



UNIVERSITY OF
ILLINOIS
URBANA-CHAMPAIGN

Roomify

Electrical & Computer Engineering

A Smart Room System

Project #67

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The Problem

Room devices such as LED lights, music systems, and TVs are **hard to coordinate**. Each device operates independently, leading to an **excess of remotes** and **non-cohesive** room environments.

The Problem

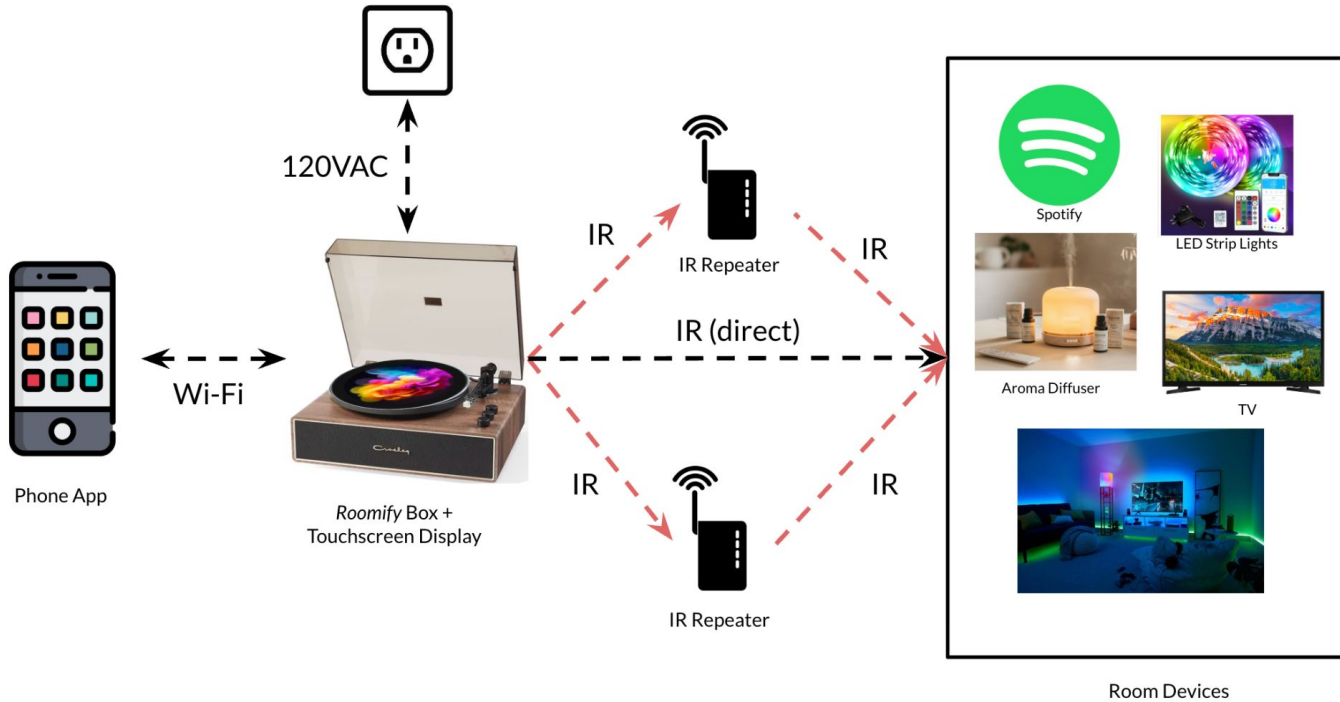
For college students and apartment residents, **budget** and room modification **restrictions** make purchasing and installing integrated smart home systems **unrealistic**.

Roomify

A **centralized room control system** that can copy, store, and transmit infrared remote codes to operate room devices via **user presets**.



Visual Aid



Core Features



Infrared Transceiving

- Receive, store, and transmit IR remote codes
- Provide omnidirectional room coverage



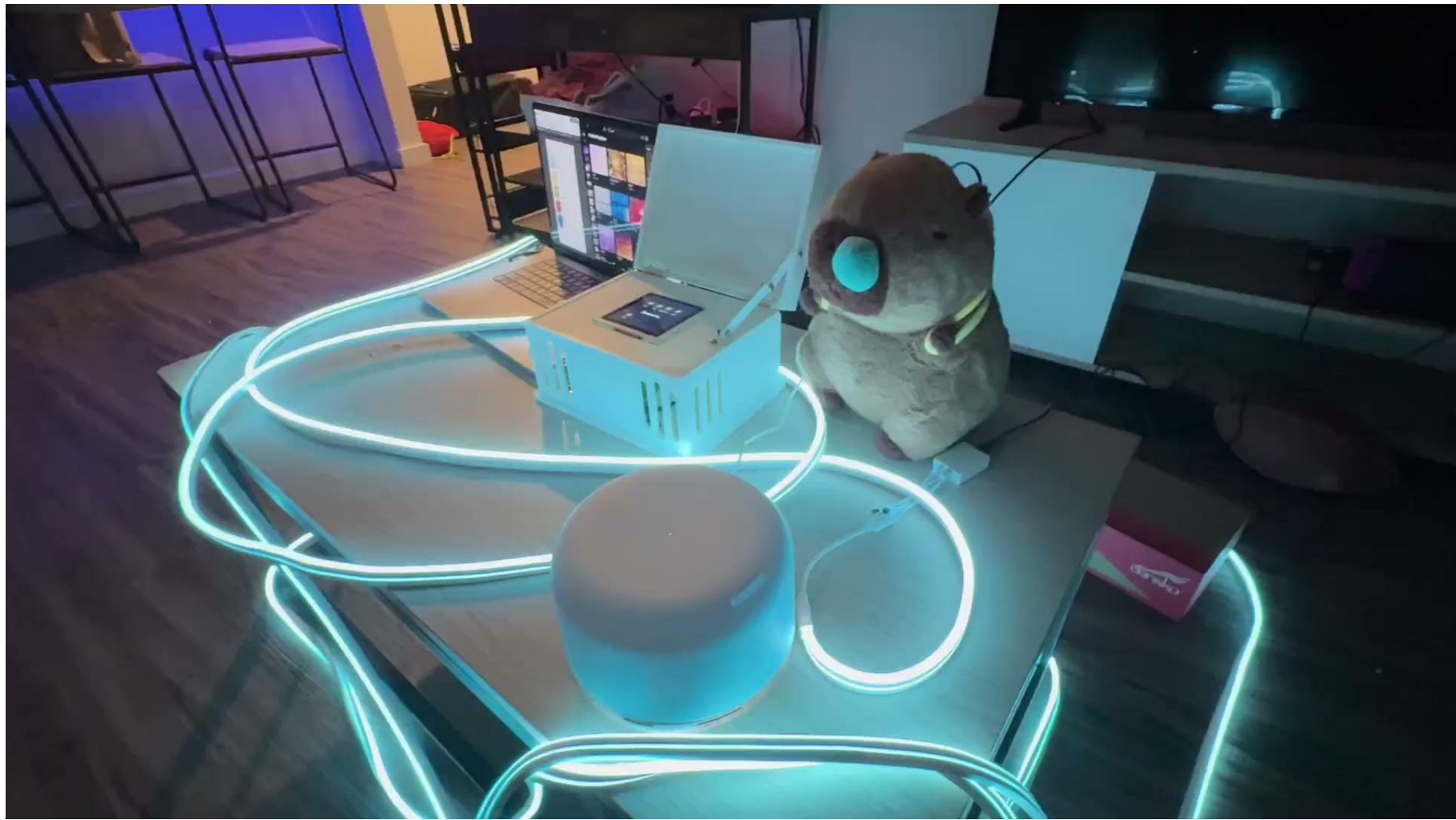
Preset Execution

- Combine and operate multiple devices at once
- Allow users to select presets with a single button press



