# A MINIATURE HIGH PRECISION CONDUCTIVITY AND TEMPERATURE SENSOR SYSTEM FOR OCEAN MONITORING

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## ABSTRACT

This paper describes a miniature high precision conductivity and temperature (CT) sensor system for ocean salinity monitoring. The CT sensor is manufactured using micro fabrication technology. A 7-electrode conductivity cell with no external field and a platinum resistor temperature bridge are used as the CT sensors. An impedance measurement circuit with 3-parameter sine fitting algorithm is used to support the CT sensors with a battery life of 1 month. The CT sensor system is packaged in a 10 x 10 x 15 cm plastic pot. Calibration result indicates that the accuracies of conductivity and temperature measurements are 0.03 mS/cm and 0.005 $^{o}$C respectively. Furthermore, a cruise deployment has been carried out to test the system in real environment.

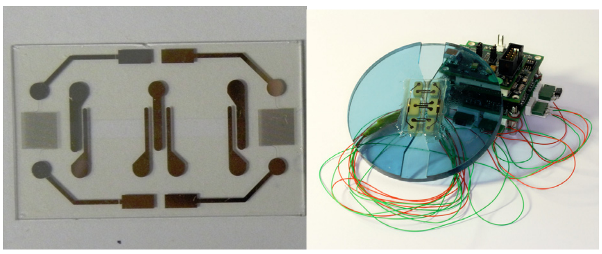
**KEYWORDS:** Ocean Sensors, Temperature, Conductivity, Salinity, Measurement System.

## INTRODUCTION

The Conductivity, Temperature, Depth (CTD) sensor is the primary tool for determining the salinity of sea water. Several high accuracy CTD sensors are commercially available [1], but they are all very large. Smaller systems have been developed to measure temperature and salinity but they are inaccurate [2]. This paper describes a low power, small sensor system for high accuracy ocean monitoring.

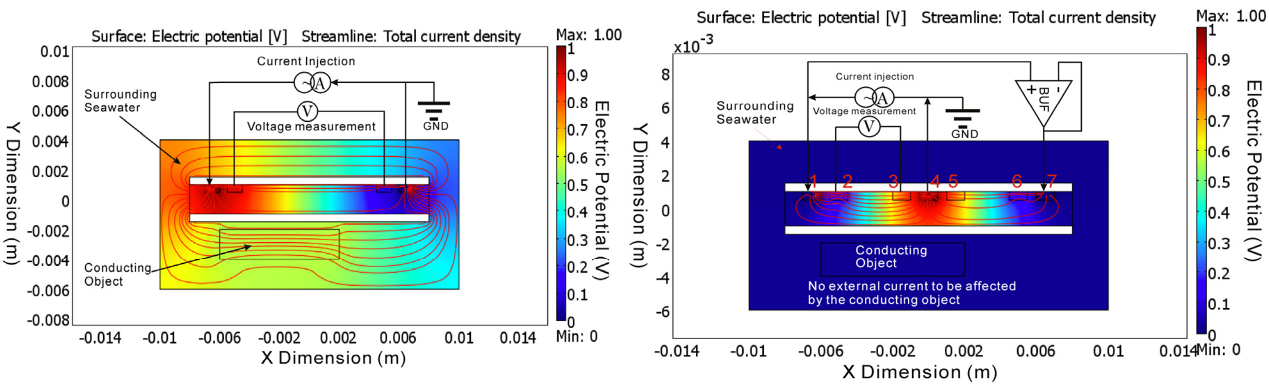
## THEORY

The conductivity of water is often determined by measuring the impedance between electrodes that are directly exposed to the water, but in the high salinity of sea water, making accurate measurements is extremely challenging. A simple way to measure conductivity has been previously reported [3], where two electrodes were fabricated within a channel that defined the geometry of the measurement cell. To reduce the errors caused by the voltage drop across the electrode interface (the Double layer), a four electrode method is preferable [4], again enclosed by a channel to define the measurement volume. Other designs use four-electrode sensors without channels [5, 6].



