Use of the SBE9*plus*/11*plus* RS-232 Uplink Channel for Real-time Monitoring of Lowered ADCP (LADCP) Velocities

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ABSTRACT

As a specific application of the optional RS-232 serial uplink channel on the SBE 9*plus*/11*plus* CTD unit, a lowered ADCP (LADCP) can be interfaced with the SBE9*plus* to allow transmission of and access to real-time serial output data from the ADCP. This configuration, which is a straightforward and less costly alternative to custom hydrowires and data transmission systems, has been shown to be very robust with extensive field testing. Access to the additional LADCP real-time data stream has a number of advantages for both CTD and LADCP data collection—including improved bottom detection, information on the carousel/rosette motion and the ability to sample velocity adaptively.

1. Introduction

Although the measurement of deep ocean velocity by the lowered-ADCP approach has been taking place since the early 1990's (e.g., Firing and Gordon 1990; Fischer and Visbeck 1993), advances in LADCP hardware (e.g. TRDI "new-build" transducers), processing techniques (Visbeck 2002), and better quantification of LADCP velocity uncertainties (Thurnherr 2009) has led to the growing interest in and application of LADCP data collection. The scientific value of collecting LADCP data along with standard CTD data has also been highlighted by a number of relatively recent studies (e.g., Kunze et al. 2006) (more?).

In this configuration, autonomously sampling ADCPs (or a single ADCP) are mounted to the rosette, with water velocity data sampled simultaneously with CTD casts to obtain velocity profiles far below the range of standard ship-mounted ADCPs (to full ocean depth 6000 m). In contrast to CTD operations where data is viewed and recorded in real-time on deck, LADCP data is logged internally by the ADCPs with, in most cases, no real-time data logging or access. Velocity data are downloaded from the ADCPs on deck at the end of the cast.

There are a number of clear advantages that accompany real-time monitoring of lowered ADCP (LADCP) velocities and other ADCP auxiliary parameters, however. At the most basic level, a continuous real-time data stream indicates the operational status of the LADCP system—whether it is working or not—which helps to avoid wasting valuable ship time. If, for example, a LADCP system were to stop sampling during a long yo-yo operation during which the CTD was not brought aboard between casts and, thus, the operational status of the LADCP system was unknown, potentially days of ship time could be wasted. The standard output serial data stream from Teledyne RDI (TRDI) ADCPs (**?**) also provides the current and voltage during the transmit cycle to an empirically determined constant, which is very useful in gauging *how long* the current meters will operate if powered by batteries.

Other auxiliary data such as ADCP pitch/roll/heading have proven to be useful for interpretation of CTD rosette motion—which is useful in evaluating stresses on the hydrowire and for assessing limitations for tow-yo operations (towing the package slowly while yo-yo-ing). With LADCP firmware a down-looking TRDI ADCP outputs the range to the bottom, which was found to be a superior measurement to that provided by a standard altimeter mounted on the CTD rosette in terms of both range and reliability. Scientifically, real-time absolute velocity data when within bottom-tracking range or estimates of absolute velocities using the "shear-method" (Firing and Gordon 1990) allows adaptive sampling—or modification of a sampling plan based on what is observed in-real time. However, because of the necessary wire lengths needed for deep ocean sampling (> 9km) doing so independently of the SeaBird CTD (SBE9*plus*/SBE11*plus*) instrumentation can be both costly and challenging. Here we describe a robust, low-cost, simple setup that streams real-time serial LADCP data via the SBE9*plus*/11*plus* uplink channel.

2. SBE 9*plus*/11*plus* serial UPLINK channel

As described in the SBE11*plus* User's Guide (**?**), a 9*plus*/11*plus* system can be equipped with an optional serial RS-232 9600 or 19200 baud uplink channel, which allows serial data from a remote instrument to be sent to the 11*plus* deckset in real-time along with the standard CTD data stream. The remote instrument, which is set to output either binary or ascii serial data, is connected to the JT4 connector on the SBE9*plus*, with settings 9600/19200, 8, N, 1 (baud rate, data bits, parity, stop bits). Note that the uplink baud rate can be set at the factory to 9600 or 19200, but if 19200 is selected the overall baud rate of the remote instrument can not exceed 9600. The SBE9*plus* multiplexes the uplink data stream with the standard CTD data stream and the deckset (11*plus*) demultiplexes the uplink data stream and outputs it (at 19200, 8, N, 1) via a 9-pin D-sub connector on the back of the 11*plus* deckset. Note that the deckset acts as a DTE, so a null modem cable (or standard serial cable and a converter) is needed between the deckset and the computer reading the serial data stream.

