ACOUSTC NOISE MEASUREMENTS OF VESSELS WITH ADAPTIVE CHANNEL EQUALISATION

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Abstract:

This paper reports on recent measurements and analysis of acoustic noise of fishing vessels. The measurements were conducted according to internationally accepted standards with a hydrophone close to the bottom and with the vessel following straight tracks of 1-2 km and passing the hydrophone at a distance of about 100 - 200 m distance. The measurements confirm that with a shallow source, as a surface vessel, the Lloyd's mirror effect, which is caused by interference between a direct arrival and a surface reflected arrival. A novel technique is presented for adaptive calibration for the Lloyd's mirror effects in noise measurement of noise from surface vessels. This technique uses a probe signal and signal processing combined with propagation modelling to estimate the actual underwater acoustic channel thereby reducing the distortion effects on the measured noise spectrum. The paper presents the concept and demonstrates the feasibility by using data from a recent sea trial.

Keywords: *Acoustic noise, channel estimation, Lloyd's mirror effects, fishery acoustics*

1. INTRODUCTION AND MOTIVATION

This contribution concerns measurement and characterization of underwater acoustic noise from vessels in general, but mainly from fishing vessels. The motivation for this work is that self-noise from fishing vessels may affect the catch rate. Equally important is to find the origins of the generated noise: whether the noise is coming from the propeller, the machinery or from vibration in the hull. The focus is on low frequencies since most of the commercial species of fish are sensing sound mainly at frequencies below 300 Hz.

2. NOISE MEASUREMENTS OF VESSELS

The standard way for noise measurement [1] is to let the vessel passing a fixed hydrophone on the bottom and the sailing tracks may extend to distance of about 1500 m of either side of the hydrophone position. Figure 1 shows one of the measured vessel and example of the sailing tracks. Figure 2 shows a 1200-second of one of the recordings and the highlighted 30-second section that is normally used and analysed in third octave bands, also displayed in the figure taken from [2].

Figure 1 Fishing vessel Kongsfjord (left) and sailing tracks during recordings (right).

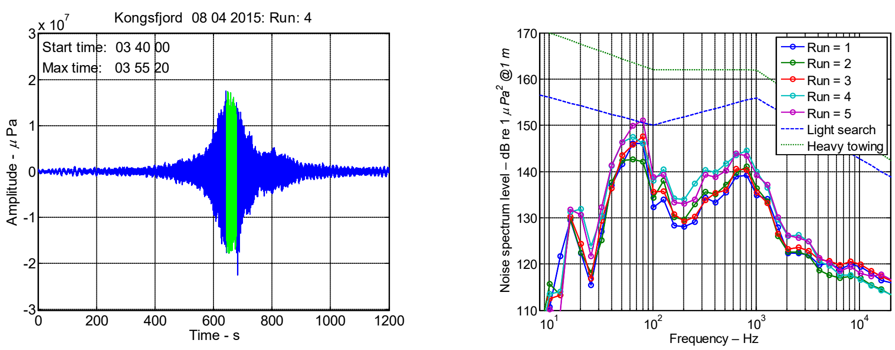

Figure 2.recorded signals of length 1200 second with the 30-second window (left) analysed in third octave bands (right).

Many species of fish can hear quite well, and this is also true for codfish having maximum hearing sensitivity in the frequency band of 30 Hz to 300 Hz as shown in Figure 3 (left) taken from [3, 4]. Since the project focusses on fishery acoustics, this band is subjected to high-resolution spectra analysis. The example in Figure 3 (right) shows the results of 1/24 octave analysis. It shows that the dominating noise is spectral lines in the frequency range of maximum sensitivity of cod. Many of these are caused from resonance of the outer plates of the hull, but some also come from multipaths propagation.

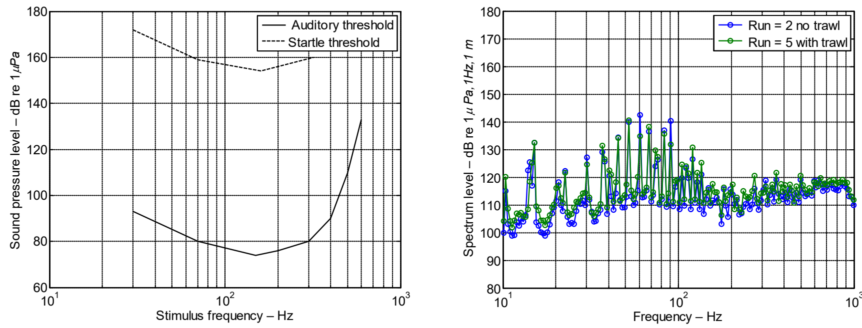

Figure 3 Auditory and startle threshold for Atlantic cod (left) and high resolution spectral analysis of noise in frequency band that the fish can hear (right).

