SUBMERSE

07-11-2024

# Deliverable 2.4

# State of Polarisation Design and Infrastructure Integration Model

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## Abstract

This deliverable summarises the work done in the state of polarization (SoP) Task In WP2 and sets parameters and principles for the integration of SoP measuring devices into the infrastructure engaged in the SUBMERSE project


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# Document Revision History

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# Executive Summary

The SUBMERSE project endeavours to develop a pan-European The aim is to build a system for continuous acquisition and dissemination of sensing data using submarine distributed fibre infrastructure, specifically designed to meet the needs of European research infrastructures. Using sensors attached to submarine fibre-optic communication cables, the project harnesses the capabilities of distributed acoustic sensors (DAS), state of polarisation (SoP), and polarimeter technologies. The system's instrumentation will be installed on at least three remote cable systems in Greece, Norway, and Portugal, each of which must allow the simultaneous acquisition of data generated by multiple devices.

This deliverable summarises the key results and lessons learned from Task T2.3 State of Polarisation, which developed, tested, and deployed sensor systems monitoring polarisation changes on selected submarine links within the SUBMERSE project. The implementation of these systems on one of the experimental sites, and a verification of their functionality provided the basis for an Infrastructure Implementation Model, which defines clear principles and procedures for the deployment of additional submarine optical links within this project.

This deliverable is based on, further extends, and refines deliverable *D2.1 SUBMERSE Technical Architecture Report* [1].

# 1. Introduction

The state of polarisation (SoP) in optical fibre refers to the orientation of the electric field vector within the light wave propagating through the fibre. Due to birefringence caused by imperfections in the fibre's structure or external influences, the SoP can change along the entire fibre's length. This can lead to polarisation mode dispersion (PMD), which can uncorrectably degrade the performance of optical communication systems that are not coherent. To mitigate PMD, polarisation-maintaining fibres can be installed in non-coherent transmission systems (for example, special photonic services such as time and frequency transfers, quantum key distribution transmissions, or other simple, unmodulated signals). SoP fluctuation correction in modern, high-speed coherent transmission systems is also implemented in Digital Signal Processors (DSP).

By understanding the SoP and the techniques used to measure it, researchers and scientists can track slow and fast state changes of a fibre medium to detect and measure external vibrations or perturbations around the fibre [2]. To unleash the full potential of distributed fibre sensing, it is crucial to "know the fibre", in other words, to distinguish between the SoP changes due to fibre imperfections (internal-caused SoP changes) and external SoP changes (influenced by external events, like vibrations). SoP can be described by three Stokes parameters and visualised on a so-called Poincaré Sphere. Analysis of all three Stokes parameters adds complexity, and using one variable instead of three is recommended to determine SoP Angular Speed (SOPAS) [3].

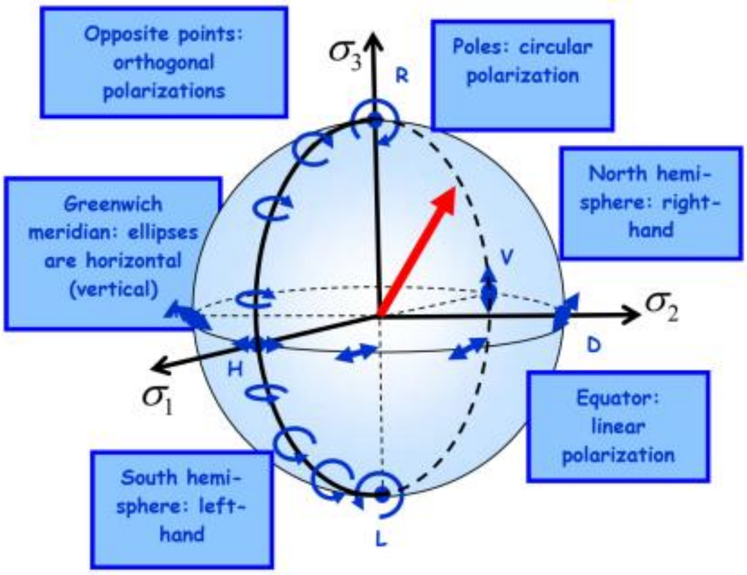


Figure 1.1: Poincaré Sphere

There are two primary states of polarisation: linear polarisation and circular polarisation. There is also an elliptical polarisation as a special case of linear polarisation, which will not be the main focus of the SoP and this deliverable.

