FadeX: Automated Nicotine Tapering Device

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Abstract

In this project, we created a new nicotine cessation option. The tool is made up of three components that work together in order to provide users with a controlled tapering experience. Our FadeX app is able to take user input and adjust the tapering schedule accordingly. The Vape records usage information and transmits it to our Homebase in order for further modifications to the tapering schedule. Wrapping it all together, the Homebase is able to communicate with the Vape and the App, whilst creating the new tapered concentration based on all of the collected information. The combination of the three components was able to deliver accurately mixed concentrations of ascorbic acid and water based on the information collected in the app from the other two devices.

Contents

1 Introduction

1.1 Problem

Electronic cigarettes, originally conceptualized as smoking cessation tools, have evolved into a significant driver of nicotine dependency. Current nicotine replacement therapies (NRTs), such as nicotine patches or medicated gums, exhibit high failure rates primarily because they decouple the physiological delivery of nicotine from the sensorimotor reinforcement associated with vaping [1]. Specifically, NRTs fail to address the oral fixation and inhalation rituals, which are behavioral habits that are clinically shown to be as addictive as the substance itself [2].

Furthermore, current manual tapering strategies are fundamentally limited by commercial availability and human error. Users attempting to reduce intake must navigate discrete, infrequent concentration steps (e.g., a 40 % drop from 5 % to 3 % nicotine), which often triggers acute withdrawal and subsequent relapse [3]. There is a distinct absence of a closed-loop or automated system capable of delivering a computationally linear taper while maintaining the user's behavioral routine. This gap in the cessation market represents a critical failure in public health and addiction science. A device that enables controlled, micro-dosed nicotine reduction while maintaining behavioral continuity may significantly reduce relapse rates and improve cessation outcomes.

1.2 Solution

FadeX is an automated fluidic delivery system with wireless communication capabilities designed to completely obfuscate the nicotine tapering process from the user. To achieve this without burdening the user with a heavy, complex handheld device, FadeX utilizes a two-part architecture: a stationary Batch-Mixing Home Base Station and a Handheld Vaporizer.

By mixing the non-nicotine and nicotine juices into a central container, the base station enables an imperceptible and customizable reduction curve (e.g., 5.0 % to 4.95 % to 4.90 %) that is unable to be achieved with pre-mixed commercial liquids. The Base Station utilizes an ESP32 microcontroller to drive high-precision stepper peristaltic pumps, which meter fluid into an internal main reservoir. This homogenization is verified via a closed-loop gravimetric load cell to ensure strict volumetric accuracy.

Once the periodic algorithmic ratio is prepared, the user docks their Handheld Vaporizer (Vape). A secondary transfer pump safely injects the custom-blended dose through a dry-break silicone septum into the handheld's internal "Daily Tank." To address safety and compliance, FadeX implements firmware-level dosage caps and thermal interlocks, preventing both user "cheating" and hardware failure. By maintaining the behavioral ritual in a sleek handheld format while the Base Station systematically reduces the chemical stimulus, FadeX provides a scientifically grounded, hands-off pathway to complete cessation.

One important change, our project used ascorbic acid as a nicotine surrogate in this project. We did not use any nicotine liquids, but much of the research and development of the project was with the intent of using nicotine. It became difficult to get approval to use nicotine and find space to experiment with it and store it, so we quickly pivoted to our researched backup plan, ascorbic acid (Vitamin C) instead. It exhibits similar light absorption characteristics as nicotine, which is important for the optical concentration sensing to translate accurately. It also provides a safer testing experience for ourselves and those in the lab spaces around us. References to the nicotine/concentrate refer to ascorbic acid, and references to diluent should be replaced by water, for our project's purposes.

1.3 High Level Requirements

- **Asynchronous Volumetric Mixing Precision:** The dual-pump fluidic subsystem must achieve a commanded nicotine-to-diluent ratio with a steady-state error of less than 15 %. Given that industrial laboratory standards allow for a 10 % tolerance, this requirement ensures medical-grade feasibility while accounting for the mechanical tolerances of micro-peristaltic tubing and Pulse Width Modulation (PWM)-driven DC motors.

- **Dynamic Usage-Responsive Tapering Algorithm:** The system must implement a closed-loop feedback algorithm that adjusts the nicotine concentration based on user data. The user will set a taper schedule and starting concentration, and the software developed by our group should calculate the tapering trajectory. This data would then be implemented on the firmware of the MCU in the docking system. The algorithm would also collect data during the trial phase of the user to predict future use and success with the current tapering trajectory and adjust if needed.

- **Wireless Communication of Data:** The system must maintain a Bluetooth Low Energy (BLE) link to the mobile application with a data synchronization interval of less than 500 ms. This ensures that usage analytics (puff duration, frequency, and current concentration) are reflected in the user dashboard in near real-time, and that algorithm setpoints from the app are pushed to the mixing station without much delay.

1.4 Block Diagram

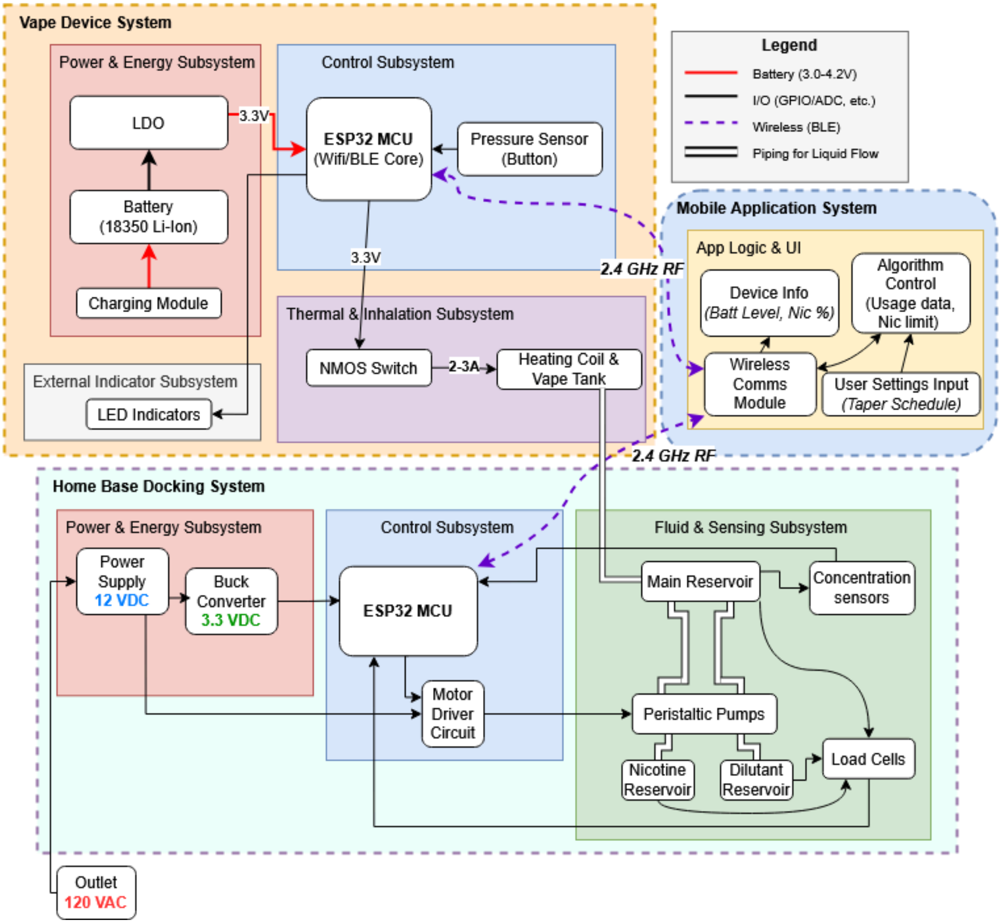

Figure 1: Block diagram of the FadeX Vape, Home Base, and Software Systems design

The architectural framework of the FadeX product, illustrated in Figure 1, consists of three integrated systems: the Mobile Application, the Handheld Vape Device, and the Home Base Docking Station. Control and data transmission follow a linear path, originating from the Vape, moving to the App, and concluding at the Home Base.

The Handheld Vape Device is designed to resemble mod-style devices and is powered by a 3.7 V 18650 Battery. It uses an ESP32-WROOM-32E to wirelessly transmit user usage data, specifically inhale ("puff") duration and time of day, to the Mobile Application. The ESP32 is powered by the battery with an intermediate Low Dropout Regulator (LDO).

The Mobile Application functions as the central control hub, collecting this data and interfacing with the user by providing necessary information and allowing user input. It also can result as a destination point for physicians to monitor and adjust a patient’s nicotine cessation. It houses the FadeX tapering algorithm, which accounts for user data through a baseline survey before the journey begins, usage data during the process, and feedback surveys at certain checkpoints. The algorithm will categorize the user's current state to determine the precise amount of dilution required for the next batch mixture. This target concentration is then transmitted to the Home Base.

The Home Base houses all components related to the precision mixing and sensing of e-juice doses. It is powered by a 12 V DC power supply cable to allow our pumps to run at their operating point. It has its own ESP32-WROOM-32E microcontroller, and a buck converter is used to efficiently step down and power the ESP32. That concentration value is used as a reference value in a control feedback loop to accurately dose the new mixture. Volume is measured and verified using load cells, while the concentration of ascorbic acid in the solution is measured using an ultraviolet optical sensor module.

2 Design & Verification

2.2 Power & Energy Management Subsystems

Both the Home Base and Vape required reliable and accurate power delivery in order to achieve the important feats both devices were to accomplish. The two systems deliver power to the microcontrollers and peripherals in different ways to optimally fit both designs in their respective way.

