408J - Hi-Fi Fighters
High Level Integration Speaker Design

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Introduction

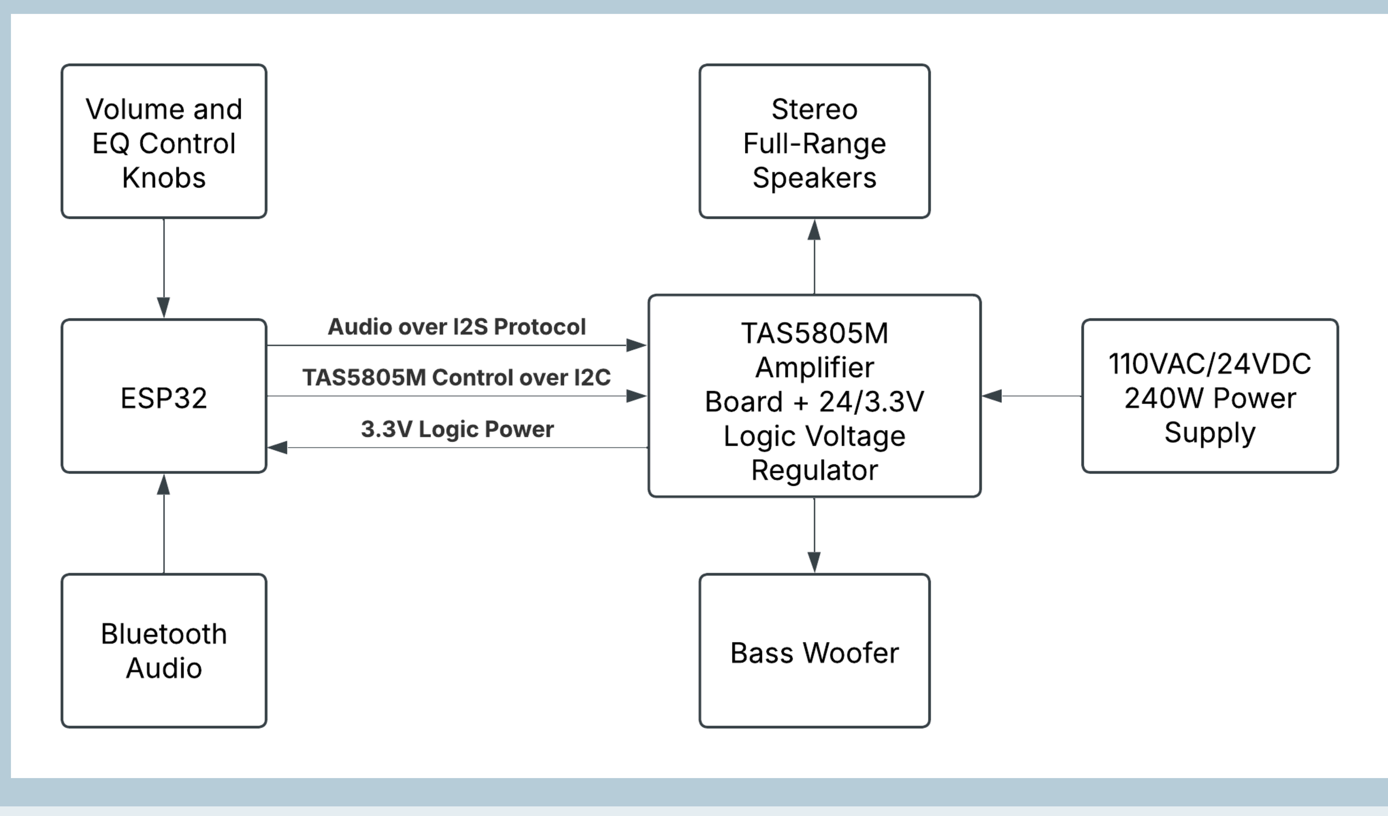
Our goal with this project was to build a standalone speaker unit but with much more custom parts, control, and quality than something that could be made with COTS parts for a similar price.

