TESTING A PROTOTYPE DIGITAL HYDROPHONE FOR USE AT MOD MARITIME ACOUSTIC RANGES

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1 BACKGROUND

QinetiQ have utilised analogue hydrophones on MoD maritime acoustics ranges for decades. As part of a wider modernisation programme, the requirement for a digital hydrophone emerged. A supplier was chosen from a short list who could meet QinetiQ's requirements, primarily that the hydrophone self-noise should reach an acceptable compromise between self-noise and measurement bandwidth. This is to attain the widest possible bandwidth for which self-noise remains below Sea State 0, whilst permitting accurate measurement at high frequencies, for example One-Third Octave centered on 100kHz. The former requires a large sensor element but the latter requires a small one, which presents a design challenge to overcome that dichotomy.

QinetiQ first chose Seiche Ltd as their partner to design and develop a prototype Ethernet hydrophone in 2017, to include auxiliary sensors for temperature, depth, vibration and orientation. Since then the hydrophone transitioned through multiple iterations, with fully operational prototypes of the QQ1000[1] delivered to QinetiQ in 2021. These prototype hydrophones were thoroughly tested for two years, and in 2023 QinetiQ approved the design ready for deployment on several MoD maritime acoustic ranges for the purpose of quantifying ship noise. This paper reviews the final stage of testing which QinetiQ undertook to inform their decision to approve the design of the hydrophone, which involved testing the prototype alongside an NPL-calibrated analogue hydrophone in June 2023.

QinetiQ undertook testing on a prototype digital hydrophone to compare the performance with an analogue hydrophone using projectors and small boats as noise sources. Transmissions from Neptune D11 and D70 projectors were split into the groups 'Low Frequency', 'Mid Frequency', 'High Frequency' and 'Very High Frequency'. The pulses were short duration for direct path measurements, with the test setup located 13.8m below the surface of the water. Comparisons were made between the analogue reference hydrophone, which had a 25mm ball, and the prototype digital hydrophone, which had a 12.7mm ball.

2 TEST SETUP

2.1 Lab Setup

Signals were sent to and received from the in-water equipment via cables fed through a porthole behind the lab equipment. A diagram and photos of the setup are presented in Figure 1 and Figure 2.

