# DEVELOPMENT OF DIGITAL ACOUSTIC SENSOR FOR REMOTE APPLICATIONS

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## ABSTRACT

Centralized sampling acquisition systems are commonly used to acquire and digitize data from arrays of acoustic sensors. These systems have centralized/co-located connection points for multiple sensor channels and contain digitization and processing electronics that can be shared across these inputs. While this system architecture can simplify the electronics design, it has several intrinsic properties that degrade the data quality and increase system complexity for certain application parameters. Advancements in high speed, low power electronics have made distributed sensor digitization feasible for applications with limited available power such as remote underwater surveillance and autonomous underwater vehicle systems. This paper explores some limitations of centralized systems in underwater acoustic applications and presents some examples of where the benefits of distributed digital sensors were realized.

## RÉSUMÉ

Les systèmes centralisés d'acquisition d'échantillons sont couramment utilisés afin d'obtenir et de numériser les données en provenance des réseaux de capteurs acoustiques. Ces systèmes sont dotés de prises centralisées/adjacentes pour de multiples canaux de capteurs et contiennent des électroniques de traitement et de numérisation auxquels tous ces canaux ont accès. Tandis que ce système d'architecture peut simplifier la conception électronique, il possède plusieurs propriétés intrinsèques qui dégradent la qualité des données et accroissent la complexité du système pour certaines applications. Des avancements au niveau de l'électronique à haute vitesse à faible puissance ont permis la numérisation à partir de capteurs décentralisés pour des applications ayant une puissance restreinte, telles que la surveillance sous-marine à distance et les systèmes de véhicules sous-marins autonomes. Cet article examine certaines limites des systèmes centralisés dans des applications acoustiques sous-marines, et présente quelques exemples de situations où les avantages des capteurs numériques décentralisés ont été réalisés.

## 1. INTRODUCTION

Acoustic sensor arrays are used in a variety of complex underwater applications from static environmental monitoring antennas to non-linear towed hydrophone arrays.

In centralized sampling systems, piezo-electric acoustic sensors are distributed throughout the array and wired on individual electric pairs to a central data acquisition unit. In analog piezo-electric arrays, signals from the sensors are typically transmitted as analog current through a dedicated loop or as a pre-amplified voltage on a differential pair.

Within the past decade, high speed digital sampling, processing and transmission electronics have been relatively high cost and have had relatively high power consumption. This limited the use of sensor-integrated digitization to systems with high capacity power sources and large budgets. The proliferation of portable, battery powered handheld computing devices and phones has led to rapid advancements in low power, small, cost effective electronics well suited for acoustic data acquisition and processing. Distributed digital sensor arrays today can be designed and manufactured with little or no design overhead and similar, or even reduced, circuit complexity. Digital sensors can achieve advantages over analog equivalents in many areas. High level concept comparisons and application examples where digital acoustic sensor arrays have been successfully deployed are given in the following sections.

## 2. ELECTRO-MAGNETIC NOISE

Electro-magnetic interference (EMI) is a common source of signal noise in measurement systems. The magnitude and spectrum of the interference depends on several factors that are often outside the control of the acoustic system engineer or scientist. Influence on analog signals from EMI generated from external sources can be minimized by electrical shielding, shortened cable runs,

and other techniques. Often acoustic sensors are integrated into existing systems or spaces where removal of noise sources or relocating sensors is not possible. The levels and sources of EMI are not known as systems are designed for use in a multitude of spaces, locations and installations. EMI is not limited to high frequencies or nearby sources. Power line frequencies from high voltage transmission lines and electric railways can produce detectable interference over large distances in sensitive electronics. This interference can be detectable on analog acoustic arrays deployed in near littoral waters and in harbors.
When the acoustic system has to operate in environments with potential sources of EMI, digital data transmission from sensors ensures data collected at the sensors is not degraded and removes a variable error source from the system.

## 3. SMALLER CABLES AND CONNECTORS

Omnitech Electronics has designed acoustic arrays with more than 60 digital hydrophones over lengths greater than 1 km using fewer than five conductor pairs. If these arrays were built using analog sensors, the cable would require more than 120 conductors and connector pins. The number of conductors in a cable increases the size and weight of the cable which makes transport, handling and deployment of the array more difficult.

Since digital hydrophones can share power and data wires, the number of required conductors can be as few as four (two pairs) depending on the length of the array, sampling rate, and data capacity of the cable and transceivers. Fewer conductors allows for smaller, lighter, lower cost, and more flexible cable as well as simpler, smaller and less expensive connectors. In bottom deployed acoustic arrays, the smaller, lighter cables can be deployed from small vessels without any handling equipment. For AUV and other applications, small cables and connectors are more easily integrated into, and routed through, existing spaces.

## 4. RELIABILITY AND REDUNDANCY

All else equal, a cable with fewer conductors and connector pins has fewer points of failure and is more reliable than an equally made cable with more connections [1] . In addition, a digital signal is more easily paralleled to allow for redundancy. Omnitech has added redundant digital communication and power to systems where customers were worried about possible cable damage, a feature not economically possible with high sensor count analog arrays.

