Finalizing the DTAG: Implementation and Testing of Design Improvements for Reliability and Availability

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LONG-TERM GOALS

Here we propose to make design changes to improve reliability and manufacturability of the DTAG, a sound recording multi-sensor tag.

OBJECTIVES

DTAGs have proven to be a valuable tool for the study of marine mammal acoustics and fine scale motion. The success of the DTAG has resulted in an increased demand for the instrument from researchers both within the Navy and the marine mammal community as a whole. However, the current DTAG design has cost, robustness, and reliability issues that make it unsuitable for the scaled-up manufacturing necessary to meet demand. To address this, we will improve reliability and manufacturability of the tag, and evaluate the new design by fabricating a small number of tags for testing. Additionally, this project will implement these design changes to create a pool of field-ready and cost-effective DTAGs available to marine mammal researchers.

APPROACH

The project involves four tasks to be performed over the course of two years. The first part of the project involve the tag redesign: **1)** implementation of design changes to address tag failure modes; **2)** improved design for manufacture; and **3)** a small test build (4 units) of the new DTAGs, which will be tested rigorously. Following the completion of these first tasks will result in a robust and economically viable tag design suitable for larger scale manufacture. At which point we will perform the final part of

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the project: **4)** the fabrication of a quantity of the revised tags for use by the marine mammal science community via a lease pool. The development of this pool will alleviate the current DTAG availability bottleneck while providing a mechanism to incorporate experience from the field about long-term reliability of the tags.

WORK COMPLETED

Implementation of design changes to address tag failure modes

Compared to earlier DTAG designs, the DTAG-3 involved substantial design changes, which were taken both to reduce the size of the device and to increase its performance. The electronic circuit, the accompanying software, and the housing were all radically changed to produce a much more capable device with a volume about one-half of the DTAG-2. With such major changes, unforeseen problems are inevitable and many of these have been identified and overcome over the last year. As a result, the electronic circuit and software are now completely field-ready. However, there are still several issues with the mechanical design, and the integration of the electronic systems, that have arisen during field use and must be addressed. Although all DTAGs pass a series of pressure and bench tests before they are used in the field, a number of failures have occurred either during or following field use of the tags that have revealed flaws in the current design relating to: 1) pressure tolerance of the electronics packaging; 2) sea water ingress into the housing; 3) inadequate floatation in fresh and brackish water; 4) light sensitivity of the electronics; and 5) hydrophone vulnerability. Subtasks with respect to major components and the status of those subtasks:

1) Main Electronics Board
   - Existing design for the main board (V1.1) will be used
   - Ordered and received 4 boards for the proto-type
2) Audio Board
   - Existing design for the audio board (V1.1a) will be used
   - Ordered and received 4 for proto-type builds
3) Battery
   - 1200 mAHr cell batteries currently in the tag will be used
4) Epoxy potting scheme (vacuum invested material)
   - Testing of the encapsulation methodology is currently being evaluated experimentally (see **Section A**)
5) Pressure transducer
   - Pressure tests of the new assembly have been conducted (see **Section B**)
6) USB Interface (integrated with electronics box)
   - A new USB PCB design has been design and fabricated
      i. Salt water testing to examine susceptibility to corrosion and water leakage have been conducted (see **Section C**)
7) Syntactic foam
   - Currently in design

8) Electronics Box
   - Currently in design
   - Design integration with the electronics box is underway
9) Ceramic selection for acoustic sensors
   - The 0.375" spheres from the current design have been selected
   - Integrated sensor mount is currently in design
10) VHF Antenna
   - Currently in design
11) Hydrodynamic housing over-mold
   - Currently in design