Device Compatibility

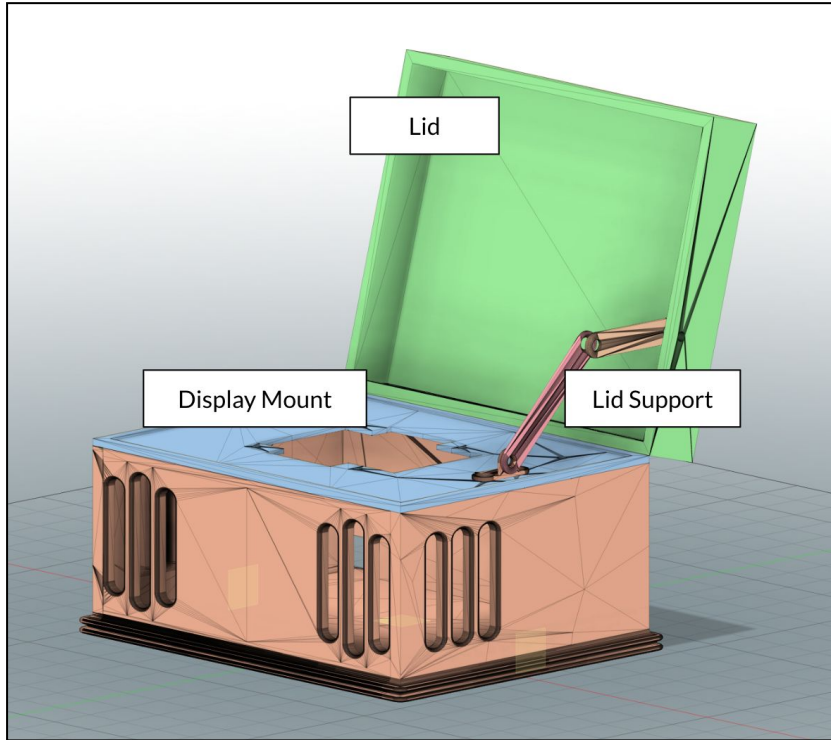
- Extensible, centralized system for variety of devices
- Target multiple types of room decor and accessories