The serial uplink is unidirectional (from 9*plus* to 11*plus*–thus “uplink”). Two-way communications are possible with the serial instrument, however, by use of the 300 baud FSK modem typically used for the bottle sampler (e.g. SBE 32). Using the FSK modem, the SBE9*plus* will communicate with the remote instrument at the baud rate of the instrument. Note that two-way communications with the remote serial instrument precludes the use of the bottle sampler.

3. Interfacing the TRDI ADCP with the SBE9*plus*

In this specific application, a down-looking 150 kHz Quartermaster ADCP, which was the “master” in an up-down LADCP pair (Fig. 1), was the remote serial instrument interfaced with the SBE9*plus* via the JT4 connector. As the output power from the JT4 (15VDC) is outside the voltage range for TRDI ADCP external power (20–50VDC), the ADCP must be powered from other sources unless a voltage converter is used. Here we found it easiest and most robust to use two 24V Deep Sea Power and Light Sea Batteries wired in series. The capability to *recharge* vs. *replace* batteries is advantageous as it does not interfere with ADCP compass calibrations conducted pre-cruise with the ADCPs and batteries mounted on the rosette. (**include general schematic dwg of system here**)

As there had been some expectation of a degradation of uplink signal quality with cable lengths in excess of ~9km, a similar set-up was tested (though not used operationally) aboard several vessels with varying wire lengths and ages (R/V *Thompson*–10000 m, R/V *Revelle*–9700 m, R/V *Kilo Moana*–9800 m) before the full implementation of the system onboard the R/V *Revelle* for 38 days during the summer of 2012 (**verify wire lengths**). However, for both tests and the most recent extended operations, no indication of signal degradation was detected. With this configuration the uplink data stream performed without exception for all of more than 100 full-ocean-depth (to ~5000 m) LADCP/CTD casts and a number of extended (>24 hrs) tow-yos. Mentioned previously as one of the benefits of a real-time data stream, the only instances of the LADCP uplink data stream being interrupted were when the external power to the master LADCP was interrupted, which subsequently led to the discovery of a failing battery.

a. Cabling

Sometimes referred to as a "star cable" or "octopus cable," the underwater cabling harness must perform a number of functions:

1. Power must be supplied to each of the ADCPs unless they will be powered from internal packs (which, as previously noted becomes problematic for compass calibrations when operations exceed battery life).

2. The master and slave ADCPs are typically synchronized on the ADCP RS-485 channels [pg. 23 Lowered ADCP User's Guide (TRDI 2008)].

3. Serial output data from one LADCP, usually the master, is received by the 9*plus* (uplink data).

4. If two-way communications are not needed during LADCP sampling, the cable connecting the SBE9*plus* and one LADCP (the master) can also be designed for two-way, on-deck communications.

5. If two-way LADCP communications are desired during sampling, the receive on the uplink LADCP must be connected to the transmit channel on the Water Sampler connector (JT7). This, however, would require a split communications cable on deck if one desired to use the cabling harness for on-deck downloads.

The cabling harness required to allow one-way uplink LADCP data is actually the same as that for standard LADCP operations, with the addition of a "leg" that connects the TX and COMMON RS-232 conductors from the master LADCP to the RX and COMMON pins on the JT4 bulkhead connector (Appendix Figs. 3, 4). This leg of the harness may already be present on a cabling harness for standard LADCP operations to allow data-download and communications with either the master or slave ADCP through the cabling harness, vs. separate communications cables, in which case only an in-line adaptor cable may be needed for bulkhead/cable connector compatibility. The JT4 bulkhead connector will be either an Impulse MCBH-4-MP or XSG-4-BCL-HP-SS, thus the leg of the cabling harness that connects to the JT4 connector will have to end with an Impulse MCIL-4-FS or RMG-4-FS [pg. 23 SBE 9*plus* CTD User's Manual (SBE 2010)] (Appendix Fig. 5) (**need to reset fig counter for appendix figs**). To permit use of the cabling harness with either type of JT4 bulkhead connector on the 9*plus*, one can fabricate an adaptor cable that "converts" the MCIL-4-FS to a RMG-4-FS (i.e. MCIL-4-MP on one end and RMG-4-FS on the other).

