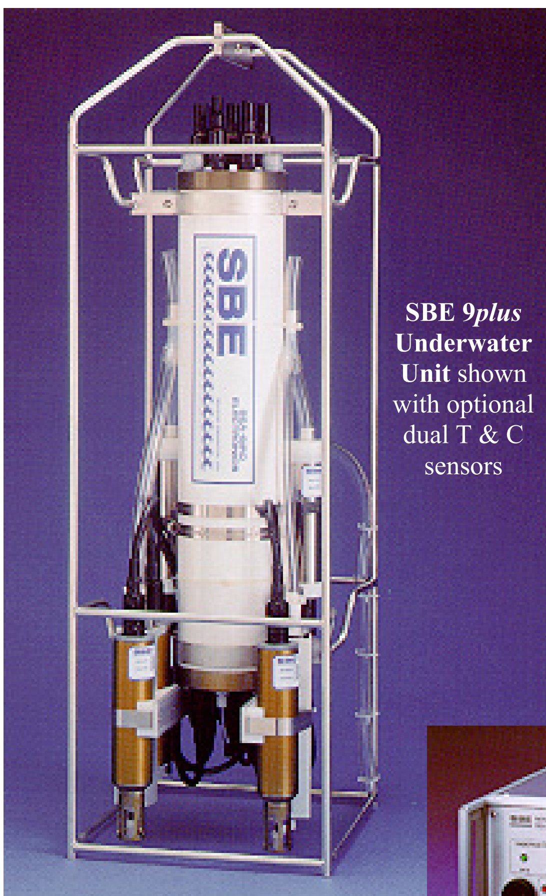
SBE 911*plus* CTD

Sea-Bird's ***911plus CTD*** is *the* primary oceanographic research tool chosen by the world's leading institutions.

SBE 9*plus* underwater unit mounted to Carousel Photo by S. Compoint / Sygma



SBE 9*plus* Underwater Unit shown with optional dual T & C sensors

FEATURES

- Accurate and stable, modular T & C sensors
- Paroscientific Digiquartz® pressure sensor
- *TC-Ducted Flow* and pump-controlled time responses to minimize salinity spiking
- 24 Hz all-channel scan rate
- Depth capability 6800 or 10500 meters
- Built-in interface for dual C & T sensors (sensors optional)
- 8 A/D channels and high power capability for auxiliary sensors
- Modem channel for real-time water sampler control (without data interruption)
- Built-in NMEA 0183 interface to merge real-time GPS data with the CTD data
- Optional Serial Data Uplink allows 9600 baud data pass-thru on shared CTD telemetry channel
- Optional SBE 17*plus* V2 SEARAM module for *in-situ* recording and programmable Carousel bottle firing
- Powerful Windows software included

SBE 11*plus* V2 Deck Unit

SYSTEM ENGINEERED - PERFORMANCE PROVEN - TIME TESTED

System Engineering and the Fundamental Principles of CTD Accuracy

The SBE 911*plus* CTD produces profiles of ocean temperature, salinity, and density at the highest possible absolute accuracy, because its performance under both static and dynamic conditions has been optimized. Static accuracy (as demonstrated in an equilibrated calibration bath) ensures that the deep-ocean readings will be correct and allows meaningful comparison of results obtained by different researchers at different times and places. Dynamic accuracy is necessary to present water column features in clear detail, and is *critical* for maintaining absolute accuracy under oceanic (non-equilibrated) conditions. This is because salinity, density, and other oceanographic variables are calculated from separate measurements of pressure, temperature, and conductivity. If the calculated values are to be correct, the separate measurements must be made at the same time and on the same sample of water.

Time response and spatial mismatches not only create *spiking*, but also produce bias errors that are indistinguishable from static errors because they cannot be *averaged out*. For example, if the temperature sensor responds slowly, averaging its readings through a temperature gradient will produce a bias error of sign opposite to the gradient. Similarly, the spiking caused by a mismatch in time-response of the temperature and conductivity sensors will bias the results unless the correct time lag is applied in post-processing. Corrections are possible in practice only if the sensor time responses are constant, a condition that cannot be met by free-flushing (unpumped) conductivity sensors. The time responses of free-flushing sensors are inevitably affected by the influence of ship-coupled motion on profiling speed.

