Ultrasound Signal Processing

Public version

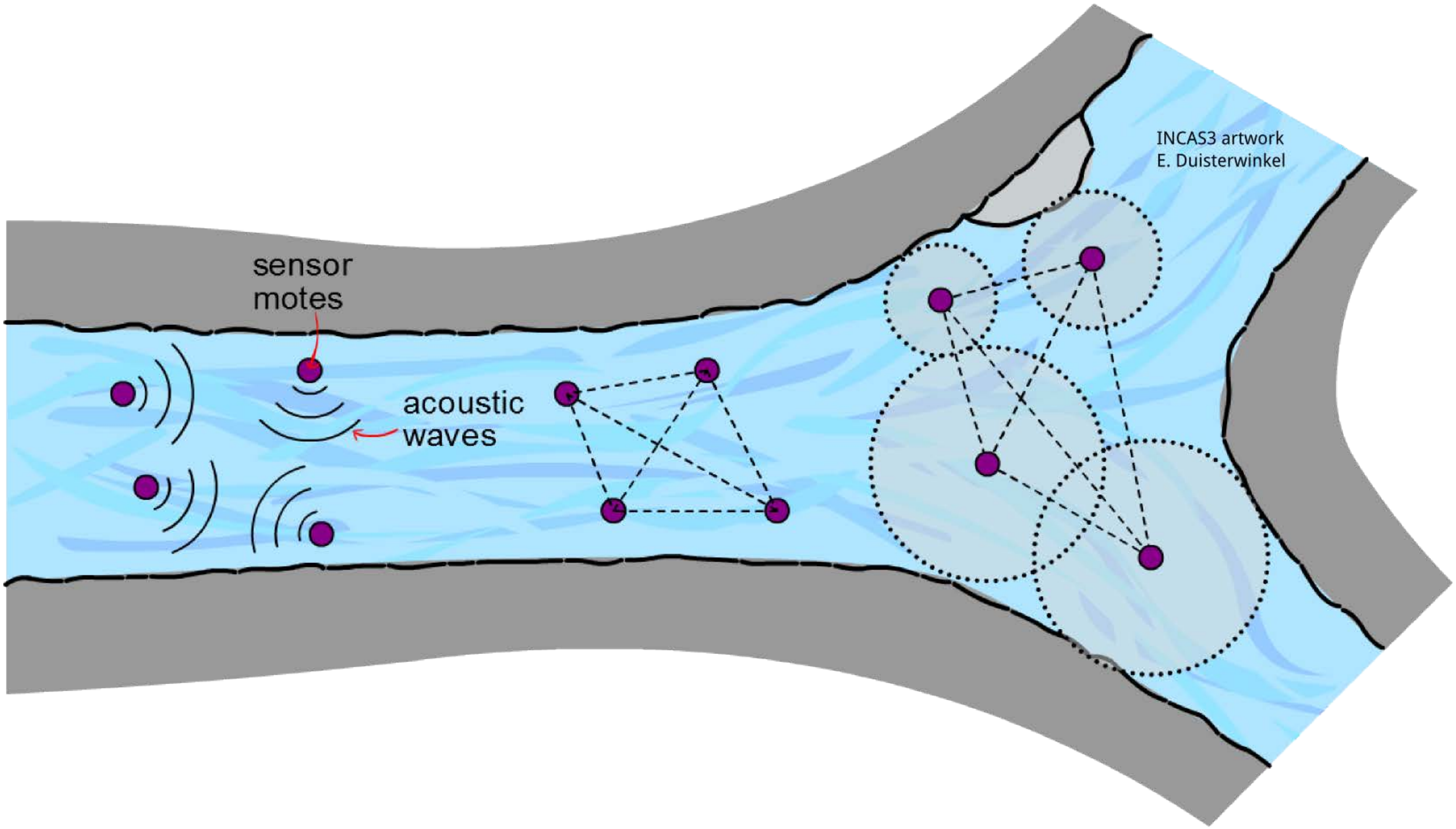
06-11-2015

Erik Duisterwinkel

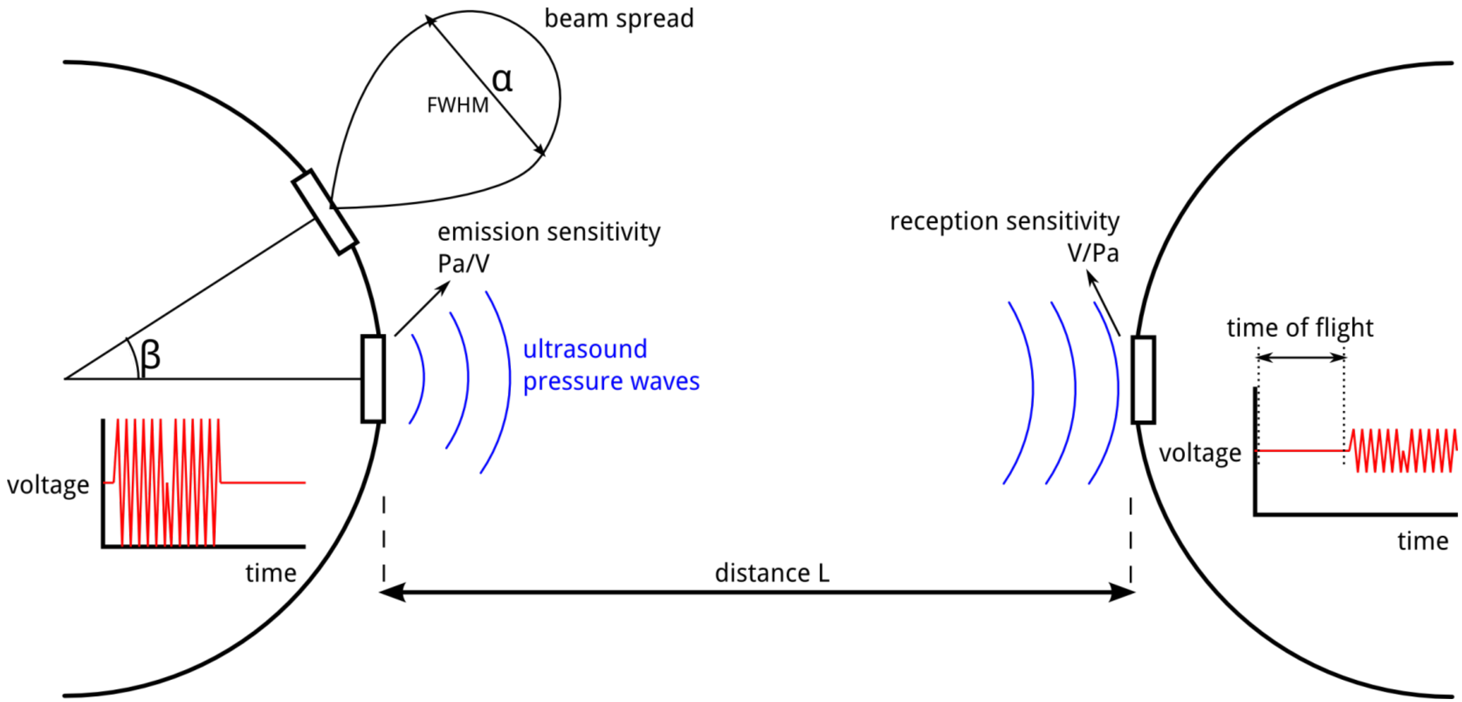
Haoming Xin

Funded by
the European Union

Ultrasound in Mote Swarms

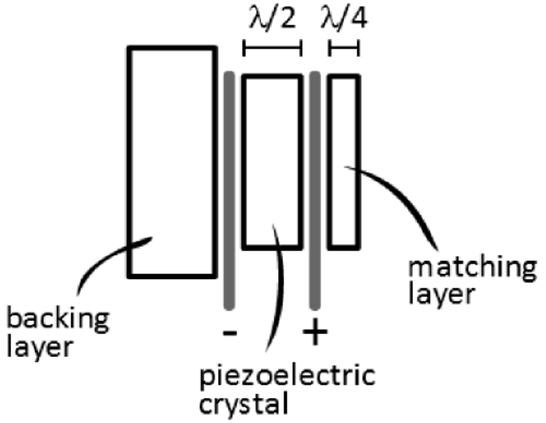


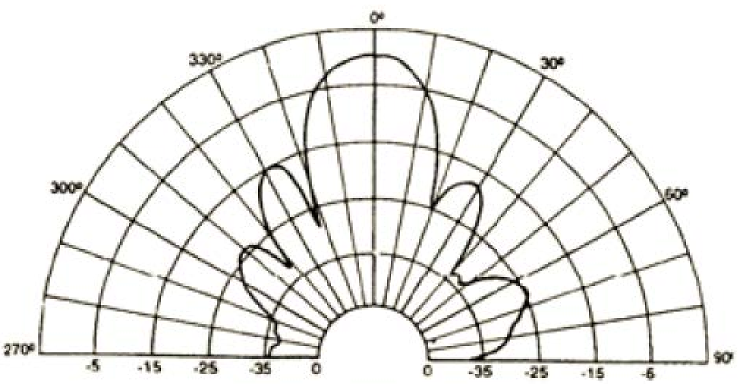
Ultrasound Signal Transmission