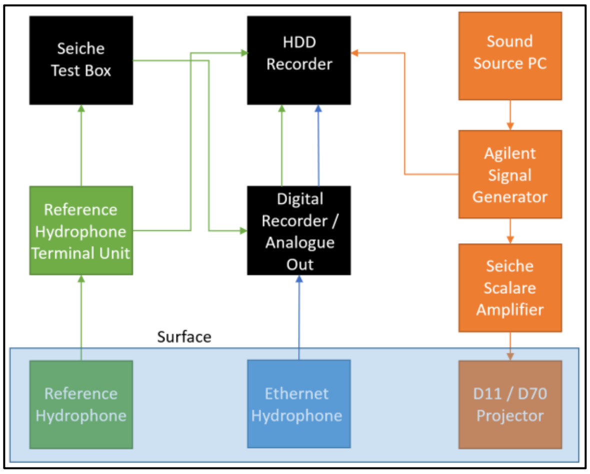

Figure 1: System diagram of the lab setup

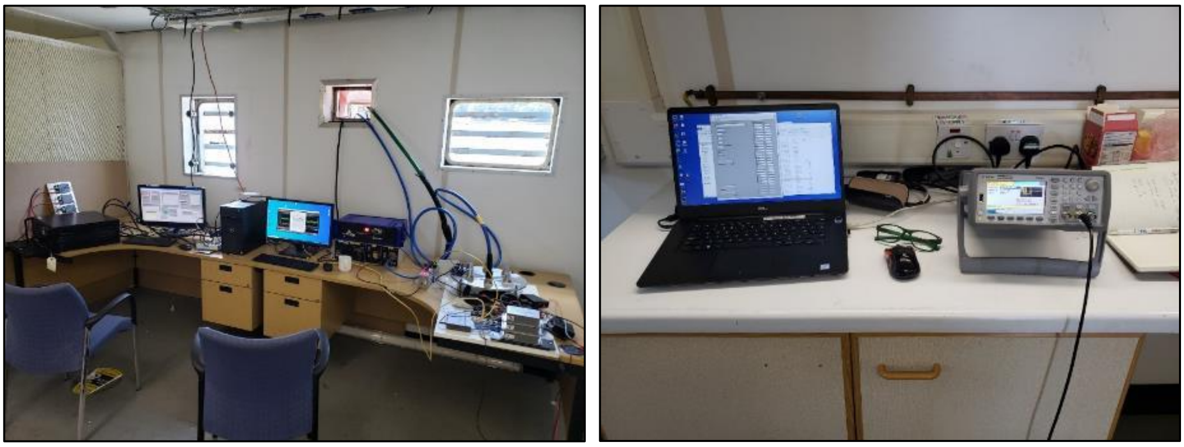
Figure 2: Photos of the lab setup

2.2 In-water Setup

The two hydrophones, the Ethernet hydrophone and the NPL calibrated analogue hydrophone, were connected to a hollow polypropylene brace which kept them 2.6m apart. The hydrophones were hung from this brace with weights connected to the cable behind each hydrophone, ensuring they hung in a consistent position. The brace was bolted to the base of a multi section hollow steel pole which was lowered 13.8m below the surface of the water.

The projectors were lowered into the water using a slimmer hollow steel pole, also held in position by weights attached to their cable, 13.8m below the surface of the water The D70 and D11 projectors were 3.75m and 5.0m respectively from the position of the hydrophones.

Figure 3 shows a diagram of the in-water setup and Figure 4 shows photos of the in-water setup as it was lowered into the water.

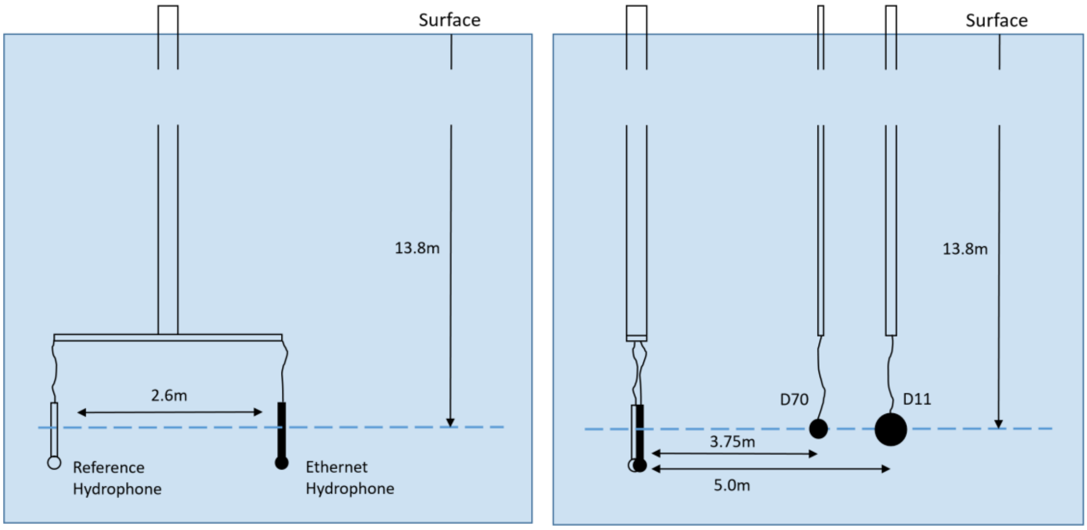

Figure 3: Diagrams of the in-water setup

Figure 4: Photos of the in-water setup being installed

2.3 Data Recording

As mentioned previously, two data recording methods were used for comparison of both sets of results. The first recording method was a standalone PC, which has an analogue input and converts and records signals as 16-bit digital files. This meant the Ethernet hydrophone data had to be converted to analogue in order to be compatible. The PC recorded the signal from the Agilent signal generator, the calibrated analogue hydrophone and the Ethernet hydrophone. The second recording method was a digital recorder, written for the Ethernet hydrophone, which recorded digital signals from the Ethernet hydrophone and the calibrated analogue hydrophone.

