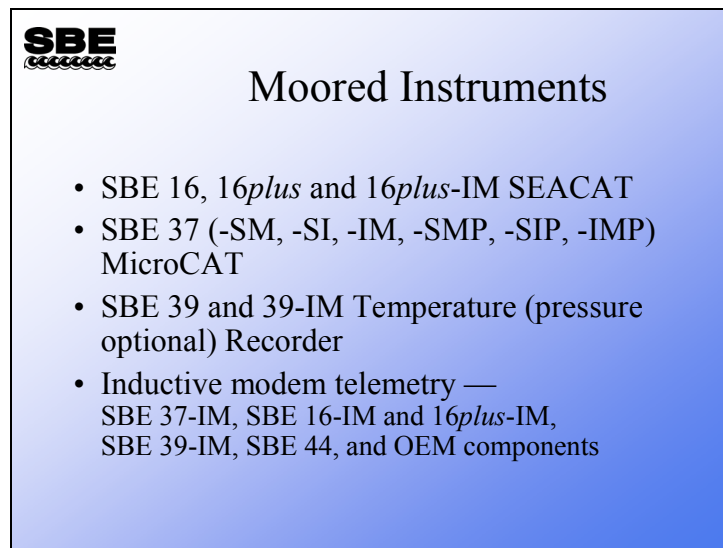


Module 10

Moored Instruments

Overview



The slide features the SBE logo in the top left corner. The title "Moored Instruments" is centered at the top. Below the title is a bulleted list of instrument models and their capabilities.

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Moored Instruments

- SBE 16, 16*plus* and 16*plus*-IM SEACAT
- SBE 37 (-SM, -SI, -IM, -SMP, -SIP, -IMP) MicroCAT
- SBE 39 and 39-IM Temperature (pressure optional) Recorder
- Inductive modem telemetry —
SBE 37-IM, SBE 16-IM and 16*plus*-IM,
SBE 39-IM, SBE 44, and OEM components

In this module we will present Sea-Bird instrumentation intended for mooring.

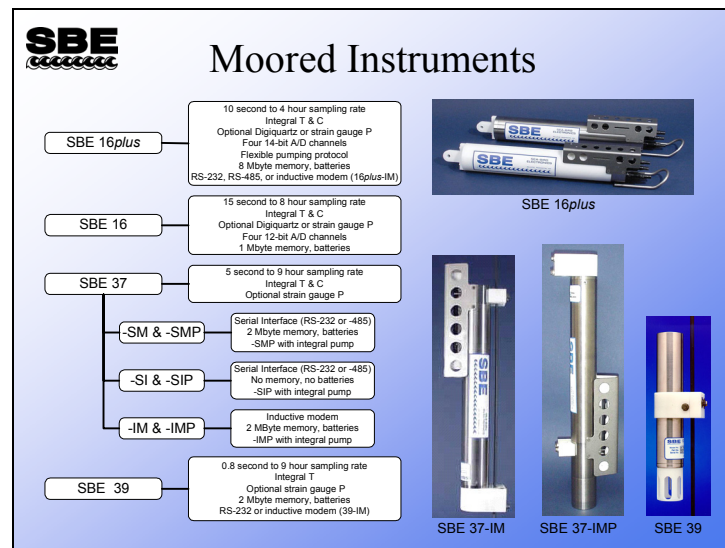
The SBE 16 family provides power and A/D inputs for auxiliary sensors.

The MicroCAT family is smaller and less expensive, but does not have power for external sensors nor auxiliary A/D inputs, while the SBE 39 family has only temperature and pressure. As an accessory to our moored instruments, Sea-Bird offers inductive telemetry for mooring. This technology allows communication with moored instruments in real-time without cable breakouts. The SBE 44 is a stand-alone modem meant for interfacing other manufacturer's instrumentation to the inductive mooring string.

When we complete this module you should:

- Be aware of the instrument platforms available for moored applications
- Understand the means of telemetering real-time data from the mooring to the land-based receiving station

Introduction to SBE 16, 16*plus*, 37, and 39



The SBE 16 and 16*plus* are moored versions of the SBE 19 and 19*plus*. The 16*plus* is actually a 19*plus* in moored mode, with optional pressure sensor. The 16 and 16*plus* have the capability to power external sensors and log analog A/D data from them. This is the instrument of choice if you require more data than C, T, and P. The 16*plus* is available with serial interface (RS-232 or RS-485) or inductive modem interface (16*plus*-IM).

