Voices from the deep – Acoustic communication with a submarine at the bottom of the Mariana Trench

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ABSTRACT

In March 2012 the first solo submarine dive to the bottom of the Mariana Trench was successfully completed by movie director and explorer, James Cameron. An Australian built submarine was piloted untethered 10.9 km downwards to the deepest ocean point on earth, whilst maintaining reliable voice and data communications to two surface vessels throughout the journey. This paper gives an account of the dive, and describes how the communications equipment was made to perform reliably in these unique circumstances.

INTRODUCTION

In mid 2011, L-3 Nautronix was engaged by an Australian company building a new submarine for deep sea exploration to provide communications to the deepest point of the ocean.

Figure 1. Modems installed on *DEEPSEA CHALLENGER*

The underwater acoustic communications solution engineered by L-3 Nautronix in collaboration with Acheron Project Pty was designed to support a range of important functions including:

- Voice and SMS text communications between the submarine and surface for status updates, mission support and co-ordination.
- Monitoring of the submarine's heartbeat (vital signs) by way of a periodic message sent to the surface with important data such as oxygen and battery levels, depth, heading and speed.
- Provision of time-of-flight data to be used to compute range of the submarine and assist with tracking its location.
- The capability to control certain critical submarine functions from the surface.
- The capability to control Lander (unmanned submersible science platform) functions such as lighting and camera systems from either the surface or from the submarine.

THE CHALLENGE

From the beginning of the project it was clear that L-3 Nautronix had to address two significant problems, the first being the technical hurdles to reliably communicate over such a long distance underwater and the second, the very short period of time in which the system had to be built, installed and integrated into the submarine and surface ships to meet the expedition schedule.

Long range hydro-acoustic communication can best be described as a challenging proposition; with slow propagation time, multi-path and inter-symbol interference, ray bending, severe frequency dependent attenuation and limited bandwidth some of the challenges faced by system designers. The characteristics of the underwater channel are also variable and may be subject to noise levels that fluctuate depending on sea state, rain, wind, biological activity and noise from shipping or other human activities. The relatively low carrier frequencies necessitated by underwater acoustic signals are also severely affected by Doppler shift due to movement at either the sender or receiver. Transmit power is limited by cavitation, environmental or Occupational Health & Safety limits as well as power supply restrictions.

Successful results are obtained by a methodical approach including analysis of the environmental and propagation conditions (see Figure 2), selection of a solution with a good operating margin, planning of the installation and validation of the system in its operating environment. Additional time should be allowed for interfacing and integration with external systems and the implementation of any necessary adaptations, final tuning or fixes to get an overall solution operational.

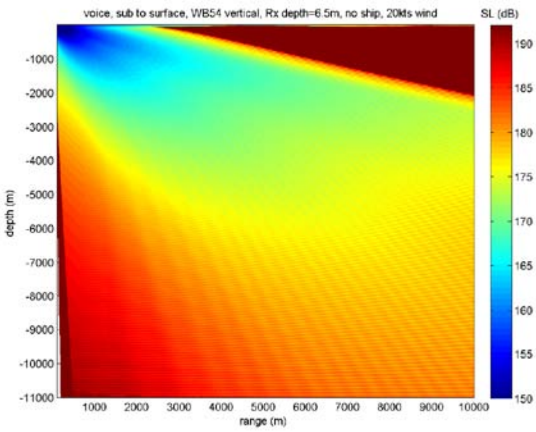

Figure 2. Sonar Prediction modelling for voice communications from the submarine to the WB 54 transducer on the RHIB in moderate ocean conditions. Submarine positions are gridded (horizontal range and depth) and colourised according to the signal level required for voice communications to the surface. (Ignore the modelling artefact for the 100% vertical aspect)

At the time that L-3 Nautronix was approached by Acheron, a well proven digital communications system with communications validated beyond 10km was available based on the UT 3000 from L-3 Elac in Germany and MASQ software from L-3 Nautronix. The hardware consists of a 19” rack mounted console and transducer suitable for fitting to surface ships. However its size, weight and power consumption were ill suited to the needs of the small and sleek one person submarine being designed. A design for a compact system housed in a single instrument bottle (modem) had been developed, however none had been built and the customer was looking for delivery within a few months. L-3 Nautronix undertook the task of building the electronics and transducer assembly according to the demanding schedule and Acheron would build the titanium housings. The modems would then be integrated and factory tested by L-3 Nautronix prior to being tested at sea.

