APPLICATION NOTES

Sea-Bird Electronics, Inc.
13431 NE 20th Street
Bellevue, WA 98005
USA

+1 425-643-9866
seabird@seabird.com
www.seabird.com

APPLICATION NOTE NO. 2D **Revised March 2014**

Instructions for Care and Cleaning of Conductivity Cells

This application note presents recommendations for cleaning and storing conductivity sensors. The application note is divided into four sections:

- General discussion
- Identifying damaged of severely fouled conductivity cells
- Rinsing, cleaning, and storage procedures
- Cleaning materials

General Discussion

Since any conductivity sensor's output reading is proportional to its cell dimensions, it is important to keep the cell clean of internal coatings. Cell electrodes contaminated with oil, biological growths, or other foreign material will eventually cause low conductivity readings. To control growth of bio-organisms in the conductivity cell, follow these rinsing and cleaning recommendations.

- Bleach is extremely effective in controlling growth of bio-organisms in the conductivity cell. Sea-Bird recommends cleaning the conductivity sensor in a dilute bleach solution.
- Triton X-100 is a mild, non-ionic surfactant (detergent), valuable for removal of surface and airborne oil ingested into the CTD plumbing as the CTD is removed from the water and brought on deck. Sea-Bird recommends rinsing and cleaning the conductivity sensor in a Triton solution.
- White vinegar, which is 5 – 8% acetic acid, **may** be used to remove minor mineral deposits on the inside of the cell.

No adverse effects have been observed as a result of dry storage, if the cell is rinsed or soaked with fresh, clean water before storage to remove any salt crystals. This leads to the following conductivity cell storage recommendations:

- Short-term storage (< 1 day, typically between casts): If there is no danger of freezing, store the cell with a dilute bleach solution in Tygon tubing looped around the cell. If there is danger of freezing, store the cell dry, with Tygon tubing looped around the cell.
- Long-term storage (> 1 day): Since conditions of transport and long-term storage are not always under the user's control, store the conductivity cell dry, with Tygon tubing looped around the cell ends. Dry storage eliminates the possibility of damage due to unforeseen freezing, as well as the possibility of bio-organism growth in water in the cell. Filling the cell with a Triton X-100 solution for 1 hour before deployment will *rewet* the cell adequately.

The Tygon tubing looped around the ends of the conductivity cell, whether dry or filled with a bleach or Triton solution, has the added benefit of keeping air-borne contaminants (abundant on most ships) from entering the cell.

Identifying Damaged or Severely Fouled Cells

Every conductivity calibration certificate has a frequency output for *zero* conductivity, obtained from a cell thoroughly rinsed in distilled or de-ionized water, with all the water shaken out (**dry cell**). A *zero conductivity frequency* that has changed by more than a few 10ths of a Hertz may indicate a cell that is damaged or considerably out of calibration. Noisy readings (± a few 10ths of a Hertz) indicate a dirty cell; follow the procedure for *Cleaning Severely Fouled Sensors* to clean a dirty cell.

Example Calibration Sheet

Frequency associated with *zero conductivity* (dry conductivity cell). Variation of ± few 10ths of a Hz indicates a dirty cell.

BATH TEMP (ITS-90)	BATH SAL (PSU)	BATH COND (Siemens/m)	INST FREQ (Hz)	INST COND (Siemens/m)	RESIDUAL (Siemens/m)
22.0000	0.0000	0.00000	2448.38	0.0000	0.00000
1.0000	34.6962	2.96668	4921.91	2.9667	0.00000
4.5000	34.6766	3.27284	5108.92	3.2728	-0.00000
15.0000	34.6339	4.25160	5664.72	4.2516	-0.00000
18.5000	34.6244	4.59565	5847.26	4.5957	0.00000
24.0000	34.6134	5.15177	6130.50	5.1518	0.00000
29.0000	34.6065	5.67181	6383.64	5.6718	0.00000
32.5000	34.6019	6.04282	6558.06	6.0428	-0.00000

Rinsing, Cleaning, and Storage Procedures

Note: See *Cleaning Materials* below for discussion of appropriate sources / concentrations of water, Triton X-100, bleach, white vinegar, and tubing.

CAUTIONS:

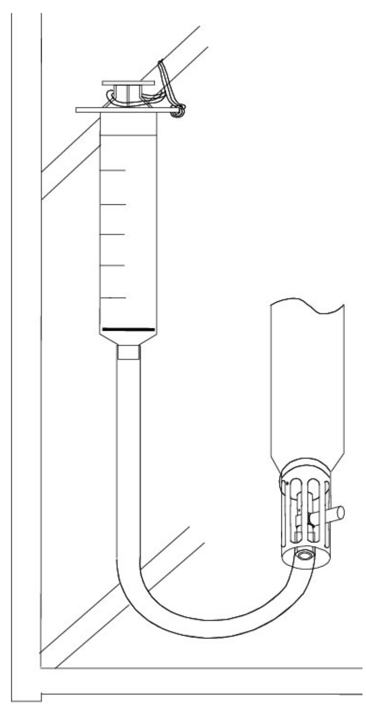
- The conductivity cell is primarily glass, and can break if mishandled. Use the correct size Tygon tubing; using tubing with a smaller ID will make it difficult to remove the tubing, and the cell may break if excessive force is used. **The correct size tubing for cleaning / storing all cells produced since 1980 is 7/16" ID, 9/16" OD**. Instruments shipped prior to 1980 require 3/8" ID tubing.
- **Do not put a brush or object (e.g., Q-Tip) inside the conductivity cell to clean it or dry it.** Touching and bending the electrodes can change the calibration; large bends and movement of the electrodes can damage the cell.
- **If a dissolved oxygen (DO) sensor is plumbed to the CTD** - Before soaking the conductivity cell for more than 1 minute in Triton X-100 solution, **disconnect the tubing between the conductivity cell and DO sensor** to prevent extended Triton contact with the DO sensor membrane (SBE 43) or optical window (SBE 63). Extended Triton contact can cause sensitivity [slope] changes, usually temporary, to the sensors. For rinsing, cleaning, and storage, see *Application Note 64* for the SBE 43 or the SBE 63 manual for the SBE 63.
- **IDO** and **ODO MicroCATs** (37-SMP-IDO, SIP-IDO, IMP-IDO, 37-SMP-ODO, SIP-ODO, IMP-ODO) have an integrated dissolved oxygen sensor. **Do not follow the rinsing, cleaning, and storage recommendations in this application note;** extended Triton contact with the DO sensor membrane (IDO MicroCATs) or DO sensor optical window (ODO MicroCATs) can cause sensitivity [slope] changes, usually temporary, to the sensors. For rinsing, cleaning, and storage, see the applicable MicroCAT manual.

Active Use (after each cast)

1. Rinse: Remove the plumbing (Tygon tubing) from the exhaust end of the conductivity cell. **Flush** the cell with a **0.1% Triton X-100** solution. **Rinse** thoroughly with **fresh, clean water** and drain.
   - If not rinsed between uses, salt crystals may form on the conductivity cell platinized electrode surfaces. When the instrument is used next, sensor accuracy may be temporarily affected until these crystals dissolve.
2. Store: The intent of these storage recommendations is to keep contamination from aerosols and spray/wash on the ship deck from harming the sensor's calibration.
   - ***No danger of freezing***: **Fill** the cell with a **500 – 1000 ppm bleach** solution, using a loop of Tygon tubing attached to each end of the conductivity sensor to close the cell ends.
   - ***Danger of freezing***: Remove larger droplets of water by blowing through the cell. **Do not use compressed air**, which typically contains oil vapor. Attach a loop of Tygon tubing to each end of the conductivity cell to close the cell ends.

Routine Cleaning (no visible deposits or marine growths on sensor)

1. **Agitate** a **500 – 1000 ppm Bleach** solution warmed to 40 °C (wrist warm) through the cell in a washing action (this can be accomplished with Tygon tubing and a syringe kit – see *Application Note 34*) for **2 minutes**. **Drain and flush** with warm (not hot) fresh, clean water for **5 minutes* or until rinsed thoroughly**.
2. **Agitate** a **1%-2% Triton X-100** solution warmed to 40 °C (wrist warm) through the cell many times in a washing action (this can be accomplished with Tygon tubing and a syringe kit). Fill the cell with the solution and let it **soak** for **1 hour**. **Drain and flush** with warm (not hot) fresh, clean water for **5 minutes* or until rinsed thoroughly**.



* If you do not have a large supply of fresh water: As a minimum, flush the cell with enough warm, fresh, clean water to fill the cell five times, or until rinsed thoroughly.

Cleaning Severely Fouled Sensors (visible deposits or marine growths on sensor, and/or shift in zero conductivity frequency)

1. Repeat the *Routine Cleaning* procedure up to 5 times.
   A. Thoroughly rinse in distilled or de-ionized water, and shake out all the water. With the conductivity cell dry, take and record a raw conductivity reading (in Hz). Compare to the *zero conductivity frequency* on the calibration sheet. The output should be within a few tenths of a Hz of the *zero conductivity frequency*. If not, proceed to Step 2.
2. Clean with a white vinegar solution or diluted HCl solution; see the *Cleaning Materials* section of this application note for details.

If the zero conductivity is still outside the expected range, the conductivity cell may require factory cleaning.

Long-Term Storage (after field use)

1. Rinse: Remove the plumbing (Tygon tubing) from the exhaust end of the conductivity cell. **Flush** the cell with a **0.1% Triton X-100** solution. **Rinse** thoroughly with **fresh, clean water** and drain. Remove larger droplets of water by blowing through the cell. **Do not use compressed air**, which typically contains oil vapor.
2. Store: Attach a loop of Tygon tubing to each end of the conductivity cell to close the cell ends and prevent contaminants from entering the cell.
   - Storing the cell dry prevents the growth of any bio-organisms in water in the cell, thus preserving the calibration.
3. When ready to deploy again: **Fill** the cell with a **0.1% Triton X-100** solution for **1 hour** before deployment. Drain the Triton X-100 solution; there is no need to rinse the cell.

Cleaning Materials

Water

De-ionized (DI) water, commercially distilled water, or fresh, clean, tap water is recommended for rinsing, cleaning, and storing sensors.

- On ships, **fresh water is typically made in large quantities by a distillation process, and stored in large tanks. This water may be contaminated with small amounts of oil, and should not be used for rinsing, cleaning, or storing sensors**.

Where fresh water is extremely limited (for example, a remote location in the Arctic), you can substitute **clean seawater** for rinsing and cleaning sensors. If not immediately redeploying the instrument, follow up with a **brief fresh water rinse** to eliminate the possibility of salt crystal formation (which could cause small shifts in calibration).

- **The seawater must be extremely clean, free of oils that can coat the conductivity cell. To eliminate bio-organisms in the water, boil the water or filter it with a 0.5 micron filter.**

Triton X-100

Triton X-100 is Octyl Phenol Ethoxylate, a mild, non-ionic surfactant (detergent). Triton X-100 is included with every CTD shipment and can be ordered from Sea-Bird, but may be available locally from a chemical supply or lab products company. It is manufactured by Avantor Performance Materials (http://avantormaterials.com/commerce/product.aspx?id=2147509608). Other liquid detergents can probably be used, but scientific grades (with no colors, perfumes, glycerins, lotions, etc.) are required because of their known composition. It is better to use a non-ionic detergent, since conductivity readings taken immediately after use are less likely to be affected by any residual detergent left in the cell.

100% Triton X-100 is supplied by Sea-Bird; dilute the Triton as directed in *Rinsing, Cleaning, and Storage Procedures*.

Bleach

Bleach is a common household product used to whiten and disinfect laundry. Commercially available bleach is typically 4 % - 7% (40,000 – 70,000 ppm) sodium hypochlorite (Na-O-Cl) solution that includes stabilizers. Some common commercial product names are Clorox (U.S.) and eau de Javel (French).

Dilute to 500 – 1000 ppm. For example, if starting with 5% (50,000 ppm) sodium hypochlorite, diluting 50 to 1 (50 parts water to 1 part bleach) yields a 1000 ppm (50,000 pm / 50 = 1000 ppm) solution.

Tygon Tubing

Sea-Bird recommends use of Tygon tubing, because it remains flexible over a wide temperature range and with age. Tygon is manufactured by Saint-Gobain (www.tygon.com). It is supplied by Sea-Bird, but may be available locally from a chemical supply or lab products company.

Keep the Tygon in a clean place (so that it does not pick up contaminants) while the instrument is in use.

White Vinegar

White vinegar is a common household product used to dissolve mineral deposits, and may be used to remove minor mineral contamination of the conductivity cell. Commercially available white vinegar is typically 5 – 8% acetic acid (CH_3COOH) in aqueous solution; verify that there are no oils or other ingredients.

1. Prepare for cleaning:
   A. Place a 0.6 m (2 ft) length of Tygon tubing over the end of the conductivity cell.
   B. Clamp the instrument so that the cell is vertical, with the Tygon tubing at the bottom end.
   C. Loop the Tygon tubing into a U shape, and tape the open end of the tubing in place at the same height as the top of the glass cell.
2. Clean the cell:
   A. Pour **weak white vinegar** solution (1 part white vinegar, 2 parts water) into the open end of the tubing until the cell is nearly filled. **Let it soak for 2-3 minutes only.**
   B. Drain the solution from the cell and flush for 5 minutes with warm (not hot), clean, de-ionized water.
   C. Rinse the exterior of the instrument to remove any spilled solution from the surface.
   D. Fill the cell with a **1% Triton X-100** solution and let it stand for 5 minutes.
   E. Drain and flush with warm, clean, de-ionized water for 1 minute.
   F. Carefully remove the 0.6 m (2 ft) length of Tygon tubing.
3. With the conductivity cell dry, take and record a raw conductivity reading (in Hz). Compare to the *zero conductivity frequency* on the calibration sheet. The output should be within a few tenths of a Hz of the *zero conductivity frequency*. If not, repeat Steps 1 and 2 with a moderate white vinegar solution (1 part white vinegar, 1 part water) and repeat the test. If still outside the expected range, repeat with a full strength white vinegar solution and repeat the test. If still outside the expected range, return to the factory or see *Hydrochloric Acid (HCl)* below.
4. Prepare for deployment, **or** follow recommendations above for storage.

Hydrochloric Acid (HCl)

Many years ago, Sea-Bird recommended cleaning with a hydrochloric acid (HCl) solution to eliminate bio-organisms or mineral deposits on the inside of the cell. However, bleach cleaning has proven to be effective in eliminating growth of bio-organisms, and is much easier to use and dispose of than acid. Data from many years of use shows that mineral deposits are an unusual occurrence. Sea-Bird recommends that, **in most cases, hydrochloric acid should not be used** to clean the conductivity sensor. ***In rare instances***, it may still be required for mineral contamination of the conductivity cell. ***Sea-Bird recommends that you return the equipment to the factory for this cleaning if it is necessary***. Information below is provided if you cannot return the equipment to Sea-Bird.

CAUTIONS:

- **SBE 37-IMP, SMP, SIP, IMP-IDO, SMP-IDO, SIP-IDO, IMP-ODO, SMP-ODO, SIP-ODO MicroCAT; SBE 49 FastCAT; SBE 52-MP Moored Profiler CTD; or other instruments with an integral, internal pump - Do not perform acid cleaning,** which may damage the internal, integral pump. Return these instruments to Sea-Bird for servicing if acid cleaning is required.
- **SBE 9*plus*, 25, or 25*plus* CTD** – Remove the SBE 4 conductivity cell from the CTD and remove the TC Duct before performing acid cleaning.
- **All instruments that include AF24173 Anti-Foulant Devices** – Remove the AF24173 Anti-Foulant Devices before performing acid cleaning; see the instrument manual for details and handling precautions.

WARNING! Observe all precautions for working with strong acid. Avoid breathing acid fumes. Work in a well-ventilated area.

The acid cleaning procedure for the conductivity cell uses approximately 50 - 100 cc of acid. Sea-Bird recommends using a 20% concentration of HCl. However, acid in the range of 10% to full strength (38%) is acceptable.

If starting with a strong concentration of HCl that you want to dilute:
For each 100 cc of concentrated acid, to get a 20% solution, mix with this amount of water -
Water = [(conc% / 20%) – 1] * [100 + 10 (conc% / 20%)] cc
Always add acid to water; never add water to acid.

Example -- concentrated solution 31.5% that you want to dilute to 20%:
[(31.5% / 20%) – 1] * [100 + 10 (31.5% / 20%)] = 66.6 cc of water.
So, adding 100 cc of 31.5% HCl to 66.6 cc of water provides 166.6 cc of the desired concentration.
For 100 cc of solution:
100 cc * (100 / 166.6) = 60 cc of 31.5% HCl 66.6 cc * (100 / 166.6) = 40 cc of water

For acid disposal, dilute the acid heavily or neutralize with bicarbonate of soda (baking soda).

1. Prepare for cleaning:
   A. Place a 0.6 m (2 ft) length of Tygon tubing over the end of the conductivity cell.
   B. Clamp the instrument so that the cell is vertical, with the Tygon tubing at the bottom end.
   C. Loop the Tygon tubing into a U shape, and tape the open end of the tubing in place at the same height as the top of the glass cell.
2. Clean the cell:
   A. Pour **10% to 38% HCl** solution into the open end of the tubing until the cell is nearly filled. **Soak for 1 minute only.**
   B. Drain the acid from the cell and flush for 5 minutes with warm (not hot), clean, de-ionized water.
   C. Rinse the exterior of the instrument to remove any spilled acid from the surface.
   D. Fill the cell with a **1% Triton X-100** solution and let it stand for 5 minutes.
   E. Drain and flush with warm, clean, de-ionized water for 1 minute.
   F. Carefully remove the 0.6 m (2 ft) length of Tygon tubing.
3. Prepare for deployment, **or** follow recommendations above for storage.