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Physical Design

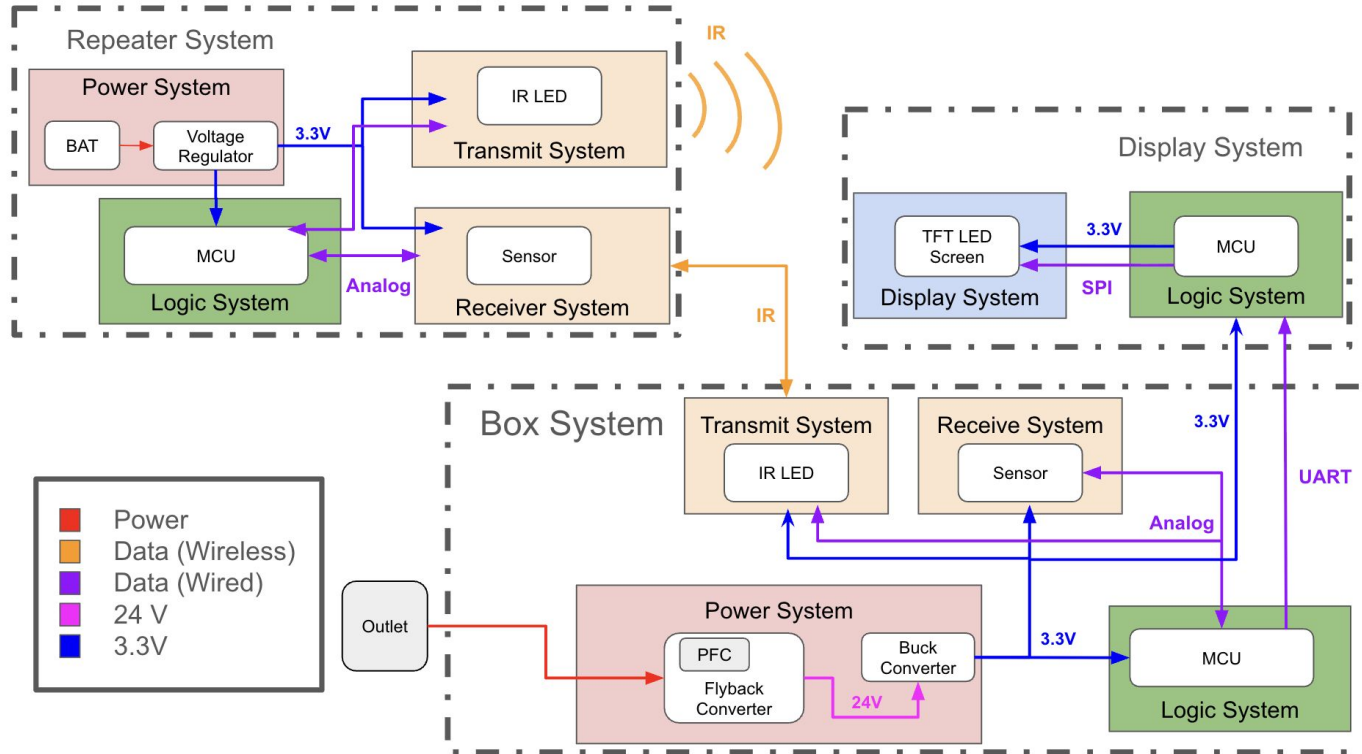
Box CAD



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Hardware Systems

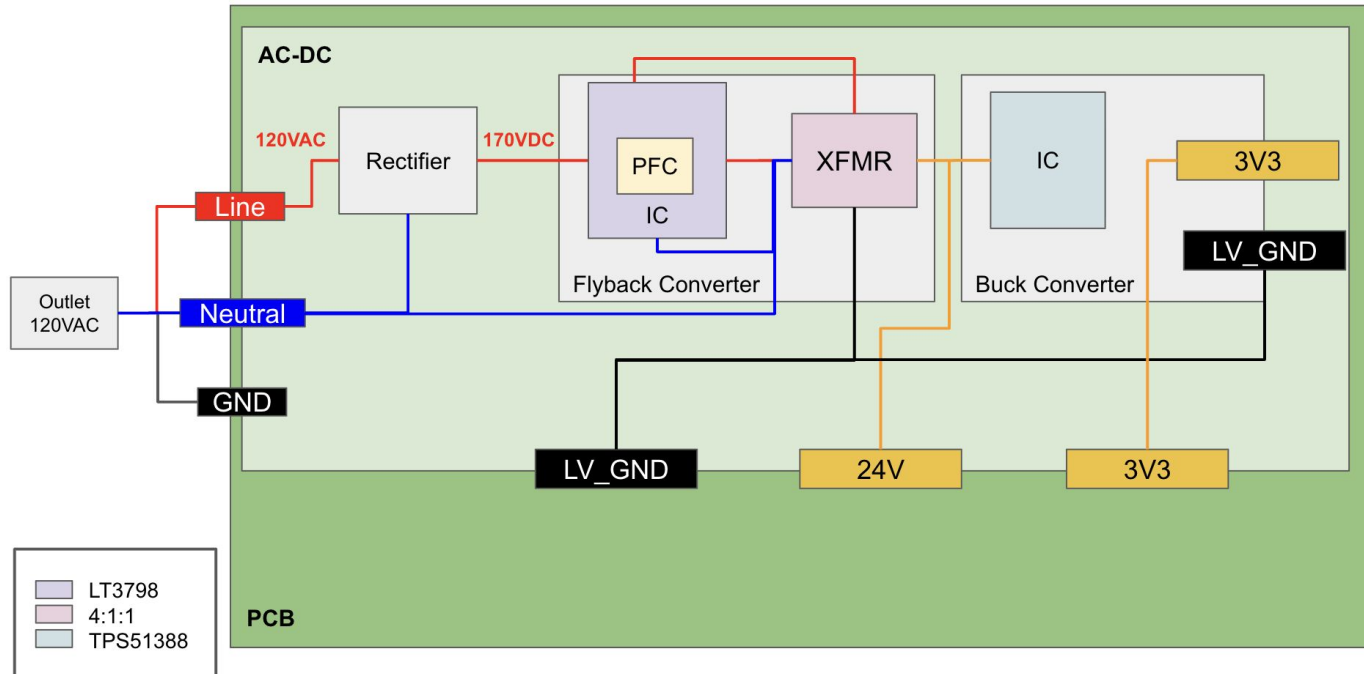
Block Diagram



Block Diagram



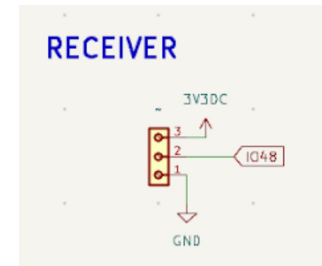
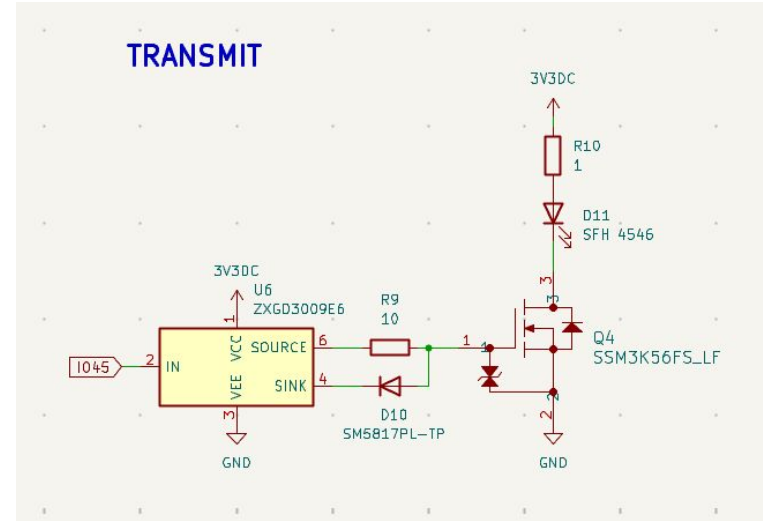
AC-DC Converter Block Diagram



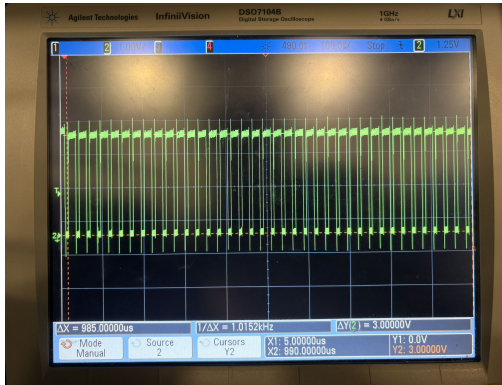
IR Transceiver



- Receive and omnidirectionally transmit 38 kHz NEC infrared signals
- IR LED connected to 3.3V line, gate driver controlled by GPIO
- Used IRRemote library to send and receive NEC IR protocol signals



IR Transceiver: Calculations



$V_{D,on}$: 2.1 Volts

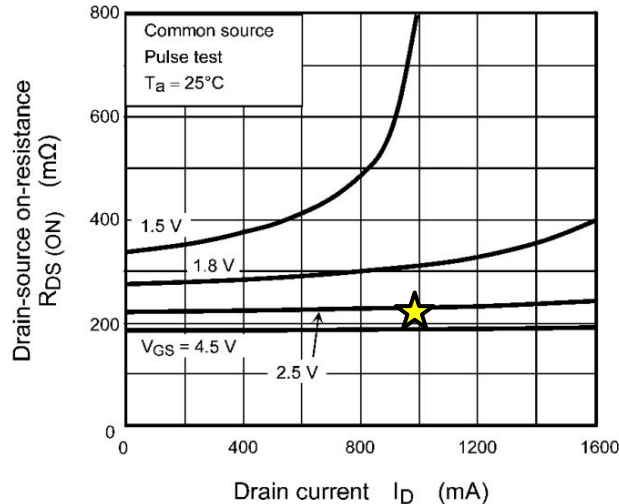


Fig. 7.4 $R_{DS(ON)} - I_D$

IR LED Current

$$I_D = \frac{V_{DD} - V_{D,on}}{R + R_{on}}$$

$$I_D = 0.917A$$

Emitted Irradiance: Transmitter

$$E_e \sim 7 \frac{mW}{m^2}$$

Threshold Irradiance: Receiver

$$E_e = 0.15$$

Link Budget

$$|E|_{dB} = 10 \log_{10} \left(\frac{E}{E_{min}} \right)$$

$$|E|_{dB} = 9.37dB$$

Box MCU



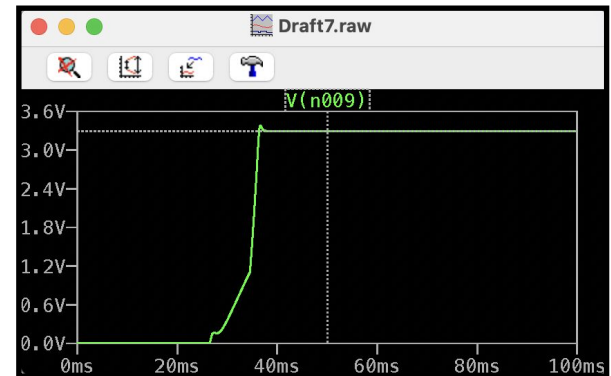
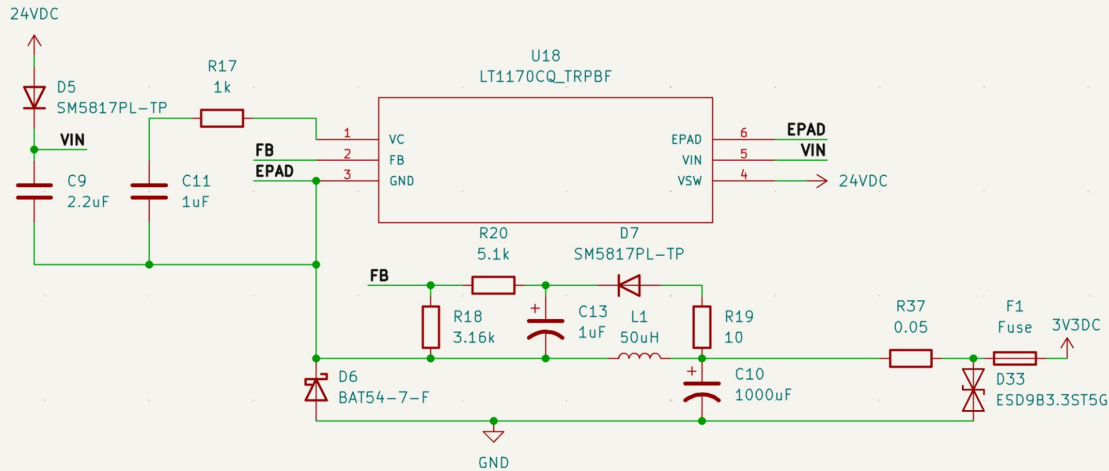
- Touchscreen display to execute presets
- Control transceiver units
- 14 IR LEDs, Fully Omnidirectional
- HTTP communication with server to
fetch/store user data



Box MCU: Power System



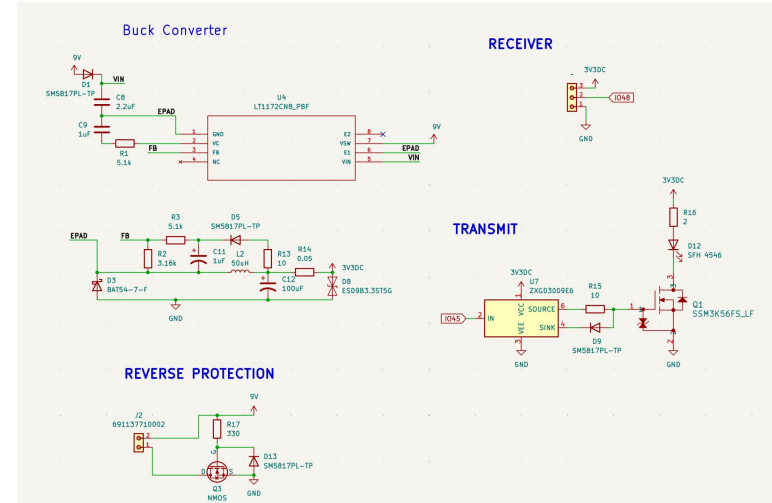
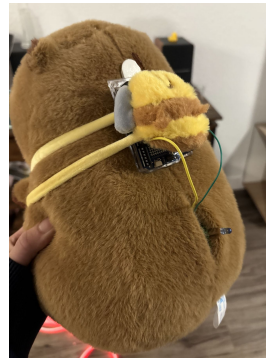
Buck Converter