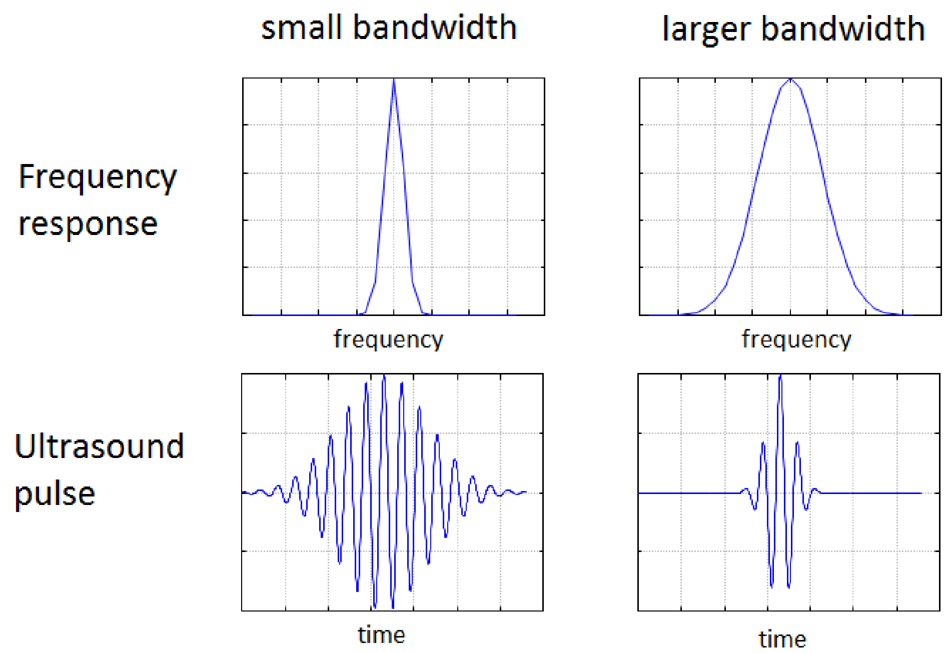
Transducer Properties

transducer





Typical Beam Pattern At 50 kHz



Note: example is a piezo transducer. Other types are available and should be investigated

Ultrasound Trade-offs

- Parameters:
  - Beam spread α (67°)
  - Transducer frequency f_{us} (100kHz)
  - Transducer diameter D_{us} (1.4cm)
  - Emitted energy E_{em} (?)
  - Transducer sensitivity S (?)

$$\sin\left(\frac{\alpha}{2}\right) = 0.514c/f_{us}D_{us}$$

$E_{em} \propto D_{us}^2$,
More E_{em} leads to a relaxed S

- Reduce D_{us} to mm size
  - Increase f_{us} to e.g. 1MHz, D_{us} down to 1.4mm (other p same)
  - Less E_{em}, more sensitivity needed
  - Other choice (e.g. increase α)?

