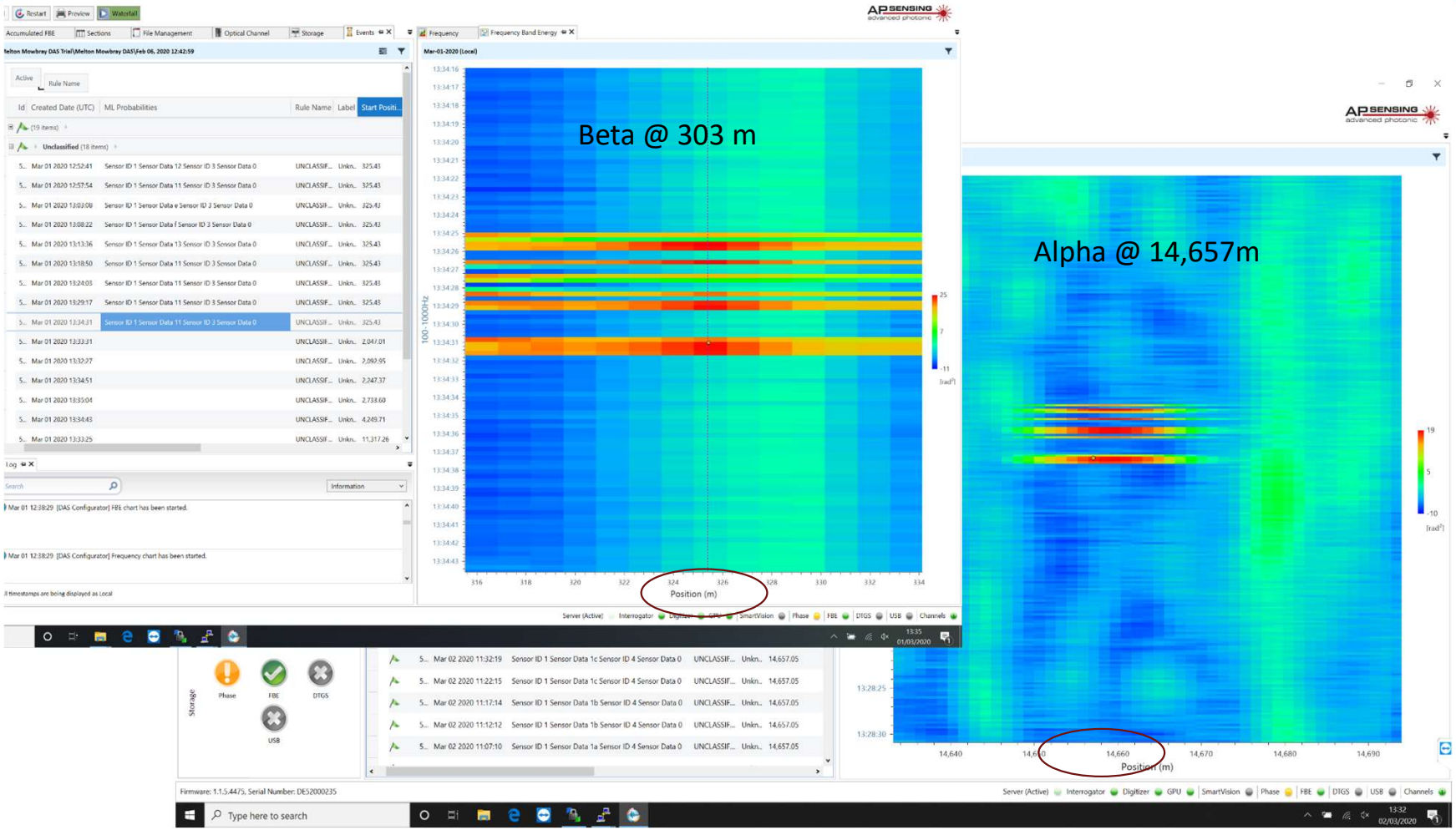
Flame sensor data

577623	Mar 01 2020 15:33:03	Sensor ID 1 Sensor Data 11 Sensor ID 4 Sensor Data 0	UNCLASSIF... Unkn..	14,657.0
577575	Mar 01 2020 15:28:02	Sensor ID 1 Sensor Data 10 Sensor ID 4 Sensor Data 0	UNCLASSIF... Unkn..	14,657.0
577501	Mar 01 2020 15:23:02	Sensor ID 1 Sensor Data 12 Sensor ID 4 Sensor Data 0	UNCLASSIF... Unkn..	14,657.0
577301	Mar 01 2020 15:08:00	Sensor ID 1 Sensor Data f Sensor ID 4 Sensor Data 0	UNCLASSIF... Unkn..	14,657.0
577131	Mar 01 2020 14:56:09	Sensor ID 1 Sensor Data c Sensor ID 4 Sensor Data 0	UNCLASSIF... Unkn..	14,657.0
577107	Mar 01 2020 14:54:35	Sensor ID 1 Sensor Data c Sensor ID 4 Sensor Data 0	UNCLASSIF... Unkn..	14,657.0
577053	Mar 01 2020 14:50:46	Sensor ID 1 Sensor Data d Sensor ID 4 Sensor Data 0	UNCLASSIF... Unkn..	14,657.0
577020	Mar 01 2020 14:48:45	Sensor ID 1 Sensor Data d Sensor ID 4 Sensor Data 0	UNCLASSIF... Unkn..	14,657.0
576734	Mar 01 2020 14:27:47	Sensor ID 1 Sensor Data 0 Sensor ID 2 Sensor Data 15	UNCLASSIF... Unkn..	14,657.0
576732	Mar 01 2020 14:27:33	Sensor ID 1 Sensor Data 0 Sensor ID 2 Sensor Data 15	UNCLASSIF... Unkn..	14,657.0
576729	Mar 01 2020 14:27:20	Sensor ID 1 Sensor Data 0 Sensor ID 2 Sensor Data 15	UNCLASSIF... Unkn..	14,657.0
576557	Mar 01 2020 14:15:20	Sensor ID f Sensor Data ff Sensor ID f Sensor Data fe	UNCLASSIF... Unkn..	14,657.0

