Measuring underwater background noise in high tidal flow environments

Miles R. Willis, Mérin Broudic, Charlotte Haywood, Ian Masters, Sara Thomas

Marine Energy Research Group, School of Engineering, Swansea University, Wales, UK
Ecole d'Ingénieurs en Génie des Systèmes Industriels (EIGSI), La Rochelle, France
Tidal Energy Limited, Cardiff, Wales, UK

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ABSTRACT
Understanding the effect of marine energy development on the underwater noise levels in a proposed installation area forms a crucial part of any Environmental Impact Assessment. This paper uses boat-based hydrophone survey data taken from an area subject to tidal currents up to 3 m s\(^{-1}\) and determines how the background noise levels change with tidal flow and flow direction. It was found that a more meaningful expression of background noise was gained by reference to "Power level" as measured by the Root Mean Square of the spectrum. Hydrophone measurements were taken during low season (with respect to other maritime activity) and in high season over the entire tidal cycle. Background noise levels ranged between 72 and 108 dB re 1 \(\mu\)Pa\(_{\text{RMS}}\) with higher sound pressure levels occurring at frequencies below 100 Hz. Background noise levels increased with increasing tidal flow and were higher on ebb tides than flood tides.

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1. Introduction
The potential environmental impact of marine energy devices on the ocean and their associated land-fall infrastructures must be addressed as part of an environmental impact assessment. The increase in leases to the emerging wave and tidal stream sector around the UK coast will inevitably lead to a large number of environmental consent applications for both small scale pre-commercial demonstration devices and the next generation of small arrays of devices.

Based on work by Willis et al. [1] environmental stressors include: the physical presence of the device, their dynamic effects, energy removal effects, chemical, electromagnetic and acoustic effects. The environmental stress related to the marine energy device will need to be considered at various stages of operation, from surveying through to decommissioning. This paper is considering underwater acoustics and in particular how to measure and report underwater acoustics from sites typical of accommodating tidal stream energy devices.

The noise emitted by the marine engineering works associated with the installation, operation, maintenance and removal of a marine energy device is geographically and technology-specific however these anthropogenic sources must be put into the context of the existing, or background noise levels. Background noise originates from a variety of sources across a range of frequency bands from metocean sources (waves, rain/hail, wind, sediment movement) to anthropogenic (shipping, leisure, fishing, military and industrial) and biological (cetaceans) [2]. Nedwell and Howell [3] define background noise as the sound that is measured in the environment not originating from the sensor, or from an identifiable localised source. The makeup of the background noise will also depend on the bathymetry of the area, water depth, the state of the tide and the technique chosen to evaluate and report the noise levels themselves.

This paper has characterised the background noise of a site that is subject to fast tidal currents and is typical of the type of site that could be used for tidal stream device deployment. The site has been selected by Tidal Energy Ltd (TEL) for the proposed deployment of the DeltaStream demonstration tidal stream device. TEL wanted to understand the background noise characteristics at the site as part of their environmental assessments. The techniques developed are applicable to other sites (across the marine energy technologies) and should be adopted when eventually comparing to the anthropogenic noise emissions associated during on-site marine operations and its effect of the resident marine wildlife.

2. Methodology
2.1. Survey area

Acoustic measurements were taken in late spring and mid-summer 2009 in Ramsey Sound, Pembrokeshire, West Wales (refer Fig. 1).
Ramsey Sound, as part of Pembrokeshire Coast National Park has been designated as a Marine Special Area of Conservation (Marine SAC), and lies adjacent to a Special Protection Area (SPA), a Site of Special Scientific Interest (SSSI) and a National Nature Reserve. It has a resident population of harbour porpoise [4,5] and is host to the largest colony of grey seals in southern Britain. The main recreational activity in Ramsey Sound is wildlife/nature tour boat trips which operate from April to October. No commercial shipping or trawling activities operate the Ramsey Sound.

