HfM Detmold
HOCHSCHULE FÜR MUSIK

Acoustic Impedance Probe for Oboes, Bassoons, and Similar Narrow-bored Wind Instruments

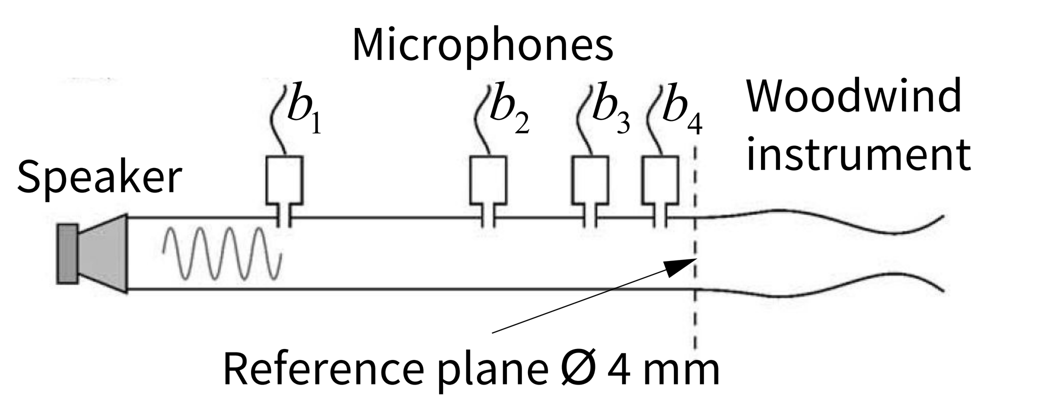
Dustin Eddy, Timo Grothe
Erich Thienhaus Institut - HfM Detmold

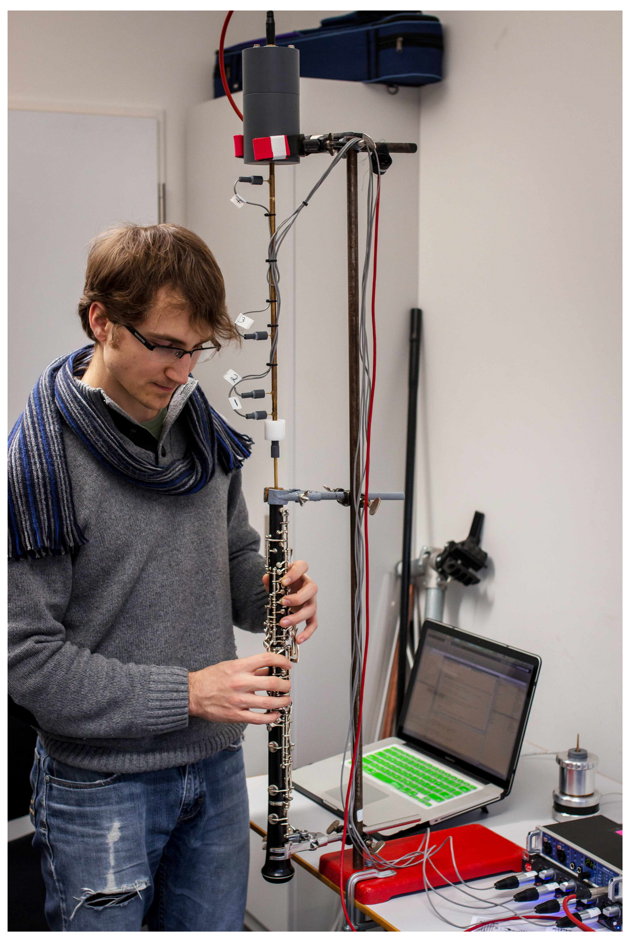
Motivation

- Air column resonances largely determine the intonation and sound characteristics of wind instruments.
- Acoustic impedance measurements unravel their resonant behaviour.
- So far, there is no tailored impedance probe available for narrow-bored wind instruments.