- In **linear polarisation**, the signal vector oscillates in a single plane, creating a straight-line pattern. The direction of this plane can be either horizontal, vertical, or at any angle in between. Linear polarisation can be achieved through various methods, such as using polarisation filters. Linear polarisation is also used in various modulation schemes, adding another degree of freedom.
- **Circular polarisation** occurs when the field vector rotates in a circular pattern as the wave propagates. This rotation can be either clockwise or counterclockwise. Circular polarisation is created when two

linear polarised waves of equal amplitude and frequency, but with a phase difference of 90 degrees, are combined.

- **Elliptical Polarisation**: As it propagates, the electric field vector traces an elliptical path. This occurs when two linearly polarised waves are combined with unequal amplitudes, and a phase difference occurs.

The state of polarisation of a light wave can be measured and detected using:

- Polarising Filters: These filters transmit only light with a specific polarisation, allowing the measurement of the polarisation component of the incident light.
- Polarimeters: These instruments use a combination of polarising elements to measure the polarisation state of a light wave. They can determine the degree of polarisation, the orientation of the polarisation plane, and the handedness of circular polarisation.
- Interferometry: This technique combines two light waves to create interference patterns that can be analysed to determine the polarisation state.
- Coherent transmission systems via digital signal processors (DSP).

# 1 Deployment Infrastructure Overview

The equipment to monitor changes in the state of polarisation was placed in three geographically separated locations in the first half of the project (Table 1.1):

- **Arctic region**: Svalbard (Norway) - Ny-Ålesund and Longyearbyen sites.
- **Atlantic Ocean area**: Portugal to Brazil - Sines (Portugal), Madeira (Portugal), and Fortaleza (Brazil) sites.
- **Mediterranean area**: Greece and Italy - Preveza (Greece) and Crotone (Italy).

Every eligible site for the deployment has been surveyed in advance to get as much information as possible before the installation(s). This information included: uninterruptible power supply (UPS), cooling, IP connectivity availability, fire protection, and the responsible persons for the site. See the sample below for the location Ny-Ålesund (1) - Longyearbyen (2).

| Region/Area | Site Name | Location(s) | Fibre Length (km) | Concurrent Technology |
|---|---|---|---|---|
| Arctic | Svalbard | Ny-Ålesund<br>Longyearbyen | 255km | SoP + DAS |
| Atlantic | Portugal | Sines<br>Madeira | ? | DAS |
| Mediterranean | Greece<br>Italy | Preveza<br>Crotone | ? | DAS |

Table 1.1: Sites for Deployment Overview


Figure 1.1: Svalbard Situation Map: Site 1 Ny-Ålesund and Site 2 Longyearbyen

Although the selected sites were deemed suitable for the deployment of sensing interrogators, further technical design and equipment implementation work were needed prior to deployment. For reasons that could not be foreseen at the beginning of the project, Polboxes were only located in the Svalbard location at the time of writing. Specifically, two Polboxes, version 2.0, have high-sensitivity detectors and can record even very weak signals that can be amplified internally. These prototype devices are available in very limited numbers, and the Svalbard area was chosen for their experimental verification due to the fundamental readiness of the two cable landing stations. More details about Polbox functionality and features may be found in Section 3.

The Svalbard location is very interesting for sensing for many reasons. First, it is a relatively quiet location where the sensing of geophysical events is not affected by ship movements or other disturbing elements. It is, therefore, a very suitable location for environmental research. Second, the Norwegian National Research and Education Network (NREN) operator, SIKT, has already equipped both ends of the fibre optic infrastructure depicted above with DAS and SoP sensing equipment from commercial vendors. As these are fibre optic paths with very similar fibre footprints, it is possible to perform distributed sensing of events at one location with different technologies that work with different operation principles and sensitivities.