To obtain the *highest possible absolute accuracy*, the SBE 911*plus* CTD incorporates certain key features:

- A single temperature sensor that is both accurate and fast
- A conductivity sensor with a totally internal field that is immune to proximity effects
- Constant (pumped) flow, providing constant time responses in T and C
- A *TC Duct* to ensure that the temperature and conductivity sensors measure the same water
- A dramatically superior quartz pressure sensor
- Modular sensors that can be separately calibrated
- Acquisition electronics free of significant error

The temperature accuracy that can be achieved under controlled laboratory conditions with an **S**PRT (**S**tandards-grade Platinum Resistance Thermometer) cannot be obtained in the ocean with the industrial-grade PRTs used in competing CTD instruments. The 911*plus* thermistor sensor's better ocean accuracy derives from its 10 times higher sensitivity and 100 times higher absolute resistance (at the ice-point, the thermistor resistance changes by about 1 ohm/mK while the resistance of a PRT changes by about 0.001 ohm/mK), its inherently fast response that eliminates the need for *fast* and *slow* sensor combinations (and the errors that arise when merging data from separate sensors), and because it is not measurably affected by shock and vibration.

Sea-Bird's conductivity cell designs reflect our recognition that the primary causes of conductivity errors are mineral and biological deposits on the sensor, proximity affects arising from external fields, and uncontrolled time-responses. Deposits occur with all conductivity sensor designs (they are more serious with sensors that are smaller than Sea-Bird's) and can be minimized by periodic detergent and bleach cleaning of the cell. The four-electrode and inductive-cell types used on competing CTDs have significant external fields that often completely preclude high-accuracy laboratory calibration and that lead to in-situ proximity errors induced by guards, mounting brackets, and other nearby sensors. Sea-Bird's totally internal field conductivity cell eliminates proximity errors, permits constant-flow pumping to control time response, and is connected to the temperature sensor by the *TC Duct* to ensure that the measurements of T and C are made on *exactly* the same water.

The highest possible pressure accuracy is obtained by using the Paroscientific Digiquartz® pressure sensor. The inexpensive pressure sensors used in other CTD systems have excessive hysteresis and thermal transient errors, requiring costly sensor-specific characterization and tedious postprocessing. Sea-Bird's choice of a costly, but dramatically superior, pressure sensor eliminates most of these errors before they get into the data set. Careful shock mounting of the Digiquartz has resulted in negligible failure rates.

The SBE 911*plus'* modular sensors can be calibrated in well-insulated temperature/salinity baths that have smaller gradients and better accuracy than baths built to accommodate (and absorb the heat produced by) an integrated CTD. Unlike some competing sensor designs where trim pots are adjusted and drift history is lost each time a calibration is performed, the Sea-Bird calibrations are preserved as sets of numerical coefficients. As a result, all calibrations of Sea-Bird sensors can be intercompared and a complete drift history established (Sea-Bird maintains such histories - some of them spanning more than 20 years - on thousands of sensors). The information in these histories continues to play an important role in Sea-Bird's ongoing improvements to its sensor designs.

The SBE 911*plus* sensors can be calibrated separately without significant loss of overall CTD accuracy because the SBE 9*plus* digitizes the temperature, conductivity, and pressure sensor output signals by frequency counting, an inherently binary process whereby a count either registers or does not. Cable resistance, connector properties, and noise cannot degrade the overall system acquisition accuracy, which is limited only by the stability of a quartz master clock. Errors attributable to this clock are demonstrably negligible.

While competing designs offer elegant solutions to *part* of the CTD measurement problem, we have carefully balanced the engineering trade-offs to get better *overall results*. The SBE 911*plus* has the ability -- under conditions of rapidly changing temperature and immense pressure loading -- to obtain the independent measurements precisely coordinated in space and time that are the essence of CTD accuracy. Its design is a synthesis of ideas based upon a thorough understanding of the marine environment, the operational requirements of oceanographers, and the fundamental principles affecting CTD accuracy. *System Engineering* has made the 911*plus* CTD the *World's Most Accurate CTD*.

How the SBE 911*plus* CTD Works

Sensor Operation: The **temperature sensor** (SBE 3*plus*) is a compact module containing a pressure-protected, high-speed thermistor and *Wien-bridge-oscillator* interface electronics. The thermistor is the variable element in the Wien bridge, while a precision Vishay resistor and two ultra-stable capacitors form the fixed components. The **conductivity sensor** (SBE 4C) is similar in operation and configuration to the temperature sensor, except that the Wien-bridge *variable element* is the cell resistance (cell resistance is the reciprocal of cell conductivity). The Digiquartz® **pressure sensor** also provides a variable frequency output. Embedded in the pressure sensor is a semiconductor temperature sensor used to compensate the small ambient temperature sensitivity of the Digiquartz. The calibration information for each sensor (C, T, and P) is contained in a series of numeric coefficients used in equations relating frequency to the measured parameter.

