

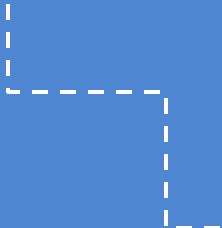
The background is a solid blue color. It features several abstract geometric elements: a small solid blue circle in the top left with a dashed line extending from it; a large solid blue circle in the top right with a dashed line extending from it; a medium solid blue circle in the middle right with a dashed line extending from it; a small solid blue circle in the bottom right with a dashed line extending from it; and a small solid blue circle in the bottom right with a dashed line extending from it. The title text is positioned on the left side of the image.

5-Way Active Crossover with 5-band Equaliser

By Ayra, Chun, and Tuong



Introduction, Purpose and Context



Project Goal:

Design, simulate, and prototype a five-way audio crossover with an integrated multi-band equalizer.

Purpose:

Enhance audio quality by splitting input signals into frequency bands and routing them to suitable speakers.

Functionality:

Active crossover network splits audio into different bands, each with an equalizer stage.



Real-World Relevance:

Simulates how audio systems operate in consumer and professional settings.

Learning Objective:

Apply theoretical knowledge in filters, frequency response, and signal processing to a hands-on engineering problem.

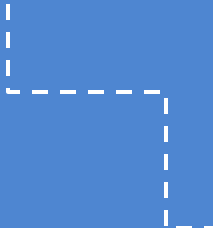
Skill Development:

Apply practical skills in circuit design, simulation, prototyping, and testing. Use teamwork, project planning, and communication.





Methodology and Design Procedure



Conceptualisation Phase

- Specify requirements: frequency splitting, volume control, stretch capability.
- Preliminary research of existing designs.

Design Phase

- Designed each module with logical functionality and component values.
- Created block diagrams for visualisation.

Simulation Phase

- 
- Simulated each module in LTSpice.
 - Simulated complete response to input signals.
 - Tested additional stretch capabilities.
 - Revised circuit design via simulation and checked for any discrepancies.

Prototyping Phase

- Built design on breadboards.
- Combined modules and tested with audio sources and speakers.
- Tested at different volumes, frequencies.
- Troubleshooted noise, unexpected behaviour.

Testing and Iteration Phase

- Used AD2 Network Analyser to check frequency responses of modules, full-system inputs and outputs.
- Adjusted designs based on performance and frequency responses.

Finalisation and Presentation Phase

- Document and justify findings and design choices.
- Present and evaluate the project outcome.

Project Planning, Review, and Research

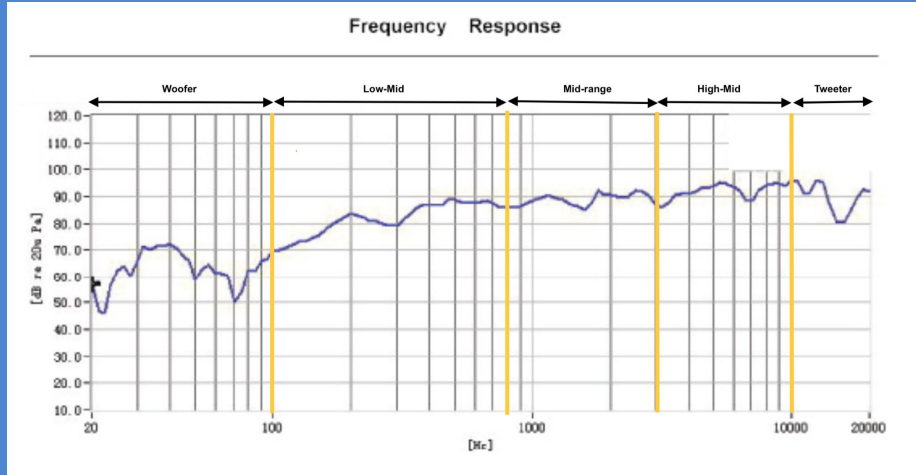
Stretch Capability: 5-band equalizer

- More responsive control over audio spectrum.
- Adds functionality, also being scalable and modular.
- More closely models commercial equalisers which typically have between 6-31 bands.

