# ENABLING WIRELESS SENSORS FOR SHIPBOARD MEASUREMENT APPLICATIONS

Ayodele Lawal*, Pete Cooper*, Graeme Awcock**, Simon Busbridge**, James Spenceley*, Daniel Rodriguez Sanmartin*, Elias Stipidis**
*PSM Instrumentation Ltd, Burrell Road, Haywards Heath, West Sussex, RH16 1TW, UK
E-mail: ayodele.lawal@psmmarine.com, a.lawal@brighton.ac.uk
**The University of Brighton, Faculty of Science and Engineering, Lewes Road, Brighton BN2 4GJ, UK

## Abstract

*PSM Instrumentation Ltd. – a marine-focused instrumentation company, is working together with the University of Brighton in a collaborative (KTP) project aimed at incorporating wireless technology into their existing range of liquid level sensors used in shipboard tank gauging applications, etc. With the growing trend in the deployment of wireless technology in industrial and commercial environments, its introduction in the marine industry could save tons of copper cables by using marine-compliant wireless sensors for various monitoring and control functions involved in the safe operation of the ship.*

*This paper describes the efforts being made to achieve regulatory compliance by leveraging standards-based wireless communications technology. Furthermore, the paper gives insights into how an existing sensor's electronics have been re-designed to operate at ultra-low power levels in order to facilitate extended battery lifetimes and/or 'fit-and-forget' energy harvesting solutions. For the intended application, it is critical that this must be achieved whilst, at the same time, maintaining compliance with intrinsic safety and electromagnetic compatibility regulations.*

## 1 Introduction

PSM Instrumentation Ltd. design, manufacture and supply measurement and control instrumentation primarily for the marine industry. The product range includes sensors, transmitters, systems and controls to measure liquid level, pressure, flow, temperature and density. Traditionally, for a deployment of such marine/process instruments, tons of cable snake their way through cable trays, termination racks, cabinets, enclosures and conduits. However with the availability of low cost microcontrollers suitable for marine instrumentation, the bulk of these cables have since been removed as a result of adopting a bus-connected architecture. Simultaneously, the quality and amount of data available for monitoring and control operations involved in maintaining the ship in its normal operational and safe conditions is enhanced.

The growing trend in the deployment of wireless technologies in industrial and commercial environments has inspired marine instruments suppliers, including PSM, to consider the prospects of using that technology to further reduce the amount of cabling used for shipboard measurement and control instrumentation. PSM is currently engaged in a collaborative (KTP) project with the University of Brighton aimed at incorporating wireless network technology into their existing range of digital products.

The remainder of this paper is organized as follows. Section 2 describes the evolution of shipboard instrumentation system. Section 3 discusses the application requirements any wireless instrumentation used for monitoring and control onboard ships must satisfy. In Section 4, we discuss the essential enabling step of re-designing an existing conventional sensor's electronics to achieve operation at ultralow power levels and then present the architecture of the wireless solution for shipboard tank gauging applications. Section 5 presents the conclusion. Future work is given in Section 6.

## 2 Evolution of Marine Instrumentation Systems

Conventionally, measurement and control instrumentation in the marine industry have been implemented using analogue point-to-point interfaces as shown in Figure 1. In this architecture each sensor or actuator has an individual cable connection to the central control unit; thus utilizing a considerable volume of cabling on a typical ship. The analogue architecture then evolved into a pseudo-digital Highway Addressable Remote Transducer (HART) system which superimposes digital signals on top of the analogue interfaces. The HART system, though not reducing the amount of cable used compared to the analogue system, provides useful device identification, configuration and diagnostics information which enhances system operation and management.

To reduce the volume of cabling and utilize the benefits of true digital transmission such as networking and system-health monitoring capabilities, the fieldbus technology was developed. This has been widely adopted in many industries including the manufacturing, process automation, automotive industries, etc.

Based on the fieldbus paradigm, PSM has developed a true digital network of intelligent sensors targeted at the marine industry as shown in Figure 2. This has achieved a significant reduction in the volume of cable used for instrumenting a ship.

