General Requirements for Sensor Enabled and Reliable Telecommunications (SMART) Cable Systems

JTF Engineering Team

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1 Introduction

1.1 Summary

These requirements identify the minimum performance capabilities of fiber optic submarine cable systems equipped to measure temperature, absolute pressure, and three axis acceleration at regular intervals along the cable. These are referred to herein as Sensor Enabled and Reliable Telecommunications (SMART) cable systems.

These requirements were previously issued as a draft Recommendation to ITU-T Study Group 15. They are re-issued here to provide a source document which is not connected to the ITU-T Study Group. This paper culminates both the draft Recommendation and all previous work regarding functional requirements for SMART cable systems and the associated wet demonstrator project.

1.2 Background

Three UN specialized agencies (International Telecommunication Union (ITU), World Meteorological Organization (WMO) and Intergovernmental Oceanographic Commission (IOC) of UNESCO) have jointly proposed the development of mini-observatories on trans-ocean submarine cables to measure key ocean seafloor observables, with the concept and applications being developed further through a Joint Task Force (JTF). The latter was established in 2012 with a wide membership including scientists, engineers, cable owners and operators, regulators and legal experts.

The JTF initiative addresses two main needs: a) increased reliability and integrity of the global tsunami warning network, and b) sustained climate-quality data from the sparsely observed deep oceans. Deployment of seismic and pressure sensors is directed at the first of these. Pressure and temperature measurements support the second need. The extent and impact of damage from tsunamis and earthquakes is a major societal issue for coastal communities throughout the world. Ocean temperature is a critical variable, particularly regarding climate change, sea level rise and ecosystem stress. These aspects of the health and status of marine environments could be monitored globally in real-time through a new generation of ocean sensors hosted on telecommunication cables. Measurements provided by these systems will increase our understanding of the planet and its ecosystems on decadal time scales.

The requirements presented here are developed in conjunction with the scientific community and represent a realistic appraisal of end user needs.

These requirements specify functionality and not the method of delivering such functionality. The determination of methods is left to the system suppliers, whose development and prototyping capabilities are best equipped to implement innovative solutions.

The objective of standardization is to provide the same quality of data regardless of supplier. End users expect consistent, traceable and defensible data. Standardizing the sensor performance is intended to achieve this result. Implementation details, including mechanical housings, circuit board operation, power delivery and communications protocol, must be such that they have no impact on the quality of the data gathered.

1.3 Note

Compliance with this Recommendation is voluntary. However, the Recommendation may contain certain mandatory provisions (to ensure, e.g., interoperability or applicability) and compliance with the Recommendation is achieved when all of these mandatory provisions are met. The words "shall" or some other obligatory language such as "must" and the negative equivalents are used to express requirements. The use of such words does not suggest that compliance with the Recommendation is required of any party.

1.4 Intellectual Property Rights

Attention is drawn to the possibility that the practice or implementation of these functional requirements may involve the use of a claimed Intellectual Property Right. The JTF takes no position concerning the evidence, validity or applicability of claimed Intellectual Property Rights, whether asserted by JTF members or others outside of the functional requirements development process.

2 Scope

These functional requirements apply to optical fiber submarine cable systems equipped with temperature sensors, absolute pressure gauges and three-axis accelerometers at regular intervals along the cable. The purpose of these requirements is to ensure that collected data is robust, valid, and scientifically useful. These requirements are intended to address integration of sensor capabilities into telecommunications cable systems, but may also be applied to systems whose sole purpose is data collection.

The term “client” is used in this recommendation to denote the user or recipient of collected sensor data. “Client” may also represent a data processing system which receives the sensor data.

3 References

The following ITU-T Recommendations and other references contain provisions which, through reference in this text, constitute provisions of this Recommendation. At the time of publication, the editions indicated were valid. All Recommendations and other references are subject to revision; users of this Recommendation are therefore encouraged to investigate the possibility of applying the most recent edition of the Recommendations and other references listed below. A list of the currently valid ITU-T Recommendations is regularly published. The reference to a document within this Recommendation does not give it, as a stand-alone document, the status of a Recommendation.

