MEASURING UNDERWATER NOISE: PERILS AND PITFALLS

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INTRODUCTION

Underwater noise is a key factor in determining the performance of underwater acoustic systems. This applies to both biological and anthropogenic systems. If noise levels increase sufficiently then both types of system can suffer considerable impairment of performance and eventually may be damaged. It is important therefore that the characteristics of underwater noise are understood in order to predict the performance of sonar systems, and to predict the impact of noise on marine organisms.

Interest in underwater noise originated from military sonar systems during WWII and led to some detailed research programmes in the post war years (e.g. Knudsen *et al*, 1948). As sonar systems became more sophisticated with the introduction of solid-state electronics and then integrated circuits so there was a continuing need to understand how the system responded to underwater noise. These programmes led to the important report on sources of underwater noise (Wenz, 1962) that resulted in the much reproduced deep water noise curves shown below in figure 1.

Following this there was a period of lower interest until the mid 1980's when again interest increased, initially in understanding the contributions to ambient noise and then looking at the impact of underwater noise on active sonars. More recently there has been increased interest in looking at the impact of noise on marine life and in the way that organisms react to high levels of underwater sound.

This paper will review the definition of common terms used and suggests some minor amendments to accepted definitions. It will then look at how we measure ambient and radiated noise and consider how it is possible to reduce self-noise. Lastly it will review measuring systems and how they can be optimised for particular measurements.

This paper does not attempt to describe the contributions to ambient noise from the many noise sources in the sea. For a detailed discussion of ambient noise see the SEA (Harland *et al*, 2007) and SEA 7 (Harland and Richards, 2006) technical reports on underwater noise prepared for the UK DBERR. Also look at chapter 5 of Richardson's book on marine mammals and noise Richardson et al, 1995), or chapter 7 of Urick (Urick, 1983). More information on radiated noise is available from a report prepared by QinetiQ (Richards *et al*, 2007) as part of an environmental assessment for marine renewables prepared for the Scottish Executive (Anon, 2007). The SEA and Scottish Executive reports are downloadable from the internet.

2 DEFINITIONS

2.1 AMBIENT NOISE

There have been a number of definitions of ambient noise over the years. They generally include most noise to be found in the sea but some exclude specific sounds. Wenz, in his key paper of 1962 (Wenz, 1962) excluded 'obvious noise from marine life, nearby ships, and other sources of intermittent and local noise'.

Urick in his textbook on underwater sound (Urick, 1983), used the definition:

It is that part of the total noise background observed with a non-directional hydrophone which is not due to the hydrophone and its manner of mounting or to some identifiable source of noise.

Richardson, in his book on marine mammals and noise (Richardson *et al*, 1995) used a much simpler definition:

Ambient noise includes the sounds that exist if the hydrophone were not there.

A real measurement cannot be made using any of these definitions. In terms of impact on systems, it is the summation of all the noise contributions that matter. It does not matter if the sound originates from a shipping lane hundreds of miles away, or a snapping shrimp ten metres away, they both increases the noise level seen by the acoustic system and are beyond the control of the system designer. I therefore recommend the following definition for ambient noise:

That sound in the ocean, received by an omni-directional sensor, which is not from the hydrophone itself or the manner in which it is mounted and/or deployed.

Ambient noise is made up of many contributions from natural, biological and anthropogenic sources. Each contributor may be continuous, intermittent or transient in nature. Each contribution may vary in level randomly or in a cyclical manner. The cycle length may be tidal, diurnal, weekly, lunar, monthly, or annual, depending on the source of the noise.

Wenz (Wenz, 1962) produced the diagram shown below in figure 1. This attempts to summarise the major contributors to ambient noise in deep water. At low frequencies distant shipping dominates while at higher frequencies wind and precipitation noise dominate.

In shallow coastal and shelf waters these curves may be severely modified by the differing acoustic conditions. There may also be large variations in the shape of the spectrum over comparatively small geographic areas.

