Introduction to Canada’s Ship and Submarine Acoustic Ranging Analysis Systems (SARAS)

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ABSTRACT
The Royal Canadian Navy actively manages its naval combatants ‘ship signatures’ including acoustic, magnetic, infrared and radar cross section emissions. To quantify acoustic ‘noise’ emitted into the water column, Canada maintains fixed installation acoustic ranges on its coasts. In recent years, the requirement for Canada to measure warship emissions in operational theatre has taken on increased priority with this capability being realized as an evolution of the technologies already developed for our fixed ranges. Our most recent developments in these portable systems permits Canada to range our submarines dynamically while submerged.

This paper introduces the nominal concepts of acoustic silencing of warships, quantification of equipment/machinery lineups and dynamic runs, the design and build of an acoustic range using commercial off the shelf hardware and the furtherance of that design into a transportable range for both surface vessels and submarines. Both surface and underwater tracking systems have been developed to support the dynamic acoustic ranging.

Keywords: Acoustic, Submarine, Ranging, Undersea, Tracking

1. INTRODUCTION

The measurement and subsequent analysis of a combatant vessel’s acoustic signature is paramount to minimizing its susceptibility as a direct function of its detectability (which also includes [electro]magnetics, radar cross section and infrared signatures).

In broad terms, an acoustic signature is comprised of a number of individual elements which include:

a. **Machinery noise**: noise generated by a ship’s engines, propeller shafts, fuel pumps, air conditioning systems, etc.;

b. **Cavitation noise**: noise generated by the creation of gas bubbles by the turning of a ship’s propellers; and

c. **Hydrodynamic noise**: noise generated by the movement of water displaced by the hull of a moving vessel.
Emissions into the water column depend on a hull's dimensions, the installed machinery and ship's displacement. Therefore, different ship classes will have different combinations of acoustic signals that together form a unique signature.

Hydrophones and sonars operating in passive mode can detect acoustic signals radiated by otherwise invisible submarines, and use these signals to attack targets.

Modern naval mines and torpedoes such as the CAPTOR mine can be programmed to distinguish between the acoustic signatures of different vessels, leaving friendly vessels unmolested and attacking high-value targets when faced with multiple possible targets, e.g. distinguishing an aircraft carrier from its escorts.

Canada has long had the ability to range surface combatants via fixed installation/permanent ranges, and in recent years has added the capability to range in-theatre. The systems are described herein.

2. NAVAL ACOUSTICS OVERVIEW

Fixed Naval acoustic ranges have been established on Canada’s Atlantic and Pacific coasts, under the authority of National Defence Headquarters by provisions of CFCD 109 (Naval Vessel Signature Control Manual Revision 1). These acoustic ranges are used to capture and quantify three broad categories of noise that affect the underwater acoustic monitoring operations of a surface or sub-surface platform:

a. **Ambient Noise** is the environmental noise present in a body of water. Ambient noise levels and characteristics vary with location, depth, season and time of day. Ambient noise will influence vessel detectability and underwater sensor performance;

b. **Self Noise** is the acoustic effect of a vessel on its own sonar. It consists of structure-borne noise from the machinery plant, fluid-borne noise due to liquid flow in the vicinity of the hull and from electronic processing system noise; and

c. **Radiated Noise** is a vessel’s acoustic signal as detected by other vessels’ passive sensors. Radiated noise is controllable to a large extent but takes deliberate action and attention to detail. Radiated noise originates from machinery, propellers, and hull and piping system flow noise. The level of radiated noise depends on vessel speed, machinery in use, hull and underwater appendage conditions and activities of the vessel’s company.

The Naval acoustic ranges are specially designed to measure these categories of noise to quantify ship-board generated “noise” as radiated from the vessel into the sea. These measurements help determine the technical performance characteristic of noise-critical machinery and the potential impact their noise might have on a warship’s tactical operations. A calibrated report of the vessel’s acoustic signature level and noise deficiencies is produced and several CF organizations will utilize this information for a wide variety of reasons.

