Smart Auto-Equalization Sound System

Critical Design Review

Group 31

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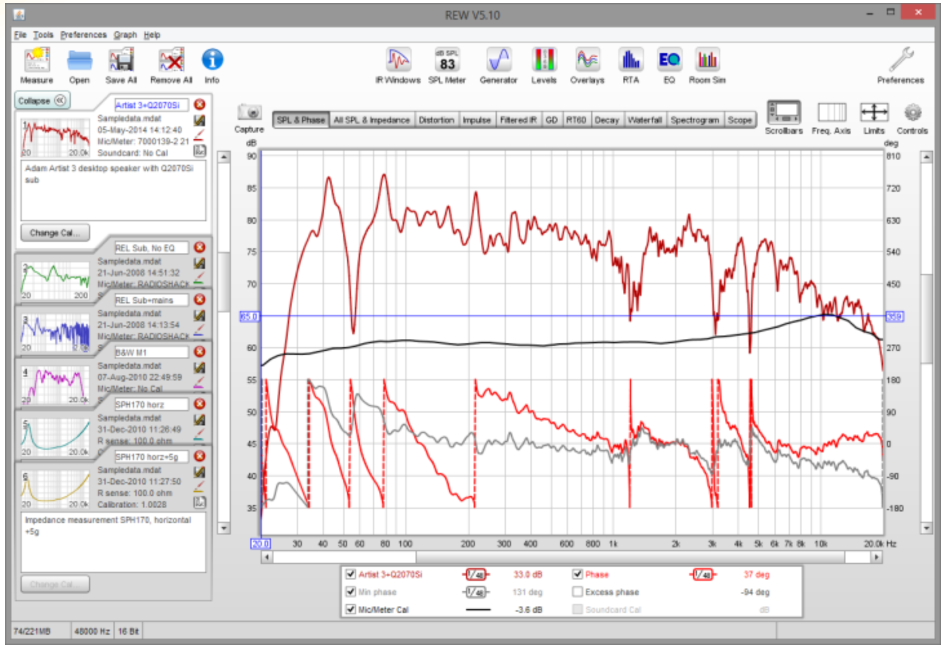
Motivation & Background



- Manual EQ is time-consuming
- Room acoustics change sound drastically
- Existing solutions require external tools or audio expertise
- To create an ecosystem between the speaker and audio adjustment software, removing the need for 3rd party services.
- Our goal: provide an easy-to-use system that automatically measures the room and corrects itself

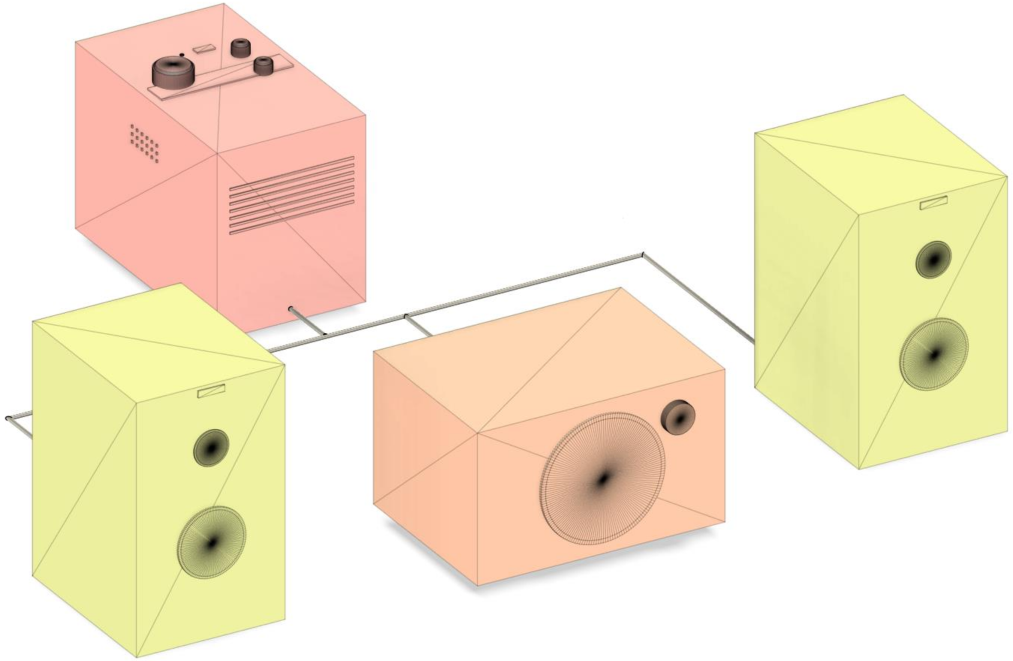
Goals & Objectives

- Basic Goals
  - 2.1 System
  - Auto-EQ
  - Mobile App
- Advanced Goals
  - DSP
  - Adaptive Filtering
  - Noise Sweeps
- Stretch Goals
  - Bluetooth Streaming
  - Distortion Prevention

- Basic Objectives
  - Create an EQ algorithm that is fast, and reliable.
  - Implement correct amplification factor to achieve sufficient power.
  - Achieve a base equalization setting, to help the algorithm figure out a starting point
- Advanced Objectives
  - Provide a fast and reliable connection between the app and the system.
- Stretch Objectives
  - Achieve a runtime of N*log(N) N where the number of samples.
  - Provide the user with real-time data including histograms and charts.

3D Illustration of System

- Fully integrated 2.1 audio system
- Central processing & control enclosure
- Dedicated mid/high speakers and subwoofer
- Custom amplification and DSP control



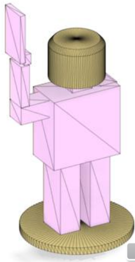


Table of Engineering Specifications

Specification	Target Value	Notes
Frequency Response Range	20 Hz – 20 kHz	Full audio spectrum
Total Harmonic Distortion (THD)	≤ 0.5%	At rated power
Amplifier Output Power	50W RMS (subwoofer), 25W RMS (mid/high)	Per channel
MCU Processing	≥ 240 MHz dual-core with FPU/DSP	ESP32-S3 candidate
Microphone Accuracy	≤ ±1 dB	Acoustic measurements
Power Supply	±12V to ±24V (audio), +5V/+3.3V (logic)	Linear + switching regulation
Latency (Mic-to-DSP-EQ)	≤ 20 ms	Real-time correction

Processor Technologies Comparison

Specification	SBC	FPGA	MCU
Processing Power	High	High	Moderate – Low
Throughput	High	High	Low
Programming (Difficulty)	Moderate - High	High	Moderate – Low
Project Fit	Moderate	Good	Very Good
Price	Moderate	High	Low

MCUs Comparison

Specification	ESP32-S3-N16R8	STM32H735ZGT6	i.MX NXP RT1170
Processor	Xtensa LX7	Arm Cortex-M7	Arm Cortex-M7, Arm Cortex-M4
Frequency (max.)	240 MHz	550 MHz	1 GHz, 400 MHz
Bluetooth (BLE)	✓	✗	✗
DSP	ESP-DSP Library	CORDIC, FMAC, CMSIS Library	CMSIS Library
ADC	2 x 12-bit	2 x 16-bit, 1 x 12-bit	2 x 12-bit
DAC	✗	2 x 12-bit	1 x 12-bit
Price (Approx.)	$ 6.00	$ 13	$ 26

DAC vs CODEC

- The DAC is the only component missing in the MCU.
- A CODEC would amplify the performance of the design.
- CODECs often offer better resolution → but more connections (software & hardware) would need to be done.

DAC Comparison

Specification	**DAC8555IPW**	**AD1934WBSTZ-RL**	**AD5664ARMZ-REEL7**	**DAC8574IPW**
Resolution (bits)	16	24	16	16
Channels	4	8	4	4
SNR (dB)	95	108	N/A	N/A
THD (dB)	-85	-94	-80	-65
Operating Freq. (Max.)	50 MHz	27.6 MHz	50 MHz	3.4 MHz
Interface	SPI, DSP	SPI, I2S	SPI, DSP	I2C
Price (Approx.)	$ 15	$ 11	$ 18	$ 23

ADC

- ESP32 has a 12-bit ADC onboard, but is nonlinear and is said that 3 bits are noise
- Original plan was to use the ESP32 ADC
- To minimize potential issues, an external ADC was introduced to the design during the early stages of SD2
- The ADC is the ADS8320 by TI
- ADC is 16-bit, utilizes minimal connections, and has SPI communication
- SPI chosen for speed and simple operation

Amplifier Topologies

- Multiple amplifier classifications to choose from
- The main topologies used for audio electronics are Class AB and Class D
- Class A is also used but is highly inefficient so use is minimal
- Amplifiers can be integrated on an IC, perfect for simple integration for our project

Class	A	B	AB	D
Efficiency	Very Low	High	Medium	Very High
THD	Low	Very High	Low-Medium	Low-Medium
Footprint	Large	Medium	Large	Small
Heatsink	Large	Medium	Large	Small
Cost	High	Medium	High	Medium

Mids and Highs Amplifier

- Most considerations were for Class D amplifiers for efficiency
- TPA3116 was chosen to for THD and power output
- LM3886 is a backup choice as we have been warned of issues with TPA amplifiers

Device	Topology	Power	THD	Efficiency	Price
TPA3116D2DADR	Class D	2x50W @ 4Ω	<0.1%	~90%	$3.10
TPA3112D1QPWPRQ1	Class D	1x25W @ 8Ω	0.1%	94%	$2.84
		1x20W @ 4Ω	10%	Not Considered	
MAX9709ETN+D	Class D	2x25W @ 8Ω	10%	Not Considered	$21.80
		1x35W @ 4Ω	0.5%	~85%	
LM3886	Class AB	2x38W @ 8Ω	<0.1%	~50%	$7.01
		1x68W @ 4Ω	<0.1%	<50%	

Subwoofer Amplifier

- TPA3251 chosen for multitude of options, and THD
- Other options border our THD specification, offering no room for error in board layout or audio processing

Device	Topology	Power	THD	Efficiency	Price
TPA3251D2DDVR	Class D	2x55W @ 8Ω	0.5%	90%	$7.81
		2x100W @ 4Ω	0.01%	90%	
		2x100W @ 3Ω	0.01%	85%	
		1x60W @ 8Ω	0.5%	N/A	
		1x125W @ 4Ω	0.01%	N/A	
		1x200W @ 2Ω	0.01%	N/A	
TDA7293	Class AB	1x90W @ 8Ω	0.5%	N/A	$8.49
		1x70W @ 4Ω	0.5%	N/A	
TPA3221DDVR	Class D	1x45W @ 8Ω	0.5%	90%	$4.39
		1x80W @ 4Ω	0.5%	80%	
		1x100W @ 3Ω	0.5%	80%	
		1x100W @ 4Ω	0.5%	90%	
		1x100W @ 2Ω	<0.1%	85%	

Microphone

- The ECM99 is the cheapest choice even with having an attractive SNR decibel level compared to the UMIK-1
- The UMIK-1 although the most expensive option, does have the highest SNR decibel level
- The EMM-6 has the highest sensitivity and a close SNR to both the ECM99 and UMIK