b. Software

At the most basic level, one can connect a terminal computer serially to the uplink D-Sub connector on the back of the SBE11*plus* and simply monitor and log the output with a basic serial communications application. However, to take full advantage of the LADCP data stream, one must log, parse and display this data stream in real-time. Here a Matlab GUI was created which used the Matlab Instrument Control Toolbox to perform all three tasks. There are likely more efficient ways to achieve similar results (e.g. transmitting in binary vs. hex-ascii and parsing directly), but this approach allowed simple integration of pre-existing Matlab ADCP processing scripts.

In addition to the raw streaming hex-ascii (a basic indicator of LADCP system status), the GUI displayed the following operational data: ensemble number, ADCP pressure, pitch, roll, heading, bottom range, time, echo intensity and supply voltage during the transmit cycle. The latter was obtained by determining an unknown constant between the raw counts (Variable Leader Data Format, ADC Channel 1 **?**) and measured input voltage. It was determined that for the purposes of determining LADCP battery longevity, one could obtain this constant (here 0.28?) by simply dividing the on-deck voltage measured at the batteries (under load if practical) by the initial add-chan01 counts of the LADCP deployment. Note that this constant appears to be specific to each ADCP unit. Due to processing overhead, new "operational" plots were generated every 4 seconds, with plots of shear-method velocities and absolute velocities when within bottom-tracking range updated every 12? seconds. Figure 2 shows a screen-shot of version 1.0 of this software, which did not yet include the battery voltage or the plots of absolute velocities. This software is freely available *as-is* and without support at `http://kipapa.apl.washington.edu/LADCP`.

Extensive LADCP operations showed that the advantages of logging and displaying the uplink data were manifold. Logging the uplink data provided a redundant copy of the master LADCP data, which would be invaluable in the event that the internally-recorded ADCP data could not be retrieved. The streamed data and input voltage provide a "heartbeat" and a means of estimating battery longevity if battery discharge curves are known. Here battery curves were initially verified directly by plotting the voltage as a function of elapsed deployment time, with system endurance estimated with some knowledge of the "roll-off" voltage. ADCP pressure, though not as accurate as the CTD pressure, provides a rough check of system performance. Roll, pitch and heading proved to be useful when conducting tow-yo operations as these data provided real-time information on the rosette package motion when under tow, which permitted an estimation of stresses on the hydrowire. Twisting of the hydrowire, for example, can significantly stress the strands, and either tow speed can be adjusted to minimize spin or the weight distribution/drag profile on the rosette can be adjusted.

Given the potentially mission-ending consequences associated with LADCP/CTD package bottom contact and the poor performance of standard altimeters for some bottom types, one of the more valuable LADCP uplink variables was bottom range. Using a 150kHz Quartermaster LADCP, bottom range was detected at roughly 280 mab, or roughly three times the range of the standard altimeters when the latter are reporting accurate values at maximum range (which is rarely the case). When profiling over rough and variable topography, the increased range of bottom detection significantly decreases the risk of bottom contact, thus permitting more confident and accurate near-bottom sampling. With independent range estimates from four beams, the LADCP bottom range was found to be more reliable and robust than the standard altimeter where measurements overlapped (40-90 mab). When within roughly 30 to 40 m of the bottom LADCP side-lobe interference (**and return signal saturation?**) excluded bottom range estimates. At this distance, however, the standard altimeter typically worked well, so the two measurements were somewhat complimentary.

