Optimal Bass Reflex Loudspeaker Port Design

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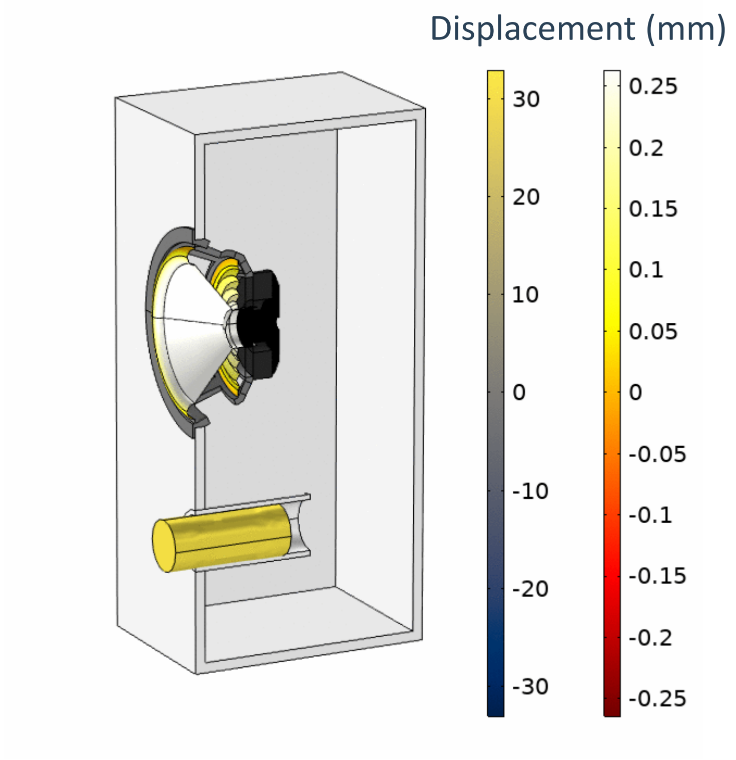
2019/10/03

Loudspeaker Ports



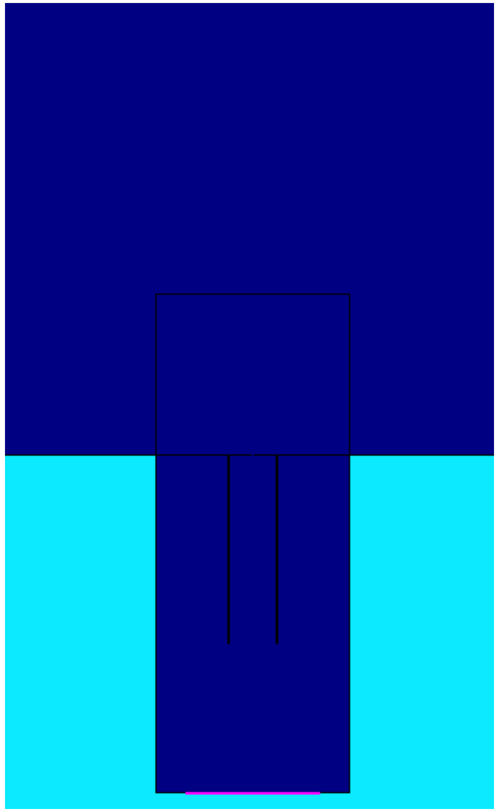
- Mass of air in port and compliance of air in enclosure form a resonator
- Bass reflex (vented) can be abstracted to a 2-Mass-Spring-Damper System
- Excursion of the diaphragm is reduced compared to a sealed box with same SPL
- Nonlinear distortions are reduced

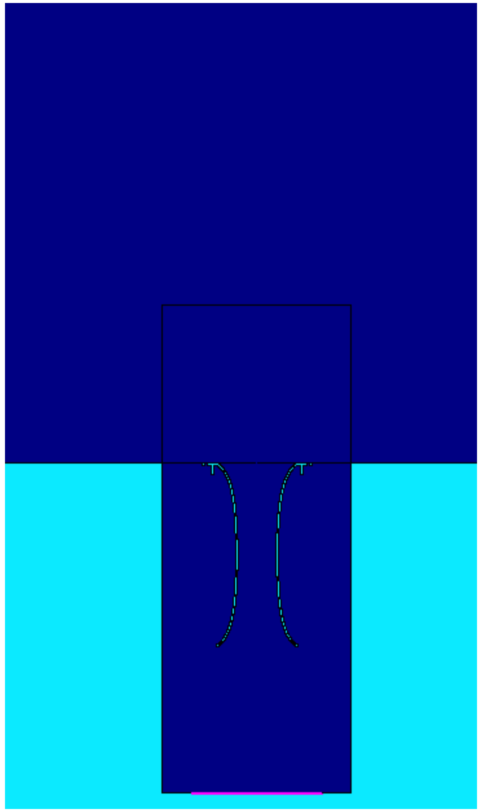
Turbulence, Vortex Shedding, and Port Noise

- At high output, air in port tube can become turbulent
- Flow separation and vortex shedding occurs
- Experience tells us that continuously flared port tubes sound better

- *How much flare is optimal?*

- Fully turbulent models are numerically expensive and impractical as design tools