Microphone	Cost	Sensitivity	SNR	Frequency Range
Superflux ECM99	$49.99	37dB	77dB	20kHz
miniDSP UMIK-1	$128.95	39dB	78dB	20kHz
Dayton Audio EMM-6	$59.98	40dB	70dB	20kHz

Power Supply Unit (PSU)

	LRS-600-48	LRS-600N2-36	LAD-600C	LAD-600CU
Output Voltage (V)	48	36	41.5	41.5
Output Current (A)	12.5	16.6	11.45	11.45
Efficiency (%)	92	92	91	91
Temp Range (C)	-20 to +65	-20 to +65	-20 to +60	-20 to +60
Distinguishing Features	Fan	Fan and 200% peak power capability	Battery Charger	UART and Battery Charger
Price	$59.90	$64	$77.90	$89.30

Component Comparison (Tweeter)

Speaker Consideration	Frequency Range	Power Handling	Sensitivity
Peerless by Tymphany BC255C08-04	2,500 Hz – 20,000 Hz	100 W	98 dB
Peerless by Tymphany XT25SC40-04	2,500 Hz – 20,000 Hz	100 W	91.1 dB
Mr. DJ HDT5005	???	100 W	109 dB

Component Comparison (Subwoofer)

Speaker Consideration	Frequency Range	Power Handling	Sensitivity
Kicker 43CVT102	25 Hz – 500 Hz	350 W – 700 W	87.2 dB
Goldwood GW-212/4	28 Hz – 4,000 Hz	120 W – 240 W	92.3 dB
Goldwood GW-10PC-4	25 Hz – 3,000 Hz	200 W – 400 W	92.7 dB

Component Comparison (Mid-Gain Speaker)

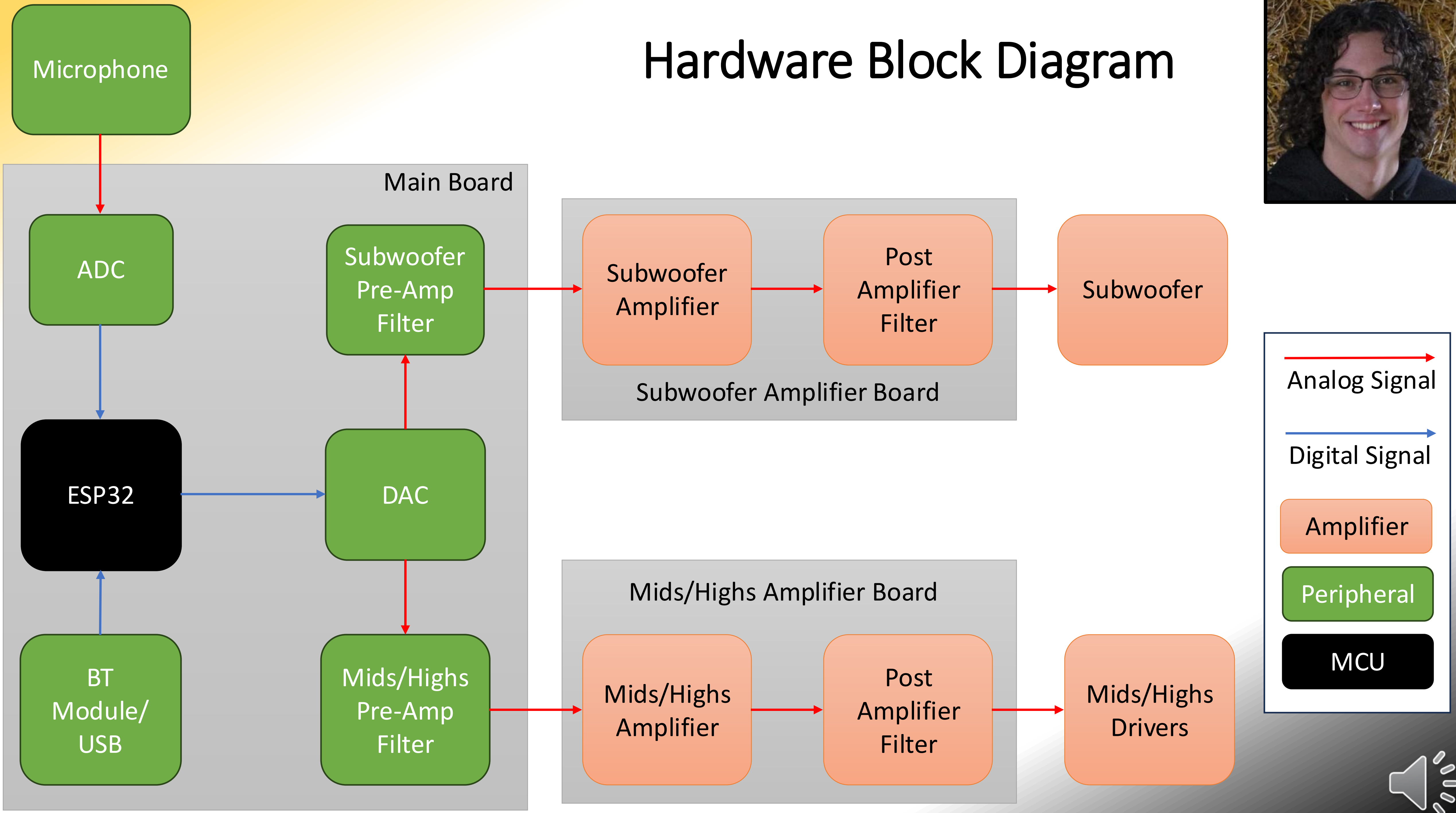
Speaker Consideration	Frequency Range	Power Handling	Sensitivity
Dayton Audio DC130B-4	50 Hz – 5000 Hz	40 W – 80 W	92.1 dB
Goldwood GM-65/4	550 Hz – 15,000 Hz	50 W – 100 W	92 dB
Goldwood GM-85/4	500 Hz – 15,000 Hz	60 W – 120 W	92 dB

Bluetooth Module

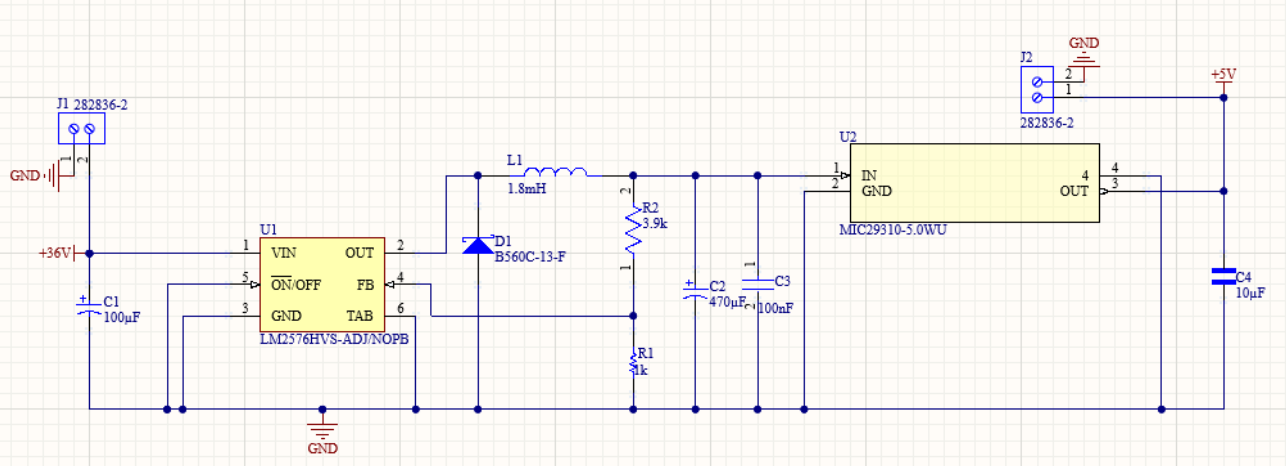
- Bluetooth module needed for A2DP communication protocol
- FSC-BT1026 has many features unnecessary to our design
- BM83 was chosen for its price and ease of integration

Device	**BM83**	**BM64**	**FSC-BT1026**
Transmission Power (dBm)	+11	+15	+9
Receiver Sensitivity (dBm)	-90	-90	-100
Transfer Rate	2	2	3
Antenna	PCB	PCB	PCB or External
Price	$12.20	$18.13	$14.46

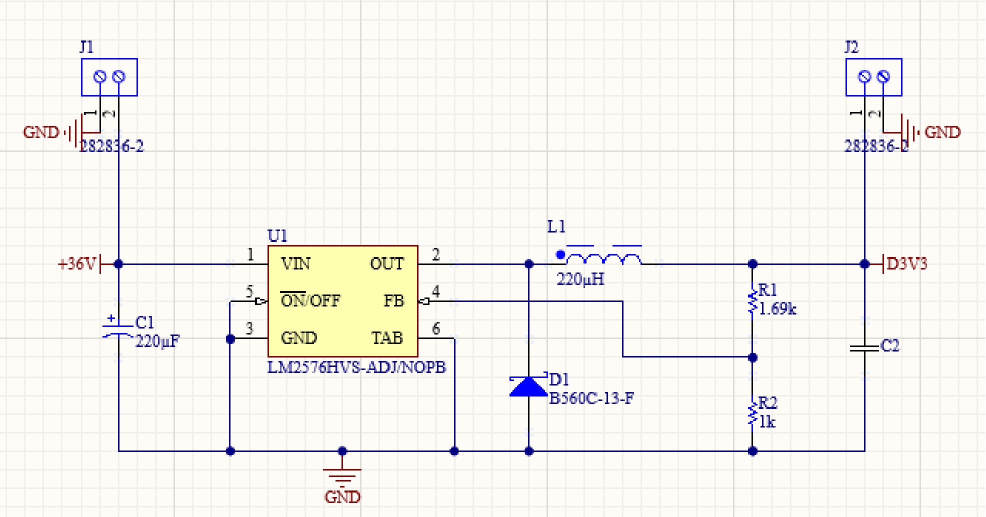
Hardware Block Diagram



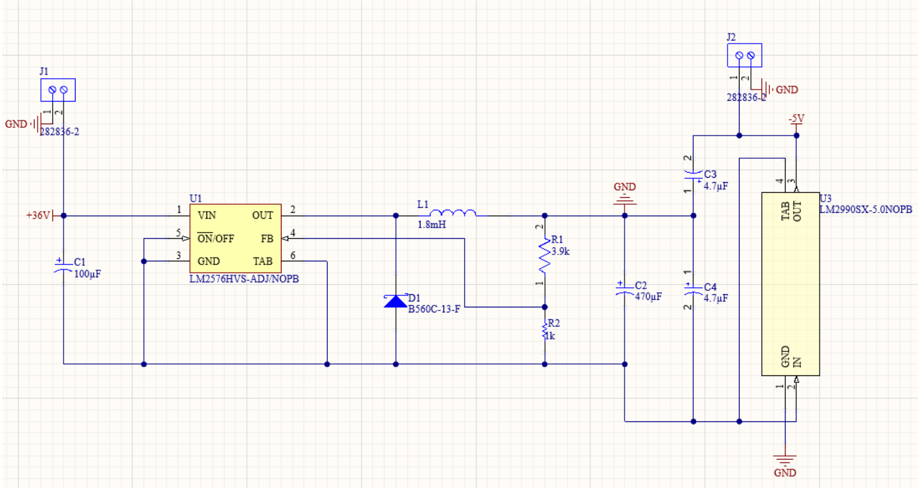
PCB Design (MCU Regulators)



