Sensor Enabled Scientific Monitoring And Reliable Telecommunications (SMART) Cable Systems: Wet Demonstrator Project Description

JTF Engineering Team

White Paper

Issue 1.0
July 2016

DOCUMENT CONTROL SHEET

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Issue	Date	Status / Reason
0.1	9 June 2016	First Draft for Engineering team review
0.2	13 June 2016	Revised draft
0.3	8 July 2016	Draft incorporating engineering team input
1.0	11 July 2016	Document released.

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1 Introduction

The use of submarine telecommunications cable systems for environmental monitoring and disaster warning has received significant attention since first proposed over five years ago. The International Telecommunication Union (ITU), the Intergovernmental Oceanographic Commission of the United Nations Educational, Scientific and Cultural Organization (UNESCO/IOC), and the World Meteorological Organization (WMO) established the Joint Task Force (JTF) in late 2012 to address the technical, commercial and legal aspects of adding this capability to commercial telecommunications cable systems. Efforts to define and develop suitable methods of integrating temperature, pressure, and acceleration sensors into such cable systems have been ongoing during that time, but have not progressed beyond high level requirements and conceptual designs.

Many entities are intrigued by the concept of a sensor enabled cable system; however, the business case or owner encouragement to introduce long term monitoring capability into commercial cable systems has not yet occurred. It has thus become clear that further development of sensor enabled Scientific Monitoring And Reliable Telecommunications (SMART) cable systems requires additional political, financial, and scientific commitments. Obtaining such commitments in turn require a demonstration of the effectiveness and practicality of the proposed approach. The concept of a “Wet Demonstrator” system suitable for deployment and medium term operation has been put forth as a first critical step towards industry acceptance.

This paper presents a new approach to development of the Wet Demonstrator. The background and rationale for pursing this new approach are described. The project scope and major assumptions are defined. The project is presented in two major sections: first the system design is presented in Section 8, then the project activities are described in Section 9. Finally, operations and data validation are discussed.

2 References

The readers of this paper are assumed be familiar with the following material:

1. **Joint Task Force Home Page**

   http://www.itu.int/en/ITU-T/climatechange/task-force- sc/Pages/default.aspx

2. **Overview Presentation**

   http://www.itu.int/en/ITU-T/climatechange/task-force-sc/Documents/Sensing_the_Oceans.pdf

3. **ITU-WMO-UNESCO IOC Joint Task Force Frequently Asked Questions**

   http://www.itu.int/en/ITU-T/climatechange/task-force-sc/Documents/JTF_FAQs.pdf

4. **General requirements of a SMART cable**

   JTF Engineering White Paper dated 13 June 2016.

5. **5th Workshop on "SMART Cable Systems: Latest Developments and Designing the Wet Demonstrator Project",** Dubai, United Arab Emirates, 17-18 April 2016.

   http://www.itu.int/en/ITU-T/Workshops-and-Seminars/5-ws-smart-cable-systems/Pages/Programme.aspx

3 Purpose

This paper serves several purposes. First is to document a consensus among the members of the JTF Engineering committee regarding a possible approach. Second is to allow assessment of the proposed approach by interested parties outside the JTF. Third is to permit potential project participants, including suppliers, integrators, observatory operators, and marine installers, to evaluate their potential role in the proposed system development. Potential participants are asked to indicate their level of interest and capabilities in a Request for Information (RFI) to be issued by the JTF during the third quarter of 2016. Finally, the proposed system design combined with the RFI replies will provide a basis for proposals to funding agencies.

4 Background

Functional requirements for the wet demonstrator have been developed and documented, with the expectation that one or more suppliers, funding source(s), or beneficial owner(s) would step forward to lead the development and deployment. The functional requirements are not descriptive; implementation details are intentionally left to the discretion of the project developer or their chosen supplier. Development of a working system from the functional requirements requires a project team with experience in both submarine telecommunications systems and ocean observing systems. The project is within the capabilities of most of the commercial cable system suppliers, however, the suppliers to the commercial telecom market have been unable to justify development of new capabilities for which the market demand and business model are unproven.

Compounding this difficulty are concerns regarding the commercial and legal aspects of sensor enabled cables, which have resulted in reluctance among potential owners of such a system to include this new technology without extensive qualification efforts and careful consideration of the international legal framework for scientific research in the oceans. Public sector funding for medium to large projects is constrained. In spite of the work done to date, efforts to engage funding sources, potential cable owners, and potential suppliers have not yet reached a 'proof of concept' stage.

5 Scope

This document presents an implementation plan for a demonstration project. This demonstration is intentionally limited to scientific functions. Demonstration of the capability to deploy sensors using unmodified cable laying methods is the key objective. The project includes the mechanical integration of sensors with housings and cable which are representative of a commercial telecoms cable. In particular, repeater housings and cable which are identical to those used in a commercial telecom system must be used. Cable laying methods must likewise be identical to those used for commercial telecommunications systems, with the exception that the hookup to an existing ocean observatory may employ appropriate methods. Integration of powering and communications functions with a telecom system will not be undertaken; instead off-the-shelf communications components and simple custom power supplies will be employed. These items will be internal to the housings and will not impact the ability to deploy or recover the system. Existing sensor designs and sensor electronics will be used.

The system design and project plan outlined here represent an initial proposal intended to illustrate one possible approach. Alternative methods which improve the results, reduce cost, improve delivery times, or reduce risks may also be considered.

6 Demonstration System Development

A modified approach to the development of a SMART cable wet demonstration system is proposed. This approach is based on the methods used over the last decade to develop cabled oceanographic observatories. The successes (and occasional setbacks) encountered in constructing and operating these observatory systems provide a useful framework on which to build. Many of the elements necessary to construct the wet demonstrator have already been proven, including Ethernet based communications systems, cable termination assemblies, the sensors themselves, and on-shore data management and powering systems.

In the proposed approach, suppliers will be engaged primarily to deliver and integrate existing products. Off-the-shelf components are used to the greatest extent possible. Some development work will be needed, principally for mechanical items and the power supplies, but these can be addressed by existing low-cost, commercial technology. Where new development is required, specialists will be engaged to address focused tasks. The detailed (and costly) development and qualification work necessary to support integration into a functioning commercial cable is deferred until after demonstration is successfully completed.

This modified approach simplifies the scope of work of each potential supplier. Most importantly, the scope for the cable supplier is limited to the supply and integration of cable and empty repeater housings. With the removal of any development effort, it is anticipated that one or more cable system suppliers could support the project.

This modified approach comes with one caveat: no single entity will be solely responsible for the overall performance of the project. The usual industry approach is to engage a prime contractor, who oversees the project schedule, secures all resources necessary to complete the project, manages all project costs, and is fully responsible for technical performance. One of the impediments to development of the wet demonstrator is that, to date, no entity has been willing to take on this responsibility. Under the proposed approach, functional performance must be managed collaboratively through design reviews and integration testing. This mirrors the approach used on cabled observatory systems and, when properly implemented, has been shown to be effective. Risk of cost overruns will be managed through the use of clearly defined work scopes, design reviews, carefully managed integration activities and, wherever possible, competitive procurement.

An overall project manager is envisioned, but the role will be strictly that of directing project activities and facilitating communication; the project management entity will not be asked to absorb unforeseen costs. Given the structure of the proposed project, it is likely, but not necessary, that the operator of an existing observatory can act as the project manager.