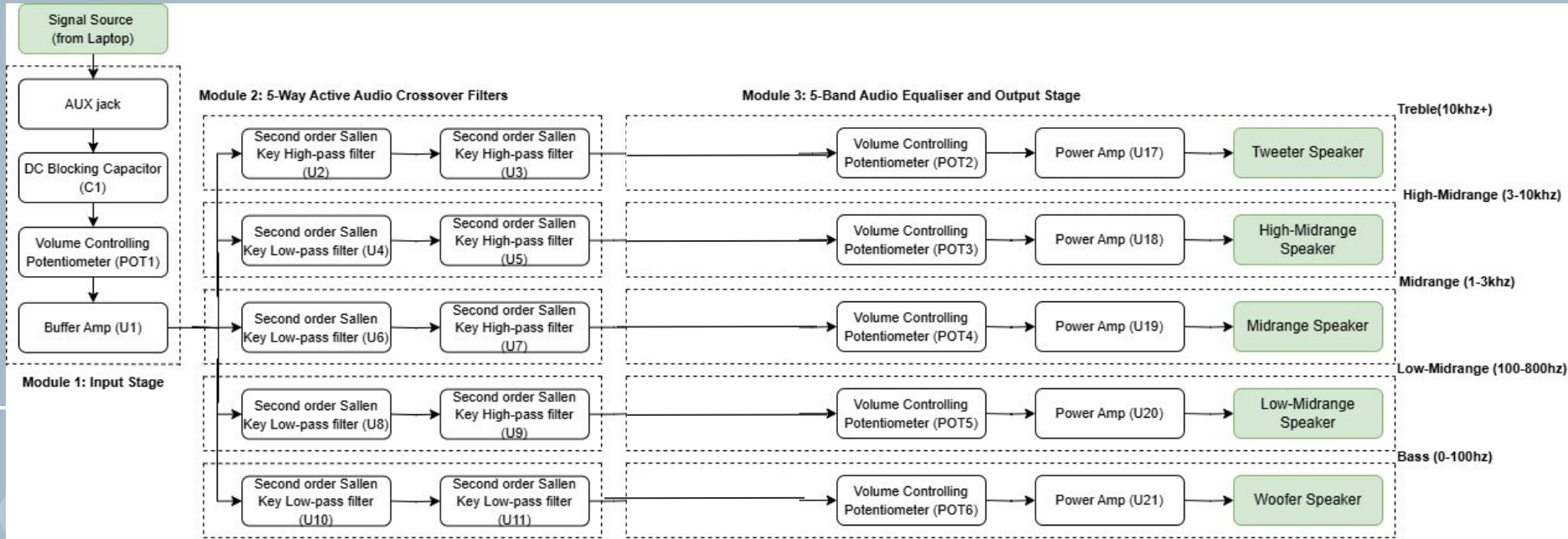
Frequency Band Selection:

- Woofer: 0–100 Hz
- Low-Mid: 100–800 Hz
- Mid: 800–3000 Hz
- High-Mid: 3000–10,000 Hz
- Tweeter: 10,000+ Hz

