Final Report
Living Marine Resources: ID-33
Technology Demonstration for
Fleet Passive Acoustic Monitoring

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Executive Summary

The High-frequency Acoustic Recording Package (HARP) was upgraded to have a new disk storage format, and larger data storage capacity, as part of a Living Marine Resources (LMR) supported project under the category of "Technology Demonstration for Fleet Passive Acoustic Monitoring." The HARPs and previous generation Acoustic Recording Packages (ARPs) have been used for more than 15 years for passive acoustic monitoring of marine mammals in areas of naval training. The data generated by HARPs have been used for marine mammal population assessment and study of the potential impact of naval training activities on marine mammals. By upgrading the HARPs to a modern disk storage format (SATA) their data storage capacity has been expanded to up to 16 TB, allowing more than a year of continuous recording, even at the highest data rate of 320 kHz sampling. The upgraded HARPs have been transitioned for use in Fleet passive acoustic monitoring.

Background

Passive acoustic monitoring (PAM) is a valuable tool for monitoring marine mammals throughout the world's oceans. The High-frequency Acoustic Recording Package (HARP) is a state-of-the-art PAM device designed for long-term, wide bandwidth, autonomous recordings (Figure 1; Wiggins and Hildebrand, 2007). HARPs, and their predecessor the Acoustic Recording Packages (ARPs – Wiggins, 2003), have been used on Navy ranges for more than 15 years to monitor marine mammals from low-frequency baleen whales such as the blue whale with calls ~10 – 100 Hz to high-frequency odontocetes such as beaked whale, dolphin and porpoise echolocation signals up to and above 100 kHz. To keep operational costs low, long-term deployments with fewer servicing trips require low-power data logging electronics with large battery capacity and large data storage capacities. Prior to this project HARPs featured low-power (<1W), high bandwidth (10 Hz up to 160 kHz), and large battery capacity (336 Ahr for alkaline cells; 720 Ahr for lithium cells) including data compression for more efficient data storage, low-drift clocks for large (>1 km) aperture tracking arrays (Wiggins *et al.*, 2013), and multiple-hydrophones (up to 4) for small (~1 m) aperture tracking array capabilities (Wiggins *et al.*, 2012). Their data storage capacity was 5 TB ($5x10^{12}$ bytes), which provided about 10 months of continuous data collection at 200 kHz sampling.

Large data storage is key to providing long-term wide-band recordings. In 1999, ARP data loggers had 10-500 Hz bandwidth and used two 3.5" Small Computer System Interface (SCSI) Hard Disk Drives (HDDs) each with 18 GB ($18x10^{9}$ bytes) of storage providing about one-half year of recording capacity using a sample rate of 1 kHz or one year sampling at 500 Hz, which allowed monitoring of only low-frequency baleen whales and seals calls. In 2004, HARP data loggers were developed and could sample up to 50 kHz; they stored data onto an array of 16, 2.5" Parallel Advance Technology Attachment (PATA, originally Integrated Drive Electronics – IDE) HDDs each with a capacity of 40 GB, or 480GB for the entire system (Figure 2). In addition to the HARP's larger capacity data storage, the 2.5" laptop computer type HDDs used less power than the 3.5" desktop computer type HDDs of the ARPs. However, while data storage for the 2004 vintage HARP was over 13 times larger than the ARP, the maximum sample rate (bandwidth) had also been increased by a factor of 50 such that the recording duration was reduced to less than 2 months (55 days). Increased bandwidth was required to monitor higher frequency sounds such as whistles and clicks from odontocetes at the cost of shorter continuous recording periods or alternatively, the use of scheduled on and off recording periods (i.e., duty cycle sampling).