2.2.2 Homebase Power Subsystem

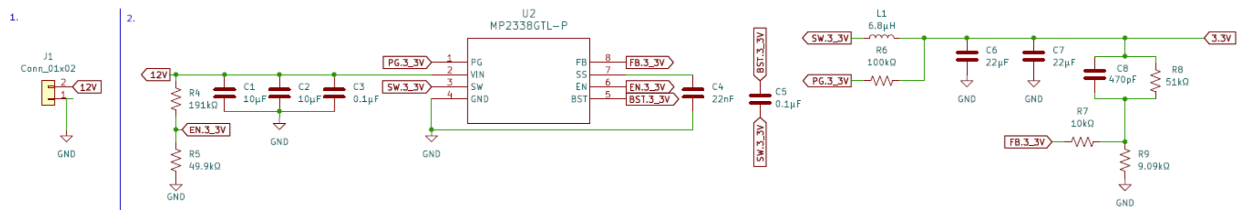

Figure 2: Homebase Power Subsystem Schematic

The biggest consideration for this power subsystem was the voltage required to operate the pumps. In our homebase the pumps are 12 V, which meant it was necessary to have a 12 V line present to power the pumps while also being able to step it down to 3.3 V for the other devices in the Home base. To step down the voltage we utilized a buck converter IC and corresponding circuitry. The assisting circuitry for the buck converter IC was provided in the data sheet of the MP2338GTLP [4] along with other important performance metrics of the IC. We could've chosen to use an LDO, which would've condensed the components list needed to step down 12 V to 3.3 V, but a lot of efficiency would've been lost (Figure 3). For that reason we felt the buck converter was a much better option, and the lack of size constraint on the PCB relative to the actual size of the physical Homebase and the slight increase in cost made it even better of an argument to save on efficiency.

$$\frac{3.3\ \mathrm{V}}{12\ \mathrm{V}} \times 100 = 27.5\%$$

Figure 3: Homebase LDO Efficiency Calculation

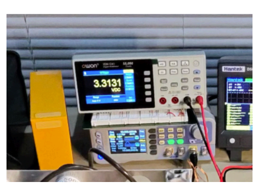

Figure 4: Homebase Buck Converter Verification

One of our requirements for this project was to make sure that the 12 V rail gets stepped down via buck converter (MP2338GTLP) to between 3.125-3.465 V. To verify this, we used a multimeter and placed the positive probe on the 3.3 V side of the 6.8 µH inductor and the negative to ground. Upon doing this we were able to confirm that the power requirement was met, which is shown in figure 6.

2.2.3 Vape Power Subsystem

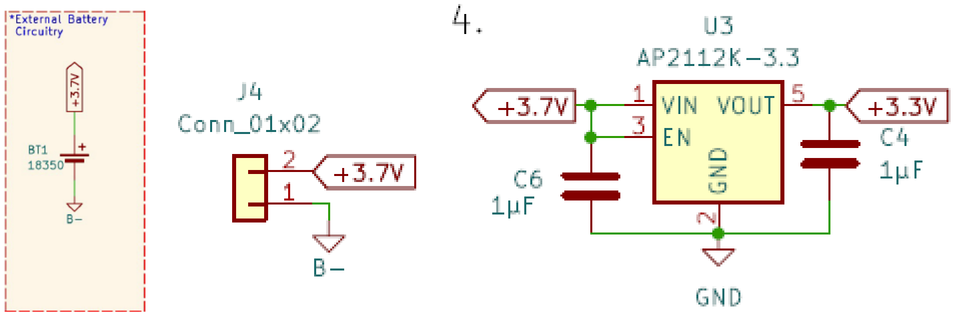

Figure 5: Vape Power Subsystem Schematic

The Vape had a different set of criteria when it came to designing its power subsystem, consisting of two main factors. The first factor was the largest voltage required on the PCB. That requirement was relatively easy as all of the components required 3.3 V to function or the battery voltage. The second factor was how much current did we need to source to the coil to get it to vaporize our E-liquid. This consideration over the lifespan of the project became less important as we decided not to vaporize anything for this project. With those two factors in mind, we decided to power the components on board with a large reserve 3.7 V 18650 battery. This battery provided enough power if needed to heat a coil, while also being close to 3.3 V to use an LDO. A buck converter in this circuit wouldn't make as much sense because the efficiency of the LDO is already high and the physical Vape adds a much more immediate size constraint to the PCB size.

$$\frac{3.3\text{ V}}{3.7\text{ V}} \times 100 = 89\%$$

Figure 6: Vape LDO Efficiency Calculation

Figure 7: Vape LDO Verification

Another power requirement that our project had was that the LDO on the Vape PCB steps down the battery voltage to 3.3 V. We used the AP2112K [5] because of its current requirement and footprint. In order to verify this we used a multimeter and placed the positive probe on the VOUT pin to measure the LDO output voltage, and the negative probe on ground. We originally had gotten this to work, though after accidentally reverse biasing the LDO during testing, it ceased to step down the battery voltage. We also desoldered the chip to isolate it and applied the battery voltage and again it wouldn't regulate the voltage to 3.3 V.

2.2.3 Programming Circuitry

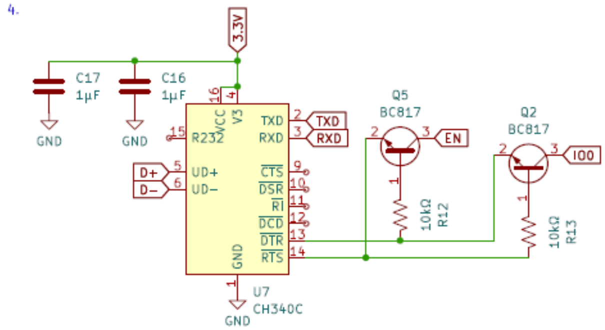

Figure 8: Vape and Homebase Programming Circuitry

The Homebase and Vape also included on board programming circuitry. We utilized the CH340C [6] to convert the USB4 protocol to UART in order to program the ESP32. The BC817 NPN transistors [7] were used to switch on and off the EN and IO0 pins on the ESP32. This allowed for the ESP32 to boot into program mode. One problem we had with this module is that the TXD and RXD connections from the CH340C to the ESP32 were flipped. To solve this error, wires were introduced to the CH340C TXD and RXD pins, which were bent upwards to avoid the pads that connected the traces. Then those wires were soldered to the correct TXD and RXD pins on the ESP32. The pictures of this can be seen in appendix B, figure 5 and 6.

2.3 Control, Safety Logic, & Connectivity Subsystem

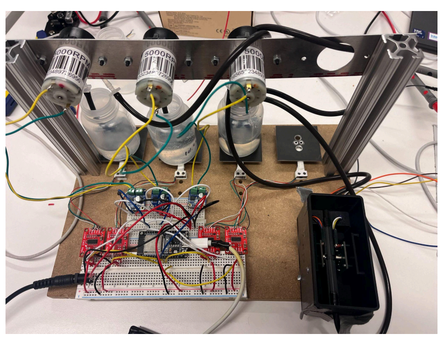

Figure 9: Homebase Model

2.3.1 Wireless Communication and System Control

The homebase ESP32 [8] acts as the main controller for FadeX by receiving puff activity from the handheld ESP32, running the dosing algorithm, and controlling the pumps and sensors. The handheld sends puff count and puff duration to the homebase using ESP-NOW, which allows the two ESP32 boards to communicate directly without needing the handheld to connect to Wi-Fi. The homebase also connects to the Blynk app over Wi-Fi so user inputs, dashboard values, and system status can be displayed. Because ESP-NOW and Wi-Fi must operate on the same channel, the homebase controls the communication setup so that puff data and app updates stay synchronized.

2.3.2 Closed-Loop Dosing and Safety Logic

The control algorithm uses feedback from the load cells and UNC sensor to make dosing more accurate than a simple timed pump system. Pump 1 delivers the nicotine surrogate or concentrate, Pump 2 delivers diluent, and Pump 3 circulates the mixed solution through the UNC sensor so concentration can be checked. Before dosing, the system zeroes the load cells so the empty container weight is removed, then it uses the mixing chamber load cell to verify how much liquid has actually been delivered. The firmware uses staged pump pulses, slowing down near the target volume to reduce overshoot. Safety logic prevents dosing if readings are unstable, limits the mixing chamber volume, and includes emergency stop commands that shut off all pumps immediately.

2.3.3 Vape coil control

At the start of the project we wanted to create an atomizing Vape, though throughout the course of the project priorities shifted and we didn’t have the time to create the atomizing portion of the Vape. To substitute and still deliver some functionality metrics, we decided to just use a resistor of known value instead of a coil. Furthermore, because we weren’t atomizing anything, we didn’t need to draw a bunch of current and thus use a low ohm resistor. To prove the coil firing mechanism worked, we instead used a program to activate the coil MOSFET [9] when the button is pressed, and measure the voltage across the resistor. This allowed us to verify the functionality of the MOSFET switch because when the button was unpressed, the resistor saw no voltage drop across it, thus no current going through it.

2.3.4 Vape Coil Safety Cutoff

Another important safety feature of the Vape was going to be the coil cut off. This would deactivate the coil after 10 seconds of use to prevent damage to the vape or more importantly, harm to the user. This feature is something that could’ve been handled in software but for the final demonstration did not make it into our code. This was due to running out of time while making the other larger aspects of the project.

2.4 Mobile Application Subsystem (Software)

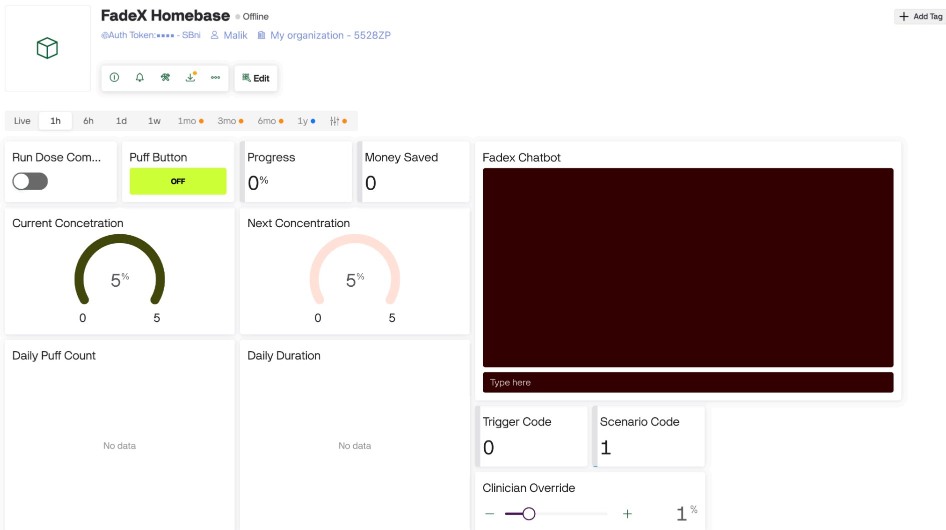

Figure 10: Blynk Application Dashboard

2.4.1 User Background and Purpose

FadeX is designed for nicotine users who need a more adaptive way to taper than a fixed reduction schedule. In real use, cravings and puff behavior can change depending on stress, withdrawal, habits, or social triggers, so the system uses both objective puff data and user self-report to guide each dose. The goal of the app is to make the taper easier to follow by showing the user their progress, current concentration, next concentration, puff activity, and treatment week in a clear format.