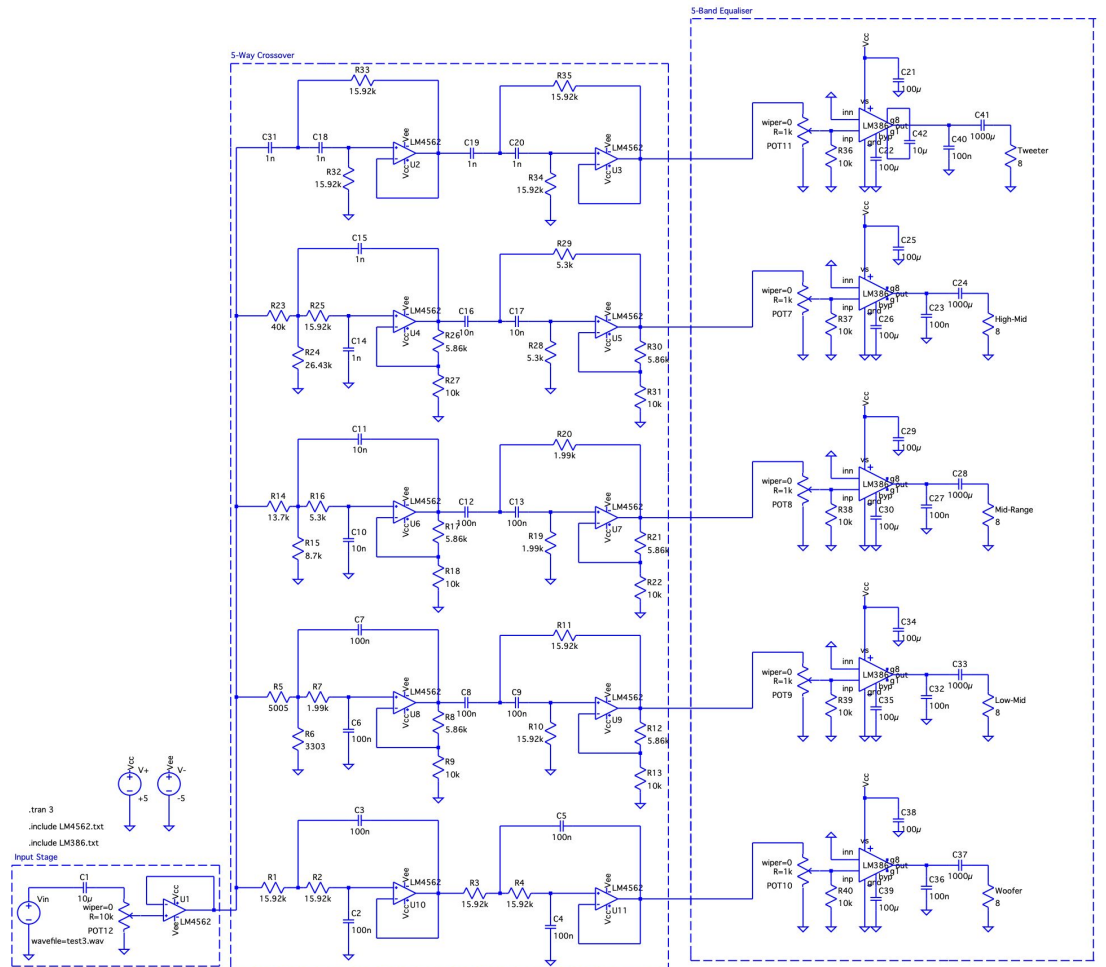
Based on: Human audible range (20 Hz – 20 kHz), CE08483 speaker response graphs and audio sweep tests using AD2.



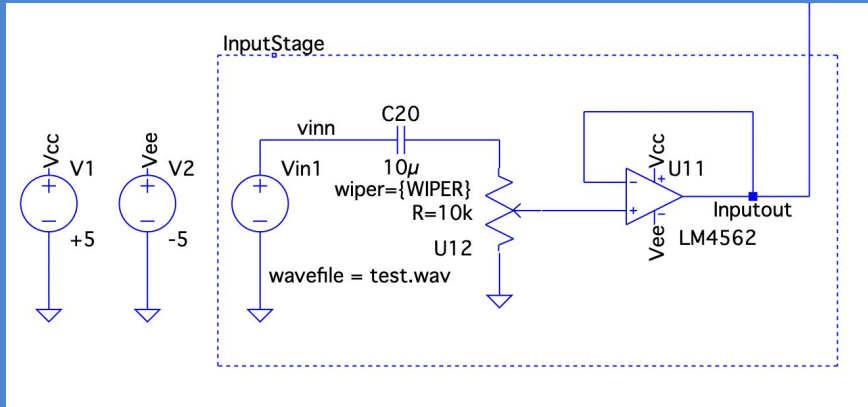
Design Overview



Overall Design



Module 1: Input Stage



Input Stage Design:

- Connects audio source to the rest of the system.
- ASUS Zenbook audio jack specs: 1Vrms, 20–50mW.
- Consists of: AUX jack input (FC68131), DC blocking capacitor, master volume control (potentiometer) and buffer amp for loading prevention.



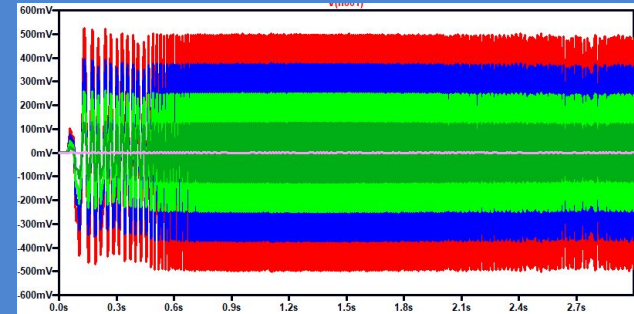
Development and Simulation

Modular Approach: Each module individually developed and simulated to check functionality before integrating into the full system.