(a) (b)

*Figure 1.(a) Photograph of the CT sensor chip; (b) Photograph of the unpackaged CT sensor system*




(a) (b)

*Figure 2. Signal excitation method and FEM simulation result of a common four-electrode conductivity cell (a) and our seven-electrode conductivity cell (b).*

Figure 1 shows our sensor system, with a geometry that was optimized by numerical modeling. In order to maximize the precision, a new method of the signal excitation was used as shown in figure 2. The platinum electrodes are fabricated on a glass chip, covered with a plastic block with a channel 2mm x 2mm through which water flows. There are seven symmetrical electrodes on the chip. Electrodes one and four are used in a classical four-electrode configuration to inject the current. The $7^{th}$ electrode is kept at the same voltage as the $1^{st}$ electrode to prevent current leakage out of the channel, eliminating any proximity effects (insulating or conducting objects moving near the sensor). The $5^{th}$ and $6^{th}$ electrode keep the sensor symmetrical, which further reduces proximity error. By comparing with a common four-electrode conductivity cell in figure 2, there is no external current for the seven-electrode cell, and the proximity effects are eliminated.

In addition to the conductivity sensor, two platinum wire resistors are fabricated for temperature sensing. These platinum resistors are insulated using an epoxy laminate.

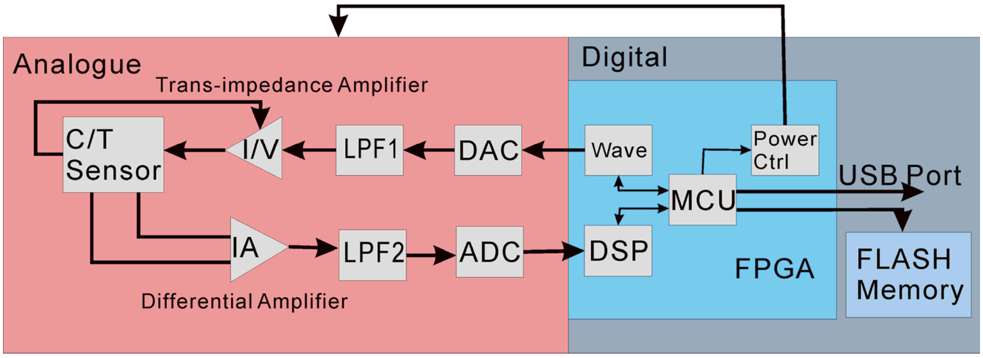


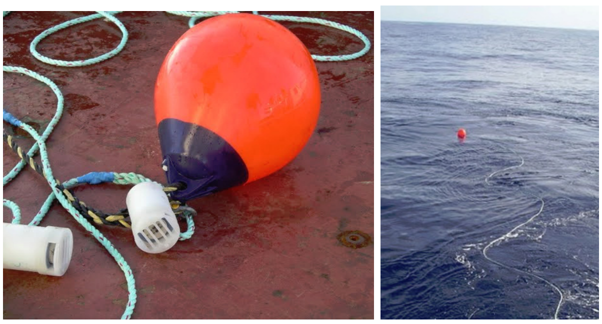

*Figure 3. Block diagram of CT sensor system, including CT sensors and supporting circuit for impedance measurement.*

An impedance measurement circuit is included in the system to support the CT sensors. As shown in Figure 3, an analogue circuit is used to excite the sensors with 1.56 kHz sine-wave, and convert the voltage response of the C/T sensor into digital signal. A digital circuit is used to process the response signal, calculate the impedance using a 3-parameter sine-wave fitting algorithm, and record the data into a 512 Mbit FLASH memory. Then the CT values can be calculated using a PC by reading the recorded data through a USB port.

## EXPERIMENTAL

The sensor system was calibrated in the Calibration laboratory at the National Oceanography Centre (NOCS) using saline sample of varying conductivity, between 20 to 60 mS/cm, and temperature, 4 $^oC$ to 34 $^oC$. The measurement accuracy is 0.03 mS/cm for conductivity, 0.005 $^oC$ for temperature, and 0.03 psu for salinity. The system is powered by a PP3 battery and utilizes wake-up circuitry, consuming 9.2 mA current when measuring and 200 uA when quiescent, with 100 ms measurement time.