The level of EMI adds to the noise floor and reduces the effective dynamic range of the sensors. Relative immunity to EMI is a major advantage of digital signal transmission. In distributed digital systems, all acoustic signals are digitized as close to the analog sensor as possible thereby reducing the susceptibility to EMI. Digital data is transmitted to a central processing and/or data recording unit. As a digital signal, the data is immune to small signal EMI.

## 5. PRICE PER PERFORMANCE

As sensor count and cable distances increase so does the cost of cabling and connectors. In analog sensor arrays the cost of long cables can be the most significant cost of the system. With digital sensors, the cable cost represents a much lower portion of the total system thus significantly reducing the cost of large systems allowing a redistribution of funds away from costly cables to improved sensor performance. Funds that would be spent on passive cabling can be better spent on increased sensitivity, additional sensors, higher sample rates, increased processing, etc.

## 6. LOSS-LESS REPEATERS

Cable lengths on a digital data bus can be extended through the use of repeaters or optical converters without any additional signal loss or distortion. With analog sensors, adding cable length adds output capacitance, resistance and inductance and will affect the signal properties and frequency response of the sensors. Analog repeaters add signal distortion and increase power consumption and ultimately limit the performance of systems with long cable runs.

## 7. INTEGRATED ACOUSTIC CALIBRATION

Digital acoustic sensors can be made ‘smarter’ than analog sensors. Each individual sensor in an array can be configured with a unique identification number that allows that particular sensor to be tracked and correlated to recorded data without any error prone external data records. Furthermore, Omnitech’s implementation of the digitalization circuitry allows for in-sensor acoustic calibration. Coefficients for calibrated sound pressure levels, in engineering units, can be stored in each sensor and all acoustic outputs adjusted ‘in-sensor’. In this approach, calibration factors remain with the sensor wherever that sensor is used and requires no externally stored information. This feature is impractical to implement and error prone in a centralized system in which the analog array can be detached and interchanged with the digitization circuitry and/or calibration software.

## 8. Mixed Signal Sensors

Some detection, monitoring, diagnostic and classification applications benefit from simultaneously sampled, mixed signal sensors. With distributed digital arrays, multiple types of sensors can be integrated into the acoustic array and simultaneously sampled on a signal cable. Omnitech has successfully integrated both magnetic and electric field sensors along with high resolution pressure, heading, optical and temperature sensors in to acoustic arrays. Digital sensors can be configured with sensor identification data and parameters. Upper level systems and software can read this data from the sensors thus reducing the amount of user entered information in reconfigurable and traceable systems.

## 9. Sensor Design and System Flexibility

Omnitech has been developing distributed digital sensors for acoustic and mixed sensor systems and arrays since 2001. Initial arrays were developed to be disposable, and rapidly deployable in shallow water (< 200 m depth). These systems were used in technology demonstration projects with Defence Research and Development Canada as part of Underwater Canadian Acoustic Research Arrays (UCARA) and Rapidly Deployable Systems (RDS)[2] projects. Omnitech continues to make significant improvements to design concepts from these projects and has demonstrated the benefits of distributed digital sensors in a variety of custom applications. Since 2007, Omnitech has refined system components to create a flexible platform for highly customizable systems. The power efficiency achieved through use of new advances in power efficient electronics allows these digital systems to be used in applications with limited available power.

The advantages of distributed sensors systems can be realized in more than just underwater applications. Any system with multiple analog sensors and central data collection can benefit. Example applications include building monitoring, seismic surveys, microphone arrays, large area surveillance, noise source localization and diagnostic measurements.

## 10. Real-Time Gain Control

Most acoustic sensors in conventional arrays have a fixed gain preamplifier that drives signals to the central digitizer. If this preamplifier gain is too low, small signals will be lost in the system noise whereas if it is too high, larger signals are distorted by clipping.

With Omnitech's distributed digital sensors, all gain stages can be adjusted in real-time to maximize the dynamic range of the system according to the optimal settings required for the given measurement. For example, Omnitech's 24-bit deep water hydrophone has real-time gain control settings from 0 – 90 dB in 10 dB steps. This flexibility allows the same system to measure very small and very large sound pressure levels without hardware changes in the array. The same digital array can be deployed for measuring seismic blasting or ambient noise without modifications.

## 11. Low Cost Monitoring Arrays

Omnitech has designed and built low cost shallow water (< 200 m) arrays for use in harbour and coastline surveillance[3] and asset protection. In these arrays, sensor elements and digitization electronics are molded directly into the cabling as shown in Fig. 1. The resulting arrays are light weight, rugged and can be deployed by hand from small vessels and connected to surface, shore or small underwater data collection and/or processing units. Omnitech has delivered these arrays with various sensor configurations of 48 single frequency or mix sampling rate acoustic, environmental, and orientation sensors and with connector breakouts and for customized low frequency and high frequency electro-magnetic sensors.