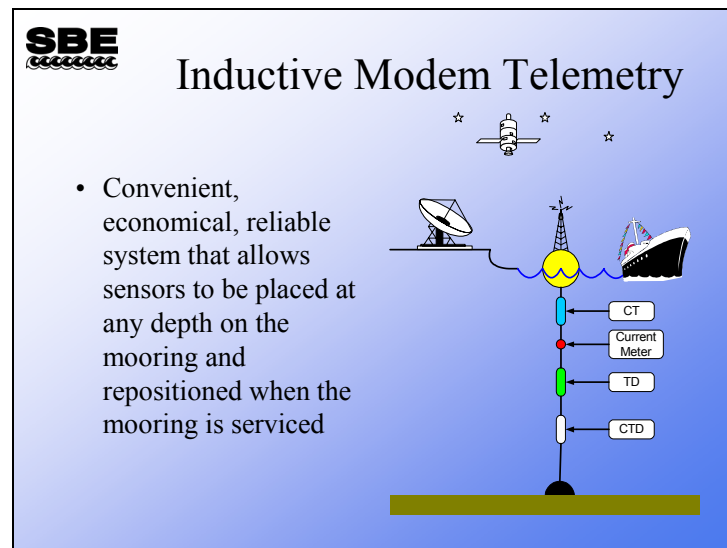
Like the 16 and 16*plus*, the MicroCAT has integral T and C sensors, and may also be equipped with a pressure sensor. The MicroCAT comes in three main types:

- The SM has memory, batteries, and a serial interface (RS-232 or RS-485). It is meant for moorings that do not require communication with the surface during deployment.
- The SI has no memory and no batteries, but does have a serial interface (RS-232 or RS-485). It is intended for ROVs, submarines, etc. as a companion for instruments requiring T and C, such as acoustic Doppler profilers or optical instruments.
- The IM has memory, batteries, and an inductive modem for communications in real-time with the surface.

All three types of MicroCAT are available with an integral pump (SMP, SIP, and IMP).

The SBE 39 is a temperature recorder, and may also be equipped with a pressure sensor. An example of its use is mounted on bottom trawls to measure bottom depth, time on bottom, and temperature. The SBE 39 is available with serial interface (RS-232) or inductive modem interface (39-IM).

Inductive Modem Telemetry

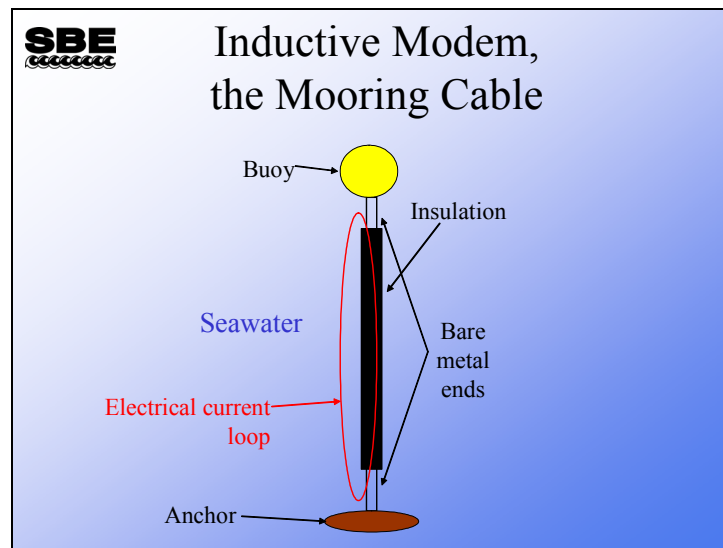


An inductive modem uses electrical current loops to transmit information. Recall from physics class, electrical current flowing in a wire loop induces current to flow in a loop that passes through it. You can think of these loops as links in a chain. The first loop is in the surface buoy. The second loop is formed by the mooring cable and the seawater. The third loop is at the instrument, underwater. Because all coupling is done in loops, no cable breakouts are required.

The communications link is one way only, meaning that if the surface modem is transmitting to the remote instruments, then the remote instruments must all be listening. Conversely, if one of the remote instruments is transmitting, then the surface modem must be listening. To achieve this, all instruments have a unique two-digit address from 00 to 99.