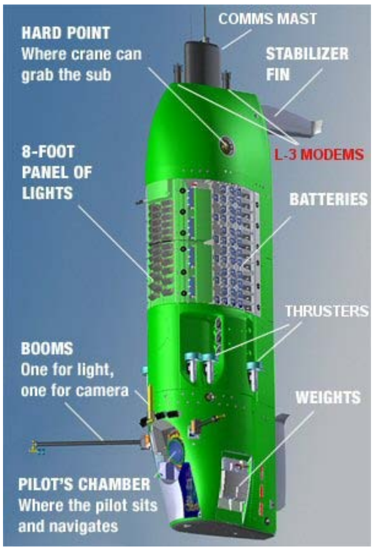

Figure 3. *DEEPSEA CHALLENGER* Systems (Courtesy Acheron Project Pty Ltd)

THE SOLUTION

The *DEEPSEA CHALLENGER* acoustic communications system allowed the pilot to communicate with the surface via voice or SMS style messages. Voice communication was the preferred mode so that the solo pilot could simultaneously operate the submarine. The submarine control system (PAC) was also set up to periodically send data strings with “vitals” data such as oxygen and battery levels, depth and speed. Standard underwater telephone communication channels were used for voice and digital data was sent via L-3 MASQ packets. MASQ is a spread spectrum signalling system developed by L-3 Nautronix to provide reliable through-water communications at speed and depth.

Figure 4. GPM 300 Modem in full ocean depth housing

Two L-3 Nautronix GPM 300 acoustic modems in full ocean depth housings were installed on the top of the *DEEPSEA CHALLENGER* (see Figure 4) and interfaced to the submarine’s electrical and control systems. Power was provided by the submarine’s Lithium Ion battery packs.

One modem was used as the primary modem and carried audio (voice) and data (via RS232). This was cabled into the pressure sphere. An operator interface box inside the sphere interfaced the audio to a lightweight microphone and loudspeaker and the data to a tablet PC.

The second modem was used as an independent stand-alone system and was connected to a controller that interfaced to a strobe light and emergency weight release.

L-3 Nautronix GPM 300 modems were also installed on the expedition Landers (Figure 5). The Landers were autonomous, unmanned platforms equipped to capture images and scientific samples. The L-3 modems facilitated control of Lander functions as well as conveying depth and range to the Lander to assist with recovery and submarine rendezvous.

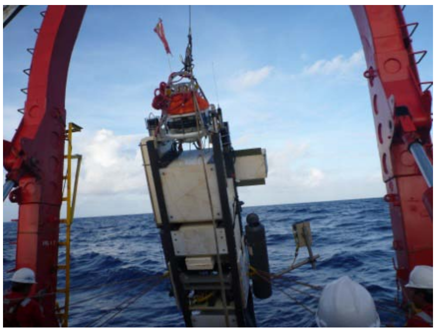

Figure 5. Lander with modem installed

The two support vessels *MERMAID SAPPHIRE*; the expedition mothership and *PRIME RHIB*; a Rigid Hulled Inflatable Boat, had L-3 ELAC UT 3000 MASQ communication systems (Figure 6) installed on them with L-3 ELAC WB 54 omni-directional transducers as well as L-3 Nautronix dunking transducers. Each surface UT 3000 system was also connected to a PC running the MASQ control software (an email style client software for sending/receiving digital data) and the ship’s network. Range data from the data receptions was entered into a navigation computer running Hypack and was used to plot the position of all surface participants and range rings to track the approximate submarine position.