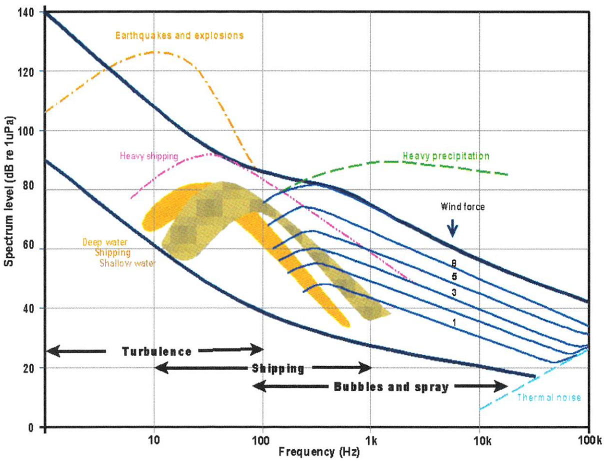

Figure 1. Deep water noise curves. Adapted from Wenz, 1962.

2.2 SELF-NOISE

My recommended definition of self-noise is:

That noise, from an underwater acoustic sensor, which originates within the sensor itself, the method of mounting the sensor, or from the platform from which the sensor is deployed.

Self-noise can originate from a various of causes. See section 4 below for a more detailed discussion. Self-noise can be very difficult to recognise, and even more difficult to eliminate. However, it is important to make every effort to reduce self-noise levels if optimum system performance is to be obtained.

2.3 RADIATED NOISE

Many mechanical systems radiate noise into the marine environment. All of these contribute to ambient noise. A recommended definition of radiated noise is:

That acoustic noise radiated from a source of finite physical extent and for which it is possible to make a far-field measurement.

Note that distributed noise sources like rain or wind noise do not come within this definition because of the physical extent of the source. There is also a grey area where a noise source is made up of many individual sources. As an example, it is possible to characterise the radiated sound from a single snapping shrimp, but when looking at acoustic system performance or ambient noise levels, the noise due to a large gathering of shrimps is more important. The noise from such a gathering cannot be said to be radiated noise as defined above because of the physical extent of the group.

3 MEASURING UNDERWATER NOISE

3.1 METHODS

In recent years the measurement of underwater noise has often consisted of hiring a small boat to get out to the measurement site. A single hydrophone is then deployed to a suitable depth and recordings made of the underwater sound field. This may be ambient noise or radiated noise from a nearby source. On completion the recordings are returned to base and analysed to produce the required data. This is a simple procedure and at first sight should be capable of characterising the sound field.

However, many recent measurements have produced some highly suspect results and used badly planned measurement methods. Consider the potential problems with the simple method described above:

a) The small boat hired has unknown radiated noise characteristics and may contribute to the self-noise problem during the measurement.
b) The stability of the small boat at low speeds or stationary is not known and may result in flow noise from the measuring hydrophone.
c) The depth of the measuring hydrophone is rarely measured. At best it is estimated from length of cable paid-out.
d) The depth of water is rarely measured, or if it is then it is not reported.
e) Supporting oceanographic measurements are rarely made e.g. temperature profile, wind speed/direction, precipitation type and rate, seabed type.
f) For radiated noise measurements the relative positions of source and hydrophone are rarely measured accurately
g) Correcting for range to get the source level of radiated noise is often carried out using inappropriate methods.
h) There is rarely an attempt to characterise, understand, and minimise the self-noise of the measuring system.
i) During radiated noise measurements it is important to characterise ambient noise to ensure the resulting collected data is well above ambient levels. This is not always done.

j) When recording and processing data it is important to ensure that the processing does not corrupt the data by introducing non-linearity or insufficient dynamic range. This check is rarely done.