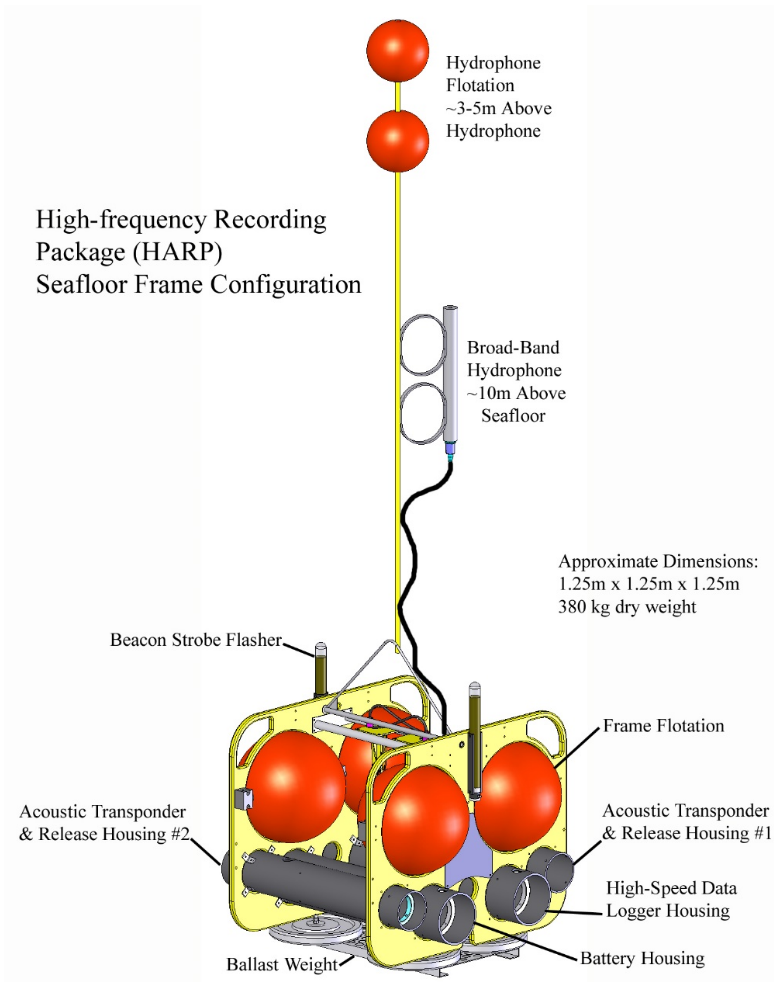

Figure 1. High-frequency Acoustic Recording Package (HARP) seafloor-mounted frame configuration with hydrophone tethered 10 m above instrument frame housing data logger electronics and battery pressure housings.

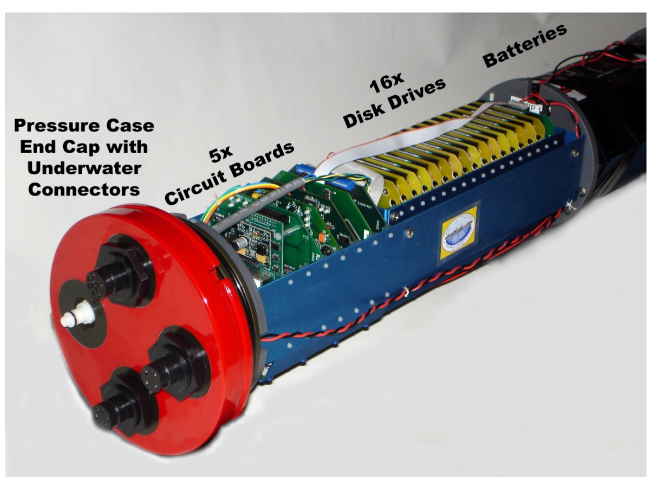

Figure 2. HARP vintage 2004, with data logger electronics, including array of 16 Parallel ATA laptop computer style (2.5”) hard disk drives and battery pack.

Over the years, PATA HDD capacities increased from 40 GB to 320 GB, or 480 GB to 5 TB for total HARP data storage, along with a factor of two data compression, effectively increasing the data storage to 10 months of continuous recording at 200 kHz (Figure 3). However, as the computer industry advanced, providing larger capacity HDDs, so has the interface technology such that PATA has been replaced with the Serial ATA (SATA) interface. Since PATA was no longer the industry standard and most manufacturers stopped producing them in 2013, these types of HDDs are difficult and expensive to purchase, requiring the HARP data storage system to be redesigned to write data to SATA HDDs. In addition to avoiding obsolesce, SATA provide faster data transfers, larger capacity HDDs (currently up to 2 TB each), and recently, affordable large capacity Solid State Disks (SSDs) which are lower power than HDDs and more robust to shock and vibration often experienced by autonomous acoustic recorders. HARP modifications and enhancements to allow SATA data storage is the topic of this report.