Ultrasound Propagation

From Thomas L. Szabo, 2004

$$p(\bar{\rho}, z, \lambda) \approx \frac{ip_0 \pi a^2}{\lambda z} \frac{2J_1(2\pi pa/(\lambda z))}{2\pi pa/(\lambda z)} = ip_0 cu_0 \left(\frac{\pi a^2}{\lambda z}\right) jinc\left(\frac{\bar{\rho} a}{\lambda z}\right) \quad (6.17b)$$

where

$$jinc(x) = 2J_1(2\pi x)/(2\pi x) \quad (6.18a)$$

and J_1 is a first order Bessel function. The far-field beam cross section is shown in Figure 6.11. The FWHM for this aperture is

$$FWHM = 0.7047\lambda z/a \quad (6.18b)$$

An exact expression without approximation can be obtained for on-axis pressure,

$$|p(0, z, \lambda)| = 2p_0 \sin\left\{\frac{kz}{2}\left[\sqrt{1 + (a/z)^2} - 1\right]\right\} \quad (6.19a)$$

which under the Fresnel approximation, $z^2 \gg a^2$, is

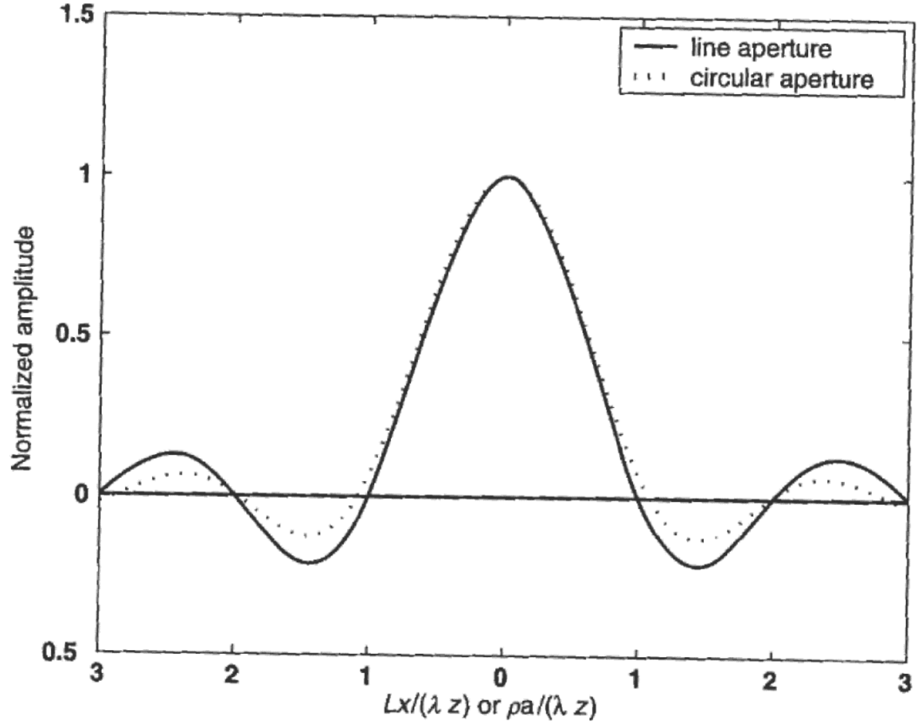
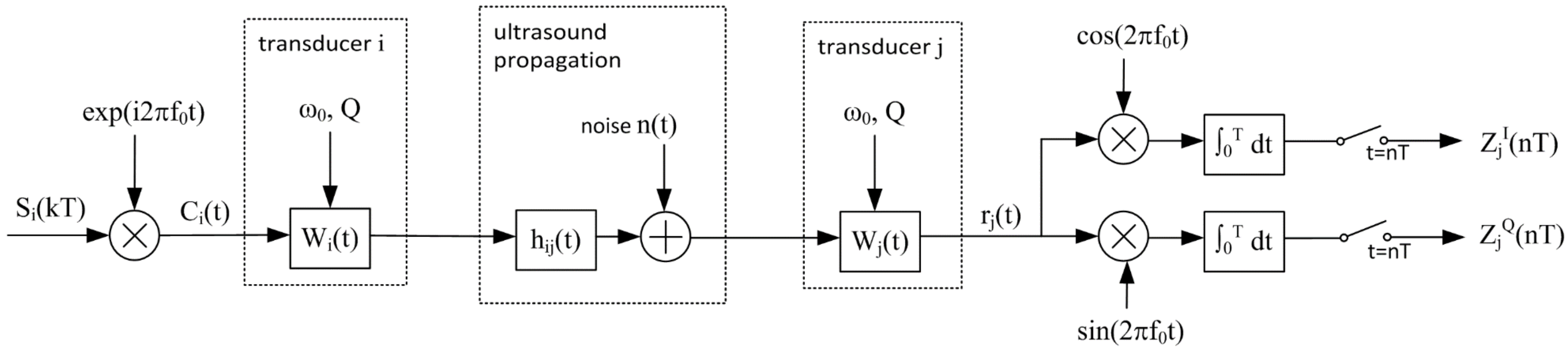


