A Submersible-Based Data Display and Data Logging System

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Harbor Branch Foundation, Inc., a not-for-profit research organization located in Fort Pierce, Florida has developed a Data Display and Acquisition system for use aboard the JOHNSON-SEA-LINK submersible. The system allows the simultaneous recording of up to twelve channels of data on a cassette-based Data Logger. After the submersible dive, a Hewlett-Packard Series 9000 minicomputer, aboard the surface support ship, allows the scientist to have rapid access to the data and provides graphical display via CRT or plotter. For long-term data storage and further analysis, the system also includes a means of transferring data to the Harbor Branch Foundation PRIME 750 super-minicomputer system. This paper will outline and discuss the major components of the system and how the system functions. Examples of the system configuration and representative samples of the data will be presented.

INTRODUCTION

The Harbor Branch Foundation, Inc. was established in 1971 by J. Seward Johnson and Edwin A. Link as a center for research in marine science and ocean engineering. Since its inception, the Foundation has developed an extensive array of tools and systems which are used in research programs conducted by Harbor Branch Foundation scientists and engineers as well as by outside investigators from the marine science community. At the forefront of the research systems are the pair of manned submersibles, JOHNSON-SEA-LINK I and II, and their surface support vessels, R/V SEWARD JOHNSON and R/V EDWIN LINK.

The four-man JOHNSON-SEA-LINK submersibles, originally designed as observation and diver-lock-out systems, have advanced in sample collection capabilities from an original rudimentary manipulator and fixed collection basket to its present system of integrated manipulator, multiple suction heads and pumps, and a multi-bin sample collection system. The tasks of visual data collection have evolved from photographing through the pilot sphere to an array of still and television cameras, lights and aiming and ranging equipment. The submersible capabilities for data display, collection and analysis have also advanced from external mounted sensors, read through the pilot sphere, to an integrated data display and collection system. Associated data reduction equipment, available aboard the surface support vessels or back at the Foundation laboratories in Fort Pierce, Florida allow detailed analysis of recorded data. This paper will document the system development, operation and capabilities of the data system.

DATA ACQUISITION NEEDS

The original data collection needs of the marine scientist, back at the start of JOHNSON-SEA-LINK operations, were generally satisfied by the direct observation of the marine environment from the panoramic vantage point of the acrylic pilot sphere. These direct observations allowed one scientist to undertake beginning efforts in qualitative research but lacked the means of providing permanent records of the dive which could be shared with colleagues. This early period of submersible usage was the start of the learning curve as the scientists discovered what could or could not be accomplished by the submersible. As the scientist became familiar with the use of the submersible as a research tool, his requirements for data collection increased rapidly. The addition of photographic and video systems had solved the need for visual documentation; however, quantitative data was still not readily obtainable. Early efforts placed sensors, such as a direct reading thermometer outside of the pilot sphere where occasional reading by the scientist could be made. The scientist's ability to know physical parameters of the water mass surrounding the submersible only served to whet the appetite of the researcher; additional information on the salinity, turbidity and depth, in addition to temperature, were quickly and universally desired.

The next evolutionary step was the development of an on-board CTD (conductivity, temperature and depth) display system which would provide digital readout, inside the pilot sphere, of the desired physical parameters. The displayed information was recorded in the observer's notebook or on a portable recorder carried by the scientist for note-taking. This system allowed the scientist to record the conditions at a particular study site but made detailed profiles of the water column tedious or impossible to obtain.

The most recent step in the process has been the addition of a cassette-tape-based Data Logger which is externally mounted in its own pressure housing and connected to the same sensors used for data display. The scientist has the control of the Data Logging System from within the pilot sphere. This Data Logging System, as currently configured, is capable of recording up to twelve channels of data including the permanently installed temperature, conductivity, depth and turbidity sensors.

DISPLAY PANEL AND SENSOR SUB-SYSTEM

The first portion of the submersible-based data system is the Data Acquisition and Display package which consists of four permanently-installed sensors which provide the researcher with information on water temperature, conductivity, depth and turbidity. The output from each of these sensors is displayed on the Switch and Display Panel located overhead in the acrylic pilot's sphere. The four Light Emitting Diode (L.E.D.) displays provide real-time data on the environment surrounding the JOHNSON-SEA-LINK submersible.

