Diffuse Sound Ambience Using a Circular Diffusing Speaker

AME 292

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1 Introduction

Traditional stereo systems often fail to recreate a fully immersive sound environment. Multi-channel systems attempt to compensate but can introduce localization errors. A recent approach suggests that supplementing a stereo system with horizontally isotropic, diffusing speakers can significantly enhance immersion without increasing complexity [1]. To test this, we designed, built, and characterized a circular diffusing speaker with a conical diffuser to enhance immersive sound reproduction. This involved optimizing the placement of the diffuser and evaluating its effectiveness by measuring its frequency response and sound radiation directionality.

To conduct these measurements, we used the CLIO Pocket system, an acoustic measurement tool capable of capturing "anechoic" frequency response data by isolating the direct sound component from reflections. By comparing the frequency response of the loudspeaker with and without the conical diffuser, we could observe its directionality characteristics.

2 Speaker and Diffuser Design

Following the general design principles outlined in "The Science of Hi-Fi Audio" [1], we began by surveying existing products to inform our design direction. Our primary inspiration for the diffuser shape came from Duevel's omnidirectional loudspeakers [2], which feature a conical diffuser made from specialty wood. A behind-the-scenes video showing the manufacturing process inspired us to pursue a similar geometry, redesigned for simplicity and accessibility.

Fig. 1. *Duevel Venus omnidirectional loudspeaker, used as inspiration for diffuser design.*

Initial design sketches explored various construction materials, such as Teflon sheets, pre-formed cones like bird feeders, party hats, and funnels. However, 3D printing a custom-designed conical diffuser was ultimately selected as the most precise and adaptable solution. This method allowed us to tailor the dimensions to fit the speaker driver closely and optimize the diffuser's placement relative to the diaphragm.

The final diffuser was designed to match the width and approximate radiation angle of the 3FR-4 full-range 3" speaker driver, which was placed inside a 9" x 9" x 9" wooden enclosure. Threaded rods were mounted at each corner of the enclosure, enabling the diffuser to be held securely above the speaker while allowing adjustments to the diffuser's height. The diffuser included four ¼-inch mounting holes so that the threaded rod could be easily inserted.

Two diffuser variations were produced: one with a fully conical shape, and another with a central indent to allow placement closer to the speaker diaphragm if needed (Figure 2, 3).

Fig 2. *3D-printed diffusers (conical and indented version) alongside the speaker driver.*

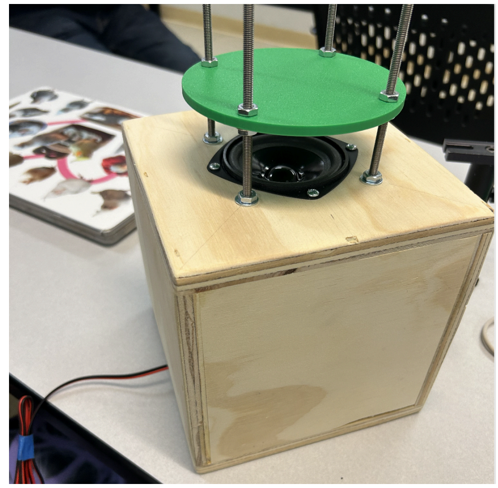


Fig 3. *Completed speaker and diffuser assembly with adjustable mounting structure.*

3 Experimental Setup

3.1 Test Environment

All measurements were performed using the CLIO Pocket system, a calibrated audio measurement system capable of providing "anechoic" frequency response measurements by isolating the direct sound arrival from room reflections [3]. The CLIO software generated a logarithmic chirp test signal, which was played through an amplifier into the speaker, while a calibrated microphone captured the radiated sound at a fixed distance.

Measurements were conducted inside a WhisperRoom isolation booth (Figure 4) located in the Acoustics Laboratory (CSB 512) to minimize reflections and external noise. The microphone was positioned approximately 20 cm from the speaker box, aligned at the same height as the driver for consistent measurement conditions.