System Operation: The SBE 11*plus* V2 Deck Unit provides power to the sea cable, decodes the data arriving from the underwater unit, and interfaces to a computer via RS-232 or IEEE-488. Push buttons and status lights for SBE 32 Carousel Water Sampler operation are provided, and there are connections for back-up data recording and playback using an audio tape recorder. The SBE 9*plus* underwater unit comprises modular temperature and conductivity sensors, a small external pump, and a main housing supplied with surface power from the sea cable. Electronics in the main housing provide three primary functions, including regulation of the several voltage levels required by the internal circuits, external sensors, and pump; acquisition (digitization) of sensor signals; and data telemetry.

Sea cable power supply: Unlike competing CTD systems in which the deck unit supplies a fixed *current*, the SBE 11*plus* V2 presents a constant *voltage* to the sea cable. The SBE 9*plus* receives this voltage (minus the sea cable I-R drop), regulates it to a constant value, and presents it to a high-efficiency DC/DC converter that generates the system supply voltages (+14.3/-13.5, +8, and +5). Two advantages derive from this method: less power is lost in the sea cable (and more is delivered to the underwater unit); and the underwater unit is not required to dissipate unneeded power, (freeing the user of the need to monitor and adjust the surface sea cable supply).

Signal acquisition and data telemetry: Connectors on the SBE 9*plus* bottom end cap supply power to (and receive variable frequencies from) the modular conductivity and temperature sensors. The C and T variable frequencies plus the internal Digiquartz frequency are routed to separate counters that are allotted exactly 1/24 second to derive 24-bit binary values representative of each sensor frequency. Sea-Bird's hybrid counter technique combines integer and period counting to produce digital results that are simultaneous (time coincident) integrals of C, T, and P. The 9*plus* provides four bulkhead connectors for optional auxiliary sensor inputs. Each connector provides +14.3 volts power and permits access to two differentially-amplified and low-pass-filtered digitizer channels with 0 to 5 volt range and 12-bit resolution. Binary data from the entire suite of C, T, P, and auxiliary sensors are transmitted serially 24 times per second using a 34560 Hz carrier differential-phase-shift-keyed (DPSK) technique. This telemetry system is suitable for all single- and multi-conductor cables having a conductor resistance of 350 ohms or less.

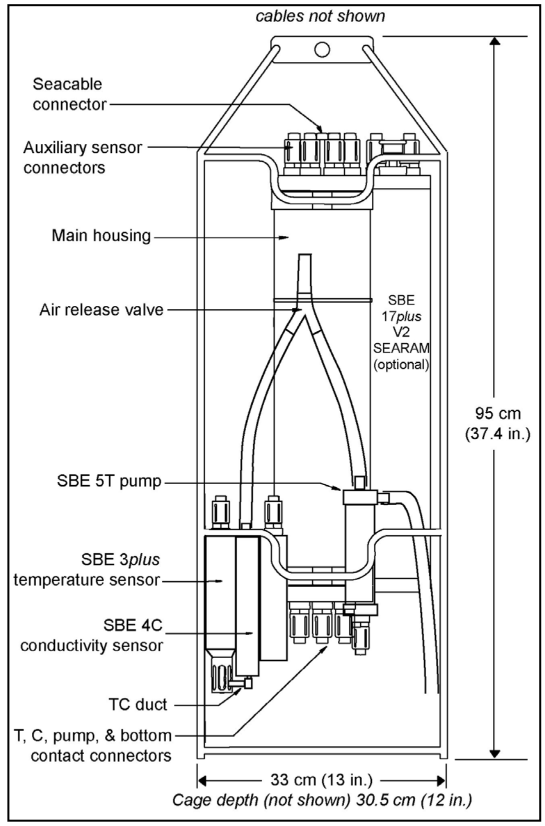
Subcarrier modem and SBE 32 Carousel Water Sampler control: A 300 baud full-duplex FSK subcarrier modem (2025/2225 Hz downlink; 1070/1270 Hz uplink) provides a separate communications channel for control of the Carousel. Bottles can be fired with push buttons on the deck unit's front panel, through SEASOFT©, or via a separate computer connected directly to the modem port on the back panel. There is no interruption of CTD power or data during the bottle firing process. An optional interface card in the SBE 9*plus* permits control of older multi-bottle sampler types, and the modem channel is also available as a general purpose RS-232 interface for custom user applications.

