MEASUREMENTS OF UNDERWATER NOISE FROM THE *RV INVESTIGATOR*

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Abstract

Australia's Marine National Facility, operated by CSIRO, has recently taken delivery of a new, $126 million, multi-purpose blue-water marine research vessel, *RV Investigator*. The ship is equipped with an extensive suite of active acoustic instrumentation that include an omnidirectional sonar, three multibeam echosounders, six split beam scientific echo sounders, two acoustic Doppler current profilers and a sub-bottom profiler. Permanently installed seismic compressors also prepare the ship to undertake geophysical survey missions. The ship has been designed to maximise the performance of these systems through innovative hull design to minimise air bubble entrainment under the acoustic transducers, and by reducing the underwater sound radiated from the ship through an innovative propulsion system, coupled with advanced isolation of vibration from the primary power generation machinery. This paper discusses some recent underwater noise measurements that were carried out in southern Tasmanian waters following Det Norske Veritas (DNV) guidelines in order to determine baseline underwater noise signatures for the vessel, and to characterise the noise performance of the various acoustic instruments. The baseline measurements obtained are compared to the ship's design criteria of DNV Silent-R and the expected background wind and thermal noise. The potential variability in vessel noise spectra obtained when following DNV noise measurement guidelines are also discussed.

1. Introduction

In late 2014 Australia's Marine National Facility, operated by CSIRO, took delivery of *RV Investigator*, a purpose-built, $126 million, blue water research vessel (see Figure 1). The ship's capability is enhanced by a large suite of permanently mounted active acoustic instrumentation that can provide a diverse range of measurements of the physical and biological properties of the water column and seabed, and by the installation of large compressors capable of running seismic airgun arrays for geophysical exploration. The ship also has the capability to tow and deploy a variety of other acoustic instruments.

All ships contain a wide variety of machinery, the vibrations from which can couple to the hull, resulting in sound being radiated into the water. This acoustic "self-noise", combined with any propeller cavitation noise, can interfere with the acoustic instrumentation. To maximise the effectiveness of its acoustic equipment, *RV Investigator* was designed to have a particularly low underwater noise signature, and in particular was designed and built to comply with the DNV Silent-R specification for research vessels [1]. This was achieved through the use of diesel-electric propulsion and by vibration isolation of all mechanical equipment from the hull.

Figure 1. *RV Investigator* loading equipment in Hobart.

RV Investigator's main propulsion system consists of three 9-cylinder diesel generators, each producing up to 3 MW of electrical power, and two 2.6 MW reversible electric propulsion motors, each directly coupled to a 5 blade fixed pitch propeller. The ship can operate with one, two, or three generators running, but in most situations either one or two are used. The diesel generators run at a constant speed of 750 rpm irrespective of load.

The ship's acceptance trials were carried out near Singapore and included underwater noise measurements intended to verify that the vessel met the DNV Silent-R specification. This was found to be the case after a problem with a "singing" (vibrating) propeller was corrected. A further set of underwater noise measurements was carried out on 17th April 2015 in Storm Bay, Tasmania. These measurements were carried out in order to develop and test a measurement methodology, and to provide baseline data at a location convenient to the vessel's home port (Hobart), thus enabling regular checks of the vessel's underwater noise signature to be carried out in the future. It was also hoped to obtain a better understanding of how the configuration of the vessel's propulsion machinery affected her underwater noise signature. This paper describes the Storm Bay measurements and presents some representative results.

2. Methods

The measurement procedure was based on the procedure detailed in the DNV Silent R specification [1], however as this was not a compliance test there were some deviations from the specification, particularly with regard to calibration procedures, and the use of underwater recording systems rather than a hydrophone cabled to shore. Measurements were made using three independent hydrophones, each with its own recording system. These systems included a Centre for Marine Science and Technology (CMST) low frequency (LF) sea noise recorder fitted with a HTI90-39 hydrophone, a CMST high frequency (HF) sea noise recorder fitted with a Reson TC-4033 hydrophone, and an Ocean

Sonics SB35-ETH recorder provided by the CSIRO's Marine National Facility (MNF), the organisation that operates the ship. Their recording bandwidths, as configured for this experiment, were 4 kHz (CMST LF), 30 kHz (CMST HF), and 100 kHz (OceanSonics).