**Figure 1. Low cost acoustic array, elements (darker), molded directly into the cable**

## 12. Long Range Acoustic Bearing for AUVs

Omnitech has used digital hydrophones to create a long range acoustic bearing system (LRAB) using a three axis direction acoustic array. LRAB designed for under-ice operation in an AUV and was used in DRDC's project Cornerstone in support of the United Nations Convention on the Laws of the Sea (UNCLOS) data collection for Natural Resources Canada. These arrays were able to accurately calculate a homing bearing to a 190 dB, 1350

Hz sound source at ranges of more than 50 km and survive to depths greater than 3 km under the ice in the Canadian Arctic. A photo of the AUV under the ice during Cornerstone is shown in Fig. 2.

**Figure 2. AUV under the Canadian ice sheet, using LRAB acoustic bearing array**

The arrays had to function in close proximity to high power bottom sounding sonar and electronics and relatively high levels of vehicle noise. Each array is paired with a custom low power embedded processing board that runs the array data collection and processing software and communicates with the vehicle control computer via Ethernet. The entire system uses less than 2 W from the AUV power supply. The array used in the Project Cornerstone AUV, is 17.5 inches in diameter and uses seven (7) digital hydrophones connected to a 4-wire connector through the AUV pressure hull. This array is shown mounted in an AUV nosecone in Fig. 3. Omnitech has also developed a reconfigured version that is 5.8 inches in diameter for smaller AUVs with shorter homing range and reduced depth requirements. Fig. 3 shows

**Figure 3. Digital LRAB Array mounted in AUV nose cone (left), Deep water digital hydrophone (right)**

## 13. ARCTIC SURVEILLANCE

Arctic sovereignty has become a high profile priority for Canadian and international governments, companies and communities. Omnitech has developed acoustic arrays designed for multi-year deployment in remote arctic locations.

**Figure 4. DRDC Artic Research Camp, Devon Island, NU**

These arrays are part of a technology demonstration project with DRDC Atlantic[3] . A photo of the remote camp for these trials is shown in Fig. 4. The low power design of Omnitech's digital arrays is critical in remote locations such as the Arctic. Even when arrays are tethered to shore, power over long-term, unmanned deployments is limited and must be supplied by onsite power generation that can survive and operate through Arctic winters.

## 14. AUV TOWED ARRAYS

Digital distributed sensors have a significant advantage over analog hydrophones in AUV applications in several regards. Digital arrays can make use of smaller connectors through bulkheads to dry bays in the AUV since data from dozens of sensors can be multiplexed onto a signal communications data bus. Electronic components required for filtering and sampling the acoustic data are distributed into the hydrophones rather than located in the dry bay of the AUV. With all else equal, this reduces the required size of the internal electronics and saves space that is often at a premium within the vehicle. All sensitive analog electronics are located in the array, away from potential EMI sources in the AUV such as switching power supplies, pulse-width modulation (PWM) based servo motor controllers and partial duty cycle sounders or sensors that create periodic power loads. Modern digital electronic components are small compared with the low-noise, high-sensitivity piezo-electrical hydrophones elements. As a result., integrating the digitization circuitry with the analog amplifier can be done with only a marginal increase in the size of the sensing element in the array.

## 15. DEEP WATER ACOUSTIC ARRAYS

In water depths greater than approximately 1000 m, the hydro static pressure becomes too high for encapsulated electronic components to survive without being enclosed in a pressure vessel versus epoxy or urethane encapsulation often used for shallow water sensors. In Omnitech's deep water products all electronic components are enclosed in connectorized pressure vessels and all individual hydrophones are pressure tested before integration into the overall system. Digital data from deep water sensors can be transmitted to shore, surface buoy, or stored in underwater data collection units. Omnitech's deep water array and data collection unit can operate for up to six weeks recording continuous data from 64, 24-bit digital hydrophones at 5 kSp/s plus a high frequency hydrophone at 40 kSp/s.

## 16. CONCLUSION

Distributed digital sensors offer significant advantages over centralized sampling of analog sensors in multi sensor systems common to underwater acoustic and other applications. These advantages have been realized in many successful projects that would not have been manageable or cost effective using distributed analog arrays. Low power modern electronics allow digitization and communication circuitry to be integrated into sensing elements with minimal increase in size. Smaller cables and reduced connector pin counts reduce the handling requirements, weight and cost of wiring while also increasing reliability of connections. The advantages of distributed digital sensors should be considered when designing any acoustic or mixed signal measurement system.

## 17. REFERENCES


[1] Military Standard, MIL-HDBK-217F Notice 2, (1995) "Military Handbook – Reliability Prediction of Electronic Equipment", Section 17.1., US Department of Defence.

[2] Rapidly Deployable Systems Array Technology. Defence Research and Development Canada Atlantic Fact Sheet NO. NetALS0108, 2008.

[3] G.J. Heard, N. Pelavas, C.E. Lucas, I. Peraza, D. Clark, C. Cameron, V. Shepeta ,"Development of Low-cost Underwater Acoustic Array Systems for the Northern Watch Technology Demonstration Project"., , Canadian Acoustics Vol. 39(3), pp 200 - 201, (Sept. 2011).