Application Note Revision History

Date	Description
January 1998	Initial release.
October 2002	Remove reference to part number for the small anti-foul cylinders (that have been eliminated) in Tygon tubing.
January 2005	Change in recommendations. Clean with bleach solution as well as Triton. Acid cleaning is not recommended in general, but some information on acid is still provided for the few cases where it is necessary. A section on Materials added, defining water, Triton, etc. in more detail.
July 2005	Include information on common names of commercially available bleach
October 2006	Update manufacturer name and website link for Triton
September 2008	Add SBE 52-MP to list of instruments with integral, internal pump that should not have acid cleaning.
October 2010	• Add reference to IDO MicroCATs, with caution to following cleaning and storage procedures in Application Note 64 instead of in this application note. • Update address.
October 2012	• Update manufacturer information for Triton. • Add information on 25plus. • Add reference to ODO MicroCATs, with caution to following cleaning and storage procedures in ODO manual instead of in this application note. • Eliminate 'new' language regarding cleaning and storing, since recommendations date from 2006.
March 2014	• Add information on cleaning with white vinegar. • Add information on checking zero conductivity frequency to verify cleanliness. • Add information on cleaning if SBE 63 Optical Dissolved Oxygen Sensor on system. • Update language on *recent* recommendations (which dated back to 2005).

Sea-Bird Electronics, Inc.
13431 NE 20th Street
Bellevue, WA 98005
USA

Phone: +1 425-643-9866
Fax: +1 425-643-9954
E-mail: seabird@seabird.com
Web: www.seabird.com

APPLICATION NOTE 27Druck **Revised February 2014**

Minimizing Strain Gauge Pressure Sensor Errors

The following Sea-Bird instruments use strain gauge pressure sensors manufactured by GE Druck:

- SBE 16*plus*, 16*plus*-IM, 16*plus* V2, and 16*plus*-IM V2 SeaCAT (not 16*) with optional strain gauge pressure sensor
- SBE 19*plus* and 19*plus* V2 SeaCAT Profiler (not 19*)
- SBE 25 Sealogger CTD, which uses SBE 29 Strain-Gauge Pressure Sensor (built after March 2001)
- SBE 25*plus* Sealogger CTD
- SBE 26*plus* Seagauge Wave and Tide Recorder with optional strain gauge pressure sensor in place of Quartz sensor
- SBE 37 MicroCAT (IM, IMP, IMP-IDO, IMP-ODO, SM, SMP, SMP-IDO, SMP-ODO, SI, SIP, SIP-IDO, SIP-ODO) with optional pressure sensor (built after September 2000)
- SBE 39 (built after September 2000) and 39-IM Temperature Recorder with optional pressure sensor
- SBE 39*plus* Temperature Recorder with optional pressure sensor
- SBE 49 FastCAT CTD Sensor
- SBE 50 Digital Oceanographic Pressure Sensor
- SBE 52-MP Moored Profiler CTD and DO Sensor

*** Note:** SBE 16 and SBE 19 SeaCATs were originally supplied with other types of pressure sensors. However, a few of these instruments have been retrofitted with Druck sensors.

The Druck sensors are designed to respond to pressure in nominal ranges 0 - 20 meters, 0 - 100 meters, 0 - 350 meters, 0 – 600 meters, 0 – 1000 meters, 0 – 2000 meters, 0 – 3500 meters, and 0 – 7000 meters (with pressures expressed in meters of deployment depth capability). The sensors offer an initial accuracy of 0.1% of full scale range.

DEFINITION OF PRESSURE TERMS

The term *psia* means *pounds per square inch, absolute* (*absolute* means that the indicated pressure is referenced to a vacuum).

For oceanographic purposes, pressure is most often expressed in *decibars* (1 dbar = 1.4503774 psi). A dbar is 0.1 bar; a bar is approximately equal to a standard atmosphere (1 atmosphere = 1.01325 bar). For historical reasons, pressure at the water surface (rather than absolute or total pressure) is treated as the reference pressure (0 dbar); this is the value required by the UNESCO formulas for computation of salinity, density, and other derived variables.

Some oceanographers express pressure in Newtons/meter^2 or *Pascals* (the accepted SI unit). A Pascal is a very small unit (1 psi = 6894.757 Pascals), so the mega-Pascal (MPa = 10^6 Pascals) is frequently substituted (1 MPa = 100 dbar).

Since the pressure sensors used in Sea-Bird instruments are *absolute* types, their raw data inherently indicate atmospheric pressure (about 14.7 psi) when in air at sea level. Sea-Bird outputs pressure in one of the following ways:

- CTDs that output **raw data** (**SBE 16*plus*, 16*plus*-IM, 16*plus* V2, 16*plus*-IM V2, 19*plus*, 19*plus* V2, 25, 25*plus*, 37*, and 49**) and are supported by Seasoft's Seasave V7 (real-time data acquisition) and SBE Data Processing (data processing) software – In Seasoft, user selects pressure output in psi (*not* psia) or dbar. Seasoft subtracts 14.7 psi from the raw absolute reading and outputs the remainder as psi or converts the remainder to dbar.
  *Note: SeatermV2 can upload raw data from SBE 37 MicroCATs with firmware 3.0 and later and all SBE 37 IDO and ODO MicroCATs. This data is compatible with Seasoft's SBE Data processing (but not Seasave).
- **SBE 26*plus*** – Real-time wave and tide data is output in psia. Wave and tide data stored in memory is processed using Seasoft for Waves' Convert Hex module, and output in psia. Tide data can be converted to psi by subtracting a barometric pressure file using Seasoft for Waves' Merge Barometric Pressure module.
- **SBE 50** – User selects output in psia (including atmospheric pressure) or dbar. Calculation of dbar is as described above.
- Instruments that output **converted data in engineering units** (**SBE 16*plus*, 16*plus*-IM, 16*plus* V2, 16*plus*-IM V2, 19*plus*, 19*plus* V2, 37, 39, 39-IM, 39*plus*, 49, and 52-MP**) – Instrument subtracts 14.7 psi from the raw absolute reading and converts the remainder to dbar.

Note: SBE 16*plus*, 16*plus*-IM, 16*plus* V2, 16*plus*-IM V2, 19*plus*, 19*plus* V2, 37, 39*plus*, 49, and 52-MP can output raw **or** converted data.

RELATIONSHIP BETWEEN PRESSURE AND DEPTH

Despite the common nomenclature (CTD = **C**onductivity - **T**emperature - **D**epth), all CTDs measure *pressure*, which is not quite the same thing as depth. The relationship between pressure and depth is a complex one involving water density and compressibility as well as the strength of the local gravity field, but it is convenient to think of a decibar as essentially equivalent to a meter, an approximation which is correct within 3% for almost all combinations of salinity, temperature, depth, and gravitational constant.

For **oceanic applications**, salinity and temperature are presumed to be 35 PSU and 0^{o} C, and the compressibility of the water (with its accompanying density variation) is taken into account. This method is recommended in UNESCO Technical Paper No. 44 and is a logical approach in that by far the greatest part of the deep-ocean water column approximates these values of salinity and temperature. Since pressure is also proportional to gravity and the major variability in gravity depends on latitude, the latitude is used to estimate the magnitude of the local gravity field.

For **fresh water applications**, compressibility is not significant in the shallow depths encountered and is ignored, as is the latitude-dependent gravity variation. Fresh water density is presumed to be 1 gm/cm, and depth (in meters) is calculated as 1.019716 * pressure (in dbars). No latitude entry is required for freshwater applications:

Seasoft (most instruments)

In Seasoft's Seasave V7 (real-time data acquisition) and SBE Data Processing (post-processing), the calculation of depth from pressure is dependent on the selection of saltwater depth or freshwater depth as the output variable.

- **Depth, Salt Water:**
  - Seasave V7 - User enters latitude on the Miscellaneous tab in the Configure Inputs dialog box; the entry is used if Depth [salt water] is selected as a display or output variable.
  - SBE Data Processing - User is prompted to enter latitude if Depth [salt water] is selected as an output variable in the Data Conversion or Derive module. Latitude can also be changed on the Miscellaneous tab in those modules.

  Note: For both Seasave V7 and SBE Data Processing, if the data includes NMEA data, the software uses the latitude from the NMEA data instead of the user entry for latitude when calculating depth.
- **Depth, Fresh Water:** No latitude entry is required or used in the calculation.

Some instruments can output depth directly. Setup is accomplished using one of Seasoft's terminal programs:

- SBE 37-SI, SIP, SIP-IDO, SIP-ODO – Depth can be directly output from these instruments if **OutputDepth=Y**. Latitude is entered in the instrument's EEPROM using the **Latitude=** command (use Seaterm for SI and SIP with firmware < 3.0; use SeatermV2 for SI and SIP with firmware $\geq$ 3.0, and all SIP-IDO and SIP-ODO).
  Note: The firmware does not differentiate between freshwater and saltwater applications when calculating depth; the **Latitude=** entry is always used for the depth calculation.
- SBE 39 and 39-IM – User is prompted to enter latitude if conversion of pressure to depth is requested when converting an uploaded .asc file to a .cnv file in Seaterm.
  Note: The Convert utility in Seaterm does not differentiate between freshwater and saltwater applications when calculating depth; the user is always prompted to enter latitude if conversion of pressure to depth is requested.
- SBE 39*plus* - User is prompted to enter latitude if conversion of pressure to depth is requested when converting an uploaded .xml file to a .cnv file in SeatermV2.
  Note: The Convert utility in SeatermV2 does not differentiate between freshwater and saltwater applications when calculating depth; the user is always prompted to enter latitude if conversion of pressure to depth is requested.
- SBE 50 - The desired output (Depth, saltwater or Depth, freshwater) is entered in the instrument's EEPROM using the **OutputFormat=** command in Seaterm. Latitude (needed for the saltwater depth calculation) is also entered in the instrument's EEPROM using the **Latitude=** command.

Seasoft for Waves (SBE 26plus Seagauge Wave and Tide Recorder)

Seasoft for Waves' Merge Barometric Pressure module subtracts a user-input barometric pressure file from the tide data file, and outputs the remainder as pressure in psi or as depth in meters. When converting to depth, the compressibility of the water is taken into account by prompting for user-input values for average density and gravity.
See the SBE 26*plus* manual's appendix for the formulas for conversion of pressure to depth.

CHOOSING THE RIGHT SENSOR

Initial accuracy and resolution are expressed as a percentage of the full scale range for the pressure sensor. The initial accuracy is 0.1% of the full scale range. Resolution is 0.002% of full scale range, except for the SBE 25 (0.015% resolution). For best accuracy and resolution, select a pressure sensor full scale range to correspond to no more than the greatest depths to be encountered. The effect of this choice on CTD accuracy and resolution is shown below:

Range (meters)	**Maximum Initial Error (meters)**	**SBE 16*plus*, 16*plus*-IM, 16*plus* V2, 16*plus*-IM V2, 19*plus*, 19*plus* V2, 25*plus*, 37, 39, 39-IM, 39*plus*, 49, 50, and 52-MP - Resolution (meters)**	**SBE 25 - Resolution (meters)**
0 – 20	0.02	0.0004	0.003
0 – 100	0.10	0.002	0.015
0 – 350	0.35	0.007	0.052
0 – 600	0.60	0.012	0.090
0 – 1000	1.0	0.02	0.15
0 - 2000	2.0	0.04	0.30
0 - 3500	3.5	0.07	0.52
0 - 7000	7.0	0.14	1.05

Note: See the SBE 26*plus* manual or brochure for its resolution specification; 26*plus* resolution is a function of integration time as well as pressure sensor range.

The meaning of *accuracy*, as it applies to these sensors, is that the indicated pressure will conform to true pressure to within ± *maximum error* (expressed as equivalent depth) throughout the sensor's operating range. Note that a 7000-meter sensor reading + 7 meters at the water surface is operating within its specifications; the same sensor would be expected to indicate 7000 meters ± 7 meters when at full depth.

Resolution is the magnitude of indicated increments of depth. For example, a 7000-meter sensor on an SBE 25 (resolution 1.05 meters) subjected to slowly increasing pressure will produce readings approximately following the sequence *0, 1.00, 2.00, 3.00* (meters). Resolution is limited by the design configuration of the CTD's A/D converter.
For the SBE 25, this restricts the possible number of discrete pressure values for a given sample to somewhat less than 8192 (13 bits); an approximation of the ratio 1 : 7000 is the source of the SBE 25's 0.015% resolution specification.

Note: Seasoft (and other CTD software) presents temperature, salinity, and other variables as a function of depth or pressure, so the CTD's pressure resolution limits the number of plotted data points in the profile. For example, an SBE 25 with a 7000-meter sensor might acquire several values of temperature and salinity during the time required to descend from 1- to 2-meters depth. However, all the temperature and salinity values will be graphed in clusters appearing at either 1 or 2 meters on the depth axis.

High-range sensors used in shallow water generally provide better accuracy than their *absolute* specifications indicate. With careful use, they may exhibit *accuracy* approaching their *resolution* limits. For example, a 3500-meter sensor has a nominal accuracy (irrespective of actual operating depth) of ± 3.5 meters. Most of the error, however, derives from variation over time and temperature of the sensor's *offset*, while little error occurs as a result of changing *sensitivity*.

MINIMIZING ERRORS

Offset Errors

Note: Follow the procedures below for all instruments except the SBE 26*plus* (see the 26*plus* manual for details).

The primary *offset* error due to drift over time can be eliminated by comparing CTD readings in air before beginning the profile to readings from a barometer. Follow this procedure:

1. Allow the instrument to equilibrate in a reasonably constant temperature environment for at least 5 hours. Pressure sensors exhibit a transient change in their output in response to changes in their environmental temperature; allowing the instrument to equilibrate before starting will provide the most accurate calibration correction.
2. Place the instrument in the orientation it will have when deployed.
3. Set the pressure offset to 0.0:
   - In the configuration (.con or .xmlcon) file, using Seasave V7 or SBE Data Processing (for SBE 16*plus*, 16*plus*-IM, 16*plus* V2, 16*plus*-IM V2, 19*plus*, 19*plus* V2, 25, 25*plus*, 49).
   - In the CTD's EEPROM, using the appropriate command in the terminal program (for SBE 16*plus*, 16*plus*-IM, 16*plus* V2, 16*plus*-IM V2, 19*plus*, 19*plus* V2, 25*plus*, 37, 39, 39-IM, 39*plus*, 49, 50, 52-MP).
4. Collect pressure data from the instrument using Seasave V7 or the terminal program, as appropriate (see instrument manual for details). If the instrument is not outputting data in decibars, convert the output to decibars.
5. Compare the instrument output to the reading from a good barometer placed at the same elevation as the pressure sensor. Calculate *offset* (decibars) = barometer reading (converted to decibars) – instrument reading (decibars).
6. Enter calculated offset (positive or negative) in decibars:
   - In the configuration (.con or .xmlcon) file, using Seasave V7 or SBE Data Processing (for SBE 16*plus*, 16*plus*-IM, 16*plus* V2, 16*plus*-IM V2, 19*plus*, 19*plus* V2, 25, 25*plus*, 37 [see Note 2 below], 49). **AND**
   - In the CTD's EEPROM, using the appropriate command in the terminal program (for SBE 16*plus*, 16*plus*-IM, 16*plus* V2, 16*plus*-IM V2, 19*plus*, 19*plus* V2, 25*plus*, 37, 39, 39-IM, 39*plus*, 49, 50, 52-MP).

Notes:
1. For instruments that store calibration coefficients in EEPROM and **also** use a configuration (.con or .xmlcon) file (SBE 16*plus*, 16*plus*-IM, 16*plus* V2, 16*plus*-IM V2, 19*plus*, 19*plus* V2, 25*plus*, and 49), set the pressure offset (Steps 3 and 6 above) in both the EEPROM and in the configuration file.
2. For SBE 37 data uploaded using SeatermV2 version 1.1 and later: SeatermV2 creates a .xmlcon configuration file when it uploads the data. Set the pressure offset (Steps 3 and 6 above) in both the EEPROM and in the configuration file.

> *Offset Correction Example*
> *Absolute* pressure measured by a barometer is 1010.50 mbar. Pressure displayed from instrument is -2.5 dbars.
> Convert barometer reading to dbars using the relationship: mbar * 0.01 = dbars
> Barometer reading = 1010.50 mbar *0.01 = 10.1050 dbars
> Instrument's internal calculations and/or our processing software output gage pressure, using an assumed value of 14.7 psi for atmospheric pressure. Convert instrument reading from gage to absolute by adding 14.7 psia to instrument output:
> - 2.5 dbars + (14.7 psi * 0.689476 dbar/psia) = - 2.5 + 10.13 = 7.635 dbars
> Offset = 10.1050 – 7.635 = + 2.47 dbar
> Enter offset in configuration file (if applicable) and in instrument EEPROM (if applicable).

