

MTM4 (MSE) Axis BIN Failure Report

Rev.

1.0 16AUG07 – initial draft. Mark Chaffey
2.1 14AUG08 – added ODI results.

3.0 18AUG08 – early released version.
3.1 19AUG08 – final released version

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1. Summary

The MOOS mooring project was proposed to design and field-test a novel portable ocean observatory that allows instrumentation to be deployed and time series data returned in near-real-time from the seafloor to the surface and hence to shoreside. To achieve this objective the project deployed a series of four moorings of increasing capability and complexity to test the parts of the system considered to be high risk elements. The field data gathered from these deployments has been used to verify the mathematical models used in the mooring design and to guide redesign efforts necessary to improve the overall performance. Laboratory destructive testing was also used to reproduce the wear mechanisms identified in field testing and to confirm the results of subsequent design improvements. Using the techniques of dynamic modeling, accelerated laboratory fatigue testing and year-long field test deployments, the survivability of the MOOS mooring riser cable system has improved dramatically.

The MOOS/MSE surface mooring was installed by the vessel Pt. Sur at Shepard Meander on June 29, 2006 as the fourth in a series of test moorings. In subsequent cruises with the Western Flyer/Tiburon system, two fully instrumented seafloor Benthic Instrument Nodes (BIN's) were cabled and installed, one on the Monterey Canyon Shelf on July 8th and a second in the Canyon Axis on November 3, 2006. The collection of MSE instruments telemetered data back to shore via a Globalstar satellite data link.

On April 27 of 2007 a "routine" replacement swap of the Shelf BIN was undertaken to install a replacement BIN that had improved computer firmware and a new software release. This swap would be the first in what was planned to be an annual maintenance schedule for instrument calibration and back-up battery replacement on the two BINs.

When the replacement Shelf node was installed and powered up after the replacement, it powered up and ran normally for approximately 40 minutes. It then detected an over-current condition on the output power to the downstream Canyon Axis BIN, and tripped a "smart" circuit breaker. Subsequent remote testing confirmed that the fault was real and existed in the electrical connectors or cable segment between the Shelf and the Axis BINs. This failure resulted in the Axis BIN being non-operational after the Shelf BIN swap operation in April 2007, until the experiment was recovered in December of 2007.

After recovery all segments of the MTM4/MSE system were tested for electrical leakage in an attempt to locate the electrical fault. No faults were found in any portion of the system except the

benthic cable to ROVmate connector Field Installable Termination Assemblies (FITA)(See appendix B). These cables/connectors/FITA assemblies are commercial products supplied by Ocean Design Inc. (ODI) and South Bay Cable Inc. The splicing of the connectors to the cable is performed by Ocean Design Inc. field assembly technicians under an outside services contract.

After post-recovery testing was performed by ODI on the connectors and splices associated with the failed cable segment, it was felt that there was a strong possibility that a failure had occurred in the splice chamber caused by a combination of a design weakness, difficulty of working with our specific cable construction and possible workmanship issues in the termination. ODI agreed to replace and re-terminate the suspect splice chambers and connectors at no charge.

As a result of this electrical failure the Axial BIN data collection period was from November 5, 2006 until April 21, 2007 or approximately 6 months. The Shelf data collection period was for the full length of the experiment, July 7, 2006 until recovery on December 12, 2007 (17 months). Unfortunately the Axial BIN was the experimental (as opposed to control) node located in the Monterey Canyon axis so the MSE experiment was severely compromised by the node failure.

To prevent this type of failure from occurring in the future it is recommended that each subsea assembly such as the benthic cable/connector/FITA assembly be pressure tested prior to deployment, not just to qualify the design but to qualify each individual component.

It is also recommended the suitable spares always be maintained to allow the quick replacement of any field replaceable module to restore full observatory function in case of a component failure. Specifically in this case, maintaining a spare benthic cable in stock might have allowed the experiment to be quickly restored.

2. Background Information

The Benthic cable used for MSE has been reused from the Canyon Dynamics project. The MSE installation initially required two reels of cable, as shown in fig. 3. This cable had been originally ordered from South Bay Cable and terminated by the Canyon Dynamics project. One additional reel of cable of the same design specification was purchased for MSE in 2005 and the termination of this cable planned for 2006 to provide a spare. This spare benthic cable was to allow the MSE installation to proceed if one of the cables was damaged during installation.

The ability to reliably lay seafloor cable between the mooring base and the BINs was considered critical for the overall projects success. Developing and testing this capability was part of the MOOS companion "Tiburon Cable Laying Toolsled Testing" and "Canyon Dynamics" development projects. Cable laying has been successfully demonstrated with an identical cable on Ventana (<1400 meters) and with a generic, non-representative cable on Tiburon (3200 meters). The deployed Benthic cable design is a compromise between designing as robust a cable as possible for survivability that is light enough in seawater to meet the ROV payload limitations. For this reason the cable has steel armor only in the 25 meters at each end, and depends on Kevlar as a strength member for most of its length (see appendix D, E and F).

The installation of the MSE experiment began with the deployment of the Surface mooring and riser cable from the Pt. Sur on June 29, 2006. The riser cable had a loopback connector installed at the anchor end. Testing showed the riser cable system to be intact after deployment. The following week the Western Flyer and Tiburon dove to the base of the mooring with the cable laying sled. The loopback connector at the base of the mooring was removed and replaced with the armored end of the 4000 meter cable section on the reel. As the ROV moved away from the base of the mooring toward the site of the Shelf BIN, cable was spooled from the cable sled reel. An optical

and electrical loopback connector on the ROV cable spool end of this segment allowed continuous testing of the cable performance as it was being laid away from the mooring anchor toward the Shelf BIN. After transitioning to the unarmored section of the cable it became very difficult to lay the cable out without numerous loops or coils forming in the cable, apparently due to pressure induced torque imbalance in the cable. This problem had not been observed in cable lay testing in 1400 meter depths. After several hundred meters of cable lay optical power was lost. A subsequent fly-back along the cable showed that a loop had pulled tight causing a severe kink. The cable optical core is armored with Laser Armor Tech tubing and is not tolerant of kinks. The second cable reel (spare) was installed and successfully laid from the mooring to the Shelf BIN. The cable exhibited similar coiling effects, however with great effort and exceptional ROV piloting, it was successfully laid in place.