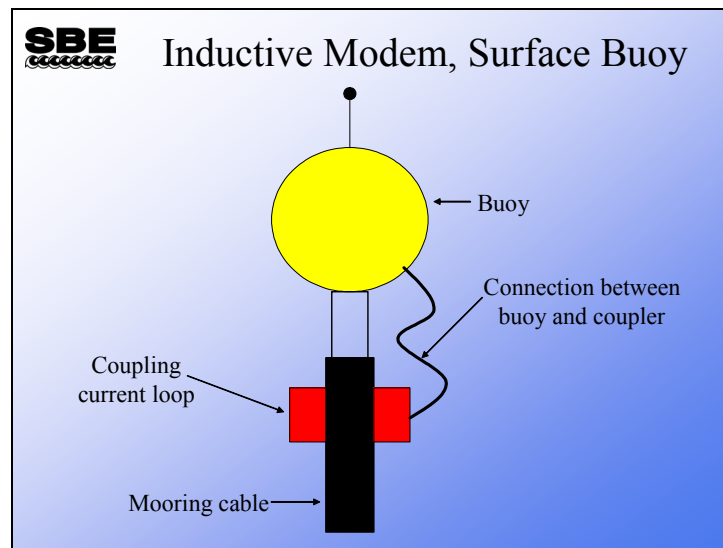
The electrical current carries an AC signal that is phase-shift-keyed. Digital data is encoded by the transmitting modem into an AC signal that is impressed on the current loop, and it is received and decoded by the remote modem's receiver.

Inductive Modem Telemetry (*continued*)



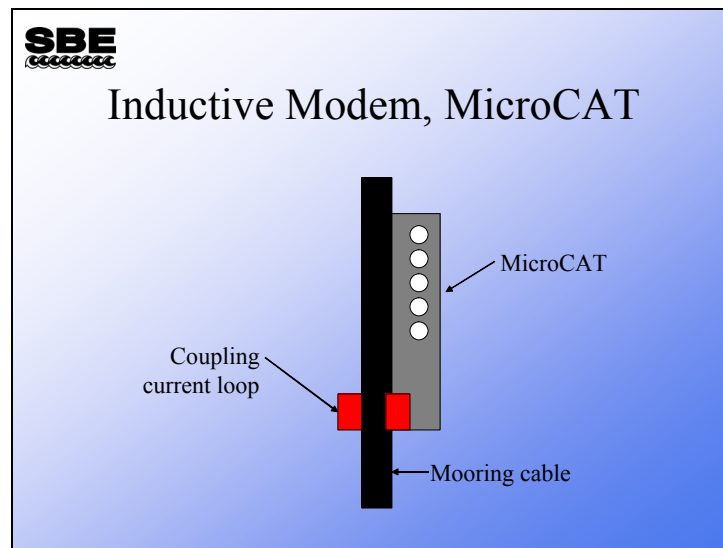
The first current loop is made by the mooring cable itself and seawater. The cable is bare metal on the top and bottom and insulated in the middle.

Inductive Modem Telemetry (*continued*)



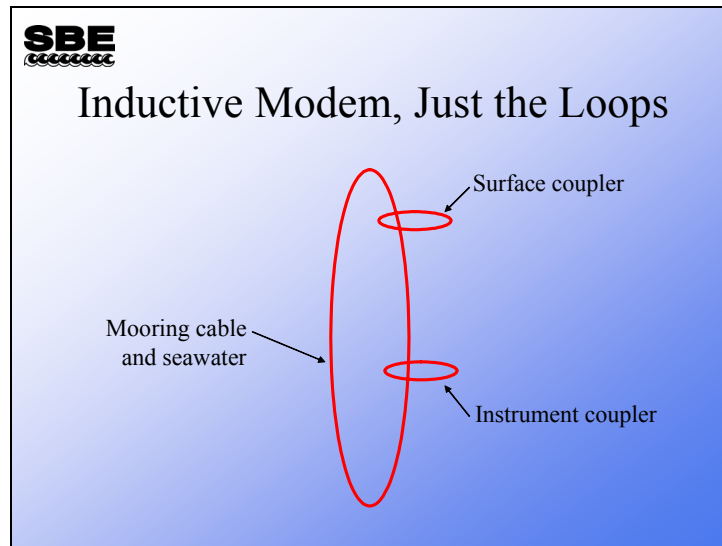
The second current loop is made around the mooring cable. The coupler is a ferrite donut. Ferrite is the stuff that magnetic tape is made from. The electrical current that flows around the coupler induces a current that flows through the mooring cable and the seawater. Thus, the modem signal is transmitted by the surface buoy into its coupler, and the coupler induces a current in the seawater and mooring cable.