Another source of *offset* error results from temperature-induced drifts. Because Druck sensors are carefully temperature compensated, errors from this source are small. Offset errors can be estimated for the conditions of your profile, and eliminated when post-processing the data in SBE Data Processing by the following procedure:

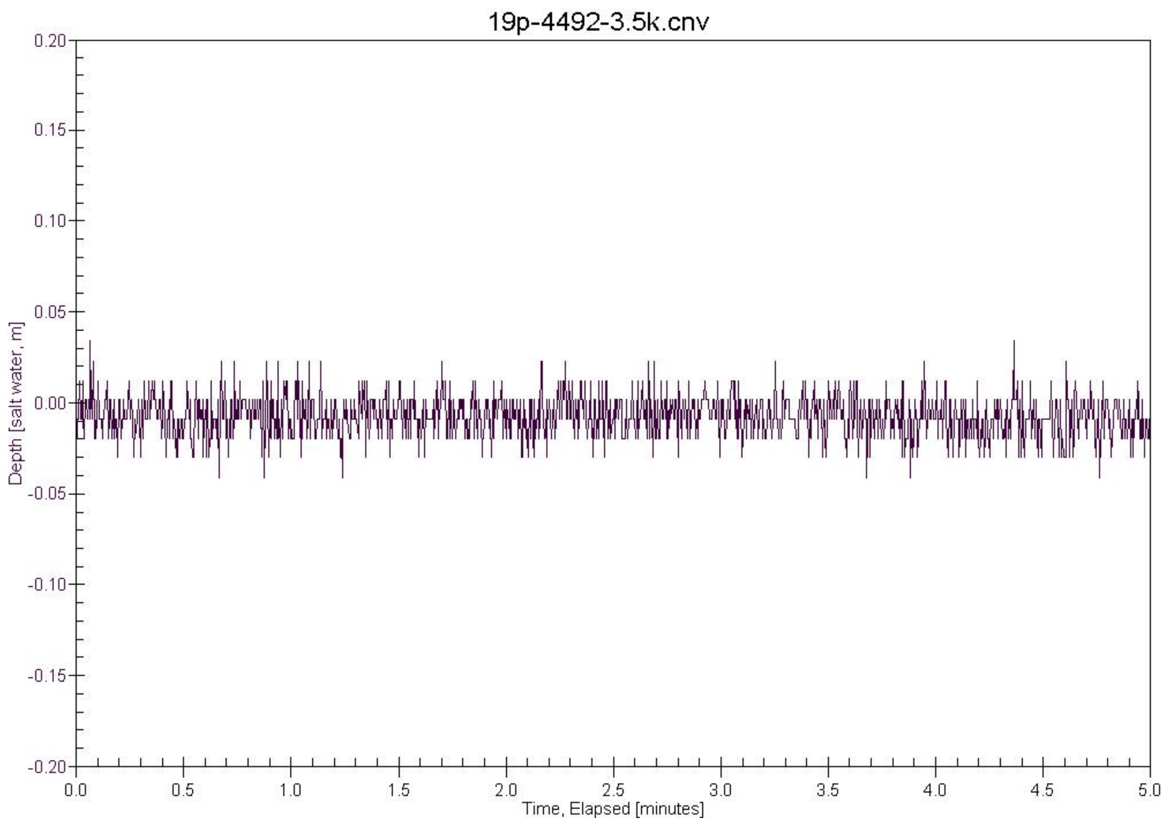
1. **Immediately** before beginning the profile, take a pre-cast *in air* pressure reading.
2. **Immediately** after ending the profile, take a post-cast *in air* pressure reading with the instrument at the same elevation and orientation. This reading reflects the change in the instrument temperature as a result of being submerged in the water during the profile.
3. Calculate the average of the pre- and post-cast readings. Enter the negative of the average value (in decibars) as the *offset* in the configuration (.con or .xmlcon) file.

Hysteresis Errors

Hysteresis is the term used to describe the failure of pressure sensors to repeat previous readings after exposure to other (typically higher) pressures. The Druck sensor employs a micro-machined silicon diaphragm into which the strain elements are implanted using semiconductor fabrication techniques. Unlike metal diaphragms, silicon's crystal structure is perfectly elastic, so the sensor is essentially free of pressure hysteresis.

Power Turn-On Transient

Druck pressure sensors exhibit virtually no power turn-on transient. The plot below, for a 3500-meter pressure sensor in an SBE 19*plus* SeaCAT Profiler, is representative of the power turn-on transient for all pressure sensor ranges.



Thermal Transient

Pressure sensors exhibit a transient change in their output in response to changes in their environmental temperature, so the thermal transient resulting from submersion in water must be considered when deploying the instrument.

During calibration, the sensors are allowed to *warm-up* before calibration points are recorded. Similarly, for best depth accuracy the user should allow the CTD to *warm-up* for several minutes before beginning a profile; this can be part of the *soak* time in the surface water. *Soaking* also allows the CTD housing to approach thermal equilibrium (minimizing the housing's effect on measured temperature and conductivity) and permits a Beckman- or YSI-type dissolved oxygen sensor (if present) to polarize.

Application Note Revision History

Date	Description
November 2003	Initial release.
July 2005	• Add 0 – 600 meter range. • Add information on SBE 37-SIP, 26*plus*, 39-IM, and 52-MP.
April 2008	• Add information on V2 SeaCATs. • Update descriptions of Seasave V7 and SBE Data Processing regarding depth and latitude.
February 2010	• Add information about SeatermV2 for newer SBE 37-SI and 37-SIP. • Add information about .xmlcon configuration files. • Update address.
October 2010	• Add information on IDO MicroCATs. • Add information on .xmlcon files for MicroCATs with data uploaded using SeatermV2 1.1 and later.
October 2012	Update to include SBE 25*plus* and SBE 37 ODO MicroCATs.
February 2014	• Update to include SBE 39*plus*. • Clarify statement about MicroCATs with firmware 3.0 (update to '3.0 and later').

Sea-Bird Electronics, Inc.
13431 NE 20th Street
Bellevue, WA 98005
USA

Phone: (425) 643-9866
Fax: (425) 643-9954
E-mail: seabird@seabird.com
Web: www.seabird.com

APPLICATION NOTE NO. 69 July 2002

Conversion of Pressure to Depth

Sea-Bird's SEASOFT software can calculate and output depth, if the instrument data includes pressure. Additionally, some Sea-Bird instruments (such as the SBE 37-SI or SBE 50) can be set up by the user to internally calculate depth, and to output depth along with the measured parameters.

Sea-Bird uses the following algorithms for calculating depth:

Fresh Water Applications

Because most fresh water applications are shallow, and high precision in depth not too critical, Sea-Bird software uses a very simple approximation to calculate depth:

depth (meters) = pressure (decibars) * 1.019716

Seawater Applications

Sea-Bird uses the formula in UNESCO Technical Papers in Marine Science No. 44. This is an empirical formula that takes compressibility (that is, density) into account. An ocean water column at 0 °C (t = 0) and 35 PSU (s = 35) is assumed.

The gravity variation with latitude and pressure is computed as:

$$g\ (m/sec^2) = 9.780318 * [\ 1.0 + (\ 5.2788x10^{-3} + 2.36x10^{-5} * x) * x\ ] + 1.092x10^{-6} * p$$

where
$x = [\sin(\text{latitude} / 57.29578)\ ]^2$
p = pressure (decibars)

Then, depth is calculated from pressure:

$$\text{depth (meters)} = [(((-1.82x10^{-15} * p + 2.279x10^{-10}) * p - 2.2512x10^{-5}) * p + 9.72659) * p] / g$$

where
p = pressure (decibars)
g = gravity (m/sec^2)

Sea-Bird Electronics, Inc.
13431 NE 20th Street
Bellevue, WA 98005
USA

Phone: (425) 643-9866
Fax: (425) 643-9954
E-mail: seabird@seabird.com
Web: www.seabird.com

APPLICATION NOTE NO. 73 **Revised February 2014**

Using Instruments with Pressure Sensors at Elevations Above Sea Level

This application note covers use of a Sea-Bird instrument that includes a pressure sensor at elevations above sea level, such as in a mountain lake or stream.

Background

Sea-Bird pressure sensors are absolute sensors, so their raw output includes the effect of atmospheric pressure. As shown on the Calibration Sheet that accompanies the instrument, our calibration (and resulting calibration coefficients) is in terms of psia. However, when outputting pressure in engineering units, most of our instruments output pressure relative to the ocean surface (i.e., at the surface the output pressure is 0 decibars). Sea-Bird uses the following equation in our instruments and/or software to convert psia to decibars:

Pressure (db) = [pressure (psia) – 14.7] * 0.689476
where 14.7 psia is the assumed atmospheric pressure (based on atmospheric pressure at sea level).

This conversion is based on the assumption that the instrument is being used in the ocean; the surface of the ocean water is by definition at sea level. However, if the instrument is used in a mountain lake or stream, the assumption of sea level atmospheric pressure (14.7 psia) in the instrument and/or software can lead to incorrect results. Procedures are provided below for measuring the pressure *offset* from the assumed sea level atmospheric pressure, and entering the offset in the instrument and/or software to make the appropriate correction.

- **Perform the correction procedure at the elevation at which the instrument will be deployed.** Allow the instrument to equilibrate in a reasonably constant temperature environment for at least 5 hours before starting. Pressure sensors exhibit a transient change in their output in response to changes in their environmental temperature. Sea-Bird instruments are constructed to minimize this by thermally decoupling the sensor from the body of the instrument. However, there is still some residual effect; allowing the instrument to equilibrate before starting will provide the most accurate calibration correction.

Inclusion of calibration coefficients in the instrument itself or in a file used by our software to interpret raw data varies, depending on the instrument. Commands used to program the instrument vary as well. Therefore, there are variations in the correction procedure, depending on the instrument. These instruments are addressed below:

- SBE **9*plus*** CTD and SBE **25** Sealogger CTD
- SBE **16*plus*** and **16*plus* V2 (RS-232 versions)** SeaCAT C-T (pressure optional) Recorder,
  SBE **19*plus*** and **19*plus* V2** SeaCAT Profiler CTD,
  SBE **25*plus*** Sealogger CTD, and
  SBE **49** FastCAT CTD Sensor
- SBE **16*plus* (RS-485 versions)** SeaCAT C-T (pressure optional) Recorder, and
  SBE **16*plus*-IM** and **16*plus*-IM V2** SeaCAT C-T (pressure optional) Recorder
- SBE **37** MicroCAT (all IDO and ODO models, and all other models with firmware version ≥ 3.0)
- SBE **37** MicroCAT (all models with firmware version < 3.0, except IDO and ODO models)
- SBE **39-IM** Temperature (pressure optional) Recorder
- SBE **39** Temperature (pressure optional) Recorder
- SBE **39*plus*** Temperature (pressure optional) Recorder
- SBE **50** Digital Oceanographic Pressure Sensor
- SBE **52-MP** Moored Profiler CTD and DO Sensor
- SBE **26*plus*** Seagauge Wave and Tide Recorder and SBE **53** BPR Bottom Pressure Recorder

SBE 9*plus* and 25

Sea-Bird real-time data acquisition software (Seasave) and post-processing software (SBE Data Processing) use calibration coefficients programmed in a configuration (.con or .xmlcon) file to convert raw data from these instruments to engineering units.

Follow this procedure to correct the pressure:
1. With instrument in air, place it in orientation it will have when deployed.
2. In Seasave, in .con or .xmlcon file, set pressure offset to 0.0.
3. Acquire data in Seasave, and display pressure sensor output in decibars.
4. Calculate *offset* = (0 – instrument reading).
5. Enter calculated offset in .con or .xmlcon file.

Offset Correction Example:
Pressure displayed at elevation is -1.655 db. *Offset* = 0 – (-1.655) = + 1.655 db
Enter offset in .con or .xmlcon file.

SBE 16*plus* and 16*plus* V2 (RS-232 versions), 19*plus* and 19*plus* V2, 25*plus*, and 49

Sea-Bird real-time data acquisition software (Seasave) and post-processing software (SBE Data Processing) use calibration coefficients programmed in a configuration (.con or .xmlcon) file to convert raw data from these instruments to engineering units. These instruments are also able to directly output data that is already converted to engineering units (pressure in decibars), using calibration coefficients that are programmed into the instrument.

Follow this procedure to correct the pressure:
1. With instrument in air, place it in orientation it will have when deployed.
2. In Seasave, in .con or .xmlcon file, set pressure offset to 0.0.
3. Acquire data in Seasave, and display pressure sensor output in decibars.
4. Calculate *offset* = (0 – instrument reading).
5. Enter calculated offset in .con or .xmlcon file.
6. Also enter calculated offset in instrument (**POffset=** or **SetPOffset=** in terminal program*).
   *Note: SBE 16*plus* V2, 19*plus* V2, and 25*plus* use SeatermV2 terminal program; other instruments use Seaterm. SBE 25*plus* uses **SetPOffset=**, other instruments use **POffset=**.

Offset Correction Example:
Pressure displayed at elevation is -1.655 db. *Offset* = 0 – (-1.655) = + 1.655 db
Enter offset in .con or .xmlcon file and in instrument.

SBE 16*plus* (RS-485 versions), and 16*plus*-IM and 16*plus*-IM V2

Sea-Bird real-time data acquisition software (Seasave) and post-processing software (SBE Data Processing) use calibration coefficients programmed in a configuration (.con or .xmlcon) file to convert raw data from these instruments to engineering units. These instruments are also able to directly output data that is already converted to engineering units (pressure in decibars), using calibration coefficients that are programmed into the instrument.

Follow this procedure to correct the pressure:
1. With instrument in air, place it in orientation it will have when deployed.
2. In terminal program*, set pressure offset to 0.0 (**#iiPOffset=0**) and set output format to converted data in decimal form (**#iiOutputFormat=3**).
   *Note: SBE 16*plus*-IM V2 uses SeatermV2; other instruments use Seaterm.
3. Acquire data using **#iiTP**.
4. Calculate *offset* = (0 – instrument reading).
5. Enter calculated offset in instrument (**#iiPOffset=**).
6. Also enter calculated offset in .con or .xmlcon file, using SBE Data Processing.

Offset Correction Example:
Pressure displayed at elevation is -1.655 db. *Offset* = 0 – (-1.655) = + 1.655 db
Enter offset in .con or .xmlcon file and in instrument.

SBE 37 (all IDO [Integrated Dissolved Oxygen] and ODO [Optical Dissolved Oxygen]models, and all other models with firmware version ≥ 3.0)

The SBE 37 is able to directly output data that is already converted to engineering units (pressure in decibars), using calibration coefficients that are programmed into the instrument. If using SeatermV2 (version 1.1 and later) to upload data, SeatermV2 creates a configuration (.xmlcon) file along with a .hex data file. Sea-Bird post-processing software (SBE Data Processing) uses the calibration coefficients in the .xmlcon file to convert raw data to engineering units.

Follow this procedure to correct the pressure:
1. With SBE 37 in air, place it in orientation it will have when deployed.
2. In SeatermV2 terminal program, set pressure offset to 0.0 and pressure sensor output to decibars. *
3. Acquire data. *
4. Calculate *offset* = (0 – instrument reading).
5. Enter calculated offset in SBE 37 in SeatermV2. *
6. If you have already uploaded data, also enter calculated offset in .xmlcon file, using SBE Data Processing.

Offset Correction Example:
Pressure displayed at elevation is -1.655 db.   *Offset* = 0 – (-1.655) = + 1.655 db
Enter offset in SBE 37.

* NOTE: Commands for setting pressure offset, setting output format, and acquiring data vary:

Instrument	Pressure Offset Command	Output Format Command	Command to Acquire Data **
MicroCATs with Inductive Modem (IM) or RS-485 telemetry	**#iiPOffset=**	**#iiOutputFormat=1**	**#iiTSn:100** (measures and outputs data 100 times)
MicroCATs with RS-232 telemetry	**POffset=**	**OutputFormat=1**	**TSn:100** (measures and outputs data 100 times)

** See MicroCAT manual for location of pressure data in output data string.

SBE 37 (all models with firmware version < 3.0, *except* IDO [Integrated Dissolved Oxygen] and ODO [Optical Dissolved Oxygen] models)

The SBE 37 is able to directly output data that is already converted to engineering units (pressure in decibars), using calibration coefficients that are programmed into the instrument. These SBE 37s do not use a configuration (.con or .xmlcon) file.

Follow this procedure to correct the pressure:
1. With SBE 37 in air, place it in orientation it will have when deployed.
2. In Seaterm terminal program, set pressure offset to 0.0 and pressure sensor output to decibars. *
3. Acquire data. *
4. Calculate *offset* = (0 – instrument reading).
5. Enter calculated offset in SBE 37 in Seaterm. *

Offset Correction Example:
Pressure displayed at elevation is -1.655 db.   *Offset* = 0 – (-1.655) = + 1.655 db
Enter offset in SBE 37.

* NOTE: Commands for setting pressure offset, setting output format, and acquiring data vary:

Instrument	Pressure Offset Command	Output Format Command	Command to Acquire Data
MicroCATs with Inductive Modem (IM) or RS-485 telemetry	**#iiPOffset=**	**#iiFormat=1**	**#iiTP** (measures and outputs pressure 30 times)
MicroCATs with RS-232 telemetry	**POffset=**	**Format=1**	**TP** (measures and outputs pressure 100 times)

SBE 39*plus*

The SBE 39*plus* is able to directly output data that is already converted to engineering units (pressure in decibars or psi), using calibration coefficients that are programmed into the SBE 39*plus*. The SBE 39*plus* does not use a configuration (.con or .xmlcon) file.

Follow this procedure to correct the pressure:

1. With SBE 39*plus* in air, place it in orientation it will have when deployed.
2. In SeatermV2 terminal program, set pressure offset to 0.0 (**POffset=0**) and pressure sensor output to decibars (**SetPressUnits=0**).
3. Acquire data using **TP**.
4. Calculate *offset* = (0 – instrument reading).
5. Enter calculated offset in SBE 39*plus* in SeatermV2 (**POffset=**).

   Offset Correction Example:
   Pressure displayed at elevation is -1.655 db. *Offset* = 0 – (-1.655) = + 1.655 db
   Enter offset in SBE 39*plus*.

** See SBE 39*plus* manual for location of pressure data in output data string.

SBE 39-IM

The SBE 39-IM directly outputs data that is already converted to engineering units (pressure in decibars), using calibration coefficients that are programmed into the SBE 39-IM. The SBE 39-IM does not use a configuration (.con or .xmlcon) file.