2.4.2 Scenario Codes and Adaptive Feedback

The algorithm uses scenario codes to describe the user's current state based on puff behavior and survey feedback. After the system receives puff metrics, the FadeX Chatbot asks the user how they are feeling using options such as Better, Neutral, Struggling, or Worse. If the user reports that they are struggling or worse, the chatbot can also ask for the main trigger category. These inputs help the algorithm decide whether to continue tapering normally, slow the taper, or temporarily stabilize the concentration to reduce relapse risk.

2.4.3 Dashboard and FadeX Chatbot Interface

The Blynk dashboard acts as the main app interface for displaying system and user progress. It shows values such as current concentration, next concentration, daily puff count, daily puff duration, treatment week, dose volumes, milestone progress, money saved, and relapse-risk status. The FadeX Chatbot guides the user through the dosing process by showing system status, asking short check-in questions, and explaining what the system is doing before the dose is calculated. The app collects user-facing inputs, while the homebase ESP32 remains responsible for safety-critical pump control and dosing decisions.

2.5 Fluid, Mixture, & Sensing Subsystem

The Fluid, Mixture, and Sensing Subsystem is responsible for storing the raw liquids, metering them to precise volumes and concentrations, and optically verifying the final mixture in a closed feedback loop. This subsystem is responsible for its own safe operation in order to prevent harmlight UV light from leaking out of its enclosure and nicotine from escaping its tubing paths.

2.5.1 Fluid Transfer

Fluid Transportation is handled by 12 V Adafruit peristaltic pumps [10] driven by Adafruit DRV8871 motor driver breakout boards [11]. These pumps are ideal for highly viscous liquids, like the diluent of e-juices: vegetable glycerin (VG) and propylene glycol (PG). The drivers are sent a PWM signal to power the pumps to draw specific ratios of concentrate and diluent into a central mixing chamber. They are turned on when adding liquid from either the concentrate (ascorbic acid) or the diluent (water) to the mixing chamber and when circulating newly mixed liquid through the nicotine sensor is required.

The fluids are transported to and from 100 mL Nalgene bottles to house the chemicals safely while providing a measurement of volume. Chemical-safe silicone rubber tubing connects the reservoirs to provide flexibility to easily make intermediate connections while still being durable. The tubing has a 5mm Outer Diameter (OD) and 3 mm Inner Diameter (ID), chosen in accordance with requirements for the quartz tubing in the optical sensing system so that it could fit around the quartz tubing's 4 mm OD tightly but comfortably. The silicone tubing is opaque black so as to absorb all UV light that scatters inside the sensor. The tubing diameter also matches that of the pumps, using a barbed connector to securely connect the two silicone tubings.

The mixing chamber has a pump and tubing dedicated to stirring and sensing. It draws from this reservoir and circulates its solution through an optical sensor. This action doubles as a way of mixing the liquid evenly, which is necessary for accurate concentration sensing and outputting a proper refill dose.

One design choice we had to make while choosing pumps was how powerful pumps we wanted. We understood that pumping viscous fluids would require strong pressure. That led us to choosing 12 V peristaltic pumps over other smaller voltage pumps. The trade off is the consumption of more power in from the pumps as well as form (6 V pumps would be smaller and quieter).

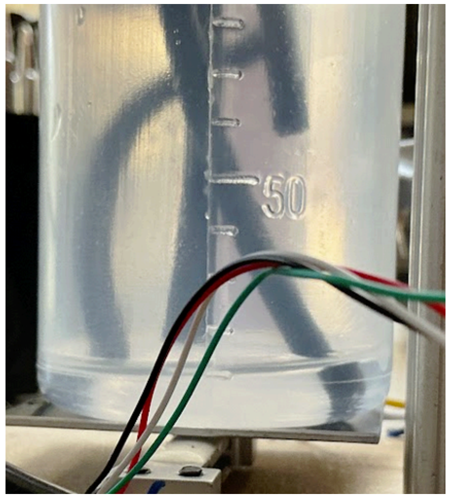

Figure 11: Fluid Transfer Accuracy Verification

Our requirement for the pumps was to ensure we could pump a desired amount of liquid within 5 % of the target amount. To verify this requirement we started by making sure the reservoirs were empty of any liquid. From there we proceeded to run the pumps to fill the tubes with liquid so that we remove any offset of pumping from our pumping time to fill the container with the target amount. From there, we ran our program, set to the target amount, and verified that the amount of liquid in the reservoir was accurate within 5 %. We were able to achieve this metric, and verify it because our reservoirs had mL markings on the side of the containers. Also because the conversion of weight to volume for water (1 g is equal to 1 mL), we were also able to verify this volume using the load cells.

2.5.2 Mass-Volume Validation

To monitor fluid levels and prevent overflow, the system uses three 500 g micro load cells [12] paired with HX711 24-bit ADC [13]. The 500 g load cells were specifically selected instead of standard 100 g versions because a full 100 mL reservoir of dense e-liquid base (propylene glycol and vegetable glycerin) weighs roughly 126 g, which would physically overload the smaller sensors. These load cells also served as an alternative (backup) method to measure the concentration of nicotine in the mixed chamber. The load cells are mounted firmly to the home base floor with custom square plates mounted on top of them to fit the reservoir bottles. The load cell outputs are fed into ADC GPIO pins and allow the software to zero and measure the mass on command. This mass can then be converted into volume when densities are known. Using these to measure concentration turned out to be unreliable, as we predicted, due to the tubing jostling the bottles around during pumping, and slight disturbances (bumping the home base) would cause errors outside of our desired tolerance range; however, they were able to dispense a desired volume to an accuracy within 2.0 % if needed.

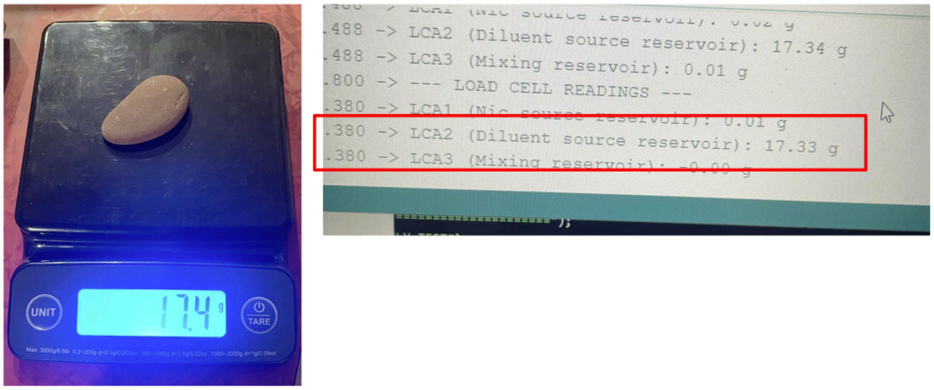

Figure 12: Load Cell Accuracy Verification

The requirement for the load cell module of the homebase was to measure the weight of the reservoirs within 0.5 grams. In the figure above we used a readily available object of similar weight to demonstrate the load cell accuracy. To verify the accuracy of the load cells in general, we placed an object onto our scale and got its weight in grams. Then we proceeded to zero the load cells and place the object of known weight onto each load cell and read the value. In figure 12 it is shown that the accuracy of our load cells were well within that 0.5 gram tolerance.

2.5.3 Ultraviolet Nicotine Concentration Sensor (UNCS)

Once the liquid is mixed, a dedicated circulation pump pushes the solution through a custom continuous flow cell for optical verification. This module is called the Ultraviolet Nicotine Concentration Sensor (UNCS). The UNCS framework utilizes a 295 nm UVC LED [14] shining through a 2mm ID quartz glass tube that contains liquid nicotine within 0-5 % (0-50 mg/mL) concentration. Quartz is strictly required for this beam path because standard clear silicone tubing completely blocks UVC light. The light that is transmitted through the liquid is detected by a UVC photodiode [15], which generates photocurrent in the nano-to-microampere range. This small photocurrent is then amplified by an OPA380 [16] transimpedance amplifier (TIA), which outputs a readable 0–3.3 V analog signal to the ESP32. The TIA is needed, since the microcontroller reads voltage and not current. The ESP32 uses this voltage to calculate the real-time concentration and adjusts the pumps accordingly to hit the target mixture.

Design Alternatives

An alternative to our optical sensor is an electrochemical sensor: a g-C3N4/CNT (carbon nitride and carbon nanotube) composite developed specifically for e-liquids. While this method measures nicotine directly, we ultimately rejected it due to its extreme complexity, lack of commercial availability, and short lifespan. The research lacks the step-by-step manufacturing instructions needed to build the nanomaterial electrodes from scratch, making it not feasible for this semester’s project. Furthermore, these electrochemical strips degrade after just a few weeks of physical contact with thick PG/VG liquids. Since our device is designed to support a user's tapering program over several months, this short shelf life and the need for constant part replacements made our solid-state, non-contact UV optical approach the much more practical and reliable choice. One decision that was averted was the method of grabbing liquid to measure from the mixing chamber. Originally, the UNCS enclosure was to have one hole on one side, and liquid would flow into the test tube attached towards the bottom half of the mixing reservoir's side wall while it was being filled. The tubing inner diameter was too small for this, so we required the force of pumps to do the job. This meant that the tubing needed an exit and to flow back to the mixing chamber to prevent pressure build up and a connection failure (miniature pipe-burst).

Design Procedure

The UNC Sensor uses UV light at 290 nm since nicotine only absorbs light deep into the UV spectrum, and not visible light [17]. Appendix C shows many of the UNCS design equations, calculations, simulations, and schematics. Figure C1 shows there is a specific peak in absorption for nicotine at around 265 nm. Using the Beer Lambert Law [18] to calculate the amount of light absorbed (Eq. C1) for nicotine's 265 nm molar extinction (ε) of about 3000, a path length (l) of 2 mm, and a concentration (c) of 5%, or 0.308 mol/L, all of the light would be absorbed. Therefore, the decision to move to a higher wavelength was made. The new wavelength chosen was higher instead of lower, since the hardware is easier to make due to lower energy levels of the photons and therefore bandgap requirements of the semiconductor materials. Figure C1 shows that 295 nm exhibits a much lower ε value of around 10. Revisiting the same calculations gives a minimum light transmitted of 24 %. This is much more feasible to work with for the maximum absorption we will need to account for.