Inductive Modem Telemetry (*continued*)



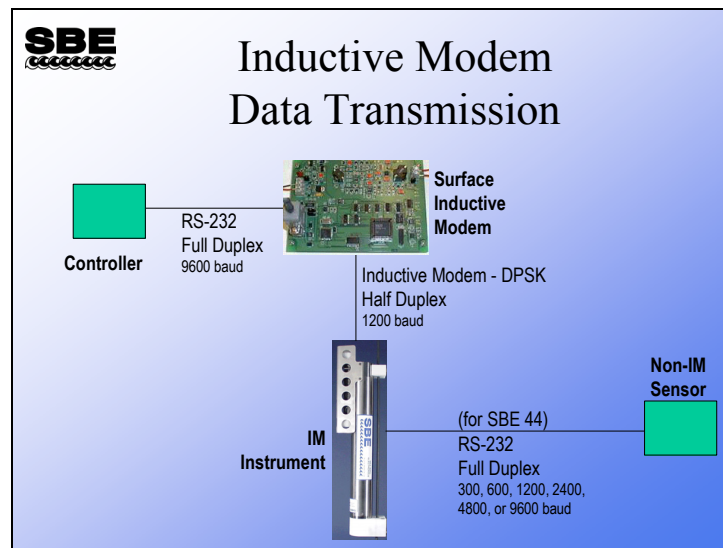
The last loop is at the remote instrument. It has a coupler just like the surface buoy. The current that the surface buoy has induced in the seawater mooring cable loop in turn induces a current in the remote instrument's coupler. The modem in the remote instrument receives and decodes the signal. If the information contained in the signal is addressed to the remote instrument it behaves accordingly, e.g., transmitting a data scan or a status report.

Inductive Modem Telemetry (*continued*)



Here is a very simple view of the communication links. Note that there can be up to 100 instrument couplers on the mooring cable – seawater loop.

Inductive Modem Telemetry (*continued*)




Here are all the players in inductive modem data transmission. The controller is user-supplied and should be able to switch power to the surface inductive modem (SIM). The inductive modem DPSK is via the mooring cable. If you want to use sensors with serial data output made by another manufacturer, the SBE 44 is a stand-alone inductive modem supporting common baud rates with buffering sufficient for most applications.

Inductive Modem Instruments

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Inductive Modem Instruments — SBE 44

- IM interface to serial (RS-232) instruments:
 - Serial instrument samples at pre-programmed intervals, stores data in its memory (sends data through UIM on request)
 - Serial instrument samples on command, sends data through UIM (can synchronize with other instruments)
- Depths to 7000 m, real-time clock, buffer memory, battery-powered



The SBE 44 is meant to allow the use of instruments that have a serial interface and the capability to sample on demand to be used with an inductive telemetry mooring. The SBE 44 has an internal 9 volt, 7.2 amp-hour battery and can provide power to the external device. Alternatively, the external device can provide power to the 44. The inductive link operates at 1200 baud. This restricts the data rate of the external instrument; however the SBE 44 has data buffers that allow the external instrument to transmit small amounts of data at a higher rate.


Inductive Modem Instruments (*continued*)



Inductive Modem Instruments — OEM Components

- Sea-Bird can supply components to convert serial-output instruments to IM operation
 - Underwater inductive modem PCBs
 - Require supply voltage 7 - 16 volts, compatible with typical battery packs in ocean instruments
 - Interface: RS-232 full-duplex (bi-directional), 9600 baud standard
 - Split toroid core and transformer winding

Memory Capacity



Memory Capacity in Scans

- Standard memory size is:
 - 1 Mbyte for SBE 16
 - 8 Mbytes for SBE 16*plus*
 - 2 Mbytes for SBE 37
 - 4 Mbytes for SBE 39

$$\text{Memory Capacity In Scans} = \frac{\text{Memory available} - \text{Scratch Pad}}{\text{Bytes per Scan}}$$

- Scan length examples are shown in following slides

Memory capacity calculations are basically the same as seen for profiling instruments. Refer to Module 1, page 9 for an overview of this calculation; examples for specific instruments are on the following pages.