The next stage in the progressive reduction in the amount of cable used onboard ships is to replace part or all of the fieldbus cabling with wireless network technology.

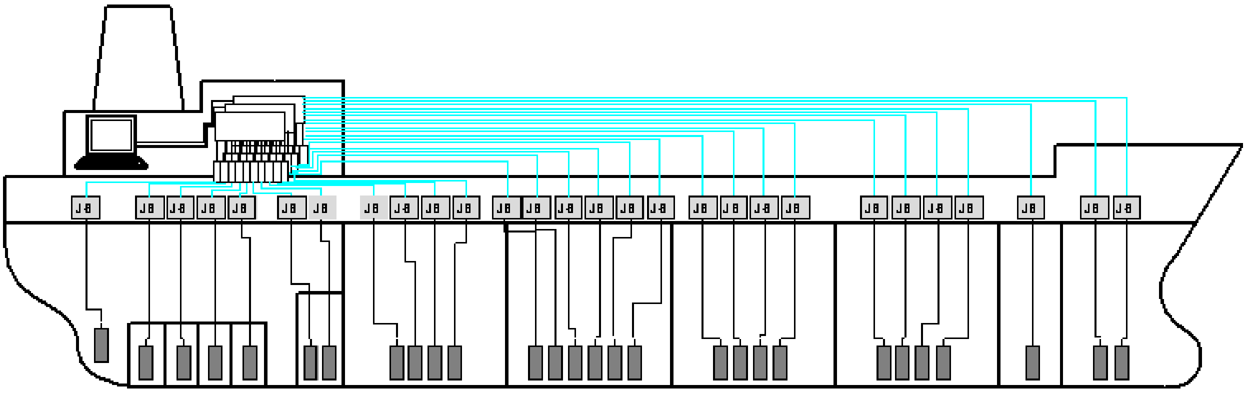

Figure 1: Conventional Analogue System: Each sensor needs a cable loop and intrinsic safety barrier

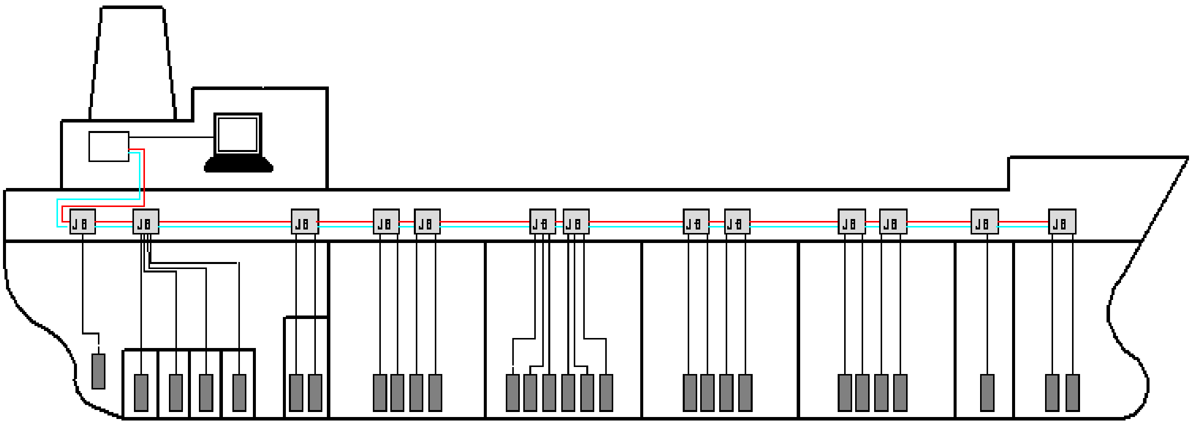

Figure 2: PSM Digital System: One cable loop and intrinsic safety barrier for all sensors

# 3 Requirements of shipboard wireless instrumentation

The use of wireless network technology as a more cost-effective alternative to the fieldbus technology is gaining more attention in the industrial sector. Standards and products targeting many industrial application domains are emerging. Due to the abundance of reflecting metal surfaces in a shipboard environment, it is naturally assumed that wireless technology would not be suitable for data communication onboard ships. However radio propagation measurements conducted by research groups have shown that carefully deployed wireless sensors can operate effectively onboard ships (Nobles and Scott 2003, Kdouh et al 2011).

