FINAL REPORT

REAL-TIME, TARGETED IMAGING OF TURBINE-MARINE LIFE INTERACTIONS

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1.0 EXECUTIVE SUMMARY

A cabled platform with the capabilities to provide real-time, targeted measurements of turbine-marine life interactions has been built and tested for use in high flows, including the Crown Lease Area of Minas Passage, Bay of Fundy. Its key sensors are an imaging sonar, that generates detailed 2-D imaging, and a pan-tilt unit on which the imaging sonar is mounted, that permits the sonar's orientation to be remotely adjusted while the platform is on the seabed, as is necessary for obtaining targeted imaging of the turbine and its surroundings.

The project proceeded in a careful, systematic fashion, utilizing the FORCE beach intertidal zone to conduct initial field tests. These tests revealed several challengees, including noise contamination in the sonar's output and insufficiently robust fibre terminations on the cables connecting the platform to shore. The latter problem required an in-house (to FORCE) engineering solution that, along with the noise solution, held up perfectly against all subsequent tests.

The resulting platform, called the Fundy Advanced Sensor Technology Environmental Monitoring System (FAST-EMS), is proven for high flow conditions and the uniquely challenging environment of the Minas Passage.

2.0 INTRODUCTION AND OBJECTIVES

Marine life in the Minas Passage varies significantly over a range of timescales, from seconds to days to seasons and longer timescales, which requires continuous, long-term measurements to fully characterize. The highest quality temporal data are acquired from seabed-mounted sensor platforms, which provide a steady base from which to sample. Given battery constraints, these platforms must be cabled for long-term deployments. However, in many cases, variability can be reasonably approximated by multiple, successive deployments of an autonomous (i.e., non-cabled) platform for several weeks at a time at the same location.

With the presence of turbines, there is a requirement for more data and additional measurement characteristics. Specifically, there is a need for **real-time** measurements, to enable immediate understanding of turbine-marine life interactions, and **targeted** measurements, to focus data capture on the region proximate to a turbine. Only a subsea platform with a cabled connection to shore can provide measurements with these characteristics.

The project 'Real-time, targeted imaging of turbine-marine life interactions' focused on establishing a robust, cabled platform equipped with a dynamic mount-imaging sonar (called the 'Fundy Advanced Sensor Technology-Environmental Monitoring System', or FAST-EMS) for use in the high-flow waters of the Crown Lease Area (CLA) of Minas Passage. An imaging sonar is the acoustic-analog of an optical video camera, which cannot be used to monitor turbine-marine life interactions because of its limited range in the turbid waters of Minas Passage. As with an optical device, an imaging sonar must be pointed towards a target to visualize it. Given the uncertainty in positioning a subsea platform (associated with seabed unevenness, challenging deployment operations etc.), the ability to re-orient the sonar after deployment, using a 'dynamic mount', is a requirement to effectively image turbine-marine life interactions from a remote subsea platform.

This report summarizes the methodologies and findings of the project. Details are contained within documentation completed through the course of the project, which are linked within the report and copied here for convenience:

A. FAST-2 post-deployment condition
B. Acoustic Release Redesign
C. Mid-project report
D. Addendum to mid-project report
E. Experimental low-flow test of the Gemini Sonar

The completed and tested FAST-EMS will be put to immediate use in support of Cape Sharp Tidal's environmental monitoring program. More broadly, the extended team (i.e., project team and local industry partners) has developed the capability to assemble, test, and deploy subsea cabled platforms, with large and varied sensor suites, in high flows. One local partner, MacArtney Canada Ltd., worked closely with the project team to adapt their multiplexer-power conditioning system (i.e., MUX) to meet the demands of connecting a large sensor suite to kilometres-long fibre optic cables. The project team included Ray Pieroway, who started the project as a FORCE intern and student of the NSCC Ocean Technology program. His previous work experience with fibre installation was instrumental towards developing a customized fibre termination solution, and he has since been hired full-time by FORCE as an Ocean Technologist.

3.0 METHODOLOGY AND RESULTS

The Real-time, targeted imaging project was completed in five stages:

1. Ruggedizing FAST-EMS
2. Integration of new sensors and cables into FAST-EMS
3. Integration of FAST-EMS into the FORCE Shore Station
4. Low-flow testing of FAST-EMS
5. Intermediate flow testing of FAST-EMS

On paper, these stages would be completed sequentially, but in practice there was significant back-and-forth between the shop (Stages 1-2) and the field (Stages 3-5). For reporting clarity, the methodologies and results of these stages are divided as above to the degree possible.

3.1 RUGGEDIZING FAST-EMS

FAST-EMS was built upon FAST-2, which was a cabled platform that collected current and wave data continuously and in real-time for eight months in 2016 (these data are archived on the Ocean Networks Canada site: http://dmas.uvic.ca/DataSearch?location=BFBR). As detailed in

FAST-2 post-deployment condition, the 2016 deployment revealed the platform's shortcomings, including two modes of failure: water ingress into its multiplexer (MUX), due to pitting corrosion on one of its ports, and failure of the platform recovery mechanism to release. These shortcomings were addressed in this first step, towards ruggedizing the platform for long-term, high-flow deployments in the FORCE region. Specifically, the following components were enhanced or added:

a) MUX mount. Metallic clamps were added to connect the MUX's pressure housing to the platform's galvanic cathodic protection system to prevent against corrosion.
b) Platform recovery mechanism. As described in Acoustic Release Redesign, the old release, a Teledyne Benthos 866-A was replaced by a Teledyne Benthos 875-TE, which is impervious to the sediment build-up that jammed the old release.
c) Ballast/galvanic cathodic protection. On FAST-2, the zinc bars served both as ballast and anode. To prevent excessive loss of ballast to corrosion, the bottom bars were replaced with lead bars.
d) Cable management system. Cable raceways were changed from enclosed plastic tubes to open, slanted, stainless steel trays to prevent sediment build-up.
e) Platform safeguards. A roll-over bar was added to protect the imaging sonar.

See Figure 1. Additional details of these enhancements are found in the Mid-project report and Addendum to mid-project report.

Figure 1: FAST-EMS platform. Left: The 'bare' platform, with ruggedized components. Right: The platform with full sensor suite (cf. Section 3.2). Recovery buoys are the orange spheres in the rear and the Gemini imaging sonar is at front and facing forward.

3.2 INTEGRATION OF NEW SENSORS AND CABLES INTO FAST-EMS

FAST-2 was comprised of a 1 km fibre optic (FO) cable and an ADCP, which interfaced through a termination canister and MUX. As laid out in the FAST-EMS schematic (Appendix A), to this was added new FO cables, new sensors, a replacement termination canister and an enhanced MUX.