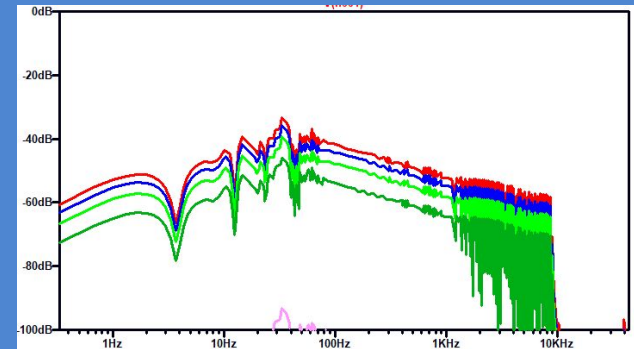
Realistic Input Signal: A .wav file with a full frequency sweep (20Hz–20kHz) to test audible range coverage.

Module 1: Audio Input Stage

- Increasing potentiometer resistance proportionally reduces output voltage (volume), without distortion.
- Frequency domain analysis confirmed decibel reduction aligned with theory.
- DC offset test verified capacitor successfully blocked DC signal.
- Volume may only be reduced, not increased, agrees with theory.



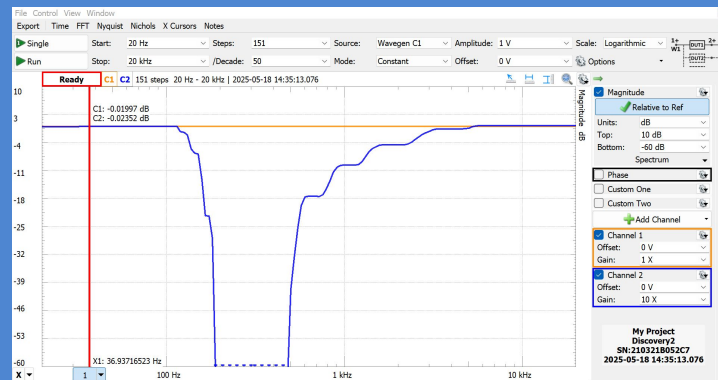
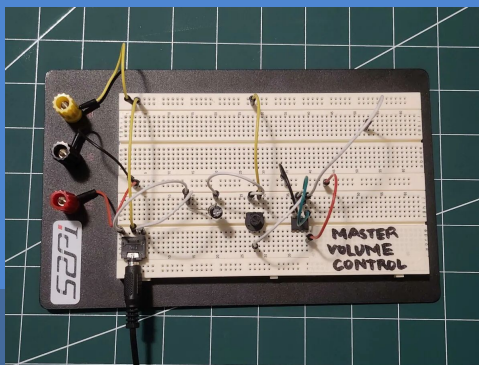
Time Domain Simulation of Input Stage



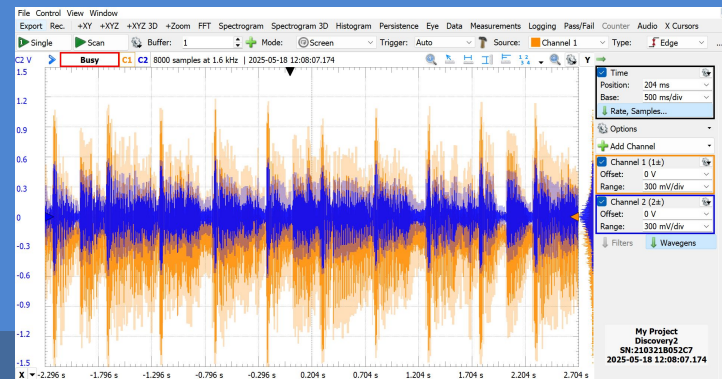
Simulated Frequency Response of Input Stage

Testing Input

- Used 3 different tests to ensure reliability and repeatability of results
- Confirms theory of only no gain capability, can only turn down volume.
- Confirms theory that the potentiometer can reliably ground the signal
- Maintains the same signal shape as potentiometer turns



Experimental Frequency Response of Input Stage



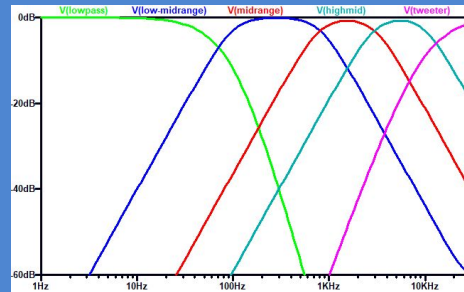
Experimental Input Stage with Song Audio Input