Setting the master LADCP to output earth-referenced velocities (i.e. EX11111 **?**) allows the display of real-time absolute velocities—calculated either by the shear-method or when within bottom-tracking range, with minimal on-deck processing compared to streamed velocity data in beam-coordinates. Standard Matlab LADCP processing software will recognize and accept either beam, instrument or earth referenced velocities, so this has no anticipated drawbacks in terms of processing of internally-recorded LADCP data. The availability of real-time LADCP velocities permits adaptive sampling—or adjusting sampling based on real-time measurements to better accomplish the scientific goals. This capability would prove to be of great advantage if searching for or focusing sampling on a specific deep flow feature such as an overflow, plume or jet.

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APPENDIX

List of Figures

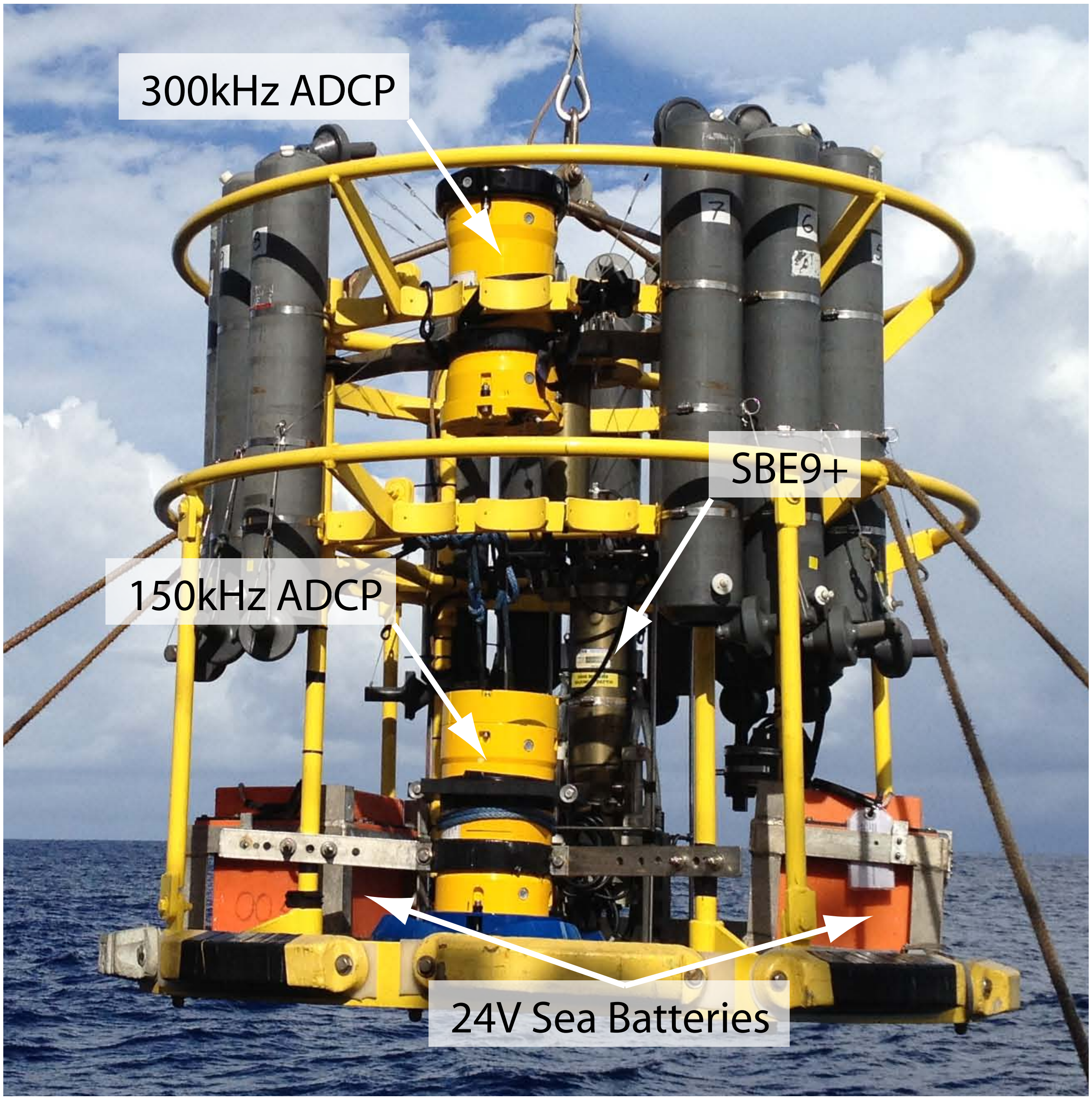

FIG. 1. Photograph of the configuration described in the text.

