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Developing an Underwater Acoustic Array System for the Northern Watch Technology Demonstration Project

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IMPORTANT INFORMATIVE STATEMENTS

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Abstract

The development of low-cost underwater acoustic array systems for the northern watch technology demonstration project is discussed. Developments since the end of the TDP project include upgraded quantization from 16 to 24-bits, an increased sampling rate range from a few Hertz to 240 kHz, reduction in power requirements for each node and the array controller (1.5W), improved digital bus structures with extra data and power pairs, and modernized interfaces including Ethernet and universal serial bus. The arrays for the Northern Watch project have been developed by Omnitech Electronics Inc. as prime under contract to DRDC. The arrays have undergone two prototype developments. The original array design was based on an absolute minimum cost and made extensive use of standard plastic piping and resin materials for the mechanical structure. The new array design also makes use of connectors to allow for hydrophone replacement.

Résumé

Le présent document examine le développement de réseaux acoustiques sous-marins à faible coût pour le Projet de démonstration de technologies (PDT) de surveillance du Nord. Les développements effectués depuis la fin du PDT comprennent une quantification améliorée de 16 à 24 bits, une plage accrue du taux d’échantillonnage de quelques hertz à 240 kHz, une réduction de l’alimentation pour chaque nœud et le contrôleur de réseau (1,5 W), des structures de bus numériques améliorées avec des données supplémentaires et des paires d’alimentation, ainsi que des interfaces modernisées comprenant des bus Ethernet et des bus série universel (USB). Les réseaux pour le projet de surveillance du Nord ont été élaborés par Omnitech Electronics Inc. en vertu d’un contrat avec Recherche et développement pour la défense Canada (RDDC). Ils ont fait l’objet de deux développements de prototypes. La conception initiale du réseau était fondée sur un coût minimum absolu et une grande utilisation de tuyaux en plastique standard et de matériaux de résine pour la structure mécanique. La nouvelle conception du réseau emploie aussi des connecteurs pour permettre de remplacer les hydrophones.

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DEVELOPING AN UNDERWATER ACOUSTIC ARRAY SYSTEM FOR THE NORTHERN WATCH TECHNOLOGY DEMONSTRATION PROJECT

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1. INTRODUCTION

1.1 The Northern Watch TDP

The Northern Watch TDP is a $30M, multi-laboratory project to demonstrate integrated surveillance over a portion of Barrow Strait near the southwest corner of Devon Island for an extended period of up to 1-year duration. The original project concept is described in the paper by Forand *et al*. [1]. Recently, the project objectives have been extended beyond those originally planned. The biggest difference between the original project and the current plan is the requirement for up to a 1-year period of continuous unmanned operation.

This change in the project's objectives has required a steady series of improvements to the base camp on Devon Island. This summer a team from DRDC Atlantic and the Canadian Forces are making major additions to the base camp. A large kitchen and mess facility, improved waste management, road construction, and additional sleeping and storage facilities are being constructed. In the coming years a 25 kW unmanned power generation facility will be installed at the camp. This power system will be remotely operated and will make use of three medium-sized diesel generators with a large fuel storage capacity. An expanded effort in system integration and autonomy is also required. Two sensor habitats will be constructed; one for the underwater sensing system and a second larger and more elaborate habitat for the surface sensor systems, which will be located on a hillside above the main camp area. A southern operator's station, to be located at DRDC Atlantic, will be established to monitor the camp facilities and receive the integrated data and detection reports. As a result of the changes, the project timeline has been extended through to March 2016.

1.2 The Underwater Array System

The underwater sensing portion of the Northern Watch TDP is being provided by ruggedized Canadian Rapidly Deployable Systems (RDS) digital arrays [2,3,4]. Two, approximately 160-m long, arrays will be deployed on the seafloor near the southwest corner of Devon Island in summer of 2013 or 2014. These arrays will be powered from shore and data from the arrays will be transmitted through copper cables with bi-directional telemetry repeaters. The cables will terminate in the Underwater Sensor System (UWSS) habitat where the data will be processed, recorded, and passed on to the system integration processor located in the habitat for the surface sensors. The arrays must be capable of operating continuously for up to 1 year and may have to remain operational for a period of at least two years during which they may be turned on or off depending on requirements of the TDP. The UWSS must be cost effective, provide a command and control path, and send the array data to the system integration processor where it will be analyzed and integrated with data from other sensor systems. Further details on the UWSS are provided in an initial array sensor system design concept document [5].

