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Miniature Omnidirectional Sound Sources Used in Acoustic Scale Modeling – Measurements and Validation

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Abstract Acoustic measurements such as scale modeling measurements require a particular type of miniature omnidirectional sound source. The most important aspects of those devices are small sizes (usually below 100 mm in diameter) and different frequency ranges compared to traditional, omnidirectional sound sources used in room acoustics. The required frequency range differs regarding the used scale factor in different models, which leads to the troubles in frequent source changes and the need for a unique source design for every model. The project will present the recent achievement in miniature omnidirectional sound sources development. The optimal sound sources for the given measurement functions were developed based on the previous numerical simulations and experiments such as FEM sound directivity simulations or transducers' parameters tolerance testing. The sound sources presented are used for applications such as acoustic sound insulation scale measurements (frequency range 800 ÷ 63 000 Hz), scaled reverberation chamber measurements (300 ÷ 80 000 Hz), or acoustic reduction models measurements (400 ÷ 70 000 Hz). The paper will cover a detailed technical explanation of the laboratory environment's source construction aspects and validation measurements.

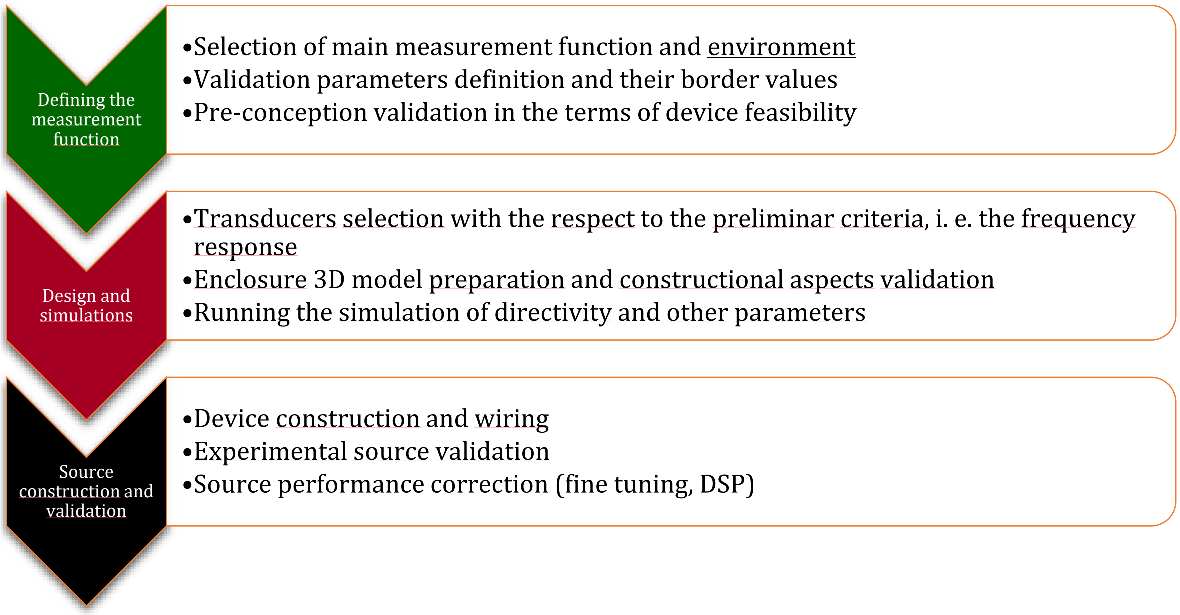
Keywords: scale modeling, acoustic reduction models, room acoustics, electroacoustics.