Follow this procedure to correct the pressure:

1. With SBE 39-IM in air, place it in orientation it will have when deployed.
2. In Seaterm terminal program, set pressure offset to 0.0 (**#iiPOffset=0**).
3. Acquire data using **#iiTP**.
4. Calculate *offset* = (0 – instrument reading).
5. Enter calculated offset in SBE 39-IM (**#iiPOffset=**).

   Offset Correction Example:
   Pressure displayed at elevation is -1.655 db. *Offset* = 0 – (-1.655) = + 1.655 db
   Enter offset in SBE 39-IM.

SBE 39

The SBE 39 directly outputs data that is already converted to engineering units (pressure in decibars), using calibration coefficients that are programmed into the SBE 39. The SBE 39 does not use a configuration (.con or .xmlcon) file. The SBE 39 is a special case, because its programmed calibration coefficients do not include a pressure offset term. The lack of a pressure offset term creates two difficulties when deploying at elevations above sea level:

- After the data is recorded and uploaded, you must perform post-processing to adjust for the pressure offset. Sea-Bird software cannot perform this adjustment for the SBE 39.
- Without adjusting the instrument range, internal calculation limitations prevent the SBE 39 from providing accurate data at high elevations. Specifically, if (0.1 * sensor range) < (decrease in atmospheric pressure from sea level to elevation), an error condition in the SBE 39's internal calculations occurs. The table below tabulates the atmospheric pressure and approximate elevation at which this calculation limitation occurs for different pressure sensor ranges.

Range (m or db) *	Range (psi) = Range (db) / 0.689476	0.1 * Range (psi)	Atmospheric Pressure (psi) at elevation at which error occurs = [14.7 – 0.1 * Range (psi)]	Approximate Corresponding Elevation (m)
20	29	2.9	11.8	1800
100	145	14.5	0.2	No where on Earth!
350	507	50.7	-	-
1000	1450	145	-	-
2000	2900	290	-	-
3500	5076	507	-	-
7000	10152	1015	-	-

* Notes:

- Although decibars and meters are not strictly equal, this approximation is close enough for this Application Note. See Application Note 69 for conversion of pressure (db) to depth (m) for fresh or salt water applications.
- Equations used in conversions -
  As shown on page 1: pressure (db) = [pressure (psia) – 14.7] * 0.689476;
  Rearranging: pressure (psia) = [Pressure (db) / 0.689476] + 14.7
  Measuring relative to atmospheric: pressure (psi; relative to atmospheric pressure) = Pressure (db) / 0.689476

From the table, it is apparent that the only practical limitation occurs with a 20 meter pressure sensor. To use the SBE 39 in this situation, change the sensor range internally to 100 meters by entering **PRange=100** in the SBE 39 (using Seaterm). This changes the electronics' operating range, allowing you to record pressure data at high elevations, but slightly decreases resolution. After the data is recorded and uploaded, perform post-processing to adjust for the pressure offset. Note that Sea-Bird software cannot perform this adjustment for the SBE 39.

CAUTION: Changing **PRange** in the SBE 39 does not increase the actual maximum water depth at which the instrument can be used (20 meters) without damaging the sensor.

Example 1: You want to deploy SBE 39 with a 20 m pressure sensor in a mountain lake at 1400 m (4590 ft). This is lower than 1800 m shown in table, so you do not need to adjust sensor range. After data is recorded and uploaded, perform post-processing to adjust for pressure offset.

Example 2: You want to deploy SBE 39 with a 20 m pressure sensor in a mountain lake at 2000 m (6560 ft). This is higher than 1800 m shown in table, so you need to adjust sensor range. In Seaterm, set **PRange=100**. After data is recorded and uploaded, perform post-processing to adjust for pressure offset.

SBE 50

The SBE 50 is able to directly output data that is already converted to engineering units (psia, decibars, or depth in feet or meters), using calibration coefficients that are programmed into the instrument. The SBE 50 does not use a configuration (.con or .xmlcon) file.

Follow this procedure to correct the pressure:
1. With SBE 50 in air, place it in orientation it will have when deployed.
2. In Seaterm terminal program, set pressure offset to 0.0 (**POffset=0**) and set output format to desired format (**OutputFormat=**).
3. Acquire data using **TS** a number of times.
4. Calculate *offset* = (0 – instrument reading).
5. Enter calculated offset in SBE 50 **POffset=**). Offset must be entered in units consistent with **OutputFormat=**. For example, if output format is decibars (**OutputFormat=2**), enter offset in decibars.

   Offset Correction Example:
   Pressure displayed at elevation with **OutputFormat=2** (db) is -1.655 db. *Offset* = 0 – (-1.655) = + 1.655 db
   Enter offset in tSBE 50.

SBE 52-MP

The SBE 52-MP is able to directly output data that is already converted to engineering units (pressure in decibars), using calibration coefficients that are programmed into the instrument. The SBE 52-MP does not use a configuration (.con or .xmlcon) file.

Follow this procedure to correct the pressure:
1. With SBE 52-MP in air, place it in orientation it will have when deployed.
2. In Seaterm terminal program, set pressure offset to 0.0 (**POffset=0**).
3. Acquire data using **TP**.
4. Calculate *offset* = (0 – instrument reading).
5. Enter calculated offset in SBE 52-MP (**POffset=**).

   Offset Correction Example:
   Pressure displayed at elevation is -1.655 db. *Offset* = 0 – (-1.655) = + 1.655 db
   Enter offset in SBE 52-MP.

SBE 26*plus* and 53

Unlike our other instruments that include a pressure sensor, the SBE 26*plus* and 53 output absolute pressure (i.e., at the surface the output pressure is atmospheric pressure at the deployment elevation). Therefore, no corrections are required when using these instruments above sea level. SBE 26*plus* / 53 software (Seasoft for Waves) includes a module that can subtract measured barometric pressures from tide data, and convert the resulting pressures to water depths.

Application Note Revision History

Date	Description
June 2004	Initial release.
July 2005	Add information on SBE 39-IM, 52-MP, and 53.
February 2009	• Add information on V2 SeaCATs and newer MicroCATs (version 3 and greater firmware). • Add information on SeatermV2 software.
October 2010	• Add information on IDO MicroCATs (37-SMP-IDO, SIP-IDO, IMP-IDO). • Add information on creation of .xmlcon file for MicroCATs with data uploaded using SeatermV2 1.1 and later. • Add information on .xmlcon files for all instruments that use configuration files. • Update address.
October 2012	• Update for SBE 25*plus* and ODO MicroCATs (37-SMP-ODO, SIP-ODO, IMP-ODO). • Remove RS-485 version of SBE 16*plus* V2.
February 2014	• Update for SBE 39*plus*.

Sea-Bird Electronics, Inc.
13431 NE 20th Street
Bellevue, WA 98005
USA

Phone: (425) 643-9866
Fax: (425) 643-9954
E-mail: seabird@seabird.com
Web: www.seabird.com

APPLICATION NOTE NO. 83 **revised February 2014**

Deployment of Moored Instruments

This Application Note applies to Sea-Bird instruments intended to provide time series data on a mooring or fixed site:

- SBE 16*plus*, 16*plus*-IM, 16*plus* V2, and 16*plus*-IM V2 SeaCAT Conductivity and Temperature Recorder
- SBE 19*plus* and 19*plus* V2 SeaCAT Profiler CTD (in moored mode)
- SBE 26*plus* Seagauge Wave and Tide Recorder
- SBE 37 (IM, IMP, SM, SMP, SI, SIP) MicroCAT Conductivity and Temperature Recorder
- SBE 37 (IMP-IDO, SMP-IDO, SIP-IDO) MicroCAT Conductivity, Temperature, and (membrane-type) Dissolved Oxygen Recorder
- SBE 37 (IMP-ODO, SMP-ODO, SIP-ODO) MicroCAT Conductivity, Temperature, and Optical Dissolved Oxygen Recorder
- SBE 39, 39-IM, and 39*plus* Temperature Recorder
- SBE 53 BPR Bottom Pressure Recorder
- SBE 56 Temperature Logger

We have developed a check list to assist users in deploying moored instruments. **This checklist is intended as a guideline to assist you in developing a checklist specific to your operation and instrument setup.** The actual procedures and procedure order may vary, depending on such factors as:

- Instrument communication interface - RS-232, RS-485, inductive modem, or USB
- Deployment interface for RS-232 or RS-485 - with I/O cable for real-time data or dummy plug for self-contained operation
- Sampling initiation - using delayed start commands to set a date and time for sampling to automatically begin or starting sampling just before deploying the instrument
- Sensors included in your instrument –
  - Pressure is optional in the SBE 16*plus*, 16*plus*-IM, 16*plus* V2, 16*plus*-IM V2, 37 (all), 39, 39-IM, and 39*plus*, and is not provided in the SBE 56.
  - Conductivity is optional in the SBE 26*plus* and 53, and is not provided in the SBE 39, 39-IM, 39*plus*, or 56.
  - Optional auxiliary sensors can be integrated with the SBE 16*plus*, 16*plus*-IM, 16*plus* V2, 16*plus*-IM V2, 19*plus*, and 19*plus* V2.

Deployment Summary

Instrument serial number	
Mooring number	
Date of deployment	
Depth of instrument	
Intended date of recovery	
Capture file printout(s) attached, or file name and location (showing status command, calibration coefficients command if applicable, any other applicable commands)	
Actual date of recovery	
Condition of instrument at recovery	
Notes	

Preparation for Deployment

Task	Completed?
If applicable, upload existing data in memory. Perform preliminary processing / analysis of data to ensure you have uploaded all data, that data was not corrupted in upload process, and that (if uploading converted data) instrument EEPROM was programmed with correct calibration coefficients. If there is a problem with data, you can try to upload again now. Once you record over data in next deployment, opportunity to correct any upload problem is gone.	
Initialize memory to make entire memory available for recording. If memory is not initialized, data will be stored after last recorded sample.	
Calculate battery endurance to ensure sufficient power for intended sampling scheme. See instrument manual for example calculations.	
Calculate memory endurance to ensure sufficient memory for intended sampling scheme. See instrument manual for example calculations.	
Install fresh batteries. Even if you think there is adequate battery capacity left for another deployment, cost of fresh batteries is small price to pay to ensure successful deployment.	
Establish setup / operating parameters. 1. Click Capture in terminal program and enter file name to record instrument setup, so you have complete record of communication with instrument. 2. Set current date and time. 3. Establish setup / operating parameters. 4. If desired, set date and time for sampling to automatically begin. 5. Send *Status* command (**DS** or **#iiDS**) to verify and provide record of setup. ** 6. Send *Calibration Coefficients* command (**DC**, **#iiDC**, **DCal**, or **#iiDCal**) to verify and provide record of calibration coefficients. **	
Get conductivity sensor ready for deployment: As applicable, remove protective plugs that were placed in Anti-Foulant Device caps **or** remove label that was placed over inlet / outlet **or** remove Tygon tubing that was looped end-to-end around conductivity cell to prevent dust / dirt from entering cell. *Note*: Deploying instrument with protective plugs, label, or looped Tygon tubing in place will prevent instrument from measuring conductivity during deployment, and may destroy cell.	
Install fresh AF24173 Anti-Foulant Devices for conductivity sensor. Rate of anti-foul use varies greatly, depending on location and time of year. If you think there is adequate capability remaining, and previous deployment(s) in this location and at this time of year back up that assumption, you may not choose to replace Anti-Foulant Devices for every deployment. However, as for batteries, cost of fresh Anti-Foulant Devices is small price to pay to ensure successful deployment.	
For instrument with external pump (16*plus*, 16*plus*-IM, 16*plus* V2, 16*plus*-IM V2, 19*plus*, 19*plus* V2), verify that system plumbing is correctly installed. See instrument manual for configuration.	
Start sampling (if you did not set up instrument with a delayed start command), or verify that sampling has begun (if you set up instrument with a delayed start command). 1. Click Capture in terminal program and enter file name to record instrument setup, so you have a complete record of communication with instrument. 2. If you did not set up instrument with a delayed start command, send command to start sampling. 3. If instrument can communicate in real-time while sampling: Send *Status* command (**DS** or **#iiDS**) to verify and provide record that instrument is sampling. Send *Send Last* command (**SL** or **#iiSL**) to look at most recent sample and verify that output looks reasonable (i.e., ambient temperature, zero conductivity, atmospheric pressure). ** Note: For instrument with pump (external **or** integral), avoid running pump *dry* for extended period of time.	
If instrument has pressure sensor, record atmospheric pressure with barometer. You can use this information during data processing to check and correct for pressure sensor drift, by comparing to instrument's pressure reading in air (from above).	
If cable connectors or dummy plugs were unmated, reinstall cables or dummy plugs as described in *Application Note 57: Connector Care and Cable Installation*. Failure to correctly install cables may result in connector leaking, causing data errors as well as damage to bulkhead connector.	
Install mounting hardware on instrument. Verify that hardware is secure.	

**** Note:** Actual instrument command is dependent on communication interface and instrument; see instrument manual.

Recovery

Immediately upon recovery

Task	Completed?
Rinse instrument with fresh water.	
Remove locking sleeve on dummy plug or cable, slide it up cable (if applicable), and rinse connection (still mated) with fresh water.	
For instrument with pump (external or integral), stop sampling. Connect to instrument in terminal program and send command to stop sampling (**Stop** or **#iiStop**). Stop sampling as soon as possible upon recovery to avoid running pump *dry* for an extended period of time (for *some* instruments, pump turns off automatically when conductivity frequency is below programmed minimum value). **	
If instrument has pressure sensor, record atmospheric pressure with barometer. You can use this information during data processing to check and correct for pressure sensor drift, by comparing to instrument's pressure reading in air.	
Gently rinse conductivity cell with clean de-ionized water, drain, and gently blow through cell to remove larger water droplets. • If cell is not rinsed between uses, salt crystals may form on platinized electrode surfaces. When instrument is used next, sensor accuracy may be temporarily affected until these crystals dissolve. • Note that **vigorous flushing is not recommended** if you will be sending instrument to Sea-Bird for post-deployment calibration to establish drift during deployment. • For instruments with integral pump or integral pump and dissolved oxygen sensor (37-SMP, SMP-IDO, SMP-ODO, SIP, SIP-IDO, SIP-ODO, IMP, IMP-IDO, IMP-ODO): Rinse all internal plumbing in addition to conductivity cell. If not rinsed between uses, salt crystals may form on pump impeller and/or on oxygen sensor membrane (IDOs) or optical window (ODOs).	
For instrument with external pump (16*plus*, 16*plus*-IM, 16*plus* V2, 16*plus*-IM V2, 19*plus*, 19*plus* V2): Remove Tygon tubing from pump head's hose barbs, and rinse inside of pump head, pouring fresh water through a hose barb. If pump head is not rinsed between uses, salt crystals may form on impeller. Over time, this may *freeze* impeller in place, preventing pump from working.	
As applicable, install protective plugs in Anti-Foulant Device caps, install label over inlet / exhaust, or loop Tygon tubing end-to-end around conductivity cell for *long term* storage. This will prevent dust / dirt from entering conductivity cell. *Note*: For short term storage of all instruments *except* MicroCATs with oxygen sensors, see *Application Note 2D: Instructions for Care and Cleaning of Conductivity Cells*. For IDO MicroCATs, see *Application Note 64: SBE 43 Dissolved Oxygen Sensor*. For ODO MicroCATs, see MicroCAT manual.	
Upload data in memory. 1. Connect to instrument in terminal program. 2. If you have not already done so, send command to stop sampling (**Stop** or **#iiStop**). ** 3. Click Upload in terminal program to upload data in memory. 4. Perform preliminary processing / data analysis to ensure you have uploaded all data, data was not corrupted in upload process, and (if uploading converted data) instrument EEPROM was programmed with correct calibration coefficients. If there is a problem with data, you can try to upload again now. Once you record over data in next deployment, opportunity to correct any upload problem is gone.	

** **Note:** Actual instrument command is dependent on communication interface and instrument; see instrument manual.

Later

Task	Completed?
Clean conductivity cell, as needed: • Do not clean cell if you will be sending instrument to Sea-Bird for post-deployment calibration to establish drift during deployment. • Clean cell if you will not be performing a post-deployment calibration to establish drift. See cleaning instructions in instrument manual. For all instruments *except* MicroCATs with oxygen sensors, see *Application Note 2D: Instructions for Care and Cleaning of Conductivity Cells*. For IDO MicroCATs, see *Application Note 64: SBE 43 Dissolved Oxygen Sensor*. For ODO MicroCATs, see MicroCAT manual.	
For instrument with external pump (16*plus*, 16*plus*-IM, 16*plus* V2, 16*plus*-IM V2, 19*plus*, 19*plus* V2): **Clean pump as described in *Application Note 75: Maintenance of SBE 5T and 5M Pumps*.**	
(Annually) Inspect and (if applicable) rinse pressure port. See instructions in instrument manual.	
Send instrument to Sea-Bird for calibrations / regular inspection and maintenance. We typically recommend that instrument be recalibrated once a year, but possibly less often if used only occasionally. Return instrument to Sea-Bird for recalibration. Between lab calibrations, take field salinity samples to document conductivity cell drift. ***Notes:*** 1. We cannot place instrument in our calibration bath if heavily covered with biological material or painted with anti-foul paint. Remove as much material as possible before shipping to Sea-Bird; if we need to clean instrument before calibrating it, we will charge you for cleaning. To remove barnacles, plug ends of conductivity cell to prevent cleaning solution from getting into cell, then soak instrument in white vinegar *for a few minutes*. To remove anti-foul paint, use Heavy Duty Scotch-Brite pad or similar material. 2. If using lithium batteries, do not ship batteries installed in instrument. See the current version of the instrument manual for shipping details.	