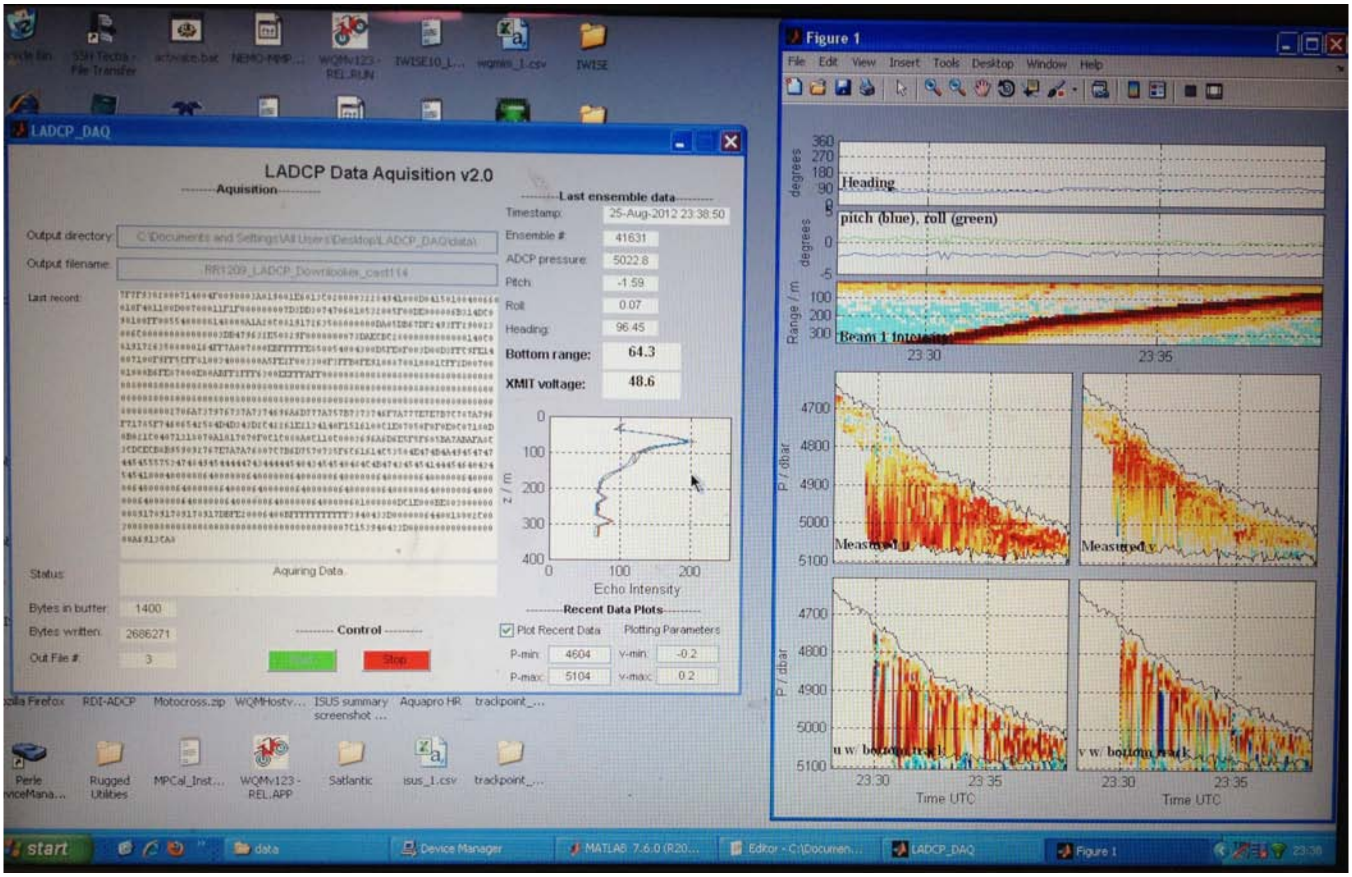

FIG. 2. Screen shot of v1.0 of the Matlab LADCP data acquisition GUI (LADCP_DAQ.m).