Ramsey Sound is subject to semi-diurnal tides (two high waters and two low waters per day). Highest high water is around 5.1 m whilst lowest low water is 0.7 m. Ramsey Sound is subject to tidal flows in excess of 4 m s\(^{-1}\) on spring tides [6]. The north flowing (flood) tide changes to south flowing (ebb) tide between 2.5 and 3 h after high water at Milford Haven (refer inset figure in Fig. 1). The change from ebb to flood occurs between 8.75 and 9.5 h after high water at Milford Haven. The bathymetry of Ramsey Sound is diverse, containing a steep sided trench up to 66 m deep LAT and several rocks, and pinnacles some of which are visible above the surface at low tide. Consequently, parts of the Sound experience extreme turbulence and upwelling.

### 2.2. Survey methodology

Measurements of background noise were taken with a C54XRS hydrophone from Cetacean Research Technology capable of measuring noise levels from 1 to 22,050 Hz at depths of up to 460 m. The hydrophone was deployed off a rigid inflatable boat (RIB) at 20 m below the sea surface to coincide approximately with the position of the centre of a hub from a pre-commercial demonstration horizontal axis turbine generator located in 31.5 m LAT of water. Sound measurements were taken with the engines turned off so that the RIB was allowed to drift down Ramsey Sound with the current in order to reduce the drag and associated increased noise on the hydrophone. Runs were made in the ebb and flow directions throughout the tidal cycle. Continuous readings of sound were uploaded onto a laptop using SpectroPro software. After each run the hydrophone was turned off and the RIB motored back up to the start position. Readings of Frequency and Amplitude (dB re 1 μPa) were taken continuously every 1.2 s to yield Total Power (TPL) and Sound Pressure Levels (SPL) in 1/3 octave bands. Readings were taken over one entire tidal cycle in late spring 2009 when Ramsey Sound was relatively free of other boats (termed “low season”) and over a tidal cycle in mid-summer 2009 when Ramsey Sound was busy with recreational and tourist boats (termed “high season”). The weather for both surveys was light variable winds and a calm sea (Sea State 1). Hydrophone measurements were taken along the direction of current flow from 51°52.716′N, 5°19.452′W to 51°51.433′N, 5°19.452′W on ebb tides and in the opposite direction on flood tides. Each run took approximately 30 min to complete although times varied according to tidal conditions. Both surveys were conducted during tides between neap and spring.

### 2.3. Analysis methodology

There are a variety of methods available for measuring the amplitude of a sound signal. The three most common measurements used to measure the amplitude of a sound signal are zero to peak pressure, peak-to-peak pressure and root-mean-square (RMS) pressure, and these are shown in schematically in Fig. 2.
The peak pressure, which is also known as 0-to-peak pressure, semi-pressure or simply amplitude, is the range in pressure from 0 to the highest positive pressure. The peak-to-peak pressure is the range in pressure from the most negative to the most positive in the sound signal. The RMS pressure is defined as the square root of the mean of the square of the pressure of the sound signal over a specified time. The RMS pressure is often used when measuring the average amplitude of a non-repeating signal, such as background noise. The RMS pressure can be used when discussing the effects of sound on marine animals, because it can be related to sound intensity. However, when considering hearing thresholds and damage to ears from sources associated with marine engineering works such as piling and drilling, peak pressure is useful as it measures the highest sound pressure of the signal. Care must be taken when using the different methods for measuring amplitude to ensure that not only the reference units are stated (in this case 1 μPa) but how the amplitude was measured (in this case using RMS) and in some cases the distance from the source.

3. Results

The total power level of the sound (TPL) was used to determine the effect of the stage of the tide on the background noise level for both surveys over the entire spectrum (up to 22,050 Hz). The RMS values are displayed in Figs. 3 and 4 for spring and summer respectively. The sea levels for Milford Haven (situated 25 km SE of Ramsey Island) have also been included in the graphs.

