

# UNDERWATER HYDROPHONE LOCATION SURVEY

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## INTRODUCTION

The Atlantic Undersea Test and Evaluation Center (AUTECH) is a U.S. Navy test range located on Andros Island, Bahamas, and a Division of the Naval Undersea Warfare Center (NUWC), Newport, RI. The Headquarters of AUTECH is located at a facility in West Palm Beach, FL.

AUTECH's primary mission is to provide the U.S. Navy with a deep-water test and evaluation facility for making underwater acoustic measurements, testing and calibrating sonars, and providing accurate underwater, surface, and in-air tracking data on surface ships, submarines, aircraft, and weapon systems. Many of these programs are in support of Antisubmarine Warfare (ASW), undersea research and development programs, and Fleet assessment and operational readiness trials. Most tests conducted at AUTECH require precise underwater tracking (plus or minus 3 yards) of multiple acoustic signals emitted with the correct waveshape and repetition criteria from either a surface craft or underwater vehicle.

## BACKGROUND

At AUTECH, there are two separate underwater tracking ranges located in the Tongue-of-the-Ocean (TOTO) and adjacent to Andros Island, Bahamas. A combination of the narrow shoreline shelf and a deep (5,000 feet) body of water isolated from the open ocean by shallow reef boundaries makes these areas ideal for acoustic analysis, detection, and tracking. Both tracking areas are instrumented with several underwater bottom-mounted hydrophones cabled directly to shore facilities where signal processing and recording equipment are located. The processed data are transmitted by microwave communications to the Main Base facility where computers process and format the data for delivery to range users and display the data for conduct of the test by range personnel.

From January to September 1992, the norther underwater tracking area, instrumented with seven hydrophones spaced at 2,000 yard intervals and in a circular pattern with six on the outer perimeter and one in the center, was enlarged with the addition of seven new hydrophones, two underwater communications transducers, and additional data processing and interfacing hardware. The expansion effort nearly doubled the tracking area for this portion of the AUTECH range from 50 to almost 100 nautical miles and significantly increased AUTECH's data collection capability. Before

this additional area could be integrated and used as part of the operational tracking area, however, a survey was required to establish the precise location of each hydrophone where it had been placed on the floor of the ocean. Average depth of the water in this area of the TOT is 6,000 feet. This paper attempts to give the reader a brief overview of how this survey was accomplished using the Global Positioning System as the Timing source for the emission of tracking source signals, but does not detail the mathematical formulas used to calculate the actual hydrophone positions.

