

# Final Speaker Design Document

March 21, 2025

## 1 Background

Speaker design for high-fidelity audio involves balancing driver characteristics, enclosure types, and amplification to achieve a flat frequency response (20 Hz–20 kHz) and consistent sound decay across nearfield (1–4 ft) and midfield (5–10 ft) listening distances. Nearfield monitoring, common in recording and mastering, prioritizes direct sound over room reflections, while midfield applications, such as home hi-fi or larger studios, require wider dispersion and higher output. Low frequencies (e.g., 80 Hz, wavelength  $\sim 14$  ft) are omnidirectional with small drivers, necessitating high excursion and power, whereas midrange (300 Hz–5 kHz) and high frequencies (10–20 kHz, wavelength  $\sim 0.03$  ft) demand controlled directivity for clarity and imaging.

Transmission line (TL) enclosures extend bass below a driver's resonant frequency (Fs) using quarter-wave resonance, unlike sealed boxes (tight bass, limited extension) or ported designs (higher output, less decay control). However, TLs risk cancellation notches from backwave reflections, mitigated here by a 1:0.5 contracting taper and internal damping. A Helmholtz resonator at 120 Hz reinforces low-mids, addressing notches and enhancing presence. These choices reflect a synthesis of acoustic theory and practical engineering, tailored for modern playback and production needs as of March 21, 2025.

## 2 Design Objectives

- **Frequency Response:** Flat 20 Hz–20 kHz ( $\pm 3$  dB for two-way,  $\pm 2$  dB for three-way) with consistent sound decay.
- **Listening Range:** Nearfield (1–4 ft) and midfield (5–10 ft), balancing directivity and sweet spot.
- **Enclosure Features:** Slotted TL with 1:0.5 contracting taper, internal damping, and 120 Hz Helmholtz resonator for bass extension, notch suppression, and low-mid reinforcement; sealed midrange chamber (three-way) for isolation.
- **Applications:** High-fidelity playback, recording, and mastering in small to medium spaces.

## 3 Two-Way Speaker System

A compact design splitting the spectrum between a woofer and tweeter, ideal for nearfield precision.

### 3.1 Drivers

#### 1. **Woofers:** Scan-Speak Revelator 22W/8851T00

- **Diameter:** 8.7" (22 cm)
- **Frequency Range:** 20 Hz–3 kHz
- **Fs:** 23 Hz
- **Xmax:**  $\pm 9$  mm
- **Sensitivity:** 87 dB (2.83V/1m)
- **Power Handling:** 100 W RMS
- **Impedance:** 8 ohms
- **Justification:** High excursion and low Fs deliver 20 Hz in the TL, while the 8.7" size balances omnidirectionality at 80 Hz ( $\sim 14$  ft) and directivity at 1–3 kHz ( $\sim 1$ –0.4 ft) for vocal clarity.

#### 2. **Tweeter:** SB Acoustics SB26ADC-C000-4

- **Diameter:** 1" (25 mm) aluminum dome
- **Frequency Range:** 2.5 kHz–20 kHz
- **Fs:** 600 Hz
- **Sensitivity:** 90 dB (2.83V/1m)
- **Power Handling:** 80 W RMS
- **Impedance:** 4 ohms
- **Justification:** Small diaphragm ensures high directivity at 10–20 kHz ( $\sim 0.03$  ft), minimizing reflections with fast decay for crisp highs.

### 3.2 Crossover

- **Type:** 2nd-order Linkwitz-Riley
- **Frequency:** 2.5 kHz
- **Justification:** Steep roll-off avoids overlap in the vocal range (300 Hz–3 kHz), ensuring transparency.

### 3.3 Amplifier Power

- **Woofers:** 150 W RMS (Class D)
- **Tweeter:** 50 W RMS (Class A/B)
- **Justification:** Bi-amping matches power to driver demands, achieving  $\sim 105$  dB SPL at 1 m with headroom for low-frequency excursion.