Application Note Revision History

Date	Description
December 2005	Initial release.
April 2006	• Add information on cleaning instrument exterior before shipping for calibration. • Add reference to document governing shipping instruments with lithium batteries.
March 2008	• Add information on V2 SeaCATs. • Make references to terminal program more generic (Seaterm not used with V2 SeaCATs).
October 2010	• Add references to Application Note 64 for cleaning IDO MicroCATs (37-SMP-IDO, SIP-IDO, IMP-IDO). • Update address.
October 2012	Update for ODO MicroCATs.
January 2014	• Update for SBE 39*plus* and 56. • Add information on removing label covering pumped MicroCAT inlet and exhaust.

Sea-Bird Electronics, Inc.
13431 NE 20th Street
Bellevue, WA 98005
USA

Phone: (425) 643-9866
Fax: (425) 643-9954
E-mail: seabird@seabird.com
Web: www.seabird.com

APPLICATION NOTE NO. 85 — revised October 2012

Handling of Ferrite Core on Instruments with Inductive Modem Telemetry

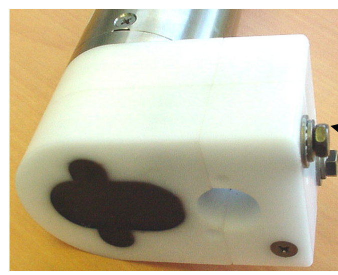
This Application Note applies to instruments and accessories that include a cable coupler for inductive modem telemetry:

- SBE 16*plus*-IM and 16*plus*-IM V2 SeaCAT C-T (optional pressure) Recorder
- SBE 37-IM MicroCAT C-T (optional pressure) Recorder
- SBE 37-IMP MicroCAT C-T (optional pressure) Recorder
- SBE 37-IMP-IDO MicroCAT C-T-DO (optional pressure) Recorder (membrane-type DO)
- SBE 37-IMP-ODO MicroCAT C-T-DO (optional pressure) Recorder (optical DO)
- SBE 39-IM Temperature (optional pressure) Recorder
- SBE 44 Underwater Inductive Modem
- Inductive Cable Coupler (ICC) – clamps to the jacketed mooring wire, and makes electrical connection with the Surface Inductive Modem (SIM) or Inductive Modem Module (IMM) via a cable housed in reinforced-rubber conduit.

The ferrite modem core in these instruments and accessories is fragile, and must be handled with care. If you are having problems with inductive modem communications, check the core for misalignment or damage as follows.

Note: All photos are for an SBE 37-IMP, except as noted. Details are similar for all instruments included in this application note, except as noted.

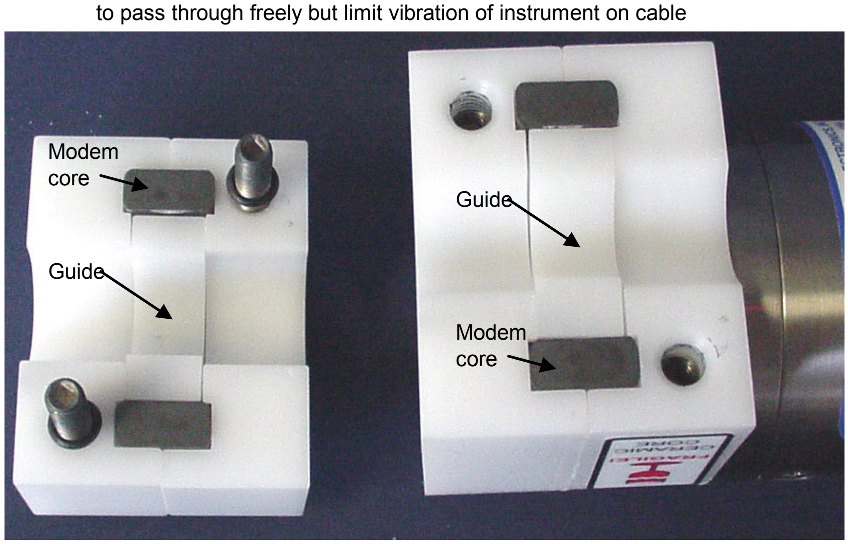
1. Open the mounting bracket by unthreading the large hex-head bolts.



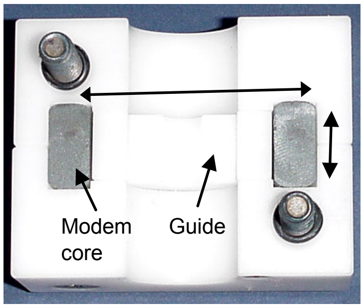
Unthread 2 hex head bolts (Note: ICC has 4 bolts)

Mounting guide / Inductive Modem Coupler Detail
Guide is sized ***slightly*** bigger than specified cable diameter, to allow cable to pass through freely but limit vibration of instrument on cable

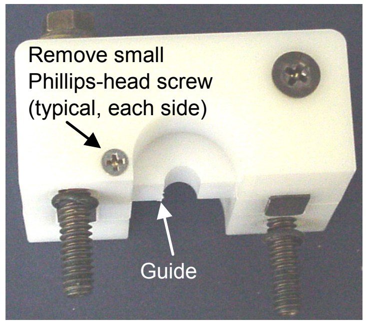
For proper communications, 2 halves of modem coupling toroid core must mate, with no gaps



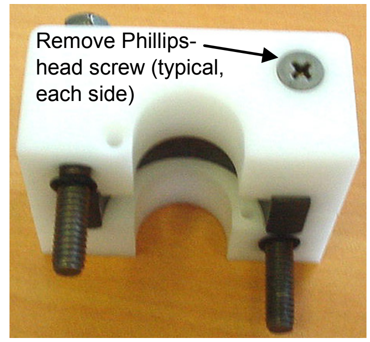
2. On the ***clamp*** side:
   A. Verify that the core provides a level surface for mating with the *instrument* side.
   B. Remove the two small Phillips-head screws securing the guide, and remove the guide.
   C. Remove the 2 larger Phillip-head screws and carefully pull the clamp apart.



Step 2A: Check that core is level in both directions shown

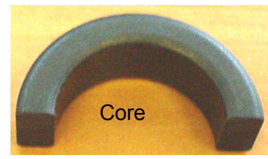


Step 2B: Remove guide



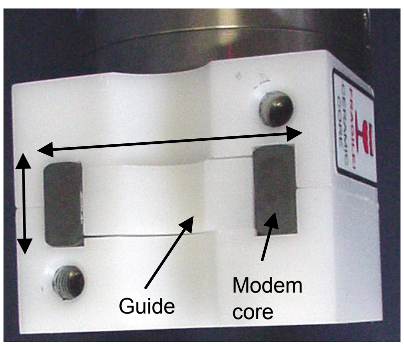
Step 2C: Pull clamp apart

   D. Examine the ferrite core for cracks or chips; replace if necessary.
   E. Reinstall the ferrite core in the two plastic pieces of the clamp, using the 2 Phillips-head screws, being careful to provide a level surface for mating with the *instrument* side.
   F. Reinstall the guide, using the 2 small Phillips-head screws.

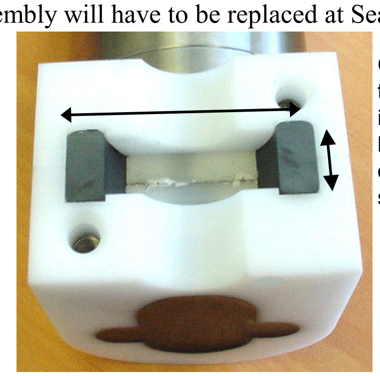


Step 2D: Examine core

3. On the ***instrument*** side:
   A. Verify that the core provides a level surface for mating with the *clamp* side.
   B. Remove the two small Phillips-head screws securing the guide, and remove the guide (similar to Step 2B).
   C. (SBE 16*plus*-IM, 16*plus*-IM V2, 37-IM, 37-IMP, 37-IMP-IDO, 37-IMP-ODO, 39-IM, and 44) The core cannot be removed for a complete inspection, because it is surrounded by potting compound. Inspect the visual portions of the core for damage; if damaged, the entire end cap assembly will have to be replaced at Sea-Bird.



Step 3A: Check that core is level in both directions shown

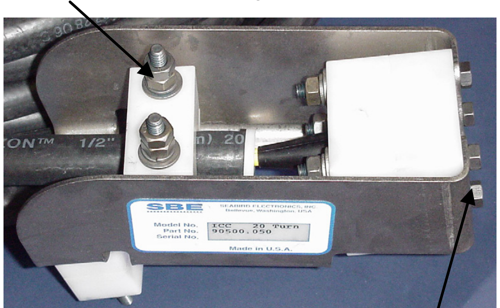

Check that core is level in both directions shown

Step 3C: Examine visual portions of core

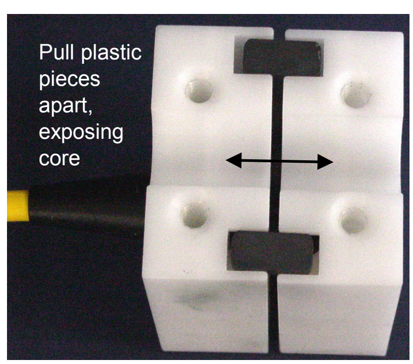
   D. (Inductive Cable Coupler) Remove the core as shown in the photos below. Examine the ferrite core for cracks or chips; replace if necessary. Reinstall the core, plastic, screws, etc.

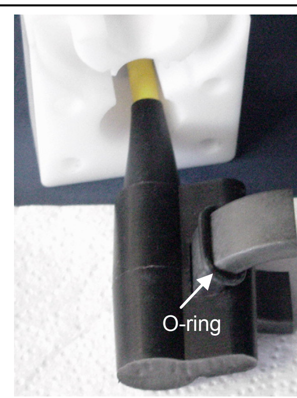
Details for ICC Only

Remove 2 hex head screws with 2 washers and 2 nuts each; pull off bracket attaching cable to metal frame



Remove 4 hex head screws with 2 washers and 1 nut each; pull off bracket attaching to metal frame



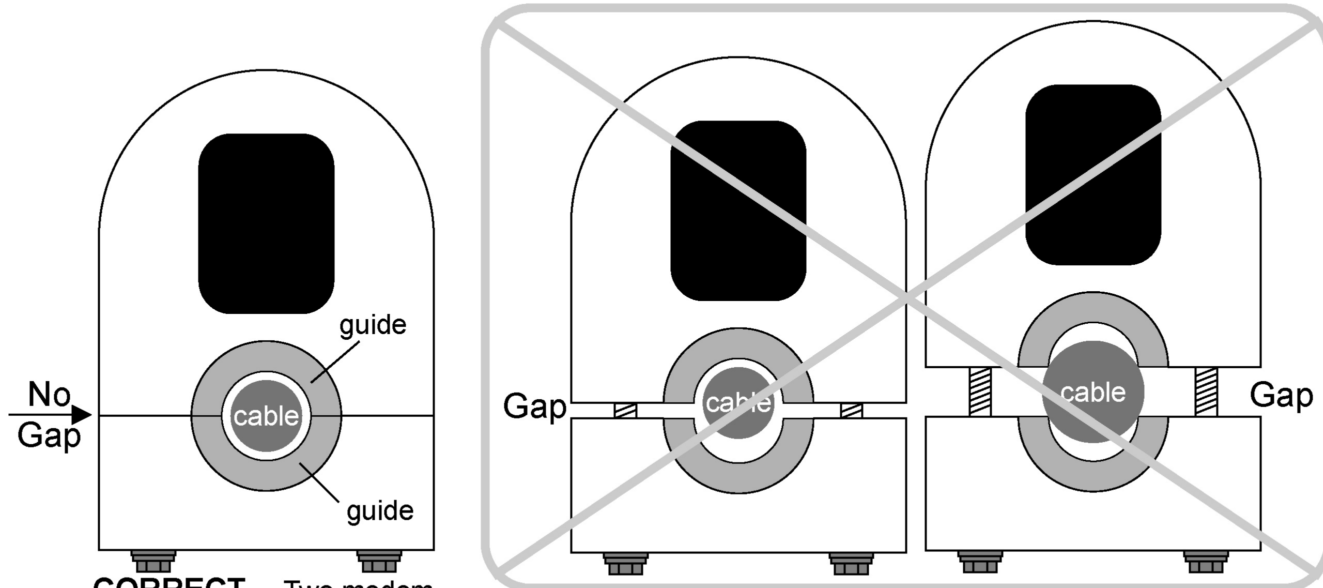


Remove o-rings from core, and slide core out of support

   E. Reinstall the guide, using the 2 small Phillips-head screws.

When installing the instrument or Inductive Cable Coupler on the cable, note the following:

Cable guide and clamp are sized at Sea-Bird to match cable size specified in your order.
If you will be using a different cable size, contact Sea-Bird to order new guide and clamp.



CORRECT -- Two modem halves mating closely (< 0.1 mm gap). Note that guide does not clamp cable.

INCORRECT -- Bolts not tightened completely, creating gap between modem halves. Hand-tighten bolts until snug.

INCORRECT -- Guide hole too small for cable, creating gap between modem halves. May damage cable or modem if over-tightened.

Application Note Revision History

Date	Description
December 2006	Initial release.
April 2008	Add SBE 16*plus*-IM V2.
October 2010	• Add SBE 37-IMP-IDO. • Update address.
October 2012	• Add SBE 37-IMP-ODO.

Sea-Bird Electronics, Inc.
13431 NE 20th Street
Bellevue, WA 98005
USA

Phone: +1 425-643-9866
Fax: +1 425-643-9954
E-mail: seabird@seabird.com
Web: www.seabird.com

APPLICATION NOTE NO. 92 **December 2013**

Real-Time Oceanography with Inductive Moorings and the Inductive Modem Module

I. Introduction

Rapid progress in the development of satellite, RF, and cell-phone telemetry has made real-time, unattended, remote oceanography increasingly practical. However, before these telemetry techniques can be exploited, the data must first be brought to the surface.

Traditionally, underwater-to-surface data transmission was accomplished using direct cable connections. Such cables are bulky, expensive, and unreliable, and the positions (and number) of individual sensors are fixed once the cable is designed and manufactured. More recently, acoustic telemetry has been investigated as a substitute for direct cables. However, acoustic methods result in an even more costly and complex system; additional battery packs are required, depth is restricted due to limited transmission range, and they are subject to a multitude of error sources and failure modes. Today's inductive modem technology provides a convenient, economical, and reliable solution while still maintaining flexibility; Sea-Bird's solution permits up to 100 instruments to be positioned and repositioned at any depth (Figure 1). For typical salt water applications, the maximum mooring depth is 7000 meters; see *Fresh-Water Inductive Mooring (Section IVE)* for fresh water limitations.

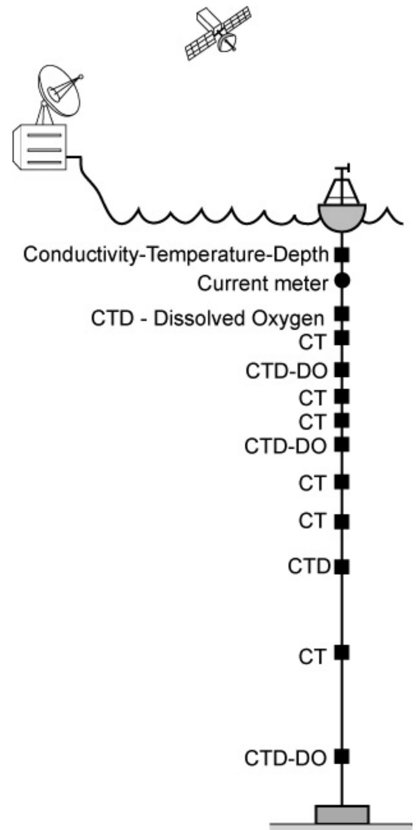


Figure 1: Inductive Mooring

II. Description of Inductive Modem

The *Inductive Modem (IM) System* (or '*Inductively Coupled Modem'*) employs the mooring cable as its transmission medium, eliminating the need for additional conductors. An Inductive Modem Module (IMM) transmits sensor data to the surface by applying a signal to the internal winding of a cable coupler. This induces a signal in the single-turn secondary winding formed by the mooring cable passing through the coupler. The signal is retrieved at the surface by a similar configuration. Each coupler is made up of two halves, allowing it to simply clamp around the cable as opposed to having to *thread* the cable through the unit.

Each cable coupler contains a transformer that magnetically couples the IMM to the mooring cable. Transformers cannot operate at zero frequency (DC) and are inefficient at very low frequencies; although it is improbable that the serial data will consist of all ones or zeros, the IM system needs to account for this possibility. To allow reliable transmission of such data, it is impressed upon a high-frequency carrier waveform. The carrier encoding is performed by MODEM devices (from MODulator-DEModulator), which modulate the carrier at the data source and demodulate it at reception back into the serial form for use by the target PC or CPU.

Sea-Bird's Inductive Modem uses the Differential Phase Shift Keying (DPSK) technique to achieve efficient data transmission with low error rates. It is the same method employed by the widely proven SBE 911*plus* CTD system, but operating at a lower baud rate (1200 vs. 8640).

The Sea-Bird IM DPSK system uses a carrier frequency of 4800 Hz, allotting four cycles of the carrier frequency to each data bit. The encoding scheme is straightforward: if the next bit is a one, the phase of the carrier is inverted (shifted 180 degrees); if the next bit is a zero, the carrier phase does not change.

The modulation and demodulation hardware required for DPSK are extremely simple. Modulation requires only an OR gate and flip-flop; demodulation is inherently coherent (bit energy is averaged rather than spot-sampled) using minimal hard logic, a shift register implementing a one-bit delay being the principle component. Sending data containing all-zeros results in a single continuous frequency (4800 Hz) being placed on the transmission cable, which is readily detected by IM instruments as the *wake-up* signal. The IM system is designed to be insensitive to the connection polarity of the coupling transformers.