1. Introduction

An omnidirectional sound source is a basic equipment used in room acoustic measurement. Performing the measurements on the models scaled with the probability theory, the requirements for the source directivity remains in charge. However, the frequency range shifts depending on the scale factor. This challenges proper scale measurement performance as a special sound source is required. The spark gap or laser sources were used [1, 2]; however, the disadvantage of this construction is the lack of full control over the measurement signal and its type. Few innovative miniature sound sources were presented in state-of-art, for example, the balloon elastomer speaker [3] or laser inducted plasma impulse sound source [4]. The traditional electroacoustic sound sources were also used [5-7] but without a detailed explanation of the design method and source verification which would allow for recreation or improvement of the miniature sound source development in the future. The further need for scale modeling sources development was noticed [8]. The current project is based on the previous research [9], where the basic FEM simulations were performed together with fundamental experiments, which allowed to formulate the design principles for optimal omnidirectional sound source construction. The recent development of novel sound sources for scale modeling is presented together with their frequency and directivity characteristics. Presented devices allow to perform in scale measurements such as sound scattering, acoustic insulation or reduced models room acoustic parameters measurements.

2. Background of the design process

The design process should be divided into three stages to provide a good quality miniature omnidirectional sound source. The suggested script for the construction is presented in Fig. 1. As the first step, the definition of the source function and working environment is essential, as it defines the parameters such as required frequency range, maximum source size, and the thresholds of acceptable directivity. For example, for acoustic insulation measurements reaching the correct SNR in measurements is essential for a possible cost of worse omnidirectional performance. Those measurements are performed in a reverberation chamber the directivity is not the essential parameter [10]. However, directivity is crucial in small-scale reduction models or an anechoic chamber, while the SNR requirements are significantly lower.



- Selection of main measurement function and environment
- Validation parameters definition and their border values
- Pre-conception validation in the terms of device feasibility

- Transducers selection with the respect to the preliminar criteria, i. e. the frequency response
- Enclosure 3D model preparation and constructional aspects validation
- Running the simulation of directivity and other parameters

- Device construction and wiring
- Experimental source validation
- Source performance correction (fine tuning, DSP)

Figure 1. The algorithm for the miniature omnidirectional sound source design process.

The middle step in the design process is the transducers selection and 3D model preparation. As the size of the miniature omnidirectional sound source usually does not exceed 100 mm in diameter, 3D printing is the most effective manufacturing technique [11]. This feature allows the use of any shape and size of the transducers that meet the frequency response criteria. The most crucial element in this step is to prepare the accurate 3D model with the optimized space to fit in with the transducers and keep the source size possibly small as it affects the directivity performance [12].

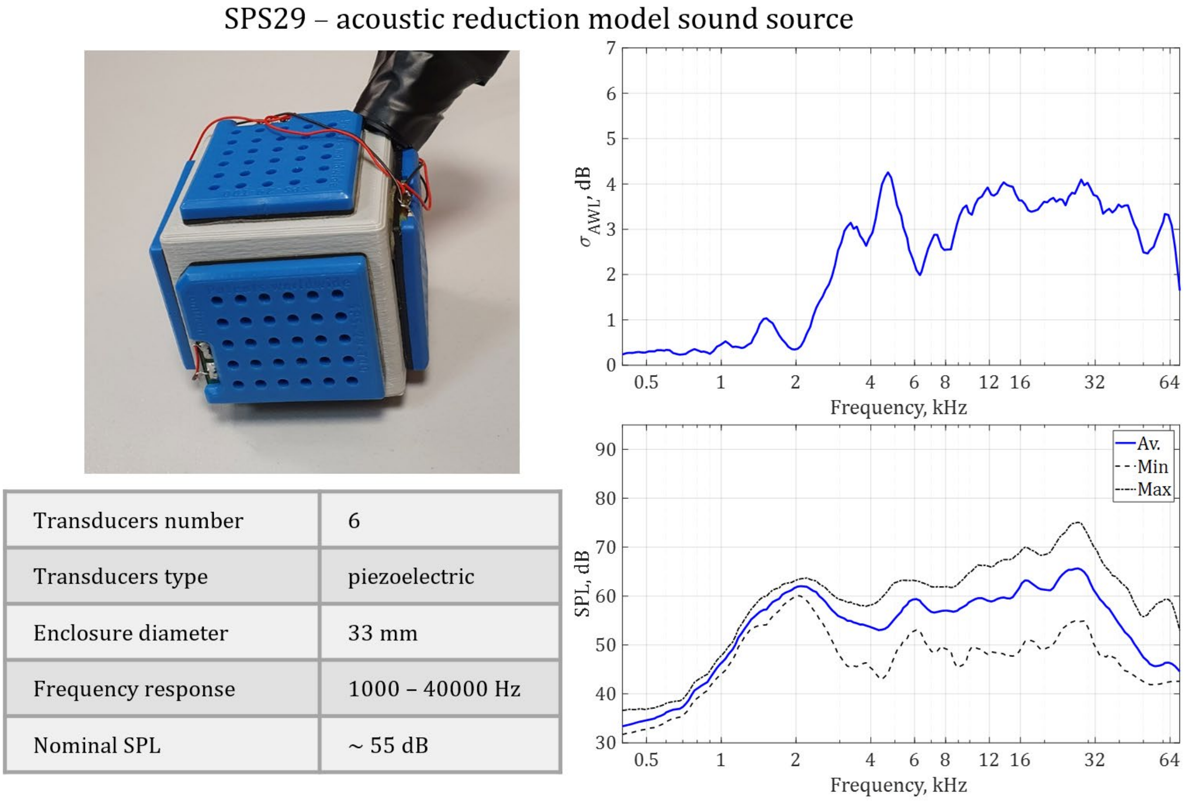
The last step in the design process is the experimental source validation. In the current research, except for the most common source parameters such as frequency response and spatial response, the INR/SNR data was provided to prove the source usability for a given measurement function. The most commonly used method for evaluating sound source directivity is described in ISO 354 standard [13]; however, it is usually used for diffuse field measurements. A detailed explanation and judgment on directivity rating parameter selection were presented in previous papers [9, 12]. We used the modified standard deviation presented in [14]:

$$\sigma_{\mathrm{AWL}}(f) = \sqrt{\frac{\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} S_{m,n}\left[L_{m,n}(f) - \langle L_{m,n}(f)\rangle_S\right]^2}{\sum_{m=0}^{M-1}\sum_{n=0}^{N-1} S_{m,n}}} \tag{1}$$

where M, N are the total numbers of measurement points on the partitioned sphere. $L_{m,n}(f)$ is sound pressure level (SPL) measured at m, n points, $\langle L_{m,n}(f)\rangle_S$ is the average SPL – measured or calculated on the sphere of a given radius, and $S_{m,n}$ is the area of the sphere part corresponding to the point number m, n. As such, σ_{AWL} is a frequency-dependent objective metric that indicates the uniformity of the sound source strength over all directions. A large value of σ_{AWL} indicates that the sound source is not omnidirectional for a given frequency band.

3. Selected designs of the miniature omnidirectional sound sources

This chapter presents the designs of miniature omnidirectional sound sources used for scale modeling constructed in the Technical Acoustic Laboratory at AGH University. To rate the acoustic performance of each device, anechoic chamber measurements were conducted by measuring the hemisphere radiation with 5-degree resolution in both azimuthal and elevation on the radius of 2 meters. Each speaker technical datasheet contains frequency response characteristics, where average stands for mean SPL value from the whole measurement hemisphere. The spatial response was derived following the equations explained in Section 2. The table contains technical information about construction, where the diameter means the size of the sphere that can be drawn over the source. In this chapter, the nominal SPL parameter was defined as the SPL averaged from the usable frequency range for the given source (the average of the presented frequency response across the bandwidth defined in the datasheet). Nominal SPL was defined to display the overall source features and clearly diverse the selected constructions to point out in which source the SPL output was the aim of source optimization. For detailed reference about the given source usability in the measurement environment, the INR/SNR measurement are presented in Section 4. Figure 2 presents the source for acoustic reduction model measurements.