2.1. Normalization and correcting for propagation effects

To correct for varying the distance between the vessels and hydrophone current practice is to assume geometric spreading of 20 log (r) or 18 log (r) [1]. This method for distance correction does not take account of varying oceanographic conditions and frequency dependency, which is demonstrated by Figure 4 showing calculated transmission loss in dB as function of range for some selected frequencies. The calculation shows the interference effect between a direct and a surface reflected under ideal conditions for a source depth of 5 m, receiver at the bottom at 140 m. Above the range of 100 m the transmission loss vary strongly with range and frequency. This variation is the Lloyd's mirror caused by interference between surface reflected and direct sounds. Normally the distances between vessel and measuring hydrophone is short, 100 to 200 m and the simple geometrical spreading are sufficient, but at longer distances this is not the case.

Figure 5 shows the measured level as function of position for some frequencies of interest for fishing. The dotted line represents level reduction of 40log(r), which is expected when the Lloyd's mirror effect is predominate. The measurements confirm that with a shallow source, as a surface vessel, the Lloyd's mirror effect is very important for the propagation of self-noise and therefore important for fishing. The implication of Figure 3 and 5 is that the fish is capable of hearing the vessel at a distance of 1000 m when the ambient noise from other natural or manmade sources is low. Note that this hearing range is considerably shorter than expected from using a level reduction of 20log(r).

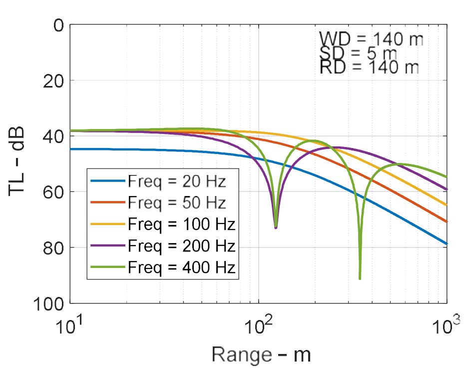

Figure 4 Transmission loss from a source at 5 me depth to a receiver at the bottom at 140 m as function of range and frequency

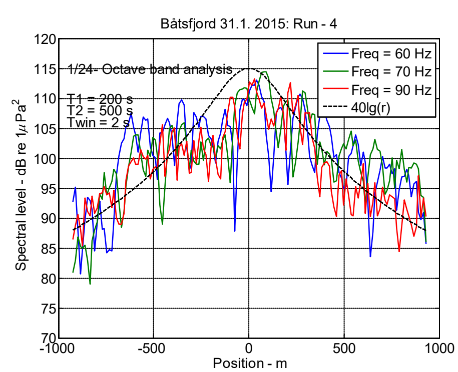

Figure 5 Measured levels in 1/24 octave bands as function of distance for selected frequencies.

3. ACOUSTIC CHANNEL ESTIMATION USING A PROBE SIGNAL

This section describes the method for acoustic channel estimation using a probe signal and matched field technique by correlating the received noise with a replica of the probe signal. The matched field output gives information of the acoustic channel impulse response. The vessel to be measured is towing an acoustic source at depth of a few meters and sending a probe signal at pre-set intervals. The probe signal should preferably be low level to avoid contaminating the noise measurement and low frequency to obtain channel estimates at frequency band of fish hearing according to Figure 3. These are conflicting requirements that cannot be satisfied at reasonable costs and size of transducer and towing gear. On the other hand, there are also relaxing arguments since the geometry is relatively simple. The noise source of the surface vessel is limited to a depth of a few meters and hydrophone is placed close to the bottom, which gives a simple multipath interference and Lloyd's mirror effects.