General System Theory

The general layout of the data display system are presented in Figures 1 & 2. Each of the sensors is externally mounted on the JOHNSON-SEA-LINK submersible. Cabling, providing power and signal, connects each sensor to a sensor interface which provides buffering and scaling of data for the Display Panel and Data Logger Systems. Independent cabling to the Display Panel and Data Logger provides separate signals to the data logger pressure housings and the pilot's spheres display panel. This independence allows each data path to be optimized for required data conversion or display needs. The data interface can be operated separately from the Data Logger should the Data Logger not be needed or not available. The Data Logger portion of the system is housed in two pressure housings, one containing the data conversion circuitry and the other containing the cassette drive and its control logic. This segmented approach was used to minimize exposure of components due to frequent opening of the pressure boundary, which is required to change cassette tapes. Control for the Data Logger System is supplied via a separate cable from the pilot's sphere.

Three of the four permanently installed sensors produce frequency-modulated sine-wave outputs, which are converted to a display of digital data within the Display Panel. The temperature, conductivity and depth sensors provide information, in the form of a sine-wave, which varies from 7 to 11 Khz over the full range of the instrumentation. Each of the three displays is, in effect, a frequency counter which allows the data to be displayed as a best-fit linear regression of the actual parameter value (Y = a * X + b). A crystal oscillator provides a stable frequency reference which is used to provide a time-gate for each of the channels. This time-gate represents the multiplication factor (or slope) of the linear regression equation. In the case of each of the sensors, the output frequency equates to the required intercept of the linear regression equation as a negative number; thus, output from the time-gated counter must be reduced by the intercept value. This reduction is accomplished by decrementing a presetable down-counter to zero before allowing the start of the actual counting interval. In using this method of data conversion, all three data channels can use identical hardware, thus reducing the required spare parts. To repair a faulty system or change the scaling factors, only two sets of binary switches must be changed to assign the desired values to the counter cards.

Temperature Sensor

Temperature information is provided by a Sea-Bird Electronics SBE-03 Oceanographic Thermometer, which has a temperature range of 8 to 25 degrees Celsius. The sensor provides a frequency-modulated output which is proportional to the temperature. The frequency to temperature conversion equation is non-linear in nature (see Equation 1) and is linearized for display in the pilot's sphere. The information provided to the scientist, during the actual dive, is therefore an approximation and yields errors at all but two points on the temperature curve. It can be seen from Table 1 that the display of the temperature provides a reasonable representation of the actual temperature. It should be noted, however, that the actual frequency from the sensor is recorded by the Data Logger System and therefore the true temperature is available as part of the permanent dive record.

Table 1
Actual vs. Displayed Temperatures
at selected frequencies

Output Freq.	Actual Temp.	Display Temp	Error
7500	2.7957	3.4250	0.62928
8000	6.0159	6.2000	0.18413
8500	9.1010	8.9750	-0.12595
9000	12.0656	11.7500	-0.31561
9500	14.9221	14.5250	-0.39706
10000	17.6806	17.3000	-0.38061
10500	20.3505	20.0750	-0.27547
11000	22.9391	22.8500	-0.08909
11500	25.4536	25.6250	0.17145
12000	27.8995	28.4000	0.50046

Note - Temperatures and Errors in Deg. C.

Equation 1
Temperature Conversion Equation

$$\text{Temp. (deg. C.)} = 1/(a+b[\ln(f_0/f)]+c[\ln^2(f_0/f)] + d[\ln^3(f/f_0)])-273.15$$

where a,b,c,d,f_0 are calibration constants

Conductivity Sensor

Conductivity measurements are provided by a three-electrode flow-through conductivity sensor built by Sea-Bird Electronics, Model SBE-04. This particular sensor has a working range of 10-50 mmhos/cm with a long-term stability of better than 0.01 mmhos/cm per month. This sensor provides a frequency-modulated output which is proportional to the conductivity. Forced water-flow through the cell is provided by a submersible pump. The equation for conversion of the output frequency of the sensor is non-linear in nature and is therefore linearized for display in the pilot's sphere. The conversion equation for the conductivity cell is given in Equation 2 and Table 2 provides a representative error function for the display. As with the temperature sensor, the output signal from the conductivity is stored as frequency data by the Data Logger and corrected conductivity information is provided in the permanent dive record.