The KTP project is focused on achieving wireless sensor solutions that can satisfy the reliability requirements of shipboard instrumentation. These typically require the following characteristics:

## 3.1 Robust radio transmission

Low bit error rate (high signal-to-interference-plus-noise-ratio) of the radio signals while transmitting at the level compatible with the electromagnetic constraints onboard ships. The wireless network must be carefully engineered and deployed to mitigate the specific challenging nature of the shipboard environment where metallic bulkheads and watertight doors will interfere with the radio propagation path.

To achieve a reliable wireless connectivity, the system is also expected to implement fault prevention, detection, diagnosis, and correction.

## 3.2 Sensor node autonomy

Low power consumption along with efficient power management capability is required to maximize the battery life of a wireless sensor node. In addition, the idea of self-powering the nodes using ambient energy has been a subject of great interest for both academia and industry. Yeatman (2007) concluded that motion or vibration energy scavenging is an attractive approach to powering wireless sensor nodes in many industrial settings. Similarly, commercial efforts have been lately directed at integrating wireless transmission with energy scavenging as demonstrated by EnOcean and GreenPeak (EnOcean 2011, GreenPeak 2011).

## 3.3 Deterministic channel access

Considering that most industrial and marine operations are time-constrained, the communication technology must be suitably implemented to support such constraints. Thus real-time operation must be achievable with any such wireless solution.

## 3.4 Fail-safe network architecture

The wireless solution is required to be able to adapt to the specific requirements of the deployment environment while providing the necessary level of reliability. This has been found to require the use of mesh-connected architecture as shown in Figure 3. In addition to providing a reliable network, it provides self-organizing and self-healing capabilities which improves the robustness of the system when compared to Figure 2.

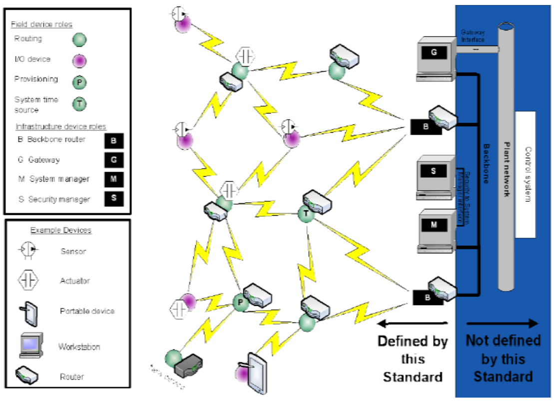


Figure 3: Mesh-connected architecture (IEC/PAS 62734, 2012)

## 3.5 Security

It is important to ensure wireless protocols for marine instrumentation implement sufficient data confidentiality, authenticity, and integrity mechanisms. Since wireless networks are potentially susceptible to cyber attacks, they must provide support for the authentication of network nodes and anti-intrusion mechanisms such as the use of joining key, encryption, etc.

## 3.6 Mechanical robustness

Wireless products must be sufficiently ruggedized for the harsh shipboard environment. For example, due to the nature of activities on a ship that can easily damage any protruding objects, conventional vertically oriented omnidirectional antennas cannot be left unprotected on a ship as would be acceptable in many industrial settings. Similarly, product enclosures must be suitably chosen to withstand the temperature and any hazardous substances of the ship environment.

### 3.7 Marine type-approval

Any wireless solution meant for the shipboard environment must comply with the relevant marine regulations on intrinsic safety and electromagnetic radiation of electronic systems. In particular, any solution for shipboard wireless instrumentation must be mindful of the regulations of the International Association of (Marine) Classification Societies (IACS). Their latest working document on the use wireless technology for shipboard instrumentation stipulates that wireless data communication must employ recognised international wireless communication protocols that incorporate effective security mechanisms (IACS 2010). In addition, it is required that the wireless system comply with the radio frequency and power level requirements of the International Telecommunications Union and the national regulations of all the countries where the ship sails.