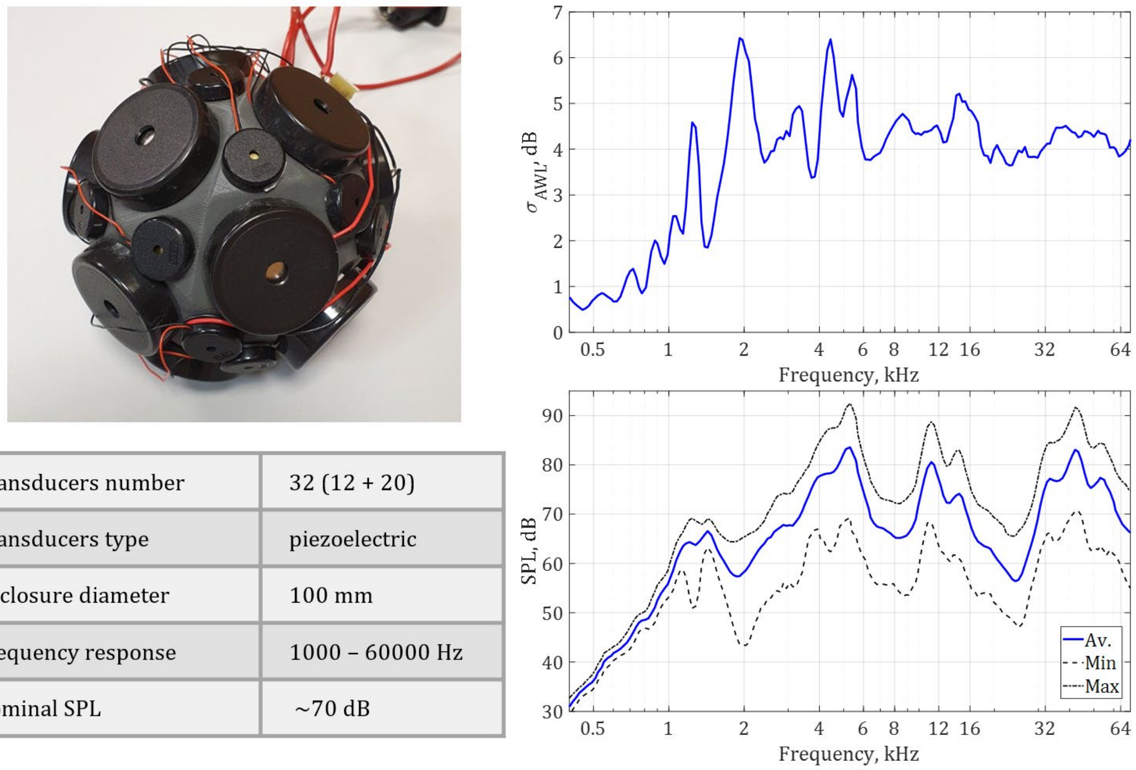

SPS29 – acoustic reduction model sound source

Transducers number	6
Transducers type	piezoelectric
Enclosure diameter	33 mm
Frequency response	1000 – 40000 Hz
Nominal SPL	~ 55 dB

Figure 2. Miniature omnidirectional sound source SPS29 used for reduction models measurements.

As proved in previous research, to achieve omnidirectional sound propagation from the source, it is essential to cover a possibly large surface of the enclosure with speakers [9, 15]. Following this principle, square transducers like piezoelectric speakers Sonitron SPS29 and cubic enclosure are possibly optimal for omnidirectional sound source creation. Those transducers offer wide-band frequency responses, including the high-frequency range achievable thanks to the piezoelectric transducers. As a result, the spatial response does not exceed the 4 dB σ_{AWL} in whole measured frequency range, which allows to use the source in reduction models without significant dispersion in measured parameters which usually occurs while the source is not ideally omnidirectional [16]. In this construction, the source size and omnidirectionality were optimized, so the overall SPL was neglected in the design process resulting in values over 50 dB in the useable frequency range (an anechoic chamber in 2 meters). As the source was designed to measure the small acoustic models, the achievable SPL should allow meeting SNR requirements in most room acoustic parameters measurements.

