TEST AND EVALUATION OF A MIDWATER
THREE DIMENSIONAL UNDERWATER TRACKING ARRAY

W. A. Venezia
Naval Surface Warfare Center
1650 S. W. 39th Street
Fort Lauderdale, Florida 33315

J. N. Aycock
Naval Surface Warfare Center
1650 S. W. 39th Street
Fort Lauderdale, Florida 33315

Abstract: A continuing need exists for accurate three dimensional tracking of submerged targets on instrument ranges. The common problems faced by developers of acoustic underwater tracking systems range from launch, recovery, and structure life to telemetry and real time processing of source signals. The Naval Surface Warfare Center controls an underwater test site that ranges from shore to water depth of 600 meters. To support long term growth, an underwater tracking system capable of operating over the majority of the range with a serviceable life of twenty years was developed and is described.

The system design goals included long term compatibility with the marine environment and stringent tracking accuracy requirements. Environmentally compatible materials selection included fiber reinforced plastics for structures, glass spheres for pressure vessels, and titanium for fasteners. Tracking accuracy is achieved using a synchronous tracking system consisting of four hydrophones on an eight meter baseline. Pulse detection and arrival time are determined using a combination of in band and out of band energy detection with replica correlation of the apex channel. The system has single bit digitizing using zero crossing detectors. Differential arrival times for two adjacent channels are determined using cross correlation with the apex channel.

This paper contributes an overview of the underwater tracking system and of the Fort Lauderdale facilities and test capabilities. A summary of experimentally obtained data on the tracking accuracy from deployments in 180 and 450 meters is given. Tracking resolutions are given as a function of environmental parameters including range from the array, depth, and ambient sound velocity profiles. Array performance characteristics are extrapolated over usable water depth based on evaluation of the arrays at the two test sites.

I. INTRODUCTION

The Fort Lauderdale Branch of the Naval Surface Warfare Center operates the only land-based, deep water test and evaluation (T&E) facility located on the Eastern Seaboard of the United States. Here, NSWC and other research and development activities conduct full-scale trials of air, surface and underwater weapon systems under a variety of oceanographic conditions. As the Navy's principal research, development, test and evaluation center for surface ship weapons systems, ordnance, mines, and strategic systems support, NSWC relies upon its Fort Lauderdale facility to support rigorous field trials in conditions comparable to the actual operating environment. The Atlantic Ocean test range features a deep water cable monitoring system, a shore tracking system, underwater and surface communications, and tracking systems. The facility's experienced technical staff, excellent shore facilities, and waterborne craft combine to offer an unparalleled environment for year around T&E operations.

The Navy established the Fort Lauderdale facility in 1952 to support the underwater mine warfare program. Through the years, facility personnel have kept pace with diverse and complex testing techniques required by today's advanced weapon systems and components. Working in close partnership with the Navy's operating forces, the facility plans and supports test programs in a variety of warfare areas for NSWC as well as for other military and civilian government activities and their contractors.

The facility is located in Fort Lauderdale, Florida. This location was chosen by the Navy because it is the at the closest approach of the Gulf Stream. This is an area from which it is possible to interface with naval and air units under ideal conditions for testing interoperable weapons and communications systems. The areas superb environmental and physical characteristics offer a rare combination of technical, environmental, and logistic advantages including: open ocean environment and unrestricted water, hard sandy ocean bottom and clear water, realistic operating environment, sheltered harbor, air lanes sufficiently free to permit air drops, and convenient to road, air rail, and sea transportation services.

Tracking, ranging, and plotting are the principal functions conducted on the NSWC's extensive Atlantic Ocean test ranges in conjunction with air drops and ranging surface ships and submerged submarines. A system of 375 miles of underwater cables monitors the performance of test hardware at depths down to 700 meters. Underwater cable types include multiconductor, coaxial, and fiber optic. Each range may be equipped with underwater tracking systems and underwater communications systems (UQC). The Fort Lauderdale facility tests and evaluates a variety of systems including; Tactical ships, autonomous vehicles, trajectory
and water entry vehicles, submerged ordnance, mine counter measures systems, torpedoes, and swimmer weapon systems. Test hardware is deployed by surface ship, submarine, or aircraft. Ranging and plotting techniques depend upon the nature of the test. Air operations use RF, microwave, and optical tracking. Surface operations use RF, microwave optical and laser tracking. Water entry uses optical and acoustic. Underwater tracking is strictly acoustic. The sections that follow detail the design, construction, and test and evaluation of the acoustic ranging system employed by NSWC Fort Lauderdale.

II. ACOUSTIC RANGING SYSTEM

The primary purpose of the acoustic ranging system (ARS) is to provide tracking and communication with a submerged submarine. Tracking requires the attachment of an ARS pinger to the submarine to provide the coded signals required for tracking. Communication with the submerged submarine is achieved using standard U.S. Navy underwater telephone (UQC) equipment on the submarine.