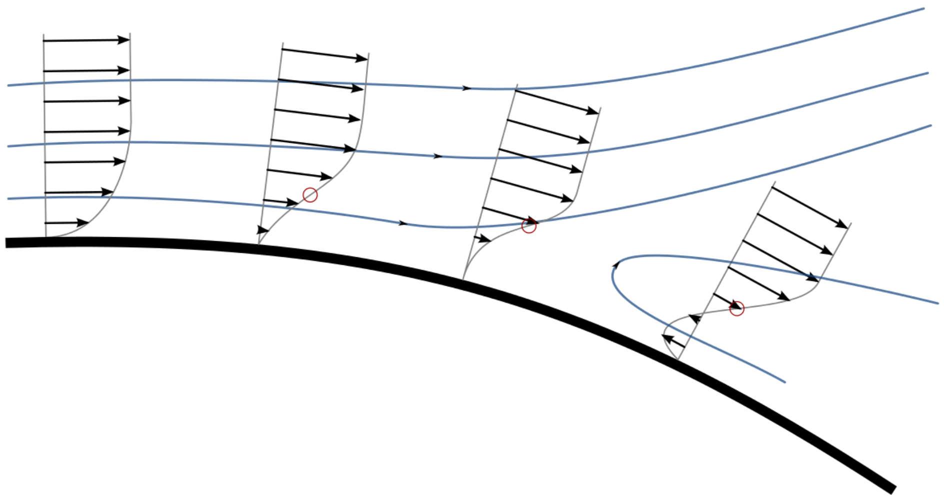


Flow Separation and Vortex Shedding

Stream-wise momentum equation:

$$u\frac{\partial u}{\partial s} = -\frac{1}{p}\frac{dp}{ds} + \nu\frac{\partial^2 u}{\partial y^2}$$

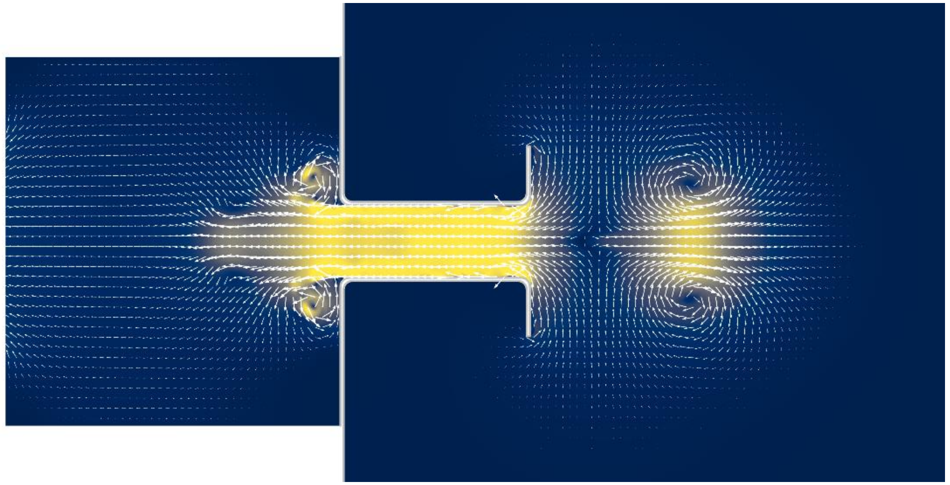
- Adverse pressure gradient when $\frac{dp}{ds} > 0$
- u can become zero or negative



Effect of flow separation:

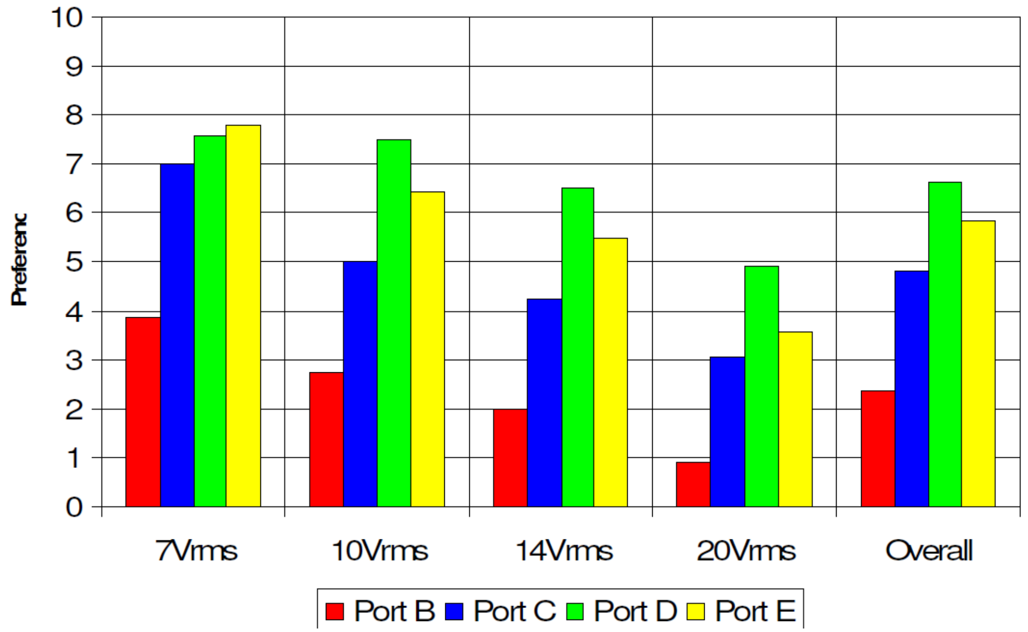
- Flow separation leads to vortex shedding
- Impulse-like excitation of air in port tube
- Excitation of *port eigenfrequencies*