All three systems were mounted on a single frame as shown in Figure 2. The two CMST recorders are intended for long duration deployments and have large housings in order to accommodate the requisite number of batteries, and these housings were attached to the bottom of the frame to provide stability. They have cabled hydrophones which were attached to the frame as shown in figure 2. The Ocean Sonics SB35-ETH recorder has a much smaller housing with an integral hydrophone and was mounted in the centre of the frame.

Figure 2. Recording system on deck prior to deployment. The two large housings under the frame are the CMST LF recorder (left) and the CMST HF recorder (right). The CMST LF hydrophone is closest to the camera and the HF hydrophone is furthest away. The Ocean Sonics recorder is mounted in the centre of the frame with its hydrophone projecting downwards.

The CMST recorders were calibrated by injecting a signal from a calibrated white noise generator into their preamplifiers. The manufacturers' calibration curves were relied on for the corresponding hydrophone calibrations. The calibration for the Ocean Sonics recorder and hydrophone combination was obtained from the manufacturer. Great care was taken to minimise mooring noise by taping all metal on metal contacts and by designing the mooring so that surface float motion could not transmit to the hydrophone mounting frame (see Figure 3). The hydrophone frame was lowered to the seafloor in 35 m of water by winch, using a line fed through a sheave on the ship's A-frame. The weights, anchor and floats were clipped to the line after it went through the sheave. The GPS touch-down position of the frame was noted and used as the reference position for distance calculations.

The DNV Silent R specification is based on measurements made at a nominal range of 200 m, beam-on to a vessel travelling at 11 knots. A total of seven runs were made past the hydrophone assembly at different speeds and with different propulsion system configurations as summarised in Table 1.

