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# Modern Oceanographic Research Vessels

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Most sonars mounted on the hull of oceanographic research vessels transmit acoustic energy downward in relatively well defined angular sectors. In order to assess how such sonar systems might affect marine organisms, particularly marine mammals, we shall review the range of acoustic frequencies used by these sonars and the corresponding level of ensonification as a function of range from the source.

In order to obtain high spatial resolution while maximizing the range from which a given sonar will receive detectable echoes, factors related to the physical attributes of the sonar and to the ocean environment must be taken into account in choosing the sonar frequency F(Hz). Physical factors include the acoustic transducer's length L measured in units of acoustic wavelength $\lambda = C/F$ (m) with sound speed C ~1500 m $s^{-1}$; its azimuthal beamwidth $\theta \sim 1/\lambda$ (rad); its bandwidth W (Hz), usually equals to 10-20 % of the centre frequency F when operated near resonance; and its far-field distance $R_o \sim L^2/\lambda$ (m).

As seen in Figure 1, these parameters define the sonar's spatial resolution as the product of the range dependent azimuthal range resolution ($R\theta$) and the range independent along-track range resolution ($\Delta R = C/2W$). For pulsed continuous wave (CW) sonar signals the bandwidth is roughly the inverse of the pulse duration. For pulsed frequency modulated (FM) sonar signals, the duration-bandwidth product is usually greater than one, and improved range resolution is achieved through pulse compression. Therefore for an elemental elevation angular sector at a given range R from the sonar, the -3 dB limits of the azimuthal cross-sectional area A of the transmit beam pattern energized by a sound pulse (CW or FM) of duration t(s) is approximated by:

$$A = R\theta C\tau \ (m^2).$$

Environmental factors include the absorption of sound in sea water, a chemical relaxation process which depends strongly on the water temperature and increases in proportion to $F^2$, the background ocean noise level in the sonar's frequency bandwidth W, the seafloor acoustic backscattering strength and the target strength of volume scatterers - both of which are functions of the acoustic wavelength $\lambda$.

Range capabilities are dominated by the absorption of sound in sea water. As a result, most hull-mounted sonar systems operate at frequencies between 3 kHz and 500 kHz (Tab. 1).

They include (Tab. 2) subbottom profilers operating over a frequency band ranging from 2 to 24 kHz; navigation and communication sonars operating at 8 to 30 kHz; fisheries

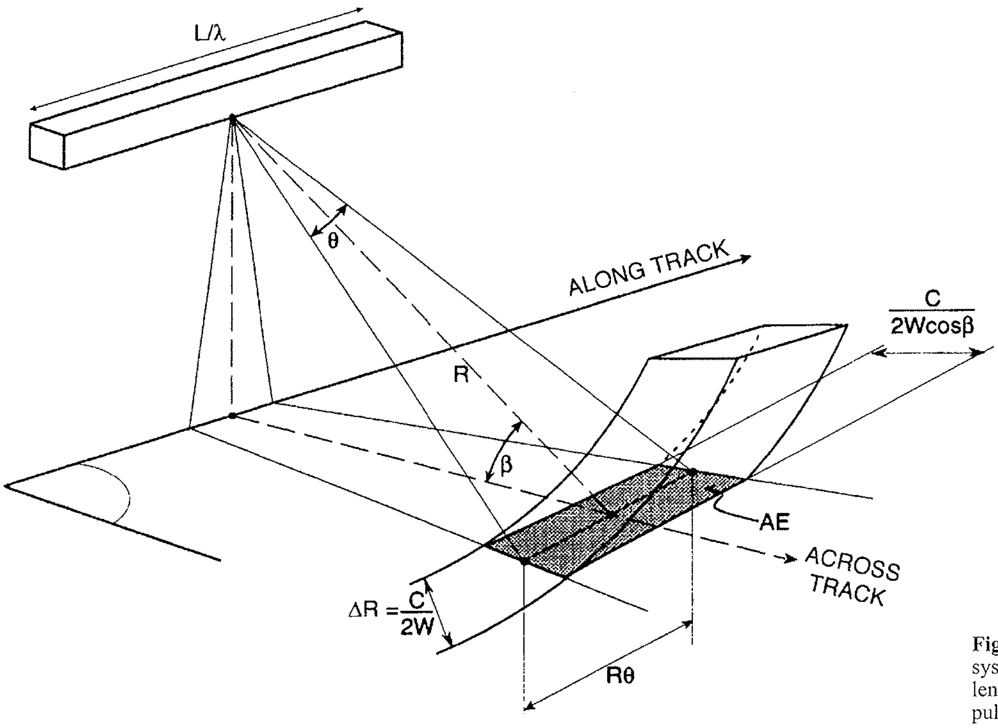


**Fig. 1:** Spatial resolution of a sonar system whose transducer is L wavelengths long and transmits a sound pulse of bandwidth S (Hz).