The analogue signals were recorded with 16-bit resolution and 10V ADC reference, and with a sampling rate of 250 kHz. The Ethernet hydrophone recording software is similar and records with 24-bit resolution and 5V ADC reference, and with a sampling rate of 250 kHz.

2.4 Calibration Injection

Calibration signals were sent from the Agilent signal generator to the calibrated analogue hydrophone, via the differential to single sided hydrophone terminal unit (see Figure 1) to test the signal path. The returning signal had its phase reversed, most likely by the hydrophones terminal unit. This reversal of phase does not affect the validity of the results but it is a notable quirk of the measurement setup. Figure 5 demonstrates this effect.

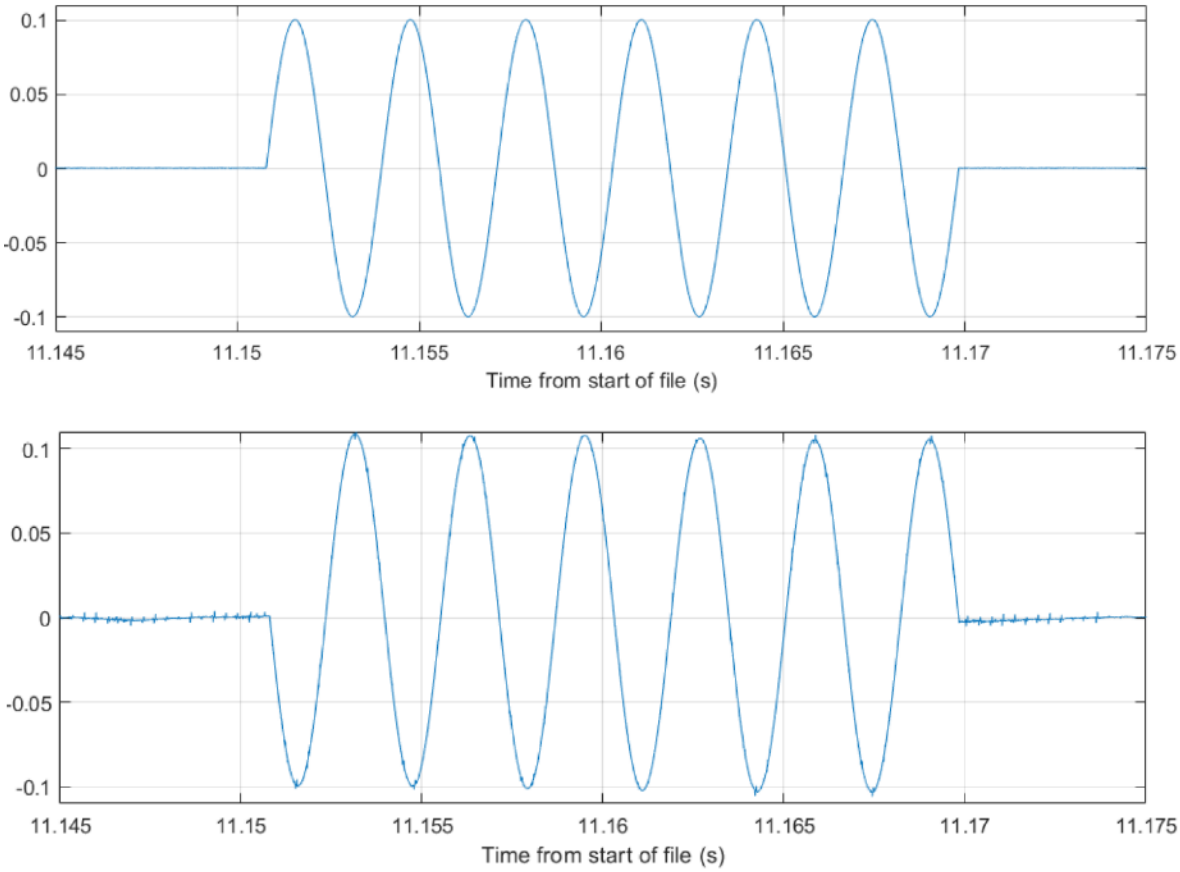

Figure 5: Example of phase reversal between the sent and received calibrated signals for the reference hydrophone.