[ITU-T G.971] Recommendation ITU-T G.971 (07/2010), *General features of optical fibre submarine cable systems.*

[ITU-T G.972] Recommendation ITU-T G.972 (09/2011), *Definition of terms relevant to optical fibre submarine cable systems.*

4 Definitions

4.1 Terms defined elsewhere

This Recommendation uses the terms defined in [ITU-T G.972].

4.2 Terms defined in this Recommendation

This Recommendation defines the following terms:

3.2.1 sensor: An element of the system that measures a physical property of the environment and returns an observed value.

3.2.2 sensor set: A group of co-located sensors consisting of one temperature sensor, one pressure sensor, one auxiliary temperature sensor associated with the pressure sensor, and three accelerometers (each sensing one axis).

3.2.3 sensor subsystem: Those components of the submarine cable system, including submerged plant and terminal equipment, whose sole purpose is the collection, transmission, storage and presentation of sensor data.

3.2.4 telecommunications functions: Functions and aspects of the cable system that are not related to sensors.

5 Abbreviations and acronyms

This Recommendation uses the following abbreviations and acronyms:

APG	Absolute Pressure Gauge
OADM	Optical Add-Drop Multiplex
ROADM	Reconfigurable Optical Add-Drop Multiplex
ROV	Remotely Operated Vehicle
NTTS	Nominal Transient Tensile Strength
SI	International System of Units
UTC	Universal Time Coordinates
UTS	Ultimate Tensile Strength

6 Conventions

Use of the words "shall" or "must" indicates a provision that is mandatory to achieve compliance with this Recommendation. The use of such words does not suggest that compliance with the Recommendation is required of any party.

Use of the words "should," "may," or "desirable" indicates a provision that is preferred but not mandatory.

Use of the word "will" indicates a provision that is assumed to be fulfilled outside the scope of this Recommendation.

Note that some sections include both a mandatory minimum requirement indicated with "shall" and a more stringent requirement indicated with the word "should."

7 Features of a sensor-enabled submarine cable system

A sensor-enabled submarine cable system incorporates temperature, pressure and three-axis acceleration sensors at regular intervals along the cable. Sensor sets are nominally located once per repeater span, however other arrangements may be considered. Sensor sets shall be no more than 150 km apart.

The system shall provide continuous power for the sensors and a means of transmitting data to one or more shore stations.

At the shore station, equipment for receiving, storing, and forwarding data generated by the sensors shall be provided.

The presence of sensors shall not preclude the use of branches, fixed OADM or ROADM. To the extent feasible, branch cable segments should also be equipped with sensors.

8 Sensor performance

8.1 General

Sensor performance requirements shall be met after taking into account:

a) any influence of the system on the surrounding environment, particularly as regards to generation and dissipation of heat,

b) variations arising from the measurement circuitry,

c) the aging of any measurement circuit components,

d) realistic positioning accuracy,

e) realistic orientation variation,

f) environmental variations, including depth, ambient temperature, and seabed conditions.

8.2 Temperature sensor

Temperature sensors shall have the performance parameters given in Table 1:

Table 1: Temperature Sensor Parameters

Range:	-5.0 to +35ºC

Initial accuracy:	±0.001ºC
Stability:	0.002ºC / year
Sampling rate:	0.1 Hz
Sample resolution:	24 bits

8.3 Absolute pressure gauge

Absolute pressure sensors shall have the performance parameters given in Table 2:

Table 2: Pressure Sensor Parameters

Range	0 to 73MPa (0 to 7,000m)
Overpressure tolerance	84MPa (8,000m)
Accuracy	±1mm relative to recent measurements 0.01% of full range absolute
Maximum allowable drift after a settling-in period	0.2 dbar / year
Accuracy after drift correction	For further study
Hysteresis	≤ ±0.005% of full scale
Repeatability	≤ ±0.005% of full scale
Sampling rate:	20 Hz
Noise Floor	0.14 Pa^2/Hz
Sample resolution:	32 bits
Temperature sensor sampling rate:	20 Hz
Temperature sensor resolution:	24 bits

8.4 Accelerometer

Accelerometers shall have the performance parameters given in Table 3:

Table 3: Acceleration Sensor Parameters

Configuration:	3-Axis
Response	0.1 to 200Hz
Resonance frequency	>2,000Hz
Full scale range:	±1.5g where g is 9.806 m/s^2
Noise:	≤ 2ng / √Hz
Amplitude response	±1% across frequency range
Linearity	±1% of full scale
Cross-axis sensitivity	<1%

Sampling rate:	200Hz
Sample resolution	24 bit

9 Capabilities of a sensor-enabled cable system

9.1 Performance

The presence of sensors and the sensor subsystem shall have no net impact on the performance of telecommunications functions. Any allocation to the system performance budget resulting from the sensors or sensor subsystem shall be identified. This allocation shall be accounted for in the system design such that the required performance and performance margins for the telecommunications functions are achieved.

9.2 Availability

The addition of sensors and the sensor subsystem shall have negligible impact on the availability of telecommunications functions. Any unavailability resulting from the presence of the sensors and sensor subsystem shall be identified.

9.3 Reliability

The expected sensor failure rate shall not exceed 1% per per year.

The expected rate of power or communications failures within the sensor subsystem shall affect no more than 0.1% of sensors per year.

9.4 Fault isolation

The sensor subsystem shall be fault tolerant.

The failure of a single sensor shall have no impact on the performance of other sensors.

The failure of the sensor subsystem components at a single location shall not prevent data being gathered from other locations.

9.5 Design life and expected ship repairs

The design life of the sensor subsystem shall be ten years or greater.

The addition of the sensor subsystem shall have no impact on the overall system design life (typically twenty-five years).

Ship repairs will be conducted only for those elements of the sensor subsystem that affect the telecommunications functions of the system, for example in-line power supply modules. Sensor failures or sensor subsystem failures that have no affect on telecommunications functions will not be repaired. The sensor subsystem shall increase the expected number of ship repairs by no more than 10% as compared to an equivalent system without sensors.

9.6 Environmental requirements

The sensors and sensor subsystem shall meet the same environmental requirements as the overall system during transport, installation and operation; this includes specifications for mechanical shock, thermal extremes, thermal shock, and electromagnetic interference.

Sensors shall be suitable for all expected seabed conditions. Submerged sensors and sensor subsystem components shall work in any seabed conditions, including buried, either by plough or by natural sedimentation, in suspension off the seabed in areas where the seabed has more relief than anticipated, or, where the seabed is jagged, when laying across protrusions.

Sensors shall operate over the temperature range from –5ºC to +35ºC.

Submerged sensors and sensor subsystem components shall withstand a shock of up to 40g without permanent damage.

9.7 Mechanical

Pressure housings shall be suitable for depths up to 8,000m (84 MPa).

Pressure seals on submerged plant shall be designed to seal against Hydrogen migration for the design life of 25 years.

Pressure seals for sensors, and for cables to sensors, shall be compatible with any other seals used in the system.

Submerged plant housing materials shall be corrosion resistant, or protected from corrosion. Materials shall be compatible, and not create corrosion in adjacent materials. Housing materials shall be uniform, and not subject to local corrosion such as crevice corrosion.

Material selection for sensors shall take into account the materials used in any adjacent housings, and be compatible with them.

Sensors and the sensor subsystem shall be electrically isolated from the housings.

9.8 Deployment

The sensors and sensor subsystem shall be compatible with conventional installation methods including, but not limited to, cable transport, cable and repeater storage on vessels, linear cable engines, three meter sheaves, plough burial, ROV burial and jetting.

All submerged sensors and sensor subsystem components shall be designed to withstand the rigors of installation from the deck of a vessel in the type of weather that may be encountered in winter in the world's oceans.

All submerged sensors and sensor subsystem components shall be designed for deployment through cable engines, over capstan wheels and along cable ways, chutes and over stern ways. To meet this requirement the exterior of all submerged plant shall be clean of protrusions and extremely robust.

Cable housing entries shall be protected by substantial cable bend restrictors that are designed to accommodate loads that exceed the cable breaking strength. The cable and housings shall be designed for the tension and snatch loads that occur during deployment in bad weather.

Sensors and sensor subsystem shall not degrade the tensile properties of the cable to less than 90% of its UTS.

All deployable sensors and sensor subsystem components shall be able to pass over a 3m diameter sheave when subject to a tension equal to the NTTS of the connected cable.