We also wanted to characterize the frequency response to tune the amplifier board for high audio fidelity and accuracy

With how custom every component is, it is easier to list the parts that were not produced by us:

- 110VAC/24VDC power supply
- ESP32 Microcontroller
- 2x 3" Full-range drivers
- 1x 4" Subwoofer
- Cable assemblies for inter-board power and communication

System Diagram

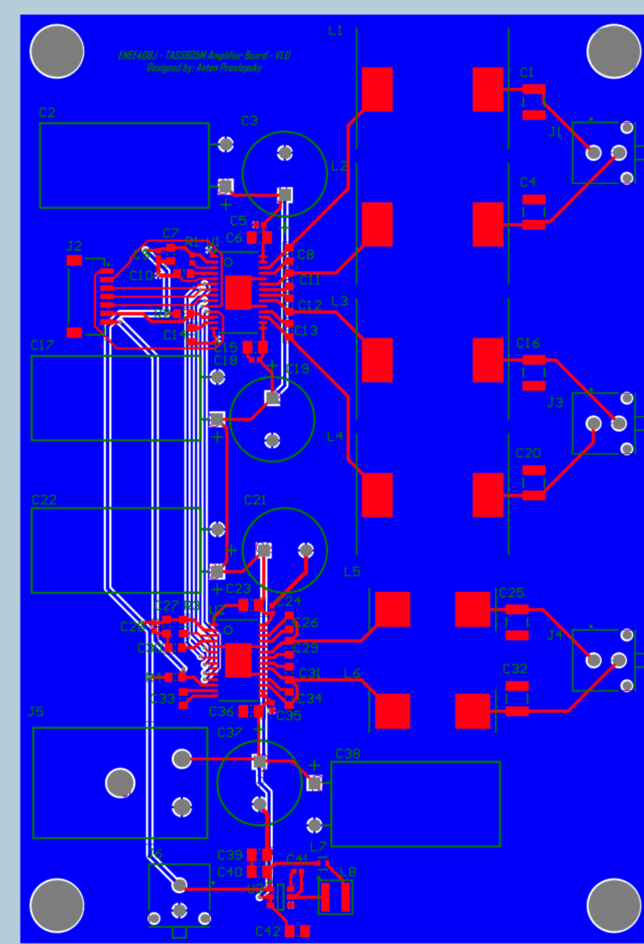


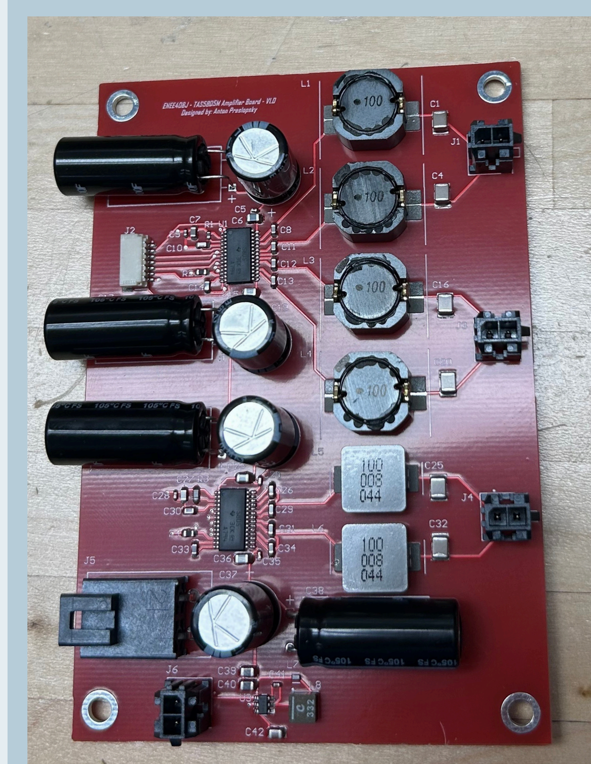
TAS5805M Amplifier Board

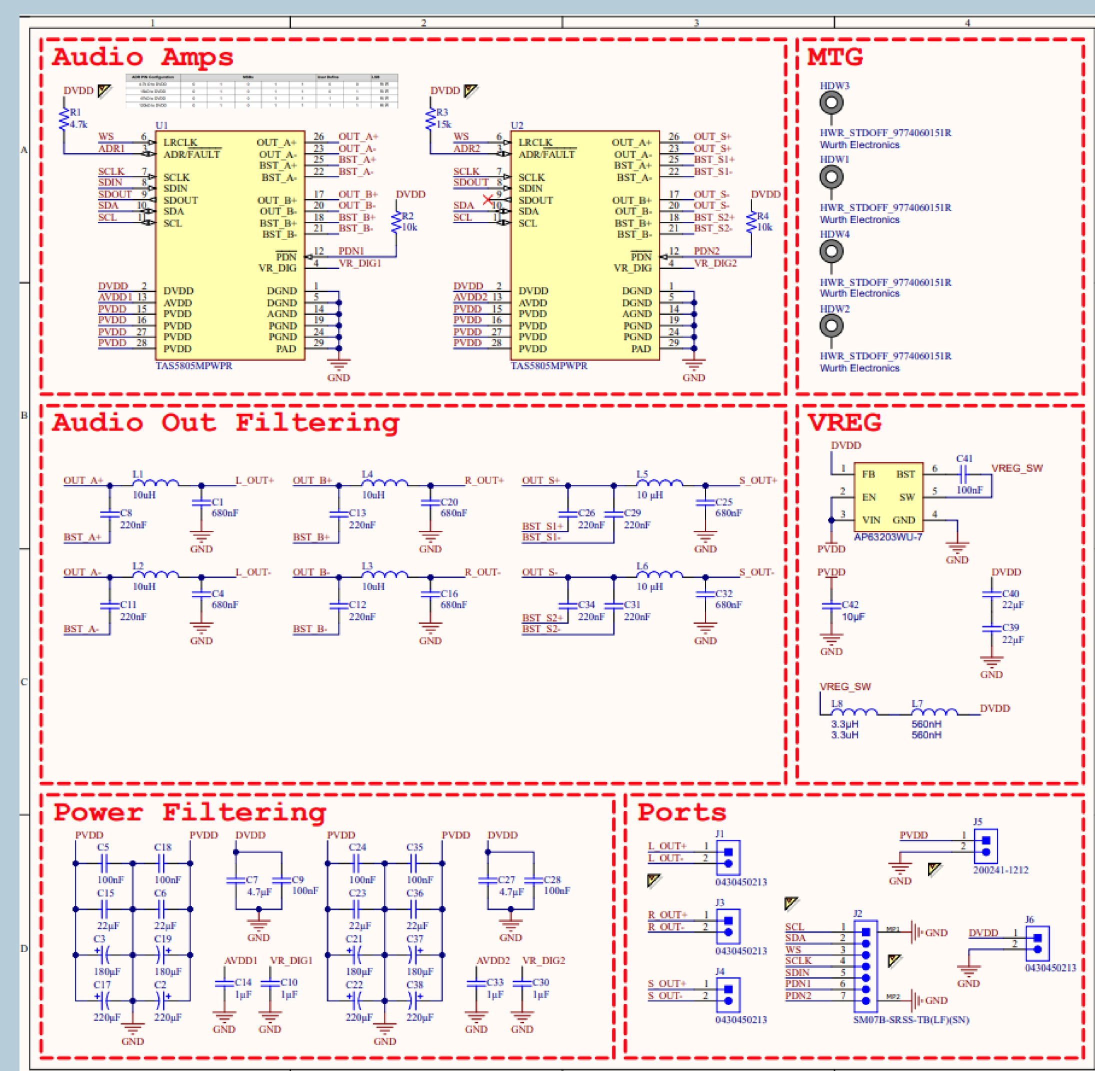
We chose the TAS5805M Amplifier ICs produced by Texas Instruments as our primary amplifier chip. Our primary informers of this choice were their price, complexity, power output, and customizability.