The control of the acoustic signature of the vessel is vital to success in ASW and Mine operations. This signature is a composite of all the noise being transmitted by or through the vessel to the surrounding water. The primary acoustic signature components are auxiliary machinery related, propulsion related or flow induced. To quantitatively measure the radiated acoustic noise level of a vessel requires two steps:
a. **Static Ranging**

The purpose of the static ranging trial is to measure the acoustic emissions from all vessels’ machinery. This trial is required before a full dynamic trial. The static ranging trial requires that the ship be in as complete a shutdown state as is possible. The ship is fixed to a four-point mooring and machines are started one at a time from a dead ship condition. This is required to identify machinery with possible acoustic defects and more importantly to develop a Quiet Running Bill, which identifies the quietest machinery line-ups to reduce acoustic signature to the least possible value for various operational states; and

b. **Dynamic Ranging**

The purpose of the dynamic acoustic ranges is to measure the total underway-acoustic signature (radiated noise) of the vessel and to determine the cavitation inception speed for the vessel. Analysis of the dynamic range data enables the identification of acoustic signature elements that pose tactical vulnerabilities to the vessel or submarine.

3. **SARAS SYSTEM ARCHITECTURES**

Canada’s Ship Acoustic Ranging Analysis System is a class of products built around a proven core architecture. The initial Mk III and IV systems were designed and built to support the fixed and permanent ranges on the Atlantic and Pacific coasts (each coast comprises a static and dynamic range), while successor variants (Mk V and VI) were built for portability and permit both surface and subsurface in-theatre rangings.

A fundamental tenant of SARAS design philosophy has always been to use Commercial Off the Shelf (COTS) hardware and software wherever possible and take advantage of next generation upgrade paths as improvements in those technologies warrant.

SARAS is a system of sensors, cabling, instrumentation and computer hardware and software that is used to perform the underwater noise ranging of HMC Ships. All variants of SARAS utilize Windows based PCs (including ruggedized notebooks), National Instruments hardware, B & K hydrophones, with a LabView GUI.

Ships that are being tested are either underway at various speeds (Dynamic trials) to assess propulsion noises and overall acoustic signatures or moored (Static trials) to evaluate the noise of individual auxiliary machines.

The system is designed to meet or exceed STANAG 1136 requirements, in that it provides 1/3 Octave band acquisition between 3.15 Hz and 80 KHz center frequencies and narrowband acquisition with resolutions of 0.67 Hz and frequencies up to 90 kHz. SARAS systems have the following capabilities:

a. Meets STANAG requirements for frequency bands and resolutions, providing port and starboard aspect signatures;

b. Provides a means for tracking ship position, and calculating and applying noise propagation corrections;

c. Provides hardcopy colour output, graphical or tabular, of 1/3 Octave and narrowband results;

d. Provides a recording function from which runs may be repeated and re-analyzed (e.g. from hard drives);

e. Provides LOFAR (spectrogram) analysis; and

f. Provides automated report generation using processed data.
3.1 General Overview of SARAS

The purpose of SARAS is to capture and time stamp all data required for Static and Dynamic sea readiness trials. The ‘Hydrophone’ Workstation receives analog hydrophone data, converts the data to digital format and then passes the data to a ‘Data Recording’ Workstation. The Data Recording Workstation receives the digital hydrophone data either via a ‘Hardware Data Diode’ or directly in secure facilities and saves this data to disk. Simultaneously vessel positional information, including heading, can either be saved on board the vessel under test or transmitted via ship to shore by the ‘Ship Tracking’ Sub-System.

SARAS consists of the following sub-systems:

a. **Hydrophone Sub-System**

   In the fixed ranges system variant four hydrophones have been placed on underwater pedestals and are connected to the shore station with shielded cables. Each hydrophone assembly contains an underwater amplifier capable of providing 20 or 40 dB of gain, selectable by the operator through the Calibration Panels. The static and dynamic Calibration Panels act as the interface between the Hydrophone cables, +24 VDC Power Supplies and the Shore-Based Acquisition Sub-System. They also provide calibration signals as appropriate, and allow the operator to set the desired underwater gain.

   The precise GPS of location of the four Static and Dynamic Hydrophones are known. During Static and Dynamic tests only two hydrophones are used at one time.