Next, the TIA needs to amplify the input photocurrent and output a voltage. The gain of this opamp is decided by a feedback resistor, R_f , and the output voltage is simply a product of the feedback resistance with the input photocurrent. Once the maximum and minimum theoretical photocurrent values were found, a resistor was chosen to meet these upper and lower bounds. Upon initial design using hand calculations, 444 kΩ was chosen to give an output voltage that falls within the bounds of 0.85 V and 3.3 V. After simulating the circuit shown in Figure C2, output voltage was being clipped at around 2.88 V, as observed in Figure C3; therefore, the resistor value was lowered to 360 kΩ. More simulations like step response and Bode plots were done to visualize stability and bandwidth requirements, and these can be visualized in Figures C4 and C5. The PCB was designed and assembled using the layout shown in Figure C6.

The PCB containing the UV LED is in Figure C6 as well. The design was straightforward, and through hole mounted cylinder shaped packages were chosen for the LED and Photodiode with the compatibility and the enclosure in mind. The UNCS needed an enclosure to prevent unwanted light from entering, and to prevent dangerous UV light from escaping. To do this, black Polylactic Acid (PLA) filament was used to 3D print the parts for the enclosure. PLA attenuates UV-range light very well, and further testing precautions were taken as well to ensure safety, like more layers of material over the enclosure and eye-protection lenses. The initial concept was to run tubing through each side of the enclosure, and have it aligned perpendicular to the middle of the light path. The holes for tubing were tightly toleranced around the tubing diameter of the silicone rubber tubing that connects to the quartz test tube, and black opaque tubing was chosen to prevent escaping light and reflection. Wire holes were made at a right angle to the light path axis to make light-escape more difficult. The initial sketches can be seen in Figure C7. The final design can be seen rendered as a CAD model in Figure C8. Finally, the full assembled and connected UNCS can be seen in Figure C9.

Testing & Verification

Once the UNCS enclosure was assembled, the next step was hardware testing. The first test was with no light and no tubing in the path. Table C1 shows changing the PWM duty cycle input to the LED changes output voltage proportionally. The voltage measurements were steadily held within 0.05 V for a period of five seconds. Three important conclusions were drawn from this: the sensor works as intended, the output voltage must be greater than 0.142 V when light is on, and the gain must be increased. Clearly, the theoretical maximum output voltage was much higher than the experimental, so a new feedback resistance was chosen. The photocurrent was calculated from the maximum voltage and the old resistance to find the new optimal feedback resistance of 2 MΩ. This brought the voltage to 2.71 V at 100 % duty cycle, which is much better.

To calibrate the UNC Sensor, a sample of diluent-only was used as a reference, which was water for our purposes. The voltage output measured while this “blank” sample was in the test tube, denoted as the blank voltage, was 1.25 V ($\pm$0.01 V over 10 s). The voltage of the maximum concentration sample of 0.5 $\pm$0.05 grams of ascorbic acid was dissolved in 100$\pm$0.5 mL of deionized water. After running the sample through the UNCS test tube for 60 s, the average value measured was 0.49$\pm$0.01 V. After testing with the concentrate running through the test tube, it contaminated the walls slightly, lowering the blank voltage to 1.13$\pm$0.01 V. This is a more realistic measurement, since the system will start out at a high concentration and taper down to 0 %, so remnants of the leftover concentrate should be accounted for. The blank voltage outputs read by the ESP32 every 25 ms are shown in Figure C10. This verifies our requirement of the voltage difference between the blank sample and the maximum concentration sample being greater than 0.5 V, since 1.13 - 0.49 = 0.64 V.

A calibration curve was constructed using a GENESYS Spectrophotometer [19] to prove that small changes in concentration could be detected at the 290 nm wavelength, which is shown in Figure C11, with subsequent calculations showing the math to convert the output voltage of a sample to its concentration. A new one was constructed with this new data: $Absorbance \ = \ 0.7528 \ \cdot \ concentration$. Using equation C10 with this gives $c = \frac{-log(\frac{V}{1.13})}{0.7528}$, successfully relating output voltage to concentration.

3 Cost and Schedule

3.1 Cost Analysis

3.1.1 Bill of Materials

Description	Manufacturer	Price	Qty	Ext. Price	Link
ESP32-WROOM-32E Bare	Espressif	$3.95	2	$7.90	ESP
Peristaltic Pump (12V) w/ Tubing 1m	Adafruit Industries	$24.95	3	$74.85	PP
Mini Load Cell - 500g	SparkFun Electronics	$15.50	4	$62.00	Load Cell
UV Photodiode (SiC) 290 nm	Sglux GmbH	$65.75	1	$65.75	DK - PD
Load Cell Amplifier HX711	SparkFun	$11.50	3	$34.50	LC Amp
120VAC - 12VDC, 3A power supply adapter	Arkare	$9.59	1	$9.59	Power cable
Li-ion Battery 16350	Vapcell	$17.59	0.25	$4.40	16350
LDO Regulator AP2112K-3.3TRG1	DigiKey	$0.22	4	$0.88	LDO
Ultraviolet (UV) Light Emitter 295 nm	EPIGAP OSA Photonics	$58.15	1	$58.15	UV LED
IC LED Driver - AL8860WT-7	Diodes Incorporated	$0.57	1	$0.57	DK - driver
Quartz Glass Tube 4 mm OD, 2 mm ID, 12"	McMaster-Carr	$2.97	0.2	$0.59	Quartz Tube
Silicone Rubber Tubing, Opaque Black, 3 mm ID, 5 mm OD, 10ft	McMaster-Carr	$12.80	1	$12.80	Silicone Tubing
Plastic barbed bulkhead fitting 10pk	McMaster-Carr	$6.45	0.2	$1.29	Link
125mL Nalgene™ HDPE Bottle	Thermo Scientific™ Nalgene™	$1.83	3	$5.49	Link
#4-40 Flat Head Machine Screw Phillips Drive Steel	Pomona Electronics	$0.36	32	$11.52	Machine Screws
USB-C receptacle, 16-pin	ATTEND Technology	$1.94	2	$3.88	DigiKey
USB to Serial Port chip CH340C	WCH	$0.57	2	$1.14	LCSC
TP4056 Battery Charger	TOP POWER ASIC	$0.09	1	$0.09	LCSC
DW01A Battery Protection	Slkormicro Semicon Co., Ltd.	$0.10	1	$0.10	DigiKey
Dual MOSFET FS8205A	EVVO	$0.34	1	$0.34	DigiKey
Coil Driver MOSFET AO3400A	Alpha & Omega Semiconductor Inc.	$0.46	1	$0.46	DigiKey
12V to 3.3V Buck Converter MP2338GTL-P	Monolithic Power Systems Inc.	$1.92	1	$1.92	DigiKey
6.8uH inductor 74437356068	Adafruit	$2.55	1	$2.55	DigiKey
Adafruit DRV8871 Motor driver Breakouts	Adafruit	$7.50	3	$22.50	Adafruit
Power Barrel Jack	Würth Elektronik	$1.02	1	$1.02	DigiKey
Transimpedance Amplifier 1 Circuit 8-SOIC	Texas Instruments	$6.21	1	$6.21	TI Opamp
Custom PCB Fabrication	JLCPCB/ PCBWay	$5.00	4	$20.00	PCBWay
Chip Resistors	DigiKey	$0.10	28	$2.80	DigiKey
Ceramic Capacitors	DigiKey	$0.08	30	$2.40	DigiKey
3D Printing Filament Black PLA 1kg	BambuLab	$13.99	0.1	$1.40	Bambu PLA
Total Parts Cost				**$417.09**	

3.1.2 Labor Cost Analysis

$$(\$50/\text{hr})\ (20\ \text{hr}/\text{week} \times 14\ \text{weeks})\ (2.5) = \$35{,}000$$

Figure 13: Estimated Per partner Labor Cost

$$(\$50/\text{hr})\ (3\ \text{hr})\ (2.5) = \$375$$

Figure 14: Estimated Outsourced CAD Labor Cost

$$(\$75/\text{hr})\ (6\ \text{hr})\ (2.5) = \$1{,}125$$

Figure 15: Estimated Machine Shop Labor Cost

3.2 Schedule

Week	Phase	Ian (MCU Logic & Hardware)	Justin (Project Management & Mechanical)	Malik (Algorithm & App Integration)
Week 7 (Mar 2)	Design Finalization & Ordering	Finalize custom PCB schematic and layout for fabrication.	Finalize Design. Order all raw components, pumps, and sensors. Order PCB.	Draft the core tapering algorithm logic in C++/Python. Set up the basic app environment.
Week 8 (Mar 9)	Prep & Prototyping	Write initial ESP32 test scripts for the I2C sensors and PWM motor drivers.	Begin CAD modeling for the Home Base acrylic housing and Handheld device tank.	Develop the BLE transmission protocol and define the data payload structure between the App and ESP32.
Week 9 (Mar 16)	Assembly & Subsystem Check	Begin breadboard testing of circuitry	3D print the first iteration of the Home Base housing. Route the FEP tubing for the peristaltic pumps.	Build UI dashboard for "Base Status" and "Vape Status".
Week 10 (Mar 23)	Mock-Up / Individual Testing	Wire ESP32 to the motor drivers and load cells. Verify pump activation.	Calibrate micro-peristaltic pumps for volumetric accuracy (±2%). Assemble Handheld vape housing.	Pair the App with the ESP32 via BLE. Send dummy concentration data to the UI.
Week 11 (Mar 30)	Integration Phase 1: Home Base	Integrate load cell feedback loop with motor drivers to achieve accurate mixing.	Mount all reservoirs, pumps, and the PCB into the physical Home Base housing. Check for fluid leaks.	Push the volumetric dilution algorithm to the Home Base ESP32. Test algorithm response to simulated data.
Week 12 (Apr 6)	Integration Phase 2: Handheld	Wire MOSFET, heating coil, and pressure sensor. Test 10-second thermal watchdog.	Integrate the Handheld PCB and 18650 battery into the portable casing. Ensure silicone septum is leak-proof.	Sync Handheld puff duration/frequency data to the mobile app. Test the "Refill Required" flag.
Week 13 (Apr 13)	Full System Integration	Establish two-way BLE comms (App to Base, Handheld to App) without packet loss.	Perform the first physical fluid transfer from the Home Base to the docked Handheld vaporizer.	Finalize app UI and historical data logging charts. Debug any BLE latency issues.
Week 14 (Apr 20)	Refinement & R&V Testing	Run through every single R&V table check. Tune the optical UV sensor thresholds.	Perform full mechanical stress tests. Polish the physical presentation of the prototype.	Run the adaptive state transition tests (simulating "High" and "Normal" puff density).
Week 15 (Apr 27)	Final Demo Prep	Receive and solder PCBs and prepare them for final demo.	Draft Final Presentation slides and Final Paper.	Polish the app GUI for the live demo. Generate sample user data for the presentation.