| Questions | Answers |
|---|---|
| **Section 1: Site and Contact Information** | Longyearbyen |
| Name of the Site | UNIS - The university centre in Svalbard |
| Country/territory where the site is located (address, Floor, Room no) | Svalbard, Norway |
| Contact information for local contact person | frode.storvik@sikt.no |
| Access regime for the site (incl. any restrictions) | All access should be coordinated with Frode at Sikt. |
| | |
| **Section 2: Cable and Landing Station Information** | |
| Who is the cable owner? | Sikt |
| Who is the cable operator? | Sikt |
| Which National authority granted a licence/permission for landing the cable in the territory of the cable landing station. | Governor of Svalbard |
| Which national authority is responsible for granting a licence/permission for the opposite cable landing station? | Governor of Svalbard<br>&<br>Kings Bay |
| Cable landing station location details | Close to Longyearbyen airport |
| What physical security is there to control access to the cable landing station | Restricted area, Should have Key to enter |
| Is there access control to the site? If so, please provide contact point. | As above (Contact Frode at Sikt for access) |
| Do you require an agreement to be signed for equipment to be installed in your cable landing station? | Yes, The equipment should be installed at UNIS site |
| Do you have a template? (If so, please provide) | no |
| Power type available | AC and DC, but AC is preferred |
| Is room free of vibration? Vibration caused by train, cars or other nearby noise sources | yes |
| Are both end of the cable accessible? | yes |
| Data connectivity available interface type | yes, 1GbE and 10GbE |
| Rack space available, (Yes No)? | yes |
| Rack dimension? | 19' |
| Available space for Submerse. Number of RU? | 10RU |
| Does the room have cooling?, capacity? | Yes, Don't know about the capacity |
| Connection for management? (100Mb/1G/10G. TP or fiber? Connector type) | 1G: TP and fiber LC<br>10G, fiber and LC |
| IP address mgmt? | could be assigned by request |

| | |
|---|---|
| Do you own or are responsible for the opposite cable landing station? If not, who is? | We at Sikt are responsible |
| Is the opposite landing station accessible? | yes |
| What is the distance (cross connect length) from the submarine fibre demarcation point to the SUBMERSE rack? | about 5km |
| What are the maximum and minimum temperature ranges experianced at the CLS? | 18-25 °C |
| | |
| **Section 3: Fibre Information** | |
| Please provide the name or label for the fibre which will be used for the SUBMERSE project | Fibers are reserved but not labeled yet |
| Is fibre dark or lit? | Both dark and lit could be provided |
| If dark, is there deployed equipment to light it? | some fiber yes and some other no |
| Type of fiber | G652.D |
| Termination point (A+B: address, floor, room, rack, ODF, fiber number, connector) | Longyearbyen: UNIS - The university centre in Svalbard, first floor<br>Ny-Ålesund, Amsterdam building, first floor |
| Any labelling | No |
| Local access to timing source (GPS, WR, Cesium, Maser ?), 1PPS/10Mhz - physical interface, cable distance to source, type of cable? | Longyearbyen: WR could be provided<br>Ny-Ålesund: GPS and WR could be provided |

Table 1.2: Site survey example required to deploy SOP interrogators.

Work continues on the other sites to make them ready to host deployments and to pass further design validation tests to assure cable operators that the use of interrogators will not interfere with or damage other systems on the same cable.

## 1.1 Sines - Fortaleza

The cable span from Sines, Portugal, to Fortaleza, Brazil, and includes ~70 repeater units. The cost of each repeater unit is around €2.5 million. Correcting a physical problem requires a suitable vessel to be dispatched to recover the repeater unit, which can take about 14 days to fully resolve, depending on the availability of suitable replacement parts. Such a vessel costs in the region of €80,000 per day to deploy on a mission to resolve a fault. It is, therefore, critical for the cable operator to ensure that there is no or minimal risk to the operation of the cable as a result of an interrogator deployment. This has required lengthy negotiations and technical evaluations with the site operator and the various equipment vendors to ensure that the cable and its associated infrastructure are not harmed physically and that the deployed system is secured from cyber threats. As a result of the unforeseen necessary discussions, it has not yet been possible to deploy a Polbox or transponder-based SoP interrogator.

## 1.2 Preveza - Crotone

As a result of the site survey, it was found that although the cable could be used for fibre sensing, there was no associated infrastructure necessary to support the deployment of interrogators or to provide data connectivity. In order for the cable landing stations to be used, further equipment needed to be deployed in both Italy and Greece in order to connect the sites to the backbone network. This added a significant delay to the deployment of any equipment. Once the cable was made live on the GÉANT backbone network, the T3 team was given the green light to start work on interrogator deployments. A subsequent survey was performed, and it was found that the cable landing station in Preveza, for example, hosts only optical networking equipment and no Ethernet equipment. It also only supported DC power, whereas the Polbox and other interrogators require AC power. At the time of writing, work is continuing to ready both cable landing stations for AC power and installation of GPS antennas in order to facilitate the deployments.

## 1.3 Kos - Rhodes

Following the initial site survey, it was found that the equipment installed on the link would not support the SoP interrogators. In order to deploy the interrogators, a dark fibre would need to be acquired to support the technology. However, the cost of such a dark fibre and associated equipment was prohibitive. It was therefore decided to seek an alternative location in Greece, which could support the technology. It is hoped that through further investigation, the equipment that has already been deployed will be able to support the SoP interrogators.