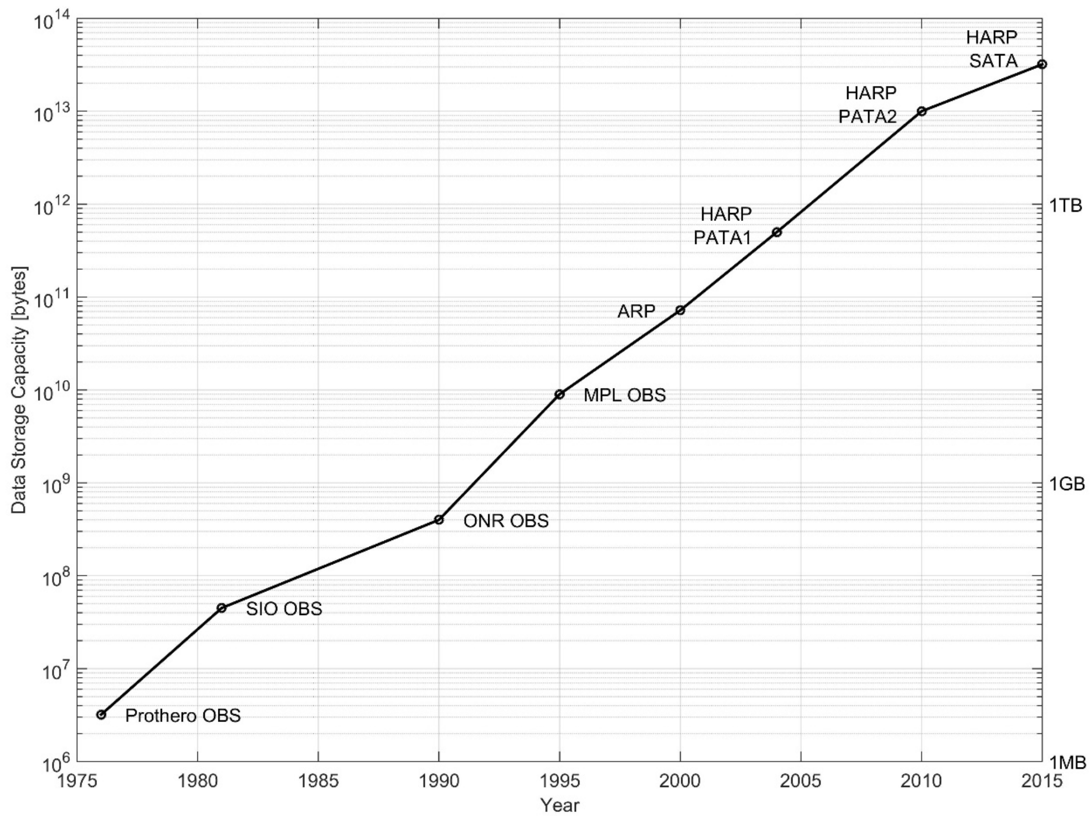

Figure 3. Data storage capacity for underwater autonomous data logging devices at SIO versus year. In the mid-1970's Ocean Bottom Seismometers (OBSs) were capable of recording only a few megabytes of digitized data; whereas, 40 years later SATA HARPs are capable of storing up to 32 terabytes, or over 10 million (10^7) times more data in similar oceanographic packaging. This trend approximately follows Moore's law which assumes a doubling in capacity every 1.5 years. ARP used 2 x 18 GB or 36 GB disks, HARP PATA1 used 16 x 40 GB disks, and HARP PATA2 used 16 x 320 GB disks.