Figure 6 shows simulated results using the propagation program PlaneRay [5] of eigenrays from a transmitter at 7 m depth to a receiver 5 m above the bottom at a horizontal distance of 400 m. The sound reaches the receiver after two or more reflections from the surface or the bottom. Figure 7 shows two examples of impulse response to a receiver 5 m above the bottom. The first two arrivals arriving with a very short time separation are the direct and surface reflected paths, and the later are from rays with multiple reflections from surface and bottom. The amplitudes of these depends on the bottom composition, Figure 7 shows the cases of hard and soft bottoms.

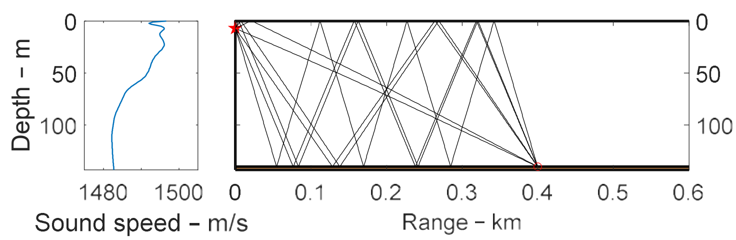

Figure 6 Eigen rays to a distance of 400 m to a receiver at 5 m above the bottom.

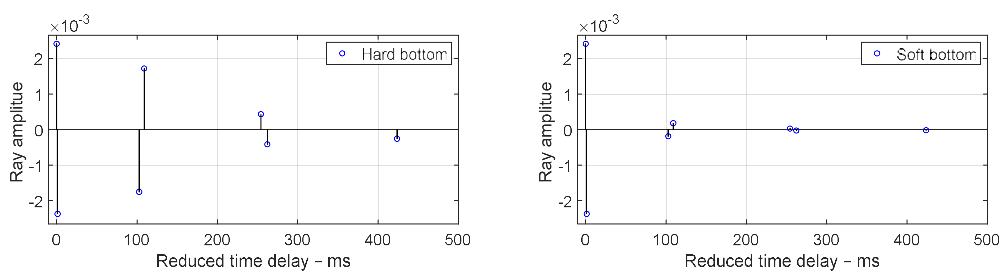

Figure 7 Impulse responses to a hydrophone at distance of 400 m received by a hydrophone 5 m above a hard bottom (left) and a soft bottom(right)

4. EXPERIMENTAL RESULTS

A sea trial was conducted in Trondheim fjord in September 2018 using the NTNU research vessel R/V Gunnerus. The main purpose was to test the concept of using a probe signal for automatic channel estimation, but also to measure the coherence of the direct arrivals compared with the surface reflected arrivals. The vessel moved at a speed of approximately 2 knots while towing a source (SonoTube 008/D13-DT from CTG) transmitting a one-second long linear FM sweep with nominal bandwidth from 7 kHz to 17 kHz and repeated every 10 second. The processing gain of a FM sweep is 10 $\log_{10}(TB)$ giving a potential processing gain about 40 dB but the actual processing may be lower. The time resolution is proportional to $1/B$. The maximum time difference between the surface reflected and a direct arrival assuming a source depth of 7.5 m is 10 ms, but the difference reduces to zero at very large distances. The time resolution should be short enough to resolve the multipath structure and with this choice the time resolution of about 0.1 ms is sufficient for the purpose.

Figure 8 shows a section of 10 seconds duration of the received signal at a hydrophone near the bottom and the frequency spectrum of the same section. The selected section is marked with time of the record position determination using ship navigation log. As can be seen the probe signal dominates over the background noise and noise from the vessel. The frequency spectrum varies from a maximum of about 7 kHz dropping gradually to about 17 kHz as expected. The peaks outside this band is probably coming from the research vessel or from other manmade sources in the area. Important to observe that the levels in amplitudes in the two plots of Figure 8 are before the processing gain applies.