Manufacturing

We had the bare PCB produced externally through JLCPCB and ordered the components from Digikey assembling the final product in Terrapin Works using their pick and place machine.


Amplifier Board PCB Design

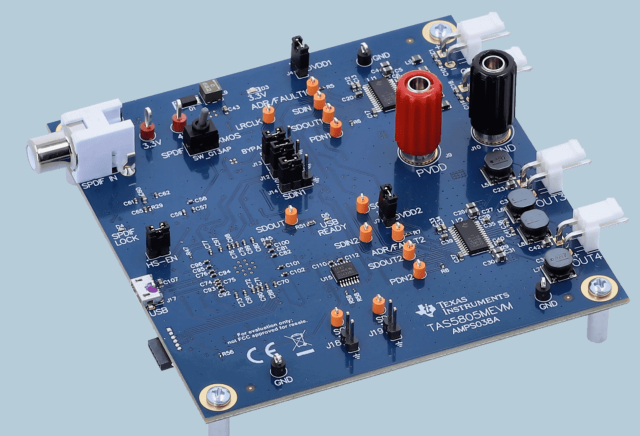

Fabricated Final Board



Amplifier Board Schematic

Development

We developed our control code in parallel with the amplifier board. For testing the control code we procured the TAS5805M EVM - a evaluation board produced by TI for the specific chips we were using. This also came with the PurePath Console 3software that made initial setup and I2C reading straightforward.

