Optimising the Edinburgh Pipe Phantom for the assessment of nonlinear imaging techniques

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Overview

Ultrasound quality assurance:

- Accurate QA measurements are critical to ensuring reliable diagnostic outcomes and maintaining confidence in imaging services.
- Phantoms are key in facilitating the delivery of QA programs - the Edinburgh Pipe Phantom (EPP) is used to measure the resolution integral - a previously validated[1] single figure-of-merit to assess imaging performance of ultrasound scanners throughout their life cycle.
- Phantoms typically consist of tissue-mimicking materials (TMM) with well-defined acoustic properties that closely match the characteristics of soft tissues (*e.g.,* attenuation, speed of sound).

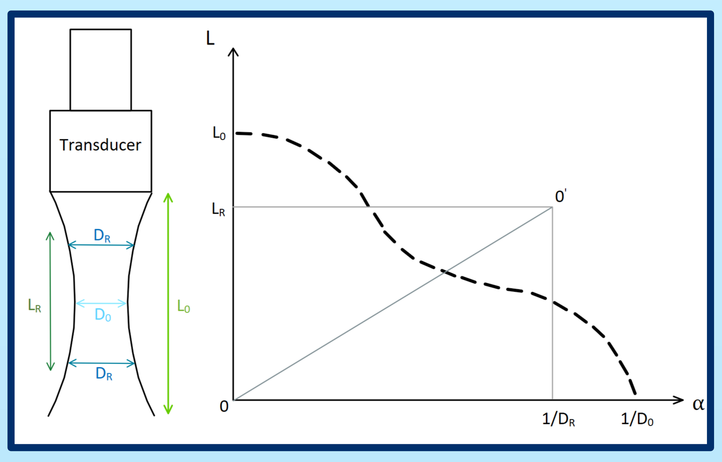

Figure 1:
A weakly focused ultrasound beam (left) with low contrast penetration, L_0 and minimum beam width D_0. The resolution integral is given by $\int_0^{\infty} L d\alpha$ and is equal to the area of the rectangle $0 - L_R - 0' - 1/D_R$. L_r and D_r are the depth of field and characteristic resolution, respectively.

Nonlinearity of tissue-mimicking materials:

- Accurate characterisation of the nonlinearity parameter, B/A, is essential in updating QA programs to account for the emergence of ultrasound imaging techniques that utilise nonlinearity.
- Phantoms such as the Edinburgh Pipe Phantom need clinically relevant B/A values to reliably assess the performance of new and emerging ultrasound imaging techniques.

Collaboration between the National Physical Laboratory (NPL), the University of Edinburgh (UoE), and NHS Lothian aims to build on previous work performed at NPL[2] to produce a methodology that will enable the development of a new TMM that matches the soft tissue B/A values of for use in the Edinburgh Pipe Phantom.

Methods

- Acoustic characterisation including the measurement of the attenuation coefficient (α) and the speed of sound (SoS) were carried out using the NPL ultrasonic materials characterisation facility.
- TMM samples were manufactured at UoE and NPL following similar IEC agar TMM protocol [3], with nominal thicknesses of *5 mm, 10 mm, 15 mm,* and *20 mm.*
- Through transmission measurements were conducted in a 5-axes motorised water tank at room temperature (*19.0 ± 0.5°C)* using a broadband transducer (*1 - 20 MHz*).