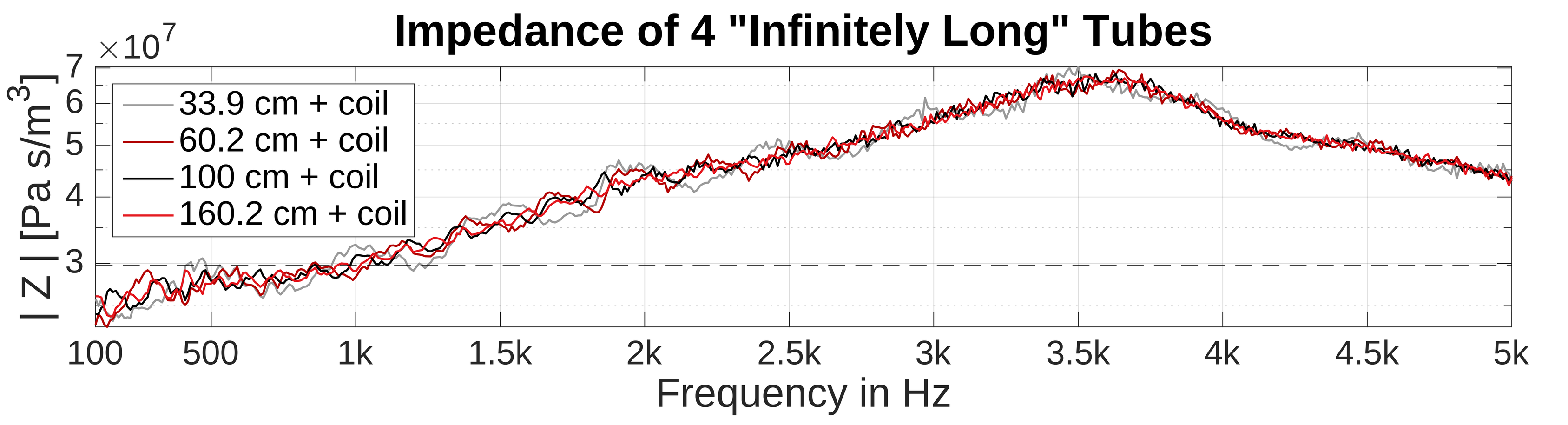
Setup

We developed a
Four Microphone Four Calibration (FMFC)
narrow tube Impedance Probe





- Source:
  - Excitation: Swept sine from 100 to 5000 Hz
  - Driver: Single Beyerdynamic DT 48
- Microphone capsules: Sennheiser KE-4's
- DAQ & signal processing: ita toolbox [2]
- Calibration: reflection acoustic free loads
  - straight tubes + plus 10m coiled tube (PVC)



Due to wall losses, a ϕ 4 mm tube of 15 m length is virtually reflection free above 100 Hz.

Theory

The unknown impedance $\boldsymbol{Z} = \frac{p}{U}$ of the woodwind instrument is obtained by solving

$$\underline{\boldsymbol{A}} \begin{bmatrix} \boldsymbol{p} \\ Z_c \boldsymbol{U} \end{bmatrix} = \vec{\boldsymbol{b}}, \qquad (1)$$

where $\boldsymbol{p}$ is the pressure, $\boldsymbol{U}$ is the volume flow and $\boldsymbol{b_n}$ are the signals of $\boldsymbol{n}$ microphones and $\underline{\boldsymbol{A}}$ is the calibration matrix of the impedance head,

$$\vec{\boldsymbol{b}} = \begin{bmatrix} b_1 \\ b_2 \\ \vdots \\ b_n \end{bmatrix}; \underline{\boldsymbol{A}} = [\vec{A_1}, \vec{A_2}]; \vec{A_1} = \begin{bmatrix} A_{1,1} \\ A_{2,1} \\ \vdots \\ A_{n,1} \end{bmatrix}; \vec{A_2} = \begin{bmatrix} A_{1,2} \\ A_{2,2} \\ \vdots \\ A_{n,2} \end{bmatrix}$$

The coefficients of the calibration matrix $\underline{\boldsymbol{A}}$ are determined by carrying out $\boldsymbol{m}$ independent calibration measurements $\boldsymbol{b}', \boldsymbol{b}'', \ldots, \boldsymbol{b}^{(m)}$ on $\boldsymbol{m}$ known calibration loads $\boldsymbol{Z}', \boldsymbol{Z}'', \ldots, \boldsymbol{Z}^{(m)}$ and solving the following two equation systems [1]

$$\vec{A_1} = \frac{A_{1,1}}{b_1^0} \vec{b}^0 \quad (2) \qquad \begin{bmatrix} [\underline{b}'] \cdot 1/Z' \\ [\underline{b}''] \cdot 1/Z'' \\ \vdots \\ [\underline{b}^{(m)}] \cdot 1/Z^{(m)} \end{bmatrix} \cdot \vec{A_2} = \begin{bmatrix} [\underline{b}'] \\ [\underline{b}''] \\ \vdots \\ [\underline{b}^{(m)}] \end{bmatrix} \cdot \vec{A_1} \quad (3)$$

