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Aspects for Evaluating an In-Situ Reflection Factor Measurement Probe

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Introduction

Several standardized methods exist for characterizing the reflection properties of materials, including the classical reverberation chamber method and the impedance tube method. In recent years, in-situ methods have also been developed, such as the Adrienne window method and the two-microphone transfer function method.

However, a major issue remains: results from different methods can vary significantly. As illustrated in Figure 1, substantial deviations are observed between the reflection coefficient of 100 mm Basotect following DIN ISO 10534–2 (impedance tube method), DIN ISO 354 (reverberation room method) and DIN 1793–5 (adrienne method). The data of the impedance tube [1] and reverberation room method [2] are taken from the manufacturer datasheet and that of the adrienne method is obtained from a measurement certificate. In addition to inter-method differences, variability within the same method has also been reported. For instance, a study by Mélanie Nolan compares absorption coefficients of the same material measured with the reverberation room method across 13 European laboratories, revealing noticeable discrepancies among the results [3].

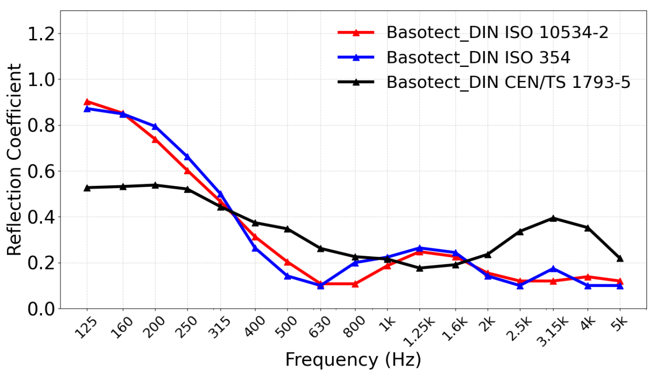


Figure 1: Reflection coefficient of Basotect (thickness: 100 mm) from three different standards

To address these issues, an evaluation concept is proposed based on four aspects: accuracy, applicability, reproducibility and robustness. An in-situ measurement probe serves as a case study to demonstrate the approach. The reflection factor of Basotect is compared with results obtained from standardized methods. The evaluation is further structured into subcategories: repeatability, sound source, sample size, environmental requirements, and geometric setup, each corresponding to the four aspects.

Evaluation Framework

A framework based on four aspects is proposed to evaluate measurement methods. To better convey the framework, one question is raised for each aspect. The questions should be kept in mind while evaluating the corresponding aspects.

- **Accuracy**: Comprising trueness (regarding validity) and precision (regarding repeatability), following ISO 5725–1 [4]. High accuracy is achieved only when both trueness and precision are high.
  • Trueness: Is the measurement result valid compared to the reference value?
  This is a challenging aspect, as the reference value itself may be unreliable. Since trueness depends directly on the chosen reference, it should be regarded primarily as an indicator of validity rather than an absolute measure.
  • Precision: Can the method provide the same result with repeated measurements?
  Repeated measurements refer to those conducted under identical conditions, including the same sample plate, sound source, receiver, environment and operator.

- **Applicability**: Under what conditions and for which cases can the method be applied?
  Applicability stems from a practical point of view. Depending on the individual measurement, all the related conditions should be listed and then tested. For common acoustic measurement methods, conditions like permissible frequency range, incident angle, sound source and receiver, room influence, geometry setup are recommended to be evaluated.

- **Reproducibility**: Can the same results be obtained in different laboratories and by different operators?
  This is a critical requirement for any measurement method. The method should not be limited to a single laboratory but yield comparable results across different laboratories. However, as noted earlier, even some standardized methods show significant variability between laboratories.