Memory Capacity: SBE 16

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SBE 16 Memory Capacity


- 1024 Kb memory standard, including 5308 byte scratch pad
- Scan length as follows:

<u>Recorded Parameter</u>	<u>Bytes/sample</u>
T + C	4 (2 each)
strain gauge P	2
Quartz P without T compensation	3
Quartz P with T compensation	5
each external voltage	1.5

Example: strain gauge P, no auxiliary sensors
T & C = 4 bytes, strain gauge P = 2 bytes
Storage space $\approx (1,048,576 - 5308) / (4 + 2) \approx 173,878$ samples

The SBE 16 has battery backed-up semiconductor memory of 1 Mbyte. Actual capacity in scans depends on how the instrument is configured.

Memory Capacity: SBE 16*plus*



SBE 16*plus*

Memory Capacity

- 8 Mb memory standard
- Scan length as follows:

<u>Recorded Parameter</u>	<u>Bytes/sample</u>
T + C	6 (3 each)
strain gauge P	5
Quartz P with T compensation	6
each external voltage	2
SBE 38 secondary T	3
date and time	4

Example: strain gauge P, no auxiliary sensors

T & C = 6 bytes, strain gauge P = 5 bytes, date & time = 4 bytes

Storage space $\approx 8,000,000 / (6 + 5 + 4) \approx 533,000$ samples

The SBE 16*plus* has considerably more memory than the 16, with 8 Mbytes of non-volatile flash memory. Again, memory capacity depends on the configuration of the instrument.

Memory Capacity: SBE 37 MicroCAT



SBE 37 (-SM, -SMP, -IM, -IMP) MicroCAT Memory Capacity

- 2048 Kb memory standard
- Scan length —

T + C: 5 (2.5 each) bytes/sample

P: 2 bytes/sample


date and time: 4 bytes/sample

Example: instrument includes P, store date and time

T & C = 5 bytes, P = 2 bytes, date & time = 4 bytes

Storage space $\approx 2,048,000 / (5 + 2 + 4) \approx 185,000$ samples

Memory Capacity: SBE 39




SBE 39 Memory Capacity

- 4 Mb memory standard
- Scan length —
 - T: 3 bytes/sample
 - P: 2 bytes/sample
 - date and time: 4 bytes/sample

Example: instrument includes P, store date and time
T = 3 bytes, P = 2 bytes, date & time = 4 bytes
Storage space $\approx 4,000,000 / (3 + 2 + 4) \approx 440,000$ samples

Battery Endurance



Battery Endurance Terminology


- Battery capacity is given in amp-hours
 - For a 14 amp-hour battery, you can get 14 amps for 1 hour or 1 amp for 14 hours
- Instrument operating current is the electrical current that the instrument and all the auxiliary sensors and pump require
- Quiescent current is the current that the instrument consumes while it is asleep
- Calculate battery endurance by converting capacity to amp-seconds and dividing by instrument's current consumption in amp-seconds/hour

Battery endurance is a topic of great interest to those who work with moored instruments. However, estimating battery endurance is a very difficult to do accurately. Battery manufacturers specify the amount of energy contained in a battery in terms of ampere hours. This is the amount of current that the battery can supply for a given length of time. If a small amount of current, 100 milliamps for example, is drawn from the battery, it will last many hours (years). Conversely if a large current is drawn, 1 amp for example, the battery will last for few hours.

Calculating battery endurance requires summing the amount of current drawn by the instrument and its auxiliary sensors for the length of time they are operating. In addition, the quiescent current of the main instrument must be included. The quiescent current is that drawn by the instrument while it is sleeping, and is required for operation of the clock and the circuits that monitor the communications lines, so that when you attempt to communicate with the instrument it awakens and responds.

For instruments that use alkaline batteries, Sea-Bird uses Duracell brand alkaline batteries exclusively; all our examples for alkaline batteries will be based on these.