IR Repeater



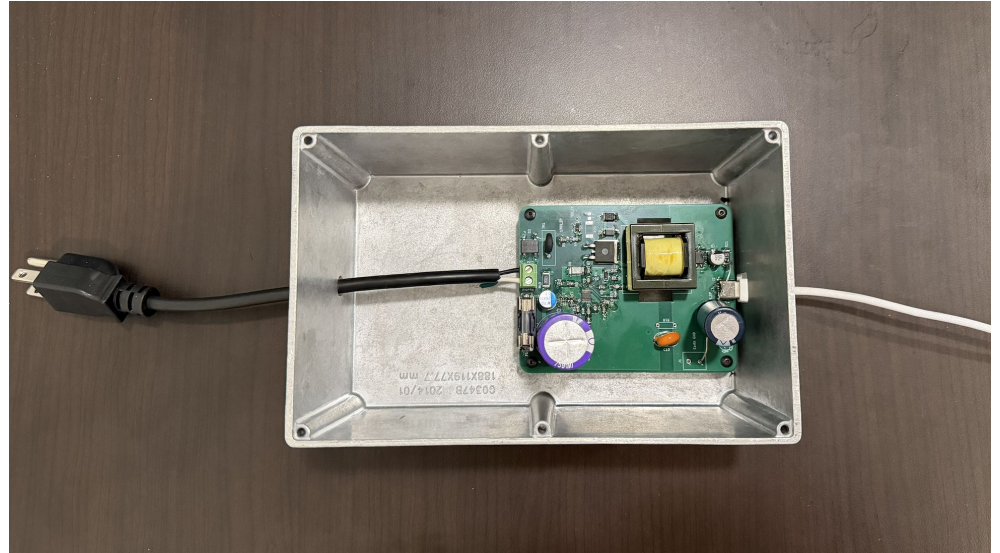
- Retransmit IR NEC signals in a single direction
- One IR transceiver unit
- Poll server (250 ms) via WiFi for new commands and maintain buffer of recently executed commands



AC-DC Power Supply



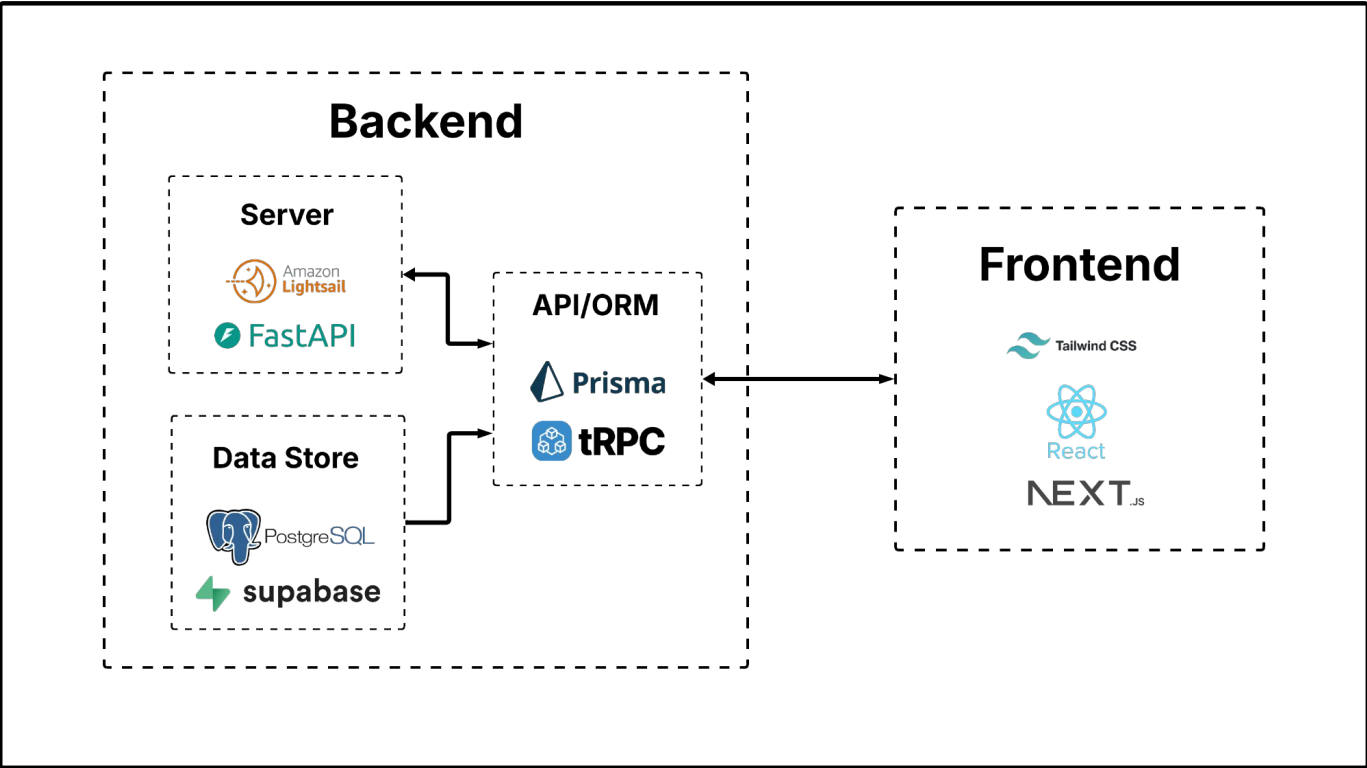
- Convert 120V AC to 24V DC
- Provides 2A peak current
- Follow UL safety standards
- USB-C Output for modularity



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Software Systems

System Design





View + Add Remotes

- Create new remotes and sync/store remote codes
- Centralized access to stored remotes