Table 2
Actual vs. Displayed Conductivities
at selected frequencies

Output Freq.	Actual Cond.	Display Cond.	Error
6000	15.5842	14.0800	-1.49675
6500	19.0384	18.4950	-0.53070
7000	22.7714	22.9100	0.15937
7500	26.7846	27.3250	0.57328
8000	31.0794	31.7400	0.71103
8500	35.6580	36.1550	0.57255
9000	40.5227	40.5700	0.15769
9500	45.6769	44.9850	-0.53365
10000	51.1243	49.4000	-1.50163

Note - All conductivities and errors are in mmhos/cm.

Equation 2
Conductivity Conversion Equation

$$\text{Conductivity} = (af^m + bf^2 + c + dt)/10 \quad \text{(mmhos/cm)}$$

where a,b,c,d,m are calibration factors and t is water temperature

Depth Sensor

Depth information is provided by a Sensotec Super-TJE pressure transducer which is located within the sensor interface pressure housing. This bridge-type pressure transducer provides a high-degree of linearity and repeatibility with low hysteresis. The nominal range of the instrument is 1000 meters with better than +/- 1.5 meter resolution. The output of the pressure transducer is a D.C. voltage which is converted to a sine-wave output of 7-11 kHz by a Voltage-to-Frequency converter. The display portion of the system is identical to the temperature and conductivity channels.

Transmissometer

Turbidity information is provided by a Sea-Tech 25-cm path-length transmissometer which provides a D.C. voltage proportional to water clarity. This transmissometer provides a collimated beam of 15 mm. diameter from an LED (660 nm.) over a water path of 25 cm. The interface pressure housing provides a scaling circuit which sends a 0-1.000 V.D.C. signal to the pilot's sphere. The voltage is then converted to a digital display using a 4-1/2 digit Digital Panel Meter. By utilizing a Harbor Branch Foundation developed Transmissometer/ Forward Scatterance sensor a second analog channel can be utilized to provide a measurement of forward scattered light at a single scattering angle.

Other Derived Parameters

Although not displayed in the pilot's sphere, several other parameters are of interest to the researcher and are derived from the recorded information. Salinity and density calculations are made from conductivity, temperature and depth information and are available with both the at-sea and laboratory data reduction systems. The algorithms for computation of salinity and density are those endorsed by the UNESCO/SCOR/ICES/IAPSO Joint Panel on Oceanographic Tables and Standards.

DATA-LOGGER SUB-SYSTEM

The data logger portion of the JOHNSON-SEA-LINK data acquisition package consists of a modified cassette-based data logger package manufactured by Sea Data Corporation. The basic features of the data logger are similar to the Sea Data Model 650 logger. The unit is capable of recording up to 8 analog channels (0-5 volts D.C.) and four channels of frequency data. The unit is capable of expansion of frequency channels to a total of eight channels. The repetition rate is adjustable from 8 samples per second to one sample every 512 seconds. In addition, the system is equipped with the added feature of being able to reduce the repetition rate, from the pilot's sphere, by selecting a slow mode multiplier. When slow mode is enabled, the scan rate is reduced by the selected multiplier. This feature enables the researcher to increase the repetition rate of the data logger during desired portion of the dive while slowing down the repetition rate when data acquisition is not important. Total data storage capacity, using a 300-foot data cassette, is 2 Mega-bits or approximately 13,500 scans of data. Using a repetition rate of 1 sample/second, a data cassette could record approximately 3.75 hours of dive information.

Data Format

The data format consists of 37-49 data bytes which represent the hexadecimal equivalent of the actual value. The first 6 bytes represent the number of one-eighth second time marks since the last clock reset. The next 2 bytes consists of scan rate indicator, fast/slow mode and user and sensor controlled event flags. The next sixteen bytes consist of the F.M. channels which hold the count of the number of pulses recorded since the last data scan. The next 12-24 bytes are the 4-8 analog channels (this provides 1-in-4096 resolution) The last byte provides for parity checking capability.

Table 3
Data Logger Tape Format

# of Bytes		Data
1)	6	Elapsed Time since Clock Reset
2)	1	Data Logger Scan Rate
3)	1	Data Logger Status & Event Flags
4-7)	16	F/M channels 1-4
8-11)	12	A/D channels 1-4
12-15)	12	A/D channels 5-8 (if used)
16)	1	Parity Byte
	--	
	37 (or 49 as required)	

Operation

To utilize the data acquisition, the user loads the data logger with a fresh data cassette and sets the desired scan and slow mode rates. The operator must note the clock reset time and dive number on the tape (the clock is normally set once at the start of each cruise and remains the same for the rest of the cruise). The system is placed in the run mode and the data logger can be mounted on the submersible. In preparation for the dive, the data logger panel in the pilot sphere is activated and a file gap is placed on the tape to signify the start of a new dive; the data logger is then placed in the stand-by mode until launch. To activate the system, the researcher only needs to place the stand-by/run switch into the Run position; the Fast/Slow mode can be set as required. The Event Marker button can be used to correlate events of interest to location on the dive record.