An investigation was conducted by Andy Hamilton and Larry Bird, in collaboration with the cable manufacturer (South Bay Cable) and it was determined that the original two cables built for Canyon Dynamics had a manufacturing defect in the braiding of their Kevlar strength member that caused a significant torque imbalance at high pressure. A 4000 meter replacement cable with corrected braiding and a more relaxed wire helix angle was manufactured at no cost by South Bay and field terminated by Ocean Design technicians in time for the cable lay from the Shelf BIN to the Axis BIN in November 2006. The connectors used in the termination were either new build or remanufactured by ODI from MBARI supplied connectors.

The cable lay from the Shelf BIN to the Axis BIN with the new cable was accomplished without major incident in spite of the very steep terrain on the edge of the canyon. The new cable performed much better when under pressure and the problem of loops forming in the cable was greatly reduced, although not eliminated entirely.

A spare Benthic cable to replace the cable lost in the initial cable lay was planned, but not ordered pending the results of the cable lay with the re-designed cable. The replacement spare Benthic cable ultimately was not ordered in 2006 because the cables in the system were functioning well, the additional spare was not in the project budget, and after the Ocean Design cable terminations came in at \$58,000 over budget there were no available funds in the project. When the Shelf – Axis cable segment subsequently failed after six months of operation, the replacement spare order was again put on hold until the cause of the failure could be determined on the chance that the failure could be due to a design or manufacturing flaw in the cable itself.

With no possibility of restoring the cable connection between the Shelf and Axis nodes without a significant delay and the large expense of a replacement cable (and to be prudent, a spare), the project instead proposed to move the experiment to a site considered to be a higher value target for high speed benthic instrumentation. This proposal was approved by management in the 2008 project cycle and in December of 2007 the ship time allocated for maintenance of the MSE experiment was used to remove the instrumentation, ROV-mateable connectors and one of the benthic cables from the seafloor.

All parts of the system were recovered except for the anchor to Shelf cable segment (the connectors were salvaged), the BIN support frames, and the Shelf to Axial cable spool with about 1000 meters of cable remaining on it. Each of the recovered elements were tested for electrical leakage to determine if they could have contributed to the electrical failure of the Shelf to Axial cable segment (see summary graphic in appendix C). The relevant Ocean Design ROV-mateable connector/FITA assemblies were returned to Ocean Design for analysis.

3. Known facts

On June 29, 2006 the MSE surface buoy was launched without incident from the Pt. Sur. Loopback testing during deployment confirmed that the riser cable was optically and electrically sound.

On July 12, 2006 the Shelf BIN was installed and powered up. The detailed of the difficulties of cable laying are described above.

On November 5, 2006 the Axis BIN and associated "new design" cable segment was installed and powered up without serious incident.

Around November 10, 2006 a "high side" ground fault quickly developed. Over the course of the next several months the ground fault severity varied, but eventually developed into a "hard fault" at the full scale of the measuring system (1 mA). After a power system shutdown and power can replacement in March 2007, the ground fault reversed polarity to a "low side" fault on March 22, 2007 when the Axis BIN was powered up. This might have been an indication that a second fault to seawater was developing, or had developed over the period of time the system was not powered during late February and March.

On April 21, 2007, the Shelf BIN was recovered by the ROV Tiburon for recalibration of its instruments and a bug fix to the internal MOOS Mooring Controller "Medusa" networking card. The bug prevented the hardware from automatically resetting the BIN if the Medusa local network switch locked up. The lockup problem could be manually overcome by power cycling the subsurface nodes, but if the outage was not noticed or responded to immediately, several day data gaps were often result. The frequency of these data gaps was about once very two months.

On April 27, 2007, the Shelf BIN was re-installed by the ROV Tiburon and connected to the seafloor cable network without incident. When the replacement Shelf node was installed and powered up, it ran normally for approximately 40 minutes. It then detected an over-current condition on the supply to the Canyon Axis BIN and tripped a "smart" circuit breaker.

The data telemetry from the mooring power system was consistent with an electrical current overload down-stream of the Shelf BIN power switch, see figure 1. The details of the power data are in appendix A.

The last record we have of the deployed Axis BIN environmental values is on 4/14/2007 6:42:23 AM. At that time the Axis BIN housing internal parameters were all nominal: Temperature: 17.6 degrees C, Pressure 693 millibars (slight vacuum), Humidity 15%. From this data is appeared that the Axis BIN did not have any water ingress or internal environmental problem prior to the failure.

Installation of a loop-back connector at the Shelf BIN output connector confirmed that the failure did not appear to be in the Shelf BIN or associated ROVmate connector plug (the BIN side of the ROV-mateable hybrid electrical-optical connector). There remained a small possibility that there was a defect in the Shelf power switching circuitry that was causing a nuisance over-current trip at a current level below the design value for the circuit.

On April 28, 2007 the newly installed Shelf BIN was replaced by a spare unit by Tiburon without incident. When a subsequent attempt was made to power up the downstream Axial BIN, it's power switch also over-current tripped.

On August 28, 2007 during a Jim Barry cruise, a loopback connector was installed on the Axial BIN end of the Shelf-to-Axial cable segment. When this segment was powered up from the Shelf BIN there was a similar over-current trip response, confirming that the electrical leakage problem was isolated to the Shelf-to-Axial cable segment and the associated connector assembly.

A spare benthic cable assembly was not available and due to the long lead time for manufacture, could not be procured before the MSE experiment riser cable was approaching the end of the cable fatigue life of two years maximum (June 2008).

On August 30, 2007 the Axial BIN was recovered and the Axial BIN end connector and splice assembly was cut from the Shelf to Axial cable segment. The cable was also cut at the Shelf side of the cable reel to facilitate future recovery of this cable segment.

On December 10, 2008 the Shelf BIN, all remaining connector/splice assemblies and most of the Shelf-to-Axis benthic cable was recovered. The mooring was disconnected from the benthic cable network and subsequently recovered with the Pt. Sur without incident.

4. Results of post-recovery electrical testing

Post-recovery inspection and electrical testing was performed on all of the recovered MSE components with the following results:

Surface Snubber and “Y” cable assembly – No electrical faults detected.
Riser cable and terminations - No electrical faults detected.
Loopback connectors used for in-situ testing - No electrical faults detected.
Shelf BIN and connectors - No electrical faults detected.
Axis BIN and connectors - No electrical faults detected.
Recovered section of failed benthic cable assembly - No electrical faults detected.
Mooring-to-Shelf connectors/FITA assembly – Failed electrical test.
Shelf-to-Axial connectors/ FITA assembly – Failed electrical test.

