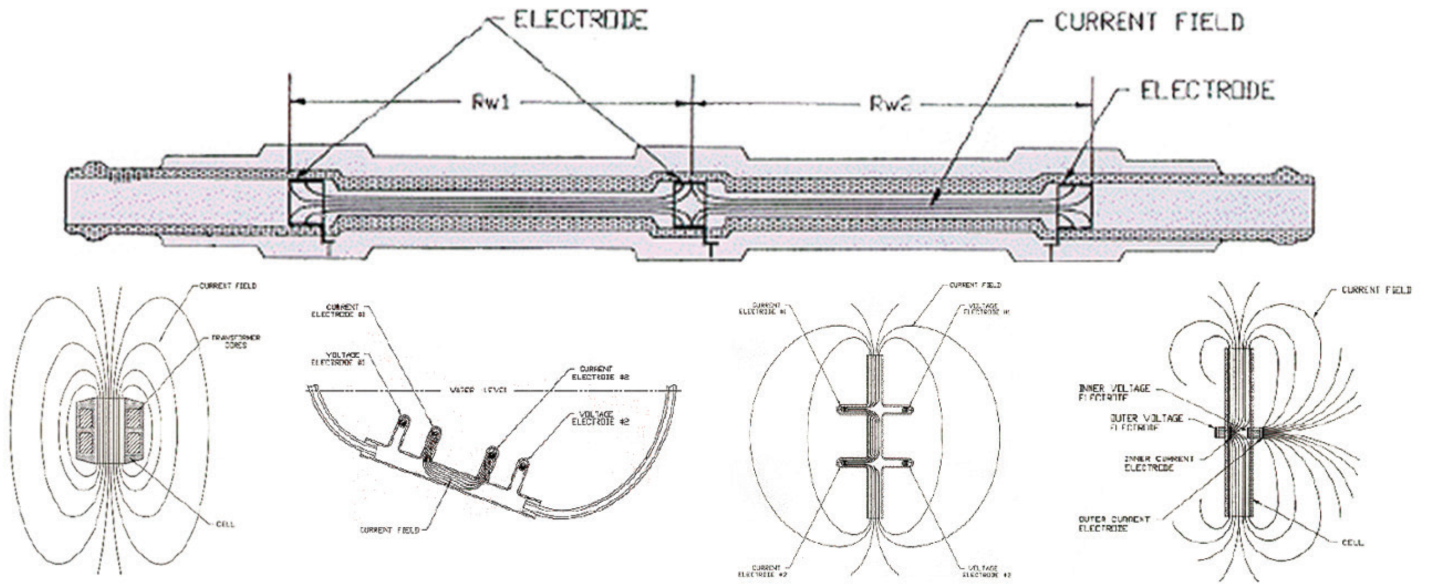
SEA·BIRD SCIENTIFIC

Technical Note

Conductivity Sensors for Moored and Profiling Operation

Sea-Bird Scientific's Borosilicate Glass Conductivity Cell

April 2020



Introduction

Salinity and density are difficult to measure directly. Physically measuring salt content or mass/volume in-situ is practically impossible and unrealistic. Instead, these variables can be derived from measurements of a sample's **conductivity**, which is measurable by a variety of sensor designs with high accuracy.

Oceanographic conductivity sensors measure **conductance** (the voltage produced in response to the flow of a known electrical current) and calculate conductivity with the measured conductance and the ratio of length/cross-sectional area of the sampled water volume. The determination of conductivity derives from the relationship:

$R = \rho l/A$

where:

- R = resistance = 1/conductance
- ρ = resistivity = 1/conductivity
- L = length of sampled water volume
- A = cross-sectional area of sampled water volume