   In the portable/submarine variant, hydrophones are suspended on cables from a small boat/RHIB. At present, they are the same model of hydrophone as used by the shore versions, with the same pre-amplifier. As our submarine ranging system development matures, the move towards an array of hydrophones is anticipated.

b. **Hydrophone Controller Workstation**

   The Hydrophone Controller consists of a highly accurate PCI Dynamic Signal Analyzer CCA and specialized RCN LabView based software installed inside of a COTS Workstation. This workstation is called the Hydrophone Controller and it is connected to the Hydrophone Connection Panel which performs A/D conversion and transfers the digital signal to the Recording Workstation, via an optional Secure Data Diode in some installations. This is achieved via a PCI-4462 CCA, a National Instruments Dynamic Signal Analyzer PCI 24 bit high accuracy data acquisition board, installed in the Hydrophone Controller Workstation. The PCI-4462 board was specifically designed for sound and vibration analysis systems. The CCA receives the raw hydrophone data from either the Static or Dynamic Calibration Panels. The PCI-4462 performs a 24-bit sigma-delta analog-to digital conversion on the raw hydrophone data. It has a 118 dB dynamic range and thus there is no need for any amplification before feeding the hydrophone signal to the DSA card. This simplifies the hardware design and actually reduces gain error compared to adding gain stages after the hydrophone. This card is the central, and only, data acquisition hardware in all versions of SARAS, both shore-based and portable.

c. **(Optional) Hardware Data Diode**

   The Secure Data Diode allows for two networks with different security levels to connect providing a one-way data path.

   The Secure Data Diode consists of a Black (Low Security Level) Proxy Server, hardware Data Diode and a Red (High Security Level) Proxy Server. Both proxy servers use DND-owned custom software specifically written for SARAS. The Secure Data Diode permits the digital Hydrophone data to be transferred to the SARAS MK IV Recording Workstation (Red) while preventing any data leakage into the Hydrophone Controller (Black) Workstation.
d. **Shore-Based Data Recording Workstation**

The Shore-Based Data Recording sub-system consists of a Workstation, Keyboard and Monitor. Depending on the physical nature of each SARAS range, this workstation may or may not be Tempest-certified. The Recording workstation receives the digital hydrophone data. This data is then appended with a time stamp and saved to a Blue Ray/DVD Drive.

The workstation is a TEMPEST level III unit at one location and standard PC at another. This workstation uses either Windows 7 or Windows XP OS and specialized software developed by LR ATG using LabVIEW.

In the case of the portable range, there is no separate Hydrophone Controller and Acquisition Workstation – rather, a single laptop with software for performing both functions is used. The processing and results are exactly the same quality and format as the shore-based SARAS.

The Acquisition software continuously reads the blocks of data coming through the one-way network from the Hydrophone Controller, or from the acquisition portion of the portable range software. It converts the time-based data to FFT and displays it in both FFT and LOFAR formats. The program uses the live track information to determine the start and end of dynamic runs, and allows the user to specify start and stop for static runs. Many forms of the data are stored, from raw unprocessed data, to fully corrected FFT, third octave, and wav-format data.

e. **Shipboard Tracking Sub-System**

The Shipboard Tracking sub-system is only required for the Dynamic Ranging Trials. This sub-system uses two GPS Receiving Units installed on the Bow and Stern of the surface ship under test. These two GPS Receiving Units are each connected to an ISM-band radio modem, and each continuously transmit their GPS fixes to the shore system, 10 times per second. An optional laptop with attached RF modem can be used on ship to display the ship's relative position to the underwater hydrophones, to show the ideal track the ship should take, as well as bow and stern distance off-track and the distance to the hydrophones. The shore system uses the live GPS fixes to determine the COMEX and FINEX times of the Dynamic runs, and to calculate distance correction factors to be applied to the acquired acoustic data. A shore-based display, similar to the ship-board laptop, also displays ship vs range position and other run-related status information.

f. **Analysis and Reporting Sub-System**

The Analysis workstation serves a multitude of purposes: it is the primary analysis tool for SARAS; it serves to review, analyze, and compare range data collected by the SARAS MK III system; and it serves to automate report generation of range trial data. The analysis software provides features such as tonal identification, identification of possible sources for the tonals, retrieval and display of past range data, and comparative functions between acoustic data and class limits. The report generation capabilities were developed using the LabVIEW Report Generation Toolkit for MS Office with the report produced as a Microsoft Word document. The analysis software makes calls to Tecplot (3rd party data visualization software), using predefined macros, for generation of plot files.