To achieve the objective of real-time, targeted imaging of turbine-marine life interactions, two new sensors were required: an imaging sonar, for imaging of the turbine and its surroundings, and a pan-tilt (PT) unit, for adjusting the orientation of the imaging sonar; i.e., for *targeted* imaging. Based on industry preferences and performance requirements, the Gemini 720is imaging sonar and Kongsberg pan-tilt unit were chosen for FAST-EMS. Two supplementary sensors – a subsea optical camera and LED light – were added to visualize the PT-Gemini itself, which was practically necessary during its trailing and which continues to serve as an important check on equipment during deployment. An acoustic Doppler current profiler (ADCP) rounds out the FAST-EMS sensor suite, which is summarized in Table 1.

Sensor integration can be divided into mechanical, electrical and data integration.

Mechanical integration was focused on maximizing the Gemini's range of view (cf. Fig. 2), subject to several constraints including:

- Minimizing the Gemini's vibrations. The Gemini was mounted on the side of the PT unit to reduce moment arm and minimize the wake.
- Avoiding reflective surfaces on the platform. The PT-Gemini was mounted at the front of the platform, pointed away from the highly reflective recovery buoys. The roll bar (cf. Section 3.1) was set back of the PT-Gemini as much as possible.
- Preventing cable entanglement. A bar was added to the roll-bar supports to facilitate cable management.

Mechanical integration is described in detail in Mid-project report.

The objective of electrical integration is to provide appropriate levels of power to the sensor suite, that ensures it operates optimally and without incurring damage. The MUX, developed by MacArtney Canada Ltd. for FAST-2 and retained for FAST-EMS, provides not only multiplexing but also has power conditioning capabilities. Without FO cables in the circuit (i.e., with a power source connected directly to sensor suite via the MUX (cf. Fig. 3, left), the existing (FAST-2) MUX handled the power conditioning without issue. As described in Section 3.3, the FORCE Shore Station cable introduced significant, uncertain levels of impedance, which began the major electrical integration challenges encountered in this project.

The MUX handled the varying data requirements of the sensor suite without issue. It was modified to be able to accommodate one of two ADCPs at a time – either the Signature 500 (Ethernet) or AWAC (serial). Since the FAST-EMS sensor suite – with one ADCP – uses all available wire feedthroughs (e.g., bulkhead connectors) on the platform MUX, no other sensors can be *directly* connected to the MUX.

FAST-2 included a 1 km cable, but additional cable length was needed to reach the CLA, where FAST-EMS would be used to monitor turbine-marine life interaction. FORCE purchased two FO cables for connecting the platform to the FORCE Shore Station: a 1 km, double-armoured cable with 2 copper cores and 6 fibre strands and a 1.5 km, triple-armoured cable with 4 copper cores and 4 fibre strands (cf. Fig. 3, right). The two cables, which are connected at sea within a 'connector pod', can reach locations on the volcanic platform while providing flexibility and relative ease of handling (compared to a single 2.5 km cable; cf. App. A). The previous 1 km cable from FAST-2 serves as back-up.

Cable termination can be divided into mechanical, electrical and fibre termination of the cable. Whereas standard methods were sufficient for mechanical and electrical termination, a customized fibre termination was developed by FORCE (Ray Pieroway (FORCE) and Murray Scotney (OceanMoor Technical Services, on behalf of FORCE)) that is robust to handling, cost-effective, and amenable to repair or replacement in-house (by FORCE). A schematic of the full cable termination is shown in Fig. 4. The armoured FO cable feeds into the mechanical/strain termination, out of which the inner (unarmoured) cable emerges. The inner cable passes through a 'penetrator' into a pressure housing (i.e., termination canister), inside of which the fibre and copper are separated. The fibre termination is detailed via a storyboard in Appendix B. Although the customized fibre termination protects against shearing and tensile forces acting on the fibres, and bending/coiling leading to signal attenuation, it is capped by connectors that are sensitive to water, dust etc. To mitigate against this sensitivity, the term can, in which these connections are made, was sealed and affixed to the FO cable connecting to the platform (i.e., the 1.5 km cable).

It should be noted that the customized fibre termination took months to engineer and systematically trial. This was not anticipated in the original project plan because of the success of the FAST-2 fibre termination, which, as it turns out, was not sufficiently robust. The new termination solution offered by FORCE is suitable not only for FAST-EMS, but for any cabled platforms earmarked for high flow environments. Furthermore, it is far less expensive than commercially available solutions. This is a key component of FORCE's plan to offer cabled platform solutions to the in-stream tidal industry at large.

Table 1: FAST-EMS sensors				
Sensor	**Unit (Supplier)**	**Voltage**	**Data**	**Reason for acquisition/notes**
Imaging sonar	Gemini 720is (Tritech Group Ltd.)	24-72 VDC	Ethernet	Favoured by in-stream turbine developers
Dynamic mount	Pan-tilt OE10-102 (Kongsberg Maritime)	24 VDC	RS-232	Short stem minimizes vibrations (of imaging sonar) Track record of performance in high flows
Subsea camera	Sculpin (SubC Imaging)	12-32 VDC	Coaxial	Live video of P/T and Gemini for troubleshooting purposes
LED light	(SubC Imaging)	12-32 VDC	RS-232	Light required for live video at depth
ADCP				
	AWAC (Nortek)	9-18 VDC	RS-422	Flow measurements on a subsea platform are standard The MUX can accommodate either an AWAC or Signature 500
	Signature 500 (Nortek)	12-48 VDC	Ethernet	

Figure 2: The results of mechanical integration of FAST-EMS, focused on maximing the Gemini's range of view.