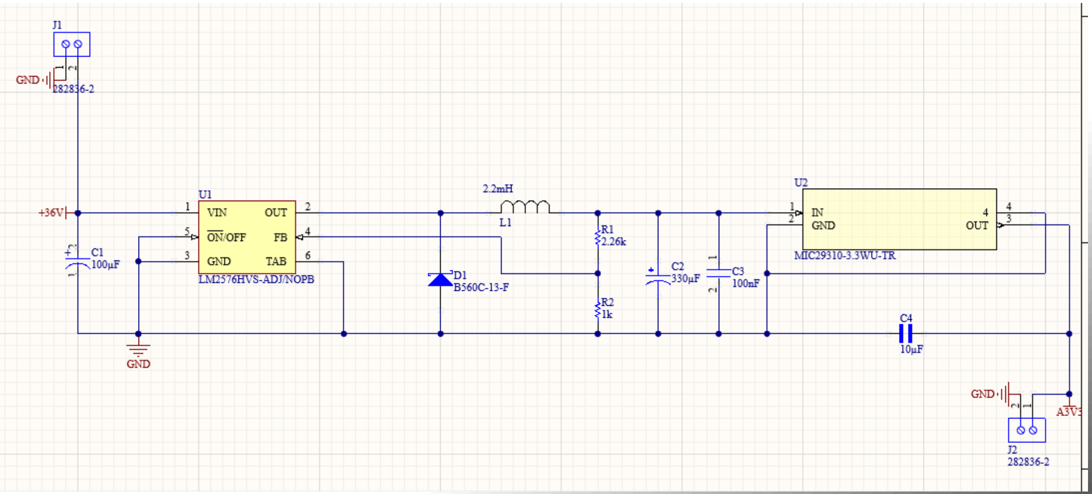
+5V Regulator



Digital 3.3V Regulator

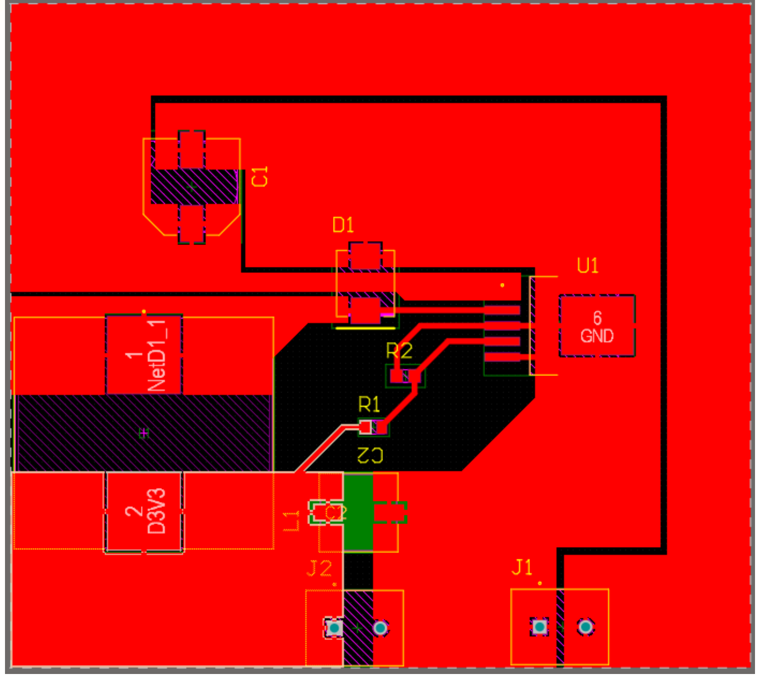


-5V Regulator

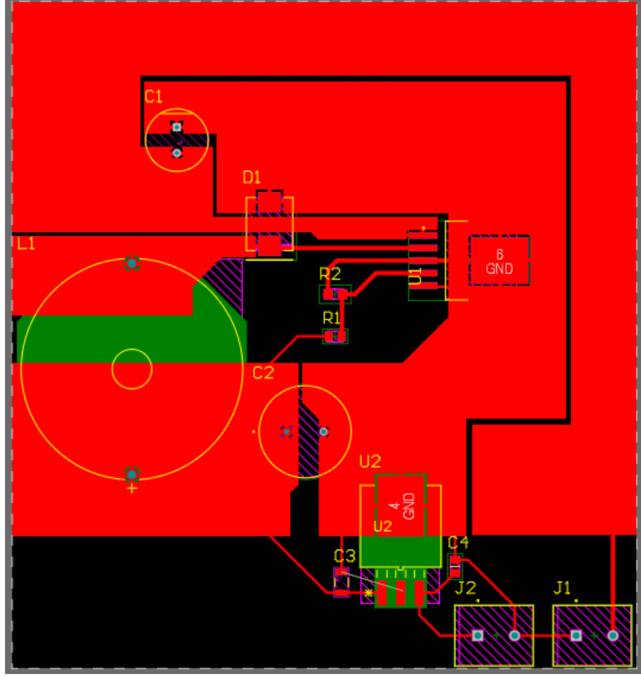


Analog 3.3V Regulator

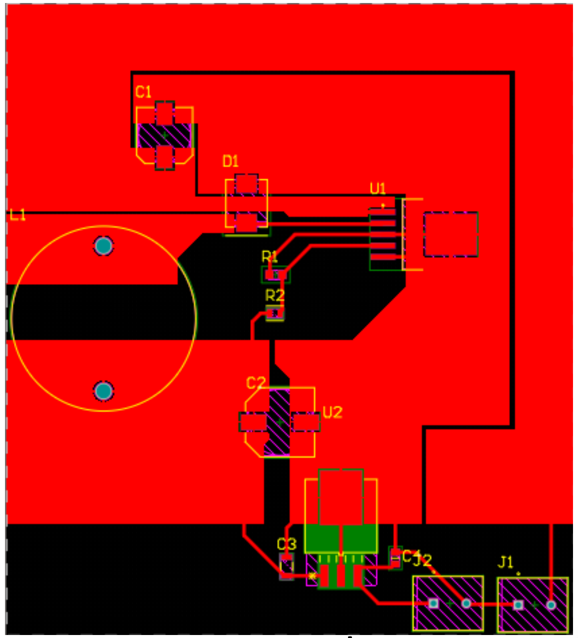
PCB Design (MCU Regulators)



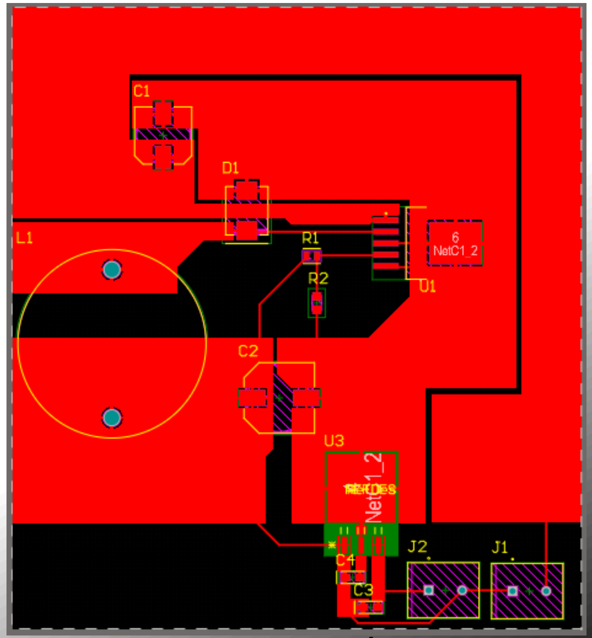
Analog 3.3V Regulator



Digital 3.3V Regulator

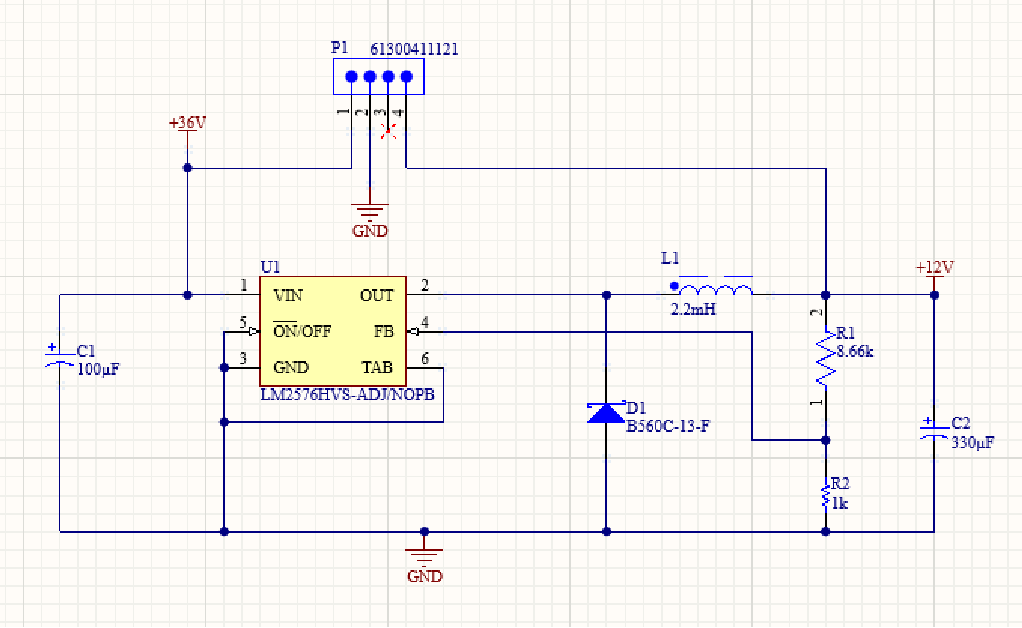


+5V Regulator

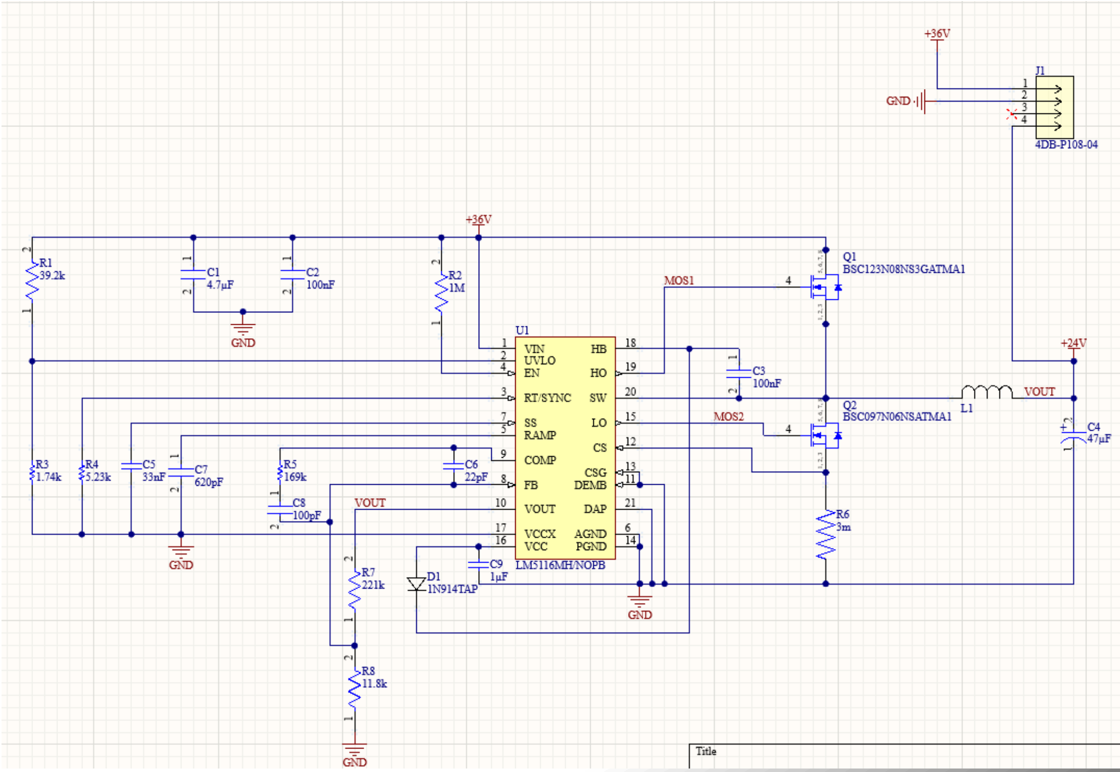


-5V Regulator

PCB Design (Amplifier Regulators)