3 DATA ANALYSIS

A Matlab acoustic analysis tool was used for the analogue data which converts the recorded data into narrowband and one third octave data files which are readable by QinetiQ's range software packages. The tool is also compatible with Ethernet hydrophone data recorder files. The tool was modified to provide a byte-shift facility for legacy recordings, another quirk of the system, and a band pass filter to remove high frequency noise and DC offset for low-frequency low-amplitude signals.

3.1 Pulsed Sinewave Analysis

To quantify the sensitivity of the Ethernet hydrophone, comparisons were made between RMS signal levels received at both hydrophones. A mean and standard deviation was made for the ratio and the dB value was added to the reference hydrophone sensitivity as an estimate of Ethernet hydrophone sensitivity.

Based on a sensitivity of -200dB re 1V/µPa for the 12.7mm ceramic ball with series wired hemispheres, the nominal sensitivity of the Ethernet hydrophone with 48dB gain is estimated to be

- 152dB re 1V/µPa. However, the purpose of this exercise was to make the first in-water quantitate estimate of the Ethernet hydrophones sensitivity, so its nominal value is used as a guide only.

The D11 projector was used at frequencies far below (approximately 5 octaves) its resonance frequency. This incurred start-up and 'end' transients attached to acoustic pulses, along with low source levels. To clean up the received pulse a band pass filter was applied, and Figure 6 presents an example of the band pass filter's effect. The user selects a suitable region of the received pulse by mouse 'click' within the Matlab acoustic analysis tool for estimation of RMS signal level.