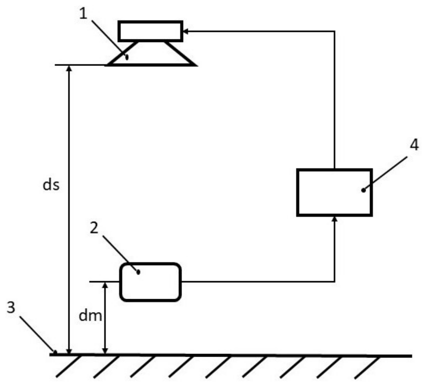
- **Robustness**: Does the method produce reliable results under non-ideal or uncontrolled conditions?
  While each method has specific requirements, it is not always possible to meet them fully in practice. A robust method should therefore still provide reasonable results even when conditions deviate from the ideal.

Case Study: In-Situ Probe

The evaluation framework is applied to an in-situ reflection factor measurement probe method designed according to DIN ISO 13472–1 [5]. This method is based on the near-field holography (NAH) to reconstruct the sound fields [6]. It has already been used for the determination of complex reflection factors of acoustic materials in shooting noise applications [7].

Measurement Setup

The measurement setup consists of a sound source (loudspeaker), a sound receiver (probe), the signal processing unit and a sample plate under test. The loudspeaker is suspended above the sample plate. Beneath it, the probe is placed directly on the material surface. Therefore the distance between the probe and sample plate (d_m) is fixed at around 80 mm. As for the signal processing chain, it includes a multitrack field recorder and a computer.



Key

1	sound source (loudspeaker)
2	the measurement probe
3	surface (sample plate) under test
4	signal processing unit
d_m	distance between the probe and the sample plate
d_s	distance between the speaker and the sample plane

Figure 2: Sketch of measurement setup

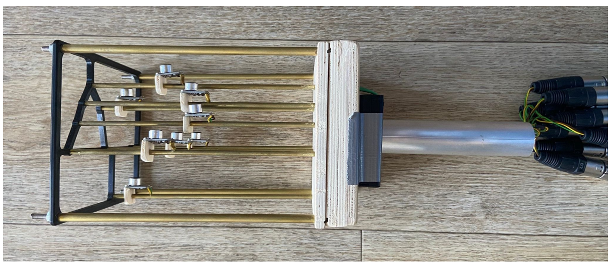


Figure 3: Measurement probe

The measurement probe is the key part of this measurement method. It consists of eight microphones, which are fixed on the rods and arranged in a hemispherical shape. The probe is developed for in-situ measurement of the reflection coefficient for perpendicular sound incidence angles in the frequency range from 500 Hz to 5 kHz.

Results

Since the proposed measurement method has not yet been conducted in other laboratories or by other operators, the reproducibility is still under test. Only the results of the other three aspects are presented and discussed.

Accuracy

Accuracy is evaluated using a classic acoustic material: Basotect. Measurements are taken on six different dates under identical conditions, namely the same distance d_s, same Basotect plate and same loudspeaker in the office room.

For trueness, the focus lies on the comparison between current results and the reference. From Figure 5, the mean curve across all measurements stays between the reference curves of the Adrienne and impedance tube methods, suggesting a high level of trueness. Nevertheless, it is important to emphasize again that the reference itself is not the absolute truth. Therefore, trueness is interpreted more as a qualitative indicator rather than a strict validation.