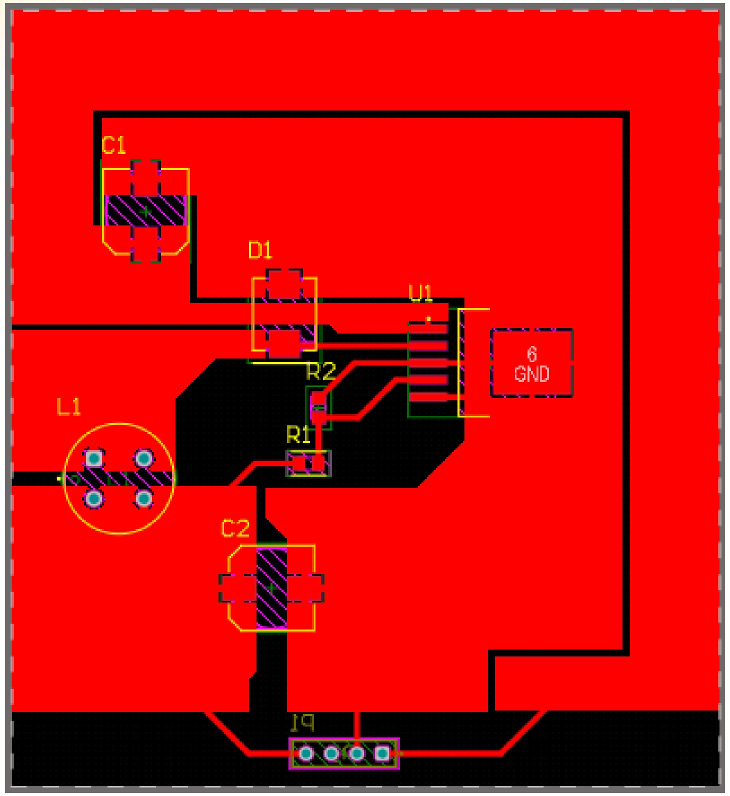


+12V Regulator

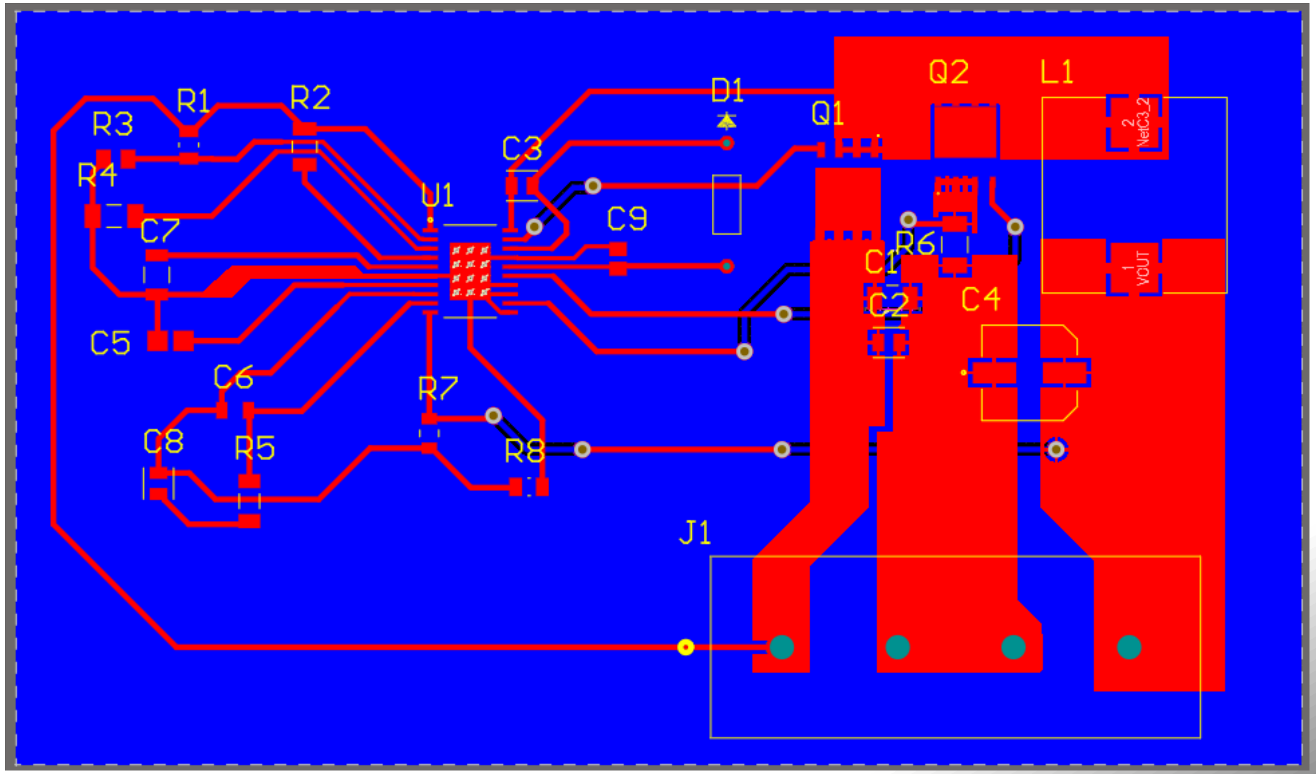


+24V Regulator

PCB Design (Amplifier Regulators)