It is assumed that the wet demonstrator will be hosted on an existing observatory, although this is not a strict requirement. The use of an existing observatory provides a convenient connection point in deep water, avoiding the cost of proving and installing an armored shore end cable. Permitting issues would also be minimized, again by avoiding the near shore area. Existing observatories also have extensive data management capabilities which can be applied to support the wet demonstrator project.

The desired result of the proposed approach is to focus the wet demonstrator project on the key objective of proving that sensors can be deployed using standard industry practices for cable and repeater installation.

7 Assumptions

The basic design assumptions for the wet demonstrator project are:

6. The design adheres to the performance requirements and guiding principles set forth in **General requirements for sensor-enabled submarine cable systems** JTF Engineering White Paper dated 13 June 2016.
7. The wet demonstrator incorporates a minimum of three sets of sensors. Three sensor sets demonstrate repeatability and can be distributed spatially such that the direction

of tsunamis can be detected.

8. The wet demonstrator design permits additional sensor sets if funding allows.
9. The wet demonstrator is designed to connect to a cabled observatory science port providing 100BASE-T Ethernet and 375-400VDC power. Connection to an out-of-service shore end or to a branch of a new commercial cable is also possible.
10. The wet demonstrator is to be installed in water depths between 1,000 and 3,000m.
11. The wet demonstrator is installed outside the territorial limit (12nm) of any country. Operational permits are the responsibility of vessel operators. Cable crossings, if necessary, are to be performed according to the International Cable Protection Committee (ICPC) Recommendation No.2. Other types of crossings should be avoided.
12. The wet demonstrator has an expected service life of three to five years. This shall be shown through reliability analyses.
13. No commercial telecommunications functions are incorporated.

8 System Description

This section provides a general description of the wet demonstrator design. The design concepts and specific examples are not intended as a final design, but rather to show that the wet demonstrator is a feasible and realistic project.

8.1 Overview

The wet demonstrator system design includes three or more sensor sets connected to a trunk cable spaced up to 50km apart. Each sensor set consists of one pressure sensor, one temperature sensor, and a three axis accelerometer. A communications sub-system ensuring the data communications between sensor sets and an interface to the host observatory is housed in a telecommunications repeater housing, along with the power supplies for the communications sub-system and the associated sensor set. The pressure and temperature sensors are placed in a pod 5-25 meters from the repeater housing; this separation is necessary to ensure the sensors are coupled to the environment and to isolate the sensors from local temperature affects caused by electronics in the repeater housing. The accelerometers may be placed in the repeater housing or in the sensor pod; the most appropriate location may be determined during detailed design. An interface pod connects the wet demonstrator to the hosting observatory. These elements and their relationships are shown in Figure 1. The host observatory delivers power and communications from a shore station to the interface point denoted by the wet mate connector. The final element of the wet demonstrator is the data management and archiving facility, which is not shown here.

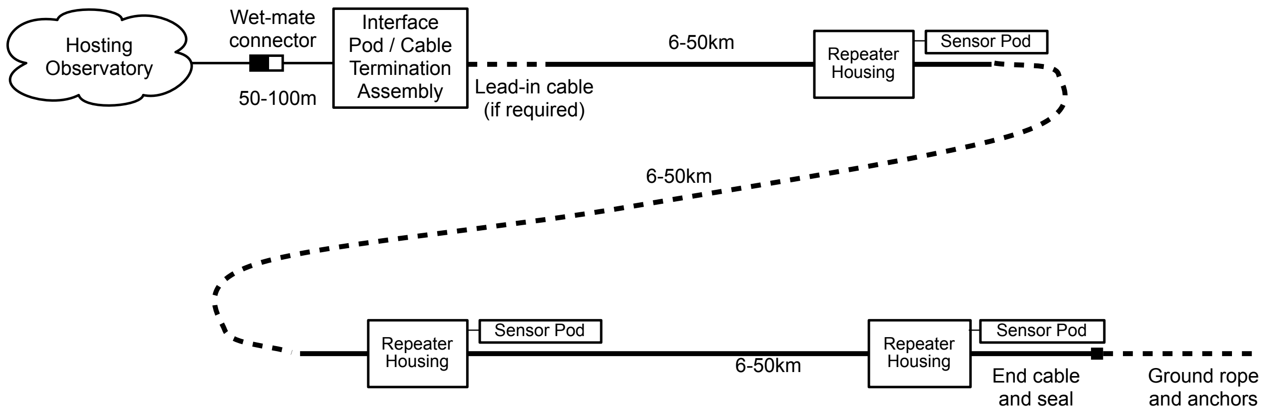


Figure 1: Overview of Wet Demonstrator

8.2 Hosting Observatory

The hosting observatory is required to provide both physical infrastructure and operational services to the wet demonstrator in a manner similar or identical to that used to support many other connected instruments and sensors. The primary connection point to the Wet Demonstrator is a wet-mate connector providing 375-400V DC power and an electrical Ethernet communication interface; in observatory parlance, this is termed a "science port." The power requirement may range from tens to several hundred watts (a substantial portion of which is dissipated as resistive losses in the cable or lost to inefficiencies in the power supply electronics). Electrical, 100 Mb/s Ethernet provides sufficient bandwidth and avoids the cost of optical wet-mate connectors. Pulse per second/precise timing is not required for the wet demonstrator (although this may be a requirement for a fully realized SMART cable system). These requirements can be supported by several existing observatories.

Aside from the basic services of power and communications, the hosting observatory also should provide data management, support any permitting requirements, and assist with installation logistics. A written scope of work for the hosting observatory is a necessary aspect of the overall project development.

8.3 Optional Hosting Locations

The wet demonstrator may also be connected to an out-of-service shore end or a branch from a new cable system. In the first case, the out-of-service cable is cut and the wet demonstrator jointed directly to the existing cable. In the case where the wet demonstrator is connected to a new cable system, the section from the shore-end to the wet demonstrator would consist of dual conductor cable, which provides an independent power feed path for the wet demonstrator. An additional fiber pair to support communications to the wet demonstrator would also be provided in this section, together with an appropriate branching unit. Dual conductor cable has been used on some special purpose systems but is not generally available in the marketplace. In both cases, a constant current power feed and a small set of networking equipment are located in the cable landing station to support the wet demonstrator.

8.4 Seabed Placement

The wet demonstrator should be installed in a location that permits surface laying of all cable. (Plow burial of sensors is not to be demonstrated in this first demonstrator project and will not be required.) At a minimum, bathymetric survey data are needed. If this is not available, a seabed survey must be conducted prior to cable laying. During the lay operation, an appropriate catenary modelling tool will be used to plan and control the laying operation and to estimate the touchdown location of the sensor packages. The estimated location may later be compared to the actual location as determined by ROV or acoustic survey.

The wet demonstrator is notionally a linear system, however that does not imply the sensors must be laid in a straight line. By laying the wet demonstrator in an "S" or shallow "U" configuration, one of the sensor sets can be placed out of line with the other two; this is so the direction of propagation of tsunamis, for example, can be more accurately determined.

A cable ship cannot make sharp turns and maintain control over placement of the cable. There must be sufficient cable length to allow gradual turns away from one repeater location and towards the next. For example, a series of 15 degree course alternations can be made to achieve the configuration shown in Figure 2: Seabed Placement. In this example, the sensors are separated by 50km of cable, the X and Y offsets are approximately 45km and 15km respectively. Alter courses are 7km apart. This placement method could also be used to test the accuracy of estimated repeater positions on the seabed.