After the dive, the researcher removes the tape from the data logger and analyzes the dive information using the data reduction system.

SHIPBOARD DATA REDUCTION SYSTEM

Evolution of the System

Following the development of the Data Logger System for the JOHNSON-SEA-LINK submersibles, the need developed for a means of retrieving and reducing this data after the completion of a dive. The Data Logger Reduction System is a software package designed by Harbor Branch to perform this task.

Evolution has brought about the development of three versions of this system, each running on a different machine. The first version was an on board reduction system written in Pascal for an Apple II. This system provided the scientists aboard the surface support ship with rapid access to the data for environmental measurements to document visual and recorded observations. This access was quite advantageous since information could be obtained for decisions for later dives. However, the cumbersome Pascal operating system and the limited storage and computational capabilities of the Apple prevented several desired program features from being implemented.

These limitations led to the development of a more sophisticated Fortran version running on the Prime 750 at Harbor Branch. After returning from a cruise, the raw dive data could be loaded from the cassette tape to the Prime for processing and formating in a fraction of the time required by the Apple. Although the Apple system would still be used to view the data while at sea, this new system introduced a variety of options available to the scientists upon returning to Harbor Branch. These options included the ability to smooth the data, produce publication quality graphics and permanently archive data on magnetic tape for future use.

The latest version of the system was developed when the decision was made to upgrade the on board data system from the Apple to a Hewlett-Packard Series 9000 minicomputer. This new system would be written in Pascal and would bring many of the enhancements offered by the Prime based system to the scientists at sea. It consists of a Model 220 computer with a 256K main memory, a 15 Mega-byte hard disk and a single 3 1/2 inch floppy drive. The computer is linked to a Sea Data Cassette Reader and an Asynchronous Reader Interface (ARI) unit via an HP-IB interface. An HP Thinkjet printer is used for printed output.

Main Menu

One major enhancement to the system was in making the entire system menu driven. This was not only for the convenience of the scientists at sea but also for the protection of the system itself, for in doing so the actual program code remains hidden from the user.

The main menu of the system is used for processing the raw dive readings and examining the reduced data. Also through the main menu the user may access the auxiliary menu or exit the system.

Dive Set Up Parameter Modification

The task of reducing the raw sensor data requires knowledge of a series of dive-related parameters. These items (the data logger clock reset time/date, the types of sensors used, their serial numbers and which channels they are connected to on the data logger) are entered by the user and written to a file on disk. These parameters can then be used repeatedly without having to be reentered. Although these parameters will seldom change once a cruise is under way, it can happen. For example, a sensor replaced mid-cruise would cause the parameter set for the dives prior to the change to be different from that of the dives after the change. In this case, before the data recorded during those dives following the replacement can be reduced the parameter file must be modified to reflect the change. The parameter modification routine allows the user to view the current parameters and modify any if necessary.

ARI/Cassette Reader Test Routine

During the development of the system a potential problem was detected: an inaccurate setting on one the dials of the cassette reader could cause severe errors during the reduction process. For example, the current configuration of the data logger produces a valid record of 37 characters. If the cassette reader is incorrectly set to only accept records with 47 characters, all valid records would be erroneously labeled as short. For this reason a test routine was added to scan a portion of the tape, displaying the status of each record. If there is a problem with the settings the user should be able to detect and correct the error before actual data reduction begins.

Data Reduction

Once the set up parameters have been established and the settings have been verified the raw data can be processed. Because it is not unusual for a dive to have several thousand records the user has the option of processing every Nth record in the file. If a reading was taken every second of a three hour dive over 10,000 records are produced. By processing one record out of every minute recorded, or every 60th record, an excellent profile of the dive is obtained yet less than 200 records are processed! This not only saves time during data reduction but also during subsequent examination of the reduced data.