AS01 – acoustic insulation scale measurements

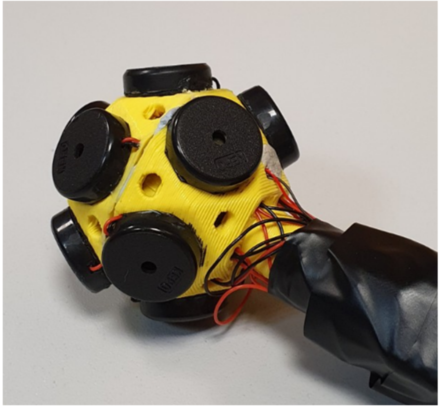


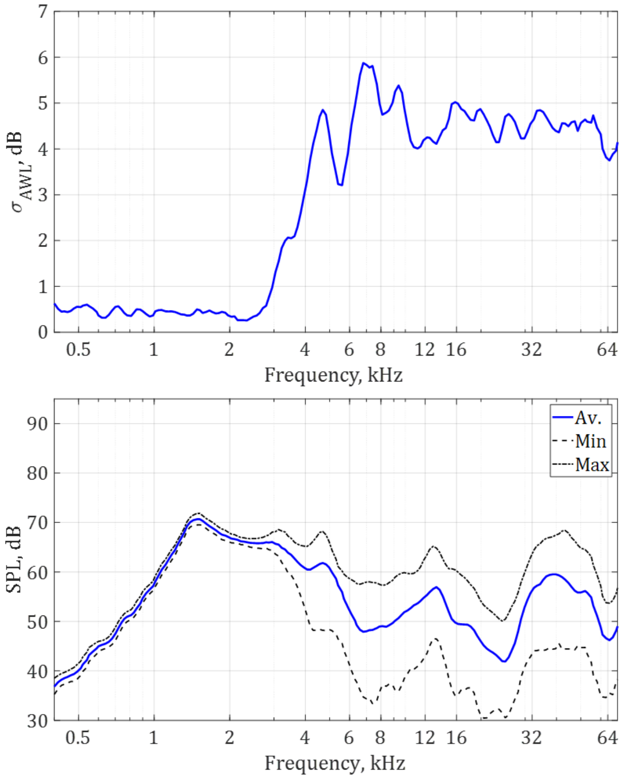
Transducers number	32 (12 + 20)
Transducers type	piezoelectric
Enclosure diameter	100 mm
Frequency response	1000 – 60000 Hz
Nominal SPL	~70 dB

Figure 3. Miniature omnidirectional sound source AS01 used for acoustic insulation scale measurements.

The following solution, presented in Fig. 3, is an omnidirectional sound source used for acoustic insulation measurement, including the different realization of transmission or insertion loss parameters in scale modeling. Compared to other omnidirectional sound sources, in the AS01 type of construction, the SPL was the essential optimization criteria for the cost of worse omnidirectionality. To increase the SPL in the high-frequency range (over 5000 Hz), the two-way speaker construction combined the round piezoelectric transducers with 28 mm and 17 mm diameters. As proved in previous research, filling in the gaps between the transducers increases the emitted SPL but may result in worse directivity [12, 17]. As this device is used in a reverberation chamber, the worse omnidirectionality should not affect the measurements. An average SPL of 70 dB was measured within the frequency range, allowing the acoustic insulation measurements for most of the materials used in scale modeling. Because of the higher number of transducers and their size, the resulting source size grew to 100 mm. However, this feature should not be a disadvantage in most scaled reverberation chambers. In small scaled models, the source should be possibly small to reflect the actual size of the source compared to the measured object. However, in acoustic insulation laboratory measurement, this principle is not mandatory. The two-way source construction with the division for low- and high-frequency range realized by the different transducers occurred as a successful design idea, so it was adapted in the next device construction used for laboratory measurements. The source datasheet is shown in Fig. 4.

AM01 – laboratory measurements, including sound scattering in scale measurements





Transducers number	14 (12 + 2)
Transducers type	piezoelectric + electrodynamic
Enclosure diameter	45 mm
Frequency response	800 – 70000 Hz
Nominal SPL	~55 dB

Figure 4. Miniature omnidirectional sound source AM01 used for scaled reverberation chamber laboratory measurements.

In the AM01 source, two-way construction was implemented using coupled speakers subassembly fitted inside the enclosure. As the source size minimization is one of the most crucial features in miniature omnidirectional sound sources construction, the free inner space in the enclosure may be used to extend the high-frequency range of the device without a significant increase in the source size. In the AM01 source, the assembly of 2 electrodynamic speakers was used in the way described in the previous research [2]. The photo of this solution is shown in Fig. 5.