3.2 **Submarine/Mobile SARAS**

The Mobile SARAS Acquisition system (MSARAS) acquires acoustic signals using two hydrophones simultaneously in practically any ocean area. It was designed and built to measure acoustic emissions from both submerged submarines and surface ships, and at present can deploy the hydrophones to a depth of 100m.

The acquisition system uses the same high-performance NI 4462 Dynamic Signal Analyzer PCI card as the shore-based SARAS systems do, and produces the same quality and scope of data as SARAS, with the same frequency range and accuracy. Files produced with the MSARAS system are fully compatible with the SARAS MK3 and MK4 Analysis and the Automated Report Generation software.
Each measurement system consists of two identical sets of equipment. During operations, the two sets are deployed in two small boats (or fixed platforms). The six main hardware components of each set are as follows:

a. **Cable reel and hydrophone case** - contains the cable reel, 100m cable, hydrophone and hydrophone amplifier and provides storage for the cable, hydrophone and amplifier, RF antenna, and GPS and RF antenna poles. There are two external connectors, one for the hydrophone connection, and an output to the Acquisition Module. The internal connector for the hydrophone is disconnected during reel extension and retraction. Once the hydrophone has been extended to the proper depth, a cable clamp is engaged to keep the cable and reel stationary, and the internal cable connector is manually connected to the Acquisition Module, through a rugged waterproof cable. This manual method of connection is used instead of slip-rings to save cost and to also ensure a better electrical connection for the hydrophone signal output.

b. **Acquisition Module** – a watertight enclosure containing the PCI chassis with DSA card, battery, UPS, radio modem, AC/DC converter, and 12V to 24V converter. It contains external connectors to allow connection to the GPS, serial output of the GPS to the laptop, hydrophone input, digitized hydrophone output to the laptop, RF antenna for communication with the Wireless Ship Tracking system and the other Acquisition Module, and AC input for charging the internal battery.

c. **Laptop** - this is a rugged laptop with acquisition and display software. The laptop computer uses two external connections to receive the GPS and radio serial data and the DSA card output, both from the Acquisition Module.

d. **GPS** - The GPS provides an accuracy of 70 cm and is used to determine the location of the fixed platform.

e. **Hydrophone Pingers** - these are small, self-contained, battery-powered pingers that are mounted to each cable close to the hydrophones.
f. **Radio Modem** - the operating software on each laptop exchanges various information with the other system using 918 MHz ISM-band spread spectrum frequency-hopping radio modems. The information transmitted includes the GPS position of each Acquisition System, pinger transmit time info, and other secondary information. This information is used to allow each Acquisition Module to determine how far apart the sub-surface hydrophones are, as well as to determine COMEX and FINEX and ideal track positions as the two Acquisition Systems move about in the sea.

The system is capable of tracking both surface and underwater targets. For surface ships, the system uses the same wireless tracking system as is used on the shore based SARAS systems. For underwater tracking the system uses a battery powered pinger mounted on the submarine hull.

![Figure 2 – Drawing of Portable SARAS system deployment](image-url)

### 3.2.1 Operational Design

The Mobile Sound Range system supports both the Wireless Tracking System for surface ships, as well as a pinger-based tracking system for submerged submarines. The tracking information is available in real-time to both Acquisition Modules and is used for several purposes; a small graphic display of ship position relative to the two Acquisition Modules for determining COMEX and FINEX, display of the real-time position of the target vessel relative to the hydrophones throughout each run, and for distance-correcting the acquired acoustic data. In addition to calibration for distance, the software also corrects for cable losses and hydrophone sensitivity. All of these corrections are applied to the data acquired for each run to provide as much accuracy as is possible.

If subsurface tracking is not possible for any reason, approximate distance measurements can be obtained either by applying the submarine’s recorded tracks to the data at a later time, or by using the sound level of a particular frequency of radiated noise to determine CPA and the relative distance from each hydrophone at CPA.
Once the distance and other correction factors have been applied, the files will be stored and a complete set of SARAS-format files will be generated for each run.