The data reduction routine uses the ARI/cassette reader to extract the raw data from the cassette tape. The ARI responds to a number of different commands from the computer allowing the program to maintain full control of the reader via the HP-IB interface. This hand-shaking permits resetting the ARI, reading records from tape and rewinding the tape. Prior to transmitting a request for data, the HP-IB bus is used to initiate a status poll request to determine the status of the ARI. The ARI responds with a single digit indicating its current status. There are three possible states for the ARI to be in when the poll is taken:

(0) - the ARI is working on a command
(1) - the ARI wants to transmit to the computer
(2) - the ARI is waiting to receive a command

When the ARI is ready to accept commands, a read command is sent to the data logger to retrieve a record from tape. The ARI performs the command then responds with a message indicating the results. If a record is successfully read from the tape the message will consist of the record followed by a comment on the condition of the data (i.e. short record, parity error or good data). A final message is then sent to the computer when the ARI is ready for the next command. If a valid record is received the data is then separated into the proper fields (time stamp, scan rate, flag bits and channel values). An internal Hewlett-Packard system routine is then used to convert the individual hexadecimal fields into their decimal equivalence.

The clock capacity or roll-over period of the data logger clock is 24 days, 6 hours, 32 minutes and 32 seconds. If one or more roll-overs has occurred between the time the clock was reset and the time the dive was made then the time stamp will indicate the time lapsed since the last roll-over rather than time lapsed since the clock was reset. In order to determine the correct base time, that is, the actual time of the most recent roll-over, roll-over periods are consecutively added to the reset time until the dive date is reached. The time stamp can then be converted to hours, minutes and seconds and added to the new base time to obtain a real clock time stamp for that particular record.

The raw sensor data is divided into fields representing the number of 16 bit FM channels and 12 bit analog channels on a data record. If a particular channel on the data logger is attached to a sensor, the data in the corresponding field will contain the raw sensor reading. Once the values in fields have been converted to decimal, the values of the FM channels must be converted to frequencies and those of the analog channels to voltages. These intermediate values are then used by the individual reduction routines to produce the final values in engineering units. The reduced data is then written to the output file on disk along with the converted time stamp and flag bits.

Examining the Reduced Data

After the raw data for a dive has been processed there are two ways a scientist can view it. The easiest of these is in the form of a hard copy report. Through this option the user can obtain a printed report of the entire dive or, by re-selecting for a particular time span, just a portion of it.

The alternative to the printed report is a screen graphics display of the data in the form of two dimensional Cartesian plots. This routine allows the user to specify any two fields of the data to be plotted against each other (i.e. time vs. depth, temperature vs. depth). Once again, the user has the option of examining the entire dive or any subset of it (see Figure 5 for sample output).

Occasionally a bad reading or "spike" is recorded in the data. Data spikes have a tendency to assign improper plot scaling and produce misleading or unreadable plots. An option in the plotting routine allows the user to eliminate severe spikes by limiting value ranges. For example, a depth spike of 2000 feet recorded on a dive that only ranged 0 to 800 feet would be quite obvious to the scientist observing the data. This spike, however, would cause the plot to be mis-scaled to allow for a maximum depth of 2000 rather than the predicted 800 feet. By limiting the depth values to a range of 0 to 800 the major spikes are eliminated and accurate scaling is preserved.

Following all re-selection, the data is automatically scaled according to the maximum and minimum values of the selected range and the axes and tick marks are appropriately labeled. The plot can then be transferred directly to the printer for hard copy results.

Auxiliary Menu

The auxiliary menu can be used to update the soft-coded portions of the system as hardware is modified or other changes occur. Depending on the change made, minor hard coded changes may also be required (i.e. the individual reduction routine must be added to the program code when a new type of sensor is added to the system).

Channel-Sensor Format

The channel-sensor format specifies which sensors are connected to which channels on the data logger. The standard channel-sensor format is that format normally in use. When the user selects to modify the dive set up parameters, he will be prompted for the channel-sensor format used during the dive. To avoid having to specify the format, the user can select the standard format, provided standard format was used. At some point this standard format is likely to change, as with the addition of a new type of sensor. When this happens the standard format modification routine can be used to update the system.