Crossover Design:

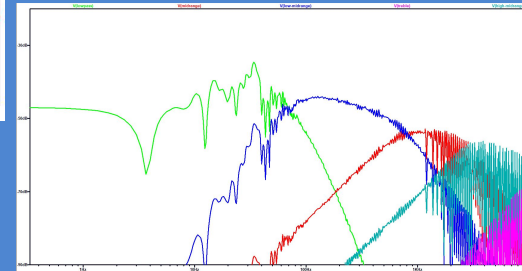
Development and Simulation

Module 2: 5-Way Active Crossover Filters

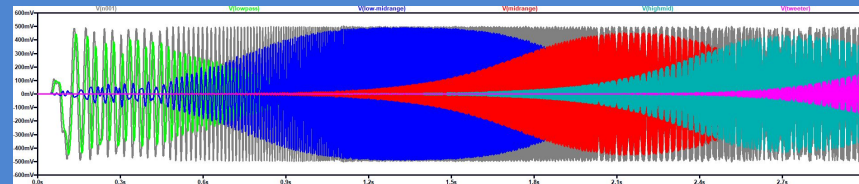
- Each output activated only within its passband.
- Smooth transitions between filters due to expected band overlap, reducing harsh frequency response changes.
- Signal attenuation from phase differences between overlapping filters (destructive interference), particularly in treble.
- Suggested mitigation via all-pass filters for phase alignment.



Theoretical Bode plot of 5-Way Crossover



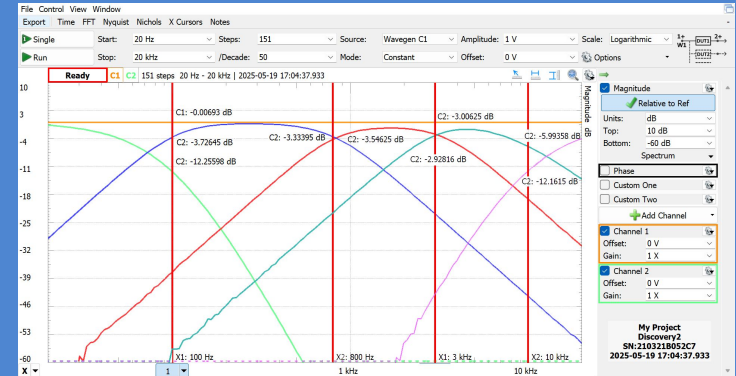
Simulated Bode plot of 5-Way Crossover



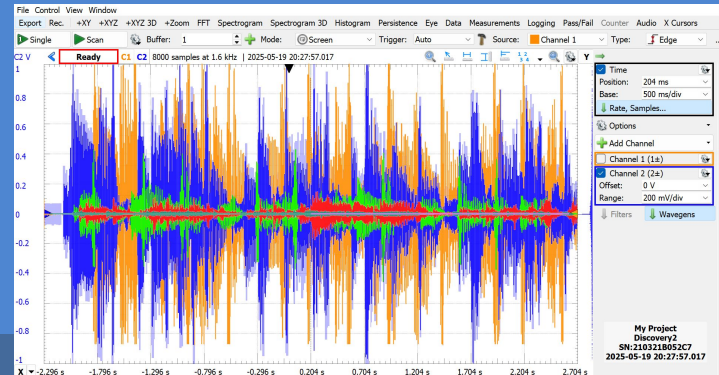
Time Domain Simulation of 5-Way Crossover

Testing Crossover

- Smooth transitions between bands, indicate that the crossover is functioning properly.
- Overlapping output and destructive interference cause some volume loss, but not very noticeable.
- The frequency bands aren't perfectly even (low-mids has larger range than high-mids), but overall they serve their function.