## 1.4 Med Sea and Control Over the Situation

Due to the impossibility of using the Kos-Rhodes line for sensing, it was decided that the systems for monitoring mechanical and acoustic vibrations will be installed in parallel on the Preveza-Crotone line. This will involve DAS (one dedicated pair of fibers) and SoP. For SoP, two technologies will be deployed in parallel:

1. Nokia CHM6 with the ability to extract orthogonal polarizations from modulation schemes.
2. PolBox, the same sensor system that is already deployed on Spitsbergen (see chapter 1).

### 1.4.1 Responsibilities

This new situation can potentially affect other milestones or tasks (especially their schedule). It is therefore advisable to determine the persons responsible for individual activities within the framework that will take care of the smooth deployment. Responsibilities were divided as follows:

1. Coordinator: Chris Atherton (GÉANT).
    a. Kurosh Bozorgebrahimi (SIKT) - deputy.
2. Risk Manager: Rudolf Vohnout (CESNET).
3. Attendees:
    a. Miquel Masanas (NOKIA (Coriant/Infinera)). Equipment deployment.
    b. GRNET appointed (Greek site). National coordinator / Deployment project. management and coordination.
    c. GARR appointed (Italian site).
    d. GÉANT NOC. Site (PoP) operations (power delivery, rack space allocation…).
    e. IslaLink (Preveza-Crotone) cable owners plus data management.

## 1.4.2 Time Schedule

Line staffing planning involves coordination between individual actors, where the preliminary timetable looks as follows:

Monitoring of mechanical and acoustic vibrations on line Preveza-Crotone
**From 2025-01-01 to 2025-10-01**

| | | | |
|---|---|---|---|
| 2 | Link procurement and verification | 2025-01-01 | 2025-03-31 |
| 3 | Ensuring PoP accessibility | 2025-04-01 | 2025-05-30 |
| 5 | Data access agreement | 2025-04-30 | 2025-05-30 |
| 4 | Equipment shipment | 2025-06-16 | 2025-06-30 |
| 6 | On-site installation | 2025-07-01 | 2025-07-15 |
| 7 | Monitoring & data acquisition | 2025-07-15 | 2025-09-31 |

1. Except for the long-term planned meeting of the PMB and WP2, we propose the following meeting schedule to ensure a smooth site sensing system deployment.

| ID | Who | When | How | Milestone ID | Potential Affect |
|---|---|---|---|---|---|
| 1 | Coordinator + Risk Manager | Bi-weekly basis | online | 2, 5 | M25, D13 |
| 2 | Coordinator + Attendees (NOKIA, GRNET) | weekly basis | online | 4, 6, 7 | M19, M23 |
| 3 | Coordinator + Attendees (GEANT NOC, Islalink) | bi-weekly basis | online | 2, 3, 5 | M25, M23 |

Table 1.3: Med Sea site relocation

# 2. Gantt Chart

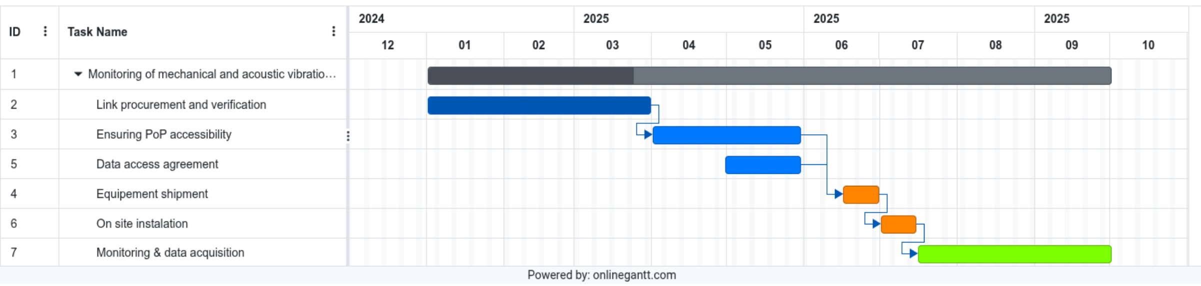


Figure 1.2: Med Sea site relocation

# 2 Polbox description

The Polbox is a ready-to-use, datacenter-grade solution developed by CESNET for long-term, continuous, SoP acquisition in a compact, 1U, rack-mountable chassis. An optical input signal could be part of existing traffic, e.g., an optical service channel, and therefore not require any additional laser source or free fibre channels. The prototype is depicted in Figure 2.1.