HARP Modifications and Enhancements

The PATA HARP configuration used a two backplane approach, where the main data logger electronics (i.e., Central Processing Unit (CPU), Random Access Memory (RAM), clock, analog-to-digital converter

(ADC), Ethernet and disk controller printed circuit boards (PCBs)) were inter-connected via a 96-pin common bus, and the PATA HDDs and disk power supply card were connected to a separate 50-pin common bus (Figure 2). Because the SATA interface is much higher speed than PATA, stricter specifications for wire trace routing and cabling are required. After a few prototype designs, we solidified the SATA HARP architecture to have one backplane for both the 96-pin common bus for the main data logger electronic boards and the SATA drive connectors (7-pin data lines and 15-pin power lines). We also changed the disk drive array configuration from 16 disks along the pressure housing axis, to 8 disks across axis with closer drive spacing to provide more room for batteries while reducing the number of cables, connectors and circuit boards (Figure 4). The increase in batteries is 25% for standard HARP configurations going from 4 to 5 battery packs. Part of the original HARP data logger general design was to keep different functions on separate PCBs so that upgrades, enhancements, and repairs could be made at the sub-system level. This approach has proven very effective and economical during the continual development of the HARP as illustrated here in which the same data logger PCBs used with the PATA HARP backplane are transferred directly to the SATA HARP backplane with only a firmware change applied to the CPU PCB. Currently, PATA HARP firmware that has been ported to SATA HARP firmware includes the following configurations: 2 channel -200 kHz sample rate without compression, 2 channel -200 kHz sample rate with compression, 320 kHz sample rate with compression, and 4 channel -hydrophone at 100 kHz sample rate per channel without compression.

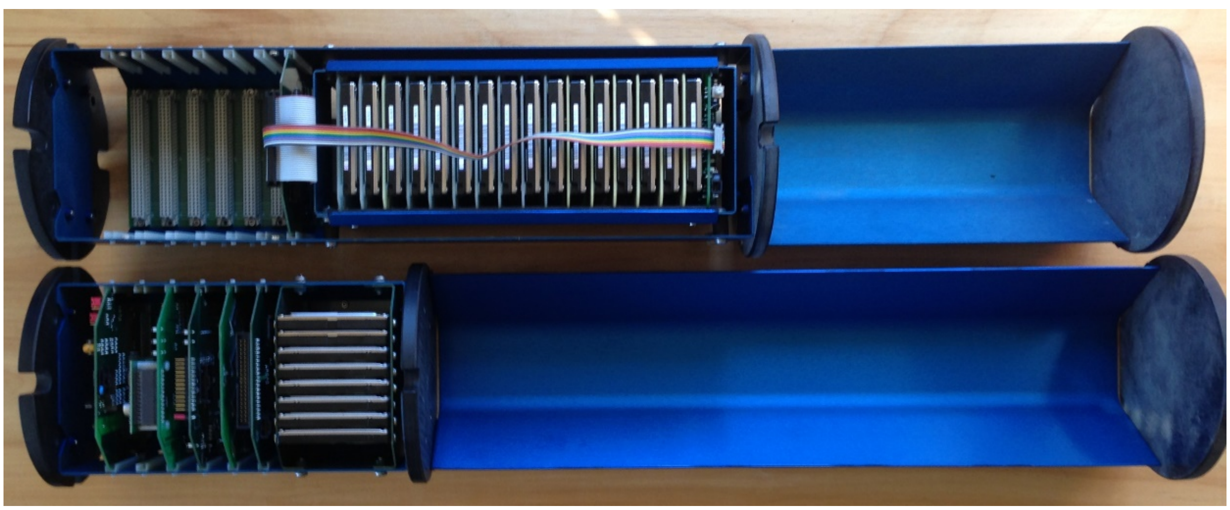

Figure 4. HARP data logger electronics, disk drives, and battery trough for old PATA (top) and new SATA (bottom) configurations. Note the increased battery volume (x2) and lack of disk cabling with the new SATA configuration. The same five main data logger electronic boards are used in both systems with the CPU firmware as the only difference. The new SATA configuration allows for one more battery pack, effectively increasing potential recording duration.

Furthermore, switching out disks during instrument refurbishment, for example, during battery replacement at sea, is easier by unfastening just a few screws and removing the entire 8-SATA disk block, rather than removing and keeping track of each of the 16 individual PATA disks (Figure 5). Also, the SATA disks are not required to be removed from the block during data processing and copying since 8 SATA-to-Universal Serial Bus (USB) converters fit on to the disks while they are still in the block. In the case of the PATA disks, each disk was handled individually and we were required to fabricate a specialized apparatus for multiple disk copying to increase data processing efficiencies.

