# Field Evaluation of a Revolutionary CTD Design

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## *I.Introduction*

A Workshop on "Salinity Measurements in the Coastal Ocean," (Woody et al. 1999) focused on the need for long-term, *in situ,* salinity measurements. Long-term measurements will support global sampling programs critical to understanding ocean-atmospheric climate variability and its causes. The participants identified sensor stability and biological fouling in a field environment as the two main impediments that new technologies must address. The Conrad Blucher Institute for Surveying and Science at Texas A&M University-Corpus Christi and Falmouth Scientific, Inc., are collaborating on a Sea Grant Technology Program project to quantitatively assess the ability of a new sensor to accurately measure salinity over long periods in a strongly biofouling coastal environment, which directly addresses the recommendations of the Workshop. The most severe test for *in situ* conductivity measurements, from which salinity is derived, usually occurs in coastal regions. River discharge and upwelling generate a large dynamic range in the conductivity signal and a high potential for biological fouling. Indeed, it is the complex biological activity that is of significant scientific and economic interest. Therefore, the suitability of a new conductivity sensor for long term deployment is best tested in a dynamic coastal zone. Having the data available in real time can accelerate the testing process, as sensor performance and results can be evaluated on a continuous basis.

Falmouth Scientific, Inc. (FSI) has conceived and is now testing a new sensor geometry, which allows for the use of various, innovative anti-fouling techniques in an inductive type conductivity sensor. The new sensor has been designated the Non-External Inductive Conductivity Sensor (NXIC). Laboratory results have confirmed the suitability of this new technology for conductivity measurements, and field tests of fouling prevention are underway.

The Workshop's desired short-term goal for an *in situ* salinity sensor is to be capable of measuring salinity to 0.1 accuracy on the Practical Salinity Scale and maintain stability for a minimum of six months (Woody et al. 1999). It should be portable, low cost, low power, and non-fouling. The long-term goal is to improve the accuracy to 0.01 with a range of values between 0.1 and 42 on the Practical Salinity Scale. Improved anti-fouling technology needs to be developed to make long term, in situ salinity measurements possible without harming the environment.

## *II. Methods and Results*

The new FSI sensor (NXIC) is an inductively coupled conductivity sensor that has essentially zero external field, and hence, its calibration is not affected by the proximity of external objects. Although the NXIC was developed specifically to address the long-term deployment problems associated with biofouling, it became apparent that the sensor had an added advantage in that the design essentially eliminates the external electro-magnetic field, allowing the sensor to measure accurately in close proximity to metallic and non-metallic objects, greatly expanding the application potential of the inductive conductivity sensor.

The new NXIC sensor geometry is unique in that it has "no" external electric field, while continuing to use "inductive" drive and current sensing, thus eliminating the need for unstable electrodes. The unit is a free flushing sensor. It consists of two ceramic tubes mounted parallel to each other. The ends of each tube are fixed to ceramic shrouds. Each tube has a pair of torroidal transformers fitted coaxially over them. The design is such that the induced currents flowing in the two tubes are opposite, and the difference, which flows externally, is zero.

Fig 1 NXIC Sensor

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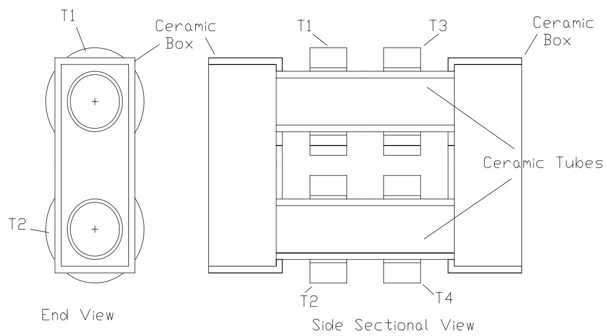


Fig 2 Outline Drawing of FSI NXIC Sensor

This has advantages in biofouling environments. Furthermore, the ability to "concentrate" antifoulants in a region or within a shuttered sensor results in "heightened" biological fouling protection. The NXIC sensor also has major advantages for calibration. FSI has demonstrated in both its own and customer laboratories that the inductive cell can be easily calibrated in a 1.0-m diameter tank with no external compression. As only the "k-factor" needs to be determined, only one bath is required, and it need not have any temperature regulation requirements. Figures 1 and 2 show photographs of the NXIC sensor.

*A. Antifouling Methods*

Long term, *in situ* sensors suffer from fouling, the major problem in coastal programs. High biological growth can severely alter sensor geometry.