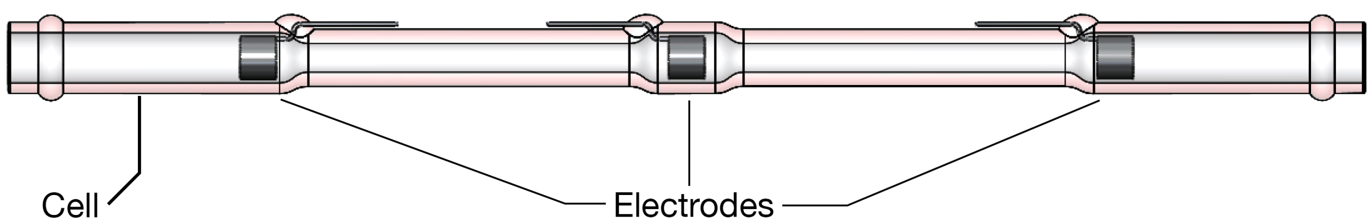
This relationship is identical to determining conductivity for a piece of wire: conductance depends on the wire's material (analagous to the salinity of the sample); longer wires have greater resistance; and a thciker conductor offers less resistance. However, unlike a piece of wire, a water sample's length and area are not rigidly defined. To calculate conductivity in seawater, the length and area correspond with the volume of water through which electrical current actually flows. Depending on the sensor type, electical current may travel through a relatively undefined volume of seawater.

The Sea-Bird Scientific Conductivity Cell

Existing designs use one of two methods to make an electrical connection to seawater:

1. **Electrodes**: requires either four-terminal technique or electrodes of sufficiently low (or stable) resistance. Sea-Bird Scientific conductivity cells use electrodes.
2. **Transformers**: The transformer (inductive) approach uses a transformer to couple a known voltage to the water, and detects the resulting current flow using a second transformer core.

Sea-Bird Scientific's conductivity cells encapsulate three electrodes in platinized borosilicate glass (below). This is a two-terminal cell in which the electrode resistances are in series with (and indistinguishable from) the cell resistance proper. Because the electrode resistances are low and the cell resistance high, errors resulting from changes in the electrode resistances are small. This design's advantages derive from a fully internal current field.

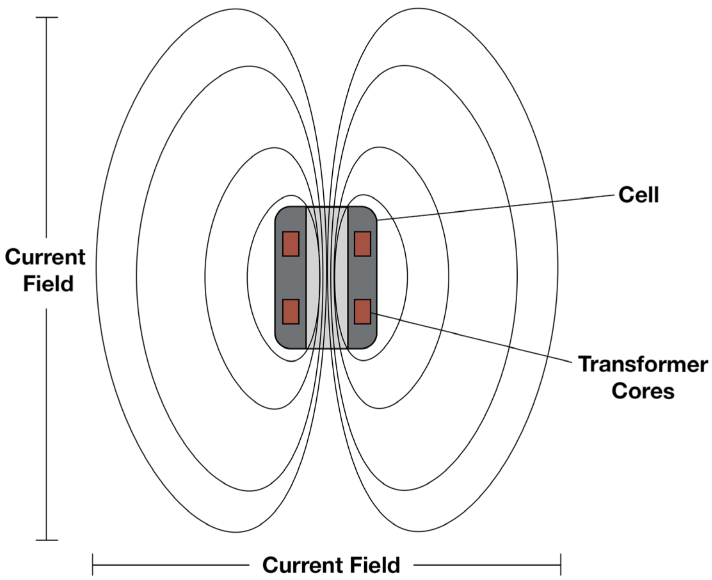


Recall that the conductivity measurement depends on the length and cross-sectional area of the volume of water through which electrical current actually flows. A fully internal field contrains the sampled volume to the cells hard parts, and ensures that the current field flows only through the seawater sample.

Other electrode-based conductivity cell designs have partly external fields, and all existing inductive cells have external fields, meaning that the current flows through a partially undefined volume and is potentially biased by objects within the current field. While these designs have advantages, a partially external field allows sources of error when objects other than the sample enter the field.