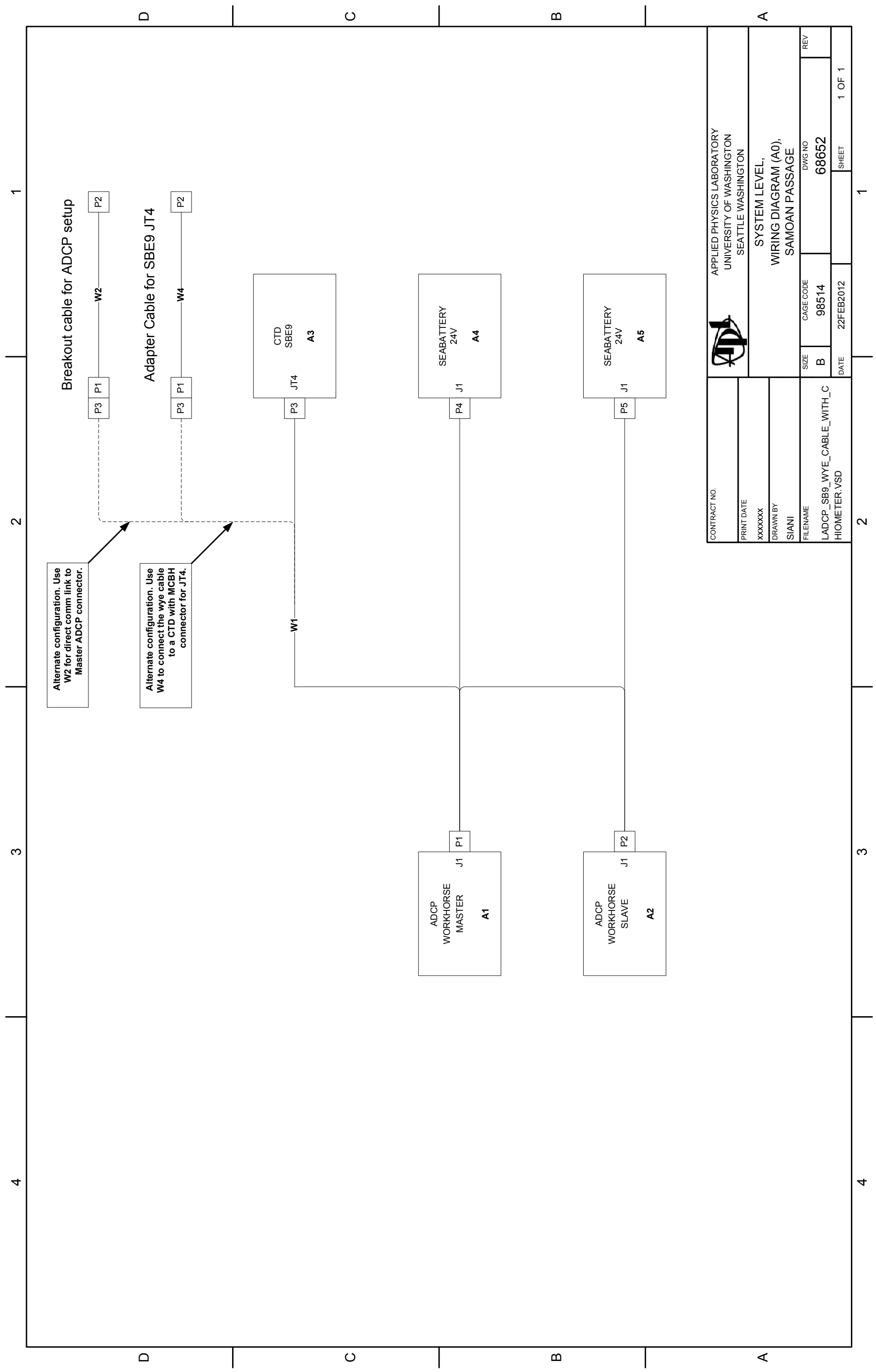

FIG. 3. System level diagram.

