



AIR LEAKAGE AND RATTLING NOISE DETECTION IN LOUDSPEAKER HOUSINGS

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Abstract

Faulty components or imprecise assembly in loudspeaker production can cause air leakage in speaker housings. Beyond degrading the impedance curve and frequency response, leakage under low-frequency, high-displacement excitation produces audible whistling artifacts that further impair the listening experience. Currently, locating defects during the development and quality control of high-end loudspeakers remains an imprecise process. Manufacturers still rely heavily on human experience and manual inspection to pinpoint air leaks. We propose a leakage detection system based on acoustic beamforming using a 64-channel Vogel spiral microphone array with an aperture of 1.5 m. To validate the approach, measurements were conducted on three loudspeakers in an anechoic chamber, capturing all four lateral surfaces. The resulting data are processed and visualized using an interactive inspection tool developed specifically for this application. Our results demonstrate that acoustic beamforming is well suited for leakage localization, and that the recovered spectral information supports root-cause identification. Furthermore, experiments with an advanced beamforming algorithm suggest that considerably fewer microphones and smaller apertures could achieve comparable detection performance, offering a path toward more cost- and space-efficient end-of-line testing.

1 INTRODUCTION

Unwanted noise emissions in loudspeaker housings represent a recurring challenge in acoustic product development and quality control. Mechanical imperfections such as air leakages, loose or rattling components can significantly degrade the perceived sound quality [1]. Identifying the exact origin of these noise sources is often difficult, as they may occur locally and only under specific excitation conditions.

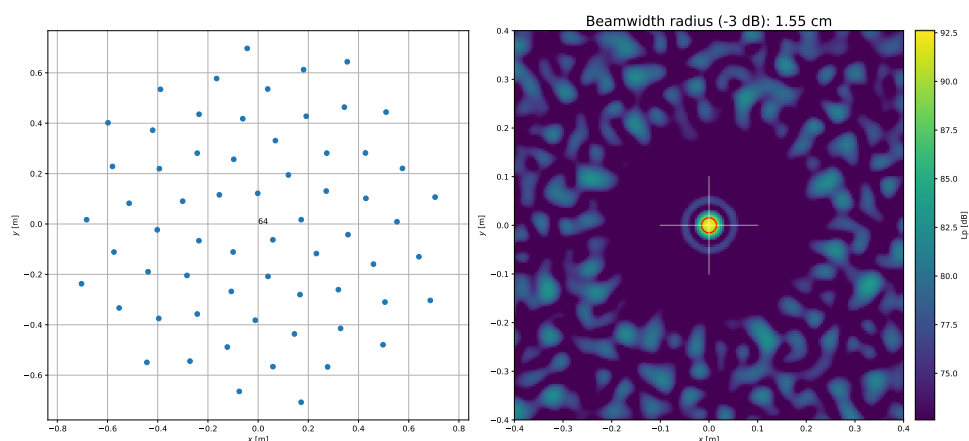


Figure 1: Array Geometry (left) and PSF for a source at distance 0.8 m at 8 kHz

Traditionally, the detection and localization of such noise sources is performed manually by trained personnel. This process typically involves listening tests combined with stepwise inspection of the loudspeaker structure. However, manual acoustic inspection is time-consuming, subjective, and highly dependent on individual hearing capabilities. Moreover, prolonged exposure to elevated sound pressure levels during testing can lead to listening fatigue and may even pose a risk to hearing health.

To overcome these challenges, automated measurement techniques are required. Microphone array systems with beamforming-based source localization have become standard practice for noise source identification across a wide range of applications, from aero-acoustic measurements on aircraft and wind turbines to fault diagnosis on rotating machinery and pass-by noise characterization of vehicles and high-speed trains [2]. Their application to loudspeaker quality control, however, has received comparatively little attention. Advanced deconvolution methods such as Clean-SC [5] have improved the achievable spatial resolution of such systems. This makes them attractive candidates for the high-resolution localization required to identify individual defects on loudspeaker enclosures. We demonstrate that defect localization on loudspeaker enclosures is feasible with a 64-channel Vogel spiral array [3], that spectral signatures at the localized region distinguish leakage from rattling defects. We also find that comparable localization performance is maintained with substantially fewer channels when Clean-SC is used.