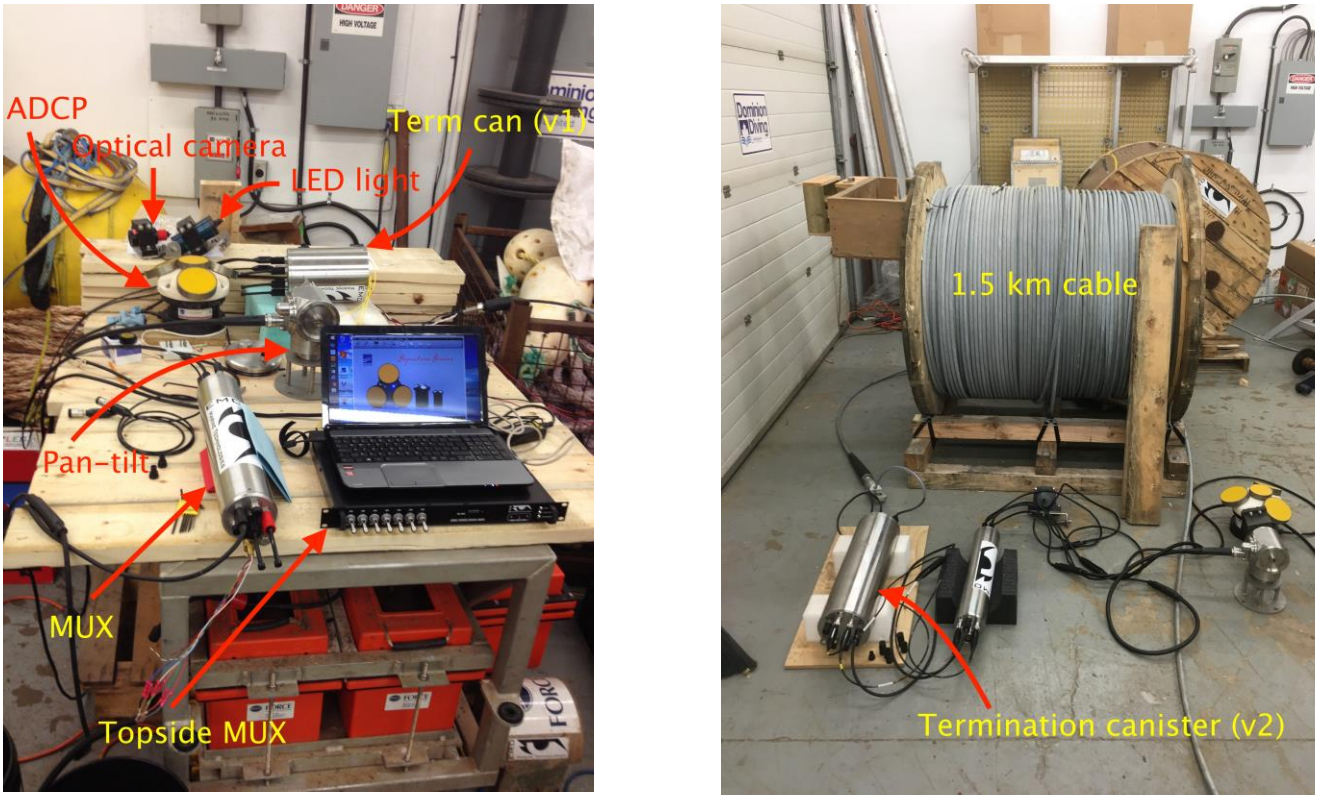


Figure 3: Electrical integration of FAST-EMS. Left: Testing of the sensor suite (Gemini not pictured). Right: Testing with the 1.5 km FO cable and new term can, which houses both power conditioning components and power and fibre connections between the FO cable and MUX.

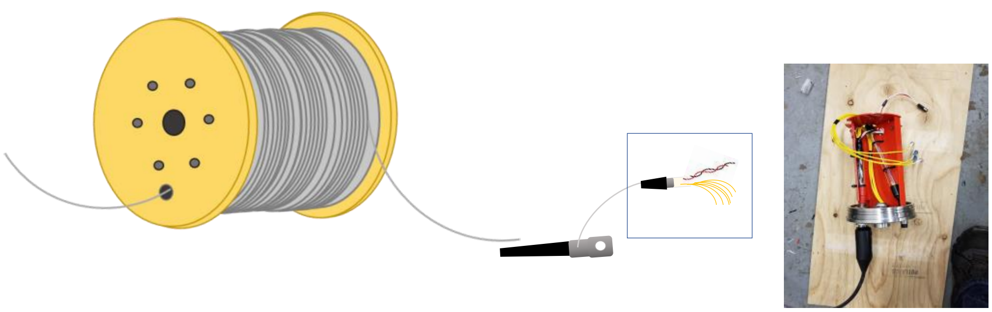


Figure 4: Schematic of cable termination. Left-right: Cable reel, mechanical termination, penetrator with fibre and power broken out (inside of term can, which is not shown), and (photograph of) FORCE's customized fibre termination, capped by ST connectors.

3.3 INTEGRATING FAST-EMS INTO THE FORCE SHORE STATION

The FORCE Shore Station is an interface between subsea cables and the outside world, consisting of:

- The FORCE Visitor's Centre (FORCE VC), which provides power and internet.
- The FORCE VC cable, connecting the FORCE VC to the FORCE beach box, which is comprised of separate cables for power (2-conductor 10 AWG) and fibre optics (with 3 working fibre strands).
- The FORCE beach box, a termination box which serves to interface the FORCE VC cable and subsea cables.

Figure 4 shows the FORCE VC, the beach box, and the subsea component of FAST-EMS: the sensor platform and its two subsea cables.

Figure 5 shows the FAST-EMS control station set up in the FORCE VC. Power is supplied to FAST-EMS by a portable power supply and, separately, the "topside MUX" controls the sensor suite via the (platform) MUX, including (de)activation of individual sensors.

Figure 6 shows block diagrams of the flow of power and data when FAST-EMS is integrated into the FORCE Shore Station.

Attempts at electrical integration of FAST-EMS into the FORCE Shore Station revealed three primary challenges:

- Satisfying the varying voltage requirements among sensors, including the requirement that the PT unit receives *no more than* 24 VDC and that the Gemini receives *at least* 24 VDC (**Problem E1**).
- Accommodating the high voltage (and hence the voltage spikes when power is first applied) required to overcome high impedance in the FORCE VC cable (**Problem E2**).
- Noise in the Gemini output (**Problem E3**).

Electrical integration problems E1 and E2 were solved by adding the appropriate power conditioning components – a DC-DC regulator and large capacitor – to the platform MUX, so that a smooth, steady 24 VDC would be supplied to the sensors. However, the *location* of this power conditioning introduced a new problem, E3. Specifically, after significant amounts of component testing and system trialing, it was found that the noise in the Gemini output was the result of electromagnetic interference (EMI) caused by the proximity of the newly added power conditioning components to the (non-fibre optic) data lines within the MUX (Fig. X). This problem was resolved by moving these components into the term can, where data are transported by EMI-immune fibre optics. A longer termination canister was fabricated (cf. Fig. 3) to accommodate both the cable termination and power conditioning components.

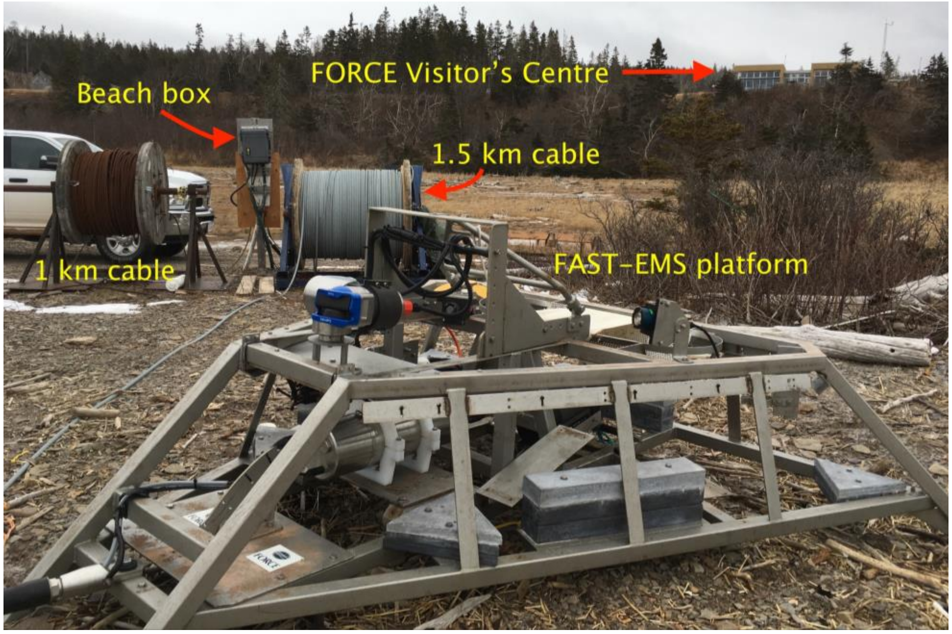


Figure 4: Full FAST-EMS system, including platform and FO cables, connected to the FORCE Shore.