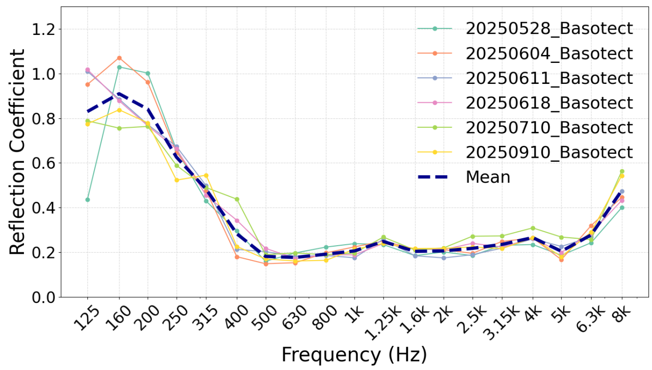


Figure 4: Measurement results of six dates

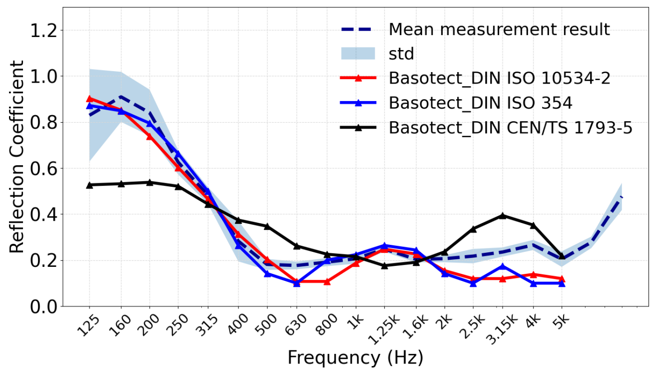


Figure 5: Trueness: comparison to references

For precision, it is more reliable to assess. The target is the variation or dispersion between repetitions. The standard deviation is calculated for the repeated measurements, which is below 0.025 for the frequency range above 500 Hz.

Applicability

The applicability cases regarding the current method are shown with abbreviations in Table 1, which include different loudspeakers, sample materials, sample sizes and rooms. With the exception of the sample material, the test conditions are generally listed in the order from least stringent to most stringent.

To test the specific applicability of a particular condition and distinguish it from other situations, all other conditions are kept constant while only this particular condition is varied.

Table 1: List of applicability cases
*Note: Sample size only shows the length of the shorter side

Sound Source	Neumann 120, ZK 106, Anker Mini
Sample Material	Basotect, RsaFiberCom, Vinyl
Sample Size* (m)	1.2, 1.0, 0.6, 0.4, 0.2
Environment	Anechoic-, Office, Reverberation-

• Applicability — Sound Source

Previously, the Neumann speaker, the one with the flattest transfer function, is used as the default loudspeaker. To test if such an expensive and heavy speaker is necessary, two smaller bluetooth speakers: ZK 106 and Anker Soundcore Mini are tested for comparison. The Neumann speaker has two different ports for high frequency and low frequency; the ZK speaker has two same ports, while Anker speaker has only one port. Apart from Basotect, Vinyl floor is tested, since its reflection coefficient should be nearly 1.

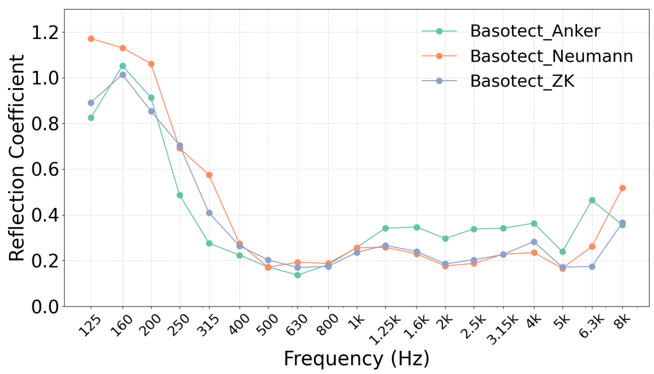


Figure 6: Speaker test: Basotect (thickness: 100 mm)

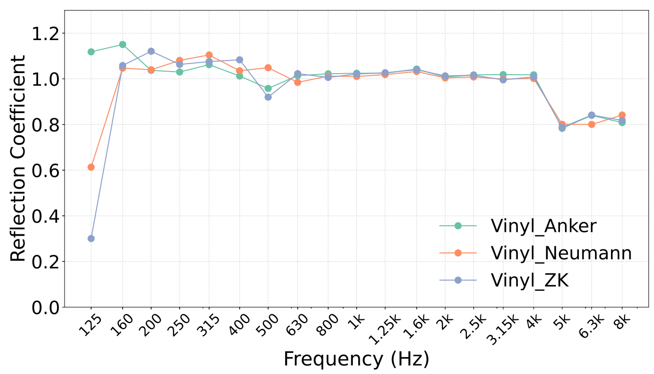


Figure 7: Speaker test: Vinyl Floor

From both Figure 6 and Figure 7, the ZK speaker behaves very similarly to Neumann speaker, which means ZK speaker is sufficient for this measurement method. For Anker speaker, despite some deviations for the result of Basotect, the general trend remains the same, and it performs well for hard material like Vinyl floor.