The suspect connector/FITA assemblies were tested for electrical insulation breakdown at MBARI and subsequently sent to ODI for their analysis, which included X-Raying of the FITA assembly and subsequent teardown inspection.

The fact that all of the connector and FITA assemblies had to be cut from the seafloor cables at depth for recovery, and subsequently all showed some electrical insulation breakdown, made the task of identifying the exact failure mechanism more difficult than it would have been had the cable and connector/FITA assemblies been able to be recovered intact. Each of the recovered Ocean Design connectors themselves passed electrical leakage tests, however each of the associated Field Installed Termination Assemblies or FITA’s failed post recovery electrical testing on at least one conductor. It was impossible to determine if this failure had occurred during routine operation or as a result of cutting the FITA’s from the cable during the recovery/salvage operation.

The two FITA’s and connectors in the failed cable segment were returned to ODI for examination. The units were X-rayed and inspected by disassembly. In email on November 19, 2007 Pat DiPersia reported that burn marks and a broken wire in side the FITA pointed to an internal FITA short and failure. This was confirmed in a phone conference between Pat DiPersia (ODI account manager), William Mudge (ODI engineer) and Mark Chaffey on May 19, 2008. The FITA failure was blamed on “the combination of FITA design issues, the benthic cable construction including electrical conductor insulation thinness, the possibility of movement between the strength member and the conductors, and possible assembly workmanship”. The hypothesis is that a pressure

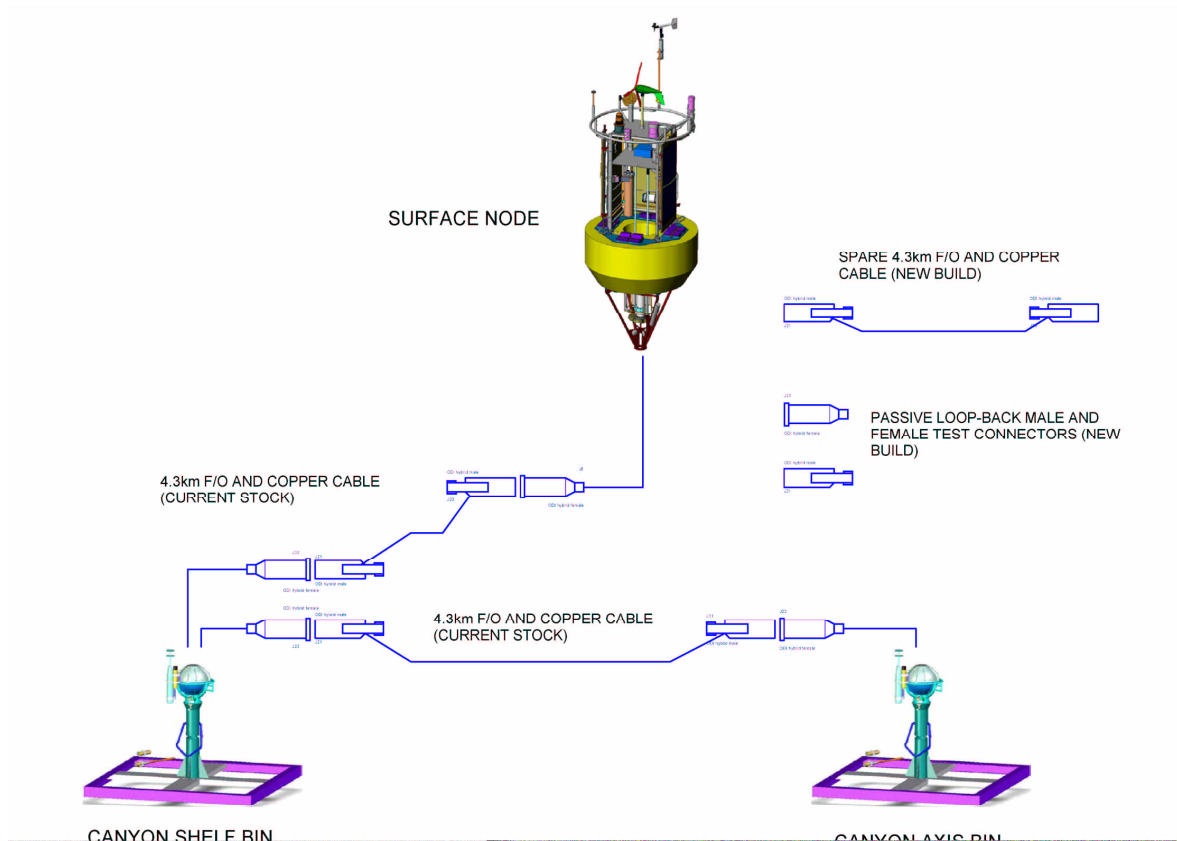


Figure 1. System layout of the MTM4/MSE observatory.

difference between the oil-compensated portion of the FITA and the one atmosphere side caused the electrical conductors to piston into the metal shell and press through their insulation. ODI agreed to replace the failed FITA's with a new design at no cost.

.Factors supporting the conclusion that the probable cause of the MSE Axial node failure was within the FITA assemblies are that:

- A) A process of elimination: no other recovered component besides the FITA's showed any evidence of electrical insulation breakdown.
- B) The terminal electrical failure was isolated in-situ to a specific benthic cable, connector and FITA assembly, i.e. the Shelf-to-Axis benthic cable/connector/FITA assembly.
- C) Post-recovery inspection by ODI of the suspect FITA showed signs of electrical breakdown, erosion of insulation and metallic plating that are consistent with electrical leakage from an energized circuit. This electrical leakage damage must have occurred before the cable cutting operation associated with recovery, which was done with the system de-energized.

It should be noted that while all of the other mooring system components passed post recovery electrical testing, there were signs of water ingress in the lower riser termination due to crevice corrosion compromising the O-ring sealing surfaces. We also cannot rule out an insulation failure in the mooring base to Shelf BIN cable/connector/FITA assembly. The double-insulated design of the mooring electrical system requires a direct conductor-to-conductor fault, OR two faults to

seawater of opposing conductors, to create a fault circuit. As noted above, a ground fault was detected in the mooring system in early November. This indicated that one conductor had compromised insulation to seawater. It is possible that this fault was either in the lower riser termination (tested OK after recovery) or in one of the benthic cable/connector/FITA segments (testing results compromised by cutting FITA's from cable at depth). The probable cause failure then became the second failure and subsequently halted the experiment. Using the mooring system built-in fault isolation and diagnostic capabilities it should have been possible to attempt to isolate the November ground fault to either the riser-to-Shelf-BIN segment or the Shelf BIN-to-Axis BIN segment. Unfortunately this was not done due to problems with the satellite link bandwidth making man-machine interaction with the system very difficult. These problems were fixed by March 2007.