Recorded SoP data is stored locally in Hierarchical Data Format version 5 (HDF5) format, which has its own self-described metadata. The Polbox can also be synchronised to remote storage. Depending on the input signal, the recorded data stream generates approximately 6-13GB on a daily basis. The details about the storage format are provided separately in Section 3, Dataset (format, attributes).


Figure 2.1: The prototype of the Polbox device.

## 2.1 Polbox hardware and technical details

The Polbox is capable of long-term, continuous SoP acquisition, limited only by internal storage. With a combination of synchronisation to external data warehouses and recycling local storage space, it can reach an “infinite” acquisition. The external synchronisation is currently supported via the rsync utility or using S3-compatible object storage.

A continuous, fast sampling rate of 20 kHz from 4 channels, with 16-bit resolution per channel, makes the device unique in the field of fibre industrial-grade polarimeters. All three Polbox prototypes are not calibrated and, therefore, cannot be used as absolute polarimeters. However, this is not crucial for sensing the changes in SoP, therefore, we deem this limitation acceptable.

The Polbox supports a variable optical input source. It can be a tap on an existing signal (e.g., optical supervisory channel) or a custom laser source on the other end of the fibre-under-test (FUT). The required power level of the input signal is generally in the range from -35 dBm to +5 dBm in the wavelength range 1520–1610 nm.

The Polbox is designed as a standard 19'' rackmount 1U device with redundant dual power sources for high availability. The device provides basic telemetry and monitoring and is compatible with InfluxDB and Grafana.

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# 3 Dataset (format, attributes)

The Polbox stores data in Hierarchical Data Format version 5 (HDF5) format. The HDF5 data format is a versatile data model designed for the storage and organisation of large amounts of data. It supports an extensive range of data types and is particularly suited for high-performance computing applications. HDF5's flexibility, efficiency, and scalability make it a powerful and popular choice for managing complex datasets in industries ranging from scientific research to financial analysis.

For better manipulation, the data is stored by default in one-hour-long chunks, which corresponds to 72,000,000 samples per channel (4 channels in total). The HDF5 format supports compression, and therefore, it is not possible to say how much space such a one-hour chunk occupies. This mainly depends on input signal characteristics and the amount of noise in such a signal. Based on observed experience, 1 hour of an acquired signal can consume approximately 250-700 MB (6–13 GB/day). An example of the first 7 rows of such recorded data is depicted in Figure 3.1.

| | 0 | 1 | 2 | 3 |
|---|---|---|---|---|
| 0 | 0.00825012 | 0.6694477 | 0.97332734 | 0.8593881 |
| 1 | 0.00831262 | 0.6693227 | 0.9731398 | 0.8587631 |
| 2 | 0.00831262 | 0.6692602 | 0.97301483 | 0.8585131 |
| 3 | 0.00831262 | 0.6692602 | 0.97307736 | 0.8590131 |
| 4 | 0.00837512 | 0.6697602 | 0.97395235 | 0.8595131 |
| 5 | 0.00825012 | 0.6694477 | 0.97213984 | 0.8583881 |
| 6 | 0.00837512 | 0.66963524 | 0.9737024 | 0.8588256 |

Figure 3.1: Example data recorded by a Polbox device: Four channels sampled at 20 kHz.

Besides the recorded data itself, the HDF5 format can also store metadata. This functionality is also used by Polbox. An example of stored metadata in each HDF5 file is shown in Figure 3.2. This metadata provides important information about data and simplifies its analysis.

| Name | Value | Type |
|---|---|---|
| channels | 4 | int32 |
| creator | polrecord2 | <class 'str'> |
| description | naprazdno LAB fel | <class 'str'> |
| duration | 3600.17280000066 | float64 |
| epoch_start | 1687504968 | int32 |
| epoch_written | 1687508580 | int32 |
| samples | 72003456 | int32 |
| sampling_frequency | 20000 | int32 |
| timestamp_start | 2023-06-23 09:22:48.467383 | <class 'str'> |
| timestamp_written | 2023-06-23 10:23:00.607414 | <class 'str'> |

Figure 3.2:Example metadata stored alongside the recorded data inside an HDF5 file by Polbox device

Figures 3.3 and 3.4 show the same sample subset of 73 s of recorded data plotted in the time domain (Fig. 3.3) or frequency domain, respectively (Fig. 3.4).