2 METHODOLOGY

2.1 Devices under Test (DUTs)

To evaluate the proposed approach, three different passive loudspeakers were investigated (Fig. 2). Their properties are described in Table 1. The DIY Woofer unit showed four bore holes of approximately 4 mm diameter on one side, arranged in a square pattern with a side length of 8 cm (Fig. 4(a)). The ATR Hifi speaker was modified by removing the lower left screw from the tweeter unit (Fig. 4(b)). For the Eltax Century 150 speaker, all four screws on the front plate of the tweeter were loosened, resulting in a rattling of the whole plate (Fig. 4(c)).



Figure 2: DUTs: DIY Woofer (left), ATR Hifi Speaker (center), Eltax Century 150 (right)

Table 1: Devices under Test

DUT	$H \times W \times D$ [m]	Design	Defect
DIY Woofer	$0.33 \times 0.33 \times 0.33$	single way, closed-box	four bore holes, 4 mm diameter
ATR Hifi	$0.64 \times 0.35 \times 0.31$	two way, vented	removed screw from tweeter
Eltax Century 150	$0.44 \times 0.22 \times 0.20$	three way, vented	loosened tweeter front plate

2.2 Array Design

A 64-channel microphone array (GRAS 40PM miniature microphones) was arranged in a Vogel spiral geometry [3] with an aperture of 1.5 m. The Vogel spiral provides uniform spatial sampling and effective sidelobe suppression compared to regular grid arrangements. The point spread function (PSF) has a -3 dB main-lobe diameter of 3.1 cm at 8 kHz for a source 0.8 m from the array, which was deemed sufficient spatial resolution for resolving individual defect features on the enclosure surface (Fig. 1).

2.3 Measurement Procedure

The array was placed facing the front side of the loudspeaker at a distance of approximately 0.8 m (Fig. 3), with the geometric center of the loudspeaker aligned with the array center. The loudspeaker was excited with a low-frequency sinusoidal signal (40 Hz or 50 Hz, depending on the loudspeaker capabilities) to induce large diaphragm displacement, which maximizes the pressure inside the cabinet and thereby the acoustic emission of any air leaks. The speaker was manually rotated by 90° and the measurement was repeated for the three remaining sides (right, back, left). The up- and downward-facing sides were omitted. The measurements took place in the anechoic chamber of TU Berlin.

2.4 Postprocessing

Beamforming was performed using the Acoular Python library [4]. Signals were sampled at 51.2 kHz for 5 s per side. For each side of the enclosure, an evaluation grid was generated on

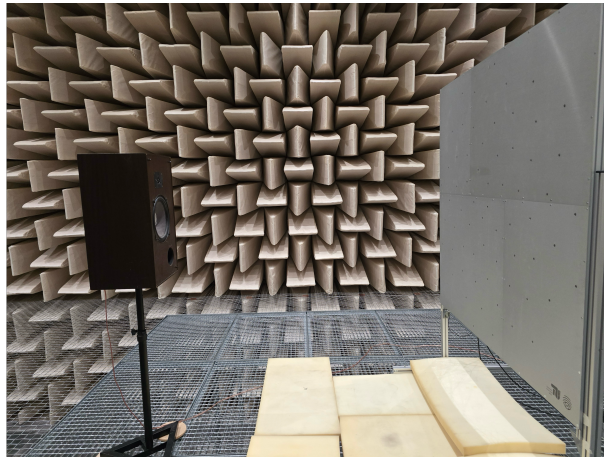


Figure 3: Measurement Setup at Anechoic Chamber, TU Berlin

the loudspeaker surface and the cross-spectral matrix was computed with an FFT length of 1024 samples and no overlap, yielding a 50 Hz bin width and 250 blocks per channel. Source maps were obtained using Clean-SC, which provided the best resolution and sidelobe suppression of the methods evaluated. Region-of-interest spectra were obtained by summing the beamformer output across grid points within a rectangular selection on the enclosure surface.

