Engineering Specifications on LTBMS Telemetry System for NanTroSEIZE 3.5 km Riser Hole

Yasuhiro Namba¹, Hisao Ito¹, Kazumasa Kato¹, Kazuhiro Higuchi¹ and Masanori Kyo¹

Abstract The international project supported by the Integrated Ocean Drilling Program (IODP) started in autumn in 2007 to drill the area off Kii Peninsula, Japan. This area is one of the most active earthquake zones in the world. In the final stage of this project, JAMSTEC plans to install the Long-Term Borehole Monitoring System (LTBMS) in 3.5 km and 6 km riser holes to take a direct look at activities of the plate boundary fault and splay faults above it. As a part of the development of this LTBMS, JAMSTEC started developing an experimental prototype (EXP) of the telemetry system with IODP funding in February 2007. In United States Fiscal Year (USFY) 2007, JAMSTEC defined the operational requirements on the LTBMS and the engineering specifications for its telemetry system with assuming the target hole as 3.5 km riser hole. In the process to define them, JAMSTEC confirmed feasibility of some technical features, such as high speed downhole data transmission, accurate time synchronization between land station and downhole systems, deployment, and so on. This paper describes the operational requirements for the LTBMS and the engineering specifications on the LTBMS telemetry system for NanTroSEIZE 3.5 km riser hole.

Keywords: Long-term, Borehole, Monitoring, 3.5 km riser hole, Telemetry, IODP, NanTroSEIZE

1. Introduction

The international project supported by the Integrated Ocean Drilling Program (IODP) started in autumn in 2007 to drill the area off Kii Peninsula, Japan. This area is one of the most active earthquake zones in the world and is shown in Figure 1 with a red circle.

This international project is called Nankai Trough Seismogenic Zone Experiment (NanTroSEIZE) and its most ambitious objective is to access and instrument the plate boundary within the seismogenic zone.¹)

In the drilling area, two- and three- dimensional seismic reflection surveys were performed. The subduction plate boundary fault and the splay faults megasplay were found in these surveys and investigated in details. ²) The simplified image of these plate boundary fault and splay faults were shown in Figure 3 with the drilling site locations and expected infrastructures on the seafloor and on land.

In the final stage of the NanTroSEIZE project, Japan Agency for Marine-Earth Science and Technology (JAMSTEC) plans to install the Long-Term Borehole Monitoring System (LTBMS) in 3.5 km (C0001) and 6 km (C0002) riser holes to take a direct look at activities of the plate boundary fault and splay faults. In addition, the LTBMS can be connected to the land station through the submarine cable monitoring network so that we can monitor the subduction zone not only vertically, but also horizontally. This submarine cable monitoring network, so-called Dense

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¹ Center for Deep Earth Exploration (CDEX), JAMSTEC

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Figure 1: Figure 1. Nankai Trough and drilling area.
Ocean-floor Network System for Earthquake and Tsunami (DONET), is under development by JAMSTEC with funding by Ministry of Education, Culture, Sports, Science and Technology of Japan. Figure 2 shows the schematic drawing of DONET at Nankai Trough.3), 4) There are/were/will be several observatories in boreholes on land and at sea, such as High Sensitivity Seismograph Network Japan (Hi-NET) by National Institute for Earth Science and Disaster Prevention (NIED)5), 6), 7), the Circulation Observation Retrofit Kit (CORK)8), 9), San Andreas Fault Observatory at Depth (SAFOD)10), and so on. However, there are no deep borehole observations of the seismogenic zone more than 3 km below the seafloor. Such deep borehole observations at and around plate boundary fault and splay faults are required to construct a physical model of earthquakes occurring along a subduction plate boundary. LTBMS is expected to meet this requirement.11) In addition, seismic observatory need to cover the entire range of seismic activity from micro-earthquakes to great earthquakes and a deep borehole observatory has advantages in noise reduction.12)

Although LTBMS is attractive from the scientific aspects, its development includes engineering and technical challenges. JAMSTEC and OD21 science advisory committee performed preliminary surveys on the feasibility of technologies necessary for obtaining new scientific results by LTBMS.13),14)

The major technical features to develop the deep ocean borehole observatory for C0001 are mainly as follows:
[1] High temperature (target: 125 ºC)
[2] Long life (target: 5 years)
[3] Complicated deployment (15000 psi wellhead system, deep well, perforation, packer, mechanical shock)
[4] Method of effective sensor coupling to formation (cement, clamp)
[6] Multipurpose monitoring (seismic, geodetic, hydrogeologic),
[7] Low power consumption
[8] Real-time monitoring (connecting to submarine cable) and high speed downhole data transmission
[9] Accurate time synchronization between the land station and downhole sensors,
[10] Wide frequency range/large dynamic range of data acquisitions

LTBMS consists of a telemetry system, various sensors, wellhead and external battery module. Figure 4 illustrates the schematic diagram of the LTBMS. The telemetry system consists of the subsea module, telemetry cables, and downhole modules that are surrounded by the red-dashed line in Figure 4. The telemetry system has interfaces (I/F) for sensors, acoustic transponder and submarine cable.

As a part of the development of LTBMS, JAMSTEC started developing an experimental prototype (EXP) of the telemetry system with IODP funding in February 2007. In United States Fiscal Year (USFY) 2007, JAMSTEC defined the operational requirements on the LTBMS and the engineering specifications for its telemetry system with assuming the target hole as 3.5 km riser hole in C0001 site. In the process to define them, JAMSTEC confirmed feasibility of some technical features, such as high speed downhole data transmission, accurate time synchronization between the land station and the downhole systems, deployment, and so on.

This paper operational requirements for LTBMS and the engineering specifications on the LTBMS telemetry system for NanTroSEIZE 3.5 km riser hole.

2. Scientific Objectives and Observatory Plan

Our target NanTroSEIZE riser hole (C0001 site) is expected to drill through five potential splay faults about 3500 meters below sea floor (mbsf). Figure 5 shows the observatory plan in C0001 with the casing configuration. Note that the sensor allocation and the casing configuration shown in this figure are subject to change.

We plan to install sensors to monitor strain, tilt, seismic activities and pore pressure for crustal deformation.

Table 1: Outline of sensor allocation in C0001.
(Note that this table is subject to change.)