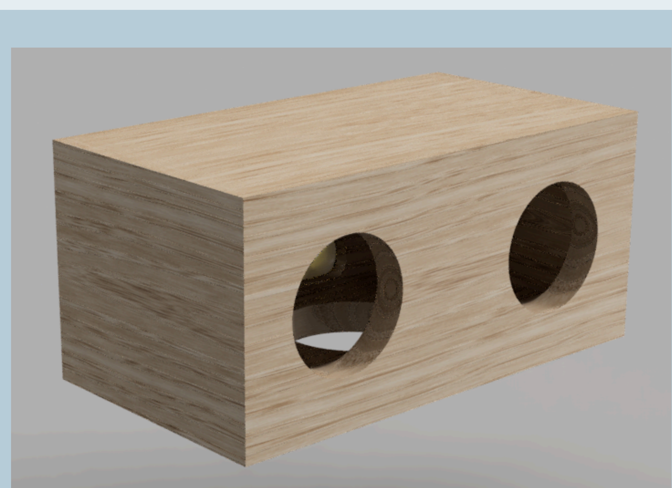

TAS5805M EVM Board

Speaker Box

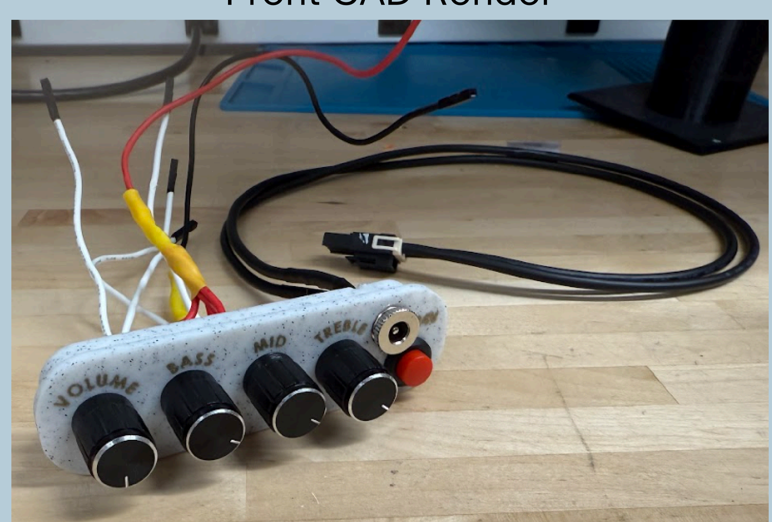
The speaker box was designed to fit our 2.1 speaker system, ESP32, and wiring while keeping good acoustics.

We also have our IO panel and air port located on the back of the box where there is a detachable panel for easy access for assembly.

The design was made in Fusion 360 and then milled on the CNC Router in the Terrapin Works woodshop out of 3/4" MDF. We then glued up the box and wrapped it with maple veneer for a better looking surface finish. Lastly, we 3D-printed a frame to cover the edges (not shown in the photos).


Front CAD Render


Rear CAD Render


IO Panel Assembly


Assembled Box

Code Flow

This is our process flow for taking in audio, configuring the TAS5805M amplifier board and sending commands for any volume adjustment and frequency response tuning.

I2C Process Flow

1. Initialize I2C Communication
2. Calculate Filter Coefficients
3. Normalize Coefficients
4. Convert to Fixed-Point Format
5. Send Filter Settings Via I2C

I2S & Bluetooth Process Flow

1. Establish Bluetooth Connection
2. Audio Conversion to I2S
3. Stream I2S Audio to TAS5805M Chips

Filter Design

Our frequency response filtering and tuning was done by generating the desired bi-quadratic filtering coefficients and then converting them to I2C and sending them to the amplifier board.

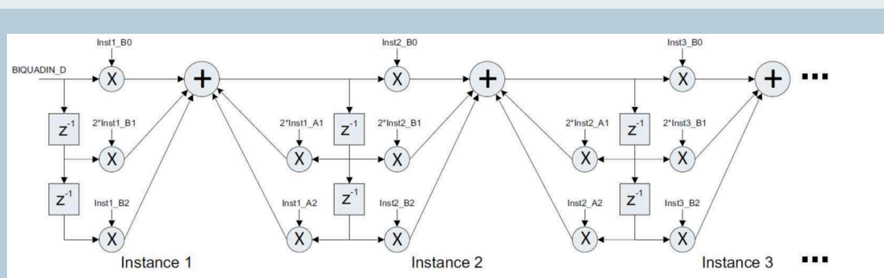


Figure 7. Cascaded BQ Structure

All BQ coefficients are normalized with a0 to insure that a0 is equal to 1. The structure requires 5 BQ coefficients as shown in Table 3.