### 3.4 Enclosure

- **Type:** Slotted Transmission Line
  - **Length:** 6 ft (tuned to 25 Hz quarter-wave, adjusted for taper)
  - **Taper:** Contracting, 1:0.5 (50 in<sup>2</sup> at driver to 25 in<sup>2</sup> at slot)
  - **Slot:** 2"  $\times$  8" (16 in<sup>2</sup>)

- **Internal Termination:** 1 ft<sup>3</sup> long-fiber wool (density  $\sim 1$  lb/ft<sup>3</sup>), concentrated near closed end, tapering to sparse near driver.
- **Justification:** Contracting taper reduces backwave amplitude, suppressing notches (e.g., 75 Hz, 225 Hz). Wool absorbs reflections, smoothing 20–150 Hz response.
- **Helmholtz Resonator:** 120 Hz
  - **Volume:** 0.6 ft<sup>3</sup>
  - **Neck:** 2" diameter  $\times$  4.5" long
  - **Justification:** Reinforces upper bass (75–150 Hz), counters TL notches, and enhances presence in nearfield settings.

### 3.5 Performance

- **Frequency Response:** 20 Hz–20 kHz  $\pm 3$  dB
- **Sound Decay:** TL taper and damping ensure even bass decay; tweeter's low mass provides fast high-frequency decay.
- **Sweet Spot:**  $\sim 60^\circ$  horizontal,  $\sim 40^\circ$  vertical at 1–5 ft
- **Max SPL:**  $\sim 105$  dB at 1 m

## 4 Three-Way Speaker System

A detailed design with dedicated woofer, midrange, and tweeter, optimized for midfield clarity and wider dispersion.

### 4.1 Drivers

#### 1. Woofer: Dayton Audio RSS315HF-4

- **Diameter:** 12" (30 cm)
- **Frequency Range:** 20 Hz–500 Hz
- **Fs:** 19.5 Hz
- **Xmax:**  $\pm 14$  mm
- **Sensitivity:** 88 dB (2.83V/1m)
- **Power Handling:** 200 W RMS
- **Impedance:** 4 ohms
- **Justification:** Large diameter and excursion handle 20 Hz in the TL, remaining omnidirectional at 80 Hz ( $\sim 14$  ft) for deep bass.

#### 2. Midrange: Morel MDM 55

- **Diameter:** 2.1" (54 mm) dome
- **Frequency Range:** 400 Hz–5 kHz
- **Fs:** 350 Hz
- **Sensitivity:** 89 dB (2.83V/1m)
- **Power Handling:** 80 W RMS
- **Impedance:** 8 ohms

- **Justification:** Small dome balances omnidirectionality at 400 Hz ( $\sim 3$  ft) and directivity at 5 kHz ( $\sim 0.07$  ft), reducing vocal smearing.

### 3. **Tweeter:** Seas Prestige 27TDFC

- **Diameter:** 1.1" (27 mm) textile dome
- **Frequency Range:** 2 kHz–20 kHz
- **Fs:** 550 Hz
- **Sensitivity:** 91 dB (2.83V/1m)
- **Power Handling:** 90 W RMS
- **Impedance:** 6 ohms
- **Justification:** Textile dome with mild horn-loading controls dispersion at 10–20 kHz ( $\sim 0.03$  ft), minimizing reflections.

## 4.2 Crossover

- **Type:** 2nd-order Linkwitz-Riley
- **Frequencies:** 400 Hz (woofer to midrange), 3 kHz (midrange to tweeter)
- **Justification:** Splits load across drivers, keeping crossovers outside vocal fundamentals for clarity.

## 4.3 Amplifier Power

- **Woofer:** 300 W RMS (Class D)
- **Midrange:** 100 W RMS (Class A/B)
- **Tweeter:** 75 W RMS (Class A/B)
- **Justification:** Tri-amping optimizes power delivery, achieving  $\sim 108$  dB SPL at 3 m with bass headroom.