2. Northern Watch RDS Arrays

2.1 The First Array Prototype Design

The arrays for the Northern Watch (NW) project have been developed by Omnitech Electronics Inc. as the prime contractor to DRDC. Omnitech has licensed the array technology and has sold several systems to industry and other government institutions [6].

The NW arrays have undergone two prototype developments. The original array design, shown in Figs. 1 & 2, was based on absolute minimum cost and made extensive use of standard plastic piping and resin materials for the mechanical structure. The initial array design included two tri-axial fluxgate magnetometer nodes and an underwater electric potential (UEP) node. These electromagnetic nodes are visible in Fig. 1 as the larger plastic cases.

Figure 1. The initial lowest-cost array design.

Each array was built with 48 hydrophones arranged in three, octave-spaced, nested-apertures. Each sub-array employed 24 hydrophones. Together the three sub-arrays provide coverage of the low-frequency acoustic spectrum from a few Hertz to about 700 Hz.

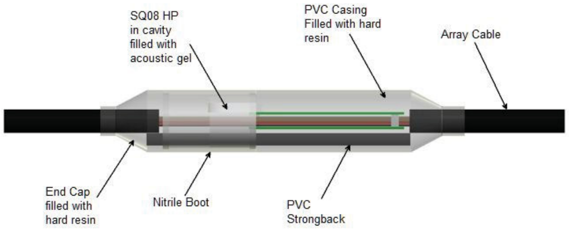

Figure 2. A sketch of the original hydrophone node design.

Although the initial mechanical design was sufficient for pressure effects and the stresses of deployment, the arrays began to allow water to leak into the hydrophone nodes after they were deployed. The arrays operated for approximately 2 weeks before they were permanently shut down. While the arrays functioned, valuable supporting data were collected by the operating hydrophone nodes [7].

Even as one or more nodes began to short-circuit the main digital bus, data from other nodes were still received. The system was able to maintain partial array operation by adjusting the current limit settings within the array. As the water found additional leak paths and seeped along the interior of the cable we were able to watch a slow degradation occur.

A forensic analysis of array failure was conducted [8] after the components were recovered. Careful inspection and dye penetrant testing revealed that material chemical incompatibilities had provided unexpected leakage paths. The incompatibility of the many plastics and resins along with some resin contamination, off-gas bubbling, and construction practices led to the array failures.

2.2 The Telemetry Cables

The arrays are connected to the shore control system through ordinary gopher-proof copper telephone cables. Two cables are used in the NW UWSS: one for each array. The cables supply operating power to the arrays and provide a command and data telemetry path. Each cable is capable of supporting two arrays or can provide redundancy in the event of a component failure in one of the telemetry channels. This choice of cable was dictated by previous successes in underwater applications. Another benefit was that these cables are inexpensive and can generally be acquired in quantity on short notice. The cables are a nominal length of 9 km each.

A high voltage DC-to-DC converter system was used to minimize resistive cable losses. Even so, the cable application was only feasible because the RDS arrays are very efficient and only require approximately 4.5 W to operate the 48 hydrophones, 2 magnetometers, single UEP sensor, and Array Controller/Receiver (ARC).

Most of the UWSS power is expended in the telemetry repeaters, shown in Fig. 3. Two repeaters are required to drive the dual channel, 3.75 Mbps data through the 10-km long cables. A third cable driver is located in the Array Extenders, which are similar to the repeaters except that they also house an ARC that is directly connected to an array. Each cable driver can handle up to 4-km of telephone cable.

The array telemetry cables have worked out extremely well. We have already successfully deployed a complete system for a 1-year interval without any issues. Some corrosion problems in the metal cages did occur and it was discovered that some metal was not as specified. X-ray inspection has turned out to be required to ascertain that the metals are of the proper type.

Figure 3. The array extenders and telemetry repeaters.

The only other problem with this cable system was found to be due to the use of polyvinyl-chloride (PVC) materials for the pressure cases. Some case lids were made with a more rigid PVC material containing less plasticizer than expected. These lids failed during pressure testing. Chemical tests have been found to be necessary to ensure that the proper materials are being used in the construction.