• Applicability — Sample Size

According to DIN ISO 13472-1, the sample area requirement is around $3\,m^2$ [5]. To find the lowest limit of sample size for the current method, the test started with $1.2 \times 1.2\,m^2$, then gradually reduced to $0.2 \times 0.2\,m^2$.

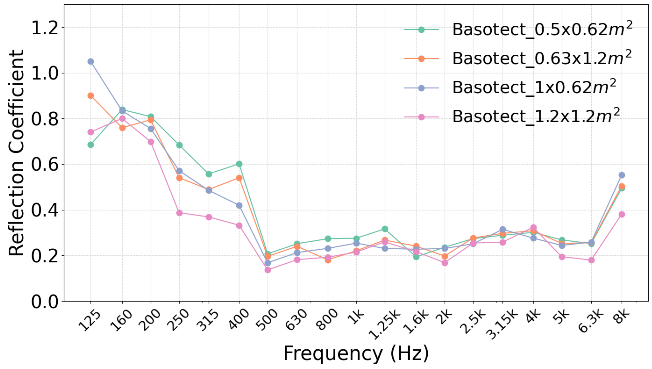


Figure 8: Sample Size: Basotect (thickness: 100 mm)

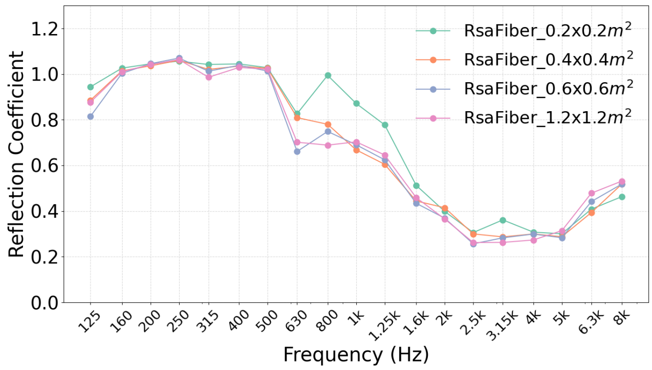


Figure 9: Sample Size: RsaFiberCom (thickness: 25 mm)

As shown in Figure 8, the method remains reliable for Basotect plates as small as $0.5 \times 0.5\,\mathrm{m}^2$ in the frequency range above 500 Hz. For RsaFiberCom, the minimum applicable size is even smaller, reaching $0.4 \times 0.4\,\mathrm{m}^2$, as illustrated in Figure 9.

• Applicability — Environment

To understand the necessary environmental condition, the probe is tested in three types of room: an anechoic chamber, an office room, and a reverberation room. The anechoic chamber with the minimal room influence, represents the best-case scenario; the reverberation room, where room effects are maximal, represents the worst-case scenario; while office room falls in between.

Results show that the probe is highly applicable to normal office environments, as the deviation from anechoic chamber results is minimal above 400 Hz (Figure 10).

Robustness

Regarding the geometric setup, the distance between the probe and the sample is fixed, while only the distance between the loudspeaker and the sample plate (d_s) is adjusable. Two cases are considered to evaluate the robustness of this configuration. In the first case, the loudspeaker is fixed while d_s is varied. In the second case, the loudspeaker is held by the operator.