$$f_p^1 = \frac{c}{\lambda} \approx \frac{c}{2L}$$

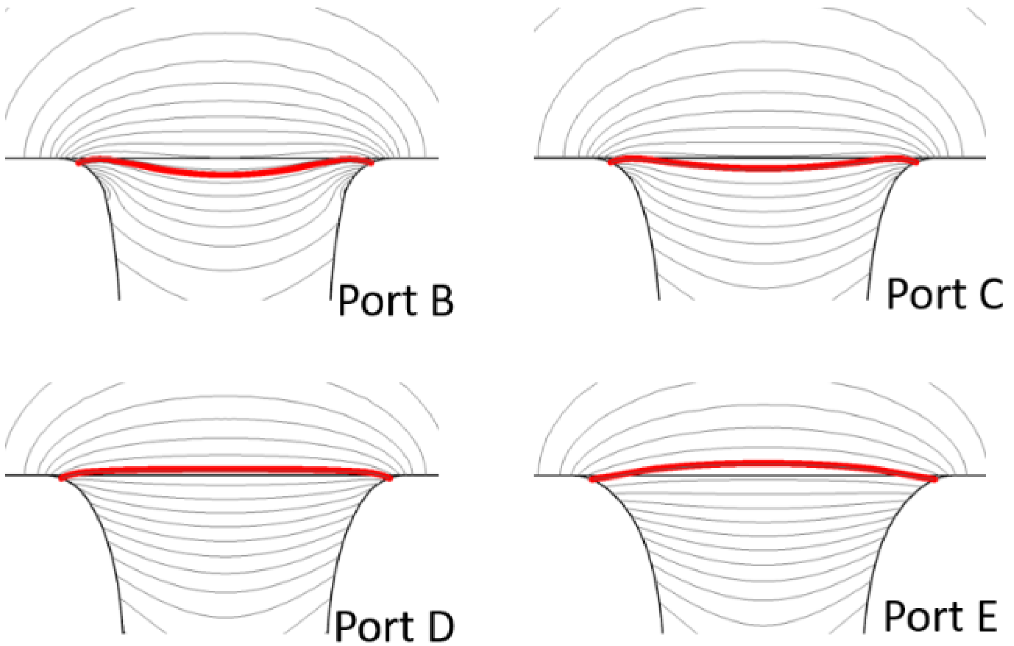


Old Research Revisited

- *Which port profile has the lowest propensity to generate turbulence, flow separation, and vortex shedding?*
- Simulated 4 port geometries from Rapoport and Devantier [1]



Velocity Contours



[1] Rapoport, Z. and Devantier, A., "Analysis and Modeling of the Bi-Directional Fluid Flow in Loudspeaker Ports," in Audio Engineering Society Convention 117, San Francisco, (2004)

Hypothesis

“The best sounding port has the lowest propensity for flow separation.

Flow separation is minimal when the particle velocity contours at port exit have minimal curvature.”

Plan for Verification of Hypothesis

Simulation

- Design ‘optimal’ ports of different L/D_0 aspect ratios
- Construct slightly under- and over-flared ports
- Maintain tuning frequency for all ports

Measurement

- Near-field hemi-anechoic measurements
- Measure noise induced by ports
- Correlation with hypothesis and simulation?

Blind Listening Tests

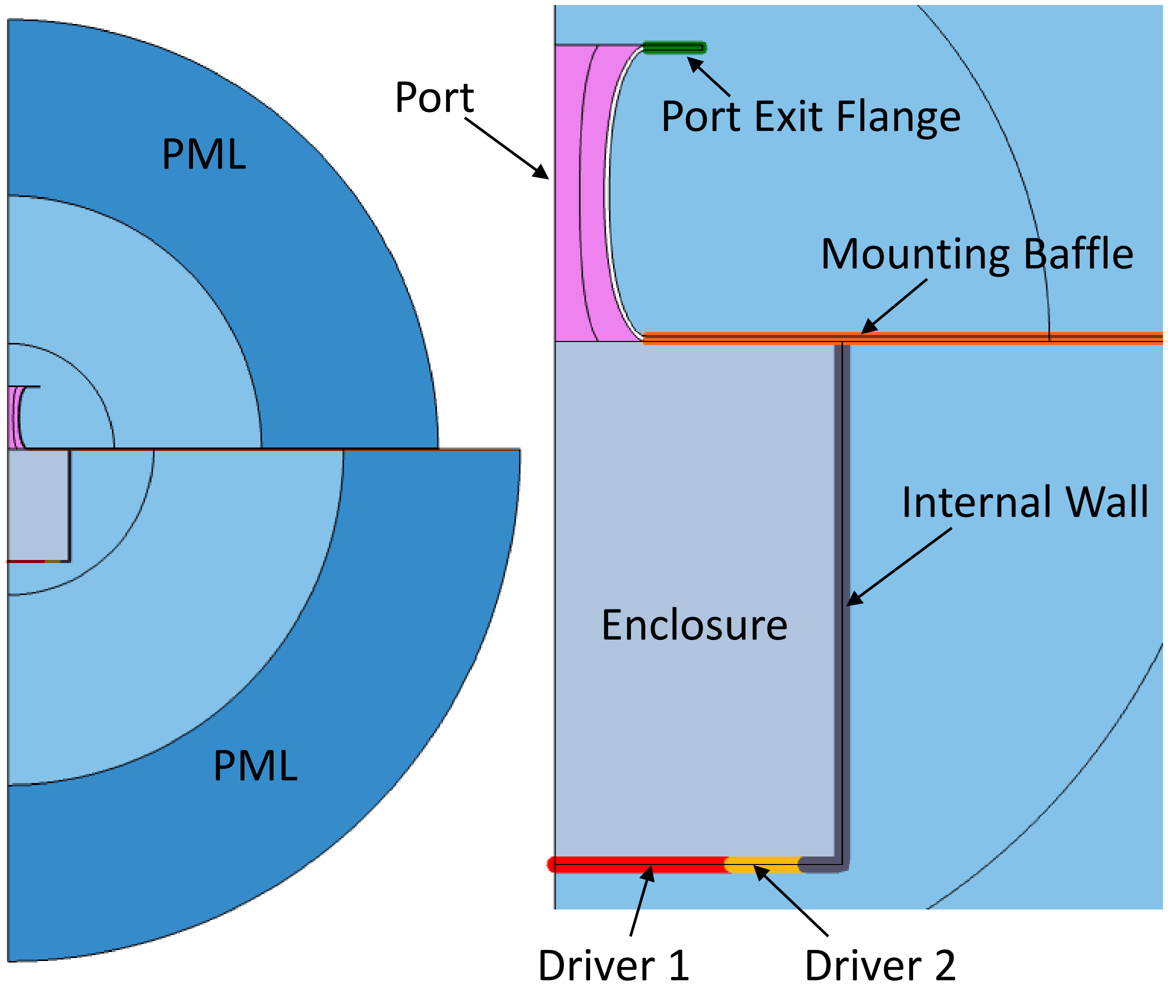
- Near-field recordings
- Double-blind playback through high-end headphones