Figure 6.11 Far-field *jinc* beam-shape from a circular aperture (dashed line) normalized to a far-field *sinc* function from a line aperture (solid line) with the same aperture area.

Signal Transfer Function

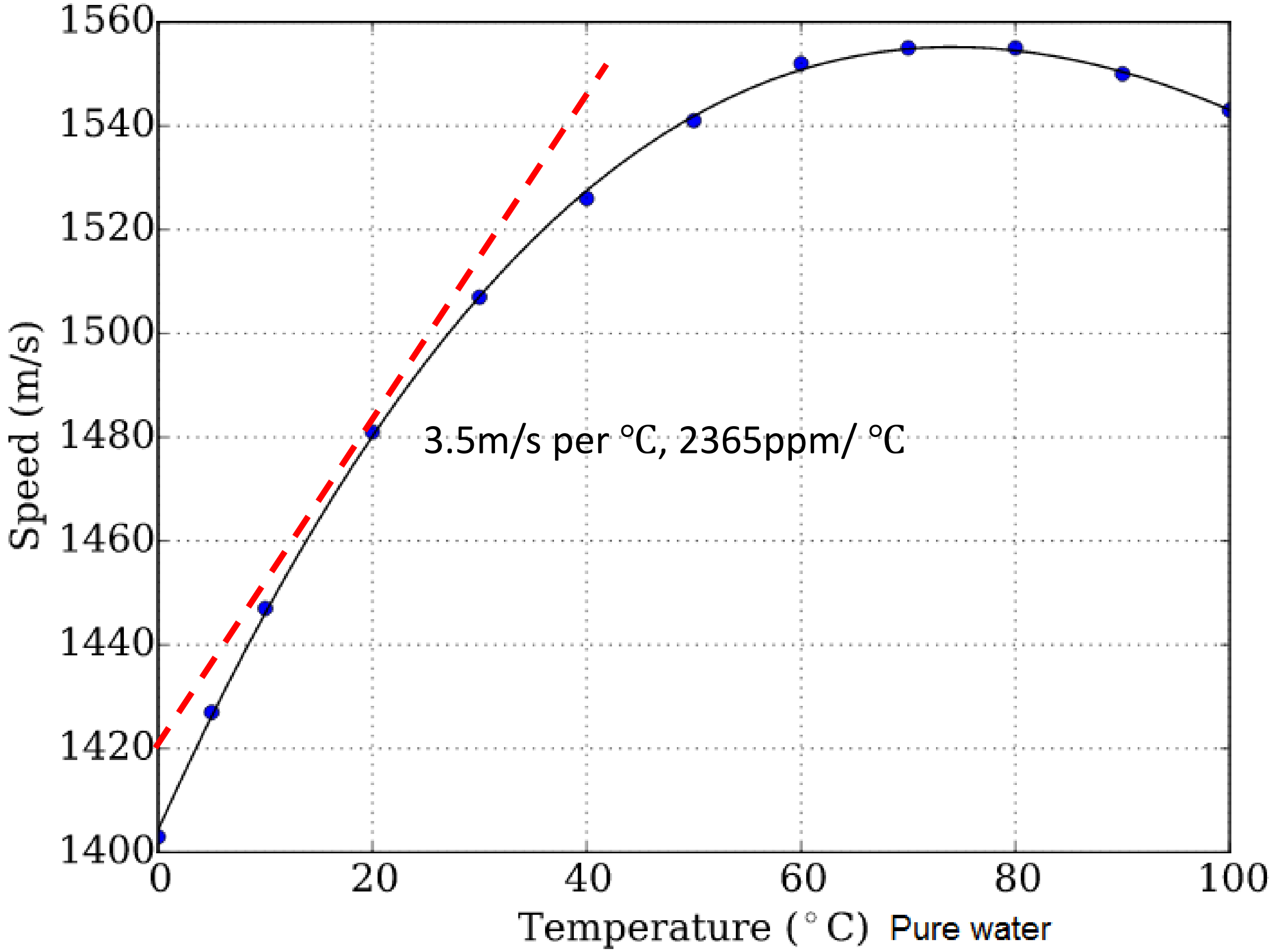
A very simple model:



Speed of Ultrasound in Water

- Speed of ultrasound in water is not fixed
- Accurate localization needs accurate speed estimation
- Parameters influencing speed
  - Temperature (a change of 3.5m/s ~ 1℃)
  - Salinity (a change of 1m/s ~ 1g/L)
  - Pressure (a change of -0.33m/s ~ 1 meter depth)

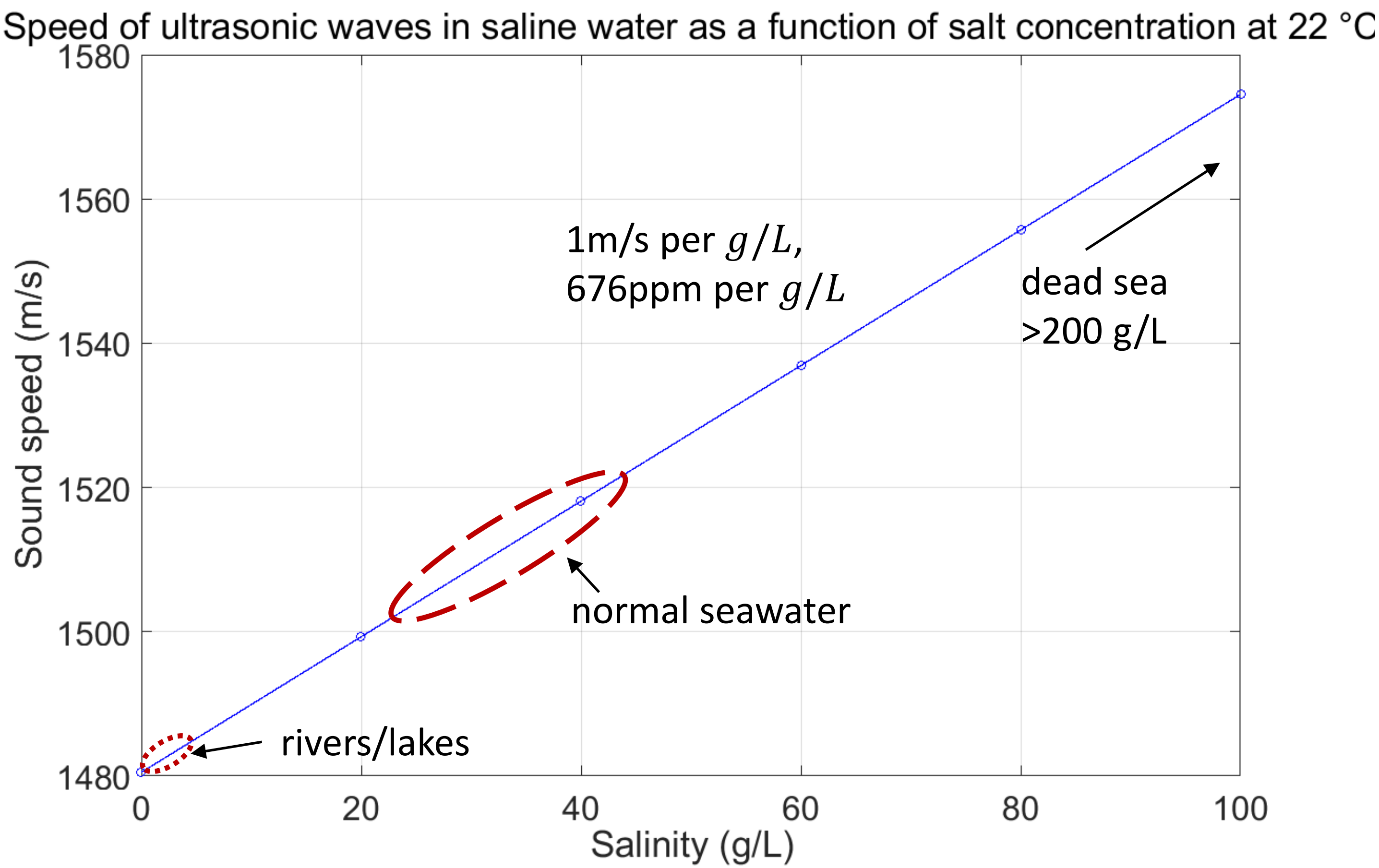
Temperature Dependence [1]