Figure 6. UT 3000

A communications room was set up on the *MERMAID SAPPHIRE* to co-ordinate surface and sub-surface communication via marine band radio and acoustics. Voice communications were relayed to and from the *PRIME RHIB* via radio. Digital data and navigation data were relayed via wireless Ethernet network.

VESSEL INSTALLATION, INTEGRATION AND TESTING

The first modems were assembled at the end of October and in-air and in-water factory tests were undertaken. Installation and testing of the systems at the customer site started in November 2011. L-3 Nautronix installed and tested the L-3 ELAC underwater telephone UT 3000 and WB 54 hydrophone on board the *PRIME RHIB* together with a GPM 300 modem. Voice and data communications as well as time-of-flight measurements were successfully demonstrated in Sydney harbour.

The UT 3000 and WB 54 were then installed on a ship of opportunity, the *MERMAID SAPPHIRE* and sea tests conducted using the modems installed on the ship's ROV deployed to 800m off the coast of Sydney. The equipment worked well under the test conditions but it was quickly realised that the loud noise from the Dynamic Positioning (DP) system routinely used on *MERMAID SAPPHIRE* was going to be a significant impediment to any long range acoustic communications.

L–3 Nautronix quickly developed an alternate solution using transducers that could be lowered over the side away from the boat noise. These were deployed via winch from the support vessels.

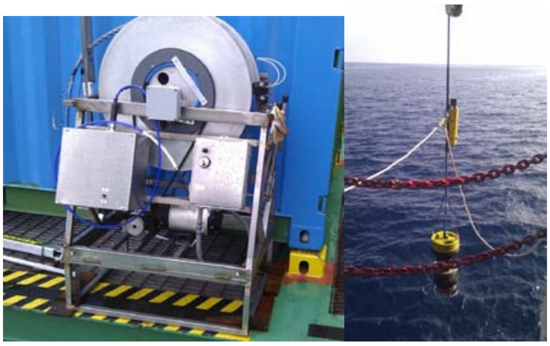

Figure 7. Deck box and winch; Directional Dunking Transducer (with weights and tracking beacon)

SUBMARINE INTEGRATION AND TESTING

In the meantime the submarine was almost ready for testing and required the modems to be installed into the systems on board. The demanding schedule and close integration with the submarine systems meant an L-3 Nautronix team remained on site working with the customer, installing and adapting the communications equipment as needed and in response to the rapidly emerging operational needs.

Figure 8. On-site integration/testing.

Sea tests of the Lander system with L-3 modems, followed by tests of the manned submarine were conducted offshore in January and February 2012 near Sydney.

During the 20m sea test in Jervis bay, voice communication from the submarine to *PRIME RHIB* and *MERMAID SAPPHIRE* was reported to be good but voice communications from *PRIME RHIB* to the submarine were described as unintelligible – something fundamental was clearly wrong with reception at the submarine.

An investigation was conducted immediately and it was found that the sphere power supplies were severely interfering with the audio and other signals from the modems.

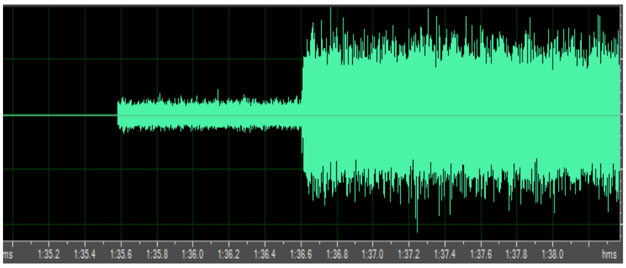

Figure 9. Audio at the headphones in the sphere showing the interference from the power supplies

The L-3 team worked closely with the customer's engineering team to solve these issues which resulted in changes to the earthing, wiring and the insertion of an in-line audio transformer. The combined effect of these changes was a vast (around 26dB) improvement in system performance.