The Proximity Effect

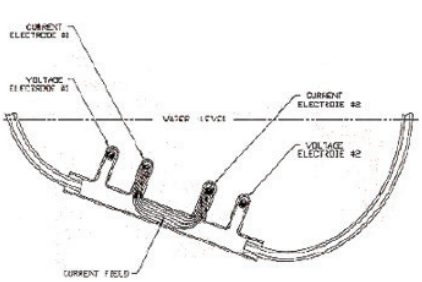
Except for the Sea-Bird (and the special case of the Guildline cell operated in a laboratory environment), available electrode cells have partly external fields. All existing **inductive cells** have external fields. Sensors that have external fields shift their calibration if nearby objects such as guards, struts, sensor housings - or marine growth - distort the external field. Antifoulant-bearing materials placed close enough to be effective also distort the external field, and in a way that will change as the antifoul material leaches out, as it must. Ironically, the calibration shifts resulting from placing antifoulant materials on the outside of an external field cell also prevent the protection of its internal hard parts.

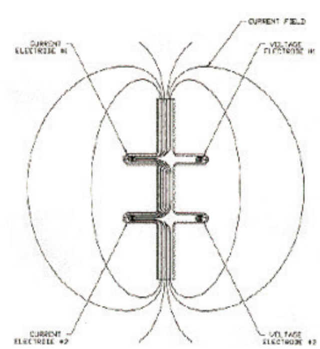


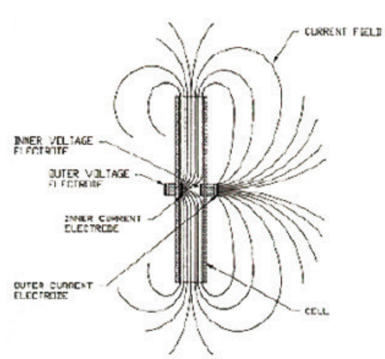
With inductive conductivity sensors (left), the electrical current flows in closed paths through the hole in the transformer cores. The magnitude of this current (and therefore the output signal from the sensor) depends on the field density along the path.

In the area away from the hole, the paths are widely separated and the resistance is low. In the hole through the cell, the paths converge and the resistance is higher; the area immediately exterior to the hole will also contribute significantly to the total resistance. But typically about 20% of the resistance occurs outside the relatively well-defined hole itself.

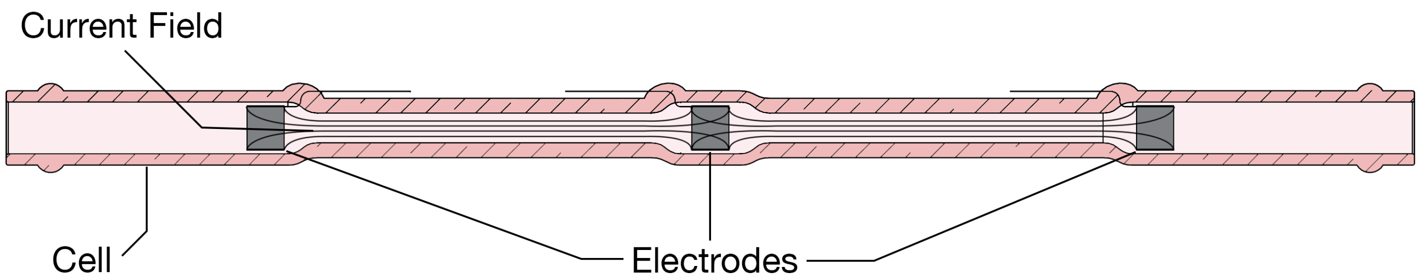
In a manner analogous to the hole in an inductive sensor, an **electrode cell's** length and crosssectional area serve to define the measured volume of seawater; however, in most electrode cells, some of the cell's sensitivity is similarly external, with the electrical current completing its path outside the cell (below). As a result, a measurable amount of the current field is external.