As this document is being written, a second, long-duration test deployment is about to be recovered after a 2-year dwell on the seafloor. The results of this test are expected to provide sufficient information to ensure a reliable solution for the NW UWSS cables. No major changes are anticipated for the telemetry cables and repeaters.

2.3 The Second Array Prototype Design

A second generation array design was undertaken that limited the role of plastics and resins. Although we believe that a successful, and very inexpensive, array design is

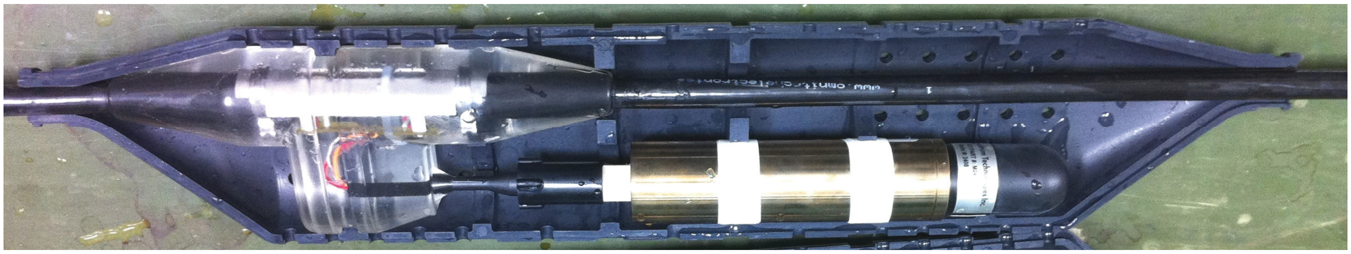

Figure 4. New cantilevered hydrophone node mechanical design.

possible with resins and plastics, we simply haven't had the time or budget to pursue this direction for the NW arrays.

The new mechanical design employs Nickel-Aluminium-Bronze (NAB) canisters for the electronics, commercially constructed hydrophones with screw mountings and O-ring seals, new transparent resin materials with an internal metal support skeleton for cable breakouts, a tough clam-shell protective casing, and a cantilevered hydrophone arrangement as shown in Fig. 4, which is a photograph of an early prototype hydrophone node.

The new array design also makes use of NAB connectors to allow for hydrophone unit replacement and testing of the cable structure without the hydrophones. No dissimilar metals are used in the construction.

The cantilevered design removes the hydrophone from the direct influence of cable tension induced strains. This helps to reduce the background noise, but results in a vulnerable appendage that would be unlikely to survive deployment or recovery operations. A free-flooding casing made of a semi-compliant polymer is used to support the hydrophone. The casing is made in two interlocking parts that are held together with tough locking bands similar to cable ties. The casing is locked in position on the cable by the resin cable breakout. The casing is extremely durable and the resin bond to the cable is now so good only a catastrophic pull is likely to cause any damage. The cable fails at roughly 1600-lb tension. Acoustic calibration tests conducted with and without the casing have shown that our current design is almost completely acoustically transparent. A final polymer formulation variation should remove the observed low-amplitude (<1 dB) response enhancements in the hydrophone pass-band.

The resin cable breakout was the result of a substantial effort on the part of Omnitech Electronics, who in consultation with one of the authors, chose a new resin material and developed a casting process that results in dramatically better bonds to the cable jacket and other parts.

Resins are difficult to deal with. There must absolutely rigid adherence to process, techniques, and practices. The working space must be absolutely clean of dust and fibres. Clothing and hair must be covered. The space must be well ventilated with dehumidified air. Both resins and parts to be encapsulated must be pretreated and the moulding process requires control of temperature throughout. The use of the transparent resin was found to be beneficial as flaws and bubbles became visible, which would otherwise have been missed.

The use of a metal support skeleton within the encapsulation was a critical component. Initially, its presence caused potential leakage paths by the generation of bubble trains, but once the bubble formation was controlled the support and mechanical strength of the skeleton was apparent in preventing repetitive strains from causing damage.

The use of connectors, commercially manufactured hydrophones, and pressure canisters has roughly tripled the cost of the original minimal cost array design; however, every part of the array is now serviceable and is much more robust. Even the resin breakout can be carved away to make repairs and then re-cast in a mold with excellent results.