5. Factors directly contributing to the failure of MSE

A) An electrical short between the 400VDC low side conductors to the Titanium case (seawater) in the Ocean Design Inc. supplied Shelf to Axial cable/connector/FITA assembly that occurred coincidentally with the April 2008 service mission.

B) An electrical short somewhere in the system between the 400VDC high side conductor and seawater that probably occurred in November 2007. The likely location for this failure would be in the Ocean Design Inc. supplied Riser-to-Shelf cable segment, possibly by the same mechanism that ultimately caused the Shelf-to-Axis segment to fail. It is also possible that this failure occurred in the riser cable lower termination.

6. Factors indirectly contributing to the failure of MSE

A) Not having a spare benthic cable on board ship or the cable laying toolsled for laying the cable prevented immediate restoration of the experiment. The lack of a spare cable was due to a combination of wanting to test the performance of the second-generation cable design before ordering additional cable and a cost saving decision to not maintain spares for the system once deployed and working successfully.

B) Not following up on the November ground fault indication. It is not clear what changes could have been made in the program based on this information that would have prevented the ultimate failure; however the isolation of the fault to either the Riser-Shelf segment or the Shelf-Axis segment would certainly have helped the subsequent failure investigation.

7. Recommendations for avoiding reoccurrences of similar failures

- Pressure test benthic cable assemblies after termination to a pressure that is at least 1.5 times the expected working pressure of the assembly. This recommendation will add a minor amount to the cost of the observatory deployment but could improve overall reliability by catching design and workmanship flaws.
- Always maintain an adequate supply of spares for any component that is field replaceable. This allows for the immediate restoration of the observatory system in case of failure.
- The loopback connectors used for system testing during operation and maintenance should fully load the system. For example, the current loopback connectors only place a nominal load on the power system. When the power over-current trip occurred and the loopback connector was installed, it could not tell us if the power system current trip circuit itself was a factor. If the

loopback connector pulled the full design load, in-situ diagnostic capability would be improved (note that there were legitimate concerns about power dissipation that drove the current design).

- Carefully weigh the risk factors associated with service missions to observatory components. For example the replacement of the Shelf BIN that coincided with the Shelf-to-Axial cable failure was not strictly necessary. It was undertaken to perform a software upgrade that would reduce data gaps and to establish an annual servicing interval for the hosted instrumentation. The risk of even this “routine” mission was graphically illustrated when the elevator carrying the Shelf BIN was struck by the Western Flyer propeller during recovery. While all indications are that the Shelf-to-Axial cable would have failed regardless of the Shelf BIN swap operation, the coincidence of this work with the subsequent failure pointed out the potential risk to the system of non-essential activity. Service intervals and operations should be managed to maximize the stability of functioning systems and minimize the risks of failure.
- Thoroughly follow up on observed system anomalies as reported by the diagnostic systems. They may be indications of a causal link in a chain of events that could lead to a system failure.
- Specific recommendations from Ocean Design Inc. for changes in the benthic cable design to create a more reliable field splice with their termination design:
 - Change the conductor insulation material to cross linked polyethylene
 - Increase the conductor insulation thickness
 - Remove the plastic rods from the middle of the conductors
 - Use tin plated copper in the conductors (this is not a dire need but a best practice)
 - Increase the conductor size and lower circuit count if possible
 - Increase the thickness of the fiber tube (it is a little flimsy right now and cannot support much loading)
 - Remove the aramid from around the conductors
 - Mold the conductors and fiber tube in a solid low density polyethylene (or some other nice cable jacket)
 - Apply the strength member (aramid is good) to the outside of this over molded cable bundle
 - Over mold the aramid with the outer layer of polyethylene (or some other cable jacket)

Appendix A

MOOS Power System

400V Switch

Current Limit, Circuit Breaker, and Telemetry Functionality

Ed Mellinger

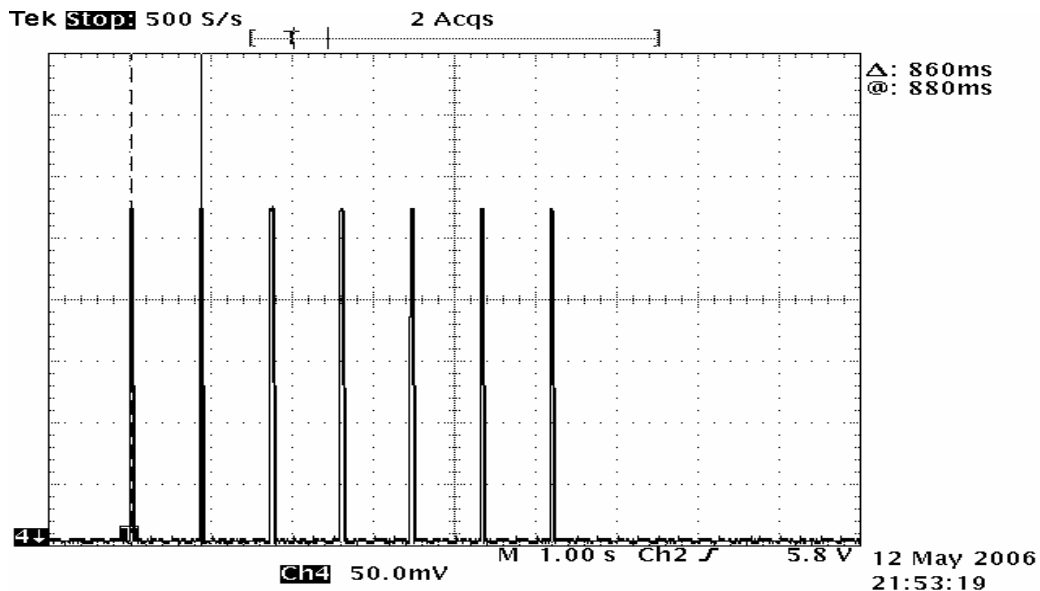
6/20/07

The circuit breaker function in the MOOS 400V switch has both a current limit feature and a sequential-retry feature, which affects the telemetry reported by the power system during a trip event.