![Figure 3 - SARAS ViewShip/Navigation Screen](image)

### 3.2.2 Tracking

For surface ships, a wireless tracking system developed in 2013 for the shore based SARAS systems was adapted to work with the MSARAS system. It consists of two individual GPS receiver and radio systems that mount on the bow and stern of the ship. They continuously transmit their positions via radio to either a central logger located on the ship, or to each of the Acquisition Modules mounted on the fixed platforms. In the case of the radio logger, the track file would be used after all runs are completed, to determine COMEX and FINEX points for all runs and to extract the acoustic data accordingly. Alternatively, the real-time position can be received by the Acoustic Module laptop, which can show relative ship position as well as determine in real-time the COMEX and FINEX points.

The underwater tracking system used on submarines is mechanized by three acoustic “pingers”. Two of them are attached to the hydrophone cables a short distance above the hydrophones themselves. The separation of the hydrophone and the pingers above each are measured and known by the respective acquisition modules. The GPS receiver on each acquisition module provides a synchronized, accurate 1 pulse-per-second signal that is fed into the same data acquisition card as the hydrophone signal. Thus when each pinger pulses, its acquisition module can calculate the exact time of transmit based on the known separation from the pinger to the hydrophone, speed of sound in water, and time between when the hydrophone detects the ping and the GPS sync pulse. That calculated time is transmitted to the other acquisition module, and when it hears the ping through its hydrophone, it can calculate the exact travel time and thus the separation between
hydrophones. This measured separation is critical because the surface separation of the acquisition modules is not the same as the sub-surface hydrophone separation due to currents, wind, drifting, and the 100m cables on which the hydrophones are attached.

The third pinger is mounted on the submarine being ranged. Because a submerged submarine's pinger has no way to synchronize itself to a common time reference such as GPS, we need to measure its actual transmit times. When the submarine performs one acquisition run, the point of CPA to the hydrophones can be determined by the amplitude of the acoustic signal, particularly at specific frequencies. At that point it is directly between the hydrophones, whose separation is known. By noting the difference in time that the sub's ping is detected at CPA by each hydrophone we can calculate the actual transmit time of the pinger relative to the GPS pulse, and thus can work backward to COMEX and forward to FINEX to determine actual submarine positions for the run, producing accurate distance corrections. Since the pinger repetition drift is fairly low we can also track the sub as it finishes the run and then turns for subsequent runs. At CPA on each run the pinger transmit time is recalibrated as above.

4. FUTURE DEVELOPMENTS

The Submarine Mobile SARAS system is currently undergoing acceptance trials. As currently envisioned, it is to be used by Canada primarily on our West Coast waters where the ocean depths are sufficient to conduct acoustic trials while maintaining safe maneuverability requirements. The overall system package is quite compact and can be easily shipped anywhere in the world via commercial means for in-situ ranging as required.

As Canada and our submarine fleet become accustomed to conducting acoustic surveys and improving the 'quietness' in our own waters, the need for a more advanced acoustic array system will probably be realized. In turn the use of acoustic arrays will lead to a semi-moored system and research into this deployment scenario is well underway.

5. CONCLUSIONS

Canada’s SARAS suite of ranging systems began nearly twenty years ago with the design principle of using common off the shelf hardware integrated via common off the shelf software wherever possible to provide robust designs that can evolve to meet new requirements. In addition, the systems can remain state of the art as the commercial technologies advance if the ‘natural upgrade’ path is followed. The systems are well proven as rangings occur on both coasts and in-theater, over many years.

The importance of our most recent development efforts, the submarine MSARAS system cannot be over-stated. The sheer cost savings of conducting submarine acoustic trials in our own waters is extremely significant. In addition to the nearly two million USD external range expenses (which was incurred for a single past ranging event!), extremely valuable submarine availability is gained due to minimal transit times to and from the range site. Also, Classified Secret data is handled entirely by Canadian government personnel without the need for enacting cumbersome procedures for data transfers to and from the host nation facility. Finally, the use of COTS hardware and software has permitted Canada to take advantage of continued industry development at comparatively low cost.