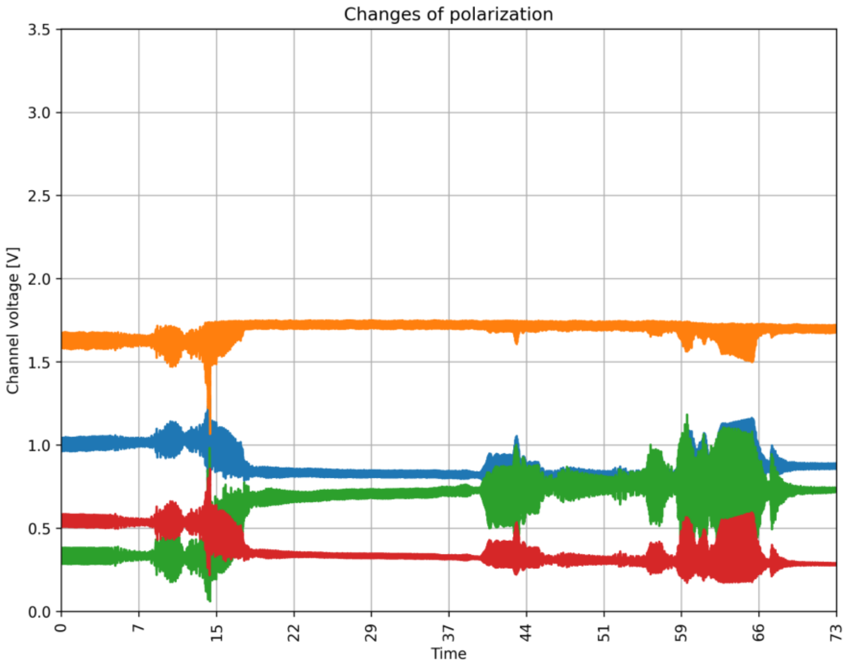


Figure 3.3: Acquired signal plotted in the time domain.

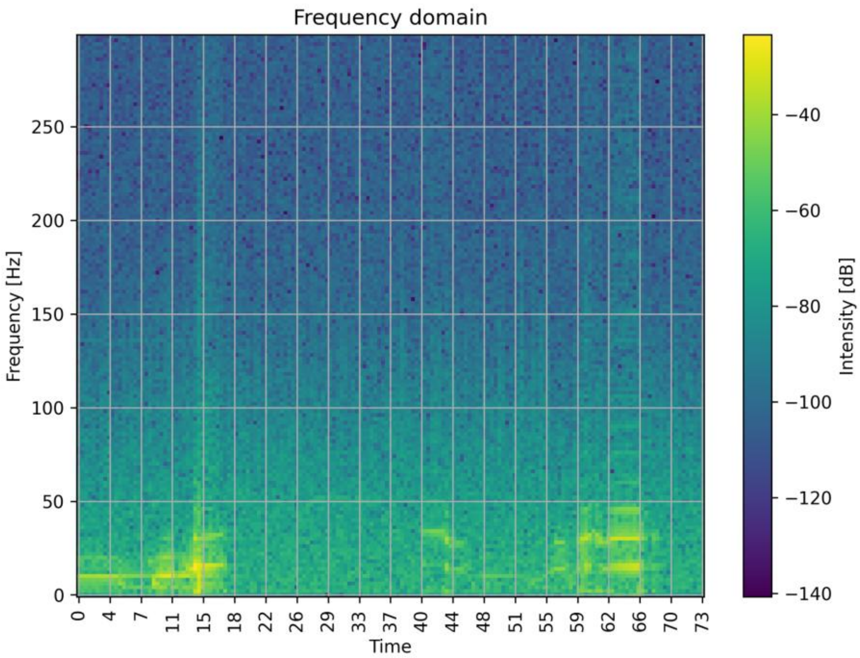


Figure 3.4: Acquired signal plotted in the frequency domain (spectrogram).

# 4 Time Synchronisation in Svalbard

In Longyearbyen, Svalbard, there is a SIKT point of presence at the University Centre (UNIS), connected by an optical cable with Norway's mainland. In a small Svalbard settlement, Ny-Ålesund, northwest of Longyearbyen (see map reference Figure 2.1), there is an active hydrogen maser (H-maser) atomic clock which primarily serves the Very-Long-Baseline Interferometry (VLBI) project, as well as an optical cable to UNIS in Longyearbyen.

