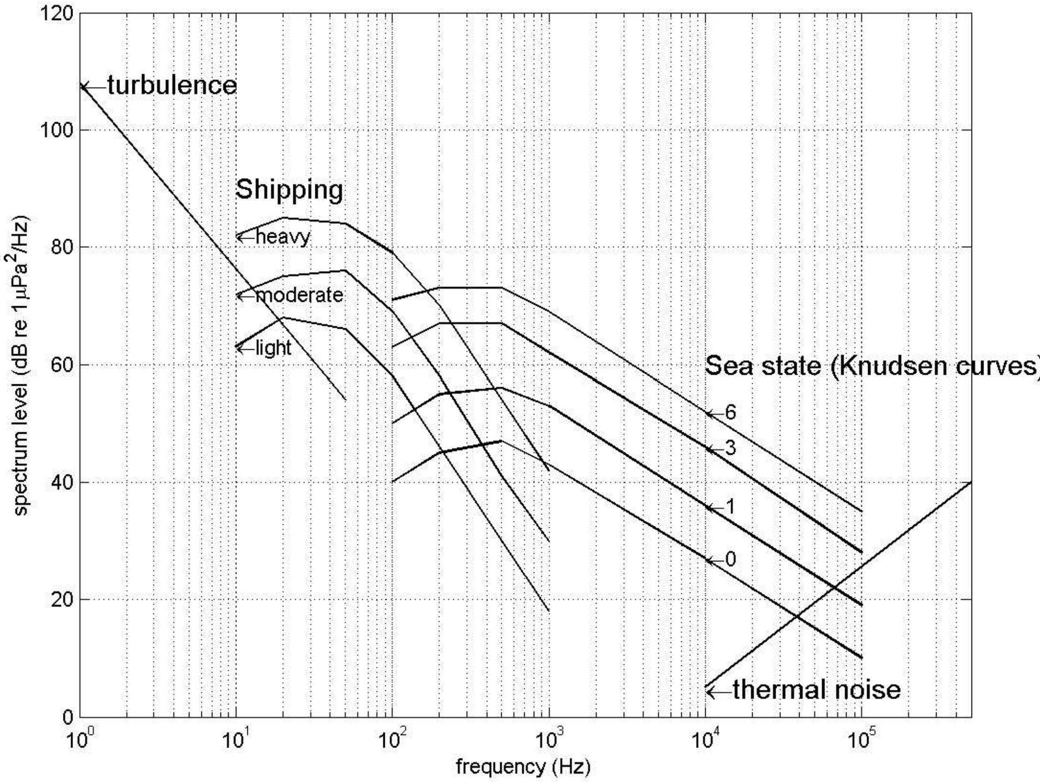
3. Underwater propagation

3.3 Noise

The background against which a sonar signal needs to be detected is *noise* (the sound that reaches the transmitter while there is no sonar transmission and no target) and *reverberation* (the sound that, while there are no targets, reaches the receiver as a result of the sonar transmission). Both noise and reverberation are always present, but the total background level equals, in general, the highest contribution. In this chapter we will consider the noise contribution. The total noise consists of sonar self noise and ambient noise.

3.3.1 Ambient noise

The 'ambient noise level' is the intensity (in dB) of the ambient noise, as measured with an omni-directional hydrophone, relative to the intensity of a plane wave with 1 μPa rms pressure. Ambient noise levels are reduced to 1 Hz frequency bands and are, therefore, called 'ambient noise *spectrum* levels'.
The ambient noise is the result of a number of sources:
Below 10 Hz turbulence (irregular arbitrary flows of water) plays an important role.
'Distant shipping' is the dominant source of ambient noise in the 50 to 500 Hz decade.
Above 500 Hz (up to about 25 kHz) the ambient noise level depends on the 'sea state' or wind speed ('wind noise'). The 'sea state' is a measure for the sea surface roughness (see section 1.7). The breaking of the whitecaps is an obvious noise generating process. The so-called *Knudsen spectra*, noise levels as a function of frequency with the wind speed or sea state as parameter, are based on a large amount of noise measurements in *deep water*.
Above 100 kHz, the ambient noise level is determined by the thermal noise of the molecules in the sea. The spectral level of this noise contribution increases with frequency.
The mean ambient noise spectra for different shipping and sea state conditions are shown in the figure below.



These levels are valid only for deep water and are indicative (uncertainty 5-10 dB, amongst other reasons due to varying propagation conditions). In shallow water the ambient noise levels show much larger variations (both spatially and temporal). The average levels are about 10 dB higher than in deep water.

3.3.2. Sonar self noise

Sonar self noise is the noise generated by the receiving platform and consists mainly of machinery noise (from the ship's motor), propeller noise, and hydrodynamic noise. To reduce the influence of machinery noise and propeller noise, the sonar is either placed as far forward on the vessel as possible, or is towed behind it.
Sonar self noise increases with ship speed and decreases with frequency. This is reflected in the following expression for the spectral sonar self noise level for hull-mounted systems (in dB re 1 $\mu Pa^2/Hz$):

$$NL_{self} = 33 + 1.8v - 20\,{}^{10}\log\left(\frac{f}{12}\right)$$

with v the ship speed in knots (1 knot = 1 nautical mile per hour = 1852 m/3600 s = 0.5144 m/s) and f the frequency in **kHz.** This expression has been derived from measurements on a number of American and British naval ships. Depending on the relative importance of the different contributions, self-noise levels might deviate from the levels as given by the above expression.

3.3.3 Estimating the total noise level

The ambient noise spectrum at any location and time is approximated by selecting the appropriate shipping and wind curves and connecting them at intermediate frequencies. When more than one source of noise is present (e.g. shipping and wind noise), the total noise background is obtained by summing the intensities of the contributing sources. When using noise levels, specified in units of spectrum level in dB re 1 $\mu Pa^2/Hz$, this summation process is accomplished using the power summation operator, which is defined as

$$\oplus = 10\ {}^{10}\log \sum_{k=1}^{N} 10^{L_k/10}$$

where L_k is the level of the k^{th} noise source (dB) and N the number of contributing noise sources. This operation effectively converts the noise level L_k to units of intensity, sums the intensities, and then converts the sum back to units of decibels.

<u>Example 1</u>
At a frequency of 100 Hz under conditions of moderate shipping and sea state 6, the individual ambient noise spectral levels are about 69 and 71 dB, respectively. The total spectral ambient noise becomes

$$69\ \text{dB} \oplus 71\ \text{dB} = 73\ \text{dB}$$

or 2 dB higher than the level due to surface weather alone.

<u>Example 2</u>
At 100 kHz the thermal noise spectral level is 26 dB (neglect wind noise) and suppose the sonar self noise spectral level is 24 dB. The total spectral noise level then becomes

$$26\ \text{dB} \oplus 24\ \text{dB} = 28\ \text{dB}.$$