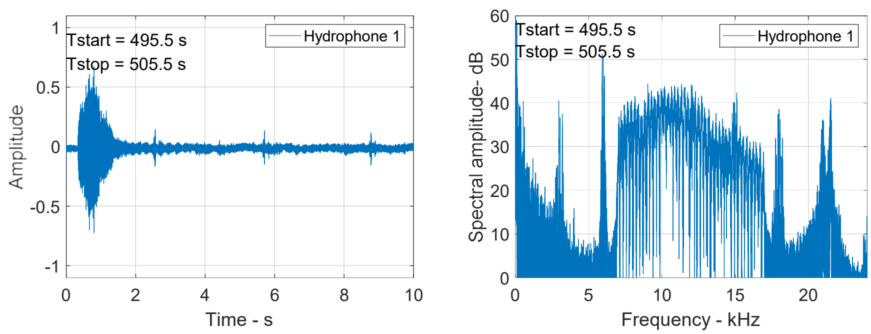

Figure 8. Selected window of 10 seconds and its frequency spectrum

For the matched filter processing a window of length 2 seconds at the beginning of the record is chosen and correlated with the FM sweep signal generated numerically and inputted to the source transducer. Figure 9 shows the cross-correlation between a section of length 2 ms of the received signal and a replica of the probe signal. The first two responses represent, respectively, the direct signal and the reflection from the surface. The rest of the response represents other reflections, but these are insignificant in comparison. Amplitudes of the plots are normalized such that with perfect correlation of one, but the actual value is about 0.4. The main reasons for the reduced amplitude is that the replica used in the correlation is the computer-generated signal input to the transducer and not the signal in the water.

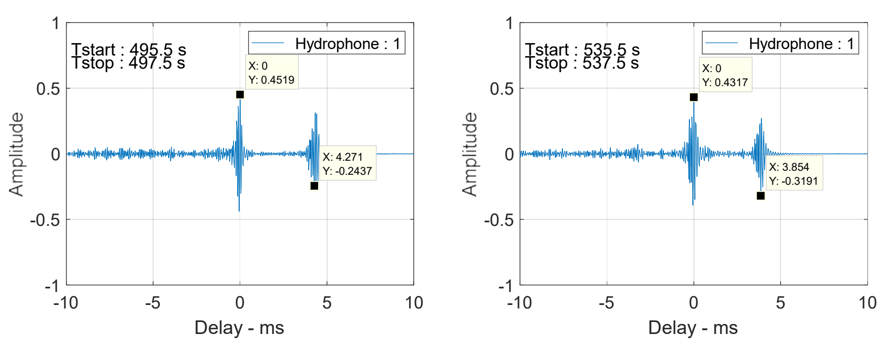

Figure 9 Matched filter output for a hydrophone 5 m above the bottom for two positions of the vessel separated in time of 40 seconds.

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5. A SIMPLE CHANNEL MODEL

The simple channel assumes that the channel is two delta functions separated in time with dt and with amplitudes y_1 and y_2. Using the amplitude values found in the two cases in Figure 9 gives the result shown in Figure 10. The curves represent the correction to transmission loss due to the Lloyd's mirror effect in addition to geometric spreading loss. For low frequencies in the range of 10 Hz to 200 Hz the corrections are from -15 to 0 dB, for higher frequencies the corrections oscillate significantly. This agrees with the measured results in Figure 5 and confirms that the Lloyd's mirror effect is important for the hearing range of fish at low frequencies.

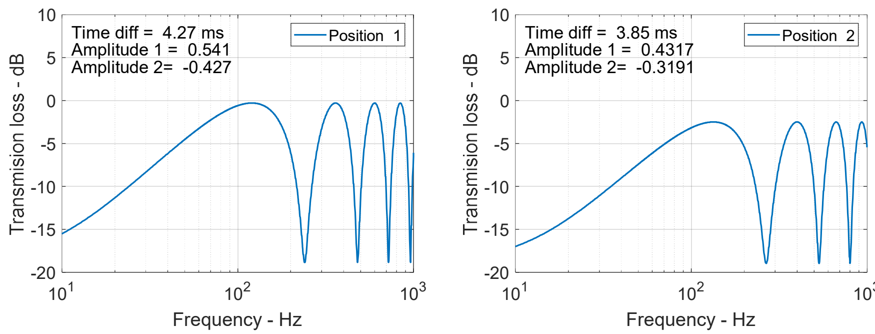

Figure 10 Correction in dB to the transmission loss caused by the Lloyd's mirror effect.

6. SUMMARY AND CONCLUSIONS

For measuring the self-noise of vessels, it is important to account for propagation effect of the propagation channel, which depends on the environmental conditions, the range depth and frequency in a way that is difficult or impossible to control. This paper has presented some preliminary works on using a probe signal and matched filtering for adaptive channel estimation in order to reduce the distortion effects on the measured noise spectrum. The paper presents the concept and demonstrates the feasibility by using data from a recent sea trial.

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