<table>
<thead>
<tr>
<th>Depth (mbfs)</th>
<th>GL (m)</th>
<th>Description</th>
<th>Types and functions of station</th>
<th>Monitoring station</th>
</tr>
</thead>
<tbody>
<tr>
<td>266-280</td>
<td>16</td>
<td>Yellow spray (F1)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>785-800</td>
<td>20</td>
<td>Sliding wall block (P2)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>954-1000</td>
<td>47</td>
<td>Fault located (F2)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1493-1500</td>
<td>47</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1886-1888</td>
<td>55</td>
<td>Spreading fault located (F2)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>1888-1750</td>
<td>53</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2463-2800</td>
<td>62</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2716-3000</td>
<td>83</td>
<td>Water spray (F4)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Around 2900</td>
<td>83</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2948-3030</td>
<td>88</td>
<td>Yellow spray (F3)</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>3101-3200</td>
<td>100</td>
<td>TD</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

Figure 5: Observatory plan for C0001. (Note that these sensor allocations and casing configuration are subject to change.) Yellow circle: temperature sensor, green triangle: pressure sensor, red circle: seismometer, blue square: tiltmeter, green rectangular: strainmeter.
at and between splay faults. Seismometer array will be used for micro- and slow-earthquakes detection and for investigation of seismic microstructures. Pore pressure and temperature will be monitored for interseismic hydrologic state change at the faults. Based on discussions with NanTroSEIZE scientists, we tentatively chose five potential splay faults mentioned above and sensors would be located around these fault zones. Summary of sensor allocation and their primary objectives are shown in Table 1 with estimated depth and temperature. Here and hereafter, we call these five splay faults F1, F2, F3, F4 and F5. Figure 6 is the detailed figure around the open hole.

3. Operational Requirements

Because the target riser hole (C0001) would have the total depth of about 3500 mbsf under the water depth of 2200 m, the deployment of LTBMS itself would be a challenging work.

Center for Deep Earth Exploration (CDEX), JAMSTEC investigated the methods of installing sensors and relating requirements on the equipments and on the installation procedure with considering scientific observatory plan. This chapter summarizes the results of investigations on such operational requirements for the LTBMS.

3.1. Required Primary Components

The following sub-sections describe primary components what are required for the LTBMS structure.

3.1.1. Tubing

Tubing is a structural backbone of the LTBMS. CDEX considers 2-3/8-in, 2-7/8-in and 4-1/2-in tubing with Premium Joint as candidates to use in 9-5/8-in casing and in 8-1/2-in openhole. While larger size of tubing is preferable for the safe sensor installation, that means smaller space around tubing. To decide the tubing size, the following items should be taken into account, i.e. instrument package size, tubing hanger design, completion equipment size, cement plug size, and so on. It is more desirable for the tubing to have mono-inside diameter for the ideal cementing.

3.1.2. Christmas Tree

It is required to prevent materials such as fluids and particulates from leaking into seawater. Thus we need wellhead to seal the hole. Based on the estimated pressure in the C0001 riser hole and considering the technical feasibility of the wellhead tools, CDEX regards the following specifications for the Christmas tree would be reasonable to be used in C0001 site.

- Max working pressure: 103.4 MPa (15000 psi).
- Electric penetrators: At least 2 for telemetry.
- Hydraulic penetrators: At least 3.
- Production valves: 2.
- Annulus valves: 2.
- Docking stations: Several.

Here, 2 of hydraulic penetrators are for packer operation and 1 for fluid sampling. Production valves should match the tubing in size. One of docking stations is for a subsea module and the others for external battery modules.

Figure 7 shows a side view of the Christmas tree in a preliminary plan. It is necessary to consider interfaces (I/F) on the subsea module for the submarine cable, the external battery modules and an acoustic transponder.

The positions and structures of penetrators should be determined with considering the cable connection by ROV.
3.1.3. Tubing Hanger

Specifications for a tubing hanger should be determined so that they can be consistent with ones for the Christmas tree and the tubing. Therefore the following specifications for the tubing hanger should be satisfied.

- Max working pressure: 103.4 MPa (15000 psi).
- Electric penetrators: At least 2 for telemetry.
- Hydraulic penetrators: At least 3.
- Bottom thread: For Premium Joint of 2-3/8-in or 2-7/8-in or 4-1/2-in.

Here, 2 of hydraulic penetrators are for packer operation and 1 for fluid sampling. It is essential to consider that tubing must run to 3500 mbsf.

3.1.4. Casings

As shown in Figure 5, the tentative casing configuration requires the following casings. Numbers in brackets mean setting depth.

- 36-in conductor casing (60 mbsf).
- 20-in surface casing, quick connector (700 mbsf).
- 16-in casing (1500 mbsf).
- 13-3/8-in casing, Premium Joint (2500 mbsf).
- 11-3/4-in casing for contingency.
- 9-5/8-in casing, Premium Joint (3000 mbsf).

3.1.5. Cement

The sensors installed in the openhole section (i.e. strainmeter, seismometer, tiltmeter and so on) would be fixed in place by cement as shown in Figure 5 and Figure 6. The temperature and pressure sensors would be attached along the tubing and it is not necessary to clamp them to the casing.

It is important to consider a method to ensure good couplings between the sensors and surrounding formations/casings.

As for the sensors in 9-5/8-in casing (seismometers, tiltmeters, and so on), CDEX regards the following two options as candidates for fixing sensors.

Option (a): Fixing sensors in place with some kinds of clamping devices.

Option (b): Fixing sensors in place with cementing.

In “Option (a)”, only the bottom part of the LTBMS will be cemented as shown in Figures 5 and 6. The LTBMS is partly retrievable in this option by cutting tubing above the cemented part with using tubing cutter such as chemical cutter.

Although the clamping methods for the sensors in the 9-5/8-in casing have not been decided yet, it is of course important to ensure good couplings between these sensors and surrounding casings/formations. Investigation of the clamping methods is now in progress considering scientific objectives, effects of tubing vibration, and so on.

In “Option (b)”, TOC in 9-5/8-in casing would be 700 mbsf and most of sensors in 9-5/8-in casing would be cemented. Although it is expected that this option realize good coupling between sensors and casing/formation, further investigations are necessary to consider the risks of such cementing, such as the effects of voids in cement on the measurement. Additionally, this option would have disadvantage in retrievability of the LTBMS.

The following cement configuration is tentatively planned for C0001 3.5 km riser hole in Nankai area.