## 4.4 Enclosure

- **Type:** Slotted Transmission Line
  - **Length:** 8 ft (tuned to 20 Hz quarter-wave, adjusted for taper)
  - **Taper:** Contracting, 1:0.5 (80 in<sup>2</sup> at driver to 40 in<sup>2</sup> at slot)
  - **Slot:** 3"  $\times$  12" (36 in<sup>2</sup>)
  - **Internal Termination:** 1.5 ft<sup>3</sup> polyester fill (density  $\sim 0.75$  lb/ft<sup>3</sup>), concentrated near closed end, thinning toward driver.
  - **Justification:** Contracting taper and damping minimize notches (e.g., 60 Hz, 180 Hz), ensuring a flat 20–400 Hz response.
- **Sealed Midrange Chamber:** 0.1 ft<sup>3</sup>
  - **Justification:** Isolates midrange from woofer backwave, maintaining purity.
- **Helmholtz Resonator:** 120 Hz
  - **Volume:** 0.8 ft<sup>3</sup>
  - **Neck:** 2.5" diameter  $\times$  5.5" long
  - **Justification:** Boosts 75–150 Hz, smoothing TL response and supporting the 400 Hz crossover.

## 4.5 Performance

- **Frequency Response:** 20 Hz–20 kHz  $\pm 2$  dB
- **Sound Decay:** Tapered TL and damping refine bass decay; sealed midrange and horned tweeter ensure fast mid/high decay.
- **Sweet Spot:**  $\sim 70^\circ$  horizontal,  $\sim 50^\circ$  vertical at 3–10 ft
- **Max SPL:**  $\sim 108$  dB at 3 m

## 5 Design Justifications

- **TL with 1:0.5 Contracting Taper:** Narrows from driver to slot, reducing backwave reflections and notch depth (e.g.,  $\sim 5$  dB vs. 10–15 dB in straight TLs). High-excursion drivers and amplifier power offset slight bass loss.
- **Internal Damping:** Long-fiber wool (two-way) and polyester fill (three-way) absorb reflections, smoothing response and enhancing decay consistency.
- **120 Hz Helmholtz Resonator:** Targets 75–150 Hz, countering TL notches (e.g., 75 Hz for two-way, 60 Hz for three-way) and room modes, adding presence without muddying mids.
- **Driver Selection:** Woofer sizes (8.7", 12") suit low-frequency omnidirectionality, midrange (2.1") balances dispersion, and tweeters (1", 1.1") control high-frequency directivity.
- **Amplification:** Class D for bass efficiency, Class A/B for mid/high fidelity, ensuring clean power across the spectrum.

## 6 Design Trade-Offs

- **TL Taper (1:0.5 Contracting):**
  - *Pros:* Reduces notch severity and simplifies damping, improving 20–200 Hz smoothness.
  - *Cons:* Lowers bass efficiency by 1–2 dB vs. straight or expanding tapers, requiring more amplifier power or larger drivers.
  - *Resolution:* High-excursion woofers ( $X_{\max} \pm 9$  mm,  $\pm 14$  mm) and ample power (150 W, 300 W) compensate.
- **120 Hz Resonator vs. 150 Hz:**
  - *Pros:* Better aligns with TL notches (60–75 Hz) and room modes, enhancing low-mid coherence.
  - *Cons:* Less reinforcement at 150–200 Hz, potentially thinning upper bass in small rooms.
  - *Resolution:* Woofer output and TL extension cover this range adequately.
- **Two-Way Simplicity vs. Three-Way Detail:**
  - *Pros (Two-Way):* Compact, cost-effective, sufficient for nearfield precision.
  - *Cons (Two-Way):* Wider driver bandwidth risks smearing in mids (1–3 kHz).
  - *Pros (Three-Way):* Dedicated midrange improves vocal clarity and dispersion.