1. Epoxy encapsulation of the electronics

Problem: Previous versions of the DTAG used an oil-filled bladder to create a pressure tolerant environment for the tag electronics. The oil floods the space around the electronic components and is essentially incompressible so that, even though, the components experience ambient pressure, there are no shear stresses due to pressure differences. Most components tolerate ambient pressure within the range experienced by marine mammals and through extensive testing, we have avoided component types that are sensitive. A drawback of oil-filled housings is that, if water is able to enter the housing, it will contact the circuit causing corrosion and eventual failure. This problem occurred in a number of DTAG-2 devices and in several of the prototype DTAG-3s. To address this issue, a water blocking re-enterable gel was used as an alternative to the oil. The gel was intended to mitigate seawater ingress by creating a second sealed layer around the electronic components, while allowing transmission of environmental pressure. Gel filled tags passed both bench top and pressure testing (to 3000 psi) at WHOI before being deployed, but failed in the field at a significantly higher rate than the oil filled tags. From studying broken tags, we have determined that the gel is too viscous to flow under the miniature components used in the tag. Under pressure, these remnant air spaces are compressed creating shear forces on the components and tag failure when these components break.

Work to date: In an effort to eliminate multiple leakage paths into the DTAG electronics we have decided to encapsulate the card sets inside the electronics box. The encapsulation will eliminate sea water ingress while at the same time producing a more robust overall package. We are currently conducting a number of lab based experiments to refine the encapsulation process. The first of which used the following methodology:

- DTAG3 card set wired together and installed into an electronics box. (see Figure 1)
- Wire an external pressure transducer and a temporary USB interface; test this system
- Fill box with Epotek 301 epoxy, enough to completely cover cards
- Set DTAG logging and test at pressure

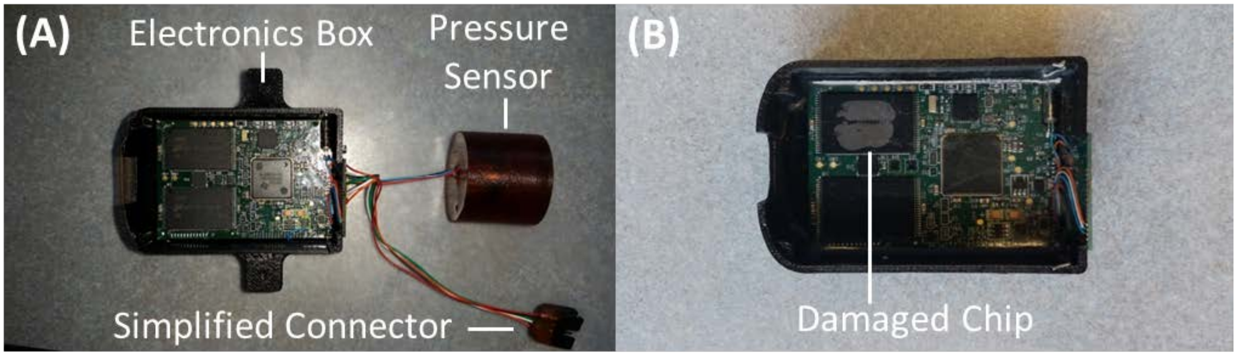

Figure 1 Encapsulated electronics with the external pressure sensor and the modified connector.

2. External pressure sensor

Problem: Previous DTAG designs located the pressure sensor within the electronics box. These tags used a compliant material to pressure compensate the electronics, effectively transmitting atmospheric pressure to the sensor. However, a rigid epoxy will be used to encapsulate the tag described in this work. As a result, the sensor must be moved outside of the electronics box.

Work to date: The currant design calls for the pressure transducer to be encapsulated in the flexible urethane housing, and positioned on the front of the electronics box between the hydrophones. To evaluate this decision, we conducted a series of bench top tests with encapsulated pressure transducer to verify that pressure was measured accurately and that the measurements were repeatable. The following **experimental equipment** was used for this evaluation:

- Identified two Keller pressure transducers to test:
    1. PA3L, 200 bar.
    2. Series 1 TAB, 200 bar.
- Encapsulated each in a 1” x 0.85” cylinder of Conap 401/701 urethane.
- Wired transducers to a LabJack USB data acquisition box, to measure pressure signal.
- Tested transducers in WHOI pressure chamber
    1. Calibration test
    2. Duration and cycling test, cycles to 2000 meters.