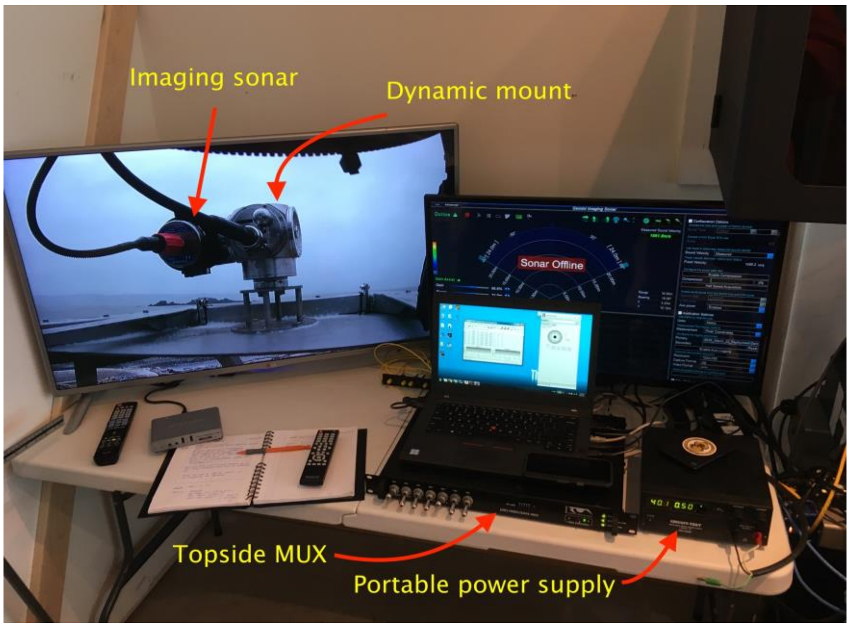


Figure 5: The FAST-EMS control station, located in the FORCE Visitor's Centre. The Gemini software is shown on the screen. The feed from the optical camera shows the PT-Gemini.

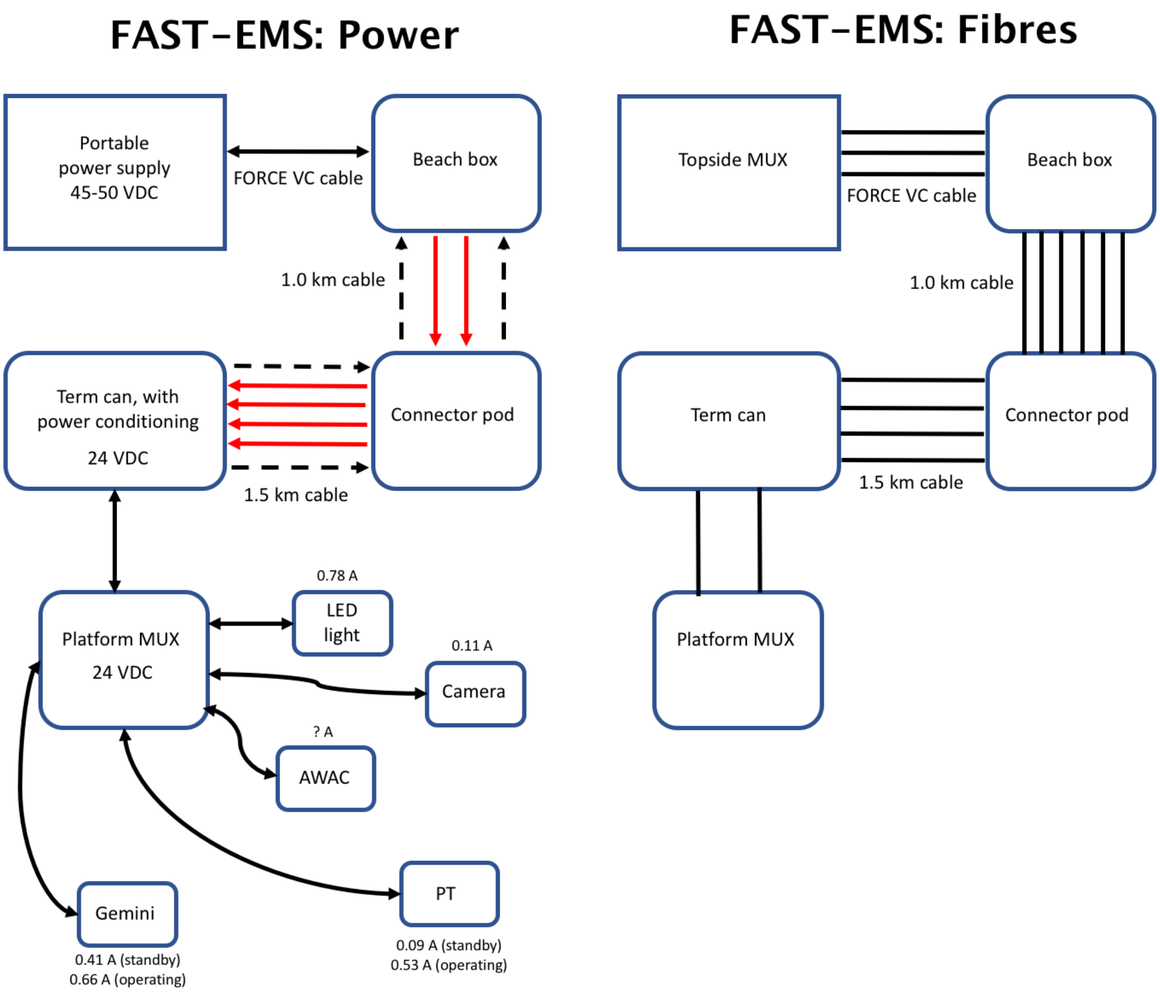


Figure 2: Block diagrams of power and fibre for the FORCE Shore Station-connected FAST-EMS. In the power schematic, current flows through the FO cable's copper cores and returns (ground) through the armour. In the fibre schematic, the number of connecting lines indicates the number of fibre strands (there is one active and one-back up strand for the full system).