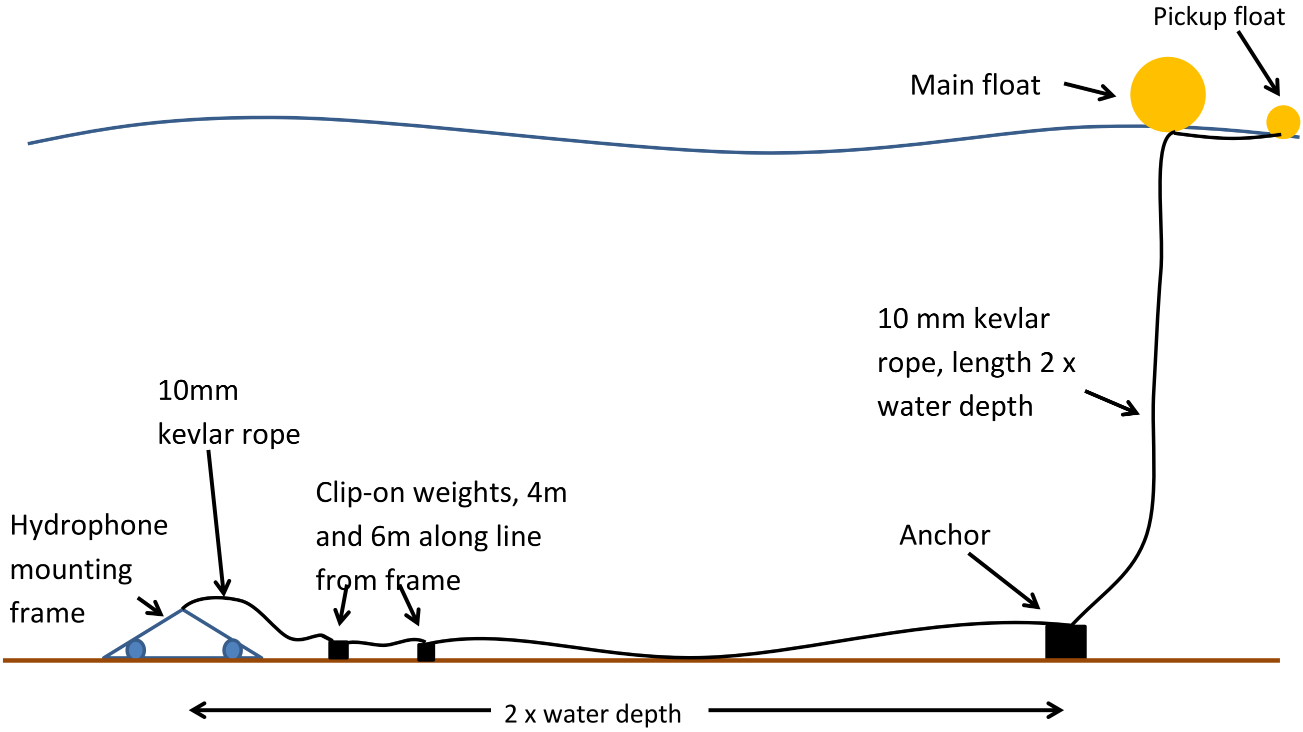


Figure 3. Mooring design

Table 1. Summary of noise measurement runs

Run	Heading (deg)	Nominal speed (kn)	Diesel generators operating	Closest approach (CPA) range to ship's coordinate reference point (m)
1	058	11	1 and 2	205
2	238	11	1 and 2	209
3	057	9	1 and 2	209
4	240	7	1	204
5	240	8	2	212
6	060	8	2	235
7	240	8	3	208

Data analysis for each of the three recording systems was carried out as follows:

1. Segments of data were extracted from the recordings as specified in [1]. This stipulates that, for vessel speeds greater than 5 knots, the data segment to be analysed should start when the bow of the vessel is abeam the hydrophone and end when the stern of the vessel is one ship length past the hydrophone. Depending on the speed of the vessel, data segment durations for the different runs varied from 32 seconds to 50 seconds.

2. The power density spectrum of each data segment was calculated using Welch's method with a Hanning window, a 5 second block length and 50% block overlap, giving a spectral resolution of 0.2 Hz, and then corrected for the frequency response and calibration constants of the recorder. Based on Chapter 13 of [4], for the worst case of a 32 second data segment the standard error of the spectral estimates due to statistical fluctuations in the data corresponds to a variation in level of -1.8 dB to +1.3 dB.

3. The corrected spectrum was integrated over 1/3 octave bands and then converted to decibels to give the received sound pressure level in each band. Using this method, the number of power density spectral bins contained in each 1/3 octave band increases with increasing band centre

frequency (and hence bandwidth). As a result, the standard error of the band level estimate due to statistical fluctuations in the data reduces with increasing band centre frequency. However, even at the lowest reported band centre frequency of 12.4 Hz there were 14 power density spectral bins within the 1/3 octave band, resulting in a standard error that corresponds to variations in the band level of +/- 0.4 dB.

4. These received levels (L_R) were converted to1/3 octave source levels (SL) using the formula specified in [1]:

$$SL = L_R + 18\log_{10} r - 5 \quad \text{(dB re 1 μPa rms @ 1m)} \tag{1}$$

where r is the closest approach (CPA) range. The -5 dB correction is described in the standard as a correction for reflections from the seabed.

3. Results

The ship was operating in the vicinity of the hydrophone frame for the entire duration of the deployment and consequently it was not possible to obtain ambient noise recordings. Instead, a comparison was made between spectra calculated from data recorded when the ship was at its minimum distance from the frame of approximately 200 m (see Table 1), and the spectra of data recorded when the ship was at the end of Run 1, just prior to commencing a turn, at which point the ship was 1.74 km from the hydrophone. It was found that the vessel noise increased significantly when the ship was turning, and so the vessel noise levels at the hydrophone frame were at a minimum just before the turn.

Frequency ranges in which there was no appreciable difference between the short and long range spectra were assumed to be dominated by ambient or electronic noise and were excluded from further analysis. The remaining frequency ranges were considered to contain valid ship noise data and are listed in Table 2.