Table 4
Channel-Sensor Format

16-bit FM channels:		
#1	:	unused
#2	:	TEMPERATURE
#3	:	CONDUCTIVITY
#4	:	DEPTH

4 12-bit ANALOG channels:		
#1	:	TRANSMISSOMETER
#2	:	unused
#3	:	unused
#4	:	unused

Sensor Calibration

Periodically the sensors are returned to their manufacturers for recalibration. Each time this calibration is done, the sensor is assigned a new set of calibration factors to be used by the individual calculation routines. There are separate calibration factor data files for each different type of sensor. When a sensor is recalibrated, the new factors must be added to the corresponding sensor calibration file through the update routine on the auxiliary menu.

Each record of a calibration file contains the serial number of the particular sensor, the date of the calibration and the various calibration factors. When the user creates a parameter file for reducing the raw data the sensor number selected by the user is used along with the date of the dive to locate the correct set of calibration factors. These are then written to the dive parameter file along with the remaining set up values for use in the data reduction routines.

Sensor Addition

When a new type of sensor is added to the data logger system several minor modifications must be made. The first step is to update the sensor log file. This step adds the new sensor type along with other information about the new sensor to a file containing a list of all available sensors. The calibration file for this sensor is created and the calibration factors added to the newly created calibration file. The standard format modification routine should then be used to incorporate the new sensor into the standard format. The final step in this process is to make the necessary hard coded modifications, or changes to the actual program code. These consist mainly of inserting the necessary calculation routines for converting the raw sensor readings to engineering units.

CONCLUSIONS

The JOHNSON-SEA-LINK data acquisition and display system has given these research submersibles the ability to provide quantitative, as well as qualitative, data to the marine scientist or engineer. The system provides an integrate approach to data collection, at-sea data verification and preliminary analysis as well as the capability of providing data, in required format, for detailed analysis at virtually any research facility.

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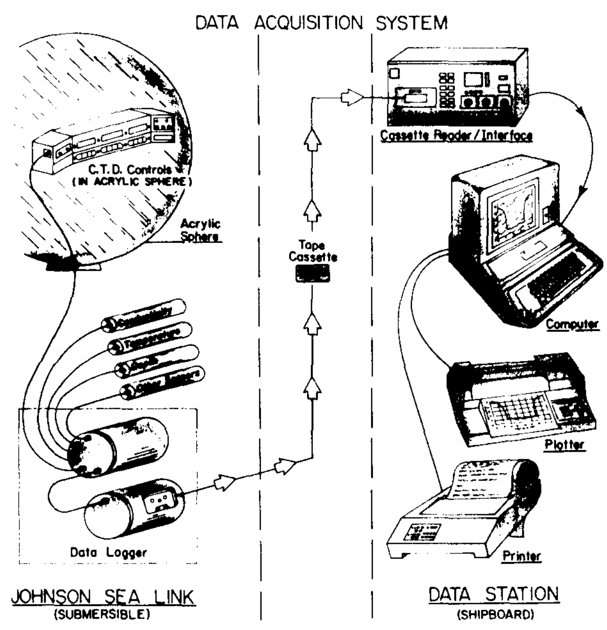