The system has been deployed in an Atlantic cruise, figure 4 shows the packaging used for this deployment and figure 5 shows typical temperature and salinity data from Atlantic.



(a) (b)

*Figure 4. (a) Photograph of two packaged CT sensor systems bound to an orange buoy with a green rope. (b) Photograph of the CT sensor systems deployed in the Atlantic. The sensor system is under water and hanged on an orange buoy floating on the water surface.*

## RESULTS AND DISCUSSION

The calibration result shows a good accuracy for our CT sensor system, and the deployment of the Atlantic cruise proves that our system can work in the real environment. In the future, more experiments need to be carried out to find out the drift error, and improve the stability of the system.

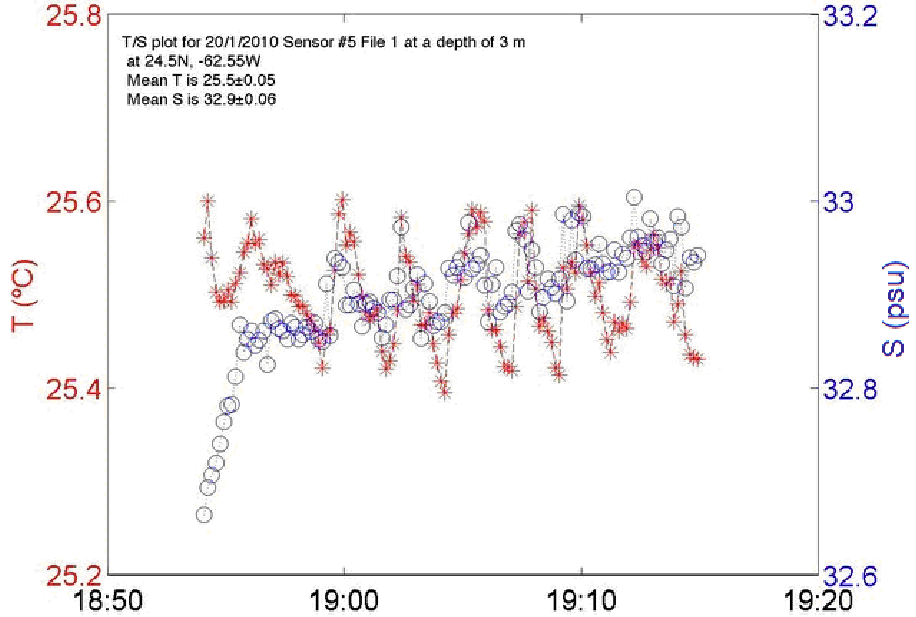



*Figure 5. Plot of the temperature and salinity data collected by the CT sensor system in 3 meters deep seawater of Atlantic at 24.5N, -62.55W*

**CONCLUSION**

Table 1 compares the performance of our system with others. As shown in table 1, our CT sensor has longer battery life and smaller dimension than the Sea-bird SBE 19+ V2 [1], and much higher accuracy than the other smaller systems. Furthermore, by integrating all the circuit into an ASIC (Application Specific Integrated Circuit), our system will be small and compact enough to be packaged in a device that will allow use as a high accuracy data logging fish tag.

*Table 1. The Comparison of CT sensor systems*

| **Sensor system** | **Accuracy for conductivity (mS/cm)** | **Accuracy for Temperature (°C)** | **Battery life** | **Dimension (cm)** |
|---|---|---|---|---|
| Our System | 0.03 | 0.005 | 30 days (10 sec interval) | 10 x 10 x 15 |
| SBE 19+ V2 [1] | 0.005 | 0.005 | 60 hours | 58 x 10 x 10 |
| Star-Oddi DST CTD [2] | 0.8 | 0.1 | 4 years | 4.6 x 1.5 x 1.5 |
| PCB MEMS-based CTD [5] | 1 | 0.5 | 22 days (15 min interval) | 10 x 10 x 10 |

**ACKNOWLEDGEMENTS**

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