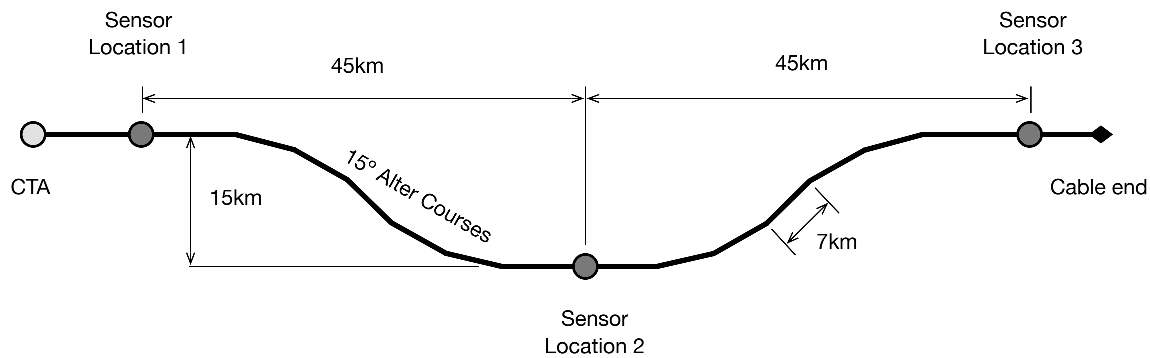


Figure 2: Seabed Placement

8.5 Cable Plant and Repeater Housings

The wet demonstrator incorporates several elements from commercial telecommunications systems, in particular the cable and repeater housings. In addition, sea electrodes to provide a power return path are needed and may be adapted from those used in commercial telecom systems. A cable termination assembly (CTA) is required to interface the telecom cable to the hosting observatory.

The repeater housings must accurately represent the suppliers' standard product. Note that the power circuits and optical amplifiers used in a telecom system are not needed for the wet demonstrator. Instead, bespoke power electronics and off-the-shelf Ethernet switches are used. Fiber optic and power connectors enter the repeater housing in the same manner as in a telecommunications system. One additional penetration is required for sensor connections; this will be a straight bore suitable for a commercially available penetrator / connector combination.

The cable likewise must be a standard product. 17mm cable is assumed, although 21mm may be used if available. 11mm or 14mm cables are not generally used for repeatered systems and are not considered here. A minimum of one fiber pair is needed, although a cable with 2 or 3 fiber pairs would provide greater utility for future reuse. Center conductor resistance is assumed to nominally be ≤ 1.6 Ω/km. The expectation is that no armoring or extra protection is required.

At the CTA, a sea electrode provides a power return path. The cathode (+) end is located near the CTA. A Mixed Metal Oxide (MMO) electrode is required and may be of the same type used with commercial branching units. At the far end of the cable, another electrode provides a path to seawater; the anode (-) end may be an MMO electrode, platinum strip, or armor wire connection.

8.6 Cable Termination Assembly

The CTA provides a transition from the backbone cable to a flying lead which is connected to the hosting observatory. Various types of CTAs have been deployed in conjunction with both observatory and oil & gas projects. For the wet demonstrator, the CTA is required to house power and communications electronics. A design based on a repeater housing would be suitable, but this does not preclude other approaches.

The internal functions of the CTA are shown in Figure 3. The power circuits isolate the wet demonstrator from the observatory power supply; this is necessary so that the observatory power supply is not connected to the seawater return, a condition that would be interpreted as a fault. The current source provides power feed to the repeater housings in a manner very similar to that used in commercial telecom cables. An Ethernet switch is used primarily for electrical/optical conversion but can also accept data from monitor circuits or local sensors. Further details of the power and communications functions are discussed in later sections. Note that the CTA could support a set of sensors if there is sufficient internal volume and space for a cable penetrator.

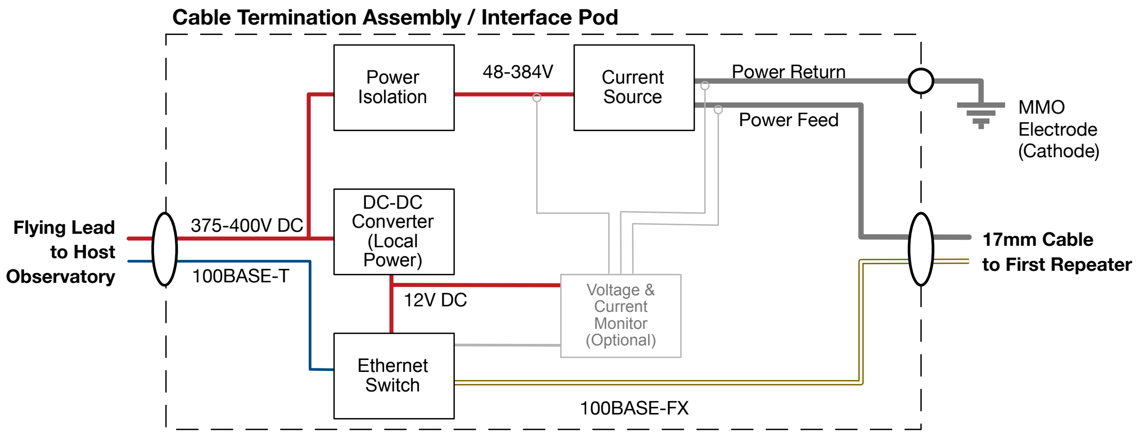


Figure 3: CTA Functional Block Diagram

8.7 Repeater Housing

The purpose of the repeater housing is to provide an actual telecommunications system repeater body to house the power and communications functions required for the demonstrator. These are derived from observatory system designs; telecommunications cable system components are not used. The internal functions of the repeater housing are shown in Figure 4. The power supply derives a constant voltage from the power feed of the cable. An Ethernet switch provides optical interfaces and collects local data. The optical links connect each adjacent repeater housing; thus each Ethernet switch acts as a regenerator for signals that are transmitted through it. Some sensors may be housed inside the repeater housing. Details of the power, communications and sensors are discussed in later sections.

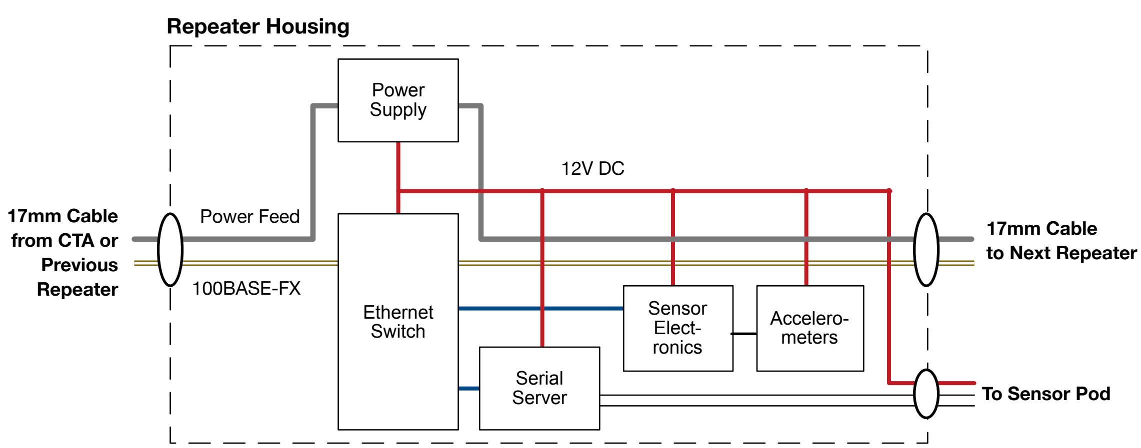


Figure 4: Repeater Housing Functional Block Diagram

8.8 Sensors and Sensor Electronics

Sensors include Pressure, Temperature and Three-Axis acceleration. Specifications for these sensors are provided in Reference 4.

