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Modelling of the sound field radiated by multibeam echosounders for acoustical impact assessment

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ABSTRACT

Multi-Beam Echo-Sounders (MBES) designed for seafloor-mapping applications are today a major tool for ocean exploration and monitoring. Concerns have been raised about their impact towards marine life and especially marine mammals, although their inherent characteristics (high frequencies, short signals and narrow transmitting lobes) actually minimize this possibility. The present paper proposes an analysis of MBES radiation characteristics (pulse design, source level and radiation directivity pattern) accounting for the various geometries met today and expressed according to the metrics used for acoustical impact assessment (maximum Sound Pressure Level, and cumulative Sound Exposure Level). A detailed radiation model is proposed, including the transmission through directivity sidelobes, and applied to three typical MBES examples. A simplified radiation model is then defined, in order to extend it to the case of the cumulative insonification by a MBES moving along a survey line. An approximated analytical model is proposed for the accumulated intensity, showing good agreement with the complete simulation of insonification; it is applied to the worst-case configuration of a low-frequency (12 kHz) multi-sector system. The computation of ranges corresponding to impact thresholds accepted today shows that impacts in terms of injury are negligible for both SPL and SEL; however behavioural response impacts cannot be excluded, and should require specific experimentation.

1. Introduction

1.1. Context and rationale

Multi-Beam Echo-Sounders (MBES) have been used for almost 40 years for seafloor mapping in support of chart-making, naval activities, and geoscience. As the resolution and capabilities of these systems have improved along the years, the applications have expanded to environmental monitoring and fisheries, surveys for hydrocarbon exploration, offshore engineering, coastal management and underwater archaeology. Structurally [1], these systems transmit a short sound pulse inside a wide angular sector steered vertically and across the carrier platform's track (Fig. 1). In reception they process the seafloor echoes inside a high number of narrow beams, providing a high selectivity in the measurement of sounding values along a number of angular directions together with an excellent efficiency in seafloor coverage. Since they can also record the intensity of the echoes (giving indications about the seafloor nature and fine structure) they are today the favourite tool for seafloor surveys, and are a very dynamic sector of technological research.

Unlike seismic sources used in offshore exploration for seafloor investigation, and large and powerful active sonars used in military applications for submarine detection, echosounders are usually considered to cause little direct impact to the marine organisms, thanks to their high spatial selectivity and high-frequency range [2,3]. However concern has been growing recently [4] about the possible impacts caused to marine mammals (MMs) by their use, raising the perspective that MBES, if considered as harmful sound sources, should be imposed with the same mitigation procedures generally applied today by both the navies and the oil industry in their activities involving low-frequency sources. Considering the huge importance of MBES systems in today's exploration, monitoring and management of the oceans, the variety and richness of their application fields, and the scarcity of observations of their negative impacts on MMs, such a perspective requires careful preliminary analysis.

In this context, and along with recent efforts by regulators to improve the guidelines for assessing the effects of anthropogenic sound on marine mammals [5], it is essential that a clear understanding of the acoustic characteristics (radiation patterns, source

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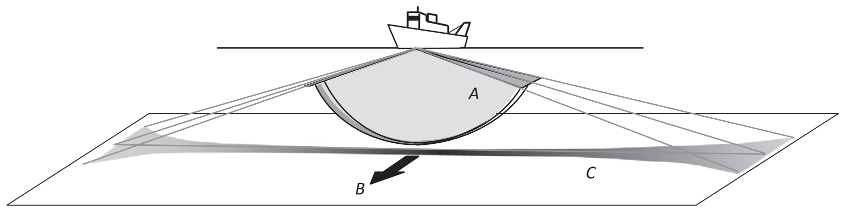

Fig. 1. The radiation pattern of a MBES features one or several (two are sketched here) transmit sectors (A), very wide across-track (typically ±70° or more) and narrow along-track (aperture 0.5–2°, according to the system model and configuration). The projection of a sector on a horizontal plane (C) is a narrow stripe perpendicular to the ship's heading direction (B) and widening at the swath ends.

levels, pulse lengths, etc.) of these systems be made widely available. Detailed studies of the impacts of active navy sonars and seismic sources have been carried out for many years [6]. Along with these studies several numerical tools (NEMO [7], ESME [8]) have been developed, combining models of acoustic propagation and MMs distributions, in order to understand the interaction of acoustic sources with animal populations; they have been made available for users to determine the potential impact needed when applying for "incidental take permits" [9] for the authorization process applicable in the USA. Each of these models requires, as a computation input, an accurate description of the acoustic characteristics of the sound source being evaluated. While such engineering descriptions have now been developed for seismic and active navy sources, there are not yet publically available models of the characteristics of multibeam sonar systems – aimed at an audience wider than specialized engineers.