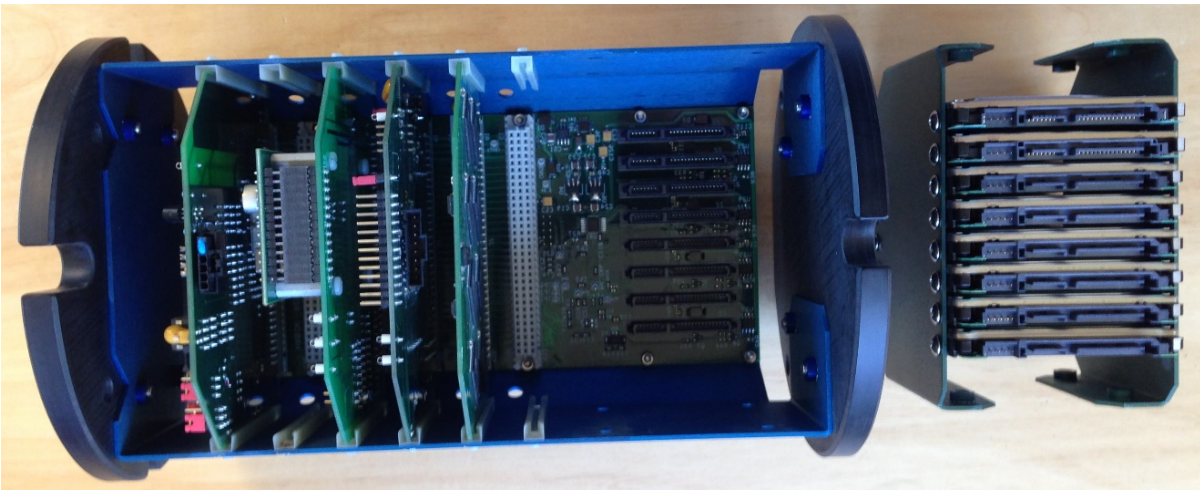

Figure 5. SATA HARP data logger backplane and main PCBs in blue sheet metal cage on left, and 8-SATA disk block in green sheet metal removed and turned upside down to show disk connectors on right.

Testing and Implementation

In addition to typical hardware and firmware testing and debugging required for newly developed electronics, lab-based freezer tests, ocean-based tests, and tests with different model disk drives were completed and used to identify any potential performance problems and measure disk power consumption. Disk power consumption is important to the overall power budget of the HARP data logger, affecting battery life and deployment duration. Typically, HARP disks are powered on for only about 20% of a recording in compression mode, but because their power consumption is relatively high compared to only sampling, they use about 60% of the total power budget. Disk manufacturers provide power consumption measures for various types of disk activities, such as reading, writing and idling, but these benchmarks typically are not comparable for HARP data writing, so disk-sample test must be conducted when choosing appropriate disk drives. Furthermore, over the years we have experienced power consumption variability that can be over 10% with disks from the same manufacturer and model, which should be accounted for when estimating battery capacities and deployment durations.

We tested eleven SATA disks (HDDs and SSDs) from eight manufacturers for functionality and power consumption and found Seagate 1 TB (M/N ST1000LM024 or STBD1000100) to have the best overall performance of the HDDs tested, and Crucial 1 TB (M/N BX100 or BX200) as the best SSD tested. Also, while SSDs were expected to have much lower power consumption than HDDs, only about 20% reduction in total power consumption was measured which is attributed to both lower power during data writing and shorter writing durations for the SSDs. However, HDD and SSD technology is quickly changing and continual testing is required to optimize disk storage for HARPs based on power, disk capacity, write speed, and compatibility with HARP electronics and firmware.

SATA HARPs have been successfully used in short (2-3 week) deployments offshore of La Jolla, California, and in long-term (multiple months) deployments offshore of Southern California and in the Gulf of

Alaska using single hydrophone non-compression and compression firmware in addition to 4-hydrophone tracking HARP configuration. Currently, Navy HARPs are being converted from PATA to SATA, tested, and used offshore of Southern California for the Pacific Fleet, in the Atlantic for the Atlantic Fleet, and for the Naval Post-Graduate School (NPGS). Also, NOAA HARPs are being converted or supplied as new SATA systems for deployments near Hawaii for PIFSC, in the Atlantic for NESFC, and in the Gulf of Mexico for SEFSC.

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