As part of the SUBMERSE project, it was decided to deploy White Rabbit (WR) technology [4] in Svalbard, where the Ny-Ålesund H-maser will serve as a time reference. The team had to deal with sub-optimal settings onsite to utilise single fibre bidirectional connectivity between the WR grandmaster in Ny-Ålesund and the slave WR box in the UNIS. Manual calibration of the delay asymmetry of the two-fibre unidirectional optical path solved the issue, which was caused by the temporary swapping of both fibres while observing the change of an offset between the clock signal of the remote H-maser and a local time source in UNIS.

There is no radio technical laboratory in UNIS, so it is necessary to travel with all the needed equipment and measurement devices. This included: the Rubidium clock as a stable frequency reference, the precise time interval counter, the oscilloscope, and a few other tools to deal with optical connectors. Together with colleagues from SIKT, the idea of designed delay asymmetry measurement has been proven. Unfortunately, due to issues with the reference signal between the H-maser and WR grandmaster in Ny-Ålesund, it was not possible to complete the full operation of the WR protocol and finish the WR path calibration during the first visit. However, the necessary preparations for the operation deployment of the WR system were made. In the summer of 2024, it became fully operational – SIKT colleagues successfully calibrated the by the same method later in September this year.

# 5 Infrastructure Integration

Based on the preliminary survey, the procedure for transportation (including means) of the SoP sensor system to the selected sites, installation, and verification of their functionality in place was set. This was preceded by intensive on-premises testing.

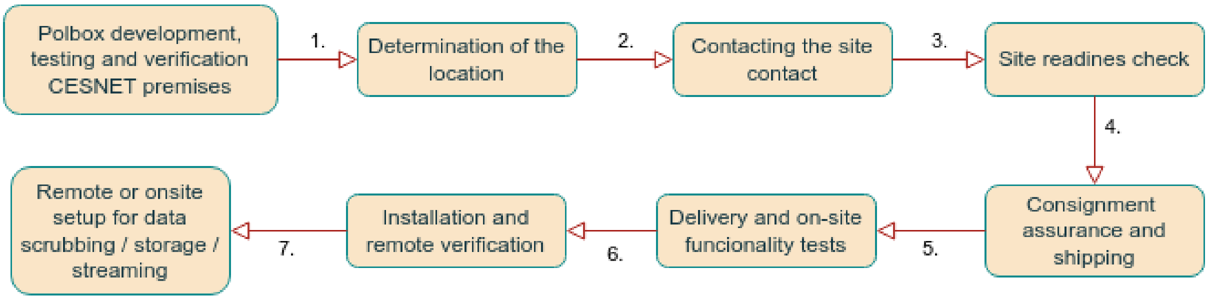


Figure 5.1: Infrastructure integration workflow of Polbox units.

## 5.1 Prerequisites

As mentioned, the Polbox is working out-of-the-box under the following conditions:

- 230 V AC (pure sinus if possible) backed up
- Public IPv4 connectivity (if possible, with a non-blocked port for telemetry)
- SSH connectivity, i.e., allowed on the path to a remote terminal
- Receiving optical power from -30 to -5 dBm

The Polbox is a ready-to-use solution for the long-term continuous state of polarisation acquisition in a compact 1U rack-mountable chassis. Optical input signal could be part of existing traffic, e.g., an optical service channel. Therefore, Polbox doesn't require any additional laser source or free fibre channels. Recorded SoP data is stored locally in HDF5 format with metadata, and could be synchronized to remote storage. Depending on the input signal, the recorded data stream needs approximately 6-13 GB daily. For more details, see Section 3Dataset (format, attributes).

It is worth noting that SoP information would also be extracted from optical transmission systems (from the project partner Infinera). Ultimately, Polbox (a CESNET-developed device) and Novoptel Polarimeter PM1000 are the only sources of SoP information.


Figure 5.2: Final installation in Svalbard showing Polbox SoP installed together with DAS from ASN.

## 5.2 Measurements and data storage/streaming

Local data storage is designed on an industry-grade SSD with batch uploading/synchronisation to a carefully selected secure repository. At first, the sensed data are directly stored in the Polbox local storage in the HDF5 file format. Currently, every hour, a batch file is created, internally Gzip-compressed, and sent out to the secured repository (in the case of Norway deployment, it is the Sigma repository managed by NTNU).

Future releases of Polbox could be equipped with some post-processing software, which could perform base data cleaning, reducing, and preliminary analysis – e.g., some kind of anomaly detection, built upon a method that is suitable from the point of the computational power of the embedded processing unit inside Polbox.