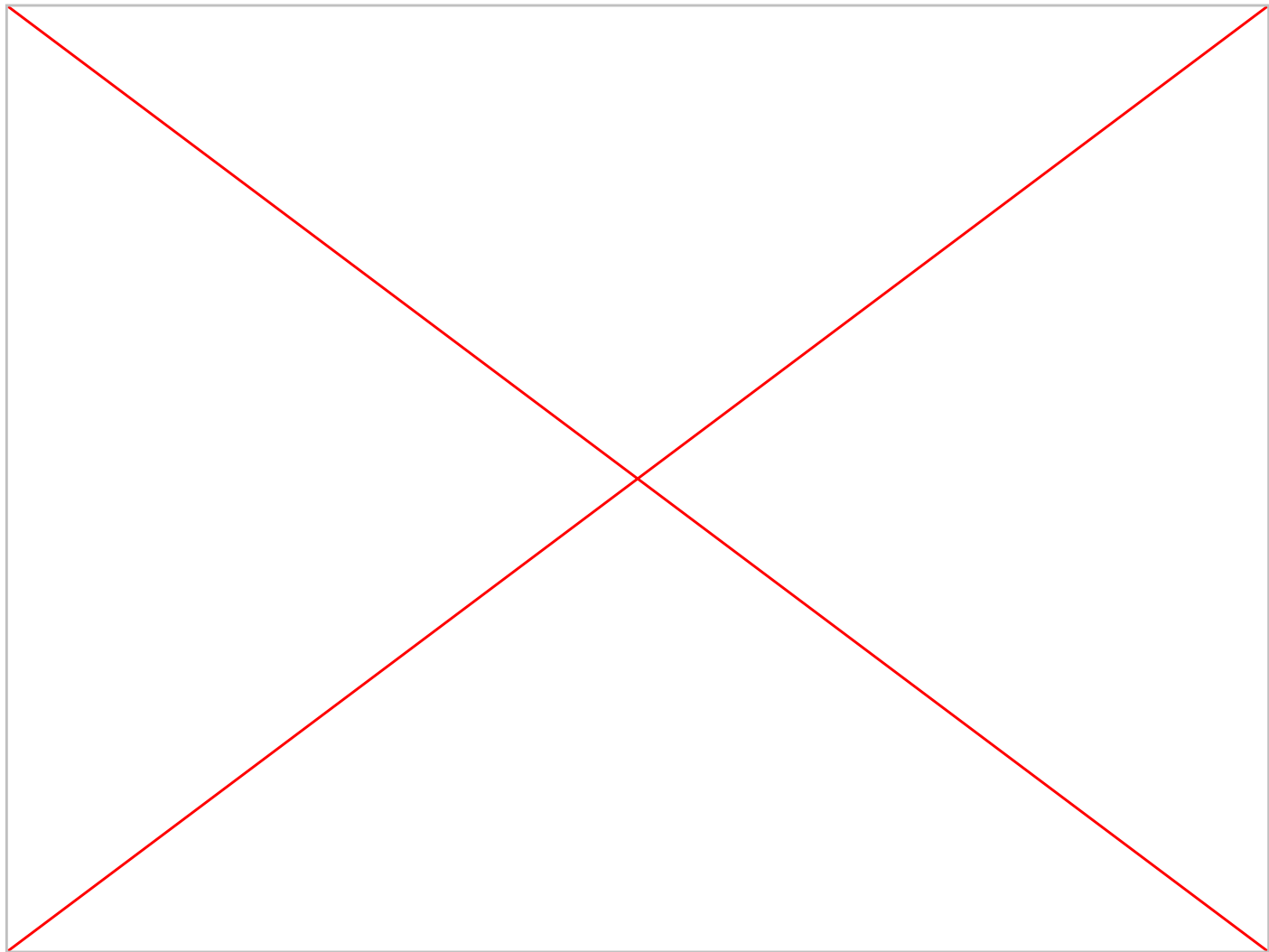
Spotify Integration

- Link Spotify accounts
- Control playback and include playlists within presets



Preset Creation + Execution

- Streamlined preset creation to group device settings
- Single-button press preset execution



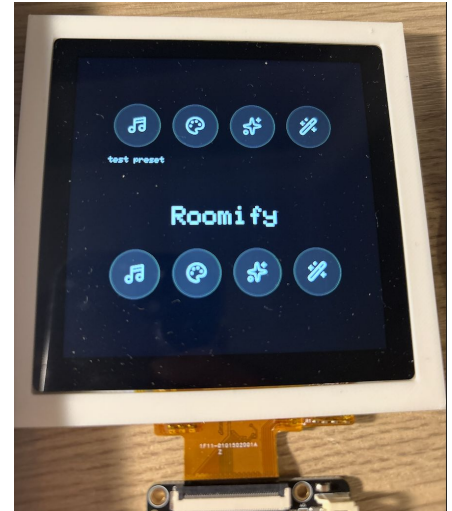
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Project Reflection

Design Changes



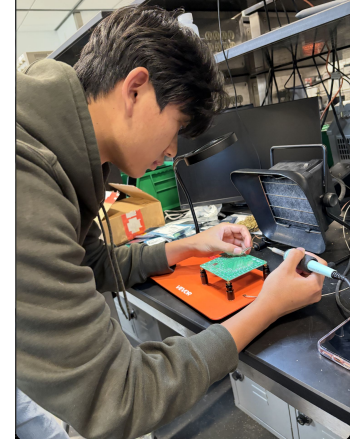
- WiFi instead of UART or IR
(repeater-MCU, display-MCU)
- Simplified touchscreen display



Challenges



- Soldering and board bring-up
- Coordinating different subsystems
 - Data and control flow

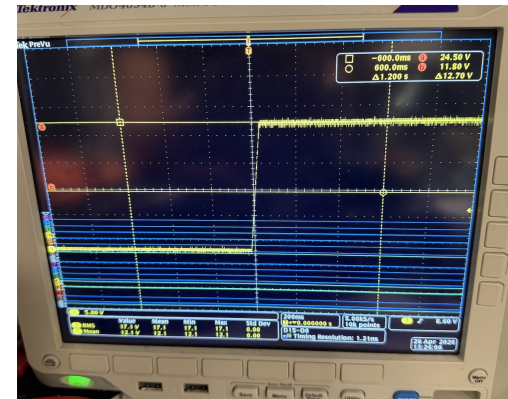
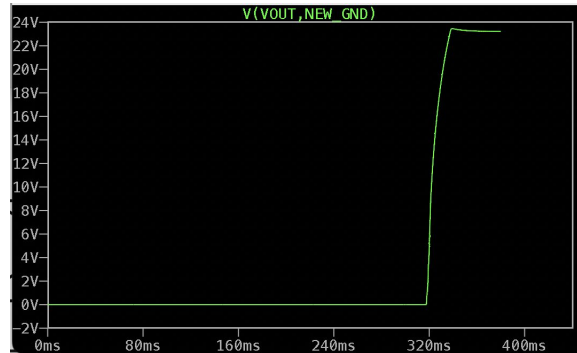
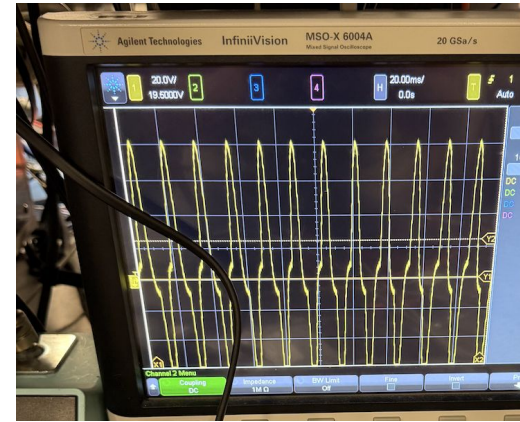


Challenges: AC-DC



- UL standards
- Issue with ringing from parasitics
- Debugging Results: Additional 24V TVS

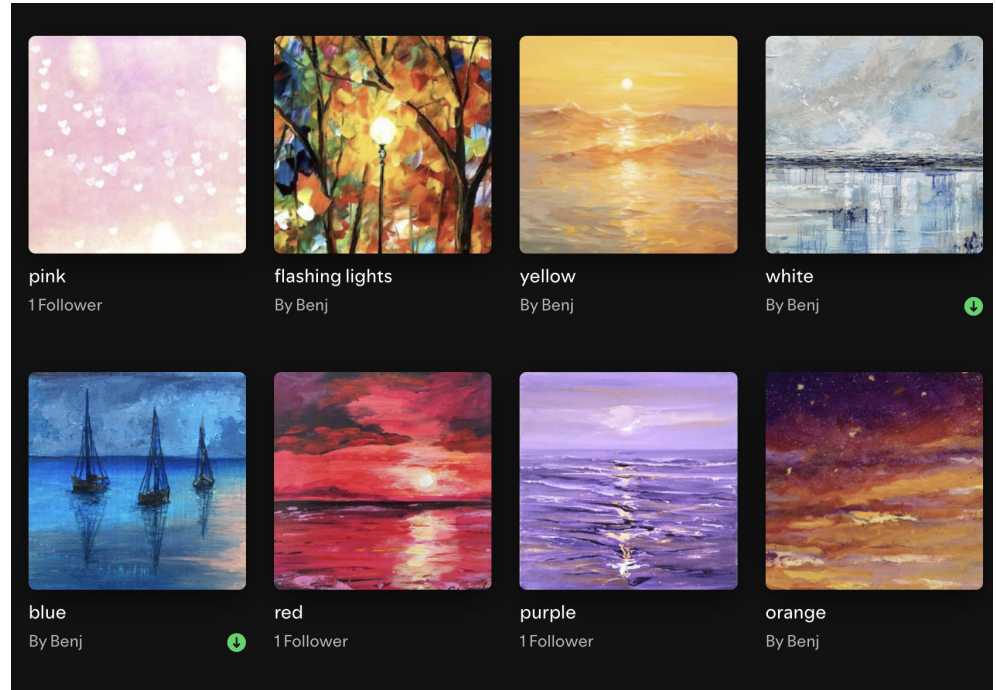
+ 1000uF Capacitance



Next Step



- Use Roomify!
- Find a better touchscreen display
- Cut costs
- Manufacture more and scale





Conclusion

With Roomify, users now have **centralized** control of all **infrared and WiFi controlled** devices in their room through their phones. With a range of over **20 feet**, it can reach devices in almost any location.