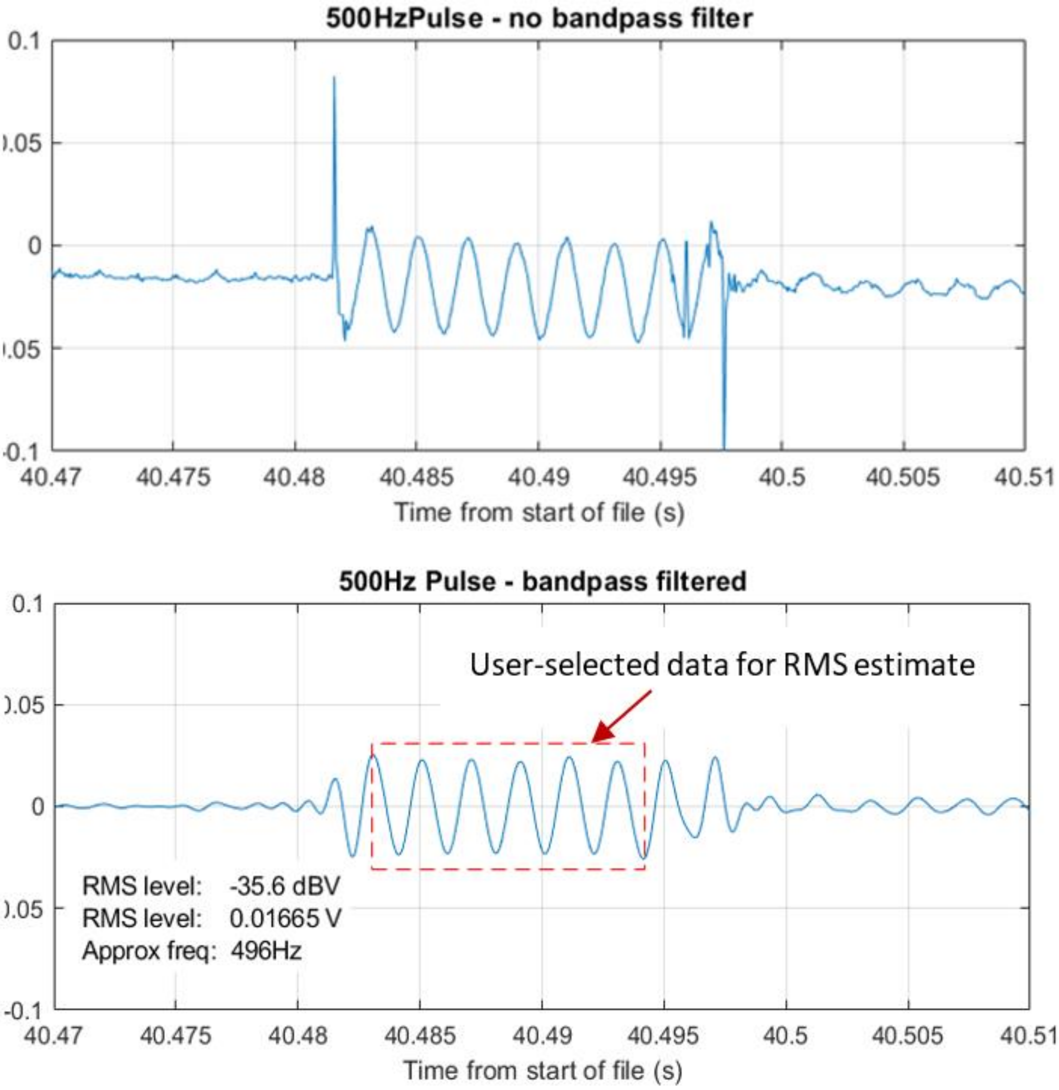

Figure 6: Example of the band pass filters effectiveness on signals recorded by the HDD

The band pass option is available for first decimated time series data (fs = 25kHz) only. For the raw data, the mean of the selected data is subtracted to 'zero' the data before RMS is estimated.

On a number of occasions, the pulse signal at the Ethernet hydrophone appeared to vary considerably at higher frequencies. The cause for this is unknown, however it only appeared in the analogue recordings of the Ethernet hydrophone. The effect may therefore have been caused by an anomaly of the recording channel used, or there may have been a local biological scatterer in close proximity to the hydrophone.

Figure 7 presents an example of variability of high frequency pulse amplitude in the recorded data for analogue and direct digital recordings.

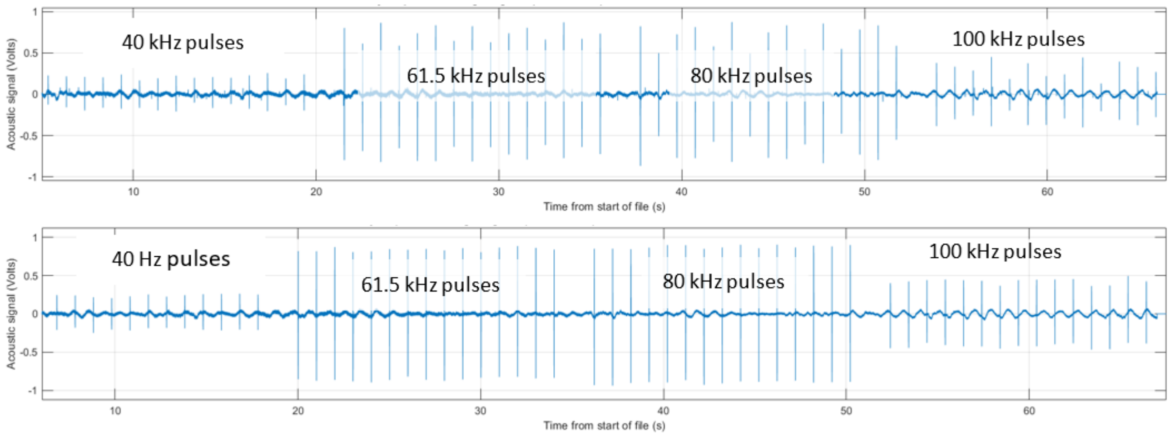

Figure 7: Example of HF pulse variability in the analogue data compared with the digital recorder

3.2 One Third Octave Analysis

Pulsed sinewave analysis is limited by low-frequency source level and the need for a direct-path signal of sufficient length for a reliable RMS estimate, and at frequencies under 500Hz it is possible that electronic self-noise from hydrophones and recording systems could contribute significantly to the RMS estimates. To extend the lower frequency comparison of Ethernet hydrophones sensitivity against the reference hydrophones sensitivity, we used boat noise to generate both high-frequency (cavitation) and low frequency (propulsion) noise. Figure 8 shows the approach of the small boat employed in this exercise.