In submarine optical cables, the measurements are significantly more complex than on terrestrial links. With SoP (as opposed to DAS), it is very difficult to detect where (at which point) the event occurred on the route. A major difference is the optical signal amplifiers laid on the seabed along with optical cables at each span (about every 50-100km). To locate the fibre cut, each amplifier returns about 1/100 of the signal back to the fibre (at 1561 nm, i.e., at the end of the C-band) to detect where the damage or cut occurred (replacement of the traditional OTDR method). However, this reverse signal portion can be used for incoherent, SoP-only measurement experiments, such as those done in 2023 [5].

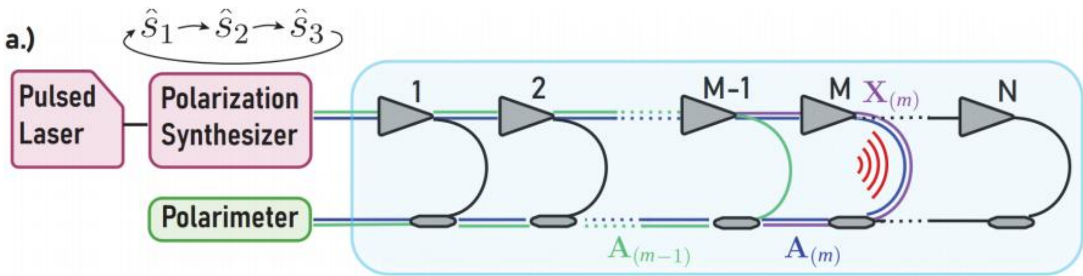


Figure 5.3: A schematic drawing of the method for detecting the location of disturbance using SOP on submarine cable.

## 5.3 Data Analysis

Sampling at 20 kHz produces a significant amount of data, where most of it, with high probability, represents noise. Thus, it is necessary to perform basic preprocessing as an initial filtering layer before the RAW data is stored, e.g., in some databases suitable for time series storage.

The well-known time series databases, such as InfluxDB, are not directly suitable for data with a sampling rate at a maximum above a few hundred Hz. Therefore, we have selected the HDF5 format, which is suitable for enormous amounts of data. On the other hand, every possible reduction in data size makes sense.

It was important that data analysis first focused on properties of SoP data, such as sensitivity (with comparison to other methods like DAS) on different frequencies of disturbances, their footprints, and their changes over time. Next, the team looked at exploring and defining the common characteristic of SoP data from different locations, e.g. is are there common data properties from all locations, or is there some feature (property) that could be utilised to distinguish between the origin location of data. The data should be analysed in both the time and frequency domains.

# 6 Conclusions

This deliverable brought a comprehensive overview of the SoP Integration Model – starting with the site descriptions where the measuring devices are to be deployed, over the technical description of the Polboxes themselves, and the way of integration. This contribution describes in detail the hardware and software parts of the devices developed in CESNET as part of its long-term research focus on open optical systems, including measurement methods, the data generated, and its format or method of storage. The deliverable concludes with the integration, the way the SoP optical sensing devices should be deployed to be sustainable in the long term, and could be used for various services (e.g., early warning systems) for the community built on top.

It should be noted that at the time of writing this deliverable, only some implementation aspects have been resolved as expected. There are still many challenges ahead for the SUBMERSE team, especially installations at other sites outside the Arctic region, methods of validating or verifying data before it can be made available to other research groups, and AAI integration etc.

# References

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# Glossary

| | |
|---|---|
| 1U | 1 Unit |
| AAI | Authentication and Authorization Infrastructure |
| AC | Alternating Current |
| ASN | Alcatel Submarine Networks |
| CESNET | Czech Education and Scientific Network (NREN) |
| DAS | Distributed Acoustic Sensor |
| DB | Database |
| dBm | Decibels relative to 1 milliwatt |
| DSP | Digital Signal Processors |
| DWDM | Dense Wavelength Division Multiplexing |
| FUT | Fibre Under Test |
| GB | GigaByte |
| GbE | Gigabit Ethernet |
| GÉANT | Pan-European Research and Education Network |
| HDF5 | Hierarchical Data Format version 5 |
| IP | Internet Protocol |
| MB | MegaByte |
| nm | Nanometer |
| NREN | National Research and Education Network |
| NTNU | Norwegian University of Science and Technology |
| PMD | Polarisation Mode Dispersion |
| SIKT | Norwegian NREN |
| SoP | State of Polarisation |
| SSD | Solid State Drive |
| SSH | Secure Shell |
| SUBMERSE | Submarine Cables for Research and Exploration |
| UPS | Uninterruptable Power Supply |
| WR | White Rabbit |