Australian Sonar Transducer Technology

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ABSTRACT

Australia is a vast island nation in an increasingly more interesting part of the world. Naval capability is paramount to our defence and economic wellbeing. Of utmost importance to any navy is an effective sonar solution for the myriad of situations that confront them. This paper presents a brief overview of the suit of sonars that a modern defence force uses, including submarine, surface ship, mine-hunting, sonobuoys and fixed arrays. In this paper I will outline some new developments in sonar technology namely the development of fibre laser sensors in collaboration with DSTO and the emergence and implications of the new relaxor single-crystal ferroelectrics that have recently become available

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INTRODUCTION

Water is the perfect medium for sound, where energy can be transmitted over long distances, and the sea is awash with sound. Sound travels through water better than any other type of radiation– for instance RF and light. Sound is created by a number of sources, such as the ship or submarine's motion through the sea, the machinery on board, and the rotation of propellers, engines, and pumps. Sound can travel long distances and if there is an array of pressure sensors and the associated electronics and signal processing, one can detect amplitude, frequency, direction and therefore derive important information such as the range and speed of a vessel or "contact".

The marine environment, however, presents many challenges to the sonar engineer - from extreme pressures, highly corrosive and electrically conductive environment, complex propagation properties due to sound speed changes with temperature, pressure and salinity, and absorption that varies with temperature and frequency. All these challenges must be met to provide high performance with highly reliable systems to the Navy.

Australia, being an island, needs a vibrant and capable Navy, supported by technologists and scientists from both DSTO and industry. A brief look to our north west shows the potential for political instability over disputed boundaries, the area around the disputed Spratley Islands immediately comes to mind. If we next look at one naval asset in the same region, we find that the waters could be crowded with submarines, China with 56 conventional and 9 nuclear, India, Japan and South Korea with more than 10 submarines each and North Korea with 21 conventional and 41 mini-submarines.

Navies utilise a wide spectrum of sound for a wide variety of tasks in the Ocean. A very condensed scenario of the various sound making and measuring devices is shown in Figure 1.

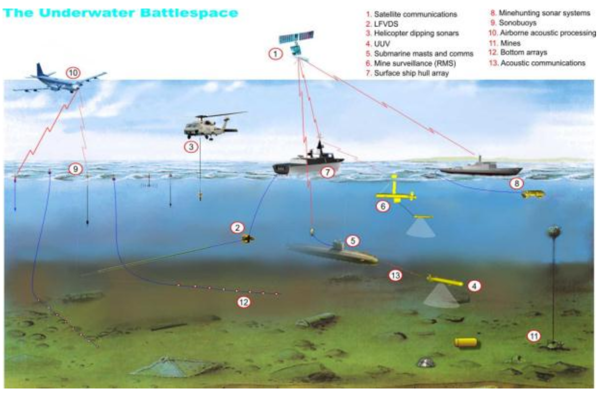

Figure 1. The Sonar Underwater Battlespace

SONAR AND NOISE SOURCES OF NAVAL ASSETS

All ships make sound, both intentional and unintentional. It is the craft of the sonar engineer to create devices that can selectively detect the noise of interest and reject all noise. The following is a list of the more common noise sources.

Surface ships -

Actively propagate sound:

- Through propulsion system and on-board equipment.
- Low frequencies through active towed body
- Mid frequencies through active sonar, depth sounders
- High Frequencies through mine and obstacle avoidance sonar

Passively receive sound:

- Through Hull mount sonar
- Through towed array

Minehunters

Actively propagate sound:

- Through propulsion system and on-board equipment although at a very much reduced level.
- Mid frequencies through active search sonar
- High to very high frequencies through mine classification sonar

Submarines –

Actively propagate sound:

- Through propulsion system and on-board equipment at a much reduced level
- Mid frequencies through active sonar, Underwater Telephone
- High Frequencies through mine and obstacle avoidance sonar

Passively receive sound:

- Through Hull mount sonars – Bow arrays, Flank Arrays, Intercept arrays
- Through towed array

Torpedoes

Actively propagate sound:

- Through propulsion system and on-board equipment
- High frequencies through active sonar homing head,

Passively receive sound:

- In certain operational modes

Mines

Passively receive sound:

- Via acoustic and pressure sensor s

Unmanned Underwater Vehicles

Actively propagate sound:

- Through propulsion system and on-board equipment
- High frequencies through active sonars including side scan and synthetic aperture

Passively receive sound:

- In certain operational modes

Helicopter

Actively propagate sound:

- Through propulsion system
- Mid frequencies through active dipping sonars

Passively receive sound:

- Through sonobuoy

Aeroplanes

Passively receive sound:

- Through both active and passive sonobuoys

BACKGROUND

The RAN and Sonar

Acoustic sensor technology and knowledge of the underwater acoustic environment and its effect on the performance of sonar systems made enormous progress in the years leading up to and during World War II. Submarines were very active in Australian waters, with 21 ships being attacked in the first half of 1943 alone along the east coast [Frame, 2005].