Early measurements of underwater noise were generally of a higher quality. They were made within well-funded military research programmes by scientists with a good background in underwater acoustics who well understood many of the problems listed above. Although the equipment available to them was primitive by modern standards, they achieved results that are still referenced today.

More recent measurements have often been made by teams who are good marine biologists, but have a limited grasp of underwater acoustics and whose principal interest is in looking at the impact of the noise on marine life, rather than the noise itself. This has led to some published data being highly misleading, and, perhaps even worse, is that this misleading data is being reproduced in summary reports and used in describing the impact of sound sources on the marine environment without being questioned by subsequent authors.

3.2 AMBIENT NOISE

Before attempting to measure ambient noise it is important to consider how the measurement should be made. We have seen that the noise level may vary in a random manner or may vary in a cyclical manner. It is important to collect a sufficient amount of data to match the subsequent processing requirements. If it is required to characterise a site before installing a noisy system such as a renewable generator unit then the minimum collection period should be one year. If however it is just required to understand the impact of a short term noise generation process then a few hours before and after the noise making may suffice.

It will also be necessary to consider the effect of bottom bathymetry and acoustic properties on the noise field. It may be necessary to make measurements at one or more sites to get a good understanding of the field. The historic vertical temperature profile information for the site and season should be considered to determine an optimum depth for the measuring system. It may be more appropriate to use a vertical array of hydrophones to sample the full water column. Also to be considered is whether the directionality of the noise field is important. If it is then perhaps a volumetric array of hydrophones should be used to determine this directionality.

Once the measurement plan has been determined, a suitable set of equipment should be assembled, fully tested, and calibrated **BEFORE** going out and making the measurements. It is all too easy when pushed for time to defer the full system tests and calibration until after the measurements. It can then be found that the system gain was wrong for optimum dynamic range or that there are some unwanted spectral lines in the middle of the band of interest which only show up under trial conditions. It can also happen that equipment is lost during a trial and data gathered on an uncalibrated system is of no use.

The importance cannot be emphasised enough of testing and evaluating measurement systems before making the required measurements. It takes time and effort, but that is a worthwhile investment if it means that high quality data is collected on the first attempt. Repeat measurements can be more expensive than preliminary testing and can damage the reputation of those involved.

During the actual measurements make sure that all required metadata is collected in a proper manner. Is it sufficient to write down the GPS position once every 30 minutes, or is it better to record the GPS position automatically every 5 seconds? How often should weather data be noted? Is it necessary to collect a temperature profile? How accurately and often do you need to measure the hydrophone and water depths. Make sure all collected data is sufficiently identified to be able to associate acoustic data with the meta-data during later analysis.

Always replay acoustic data while still at sea to make sure the quality is as expected. It is not too late then to repeat important measurements. Once back ashore it is impossible to repeat measurements and missing data may seriously impact the analysis.

3.3 RADIATED NOISE

Measuring radiated noise is similar to measuring ambient noise but can present additional challenges. All of the comments about measuring ambient noise in paragraph 3.2 above apply to measuring radiated noise.

When measuring radiated noise it is important to know the location of both the noise source and the measuring system. Remember to allow for any underwater offsets caused by deployment methods and cable angles due to currents.

It is also important to keep a detailed log of operations associated with the noise source. Some aspects thought to be trivial at the time may during later analysis be shown to be very important. It is better to collect too much detail than too little. Also keep a log of activities taking place around the measurement site, but not associated with the measurements. This may include passing ships or nearby fixed installations. Using an Automatic Identification System (AIS) receiver may help partially automate this process and can provide a lot of useful data about nearby vessels. The sounds that you measure may not originate from the noise source being characterised but from some other nearby source.

Measuring the radiated noise from mobile systems can best be achieved by using fixed ranges. These use a widely spaced array of hydrophones on or above the seabed and the noise generator, such as a ship, passes over the range on an accurately known track. This provides multiple simultaneous samples of the radiated noise from the source and allows accurate determination of source levels and any directionality in the radiated noise pattern. There are three fixed facilities in the UK used by the military, located at Portland, Loch Fyne, and Rona in the Inner Hebrides.

