B) Ambient Noise Measurements

Tutors: Mark Johnson and Mardi Hastings. **Duration:** 2 hrs.

Background

What is meant by a signal and what is meant by noise may not be that easy to discern and to define. Noise may be defined as the'unwanted component' of the sound field, as opposed to the 'wanted' signal. It is usually stochastic in its nature, but some noise sources such as propellers have tonal and / or transient components of deterministic nature.

Besides this introduction you may benefit from reading Mark Johnsons and Kristian Beedholms lecture notes on signal analysis, and Peter Madsen's notes on the sonar equation.

There is currently a great political and nature conservation interest to study how marine animals are affected by noise. If you pursue a career in marine bioacoustics you will most certainly at one point or another study effects of man-made noise on wildlife. Studies made at the present span almost anything from how mussels react to windmill noise to how whales react to military sonar. These studies are often hampered by misconceptions concerning how noise is measured, and how it is perceived by an animal. This practical aims at giving some basic understanding as to how to measure noise.

Noise power and bandwidth

Noise measurements are most conveniently expressed as the average sound power over a certain bandwidth (BW). Because of its stochastic nature, noise measurements should ideally always be accompanied by an assessment of the variation of the mean values.

A noise measurement without indicating the BW of the measure is meaningless. You may picture noise as consisting of two parts, just like the sides of a rectangle: you cannot describe the rectangle with only one side, both sides are needed. For noise, both BW and sound power is needed for a complete description. Also, note that noise cannot be quantified with a peak reading device. *Why not?*

The typical unit for noise measurements is sound (noise) power in the 1 Hz band (Pa^2/Hz). We call this the noise spectrum level or noise power spectral density. A convenient way to express the noise power spectral density (in dB) is the following:

$$10 \log (p^2/BW) = 20 \log (p/p_0)^2 - 10 \log (BW/1).$$

BW is defined as the upper "cutoff frequency" minus the lower "cutoff frequency"). The reference for BW is 1 Hz. The pressure reference (p_0) in water is 1μPa (RMS). So, we have dB re $1\mu Pa^2/Hz$ using the equation above. However, in actual measurements we normally don't measure sound power ($\sim p^2$), but sound pressure (p). We therefore sometimes see this reference unit expressed as dB re $1\mu Pa/Hz^{1/2}$, which is exactly the same as the former – *can you figure out why?*

Traditional (analog) filters used for measuring noise power spectral density is the $1/3^{rd}$ octave filter bank and the octave filter bank. These filters have specified BW's (ISO R266). For example, each filter of the 1/3rd octave filter bank has a BW = 0.23 of the center frequency (f_c); for the octave filters each filter bank has a bandwidth equal to f_c. For 1/3 octave filters this means that the BW becomes broader as f_c increases, similar to the cochlear filters in the mammalian auditory system (this is one of the primary reasons why 1/3 octave band filters are so popular among bioacousticians). You can use the 1/3 octave or the octave filter bank to measure noise power spectral density by using the equation above, or you can express the noise measurement directly in dB re 1µPa (RMS) for each filter band (and let the reader do the conversion).

White noise is defined as having the same power spectrum density from the lowest to the highest frequencies. The output of each 1/3rd octave filter band increases by 1 dB, i.e. *10 log (1/3 octave BW re to the preceding 1/3 octave BW)* for a white noise input. Most naturally occurring and man made noise (including Bach's cantata) have a 1/f weighted spectrum, When white noise is the signal being measured the output of each successive 1/3 octave band increases by 1 dB. Engineers developed a "pink" noise signal that decreases in power by 3 dB per octave such that the outputs of each 1/3 octave filter are theoretically identical. "Pink" noise can be used as a probe signal for investigating the frequency response of systems measured with the 1/3 octave filter bank. Actually, ambient noise of the oceans is not that different from pink noise in some frequency bands.

