The NEPTUNE Canada Junction Box - Interfacing science instruments to sub-sea cabled observatories

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Abstract- As the use of cabled ocean observatories expands, there is an opportunity to develop a standard interface between a wide variety of scientific instruments and the cabled observatory power, data and control systems. The NEPTUNE Canada Junction Box developed by Oceanworks International is rated to 3000m depth and can interface up to 10 science instruments to a cabled observatory. The Junction Box has been specifically designed to be modular, with a highly flexible, custom configurable architecture that can be used on a variety of projects. With an emphasis on reliability and fault resilience, the Junction Box uses a mixture of off-the-shelf technology and custom designed electronics to provide conditioned power and communications to science instruments. Following rigorous testing and qualification, the Junction Box is expected to have operational life in excess of 10 years.

I. INTRODUCTION

Cabled observatories are being deployed in oceans around the world to facilitate oceanographic and marine biology observation. A cabled observatory typically has a shore station that supplies high voltage power and high speed fiber optic communications to a standard telecommunications cable. The cable can stretch for hundreds of kilometers out into the ocean in a branching or ring topology. At points of scientific interest, a “node” is attached to the cable. A node converts the high voltage power down to a medium voltage and the fiber optic communications are routed through high speed network switches to supply Gigabit Ethernet to the node ports. The NEPTUNE Canada Junction Box plugs into a node port via an underwater mating connector to provide regulated low voltage power and communication to ten scientific instruments.

An example of such an observatory is the NEPTUNE Canada project [1]. NEPTUNE Canada has deployed an 800km loop of cable off the West coast of Vancouver Island in Canada. Along this loop are 5 nodes, each providing eight ports for power and communication. The shore-station, cable and nodes are the core infrastructure of the cabled observatory and are expected to operate unchanged for the 20 year life of the project. Instrument platforms are built around a Junction Box interfacing the scientific instruments to the observatory. The platform is lowered to the seabed from a surface support vessel and plugged in the node with an underwater remotely operated vehicle (ROV). The junction box can be located up to 10 km from the observatory node. If additional science ports are required in one location, a second Junction Box can be connected in series using a specially configured science port.

The Junction Box is a titanium pressure vessel rated to 3000m, containing custom and off-the-shelf electronics. The Junction Box accepts up to 10kW of power from 300 to 400 VDC and communications via copper 100 Megabit Ethernet or fiber optic Gigabit Ethernet.

In order to support the science objectives of an observatory, the Junction Box must interface to a wide variety of instruments, both current and future. To meet this requirement, Oceanworks has developed a Junction Box with a flexible and modular architecture that provides a wide range of user selectable power and communication interfaces, initially configured at build. The modular design is achieved by defining common space claims and wiring interfaces for each of the science port electronics. This allows the instrument ports to be configured in a variety of ways; all ten ports can individually supply 15, 24 or 48 VDC at 75 W. One port can be configured with a high power supply providing 600 W at 48 V and up to three ports can transmit the incoming 400 VDC. Port communications can be configured as 100BaseT Ethernet on all ports or, up to four ports can be configured with legacy EIA serial interfaces. If a new instrument requires a port voltage, power or communication interface that is different to the initial configuration, the modular approach allows a power module to be swapped or communication interfaces re-wired in the field.

A single board computer (SBC) with a TCP/IP interface provides control and monitoring of each port power supply and the internal health of the Junction Box. Should the SBC detect a fault, the port is automatically turned off and the surface notified.

A design philosophy for the junction box was developed to minimize technical and project risk by using commercially available, industrial grade, off-the-shelf components such as Ethernet switches and single board computers. Where no off-the-shelf solutions are available, custom electronics have been designed and qualified. The custom electronics are an
evolution of designs used and proven in the successful VENUS [2] Cabled Observatory project.

II. MECHANICAL

The Junction Box is a cylindrical pressure vessel approximately 0.3m in diameter and 1.0m in length (Fig. 1). Both heads of the cylinder can be removed and have redundant barrel seals. The removable head design improves maintenance access, can assembly and machining while redundant barrel seals ensure leak tightness. The pressure vessel is manufactured from Titanium to reduce corrosion during long deployments in the harsh environment of thermal hot vents and hydrate fields. In order to prevent galvanic corrosion between dissimilar metals, all connectors and penetrators are manufactured from the same grade of titanium as the pressure vessel. All fasteners are ceramic coated titanium to prevent seizing in the can head or shell. The pressure vessel is designed to withstand depths of 3000msw and is qualified as an implodable volume in accordance with NAVSEA 9290 [3].

The pressure vessel maintains a one-atmosphere dry nitrogen environment that facilitates the use of off-the-shelf electronics. Dry nitrogen also reduces the failure rate of electronic components, in particular electrolytic capacitors. A pressure relief valve is fitted to safely release internal can pressure should the can be taken outside its design limits and flooded.