### 3.8 Remarks on marine requirements

Several organizations have developed technology specifications to meet similar requirements for the industrial sector giving rise to competing open standards and other proprietary options. Such specifications include WirelessHART and ISA100.11a that are based on the IEEE 802.15.4 radio technology, which provides a good foundation for building low power license-free wireless mesh networks (Al Agha et al 2009).

However, end-users are indifferent about the particular wireless standard being used: WirelessHART, or ISA 100.11A, etc; what matters to them is a reliable, simple and secured wireless instrumentation with fast update rate, long battery life, redundant gateways and short settling time (Lawal 2011).

## 4 Development of marine wireless instrumentation solution

Replacing fieldbus technology with wireless network infrastructure is non-trivial because of the different characteristics of the two systems. Particularly important is that a system based on a (wired) fieldbus technology derives its energy source from the mains supply while a wireless system will require autonomous energy source. This can be achieved by using a combination of energy storage devices (batteries, supercapacitors, etc) and energy scavenging techniques.

To this end, the ongoing project has adopted a bottom-up approach of first re-designing the sensor electronics sub-systems to function at ultralow power levels. Hence, the autonomy of the resulting wireless sensor node with respect to energy source is maximized while also achieving compliance with intrinsic safety regulations.

### 4.1 Ultralow power sensor electronics sub-systems

A typical smart sensor can be represented as shown in Figure 4:

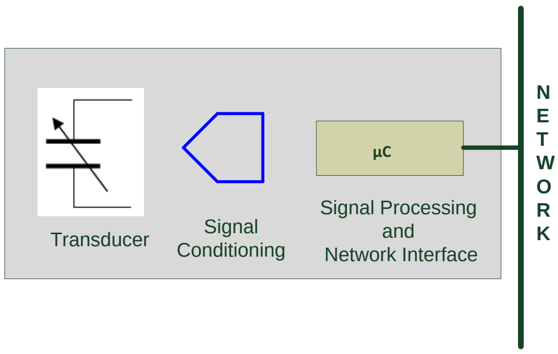


Figure 4: Smart Sensor block diagram

The transducer is essentially a mechanical element that converts physical conditions of pressure, temperature, humidity, etc. to changes in a measureable electrical parameter such as capacitance, resistance, etc. Thus, electrical power consumption of the whole sensor system is reduced by the use of energy-storing rather than energy-dissipating transducer. The project has therefore focused on using capacitance-based pressure transducer.

The signal conditioning and processing sub-systems have a big impact on the power consumption of the overall sensor system. Considerable effort has thus been committed to develop an ultralow power version of these functional blocks taking advantage of advances in power optimization of microelectronic devices and power management algorithms.

Typically, the industrial and marine sectors fieldbus installations employ a minimum device operating voltage of 9V and maximum bus voltage of 32V. This relatively high voltage is understandable given that mains supply normally provides the fieldbus power. However, with wireless network technology where node autonomy is a major requirement, the use of lower voltage becomes important. Thus, the relevant electronics have been re-designed to operate at 2.7 – 3.6V. The resulting sensor front-end board, which produces direct digital outputs, is shown in Figure 5.