where

$$\underline{b}^{()} = \begin{bmatrix} b_2^{()} & -b_1^{()} & 0 & \cdots & 0 \\ 0 & b_3^{()} & -b_2^{()} & & \\ \vdots & & & \ddots & \\ 0 & & & b_n^{()} & -b_{n-1}^{()} \end{bmatrix};$$

and $\vec{\boldsymbol{b}}^{\boldsymbol{0}}$ are the microphone signals when measuring the closed impedance head.

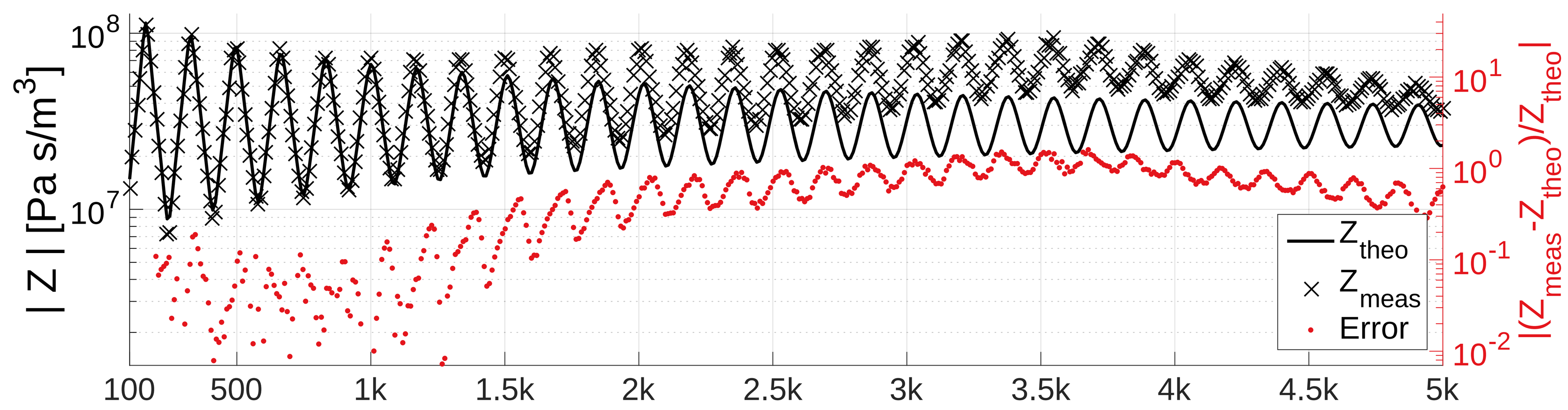
Contact

- Email: DuEddy7@gmail.com
- Web: http://www.eti.hfm-detmold.de