Incorporation of a two axis tilt sensor is not a requirement, but may be accommodated. Note that the use of tilt or other sensors in the wet demonstrator should not be construed as a requirement to incorporate them into all SMART cables.

The sensor electronics are responsible for converting raw transducer output to a digital format which can be transmitted across the data network. These may consist of off-the-shelf or bespoke components as necessary to perform the desired functions.

The sensor package may be a single housing containing Temperature and Pressure or two separate housings, whichever is most convenient. Figure 5 shows several possible arrangements.

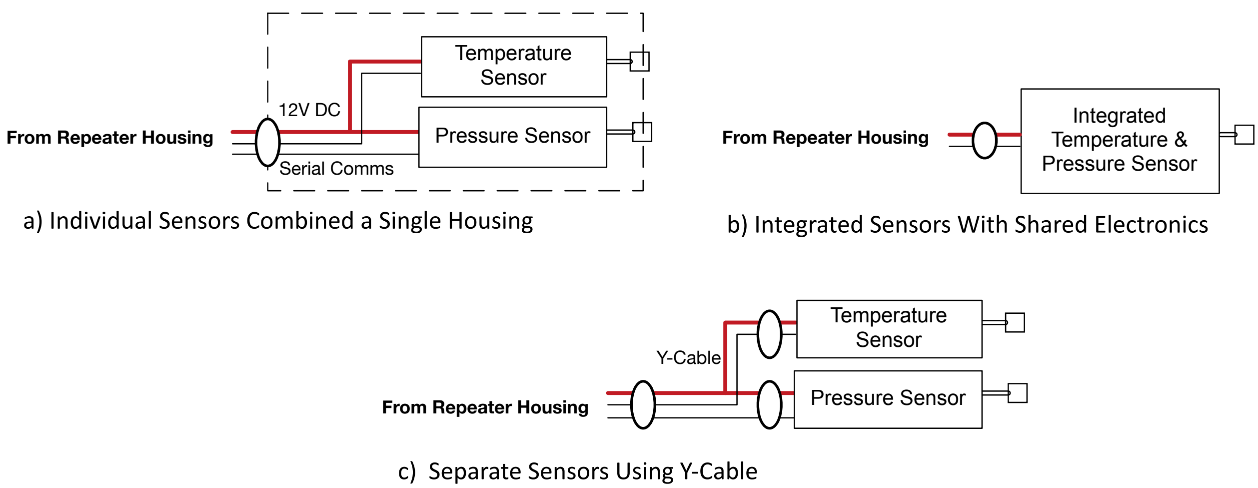


Figure 5: Options for External Sensor Pods

8.9 Sensor Attachment

Pressure and temperature sensors must be located outside the repeater housing. This is to avoid a situation where damage to the pressure sensor floods the main housing and to ensure that temperature measurements are not affected by heat generated by electronics within the repeater housing. Placement of the sensors to ensure coupling with the environment is a critical aspect of the final design for the sensor package. Acceleration and tilt sensors may be located either within or outside the repeater housing.

The remote sensors are attached to the main cable at a distance of 5-25 meters from the repeater housing. A molding similar to the boots that protect the cable ends is used. A separate cable containing power and communications circuits connect the sensor pod to the repeater housing. The sensor cable is attached to the main cable and protected by a spiral wrap or similar. Penetration into the repeater housing is via an off-the-shelf penetrator/connector combination. The penetrator will be fitted to the repeater housing during final assembly by the cable system supplier. Technical support from the connector manufacturer will be provided as needed. The resulting configuration is illustrated in Figure 6.

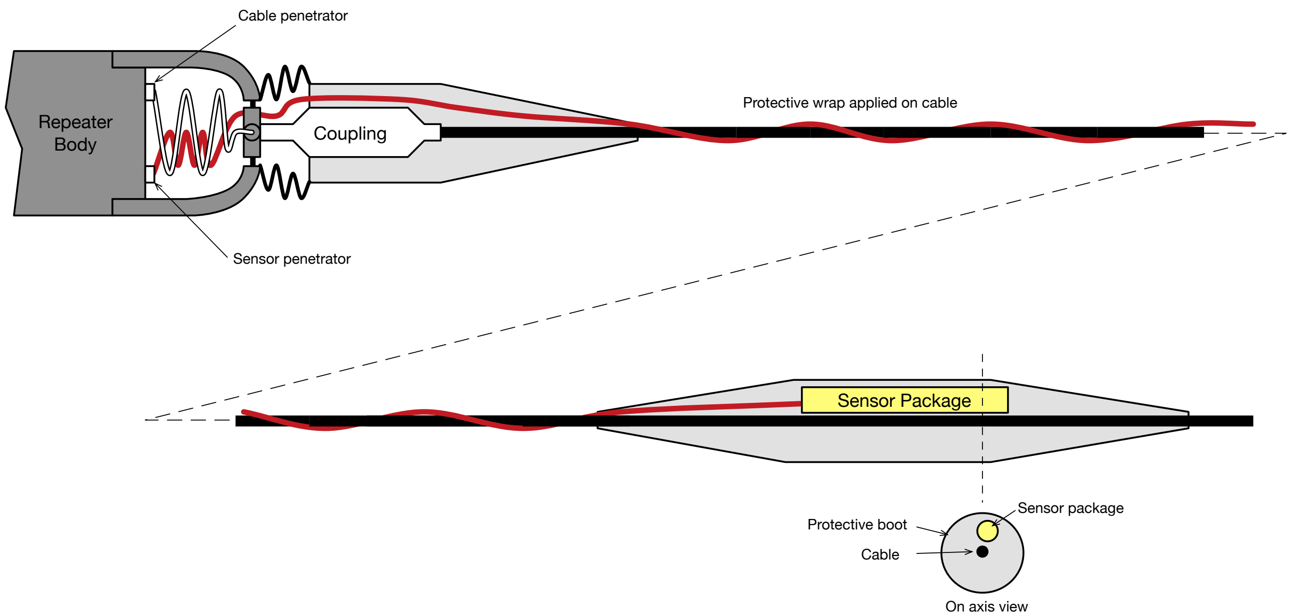


Figure 6: Sensor Attachment

The boot and protective wrap are similar to those used for connecting MMO electrodes to branching units. These designs can be used as a starting point and adapted for the wet demonstrator. It is not expected that these be qualified for use in a telecom system or even that they be previously deployed. The boot, sensor package and protective wrap must be capable of passing through all cable handling machinery and over a 3 meter diameter sheave.

8.10 Communications

The communications functions of the wet demonstrator are supported by a single, small Ethernet switch in each repeater housing. Switches with three electrical and two optical ports are commercially available. 100 Mb/s provides sufficient bandwidth while using less power than a 1 Gb/s switch. Fiber interfaces operating at 1310 nm or 1550 nm are available, with the latter providing transmission distances of up to 125km on good quality fiber. Optical links connect the Ethernet switches in adjacent housings. Each Ethernet switch acts as a regenerator for signals passing through it. It is therefore unnecessary to employ optical amplifiers and a single fiber pair is sufficient.