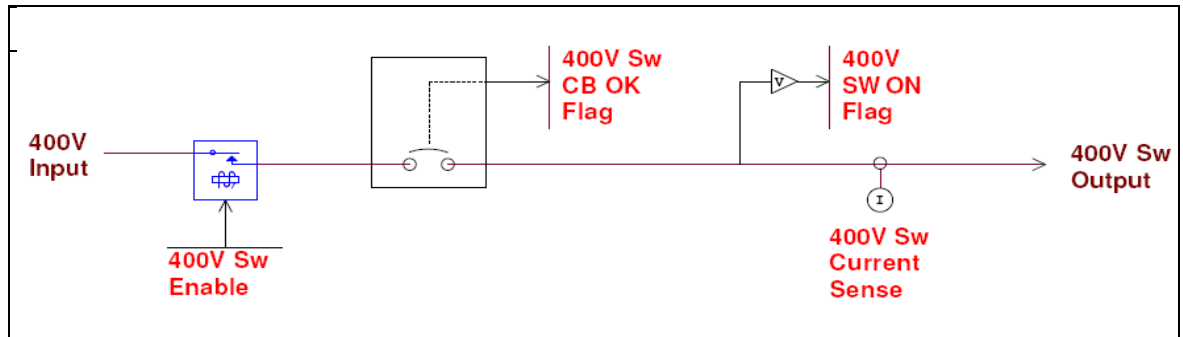
If current through the switch exceeds a threshold of about 270 mA, the switch controller chip will modulate the switch's FET gate drive to limit the current at 270 mA. The current limit prevents catastrophic fault current, protects the upstream power bus from brownout, and provides a controlled soft-start feature for downstream capacitive loads.

If the current-limited state exceeds about 50 milliseconds duration, the switch controller will turn off the FET for about 850 milliseconds to allow it to cool. Then the controller will turn the FET back on, and will again limit current for 50 milliseconds if the fault condition is still present. The controller will repeat this current-limit/off cycle for a total of seven retries, and then set a TRIP flag and remain off. The TRIP flag appears in the power system telemetry as a 'Zero' state of the "CB OK" flag.

This scope photo from lab testing shows the 400V Switch current during a typical CB trip event. Vertical scale is 50 mA/div:



The telemetry subsystem monitors 400V Switch current at a 4 Hz rate (250 millisecond period). For each telemetry averaging interval (typically ten minutes, unless manually sampled more often), the average, minimum, and maximum currents are reported in the telemetry data stream. The telemetry system also monitors switch output voltage with a one-bit comparator (optically isolated), which has an 'on' threshold of about 200 volts. This SW ON flag, as well as the above-mentioned CB OK flag, are also sampled at 4 Hz and are reported in the telemetry stream as a count of the number of 'One' states (switch ON, or CB NOT TRIPPED, respectively) per averaging interval.



Block Diagram of a Single 400V Switch Channel

This sample telemetry record shows the respective locations of several of these parameters within the telemetry stream, for BIN 400V Switch 0. (This is the switch channel in the MSE Shelf BIN which supplies 400V power to the Axis BIN.)

SIAM Timestamp	SIAM Timestamp converted to time/date (GMT)	Packet Sequence Number	String Representation of Data Buffer			
			Avg Current		Peak Current	
1177795815034	2007-04-28 21:30:15 +0000	54	ADC00	A+3.6445e+02	N0000099	L+1.4605e+02 H+3.6930e+02 E0
			ADC01	A-3.9434e-02	N0000393	L-8.7983e-02 H-2.9508e-02 E0
			ADC02	A-7.9725e-05	N0000393	L-3.1098e-02 H+7.3240e-06 E0
			ADC03	A-9.3424e-04	N0000393	L-1.3390e-01 H+1.1100e-05 E0
			ADC04	A-4.4626e-06	N0000393	L-2.2200e-05 H+1.1100e-05 E0
			ADC05	A-2.9656e-06	N0000393	L-1.1100e-05 H+1.1100e-05 E0
			ADC10	A+1.3970e+01	N0000099	L+1.3925e+01 H+1.3986e+01 E0
			ADC11	A-5.3889e-01	N0000393	L-7.1371e-01 H-3.7677e-01 E0
			ADC12	A+1.3653e+01	N0000099	L+1.3402e+01 H+1.3698e+01 E0
			ADC13	A+1.3487e+01	N0000099	L+1.3424e+01 H+1.3510e+01 E0
			ADC14	A+6.0392e+00	N0000099	L+5.0772e+00 H+1.8625e+01 E0
			BP00	N0000394 A0394 B0394	C0001	D0016 E0000 F0394 G0000 H0000
			DATA COUNT 00701			

The telemetry subsystem utilizes a delta-sigma A/D converter with an effective sample/average time of about 140 milliseconds. If the 400V Switch is in a current-limit-retry mode, the 50-millisecond current pulses will effectively be averaged over the 140 millisecond A/D sample window, causing the measured current to be reported at a fraction of its actual value. This is illustrated in the sample telemetry record above, which was received during last week's MSE cruise.

In this record, 400V Switch 0 has tripped off due to an over current event. The tripped state is indicated by the CB OK count (= 16) being less than the total sample count in the BP field (= 394). The Average Current and Peak Current fields provide backup evidence that current did flow briefly; however the Peak Current reported does not reflect the actual current of 270 mA that probably was flowing. Finally, the SW ON count (= 1) indicates that nominal output voltage was present, and captured one time, when the SW ON flag was sampled. This suggests that the overload event was not a dead short, and was capable of supporting at least 200V while drawing the 270 mA supplied by the switch.