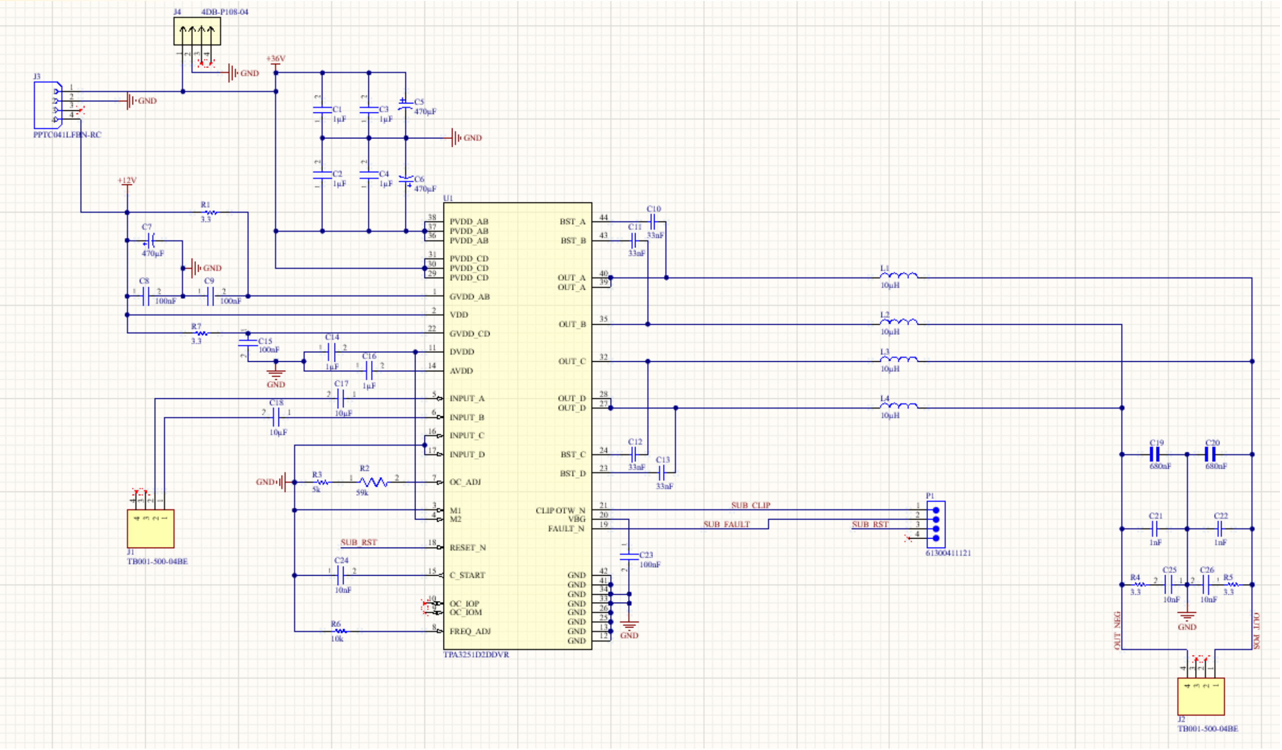


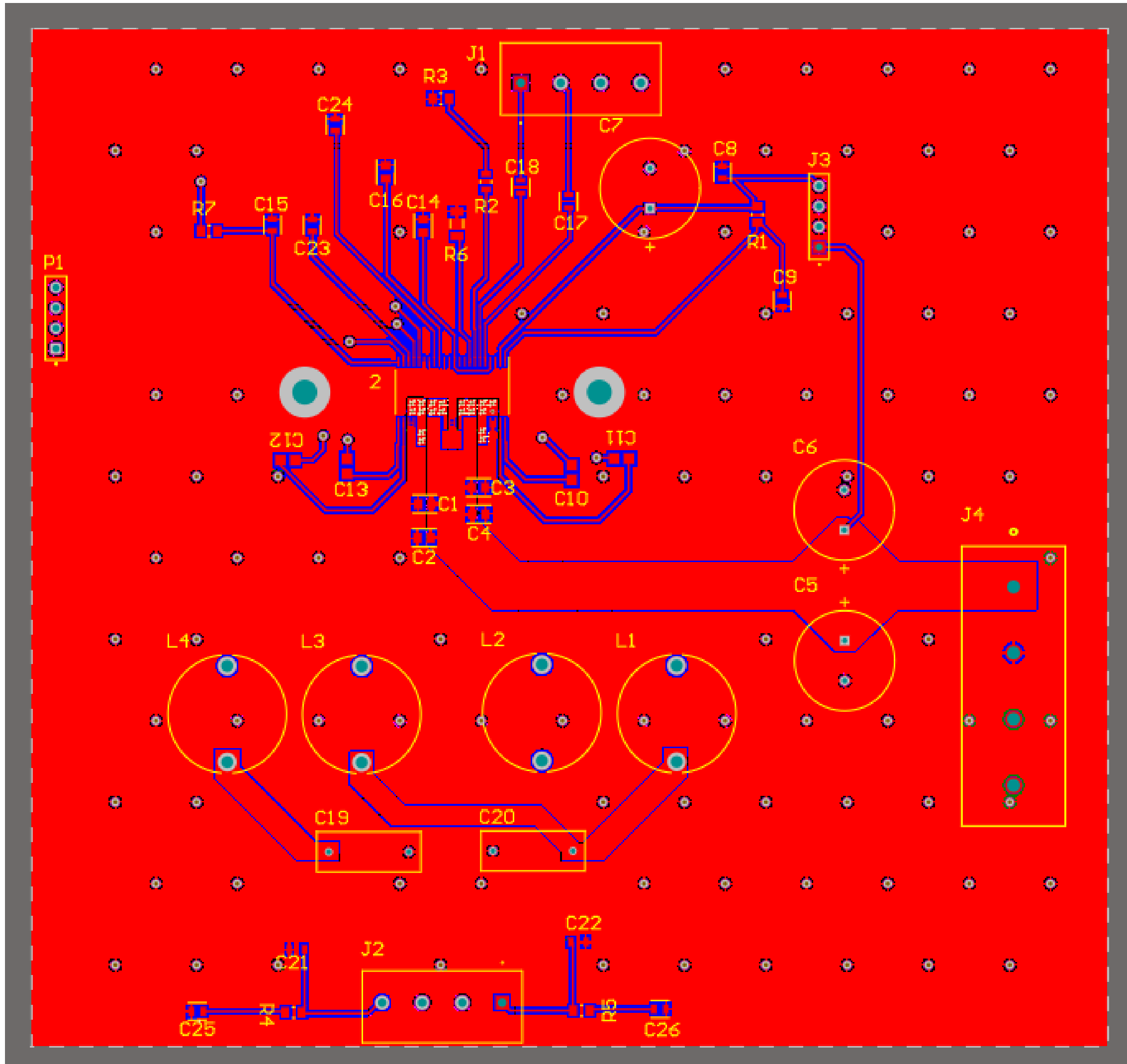
+12V Regulator



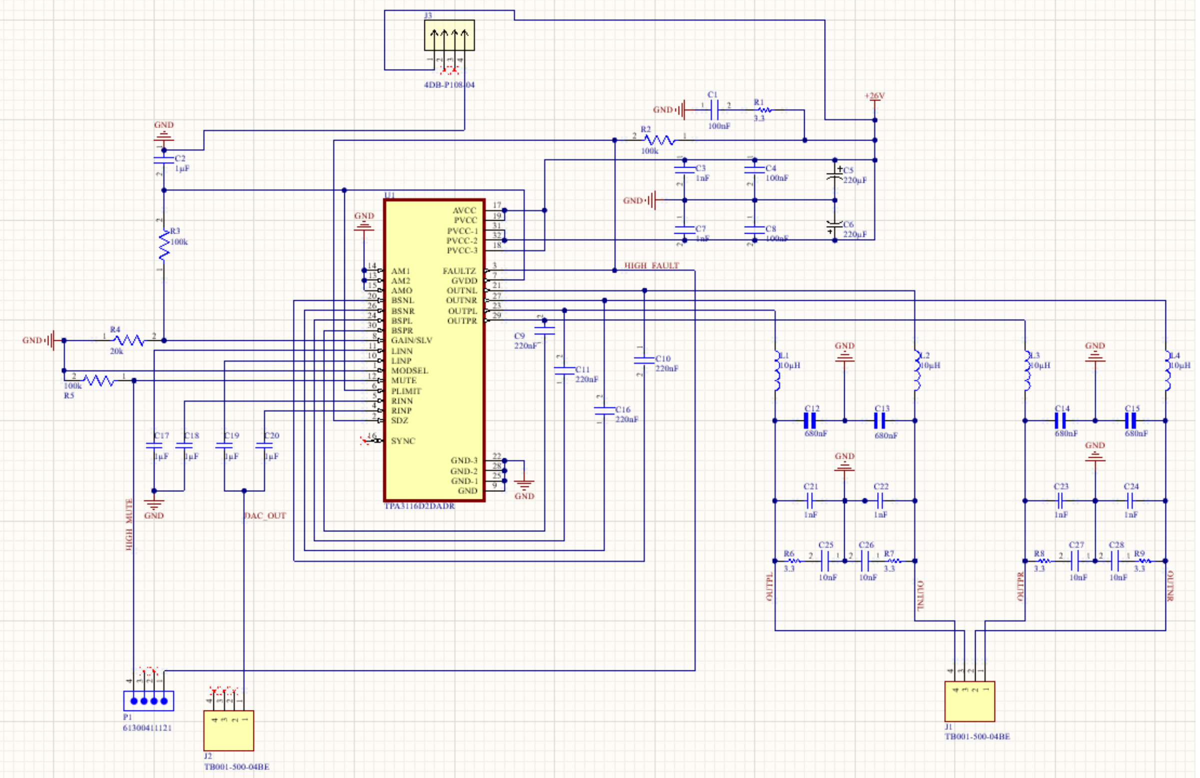
+24V Regulator

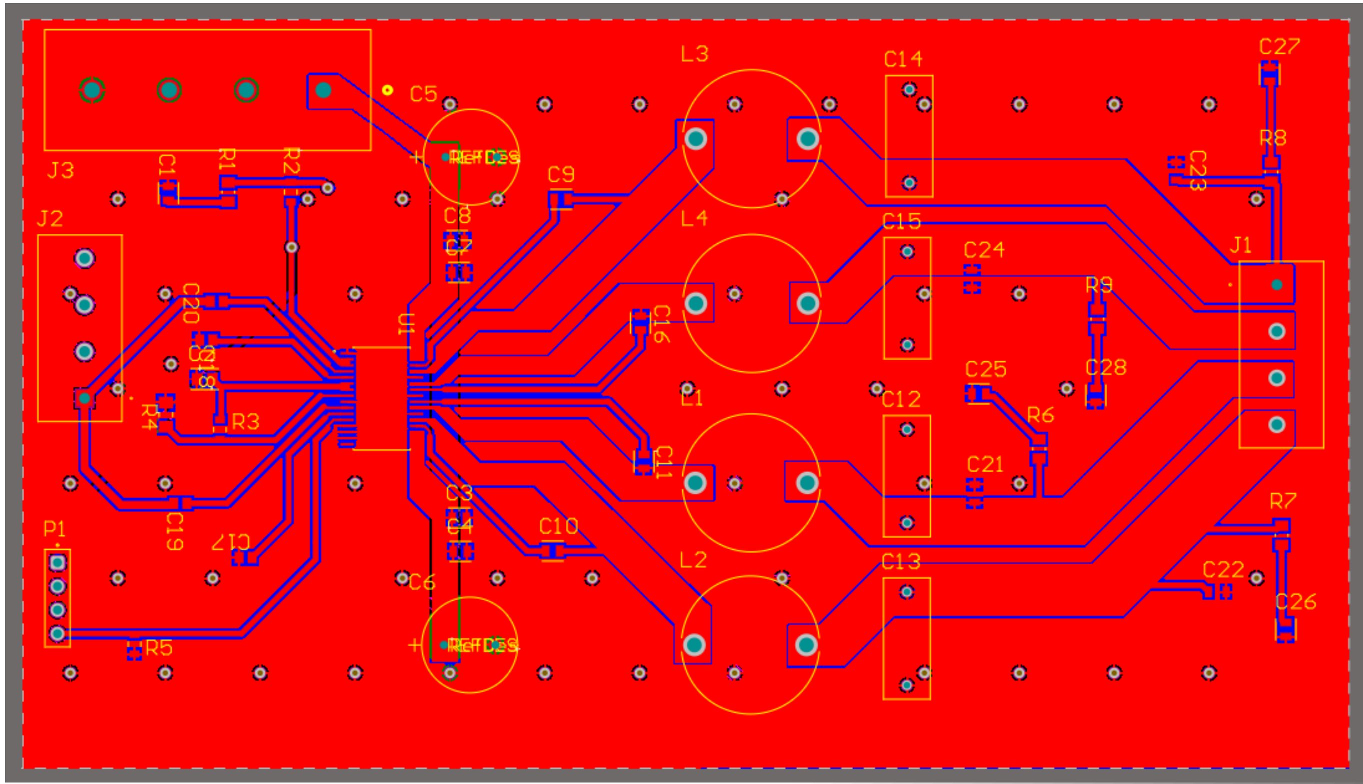
PCB Design (Subwoofer Amplifier)