4 Ethics, Safety, Engineering Standards, and Societal Impact

4.1 Societal, Economic, and Environmental Impact

This project makes a profound positive contribution to public health, directly aligning with the IEEE Code of Ethics (Canon 1) to hold paramount the safety, health, and welfare of the public. Tobacco and nicotine dependency remain a leading cause of preventable death globally. By providing a closed-loop, automated tapering system, FadeX removes the psychological burden of manual weaning, potentially increasing cessation success rates and reducing the long-term burden of smoking-related illnesses on the global healthcare system.

Economically, the lifetime cost of healthcare for a smoker, combined with the recurring cost of recreational vaping, is astronomical; successfully weaning a user generates massive financial benefits for the individual. Environmentally, traditional disposable vapes create a global e-waste crisis, sending millions of lithium-ion batteries and single-use plastics to landfills annually. FadeX mitigates this by utilizing a durable, refillable, and reusable architecture designed for a multi-year lifecycle, significantly reducing plastic and toxic battery waste.

4.2 Ethical Considerations

A primary ethical concern is the security of the user's medical data and tapering schedule. To uphold data integrity and prevent unauthorized modifications to the dosing algorithm, the devices utilize encrypted Bluetooth pairing (Security Mode 1, Level 4). Additionally, there is an inherent ethical responsibility to ensure this device acts strictly as a cessation tool rather than a recreational vaporizer. By locking the dosage ratios behind the Mobile Application's algorithm and physically automating the fluid transfer in the Home Base, the design restricts the user's ability to arbitrarily increase their nicotine intake, enforcing the medical intent of the product.

Furthermore, in direct accordance with Canon 1 of the IEEE Code of Ethics—to *"hold paramount the safety, health, and welfare of the public"*—the system architecture is designed to fail safely. Because liquid nicotine is highly toxic in concentrated doses, the inclusion of the final UVC optical concentration sensor acts as an ethical hardware failsafe. If a software glitch occurs or a fluid pump physically malfunctions, the optical sensor acts as a final verification step to cut power and prevent an accidental nicotine overdose, ensuring the user is never exposed to unsafe chemical levels during their tapering journey.

4.3 Safety Concerns and Mitigation Procedures

Because this project involves hazardous chemicals, high-current electronics, and high temperatures, strict safety procedures have been implemented for both developers and end-users:

- **Chemical Safety** (Nicotine): We decided not to handle liquid nicotine. However, in the future, we may do so. Nicotine is a highly addictive and toxic substance that can be fatal if swallowed or absorbed through the skin. To mitigate this risk, we produced and documented a formal Lab Safety Document outlining the mandatory use of Personal Protective Equipment (PPE), including nitrile gloves and splash goggles, when filling the Home Base reservoirs. All mixing occurs within a controlled, ventilated laboratory environment. Furthermore, the Home Base utilizes a secure, sealed silicone tubing path to prevent user exposure to the raw concentrated stock.
- **Optical Safety (UVC Radiation):** The non-contact nicotine concentration sensor utilizes a 295nm UVC LED. Because 295nm UV radiation is a Risk Group 3 (RG3) hazard that can cause severe photokeratitis (eye damage) and erythema (skin burns), stringent containment protocols are enforced. During the design and prototyping phase, all optical testing is strictly conducted within the Bio-Nano Lab at the Micro and Nanotechnology Laboratory (MNTL). Developers are mandated to wear UVC-blocking polycarbonate safety glasses, and all bare-circuit testing is performed inside a temporary opaque enclosure. For the final end-user device, the UVC LED and FEP optical chamber are fully encapsulated within a light-tight, matte-black 3D-printed housing. To guarantee zero user exposure, this housing incorporates a mechanical hardware interlock switch wired in series with the LED driver's 12V supply. If the enclosure is opened or tampered with, the interlock physically breaks the circuit, instantaneously severing power to the UVC source at the hardware level.

4.4 Engineering Standards

To ensure consumer safety and regulatory compliance, the design adheres to the following engineering standards:

- UL 8139 (Standard for Electrical Systems of Electronic Cigarettes): Our battery management, charging circuitry, and safety cutoffs are modeled after UL 8139 guidelines to prevent thermal runaway.
- FCC Part 15: Because the Home Base and Handheld utilize ESP32 microcontrollers for 2.4 GHz Bluetooth Low Energy (BLE) communication, the system must comply with FCC Part 15 regulations regarding intentional RF radiators and electromagnetic interference.
- IEC 62471 (Photobiological Safety of Lamps and Lamp Systems): Because our non-contact concentration sensor utilizes a 295nm UVC LED (categorized as a Risk Group 3 hazard), the physical hardware interlock and opaque, light-tight 3D-printed enclosure are designed in accordance with IEC 62471 to ensure zero actinic UV exposure to the end-user or lab personnel.

5 Conclusion

5.1 Accomplishments

During the 16 week project we were able to accomplish many of our requirements, from developing reliable power and PCB foundations to being able to sense the main chambers concentration accurately via precise mixing and our UNC sensor. The Vape records puff data and passes it on to the Homebase microcontroller. From there the Homebase processes it as well as passes it to the App for further concentration calculations. Beyond establishing 3 stages of reliable and functional communication, the Homebase was able to use the App for mixing commands and carry out those commands within acceptable margins of error.

5.2 Uncertainties

The uncertainties this project faced can be sectioned out into which module they impacted. For starters, the LDO not working on the Vape PCB, causing the ESP32 to be powered by dangerously high voltage. From the earlier discussion, this problem stemmed from a debugging error that caused the chip to break. Though after testing and identifying the LDO IC that was not functioning properly, the replacement of the LDO IC would bring that ESP32 power voltage down to 3.3 V.

5.3 Future Work

This project has a lot of room for additions and improvements. The idea of a Vape is just a single hand held device, and that's something we would've like to do given more time. The fusing of the Homebase mixing and concentration sensing system into vape is something that would take this project to the next level. Another important aspect of the project would be to incorporate nicotine vape juice so that the pumps and other calibrated peripherals can operate with the intended liquids.

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Appendix A Requirements and Verifications Tables

Table 1A: Home Base Requirements and Verifications

Home Base		
Requirements	**Verifications**	**Status**
Pump Volumetric Accuracy: The 12 V peristaltic pumps must deliver target liquid volumes with an accuracy of ±5 % (e.g., dispensing 10.0 mL must yield between 9.5 mL and 10.5 mL).	Place a dry, empty beaker on a calibrated lab scale and zero it to 0.00 g. Send a command to the ESP32 to dispense exactly 10.0 mL of distilled water (density = 1.0 g/mL). Weigh the dispensed water on the scale. Verify the final mass is between 9.50 g and 10.50 g. Repeat 3 times for both the nicotine and diluent pumps.	**Met**
Optical Verification Sensor: The UVC photodiode and TIA must output a distinct analog voltage differential of >0.5 V between a 0.0% ascorbic acid solution and a 5.0% ascorbic acid solution.	Fill the transfer tubing with 0.0 % diluent (water). Connect a DMM to the output pin of the TIA and record the baseline voltage. Flush the tube and fill it with 5% Vitamin C and 100 mL water solution. Record the new voltage. Verify that the voltage differential is 0.5 V or greater.	**Met**
Load Cell Resolution: The 500 g load cells and HX711 ADCs must detect changes in reservoir mass with a resolution and accuracy of ± 0.5 grams to ensure the mixing algorithm receives valid data.	Place an empty reservoir on the load cell and run the ESP32 HX711 zero script. Output the serial weight data to a monitor. Place a certified 50.0 g calibration weight into the reservoir. Verify the serial monitor reads between 49.5 g and 50.5 g	**Met**
Logic Power Stability: The MP2338GTLP buck converter must supply a steady 3.3 V ± 5 % (3.135 V to 3.465 V) to the Home Base ESP32.	Power the Home Base via the 12 V adapter. Connect a multimeter to the output pin of the MP2338GTLP. Verify the multimeter reading remains within the 3.135 V - 3.465 V window.	**Met**
Adaptive Tapering Precision: The control logic must calculate the next nicotine concentration using the user's current concentration, survey score, usage tier, and selected quit-plan length. It must be clamped between 0.5% - 5.0% nicotine.	Open the Blynk dashboard or Serial Monitor and start a new guided dose session. Set the quit plan to 12 weeks, current concentration to 5.00%, and enter a known test case specified in Appendix D: Figure D3.	**Met**

Table 1B: Handheld Vape Requirements and Verifications

Handheld Device		
Requirements	**Verifications**	**Status**
Voltage Regulation: The circuit battery must be connected to an LDO which then provides a stable 3.3 $\pm$ 5% V (3.135 V to 3.465 V) to the ESP32.	Measure the output from the LDO with a multimeter and verify the voltage is between 3.135 V and 3.465 V.	**Unmet**
Coil Safety Cutoff: The Handheld ESP32 must terminate the MOSFET gate signal (0V) at exactly 10.0 ± 0.5 seconds of continuous activation, regardless of continuous sensor input.	Connect an oscilloscope probe to the ESP32 pin driving the MOSFET gate. Apply a continuous 3.3V signal to the pressure sensor input pin to simulate a stuck/continuous puff. Measure the pulse width on the oscilloscope. Verify the signal drops to 0V between 9.5s and 10.5s.	**Unmet**
Coil Firing: Button will trigger A03400A MOSFET to turn on with 0.0037 mA current across a 1000 ohm Resistor to show coil getting powered by user input	Connect a multimeter across the resistors leads. Program the ESP32 to activate 3.3 V to the gate of the A03400A MOSFET. Verify battery voltage is across the resistor.	**Met**
Usage Tracking Accuracy: The ESP32 must accurately log the duration of the MOSFET firing event to within ±0.1 seconds of coil button activation.	Press the coil button for exactly 3.0 seconds, then verify via the serial monitor or BLE payload that the ESP32 records a firing duration between 2.9 and 3.1 seconds.	**Met**
Data Sync Reliability: The application must receive and log puff duration and frequency data from the Handheld Device with zero dropped packets over a continuous sequence of 20 simulated puffs.	Trigger the Handheld device's coil button 20 consecutive times to simulate user puffs, then check the application's history log to verify it accurately displays exactly 20 distinct entries matching the duration of each triggered event.	**Met**