A ten-second measurement period spanning the Closest Point of Approach (CPA) was employed to determine mean relative signal levels in one third octave bands. An example is presented in Figure 9. At very low frequencies, below 20Hz, there was little acoustic content generated by the boat passes. At high frequencies, narrowband analysis revealed significant levels of electronic self-noise from both hydrophones. For these reasons, frequencies below 20Hz and above 40kHz were rejected from the one third octave band comparison of sensitivity.

Figure 8: Photo of boat conducting a pass by of the measurement hydrophones

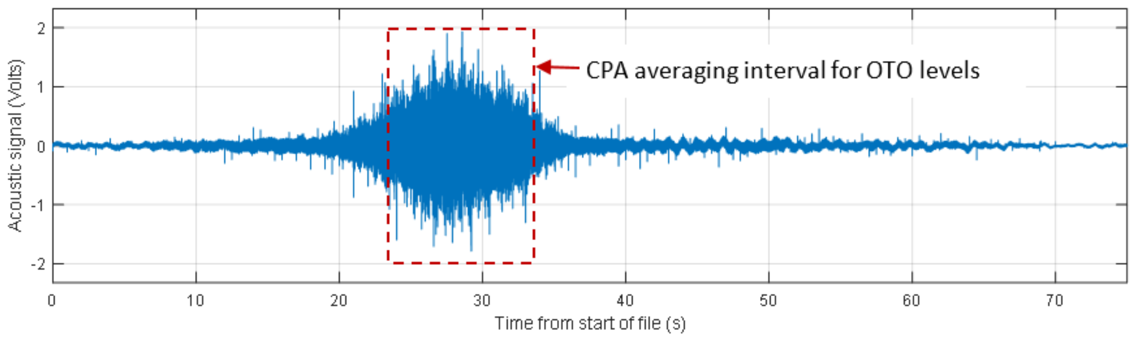

Figure 9: Example of a boat pass by recorded by the Ethernet hydrophone

One third octave band levels were compared assuming a uniform sensitivity at an arbitrary value for both hydrophones. The resulting relative levels are presented in Figure 10 below, and it can be seen that both hydrophones give a comparable shape, though the Ethernet hydrophone signal is approximately 10 dB higher than the NPL-calibrated analogue hydrophone.

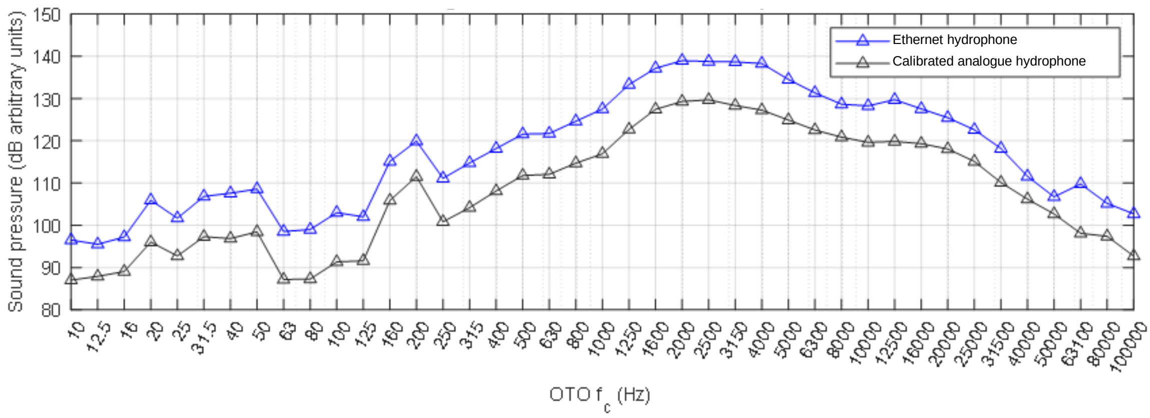

Figure 10: Comparison of boat noise recorded by the reference hydrophone and the Ethernet hydrophone