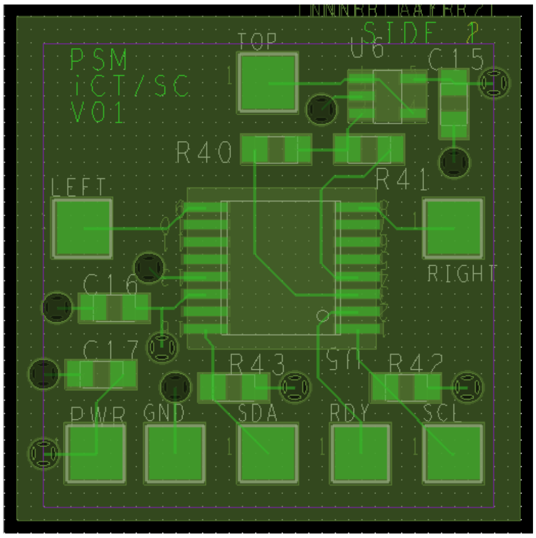


Figure 5: The new ultralow power signal conditioning and first-stage processing board

## 4.2 Modularization of sensor electronics sub-systems

In order to reduce the risk of introducing new devices as well as provide opportunity for future modifications, the project has modularized the subsequent stages of the signal processing and network interface sub-systems of a smart sensor into a stack of electronic boards as shown in Figure 6.

In addition to reducing the physical size of the resulting product, the approach allows additions and/or substitutions of functionalities in the future. For example, protocol adapter boards can be included as add-on modules that can be used as an optional deployment feature.

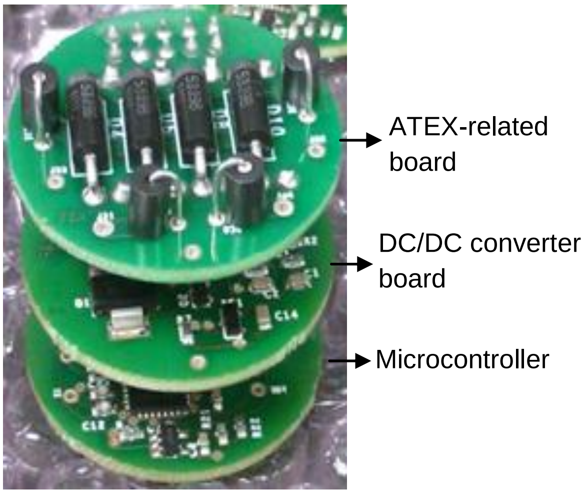


Figure 6: Modularized signal processing (subsequent stages) and network interface sub-systems.
*N.B.: ATEX is an EU directive on equipment and protective systems intended for use in potentially explosive atmospheres.*

With the modularized system, maintenance cost is also reduced as singular faulty boards could be replaced rather than replacing the whole sensor electronics board, as is done with earlier, monolithic designs.

## 4.3 Architecture of wireless sensor solution for shipboard instrumentation

The architecture adopted for the specific case of tank gauging applications onboard ships is fundamentally influenced by the nature of the sensing technique. The use of gauge pressure sensor requires that the sensor is referenced to the atmospheric pressure using a vent in the sensor cabling. Therefore, it was still mandatory to have some form of physical link from the point of measurement to the deck level or suitable reference point as shown in Figure 7.

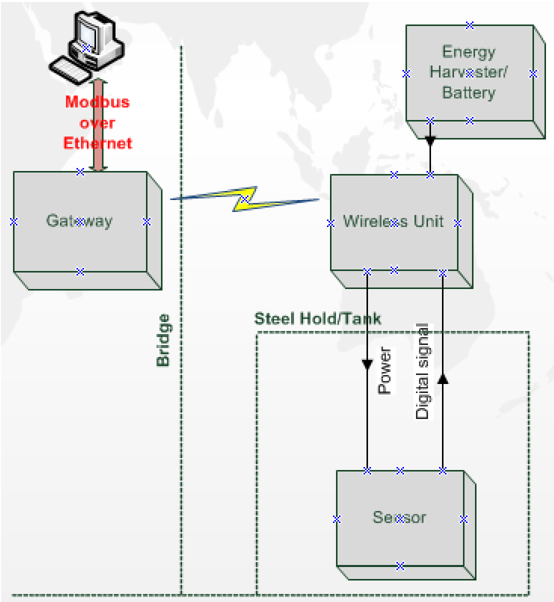


Figure 7: Architecture of wireless tank gauging instrument for shipboard application

Thus, compared to Figure 2 shown earlier the cabling in the tank is preserved but the bus cabling on the deck is replaced with wireless network infrastructure operating on a license-free band.