- Outside of 36-in conductor casing: No cement would be required as this will be set by jet-in.
- Outside of 20-in surface casing: Full hole cementing would be conducted.
- Outside of 16-in casing: Full hole cementing would be conducted.
- Outside of 13-3/8-in casing: Top/bottom plug cementing would be conducted. Current target of Top of Cement (TOC) is 700 mbsf.
- Outside of 9-5/8-in casing: Top/bottom plug cementing would be conducted. Higher TOC would be preferred to meet the scientific objectives. Current target of TOC is 700 mbsf.

3.1.6. Packer

A packer would be used to isolate the F5 section from the other sections in “Option (a)”. In “Option (b)”, cement would be used to do the same. The following specifications would be required for a packer in “Option (a)”. 

- Differential pressure: 68.95 MPa (10000 psi).
• Estimated inside temperature: 4 to 100 °C
• Penetrators for telemetry lines: 2.
• Penetrators for hydraulic lines: 7 at Max.

Here, 2 of penetrators for hydraulic lines are for packer operations. 5 hydraulic penetrators would be required for the strainmeter at the maximum. The packer would be operated by 2 hydraulic lines and should be retrievable.

### 3.1.7. Perforations

While it is necessary to isolate the fault zone from the other formations, pressure measurement section is required to have the same pressure as the fault zone has, in order to measure the pore pressure in the fault zone. Perforations can meet this requirement. We investigated current perforation technologies in the oilfield industry. We found two candidates for a perforation method, i.e. perforations before and after sensor installations.

In the former way, i.e. perforations before sensor installation, it’s possible to perforate all around on the casing. Especially, this would be useful when the formation has directivity.

In the latter way, i.e. perforation after sensor installation, the sensor cable must be avoided in the perforation job. The current perforating technology is available to detect the cables and safely perforate the casing away from them.

### 3.1.8. Telemetry Cable

The telemetry cable is used for sensor power supply, data transmission and sensor controls. We are considering two candidates of Permanent Downhole Cable (PDC) for the telemetry cable. One is mono-conductor cable with American Wire Gauge (AWG) #18, and the other is twisted pair cable with AWG#20.

![Figure 8: Mono-conductor cable, one of the telemetry cable candidates. (Conductor: #18 AWG, Insulator: ethylene-tetrafluoroethylene, Dimension :11 × 11 mm, Collapse pressure: 20000 psi)](image)

<table>
<thead>
<tr>
<th>Table 2: Telemetry cable electrical property</th>
</tr>
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<tbody>
<tr>
<td><strong>Mono conductor cable</strong></td>
</tr>
<tr>
<td>Conductor DC resistance @20 °C, 1000 m</td>
</tr>
<tr>
<td>Voltage rating</td>
</tr>
<tr>
<td>Insulation resistance @20 °C</td>
</tr>
<tr>
<td>Conductor size</td>
</tr>
</tbody>
</table>

Table 2 shows the electrical property of each cable. Both cables have the same dimension as the maximum length of 1200 m and a cross-section of 11 mm × 11 mm. The cable selection is now in progress with considering their transfer functions, changes in their properties with variations of temperature, and so on.

Figure 8 shows the illustration of the mono-conductor cable.

### 3.1.9. Downhole Modules

The downhole module is required to be mounted with sensors in the same package housing, if sensor size is small enough. Other external sensors may be attached to the bottom of module housing.

The following specifications would be required for the downhole modules considering the environmental conditions, mechanical, electrical requirements.

- **Temperature**: -25 to 125 °C (Storage) 4 to 125 °C (Operation)
- **Pressure**: 104 MPa
- **Operational life**: MTTF 5 years @125 °C
- **Shock**: 2451.55 m/s² (250 G)
- **Diameters**: OD of 63.5 mm (2-1/2”) ID of 50 mm
- **Length**: Depends on sensor design.
- **Weight**: Depends on sensor design.
- **Material**: Inconel 718.
- **Connectors**: Welded connectors for sensors.
- **Seal**: Welded.
- **Power consumption**: 3.5 W.
- **Sensor power supply**: + 5 VDC/+/-1%.
  
  [+/- 12 VDC, under investigation].

Here, the pressure rating mentioned above is required considering the fracture pressure predicted based on the Pre-Stack Depth Migration (PSDM) velocity data. MTTF means “Mean Time To Failure”. Note that the downhole modules should be deployed through casing without any damage. Although, the electric power con-
sumption is specified as 3.5 W in the list, the effort to reduce it must be continued during the detailed design. Sensor power details will be determined through the discussion with sensor developers.

3.1.10. Subsea Module
- **Temperature**: -20 to 70 °C (Storage)  
  -5 to 50 °C (Operation)
- **Pressure**: 35 MPa
- **Shock**: 98 m/s² (10 G), 11 ms half-sine
- **Vibration**: 25–150 Hz, 49 m/s² (5 G)
- **Diameter (ID)**: 266.7 mm
- **Length**: 0.61 m
- **Weight**: 34 kg (in seawater)
- **Mass Storage**: 1 Tbyte
- **Power consumption**: 5 W

The subsea module should have interfaces for data transmission and power port. For the data transmission, there are three types of communication: a fast serial communication, a slow serial communication and Ethernet communication.

3.2. Sensor Installation

We expect at least 3 types of sensor installations:
- **Installation of sensors installed inside the 9-5/8-in casing except the perforated section**: A good cement bond between outside of the 9-5/8-in casing and the formation is required since the sensors would be fixed inside the casing.
- **Installation of sensors at the perforated section of casing**: Pore pressure would be measured at the perforations. Therefore, the perforated section should be isolated from the other formation with packer and/or cement.
- **Installation of sensors in the openhole**: It is necessary for the strainmeter to be cemented.

Relating to these installations of sensors, it is necessary to consider the issues mentioned in the following sub-sections.

3.2.1. Cementing Evaluation

For the good quality of LTBMS measurements, the outside of casings should be well cemented. The cement bond between casings and formations should be evaluated by wireline loggings. Based on these log data, it would be necessary to adjust the sensor depths.

3.2.2. Sensor Module Coupling to Formation

The sensors would be installed with using a tubing. At least 2 options of the sensor clamping method are under consideration as mentioned in the Sub-section 3.1.5. The sensor installation methods should be carefully investigated considering the overall operational plan and sensors’ requirements. The operational plan must consider possible operational difficulties. For example, it is possible that we cannot cement up to the target of TOC.

3.2.3. On-board Handling

On-board handling equipments would be prepared for the sensor installation into the well.