9.9 Geographic position and orientation

It shall be possible to determine, by cable lay calculation or other means, the geographic location of 95% of sensor sets to within ±100.m.

It shall be possible to determine, by cable lay calculation or other means, the heading of the cable for each sensor set to with ±0.5º.

9.10 Recovery and repair

The sensors and sensor subsystem shall have no impact on the ability to recover and repair the submarine cable system.

9.11 System operation

The sensors and sensor subsystem shall have no impact on operation of the telecommunications functions of the submarine cable system, including supervisory performance, element management or network management.

The sensor subsystem shall require minimal intervention from cable station personnel.

10 Operational requirements

10.1 Error rate performance

The sensor subsystem shall provide data transmission between the sensors and shore stations at a bit error rate <1E-11.

10.2 9Latency

Sensor output shall be transmitted to a shore station within 200 msec of being collected.

10.3 Time stamp

The system shall record the time at which data is recorded by a sensor with an accuracy of ±100 µsec relative to UTC or other suitable external reference.

The system should record the time at which data is recorded by a sensor with an accuracy of ±1 µsec relative to UTC or other suitable external reference.

10.4 Geographic position and orientation

The sensor subsystem shall be capable of reporting the geographic location of any sensor, as determined during installation or by other means, and an estimate of the accuracy of that location.

The sensor subsystem shall be capable of reporting the heading of the cable at each sensor location as determined during installation or by other means. One sensor axis shall be aligned with this orientation.

10.5 Calibration coefficients

The sensor subsystem shall be able to report the calibration coefficients of all sensors, as determined prior to deployment or as calculated after deployment.

10.6 Sensor status

The sensor subsystem shall be able to report the current status of each sensor, e.g. normal operation, faulty, failed, off-line.

10.7 Alarm management

The sensor subsystem shall be able to generate alarms when a fault or failure is detected in a sensor or the sensor subsystem.

10.8 Performance management

The sensor subsystem should provide performance management reports such as the percentage of valid data received from each sensor over time.

10.9 Configuration management

A facility to update the configuration of the sensor subsystem following system expansion, repairs, or other intervention should be provided.

11 Data presentation

The sensor subsystem shall provide an open and fully documented interface for transfer of sensor data and metadata to client systems.

Data shall be reported in natural units, i.e. ºK or ºC for temperature, m/s^2 for acceleration, and Pa for pressure.

Raw data shall also be retained and reported. This includes counts from analogue-to-digital converters and intermediate values such as frequency measurements from the pressure sensors.

The data format shall be as simple and universal as possible and compatible with future computer architectures and formats.

The use of established formats and protocols for encoding and streaming of data is desirable. Refer to Appendix I for examples.

12 Implementation Aspects

12.1 Introduction

This annex identifies implementation aspects that are specific to sensor-enabled systems. These are in addition to the implementation aspects identified in ITU-T G.971 Annex A.

12.2 Sensor calibration

Sensors shall be calibrated to recognized standards prior to deployment in a manner that is traceable and repeatable.

Care must be taken to ensure sensor calibration is not invalidated during system assembly, transport, or installation.

12.3 Engineering data collection

Various engineering data, including but not limited to sensor pedigree, sensor calibration coefficients, and sensor geographic positions, must be gathered and retained.

12.4 Sensor subsystem commissioning

Commissioning tests of the sensor subsystem shall be performed to ensure the sensor subsystem meets its performance requirements. This work may be performed during or after routine system commissioning.

12.5 Data integrity

The sensor subsystem may transmit and record all sensor data without regard for errors or sensor impairments. Error detection and retransmission at the transport layer is desirable but not mandatory. Detection and correction of missing or erroneous data will be performed by the client system.

Detection of the positioning of the accelerometers in the X-Y plane (i.e. rotation about the cable's axis) will be performed by the client system.

13 Data delivery

13.1 Introduction

The data formats and protocols identified here may be suitable for the interface between the sensor subsystem and client systems. Details of the data presentation format are for further study.