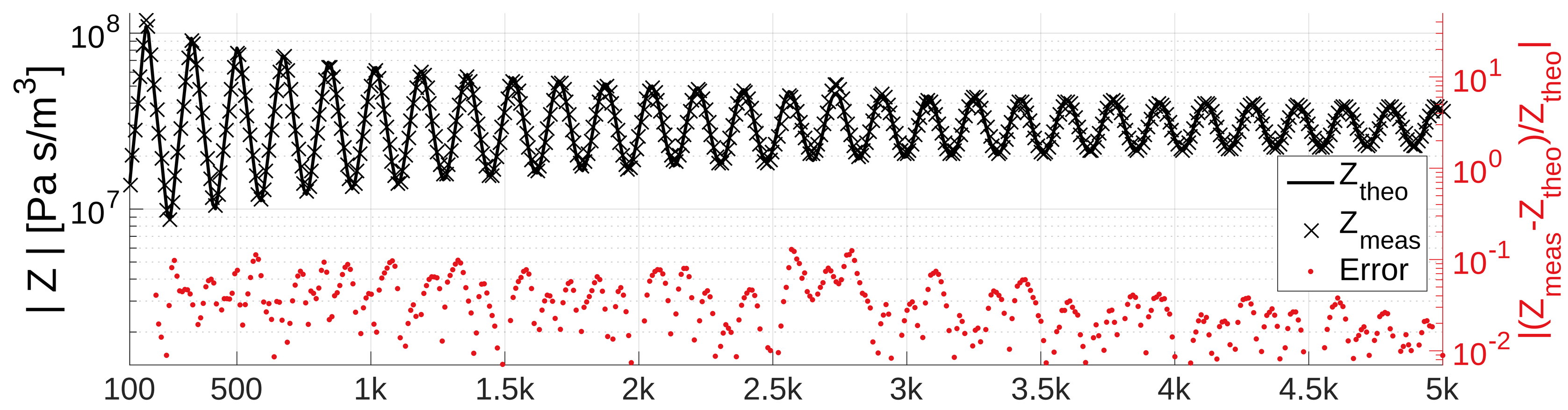
Results - Validation

The validation object is a closed ϕ 4 mm tube of 1 m length.

Commercial volume-flow source impedance head (BIAS [4]) + size adapter



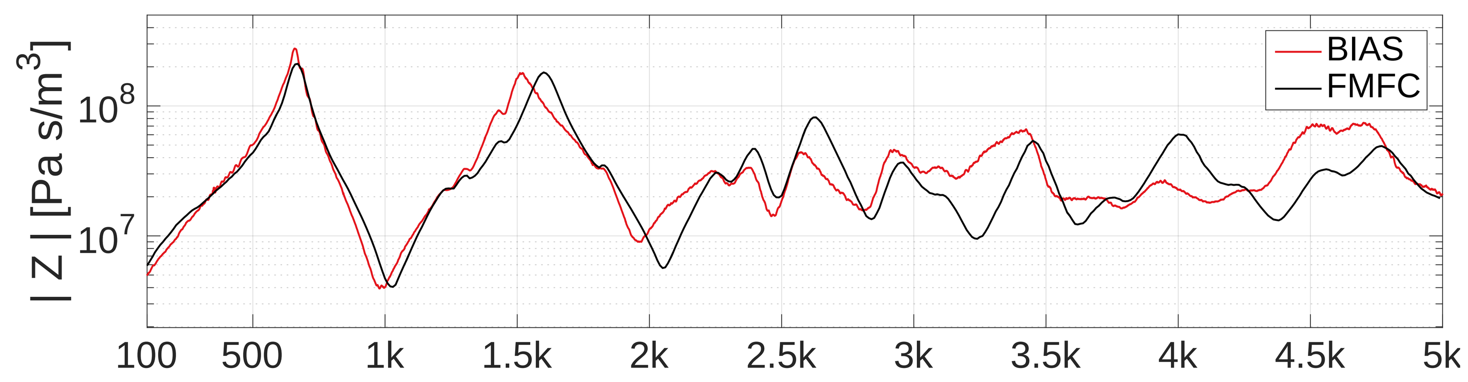
Our tailored narrow-bore impedance head (FMFC)



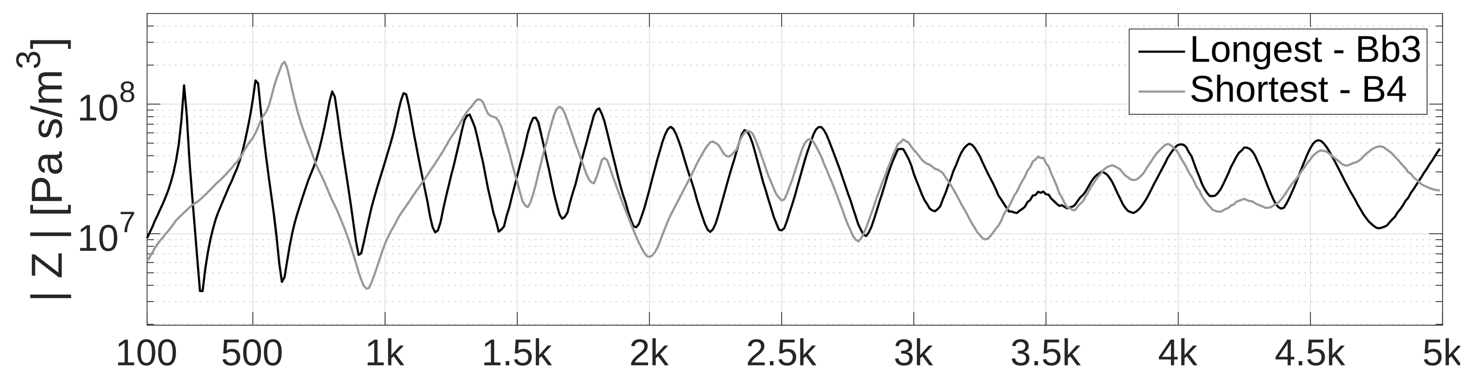
Matching adapters needed with commercial systems produce non-reversible distortions in the resonance curve above 1 kHz [5]