System Components

The SBE 911*plus* CTD consists of an SBE 9*plus* **Underwater Unit** with sensors for C, T, and P (dissolved oxygen, chlorophyll, and other auxiliary sensors are optional) and a submersible pump, and an SBE 11*plus* V2 **Deck Unit**. For real-time data collection, an electro-mechanical sea cable (single- or multi-conductor), slip-ring equipped winch, and computer for data display and logging are typically supplied by the user. An optional SBE 17*plus* V2 **SEARAM Recorder and Auto Fire Module** provides *in-situ* recording and self-contained CTD operation, and can be user-programmed to trigger bottle closure on a Carousel Water Sampler, eliminating the need for the Deck Unit, conductive sea cable, and slip-ring equipped winch.

SBE 9 *plus* Underwater Unit

The standard SBE 9*plus* Underwater Unit has an aluminum housing rated to 6800 meters, and is supplied with one conductivity and one temperature sensor (fitted with *TC Duct* and constant-flow pump) and an internally mounted, temperature-compensated, Paroscientific Digiquartz pressure sensor for 6800 meter (10,000 psia) full scale range. Input channels and bulkhead connectors are provided for an optional second (redundant) pair of temperature and conductivity sensors. Other standard features include an 8-channel, 12-bit A/D converter with differential inputs and low-pass filters, and high-power capability for support of commonly used auxiliary sensors (e.g., SBE 43 dissolved oxygen, SBE 18 or 27 pH, transmissometer, fluorometer, ambient light, altimeter), a modem channel for real-time water sampler control, and a port for connection of an optional bottom contact switch. Other pressure sensor ranges (1400, 2000, 4200, and 10,500 meters), and a 10,500 meter titanium housing are optional.



SBE 11 *plus* V2 Deck Unit

The SBE 11*plus* V2 Deck Unit includes RS-232 and IEEE-488 computer interfaces, a modem channel for real-time water sampler control (including water sampler control push buttons and status lights), NMEA 0183 interface for adding GPS position to CTD data, 12-bit A/D input channel for surface PAR sensor, switch-selectable 115/230 VAC operation, audio tape interface (data backup), LED readout for raw data, and audible bottom contact (or altimeter) alarm. The 11*plus* V2 also provides a remote pressure output (useful as an input signal for towed vehicle control) and a programmable serial ASCII data output containing up to seven variables in computed engineering units. Calibration coefficients are stored in EEPROM, and a separate microcontroller converts raw CTD data to temperature, depth, salinity, etc. The 11*plus* V2 is shipped in a free-standing cabinet with a hardware kit for mounting in a standard 19-inch electronics rack.

SBE 17 *plus* V2 SEARAM

The SEARAM provides battery power for the SBE 9*plus* CTD and SBE 32 Carousel Water Sampler, has memory for CTD data recording, and provides autonomous Carousel water sampler control (Auto-Fire). Each time the SEARAM's magnetic on/off switch is activated, date, time, and sequential cast number are recorded. The 16 Mbyte memory is sufficient for approximately 15 hours recording of C, T, and P at 24 Hz, and the SEARAM can average samples for longer recording endurance. The SEARAM can be programmed before deployment to decode pressure data from the 9*plus* and fire bottles at user-programmed depths, allowing autonomous water sampling and CTD recording without a conductive sea cable. Data upload requires about 12 minutes per Mbyte at 38.4 Kbaud. The SEARAM includes a Nickel-Metal Hydride (NiMH) rechargeable battery pack and charger.

***When the SBE 9plus is equipped with the SEARAM, the system is referred to as the 917plus*.**
See the SEARAM brochure for details.

Software - SEASOFT© for Windows

Supplied with each SBE 911*plus*, SEASOFT calculates a suite of seawater parameters, including salinity, density, buoyancy, sound velocity, etc., and fully supports auxiliary sensors for oxygen, light transmission, PAR, fluorescence, and many other variables. SEASOFT provides real-time plots or number readouts while saving raw data to a disk file from which an ASCII or binary *intermediate* file in engineering units may subsequently be made. Post-processing utilities provide bin averaging, wild point editing, filtering, time-aligning, and color video graphing / hard copy plotting of profiles, waterfall overlays, and density-contoured TS plots. When operating the 911*plus* with a water sampler, complete bottle *housekeeping* files based on firing confirmations are recorded. SEASOFT is upgraded frequently; new versions are supplied free to 911*plus* users and posted on our website for easy access by the user community.