4. MINIMISING SELF-NOISE

4.1 THE PROBLEM

Self-noise is an inescapable part of making underwater noise measurements. There are many sources of self-noise waiting to corrupt the acoustic data collected by the unwary. The following list shows some of the more common sources of self-noise:

- Debris and/or sediment impacting the hydrophone
- Flow noise
- Biological abrasion noise
- Electrical noise in preamplifier
- Non-linearity or instability in the preamplifier
- Hydrophone cable strum
- Hydrophone cables rubbing against each other or deployment equipment
- Loose mechanics in deployment system rattling
- Own ship noise due to engines/generators/wave slap
- Electrical interference from own ship
- Electrical cross-talk in multi-core cables
- Strumming on cable to surface
- Signal degradation by recorders and processing systems

Any one system may suffer from a number of these problems. It is not always easy to detect that some of them have degraded the data. As an example, a well known transducer company makes a high frequency hydrophone with integral preamplifier that appears to work well under low signal conditions and easily meets the manufacturers claimed performance. Unfortunately, when driving longer cables, the output stage is slew-rate limited at the higher part of the frequency coverage and so short, loud, high frequency pulses such as echolocation clicks have an amplitude somewhat lower than the expected level and have modified spectral characteristics.

4.2 THE SOLUTION

It is impossible to deal with the solution to each of these problems in a short report such as this. However, researchers assembling and using measurement systems must be very vigilant about self-noise corrupting their measurements and must double check the data quality at all stages of collecting and processing underwater noise.

Some general guidelines to achieving low self-noise are:

a) Be very careful about mechanical design

Make sure everything is secure and that no components can rub together
Use vibration isolation if movement is unavoidable
Use low flow noise designs if water movement is unavoidable
Use cable fairing to minimise strum

b) Ensure good electronic design

Use a low-noise preamplifier
Ensure preamplifier has the required frequency range at maximum signal levels expected
Use balanced signal transmission systems to minimise pickup and cross-talk
Use non-electrical signal transmission e.g. fibre-optics in a high noise environment
Design for highest dynamic range

c) Consider the worst that can happen

Can the measurement system work at high sea states?
Can the measurement system work at the strongest tidal currents in the area?
Can the measurement system work at high/low/varying supply voltage?
Can the measurement system cope with a noisy static invertor supply?

d) Check the signal quality

Listen to the signal – the trained ear is good at picking up problem signals
Look at the spectrogram of the incoming signal, are there obvious artefacts?
Is the measured radiated noise sufficiently above ambient noise?
Do signal levels match up with system calibrations?

5 MEASURING EQUIPMENT

One of the problems of recent ambient and radiated noise measurements associated with environmental impact assessment is that the methods of acquiring and processing the data mean that it is difficult to compare independent measurements in a meaningful manner. Some of the difficulties are:

- Different FFT bandwidths and weighting functions
- Use of both constant bandwidth and third octave measurements
- Varying and unspecified integration times
- Varying methods of averaging long timeline data
- Unspecified pre-whitening to correct for hydrophone response

It is perhaps useful to consider how airborne noise measurements are made. Measurements are now routinely made by semi-trained personnel using internationally-agreed measurement standards.

Their standard equipment consists of a hand-held unit with integral microphone which makes wideband measurements using a number of predetermined frequency responses (see figure 2).

These include a flat response and responses corresponding to human hearing at low and high levels. The more advanced instruments also include an FFT mode. In the underwater measurement field there are no agreed standards of measurements. A number of researchers have proposed the use of audiograms of various marine species in order to determine the loudness of sounds heard by these species. However, the use of individual species can result in a very large number of results from just one measurement. It is perhaps more useful to use generic audiograms for a small number of key groups of species. A possible audiogram set could be mysticete, small odontocete, beaked whale, pinniped, swim bladder fish, non swim bladder fish. The generic audiograms would need to be agreed by an international standards committee.