Another key issue recurring through the sea tests were a number of system resets. This was eventually reproduced in the factory and attributed to issues with power supplies. Adaptations were made to the power circuits to ensure that the instantaneous power required by the modem for high power transmissions could be met.

THE EXPEDITION

The expedition sailed in February from Sydney to Papua New Guinea. Two L-3 Nautronix engineers were embedded into the expedition team to complete the integration and operate the underwater communications systems. A successive number of ever deeper test dives from 1000 to 4000 and on to 8000 meters with both Lander and submersible were undertaken with excellent results. The highlight of these was an 8221 metre dive into the New Britain trench on March 7 that set a new world record for a solo dive, bringing back images and scientific samples, with the L-3 system providing excellent voice communications to James Cameron piloting the *DEEPSEA CHALLENGER.*

CHALLENGER DEEP

Following the New Britain trench dive, the expedition set sail for Guam and the Mariana Trench in March. An unmanned dive was first conducted at Challenger Deep as the final test of all submarine systems at full ocean depth before preparations were made for the historic dive.

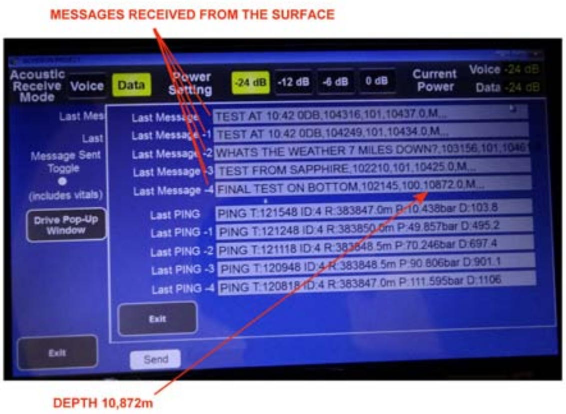

Figure 10. Submarine display screen with messages received by the submarine on the unmanned dive

Launched early on the morning on the 26th March, the *DEEPSEA CHALLENGER* commenced its historic descent. The *PRIME RHIB* was sent upstream at the start of the dive and then drifted across the dive area, maintaining continuous contact with the submarine throughout the 7 hours of dive operations. At 7.52 am local time, Cameron touched down on the bottom of Challenger Deep at 10,898 metres, at which point his wife was able to send him a congratulatory voice message from the surface system aboard *MERMAID SAPPHIRE*. A moment later his response was received via the receiver on *PRIME RHIB* and relayed back to the vessel via an open radio channel.

At a range of nearly 11 kilometres, propagation time was just over 7 seconds for sound to travel one way through the water column. Throughout the bottom time, the RHIB operators reported clearly hearing their own voice transmissions as an echo 15 seconds later followed by the submarine reply 3 seconds later and used this predictability as a cue to RF relay received voice to the *MERMAID SAPPHIRE.*

The use of the STANAG compliant voice communications (NATO 1997) also allowed the Octopus yacht; one of the vessels that had joined the expedition flotilla, to listen in and support dive operations using an L-3 ELAC UT 2200 underwater system. Paul Allen on Octopus kept the world informed on the progress of the dive via the L-3 system and his Twitter feed.

Figure 11. *DEEPSEA CHALLENGER* and *PRIME RHIB* after the dive

Cameron remained on the bottom for almost 3 hours, taking 3D video footage and picking up samples before successfully ascending, the whole time remaining in contact with the surface.

Later, when relating his experience Cameron stated “We were pleased to have solid voice comms to full-ocean-depth using the L-3 Nautronix system. It was amazing to talk to my wife Suzy from the deepest point in the world’s oceans.”

Figure 12. James Cameron with Ray Commins and Paul Roberts in the Mermaid Sapphire Comms Room

ACKNOWLEDGEMENTS

The L-3 team wishes to thank James Cameron, Ron Allum, Tim Bulman and the other members of the Deepsea Challenge team as well the expedition sponsors National Geographic and Rolex for the opportunity to have worked alongside such dedicated and talented people and to have supported this historic event.

REFERENCES

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