1. Rating of sound quality
2. How much louder can optimal ports play?

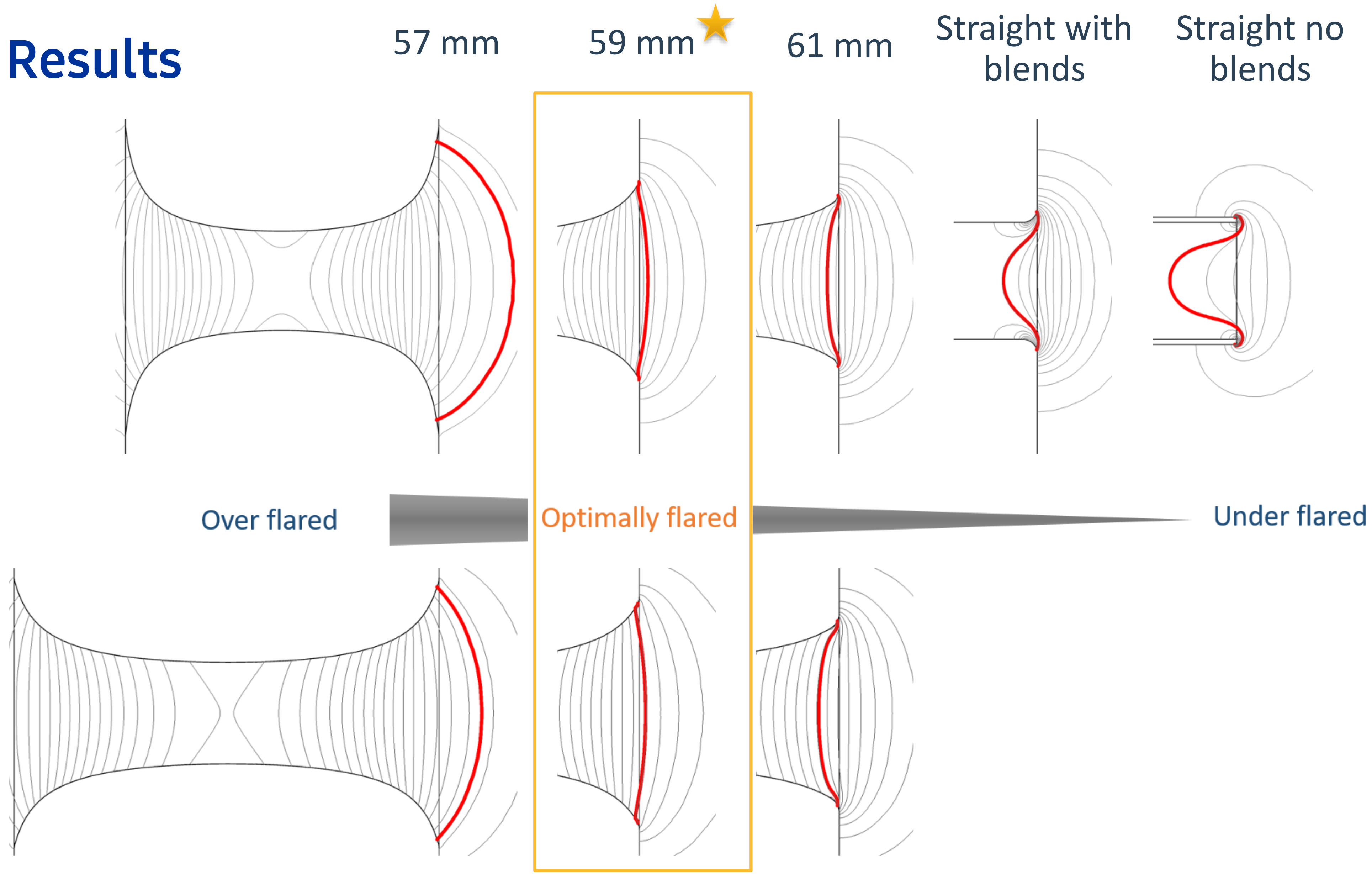
- Correlation with hypothesis, simulation, and measurements?

Simulation Setup

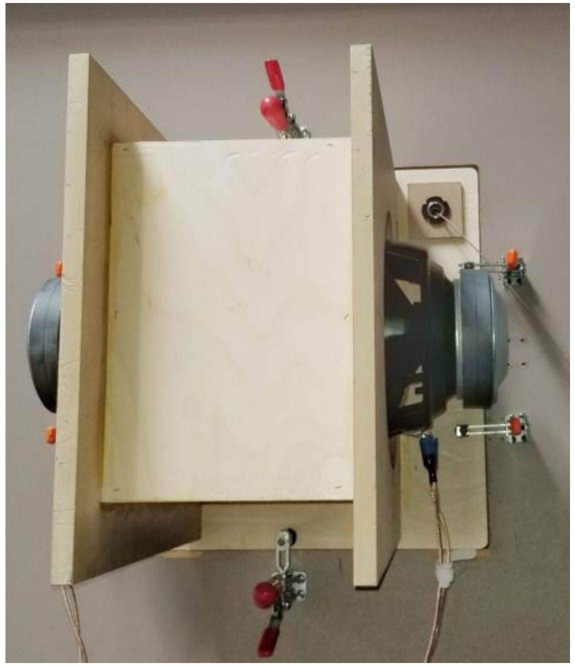
- Axisymmetric
- Acoustic-structure interaction
- Electrical circuit model for loudspeaker driver
- 3 optimization routines
  1. Find box volume for 40 Hz tuning
  2. Find optimal flare rate
  3. Find slightly over- and under-flared profiles with same 40 Hz tuning