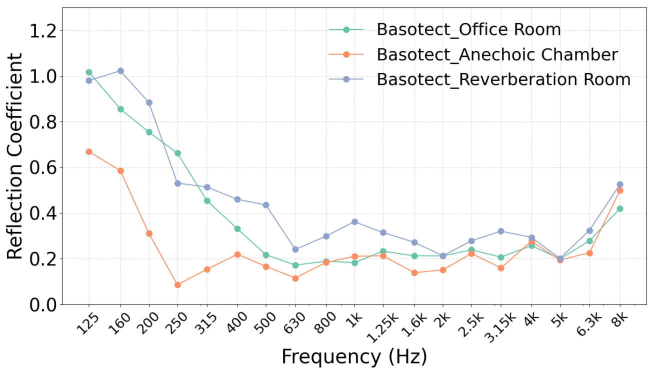


Figure 10: Room comparison: Basotect (thickness: 100 mm)

The results from the handheld case are compared with the average of fixed cases across different dates as previously shown. The results from both scenarios exhibit high consistency. Even when using a handheld sound source, the impact is negligible, indicating the method possesses a high degree of robustness.

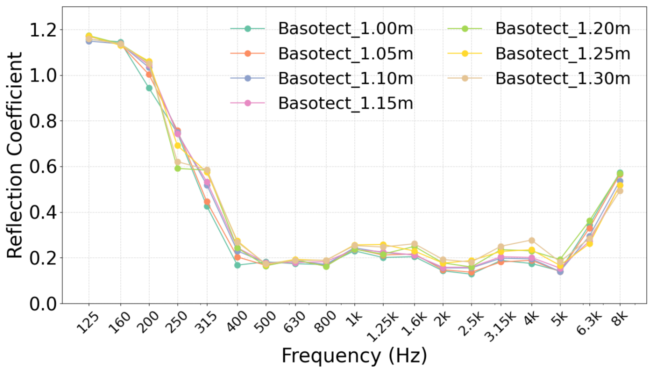


Figure 11: Robustness: d_s (loudspeaker fixed)

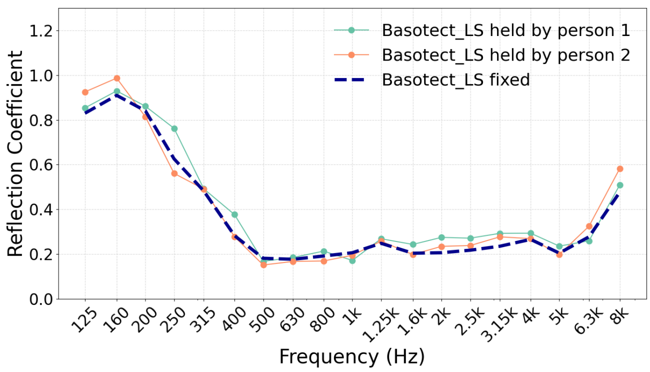


Figure 12: Robustness: loudspeaker hand-held vs. fixed

Conclusion and Outlook

As summarized in Table 2, the method demonstrates high precision, robustness, and flexibility with respect to environmental conditions and sample size. As noted previously, trueness can only be regarded as an indicative measure, therefore, it is denoted with a question mark.

Table 2: Evaluation matrix for the in-situ probe method

Aspect	Sub-category	Rating
Accuracy	Trueness	Indicated high (?)
	Precision	High
Applicability	Sample Size	$0.5 \times 0.5\,m^2$
	Environment	Normal Office
Reproducibility	undertest	undertest
Robustness	Distance d_s	High

Regarding the evaluation concept, future work will focus on identifying a more reliable reference, determining relevant parameters that are independent of each other, and extending to other measurement systems. The ultimate goal is to develop a referenceable and robust evaluation framework, which will include, for example, a comprehensive comparison matrix as illustrated in Table 3 to objectively assess different methods.

Table 3: Example of evaluation metrics

Method	Accu	Appli	Repro	Robu
Reverberation Room	Score	Score	Score	Score
Impedance Tube	Score	Score	Score	Score
In-situ Probe	Score	Score	Score	Score
Other Method	Score	Score	Score	Score

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