Differences in one third octave band levels were added to the calibration levels of the NPL-calibrated analogue hydrophone to extend the low-frequency limit of the Ethernet hydrophone's sensitivity estimates based on pulsed sinewaves. Figure 11 presents the estimated sensitivity for pulsed sinewave and boat-noise analysis. Small differences in the region of overlap are to be expected as the pulsed sinewave estimate is effectively at the one third octave band centre frequency and on the equatorial plane of the acoustic sensor. However, the one third octave estimates are over a finite bandwidth and subject to multipath propagation.

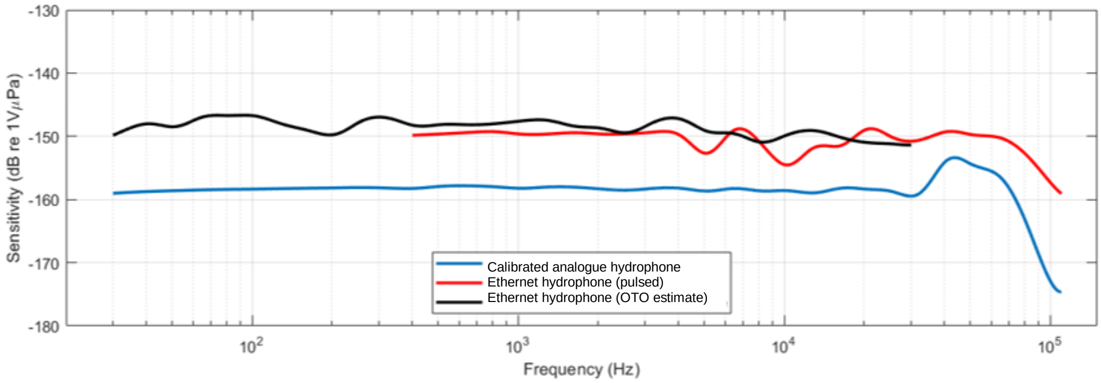

Figure 11: Comparison between the NPL calibrated reference hydrophone and two methods of assessing the sensitivity of the Ethernet hydrophone

4 SUMMARY

In this report, the sensitivity of the prototype Ethernet hydrophone has been estimated from data recorded in June 2023. Pulsed sinewave analysis shows a dip in EH sensitivity at 5kHz and 10kHz. This was confirmed in analysis of a second data set, and may be confirmed when the hydrophone is calibrated by NPL. However, the same dips in sensitivity did not appear in the one third octave analysis. There was no obvious resonance peak for the Ethernet Hydrophone using pulsed sinewave analysis. This should be confirmed when the production specification Ethernet hydrophones are calibrated at NPL.

The Ethernet hydrophone appears to be significantly more sensitive than the calibrated analogue hydrophone at higher frequencies, up to 15 dB (re $1V_{\mu}Pa$), in the region above the calibrated analogue hydrophones resonance frequency. It was not possible to obtain reliable one third octave measurements for the reference analogue hydrophone at 100kHz on account of its fall-off in sensitivity, after the principal resonance. Achieving reliable 100kHz one third octave band data was one of the design aims of the Ethernet hydrophone and is in compliance with a number of noise-measurement standards including DNV and STANAG.

The results presented in this paper helped QinetiQ decide to order the production specification Ethernet hydrophone from Seiche Ltd for use at several of MoD's maritime acoustic ranges as part of a wider investment package. The production specification hydrophones have some differences to the prototype hydrophones, which have been proven in additional tests to lower the self-noise of the hydrophone further.

5 REFERENCES

1. Seiche Ltd, Hydraq QQ1000, https://www.seiche.com/hydraq-qq1000/, [Accessed 25 April 2024]