A Multi-Use Low-Cost, Integrated, Conductivity/Temperature Sensor

Guy J. Farruggia
Areté Associates
1725 Jefferson Davis Hwy
Suite 703
Arlington, VA 22202
phone: (703) 413-0290 fax: (703) 413-0295 email: farruggia@arete-dc.com

Award Number Phase I: N0001401C397
http://www.arete.com

LONG-TERM GOALS

The goal of this SBIR project, which has completed Phase I and is in the process of starting Phase II, is the development of highly accurate, yet low-cost sensors for the measurement of oceanographic electrical conductivity, temperature, and depth (CTD). The project's initial focus is on developing an expendable device (XCTD). These low-cost XCTDs will affordably provide the greater utility of simultaneous, collocated conductivity and temperature profile measurements (as compared to just temperature (XBTs)). The technology also will be applicable in other sensor formats and can be mounted on any platform or mooring. While the initial instantiation of our technology will be for low-frequency measurement of temperature and conductivity, our approach can be applied to higher-frequency measurements as well, allowing measurement of turbulent patches in the ocean. In addition, our use of hybrid circuitry will allow for expansion to other sensed parameters without greatly increasing the volume of the electronics package.

OBJECTIVES

The main objective of this SBIR program, Phase I plus Phase II, is to develop and demonstrate one or more integrated sensor platforms. The initial device will measure, simultaneously and at the same location, temperature, electrical conductivity, and depth (via a pressure transducer). Areté is developing a sensor technology that, by design, can be mass-produced at low cost, yet achieves performance as good as or better than that currently available. This same basic technology can be employed in a variety of sensor packaging options, including:

- expendables that are air-, ship-, or submarine-launched
- devices that are free-floating, moored or bottom-mounted
- modules mounted to AUV's, UUV's, or submarines
- arrays towed from ships, submarines, or even aircraft.

In production, we anticipate the cost to the user of expendable versions of our CTDs to approach that of current XBTs.

The objective of the Phase I effort was to build a small sensor device on a single ceramic substrate which would simultaneously measure oceanic temperature and electrical conductivity at the same

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **30 SEP 2001**	2. REPORT TYPE	3. DATES COVERED **00-00-2001 to 00-00-2001**
4. TITLE AND SUBTITLE **A Multi-Use Low-Cost, Integrated, Conductivity/Temperature Sensor**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Arete' Associates,,1725 Jefferson Davis Hwy,Suite 703,,Arlington,,VA, 22202**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT
The goal of this SBIR project, which has completed Phase I and is in the process of starting Phase II, is the development of highly accurate, yet low-cost sensors for the measurement of oceanographic electrical conductivity, temperature, and depth (CTD). The project???s initial focus is on developing an expendable device (XCTD). These low-cost XCTDs will affordably provide the greater utility of simultaneous, collocated conductivity and temperature profile measurements (as compared to just temperature (XBTs)). The technology also will be applicable in other sensor formats and can be mounted on any platform or mooring. While the initial instantiation of our technology will be for low-frequency measurement of temperature and conductivity, our approach can be applied to higher-frequency measurements as well, allowing measurement of turbulent patches in the ocean. In addition, our use of hybrid circuitry will allow for expansion to other sensed parameters without greatly increasing the volume of the electronics package.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**6**	

location and with sufficient accuracy to support the reliable determination of seawater density and sound speed. The specific objectives for Phase I, including the option task, were:

1. Design and fabricate a multi-layer, collocated temperature and conductivity sensor substrate
2. Design and fabricate bread-board analog circuits for the two sensors
3. Test the sensors with their circuits to demonstrate that the temperature and conductivity sensors, individually, perform at least as well as the commercially available sensors
4. Long-term testing of the sensor immersed in seawater to verify performance and stability. (Option task)

APPROACH

Areté's approach is to develop a multi-use device that, in its initial format, will include collocated measurements of temperature and electrical conductivity on a single hybrid ceramic substrate. This ceramic substrate will include:

- an embedded thick-film two-electrode conductivity sensor,
- a glass-encapsulated thermistor bead
- a MEMS pressure transducer, and
- a multi-chip module (MCM) that will
  - contain the sensor power conditioning and analog and digital circuitry required to process the signals from the sensors,
  - apply calibration coefficients, and
  - multiplex and bus the signals to the user or storage media.