III. ARS SEA END ELECTRONICS

The ARS systems as it is currently deployed in Fort Lauderdale includes two towers on the sea floor, and one tower on shore as a spare. Sea floor ARS towers are in 200 meters and 400 meters depth. Fig. 1 shows an ARS tower being launched from one of the NSWC research vessels. The array tower electronics consist of two glass spheres and a titanium canister which houses the pitch and roll angle sensors. One sphere shown in Fig. 2, contains the electronics that interface the sea and shore circuits. The four hydrophone signals are AM modulated, summed and transmitted back to shore for processing. The UQC voice communications signals are filtered and amplified for transmission on an 8.075 kHz single upper sideband, suppressed carrier AM signal. The pinger control wave forms generated from shore are filtered and amplified before being routed to its respective transducer. The other sphere contains the lead acid batteries that power the UQC communications system.

Mounted on the ARS tower is an array of hydrophones (for reception of the ARS pinger signal and the UQC signals), a UQC transmitter, and a transmitter for remote control of ARS pingers or for operation of an audible frequency beacon. When activated, the beacon produces a pulsing 2.375 kHz signal for 5 seconds and then is quiet for 5 seconds.

The ARS pingers can operate at one of three selected frequencies, 19.23 kHz, 43.27 kHz, or 72.99 kHz. The 19.23 kHz frequency is used whenever possible since it provides both the greatest range and the highest accuracy. The two higher frequencies are available in case the lower frequency produces unacceptable interference with equipment being tested (i.e., acoustic test arrays). When propagation conditions allow sufficiently long direct path without reflections, the lower frequency can theoretically provide tracking to 4000 meters from the tower. The greater attenuation of sound at higher frequency limits the mid frequency range to 2000 m and the highest frequency to a range of 1300 m. Accuracy for the higher frequency is slightly reduced because of the heterodyne processing in the telemetry system required to transmit the high frequency signals to the shore system.

The signal transmitted by the ARS pingers is a 400 micro s cw pulse with a 180 deg. phase shift near its center. This signal is repeated at 10 or 30 s intervals as selected. Two pinger signals (denoted channels A and B) can be processed simultaneously by selecting a 5 s offset in transmission between channels. Two separate transducers are required if

Fig. 1. ARS being launched from NSWC research vessel RSB-1.

Fig. 2 ARS electronics housed in glass sphere.
both channels A and B are allocated to one pinger. Channel A will transmit at the exact minute time mark, and channel B will transmit 5 s after the minute time mark. The transmission is timed by a highly accurate clock inside each pinger that is synchronized with a master shore clock.

The pulse duration, interval between pulses, and frequencies of operation have been chosen to minimize the interference with the equipment normally tested on the NSWC range. To further reduce the chance of pinger interfering with equipment under test, the pinger can be turned off remotely, or the repetition interval can be changed by a 19 kHz coded signal transmitted from one of the ARS towers. The effective range for the remote control function is about the same as the maximum range for reliable tracking.

Tracking of a submarine operating near the tower requires a transducer mounted on the bottom of the submarine to minimize shadowing of the tower hydrophone array by the hull. However, the downward ray path caused by the normal sound velocity profile in the Fort Lauderdale test area limits the useful operating range and best results are obtained with a top and bottom mounted pinger.

The beacon signal is intended to be received and located with the submarines passive sonar. The beacon signal level is low enough that it does not interfere with a submarine's capability to locate other noise sources, such as fishing boats that may present a hazard to safe surfacing. The beacon signal is pulsed for easy identification. When activated the beacon does not interfere with tracking or UQC reception. The beacon is off for the 5 s intervals that are timed such that tracking channel A can be received during beacon operation. Applications of the beacon include aiding the submarine in moving into the tracking range to establish initial tracking communications or during an operation may be used to signal a requirement for a test parameter change.

The tower mounted UQC is a high efficiency transmitter, 500 W (peak) single sideband, suppressed carrier transmitter that is turned on by a control signal from shore. During UQC transmission, underwater tracking, pinger control, and beacon signal functions are disrupted. Power for the UQC is supplied by from a single 650 W h battery pack continuously trickle charged from shore.

IV. ARS SHORE EQUIPMENT

Each ARS tower has an associated control panel and processor drawer located onshore. An armored coaxial cable between the tower and the processor is used for down link transmission of power, control signals and UQC signals. The coaxial cable is also the up link for transmission of hydrophone signals and auxiliary data.

Up to seven processor drawers and towers can be employed at one time in conjunction with one tracking computer. The tracking computer provides real-time tracking signal outputs that have been converted from time interval measurements to locations in range, bearing and depth. The ARS shore electronics is given in Fig 3.