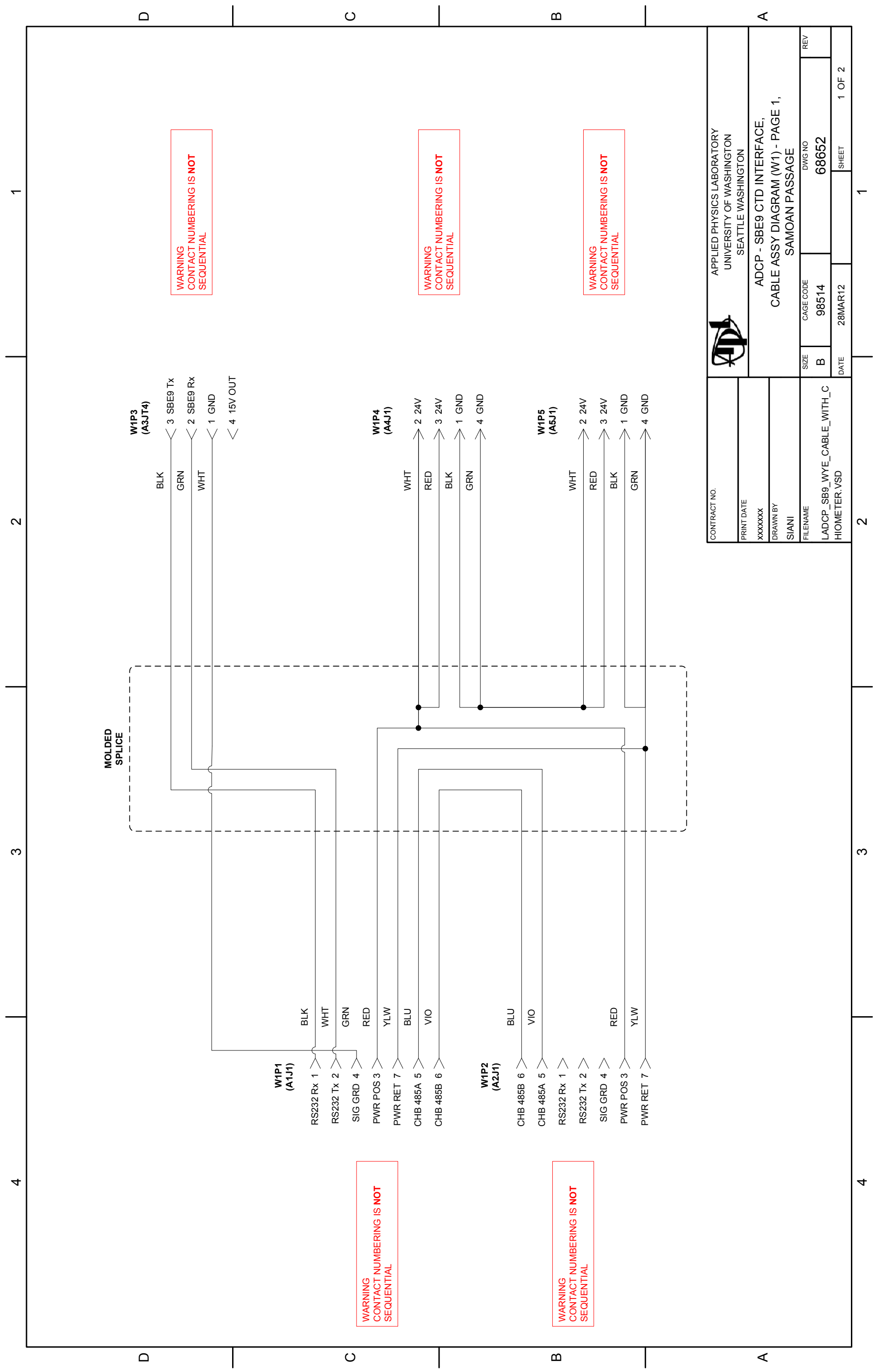

FIG. 4. Wiring diagram.

