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Detecting Speaker Leaks with Beamforming and Acoustic Holography

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ABSTRACT

The objective of this study was to investigate the possibility of detecting and localizing speaker leaks using acoustic imaging. Scanning single point detecting methods are cumbersome and time consuming. The acoustic equivalent to an optical camera would be more practical. Far field beamforming and near field acoustic holography were compared. Various leak sizes and excitation signals were tested. R&D and end of line quality testing scenarios were considered. The fundamentals of beamforming and acoustic holography are presented.

1 Introduction

The most widely used method for detecting speaker leaks involves listening at the end of a hose while systematically scanning the other end over the surface. This, along with other single-point scanning techniques utilizing microphones, intensity probes, and particle velocity sensors, can be both cumbersome and time-intensive. Acoustic imaging of broader areas offers a more practical solution. Although the underlying mathematics for beamforming and holography are well established, historically the high number of required microphones rendered these approaches cost prohibitive. However, the emergence of high-quality, affordable MEMS microphones and readily available microphone array systems has significantly improved the practicality and accessibility of these techniques today.

2 Objectives

The primary aim was to gather basic data as a foundation for the potential development of an engineering tool and, possibly, an end-of-line quality control system for detecting speaker leaks.

This foundational information can be organized into the following questions:

- Which physical phenomenon is more readily detectable: pneumatic or acoustical?
- Which algorithm—holography or beamforming—is most effective?
- What excitation signal is optimal?
- What unforeseen challenges may arise?

3 Review of Beamforming and Holography

Beamforming and acoustic holography are both established and well-understood methodologies; therefore, this paper will not provide an in-depth explanation of these techniques. Readers seeking a more comprehensive treatment are referred to the references cited at the end of this paper. However, a brief overview is warranted. Beamforming is a far-field measurement approach that utilizes the relative time delay or phase differences between microphones to determine the direction of sound propagation. Acoustic holography, particularly planar near-field acoustic holography (NAH), involves measuring sound pressure across a plane in the near field and enables calculation of the acoustic field at various distances from the source. Holography is particularly effective for low to mid frequencies, as higher frequency analysis necessitates closer microphone spacing and a greater number of microphones. In contrast, beamforming is more suited to mid to high frequencies because analyzing low frequencies demands larger array diameters.

4 Test Setup

All testing took place in CRY SOUND's anechoic chamber in Hangzhou, China, using the CRY3611 reference speaker. As shown in Figure 1, a 1.5 mm hole (circle) was made by removing a screw, and a larger 36mm $\times$ 40mm opening (rectangle) was created by taking off the BNC input faceplate; both were on the speaker's side (triangle).



Figure 1: Speaker, Left-Full Image, Right-Closeup

The CRY SOUND CRY8504 SonoCam Pi microphone array (Figure 2) was used. This self-contained system displays holography and beamforming results on its screen. The array measures 60 cm in diameter, with frequency ranges of 400 Hz–20 kHz for beamforming and 40 Hz–20 kHz for holography. It was placed 15 cm from the speaker during all measurements.



Figure 2: SonoCam Pi, Left-front, Right-Rear

5 Detectable Mechanisms

Two mechanisms have been proposed for acoustic sensing. One is a pneumatic mechanism, where significant pressure changes within a cabinet force air through holes. This airflow produces turbulence that generates broadband sound, optimally detected in the several kHz range. However, if the hole is large, the velocity of the moving air may be insufficient to create turbulent flow; a 36mm $\times$ 40mm hole was included in testing to examine this scenario.

This approach is generally not applicable to ported speakers. In addition, the excitation signal should be low frequency to ensure the transducer can produce measurable pneumatic pressure variations.

The second mechanism is purely acoustical. Here, sound generated by the transducers propagates through holes. Detecting this process typically requires high-frequency excitation, as shorter wavelengths can pass through the openings. This method is suitable for both large and small holes and is applicable to both ported and non-port speaker designs.

6 Pneumatic Mechanism

A 200 Hz tone was played through the speaker to generate pneumatic pressure changes within the cabinet. Figure 3 presents beamforming and holography results for the smaller 1.5 mm leak. The far-right column depicts a spectrum rotated 90 degrees counterclockwise, with frequency on the vertical axis and decibel level on the horizontal axis. The SonoCam Pi can display the complete spectrum measured by the microphones prior to further computations, after which beamforming or holography is performed over a selected frequency range. The rectangle at the top of the spectrum indicates the chosen frequency band of 16–20 kHz. Sound sources detected within this band are visualized as a color gradient object overlaid on the image to the left of the spectrum.

The 200 Hz excitation component and its harmonic appear in the spectrum, while no significant components are found

above 2 kHz. Turbulence from air passing through the hole is expected to produce higher frequency sounds. The image does not show beamforming or holography sources in the 16–20 kHz band.