Biological growth on the internal surfaces of the sensor can conceivably be controlled in the following ways:

- Coatings to prevent growth on the critical surfaces
- Coatings on approach tubes to control biology prior to entry into the cell
- Periodic introduction of chemicals to control biological growth within the sensor
- Mechanical isolation of the internal volume to prevent growth (during non-measurement periods)
- A combination of the above.

A potential problem with antifoulant paint is that it can alter the geometry through degradation of the paint itself. An accuracy of 0.1 is attainable for short deployments (weeks), but, even with the best anti-fouling techniques, accuracy degrades to worse than 1.0 for deployments of several months. The advantage of the NXIC cell is that it can be readily adapted to any or all of the above control methods

Presently tri-butyltin (TBT) is the most effective antifouling material but has strict environmental controls for permitting and use. Some states will allow limited use of TBT with strict guidelines. One of the authors (FJK) has had Texas Dept. of Agriculture Non-Commercial Pesticide Applicators License for the application of TBT-type antifouling paints on oceanographic instruments. However, he has discontinued the use of such paints for a variety of reasons, including the decreasing availability of such paints and complexity of the regulations for use, and he has reverted to more traditional 70%-copper based paints. With antifouling treatment, salinity sensors presently can operate for up to 3 months in coastal waters during some seasons and 2.5 years in deep water before severe accuracy degradation occurs.

There are few studies available on antifoulants and their effects on sensors and data. According to Woody (1999), one such study was conducted in the Netherlands to select a suitable sensor to measure conductivity and temperature for continuous, *in situ* monitoring of coastal waters (van Oort, *et al.*, 1998). Upon selection of the sensor, further studies were conducted on the effects of three different antifoulant paints on each of three of the chosen sensor. Bondit B2/C6 (based on ammonium hydroxide), Seajet 033 (30-60% cupricoxide and 10-30% xylene), and Jotun HSE 3410 (0-1% tri-butyltin and 30-60% cupricoxide) were used, with one additional sensor free of antifoulant for visual comparison only. The field tests were conducted in brackish, somewhat stagnant water. Conductivity data were recorded from the three test cases with reference conductivity measured weekly using a hand-held sensor of WTW, model LF196. The results showed Jotun HSE 3412 to be the most effective, and it was found that the use of antifoulant paint increased the maintenance-free period for about a week. Van Oort, et al. (1998) did not feel that this time increase was enough to justify the use of the TBT antifoulant.

In another study both the Seacat and the FSI-Micro-CTD sensors were deployed in a shipboard thermosalinograph application. They displayed comparable drift rates, even though the Seacat had antifouling protection and the FSI did not. The test was carried out on two surface salinographs collecting continuous temperature and conductivity data over a four-month interval covering a wide area of the North Atlantic (equatorial region to Iceland) in the summer of 1993 (Bitterman and Millard, 1994). Both of the salinographs showed a consistent conductivity drift with time towards lower salinity (conductivity) of between -0.0007 PSU/day (-0.255 PSU/yr) (Seabird with tribuytaltin antifoulant) and -0.001 PSU/day (-0.365 PSU/yr) for the FSI inductive cell with no antifoulant. Neither of these conductivity cells performed well enough under these conditions to meet the 0.01 PSU/yr goal.

## *B. Field tests and results*

CBI has conducted three field tests. For all three the NXIC sensor was interfaced to an FSI 2DACM current meter, which was in turn connected to a CBI real-time data Acquisition system. The first test was conducted July 1-24, 2001 close to the mouth of the Texas Aransas Pass channel, and the sensor system at 3 m depth in 15 m of water. The NXIC was fitted with a system that continuously dispensed by diffusion a very small amount of swimming pool disinfectant from a dissolving tablet in a tube affixed to the side of the NXIC. Despite the minute amount of disinfectant being dispensed, the measurements were unequivocally biased and this approached was abandoned.