Postprocessing and visualization were carried out with *LeakLens*¹, an interactive tool developed for this study. It uses Acoular as the beamforming back end, the PyQt framework for the graphical user interface, and Matplotlib for heatmap and spectrum rendering.

3 RESULTS

3.1 Defect Localization

Figure 4 shows Clean-SC beamforming maps at 8 kHz for the three devices under test with a grid resolution of 5 mm. For the DIY enclosure, all four 4 mm bore holes appear as distinct peaks with negligible sidelobe activity. On the ATR enclosure, a localized peak appears at the position of the removed tweeter screw on the lower-left of the tweeter mount; a secondary peak coincides with the tweeter diaphragm. The Eltax map shows a ring of elevated levels around the rim of the loosened tweeter, with two pronounced peaks at the screw positions.

3.2 Spectral Signatures

Restricting the spectrum to the spatial region of the localized defect yields the signatures shown in Fig. 5. The DIY and ATR spectra are broadband and qualitatively similar: an approximately flat magnitude up to 7 kHz, followed by a gradual roll-off. The Eltax spectrum, in contrast, exhibits sharp peaks and substantially higher level variability across the analyzed band.

¹The source code is available at <https://github.com/javerhoeven/LeakLens>

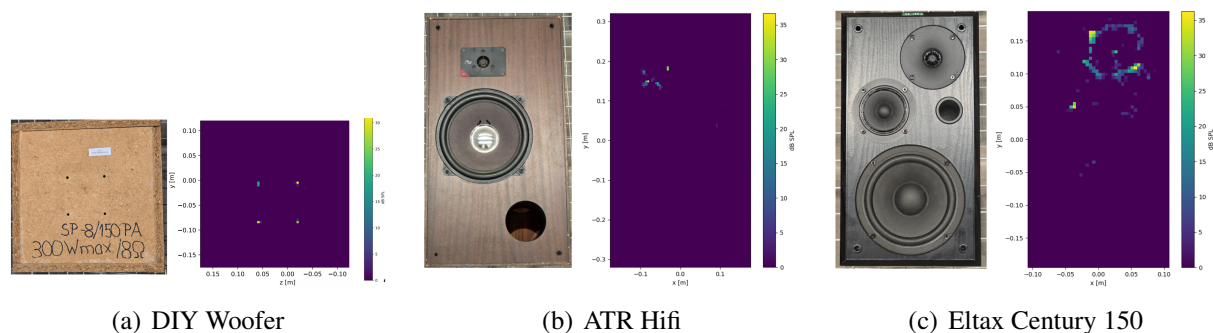


Figure 4: Defects and Heatmaps of all DUTs at 8 kHz

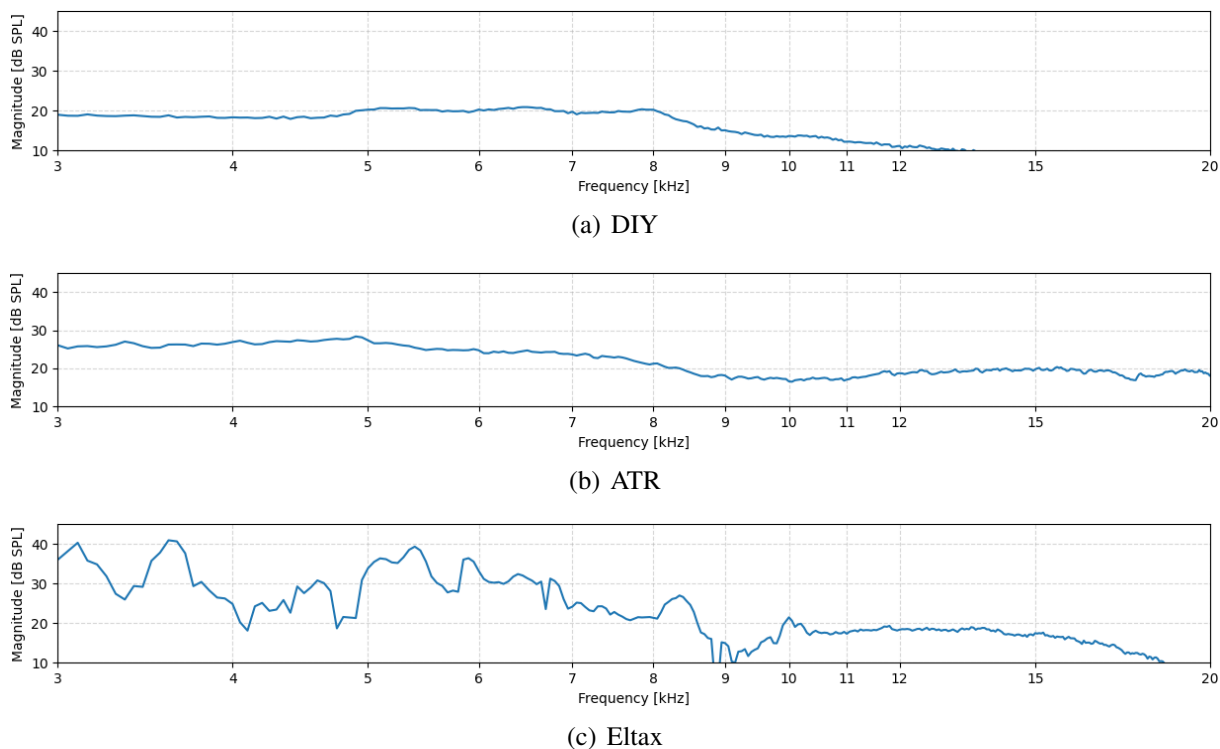


Figure 5: Region-of-interest spectra at the localized defect for the (a) DIY, (b) ATR, and (c) Eltax enclosures.

3.3 Channel and Aperture Reduction

The previous results were obtained with the full 64-channel, 1.5 m-aperture array. For practical deployment, both the channel count and the physical dimensions should be as small as the task allows. We therefore evaluate localization performance under progressive deactivation of outer microphones, which reduces both channel count and aperture. Figure 6 shows the five tested subsets, ranging from 64 channels at 1.5 m aperture to 16 channels at 0.7 m aperture.

Figure 7 reports Clean-SC maps of the DIY enclosure across the five subsets and four analysis frequencies. Three observations can be made: At 2 kHz, no configuration resolves the

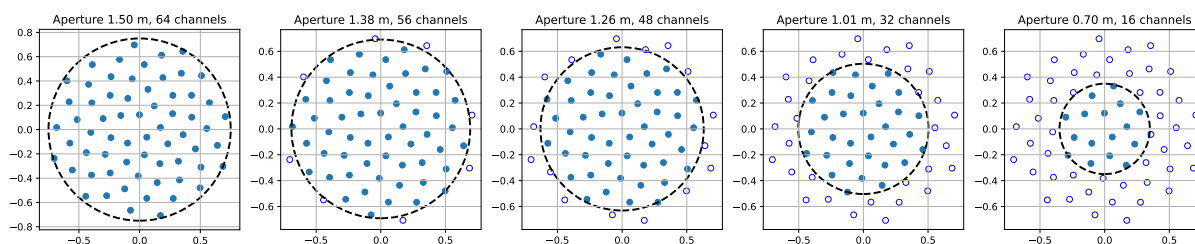


Figure 6: Microphone subset configurations used in the reduction study. Active channels are filled, deactivated channels are open.