Figure 1 - Data Acquisition and Display System Schematic

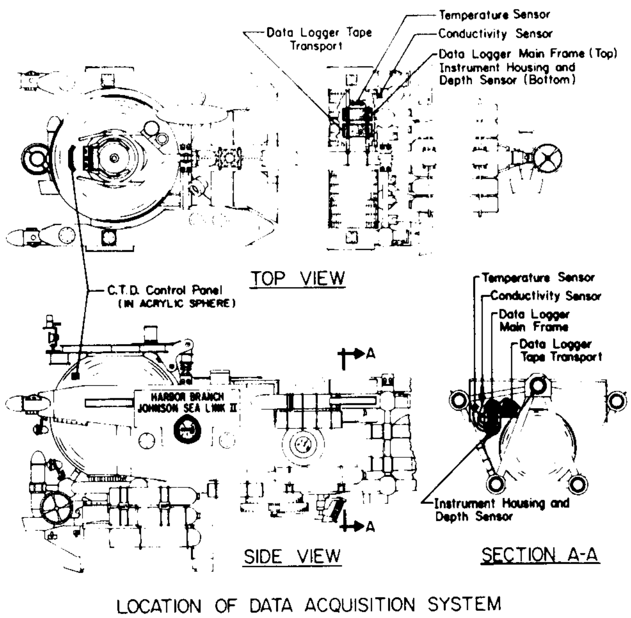


Figure 2
JOHNSON-SEA-LINK Submersible
System Location

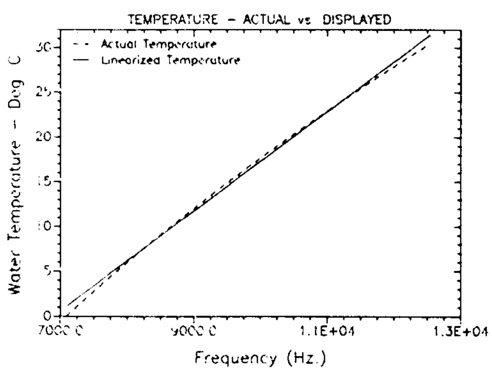


Figure 3
Graph of Actual Versus Displayed
Temperature

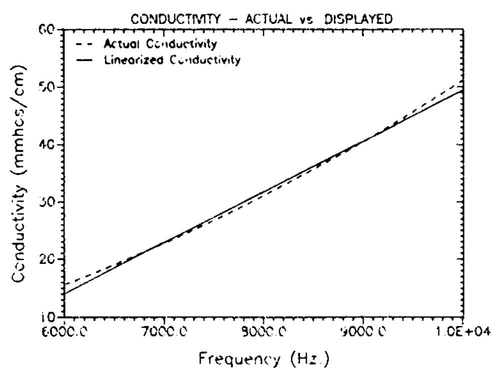
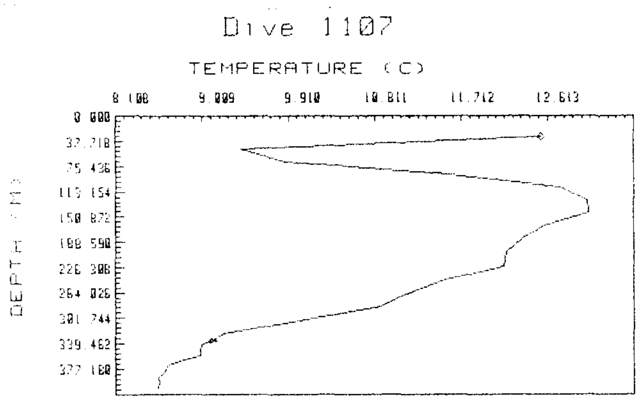


Figure 4
Graph of Actual versus Displayed
Conductivity

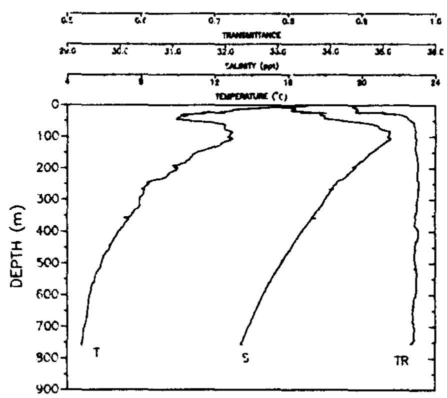
DIVE 1107

REC. #	DATE	TIME	FLAGS	TRANSMI	TEMPERAT	CONDUCTI	SALINITY	SIGMA T	DEPTH
1	7/10/85	3:55:12	00000000	0.9369	9.4044	36.3789	33.5899	25.9734	48.5827
2	7/10/85	3:58:12	00000000	0.9530	12.7451	40.8159	34.6386	26.1853	106.3798
3	7/10/85	4: 1:12	00000000	0.9573	12.5793	41.2189	34.9359	26.4482	163.4635
4	7/10/85	4: 4:12	00000000	0.9573	12.1509	40.7554	34.6430	26.3047	224.2576
5	7/10/85	4: 7:12	00000000	0.9557	10.8738	39.4784	34.3411	26.3076	284.4808
6	7/10/85	4:10:12	00000000	0.9541	9.0991	37.9864	34.3022	26.5791	334.5717
7	7/10/85	4:19:12	00000000	0.9551	8.8176	37.3471	33.8038	26.2342	364.2552
8	7/10/85	4:23:12	00000000	0.9551	8.5600	37.0773	33.6465	26.1512	397.2210
9	7/10/85	4:26:12	00000000	0.9551	8.5222	37.0388	33.5884	26.1115	412.3481



◇ indicates start of dive

Figure 5
Sample Output from HP.-9000 Data Reduction System



DIVE 1108

Figure 6
Sample Output from PRIME 750 Data Reduction System