Although we tentatively chose the sensors to set at and around splay faults in C0001 riser hole as shown in Chapter 2, It would be favorable that the choice and locations of these sensors would be flexible to optimize the observation.

Depending where and how the sensors are located, the deployment procedure may be adjusted. The deployment procedure for installing the sensors must be carefully considered and well planned.

The primary handling equipments are mentioned below.
- **Cable Spoolers**
  Zone 1 explosion proven cable spoolers are necessary for the cable deployment. These spoolers would have the function to adjust back tension on cable. Their unit footprint should be as small as possible.
- **Cable Sheaves**
  These sheaves would be used to deploy the telemetry cables. This means they would treat the cables of 11 mm × 11 mm squared cross section. (See 3.1.8)
- **Cable Protector Clamps**
  Cable protector clamps should be designed for specified tubing. Primary purpose of this clamp is to protect and hold the cables onto the tubing. The design must allow that 2 telemetry cables plus up to 7 additional hydraulic lines can be attached to the tubing. It should be considered the clamps might be cemented and also they should go through the wellhead without any significant damage.
- **Downhole Module Protector Clamps**
  Downhole module protector clamps would be designed to protect top and bottom of the downhole module. Their primary purpose is to protect downhole module during deployment.
- **Splice Protector Clamps**
  These are the mid joint protectors designed to protect cable splices. The primary purpose is to protect the cable splice during deployment.
• Intellitite Electrical Dry-Mate Connector
  Intellitite electrical dry-mate connectors would be used for connection between the downhole module and telemetry cable. There are two options for downhole splice. One is a redundant metal to metal seal design and the other is an all welded design. We investigated all welded design for reliability.

• Tubing Hanger Entry Guides
  This should be prepared to avoid cable slack nearby tubing hanger.

• Tubing Centralizers
  Primary purpose of centralizers is to centralize tubing inside casing to protect cables and sensors. They also provide standoff to optimize cementing. They should be designed not to damage the wellhead.

• Tubing Entry Guide
  A tubing entry guide is installed at the bottom of the tubing. It provides smooth entry into the wellhead and protects the sensors mounted above it. This entry guide may have cementing shoe functions also.

3.3. Sensor Deployment Operation Procedure
We are investigating two types of well completion procedure. Main difference between these two procedures is perforation timing, i.e. “Perforation before sensor deployment” and “Perforation after sensor deployment”.

3.3.1. Perforation before Sensor Deployment
The perforation before sensor deployment is relatively conventional well operation. This operational procedure is shown in Table 3. In this case, after perforation is conducted (corresponding to the 9th line of Table 3), tubing would be run with sensors and telemetry cables (the 22nd line of Table 3). This procedure corresponds to “Option (a)” in sub-section 3.1.5.

3.3.2. Perforation after Sensor Deployment
The perforation after sensor deployment corresponds to the “Option (b)” in the sub-section 3.1.5. This option would be relatively good for the coupling between the sensors and casings/ formations because in this case, both the outsides of casings and the tubing would be cemented. This means the most of equipments in the downhole such as downhole modules, sensors, and telemetry cables would be cemented. Perforation guns would be run in the tubing and the perforation would be conducted through the tubing and casing.

In this case, it is necessary for the operation of perforation to avoid the downhole modules, sensors and telemetry cables. For avoiding these downhole equipments, we would rely on Wireline Perforating Platform Completion Mapper (WPPCM) that is a directional perforation tool through tubing and casing not to damage downhole modules, sensors and telemetry cables.

This operation sequence is shown in Table 4.

4. Fundamental Investigations
In order to realize the LTBMS telemetry system, we selected the following development items as the key issues to be solved and/or considered.
- Fault tolerant concept
- Low power consumption design
- System synchronization
- High temperature and long life

For the fault tolerance of the system, we need to implement self-diagnostic system that disables a downhole module if a failure is detected. This safety feature prevents full system malfunction. We verified our design concept by making mockup and testing this feature.

For the low power consumption design of the telemetry system, we need to select low-power components and develop power management system.

In order to collect the real-time data obtained at some exact time, we need to select high accurate clock and confirm telemetry synchronization accuracy improvement. This is important to satisfy seismic data acquisition requirement.

It is important to design the telemetry hardware to make the system survived at 125°C for five years. We investigated some high temperature tools designed for downhole environment to see whether we can use some of their components for the telemetry system.

This chapter describes summaries of what has been investigated in FY07 regarding the key issues mentioned above except the last issue. (As for the “high temperature and long life” issue, we plan this issue mainly in USFY2008. We did preliminary investigation based on the database.)