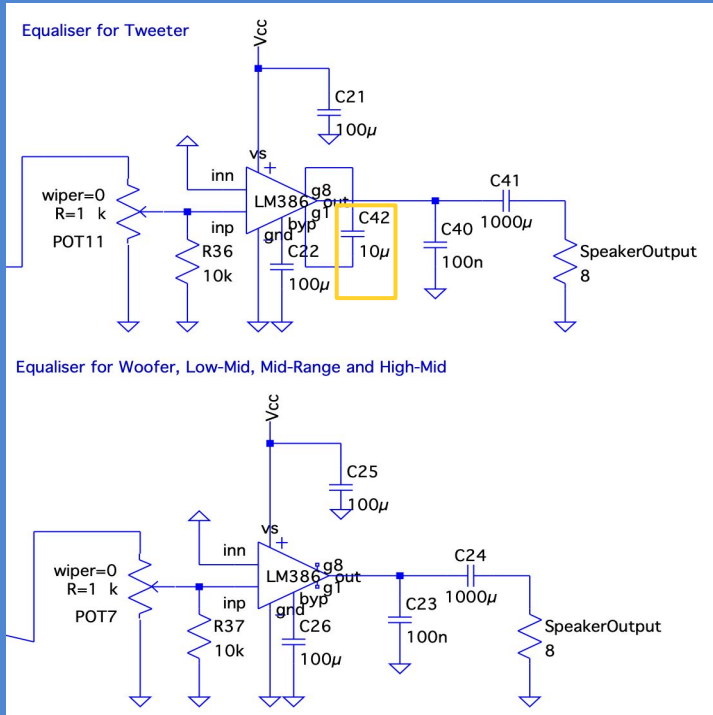


Experimental Bode Plot of 5-Way Audio Crossover



Experimental Crossover with Song Audio Input

Module 3: 5-Band Equaliser



Equalizer Design:

- Frequency bands aligned with crossover for consistent response and a simpler design.
- Utilises LM386 op-amps and 1k Ω potentiometers.
- Signal flows through potentiometer for audio adjustment.
- Pulldown resistor at input.
- DC blocking capacitor at input, output.
- Bypass/decoupling capacitors at output for noise filtering
- Each equaliser connects to a CE08483 speaker.
- Equaliser stage gain of 200 V/V for the tweeter.
- Equaliser stage gain of 20 V/V for all other stages.

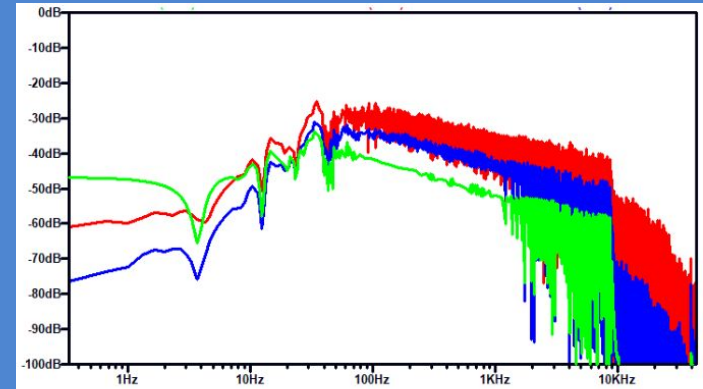
Development and Simulation

Module 3: 5-Band Equaliser and Output Stage

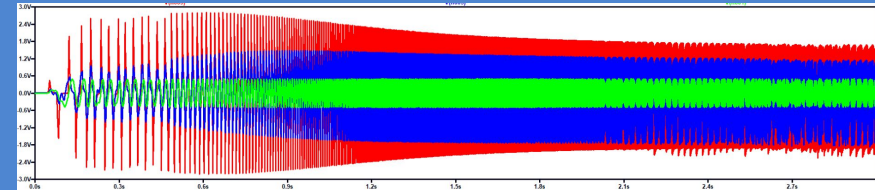
- Each output stage amplified signal appropriately without exceeding speaker voltage limits.
- Potentiometer successfully adjusted gain per frequency band.
- Minimal distortion observed due to ideal simulation environment.

Limitations:

- LM386 limitations on LTSpice, affecting accuracy in gain, distortion, frequency response, and clipping behavior.
- Observed average gain $\sim 4.9\times$ due to speaker loading.
- Simulated gain closer to $20\times$ when speaker removed, but amp saturated around 4V due to headroom.
- Frequency domain simulation not completely a straight line.