III. Principles of Inductive Coupling

Each cable coupler contains a transformer. The toroidal transformer consists of a circular ferrite core and two coils which share a magnetic field. By applying an AC voltage to an 8-turn primary winding, a voltage of half the amplitude will be induced in a 4-turn secondary winding, as shown in Figure 2.

Figure 3 illustrates the operation of such a transformer in the context of the *Direct Connection Inductive Mooring* (*Section IVB*). This is conceptually the simplest configuration, with only a single cable coupler. Both the surface modem and lower end of the mooring cable are grounded to the seawater, completing the current loop through the mooring cable. Note that the secondary winding (in this case, the mooring cable) does not have to be *wound* tightly around the transformer core. The winding must only *pass* through the core.

The *Typical Inductive Mooring* (*Section IVA*) directly grounds *both* ends of the mooring cable to seawater, and the surface modem communicates inductively via the Inductive Cable Coupler (ICC). When an IMM impresses a signal on the 100-turn winding, current flows around the loop formed by the mooring cable and seawater. At the surface, an ICC senses the current in the mooring cable and transmits it to the receiving IMM (shown pictorially in Figure 4 and schematically in Figure 5.)

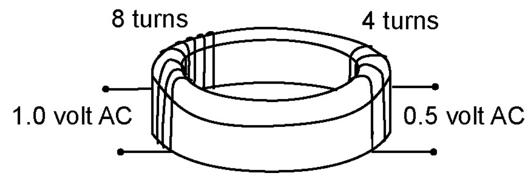


Figure 2: Transformer Operation Example

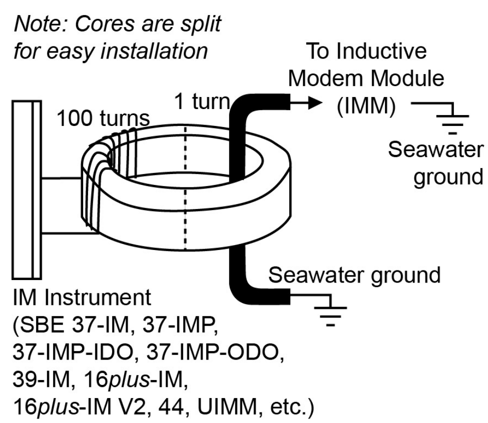


Figure 3: Sea-Bird IM System without ICC

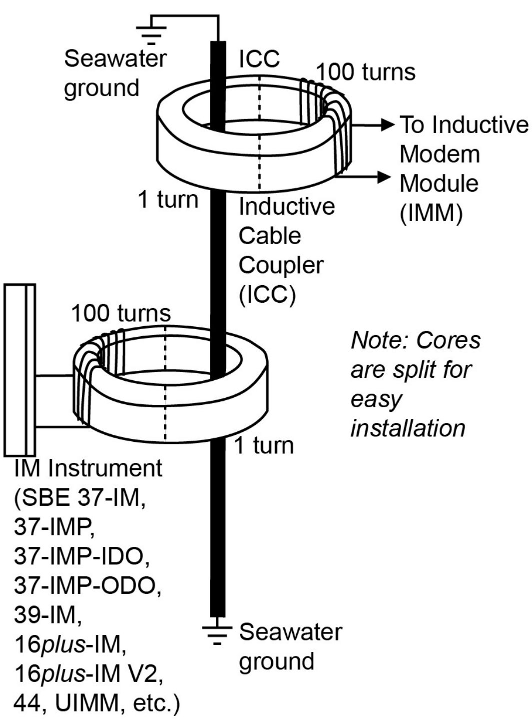


Figure 4: Sea-Bird IM System with ICC

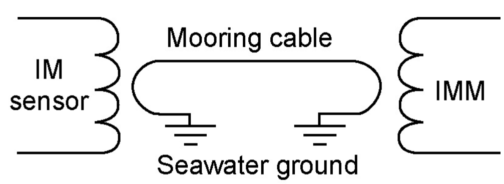


Figure 5: Inductive Coupling Schematic

IV. Inductive Mooring Configurations

A. Typical Inductive Mooring

A typical ocean mooring is shown schematically in Figure 6. The mooring cable is a plastic-jacketed galvanized steel wire rope, a type frequently used for non-inductive oceanographic moorings because of the corrosion resistance provided by the plastic jacket. The ends of the wire rope are terminated with steel thimbles or swaged eye terminals. Deep moorings typically employ synthetic line below the lowest instrument.

Individual inductive modem instruments may be clamped along the mooring cable at any position. It is not necessary to break the cable at the instrument positions or to provide any electrical connection between instrument and cable. Each instrument can be freely moved up or down the cable.

The surface buoy contains a Sea-Bird Inductive Modem Module (IMM; see *Section VC*) that communicates with the underwater components via a through-hull bulkhead connector, polyurethane cable, and Sea-Bird Inductive Cable Coupler (ICC; see *Section VD*). As with the IM instruments, the ICC simply clamps anywhere along the plastic-jacketed portion of mooring cable below the seawater ground — no electrical connection to the mooring cable is required. The buoy controller / CPU (not supplied by Sea-Bird) links to the IMM using RS-232, enabling bi-directional half-duplex communication with the entire suite of IM instruments.

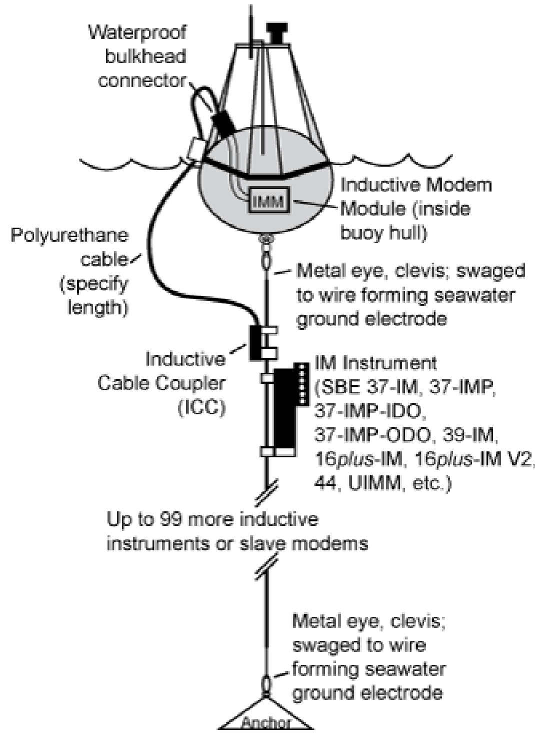


Figure 6: Typical Inductive Mooring Configuration

B. Direct Connection Inductive Mooring

A second configuration makes use of a direct electrical connection between the surface buoy and the top of the mooring cable, as shown in Figure 7. In this configuration, the plastic-jacketed cable is brought inside the buoy. The buoy must be mechanically secured to the top of the cable without compromising the electrical insulation of the plastic jacket. The IMM connects to both the galvanized steel wire rope and to the buoy hull (or other seawater return) via a small *Direct Connection PCB*, co-located with the IMM inside the buoy. The ICC is eliminated, but connecting the buoy to the mooring cable may be more complicated.

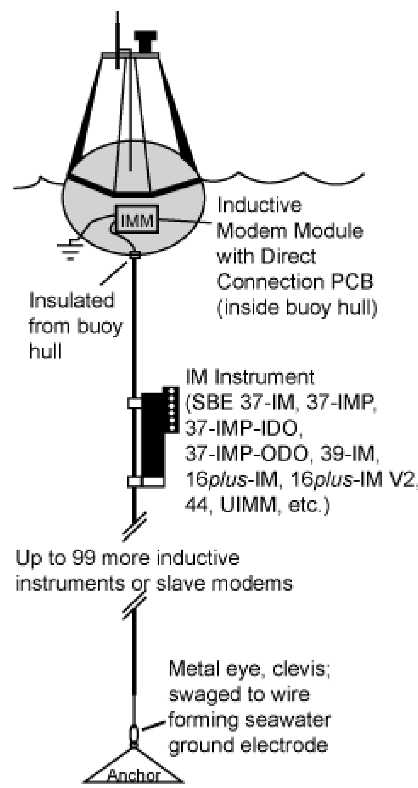


Figure 7: Direct Connection Inductive Mooring Configuration

C. Cable-to-Shore Inductive Mooring

As shown in Figure 8, instruments may be placed at any position along a plastic-jacketed wire rope leading from shore. Here the problem of insulating the inner conductor at the shore end is easily solved, making the direct-connection approach to the IMM (Figure 7) the preferred method.

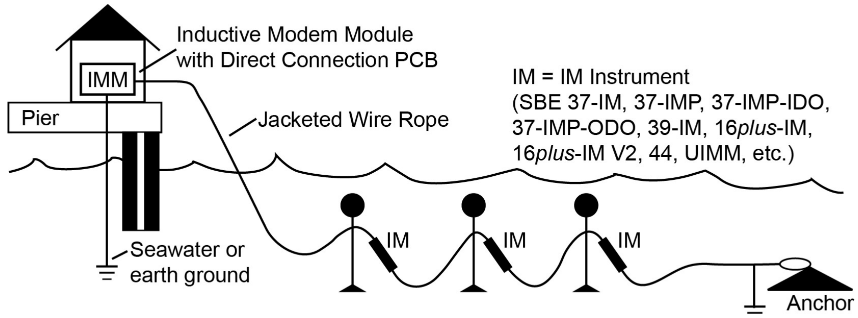


Figure 8: Cable-to-Shore Mooring

D. Through-Ice Inductive Mooring

Figure 9 shows a mooring for through-ice applications. Both ends of the mooring cable must be immersed in the seawater to complete the circuit.

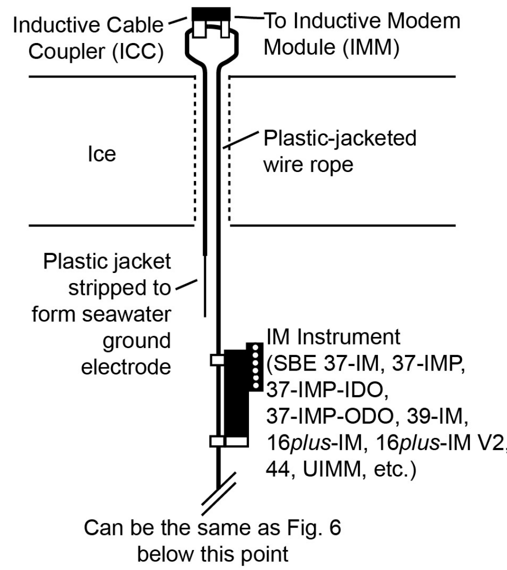


Figure 9: Through-Ice Mooring

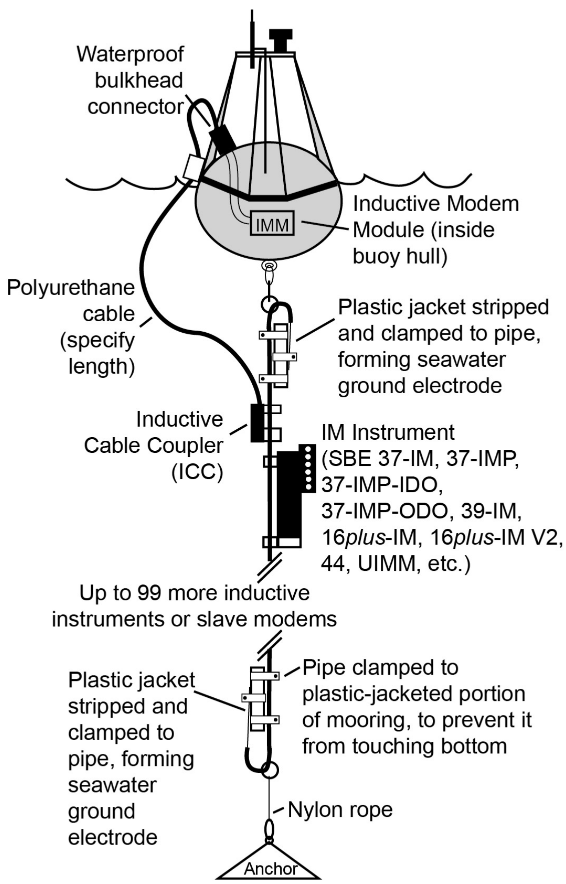


Figure 10: Fresh Water Mooring

E. Fresh-Water Inductive Mooring

Figure 10 shows a mooring for fresh-water applications, for a mooring with an Inductive Cable Coupler (ICC).

Due to the lower conductivity of fresh water, more exposed metal area is needed at both ends of the mooring line to complete the circuit. In fresh water, do not rely on the grounds provided by the eye or clevis alone. Use at least a 0.7 m (2 ft) length of 2 inch (outer diameter) or larger conductive pipe (galvanized or stainless steel) as top and bottom electrodes. Strip the ends of the mooring cable and clamp them to the pipes. Do not let the electrode pipe lie on the bottom; clamp the pipe to the mooring line at least 2 or 3 meters above the bottom. A mooring with this design should provide good communications over 1000 meters of mooring line in water with conductivity as low as 100 µS/cm.

For a mooring using a direct cable connection at the surface (no ICC), the connection to the buoy is as shown in Figure 7; several square feet of un-painted surface on the buoy is required to provide the large electrode at the top. The bottom connection remains as shown in Figure 10.

V. Inductive Modem System Components

A. Mooring Cable (not supplied by Sea-Bird)

Mooring cables are usually polyethylene-jacketed galvanized steel wire rope. Provision for electrical contact with the water must always be made at the lower end of the cable. Typically, a few centimeters of insulation are removed and a swaged eye terminal (Figure 11) is installed to provide both a means of mechanical attachment and a suitable seawater ground. Mooring cable and cable assembly sources are given in *Section VI*.

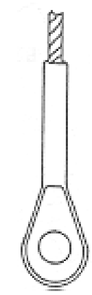


Figure 11: Swaged Eye Terminal

B. Underwater Sensors

The IM system supports both autonomously operating sensors and those that require a command to take a sample and return the data. Even with the IM connection, it is advantageous for IM sensors to store measurement data internally so that the data can be directly extracted from the instruments in the event of a failure of any part of the communications link (telemetry components, buoy, or IM). A further advantage to this scheme is that a series of samples can be retrieved for re-transmission, for example the most recent 16 samples, thereby minimizing the number of individual queries and maximizing battery life. For this to be successfully implemented, the sensor must be capable of communicating with the IM independently of acquiring data or timing its data collection to avoid conflict with IM inquiries.

1. Sea-Bird MicroCAT CT (pressure optional) Recorder, SBE 37-IM, 37-IMP, 37-IMP-IDO, and 37-IMP-ODO

The SBE 37-IM, 37-IMP, 37-IMP-ODO, and 37-IMP-IDO (Figure 12) are CT (pressure optional) recorders, with internal batteries and FLASH memory, for depths to 7000 meters (with titanium housing). The MicroCATs can be commanded to sample via the IM link. However, it is usually desirable to make use of the MicroCAT's Autonomous Mode based on its internal clock and memory. In this mode, samples are taken and recorded in memory at fixed time intervals, while the buoy uses the IM link to request the most recent results.

The 37-IMP combines the features of the 37-IM with an integral, internal pump. The 37-IMP-IDO includes the pump as well as an Integrated Dissolved Oxygen (membrane-type) sensor, while the 37-IMP-ODO includes the pump as well as an integrated Optical Dissolved Oxygen sensor.

Figure 12: From left, SBE 37-IM, 37-IMP, 37-IMP-IDO, 37-IMP-ODO MicroCAT

2. Sea-Bird Temperature (pressure optional) Recorder, SBE 39-IM

The SBE 39-IM (Figure 13) is a Temperature (pressure optional) recorder, with internal batteries and FLASH memory, for depths to 10,500 meters (with titanium housing). It operates in command or autonomous mode, similar to the MicroCAT.

Figure 13: SBE 39-IM

3. Sea-Bird SeaCAT CT (pressure optional) Recorder, SBE 16*plus*-IM V2

The 16*plus*-IM V2 (Figure 14) is a CT (pressure optional) recorder, with internal batteries and FLASH memory, for depths to 7000 meters (with titanium housing). It has six A/D input channels and one RS-232 input channel for auxiliary sensors. The 16*plus*-IM V2 operates in command or autonomous mode, similar to the MicroCAT.

Figure 14: SBE 16plus-IM V2

4. Equipment manufactured by other companies, interfacing with a Sea-Bird Underwater Inductive Modem Module (UIMM) or SBE 44 Underwater Inductive Modem (Figure 15)

The UIMM is a small underwater module containing an IMM, inductive cable coupler, and cable clamp. It allows a variety of RS-232 serial output instruments to be integrated with an IM system. The UIMM contains no batteries, and must be powered by the serial output instrument or by an external battery pack.

The SBE 44 has a built-in inductive cable coupler and cable clamp, and contains a real-time clock, buffer memory, RS-232 interface, and internal batteries. It allows a variety of RS-232 serial output instruments to be integrated with an IM system. If the serial output instrument has modest power requirements, the SBE 44 can provide the power as well as the telemetry interface. The SBE 44, an older instrument, has more limited interface capabilities than the UIMM.

Figure 15: From left, UIMM and SBE 44

5. Equipment manufactured by other companies, incorporating built-in Sea-Bird OEM IM components

Other companies can purchase an Inductive Modem Module (IMM) and a cable coupler, for integration in their own instruments at the development stage. Figure 16 shows two examples of this integration. See *OEM Components Available from Sea-Bird (Section VII)* for additional integration information.