4.1. Fault Tolerant System
Fault tolerant system distinguishes faults by itself and maintains its health. This system is able to detect faults at system power up and during monitoring. If the system detects a fault, the system automatically switches to the backup telemetry or change configuration to minimize affected section. The subsea module has a redundant system and the downhole telemetry system has a special configuration for fault tolerant function.
<table>
<thead>
<tr>
<th>Table 3: Perforation before sensor deployment</th>
<th>Table 4: Perforation after sensor deployment</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Retrieve corrosion cap</td>
<td>1. Retrieve corrosion cap</td>
</tr>
<tr>
<td>2. Run BOP</td>
<td>2. Run BOP</td>
</tr>
<tr>
<td>3. Test BOP</td>
<td>3. Test BOP</td>
</tr>
<tr>
<td>4. Set wear bushing</td>
<td>4. Set wear bushing</td>
</tr>
<tr>
<td>5. Displace seawater with mud</td>
<td>5. Displace seawater with mud</td>
</tr>
<tr>
<td>6. Drill out cement and bridge plugs</td>
<td>6. Drill out cement and bridge plugs</td>
</tr>
<tr>
<td>7. Drill out 8-1/2” suspension plug to required depth</td>
<td>7. Drill out 8-1/2” suspension plug to required depth</td>
</tr>
<tr>
<td>8. Displace mud with brine</td>
<td>8. Displace mud with brine</td>
</tr>
<tr>
<td>10. Retrieve wear bushing</td>
<td>10. Retrieve wear bushing</td>
</tr>
<tr>
<td>11. Set retrievable bridge plug (or set plug in wellhead)</td>
<td>11. Set retrievable bridge plug (or set plug in wellhead)</td>
</tr>
<tr>
<td>12. Displace brine with seawater in riser</td>
<td>12. Displace brine with seawater in riser</td>
</tr>
<tr>
<td>15. Run BOP</td>
<td>16. Run BOP</td>
</tr>
<tr>
<td>16. Displace seawater with brine in riser</td>
<td>17. Displace seawater with brine in riser</td>
</tr>
<tr>
<td>17. Test BOP, Christmas tree, subsea module and external battery module</td>
<td>18. Test BOP, Christmas tree, subsea module and external battery module</td>
</tr>
<tr>
<td>18. Retrieve bridge plug</td>
<td>19. Retrieve bridge plug</td>
</tr>
<tr>
<td>20. Rig up to run completions</td>
<td>21. Rig up to run completions</td>
</tr>
<tr>
<td>21. Mount the sensors on tubing</td>
<td>22. Mount the sensors on tubing</td>
</tr>
<tr>
<td>22. Run tubing with sensors and telemetry cables</td>
<td>23. Run tubing with sensors and telemetry cables</td>
</tr>
<tr>
<td>23. May space out a special gauge sub to land just above the splay fault, in case of use</td>
<td>24. May space out a special gauge sub to land just above the splay fault, in case of use</td>
</tr>
<tr>
<td>24. A control line set packer is installed above the expected splay fault level</td>
<td>25. A control line set packer is installed above the expected splay fault level</td>
</tr>
<tr>
<td>25. May have to fill the tubing periodically depending on cement shoe design</td>
<td>26. May have to fill the tubing periodically depending on cement shoe design</td>
</tr>
<tr>
<td>26. At least periodically check the continuity of sensors and telemetry cable during deployment</td>
<td>27. At least periodically check the continuity of sensors and telemetry cable during deployment</td>
</tr>
<tr>
<td>27. Connect umbilical cable to tubing hanger when tubing hanger at drill floor</td>
<td>28. Connect umbilical cable to tubing hanger when tubing hanger at drill floor</td>
</tr>
<tr>
<td>28. Land the tubing hanger in the Christmas tree and test the hanger</td>
<td>29. Land the tubing hanger in the Christmas tree and test the hanger</td>
</tr>
<tr>
<td>29. Establish communication and perform telemetry system check</td>
<td>30. Establish communication and perform telemetry system check</td>
</tr>
<tr>
<td>30. Rig up cementing unit to the tubing and return path to the tubing annulus</td>
<td>31. Rig up cementing unit to the tubing and return path to the tubing annulus</td>
</tr>
<tr>
<td>31. Pump sufficient cement volume to reach at least 6.68° casing shoe</td>
<td>32. Pump sufficient cement volume to reach at least 6.68° casing shoe</td>
</tr>
<tr>
<td>32. Allow sufficient time for cement to set and pressure test the tubing annulus</td>
<td>33. Allow sufficient time for cement to set and pressure test the tubing annulus</td>
</tr>
<tr>
<td>33. Through control line pressure, set the packer</td>
<td>34. Through control line pressure, set the packer</td>
</tr>
<tr>
<td>34. Test hanger and packer</td>
<td>35. Test hanger and packer</td>
</tr>
<tr>
<td>35. Run wireline logging tool through tubing to evaluate cement condition</td>
<td>36. Run wireline logging tool through tubing to evaluate cement condition</td>
</tr>
<tr>
<td>36. Set and test the internal tree cap, followed by crown plug</td>
<td>37. Set and test the internal tree cap, followed by crown plug</td>
</tr>
<tr>
<td>37. Disconnect tubing hanger running tool from the hanger and recover it</td>
<td>38. Disconnect tubing hanger running tool from the hanger and recover it</td>
</tr>
<tr>
<td>38. Displace brine with seawater in riser</td>
<td>39. Displace brine with seawater in riser</td>
</tr>
<tr>
<td>39. Retrieve BOP</td>
<td>40. Retrieve BOP</td>
</tr>
<tr>
<td>40. Set corrosion cap</td>
<td>41. Set corrosion cap</td>
</tr>
<tr>
<td>41. Run BOP</td>
<td>42. Run BOP</td>
</tr>
</tbody>
</table>

Engineering Specifications on LTBMS Telemetry System for NanTroSEIZE 3.5 km Riser Hole


Table 5: Subsea electronics power consumption

<table>
<thead>
<tr>
<th>Part name</th>
<th>Quantity (ea.)</th>
<th>Voltage (V)</th>
<th>Current (mA)</th>
<th>Power (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DSP and FPGA</td>
<td>1</td>
<td>1.2</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electronics except DSP and FPGA (see Table 1)</td>
<td>1.6 W</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal acquisition</td>
<td>0.8 W</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line separator</td>
<td>20</td>
<td>mW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Solid State Disk (SSD)</td>
<td>20 mW</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub total</td>
<td>3.677</td>
<td>W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DC-DC efficiency (for subsea electronics)</td>
<td>85% or higher</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Subsea consumption (exclude constant current regulator)</td>
<td>4.32 W</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 6: Subsea telemetry power consumption break-down (except DSP and FPGA)