Noise is usually a stochastic signal and should be described in statistical terms. You need to use between 50 and 100 degrees of freedom (df) to determine the noise power to ±1-2 dB (90% confidence interval).

$$df = 2 \cdot BW \cdot T$$

where T is the time period you use to measure the RMS value. For an fc of 16 Hz your measuring time should be at least 10 s (2·(16Hz·0.23)·10s = 74 df). For an fc of 250 Hz and higher a 1 s measuring time is sufficient.

Digital measurements

It is here assumed that you have a basic knowledge of digital signals (such as samples, sampling frequency, Nyqvist frequency, FFT size and window functions) – otherwise, have a look at the lectures by Johnson and Beedholm, or ask any of the teachers at the class.

In the Digital Fourier Transform (DFT) a number of samples (N) are transformed into a set of N/2 spectral points. All the energy / intensity of the signal should be contained in those N/2 points, so the frequency resolution of the spectrum is

$$\Delta f = \frac{f_{samp}/2}{N/2} = \frac{f_{samp}}{N}.$$

The resolution may be improved with various analysis techniques (ZOOM FFT, et cetera). This is however beyond the scope of this practical, instead you should consult books or gurus in signal analysis. Anyhow, the equation above gives an idea as to how well frequency peaks can be resolved within a spectrum, and how large band width each DFT sample contains (which is important when measuring spectra of stochastic signals).

System noise

The whole electronic chain from the hydrophone until the recorder will create electric noise. For many hydrophones the inherent noise level is actually much louder than the ocean noise (see the Appendix to the program for some specifications). Therefore, ambient noise measurements made with such hydrophones (and there are quite a few published results with this error!) should be thrown straight into the garbage can and regarded as noise in the literature.

It is therefore very important to assess the inherent system noise of the recording chain before trying to record any ambient noise. It is likewise crucial to identify any components that may create excessive noise and having them exchanged. Four things are usually crucial for reliable noise measurements:

1) The choice of hydrophone: both Reson and B&K have some models that have a built-in preamplifier that causes the hydrophone to have incredible low inherent noise levels. Hydrophones with a long cable between the element and the preamplifier are normally completely useless for noise measurements.

2) Grounding: Electric noise may increase tremendously due to grounding problems. A wire from the ground of the recording equipment and into the water can usually greatly reduce this problem.

3) Connecting equipment to the AC network is usually a great source of 50/60 Hz noise, sometimes with beautiful overtones covering most of the spectrum! Therefore, stick to battery supplies in the whole recording chain while recording!

4) Mechanical noise from hydrophone deployment must be avoided, as must the self-noise from the recording platform. Usually it is a great idea to try to mount the hydrophone so that it is as motionless as possible in the water, as far away from sea surface and sea floor as possible (if you are not specifically interested in THOSE noise components!). Also needless to say you need to switch of any engine, pumps et cetera on the recording platform.

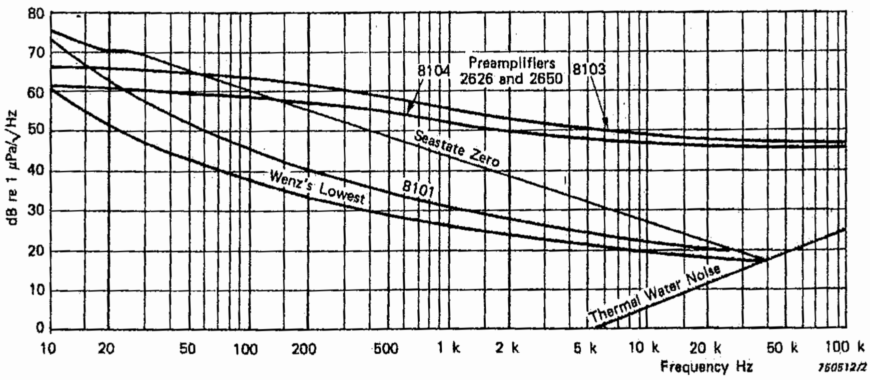

Fig. 2.7. Typical equivalent noise pressure curves for the hydrophones in water (8101/03/04)