Errors due to Doppler Shift in Measured Levels from a Moving Ship

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ABSTRACT

Standards for ship noise measurements prescribe beam aspect measurements that cover a sector of 60 degrees centered on the port or starboard. As the ship is in motion, radiated noise frequencies measured at a fixed receiver are affected by Doppler shifts. The amount of shift is usually not significant in the 1/3-octave frequency band measurements prescribed by the standards, but it can become quite significant if tones are measured in narrower bands. We illustrate that error here and suggest minimum analyzer bandwidths that should be used for narrow band measurements.

INTRODUCTION

SINCE THE 1940S several countries around the world have been conducting measurements of the radiated noise levels of navy ships. In more recent times the research community has had an increasing interest in noise from commercial cargo ships, due to concerns about the impact of high ship noise levels on marine life in the sea.

In the early days noise measurements were analyzed with analog filters that have a 1/3-octave bandwidth (spanning about 23% of the center frequency). Also, measurements were made with a vertical string of several hydrophones, in order to provide some averaging over variations caused by surface reflections and source directivity.

Based on this experience, ANSI and ISO standards for measurement of surface ship noise were developed that prescribed 1/3-octave band filters and samples spanning a long time, to provide averaging over vertical and horizontal angles of the ship's radiation [1, 2, 3]. Specifically the standards call for noise to be sampled over an azimuthal (horizontal) angle of ± 30 degrees relative to the port and starboard beam aspect. In Figure 1 this refers to the angle sector of 60 degrees centered on the starboard beam aspect as the ship passes a fixed receiver at velocity *v* at a horizontal distance *a* at closest point of approach (CPA).

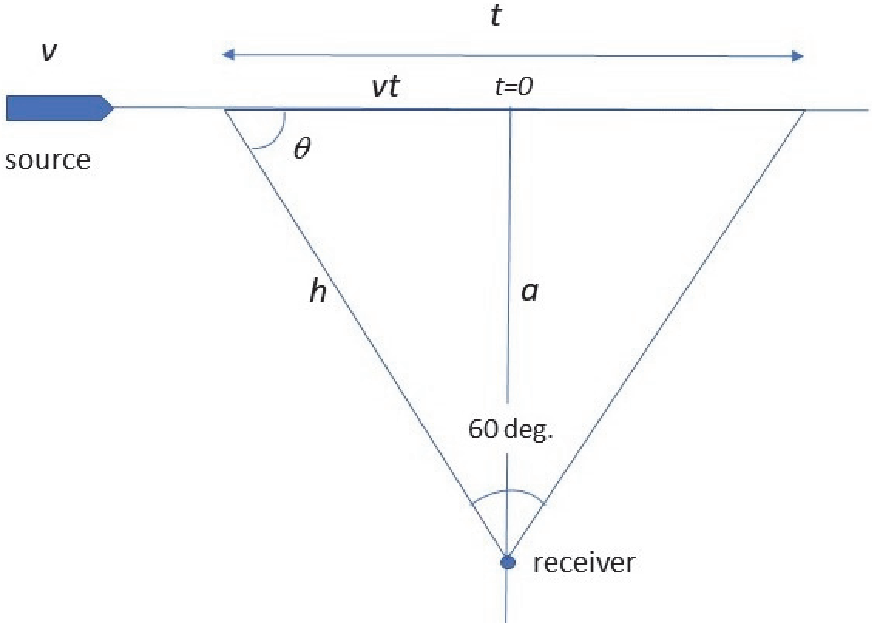

Figure 1. Top view of geometry for ship noise measurements.

By combining averages across frequency, time, and aspect angles, compliance with these standards yields relatively stable and consistent measurements of ship noise levels. However, currently, high-speed computers enable measurements to be analyzed in narrow bandwidths, such as 1 Hz "spectrum levels". This practice can result in significant errors in levels that are not seen in measurements of tones in the wide 1/3-octave bands. This article highlights one source of these errors.

ERROR DUE TO THE DOPPLER EFFECT

Ship noise typically contains a combination of wideband noise and some high-level tones, which dominate the spectrum at low frequencies. Due to the well-known Doppler principle (commonly known as the Doppler Effect), the frequencies of noise received from a moving source are shifted by a small amount. This small shift does not usually cause significant errors in measured levels of tones using 1/3-octave bands, because it will seldom shift the tone's frequency out of the wide band. But if the tone is analyzed in narrow bands (such as 1-Hz spectrum levels), the tone will not spend much of the sample time in any band, and reductions in its measured level can be quite large. This error can be calculated. For simplicity we will do the calculation in two dimensions and neglect the depth dimension (*i.e.* multiple receivers in a vertical string of hydrophones); this is because frequency shifts for deeper receivers will be smaller than the shallow receivers.