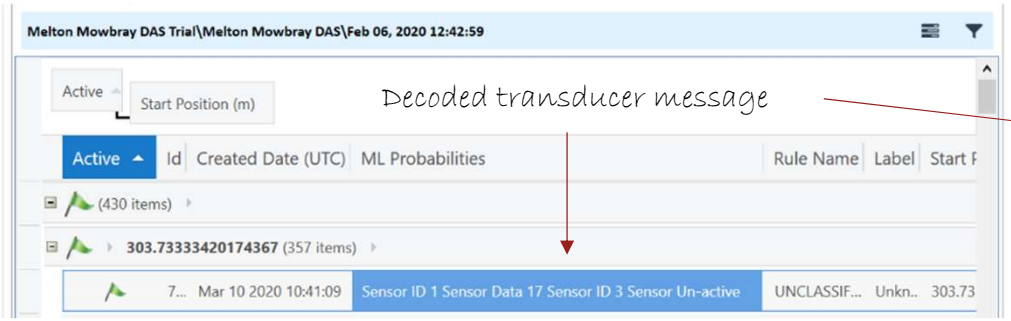
48-100Hz

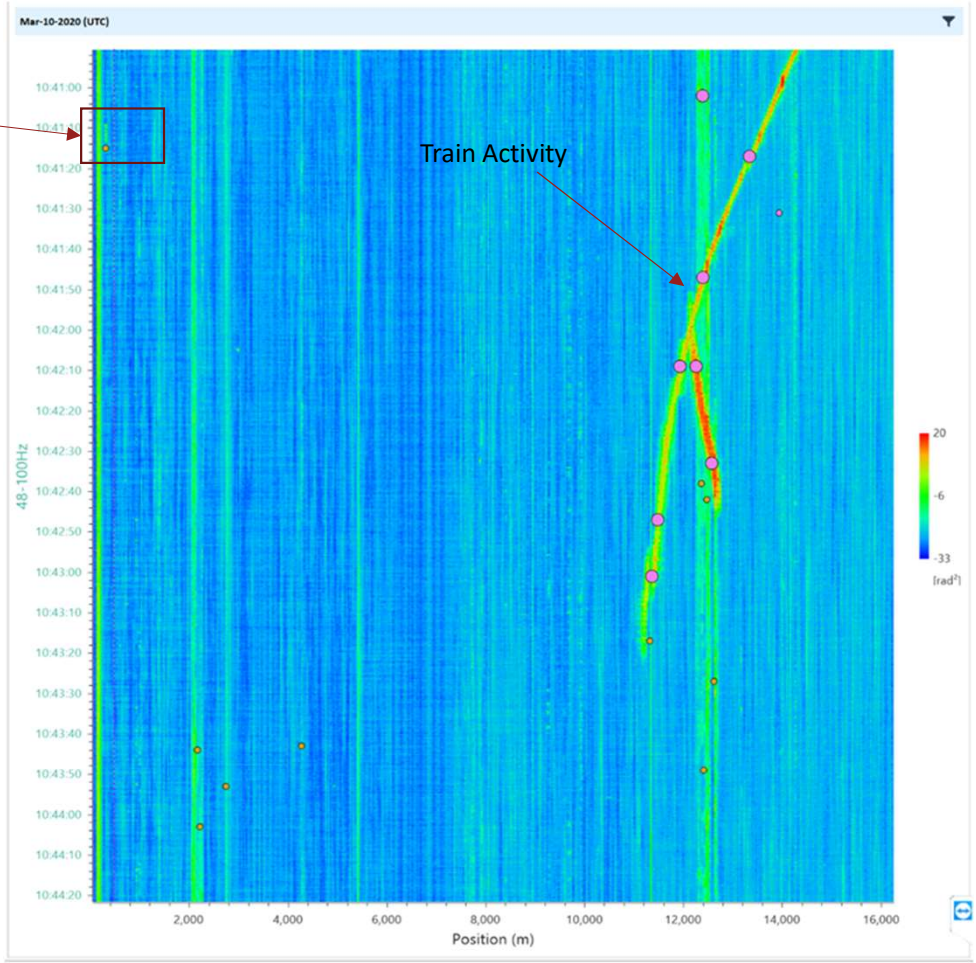
Location ~15 km away from the data centre