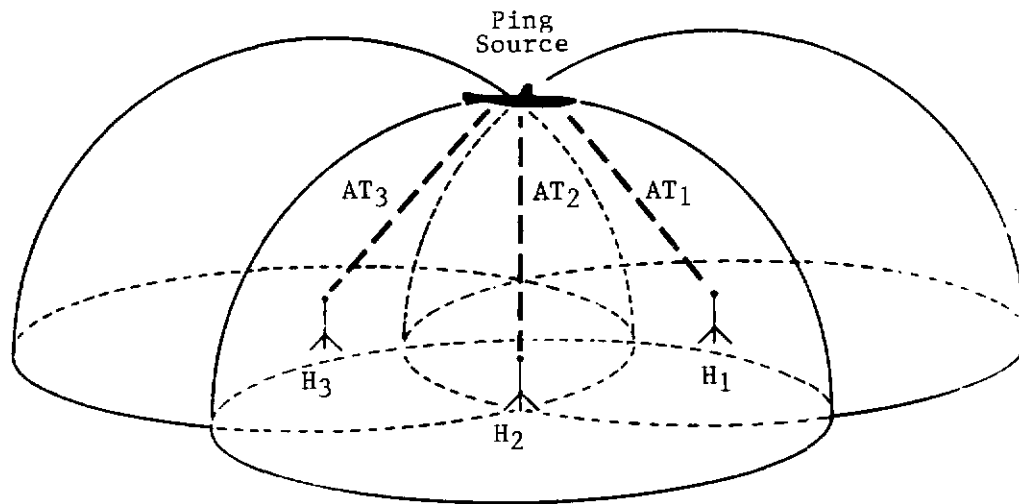
## METHOD

The Site One Expansion (SOE) survey processing of received hydrophone signals used a least-squares version of the Vanderkulk mathematical method, developed by Wouter Vanderkulk of International Business Machines (IBM). In this method, propagation delay or "transit" times of the transmitted signal from the source transducer to the bottom-mounted hydrophone were processed to yield baselines and depths for triads (or larger subsets) of hydrophones which were then combined in a least-squares sense to yield a relative set of X, Y coordinates of the hydrophone filed (see Figure 1). This relative set of coordinates was then related, translated, and scaled to optimize agreement (while maintaining the integrity of the Vanderkulk interrelationships) with an independent set of geodetic coordinates that were gathered simultaneously with the acoustic data.

For this survey, the independent set of geodetic reference points (known source locations) was provided by a shore-based, high precision tracking radar that tracked the surface craft. This surface craft, instrumented with a radar beacon, was used as the platform from which the underwater tracking signals or "pings" from a hull-mounted transducer (pinger) were emitted. A parallax offset was used to correct for X and Y positional differences between the radar beacon and the pinger.

Transit times for the Vanderkulk processing were derived from hydrophone arrival times that had been corrected for delays; namely, synchronous pinger emission offset, hydrophone cable delay, and all associated signal processor delays. In the SOE survey, the ping generation delay was compensated for by using a GPS Timing receiver to synchronize an on-board Time Code Generator (TCG) to within 300 nanoseconds of Universal Coordinated Time (UTC). Simultaneously, the shore-based signal processors, used to detect and time tag the pings received from all hydrophones, were clocked from the Central timing facility, also synchronized to within 300 nanoseconds of UTC. Delays in the ping generation hardware were removed by utilizing the propagation delay compensation circuitry in the TCG. The disciplined oscillator (5 MHz) of the GPS receiver was used to clock the TCG and maintain on-time performance. A diagram showing the equipment configuration on-board the surface craft is shown in Figure 2.

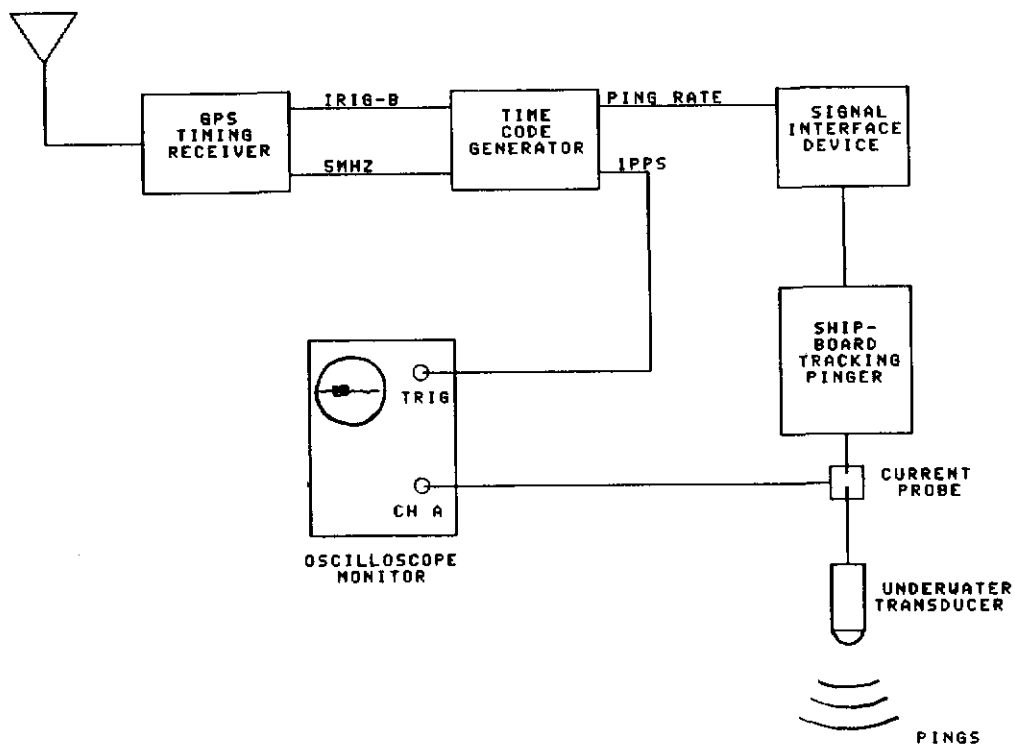
Accurate synchronization of the acoustic pinger was of significant importance for this survey because a bias of this nature will go undetected when using the Vanderkulk processing technique, thereby causing a bias error in the mathematical solutions that will manifest itself in the hydrophone depths and the scale factor of the hydrophone files. An offset of this nature will also manifest itself as a scale factor in the process of mapping the Vanderkulk coordinates into the independent reference coordinates because the collected radar tracking data are also time tagged to the Central Timing System clock.



