Speaker System Design - Electrical:E-12-BGAV-034

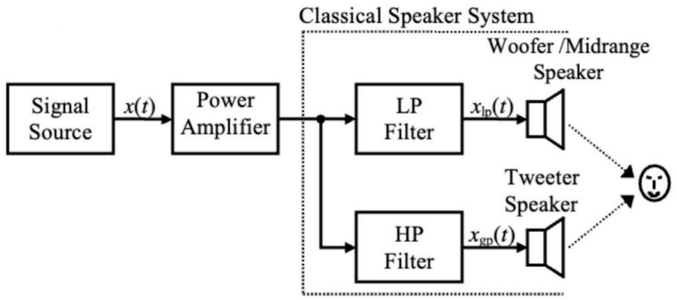
Team Members: Yuhao Cao, Chenrui Hong, Wei-Chieh Chen, Supervisor: Gavin Buskes

Discipline: Photonic and Electronic Systems (4310)

Introduction

In today's tech-driven world, the demand for high-quality sound systems is growing. Addressing this, our team designed an optimized PA speaker system to project clear, crisp sound to large audiences, ensuring every detail of the original signal is faithfully reproduced.

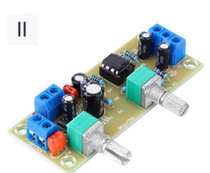
Design & Core Components Overview

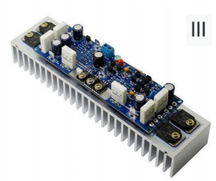


Our PA speaker system above[1] is precision-engineered for superior sound clarity and durability in large-scale broadcasts, which means the supporting frequency range is from 20Hz to 20kHz. Key features include:

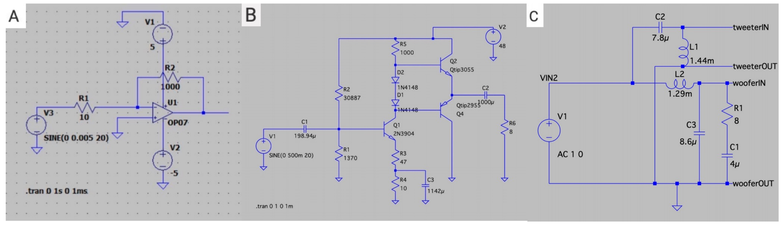
- **Signal Source[I]:** Universal XLR input, compatible with diverse audio devices from phones (with adapters) to pro mixers.
- **Pre-amplifier[II](combined with signal source):** Enhances low-level signals for amplification without noise or distortion.
- **Power Amplifiers[III]:** Dual class AB amplifiers ensure sound clarity and power, even at peak volumes.
- **Crossover Filter(Combination of LP & HP)[IV]:** Segregates frequencies; directs bass to the woofer and treble to the tweeter, maintaining audio precision.
- **Woofer[V] and Tweeter[VI] Drivers:** Tweeter for sharp highs and woofer for deep bass. Both are housed in optimized enclosures to minimize reflections and phase issues.

The design philosophy prioritizes pure, uncolored sound. Every component and connection is optimized, ensuring the audience experiences authentic sound with minimized noise and distortion.





Electrical Structure & Performance of Core Components

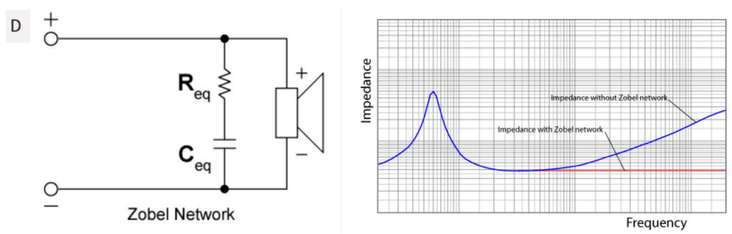


- **Pre-amplifier[A]:** This pre-amplifier is designed around the operational amplifier U_1, aiming to effectively amplify the input signal while maintaining a high-quality output.
  - **Input Impedance:** Resistor R_1 ensures good matching with the source device.
  - **Amplification Stage:** The operational amplifier U_1 collaborates with the feedback resistor R_2. The amplification factor or gain A is determined by the formula:

$$A = 1 + \frac{R_2}{R_1}$$

  - **Output:** The output from U_1 is ready to drive subsequent modules like power amplifiers directly.

  This pre-amplifier provides a clear, low-distortion amplified output.
- **Class AB Power Amplifiers[B]:** Combining the strengths of both Class A and Class B, the Class AB amplifier delivers efficient, low-distortion output suitable for a range of audio applications.
  - **Circuit Features:** Utilizes both NPN and PNP transistors for output, ensuring stable amplification. Components within the circuit ensure stable operation of the amplifier. Input signals are accurately amplified after being processed.
  - **Performance:**If input is a small sine wave, output signal showcases a clear amplification in magnitude. Rapid response with negligible delay.