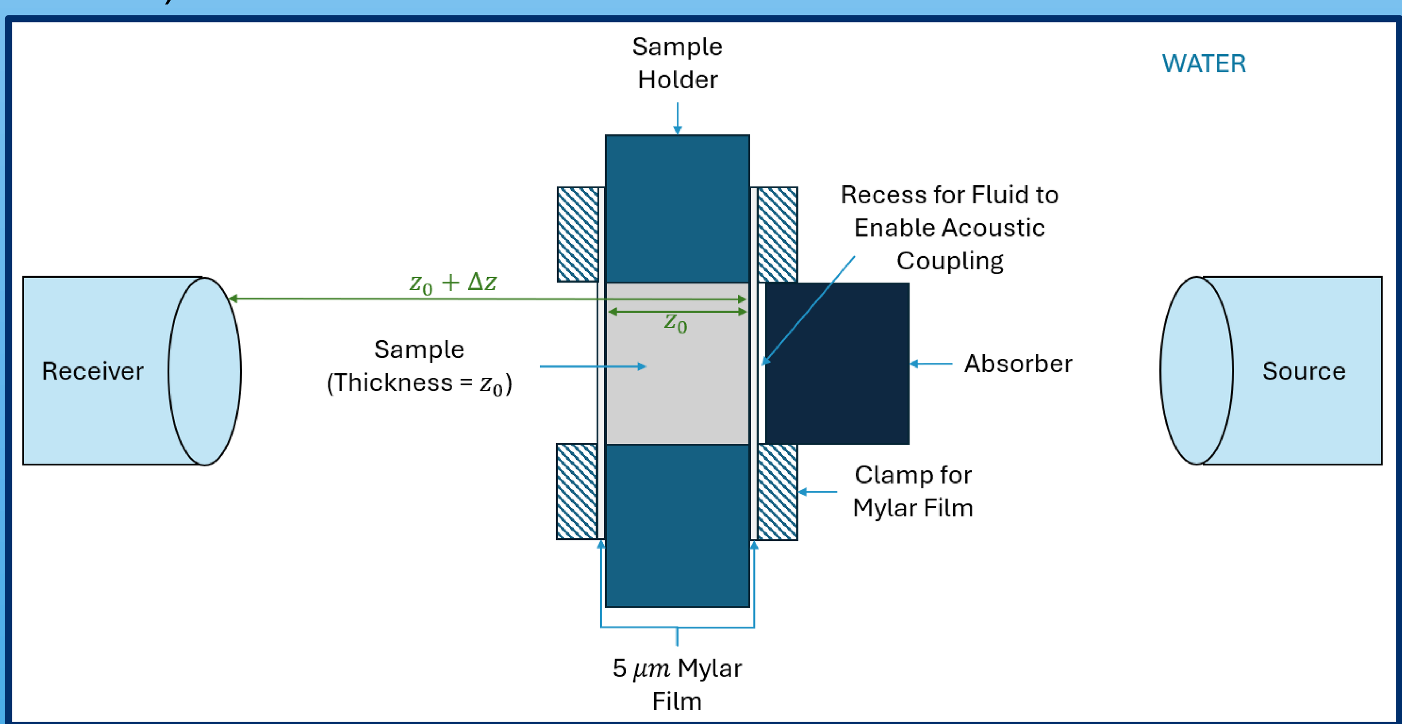

Figure 2:
A schematic view of a TMM sample in the deionised water bath. The absorber (shown in dark blue) is removed for acoustic characterisation measurements and replaced for B/A measurements which use the finite amplitude insertion substitution (FAIS) method calculated using equation 1 [4], where R_{2f} is the ratio of the through-water and through-material signal levels given by equation 2 [2].

$$R_{2f} = \frac{B/A_s + 2}{B/A_w + 2} \times \frac{(\rho_w c_w^3)}{(\rho_w c_w^3)} \times \frac{T_{f,s}^2}{T_{f,w}^2} \times \frac{exp\left(-\left(\alpha_{f,s} + \frac{\alpha_{2f,s}}{2}\right)(z_0 + \Delta z)\right)}{exp\left(-\left(\alpha_{f,w} + \frac{\alpha_{2f,w}}{2}\right)(z_0 + \Delta z)\right)}$$