Metrology Standards and Calibration Laboratories

Following consultation with the US National Institute of Standards and Technology, Sea-Bird's metrology lab was configured to achieve temperature precision of 50 µK and accuracy of 0.0005°C. To obtain this performance, premium primary references, including four Jarrett water triple-point cells (with maintenance bath) and an Isotech gallium melt cell, are operated in conjunction with two YSI 8163 standards-grade platinum resistance thermometers and an ASL Model F18 Automatic Temperature Bridge. IAPSO standard seawater and a Guildline 8400B AutoSal provide the highest obtainable salinity accuracy of 0.002 PSU.

SBE 911*plus* temperature and conductivity sensors are calibrated in low-gradient, computer-controlled baths capable of transferring Sea-Bird metrology lab accuracies within 0.0005°C and 0.001 PSU.

Calibration data from Sea-Bird's computer-controlled baths are collated to produce certificates showing the latest results. Overplots of previous calibrations allow the user to judge the stability of the sensor over time.

SBE 911*plus* Digiquartz pressure calibrations are performed by Paroscientific, Inc. using a DH Model 5206 Primary Pressure Standard (oil-operated dead weight tester) certified to an accuracy of 0.01% of reading (0.7 dbar at 6800 meters depth). Cross-comparison against independent standards has established the consistent accuracy of the Paroscientific calibrations.

Accuracy and stability of the SBE 911*plus* quartz master clock is judged against a Spectracom Model 8163 reference oscillator phase-locked to the U.S. National Institute of Standards and Technology's WWVB 60 kHz broadcast signal.

Specifications

General Specifications

Measurement Range	Conductivity	0 to 7 Siemens/meter (0-70 mmho/cm)	
	Temperature	-5 to + 35 °C	
	Pressure	0 to full scale – 2000/3000/6000/10,000/15,000 psia (1400/2000/4200/6800/10500 m)	
	A/D inputs	0 to +5 volts	
Initial Accuracy	Conductivity	0.0003 S/m (0.003 mmho/cm)	
	Temperature	0.001 °C	
	Pressure	0.015% of full scale	
	A/D inputs	0.005 volts	
Typical Stability	Conductivity	0.0003 S/m (0.003 mmho/cm) per month	
	Temperature	0.0002 °C per month	
	Pressure	0.018% of full scale per year	
	A/D inputs	0.001 volts per month	
Resolution (at 24 Hz)	Conductivity	0.00004 S/m (0.0004 mmho/cm)	
	Temperature	0.0002 °C	
	Pressure	0.001% of full scale	
	A/D inputs	0.0012 volts	
Time Response[1]	Conductivity	0.065 second	
	Temperature	0.065 second	
	Pressure	0.015 second	
	A/D inputs	5.5 Hz 2-pole Butterworth Low Pass Filter	
Master Clock Error Contribution[2]	Conductivity	0.00005 S/m	
	Temperature	0.00016 °C	
	Pressure	0.3 dbar (for 6800 m [10,000 psia] pressure sensor)	
Dimensions, mm (inches)	9*plus*	952 x 330 x 305 (37.5 x 13 x 12)	
	11*plus* V2	132 x 432 x 432 (5.2 x 17 x 17)	
Weight, kg (lbs)		***In air***	***In water***
	9*plus* (aluminum)	25 (55)	16 (35)
	9*plus* (titanium)	29 (65)	20 (45)
	17*plus* V2 (aluminum)	9 (20)	4.5 (10)
	17*plus* V2 (titanium)	12 (26)	7.3 (16)
	11*plus* V2	10 (23)	--

[1]single-pole approximation including sensor and acquisition system contributions
[2]based on five-year worst case error budget including ambient temperature influence of 1 ppm total over -20 to +70°C plus 1 ppm first year drift plus four additional year's drift at 0.3 ppm per year

Miscellaneous Specifications

SBE 9*plus* power available for auxiliary sensors	1 amp at +14.3 volts
SBE 11*plus* V2 AC power requirement	130 watts at 115 or 230 VAC 50-400 Hz
Sea cable inner conductor resistance	0 to 350 ohms
Subcarrier modem baud rate	300 baud (30 characters per second, full duplex)

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