Appendix B

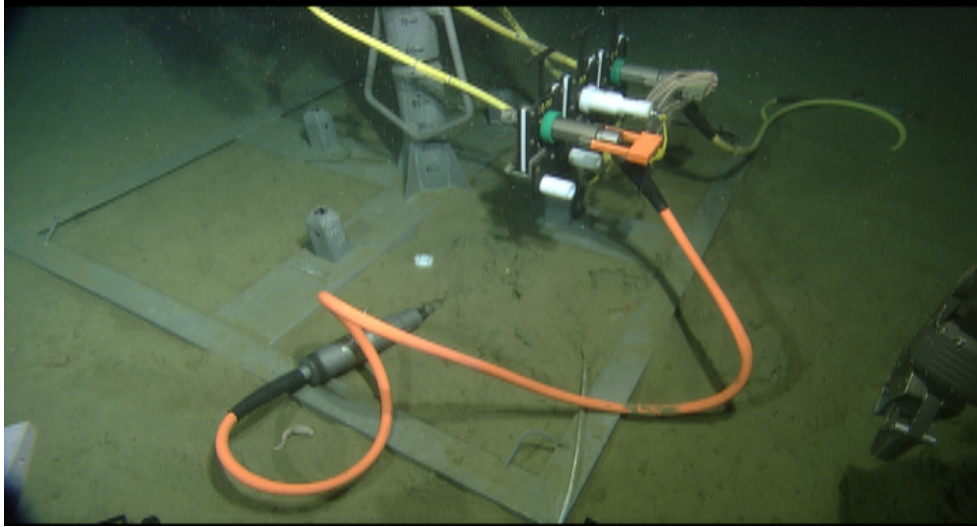
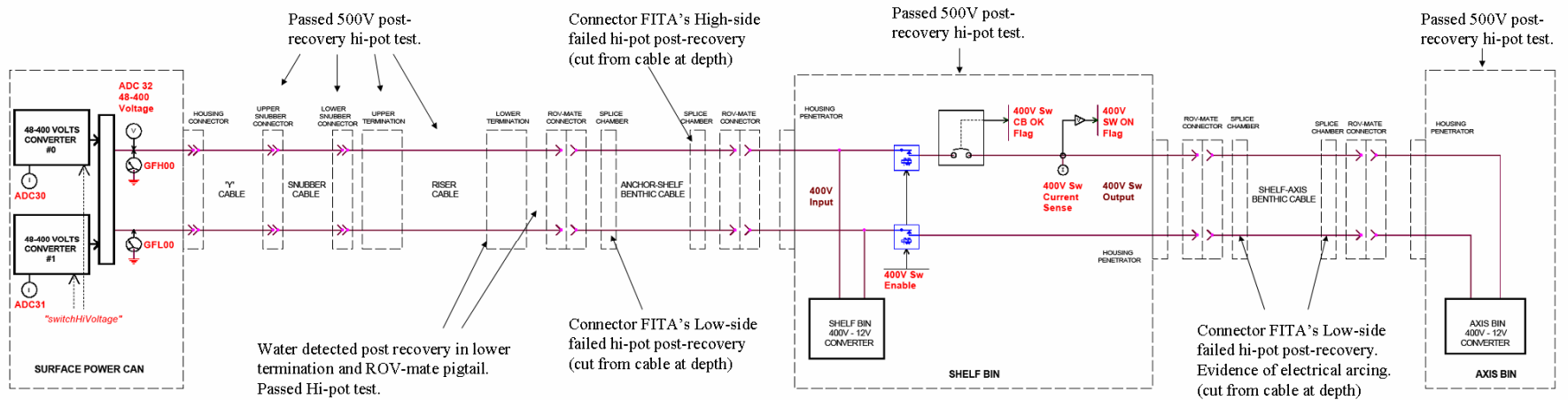


Figure 2. Photograph of the ODI connector, cable, and Field Installable Termination Assembly (“FITA”) that ultimately failed. The FITA is the cylinder laying in the mud at the end of the orange cable.



Figure 3. Photograph of internal bulkhead in the failed ODI FITA showing evidence of insulation breakdown, erosion and copper plating. This is the evidence that points to the FITA having failed during powered operation, not after being cut from the non-powered cable assembly during recovery (photo from ODI).

Appendix C



Two line diagram of the MSE experiment power system as it runs from the Surface buoy through the Shelf and Axis BINs. As discussed in the text, all of the system components except the two benthic cable/connector/FITA assemblies passed post-recovery testing. The two failed segments had been compromised during recovery operations by cutting the benthic cable, however there was evidence of electrical bridging and conductor break-down in the Shelf-to-Axis segment that probably occurred while the system was still powered up and before total failure (see appendix B).

Appendix D

MOOS BENTHIC OPTICAL CABLE SPECIFICATION

Revision 3.0 July 24, 2006

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Mark Chaffey, Ed Mellinger

Rev. 1.1 – 08FEB01

Rev. 2.0 – 08AUG05 Added mechanical values. Minor revisions and reformatting. mrc

Rev. 2.5 – 19AUG05 Minor revisions on mechanical specification. mrc

Rev 3.0 – 24JUL06 Added details about torque balancing. jah

Introduction

The Monterey Aquarium Research Institute (MBARI) has developed a deep ocean underwater science observatory. Data communication and power are supplied to the seafloor by an oceanographic buoy system. Individual instrument installations on the seafloor are connected together with an electro-optical cable to be laid on the seafloor by ROV referred to as the **Benthic Optical Cable**. Currently this system is installed in 3200m, but all components are designed for a maximum depth of 4000 meters.

An existing benthic optical cable design has proven successful in depths down to 1400 meters. At 3200 meter depths, the existing design develops an internal torque that causes the cable to twist up significantly after spooling off of the drum on the ROV. A video of this problem can be downloaded from www.mbari.org/staff/hamilton/pub/cable_sled.mpeg. It is believed that this twisting is caused by the hydrostatic pressure squeezing the copper wire helix, imparting a torque that the tensional stiffness of the cable can not resist. The existing cable consists of 5 #20 copper conductors arranged at a 28 degree helix angle. To eliminate this problem, a new design is sought that will have a minimal torque imbalance at high pressure.

All information supplied by cable vendors to MBARI in connection with this cable purchase, including proposed designs, estimated performance and cost will be held in strict confidence by MBARI. Non-disclosure agreements can be executed if necessary. For final evaluation of the cable, if necessary, design specific permission may be requested from the vendor to submit to third party test and evaluation consultants assisting MBARI with the cable purchase.

Cable Proposal Requirements.

Prospective vendors are invited to submit proposed cable designs and must include the following information:

Design and estimated performance documentation.

Description of the cable construction materials, approximate sectional dimensions and illustration for both armor protected and non-protected cable cross-sections.

Cable weight per meter in air and seawater for both armor protected and non-protected cable cross-sections.

Estimated safe working load and ultimate breaking strength of the proposed design.

Estimated strain induced rotation of the proposed design.

Estimated pressure induced rotation of the proposed design.

Cable cost.

Cable delivery time ARO.

General and Environmental.

The cable must be water blocked with all interstitial voids filled with suitable filler material.