Results - Oboe Measurements

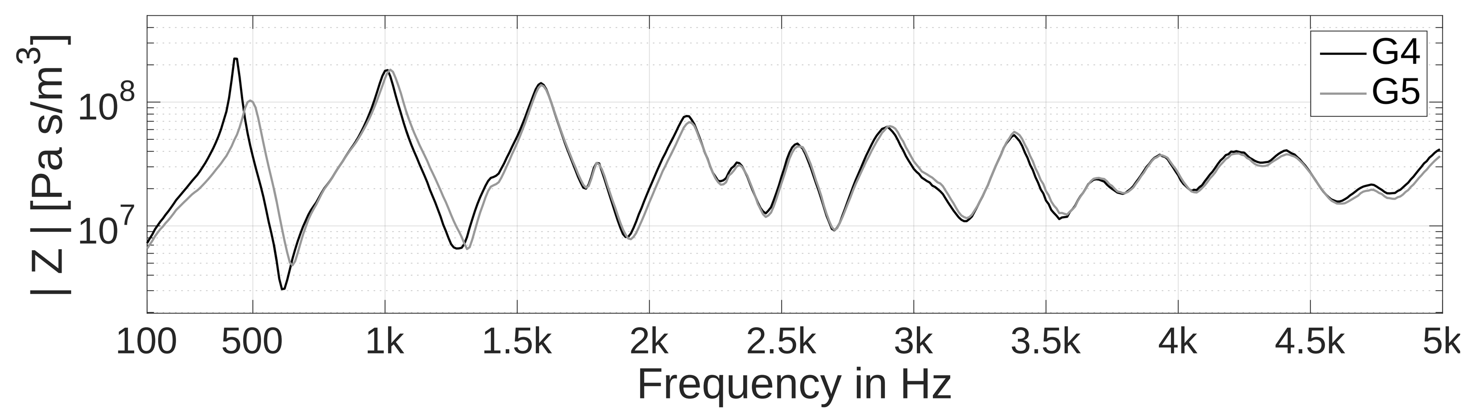
Comparing two measurement systems on an oboe:



Resonances in the oboe for the longest and shortest air column:



The effect of the register key is to weaken the fundamental resonance:



Discussion

- Our custom made impedance probe offers significantly more precision on narrow-bored objects than a commercial system + size adapter.
- A compact and portable version is quite feasable using coiled tubes.
- As a practical improvement, a thermometer should be included.
- Precision impedance curves are useful in
  - music acoustics research for sound synthesis
  - musical instrument workshops for intonation estimation [3]

Literature

[1] P. Dickens, J. Smith, and J. Wolfe. Improved precision in measurements of acoustic impedance spectra using resonance-free calibration loads and controlled error distribution. *Journal of the Acoustical Society of America*, 121(3):1471–1481, 2007.

[2] P. Dietrich, M. Guski, M. Pollow, B. Masiero, M. Müller-Trapet, R. Scharrer, and M. Vorländer. Ita-toolbox-an open source MATLAB toolbox for acousticians. In *Fortschritte der Akustik, 38. Jahrestagung für Akustik (DAGA2012), Darmstadt*, pages 151–152, 2012.

[3] T. Grothe and J. Baumgart. A comparison of intonation estimates for reed woodwinds. In *Fortschritte der Akustik, 42. Jahrestagung für Akustik (DAGA2016), Aachen*, 2016.

[4] T. Ossman, H. Pichler, and G. Widholm. Bias: A computer-aided test system for brass wind instruments. In *Audio Engineering Society Convention 87*, 10 1989.

[5] M. van Walstijn, M. Campbell, J. Kemp, and D. Sharp. Wideband measurement of the acoustic impedance of tubular objects. *Acta acustica united with acustica*, 91(3):590–604, 2005.

Acknowledgements

We thank Prof. Dr.-Ing. Malte Kob for lending us the microphones and Bernhard Laufhütte for lending us the Marigaux Oboe.