<table>
<thead>
<tr>
<th>Part name</th>
<th>Quantity (ea.)</th>
<th>Voltage (V)</th>
<th>Current (mA)</th>
<th>Power (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAC</td>
<td>2</td>
<td>5</td>
<td>0.14</td>
<td>1.4</td>
</tr>
<tr>
<td>VGA</td>
<td>2</td>
<td>10</td>
<td>0.28</td>
<td>2.0</td>
</tr>
<tr>
<td>Voltage reference</td>
<td>1</td>
<td>5</td>
<td>0.28</td>
<td>1.4</td>
</tr>
<tr>
<td>ADC</td>
<td>2</td>
<td>3.3</td>
<td>36</td>
<td>237.6</td>
</tr>
<tr>
<td>FPGA</td>
<td>1</td>
<td>5</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>EEPROM</td>
<td>2</td>
<td>5</td>
<td>36</td>
<td>237.6</td>
</tr>
<tr>
<td>Isolation amplifier</td>
<td>2</td>
<td>10</td>
<td>7</td>
<td>49</td>
</tr>
<tr>
<td>Voltage reference</td>
<td>1</td>
<td>5</td>
<td>0.275</td>
<td>1.375</td>
</tr>
<tr>
<td>Op-amp</td>
<td>4</td>
<td>10</td>
<td>45</td>
<td>180</td>
</tr>
<tr>
<td>Op-amp</td>
<td>2</td>
<td>10</td>
<td>7</td>
<td>140</td>
</tr>
<tr>
<td>ADC</td>
<td>1</td>
<td>5</td>
<td>11</td>
<td>55</td>
</tr>
<tr>
<td>Memory</td>
<td>2</td>
<td>5</td>
<td>16.5</td>
<td></td>
</tr>
<tr>
<td>Oscillator</td>
<td>1</td>
<td>3.3</td>
<td>5</td>
<td>16.5</td>
</tr>
<tr>
<td>Op-amp</td>
<td>1</td>
<td>10</td>
<td>0.3</td>
<td>3</td>
</tr>
<tr>
<td>Standard logic</td>
<td>16</td>
<td>3.3</td>
<td>0.01</td>
<td>0.328</td>
</tr>
<tr>
<td>Standard logic</td>
<td>26</td>
<td>3.3</td>
<td>0.01</td>
<td>0.858</td>
</tr>
<tr>
<td>Standard logic</td>
<td>1</td>
<td>3.3</td>
<td>0.01</td>
<td>0.033</td>
</tr>
<tr>
<td>Standard logic</td>
<td>1</td>
<td>3.3</td>
<td>0.01</td>
<td>0.033</td>
</tr>
<tr>
<td>Standard logic</td>
<td>3</td>
<td>3.3</td>
<td>0.02</td>
<td>0.198</td>
</tr>
<tr>
<td>Op-amp</td>
<td>2</td>
<td>10</td>
<td>7</td>
<td>140</td>
</tr>
<tr>
<td>ADC</td>
<td>1</td>
<td>8</td>
<td>7</td>
<td>56</td>
</tr>
<tr>
<td>DSP</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSP Supervisor</td>
<td>1</td>
<td>5</td>
<td>0.025</td>
<td>0.125</td>
</tr>
<tr>
<td>Total power consumption</td>
<td></td>
<td></td>
<td></td>
<td>1556.05</td>
</tr>
</tbody>
</table>

Table 7: Downhole module electronics power consumption

<table>
<thead>
<tr>
<th>Part name</th>
<th>Quantity (ea.)</th>
<th>Voltage (V)</th>
<th>Current (mA)</th>
<th>Power (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fault tolerant system</td>
<td>1</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Line separator</td>
<td>20</td>
<td>mW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSP and FPGA</td>
<td>570</td>
<td>W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electronics except DSP and FPGA (see Table 8)</td>
<td>830 W</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Signal Acquisition</td>
<td>800</td>
<td>W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sub total</td>
<td>2.45</td>
<td>W</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Temperature effect (-10%)</td>
<td>2.69 W</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DC-DC efficiency at high temperature</td>
<td>80%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total power consumption</td>
<td>3.37 W</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 8: Downhole module telemetry power consumption break-down

<table>
<thead>
<tr>
<th>Part name</th>
<th>Quantity (ea.)</th>
<th>Voltage (V)</th>
<th>Current (mA)</th>
<th>Power (mW)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DAC</td>
<td>1</td>
<td>3.3</td>
<td>0.005</td>
<td>0.0165</td>
</tr>
<tr>
<td>VGA</td>
<td>1</td>
<td>10</td>
<td>20</td>
<td>200</td>
</tr>
<tr>
<td>Voltage reference</td>
<td>1</td>
<td>5</td>
<td>0.28</td>
<td>1.4</td>
</tr>
<tr>
<td>ADC</td>
<td>1</td>
<td>3.3</td>
<td>36</td>
<td>118.8</td>
</tr>
<tr>
<td>SPDST switch</td>
<td>2</td>
<td>5</td>
<td>0.001</td>
<td>0.01</td>
</tr>
<tr>
<td>FPGA</td>
<td>3</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>EEPROM</td>
<td>2</td>
<td>5</td>
<td>5</td>
<td>25</td>
</tr>
<tr>
<td>Op-amp</td>
<td>2</td>
<td>10</td>
<td>45</td>
<td>90</td>
</tr>
<tr>
<td>Op-amp</td>
<td>1</td>
<td>10</td>
<td>7</td>
<td>70</td>
</tr>
<tr>
<td>Op-amp</td>
<td>1</td>
<td>10</td>
<td>1.3</td>
<td>13</td>
</tr>
<tr>
<td>Comparator</td>
<td>1</td>
<td>10</td>
<td>1.25</td>
<td>12.5</td>
</tr>
<tr>
<td>ADC</td>
<td>1</td>
<td>5</td>
<td>11</td>
<td>55</td>
</tr>
<tr>
<td>Memory</td>
<td>2</td>
<td></td>
<td></td>
<td>126</td>
</tr>
<tr>
<td>PLL</td>
<td>1</td>
<td></td>
<td></td>
<td>100</td>
</tr>
<tr>
<td>Standard logic</td>
<td>1</td>
<td>3.3</td>
<td>0.01</td>
<td>0.033</td>
</tr>
<tr>
<td>Standard logic</td>
<td>4</td>
<td>3.3</td>
<td>0.02</td>
<td>0.264</td>
</tr>
<tr>
<td>Op-amp</td>
<td>1</td>
<td>10</td>
<td>1</td>
<td>10</td>
</tr>
<tr>
<td>DSP</td>
<td>2</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSP Supervisor</td>
<td>1</td>
<td>5</td>
<td>0.025</td>
<td>0.125</td>
</tr>
<tr>
<td>Total power consumption</td>
<td></td>
<td></td>
<td></td>
<td>822.15</td>
</tr>
</tbody>
</table>

Figure 9: Subsea module block diagram.

Figure 10: Downhole module block diagram.
In USFY07, CDEX carried out experiments on the fault tolerance of the telemetry system. We made a model of the telemetry system with one model of the subsea module, four models of the downhole modules and the telemetry cables. In the experiments, we generated artificial open and short circuits at one of downhole modules or in one of the telemetry cables. These artificial failures could be detected by the fault tolerant system and the failed modules were disabled by the system successfully. As a result, it is confirmed that our concept of the fault tolerant system is feasible.

4.2. Low Power Consumption

As mentioned in Chapter 1, the LTBMS can be connected to DONET. In this case, DONET supplies energy for the LTBMS. When the LTBMS is disconnected from DONET for a certain reason, the LTBMS can continue monitoring with its own external batteries. In either case, the electricity supply for the LTBMS is strictly limited. Therefore, it is necessary to select low-power components and develop power management system.

With using the same telemetry model that was used for the experiments on fault tolerance, we performed another experiment to confirm the feasibility of the power management system. Here the power management system would have functions of selecting arbitrary downhole module and doing ON/OFF control with sending a signal from the subsea module. These functions were successfully validated in the experiment.