The assembly also will provide space for on-board power sources for expendable or short-term deployments.

The ceramic substrate will be mounted to the sensor body with the sensing elements exposed and with encapsulation protecting the portion of the ceramic that contains the MCM and power circuitry. The water- and pressure-proofing encapsulation can be tailored to the specific use of the sensor platform dependent on mission duration and depth requirements.

WORK COMPLETED

Under the Phase I contract Areté has developed a prototype sensor system, a bread-board circuit, a brass-board circuit, and a prototype power circuit. We have tested the conductivity sensor and thermistor through the circuitry. First the electronics were tested for linearity and stability. A preliminary "calibration" using artificial seawater determined sensor functionality and measurement range. The sensor tested was as an expendable sensor, but the design can be extended for other uses. A preliminary assessment of the feasibility of incorporating a MEMS-technology depth transducer on board was performed. Long-term testing of the prototype device is underway.

The measurement of temperature and conductivity were done with frequency encoding circuits. The conductivity sensor, in particular, involved a novel application of a known encoding loop with a very simple conductivity-sensing amplifier stage. This stage outputs a voltage that is a precise linear representation of conductivity.

RESULTS

The Phase I prototype C/T sensor was subjected to a series of tests to verify that it met the original design specifications. These tests were associated with sensor stability, cross talk, linearity, resolution and accuracy. Tests also were run to determine input power requirements and sensitivity to input power variability. Each of the tests has shown that the prototype meets or exceeds the design performance goals.

To test for stability and cross talk, precision decade resistor boxes were used in place of the temperature and conductivity sensors to provide a full range of simulated inputs to the electronics circuitry. To determine stability, the output frequency associated with each of several input resistances for each circuit (sensor) was noted regularly during a 60-day period. There was no measured drift or variability in the output frequency observed for either the temperature or the conductivity circuit outputs. To test for cross talk, the output of each sensor was monitored using an oscilloscope and a digital counter, while the decade resistor input for the other sensor was exercised through a full range of simulated inputs. Again, there was no measurable effect.

The C/T test for linearity and accuracy was accomplished using a bath of artificial seawater (35 ppt salinity) made from a commercial mix. The temperature of the solution was varied from 2 °C to 35 °C using a hot plate and a magnetic stirrer. The frequency outputs from the conductivity and temperature circuits were measured and recorded.

The resulting conductivity and temperature sensor output curves are shown in Figures 1 and 2. The responses of the sensors warrant three important observations:

1) The small curvature in the temperature response is the expected result of minimizing the errors in the third-order fit (a novel approach was used to minimize total errors rather than achieve best linearity)
2) The linearity of the conductivity calibration implies that the water conductivity vastly dominates cell contact impedance over the full range of conductivity measurements, and (therefore)
3) Both sensors in the frequency encoding circuits performed as expected.

These attributes will allow for an inexpensive and straightforward calibration procedure for individual sensors that will nevertheless yield excellent uniformity between production units.