A white line graphic consisting of a horizontal segment on the right and a diagonal segment on the left, pointing towards the top-left corner, is located above the word 'Appendix'.

Appendix

High-Level Requirements

1. **Infrared Remote Control Transmission.** *Roomify* should be able to decode, store, and retransmit at least 10 unique IR commands for at least three different devices with accuracy $\geq 95\%$ compared to using the original remote.
2. **Preset Execution.** *Roomify* should be able to operate multiple devices in a user-selected preset. Execution should finish within 1 second, measured from user input to the correct activation of all devices in the preset. The preset should include at least one device in the following categories: IR transmission (LED lights), API calls over Wi-Fi (Spotify), and *Roomify* screen display.
3. **Range and Coverage.** *Roomify* must provide reliable omnidirectional infrared coverage capable of controlling three separate IR-based devices within a 5-meter radius across a $\geq 300^\circ$ horizontal field using no more than three infrared repeaters.

Transceiver System

Requirements	Verification
<ul style="list-style-type: none">• Receive and decode 38kHz NEC infrared signals with irradiance $> 0.15 \text{ mW/m}^2$	<ul style="list-style-type: none">• Point and click a button with a known hex code on a device remote (LED light remote) from $\sim 20\text{ft.}$ away at the <i>Roomify</i> infrared receiver.• Compare decoded signal from <i>Roomify</i> Transceiver System to known remote hex code value and verify accuracy.
<ul style="list-style-type: none">• Transmit 38kHz NEC infrared signals at $> 130\text{mW/sr.}$	<ul style="list-style-type: none">• Test transmission of a valid remote code signal with a device receiver at up to 20 ft. and verify correct, predictable operation (e.g. turn LED lights red, then green, and then blue).• [Oscilloscope] Connect the transmit pin of the transceiver unit to the oscilloscope and observe the waveform of the transmitted signal (check for noise, voltage difference between highs and lows, etc.)
<ul style="list-style-type: none">• (Near) Omni-directional transmission of infrared signals, $> 300^\circ$ coverage along any axis.	<ul style="list-style-type: none">• Place the <i>Roomify</i> box 10 ft. away from a device receiver at the same height.• Continuously rotate the box by 90 degrees, testing correct reception of the signal at the oscilloscope (no bit flips, relatively unnoisy signal).

Repeater System

Requirements	Verification
<ul style="list-style-type: none">• Receive and decode 38kHz NEC infrared signals with irradiance $> 0.15 \text{ mW/m}^2$.	<ul style="list-style-type: none">• Point and click a button with a known hex code on a device remote (LED light remote) from ~20ft. away at the <i>Roomify</i> infrared receiver.
<ul style="list-style-type: none">• Transmit 38kHz NEC infrared signals in a single direction at $> 130\text{mW/sr}$	<ul style="list-style-type: none">• Compare decoded signal from <i>Roomify</i> Transceiver System to known remote hex code value and verify accuracy.• Test transmission of a valid remote code signal with a device receiver at up to 20 ft. and verify correct, predictable operation (e.g. turn LED lights red, then green, and then blue).• [Oscilloscope] Connect the transmit pin of the transceiver unit to the oscilloscope and observe the waveform of the transmitted signal (check for noise, voltage difference between highs and lows, etc.)

Display System

Requirements	Verification
<ul style="list-style-type: none">• Process user touch and execute action within 100ms. Complete preset execution within 500ms of the user selecting a preset.	<ul style="list-style-type: none">• Measure average end-to-end latency across >10 trials of selecting a preset and timing the response.• Requirement passes if worst-case latency < 500ms for present execution and < 100ms from when the preset begins executing.
<ul style="list-style-type: none">• Display stored user presets and settings.	<ul style="list-style-type: none">• Preload multiple presets involving >3 room devices into memory on the <i>Roomify</i> MCU.• Verify correct preset names, correct icons, and correct associated IR mapping.• Use <i>Roomify</i> touchscreen display to select a preset and confirm matching operation of room devices.

Power System

Requirements	Verification
<ul style="list-style-type: none">Convert 120V AC from outlets to 24VDC.	<ul style="list-style-type: none">Connect the Roomify box to a 120V AC outlet and power on the system.Using PCB test points, place the multimeter negative probe on GND.Measure the 24V rail with the positive probe and confirm voltage is $24V \pm 0.5V$.Measure the 3.3V rail and confirm voltage is $3.3V \pm 0.3V$.Use an oscilloscope to probe 24V and 3.3V rails.Use the oscilloscope to measure ripple voltage and confirm that it is within $\pm 0.5V$.
<ul style="list-style-type: none">Power system should provide peak 1A for the Roomify system at $3.3V \pm 0.3V$.	<ul style="list-style-type: none">Connect an electronic load to the 3.3V rail.Increase load current gradually up to 1A.Monitor voltage using a multimeter.Confirm voltage remains within $3.3V \pm 0.3V$ under full load.
<ul style="list-style-type: none">The battery system should provide peak 500mA at $3.3V \pm 0.3V$ for <i>Roomify</i> repeaters.	<ul style="list-style-type: none">Power repeater using a fully charged battery.Connect electronic load to 3.3V output.Increase current draw up to 500mA.Confirm voltage remains within $3.3V \pm 0.3V$.

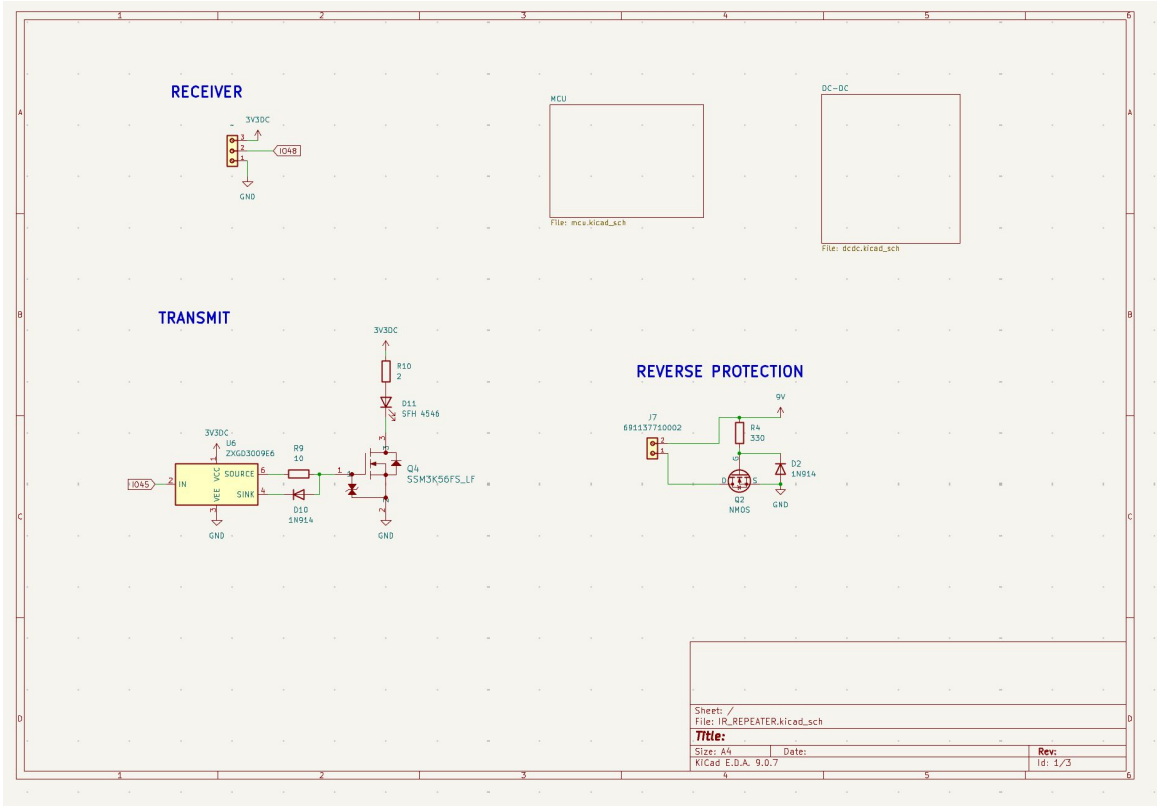
Box + MCU

Requirements	Verification
<ul style="list-style-type: none">Control the Transceiver System	<ul style="list-style-type: none">Send IR transmission commands to the Transceiver System.Verify correct operation of room devices.[Oscilloscope] Use an infrared receiver connected to an oscilloscope to validate signal transmission (check that bits match).
<ul style="list-style-type: none">Receive and process user requests over Wi-Fi within 500ms	<ul style="list-style-type: none">Connect system to Wi-Fi network.Trigger a request from the mobile/web application.Confirm that average action execution latency is < 500ms.
<ul style="list-style-type: none">Store user information (presets or remote signal codes) to a database over Wi-Fi reliably	<ul style="list-style-type: none">Restart the <i>Roomify</i> system and reload the application.Verify stored data persists and matches expected values.
<ul style="list-style-type: none">Make valid HTTP requests over Wi-Fi to Spotify API	<ul style="list-style-type: none">Use ESP32-S3 to send a HTTP request to Spotify to play a song.Verify HTTP status code is 200.Confirm correct behavior on the Spotify account (song plays).