Table 2. Recording system valid frequency ranges

Recording System	Minimum valid frequency (Hz)	Maximum valid frequency (Hz)
CMST LF	10	4,000
CMST HF	10	30,000
Ocean Sonics	1	100,000

Figure 4 compares 1/3 octave source level spectra measured by all three recording systems for runs 1 and 6. These two runs were made in the same direction, at nominal speeds of 11 knots (Run 1) and 8 knots (Run 6). Run1 was carried out with diesel generators 1 and 2 operating, whereas during Run 6 only Generator 2 was operating. All three recording systems provided similar results, although there were differences in measured levels of up to 4 dB in individual frequency bands. These differences may be due to the spatial separation of the hydrophones and the effects of acoustic shadowing and scattering by the frame and the housings.

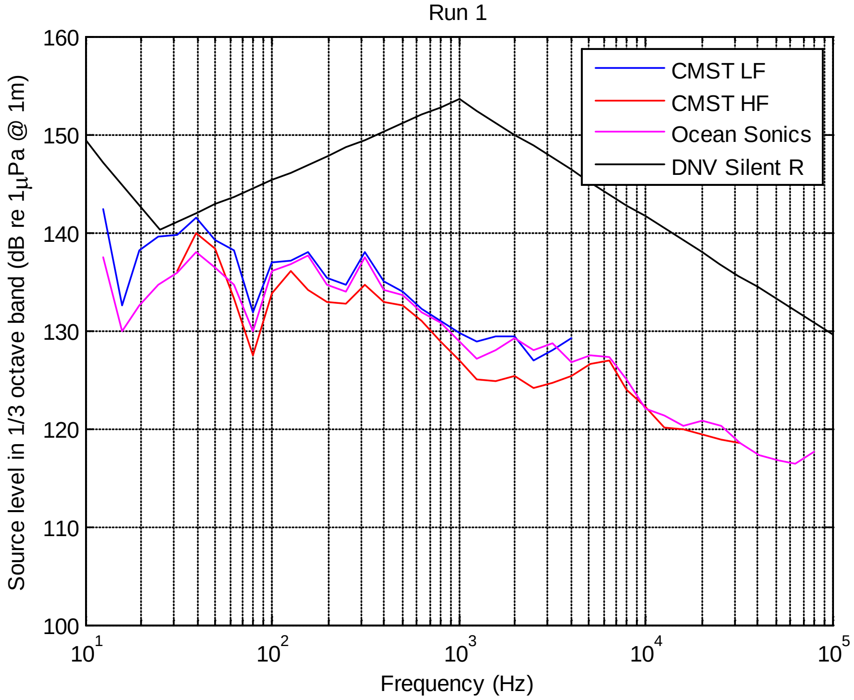
The most notable difference between the measured spectra for runs 1 and 6 is the markedly higher levels that occur in the 20 Hz and 25 Hz bands for Run 6. This was an unexpected result given that the vessel speed was lower during Run 6 than during Run 1. Inspection of the corresponding narrowband spectra (see Figure 5) indicates that this difference is due to a strong spectral line indicating a tonal signal at 22.1 Hz that was present in the Run 6 data but not in the Run 1 Data. This spectral line was found to be quite strong in the data from all runs that used a single diesel generator, but was of much lower amplitude or absent altogether in data from runs that used two generators, irrespective of vessel speed.

At 11 knots, with two generators running, the measured source spectrum was well below the

DNV Silent R curve at frequencies above 100 Hz and just below the Silent R curve at lower frequencies. This was true for both 11 knot runs (runs 1 and 2). At an alternative survey speed of 9 knots, with two diesel generators running (Run 3), the levels were several dB lower again.

4. Comments on the DNV Silent R Vessel Noise Measurement Procedure

The vessel noise measurement procedure given in the DNV Silent R specification [1] provides a relatively straightforward, practical method of measuring the underwater noise radiated by a ship. It should be noted, however, that the procedure only requires measurement at one range (which must be between 150 m and 250 m), one speed (11 knots for a vessel of more than 50 m length), and one aspect (beam-on with data averaged over a time interval during which the vessel travels two ship lengths). As a result the measurements provide a far from complete picture of the underwater noise field radiated by the vessel.