The RAN’s first recorded ASW action using sonar occurred nearly 72 years ago on 20th February 1942. The Bathurst Class Frigate HMAS DELORAINE, possibly built by my father at Morts Dock, Balmain, 1941, equipped with a UK supplied quartz based ASDIC Type 128 sonar, engaged and destroyed an enemy submarine north-west of Darwin [Navy, 2013].

Piezoelectric ceramics

Barium Titanate ceramics were discovered independently in the USA, Japan and Russia during WWII, but it was not until 1947 that the large piezoelectric properties of $BaTiO_3$ ceramics were reported. Very quickly they became the standard for underwater transducers. In the mid-1950’s Lead Zirconate Titanate perovskite ceramics were discovered to have vastly superior piezoelectric properties. The formulations were covered by worldwide patents issued in the USA. In 1970 the US Navy divided the ceramics into groups, designated Navy 1, II, III, IV, V and VI depending on application, and these broad groups are still in use today (as well as hundreds of variants)

DEFENCE SCIENCE CAPABILITY AND INDIGENOUS SONAR SYSTEMS IN POST-WAR AUSTRALIA

Australia was fortunate to have the foresight to create indigenous research establishments similar in structure to their UK and US counterparts. The Royal Australia Navy Experimental Laboratories (RANEL) was established in 1956.

RANEL formed the kernel of underwater acoustic research within the Australian defence science community and since that time has seen many name changes (RANRL in 1969, then DSTO Sydney in 1987) and organisational changes to finally emerge as DSTO Maritime Division. It has a rich history of research and concept development, often leading to the transfer to industry for the production of industrialised sonar systems. A few of the fruits of this labour are describe below.

BARRA Sonobuoy

Barra is one of the most advanced sonobuoys in the world. The concept for a directional sonobuoy was formulated in 1964 in DSTO. From 1964-72 theoretical research and feasibility studies were carried out. These studies estimated that Barra sonobuoy would be more effective in a passive detection mode, listening for quiet submarine noise. Engineering studies on some of the key subsystems were performed culminating in prototype testing at Kilsby's Hole in South Australia and sea trials near Jervis Bay in New South Wales. During 1972-73 the Barra progressed through the project definition and full scale engineering development phases where five companies - AWA, Plessey, ESAMS, CMA and the Commonwealth Aircraft Corporation - were contracted to develop subsystems and assemblies for the Barra buoy. This evolved into the production development phase from 1974-1981 where the same five companies, under Department of Defence project management, manufactured production prototypes which were extensively tested to verify the design of the Barra sonobuoy. Barra entered operational service with the RAF in mid-1980 and the RAAF in early 1981 [Warren Centre 2010]

MULLOKA (Water Devil/Manta Ray) Hull Mount Array

The Mulloka sonar system developed from RANRL studies into the performance of the Sonar Type 177M which had been designed for operation in the waters of the North Atlantic. Mulloka was developed and trialled during the 1970's on board the Yarra Class destroyers. On 17 August 1979, the Australian designed and manufactured Mulloka Sonar System, optimised for operation in Australian waters, was accepted for service into the RAN. The sonar array was industrialised by Honeywell Marine Systems Operations in Seattle, WA, USA. A technology transfer was initiated by Defence Industry Development and the first active sonar array to be built in Australia was by Plessey Australia at Meadowbank, NSW in 1984.

KARIWARA Towed Array

The KARIWARA towed array story is one of Australian innovation, ingenuity and persistence [Dunk 1993]. It commenced within DSTO around the early 1960s with studies, sea trials during the 1970s and concluding in the KARIWARA/COLTAS/SHORT-TAS configurations for the Collins Class submarines. The towed array technology developed was unique, as the thin-line submarine towed array (40mm diameter) was designed to be winched in and stored on a drum under the submarine's casing. The array itself was a Kevlar strengthened polypropylene gel-filled jacket, not fluid filled like contemporary designs and thus not prone to leaks. Post the conclusion of the feasibility study in 1985, DSTO commenced work on developing the specifications for a RAN towed array slated for the Collins class submarine while Thales Australia, the industry partner, began work on the full scale engineering development aspects. In 1997 the first batch of towed arrays became available for Collins. Technologies and techniques learned through this development program were also successfully applied to the design of civilian towed array products in the geo-seismic survey industry. During the mid-1990s, the Thales Australia seismic production line was the largest in the world.