Based on these findings, the pneumatic mechanism does not appear effective for leak detection, and further investigation into this method was discontinued. Additionally, tests on the larger 36 mm × 40 mm hole were deemed unnecessary, as the intent was to evaluate the impact of hole size on pneumatic mechanism sensing.

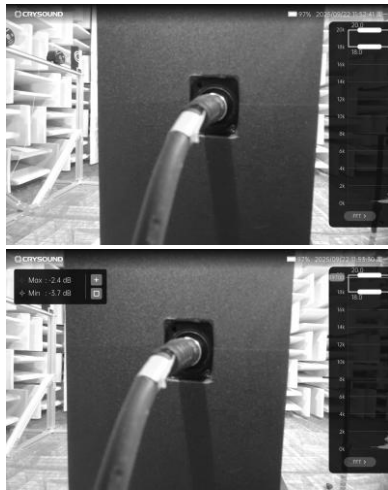


Figure 3: Top - Beamforming, Bottom - Holography

7 Holography versus Beamforming

Holography is generally effective for visualizing complex sound fields, whereas beamforming is more suitable for simple fields with few distinct sources. It can be assumed that a leak or leaks in a sealed speaker cabinet would produce a simple sound field, making beamforming an appropriate method. Figure 4 provides data supporting this assumption. In this case, the excitation was broadband noise, and the leak was a smaller 1.5 mm hole. The frequency band used for computation was 4 – 6 kHz. The beamforming image displays a sharp, defined cloud, while the holography image appears more blurred. Additionally, the holography images are influenced by sound from the front speaker, which is located at the extreme left edge of the image.

8 Excitation Signal

Various frequencies of sine tones were tested as well as white noise. Regardless of the excitation signal, the SonoCam Pi can focus on a selectable frequency span, so different frequency ranges were examined. Figure 5 below presents a comparison of results for a 5kHz tone and broadband noise analyzed between 4 kHz and 6 kHz.

The outcomes align with expectations. Beamforming encounters challenges when using pure tones; different arrival directions may produce nearly identical phase differences between microphones, leading to ambiguity regarding the direction of arrival. The bottom image, which utilized a tone, shows an additional phantom source.

Beamforming performs more effectively with broadband signals, as the variety of frequency content assists in clarifying direction, reduces grating lobes, and enhances the constructive and destructive interference that the algorithm uses.

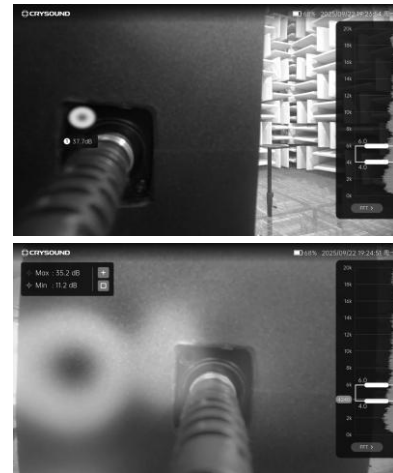


Figure 4: Top - Beamforming, Bottom - Holography

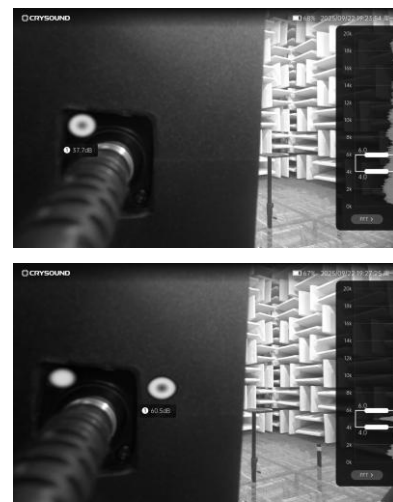


Figure 5: Top-Broadband Noise, Bottom-5kHz Tone

9 Conclusions

- Sensing the acoustical leak mechanism offers greater ease of identification compared to the pneumatic mechanism.
- Beamforming provides superior performance over holography for detecting speaker leaks.
- Utilizing a broadband excitation signal yields better results than employing a single frequency tone.
- The existence of extraneous noise sources, aside from leaks, presents significant challenges.

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10 Future Work

Although progress was made, further work is needed to develop a practical system.

- Testing should include real leaks, not just artificial ones—figure 6 shows a crack on the speaker cone as an example.
- Background noise effects need assessment.
- Consider using a microphone array like the CRY SOUND 2623M for end-of-line testing; it lacks a display but integrates easily with complex control systems.
- Test beamforming algorithms that exclude sources outside the targeted area.
- Evaluate multitone excitation signals.



Figure 6: Beamforming on a cracked cone.

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