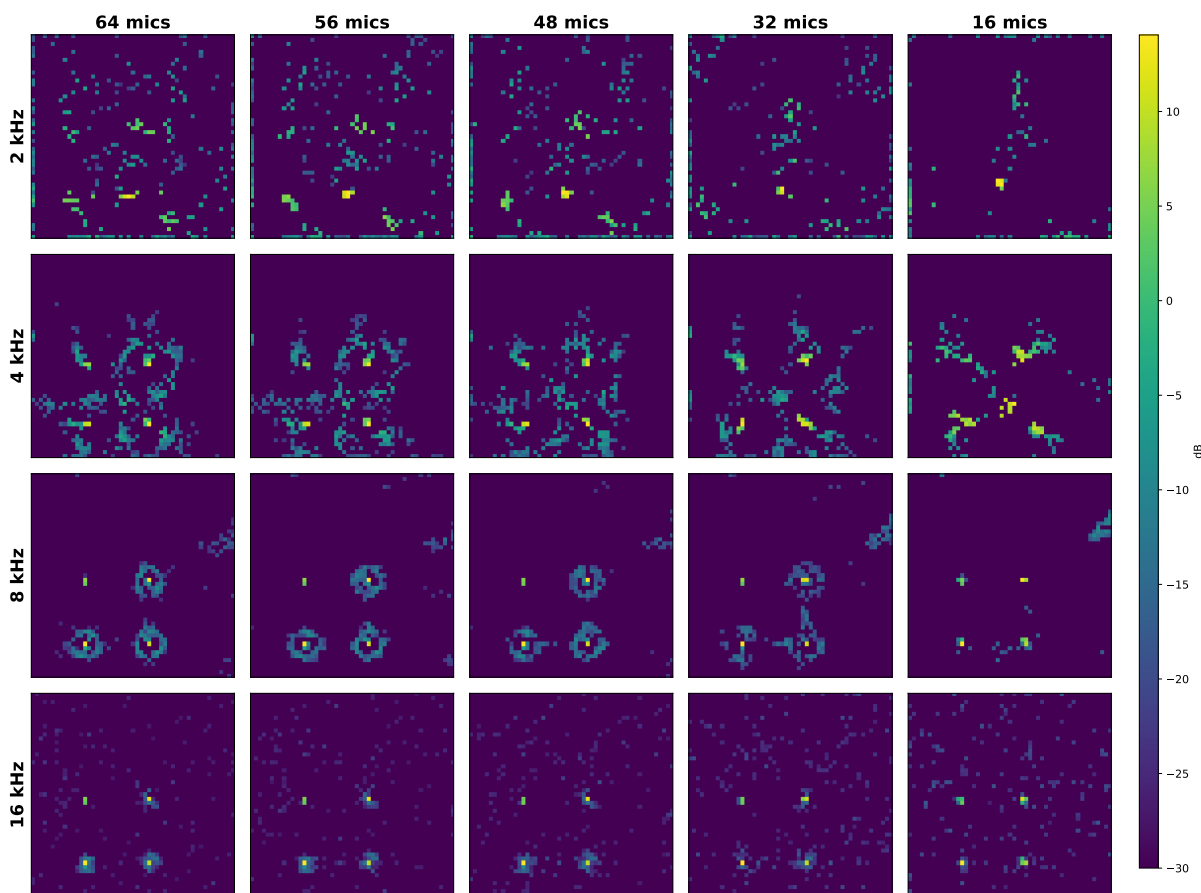


Figure 7: Clean-SC maps of the DIY enclosure for five subset configurations (columns) at four analysis frequencies (rows).

bore holes: the maps are dominated by sidelobes and incoherent structure across all channel counts, reflecting the fundamental aperture limit. At 4 kHz, the four sources begin to emerge for the larger configurations but remain corrupted by sidelobes. The 64-channel result is only marginally cleaner than the 16-channel result. At and above 8 kHz, all five configurations, including the smallest 16-channel, 0.7 m subset, recover the four bore holes with comparable clarity. The 64-channel array offers little advantage in this setting.

4 DISCUSSION

The results support three claims relevant to the use of microphone arrays for loudspeaker defect inspection.