When a source emitting a tone at frequency f moves with a velocity v, the measured frequency at a stationary receiver f_D is altered by the factor $v \cos \theta$, where θ is the angle between the source velocity vector and a line toward the receiver; this is the Doppler shift, D. Thus we have Equation (1) and Equation (2):

$$f_D = f + D, \tag{1}$$

and

$$D = f\left(v \cos \theta\right) / c \tag{2}$$

where c is the speed of sound in water.

The ship noise measurement standards prescribe samples to be acquired over a sector of 60 degrees centered at beam aspect. In this case at the start of the sample time the angle between the ship course and receiver path equals 60 degrees, so $\cos \theta = 0.5$. Then the Doppler shift is $f(1 + 0.5\, v/c)$ at the start and the shift is $f(1 - 0.5\, v/c)$ at the end of the sample, for a total Doppler shift of $fv / c = D_{total}$.

When a tone is sampled with a filter of bandwidth B, if $B < D_{total}$, then there will be an error in the measured levels. For a total Doppler shift, D_{total} and filter bandwidth B, the approximate error is $10 \log\left(D_{total} / B\right)$ given in dB.

As an example of the measurement errors that are introduced in narrow band analysis, Figure 2 presents calculated levels of a tone at 1 kHz as measured in 1-Hz bands at various ship speeds. The correct level is 0 dB. Erroneous reductions in levels of over 10 dB are evident.

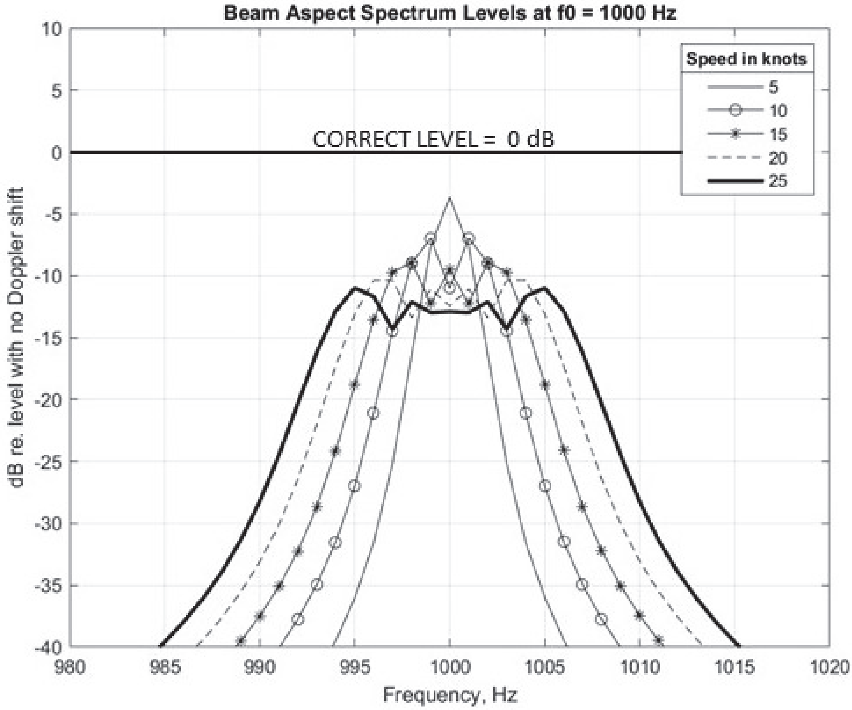

Figure 2. Calculated beam aspect 1 Hz spectrum levels of a tone at 1 kHz at various speeds.

Table 1 shows the total Doppler shifts encountered for beam aspect samples at various ship speeds (assuming sound speed = 1500 m/s).

Table 1. Total Doppler shift within a 60-degree angle sector centered on beam aspect, Hz

Speed kts. -> Freq.	5	10	15	20	25
50	.085	.17	.255	.34	.425
100	.17	.34	.51	.68	.85
200	.34	.68	1.02	1.36	1.7
500	.85	1.7	2.55	3.4	4.25
1000	1.7	3.4	5.1	6.8	8.5

CONCLUSION

Ships moving in a seaway generally encounter variable loads on the propulsion system, which causes random variations in the frequencies of machinery tones. These variations can cause errors in levels in addition to those due to Doppler shifts. As a rule of thumb, for ship speeds less than 25 knots, to reduce errors in tonal levels the analyzer bandwidth should be wider than 1% of the center frequency.

REFERENCES

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BIO

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