Battery Capacity by Instrument



Battery Capacity by Instrument

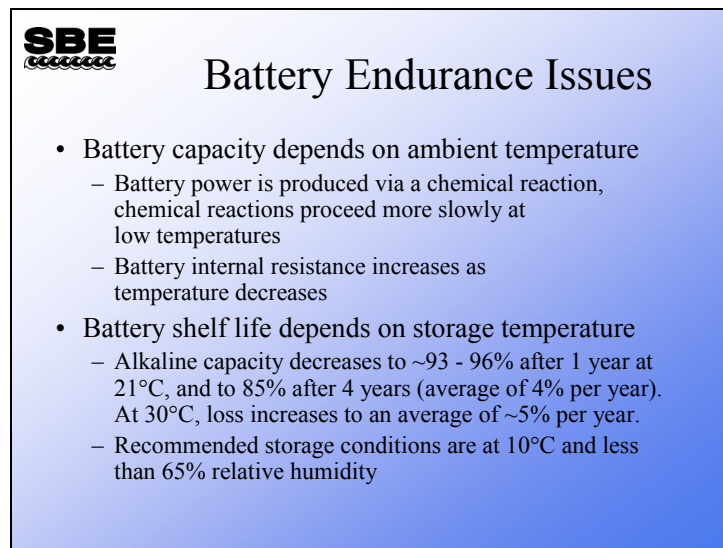
- SBE 16*plus* and SBE 16
 - Alkaline batteries in 9- or 12-cell instrument housing (12-cell not available for 16*plus*) ... more cells give higher operating voltage
 - Nominal 14 amp-hour capacity de-rated to 12.2 without pump or auxiliary sensors, 10.5 with pump and auxiliary sensors
- SBE 37 (-SM, -SMP, -IM, and -IMP)
 - Lithium batteries with nominal 7.2 amp-hours, de-rated to 5 amp-hours for planning purposes
- SBE 39
 - Lithium 9V nominal capacity is 1.2 amp-hours, de-rated to 1.1
 - Alkaline nominal capacity is 0.4 amp-hours, de-rated to 0.3
- SBE 39-IM
 - Lithium AA batteries with nominal 2.25 Amp-hours, de-rated to 2.0
- SBE 44
 - Lithium batteries with nominal 7.2 amp-hours, de-rated to 5.0

Sea-Bird offers different types of batteries depending on the type of instrument.

- The SBE 16*plus* is normally supplied with alkaline batteries; however a lithium battery pack *kit* may be supplied at the user's request (these lithium batteries are not supplied by Sea-Bird).
- The SBE 37 and 44 come with lithium batteries only.
- The end user may choose lithium or alkaline batteries for the SBE 39.
- The SBE 39-IM comes with AA lithium batteries only.

Note: A few early versions of the 39-IM used the same batteries as the SBE 39.

Battery Endurance Issues



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Battery Endurance Issues

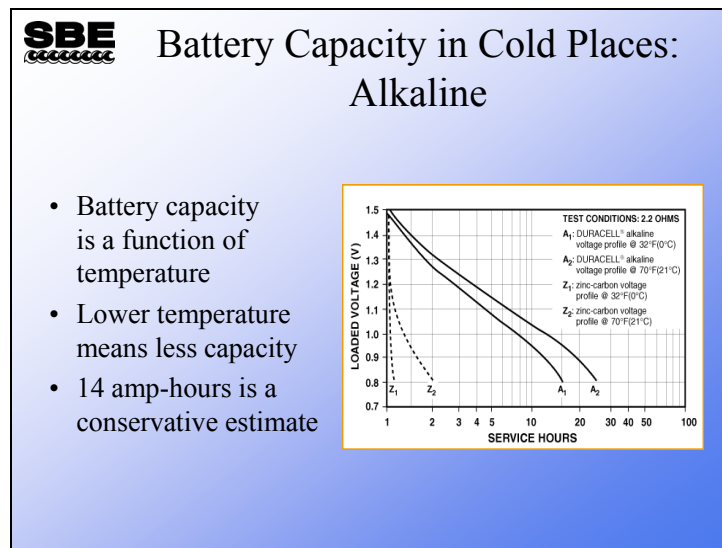
- Battery capacity depends on ambient temperature
 - Battery power is produced via a chemical reaction, chemical reactions proceed more slowly at low temperatures
 - Battery internal resistance increases as temperature decreases
- Battery shelf life depends on storage temperature
 - Alkaline capacity decreases to ~93 - 96% after 1 year at 21°C, and to 85% after 4 years (average of 4% per year). At 30°C, loss increases to an average of ~5% per year.
 - Recommended storage conditions are at 10°C and less than 65% relative humidity

As mentioned in a previous page, battery endurance is very difficult to estimate. Battery capacity depends on the temperature of their use for the reasons outlined in the slide above. In addition, batteries exhibit shelf life degradation. A battery in storage will slowly discharge at a rate that leaves about 85% capacity after 4 years in good storage conditions. Batteries stored at high temperatures will lose capacity more rapidly.