Table 3. BQ Coefficients Normalization

BQ COEFFICIENT	COEFFICIENT CALCULATION
B0_DSP	b0 / a0
B1_DSP	b1 / (a0 × 2)
B2_DSP	b2 / a0
A1_DSP	–a1 / (a0 × 2)
A2_DSP	–a2 / a0

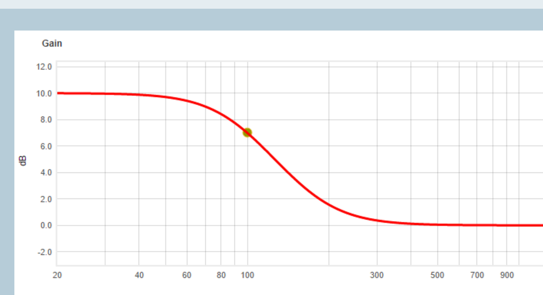
Bi-Quadratic Filter Structure

$$\omega_0 = 2\pi \frac{f_0}{F_s}$$

$$\alpha = \frac{\sin \omega_0}{2Q}$$

$$A = \sqrt{10^{\mathrm{dBgain}/20}}$$

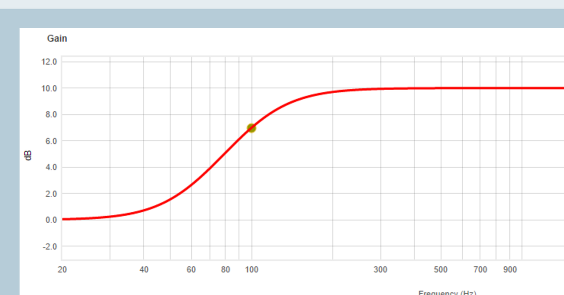
Intermediate Variables



Bass Shelf Filter Example Curve

$$\begin{aligned}
b_0 &= A\left((A+1) - (A-1)\cos\omega_0 + 2\sqrt{A}\,\alpha\right)\\
b_1 &= 2A\left((A-1) - (A+1)\cos\omega_0\right)\\
b_2 &= A\left((A+1) - (A-1)\cos\omega_0 - 2\sqrt{A}\,\alpha\right)\\
a_0 &= (A+1) + (A-1)\cos\omega_0 + 2\sqrt{A}\,\alpha\\
a_1 &= -2\left((A-1) + (A+1)\cos\omega_0\right)\\
a_2 &= (A+1) + (A-1)\cos\omega_0 - 2\sqrt{A}\,\alpha
\end{aligned}$$

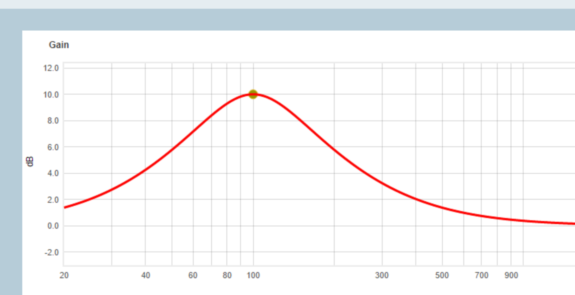
BQ Filter Coefficients



Treble Shelf Filter Example Curve

$$\begin{aligned}
b_0 &= A\left((A+1) + (A-1)\cos\omega_0 + 2\sqrt{A}\alpha\right)\\
b_1 &= -2A\left((A-1) + (A+1)\cos\omega_0\right)\\
b_2 &= A\left((A+1) + (A-1)\cos\omega_0 - 2\sqrt{A}\alpha\right)\\
a_0 &= (A+1) - (A-1)\cos\omega_0 + 2\sqrt{A}\alpha\\
a_1 &= 2\left((A-1) - (A+1)\cos\omega_0\right)\\
a_2 &= (A+1) - (A-1)\cos\omega_0 - 2\sqrt{A}\alpha
\end{aligned}$$

BQ Filter Coefficients



Peak Filter Example Curve

$$\begin{aligned}
b_0 &= 1 + \alpha A\\
b_1 &= -2\cos\omega_0\\
b_2 &= 1 - \alpha A\\
a_0 &= 1 + \frac{\alpha}{A}\\
a_1 &= -2\cos\omega_0\\
a_2 &= 1 - \frac{\alpha}{A}
\end{aligned}$$

BQ Filter Coefficients