The following **pressure loading conditions** were used to evaluate the sensors:

- Series 1 TAB: (see Figure 2A)
    1. 309 hours in pressure chamber
    2. 284 hours at > 350 meters
    3. 210 cycles to at least 1000 meters (cycles randomly to 1000m, 1500m, 2000m)
- PA3L: (see Figure 2B)
    1. 344 hours in pressure chamber
    2. 305 hours at > 350 meters
    3. 281 cycles to at least 1000 meters (cycles randomly to 1000m, 1500m, 2000m)

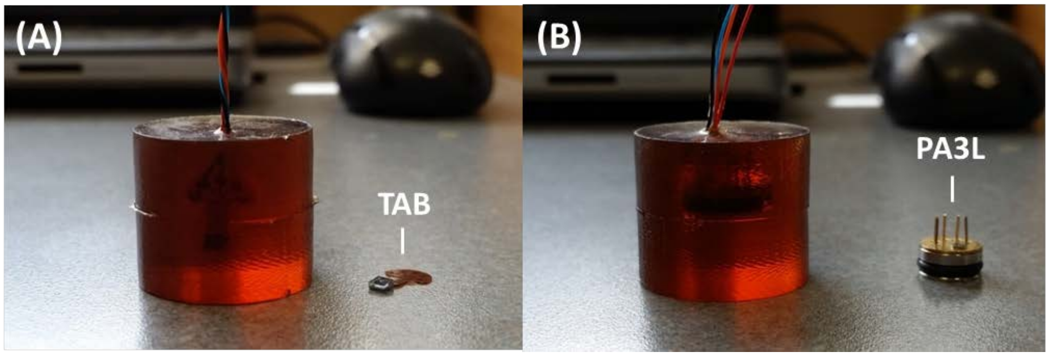

Figure 2 TAB and PA3L pressure sensors shown with and without encapsulation.

3. Sea water ingress around the connector:
Problem: Potential leakage points in the external urethane shell have been identified in the current DTAG-3 design. These arise from components such as the salt-water switch, the release and the USB connector, which necessarily penetrate the barrier. Flexure of the shell when the tag is attached to a swimming animal gradually weakens the bond at these joins opening ingress paths for water. Once water has penetrated this barrier, inconsistent bonding of the urethane shell to interior wires and metal shield layers leads to water movement into the electronics cavity, battery and external connector causing failure of one or more of these subsystems. In the current version of DTAG3 it was found that the external USB interface encountered two problems: (1) pads corroding and (2) sea water leakage path.

Work to date: To alleviate these problems we have moved away from the connector version interface to a printed circuit board (PCB) interface. (see Figure 4).

RESULTS

1. Epoxy encapsulation of the electronics
For the first test we investigated a standard open vessel pour at atmospheric pressure as this would be the simplest and most inexpensive process. The whole assembly was set logging and placed in the WHOI Pressure chamber and cycled up to 2000 meters. The epoxied card set successfully performed two 36 hours tests. However at the end of a third 36 hour test the DTAG electronics exhibited a problem. We were able to wake and communicate with the DTAG but were no longer able to access flash memory. The right image in Figure 1 shows discoloration above the top flash memory chip (top left). This is an indication that an air bubble below the chip collapsed under the electronics. We believe that this is directly connected to the flash memory failure.

Next steps: Run the same test again but with an improved encapsulation process – vacuum encapsulation. Setting up this process is underway. We are purchasing (or have purchased) the components required to setup a vacuum investment scheme at both WHOI and Univ. of Michigan. We have also identified two DTAG3 card sets to use for the testing. In order to ready the hardware for the epoxy testing the card sets required outside vendor service. The card sets have been returned from the vendor and are being prepared for the encapsulation and subsequent testing.

2. External pressure sensor
Both transducers were first calibrated in the pressure chamber against a reference transducer (Measurement Specialties MSP-600). Once calibrated the transducers were then moved to duration and cycle testing. The goal of this testing was to determine whether the transducers would hold a calibration over a period of pressure cycles. After over 600 hours of testing, both the PA3L and Series 1 TAB held their respective calibrations. Figure 3 presents data from the PA3L sensor, and includes a calibration check for the transducer at the 344 hour mark of testing (Top plot).