Note: Voltage output (analog) or frequency output sensors cannot be directly interfaced to the IM system.

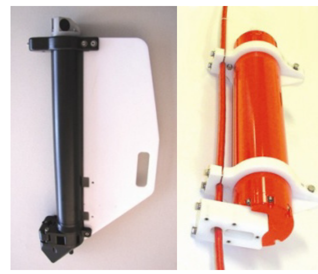


Figure 16: From left, Nortek Aquadopp IM400 and TRDI DVS with integrated IMM

C. Inductive Modem Module (IMM)

The IMM is a small printed circuit card (Figure 17) mounted in the surface buoy or on-shore (for cable-to-shore systems). When using the IMM in a Direct Connection configuration (Direct Connection and Cable-to-Shore moorings, Figures 7 and 8), it must be paired with Sea-Bird's *Direction Connection PCB* to make a good electrical interface to the mooring cable. The *Direct Connection PCB* is co-located with the IMM (Figure 18).

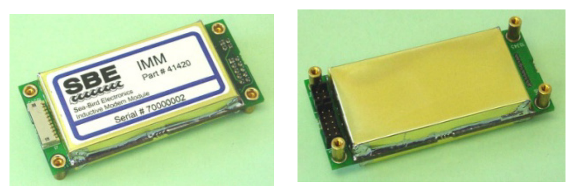


Figure 17: Inductive Modem Module (IMM)

IMM Specifications

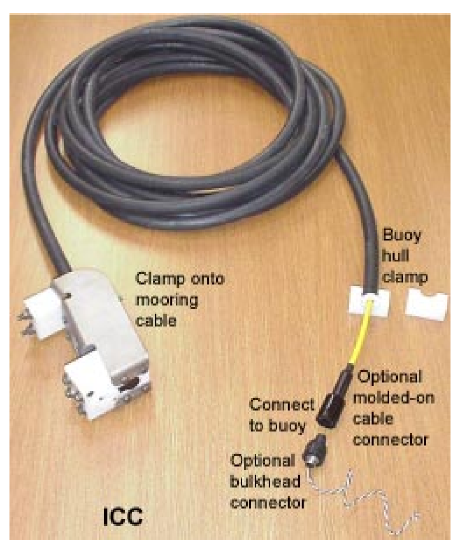
Dimensions	3.1 x 7 x 1.6 cm (1.25 x 2.75 x 0.6 in.)
Voltage	7 to 25 volts
Quiescent Current	25 microamps
Communication Current	1.42 milliamps

Figure 18: IMM with Direct Connect PCB

D. Inductive Cable Coupler (ICC)

The ICC (Figure 19) is used with the IMM for moorings similar to Figures 6, 9, and 10. The ICC is available in a number of sizes, for clamping to mooring cables with diameters from 1/4 inch to 16 mm. The ICC cable can be specified for the desired length, with a pigtail or a molded connector.

Figure 19: Inductive Cable Coupler (ICC)



E. Buoy Controller (not supplied by Sea-Bird)

The buoy controller is typically a microprocessor that schedules interrogation of the underwater instruments, interfaces to any desired atmospheric sensors, and controls the telemetry of data back to shore via RF, cell phone, satellite, or hard-wire link.

The surface buoy's CPU controller connects via RS-232 to the local Sea-Bird IMM. Although the IMM is configured by default to communicate with the CPU at 9600 baud full duplex, the IMM communicates with the underwater sensors using a half-duplex 1200 baud telemetry link. Commands to and replies from IM instruments are sequential, not simultaneous. Commands may be issued globally or to an individual sensor. Global commands are processed by all IM instruments on the IM line, but the IM instruments do not send replies. These commands are typically used to set all IM instruments to the same time and date, or to instruct all IM sensors to begin sampling now or at some time in the future. To allow for individual instruments to receive commands and to reply, each instrument is programmed with an ID number in the sequence 00 to 99. Addressed commands can be used to instruct individual sensors to acquire data, check sensor status, or transmit stored data.

IM instruments usually reside in one of three operating modes: sleep, IM Service, and Host Service. The mode of operation is not user settable and depends on the action being performed by the IMM. Throughout most of each deployment, the IMM will be in sleep mode. Upon command from the buoy CPU, the surface IMM sends a *wake-up* signal that sets all instruments to IM Service mode. In IM Service mode, IM instruments respond to both global and individual commands sent over the IM line; if no commands are received within two minutes of wake-up, an internal time-out re-establishes Sleep mode. Host Service mode is entered when communication is initiated by the local sensor to store data, change settings, etc. While in Host Service mode, the IMM does not respond to (buoy controller) commands on the IM Line. If no communication is detected from the local instrument for two minutes, the IMM re-enters Sleep mode. For power requirements, see *Inductive Modem System Components – Inductive Modem Module* (VC above).

F. Surface Buoy (not supplied by Sea-Bird)

The surface buoy houses the Inductive Modem Module, Buoy Controller / Data Logger, telemetry transmitter / receiver, and necessary batteries (Figure 20).

G. Shore Installation (not supplied by Sea-Bird)

Located on shore is the telemetry receiver (and in some cases a transmitter permitting shore-side control of buoy function), and a computer for logging, processing, and displaying buoy data.

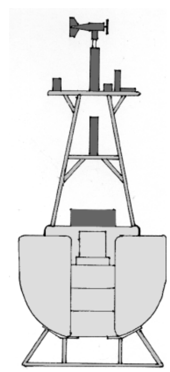


Figure 20:
Typical Surface Buoy

VI. Resources for Mooring Cable, Cable Assembles, and Other Mooring System Components

A. Jacketed Wire Cable

Sea-Bird recommends a **3x19 strand oceanographic wire rope with protective polypropylene jacketing**. Two sources for suitable jacketed wire are listed below; similar cable may also be available from other sources.

1. Loos & Co. (+1 800-533-5667, sales@loosco,com, www.loosco.com) - 3x19 Galvanized Oceanographic Cable, Plastic Impregnated
2. WireCo WorldGroup (+1 816-270-4700, www.wirecoworldgroup.com) - Macwhyte 3x19 Space-Lay Plastic Impregnated and Coated Wire Rope

B. Mooring Hardware and Design Assistance

Mooring Systems, Inc. (+1 508-564-4770, sales@mooringsystems.com, www.mooringsystems.com) - Terminated wire, cable assemblies, other mooring hardware, and mooring design assistance

C. Custom Mooring Systems

Custom mooring systems incorporating Sea-Bird Inductive Modem components have been manufactured by:

1. Fugro Oceanor (+47 73 54 52 00, trondheim @oceanor.com, www.oceanor.no)
2. RDSea and Associates (+1 727-385-3834, rdsea_inc@hotmail.com)
3. Axys Technologies (+1 250-655-5850, info@axys.com, www.axystechnologies.com)
4. MacArtney Group (+45 7613 2000, info@macartney.com, www.macartney.com)
5. MetOcean (+1 902-468-2505, sales@metocean.com, www.metocean.com)

VII. OEM Components Available from Sea-Bird

Qualified manufacturers of serial-output sensors can obtain IMM circuit cards and other components needed to convert new or existing instruments to IM operation. The IMM boardset is available with electrical pins on the bottom, to plug into electrical connections below it (as shown in Figure 17), or can be configured with the pins oriented for side connections.

Figure 21: IMM with High-Voltage Input Adapter Board

The IMM operates with supply voltages ranging from 7 to 25 VDC, and is compatible with battery packs typically used in ocean instruments. A high-voltage input adapter board is available for applications with input voltages from 20 to 80 VDC (Figure 21). The data interface is full duplex RS-232. The baud rate is user-programmable to 1200, 2400, 4800, 9600, or 19200 baud.

In addition to the IMM, a split toroid core and transformer winding is required. In designing the mechanical mount for the IM coupler, note that one half of the toroid is to be captured within the instrument and surrounded by the free-standing winding. Single-pin seal pins (not supplied) are typically used to support the winding and bring the electrical connections into the instrument. The winding and core half are then urethane potted. The potting material must adhere to the seal pins; no other adhesive bonds are critical. The winding is entirely surrounded by the potting material, so that water intrusion along the toroid surface is of no consequence. The toroid itself is unaffected by water exposure. The OEM must make provisions to lightly clamp the other toroid half into position. Figure 22 shows various aspects of the basic design. Additional details and design assistance are available from Sea-Bird.

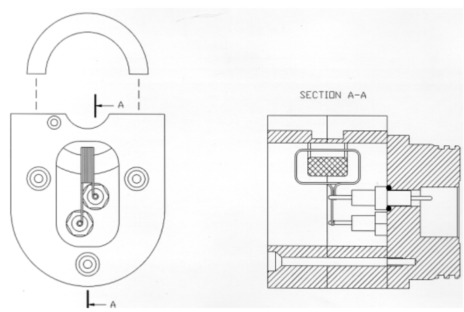


Figure 22: Typical IM Coupler Installed in Instrument End Cap

As an alternative to making the IM coupler an integral part of an end cap, the Inductive Cable Coupler (Figure 19) can be connected to a bulkhead connector on the OEM instrument (Figure 23), making the IM coupling a flexible lead of any convenient length.

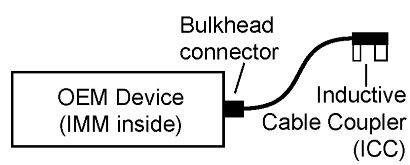


Figure 23: IM Coupler on Flexible Lead

Application Note Revision History

Date	Description
May 2011	Initial release as an application note (was previously available in our Technical Papers list). Add information on 37-IMP-IDO, and update list of mooring system vendors..
October 2012	Add information on 37-IMP-ODO.
December 2013	Delete Sound Ocean Systems from Custom Mooring Systems list.

Sea-Bird Electronics, Inc.
13431 NE 20th Street
Bellevue, WA 98005
USA

Phone: (425) 643-9866
Fax: (425) 643-9954
E-mail: seabird@seabird.com
Web: www.seabird.com

APPLICATION NOTE NO. 31 **Revised February 2010**

Computing Temperature and Conductivity *Slope* and *Offset* Correction Coefficients from Laboratory Calibrations and Salinity Bottle Samples

Conductivity Sensors

The conductivity sensor *slope* and *offset* entries in the configuration (.con or .xmlcon) file in SEASOFT permit the user to make corrections for sensor drift between calibrations. The correction formula is:

(corrected conductivity) = slope * (computed conductivity) + offset

where :
slope = (true conductivity span) / (instrument reading conductivity span)
offset = (true conductivity - instrument reading conductivity) * slope *measured at 0 S/m*

For newly calibrated sensors, use slope = 1.0, offset = 0.0.

Sea-Bird conductivity sensors usually drift by changing span (the slope of the calibration curve), and changes are typically toward lower conductivity readings with time. Any offset error in conductivity (error at 0 S/m) is usually due to electronics drift, typically less than ±0.0001 S/m per year. Offsets greater than ±0.0002 S/m per year are symptomatic of sensor malfunction. **Therefore, Sea-Bird recommends that conductivity drift corrections be made by assuming no offset error, unless there is strong evidence to the contrary or a special need.**

Example
true conductivity =3.5 S/m
instrument reading conductivity = 3.49965 S/m
slope = 3.5 / 3.49965 = 1.000100

Correcting for Conductivity Drift Based on Pre- and Post-Cruise Laboratory Calibrations

Suppose a conductivity sensor is calibrated (pre-cruise), then immediately used at sea, and then returned for post-cruise calibration. The pre- and post-cruise calibration data can be used to generate a slope correction for data obtained between the pre- and post-cruise calibrations.

If **α** is the conductivity computed from the **pre-cruise bath data** (temperature and frequency) using **post-cruise calibration coefficients** and **β** is the true conductivity in the **pre-cruise bath**, then:

$$\textbf{postslope} = \frac{\sum_{i=1}^{n} (\alpha_i)(\beta_i)}{\sum_{i=1}^{n} (\alpha_i)(\alpha_i)} \qquad \text{(postslope is typically < 1.0)}$$

Sea-Bird calculates and prints the value for postslope on the conductivity calibration sheet for all calibrations since February 1995 (see *Appendix I: Example Conductivity Calibration Sheet*)
.

To correct conductivity data taken between pre- and post-cruise calibrations:

islope = 1.0 + (b / n) [(1 / postslope) - 1.0]

where

islope = interpolated slope; this is the value to enter in the configuration (.con or .xmlcon) file
b = number of days between pre-cruise calibration and the cast to be corrected
n = number of days between pre- and post-cruise calibrations
postslope = slope from calibration sheet as calculated above (see *Appendix I: Example Conductivity Calibration Sheet*)

In the configuration (.con or .xmlcon) file, use the **pre-cruise calibration coefficients** and use **islope** for the value of slope.*

Note: In our SEASOFT V2 suite of programs, edit the CTD configuration (.con or .xmlcon) file using the Configure Inputs menu in Seasave V7 (real-time data acquisition software) or the Configure menu in SBE Data Processing (data processing software).

For typical conductivity drift rates (equivalent to -0.003 PSU/month), islope does not need to be recalculated more frequently than at weekly intervals.

* You can also calculate preslope. If **α** is the conductivity computed from **post-cruise bath data** (temperature and frequency) using **pre-cruise calibration coefficients** and **β** is the true conductivity in the **post-cruise bath**, then:

$$\textbf{preslope} = \frac{\sum_{i=1}^{n} (\alpha_i)(\beta_i)}{\sum_{i=1}^{n} (\alpha_i)(\alpha_i)} \quad \text{(preslope is typically > 1.0)}$$

In this case, pre-cruise calibration coefficients would be used and:
islope = 1.0 + (b / n) (preslope - 1.0)

Correcting for Conductivity Drift Based on Salinity Bottles Taken At Sea

For this situation, the **pre-cruise** calibration coefficients are used to compute conductivity and CTD salinity. Salinity samples are obtained using water sampler bottles during CTD profiles, and the difference between CTD salinity and bottle salinity is used to determine the drift in conductivity.

In using this method to correct conductivity, it is important to realize that differences between CTD salinity and hydrographic bottle salinity are due to errors in conductivity, temperature, and pressure measurements, as well as errors in obtaining and analyzing bottle salinity values. For typical Sea-Bird sensors that are calibrated regularly, 70 - 90% of the CTD salinity error is due to conductivity calibration drift, 10 - 30% is due to temperature calibration drift, and 0 - 10% is due to pressure calibration drift. All CTD temperature and pressure errors and bottle errors must first be corrected before attributing the remaining salinity difference as due to CTD conductivity error and proceeding with conductivity corrections.

Example
Three salinity bottles are taken during a CTD profile; assume for this discussion that shipboard analysis of the bottle salinities is perfect. The **uncorrected** CTD data (from Seasave V7) and bottle salinities are:

Approximate Depth (m)	CTD Raw Pressure (dbar)	CTD Raw Temperature (°C) *	CTD Raw Conductivity (S/m)	CTD Raw Salinity	Bottle Salinity
200	202.7	18.3880	4.63421	34.9705	34.9770
1000	1008.8	3.9831	3.25349	34.4634	34.4710
4000	4064.1	1.4524	3.16777	34.6778	34.6850

** Temperatures shown are **ITS-90**. However, the salinity equation is in terms of IPTS-68; you must convert ITS-90 to IPTS-68 (IPTS-68 = 1.00024 * ITS-90) before calculating salinity. SEASOFT does this automatically.*

The uncorrected salinity differences (CTD raw salinity - bottle salinity) are approximately -0.007 psu. To determine conductivity drift, first correct the CTD temperature and pressure data. Suppose that the error in temperature is +0.0015 °C uniformly at all temperatures, and the error in pressure is +0.5 dbar uniformly at all pressures (drift offsets are obtained by projecting the drift history of both sensors from pre-cruise calibrations). Enter these offsets in the configuration (.con or .xmlcon) file to calculate the corrected CTD temperature and pressure, and calculate the CTD salinity using the corrected CTD temperature and pressure. This correction method assumes that the pressure coefficient for the conductivity cell is correct. The CTD data with **corrected** temperature (ITS-90) and pressure are:

Corrected CTD Pressure (dbar)	Corrected CTD Temperature (°C)	CTD Raw Conductivity (S/m)	CTD Salinity [T,P Corrected]	Bottle Salinity
202.2	18.3865	4.63421	34.9719	34.9770
1008.3	3.9816	3.25349	34.4653	34.4710
4063.6	1.4509	3.16777	34.6795	34.6850

The salinity difference (CTD salinity – bottle salinity) of approximately -0.005 psu is now properly categorized as conductivity error, equivalent to about -0.0005 S/m at 4.0 S/m.

Compute bottle conductivity (conductivity calculated from bottle salinity and CTD temperature and pressure) using SeacalcW (in SBE Data Processing); enter bottle salinity for *salinity*, corrected CTD temperature for *ITS-90 temperature*, and corrected CTD pressure for *pressure*:

CTD Raw Conductivity (S/m)	Bottle Conductivity (S/m)	[CTD - Bottle] Conductivity (S/m)
4.63421	4.63481	-0.00060
3.25349	3.25398	-0.00049
3.16777	3.16822	-0.00045

By plotting conductivity error versus conductivity, it is evident that the drift is primarily a slope change. If **α** is the CTD conductivity computed with **pre-cruise** coefficients and **β** is the true bottle conductivity, then:

$$\textbf{slope} = \frac{\sum_{i=1}^{n} (\alpha_i)(\beta_i)}{\sum_{i=1}^{n} (\alpha_i)(\alpha_i)} \qquad \text{(slope is typically > 1.0)}$$

Using the above data, the slope correction coefficient for conductivity at this station is:
Slope = [(4.63421 * 4.63481) + (3.25349 * 3.25398) + (3.16777 * 3.16822)] /
[(4.63421 * 4.63421) + (3.25349 * 3.25349) + (3.16777 * 3.16777)] = **+1.000138**

Following Sea-Bird's recommendation of assuming no offset error in conductivity, **set offset to 0.0**.