3.4 LOW FLOW TESTING OF FAST-EMS

Low-flow testing of FAST-EMS occurred July 10-12, 2017, before the Gemini noise had been eliminated. The report Experimental low-flow test of the Gemini Sonar, authored by Franziska Gnann, under the supervision of project partner Dr. Hailey Viehman of Acadia University, summarizes the results of systematic testing of the Gemini's performance specifications. Key findings include:

- Range performance: 'Large' targets (on the order of 50 cm; cf. Fig. 8) were discerned without significant measurement error at distances up to 30 m from the Gemini (even with the obscuring effect of Gemini noise). There were significant errors in the measurement of smaller targets.

- Bearing performance: Resolution of large targets was unaffected by the bearing angle; i.e., could be discerned equally well at all bearings within the 120° Gemini viewing swathe. Smaller targets were affected by bearing angle.

Experimental conditions, including the presence of Gemini noise, the use of oblong targets, and the target obscuring effect of anchors, buoys and rope, were suboptimal. Hence, the 'actual' resolving capabilities of the Gemini will be at least as good as those determined from this test, which are nonetheless very promising towards the objective of monitoring turbine-marine life interactions.

In addition to testing the Gemini's performance, low-flow testing revealed that all sensors could be operated simultaneously and that the Gemini output suffered noise contamination, which was resolved as described in Section 3.3.

Figure 3: FAST-EMS being put into place for low flow/intertidal testing.

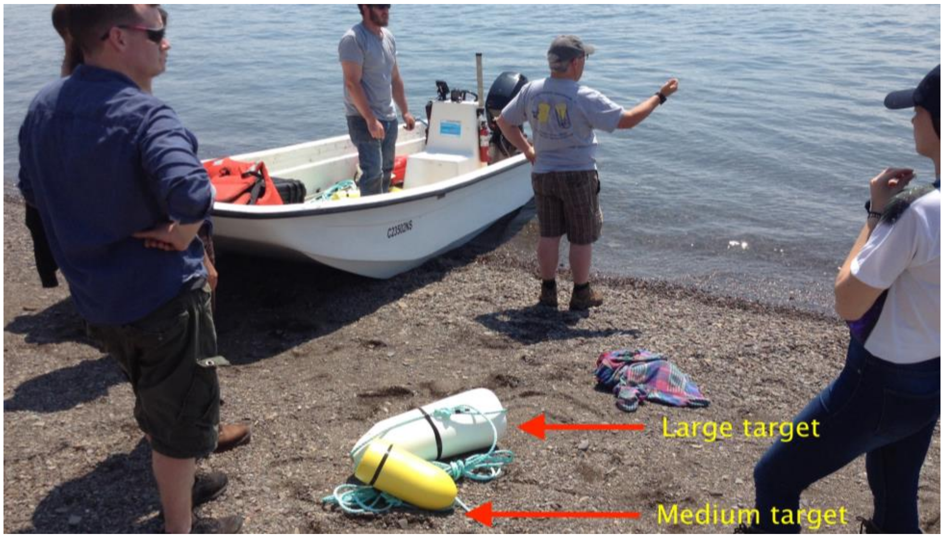


Figure 4: Preparing for low flow testing. The targets were deployed at different locations using the pictured vessel. As discussed in the main text, the large target was very well discerned up to 30 m range and across all bearings, even with Gemini noise present.

Figure 9.0

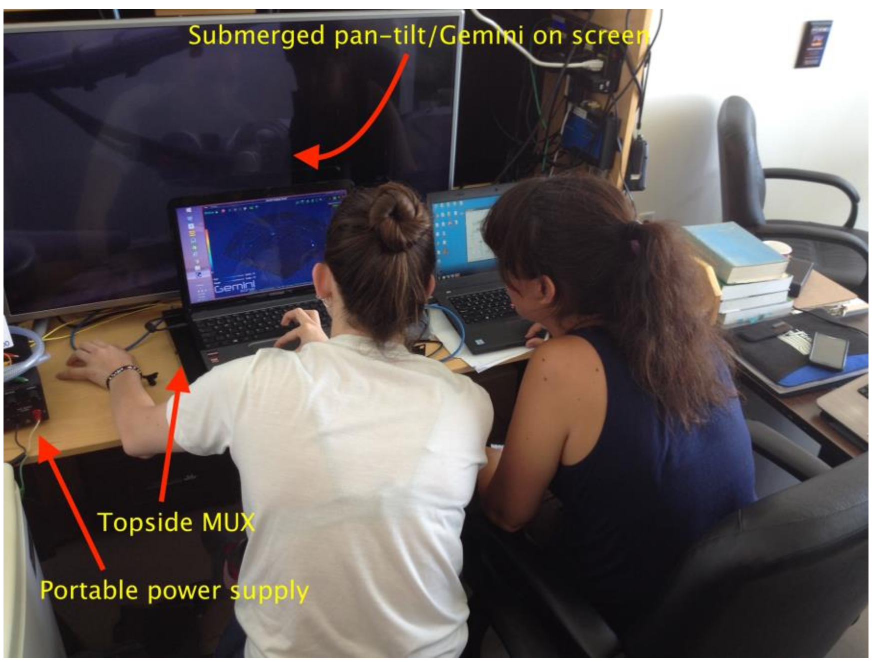


Figure 5: Operating the Gemini from the FAST-EMS control station in the FORCE Visitor Centre, as part of low flow testing.

3.5 INTERMEDIATE FLOW TESTING OF FAST-EMS

FAST-EMS was deployed in intermediate flows to test its performance in conditions better resembling those at the turbine site.

The preparation for and deployment of FAST-EMS in intermediate waters occurred on March 20-23, 2018, and recovery occurred on April 4, 2018. The platform was deployed at water's edge on a spring tide, as from shore as possible without the assistance of a marine vessel (Figs. 10 and 11). At this location, 'current' (time-averaged) speeds exceeded 2.25 m/s, as measured by the ADCP onboard FAST-EMS (Fig. 12). Since the platform was positioned in the surf/swash zone, turbulence was very high, thus posing a steep challenge to the proper functioning of FAST-EMS.

The test proved highly successful. As measured by the Gemini, data connectivity remained at 99% or 100%, thus proving the reliability of the fibre termination. The Gemini data itself was of high quality, without any significant noise contaminating the output. All sensors, including the pan-tilt unit, ADCP, optical camera and LED light, performed to specification. Finally, the platform itself showed no discernible signs of material degradation.

Figure 6: Deployment, by excavator, of FAST-EMS for the intermediate flow test.

Figure 7: FAST-EMS in position for intermediate flow testing, far from the FORCE beach berm.