In the second trial, conducted at the same location during July 25 through August 25, 2001, no antifouling measures were applied to the NXIC sensing tubes, although all external surfaces of the sensor and 2DACM were painted with copper-based antifoulant. The measured salinity (green) and along channel component of current (m/s; red) for the period July 25-August 3 are presented in Fig 3. It shows a combination of high salinity during the ebb, which is increasing from a neap to a spring tide, and decreasing coastal salinity that comes in on the flood tide. The maximum salinity is about 38, which is normal for the high evaporation and low river flux rates (barring a tropical weather event) in the late summer in Corpus Christi Bay. A CTD cast was collected on July 27. At the depth of the NXIC sensor the salinity values agreed to within about 0.1. Taking into account vertical and temporal variability this the values suggest that fouling had not begun. A second cast was made on August 9. The CTD cast yielded a salinity of about 36.47 at 3m down, while the NXIC recorded 34.0. So, the NXIC salinity values were low by about 2.5, indicating that during the previous two weeks fouling had taken hold rapidly in the unprotected cores of the NXIC tubes.

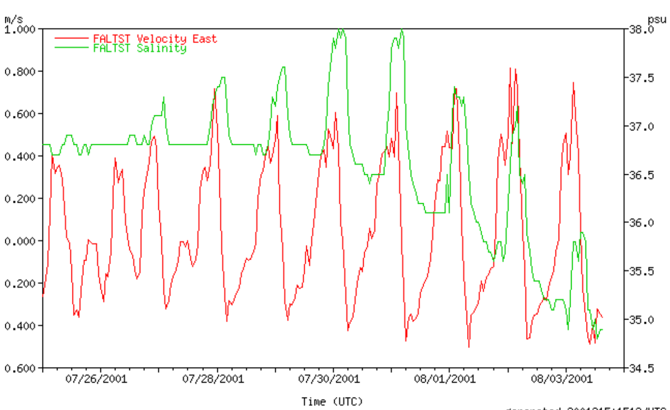


Fig 3 Salinity (green) and along channel component of current (m/s; red) measured by an unprotected NXIC sensor and 2DACM in Aransas Pass, TX channel during July 25-August 3, 2001.

For the third experiment all surfaces of the NXIC sensor, including the sensitive inner bore areas, were painted with Red Petit Trinidad 75. This is copper based anti-fouling paint and the red color has the highest amount of copper (76%) in comparison with the other colors manufactured. In addition the system was fitted with a pump to allow mechanical isolation of the internal volume during non-measurement periods. The pump was a commercially available Rule 500 gph bilge pump that was powered and controlled by the current meter. This theoretically would create an anaerobic environment during non-measurement periods that would cause the biological growth to die. All external components, including the 2-DACM, mounting bracket, cables, etc., were painted with 70%-copper Trinidad antifoulant (blue).

The location in Aransas Pass used for the first two tests provided a very dynamic flow environment. For the third test, a fairly quiescent location inside Corpus Christi Bay, near the middle (speeds typically less that 0.2 m/s), was selected. During May 1-18, 2003, the 2-DACM and attached NXIC system were hung from a wooden platform about 1.0 m below the surface in 4 m water depth. A 15 second interval of data was collected every hour. When recovered, fouling had begun on the external surfaces despite the heavy coat of antifouling paint and the short duration of the deployment (Fig 4). However, as Fig 5 shows, the internal bores of the NXIC tubes were free of fouling. Post-deployment calibration of the NXIC, without any cleaning of the system, yielded values within 0.05 of the pre-deployment ones.

One problem with the pumped system was that bubbles and/or suspended materials entered the NXIC tubes causing spiking in the salinity values. When the tubes were clear, the sample-to-sample salinity variability was less than about 0.03 (Fig 6, showing a particularly good period without spikes). However, the spiking was quite prevalent in the overall record, as another segment of it demonstrates (Fig 7). Nevertheless, during brief spike-free periods, the sample-to-sample variability is still less that about 0.03.

Fig 4 External Views of NXIC sensor and current meter after retrieval. Note that the antifouling paint, fouling has attached to the surfaces.

In a simultaneous experiment conducted at the Florida Institue of Oceanography – Seakeys program a NXIC was deployed with copper screen over each side of the sensor to test the effectiveness of it as an anti-fouling method and also to prevent intrusion of any foreign objects into the sensor. The location in the Florida Keys was chosen due to the high level of biological activity resulting in quick and severe biofouling. For this experiment a fine copper mesh screen was selected with 30 squares per inch. This was a mechanical test only and no data was collected. It was a baseline study to determine if this was a possible solution that warranted further study. The results of this test were promising, as no growth was found internal to the sensor. In the future it will be necessary to experiment with different size mesh screens (16 squares per inch) and also perform tests of longer duration.