AUSTRALIAN INDUSTRY SONAR CAPABILITY IN THE POST-WAR PERIOD

The sonar sensor ceramics facility at Thales Australia has its origins in the capacitor manufacturing division of the old Ducon Condenser Ltd company. Ducon had begun ceramic capacitor manufacture at Villawood, NSW from about 1950 and it developed a full range of dielectric and ferrite ceramic materials. The range included piezoelectric barium titanate compositions. The Ducon material scientists were eventually able to patent their own series of compositions based on PZT in 1969. These materials have formed the basis of Thales's product line since that time. Ducon was bought out by the Plessey Company of the UK and moved its operations to Meadowbank, NSW in the late 1970's.

By manufacturing our own PZT, Thales Australia has one of the most vertically integrated sonar capabilities in the world. These piezoelectric ceramic elements can be manufactured in a wide variety of shapes and sizes to suit a number of sonar applications, from small high sensitivity sonobuoy hydrophones to high power transducers used in variable depth sonar transmitters. Being part of Thales' global supply chain has enabled the Rydalmere facility to provide key transducer elements into major European sonar projects which has kept the facility viable between Australian contracts. A selection of piezoelectric ceramics manufactured in Australia utilising these formulations is shown in Figure 2 and a selection of completed sonar transducers is shown in Figure 3.

Figure 2. Piezoelectric ceramic parts

Figure 3. Assembled Sonar transducers

Some of the sonar sensors produced in-country over the last 30 years for Australian sonar systems are listed in Table 1.

Table 1. Sonar sensors manufactured in Australia for Australian sonar programs

Sensor	Platform
Barra bender and "clam" hydrophones	SSQ-801 sonobuoy
Mulloka active transducers and staves	River Class destroyers
CSU-3/41 Active and Passive Transducers	Oberon Class submarines
Sperry Micropuffs AN/BQG-4	Oberon Class submarines
Sonar Type 2007 refurbishment	Oberon Class submarines
Tuba hydrophones for Kariwara towed array	Oberon & Collins class submarines
Sonar Type 2093 ceramics and array modules	Huon Class minehunters
Cylindrical Array hydrophones & clusters	Collins Class submarines
Distributed Array hydrophones & clusters	Collins Class submarines
SHORT-TAS towed array tuba hydrophones	Collins Class submarines
Victoria active transducers	Adelaide Class & ANZAC Class frigates

In 1997, DSTO, RAN and Thales entered into an agreement to exchange information, to conduct collaborative research and development on sonar systems technology and trends and to undertake collaborative R&D in sonar system technology [DSTO 2008]. Examples of useful collaborative programs, some supported by the Australian Defence Organisation Capability Technology Demonstrator (CTD) programs, have included:

- Anzac Class Frigate "Spherion B" Broadband Hull-Mounted Sonar
- Rassputin Low Frequency Active Sonobuoy Prototype
- Fibre Laser Hydrophone Technologies
- Sonar System Performance Modelling

Acoustic sensor technologies remain a niche capability that is frequently coveted and protected by other leading nations who hold this technology advantage.

MODELLING

Sonar transducers are inherently complex to fully model, however there are Finite Element Analysis software packages available that can predict performance with accuracy. A complete understanding of all material properties, including metals, polymers and the piezoelectric ceramics is necessary. The model has to also have fluid structure interaction and infinite acoustic elements. Shown in Figure 4 is a model of a typical tonpilz (German for "sound mushroom") transducer executed in ANSYS [Ansys 2013] whilst Figure 5 shows the sound field in the water medium in front of the transducer.