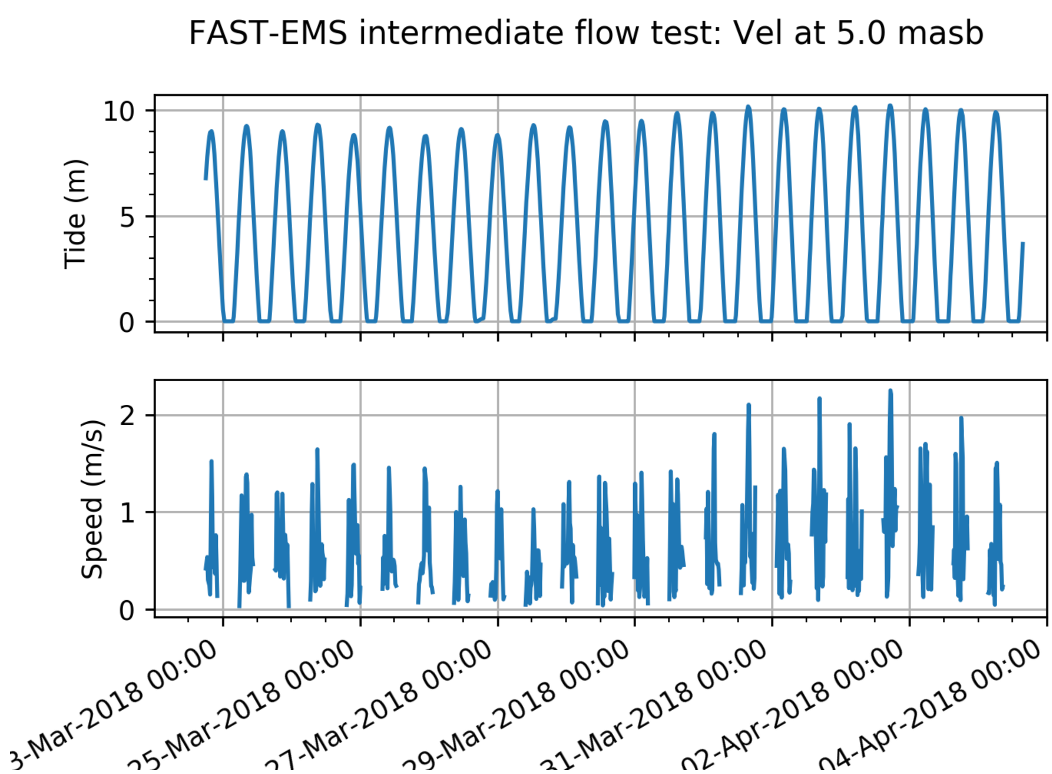


Figure 8: Depth and current speed at 5 metres above seabed, as measured by the AWAC on-board FAST-EMS.

4.0 SUMMARY

A new cabled subsea platform – the Fundy Advanced Sensor Technology Environmental Monitoring System (FAST-EMS) – was built and tested to provide the capabilities for real-time, targeted imaging of turbine-marine life interactions. In accordance with industry preferences, Tritech's Gemini 720is imaging sonar was acquired and integrated into the FAST-EMS cabled system. This sonar was mounted on Kongsberg's pan-tilt unit to provide the onshore user with the capability to remotely manipulate the Gemini's orientation (i.e, its heading and tilt). This capability is critical given the uncertainity of the orientation of the as-deployed platform and the requirement to view a specific target (i.e., the turbine). The requirement for real-time, targeted measurements from the seabed in the Crown Lease Area (CLA) necessitated the acquisition and integration of new fibre optic (FO) cables into the FORCE Shore Station.

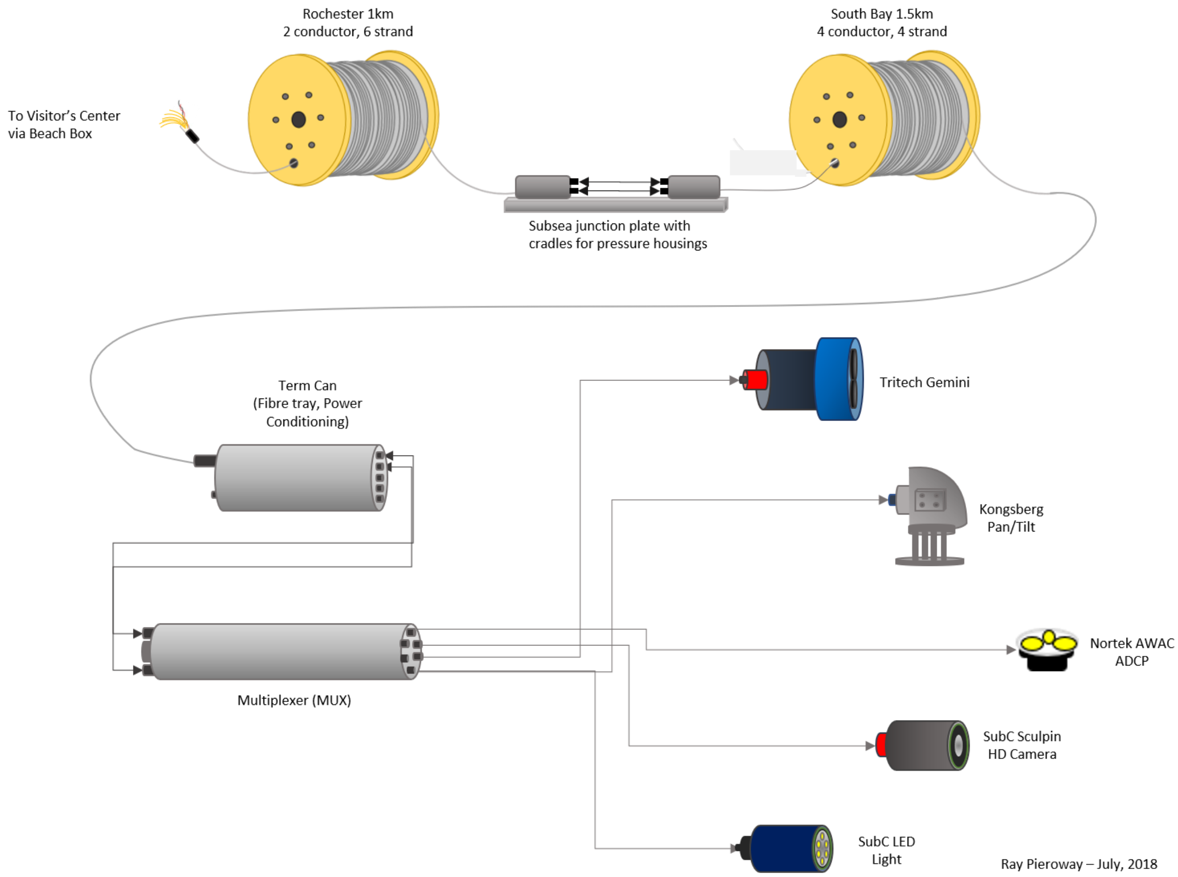
Listed below are the two significant problems encountered during this project, and their solutions:

a) **Problem**: Noise contaminating the Gemini output.
   Solution: Power conditioning components were moved into the termination canister to eliminate the electromagnetic interference (EMI) that contaminated serial data streams in the platform's onboard multiplexer (MUX).
b) **Problem**: The subsea cable's fibre terminations suffered repeated breaks during handling and operation.
   Solution: FORCE developed an in-house termination solution that proved robust during all stages of testing.