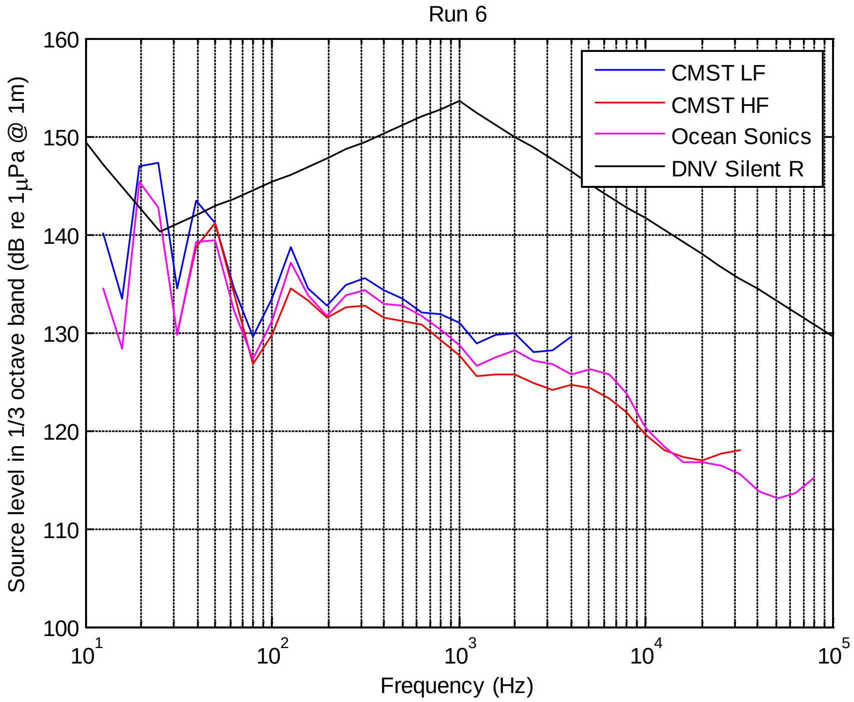
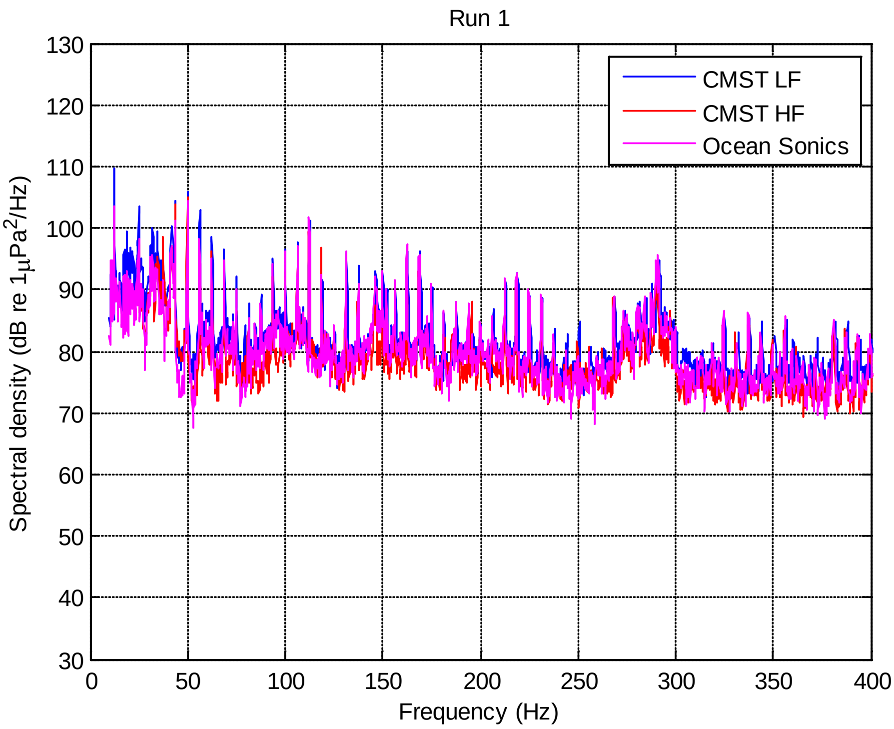


Figure 4. Measured 1/3 octave source spectra for Run 1 (top) and Run 6 (bottom)

The DNV measurement procedure also allows a wide range of water depths (any depth under the keel of 30 m or more), and allows both flat and sloping seabeds. The only requirement on the seabed composition is that "the surface shall not be perfectly flat" [1, p. 13]. This allows measurements to be made in a wide variety of locations that could have very different acoustic propagation conditions. Variations in propagation conditions are not allowed for when reducing the data to source spectra using Equation (1).