Equation 1

$$R_{2f} = \frac{p'_{2f}(sample)}{p'_{2f}(water)}$$

Equation 2

Results

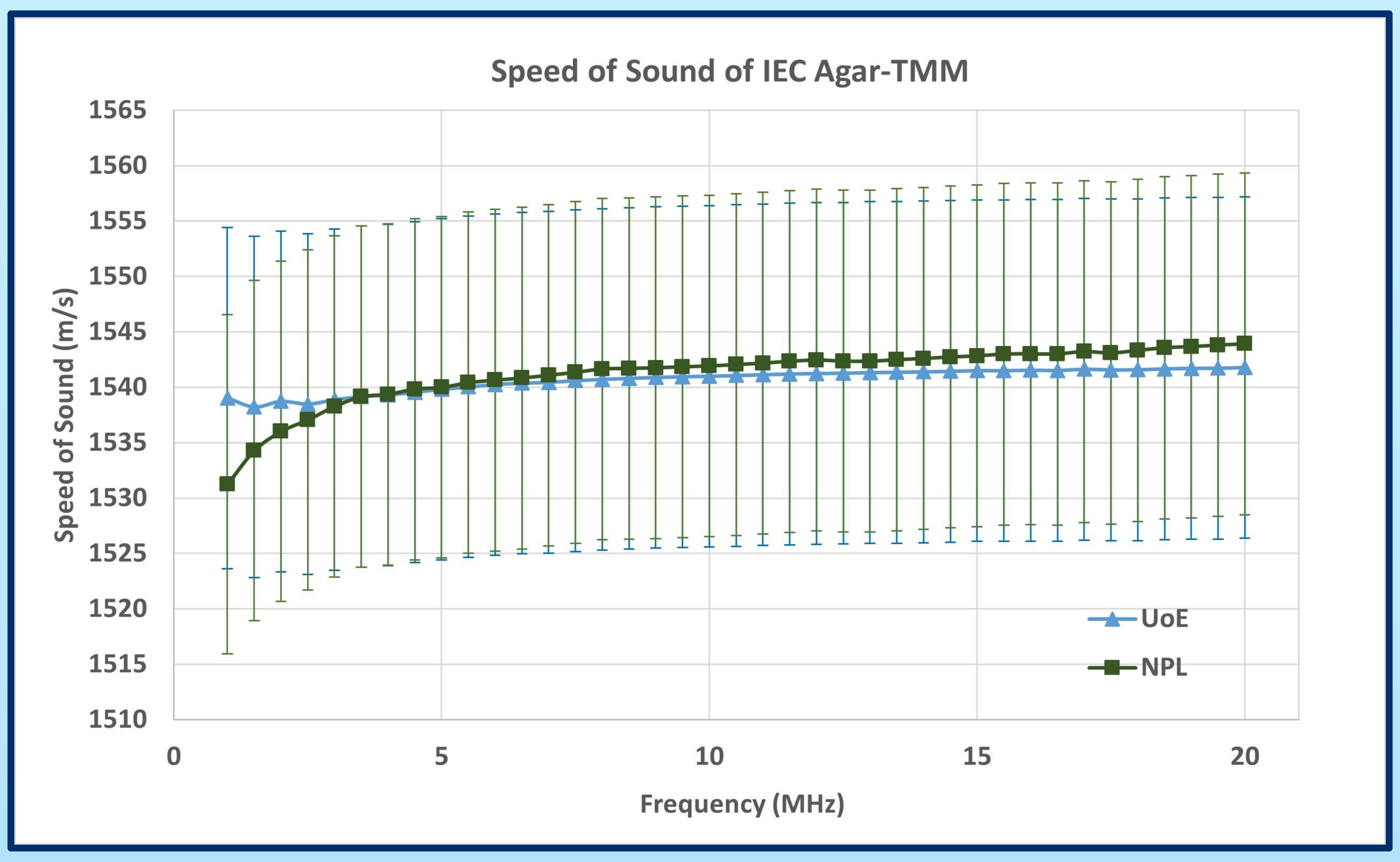

Figure 3:
Speed of sound of IEC agar-TMM samples of *5 mm, 10 mm, 15 mm,* and *20 mm* thickness over the clinical frequency range of *1-20 MHz* for UoE (△) and NPL (□). The weighted mean was calculated using type A uncertainty for each sample thickness.