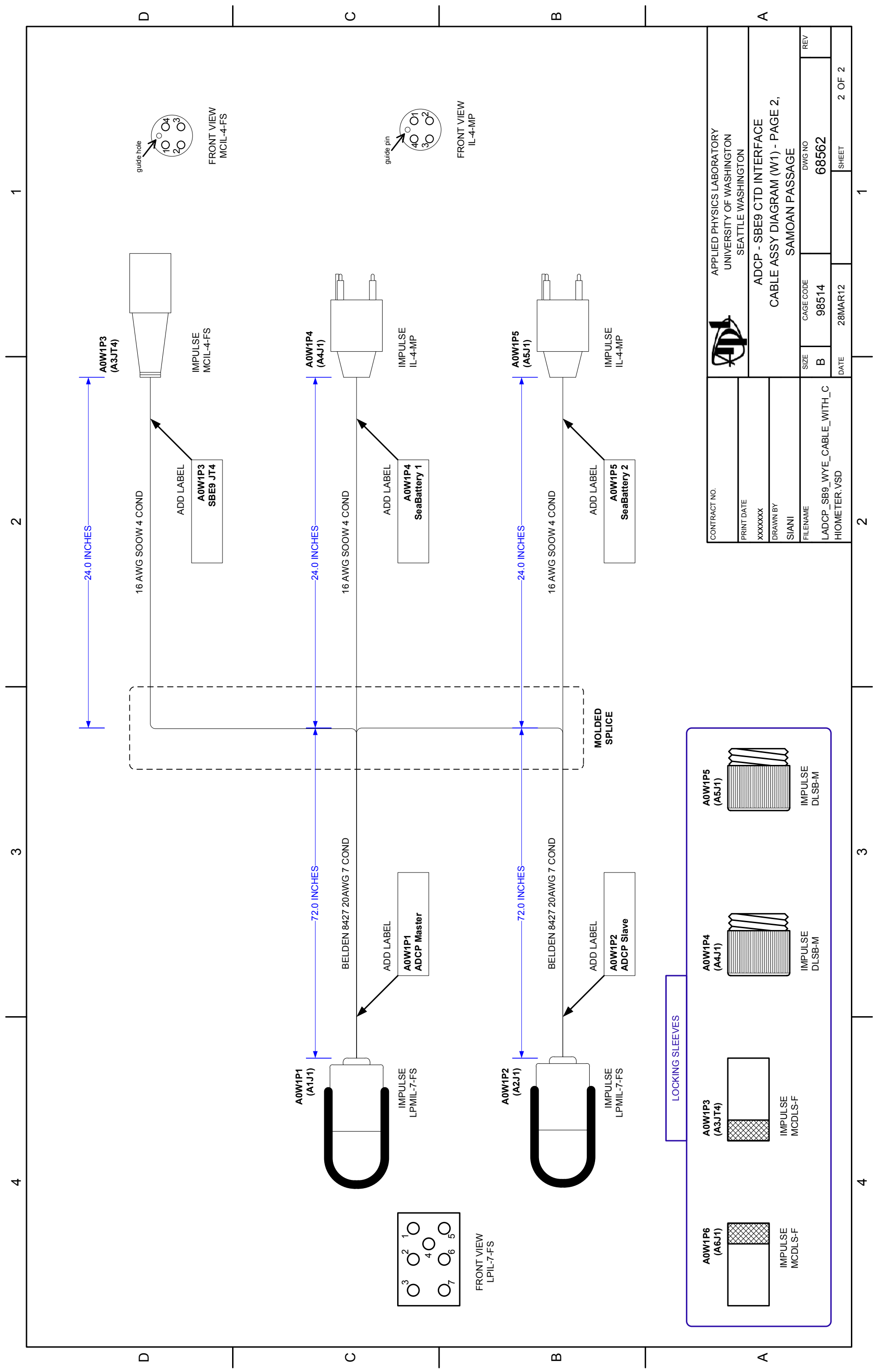

FIG. 5. Cable assembly diagram.