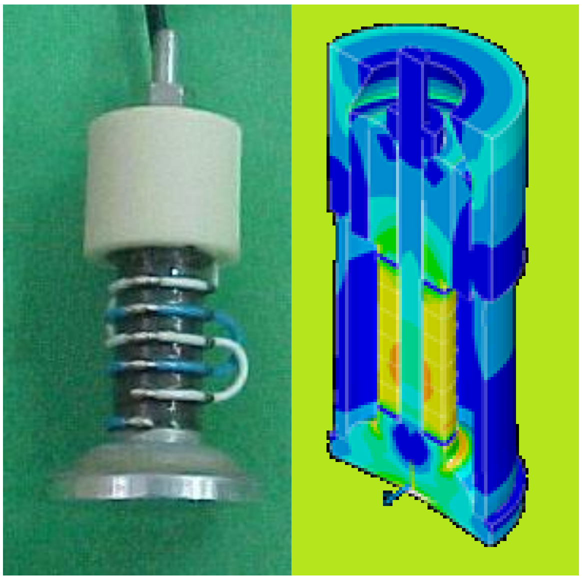

Figure 4. Finite Element Model of transducer

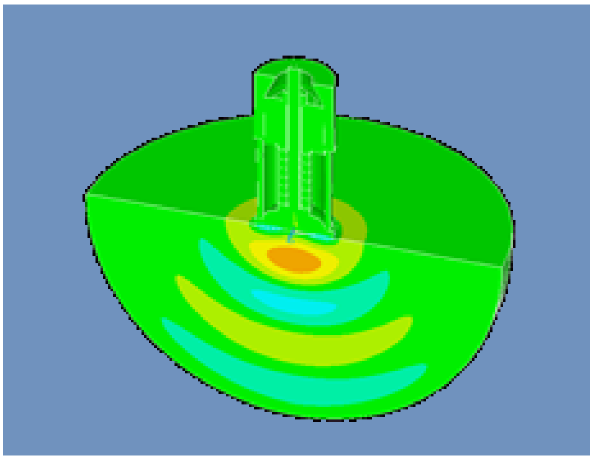

Figure 5. Finite Element Model of transducer

The technical challenges in the acoustics sensor space go straight to the ability to support the RAN in the unique waters that surround Australia and so give them the capability edge. Sonars developed for operation in cold northern hemisphere waters need to be evaluated for their performance in tropical Australian conditions. Through detailed sonar modelling and analysis sonar performance improvements can often be identified to compensate for the different underwater acoustic environmental conditions encountered in our region. A practical example of this is the analysis and ensuing modifications to the minehunting sonar Type 2093, where hardware performance improvements were identified to compensate for the increase in high frequency absorption due to the elevated water temperatures experienced off northern Australia [Cain 2012].

SOME INTERESTING NEW TECHNOLOGIES

In addition to modern submarines becoming quieter, world navies are moving away from blue water operations into the littoral region, where performance of sonar systems is a challenge – high background noise, shallow water. It is the sensor design that will be critical to sonar system performance in this environment. High sensitivity, wide bandwidth, composite hydrophones sensors need a complete understanding of sensor physics and material properties so that they can be modelled and prototyped successfully. A sonar system is only is as good as its acoustic sensor. Low noise, high sensitivity, multiple sensors, large aperture arrays are the crown jewels of established navies around the world.

If Australia is to maintain its regional capability edge, it must be able to have access to next generation sensors or alternatively have the capacity to develop its own equivalent technologies. By being vertically integrated Thales Australia has been able to model, design and manufacture a novel 1-3 composite transducer for submarine use that has excited overseas sonar houses because it offers significantly superior performance and, most importantly, has passed a gruelling qualification cycle, including explosive shocks and deep dive pressure cycles. Unfortunately funding cuts have stalled the implementation.

Another Government initiative is the Capability Technology Demonstrator (CTD) program which greatly assists in the retention of technical skills and fuel innovation in underwater acoustic technologies and systems. An example of this is the Fibre Laser Sensor, initially developed by DSTO, [Foster et al, 2005] and then developed further by Thales Australia [Bedwell & Jones, 2010] into an electro-optic hydrophone, the first of its type in the world. This technology has the potential to revolutionise sonar systems in terms of the reduction in supporting infrastructure (e.g. copper cabling, preamplifiers) and provide building blocks for future sonar systems capability (such as the Fibre Optic Towed Array, FOTA) that is impossible with current technology.

The latest breakthrough in piezoelectric ceramic materials is the realisation of ferroelectric single crystals. These are currently being grown in several overseas companies where 100 mm boules weighing more than 10 kg are routinely produced. [Zhang & Li 2012] On paper these offer a significant performance improvement as their piezoelectric properties are up to an order of magnitude greater than standard PZT. Surprisingly most of the worlds' output is used in medical ultrasound with a minimal amount used by the military. The reason for this is the perceived instability of the material to stress and cost/performance trade-offs. Where they do come into their own is on Unmanned Underwater Vehicles where space and power are at a premium, and by necessity the arrays are small. They will eventually find their way onto larger vessels and Thales Australia has the ability to model the complex behaviour of the single crystals and manufacture devices from them.

CONCLUSION

The history of sonar in the RAN is only about 70 years old. Thales Australia, in its various guises, has been providing indigenous sonar solutions for half of that time. The Underwater Systems division of Thales Australia is a world class supplier of sonar solutions not only for the RAN, but also into the UK MOD, the European FREMM project and the Littoral Combat Ship program in the USA. By collaborating with DSTO and through internal and external research and development funding Thales Australia will continue to provide cutting edge sonar technology necessary for Australia's defense.

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