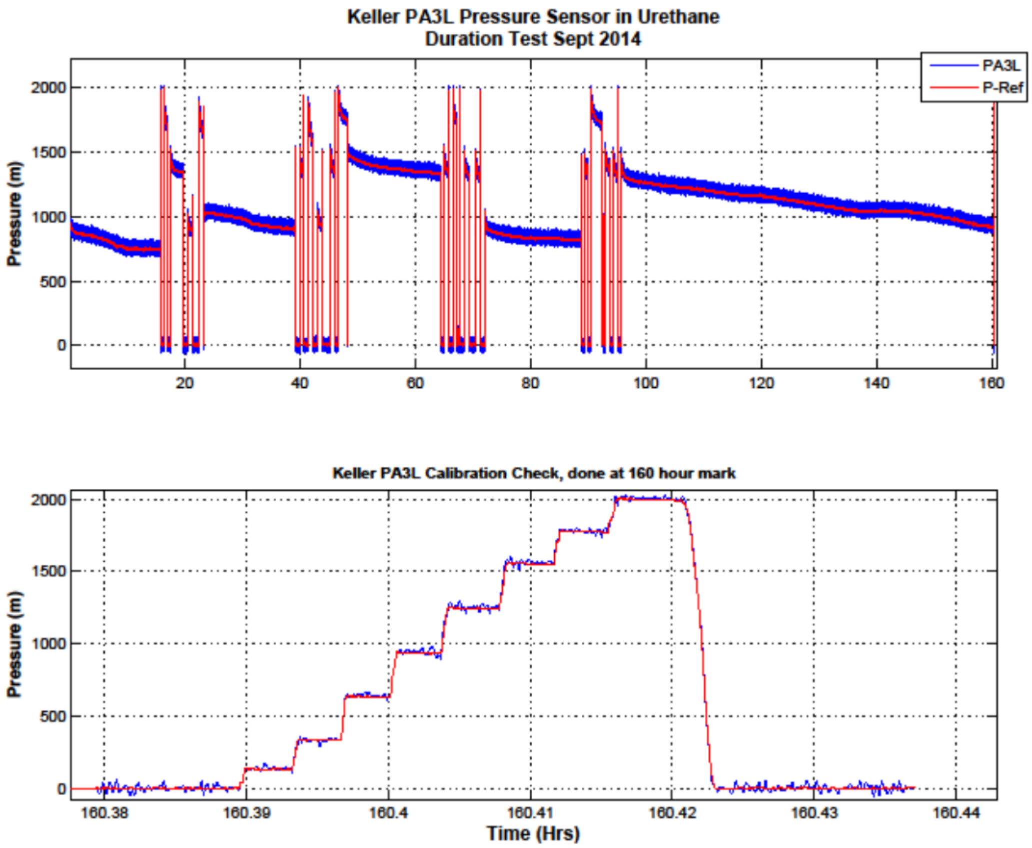

Figure 3 TAB and PA3L pressure sensors shown with and without encapsulation.

Next steps: Both sensors calibrated well after being encased in urethane and both sensors held their calibration throughout the subsequent testing. Additionally, neither sensor showed any evidence of damage or wear. As such, either would be a suitable choice and the final decision will be made after the evaluation of other criteria (e.g. cost and availability).

3. Sea water ingress around the connector:
Leakage path elimination: The PCB interface scheme is similar to how the hydrophones are wired into the electronics box. This interface has proved to be an effective means of isolating one side of the PCB (potentially exposed to sea water) form the other (electronics inside electronics box). In the new design the back side of the USB PCB will be encapsulated in epoxy, further sealing the sensitive electronics from sea water leaks. We have not yet pressure tested this as a system as we have been looking more at corrosion.