As for consideration to low power components, it is important to estimate the power consumption of the telemetry system in the case that the system would be composed with the current technology. The following subsections mention the theoretically and experimentally estimated power consumptions.

4.2.1. Subsea Module Power Consumption

Subsea module block diagram is shown in Figure 9. The power consumption of the subsea telemetry components is summarized in Table 5. The power consumption of Digital Signal Processor (DSP) and Field Programmable Gate Array (FPGA) had been estimated based on the feasibility test results. A break-down of the power consumption of the electronics except DSP and FPGA are shown in Table 6.

For the design of EXP (Experimental Prototype) of the LTBMS, the number of DSP should increase from 2 to 6 because of redundancies. Therefore, without optimization between the data transmission speed the power consumption, requirement will increase accordingly.

4.2.2. Downhole Module Power Consumption

Downhole module block diagram is shown in Figure 10. The estimated downhole module power consumption is 3.37 W as shown in Table 7. The proposed target specification is 3.5 W.

The power consumption of the downhole module telemetry except DSP and FPGA is estimated around 830 mW from the specifications of components. The modification of the electronics configuration of the module is small therefore the power consumption of the EXP module will be almost the same. The external sensor power consumption was assumed as 1 W for all the downhole modules. 125 mW was distributed to each module (125 mW= 1000 mW/8modules).

4.2.3. Total Power Consumption

Table 9 shows the total power consumption in two cases. The power consumption of the regulator for the downhole electronics was computed based on the assumption of the conversion efficiency of 85%. The cable power dissipation is computed as a function of resistance and its flowing current. Here, the consumption is a linear function of the current. The cable resistance is 37 ohm/km @150 °C (mono-conductor cable). The maximum cable length is 7000 m; the total resistance is 259 ohm.

The cable power consumption depending on the flowing current is shown in Table 10. Total power consumption depends on line power current due to cable power loss. Lower current will...
save cable power loss. On the other hand, lower current requires higher voltage for the downhole module to draw power at module. Based on this total power estimation, “100 mA drive” requires 348 V and “200 mA drive” requires 220 V at constant current regulator in the subsea module. Higher voltage power supply require higher voltage resistance component that is less efficiency in general. In addition voltage up converter consumes more power to generate higher voltage. From these design items, we need to consider efficiency of constant current regulator and loss in the cable to define optimum drive current for the best efficiency.

4.2.4. Power Management Scenario

This is provisory case study of power management based on Table 9 power consumption estimation. We have not concluded yet but we will tentatively assume 100 mA drive for this case study.

◆ Scenario 1:
The LTBMS would be operated with only DONET cable power (30 W). To have communication with DONET cable, we need Opt/Elec converter that would require 3 W. So available power for the downhole is

\[30 \text{ (DONET power)} - 4.32 \text{ (subsea power)} - 3 \text{ (Opt/Elec converter)} - 2.59 \text{ (cable loss)} = 20.09 \text{ W}\]

This power is enough only for 5 downhole modules. So the number of downhole modules must be reduced to drive with the available power (30 W). Or we must use external battery power to drive the full system.

◆ Scenario 2:
The LTBMS would be operated with DONET and external battery for 1-year period. Required power for the LTBMS is 39.1 W (Table 9) and Opt/Elec converter (3 W).

\[39.1 + 3 - 30 = 12.1 \text{ W}\]

It is necessary that the external battery supplies 12.1 W to maintain operation for 1-year (8760 hours), so total required power for the battery is 106 kWh.

◆ Scenario 3:
Without DONET cable, the LTBMS would be operated for 2 months only with battery power. For this case Opt/Elec converter is not necessary. So the total necessary power can be calculated as follows.

\[39.1 \times 1440 \text{ hours (2 months, 60 days)} = 56304 \text{ Wh}\]

◆ Scenario 4:
If we employ the Subsea Monitor Control (SMC) package as battery pack and use ELECTROCHEM BCX85 series TSD battery, one SMC module can store 14.9 kWh. Based on this condition, we can keep the full operation of the LTBMS for 15 days because

\[14934 \div 39.1 = 381 \text{ hours}\]

To keep the full-operation for 2 months only with battery packs, the following calculation

\[56304 \div 14934 \approx 4,\]
means at least 4 battery packs are required for two months stand alone operation.

4.3. Time Synchronization Concept

4.3.1. Requirements

From the data processing point of view, it is important to acquire various data set from many different observation points under synchronized condition. The requirement for the synchronization error through the whole downhole telemetry system has been set to be less than 10 µs. When the telemetry system is connected to DONET, the frame signal of DONET can be used as a universal synchronization reference.

4.3.2. DONET Synchronization Signal

If the LTBMS is connected to DONET, it is possible to synchronize the signal acquisition to the DONET frame as shown in Figure 11.

There are some signal transmission delays (Tds) and some telemetry cable delay (Tdc). Tds is a system delay of subsea module and is a constant. Tdc is a delay by the cable and depends on the length of cable. Tdc can be estimated by the cable transmission time measurement. The temperature effect on Tdc can be also evaluated through lab experiments. Therefore Tdc can be considered as a known parameter in the data analysis. In other words, as long as delays are known, it is possible to align the data set on the exact time frame.

The sampling frequency for the data acquisition is selectable; 250 Hz, 500 Hz and 1 kHz. These acquisition times could be generated from DONET frame signal.

When the LTBMS is disconnected from the DONET, the LTBMS runs with its internal clock. The measurement will lose synchronization with external reference. The accuracy of the sampling interval depends on the drift rate of the internal clock. Each data set has an associated time stamp, which comes from the internal clock counter number as a reference of time for data retrieving.

4.3.3. Delay Calculation

It is important to analyze the effect of the compensation scheme for the synchronization delay. Two kinds of delays are expected and should be investigated if those delays can be considered as constant.

4.3.3.1. System Delay (Tds)

The delay must come from the DSP’s processing. The DSP is running faster than 10 MHz system clock and the one machine cycle could be less than 100 ns. The delay should be proportional to the number of machine cycle therefore Tds could be considered as a constant. However, the system clock frequency varies with surrounding temperature, especially high temperature condition. Tds is generated in the subsea module and it is located at stable temperature. This means that the clock frequency will not vary so much and is supposed to be a constant. It is better to measure the frequency at the real operating condition during the evaluation period for confirmation.