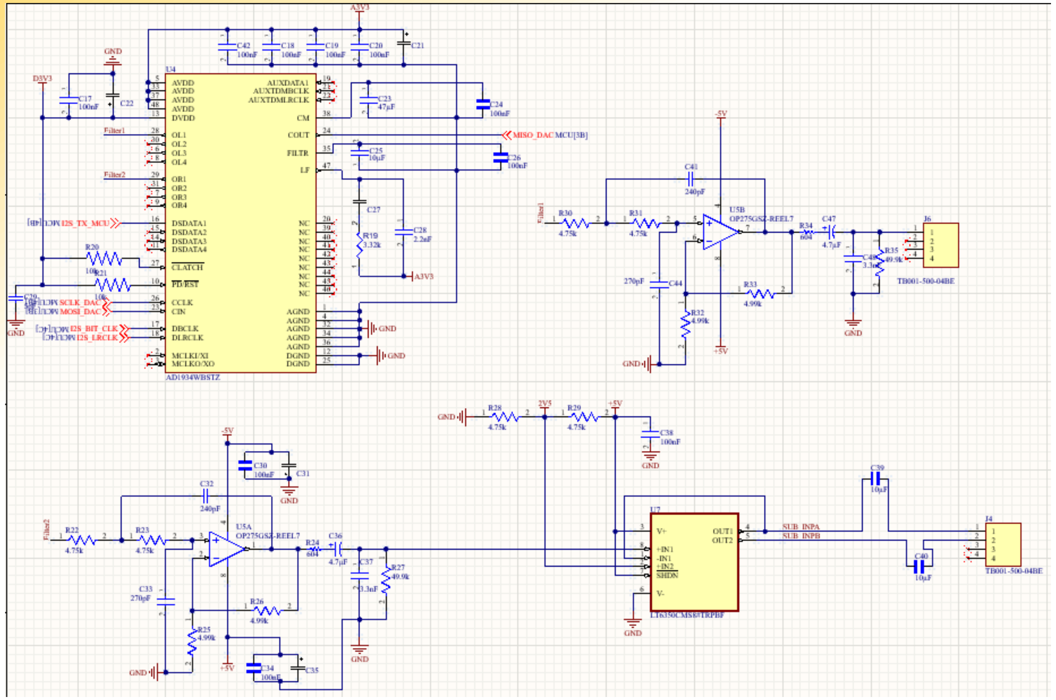


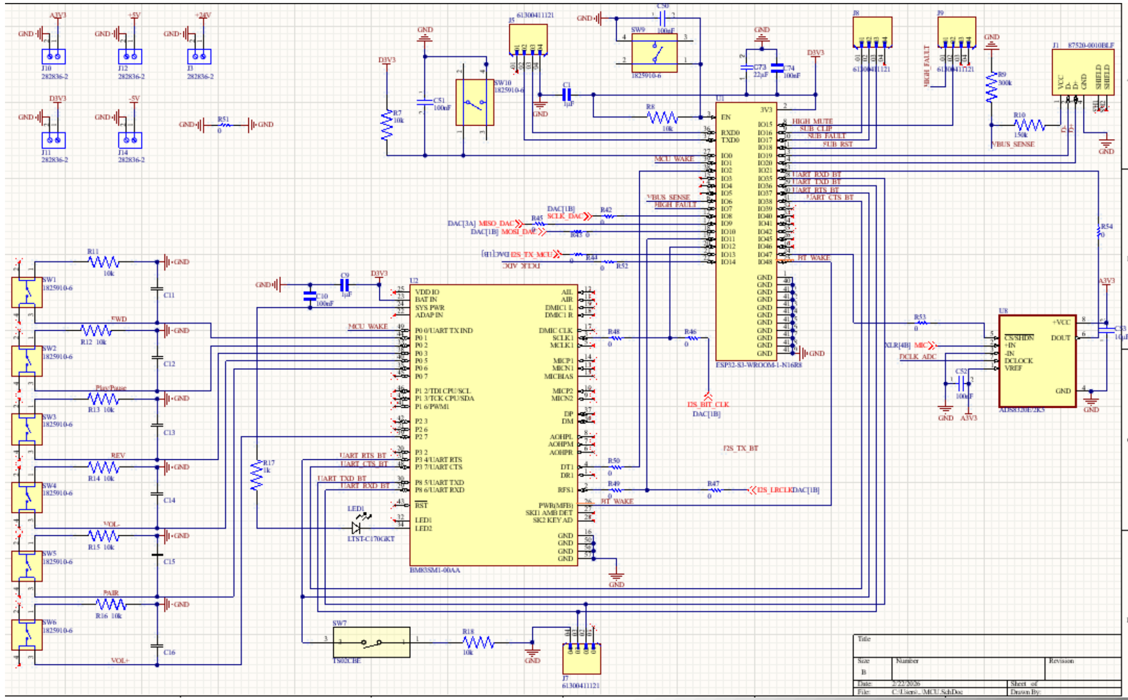
PCB Design
(Mid/High Amplifier)

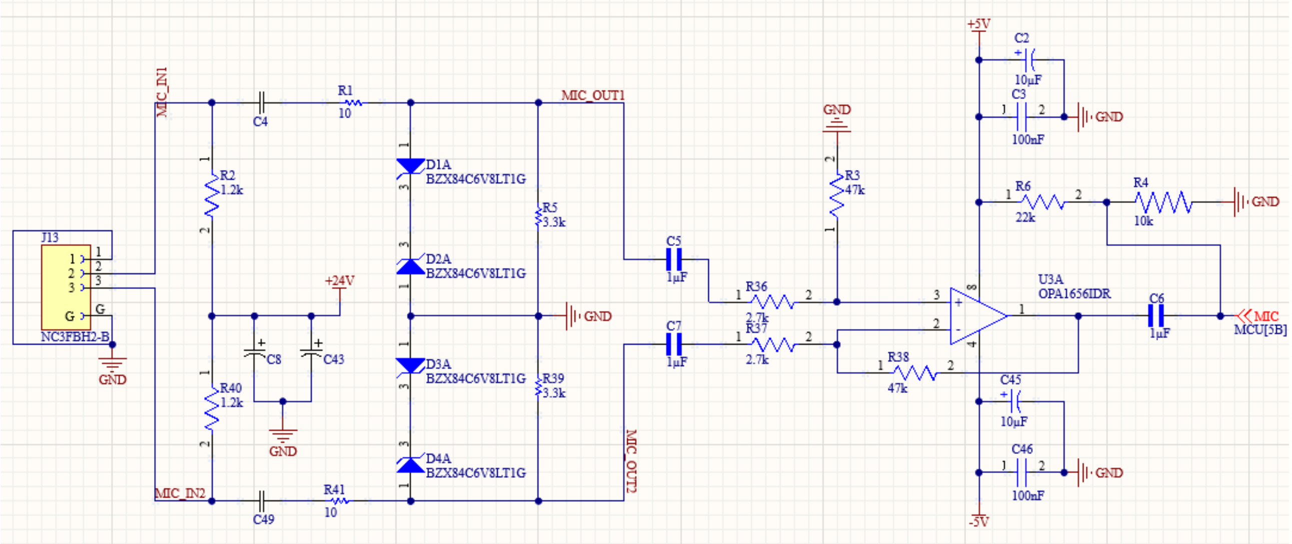




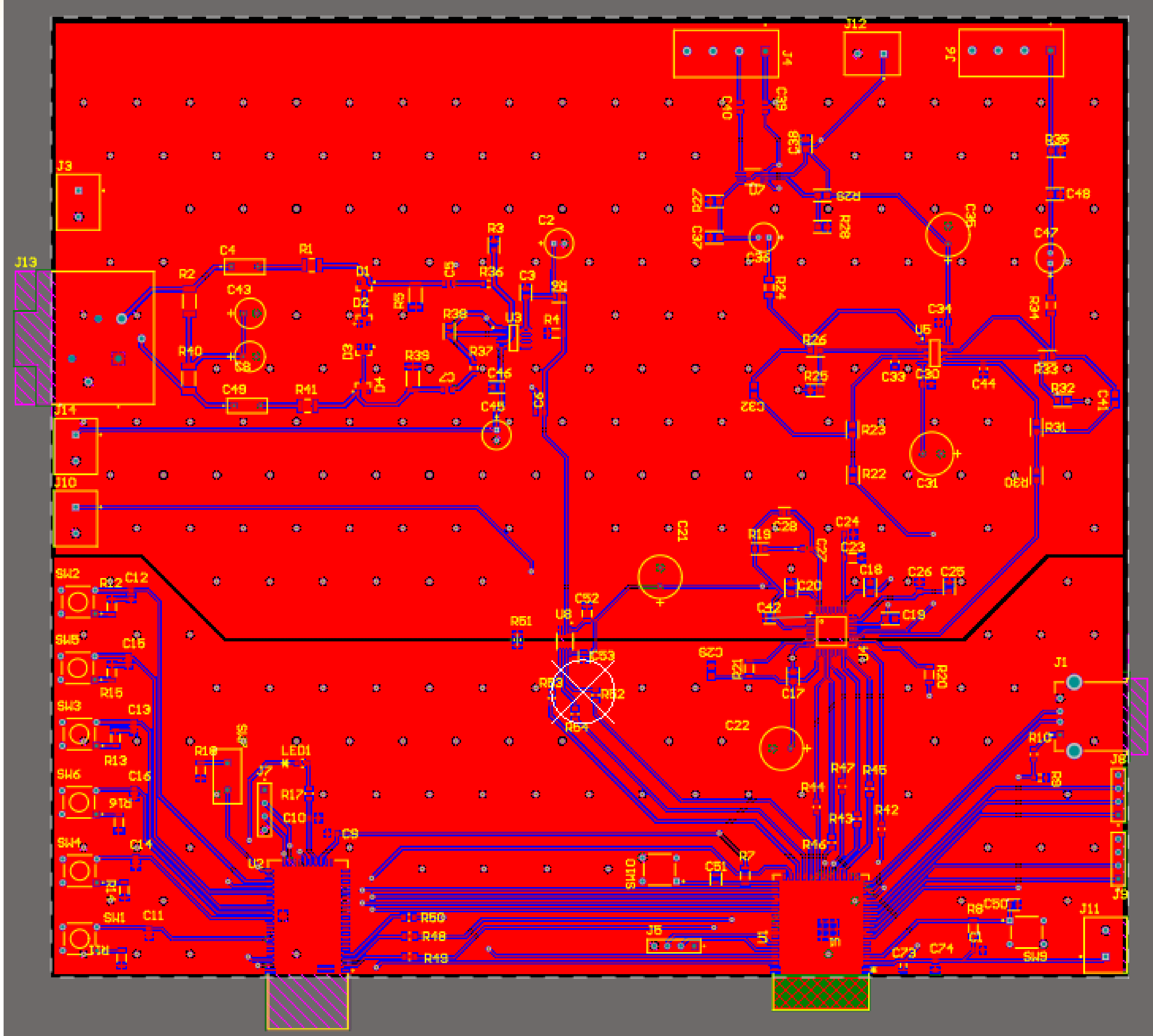
PCB Design (MCU Board)