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| SONARS | frequency range (kHz) | max source level (dB re 1 $\mu$Pa/m) | max pulse length (ms) | max duty cycle (%) | beam width (deg) |
|---|---|---|---|---|---|
| Sub-bottom Profiler | 2-24 | 210 | 50 | 0.5 | 4-30 |
| Navigation & Communication | 8-30 | 220 | 10 | 1 | 30-60 |
| Fisheries Sonar | 20-500 | >235 | 10 | 1 | 8-30 |
| Bathymetry | | | | | |
| single-beam | 12-250 | 220 | 25 | 0.1 | 5-30 |
| multi-beam | 9-450 | 240 | 24 | 0.1 | 1x 90-150 |
| Hydrographic | 50 | 230 | 30 | 1.5 | 2 x 3 |
| Doppler Sonar | 140 | 231 | 4 | 0.7 | |
| Acoustic Doppler Current Prof. ADCP | 75-300 | 230 | 20 | 1 | 3 |
| Doppler Speed Log | 200-600 | 210 | 100 | 1 | 5 |

**Tab. 1:** Acoustic characteristics of hull-mounted sonars found aboard oceanographic research vessels. Source levels are RSM values. Duty cycle is percentage of pulse length in pulse repetition rate (e.g., 10 ms pulse transmitted one a second corresponds to 1 % duty cycle).

| frequency (kHz) | 0.1 | 1 | 3 | 10 | 30 | 100 | 300 | 500 |
|---|---|---|---|---|---|---|---|---|
| Attenuation $\alpha$(dB/km) | $<10^{-3}$ | $4\ 10^{-2}$ ($6.4\ 10^{-2}$) | 0.2 | 0.6 | 3.3 | (25.4.) | 65 | (137) |
| Useful range | $>10^4$ | $>10^3$ | >50 | 25 | 8 (6) | (1.5) 1 | (0.15) 0.09 | (0.09) 0.01 |

**Tab. 2:** Underwater acoustic frequencies used in seismic and sonar (≥3 kHz) applications. Temperature dependence appears where appropriate as values representative of polar conditions at 2 °C in (), and tropical conditions at 34 °C. Absorption values calculated for sea water at atmospheric pressure, pH = 8, and salinity = 35 psu, after FRANCOIS & GARRISON (1982 a, b)

sonars operating at 20 to 500 kHz; bathymetric single and multibeam echo-sounders or side-looking sonars operating at 6 to 500 kHz; hydrographic Doppler sonars operating at 50 to 140 kHz; Acoustic Doppler Current Profilers (ADCP) operating at 75 to 300 kHz; and Doppler speed logs operating at 200 to 600 kHz. Higher frequencies (1 Mhz) are used for high-resolution applications at a few metres to sub-metre ranges in devices such as sound-velocimetres and Doppler speed logs.

Sonars used for deepwater echo-sounding applications operate at frequencies between 3 and 30 kHz which suffer greater attenuation in polar waters than in tropical waters due to the temperature dependence of sound absorption. At higher frequencies, this trend is reversed and absorption is larger in tropical waters, however, the range capabilities of sonars operating at or above 100 kHz remain limited to several hundred meters for most echo-sounding applications.

The ranges of sonar frequencies appearing in Table 2 overlap with the most sensitive region of the audiograms of several marine mammal species (RICHARDSON et al. 1995). Specifically, subbottom profilers (2-24 kHz) are likely to affect some mysticetes which are most sensitive below 1 kHz, as well as hair and eared seals whose audiograms are most sensitive between 2 and 30 kHz; navigation and communication sonars, as well as fisheries and bathymetry sonars operating in the 8 to 150 kHz range are likely to affect most odontocetes whose audiograms are most sensitive between 8 and 120 kHz; but higher frequency ADCP sonars and most sonars operating at frequencies above 150 kHz are unlikely to affect marine mammals as a whole.

To estimate the amount of acoustic energy that a marine mammal might receive from one of these hull-mounted sonars, one must consider the maximum transmitted source level and the one-way spherical spreading ($20 \log_{10} R$ (dB/m)) and absorption ($10^{-3}\ \alpha R$ (dB m-1)) losses incurred along the distance R (m) separating the sonar from the animal. Thus for a sonar transmitting 240 dB re 1 $\mu$Pa $m^{-1}$ at 10 kHz, the received level will be about 200 dB re 1 $\mu$Pa $m^{-1}$ and 180 dB re 1 $\mu$Pa at ranges of 100 m and 1 km respectively. Assuming a harassment threshold of 180 dB re 1 $\mu$Pa $m^{-1}$ at the animal, one might conclude that any animal within 1 km of this sonar would be disrupted.

However, one must also consider the area (Eq. 1) or the volume in which this energy is contained at each range. For example, some of the higher source levels are associated with deep-water swath bathymetry sonars operating around 9-15 kHz with 240 dB re 1 $\mu$Pa $m^{-1}$ of source level and 20 ms CW pulses in transmit beams, with width roughly 1° fore-aft by 35° athwart-ships, which are steered athwart-ships to cover a sector of up to 150° centered on nadir. The azimuthal cross-sectional area of such a transmit beam is about 52 $m^2$ at 100 m and 520 $m^2$ at 1 km, with fore-aft extents of 1.75 m and 17.5 m respectively. Moreover, a seafloor surveying ship usually moves at about 12 knots (6 m $s^{-1}$) and the sonar' transmission rate in deep water usually exceeds 20 s, yielding an along-track ping spacing of 120 m or more. Therefore it is unlikely that a marine mammal will be "caught" in the transmit beam of the sonar at ranges close enough to exceed the harassment threshold (180 dB re 1 $\mu$Pa $m^{-1}$, with R <1 km in this example), but if it were "caught", it would receive at most one 20 ms ping which might cause a brief temporary threshold shift in the animal's hearing. In addition, the relatively small cross-section of the beam allows the animal to move out of the acoustic field in less than one ping cycle.


*References*

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