3.2 Testing Conditions

To characterize the speaker's directional behavior, 32 horizontal-plane measurements were taken at 11.25° increments, covering a full 360° around the speaker. This procedure was repeated under four conditions:

1. Speaker without a diffuser,
2. Speaker with the diffuser placed 2.5 cm above the driver,
3. Speaker with the diffuser placed 3.5 cm above the driver,
4. Speaker with the diffuser placed 5.0 cm above the driver.

Additionally, vertical-plane measurements were conducted to capture the speaker's polar radiation characteristics. Eight measurements were taken from 0° (top) to 90° (side), again at 11.25° increments under the same four conditions as described above.

Fig 4. *Measurement setup inside the WhisperRoom.*

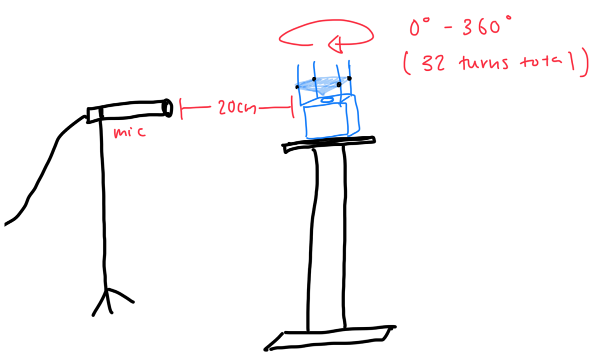
4 Results

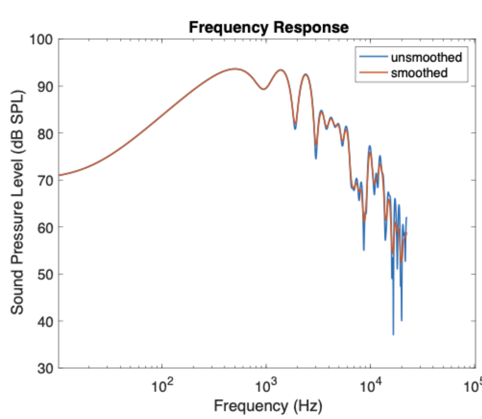
The measurement data were saved as .txt files containing frequency (Hz), magnitude (dBV), and phase (degrees) information. Using the provided MATLAB scripts from Lab 2, we processed these files to generate plots of the frequency response and polar radiation patterns. We modified the MATLAB code to convert dBV values to approximate dB SPL. This was done by applying a calculated offset based on the listed microphone sensitivity from the CLIO Pocket system (16.7 mV/Pa).

Additionally, the vertical-plane measurement data for the no-diffuser configuration were lost and are therefore not included in the vertical polar plots presented below.

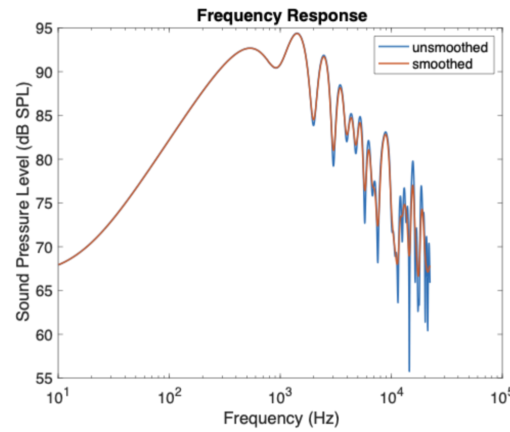
4.1 Frequency Response

For the **horizontal** plane, the setup is shown below, along with the frequency response measurements:

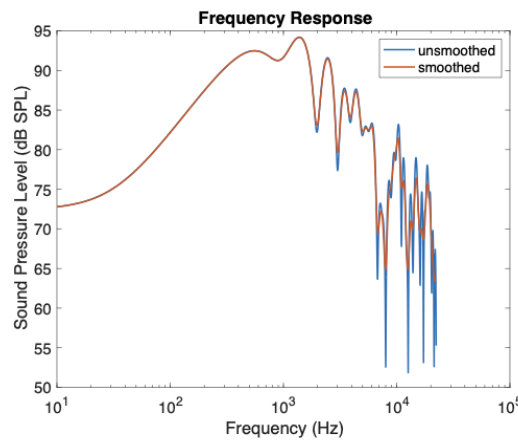




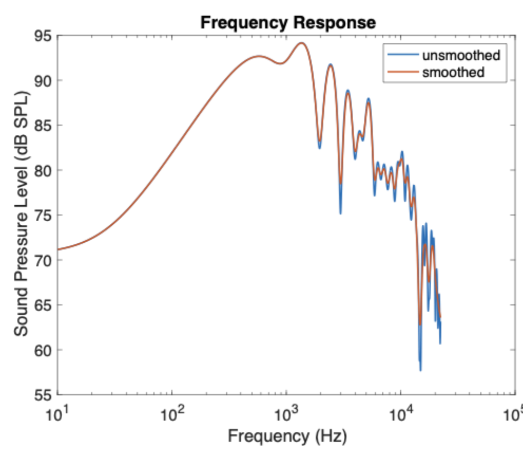
No Diffuser



Diffuser @ 2.5cm



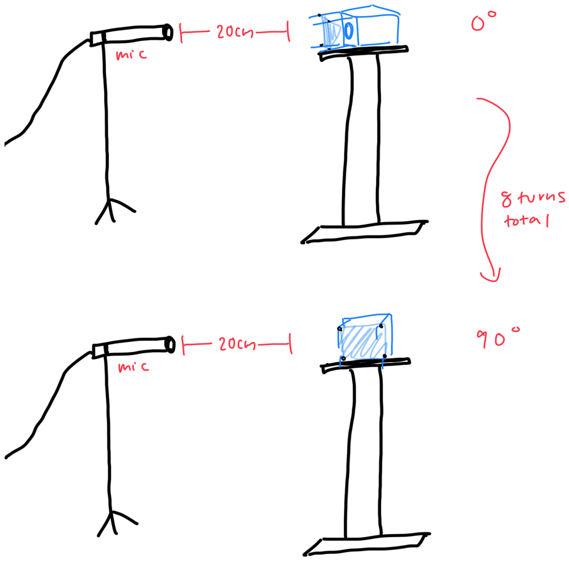
Diffuser @ 3.5cm

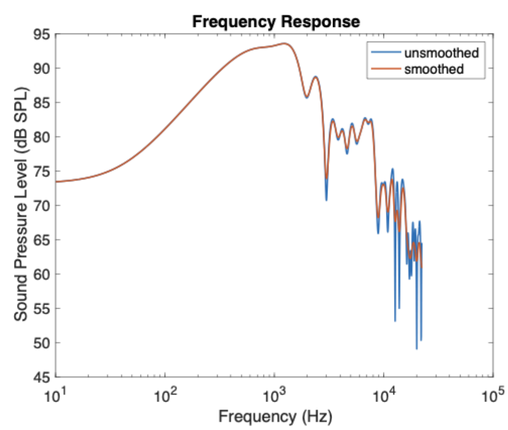


Diffuser @ 5.0cm

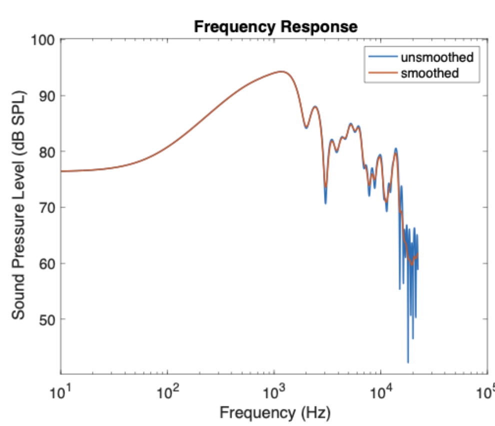
Fig 5. *Frequency response plots for the speaker under various diffuser configurations, showing the effect of diffuser placement on spectral characteristics (horizontal).*