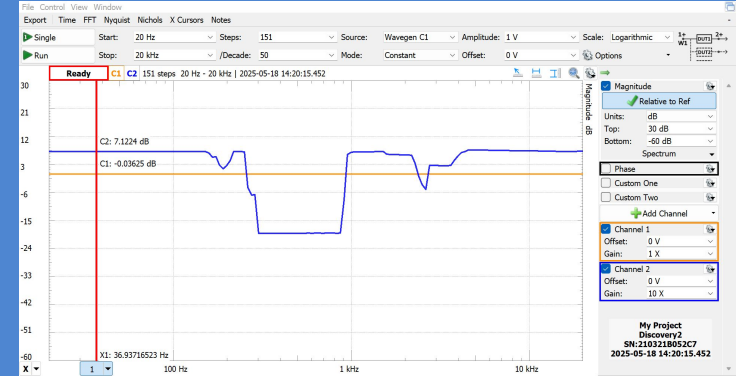
Frequency Domain Simulation of 5-Band Equaliser



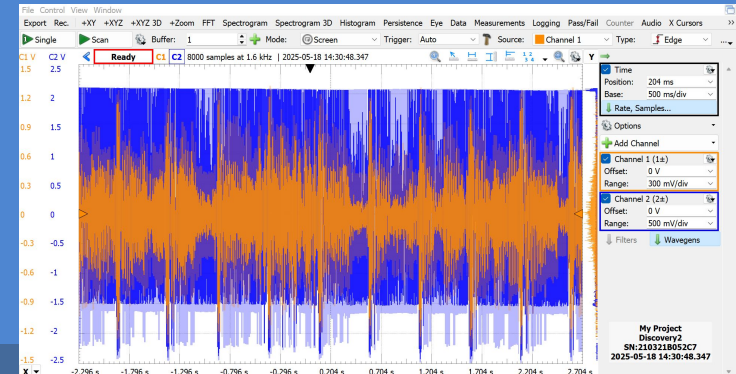
Time Domain Simulation of 5-Band Equaliser

Testing Equaliser

- Successful amplification as greater peak-to-peak voltage than input.
- Similar shapes so output has good phase alignment.
- No clipping (flatness) at the peaks indicating no saturation.
- Responsive potentiometer, minimal delay observed.
- Some distortion and voltage surges and dips but not significantly affecting the output.
- Large coupling capacitors: when potentiometer is turned, a brief voltage surge occurs as the capacitor charges or discharges, especially if also switching resistance paths rapidly and potentiometer wear.



Experimental Frequency Response of Equaliser and Output



Experimental Equaliser and Output with Song Audio Input

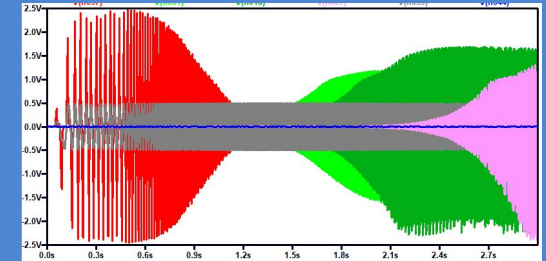
Development and Simulation

Full Simulation: Combined Crossover + Equaliser

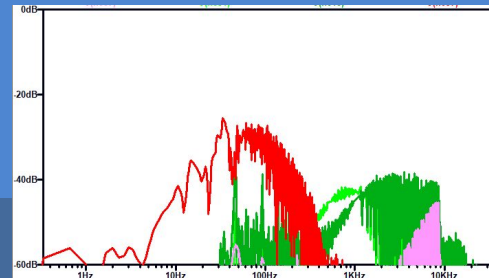
- Full simulation to check module compatibility.
- Equaliser settings tested for varying volumes.
- Simulation showed expected behaviour:
 - Bass boosted to ~5Vpp.
 - Low-mid completely attenuated (flatline at 0V).
 - Mid and high-mid boosted according to setting (~0.8x and full gain).
 - Treble output increased with frequency, up to design limit.
- Simulation validated the design goal: user-controlled volume per frequency band.
- Results aligned with theory, confirming successful implementation.

Limitations:

- Phase issues between filters caused partial signal loss.
- LM386 amplifier model had some issues in LTSpice.
- Input signal compression (35s to 3s) introduced noise and distortion.
- Gain values were approximated due to signal fluctuations.