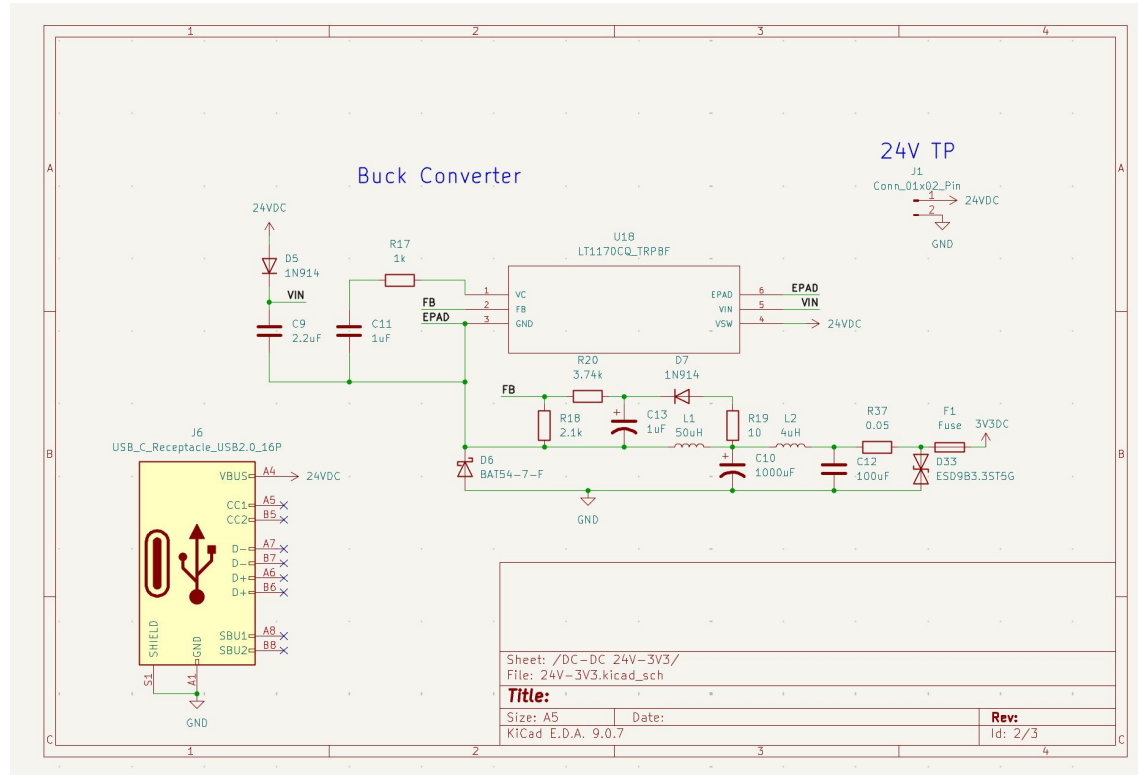
Mobile App

Requirements	Verification
<ul style="list-style-type: none">Communicate with the <i>Roomify</i> Box System over Wi-Fi with < 500ms latency	<ul style="list-style-type: none">Connect the mobile device and <i>Roomify</i> Box to the same Wi-Fi network.Verify that average response latency is < 500ms after pressing a button in the app.
<ul style="list-style-type: none">Display stored user presets and settings.	<ul style="list-style-type: none">Create a user account with predefined presets stored in the database.Log into the web application using the account.Verify that all presets, names, icons, and settings are correctly displayed.
<ul style="list-style-type: none">Provide a clean, intuitive interface for users to add new remotes, create presets, and control devices through <i>Roomify</i> (time to teach someone how to use the application should be < 3 minutes).	<ul style="list-style-type: none">Select at least 5 users unfamiliar with the system.Provide a short 1 minute explanation of the application's purpose (no walkthrough).Assign tasks:<ul style="list-style-type: none">Add a new remoteCreate a presetTrigger a deviceMeasure the time required to understand and complete tasks and verify that < 3 minutes of instruction were necessary.