A serial server provides interfaces for individual sensors via RS-232 or RS-485 ports. Industrial Ethernet switches and serial servers have both been widely used in science observatory systems with generally excellent results. Figure 7 provides an overview of the communications components. The Ethernet switches and serial servers are managed devices that permit remote configuration and may be continuously monitored.

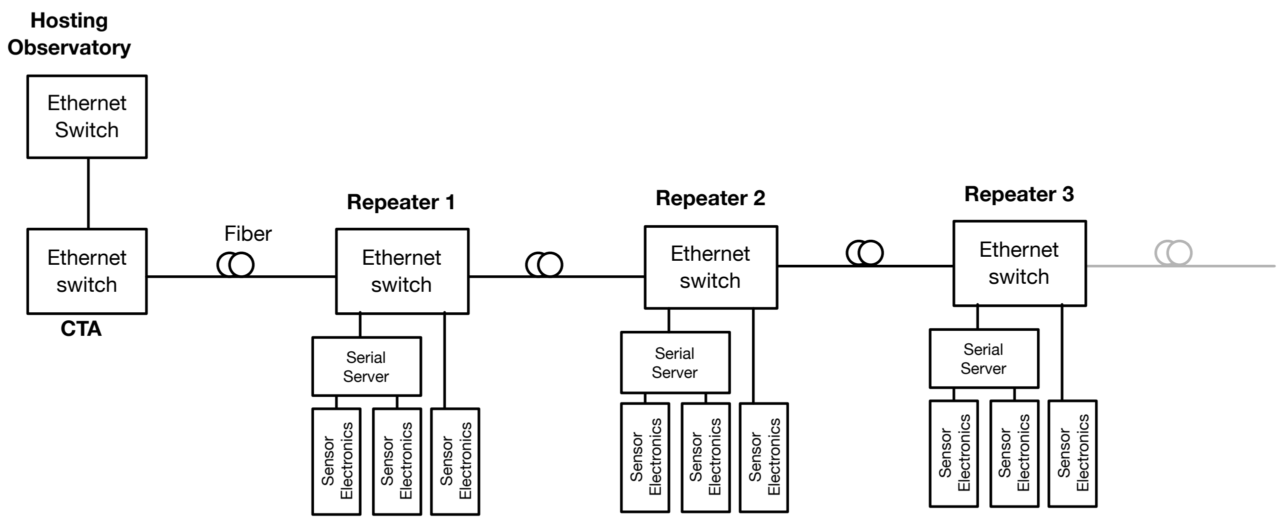


Figure 7: Communications Overview

8.11 Bandwidth Estimate

Based on the sampling rates described in Reference 4, the raw data rate generated by the sensors is about 15 kb/s. The actual bandwidth required is somewhat greater and depends on the rate at which data is forwarded. This is due to the minimum size of an Ethernet frame (64 bytes), the overhead contained in each frame (18-22 bytes), the transmission preamble (8 bytes) and the inter-frame gap (12 bytes). If a new data packet is used to send each sensor sample, then 84 bytes are used to send as little as 3 bytes of data, resulting in a 2700% overhead. As data are sent less frequently, the overhead rate diminishes. If pressure data is sent once per second and accelerometer data is sent ten times per second, the resulting data rate is about 20 kb/s and the overhead a more reasonable 25%. However, this introduces latency, since data are stored until being transmitted. The tradeoff between data rate and latency must be evaluated and appropriate sampling and data forwarding rates selected.

Table 1 provides a bandwidth calculation using the assumptions given above. Even if the data forwarding rate is increased substantially, the total data rate should not exceed 150 kb/s, or 0.15% of that available on a 100 Mb/s Ethernet link, per repeater housing. The wet demonstrator as a whole can operate with less 0.1 Mb/s and no more than 0.5 Mb/s of bandwidth through the host observatory network.

Table 1: Estimated Bandwidth Utilization per Sensor Set

	Temperature	Pressure	Acceleration	Totals
Sampling Rate, Hz	0.1	20	200	
Sample resolution, bits	24	32	24	
Quantity	1	1	3	
Raw data bandwidth, b/s	2.4	640	14,400	15,042
Packets per second	0.1	1	10	11.1
Payload, Bytes	3	80	180	
Packet size, Bytes	64	102	202	
Octets on layer 1 (including preamble and inter-frame	84	122	222	
Layer 1 bandwidth, b/s	67.2	976	17,760	18,803

8.12 Power Feed

The power system design presented here is an example and is intended to demonstrate that a feasible design can be developed. Actual voltage and current values will be adjusted during the final design depending on the length of the system, actual power requirements, cable center conductor resistance and other factors.

8.1.1 Overview

The power feed for the wet demonstrator system emulates that used for telecommunications systems. A constant current is fed through a single conductor and seawater is used as a return path. At the CTA, the power supply is isolated from the host observatory by DC-DC converters. A constant current output is then derived from this isolated source. This permits the use of seawater as a return path; without isolation from the host observatory, any connection to seawater would be viewed as a fault. The current source may use either bi-polar transistors or a switched mode converter. A more complex switched mode converter could be used to provide both isolation and the current source, however the use of off-the-shelf DC-DC converters for isolation is a proven approach, provides a known interface to the host observatory and allows for a simpler design for the current source. At each repeater, a diode bridge provides a 12V supply to the communications devices and sensors.

Figure 8 provides an overview of the power supply. Filtering and surge protection components have been omitted, but would be an essential part of the final design. In this diagram, current flows from right to left. A bypass diode allows the system to be powered by an external supply from the far (right) end during installation or for testing. This permits a cable ship to power the system prior to connection to the host observatory.

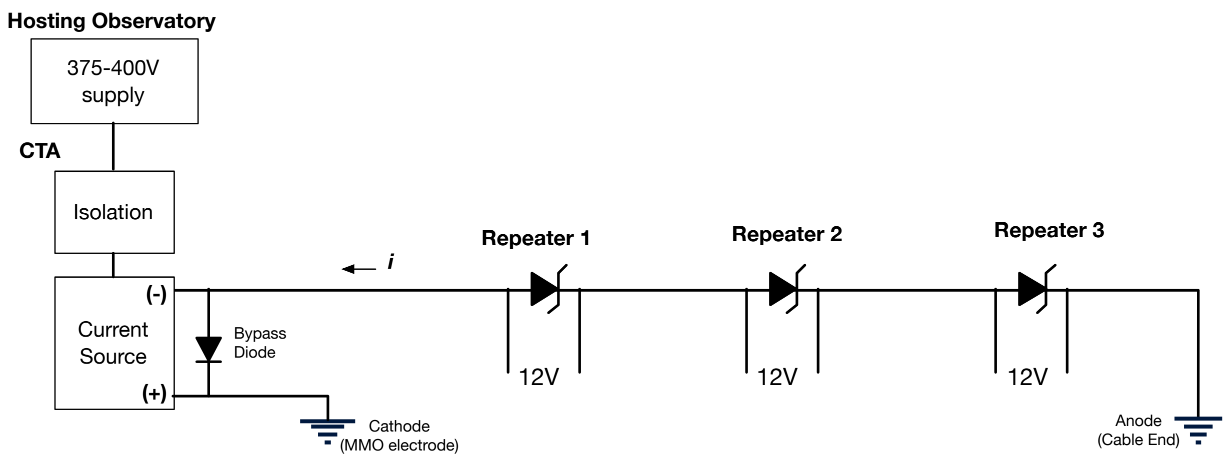


Figure 8: Overview of Power Feeding

In this application, constant current power feeding has a number of advantages over constant voltage power feeding. Only a single conductor is required in the cable. A constant voltage system would require two conductors or a sea earth at each repeater. The power supply in each repeater receives the same current, whereas a constant voltage feed at one end of the cable would deliver a different supply voltage to each repeater due to resistive losses in the cable. The power supply design is relatively simple and can be built in small volumes without a large development cost.