Pad Corrosion: The addition of a printed circuit board (PCB) for the USB communications interface also allows for some circuitry to electrically isolate individual pads. The intent is to isolate the ground pad from the corrosive currents generated when release the DTAG3. (burning the nicrome wire) This was tested on the bench by mocking up a release and monitoring the ground currents. (see Figure 4B) A DTAG3 card set was used to fire the nicrome release. The nicrome release, a ground return pin and the USB PCB were all put into a beaker of sea water. Digital Multi-Meters were used to monitor two ground currents: (1) the desired current path through the release ground return pin and (2) the ground pad on the USB PCB. The expectation was that minimal current would flow through the USB PCB thus minimizing corrosion of that pad. This did not happen, and the experiment measured currents in both ground returns.

Next steps: Corrosion was not a significant problem. During field deployments, if the pads are cleaned and maintained properly communications are expected to remain reliable over the life of a DTAG. We will continue to investigate USB PCB circuit additions to determine if we can eliminate corrosive currents altogether, but a fallback is to fabricate a cover for this connector while the DTAG is deployed. We are confident that we have eliminated this interface as a leakage path but do plan further testing to support this conclusion. This testing is underway on the bench, we will then move to testing at pressure.

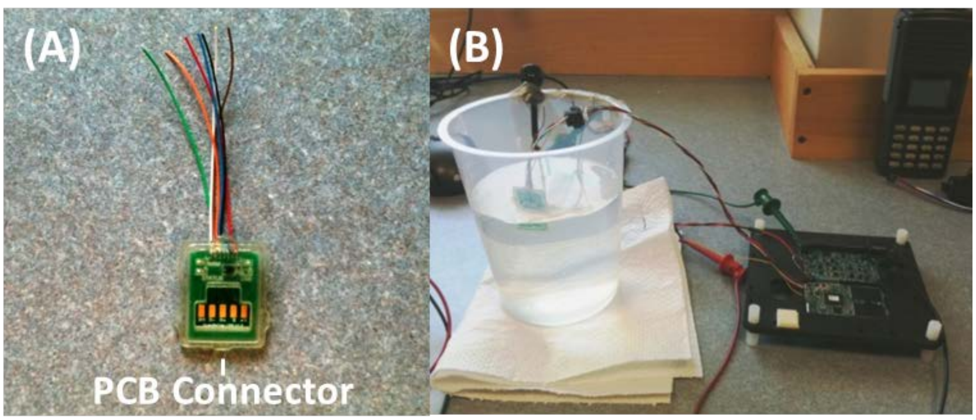

Figure 4 (A) New PCB connector and (B) Experimental setup to test performance in sea water.

Improved Design for manufacturability

We are concurrently working on the modular design for the new DTAG as we complete individual component design and selection (as described above). The modular design will break the current single unit design into 3 main sub-assemblies: 1) foam, 2) external sensors, and 3) electronics. This separation will enable rapid quality assurance on individual sub-assemblies, leading to improved yield, increased throughput, and reduced cost. Additionally, we are working with external companies in an effort to have as much manufacturing and assembly performed externally as possible in order to reduce labor costs. In this scenario, final assembly, testing, and calibration of the tag would then be performed at Michigan/WHOI.

Prototype Build Status:

Systematic testing is currently underway (as described above) and will continue to be performed throughout the design-build cycle. Following the successful testing of individual parts and sub-assemblies, a small set of tags (n=4) will be assembled for testing and evaluation. Pressure and environmental testing facilities will be used to simulate field deployments in a condensed period of time under controlled environmental conditions. Tags will also be mounted on a moving platform and tested in a salt water flume or aquarium to mimic field conditions. Dock testing of tag assemblies will be used to evaluate the effect of the marine environment on tag materials.

Following the lab evaluation, opportunistic field testing of the new design will be conducted by collaborators already using DTAGs for their existing field work. This will involve no new animal use. A database will be created containing details of the fabrication, test results and use history of each device enabling any new problems to be detected and tracked. Information gained from the lab and opportunistic field work will be used to updated and improve the new design.