I.2 Additional definitions

This Appendix uses the following abbreviations and acronyms:

ASCII	American Standard Code for Information Interchange
CSV	Comma Separated Values
XML	eXtensible Markup Language

13.2 Text files

CSV ASCII text files containing data in natural SI units are nearly universal. Methods of appending to and reading from such files are widely implemented.

13.3 Open Geospatial Consortium Sensor Web Enablement

The Open Geospatial Consortium Sensor Web Enablement is a family of standards and specifications based on XML for interoperable interface requirements for in-situ sensors and sensor networks.

13.4 SeedLink

SeedLink is a real-time data acquisition protocol based on TCP that has become the de facto standard for exchange of seismic data. Plug-ins are available for many widely used seismometer acquisition software packages.

14 General requirements for a demonstrator system

14.1 Introduction

This section provides general requirements for a system to demonstrate the capabilities of sensor-enabled systems. The purpose of the demonstrator system is to permit sensor performance to be validated against existing instrumentation without the need for integration into an active telecommunications system. The demonstrator system must provide a realistic deployment and operational scenario for the sensors, make use of representative cable, housings, sensors and other mechanical fixtures, be installed using conventional cable laying methods, and remain deployed for months or years. The demonstrator system must provide power and communications for the sensors; however, the power and communications components need not be representative of those that would be used in a full-scale sensor-enabled system.

14.2 Technical goals and scope

The objective of the demonstrator system is to satisfy interested parties of the feasibility of manufacturing, deploying, and operating sensors to measure temperature, pressure, and three axis motion when deployed as part of a submarine cable system. The demonstrator system must show that:

a) Sensors can be integrated into the cable system,

b) Sensors can survive deployment stresses,

c) Data can be collected and transmitted to shore,

d) Data will provide value to science, and

e) The sensors can continue to operate for months or years.

The demonstrator system is similar in some respects to the qualification testing routinely performed by submarine cable system suppliers, but is not intended as a replacement for such testing. In the event a participating supplier wishes to use the demonstrator system as a qualification test, it would need to provide its own scope, measurements, and pass-fail criteria.

Validation of sensor data is essential to justify the deployment of these instruments. Methods for comparison of data collected by the demonstrator system to data collected from other sources, verification of sensor accuracy and repeatability, and other such validation are outside the scope of this document.

14.3 Additional definitions

This Appendix uses the following abbreviations and acronyms:

LW	Light Weight
LWP	Light Weight Protected
RPL	Route Position List

SLD Straight Line Diagram

14.4 Demonstrator system configuration

The demonstrator system shall comprise a minimum of 20 km of submarine cable and a minimum of three sensor sets.

Each sensor set shall consist of one temperature sensor, one pressure sensor, and one three-axis accelerometer meeting the performance parameters provided in the main body of this Recommendation.

Sensors shall be housed in or placed adjacent to a cable body that matches the physical and mechanical characteristics of a repeater, joint or other housing.

The submarine cable shall be a conventional 17mm, 20mm or 21mm type suitable for the expected deployment conditions. The use of the cable center conductor for powering implies that 11mm or 12mm cable designs are likely to be unsuitable.

Power and communications shall be provided to the sensors. Note, however, that the power feeding and communications methods are not required to be those intended for use in a full-scale system.

The minimum distance between sensor sets shall be three times the water depth at the test location; this is to prevent interference between the sensor sets during installation and recovery.