Appendix B Design Schematics

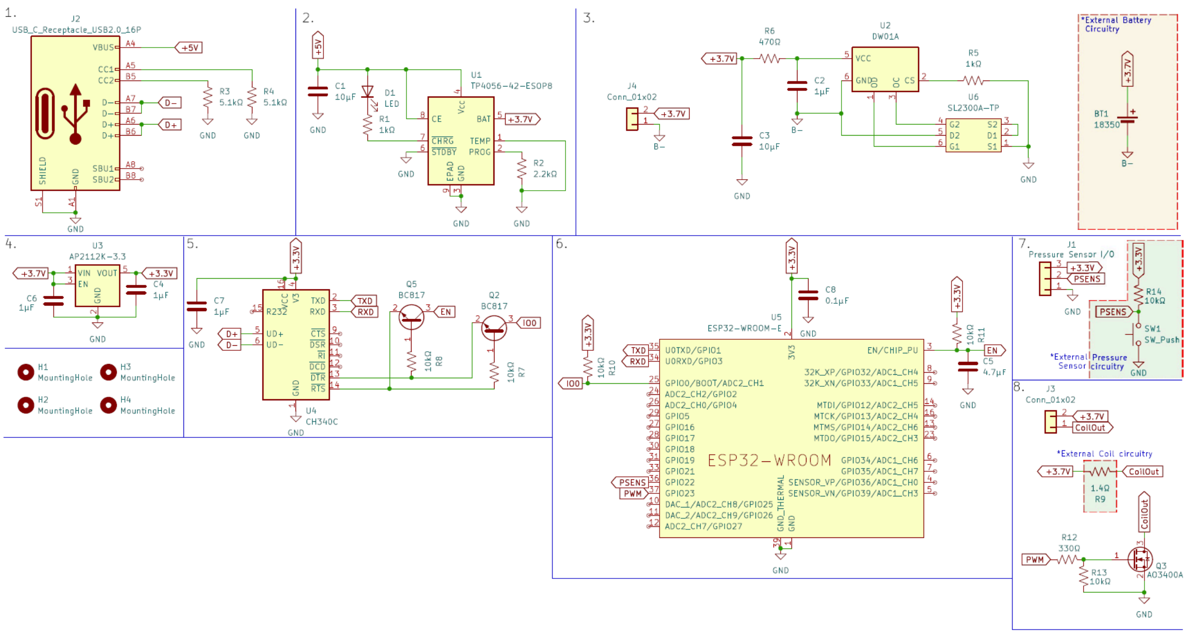

Figure B1: Vape Schematic

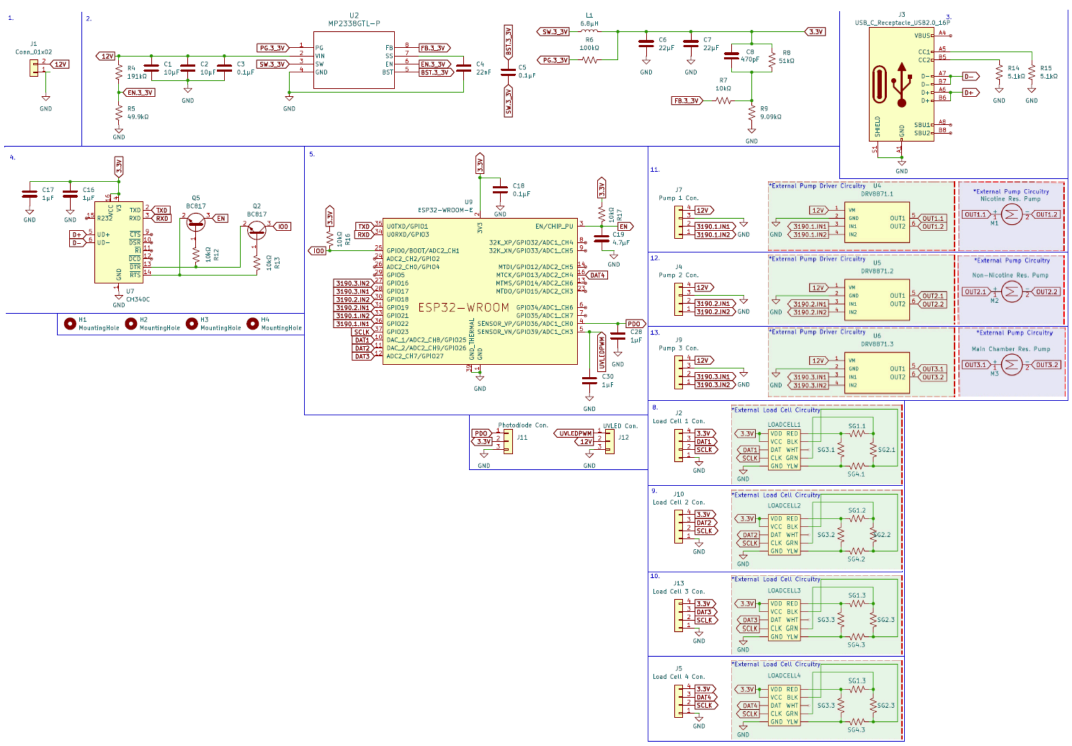

Figure B2: Homebase Schematic

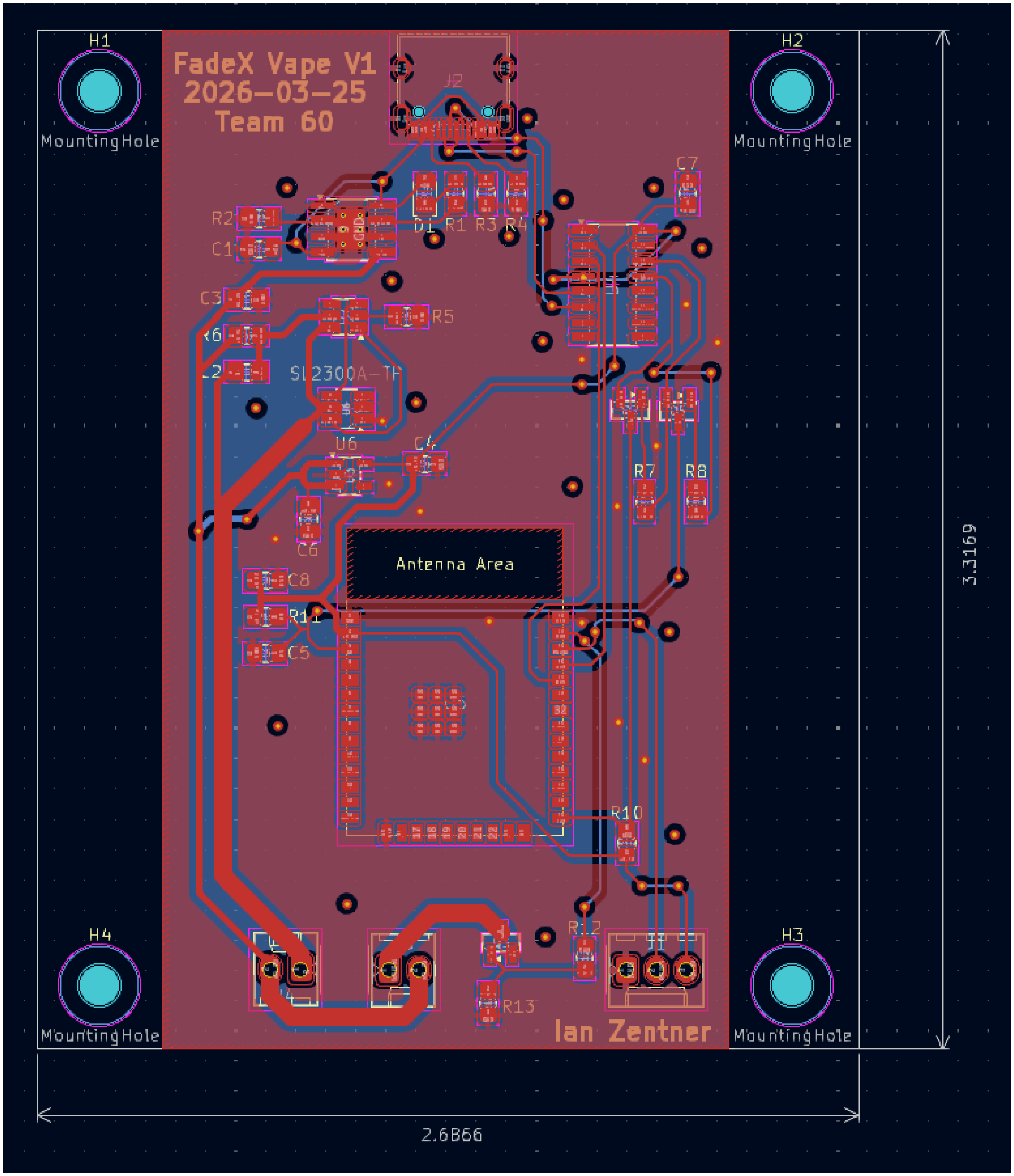

Figure B3: Vape PCB