Simulation Results

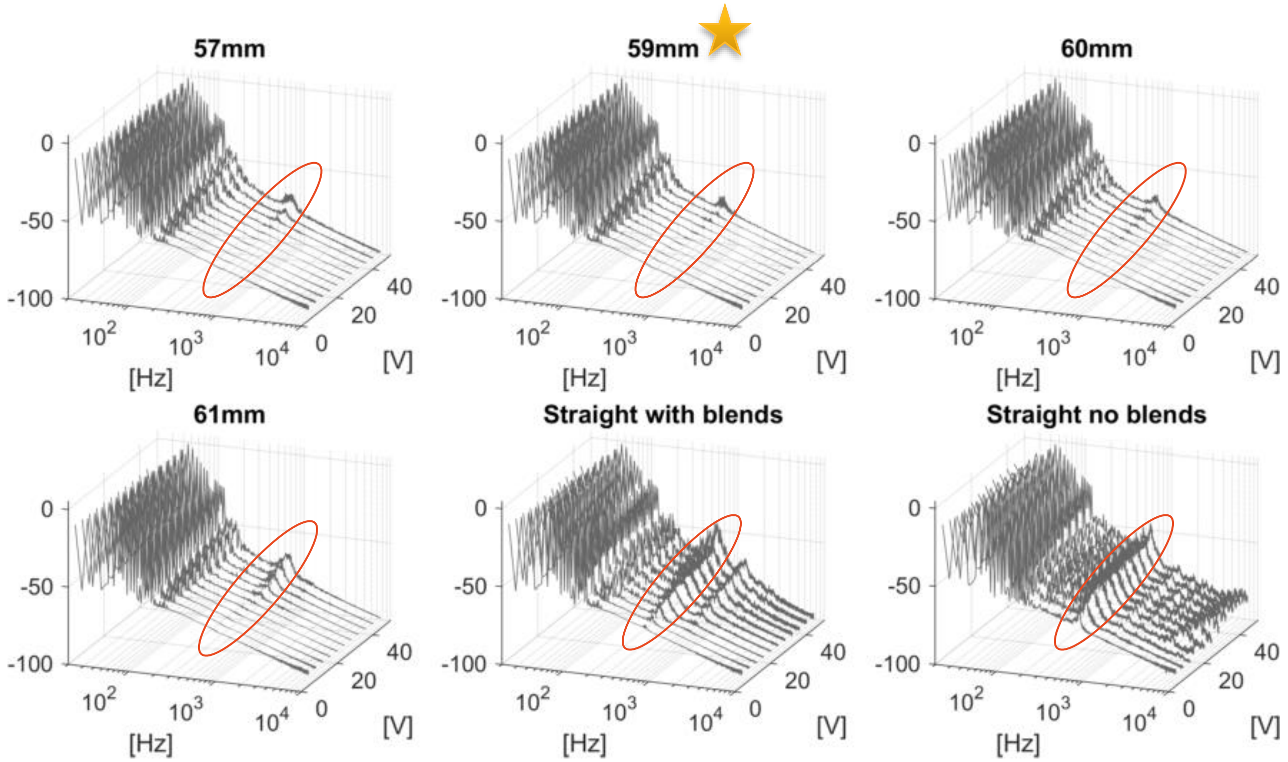


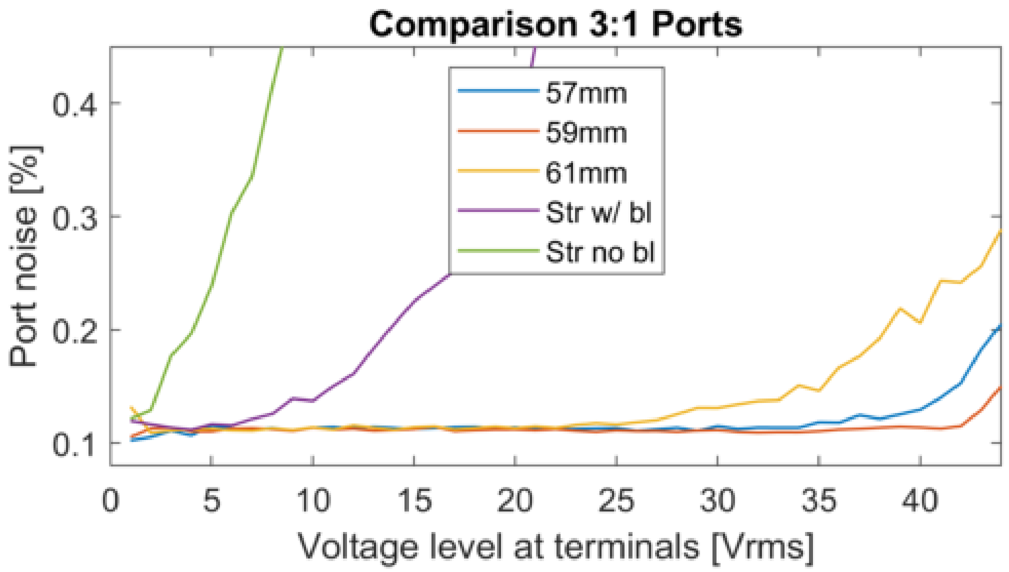
Measurements



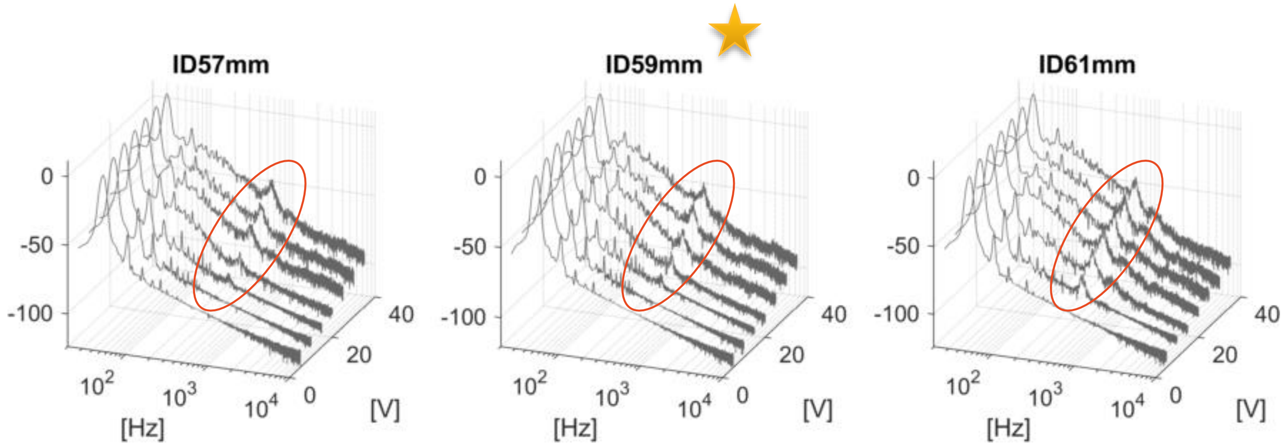
- Hemi-anechoic (2π) chamber
- 2 x 10-inch woofers
- Near-field measurement with G.R.A.S 46 AM microphone
- Signal: Multi-sine from 20 Hz to 80 Hz for 3:1 ports, 40 Hz sine for 4:1 ports