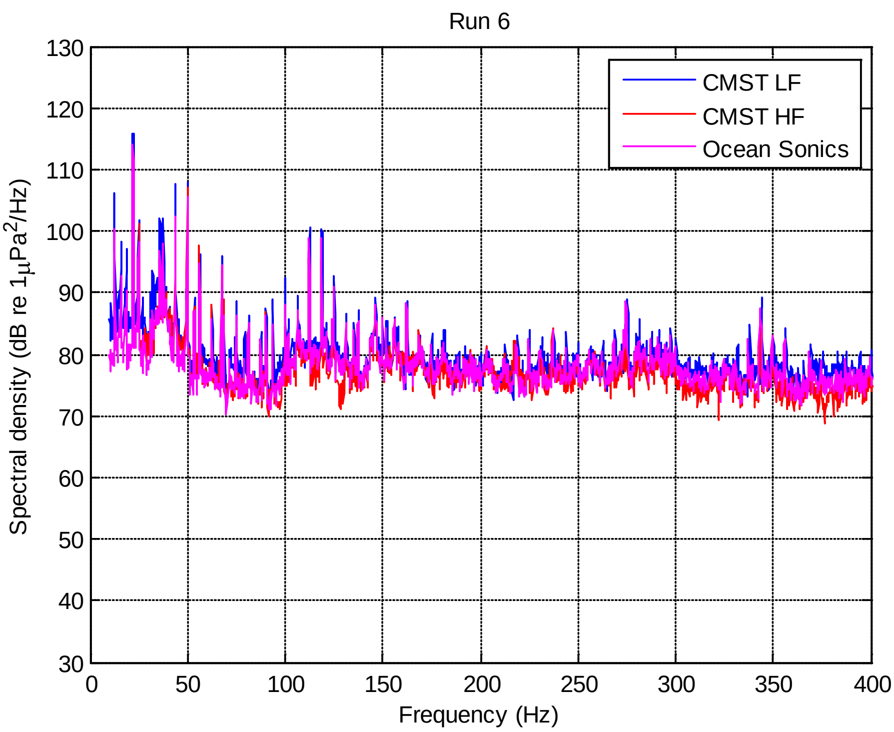


Figure 5. Narrow-band received spectra for frequencies up to 400 Hz for Run 1 (top) and Run 6 (bottom)

An example of the effects that propagation conditions can have is given in Figure 6 which plots the modelled acoustic transmission loss between a source at a depth of 3.1 m and a receiver 0.2 m above the seabed at 200 m range, for two environments. These environments were chosen as being representative of the locations of the Storm Bay measurements (35 m water depth, sand seabed), and the Singapore measurements (54 m depth, silt seabed). The seabed characteristics at the Singapore measurement site were not documented, so the silt seabed was chosen purely for illustrative purposes. Both seabeds were modelled as uniform halfspaces, with geoacoustic properties from [2]. In both cases the water column was modelled as isovelocity because the true sound speed profiles were unknown and refraction is unlikely to have a measureable effect at such a short range.

The transmission loss was calculated at 1 Hz intervals from 10 Hz to 2 kHz using the wavenumber integration program, SCOOTER [3], and was then incoherently averaged over 1/3 octave bands. As can be seen in Figure 6, in most frequency bands the more reflective sand seabed and shallower water of the Storm Bay site would be expected to result in lower transmission loss and hence higher received levels than at the Singapore site. However, as a result of interference effects this situation is reversed at some frequencies. A caution on the use of Figure 6 is that the modelling assumes the sound emanates from a single point source, whereas in reality the vessel will act as a distributed source with sound being radiated from various parts of the hull and from the propellers. The distributed nature of the real source will tend to smooth out some of the transmission loss fluctuations.