Both sensor nodes are active and can be detected



Transducer signals can be detected and decoded during train runs

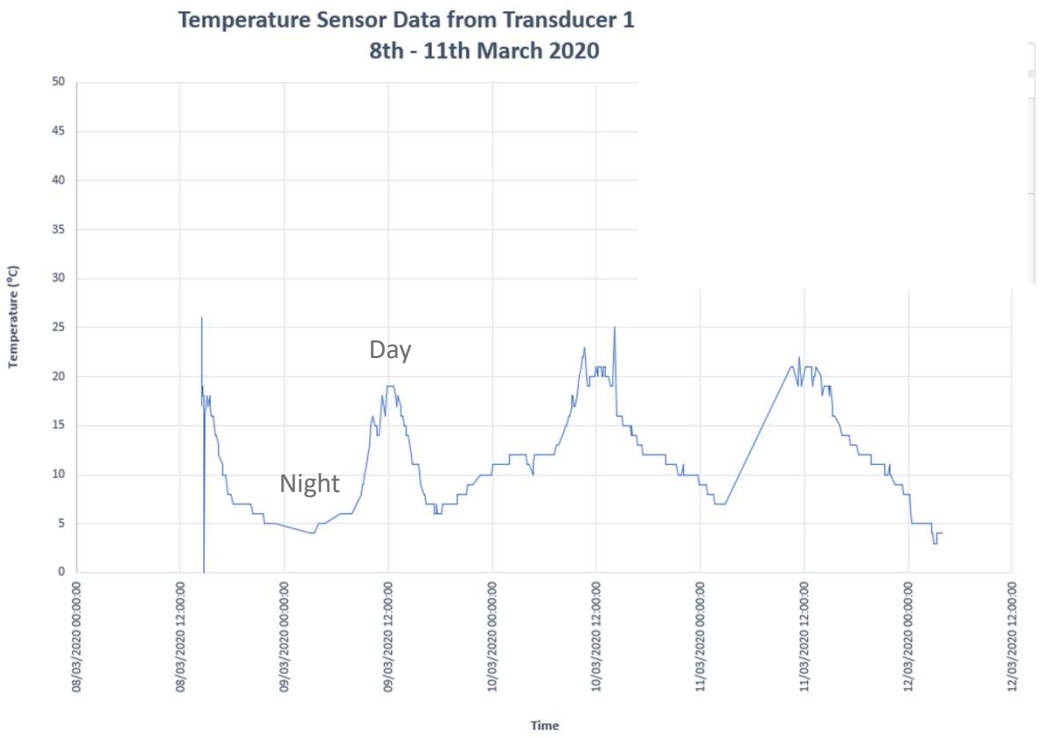


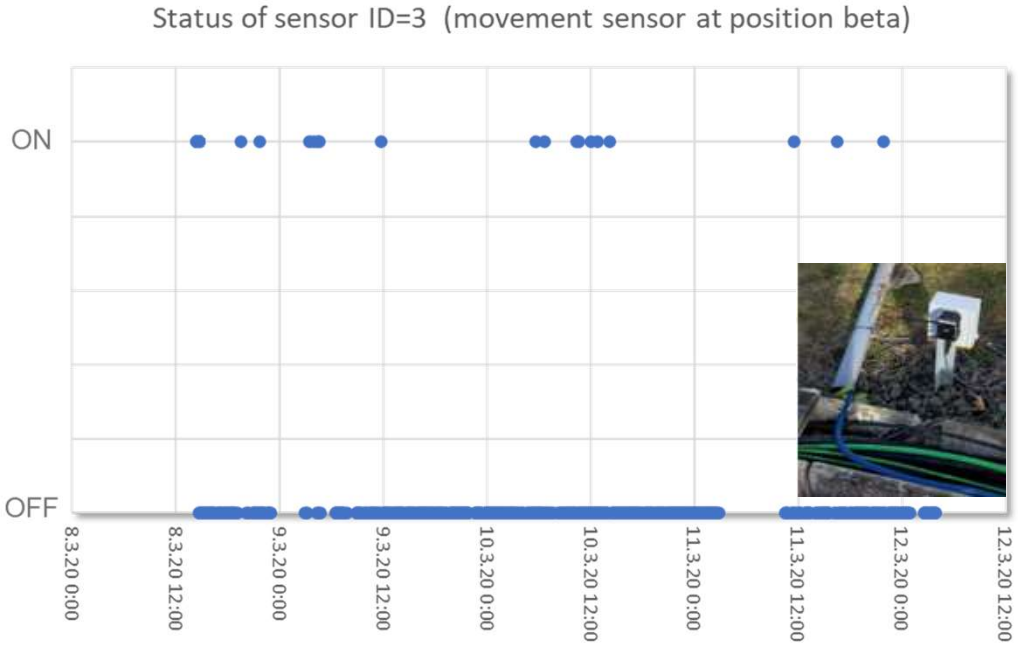


- Fibre optic sensor signals of a train comprise a broad frequency spectrum and high level of intensity.
- Software-based event detectors for train and transducer events were used

The transducer activity can be distinguished from train signals

The energy harvesting module supplies power to the sensor nodes even at night





Results from the field test

- SpectRail is simple, fast to fit and able to sense at a majority of locations.
- The attractive functions of DAS are complemented with low cost point measurements, offering the ability to sense almost anything, anywhere in the vicinity of where an optical fibre runs.
- Various point sensors can be connected via a transducer module with minor effort to a fibre optic cable along the track.
- Multiple sensor nodes can be used along the fibre optic cable.
- Transducer uses a stable protocol to encode the point sensor's signal into a vibrational signal.
- The vibrational signal can be detected and decoded by the DAS.
- Running trains and other events along the sensor cable does not affect the data transmission of the sensor/transducer element.
- Low power requirements open the way to energy harvesting, allowing the nodes to be self-powered and removing the need for external power supply.

Merci

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