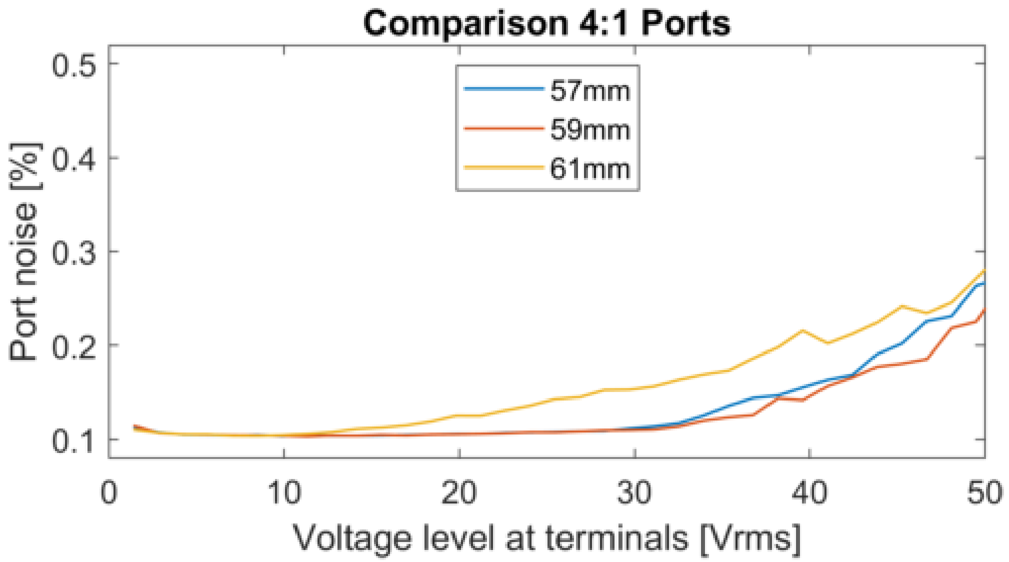
Measurement Results
3:1 Ports





Measurement Results
4:1 Ports





Double-Blind Listening Tests

Preference Test

- 3 different sound files with fundamental at 40 Hz
  - Kick drum
  - Whale drum
  - Bass guitar
- Recorded at 4, 20, 40, 60 V
- Playback through headphones, normalized for loudness
- *Preference scale 0-100*