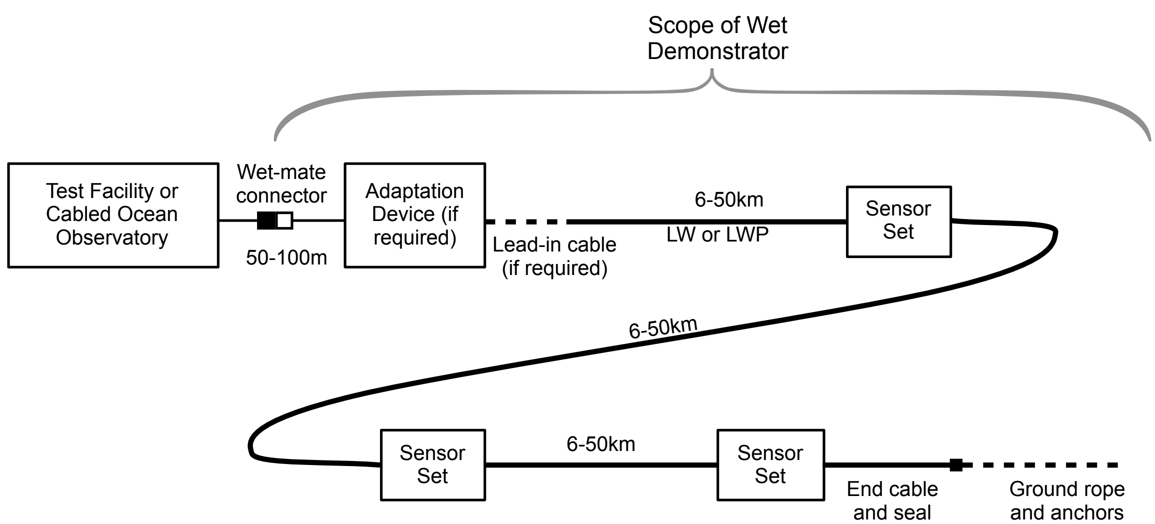

Figure 1 Conceptual diagram of a demonstrator system

14.5 Support infrastructure and interfaces

The demonstrator system will be laid in an area of seabed supported by a cabled observatory. The demonstrator system shall include any equipment necessary for connection to the observatory. Following installation of the demonstrator system, an ROV and extension cable will be used to connect the demonstrator system to the cabled observatory. The overall scope of the demonstrator system is illustrated in Figure 1.

The observatory operator will make data from the demonstrator system available to interested parties for review and verification.

Additional sensors shall be installed on nearby observatory platforms for the purpose of data validation

The demonstrator system shall include a suitable wet-mate connector for connection to a cabled observatory.

The demonstrator system shall include any necessary adaptation to convert power received from the cabled observatory to power needed for the sensors.

The demonstrator system shall include any necessary adaptation to connect the sensors and the demonstrator system to the communications interface provided by the cabled observatory.

14.6 Demonstrator system deployment

Demonstrator system deployment shall be conducted in accordance with written methods of procedures for safety, ship loading, stowage, ship board testing, installation, cable handling, and initial testing. Route Position Lists (RPLs) and Straight Line Diagrams (SLDs) shall be prepared and utilized during the deployment.

The demonstrator system shall be laid using conventional cable lay equipment (preferably from a cable ship) in at least 2,000m water.

At least one sensor location shall be visually inspected by ROV after installation to verify orientation and to assess the interaction between sensors and the seabed. The housing that is to be inspected shall be marked to allow the orientation to be checked visually.

The demonstrator system cable will be laid at typical speed for repeater installation. No attempt shall be made to reduce loads on the instrument housing.

14.7 Deployment duration

The demonstrator system shall remain deployed for a period of six to eighteen months.

The demonstrator system should remain deployed indefinitely.

14.8 Testing and validation

14.8.1 Manufacturing and deployment

The validity and integrity of the demonstrator system shall be proven through a series of tests that are representative of those typically employed by the submarine cable industry.

Detailed procedures shall be developed and agreed prior to the testing.

Tests shall include:

a) Sensor characterization and calibration

b) Factory tests

c) System assembly tests

d) Shipboard tests

e) Initial sensor tests upon power up

f) Load and lay report

g) ROV video inspection

14.8.2 System performance

The availability of the sensors in the demonstrator system shall be evaluated on a continuing basis against the expectations for multi-year life. Outages due to factors outside the demonstrator system shall be excluded from the analysis.

14.8.3 Data integrity

A procedure for validation of the sensor data shall be developed and carried out. Qualitative criteria for validation shall be agreed among interested parties, sensor supplier(s), system integrator, and installer, prior to deployment.

14.9 Success criteria

The success of the demonstrator system depends on the value and validity of the collected sensor data. The ability to manufacture and deploy a sensor-enabled system is a prerequisite, but not the ultimate objective.

Criteria for success shall include:

a) All sensors operational following installation

b) 99.99% availability of sensor data over an assessment period of six months or more

c) No more than one sensor failure during the first six months of operation

d) Successful validation of sensor data based on agreed qualitative and quantitative criteria.

~end~