Obviously, a fresh battery has the most capacity.

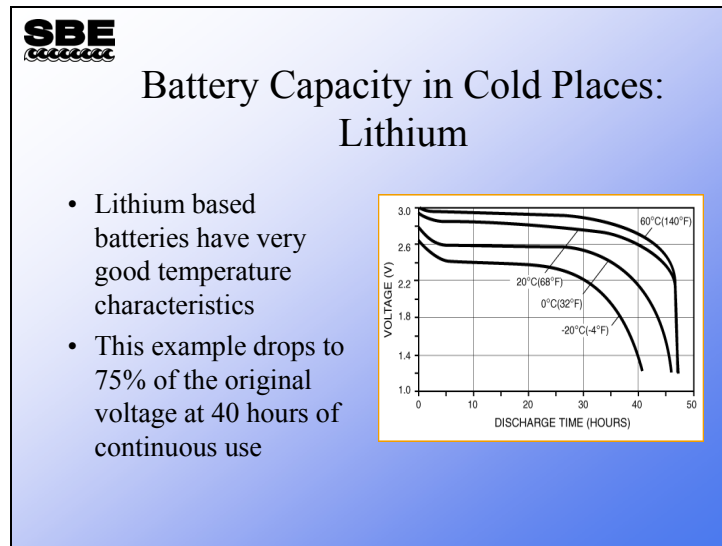
- A battery operated at high temperature will gain capacity due to a faster chemical reaction and lower internal resistance, but will lose capacity due to more rapid shelf life degradation.
- Conversely, a battery operated at low temperature will gain from better shelf life but lose due to less efficient chemical reaction and higher internal resistance.

Battery Endurance: Alkaline Battery Capacity




Considering the time and money involved in making a mooring, fresh batteries are a small expense. We estimate the battery life in an SBE 16 or 16*plus* assuming that it begins with 14 amp-hours of power. As you see from the plot, 14 amp-hours is a conservative estimate. At 0 °C an alkaline battery is expected to supply 0.8 volts after 15 hours of service. A standard, 9-cell battery pack starts at 13.5 volts and drops to 7.2 volts after 15 hours. Sea-Bird instruments measure the battery voltage and will not sample if the voltage is below a cut-off threshold. The value of 7.2 volts is above the cut-off for an SBE 16 and just below it for a 16*plus*.

Battery Endurance: Lithium Battery Capacity



Lithium batteries offer better performance. The main drawback to using them is international shipping restrictions on lithium. For example, the battery pack used by the SBE 37 is made of 6 batteries. It is legal to ship them separately; however, once assembled into the battery pack they become illegal to ship, as they are too large a mass.

Battery Endurance: SBE 16



SBE 16 Battery Endurance

- 9 alkaline batteries — de-rated to 12.2 Amp Hours
- Sampling time 4 seconds
- Current consumption —

Sampling (no auxiliary sensors):	130 mA (with Digiquartz P)
Quiescent:	50 μ A

Example: Sample every 10 minutes, no pump or auxiliary sensors

Sampling current = 130 mA * 4 seconds = 0.520 amp-seconds
 In 1 hour 0.520 amp-seconds * 6 samples = 3.12 amp-seconds/hour

Quiescent current = 0.05 mA * 3600 seconds/hour = 0.180 amp-seconds/hour

Total current = 3.12 + 0.180 = 3.3 amp-seconds/hour
 Capacity = (12.2 amp-hours * 3600 seconds/hour) / 3.3 amp-seconds/hour
 Capacity = 13,309 hours = 554 days = 1.5 years

Recall the slide on memory endurance for the SBE 16. We can calculate that we have memory for 115,918 samples if measuring temperature, conductivity, and Digiquartz pressure, with no auxiliary sensors ($115,918 = [1,048,576 - 5308] / [4 + 5]$). This is enough memory for 19,319 hours of operation if sampling every 10 minutes. We will run out of battery power before we run out of memory.