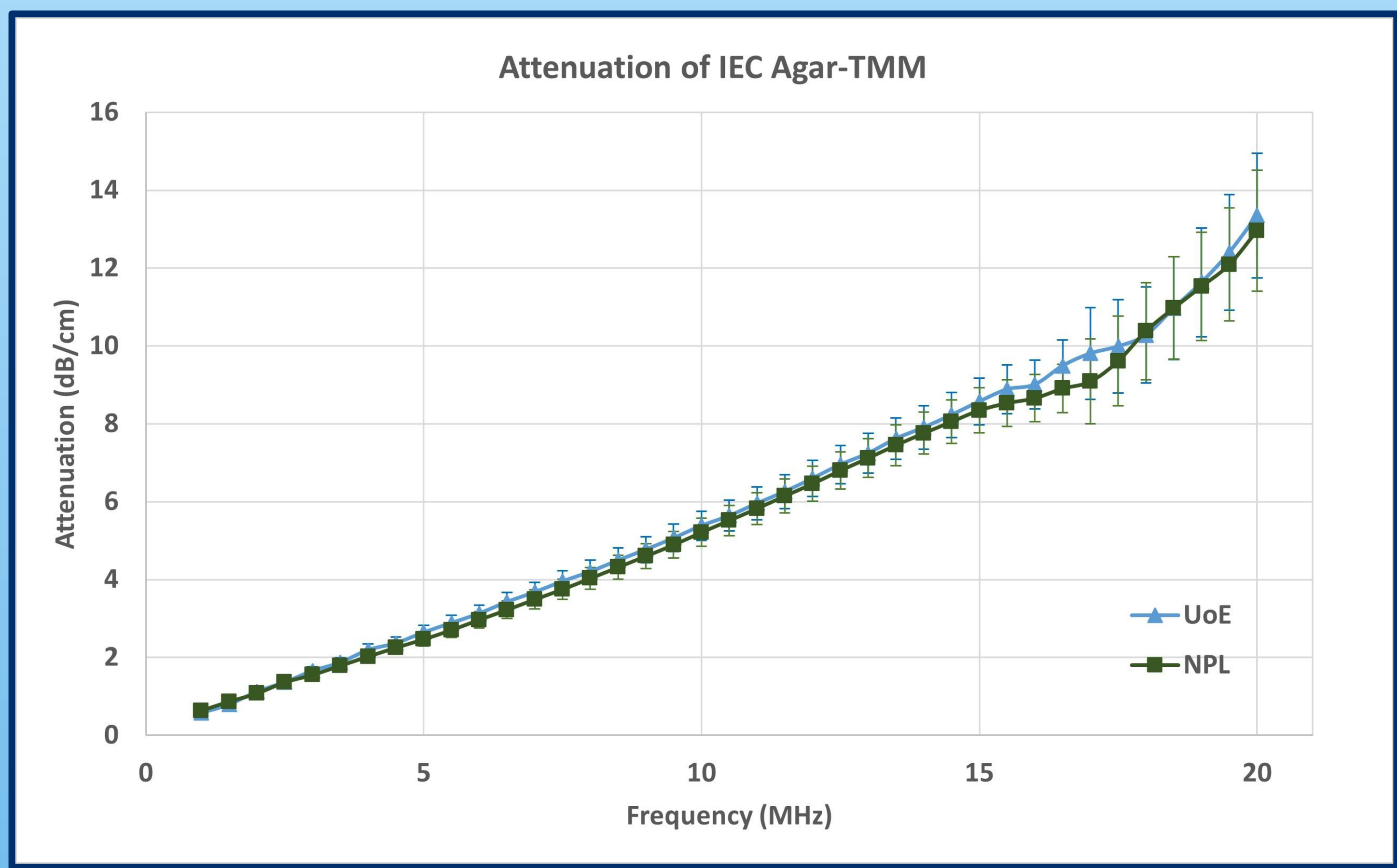

Figure 4:
Attenuation coefficient of IEC agar-TMM samples of *5 mm, 10 mm, 15 mm,* and *20 mm* thickness over the clinical frequency range of *1-20 MHz* for for UoE (△) and NPL (□). The weighted mean was calculated using type A uncertainty for each sample thickness. All values had a normalised error < *1.*

Initial B/A system validation measurements:

- The methods of acoustic characterisation employed for agar TMM, were subsequently used for validation measurements using ethylene glycol samples (*25 mm* and *60 mm*):
- At $2\ MHz: SoS = 1678 \pm 17 ms^{-1}$, $\alpha = 0.08\ \pm 0.004\ dB\ cm^{-1}$
- At $4\ MHz: SoS = 1676 \pm 17 ms^{-1}$, $\alpha = 0.28 \pm 0.004\ dB\ cm^{-1}$

Conclusions

- Acoustic characterisation has confirmed the acoustic properties of IEC Agar TMM are uniform between centres.
- The outlined techniques have been used to acoustically characterise ethylene glycol matching expected literature values[2] for the attenuation coefficient and the speed of sound - these values and the FAIS method have been employed to perform initial B/A validation measurements.

References:

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