Temperature. The cable must meet the optical and electrical performance specifications and remain flexible enough to spool and un-spool from the specified minimum diameter storage drum from –2 degrees Centigrade to +25 degrees Centigrade.

Pressure. The cable must meet the optical, electrical and mechanical performance specifications while continuously submerged in 4000 meters of seawater.

Materials Compatibility. The cable jacket construction materials must be compatible with 5 years of seawater emersion. The individual copper conductor insulation must be compatible with silicone oil OR food grade mineral oil.

Storage Conditions. The cable must not be damaged by storage for five years on a storage reel meeting the minimum radius specifications.

Service Life. The cable shall provide a minimum of five years of service while continuously submerged.

Mechanical Specifications.

Length. Lengths up to 4000 meters will be required.

Diameter. The completed cable shall have a maximum diameter of 0.320 inches.

Weights. The cable weight in seawater shall not be less than 20 lbs per 1000 feet or greater than 25 lbs per 1000 feet. In air, the cable shall not be greater than 55 lbs per 1000 feet.

Working Strength. The cable working load shall be a minimum of 250 lbs.

Minimum Bend Diameter. The cable minimum bend diameter shall not be greater than 14 inches.

Armoring: 25 meters of each end of the cable shall be steel armored and not exceed 0.500 inches in diameter. The weight of the armored section must not exceed 270 lbs per 1000 feet in air or 210 lbs per 1000 feet in water.

Markings: The cable shall be a high visibility yellow color, dark contrasting bands and/or numeric meter markings every 1 to 5 meters on the cable are desirable.

Optical Specifications.

Fiber Count. There shall be **four** single-mode optical fibers. Fibers shall be Corning “SMF-28”. Substitution of alternate fiber shall only be by written agreement between vendor and MBARI. The optical specifications below must be met over the specified cable service life during continuous operation at ocean depths to 4000 meters.

Optical Attenuation. Attenuation in each fiber shall not exceed the following values under cable working conditions (see mechanical specifications for working condition values):

0.7 dB per kilometer at 1310 nm wavelength

0.7 dB per kilometer at 1550 nm wavelength

Optical Attenuation Uniformity. No single point attenuation discontinuity in any fiber in the finished cable shall be greater than 0.15 dB at either 1310nm or 1550nm wavelengths, as measured with an OTDR.

Optical Dispersion. Individual fiber specifications for optical dispersion in the completed cable shall meet the pre-cabled fiber manufacturer’s specifications for the fiber used, as measured by EIA/TIA 455-175.

Fiber Proof Test. Individual fibers will be proof tested at the time of manufacture to a minimum of 100kpsi.

Fiber Identification. Fibers or their over-jacketing shall be color coded or otherwise indelibly marked at least every meter for identification.

Electrical Specifications.

General. The cable will be used for electrical power transmission while submerged in the marine environment. The cable shall provide a minimum of two electrical conductors insulated from one another, and from seawater.

Working Voltage. The cable will be used at a working voltage between conductors, or between conductors and seawater, of up to 425 Volts DC. At this voltage, the maximum electrical stress present at any point in the cable insulation system shall be less than or equal to 2.0 kV/mm (51

volts/mil). The insulation system used must be suitable for continuous high DC electric field stress.

Insulation Resistance. The Insulation Resistance of each conductor in the as-built cable shall be a minimum of 3,000 Megohms per kilometer, measured at the working voltage of Section 0 above. The resistance shall be measured between the test conductor, and the other conductor(s) plus the cable armor plus any other metallic cable elements, tied together.

Conductor Resistance. The cable will be used at a working current of up to one ampere per conductor. The maximum as-built, as-cabled, round trip (two way) resistance of the two cable conductors in series shall be a maximum of 52 ohms per kilometer (nominally 26 ohms per kilometer per conductor, although equal resistances are not required), measured at a conductor temperature of 20 degrees C. The as-built conductor resistance shall have a tolerance of +/- 5%.

Production Testing. Each individually insulated conductor shall be tested for insulation resistance, before cable assembly, in a water bath or bead curtain test line. The test conditions and criteria for acceptance shall be as specified in Section 0 above. The completed cable shall be evaluated for Partial Discharge at the working voltage of Section 0 above. No detectable discharge is permitted, within the detection limits of the test equipment employed.

Conductor Identification. The individual conductors shall be color coded or otherwise made visually distinguishable from one another, either throughout their length, or at regular increments not to exceed 0.33 meter.

DELIVERY.

Delivery shall be quoted FOB destination, Moss Landing, California, 95039. Cable shall be delivered suitably packaged for transportation and storage.

Cable shall be delivered in a continuous length of 4000 meters (+5%-0%). A minimum of five meters shall be accessible at both ends of the cable to allow for testing on the shipping drum without re-spooling. A three flange reel is preferred.