Fig. 3 Foreground rack ARS control panels and processor drawers. ARS tracking computer in background.

The tracking computer displays the auxiliary signals in easy to understand format. It can generate control signals for transmission down the cable to the in water electronics. For example, when Base-line mode is selected a signal is generated and transmitted to determine the sound velocity at the tower by measuring arrival times to the hydrophones adjacent to the apex hydrophone which is chosen on the front panel of the processor. This is a necessary function before creation of a sound velocity profile. A sound velocity profile is usually generated by using a temperature profile and salinity measurements. The above mentioned procedures should always be followed before conducting a tracking session.

A display of the data from all of the towers located in one range area can be obtained in real time, with tracking automatically switched to the nearest tower receiving the pinger signals. Tracking data from all towers in use are stored and are available for later use. The tracking computer also provides a display of the auxiliary data required for system setup and troubleshooting.

Timing onshore originates in the master clock that connects each processor drawer and the tracking computer. It also provides timing and reference frequencies to the multiport charge and synchronization panel. The master clock contains a UPS to maintain accurate timing during power outages up to three hours.

The multiport charge and synchronization panel provides signals that automatically adjust the oscillator frequency in each of the pingers to correct frequency and also synchronize the pinger clocks to transmit the tracking
signal at the correct times. For dc powered pingers, the batteries are automatically charged whenever the pingers connected to the panel.

V. ARS PINGERS

Two types of pingers are used; one is ac powered and the other is dc powered. The ac powered pinger contains a battery that provides power up to 7 h to the oscillator and the clock circuits to allow time for transportation and submarine installation without loss of timing accuracy. The dc powered pinger contains sufficient battery power to allow up to six days operation without recharging, but timing accuracy is less than usually desired from about five days after synchronization.

The ac powered pinger is intended for use in protected locations, such as inside the submarine. Its case provides protection against rain water or splash during transit.

The dc powered pinger has a titanium pressure case suitable for water depths up to 1000 m. A water activated switch incorporated in the transducer cable prevents acoustic transmission in air. The dc powered pinger is intended for use on towed targets, autonomous targets, or on submarines where hull penetrations are not available.

VI. TRACKING CALIBRATION PROCEDURES

One of the most important aspects of this system is the accurate determination of the ARS tower position on the ocean floor with respect to a known surveyed point, in this case the NSWC Range House, as the origin (0,0,0) of the tracking range. Geodetic position accuracy is needed because many systems are tested on the range and require absolute position accuracy of one meter. The NSWC Facility has an independent positioning system, but an additional survey is often required. The first step in the survey process is to measure a sound velocity profile (SVP) and feed it into the computer prior to the tracking session. The SVP is often approximated from a temperature profile taken in the vicinity of the tower or towers being used. Next the depth of the ocean at the tower is verified by deploying a tracking transducer at various measured depths and comparing this information with that generated by the tower system. Once the preceding information is loaded into the computer, the vessel positions itself in one of the four quadrants of the tower location approximately one to two times the distance from the tower as the water depth. The vessel holds position as tightly as possible (less than 2 meters) and deploys the pinger transducer in such a manner that an independent tracking system is able to track the pinger position to a high degree of accuracy. The ARS tracking computer outputs a range and a bearing from the tower, and this is compared with a known position on the range generated by the independent tracking system. Both tracking systems are synchronized timewise by a satellite clock. After data has been collected from each of the four quadrants about the tower, approximately five minutes at each position, the computer calculates a refined position. This is done essentially by taking a known position from the independent system at given times and drawing arcs using the range determined by the ARS system at those same times. The intersection of the arcs will determine the correct position. However, sometimes bad points are generated for various reasons and could corrupt the data. A standard deviation from the calculated position is then calculated, and if it is too large, will alert the user to recheck the data points. The rotation of the tower relative to geodetic north is also calculated by comparing the bearing angles of each system. This method of position determination has proven to be very effective, and has enabled NSWC Ft. Lauderdale the capability of providing range users with highly accurate and safe operations on the tracking range. Fig. 4. gives typical simultaneous track from optical tracking and acoustic tracking of a surfaced submarine.

During the period January 1993 to July 1993 a series of tracking accuracy tests were conducted on the NSWC Fort Lauderdale underwater tracking range. It is now known that tracking accuracy is 1 meter at ranges less than 500 meters. Acceptable tracking accuracy's of 3 meters were obtained at ranges less than 1500 meters at the shallow site and 2000 meters at the midwater site based on experimental validation in typical sound velocity profiles.

![Fig. 4 Simultaneous submarine tracking on surface, ARS (upper), Optical (lower) offset for clarity. Dimensions are in meters.](image)

VI. ACKNOWLEDGEMENTS

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