It appears from Figs. 3 and 4 that the TPLRMS for background noise peaks during periods of normally associated with slack tide (i.e. low or high water) however, as mentioned earlier, the ebb tide in Ramsey Sound starts approximately 2.5 h before HW Milford Haven until 2.5 h after LW whereas the flood tide starts approximately 2.5 h before HW Milford Haven until 2.5 h after HW. Slack tides occur during the change from ebb to flood and vice versa although may only last 10 min. TPLRMS values increase by 10–15 dB re 1 μPaRMS as the tidal flow increases in Ramsey Sound.

Figs. 3 and 4 were calculated by averaging across all frequency levels however a more precise measurement of background noise must take into account the contribution of different frequency bands. Usually these are expressed as low, medium or high however the data presented in Figs. 3 and 4 were then reanalysed for the Sound Pressure Level (SPL expressed as a root mean squared value) for individual 1/3 octave intervals up to 22,050 Hz. The resulting Figs. 5 and 6 show the Sound Pressure Level SPLRMS for each run in spring and summer in 1/3rd octave frequency bands. Although this is an intensive analysis (each data point on the graph requires a “real-time” run of approximately 30 min) the contribution to the overall ambient noise made by each frequency banding is now discernable.

4. Discussion/conclusions

There are a number of differences between the background noise curves presented in Figs. 5 and 6. Noise levels reduced as the tidal flow slowed across the frequency range for both surveys. Sound pressure levels between 5 and 10 Hz were 92.6 dB re 1 μPaRMS ± 3.9 dB re 1 μPaRMS for the spring survey compared to 104.7 dB re 1 μPaRMS ± 2.2 dB re 1 μPaRMS for the summer survey. Sound pressure levels around 100 Hz during spring were 85.9 dB re 1 μPaRMS ± 2.4 dB re 1 μPaRMS compared to 104.6 dB re 1 μPaRMS ± 2.4 dB re 1 μPaRMS during the busier period in the summer.

It should be noted that the peaks occurring in Figs. 5 and 6 at 1 kHz are caused by resonance of the hydrophone.

Ebb tides appeared noisier than flood tides by 5–20 dB re 1 μPaRMS. The main difference in background noise response between low season and high season is the second low frequency peak around 100 Hz visible during high season. Below 2 kHz the noise is thought to come from boat traffic. Large tankers and ships are known to operate in the vicinity of St Bride's Bay (approximately 7 km due south of Ramsey Sound) that tend to emit lower frequency noise than smaller recreational craft due to their larger drafts, slower turning propellers and greater power [7].

The peak in SPLRMS around 10 Hz is thought to originate from a variety of shipping-related sources including propeller-excited hull resonance [8], hull pressure or propeller blades which could

![Fig. 3. Variation in background noise levels (TPLRMS) with tide height at Milford Haven during a typical day in low season, Ramsey Sound, Pembrokeshire.](image1)

![Fig. 4. Variation in background noise levels (TPLRMS) with tide height at Milford Haven during a typical day in high season, Ramsey Sound, Pembrokeshire.](image2)

![Fig. 5. The variation of background noise levels (TPLRMS) in 1/3 octave frequency bands with times after high water at Milford Haven during a typical day in low season, Ramsey Sound, Pembrokeshire.](image3)
appear from 4 to 70 Hz [9]. Richardson believes that these lower frequencies could originate from surface noise due to waves associated with shipping or breaking on the rocks [7]. The survey taken in the summer during periods of increased tourist boat activity shows a distinct peak around 100 Hz that is not apparent during the low season survey. The origin of this noise is likely to be diesel engines, propeller cavitations, engine harmonics and gearboxes. A more detailed examination of the contribution of shipping to background noise is available from Wenz in the form of Wenz curves for varying sea state conditions [10]. Ambient sound pressure levels have been recorded up to 108 dB re 1 \mu Pa\text{RMS} at frequencies below 100 Hz thought to originate from local and distant vessel movement.

This paper highlights the importance of stating how the background noise is presented, particularly when the ambient noise is to be compared with anthropogenic noise.

The existing survey data set will now be extended to include the effect of weather and sea state on background noise and will eventually be compared to marine engineering activities in the area to determine the impacts of underwater noise on the local biota community.

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