Appendix E

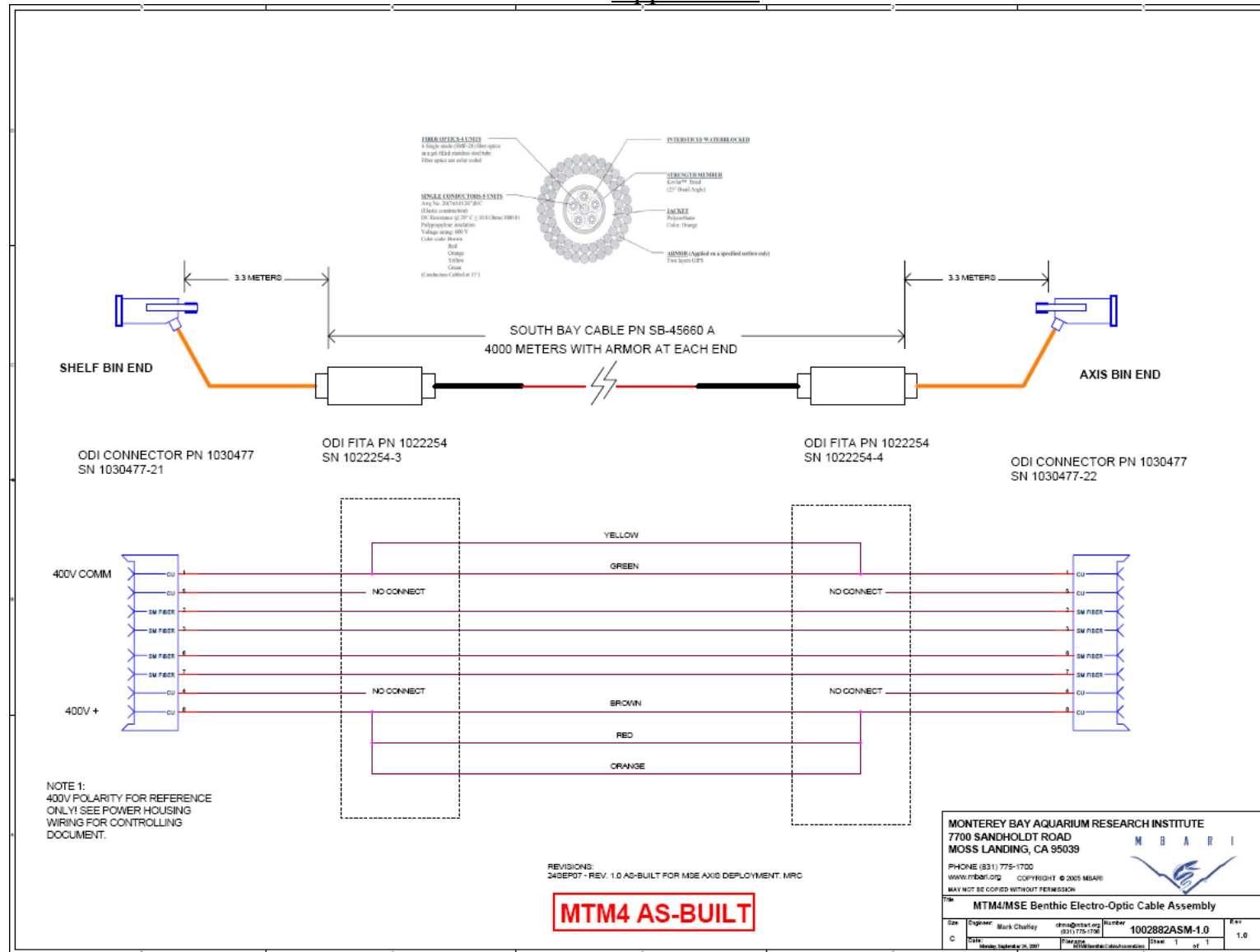


Figure 4. MTM4/MSE benthic cable assembly showing the location of the Field Installable Termination Assembly (FITA), labeled PN 1022254, and the electrical schematic.

Appendix F

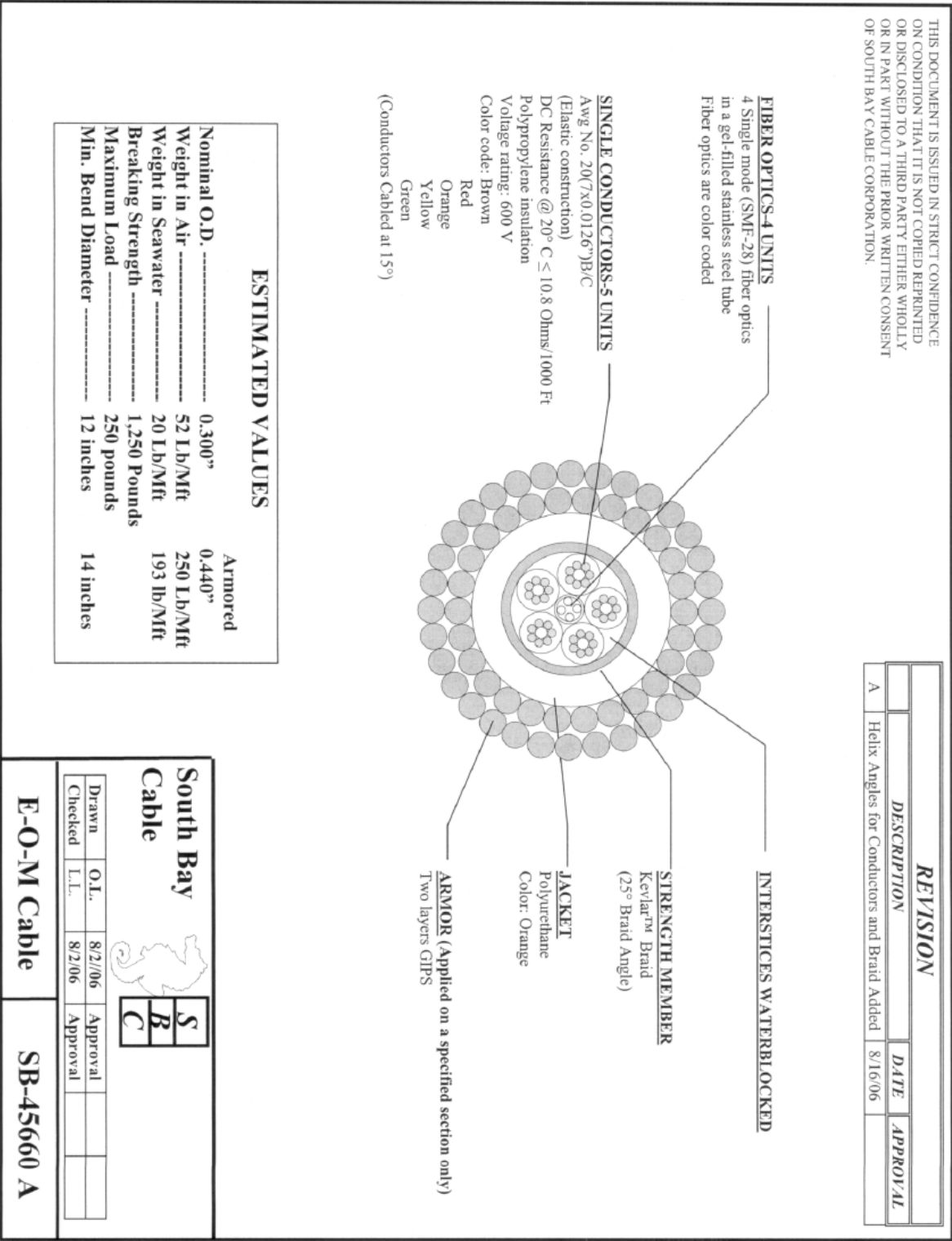


Figure 5. Improved cable design used for Shelf-to-Axial cable run (armor section). This cable had better torque performance at MSE depths then the previous design which tended to form numerous loops during cable laying operations. It is the cable design that was used on the failed segment.