The overall system architecture illustrated in Figure 8 supports various topologies such as star and mesh, as well as combinations thereof, depending on the prevailing conditions of the radio channel. Thus, the network will be able to reconfigure itself into the optimal type based on the measured link quality and other user-definable parameters.

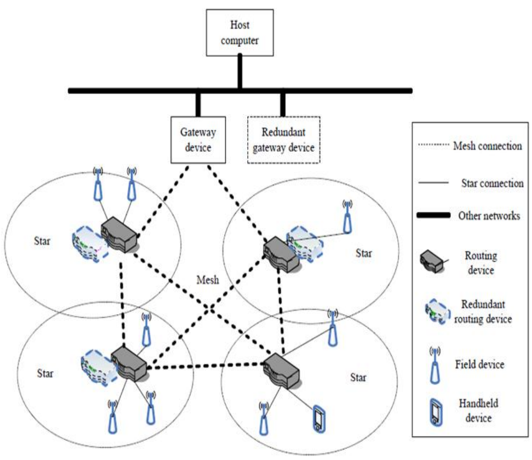


Figure 8: Hybrid star-mesh architecture (IEC 62601 2011)

## 5 Conclusion

The possible replacement of (wired) fieldbus network infrastructure with wireless network technology for shipboard measurement application involves significant changes to conventional sensor electronics and a careful attention to an array of marine type-approval requirements.

The modularized sensor electronics design strategy has produced flexible approach for adding new functions to the smart sensor.

It has been recognized that a viable wireless solution must be based on a globally license-exempt frequency band in order to simultaneously satisfy various flag state requirements.

## 6 Future Work

Immediate future work on the project includes integrating commercially-off-the-shelf industrial wireless modules with liquid level sensors in order to carry out series of wireless reliability tests onboard ships. This will give the practical information about the radio propagation characteristics of the shipboard environments needed for any field deployment of the resulting wireless instrumentation.

## References

Al Agha, K., Bertin, M., Dang, T., Guitton, A., Minet, P., Val, T. and Viollet, J. (2009) Which Wireless Technology for Industrial Wireless Sensor Networks? The Development of OCARI Technology. **IEEE Transactions on Industrial Electronics,** 56(10) October, pp. 4266 – 4278.

EnOcean (2011) **Energy Harvesting Wireless Technology** [Internet], Available from: <http://www.enocean.com/en/energy-harvesting-wireless> [Accessed 10 April 2011]

GreenPeak (2011) **Ultra low power wireless control networks** [Internet], Available from: <http://www.greenpeak.com> [Accessed 10 April 2011]

IACS (2010) **International Association of Classification Societies E22 - On board use and application of programmable electronic systems**

IEC/PAS 62734 (2012) **Industrial communication networks – Fieldbus specifications – Wireless systems for industrial automation: process control and related applications**

IEC 62601 (2011) **Industrial communication networks – Fieldbus specifications – WIA-PA communication network and communication profile**

Kdouh, H., Brousseau, C., Zaharia, G., Grunfelder, G. and El Zein, G. (2011) Measurements and Path Loss Models for Shipboard Environments at 2.4GHz. In: **Proceedings of the 41st European Microwave Conference, October 10-13, 2011, Manchester UK.** USA, IEEE, pp. 408-411.

Lawal, A. (2011) **Report on WirelessHART Seminar, February 24, 2011, Manchester UK.** KTP report: University of Brighton and PSM Instrumentation Ltd.

Nobles, P., and Scott, R. (2003) Wideband Propagation Measurements onboard HMS Bristol. In: **Proceedings of Military Communications Conference, October 13-16, 2003, Boston USA.** USA, IEEE, pp. 1412-1415.

Yeatman, E.M. (2007) Energy scavenging for wireless sensor nodes. In: **Proceedings of the 2nd International Workshop on Advances in Sensors and Interface, June 26-27, 2007, Bari Italy.** USA, IEEE, pp.1-4.