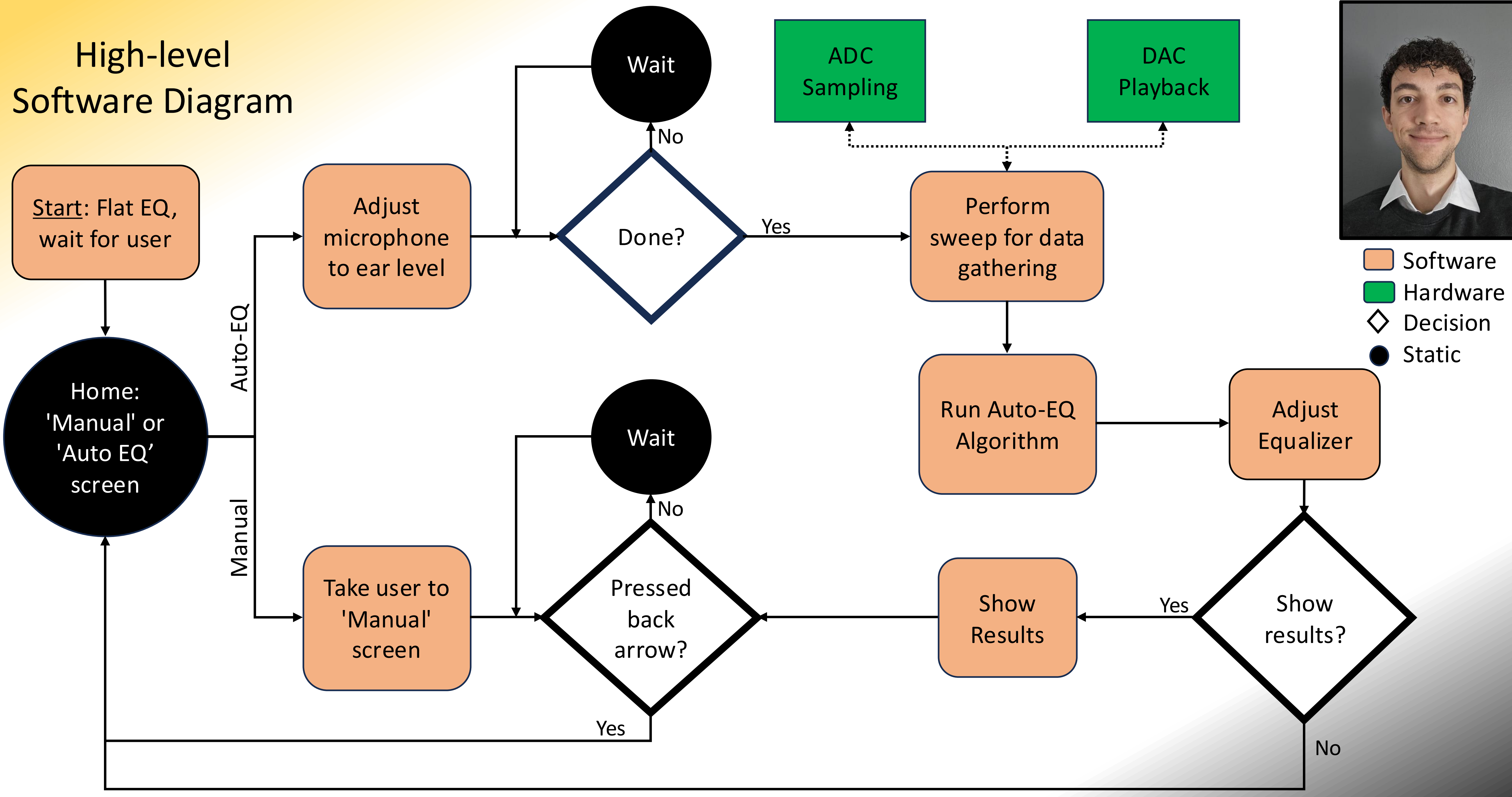




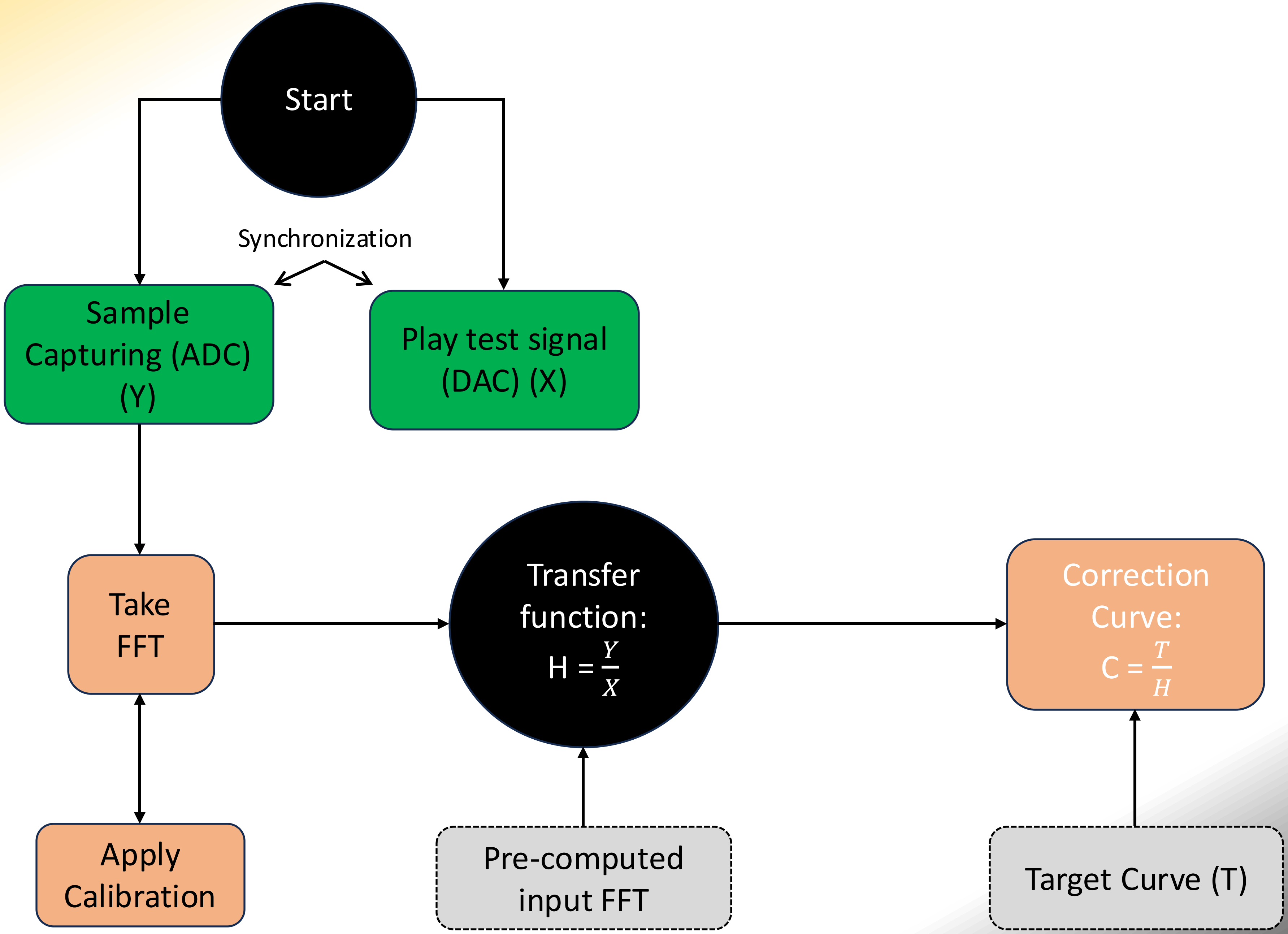
PCB Design (MCU)



High-level Software Diagram

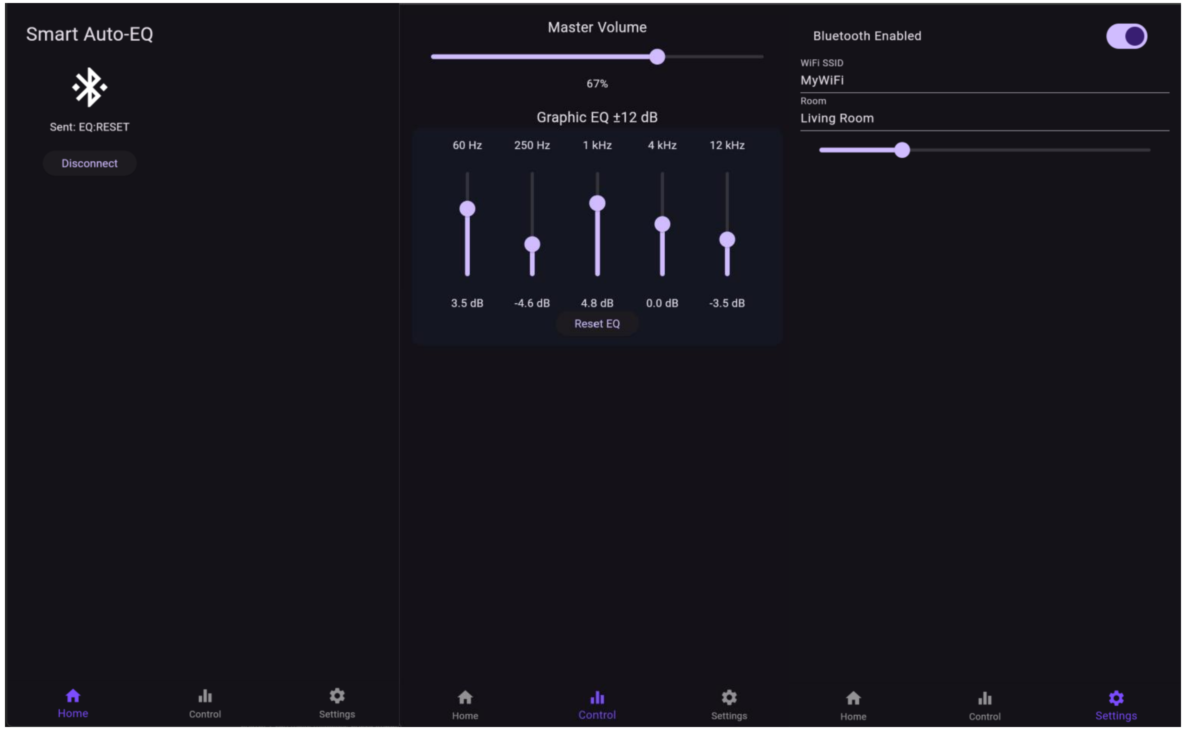


Auto-EQ Algorithm



Software
Hardware

Mobile Application



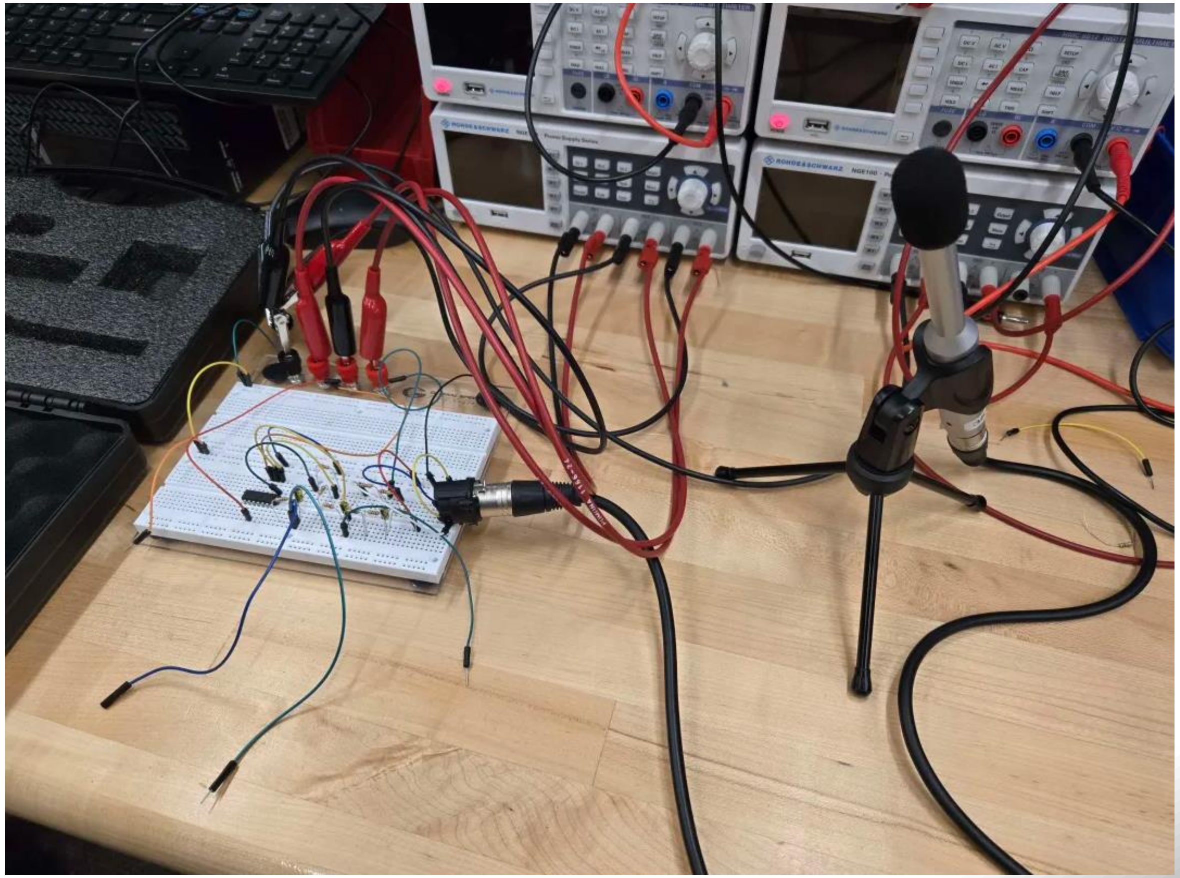
- **App Framework – Comparison**
  - Flutter (selected)
  - Single codebase for OS
- High-performance UI rendering
- Strong support for:
  - Socket / serial-style communication
  - Real-time UI updates
  - Custom controls and visualization
- Rapid iteration during development
- **Alternatives Considered**
- React Native
  - JS bridge overhead
- Native iOS / Android
  - Duplicate codebases
  - Increased development time