The electronics and sensors in each repeater are not isolated from the power supply and, as a result, are biased with respect to seawater by whatever the cable voltage happens to be at each repeater. For the wet demonstrator, this voltage should not exceed 300V. In an actual telecommunications system, this could be as much as 15kV. This is one of the critical differences between the wet demonstrator and a working SMART cable; isolating the sensors from the cable voltage is an essential aspect of any future design effort.

8.1.2 Isolation Stage

The isolation stage in the CTA is constructed from a stack of DC-DC converters with the outputs in series. This method has been used in other observatory systems and sensor designs. The use of off-the-shelf DC-DC converters with known isolation characteristics is expected to be easier than developing and proving a new isolated power supply design. The desired output voltage is set by the number of DC-DC converters used; an example is illustrated in Figure 9. Low pass filters are normally added to both the input and output sides of the converters, this is not shown here. A circuit board designed for six or eight converters can be populated as needed once the final design voltage is selected.

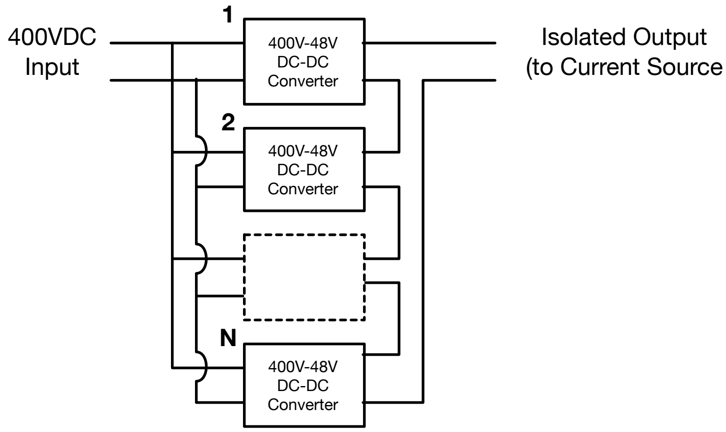
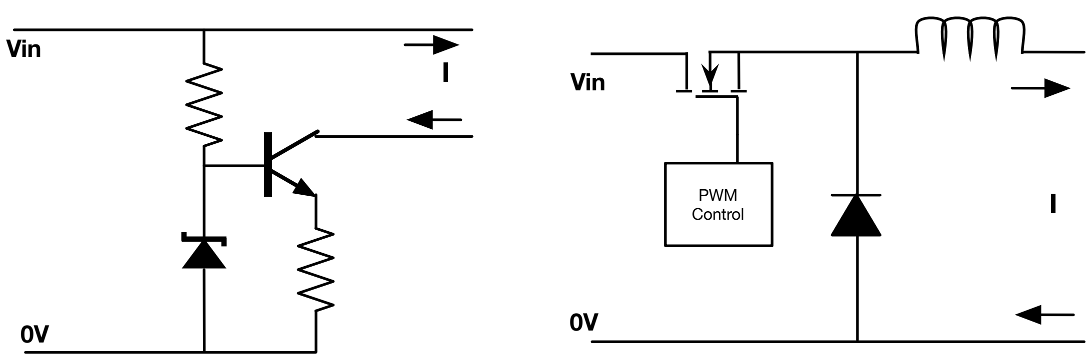


Figure 9: DC-DC Isolation

8.1.3 Current Source

Figure 10 shows two simple current source circuits, one based on a bipolar transistor, the other using a switched mode power supply. A current source using a bipolar transistor is regulated by the Zener diode, operates in steady state and is straightforward to analyze and design, but suffers the drawback of being relatively inefficient; any excess voltage not needed to drive the current loop is dissipated as heat. The switched mode design requires development of a Pulse Width Modulation (PWM) control circuit driven by a current sensor; this can be based around readily available integrated circuits. A practical implementation would include filtering elements and may add additional transistors for redundancy, increased gain, or to more easily dissipate heat. A more complex flyback converter design could also be used. Regardless of the design chosen, the development effort required is clearly manageable.



a) Bi-polar transistor

b) Switched mode

Figure 10: Example Current Source Circuits

8.1.4 Power Supply Design: Line Current

The line current provided by the power supply must be sufficient to power all sensors and electronics in the repeater housing. Table 2 provides an initial estimate of the line current based on published specifications. All devices operate from the 12V supply which is regulated by the Zener diode.

Table 2: Example Line Current Calculation

Device	mA @ 12V
Ethernet Switch	300
Serial Server	120
Temperature Sensor & Electronics	6
Pressure Sensor & Electronics	32
Accelerometers and Electronics	125
Total Required Current	583
Line Current	625

Based on these values, a line current between 600 and 625mA would be selected. This preliminary estimate (conveniently) results in a 1 volt drop per kilometer of cable given the conductor resistance of 1.6 ohms/km. Establishing working ranges and tolerances is a necessary part of the detailed system design. Note that any excess current is dissipated as heat in the Zener diode. In this design, the power dissipated by the Zener should not exceed 2W; 10W Zener diodes are commercially available.

8.1.5 Power Supply Design: Voltage Drop

The power supply is the limiting factor in both the cable length and the number of repeater housings. The total voltage drop must not exceed the capability of the current source. The voltage drop in the cable is given by:

$$V = L * I * R + N * S + B + Z$$

Where

$$V = TotalVoltage$$

$$L = Cable\ Length\ in\ km$$

$$I = Power\ Feed\ Current$$

$$R = Cable\ Resistance\ in\ \Omega/km$$

$$N = Number\ of\ repeater\ housings$$

$$S = Voltage\ Drop\ per\ Repeater\ Housing$$

$$B = Voltage\ required\ to\ bias\ the\ current\ source$$

$$Z = Other\ voltage\ losses, for\ example\ in\ leads\ to\ the\ MMO\ electrode$$

Table 3 provides a preliminary voltage drop calculation for a system with four housings separated by 50km. The first housing is 10km from the CTA and a 10km tail is allowed after the fourth housing. This example meets or exceeds the requirements of the wet demonstrator and is intended to show that a working design can be realized using readily available components.

Table 3: Example Voltage Drop Calculation

Number of Housings	4
Voltage Drop per Housing	12V
Total Voltage Drop in Housings	48V
Total Cable Length	170km
Conductor resistance	1.6Ω/km
Line Current	625mA
Voltage Drop in Cable	170V
Bias voltage in current source	5V
Allowance for drop in CTA	3V
Total voltage required to supply current source	226V

In this example, the isolation stage could be constructed from five 48V converters providing a source voltage of 240V. Note that the current source based on bipolar transistors must dissipate any excess voltage as heat. For this reason, the number of converters in the isolation stage should be matched to the planned cable length. A switched mode converter does not have this limitation. If the system is intended to be extended, then a current source with a wide output range would need to be developed.