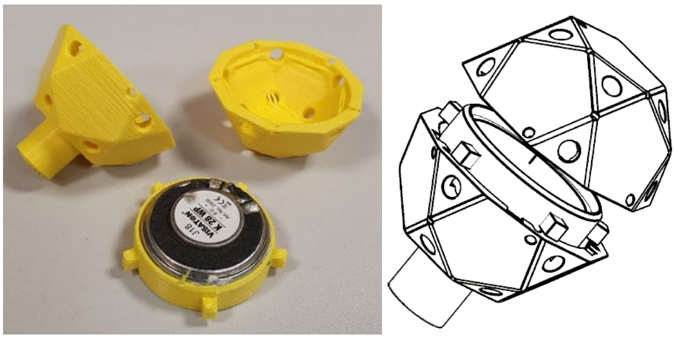


Figure 5. Inner electrodynamic speakers subassembly inside the AM01 source.

This solution allowed to extend the frequency range to 700 – 800 Hz, but because of the small number of piezoelectric transducers used in dodecahedron configuration, the overall SPL was set around 55 dB. The source is used in a scaled reverberation chamber's absorption and scattering coefficient measurements [8]. The final size of the source was 45 mm in diameter, which also fits the requirements for some other scaled models than the 1:8 reverberation chamber used in AGH.

4. Experimental validation of selected miniature sources in the scaled reverberation chamber

Defining the minimum SPL the sound source should provide in a given measurement is difficult as it depends on the used amplifier. Also, when the higher power is used, it results in a bigger distortion. The final source classification for the measurement should be performed with the SNR/INR measurement with the complete signal path setup in the environment the measurements should be performed. In the current research, the scaled reverberation chamber measurement validation was performed. In Technical Acoustic Laboratory in AGH, with the scaled measurement signal path, the following devices are used:

- RME UFX sound card,
- CREST CPX3800 power amplifier,
- GRAS 46BE microphones,
- GRAS 12AL microphone preamplifiers.

The selected equipment meets the required scale modeling measuring conditions, including high sampling frequency and power amplifier without attenuating up to 100 kHz. The results of SNR/INR calculations with the measurement stand photo are shown in Fig. 6.