4.3.3.2. Cable Delay (Tdc)

This delay depends on the telemetry cable length and is constant in time domain. The delay is planned to be measured in deployment. The accuracy and resolution of this measurement depend on measurement method and device. TDR (Time Domain Reflectometers) is one of the measurement equipments for the cable length. We can regard this delay as constant, not as variable in time domain.

4.3.4. Absolute Time Conversion

Absolute time conversion method is explained in this section. Due to “Real time data file delay”, the received file contains signals acquired in the past. The signal acquisition is synchronized with the DONET frame. “Real time data file delay” depends on the number of modules and the sampling rate. The data transmission should start synchronization with the DONET frame.

Receiving the DONET frame signal, the subsea module acquires signals synchronized with the frame signal. Depending on the selected sampling rate, the acquisition interval changes.

Figure 12 shows the example of 500 Hz sampling rate that corresponds to 2 ms. Waiting for 48 signal acquisitions (this waiting duration depends on the sampling rate) and data formatting at subsea, data set is ready for transmission. Once the data set is assembled, subsea waits for next DONET frame signal for time synchronization. The data set transmission starts at the next DONET frame signal after Tdf, which could be a delay due to DONET systematic error and the fixed delay on the subsea system.

The data set has information such as the number of modules and the sampling rate, which affect the “Real time data file delay”. So it is possible to calculate the delay of the data set transmission from the first signal acquisition. The land station has a DONET frame counter for time synchronization. Knowing the number of the DONET frames and the calculated delay, it is possible to determine the first signal acquisition frame number.

4.3.5. Conclusions

The use of DONET frame signal as a synchronization reference is possible. The method provides the synchronization tolerance within 10 µs against the reference in
the land station by eliminating known delays. The exact delay must be measured during the fabrication and implementation phase and the delay must be clarified.

5. Engineering Specifications for the Telemetry System

On one hand, the telemetry system should meet the requirements on the long-term borehole monitoring as much as possible so that we can achieve the goal of constructing a physical model of earthquakes and a real-time monitoring network; on the other, there are many technological, engineering and operational to develop and produce the system. CDEX identified the engineering specifications on the telemetry system considering the trade-offs among them.

5.1. LTBMS Configuration

Considering the observatory plan in Chapter 2, the following configuration of the telemetry system was assumed. The telemetry system consists of one subsea module, eight downhole modules and the telemetry cables. The subsea module controls the entire measurement system. Each module acquires sensor data and sends it to the subsea module according to the specified data format. The land station acquires the data and manages the signal for the LTBMS through the submarine cable network. The telemetry system has interfaces (I/F) for sensors, acoustic transponder and submarine cable.

System block diagram is shown below (see Figure 13). The subsea module has two major interfaces. One is a subsea interface to send downhole sensor data to the land station and receive commands from the land station through the submarine cable. Another is a downhole telemetry interface for downhole module communication.

The subsea module is located on the Christmas tree and contains telemetry electronics and the mass storage devices. The external battery will be fixed at the Christmas tree. The external battery module size depends on the numbers of batteries to be packed. Subsea module on the Christmas tree connected to ROV connection panel.

The connection panel has Wet Mate Connecters (WMCs) for the submarine cable, external batteries and other expandable connections if necessary.

5.2. Summary of the Engineering Specifications for the Telemetry System in NanTroSEIZE C0001 riser hole

Based on the investigations done in USFY2007 and considering the scientific, engineering and operational requirements, JAMSTEC identified the engineering specifications for the telemetry system for the LTBMS. A part of this specification would be summarized as follows.

[Downhole (DH) Telemetry System]
- Synchronization accuracy : < 10 µs (PLL jitter)
  @1.024 Mbps
  with 8 modules
- Number of DH modules : 8 modules
- Uplink speed : Selectable from
  2.048 Mbps
  1.024 Mbps
  512 kbps
- Uplink bit error rate : < 10^-9
- Downlink command speed : 500 bps
- Downlink carrier freq. : 2 kHz
- Maximum module distance: 1000 m @2.048 Mbps
  1500 m @1.024 Mbps

Note that the synchronization accuracy depends on the uplink speed and number of downhole modules.

[Subsea Module]
- Diameter (ID) : 266.7 mm
- Length : 0.61 m
- Temperature : -20 to 70 °C (Storage)
  -5 to 50 °C (Operation)
Y. Namba et al.,


- Pressure : 35 MPa
- Shock : 98 m/s² (10 G)  
  11 ms half-sine  
  *IWIS compliant (ISO 13628-6)
- Module weight : 34 kg  
  (in seawater with flotation)
- Power consumption : 5 W
- Mass storage size : 1 Tbyte
- Subsea I/F for electric power supply:
  2 kinds of port  
  (Submarine cable / additional battery port)
- Subsea interfaces for data transmission:
  3 kinds of port  
  (RS-232C, RS-422, Ethernet)
- High speed analog signal input (seismic ch):
  4 ch / module (Voltage proportional to signal)
- Dynamic range : 120 dB  
  (A/D 24 bit ΔΣ Minimum phase)
- Frequency range : 0 to 400 Hz
- Pre-amplifier
  Input voltage range : 5 Vpp (differential)
  Input impedance : > 10 Mohm
- Low speed analog signal input:
  8 ch / module (Voltage proportional to signal)
  Dynamic range : > 97 dB @ 10 Hz Sampling
  Frequency range : 0 to 8 Hz  
  *Upper frequency limit depends on sampling rate
  Drift : 50 ppm (1000 hours)
  Pre-amplifier
  Input voltage range : -2.5 V ~ +2.5 V
  Input impedance : > 10 Mohm
- Digital input : RS-232C, RS-485, SPI (Optional)
  Command out for sensor : 4 bits
  Command in for status monitor : 8 bits

6. Conclusions

This paper reports the results of works in USFY 2007 for the development of the telemetry system. In USFY2007, the engineering specifications for the telemetry system were defined considering the scientific objectives, observatory plan, engineering requirements, and operational requirements. In the process to define the specifications, some experimental and theoretical studies were carried out. The observatory plan was made and the operational requirements on the LTBMS were defined based on the operational plan. Some fundamental investigations were performed and in these investigations, some power consumption scenarios were studied. Feasibilities of the fault tolerant system, system synchronization, and so on were confirmed.

Based on the engineering specifications and relating studies what are described in this paper, JAMSTEC plans to fabricate an EXP of the telemetry system and carry out an experiment in a borehole on land in USFY 2009.

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References

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