- **Why Flutter Fits This Project**
- Clear separation between:
  - UI layer
  - Control logic
  - Data handling
- Handles:
  - Auto-EQ execution control
  - Manual EQ parameter updates
  - System telemetry and status
- Clean integration with ESP32 communication stack

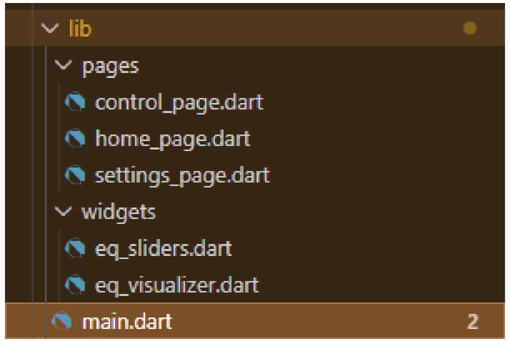
- **App Deployment & Backend Design**
- Local deployment (APK / iOS build)
- No cloud backend
- ESP32-S3 acts as backend
  - Handles:
    - DSP processing
    - Audio routing
    - Control command parsing
    - Status reporting

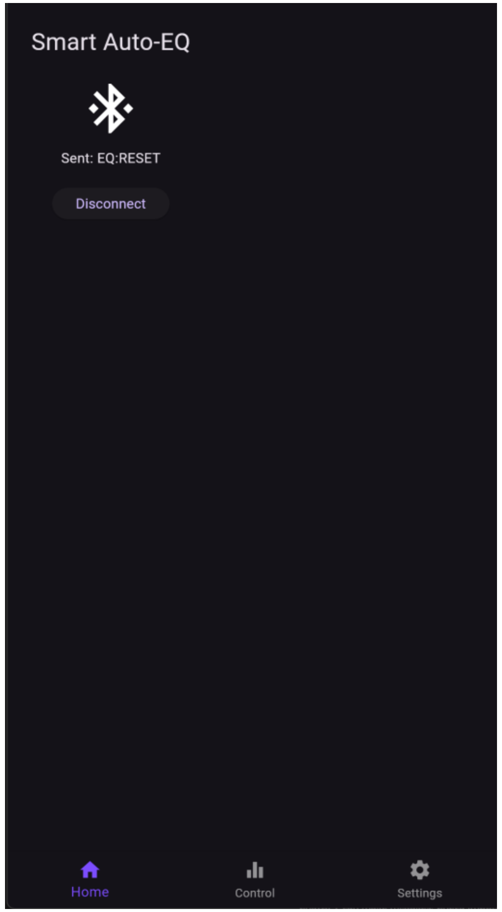
Microphone Demo Testing

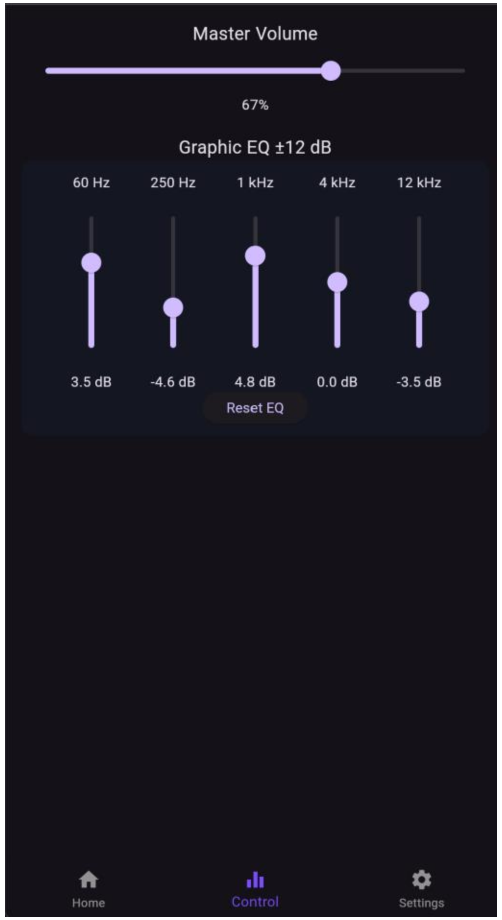
- We were able to replicate the amplitude of the sine wave being tested from the microphone to the ESP
- Further testing includes being able to read the correct frequency from the microphone to the ESP

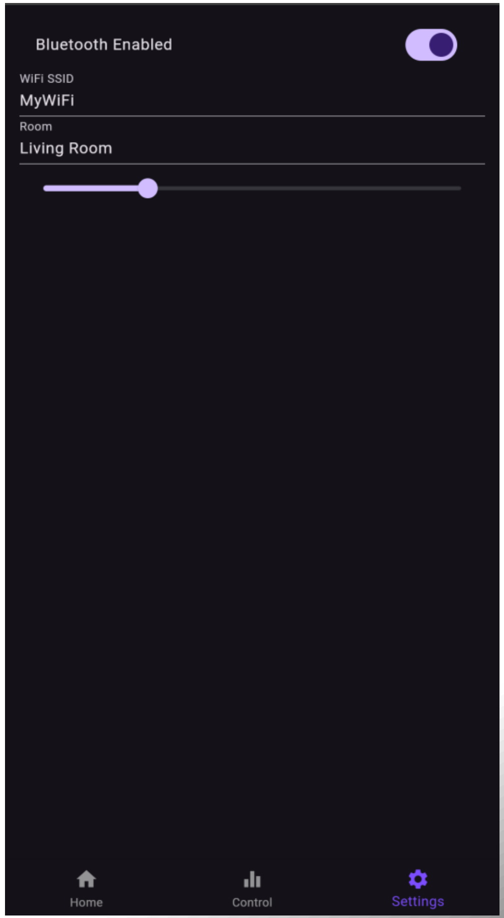


App Capability Demo Testing



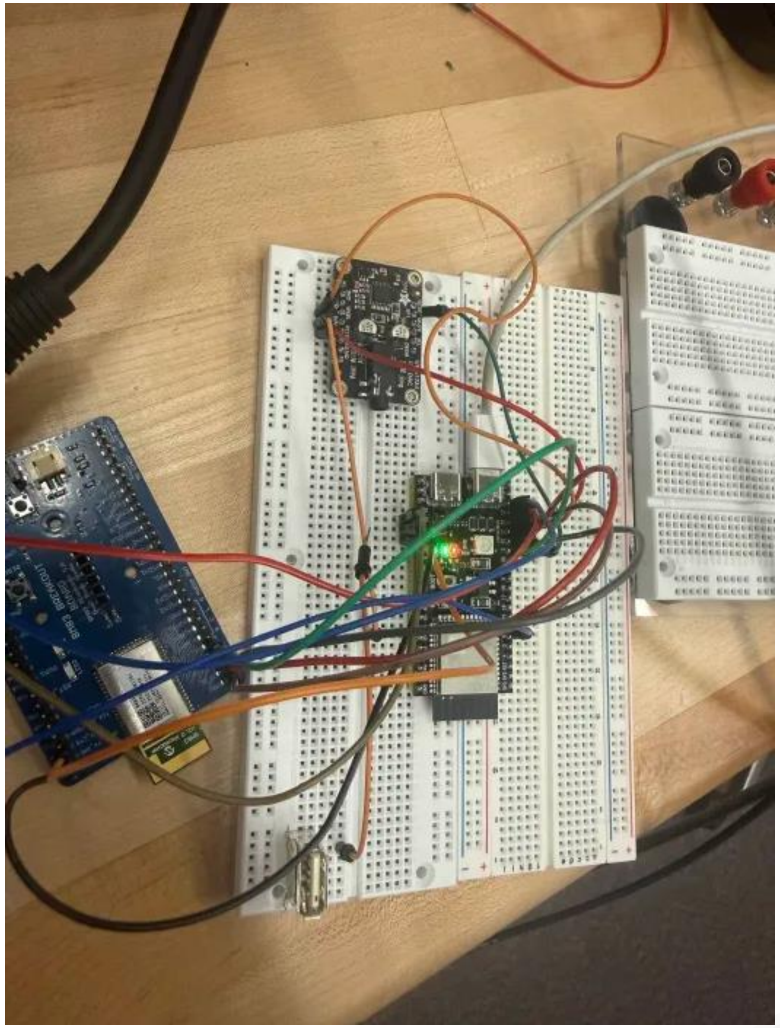






Bluetooth Data Streaming and I2S Communication Protocol Demo Testing

- Pipeline: Bluetooth -> MCU -> DAC
- We were able to connect to the Bluetooth unit via A2DP to send a 1kHz sine wave.
- Implemented I^{2}S communication between the BT module, the MCU and the DAC (substitute).
- Further testing will include streaming more complex audio (not a simple sine wave).



Work Distribution

Noah
MCU Board
Regulator Design
Microphone Integration
Speaker Drivers Selection

Jordan
Amplifiers Boards
Bluetooth Hardware
Enclosure Design
Power Supply

Xander
GUI (App) Design
UI/UX Design
Bluetooth (BLE) Integration

Matias
Auto-EQ Algorithm
Embedded Design & Programming

Bill of Materials

Component	Name	Price	Quantity
MCU	ESP32-S3-WROOM-1-N16R8	$6.56	1
Mids/Highs Amp	TPA3116D2DADR	$3.10	1
Subwoofer Amp	TPA3251D2DDVR	$7.81	1
BT Module	BM83	$13.18	1
DAC	AD1934WBSTZ-RL	$7.81	1
ADC	ADS8320	$13.13	1
Microphone	Dayton Audio EMM-6	$59.98	1
Power Supply	LRS-600N2-36	$64	1
Regulators	LM2576HSV-ADJ/NOPB	$8.48	5
24V Regulator	LM5116MH/NOPB	$6.67	1
XLR Connector	IO-XLR3-F-EH	$2.63	1
USB-A Connector	87520-0010BLF	$0.91	1
Tweeters	BC255C08-04	$23.95	2
Midrange Drivers	Goldwood GM-85/4	$15.98	2
Subwoofer	Goldwood GW-10PC4	$79.98	1
PCBs	N/A	$479.41	N/A
Miscellaneous	Capacitors, Resistors, etc.	$150.77	N/A
Total Row	N/A	$1034.09	N/A

Progress and Plan for Completion