Temperature Sensors

The temperature sensor *slope* and *offset* entries in the configuration (.con or .xmlcon) file in SEASOFT permit the user to make corrections for sensor drift between calibrations. The correction formula is:

corrected temperature = slope * (computed temperature) + offset

where :

slope = (true temperature span) / (instrument reading temperature span)
offset = (true temperature - instrument reading temperature) * slope *measured at 0.0 °C*

For newly calibrated sensors, use slope = 1.0, offset = 0.0.

Sea-Bird temperature sensors usually drift by changing offset (an error of equal magnitude at all temperatures). In general, the drift can be toward higher or lower temperature with time; however, for a specific sensor the drift remains the same sign (direction) for many consecutive years. Many years of experience with thousands of sensors indicates that the drift is smooth and uniform with time, allowing users to make very accurate drift corrections to field data based only on pre- and post-cruise laboratory calibrations.

Span errors cause slope errors, as described in the equation for slope above. Sea-Bird temperature sensors rarely exhibit span errors larger than 0.005 °C over the range -5 to 35 °C, even after years of drift. Temperature calibrations performed at Sea-Bird since January 1995 have slope errors less than 0.0002 °C in 30 °C. Prior to January 1995, some calibrations were delivered that include slope errors up to 0.004 °C in 30 °C because of undetected systematic errors in calibration. A slope error that increases by more than ±0.0002 [°C per °C per year] indicates an unusual aging of electronic components and is symptomatic of sensor malfunction. **Therefore, Sea-Bird recommends that drift corrections to temperature sensors be made assuming no slope error, unless there is strong evidence to the contrary or a special need.**

Calibration checks at-sea are advisable for consistency checks of the sensor drift rate and for early detection of sensor malfunction. However, data from reversing thermometers is rarely accurate enough to make calibration corrections that are better than those possible by shore-based laboratory calibrations. **For the SBE 9*plus***, a proven alternate consistency check is to use dual SBE 3 temperature sensors on the CTD and to track the difference in drift rates between the two sensors. In the deep ocean, where temperatures are uniform, the difference in temperature measured by two sensors can be resolved to better than 0.0002 °C and will change smoothly with time as predicted by the difference in drift rates of the two sensors.

Correcting for Temperature Drift Based on Pre- and Post-Cruise Laboratory Calibrations

Suppose a temperature sensor is calibrated (pre-cruise), then immediately used at-sea, and then returned for post-cruise calibration. The pre-and post-cruise calibration data can be used to generate an offset correction for data obtained between the pre- and post-cruise calibrations.

Calibration coefficients are calculated with the post-cruise calibration. Using the pre-cruise bath data and the post-cruise calibration coefficients, a mean residual over the calibration temperature range is calculated.

residual = instrument temperature – bath temperature

Sea-Bird calculates and prints the value for the residual on the temperature calibration sheet (see *Appendix II: Example Temperature Calibration Sheet*).

To correct temperature data taken between pre- and post-cruise calibrations:

Offset = b * (residual / n)

where

b = number of days between pre-cruise calibration and the cast to be corrected
n = number of days between pre- and post-cruise calibrations
residual = residual from calibration sheet as described above (see *Appendix II: Example Temperature Calibration Sheet*)

In the configuration (.con or .xmlcon) file, use the **pre-cruise calibration coefficients** and use the calculated **offset** for the value of offset.

Note: In our SEASOFT V2 suite of programs, edit the CTD configuration (.con or .xmlcon) file using the Configure Inputs menu in Seasave V7 (real-time data acquisition software) or the Configure menu in SBE Data Processing (data processing software).

Example
Instrument was calibrated (pre-cruise), used at sea for 4 months, and returned for post-cruise calibration. Using **pre-cruise bath data** and **post-cruise coefficients**, the calibration sheet shows a mean residual of -0.2 millidegrees C (-0.0002 °C).

For preliminary work at sea, use the **pre-cruise calibration coefficients** and **slope = 1.0, offset = 0.0**. After the cruise, correct temperature data obtained during the cruise for drift using properly scaled values of correction coefficients:

For data from the end of the first month (30 days) at sea:
Offset = b * (residual / n) = 30 * (-0.0002 / 120) = - 0.00005;
Convert data using **pre-cruise coefficients** and **-0.00005** as the offset in the configuration file.

For data from the end of the second month (60 days) at sea:
Offset = b * (residual / n) = 60 * (-0.0002 / 120) = - 0.0001;
Convert data using **pre-cruise coefficients** and **-0.0001** as the offset in the configuration file.

For data from the end of the third month (90 days) at sea:
Offset = b * (residual / n) = 90 * (-0.0002 / 120) = - 0.00015;
Convert data using **pre-cruise coefficients** and **-0.00015** as the offset in the configuration file.

For data from the end of the 4-month cruise:
Offset = - 0.0002;
Convert data using **pre-cruise coefficients** and **-0.0002** as the offset in the configuration file, or using **post-cruise** coefficients and **0** as the offset in the configuration file.

Appendix I: Example Conductivity Calibration Sheet

SEA-BIRD ELECTRONICS, INC.
1808 136th Place N.E., Bellevue, Washington, 98005 USA
Phone: (425) 643 - 9866 Fax (425) 643 - 9954 Email: seabird@seabird.com

SENSOR SERIAL NUMBER: 2218
CALIBRATION DATE: 30-Dec-99

SBE4 CONDUCTIVITY CALIBRATION DATA
PSS 1978: C(35,15,0) = 4.2914 Seimens/meter

GHIJ COEFFICIENTS

```
g =  -1.02414422e+001
h =   1.49331006e+000
i =  -1.50844862e-003
j =   1.99364517e-004
CPcor = -9.5700e-008 (nominal)
CTcor =  3.2500e-006 (nominal)
```

Coefficients from *30-Dec-99* calibration.

ABCDM COEFFICIENTS

```
a =   3.56563909e-006
b =   1.48964234e+000
c =  -1.02346588e+001
d =  -8.62052534e-005
m =   5.4
CPcor = -9.5700e-008 (nominal)
```

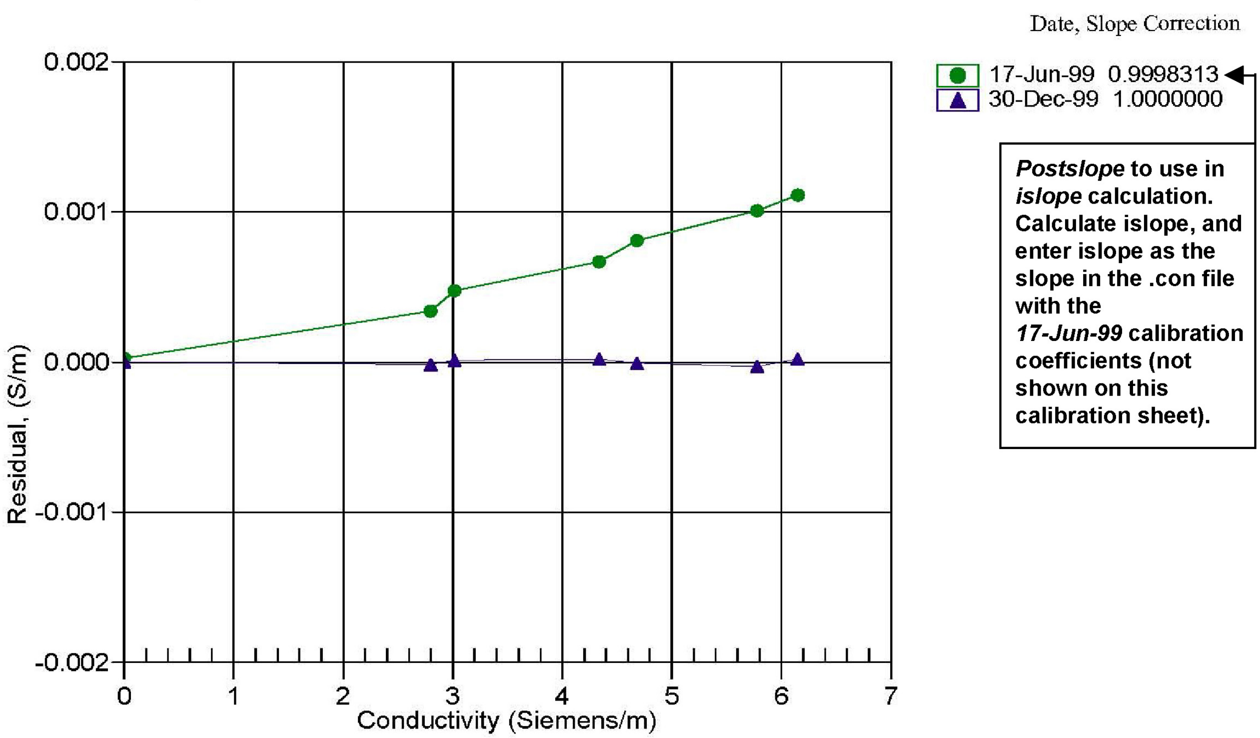
BATH TEMP (ITS-90)	BATH SAL (PSU)	BATH COND (Siemens/m)	INST FREQ (kHz)	INST COND (Siemens/m)	RESIDUAL (Siemens/m)
0.0000	0.0000	0.00000	2.62109	0.00000	0.00000
-1.3895	35.1839	2.79817	5.06354	2.79815	-0.00002
1.1492	35.1843	3.01746	5.20666	3.01747	0.00001
15.2688	35.1829	4.33837	5.99642	4.33839	0.00002
18.7065	35.1798	4.68224	6.18534	4.68224	-0.00001
29.2500	35.1699	5.78041	6.75306	5.78038	-0.00003
32.6897	35.1622	6.15002	6.93359	6.15004	0.00002

Conductivity = $(g + hf^2 + if^3 + jf^4)/10(1 + \delta t + \varepsilon p)$ Siemens/meter

Conductivity = $(af^m + bf^2 + c + dt) / [10 (1 + \varepsilon p)$ Siemens/meter

t = temperature[°C)]; p = pressure[decibars]; δ = CTcor; ε = CPcor;

Residual = (instrument conductivity - bath conductivity) using g, h, i, j coefficients



Appendix II: Example Temperature Calibration Sheet

SEA-BIRD ELECTRONICS, INC.
1808 136th Place N.E., Bellevue, Washington, 98005 USA
Phone: (425) 643 - 9866 Fax (425) 643 - 9954 Email: seabird@seabird.com

SENSOR SERIAL NUMBER: 2700
CALIBRATION DATE: 28-Dec-99

SBE3 TEMPERATURE CALIBRATION DATA
IPTS-90 TEMPERATURE SCALE

ITS-90 COEFFICIENTS

g = 4.36260004e-003
h = 6.49083037e-004
i = 2.42497805e-005
j = 2.36365545e-006
f0 = 1000.0

Coefficients from *28-Dec-99* calibration.

ITS-68 COEFFICIENTS

a = 3.67991178e-003
b = 6.04738390e-004
c = 1.65374250e-005
d = 2.36525963e-006
f0 = 2978.914

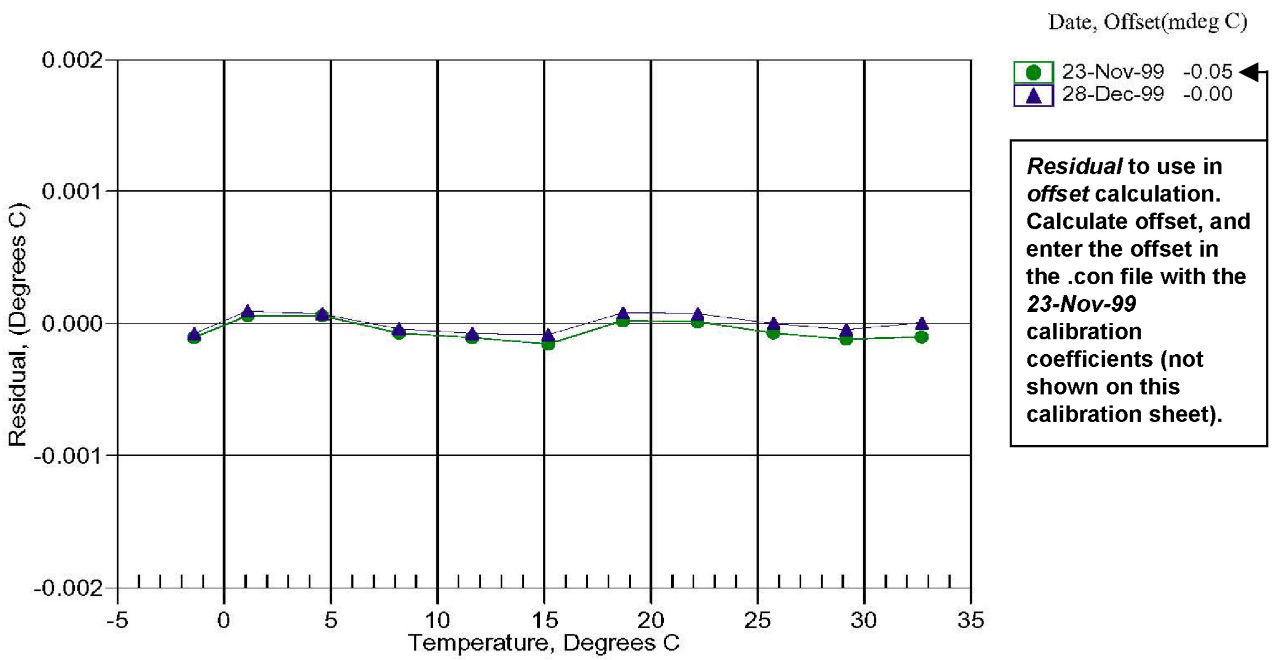
BATH TEMP (ITS-90)	INSTRUMENT FREQ (Hz)	INST TEMP (ITS-90)	RESIDUAL (ITS-90)
-1.4039	2978.914	-1.4040	-0.00008
1.1062	3149.847	1.1063	0.00009
4.5979	3399.248	4.5980	0.00007
8.1955	3670.718	8.1954	-0.00004
11.6295	3943.970	11.6295	-0.00007
15.1862	4241.874	15.1861	-0.00009
18.6903	4550.560	18.6904	0.00008
22.1892	4874.139	22.1893	0.00007
25.7491	5219.423	25.7491	-0.00000
29.1638	5566.173	29.1637	-0.00005
32.6970	5941.274	32.6970	0.00001

Temperature ITS-90 = $1/\{g + h[ln(f_0/f)] + i[ln^2(f_0/f)] + j[ln^3(f_0/f)]\} - 273.15$ (°C)

Temperature IPTS-68 = $1/\{a + b[ln(f_0/f)] + c[ln^2(f_0/f)] + d[ln^3(f_0/f)]\} - 273.15$ (°C)

Following the recommendation of JPOTS: T_{68} is assumed to be 1.00024 * T_{90} (-2 to 35 °C)

Residual = instrument temperature - bath temperature



Sea-Bird Electronics, Inc.
13431 NE 20th Street
Bellevue, WA 98005
USA

Phone: (425) 643-9866
Fax: (425) 643-9954
E-mail: seabird@seabird.com
Web: www.seabird.com

APPLICATION NOTE NO. 67 — October 2001

Editing Sea-Bird .hex Data Files

After acquiring real-time .hex data or uploading .hex data from CTD memory, users sometimes want to edit the header to add or change explanatory notes about the cast. Some text editing programs modify the file in ways that are not visible to the user (such as adding or removing carriage returns and line feeds), but that corrupt the format and prevent further processing by SEASOFT (both DOS and Windows versions). **This Application Note provides details on one way to edit a .hex data file with a text editor while retaining the required format.** The procedure described below has been found to work correctly on computers running Win 98, Win 2000, and Win NT. If the editing is not performed using this technique, SEASOFT may reject the data file and give you an error message.

1. Make a back-up copy of your .hex data file before you begin.

2. Run **WordPad**.

3. In the File menu, select Open. The Open dialog box appears. For *Files of type*, select *All Documents (*.*)*. Browse to the desired .hex data file and click Open.

4. Edit the file as desired, **inserting any new header lines after the System Upload Time line**. Note that all header lines must begin with an asterisk (*), and *END* indicates the end of the header. An example is shown below, with the added lines in bold:

```
* Sea-Bird SBE 21 Data File:
* FileName = C:\Odis\SAT2-ODIS\oct14-19\oc15_99.hex
* Software Version Seasave Win32 v1.10
* Temperature SN = 2366
* Conductivity SN = 2366
* System UpLoad Time = Oct 15 1999  10:57:19
* Testing adding header lines
* Must start with an asterisk
* Can be placed anywhere between System Upload Time and END of header
* NMEA Latitude = 30 59.70 N
* NMEA Longitude = 081 37.93 W
* NMEA UTC (Time) = Oct 15 1999  10:57:19
* Store Lat/Lon Data = Append to Every Scan and Append to .NAV File When <Ctrl F7> is Pressed
** Ship:      Sea-Bird
** Cruise:    Sea-Bird Header Test
** Station:
** Latitude:
** Longitude:
*END*
```

5. In the File menu, select Save (**not** Save As). If you are running Windows 2000, the following message displays:
   You are about to save the document in a Text-Only format, which will remove all formatting. Are you sure you want to do this?
   Ignore the message and click *Yes*.

6. In the File menu, select Exit.

NOTE: This Application Note **does not apply to .dat data files**. Sea-Bird is not aware of a technique for editing a .dat file that will not corrupt the file.