Method of Adjustment Test

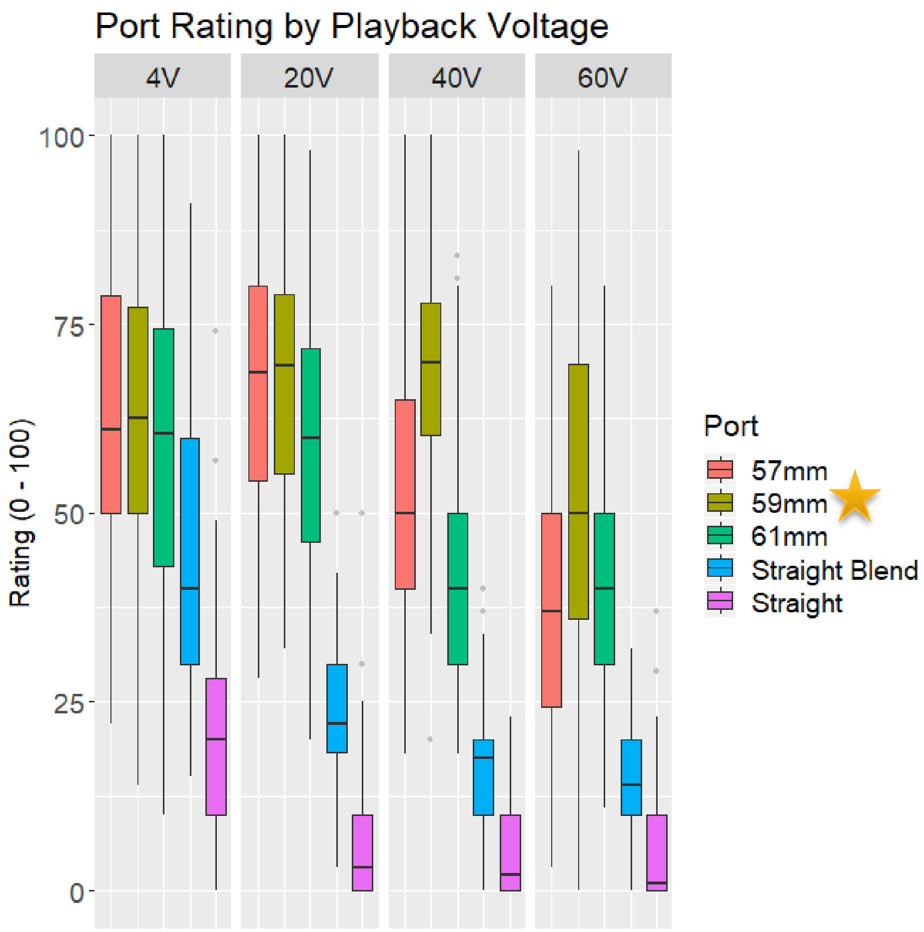
- Whale drum signal
- Reference is 59 mm port at 52 V
- *Adjust drive level until port noise is equally objectionable*

Whale drum examples at 52 V:

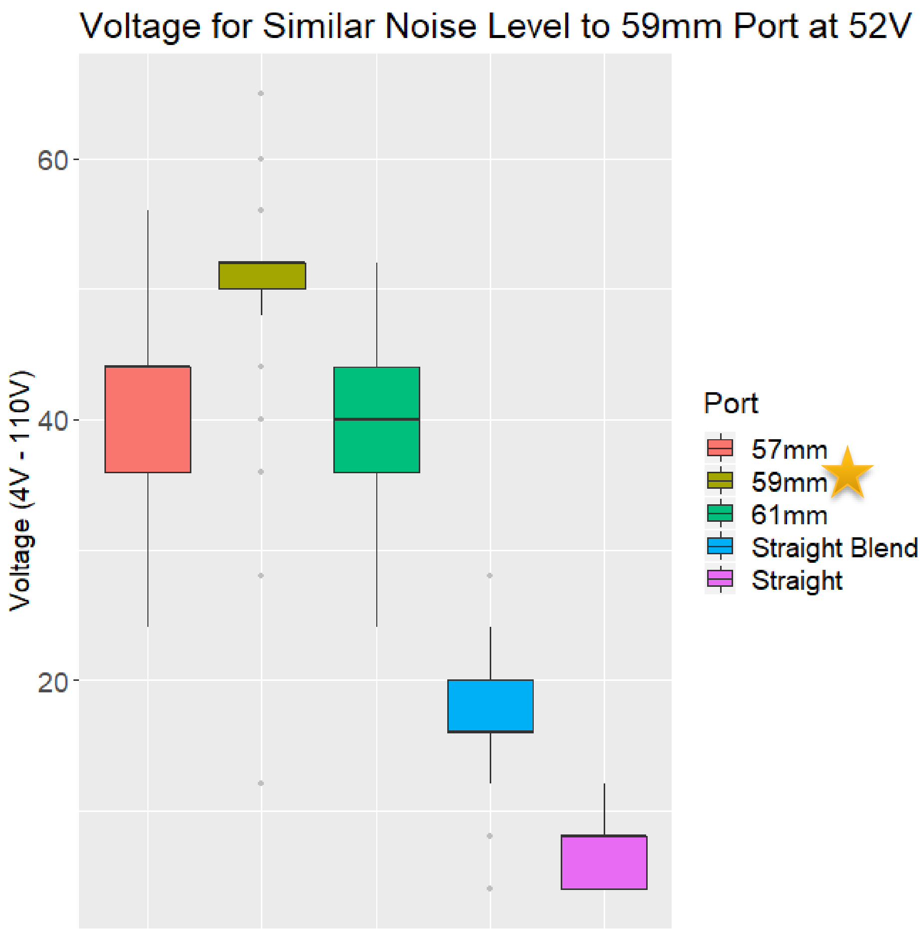
57 mm	59 mm	61 mm	Straight with blends	Straight no blends

Listening Test Results

Preference Test



Method of Adjustment Test



Conclusions

- Optimal amount of flare is now predictable!
- Acoustic simulations are fast and amenable for optimization
- Simulations, measurements, and listening tests correlate and validate the hypothesis:

  "The best sounding port has the lowest propensity for flow separation.

  Flow separation is minimal when the particle velocity contours at port exit have minimal curvature."

- Optimally flared ports can be played *>10 dB louder* than straight ports!
- Optimally flared ports can be played *>1 dB louder* than slightly under- or over-flared ports

Thank you!