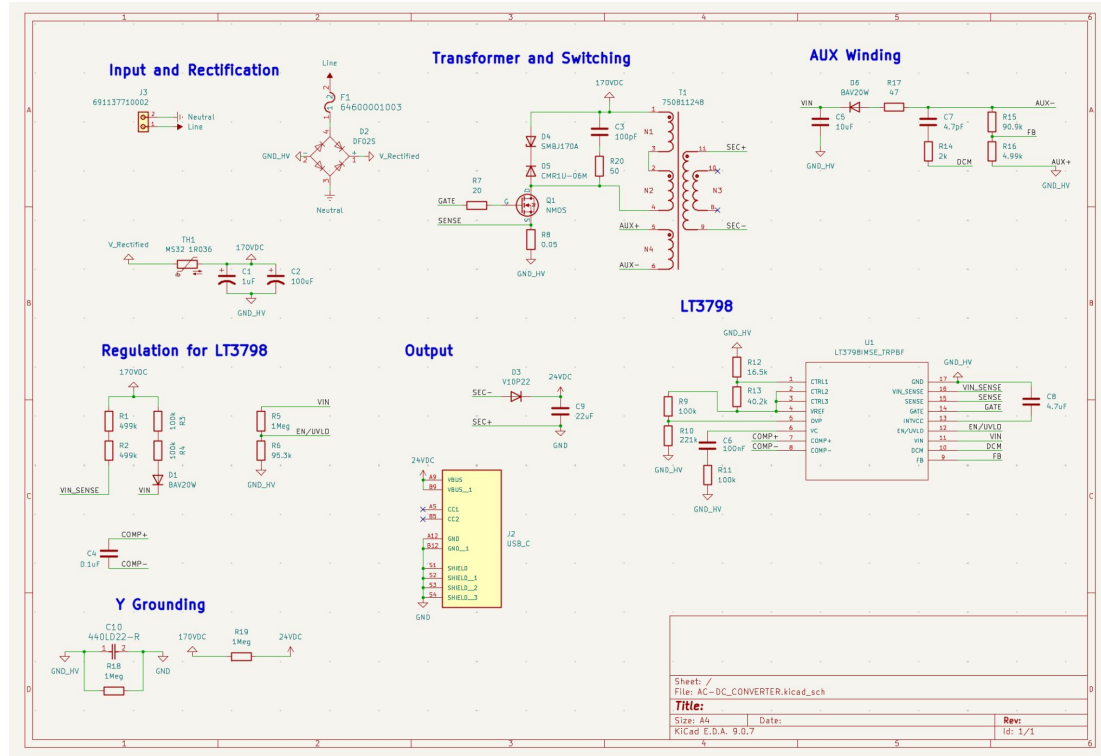
Transceiver System



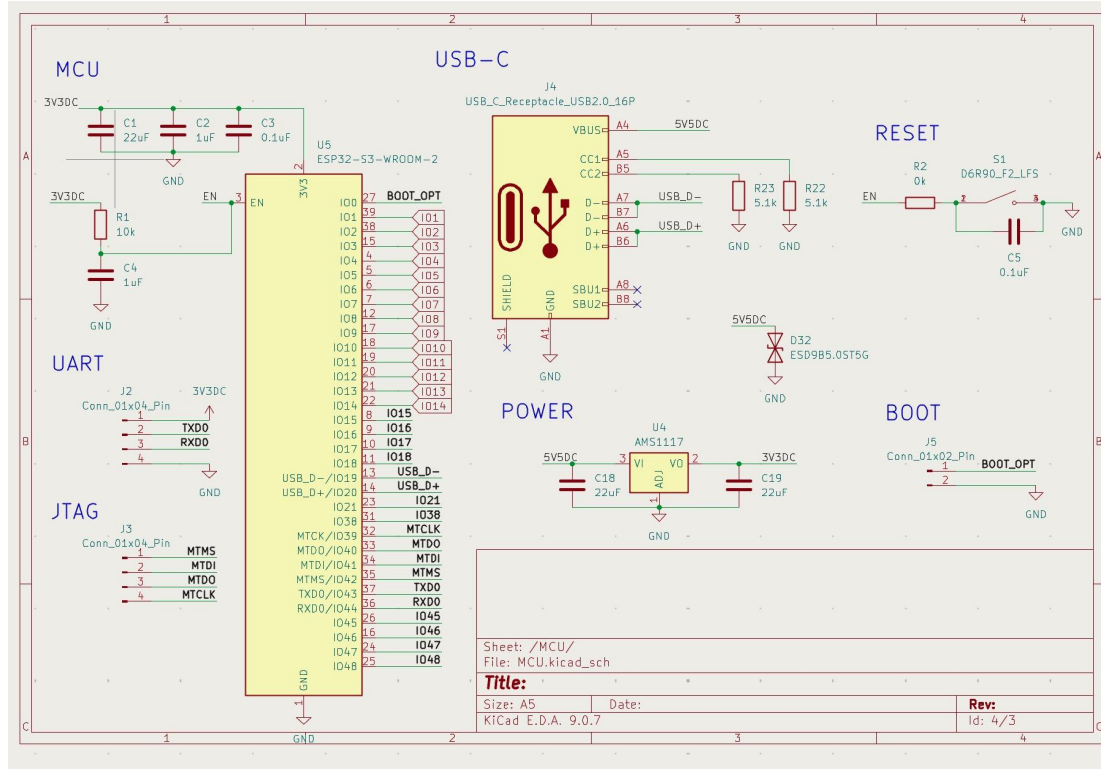
Power System



AC/DC



MCU



IR Range Analysis

From the [datasheet](#) for the [infrared LED](#) we plan to use, the IR LED has a radiant intensity of 130 mW/sr when using 200mA pulses [9]. To determine how much power reaches the receiver, we multiply this value by the solid angle subtended by the receiver.

Assuming a worst case distance of 10m (for a 15 ft. x 15 ft. x 10ft. room, the distance from opposite corners of the room is 7 meters), we can calculate the irradiance of the signal at the receiver as follows:

$$E = \frac{I_e}{r^2}$$

$$E = \frac{130 \frac{mW}{sr}}{100m^2}$$

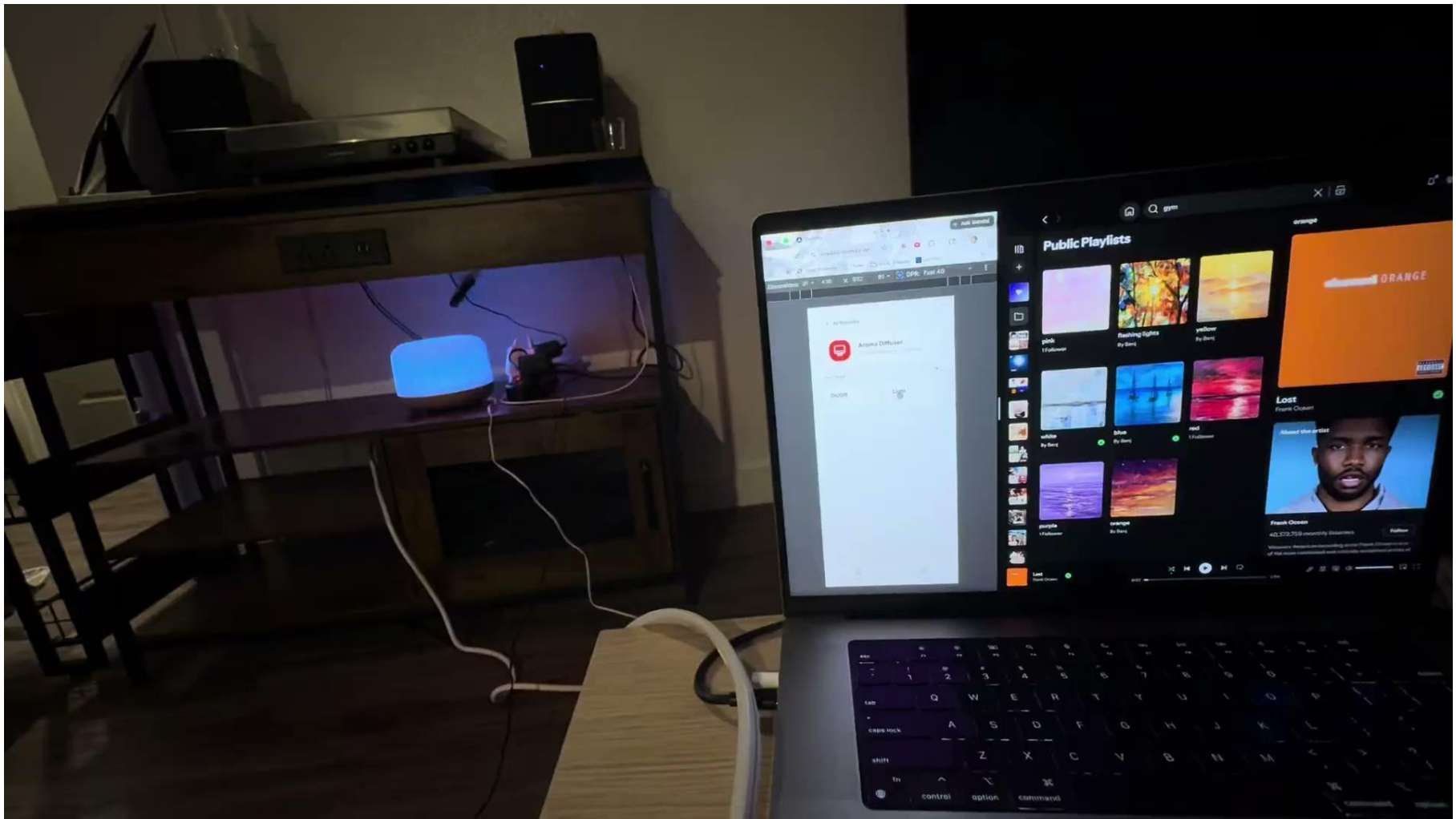
$$E = 1.3 \frac{mW}{m^2}$$

IR Range Analysis

Standard infrared receivers have $E_{\min} > 0.15 \frac{mW}{m^2}$ [10]. Calculating the link margin as $10 \log_{10}(E/E_{\min})$, we get a link margin of 9.37 dB.

To account for insertion loss from the PLA box, we assume signal attenuation of approximately -0.5 dB, resulting in a substantial margin of 8.87 dB for our device. In addition, the maximum rating for the infrared LED is 1A pulses (for 750 mW/sr), meaning we can increase signal strength significantly compared to using 200mA pulses if necessary.

With 1A pulses, the irradiance at a receiver 10 meters away is about $7.5 \frac{mW}{m^2}$.



Spotify interface showing a search or artist page for "Frank Ocean". The page includes a red Spotify logo, the name "Frank Ocean", and a "Follow" button. The background is a light blue gradient.

Spotify interface showing "Public Playlists". The page features a grid of playlist covers with titles like "pale", "Rustling Lights", "yellow", "white", "Dark", "red", "People", "orange", and "Lost". A large orange playlist cover is on the right. Below the grid, there is a profile for "Frank Ocean" with a photo and the text "40,572,759 monthly listeners".