AT<sub>i</sub> = Arrival Time

H<sub>i</sub> = Hydrophone

FIGURE 1. ARRIVAL TIME DIAGRAM



## QUESTIONS AND ANSWERS

**J. Wisnia, Kernco:** I am rather naive on underwater sound but doesn't the speed of sound depend on the temperature of the water and what did you do to account for that?

**J. Cecil, Naval Undersea Warfare Center:** We take frequent sound velocity profile measurements. We have capability of going down to the full depth and we incorporate that into the data in the software. So there are lots of things that I did not mention, that I did not go into, that are also a part of this formula and part of doing this task. We do consider that as one of the important things that we crank into the software. There are other things like processor delay, that are also injected in there. They are really constants and we do that on a typical basis with our other hydrophones. I tried to emphasize the things we did differently for this exercise because of the survey of surveying these hydrophones in. For the normal tracking that we do at AUTEK, we use a hyperbolic formula and we use four hydrophones per track because the pinger is asynchronous. It is not synchronized to any particular device and we do derive the time with four hydrophones.

**D. Allan, Allan Time:** Perhaps two comments or questions, one is like GPS why couldn't you use four instead of 3 and have the solution from the four.

**J. Cecil:** Well because it reduced the amount of processing time and it reduced the complexity of the software involved. Four is just another unknown that you are throwing in there that we would rather not have in the surveying process. Because we do not, we use the hyperbolic method typically when we track on our existing known hydrophones. When we resurvey, we usually use a synchronous pinger. This is really the first time that we used this Vanderkulk technique - this Vanderkulk method. We think we are going to get a significant improvement over the other survey results; and we may. One of the things we are considering is going back over all of our other hydrophones now and surveying all of those in with the same technique. It was just something that we did not want to deal with; the resolution of time in this instance.

**D. Allan:** The second question: It seems like you could also put the other hardware delay solution into the software like you did with the temperature variations, etc. I was pleased to hear that, very often, these things can be dealt with in the software and get a lot more flexibility, rather than make a hardware solution. In the case you showed you had a hardware solution to a delay problem and that could also be put in the software, I believe, could it not?

**J. Cecil:** Yes it could. One of the things we wanted to be able to accomplish here was stability. With the stability of the on-board clock to keep in synchronization during the entire exercise because when we go out and survey the hydrophones, we did not survey just three hydrophones, we surveyed seven hydrophones; seven new hydrophones. It took us a period of 12 to 14 hours to complete this survey because the geodetic data that this survey was fitted in with was accomplished through radar track. Precision air tracking radars were tracking the vessels simultaneously; so what I was after was some stability over a long period of time, say over 12 hours. The time code generators that we typically have at AUTEK will not give us that kind of stability. When you can go out and do a pretest measurement and then turn around and do a post test measurement, but that does not tell you what the clock was doing in between. The clock could have been doing this in between; so this gives us a feeling of clock stability.

**P. Talley, The Aerospace Corporation:** I have a comment regarding this paper, and that I personally was involved in 1959 on the early testing of the Polaris Missile System and we were firing into the hydrophone and we found that the islands were misplaced by over a mile and that the hydrophones had been referenced to the land mass. The inertial guidance of the

Polaris Missiles recalibrated the hydrophone net. That was interesting that GPS is now helping to calibrate the hydrophone net a little further.

**J. Cecil:** Yes, it is the only constraint here is the fact that have to have a radar fix on the vessel all the time we are going through this exercise. So, if you get into remote areas around the globe you do not have that. Because we have our radar, our existing in air tracking radars, we could tie the data and correlate this data, it made things a lot easier.