- *Cons (Three-Way)*: Larger, more complex, and costlier.
- *Resolution*: Two-way for budget nearfield; three-way for premium midfield.
- **TL vs. Sealed/Ported:**
  - *Pros*: Extended bass (20–25 Hz) with better decay than ported designs.
  - *Cons*: Larger footprint and construction complexity vs. sealed boxes.
  - *Resolution*: TL chosen for superior low-end performance in target applications.

## 7 Comparable Ready-Made Speakers

- **Two-Way**: *PMC TwoTwo 6*
  - **Specs**: 6.5” woofer, 1” tweeter, TL design, 40 Hz–25 kHz, 200 W total.
  - **Alignment**: Similar TL with presumed mild taper and damping; approximates 120 Hz reinforcement.
- **Three-Way**: *PMC 6-2*
  - **Specs**: 2×6” woofers, 2” mid dome, 1” tweeter, TL, 33 Hz–25 kHz, 400 W total.
  - **Alignment**: TL with multi-driver config and damping, mimicking the 120 Hz resonator’s effect.

## 8 Optimum Designs

Unconstrained by cost or availability, these represent the pinnacle of performance for nearfield and midfield use.

### 8.1 Optimum Two-Way

- **Woofer**: Seas L26ROY (10”, 20 Hz–2.5 kHz,  $F_s$  20 Hz,  $X_{max}$   $\pm 15$  mm, 88 dB, 200 W, 8 ohms)
- **Tweeter**: Scan-Speak D3004/664000 (1.1”, 2 kHz–30 kHz,  $F_s$  470 Hz, 91 dB, 100 W, 4 ohms)
- **Crossover**: 2nd-order Linkwitz-Riley at 2 kHz
- **Amplifier**: Woofer 200 W (Class D), Tweeter 75 W (Class A/B)
- **Enclosure**: 6.5 ft TL (1:0.5 taper, 60 in<sup>2</sup> to 30 in<sup>2</sup>, 1 ft<sup>3</sup> wool), 120 Hz resonator (0.6 ft<sup>3</sup>, 2” × 4.5”)
- **Performance**: 20 Hz–20 kHz  $\pm 2$  dB,  $\sim 108$  dB SPL at 1 m
- **Justification**: Larger woofer and extended tweeter range push fidelity and output limits.

## 8.2 Optimum Three-Way

- **Woofers:** AE TD15M (15", 20 Hz–400 Hz,  $F_s$  18 Hz,  $X_{max}$   $\pm 18$  mm, 90 dB, 400 W, 8 ohms)
- **Midrange:** Accuton C90-6-724 (3", 300 Hz–6 kHz,  $F_s$  80 Hz, 89 dB, 120 W, 6 ohms)
- **Tweeter:** RAAL 70-20XR (1.2" ribbon, 2 kHz–40 kHz, 95 dB, 100 W, 8 ohms)
- **Crossover:** 2nd-order Linkwitz-Riley at 350 Hz, 3.5 kHz
- **Amplifier:** Woofer 400 W (Class D), Midrange 120 W (Class A/B), Tweeter 100 W (Class A/B)
- **Enclosure:** 9 ft TL (1:0.5 taper, 100 in<sup>2</sup> to 50 in<sup>2</sup>, 2 ft<sup>3</sup> polyester), 0.2 ft<sup>3</sup> mid chamber, 120 Hz resonator (0.9 ft<sup>3</sup>, 2.5"  $\times$  6")
- **Performance:** 20 Hz–20 kHz  $\pm 1.5$  dB,  $\sim 112$  dB SPL at 3 m
- **Justification:** Premium drivers maximize bandwidth, dynamics, and dispersion control.

## 9 Conclusion

These designs deliver high-fidelity audio from 20 Hz–20 kHz with even decay, leveraging a tapered TL, internal damping, and a 120 Hz resonator for smooth bass and enhanced presence. The two-way excels in nearfield precision, the three-way in midfield versatility, and the optimum designs push performance boundaries. Practical for DIY or as benchmarks for commercial systems like PMC's, further details (e.g., blueprints, simulations) are available upon request.