For the **vertical** plane, the setup is shown below, along with the frequency response measurements:

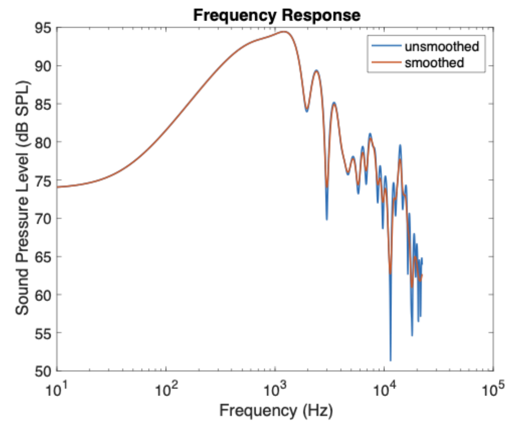




Diffuser @ 2.5cm



Diffuser @ 3.5cm

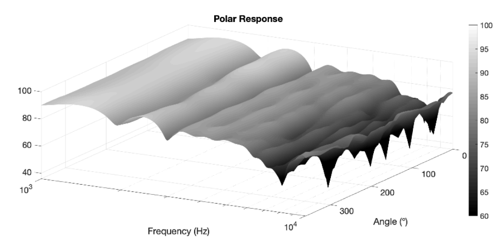


Diffuser @ 5.0cm

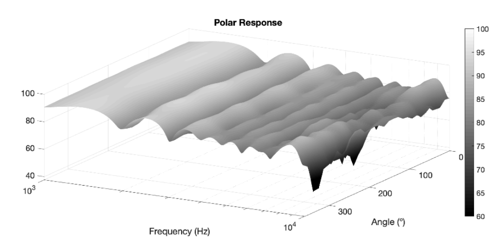
Fig 6. *Frequency response plots (vertical).*

4.2 Polar Response

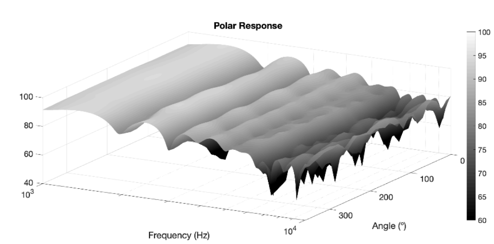
With the same setup as above, we concurrently took measurements of the polar response as well. The horizontal-plane results are plotted only from 1 kHz to 10 kHz to provide a clearer view of the most relevant range.



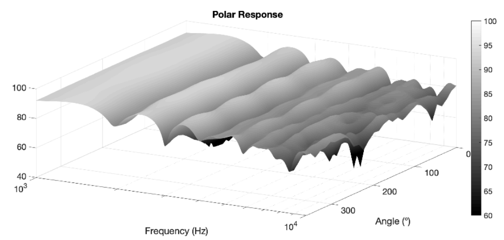
No Diffuser



Diffuser @ 2.5cm

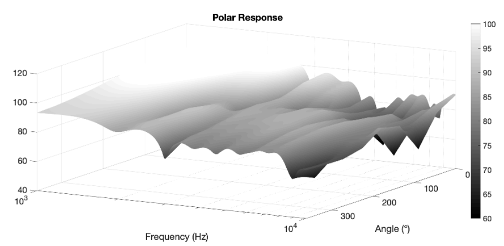


Diffuser @ 3.5cm

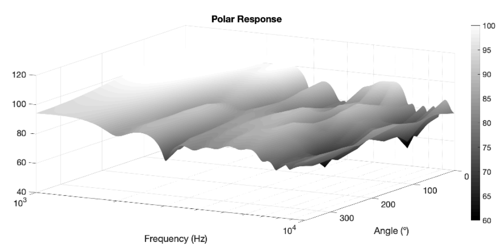


Diffuser @ 5.0cm

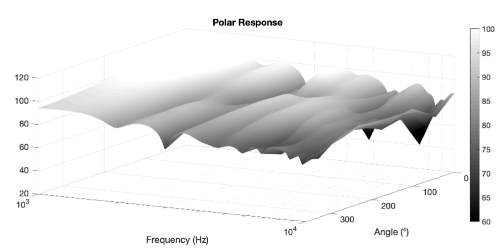
Fig 7. *Polar response plots (horizontal)*