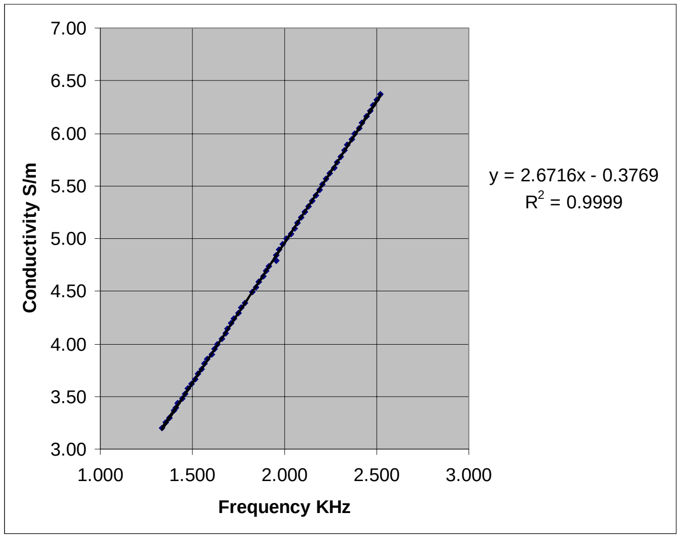

Figure 1. Preliminary Conductivity Calibration.
Conductivity was calculated from salinity and temperature and compared to the output of the sensor. A linear fit relationship resulted.

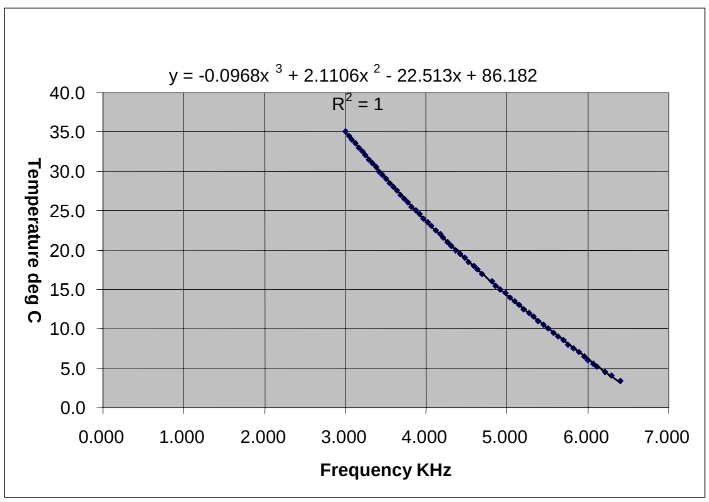

Figure 2. Preliminary Temperature Calibration.
The temperature sensor's frequency outputwas plotted against the known temperature in the bath. The expected smooth cubic fit was achieved.

A test of the power circuit also was performed. Sensor outputs were found to be stable (no observed frequency change) for input voltages from 5.4 Vdc (the minimum voltage required to drive the two series voltage references) to 6.0 Vdc. The current drain was measured at 2.7 mA @ 5.4 Vdc. The observed low current requirement and the insensitivity to voltage drop, are the sought attributes of the C/T circuit for battery operation.

The Phase I option task contract was received just prior to the writing of this report. We are just commencing the long-term testing. No data is available at this writing.

IMPACT/APPLICATIONS

A versatile, low-cost, collocated temperature/conductivity sensor can become an enabler for a multiplicity of applications. By emphasizing low cost as a primary design consideration from the outset of the project, we believe we will be able to achieve dramatic cost reductions in each commercial application, since each device format will be derivative of a common sensor design. Using multi-layer ceramic circuits as a common sensor and electronics platform will minimize R&D costs and allow the multiple product lines to benefit in manufacturing from the economies of scale. Therefore, even low-volume applications will be realized at lower cost to the end user than is possible today.

TRANSITIONS

If Phase II is successful, Areté Associates intends to commercialize the technology. Thus, transition will occur by the Navy and its contractors purchasing the finished product. Ongoing programs that could directly benefit from this technology include ONR-sponsored UUV development and Chemical Sensing in the Marine Environment (CSME) programs.

RELATED PROJECTS

Areté Associates is developing a suite of sensors for a joint US/UK program (Strelley) sponsored by OSD. These sensors are a temperature and conductivity sensor suite to actively measure turbulence fluctuations in the ocean. They are large and expensive compared to the sensors described in this report. Both projects will directly benefit, however, from the new technology developed in each project.