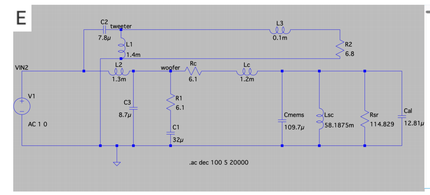


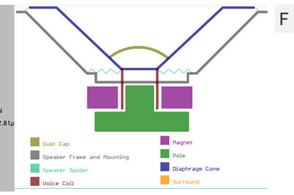
- **Crossover Filter(LP & HP)[C] & Zobel Model[D]:** The crossover divides the audio signal into distinct frequency bands, directing frequencies below 1500Hz to the woofer and those above to the tweeter.Zobel Network is comprised of R_1 and C_1(equivalent to R_{eq} and C_{eq} in D), it ensures the stability of the woofer across various frequencies.
  - **Crossover:** With a selected frequency of 1500Hz, it harmoniously combines the outputs of both the woofer and tweeter.
    - **Frequency Selection:** 1500Hz was chosen based on the performance characteristics of both the woofer and tweeter.
    - **Performance:** The rapid transition in the frequency response around 1500Hz indicates an optimal integration of audio waves between the woofer and tweeter.
  - **Zobel Network[2]:** This network is essential for stabilizing the speaker's impedance across the frequency spectrum.
    - **Purpose:** Specially designed to counteract the inductive effects of the speaker coil at higher frequencies.
    - **Components and Calculation:** Comprising a parallel resistor (R) and capacitor (C), they're selected based on the speaker coil's inductance (L) and the speaker's nominal impedance (Z). The governing equations are:

$$R = Z$$
$$C = \frac{L}{R^2}$$

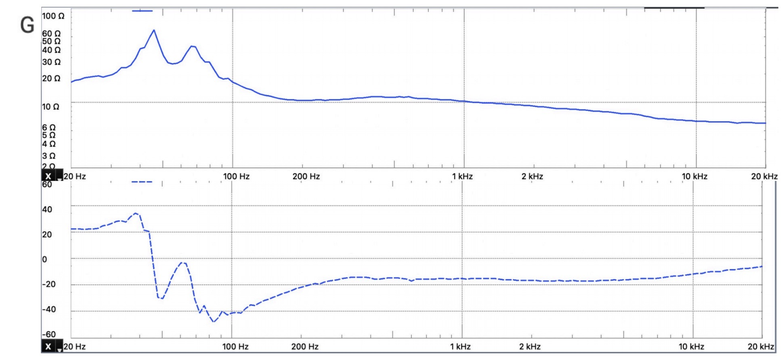
- **Woofer and Tweeter connected with crossover[E] Drivers:** The woofer is designed to produce low-frequency sounds, providing depth and richness to the audio output, while the tweeter specializes in delivering clear and crisp high-frequency tones, ensuring the intricacies of the sound are heard with clarity.

- Equivalent RLC Model of the Drivers[3]:
  - **Core of the Speaker:** The speaker converts electrical energy into mechanical energy, which then generates sound through vibrations. Its construction[F] includes components like the voice coil, diaphragm cone, spider, and magnet.
  - **Basic Electrical Model:** Due to the resistance and inductance of the speaker's voice coil, the simplest equivalent model comprises a resistor R_e and an inductor L_e.
  - **Mechanical Properties of the Speaker:** The vibration of the speaker is not entirely free but is influenced by various factors, such as the mass of the diaphragm, suspension compliance, and resistance. These mechanical properties can be simulated using equivalent resistors, capacitors, and inductors.
  - **Suspension Compliance:** Represented by the inductor L_{sc}.
  - **Suspension Resistance:** Represented by the resistor R_{sr}.
  - **Mass of the Diaphragm and Air Movement Through It:** Represented respectively by capacitors C_{mems} and C_{al}.





Overall Impedence Magnitude & Phase Results[G] with Conclusion



- **50 Hz Peak:** The 50 Hz peak represents the woofer's primary resonance, where it most efficiently transforms electrical power into pronounced sound. This frequency often signifies enhanced bass performance in woofers.
- **70 Hz Peak:** The peak near 70 Hz, closely following the first, could arise from the woofer's secondary resonance or its interaction with a ported enclosure, which inherently amplifies specific bass frequencies.

Our PA speaker system delivers pristine sound for frequency range from 20Hz to 20kHz, with optimized components ensuring authentic audio. Advanced design and impedance analysis guarantee unmatched audio fidelity.

References

[1] Sourav Gupta.
Simulate speaker with equivalent rlc circuit, 11 2018.

[2] John L. Murphy.
Neutralizing l(e) with a zobel, 6 2014.
Technical Discussions of Audio and Loudspeaker Issues, Topic No. 8.

[3] K. P. Sozański, R. Strzelecki, and Z. Fedyczak.
Digital control circuit for class-d audio power amplifier, n.d.