Unlike inductive and other electrode cells, the Sea-Bird Scientific cell (below) has zero external field because its outer electrodes are connected together; no voltage difference exists to create an external electrical current. The sample volume - entirely determined by the cell's hard parts - is immune to proximity errors and readily protected from fouling by anti-biology (toxic) gatekeepers placed at the ends of the cell.



Advantages and Disadvantages of Available Sensor Types

Inductive Sensors Advantages

The main advantages of inductive sensors are robust construction, and they can be cleaned with soap or solvents and a brush to preserve the cell geometry. There are no electrodes, so there is low possibility of their damage. Inductive sensors usually have a fairly large hole, which permits free flushing. For profiling applications, this means that inductive sensors can often be used without a pump, reducing the overall power requirements of the system.

Inductive Sensors Disadvantages

The main disadvantages are that a significant part of the measurement is external, inviting potential error from the proximity effect. Major consequences result from this external field:

1. The external volume is very difficult to protect from the effect of biological fouling or intrusion of adjacent objects such as cables and other sensor housings. The intruding object need only be of different conductivity than the seawater for proximity errors to occur. Antifoul material - if placed close to the sensor - will cause proximity errors. If placed sufficiently distant, its antifoul effectiveness will be poor.
2. Mounting of the sensor to companion packages (ALACE floats, current meters, AUVs, Rosettes, etc.) must be undertaken to avoid intrusion into the external area. Because final package geometry influences the results, the calibration must be performed on the fully assembled package. Depending on the package size, this may not be possible.
3. Calibration is awkward because clearance in the calibration baths must be provided for the external field. Calibration is especially inconvenient if the sensor is already mounted to a relatively large companion package such as an ALACE float.

SBS Conductivity Sensors Advantages

The main advantages of Sea-Bird's electrode cells derive from their fully internal field. Because the field is internal, small amounts of antifoul material placed at the ends of the cell (but not in it) are demonstrably effective in preventing internal fouling and attendant drift. Since there is no external field:

1. There is no proximity effect. The SBS cell does not require mounting on the end of a fragile strut, and mechanical protection is easily arranged. Its rugged reliability has been proven in more than 6000 SBE cells that have been deployed long term and unattended - large numbers on multiple deployments spanning many years.
2. SBS conductivity sensors can be calibrated in small baths without concern for proximity effects. We routinely calibrate 10 sensors in one automatically controlled bath of less than 50 liters capacity, obtaining out of the box accuracy corresponding to better than 0.005 psu. Conductivity sensors do not need to be calibrated on the fully assembled package for optimal accuracy.

SBS Conductivity Sensors Disadvantages

The primary disadvantage of the SBS sensor is its relatively poor flushing due to the small opening on the conductivity cell. While this is actually advantageous in that it enhances the antifoul capabilities of the cell (allowing antifoulant chemicals to accumulate inside of the cell), it is a drawback where very small spatial scales must be resolved. To correct this issue, SBS conductivity sensors are often paired with a pump for profilng and some moored applications. Generally, the SBE cell will give good results for measurements on second time scales for flow rates of 10 cm/second or more. The response time of the SBS conductivity cells has been well characterized, allowing for corrections to conductivity data in dynamic environments. Moored applications (with measurements typically on minute boundaries or greater) have exhibited scientifically satisfactory data even in lowflow environments.

A secondary disadvantage is that the SBE cell cannot be easily cleaned in the field. Placing objects inside of the glass cell will upset the calibration This is not generally important in autonomous or moored applications where no one will be there to do the cleaning.

Summary

Stable measurement of conductivity in unattended biologically active deployments is a proven reality with Sea-Bird Scientific conductivity sensors. Sea-Bird cells do resist fouling because their lack of external sensitivity permits the use of effective antifoul protection. They are rugged and reliable, as proven by thousands of successful deployments and a wealth of published results.

Adapted for print from https://www.seabird.com/technical-papers/conductivity-sensors-for-moored-and-autonomous-operation, 2003