8.1.6 Power Supply Design: Other Considerations

The power supply design proposed here uses a limited number of components and is intended to be both simple and robust. Achieving robustness in practice is highly dependent on component selection. All components should be rated well in excess of the expected voltages, currents, and power dissipation. Proper heat sinking is essential. Simulated overload conditions should be tested during the prototype stage.

8.13 Repeater Housing Mechanical and Thermal Considerations

All devices placed inside the repeater housing must be mounted on a suitable chassis. All components must be evaluated to determine whether heat sinking is required. Mechanical design of a chassis and thermal modeling are critical aspects of the system design, but should be straightforward. Thermal modeling can be performed using appropriate software packages. The chassis should be designed so it can be manufactured using basic machine tools.

8.14 Data Management

The hosting observatory is required to provide data management services for Temperature and Pressure sensors. Tri-axial accelerometer data may gathered by the hosting observatory or be streamed to a seismic data center. Data from tilt sensors, if included, would also be the responsibility of the hosting observatory.

8.15 Spares

Two to three sets of spares should be produced for all custom manufactured items, including circuit boards, internal chassis, and the protective instrument pods, as re-manufacturing can be logistically difficult and expensive. Off the shelf items should not be spared, because replacements can be acquired as necessary to support repair cruises. Note that items which may be discontinued should be spared if a suitable replacement cannot be identified.

If funds are available for an additional, completed repeater housing, it is recommended this be deployed as part of the initial system rather than retained as a spare. The additional housing increases the quantity and value of the data collected while acting as an "on-line" spare. If any sensors or communications devices fail, having additional units on the seabed may still allow the wet demonstrator to complete its objectives.

9 Project Description

This section provides a high level description of each of the activities that must be carried out to successfully complete the wet demonstrator project. As with the design itself, the project description is not intended to be a final solution, but rather to illustrate that feasible solutions are readily available. Each project activity should be manageable, with clearly defined requirements, interfaces, and have realistic methods for meeting its requirements. Each activity can be thought of as a separate scope of work; however, a single entity or supplier may perform several of these activities.

9.1 Owner

The owner of the wet demonstrator is expected to be either a research institution or special purpose entity (SPE). The owner receives and disburses funds for development, construction, installation and operation of the system. Title to the system is vested in the owner. Intellectual Property required to construct or operate the wet demonstrator must be licensed to the owner.

9.2 Host Observatory or System

The host observatory or system provides an off-shore interface that delivers power and communications to the wet demonstrator from a shore station. The host may be a science array, a commercial telecommunications cable, or an out-of-service cable. The host may provide other services including design input, lab or workshop facilities, data management. It is possible, but not mandatory, that the host and owner will be the same entity.

9.3 Project Management

Project management coordinates all other activities by facilitating communication, preparing routine reports, maintaining a project plan of work, and tracking action item lists. Project management also controls the project budget, places orders, and approves payment to suppliers and contractors. Where necessary, project management negotiates agreements and contracts to supply products or perform services.

9.4 Design Authority

The design authority acts as a technical advisor to the project manager. All design work, test plans, procedures results, and any technical changes must be approved by the design authority. As this project requires many areas of expertise, the design authority must be able to call upon individuals with suitable expertise as required. The design authority may be a part of the project management organization or a separate, contracted entity.

9.5 Health Safety and Environment

Health, Safety and Environmental (HSE) review is now an essential part of all major projects. HSE ensures that all project activities are carried out in a manner that is safe and environmentally sound. HSE may be part of the project management organization or a separate, contracted entity.

9.6 Quality Assurance

Quality assurance verifies that all project activities are carried out in accordance with written, traceable procedures. Quality assurance may be part of the project management organization or a separate, contracted entity.

9.7 Permitting

Permitting activities center around obtaining lawful permissions to perform any work. Permitting may also include liaison activities with other seabed users, such as fishermen and those with hydrocarbon or mineral rights. Permitting may be part of the project management organization or a separate entity managed under contract.

9.8 Site Selection and Marine Survey

Selection of a suitable site must occur early in the project so that other activities are not delayed by unknowns. Permitting, manufactured cable length, cable type, and CTA design all depend on location and seabed conditions. A preliminary cable route is selected prior to survey and adjusted based on survey results.

In the interests of accurately representing the installation procedures for telecom cable, similar marine survey data should be collected. In water depths over 1,000m, this is usually limited to swath bathymetry but may include side scan sonar in areas where the seabed is known or suspected to be hazardous.

Given the relatively short route length of the wet demonstrator, it would be beneficial to share mobilization costs with other survey activities, whether as part of the observatory operations, science cruise, or for a nearby commercial telecom cable.

9.9 Provision of Cable, Repeater Housings, and System Assembly

The use of conventional telecommunications cable and repeater housings are central to achieving the objectives of the wet demonstrator design. Cable and repeater housings are typically furnished together by a single supplier as part of an assembled system. However, there is no requirement that cable and repeaters for the wet demonstrator be furnished by the same supplier. There are several circumstances in which cable and repeaters might be procured separately. For example, if retired spare cable were made available at little or no cost, the expense of new cable could be avoided. A system comprising repeater housings from two or more suppliers could also be developed to permit demonstration of different suppliers' capabilities.

Regardless of how the cable and repeater housings are procured, the wet demonstrator system must be assembled and tested prior to deployment. The conventional approach is to perform this assembly and test in a cable factory, after which the system is loaded onto the cable laying vessel. Alternatively, system assembly may be performed at a dockside facility or on board the cable laying vessel. The cable, repeaters, and all necessary ancillary equipment can be transported by freighter to a convenient location where the assembly work is performed. Such alternative methods can provide cost savings (for example, by reducing cable ship mobilization and transit time), but afford less opportunity to correct problems should they arise.

Regardless of the exact method used, several events must occur to complete the wet demonstrator system. First, the internal and external components of the repeater must be assembled, tested, and the repeater housing closed. Second, the repeater housings must be coupled to the cable. This coupling can connect the repeater directly to the system cable or a short "tail" may be used which is later jointed to the system cable. In the case where final assembly occurs outside a cable factory, the repeaters will be delivered as tailed repeater assemblies. Next, any jointing required to complete the system assembly occurs. Finally, the assembled system is tested.

The location and method for system assembly will depend on the capabilities of participating suppliers, the final system length, the system location, and logistical factors such as cable ship transit and mobilization times. At this stage, the wet demonstrator design must retain the flexibility to allow which ever approach provides the most economic approach.

9.10 Cable Termination Assembly

The cable termination assembly (CTA) which connects the wet demonstrator to the host observatory will require a unique design. A one atmosphere housing is required for communications and power conversion equipment. Connection to both a wet-mate connector and the telecommunications cable are required. The assembled CTA must be installed by the cable laying vessel within 50 meters (ideally 10 meters) of the desired location. The wet-mate connector and its associated flying lead must be manipulated by an ROV to complete the connection to the host observatory.

CTAs have been deployed as part of cable ocean observatories and to support oil & gas projects. The inclusion of a 1 atmosphere housing is not typical and may require some design effort. Nonetheless, all required components are commercially available or can readily be fabricated, including titanium housings, wet mate connectors, couplings to the telecommunications cable and frames.