The electronic components for this second array design remain largely similar to the first arrays, except that additional data buses are added to provide for an isolation capability of sections of the array in the event of bus shorts. The first array made use of two data buss pairs, while the new arrays will use four data buss pairs.

The mechanical and electrical changes have resulted in a very robust, and still relatively low-cost, array design.

3. Acoustic and Mechanical Testing

The electronic assemblies used in the RDS arrays are routinely tested and *burned in* by running the node electronics at both elevated and reduced temperatures. This approach has been used from the early days of the development of the digital RDS array technology. The results have been a highly reliable electronic system. In the roughly 1800 digital hydrophone nodes that have been constructed to date, we are unaware of any that have failed, except for those units that have suffered water leaks, been crushed by excessive pressure, or inadvertently connected to an inappropriate power source. The pressure failures that were observed occurred in the development of an uncased hydrophone for use at hydrostatic pressures of up to 8200 psi [9].

Pressure testing and pull testing has been used with all of the array components that have been built previously; however, the acoustic and mechanical testing applied to the new array design has been dramatically increased. The first design arrays were calibrated in the ocean and subjected to a hydrostatic pressure test. These arrays survived this testing and then later failed after a short time in the ocean. The failure was partly due to the passage of time, which allowed for the chemical issues to affect the resin bond to neighbouring materials, but also because the tests were too safe and did not subject the array components to a variety of stresses and strains from working loads, thermal effects, and pressure.

To ensure that the arrays are long-lived, short prototype array segments and component assemblies have been produced and subjected to extensive pressure, strain, temperature, and calibration tests. Ideally, all of these stresses should be simultaneously and dynamically applied. Unfortunately, this is not possible at present.

The new array segments have been repeatedly acoustically calibrated at intervals during the stress testing to ascertain not only mechanical survivability, but also electronic and acoustic reliability. No significant changes were observed over the testing period.

The new array segments have been pressure tested to ten times their operational depth requirement of 200 m over 24 cycles. Interspersed among the pressure tests have been a sequence of freezing and heating of wet soaked components. The intent was to try to open cracks and create leakage paths. The arrays were operated continuously during testing to ensure stable data telemetry and acoustic sampling.

In addition, the array segments have been operated while being dynamically mechanically strained (Fig. 5) to more than 600 lb or about four times the stress loads expected during deployment. Pressure and calibration tests followed the mechanical pull tests. All tests were successfully passed by the prototype units. Finally, the segments were mechanically strained to destruction at over 1600 lb, while still operating to determine the failure mode, symptoms, and ultimate cable strength.

While we currently believe that the new array design is more than adequate to meet the mechanical loads of deployment and operation, we will continue to test prototype array sections for extended periods over the next two years to ensure that there is no significant degradation of the materials involved.

4. Deployment and Recovery

Array deployment is carried out by hand at slack tide. A dumb barge, equipped with safety rails, and pushed by a powered barge, Fig. 6, is the preferred deployment platform. Figure 1 shows the working surface of the dumb barge with an array laid on deck ready for deployment. At the far end of the barge are three wooden reels mounted on stands. Each reel holds a nominal 3-km length of telephone cable.

Deployment begins out at sea with a small anchor attached to a length of line that is approximately twice the depth of the water. Once the anchor is firmly biting into the sea floor the line is deployed from astern as the powered barge tows the dumb barge. The array components are deployed by hand while maintaining a tension of up to 150 lb pull. It requires experience to ensure that the array is not being dragged or piled on the sea floor. Length markings and GPS positions are constantly monitored to ensure that the barge location and scope of array system overboard match the deployment plan.