The goal of this paper is hence to provide the reader and the broader community with accurate descriptions and magnitudes of the elements useful for understanding and possibly estimating the sound radiation by MBES, in the context of their potential impact on MMs. After an overview of the analysis, the fundamentals of MBES working principles (in transmission) are presented, giving the notions and practical characteristics of source level, directivity patterns, and emitted pulses. The next chapter couples these notions with a basic propagation model (whose limits are discussed) and proposed simulations of the radiated field of a few archetypes of MBES, expressed within the context of the two metrics of the maximum received Sound Pressure Level (SPL) and the Sound Exposure Level (SEL) commonly used in today's studies of sound impact to MMs [9]. The last part of the paper proposes an approximated model for estimating analytically the *SEL* accumulated during survey lines, under simplifying hypotheses regarding mainly the transmission (Tx) radiation pattern; the model is then applied to a case study of a low-frequency MBES in deep water.

The possible impacts of MBES signals on MMs in terms of physiological or behavioural effects are not addressed for themselves in this paper, which is written strictly from an engineering point of view. The goal here is to provide an appropriate objective starting point for MBES radiation modelling, usable to determine the potential insonification levels of marine animals by these echosounders.

1.2. SL, SPL and SEL

The field radiated by an acoustic source, with respect to its potential impact on marine living organisms, must be expressed [5,10] both in terms of instantaneous maximum of received pressure (Sound Pressure Level, or SPL) and cumulative intensity (Sound Exposure Level, or SEL). This implies accounting for the source nominal transmitted sound level, its frequency (defining both its harmfulness and its propagation losses), its spatial distribution (angular directivity), and its temporal characteristics (pulse duration and repetition frequency). Obviously, the received sound field also depends on several propagation phenomena (transmission losses and multipath structure).

The approach proposed along this paper is based on a simple expression of the "sonar equation". Widely used in underwater engineering, the sonar equation is an energy budget between transmitted, received and processed sonar signals [1,11,12]. Relevant forms of SPL and SEL for the present purpose are:

$$\begin{aligned} SPL(R) &= SL + DF - TL(R) \\ SEL(R) &= SL + DF - TL(R) + ED \end{aligned} \tag{1}$$

Expressed in dB (deciBels), the Eq. (1) feature the various following terms:

- *SL* is the source level, defined as the maximal value (according to angle) of acoustic pressure at $R_0 = 1$ m from the source, in dB re 1 μPa at 1 m. *SL* is usually expressed by its RMS value; one should add 3 dB if a peak value is requested;
- $SPL(R)$ is the level of acoustic pressure received at range *R*, in dB re 1 μPa; it is normally a RMS value, but can be changed into a peak value, similarly as *SL*;
- $SEL(R)$ is the Sound Exposure Level at range *R*, given by the integration of received intensity over the exposure time, simplified into the integration of the squared pressure – hence expressed in dB re 1 μPa^2 s;
- *DF* is the directivity function of the source, describing the spatial distribution of transmitted intensity; conventionally $DF = 0$ dB in the maximum intensity direction corresponding to the above definition of *SL*;
- $TL(R)$ is the transmission loss at range *R* during the signal propagation in the ambient medium; it features [1,12] both a geometrical term (spherical loss, or multipath summation) and an absorption term, whose influence increases very strongly with frequency;
- *ED* expresses the exposure duration effect caused by the accumulation of energy received over time; it can be roughly modelled as $10\log T$ if *T* is the cumulative duration of exposure (in s) of the receiving organism to a signal of constant amplitude.

The Sound Exposure Level is defined as the time integration of the squared acoustic pressure:

$$SEL = 10\log\left[\int p^2(t)dt\right] \tag{2}$$

So for one single sine-wave ping of constant maximum amplitude p_0 over a duration *T*, it is simply:

$$SEL_1 = 10\log[p_0^2 T/2] = 10\log[p_0^2/2] + 10\log T = SPL + ED \tag{3}$$

where *SPL* is a RMS value. For a series of pings, the *SEL* value has to be accumulated in order to integrate the received energy along time. For instance, considering a series of *N* pings received with the same level *SPL* at a given range, the cumulative SEL_N should be written as:

$$SEL_N = SEL_1 + 10\log N \tag{4}$$

For more general configurations where the received level varies from ping to ping, the cumulative SEL_N should be computed from