First, Clean-SC beamforming on a Vogel spiral array localizes both leakage and rattling defects on the enclosure surface with sufficient spatial resolution. On the DIY woofer, all four bore holes are separated cleanly, demonstrating that even closely spaced sound sources can be resolved as individual peaks. On the ATR enclosure, the removed tweeter screw appears as a single localized peak at the expected position on the lower-left of the tweeter mount. The secondary peak coinciding with the tweeter diaphragm itself is attributed to broadband amplifier noise: the low-frequency excitation is routed by the passive crossover to the woofer only, so the tweeter is not driven by the test signal, but it still radiates the residual noise floor of the amplifier. On the Eltax enclosure a ring of elevated levels surrounds the loosened tweeter front plate, with two pronounced peaks at screw positions. This is consistent with the front plate vibrating against the cabinet. The fact that only two of the four loosened screws appear as distinct peaks is plausibly explained by their being more loosely seated than the remaining two, so that both air leakage and contact rattle are locally stronger at those positions.

Second, the spectrum recovered at the localized region distinguishes leakage from rattle and thereby supports root-cause discrimination from a single measurement. The DIY and ATR spectra are broadband and roughly flat up to 7 kHz, which is the shape one expects from turbulent flow through a small aperture and supports interpreting both defects as leakage-dominated. The Eltax spectrum, in contrast, exhibits sharp peaks and substantially higher level variability across the analyzed band, consistent with intermittent mechanical contact between the tweeter plate and the cabinet rather than with continuous airflow. The contrast between these spectral signatures is sufficiently clear that the failure mode could in principle be classified from the spectrum alone, without prior knowledge of the defect type.

Third, this performance is largely maintained when the channel count is reduced from 64 to 16 and the aperture from 1.5 m to approximately 0.7 m, provided a deconvolution beamformer is used. For defect localization at frequencies above 8 kHz, a 16-channel array of approximately 0.7 m aperture is therefore sufficient — a quarter of the channels and roughly half the aperture of the reference configuration. The corresponding reduction in hardware cost, physical dimensions, and integration complexity suggests that the entry barrier for array-based inspection in an end-of-line setting can be quite low.

It is worth noting that the excitation and observation bands differ: low-frequency sinusoidal excitation drives the defect, while localization and spectral discrimination rely on high-frequency emission. An inspection system of this kind should therefore be designed around the high-frequency content of the defect signature, not the excitation frequency itself.

4.1 Limitations

All measurements were carried out in an anechoic chamber. Performance in more reverberant conditions and under production and ambient noise is untested and will likely pose problems for the beamforming algorithms. The reduction study used a single array realization with deactivated channels rather than physically distinct smaller arrays or other geometries. Further improvements could be achieved with other combinations of aperture, channel count and array geometry.

4.2 Toward Industrial Deployment

The results suggest a plausible path from the present proof-of-concept to a deployable system. On the hardware side, the channel- and aperture-reduction findings indicate that a compact array based on low-cost MEMS microphones is a realistic target, and the reduced dimensions would be compatible with an end-of-line testing scenario. On the procedural side, the manual rotation of the device under test between four sides should be replaced by a controlled turntable to enable consistent four-sided inspection without operator intervention, reducing errors and allowing for a fully automated process. Regarding the postprocessing, the most pressing open question concerns robustness in non-anechoic environments.

5 SUMMARY

We present a beamforming-based approach to detecting and localizing air leakage and rattling defects in loudspeaker enclosures, using a 64-channel Vogel spiral array with 1.5 m aperture in combination with Clean-SC. Measurements on three loudspeakers in an anechoic chamber show that the approach resolves defects on the order of a few centimetres and that the spectrum at the localized region distinguishes leakage from rattling. A reduction study further indicates that, above 8 kHz, comparable localization performance is achievable with as few as 16 channels and an aperture of 0.7 m. This suggests that compact and cost-efficient arrays are a realistic target for end-of-line inspection. Robustness in non-anechoic environments and integration with automated test fixtures remain the primary directions for future work.

6 REFERENCES

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