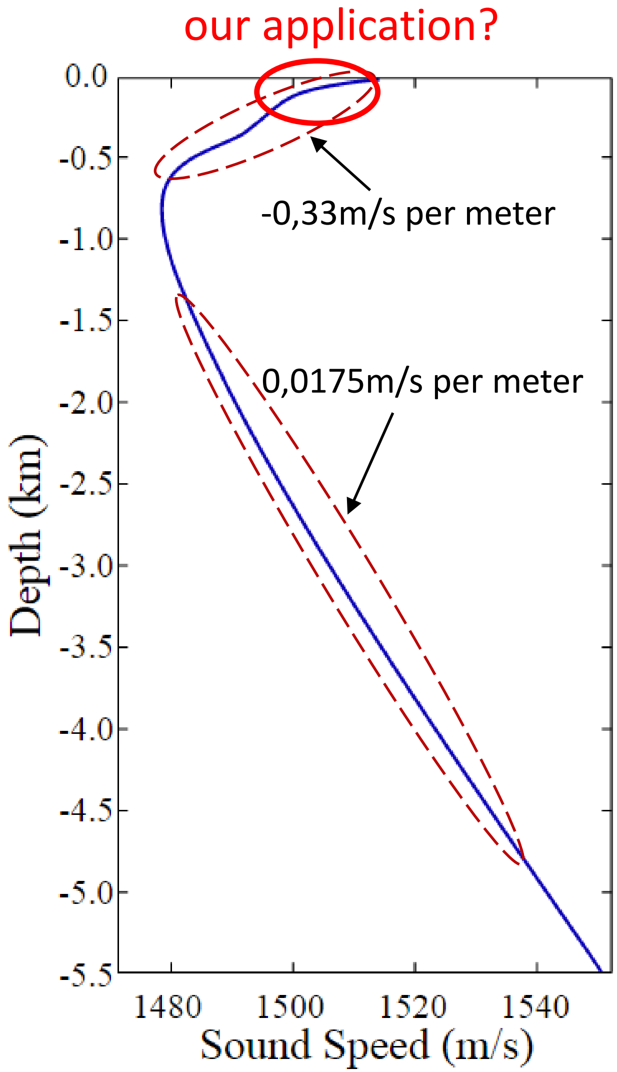
[1] https://en.wikipedia.org/wiki/Speed_of_sound

Salinity Dependence [2]

[2] Y. N. Al-Nassar, A. M. Al-Jalal , M. A. Khan, and S. A. Al-Kaabi, “Functional Dependence of Ultrasonic Speed in Water on Salinity and Temperature.”



Pressure (Depth) Dependence [3]



[3] https://en.wikipedia.org/wiki/Speed_of_sound

Sound speed as a function of depth at a position north of Hawaii in the Pacific Ocean derived from the 2005 World Ocean Atlas.

Our application: <200m depth?