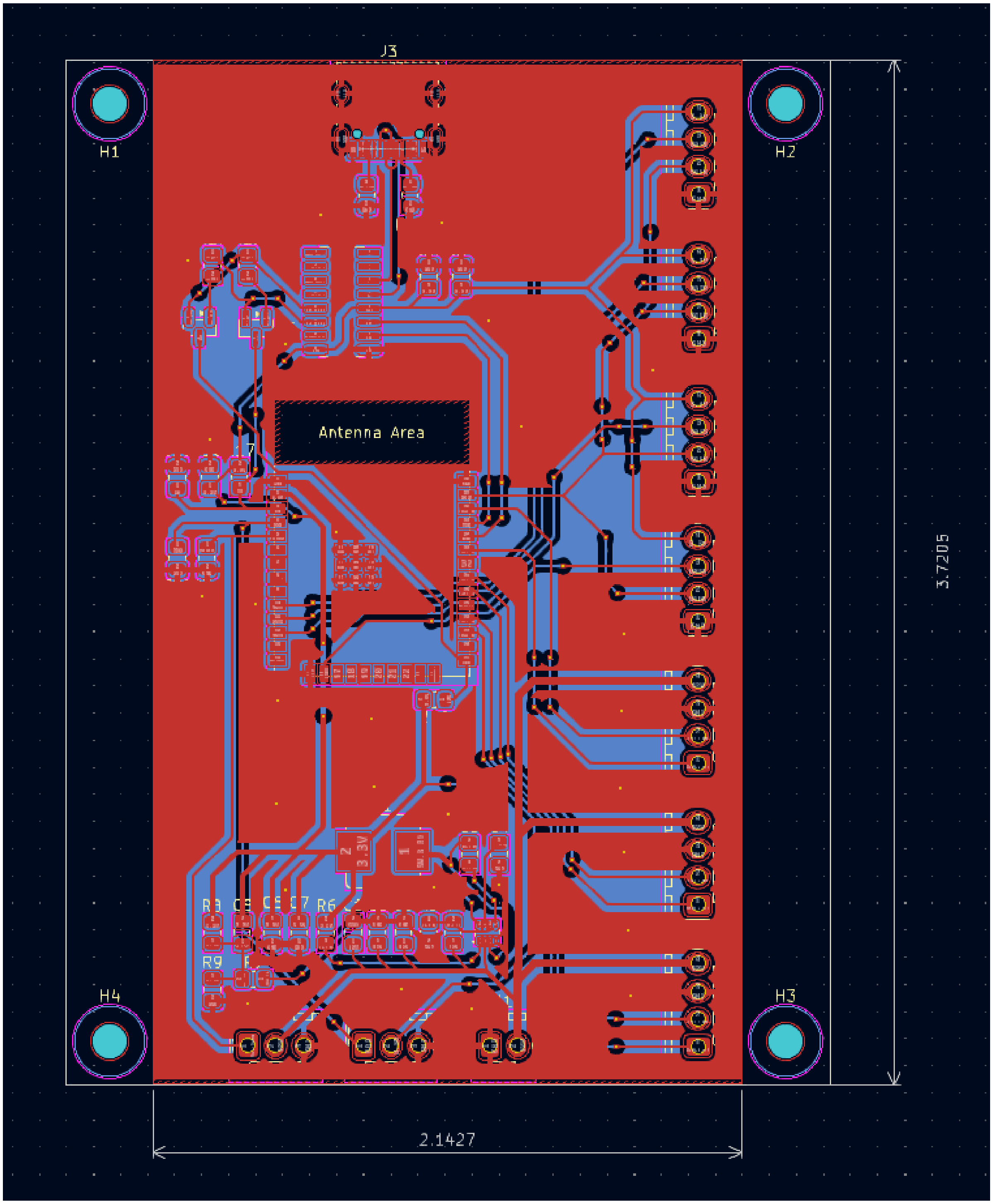

Figure B4: Homebase PCB

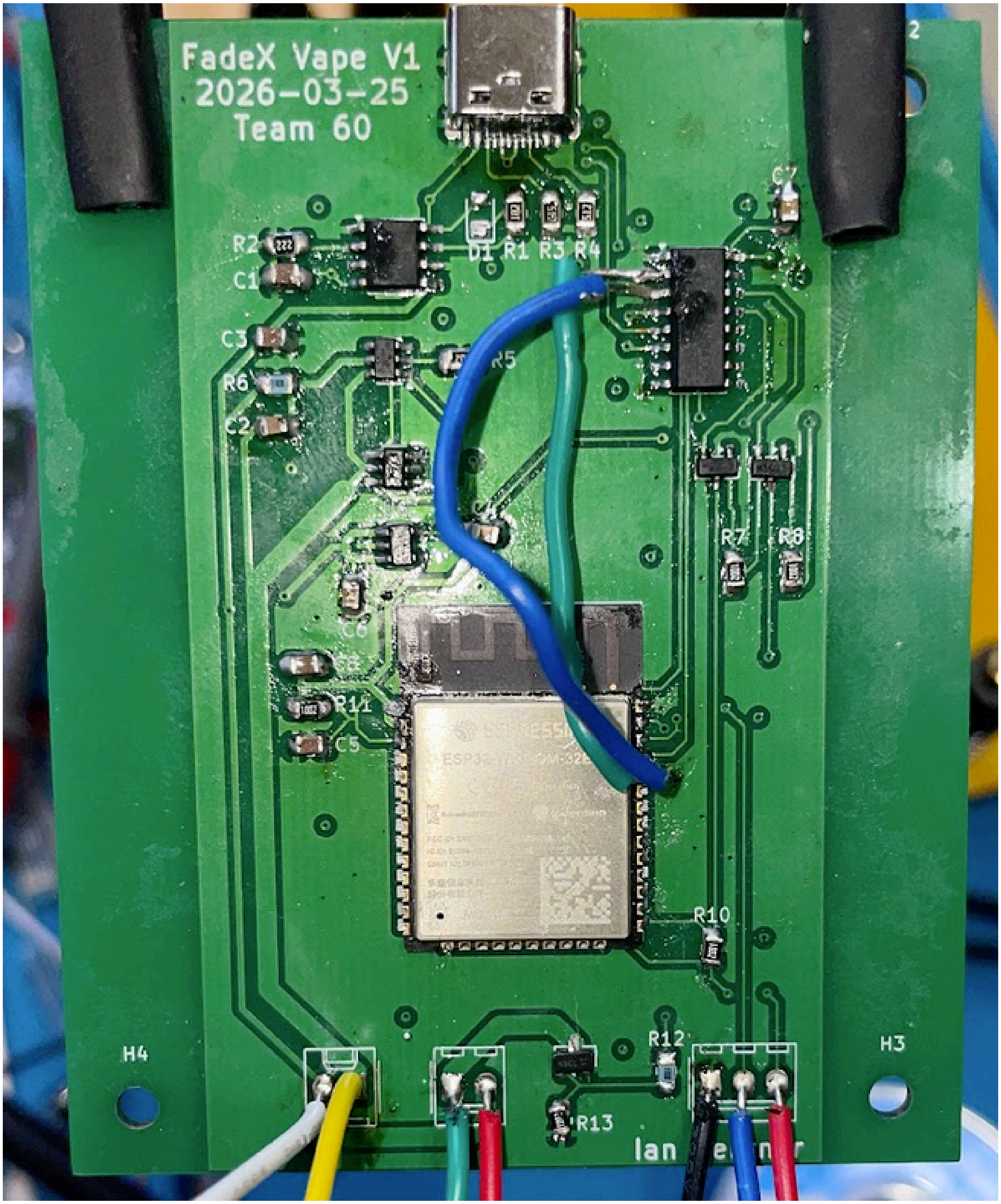

Figure B5: Vape PCB

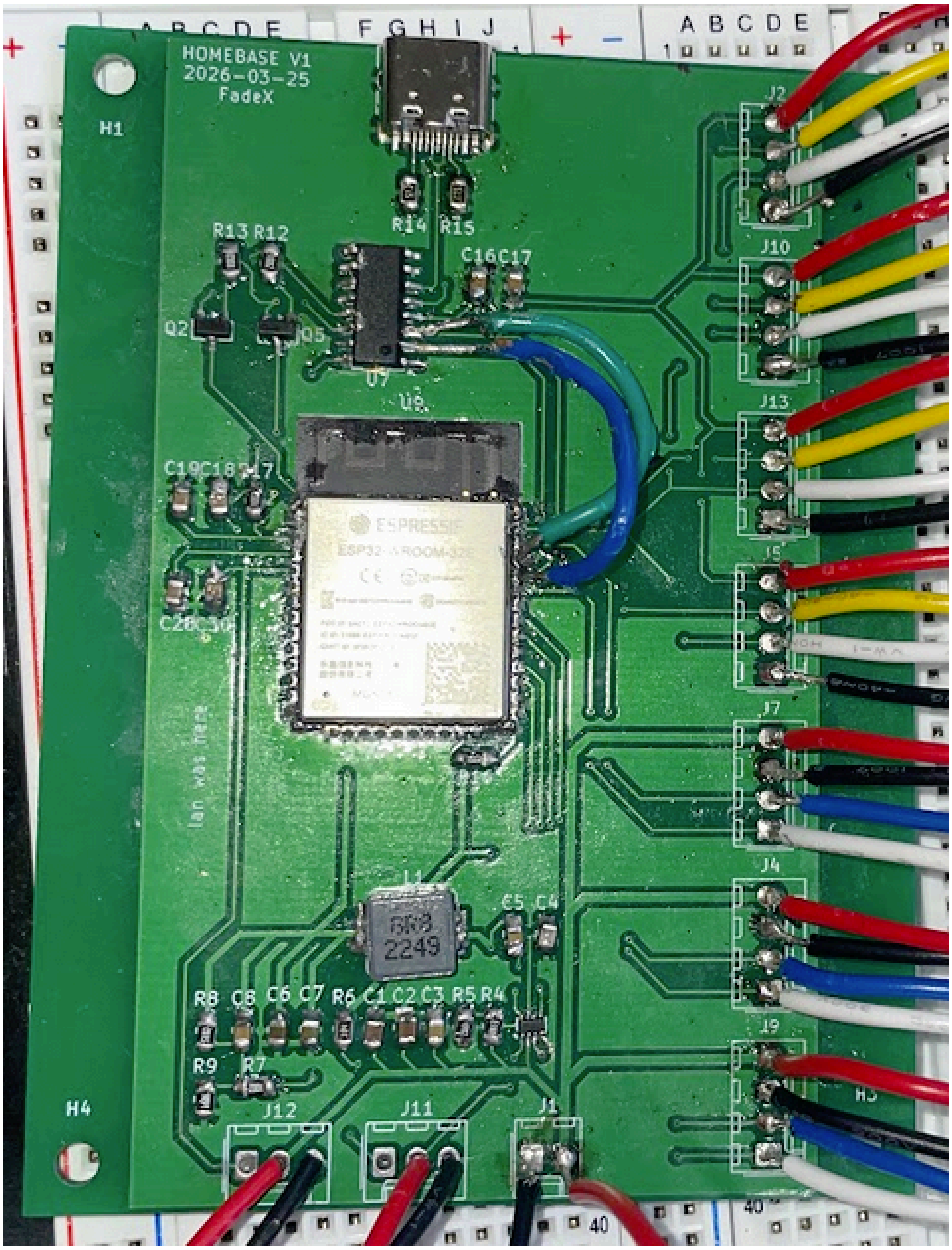

Figure B6: Homebase PCB

Appendix C Ultraviolet Nicotine Concentration Sensor (UNCS)