Experimental Overall Design with Song Audio Input



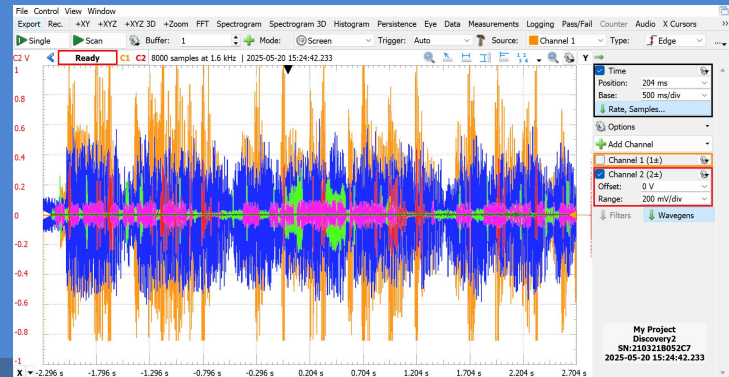
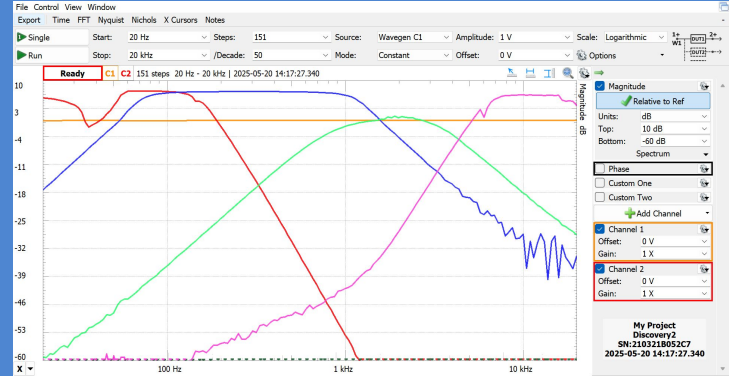
Experimental Bode Plot Overall Design

Testing Overall Design

- Overall, successful plays sound at different frequencies without significant distortion.
- All modules work together.

Limitations:

- No dynamic range control, which could lead to: overdriving speakers, unintended distortion or clipping and reduced reliability.
- No visual indicators (LEDs), so cannot see real-time volume per band, monitor output clipping or signal presence or adjust EQ accurately live.



Design Iterations

Aesthetic Changes

Dupont wires to U wires and change of potentiometers with knobs

Removed 5 buffer amps

Reduce cost and power consumption - the amps provided minimal benefits

Removed Zobel network

Distorted the signal and added a 'static' background noise

5 Breadboards

More user friendly and helped with thermal buildup issues

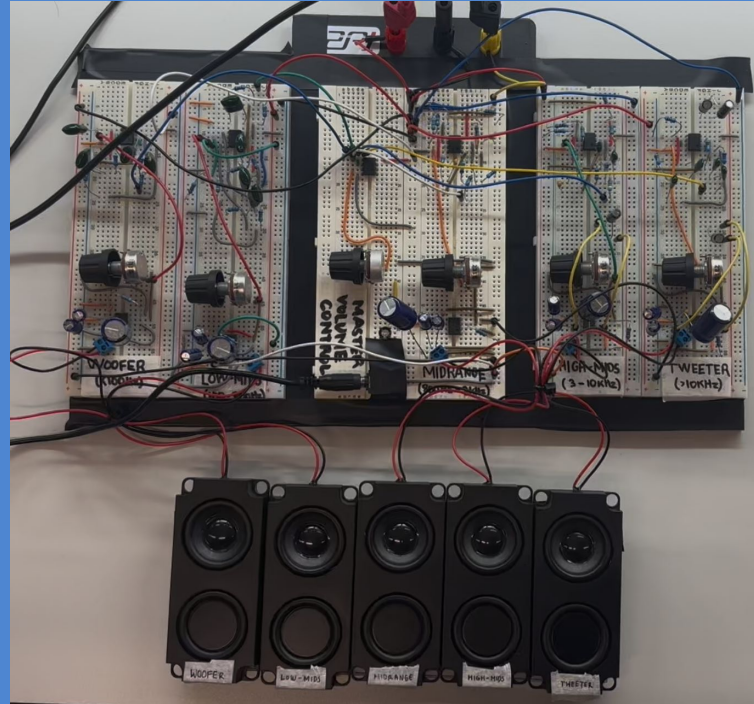
5 speakers

No summing amplifier needed and allows for edge case considerations

Increase Vcc and Vee to +- 10V

Reduce the 'popping' noise due to signal saturation with +-5V

Overall Design



Final Prototype

Live Demo

Choice of song: Starboy by The Weeknd

This song was chosen due to its dynamic range.



Q&A