All electronics are mounted on a chassis heat sink. The chassis is a machined aluminum inverted ‘T’ section with a curved base. The curved base matches the radius of the inside of the pressure vessel and when inserted into the can, an expansion mechanism pushes the chassis into the can wall. This design provides an excellent heat transfer path from the power supply electronics to sea water and was verified by finite element thermal analysis. By keeping the electronics cool, component ageing is reduced, improving the reliability of the Junction Box. The completed chassis will undergo vibration and shock load testing to ensure the design strength meets expected transport and deployment conditions according to [4].

III. COMMUNICATIONS

Communications from the cabled observatory to the Junction Box can be either 100BaseT copper Ethernet (if the Junction box is located within 70 meters of the observatory node) or 1000BaseLX fiber optic Ethernet (either single or redundant links). In both cases, underwater mating connectors are used to enable the Junction Box to be plugged into an observatory node whilst submerged. Off-the-shelf industrial Ethernet switches route data to and from the control computer and the ten instrument interfaces as required. Should science instruments require legacy serial interfaces, a four-port Ethernet to serial server provides EIA232, EIA422 and EIA485 protocols. Each serial channel is optically isolated at the server from the hotel supply and from each other. The physical connector for all science ports is a 10 Pin SEACON MINICON Size K. All ports have the same pin configuration and use visual indicators to prevent an instrument from being plugged into an incompatible port.

IV. POWER DISTRIBUTION

The Junction Box receives up to 10KW of medium voltage power from the observatory node in a range from 300 to 400 VDC depending on line losses. The medium voltage is conditioned and distributed to off-the-shelf isolated DC-to-DC converters, one for each port. DC-to-DC converters are used to efficiently step-down and regulate the medium voltage power to working voltages of 15, 24 and 48 VDC. Other voltages can be accommodated if required. The low voltage ports can supply 75 W of power with one port able to supply 600 W at 48 V.

The incoming (unconditioned) medium voltage supply is also available on up to three science ports. These ports are switched with a custom designed breaker that soft starts any downstream load to reduce inrush currents and nuisance trips on upstream breakers. The medium voltage ports can supply 15A and are unregulated.
V. TRANSIENT PROTECTION

Analysis of off-the-shelf DC-to-DC converters has shown damage could occur if the supply voltage peaks above 425VDC. Data from the NEPTUNE nodes showed 10% voltage spikes could be seen on the 400VDC supply during transient load changes. Coupled with this, the inductance and capacitance of a cable from the observatory node to a junction box located at the maximum 10km distance from the node could induce additional voltage spikes.

A detailed analysis of the 10km cable was undertaken using the electro-magnetic transients software package ATP [4]. The results graphed in Fig. 2 show the potential for voltage spikes in excess of 600VDC for periods of 5ms or greater. To be confident that the junction box electronics are not damaged, a dedicated over-voltage-protection (OVP) circuit is provided. The OVP is based on a transistor linear regulator circuit with additional passive protection and guarantees that the voltage distributed inside the Junction Box will never exceed 410VDC, which is within the operating range of the DC-to-DC converters.

The final design of the OVP protects the Junction Box from voltage spikes up to 1200VDC for up to 50ms in duration. If the total energy to be dissipated exceeds the capabilities of the OVP, the output is automatically turned off to protect the Junction Box electronics.

VI. SOFTWARE

The Junction Box uses an off-the-shelf single board computer to control and monitor the junction box ports. The computer is attached to a custom interface board which in turn connects to the port power supplies and breakers.

The principal functions of the sub-sea software are to:

- Monitor current, voltage and ground-fault values for each port;
- Monitor other operational values for the junction box, such as hotel power supplies, board temperature and case pressure;
- Shut down a port that exceeds the allowed parameters for current, voltage or ground-fault;
- Send telemetry regarding the status of the junction box to the surface; and
- Accept commands from an operator (or surface control software) that controls the functions of the junction box.

The sub-sea software is written in C for efficient code in terms of execution speed and space requirements. OEM multitasking extensions allow for the simple implementation of the multitasking components of the control system without the overhead of an operating system. The extensive OEM libraries simplify the implementation of the data acquisition and communication functions; minimize development risk and enhance the robustness of the system.

A remote programming board is used to allow for post-deployment remote programming and debugging of the sub-sea software via a TCP interface.

On power-on of the NEPTUNE junction box, the software initializes itself, starts transmitting telemetry data on the default TCP address and ensures that all ports are turned off.

A hardware watchdog will restart the software should the code enter a locked up state.

The command interface is designed to be simple, robust and easily extensible. Commands are sent via a Telnet interface on the standard TCP Telnet port. All communication sent to and from the sub-sea software are ASCII alphanumeric.

The operational parameters of port current, voltage and ground fault are monitored by the control software. Voltage and ground-fault values are acquired once a second. Current is sampled at 4 Hz; the peak current in the previous second as well as the current value on the second are recorded.

The current, voltage and ground-fault values are compared to their allowable limits for the particular port and, if the limits are exceeded, the port is shut down and an error status flag is raised for the port indicating an alarm condition.

All measured values and system states are reported to the surface in a data structure that is transmitted once a second using UDP as a protocol. The structure of the data frame is such that it may be easily expanded to meet future requirements.
VII. FLEXIBILITY

Recognizing the need to interface to a wide variety of current and future scientific instruments, the junction box is designed with a modular architecture shown in Fig. 3. This architecture allows the configuration of each port to be defined when the Junction Box is built.