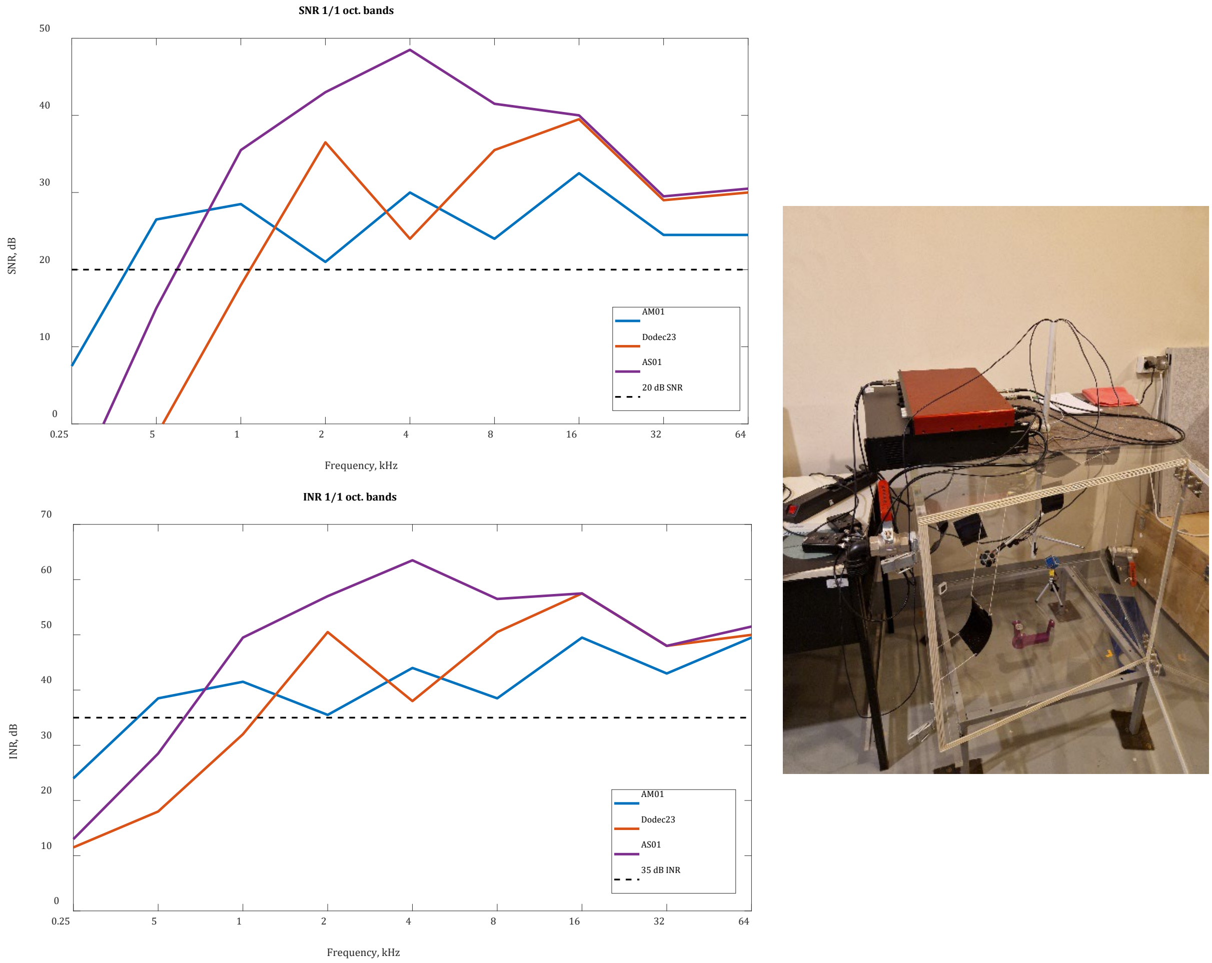


Figure 6. Miniature omnidirectional sound sources experimental verification with SNR calculation in the scaled reverberation chamber.

The measured SNR/INR values can be the final indicator of source validity for the given measuring stand. Figure 6 marked the suggested sufficient SNR and INR value threshold. Previous research [13] conducted a relevant discussion on the difference between SNR and INR meaning. At the same time, in state-of-the-art, it was proven that 20 dB of SNR should be sufficient for sine sweep measurements [18] – following [19], the 20 dB SNR should correspond with a 35 dB INR value. However, the SNR parameter includes all noises that occur in the measured impulse response (IR), including those which are the effect of harmonic distortion. At the same time, those products do not affect the sine sweep method and further room acoustic parameters calculations as they are moved to the end of the result IR and are not included in the calculation [20]. The

SNR values are lowered with the high THD value, while the INR should remain unaffected in most measuring setups. Following this discussion, it is strongly recommended to use both SNR and INR for source validation.

In most cases, insufficient SNR with a high INR value still proves the source validity for the given measurement. The SNR measurements could be also used as the border-driven power thresholds to set the volume limitation for the given source. Usually, there is a limit above which the THD and other distortions start to increase exponentially. No further SNR and INR gain is observed with the increasing the output amplifier power.

5. Summary and future works

The paper presented the miniature omnidirectional sound sources used in Technical Acoustic Laboratory in AGH for scale measurements. Different constructions were prepared to meet the measurement conditions for the parameters such as acoustic insulation, sound absorption or scattering, and room acoustic parameters scale measurements. The paper covered the essential remarks on the design process, such as the source function definition, measuring environment selection, and source constructional aspects. Final scaled reverberation chamber INR/SNR validation was discussed. Future works on this topic will focus on electrical and mechanical source performance improvement methods. The possible use of separated driving with individual signal correction and the other novel types of loudspeaker enclosure types will be investigated, which may result in further low-frequency range extension.

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