9.11 Procurement of Off-the-Shelf Items

Many of the components of the wet demonstrator are off-the-shelf items; these include connectors, cables, sensors, some of the sensor electronics, Ethernet switches and serial servers. Procurement of these items is a straightforward activity.

9.12 Provision of Integrated Sensor Package and Cabling

In the case where the off-the-shelf packaging of the sensors is not suitable, a separate sensor package or pressure case must be procured or developed as necessary. In either case, cables and connectors for the temperature and pressure sensors must be assembled. This work is similar to that performed for sensors attached to existing observatories.

9.13 Attachment Hardware Design and Manufacture

Design and manufacture of the boot or pod which holds the sensors/pressure case and the spiral wrap to retain the sensor cable is the first of two areas requiring new development. This work includes selection and integration of a suitable penetrator for the repeater housing and must therefore be closely coordinated with the supplier of the repeater housings. This work may be undertaken by the cable supplier or sourced separately. If existing parts cannot be adapted, injection molding or similar methods must be used to manufacture the sensor pod. (3-D printing may be used, but is not essential.)

9.14 Power System Development

Design and assembly of the various power supply components (power isolation, current source, and Zener based power supplies for each housing) is the second major area of new development. Computer modeling of the power system should be performed as part of the design process; this is particularly useful for verifying the power system can deal with transient or other abnormal conditions. If suitable expertise is not available within the project organization, then a contractor or consultant may be retained to perform the design, manage the assembly, and oversee testing of these components. Individuals with suitable expertise have participated in previous observatory projects.

9.15 Communications System Design

The communications system does not include any custom components. Specification, purchase, and configuration of the communications components and preparation of wiring diagrams are straightforward tasks that can be performed by the host observatory or other project participant.

9.16 Mechanical and Thermal Design

Mechanical design and thermal analysis of the chassis for mounting components in both the CTA and repeater housing is the third and final area requiring custom development work. As with the power system development, this could be performed by any one of the project participants or an outside expert. Manufacturing and assembly of the chassis requires access (and knowledge of) a machine shop. (CNC or 3-D printing may be used, but are not essential.)

9.17 Initial Bench Tests

It is valuable to begin bench tests of any available components, even before design work is finished on other aspects of the project. This testing serves to identify issues early, before changes and corrections become costly and time consuming.

The communications equipment and sensors are off-the shelf items; a representative set of this equipment should be purchased early in the project, configured, debugged, and placed on-line in a test environment to support development of interfaces (drivers) within the data management systems.

Power boards must be tested and validated at the prototype stage, in particular surge testing and other abnormal conditions can be tested to validate the computer model.

Similarly, an early mockup of any mechanical items will ensure that finished units can be properly assembled. This can also serve to validate thermal models.

9.18 Preliminary Integration

Following completion of the design, all components except the cable and housings should be integrated into a working system and tested from end-to-end. This type of testing is typically performed in a lab or workshop setting and it would be appropriate for the host observatory to provide facilities for this stage of testing. Fiber optic attenuators and power resistors can be used to simulate the cables between each housing. This will ensure that working units are delivered to the repeater housing manufacturing for installation into the housings. This also provides a final opportunity to valid and reconfigure the system before it is sealed into the repeater housings.

9.19 Cable Plant Integration

At the cable plant, the internal components are installed into the repeater housings, and the housings sealed. Then the couplings with attach the repeaters to the cable are made up. The sensor pods must be attached at this stage. Following integration, the system can again be powered and tested. The completed system is then loaded to a cable ship or freighter.

In the case where final assembly occurs dockside, the integrated and tailed repeaters are shipped from the repeater factor to the assembly facility where the remaining steps are performed.

9.20 Installation

Installation activities include loading the finished system onto the cable laying vessel, shipboard test, placement of the CTA, and surface laying of the system. The system is designed such that it can be powered and monitored from the far end (the end farthest from the CTA) during installation. The shipboard PFE is adequate for this and only an Ethernet switch and laptop computer are required to monitor the communications.

As with the marine survey, it is beneficial if the installation work can be shared with or "piggybacked" on a larger project to reduce mobilization costs.

Connection of the CTA to the host observatory requires an ROV. This can be performed by a research vessel during a science cruise; any vessel which is adding or maintaining other observatory sensors will have a suitable ROV on board. One or more repeater housings can be inspected by the ROV, either during the same or a subsequent dive.

9.21 Commissioning

System commissioning is performed by powering up and verifying that all devices are operating. A brief test must be conducted before releasing the cable ship and a longer term test may be performed before data is released for use.

ROV inspection of at least one sensor site is a stated objective of the wet demonstrator system and should be performed as soon as practical after installation. Re-inspection at annual intervals should be conducted to allow settling and sediment deposit to be observed.

9.22 Data Management

The hosting observatory is responsible for data management, including data quality control, of sensor and pressure data. Accelerometer data may be streamed to a seismic data repository.

9.23 Summary

A diverse set of resources and skills are needed to develop the wet demonstrator. This description is a first, high level, summary of the necessary capabilities. This list is not exhaustive and other resources may be required as the project develops. Table 4 provides a summary of the project activities by role and type of activity.

Table 4: Summary of Project Activities

Role	Provision of Services	Provision of Materials	Design	Manufacture	Integration Activities	Validation and Testing
Owner	X					
Host Observatory	X				X	X
Project Management	X					
Design Authority	X					
HSE	X					
QA	X					
Permitting	X					
Marine Survey	X					
Wet Plant						
Supply Cable		X				
Supply Repeater Housings			X	X	X	
Assemble Repeater Housings				X	X	
Perform system assembly and test					X	X
Supply CTA			X	X	X	
Supply Sea Electrodes			X	X	X	
Assemble CTA				X	X	
Provide Sensors						
Temperature		X				
Pressure		X				
Acceleration		X				
Provide Sensor Electronics						
Temperature		X				
Pressure		X				
Acceleration		X				
Provide Communications Devices						
Ethernet		X				
Serial		X				
Provide sensor cabling			X	X		
Provide sensor attachment hardware			X	X		
Connect sensors to repeaters					X	X
Develop power systems			X	X	X	X
Develop chassis			X			
Manufacture chassis				X	X	X
Perform thermal modeling	X					
Perform initial bench testing	X				X	X
Perform preliminary integration	X				X	X
Provide marine installation services	X					
Validate sensor performance	X					

10 Operations and Evaluation

The wet demonstrator is designed for continuous operation with no operator intervention. Sensors and communications devices in the wet demonstrator are monitored continuously by the host observatory's data management system.

In the event of a loss of power or communications, these should be restored as soon as practical and the wet demonstrator system will automatically restart.

In the case of a fault or damage to the wet demonstrator, a cable ship will be required to recover and repair the faulted portion. A failed repeater housing can be cut out of the system, allowing the remaining housings to continue operation.

11 Plan of Work

Development of a detailed plan of work is the responsibility of the project manager. There is insufficient information at this stage to provide a plan of work. A realistic expectation is for a project of eighteen to twenty-four months duration. Taking advantage of opportunities to share vessel mobilization may have a significant impact on the schedule.

12 Budget

Maintaining a detailed budget is the responsibility of the project manager. There is insufficient information at this stage to provide a complete project budget. A realistic expectation is for a project cost between $5 and $15 million, with the most significant variables being mobilization costs for the marine survey and cable lay vessels followed by engineering and development costs for items which are not available off-the-shelf.

~end~