Extension of reciprocity calibration of microphones to frequencies below 1 Hz

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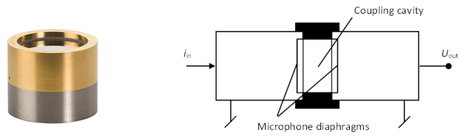
Reciprocity calibration

- (Laboratory standard, LS) condenser microphones are reciprocal devices – the ratio of the unloaded output voltage to a sound pressure is the same as the ratio of the unloaded diaphragm volume velocity to a current though the terminals
- When two reciprocal microphones are acoustically coupled with a known acoustical transfer admittance, the product of their sensitivities can be calculated from measurement of the ratio of the output voltage to the input current



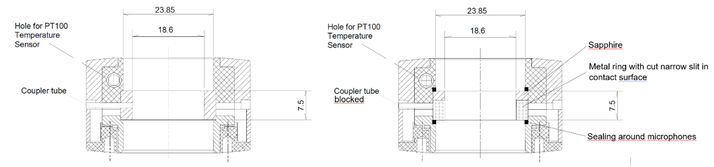
LS microphone Brüel & Kjær Type 4160 and sketch of measurement configuration

- From the products measured with the three combinations of three microphones, the three sensitivities can be calculated
- It is an absolute method – linked to the SI through dimensions, DC-voltage and electrical impedance (AC voltage and current)
- Established method for many years
- Single method that covers the entire frequency range of pressure sensitivity from its lower frequency limit to 10 kHz for LS1 (one inch) microphones and 20 kHz for LS2 (half inch) microphones
- Validated down to 2 Hz in International key comparisons CCAUV.A-K5 and CCAUV.A-K6 [1,2]
- Rely on accurate calculation of acoustical transfer admittance
- Calculation methods improved in recent years [3,4]
- Standardized in IEC 61094-2 with amendment 1 [5]

Challenges in lowering the lower frequency limit with present couplers

- Leakage between coupler and microphone surfaces too large and not sufficiently reproducible
- Full sealing gives instable measurements, possibly due to thermal fluctuations

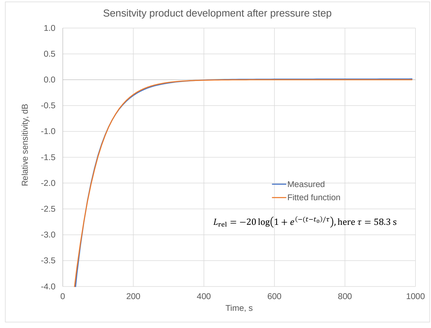
Prototype couplers and verification



Standard Brüel & Kjær plane wave coupler (left) modified to prototype coupler for Infra-AUV measurements (right)

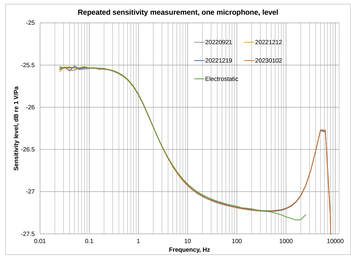
- Coupler cavity is made from sandwich of sapphire ring and metal ring
- Coupler tube normally used for pressure equalization is blocked
- Sealing around microphones
- Pressure equalization is established with cut narrow slit in contact surface of metal ring
- Time constant of cavity in range 50 s to 100 s

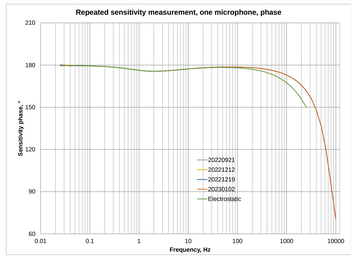
- Verification of time constant of pressure equalization – for each coupler it shall remain the same within a few seconds
- Due to a much lower time constant of the microphone pressure equalization, the change in sensitivity is approximately proportional to the pressure difference between the coupler cavity and the surrounding air
- The change in sensitivity product with time after a pressure step is measured and fitted to a model function

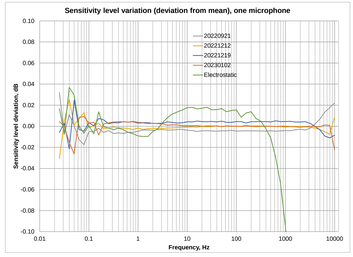


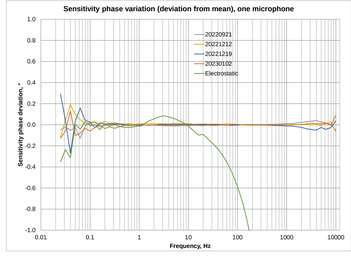
Reproducibility of measurements

- Reproducibility is satisfactory from 25 mHz
  - It may be possible to extend the method to even lower frequencies
- However, there are regularly outlier measurements
  - Not shown, probably due to difficult positioning of microphone
  - In most cases, repeating one sensitivity product measurement is sufficient
  - Mounting of and sealing around microphones shall be improved for use of the couplers in commercial calibration service
- Consistent with measurements with electrostatic excitation
  - Deviation with increasing frequency is due to air mass load of diaphragm – details shall be worked out for better verification









References:

[1] CCAUV.A-K5 Final Report, 2014, *Metrologia* 2014, **51**, Tech. Suppl., 09007

[2] CCAUV.A-K6 Final Report, 2023, *Metrologia* 2023, **60**, Tech. Suppl. 09001

[3] Olsen E and Frederiksen E: Microphone acoustic impedance in reciprocity calibration of laboratory standard microphones, Inter-noise 2014.

[4] P. Vincent et. al.: " Acoustic transfer admittance of cylindrical cavities in infrasonic frequency range", *Metrologia* **56**, 2019

[5] IEC 61094-2:2009+AMD1:2022 "Measurement microphones - Part 2: Primary method for pressure calibration of laboratory standard microphones" with amendment 1, IEC 2009 and 2022

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