Diffuser @ 2.5cm



Diffuser @ 3.5cm



Diffuser @ 5.0cm

Fig 8. *Polar response plots (vertical).*

5 Discussion

5.1 Interpretation of Results

The frequency and polar response measurements exhibited similar characteristics across all four conditions (speaker without diffuser and diffuser placements at 2.5cm, 3.5cm, and 5.0cm), indicating that the current diffuser design and experimental setup did not produce a pronounced diffusing effect. The most notable variations occurred within the 1–10 kHz band, which is ideal because it's the most significant range for most loudspeaker applications anyways (Figure 5). Within this range, the no-diffuser configuration displayed a relatively smooth amplitude response at discrete angles, whereas the diffuser configurations showed sharper amplitude fluctuations. These pronounced peaks and dips suggest increased scattering and diffusion, consistent with the intended effect of the conical diffuser.

The polar radiation patterns further support these observations. The 5.0 cm offset shows the most uniform horizontal and vertical dispersion, suggesting a broader and smoother diffusion field. However, the overall differences between conditions were marginal, making it difficult to confirm the diffuser's effectiveness.

5.2 Limitations

Several factors may have obscured the expected diffusing effects:

- We lost the vertical-plane measurements for the no-diffuser case, preventing a full baseline comparison.
- The test signal was too loud: although we set volume to around 80 dB SPL using white noise, when we changed to the chirp signal for the actual measurements, it peaked near 100 dB SPL, which may have introduced nonlinearities.
- We initially forgot to remove room reflections from the impulse responses and manually truncating the decay tails improved the plots slightly but did not achieve the expected results.
- The size of the diffuser is very small, with an apex angle of only 1.64°, which may be too shallow; by comparison, commercial

designs like Duevel use cone angles exceeding 45°.

5.3 Future Work

Future studies should address these limitations and explore design variations to enhance diffusion:

- Test diffusers with steeper cone angles (e.g., >45°) to improve scattering.
- Try different shapes (such as spheres) and materials to see their effects.
- Use other materials with different masses to assess their impact on acoustic performance.

6 Conclusion

This project described the design, build, and acoustic testing of a speaker fitted with a 3D-printed conical diffuser. Measurements of frequency response and polar radiation showed only small differences between the no-diffuser case and the diffuser placements, with the clearest changes occurring in the 1–10 kHz range and the 5.0 cm position producing the most even dispersion. Experimental issues—data loss, signal peaks above target SPL, and the diffuser's shallow cone angle—prevented us from clearly proving the diffuser's benefit. Future work will focus on improving diffuser shape, tightening measurement methods, and testing other materials and forms. Despite these limits, using small diffusers to enhance sound dispersion remains a worthwhile direction for further study.

7 Acknowledgements

We would like to thank Professor Bocko for his assistance with 3D printing the diffusers, and Paul Osborne for his help in constructing the speaker enclosure.

6 References

[1] J. G. Beerends and R. Van Everdingen, "The Science of Hi-Fi Audio," American Scientist, vol. 113, no. 1, Jan.–Feb. 2025. [Online]. https://www.americanscientist.org/article/the-science-of-hi-fi-audio

[2] Duevel, "Venus," Hifi Rundstrahler. [Online]. https://www.duevel.com/Venus.

[3] Audiomatica, "ARTool USB," [Online]. https://www.audiomatica.com/wp/?page_id=3557.