A standard wiring harness is used inside all Junction Box chassis. All Low Power Supplies have the same space claim and are interchangeable. The High Voltage Breaker and high power supply also share the same space claim and are interchangeable.

Port communication also use standard wiring terminated in a Cat5 RJ45 connector. If a serial connection is required, the port is simply routed to the serial isolation board instead of the Ethernet switch.

Regardless of the Junction Box configuration, all chassis are wired to a bulkhead just behind the connector head of the pressure vessel. To change a port from serial to Ethernet, the can head is removed and the port RJ45 connector is moved from the serial socket to an Ethernet socket. If a port voltage is required to be changed or populated, the new power supply card is fitted and the pre-wired connectors are plugged in.

Future support for fiber optic connections to instruments is included and can be easily expanded. The pressure vessel has three ODI penetrator locations that can support hybrid cables. In addition, the selected MINI-CON series of connector supports an increasing range of hybrid inserts.

As science needs evolve over the coming years, the Junction Box can be adapted to keep up with the new demands. If a new instrument requires a new port voltage, the Junction Box could be opened in the field, the new Low Power Supply card populated and connected, the can closed, leak tested and be ready for redeployment in just a few hours.

VIII. RELIABILITY AND QUALIFICATION

The reliability of a Junction Box is extremely important to the viability of a cabled observatory. With instruments deployed in thousands of meters of water, several hundred kilometers off shore, the cost of unscheduled maintenance is prohibitive and will likely result in the loss of science data until the next scheduled visit, which may be several years in the future.

Although the loss of one instrument would be disappointing, the loss of a junction box and all ten attached instruments could be disastrous for a science project. With this in mind, the junction box has been designed to prevent internal and external port faults effecting the rest of the Junction Box.

Each subsystem in the Junction Box is extensively type tested, with stress testing at elevated temperature and forced fault conditions in order to ensure that potential failures will be graceful and localized. For example, in the High Power Supply, the output relay is forced to break full current at maximum voltage to ensure the contacts can repeatedly break the circuit, even though in normal conditions, the DC-to-DC converter turns off before the relay opens, so that no voltage or current are switched.

All subsystems undergo a burn-in period to reduce infant mortality. For key components, such as the DC-to-DC converters, components grades that provide a burn-in period are selected to further reduce project risk. Statistical modeling is used to obtain MTBF figures to MIL-HDBK-217F [5] for all subsystems and is used to highlight high risk areas.

After assembly, each completed junction box undergoes full functional tests, leak tightness tests and finally 168 hours of full load operations in water prior to leaving the factory.
IX. FAULT TOLERANCE AND DETECTION

By design, each instrument port is powered from its own independent DC-to-DC converter to prevent a single failure affecting the rest of the Junction Box. For both the Low and High Power Supplies, the DC-to-DC converter is connected to the Junction Box power bus via a normally open relay and an inline fuse. If the DC-to-DC converter, or any of the associated monitor electronics fail catastrophically, the port can be disconnected from the Junction Box bus to ensure no fault propagation. Should an instrument connected to the port fail, the DC-to-DC converter can withstand an indefinite short circuit on the output side while the subsea software detects the fault state and shuts the power supply down. Shutting the power supply down also opens the input relay, output relay and if used, the serial communications relay. This ensures all the port pins are completely disconnected from all circuitry in the Junction Box eliminating any sustained ground faults that could affect the integrity of the pressure vessel or connector pins via galvanic corrosion.

With the use of isolated DC-to-DC converters on each port, the problem of ground faults is significantly reduced by design. A single conductor from all ports can be indefinitely connected to seawater and no ground fault current will flow. However, as such an event will be indicative of a greater problem, the power output of each port is center referenced to sea water via a high impedance path. This center point is monitored and if it is pulled high or low by a sea water path, the port is automatically turned off and isolated. However, the port can still be forced on at the user’s discretion.

Although all serial channels are optically isolated from the Junction Box supply and one another, a current path exists through the data pins, should these be shorted by a cable or a flooded instrument external to the Junction Box. To prevent this current path, all serial data lines pass through normally open relays that are only closed when the associated port is on.

X. CONCLUSION

The NEPTUNE Canada Junction Box designed by Oceanworks International defines standard interfaces for ten instruments to a cabled ocean observatory node. The Junction Box can plug (via an underwater mating connector) into any observatory node that can supply 300 to 400 VDC of power and either copper 100 Megabit Ethernet or fiber optic Gigabit Ethernet communications. An over-voltage protection circuit absorbs transmission line voltage transients, allowing the Junction Box to be located up to 10 km from the node.

By designing a modular architecture for the Junction Box, instrument ports can be configured with a range of voltage, power and communications options that will meet current and future instrument requirements. As the project progresses, ports can be re-configured to support new instruments in the field.

Building on designs used in the successful VENUS project and a rigorous test and verification process, the NEPTUNE Junction Box can be expected to provide reliable operations over its design life of 10 years.

REFERENCES

[4] NASA transportation requirements in Table 1 from NASA SP-8077