Appendix 2

Peter Madsen and Magnus Wahlberg

Basic Sound Metrics

Absorption	(dB/km) Frequency dependant loss of sound energy as heat via ionization and relaxation of molecules in the transmission medium. Can be approximated by 0.035 x $f^{1.5}$, where f is the frequency in kHz.
Apparent source level	(ASL, dB re. 1µPa in water) The sound level back-calculated to one meter distance from a directional sound source of unknown orientation with respect to the receiver.
dB	Decibel. A Bel is the unit of level given by the Log_{10} to the ratio (r) of two powers. A decibel is one tenth of a bel: dB = $10\log_{10}(r)$.
Decade	A tenfold increase in frequency.
Directionality index (DI)	The intensity ratio between the source level of a directional source and the source level of an omnidirectional source radiating the same power.
Energy flux density	(dB re. J/m^2) The energy carried by a sound pulse given by the rms intensity integrated over the duration. Is often given in the unit of dB re. 1µPa ^{2}s since it is proportional to Sound Exposure Level for a plane wave in an unbounded medium.
Hertz (Hz)	Unit of frequency in cycles per second.
Impedance	The acoustic resistance of a medium given by the ratio of the sound pressure and the particle velocity. In the free acoustic field the impedance is given by the product of the sound speed (m/s) and the density (kg/m^3)
Intensity	(W/m^2) Power per unit of area in the direction of propagation. Is proportional to the instantaneous pressure squared of a plane wave in an unbounded medium. For all sound waves it is defined as the product of pressure and particle velocity.
Octave	When the frequency is doubled or halved.
Particle motion	The oscillation of particles in the medium in which the pressure wave of sound travels. Can be quantified in units of displacement, velocity and acceleration. The instantaneous sound particle velocity is always given by the instantaneous sound pressure divided by the impedance of the medium. In the case of plane waves, this simplifies to the sound pressure divided by the sound speed and density.
Power spectral density	(dB re 1uPa/Hz$^{1/2}$) RMS power in 1 Hz bands.
Pascal (Pa)	The unit of pressure is the force of 1 Newton acting upon an area of one square meter
Pink noise	Noise that drops 3 dB per octave with increasing frequency. Often used to approximate ambient noise characteristics in the ocean.
Power	(J/s) Energy per second. Is proportional to the instantaneous squared pressure of a plane acoustic wave.

Received level (RL)	The sound level impinging on a receiver. Relates to SL or ASL by: RL = (A)SL-TL.
RMS	The root of the mean of the pressure squared over a given window.
Sound	Sound is subjectively defined as what can be heard, but physically it is defined as a mechanical disturbance that propagates in an elastic medium. Note that while the sound propagates as a pressure wave, the particles of the medium oscillate around their static position, but do not propagate with the sound wave.
Sound Exposure Level	(dB re. 1μPa ^{2}s) The integrated squared pressure over the duration of a sound pulse. Is proportional to Energy flux Density for a plane wave in an unbounded medium.
Sound pressure	A dynamic variation in ambient pressure caused by a sound wave.
Sound pressure level	(dB re. 1μPa in water). Log scale expression of the ratio between a given sound pressure and a reference pressure. The latter is usually 1μPa in water and 20 μPa in air.
Sound speed (c)	(m/s). The speed at which the pressure wave travels in a given medium. Varies with environmental factors such as ambient temperature, salinity and pressure. The sound speed is around 1500 m/s in water and 340 m/s in air.
Source level (SL)	(dB re. 1μPa in water). The sound level at one meter distance from a sound source measured on the acoustic axis. SL is normally expressed in pressure units.
Target strength (TS)	The ratio between the resulting echo level measured 1 meter from the target on the axis of ensonification, and the received level of the ensonifying sound at the target.
Third octave level (TOL)	(dB re. 1uPa) RMS sound pressure level in a third octave band. The bandwidth of TOLs is approximated by 0.23 x center frequency. The center frequencies are given by $10^{n/10}$, where n = 1...N gives the filter number.
Transmission loss	The reduction in sound level as the sound power is distributed over an expanding area as it propagates away from a source + what is lost to absorption and scattering. Relates to SL by: TL = SL – RL.
Wavelength (λ)	(m) The length in meters of one pressure cycle. It is given by the sound speed c (m/s) divided by the frequency f (Hz). E.g. the wavelength at 1 kHz is 1.5 m in water, but 0.34 m in air
Watt (W)	(J/s) Joules per second.
White noise	Random noise where the average power is constant for the same band width irrespective of frequency.

Things to remember for underwater sound recordings

One will always record something if the system is powered up and running, but the question is if the recorded sounds are representative of what was impinging on the hydrophone, or generated artefacts during the recording process. Recording and quantification of sound are inherently difficult and the following points will hopefully assist in preventing the most common errors.

1) Know the frequency response of the recording system and make sure that it matches the frequency range of the sounds you want to record. For digital recordings it is a good rule of thumb to sample three faster than the maximum frequency you want to measure (i.e. if you want to measure up to 100 kHz then sample at 300K). Use low-pass filters when using digital recording systems to avoid aliasing (frequency ambiguity around the Nyquist rate of the system) and high pass filters in all recordings to avoid saturation of the recording system by low frequency noise.
2) Make sure that the dynamic range (the magnitude difference between the system noise floor and overload) matches the dynamic range of sounds you anticipate will hit the hydrophone. Adjust the gain and use a suitable hydrophone to make sure that clipping is avoided in all parts of the recording chain. This is especially important for hydrophones with preamplifiers which will have a maximum voltage output. The same applies for any amplifier, so the whole recording chain must be thoroughly thought of.
3) Do not add on cable to hydrophones without preamplifiers as that will change the sensitivity of the hydrophone. Make sure that the input impedance of the amplifier connecting to your hydrophone is very high (typically at least 1 MΩ). The lower frequencies you are interested in detecting, the higher the input impedance must be.
4) Measure the system noise of the entire recording chain and make sure that it is at least 10 dB lower that any noise levels you anticipate to quantify in any given frequency band.
5) All hydrophones are directional and the directionality increases with frequency. The use of hydrophones with a differential spatial sensitivity at high frequencies will not provide a true measure of the isotropic noise field. Small hydrophones have omni-directional receiving characteristics at high frequencies, but are also less sensitive and have accordingly a higher self-noise which may impair quantification of ambient noise at high frequencies.
6) It is important to consider constructive and destructive interference from surface and bottom reflections with the direct sound path. To record only the direct path you need to place the hydrophone at a depth sufficiently far away from the surface and sea floor. The desired hydrophone depth depends on the source to hydrophone range and the duration of the signal. In many cases it is not possible to avoid reflections, and great care must be taken in interpreting the data: are spectral ripples caused by the source or by e.g. the Lloyd Mirror effect?
7) Make sure to fasten the hydrophone cable before you deploy it. Many projects have been terminated prematurely by sacrificing the hydrophone to King Neptune.
8) Record a calibration signal through your entire recording system before and after each recording session to ensure that the system sensitivity remained the same throughout the recording.