Equation (1) can be seen to give a reasonable approximation to the modelled transmission loss at frequencies above about 200 Hz, but to grossly underestimate the transmission loss at lower frequencies. As a result, source spectra derived using the method given in [1] would significantly underestimate the vessel's source level at frequencies below 200 Hz and therefore should not be used as input to numerical models for predicting the vessel's underwater noise field at other ranges or in environments other than those in which it was measured.

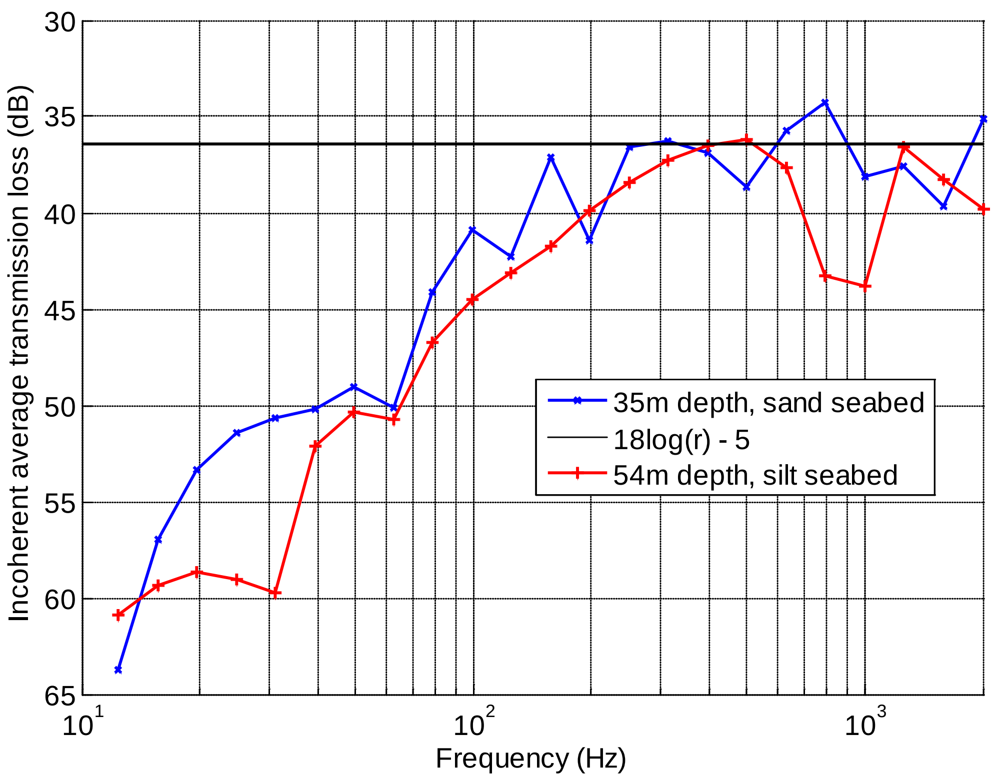


Figure 6. Modelled transmission loss for a source at 3.1 m depth and a receiver 0.2 m above the seabed at a range of 200 m. The blue curve is for conditions representative of the Storm Bay measurements, whereas the red curve is for conditions representative of the Singapore measurements. The black line is Equation (1).

4. Conclusions

Measurements of the underwater noise radiated by *RV Investigator,* carried out in Storm Bay, Tasmania, were successful in testing the measurement methodology and in establishing a set of baseline measurements of the vessel's underwater noise signature that can be used for comparison with future measurements. The vessel's underwater noise signature at low frequencies was found to be significantly lower when operating on two diesel generators than when operating at the same or a lower speed on a single generator. This was found to be due to a single spectral line at 22.1 Hz that was absent or of a much lower amplitude when two generators were being used. The source of this spectral line is being investigated.

The very specific nature of the measurement procedure and data analysis methods prescribed in the DNV Silent R specification [1] mean that the results obtained, while useful for comparison to other measurements made in the same location using the same method, should not be generalised to other locations, ranges, and directions from the ship. Further analysis of the raw data, combined with numerical acoustic propagation modelling, would be required in order to provide source spectra that were more generally applicable.

References

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