It would then be possible to produce a hand-held instrument similar to the airborne noise instruments, but with an external hydrophone as shown in figure 3. Operators would be required to complete a short training course before being allowed to make measurements. These units could then be used to make routine measurements of underwater noise levels such as those associated with the construction industry.

Figure 2 Typical noise meter

Figure 3. Underwater noise meter

The available airborne noise measurement equipment also includes self-contained units that can be deployed for long periods to characterise a site. There is no equivalent system in the underwater noise measurement field. There are a number of underwater recording systems that have been devised for listening for whale calls or monitoring earthquake activity, but these are not ideal for the ambient noise application either because of high self-noise levels or inappropriate spatial and/or frequency coverage. It would not be difficult to design a system optimised for ambient noise measurements with low self-noise and the correct acoustic responses. Such units could be deployed around noise-generating activities to produce full timelines of the noise put into the water or could be used to characterise ambient noise.

Such units can also be extended to included automated detection of predetermined sounds such as marine mammal calls or sonar operation, and can also make basic oceanographic measurements such as water temperature and depth. For very long deployments the acoustic data will need to be processed on board to reduce the storage requirements. Raw data can still be sampled at pre-determined intervals as a check on data quality. Telemetry can be used to acquire small amounts of data as a quality check, but be aware that this could affect the data being acquired.

6 CONCLUSIONS

The accurate and detailed characterisation of underwater noise is a common requirement, but a very difficult measurement to make. It entails careful planning of the measurements required to fulfill the aims of the work. Great care must be taken in constructing and testing the measurement system.

The deployment and operation of the measurement system at sea is always challenging and care must be taken to avoid contaminating signals with self-noise artifacts. Care must also be taken during the recording and analysis of the data to ensure it does not suffer further degradation. This paper has suggested ways in which all of these problems can be addressed.

This paper also suggests that there is now a need for the standardisation of measurement methods so that the comparison of results from independent measurements is possible. It has proposed that standard generic audiograms are used when making wideband measurements.

The long term characterisation of underwater noise requires a new autonomous system that can monitor for prolonged periods and compress the data in a standardised way.

REFERENCES

Anon (2007) Scottish Marine Renewables Strategic Environmental Assessment (SEA): Environmental Report. Scottish Executive, Glasgow. http://www.seaenergyscotland.co.uk/

Harland EJ, Jones SAS, Clarke T (2005) SEA 6 Technical report: Underwater ambient noise. QinetiQ, QINETIQ/S&E/MAC/CR050575, London. http://www.offshore-sea.org.uk/site/scripts/consultation_download_info.php?downloadID=150

Harland EJ, Richards SD (2006) SEA 7 Technical report: Underwater ambient noise. QinetiQ, London. QINETIQ/06/00531. http://www.offshore-sea.org.uk/site/scripts/consultation_download_info.php?downloadID=187

Knudsen VO, Alford RS, Emling JW (1948) Underwater ambient noise. Journal of Marine Research 7: 410-429.

Richards SD, Harland EJ, Jones SAS (2007) Underwater Noise Study Supporting Scottish Executive Strategic Environmental Assessment for Marine Renewables. QinetiQ. QINETIQ/06/02215/2. http://www.seaenergyscotland.net/public_docs/Appendix%20C17_A%20-%20QinetiQ_Noise_06_02215_2.pdf

Richardson WJ, Greene CR, Jr., Malme CI, Thomson DH (1995) Marine mammals and noise. Academic Press Inc, San Diego.

Urick RJ (1983) Principles of underwater sound. McGraw-Hill Book Company, New York.

Wenz GM (1962) Acoustical ambient noise in the ocean: Spectra and sources. Journal of the Acoustical Society of America 34: 1936-1956.