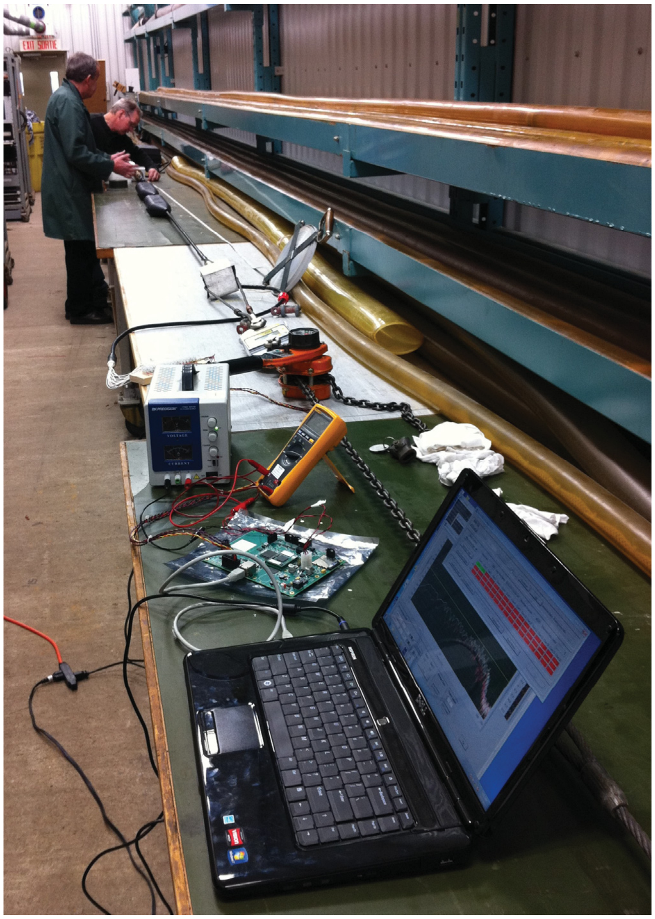

Figure 5. Array segment pull testing.

The array deployment is immediately followed by the deployment of an Array Extender, Fig. 3, and the first 3-km length of telemetry cable. Throughout the entire deployment process, the arrays are energized and reporting status to a monitor station. Figure 7 shows one of the telemetry cable segments being deployed.

Rechargeable batteries and a wireless array controller are mounted on the side of each reel. Using this powered array deployment technique, issues with the array are immediately known.

When the 3-km length is almost fully deployed a repeater unit is connected to the next cable section, the array is turned off, and the barges hold position for a few minutes while the end of the in-water cable section is attached to the repeater. Once the repeater connects the two cable sections, the next wireless array controller is used to power on the repeater and conduct a system test. If this test is passed, the array is then re-powered and the entire system status is checked. If everything is working properly the barges continue on the deployment track as telemetry cable is paid out.

Figure 6. **Dumb and powered barges.**

Figure 7. **Telemetry cable deployment.**

Gloved hands on the cable and reel are sufficient to control the feed rate of the cable. A careful watch of the track and cable scope is maintained. It is very hard to know when water currents are pulling the cable out unless the motion of the barge and cable scope are continuously compared.

On reaching the shore, the telemetry cable is mated to another cable segment that has been previously run through a bored hole in the bedrock. One end of this hole is well above high tide on land, while the other end is in sufficient depth of water to avoid contact with ice keels near the shore. This bored hole is the only known successful method of protecting cables at the water edge from the action of heavy ice in the winter season.

Two different techniques are used to recover the arrays or to make repairs to deployed systems. The complete recovery of an array and telemetry cable is accomplished with a large powered reel as shown in Fig. 8. Motion of all parts is restricted to slow speeds for safety considerations. Recovery takes 6-9 hours and can be started from either the land or sea ends of the cables.

An acoustic release is used near the first deployed anchor to allow the far end of the array to be recovered when desired.

Figure 8. **Array system recovery technique.**

Figure 9. **Using the mule to under-run an array cable.**

Repairs to components are made using the two barges equipped with a rubber-tired mule as shown in Fig. 9. The barges are driven along while the mule lifts the cables and pulls the components up from the seafloor. The mule can run in either direction and an entire 9-km cable can be under-run in 3 hours.

5. CONCLUSIONS

The new mechanical array design for Northern Watch appears to bring the system packaging development in line with the electronic development. Extremely robust, low-cost arrays are now possible.

The telemetry cable with associated repeaters and array extenders has been shown through extended deployment trials to be a sound and reliable means of powering the arrays and transporting data to the shore station. Even if we find failures in the test components that have been deployed for a 2-year period it is certain that we will now know enough to construct new cables and repeaters that will last for a multi-year period.

Multiple deployments, repairs, and recoveries have been made to the test gear for NW. The deployment equipment is simple and low-cost, but does require good weather conditions for operations. In the Arctic prolonged periods of poor weather are not infrequent and it is necessary to watch conditions closely for the right opportunity. The technique of under-running the array cable using a rubber-tired mule is surprisingly easy and effective. Multiple under-run events have been successfully carried out with no damage to the array system.

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