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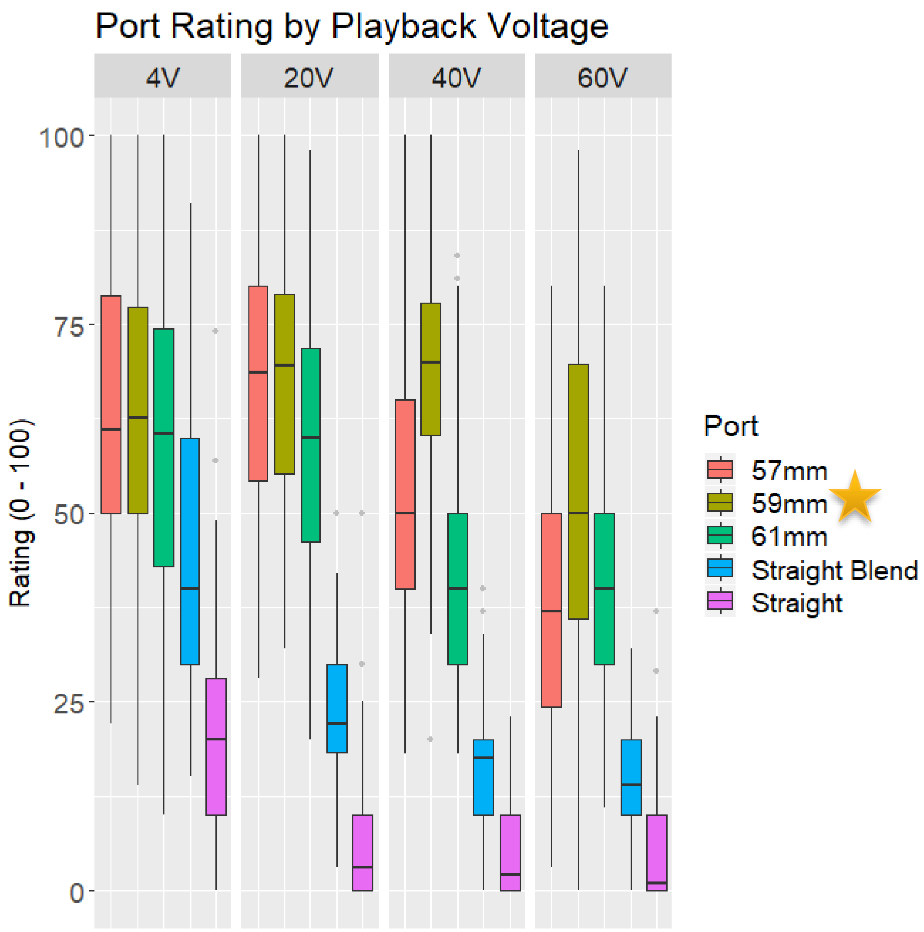
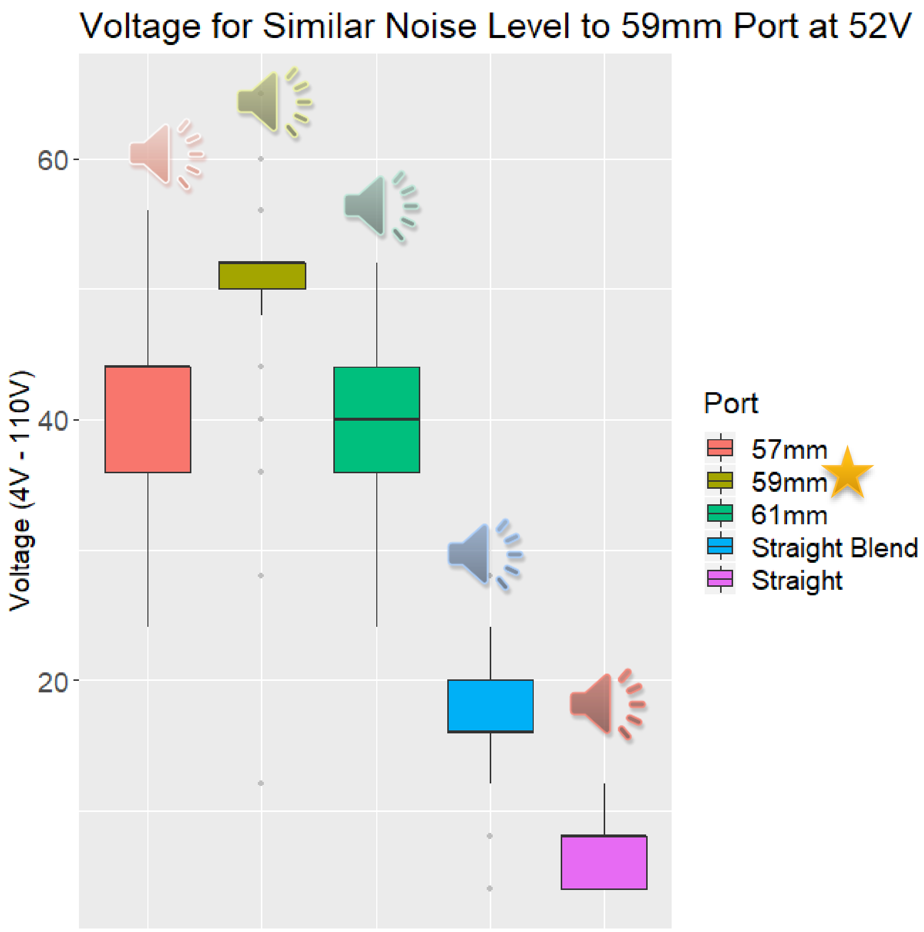
Listening Test Results

Preference Test



Method of Adjustment Test



Different Ports

Port	57 mm	59 mm ★	61 mm	Straight w/ blends	Straight no blends	57 mm	59 mm ★	61 mm
Aspect Ratio	3:1	3:1	3:1	3:1	3:1	4:1	4:1	4:1
Length [mm]	180	180	180	180	180	240	240	240
Dc [mm]	57	59	61	69	69	57	59	61
De [mm]	177	117	97	69	69	150	126	102
Rb [mm]	8.4	8.4	8.4	8.4	-	10.1	10.1	10.1
Vbox [L]	30.6	30.6	30.6	30.6	30.6	24.6	24.6	24.6