Fig 5 View of the inside tubes of the NXIC sensor after deployment - no fouling

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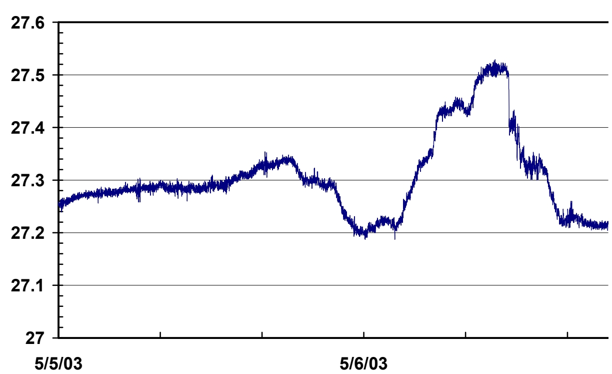


Fig 6 Salinity values measured by the NXIC sensor at a 15-second sample interval during May 5-6 of the May 1-18 deployment period. Note that he sample-to-sample variability is less than about 0.03.

*C. CBI's Real-time Sites*

To accelerate the testing of the NXIC sensor and various approaches to anti-fouling the sensor is integrated into an existing telemetering sensor program. Each remote site is controlled by a Data Acquisition System (DAS), designed with the premise that it should provide a stable, Windows-based data collection/logger platform that has the ability to interface with a wide variety of sensor instruments and their software while being able to hold the large amounts of data until transmitted back to CBI

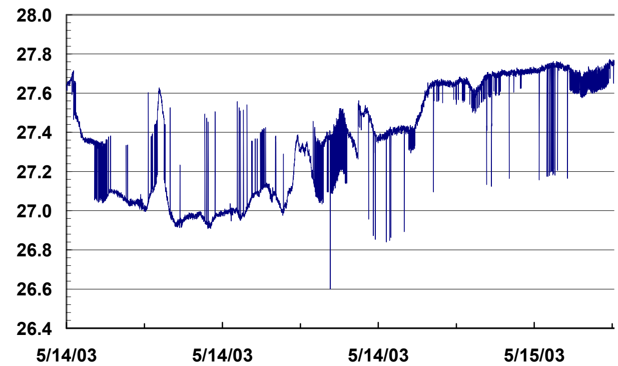


Fig 7 Same as Fig 6, but for a period with spiking.

The DAS is a PC-104-card based remote data logger running Windows 2000 Professional OS, that is loaded onto a 1.8GB Flash drive, all mounted within a 5" x 5" x 10" extruded aluminum enclosure. Three cards make up the "stack," the fist card being the power board. The Power Distribution-1 by Parvus is a 20-watt DC-DC converter designed to generate the required PC104 voltages (+-5VDC, +-12VDC) from an external DC power supply. The next card is the motherboard. It is a Pentium-ClassCool RoadRunner-2 by Lippert. Ours has a 300Mhz Clock speed and 256MB SODIMM. It is a complete motherboard with sound, VGA, 2 USB, 2 PCI, 2 Serial and one Ethernet port. The third card is the Xtreme8 by ConnectTech. This PC104 board provides 8 RS-232 serial connectors. It supports data communication speed up to 460.8KBPS

Data transmission is accomplished through the use of a FreeWave 900-MHz Spread Spectrum long range Ethernet Bridge with a baud rate as high as 115k. It connects via the Ethernet port. Visualization of the DAS desktop is achieved by using VNC, a program that is always running on the DAS and which can be logged into to provide a virtual desktop across the Ethernet link.

Power is provide by three 12V Marine batteries charged by 55-Watt solar panels filtered through three PV Charge Controllers, one for each battery.

### *III. Conclusion*

The first baseline deployment of a NXIC cell with no anti-fouling measures showed signs of fouling within several days of deployment. This third experiment using a combination of anti-fouling paint applied both internally and externally with mechanical isolation of the conductivity sensor worked well to prevent fouling. After retrieval there was extensive fouling on the external portions of the system where anti-foulant was applied but no fouling was evident on the sensitive interior bore areas of the conductivity sensor. Occasional spiking was shown in the data and this was due to bubbles and/or suspended material entering the NXIC sensor. However the sample-to-sample ratio variable was less than .03 PSU and exhibited no drift associated with fouling. Following the positive results of this short test longer-term deployments need to be conducted to ascertain long-term effectiveness. Future experiments should include tests painting all surfaces of the conductivity cell without a pump, mechanical methods only and possibly another combination of not painting the interior of the NXIC cell in conjunction with the pump. Another method that shows early promise is the installation of copper mesh screens to the intake ends of the NXIC sensor.

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