Each of these problems took months of engineering and testing to properly resolve. The fibre termination solution was developed in-house (i.e., by FORCE), which provides, going forward, a product that is significantly cheaper than commercially available solutions, can be repaired in-house, and is applicable to the development of future high-flow, cabled platforms.

Since completion of the project, FAST-EMS has been deployed at the FORCE deep-water site, where flow conditions are very similar to those in the Crown Lease Area (CLA), for a period of several weeks. The system performed as well as it did for intermediate flow testing, giving confidence that FAST-EMS will perform to specification in high flow tidal site, including in support of environmental monitoring of the OpenHydro turbine in the CLA.

APPENDIX A – SCHEMATIC DIAGRAM OF FAST-EMS

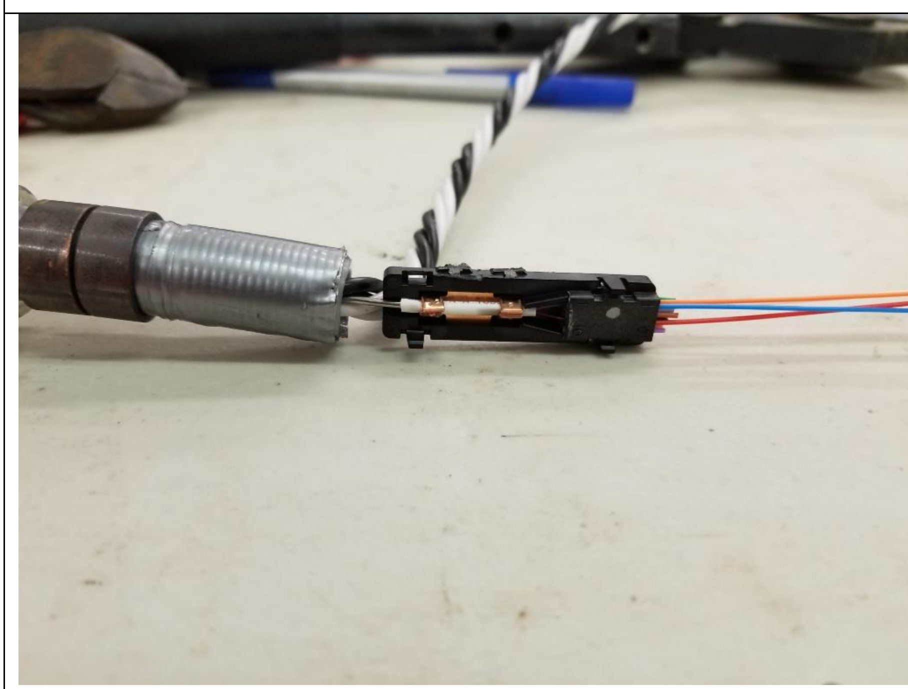


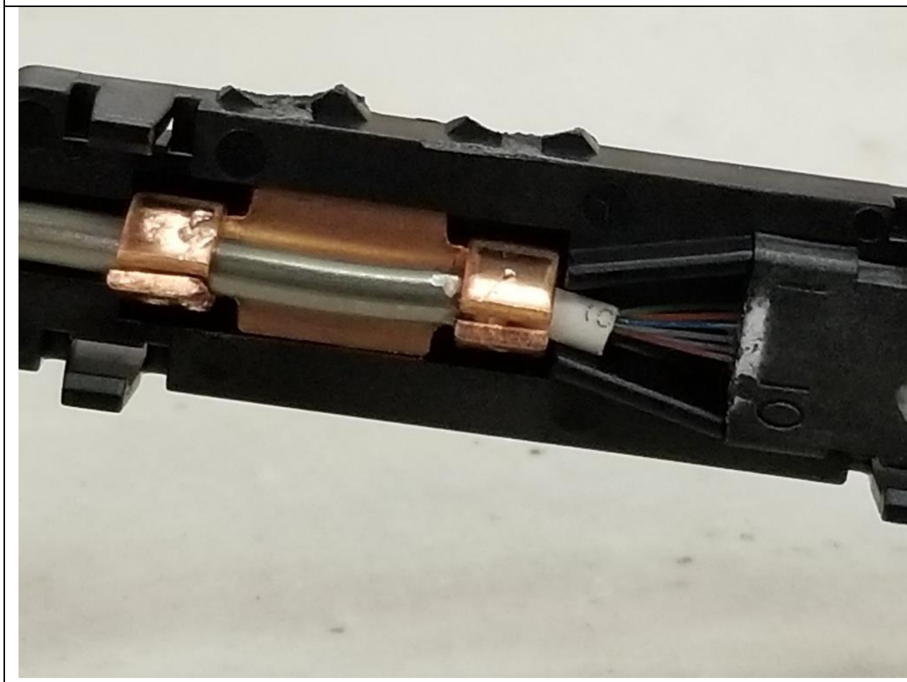
APPENDIX B – FIBRE TERMINATION STORYBOARD