Battery Endurance: SBE 16plus

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SBE 16plus Battery Endurance

- 9 alkaline batteries — de-rated to 10.5 amp hours
- Deployed with 5M pump (on for 0.5 seconds/sample), no pressure sensor, no auxiliary sensors, sample every 10 minutes
- Sampling time is 2.2 seconds plus pump time
 - Sampling current consumption = $50 \text{ mA} * (2.2 \text{ sec} + 0.5 \text{ sec})$
= 0.135 amp-sec/sample
In 1 hour, sampling consumption = $6 * 0.135 \text{ amp-seconds}$
= 0.81 amp-sec/hour
 - Pump current consumption = $100 \text{ mA} * 0.5 \text{ sec} = 0.05 \text{ amp-sec/sample}$
In 1 hour, pump consumption = $6 * 0.05 = 0.30 \text{ amp-sec/hour}$
 - Quiescent current consumption = $0.03 \text{ mA} * 3600 \text{ sec/hour}$
= 0.108 amp-sec/hour
 - Total current consumption = $0.81 + 0.30 + 0.108 = 1.22 \text{ amp-sec/hour}$
 - Capacity = $(10.5 \text{ amp-hours} * 3600 \text{ sec/hour}) / (1.22 \text{ amp-sec/hour})$
= 30983 hours = 1290 days = 3.5 years
But, we recommend not counting on more than 2 years!

Recall the slide on memory endurance for the SBE 16plus. We can calculate that we have memory for 800,000 samples if measuring and storing only temperature, conductivity, date and time ($800,000 = 8,000,000 / [6 + 4]$). However, we have battery power for only 185,000 samples ($\approx 30983 \text{ hours} * 6 \text{ samples/hour}$). As with the SBE 16, we are battery-limited.

Note that battery capacity depends on operating temperature; capacity is reduced as battery temperature goes down. With profiling applications, an instrument may spend part of its time in cold water. In moored applications it is not unusual for an instrument to spend its entire deployment in cold water.

Battery Endurance: SBE 37 MicroCAT




SBE 37-IM MicroCAT Battery Endurance

- Six 9-volt lithium batteries, de-rated to 5 amp-hours
- 10 Inductive modem MicroCATs with pressure sensors deployed to sample every 10 minutes and be queried every hour
- Sampling time is 3 seconds
 - Sampling current consumption = $30 \text{ mA} * 3 \text{ seconds} = 0.09 \text{ amp-sec/sample}$
In 1 hour, sampling consumption = $0.09 * 6 = 0.54 \text{ amp-sec/hour}$
 - Communications current consumption/query = $5 \text{ mA} * 0.5 \text{ sec/MicroCAT} * 10 \text{ MicroCATs} = 0.025 \text{ amp-sec/hour}$
 - Quiescent current consumption = $0.1 \text{ mA} * 3600 \text{ sec/hour} = 0.36 \text{ amp-sec/hour}$
 - Total current consumption = $0.54 + 0.025 + 0.36 = 0.925 \text{ amp-seconds/hour}$
 - Capacity = $(5 \text{ amp-hours} * 3600 \text{ sec/hour}) / 0.925 \text{ amp-sec/hour} = 19459 \text{ hours} = 810 \text{ days} = 2.2 \text{ years}$

As we have come to expect, the MicroCAT has more memory than batteries.

Battery Endurance: SBE 39



SBE 39 Battery Endurance

- SBE 39 with pressure sensor, samples every 5 minutes
 - Sampling current consumption = 0.023 amp-sec/sample
In 1 hour, sampling consumption = $12 * 0.023 = 0.276$ amp-sec/hour
 - Quiescent current consumption = $0.01 \text{ mA} * 3600 \text{ sec/hour} = 0.036$ amp-sec/hour
 - Total current consumption = $0.276 + 0.036 = 0.312$ amp-sec/hour
- Lithium battery capacity =
 $(1.1 \text{ amp-hours} * 3600 \text{ sec/hour}) / 0.312 \text{ amp-sec/hour} = 12692$ hours
= 528 days = 1.45 years
- Alkaline battery capacity =
 $(0.3 \text{ amp-hours} * 3600 \text{ sec/hour}) / 0.312 \text{ amp-sec/hour} = 3461$ hours
= 144 days

Sea-Bird provides a battery endurance calculator, SBE Battery Budget Calculator, which can perform these calculations for our moored instruments. The calculator, an Excel spreadsheet, is available on the training CD as well as on our website.

Activity



Activity: Calculate Battery Endurance

- 37- SM MicroCAT with pressure sensor samples every 10 minutes
 - 2.7 seconds sample time
 - 20 mA sampling current
 - 0.01 mA quiescent current