1. Armoured jacket in Esmet termination. Fibre and copper in clear tubing.


2. Water blocked penetrator to be installed on term can end.

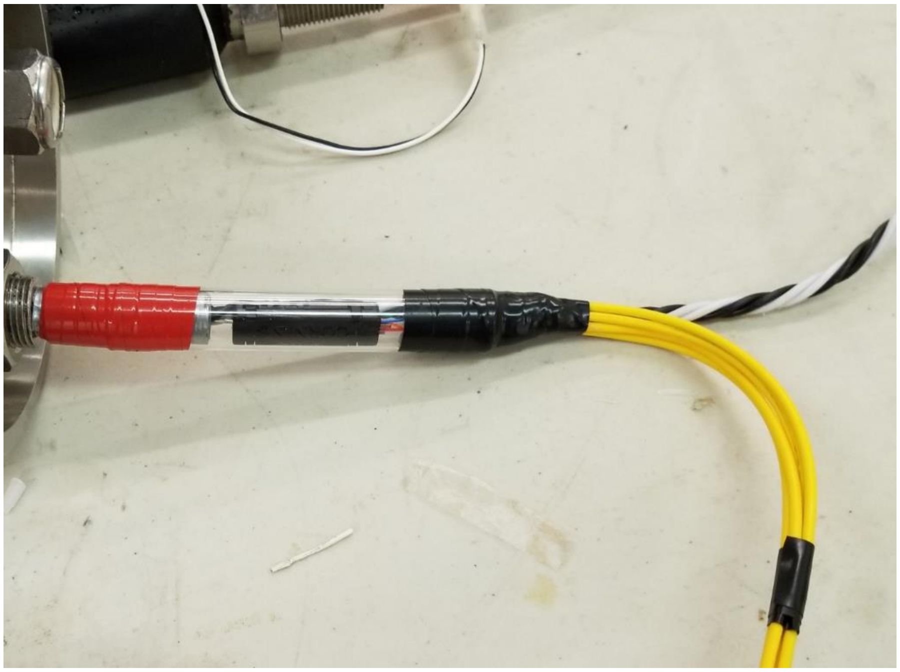

3. Coating stripped off revealing 2 or 4 conductors (depending on cable) and stainless tubing containing fibres


4. Fibre break out kit installed on stainless tube.


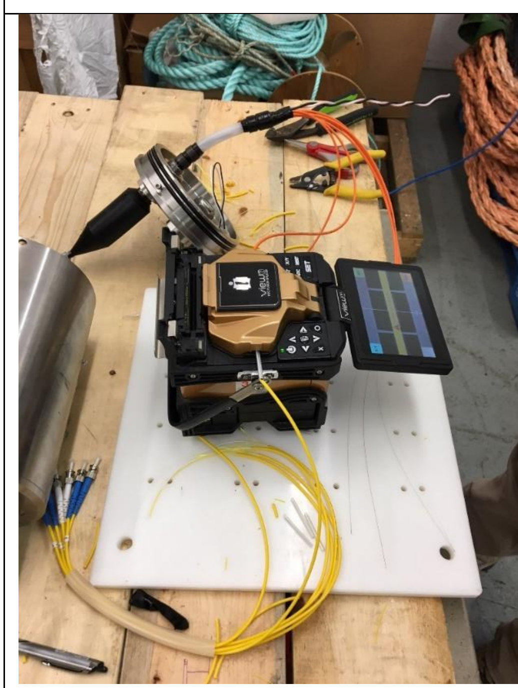
5. Inside fibre break out kit. White shrink tubing inserted inside stainless tube to mitigate chafing and fibre breakage.


6. Break out kit sealed. Rigid acrylic tubing slid over break out and copper conductors. Fibres fed individually through loose yellow tubing. Silicone application to follow on end of acrylic tubing end.

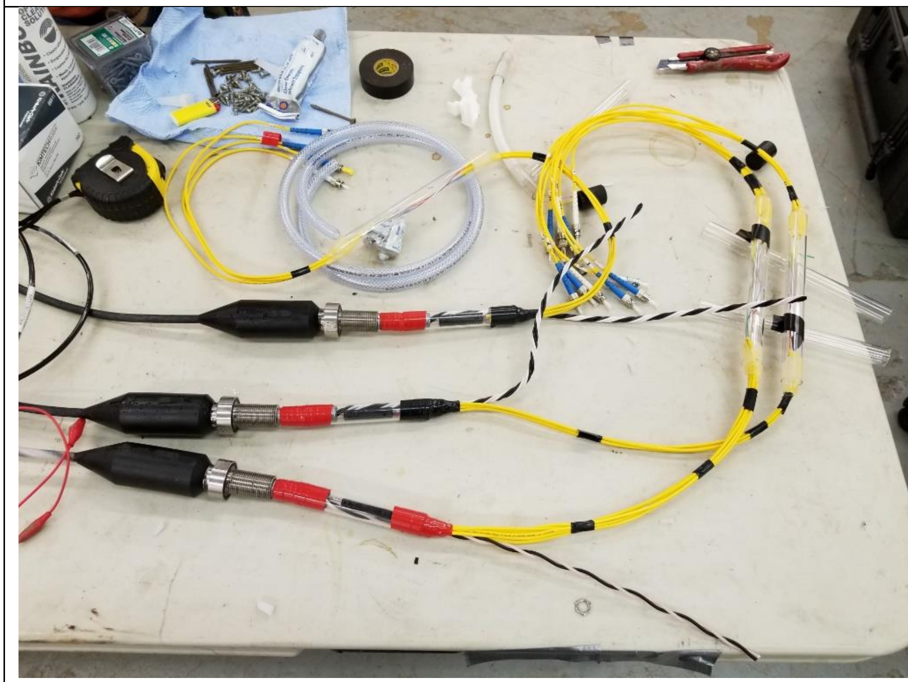

7. Completed penetrator end.



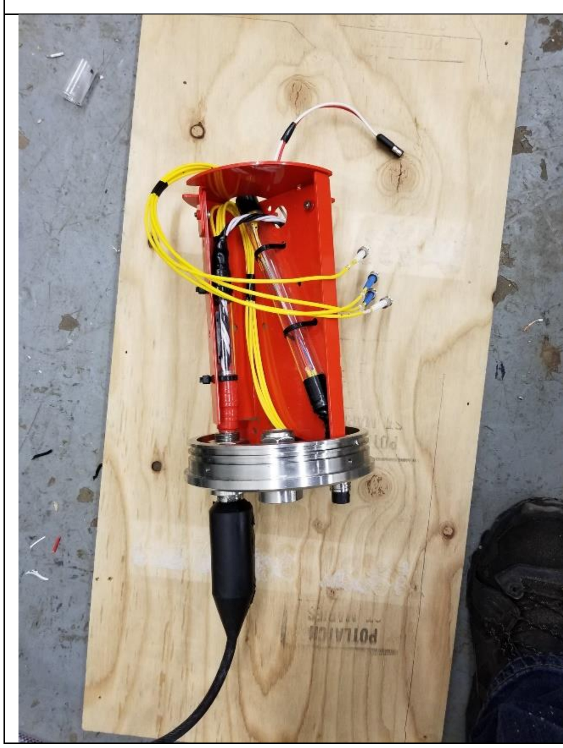
8. Completing fusion splices. Connector ends pre-inserted into additional section of 3/8” tubing. This will house the splices following fusing.



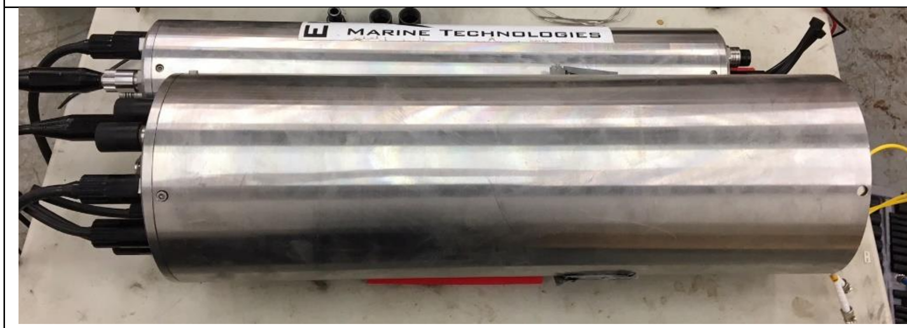
9. Three finished penetrator ends. Completed fusion splices in secondary acrylic tubing, with loose ST fibre connectors branching out.



10. Penetrator fed through term can end cap and fixed to fibre bracket.



11. End cap and fibre bracket to be inserted in term can ensuring no kinks occurring.



12. Power conditioning equipment pictured opposite fibre bracket end.