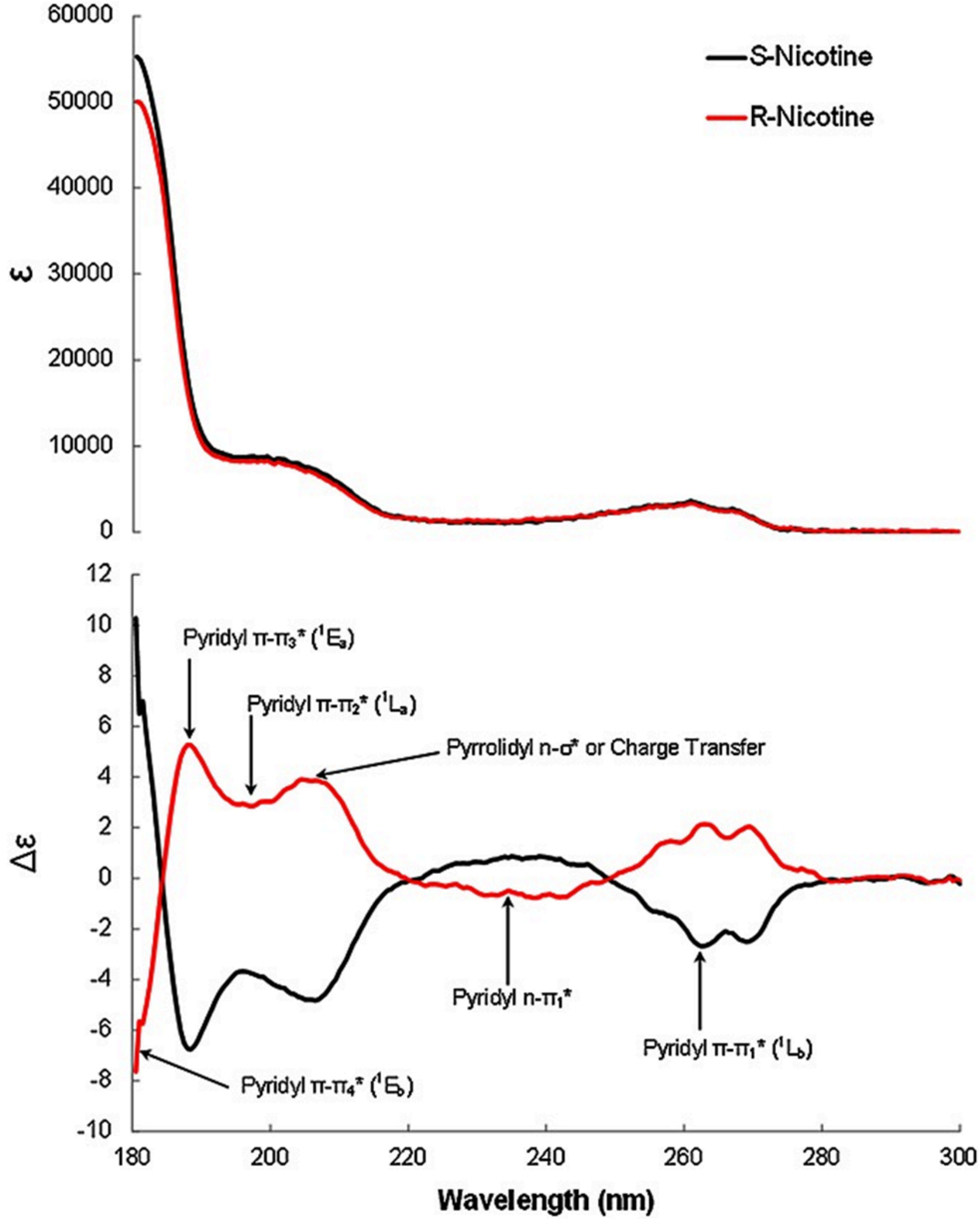

Figure C1: "Spectropolarimetric UV absorption and ECD spectra of (S)-(−)-nicotine (30.6 μg/ml, pH 8.68) and (R)-(+)-nicotine (30.8 l μg/ml, pH 8.88) in water showing suggested spectral assignments at 20 °C. The pathlength was 0.5 mm" [17].

UNCS Optics and Gain Calculations for Design

$$I = I_0 \cdot 10^{-A} \quad \text{(C1a)}$$

$$A = \varepsilon \cdot l \cdot c \quad \text{(C1b)}$$

In Eq (C1) [18], I is the intensity of the light that transmits through the solution and I_0 is the initial intensity of the light incident on the solution. Absorption $A = \varepsilon \cdot l \cdot c$, in which l is the path length (in cm), or the distance that the light travels through the solution, and c is the concentration of the solution (in units M or $\frac{\text{mol}}{\text{L}}$). For a 50 mg/mL ($\approx 0.31\ M$) stock solution of e-juice that we plan to use as our maximum concentration, a 2mm ($or\ 0.2\ cm)$ quartz tube path length that will hold the aqueous solution, we find that the upper limit of absorption would be

$$A = (3000)(0.2)(0.31) \approx 190. \quad \text{(C2)}$$

Plugging this into Eq. (1) gives a ratio of transmitted light to incident light to be

$$\frac{I}{I_0} = 10^{-190} \quad \text{(C3)}$$

which is practically zero. At 260 nm, the fluid becomes optically opaque, blocking effectively 100% of the transmission light. To resolve this, I pivoted our hardware architecture to utilize a 295nm LED and a 290nm silicon carbide (SiC) photodiode. Operating further down the absorption tail drastically lowers the ε value, ensuring sufficient photon transmission to yield a readable delta. Using Eq. (C2) again with an arbitrary $\varepsilon \approx 10$ gives

$$A = (10)(0.2)(0.31) = 0.62. \quad \text{(C4)}$$

Then, using Eq. (3) again gives,

$$\frac{I}{I_0} = 10^{-0.62} \approx 0.24 \quad \text{(C5)}$$

or 24% of light transmitted to the photodetector. This is a much more reasonable number, and now the photocurrent from generated can be calculated. The photodiode's responsivity (R_λ) in units A/W is the amount of photocurrent (I_{ph}) in Amps generated by incident light (I) and is shown in Eq. (C6).

$$I_{ph} = I * R_\lambda \quad \text{(C6)}$$

The UV-LED radiates light at an intensity (I_e) of $26\ \mathrm{mW}/sr$ at a highly focused beamwidth with a view angle of 10°. The photodiode has an active area of $0.20\ \mathrm{mm}^2$ and a maximum responsivity $R_\lambda = 0.16\ \frac{\mathrm{A}}{\mathrm{W}}$. This can all be used to find the photocurrent using Eq. (C6), the result of Eq. (C5), and the following relationship in Eq. (C7).

$$I_{ph} = \frac{I_e * \frac{I}{I_0}}{d^2} * Area * R_\lambda \approx \frac{2000}{d^2}\left[\frac{nA}{cm^2}\right] \quad \text{(C7)}$$

Clearly, a choice of d needs to be carefully considered, since photocurrent has an inverse-square dependence on the distance the light travels. Choosing a reasonable value that would be used for our design of $d = 1\ cm$ gives $I_{ph} = 2000$ nA.

To convert the microscopic nanoamp output of the SiC photodiode into a readable voltage for the ESP32's Analog-to-Digital Converter (ADC), I simulated and designed a Transimpedance Amplifier (TIA) circuit utilizing the Texas Instruments OPA380 precision op-amp. The viability of this TIA topology for our specific application was confirmed through a design consultation with Rakibul Islam, a Teaching Assistant for ECE 483 (Analog Circuit Design) with extensive research experience in low-current TIA layouts.

The Gain of the TIA shown in Eq (C8) allows for a choice of R_f to decide the gain.

$$V_{out} = I_{ph} * R_f \quad \text{(C8)}$$

The choice of the feedback resistance depends on the ADC pin resolution of our microcontroller, the ESP32-WROOM-32E. The 12-bit ADC pin receives 3.3 V, so the choice of R_f cannot cause V_{out} to exceed 3.3 V for the maximum photocurrent case (when the concentration of nicotine $c = 0$). To find the system's sensitivity in sensing concentration, the process involves finding the minimum resolvable voltage of the ESP32, as shown in Eq. (C9).

$$\Delta V_{out} = \frac{3.3V}{2^{12}} = 0.805\ \mathrm{mV} \quad \text{(C9)}$$

Therefore, to successfully detect an incremental change in nicotine concentration (Δc), the resulting change in photocurrent must produce a ΔV_{out} strictly greater than $0.805\ \mathrm{mV}$.

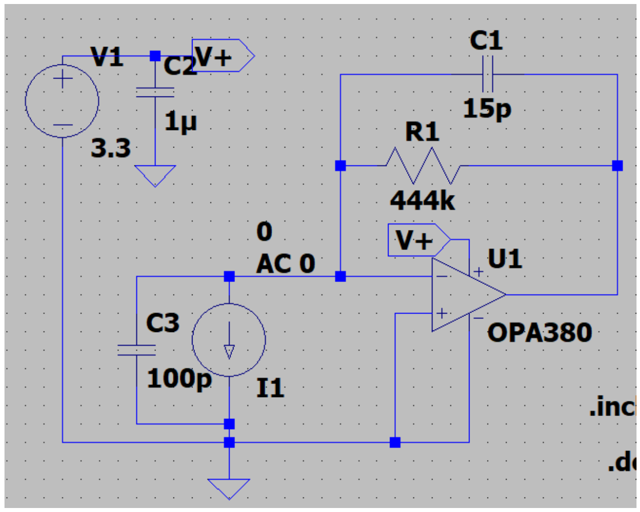

Figure C2: Initial simulated OPA380 op-amp circuit design

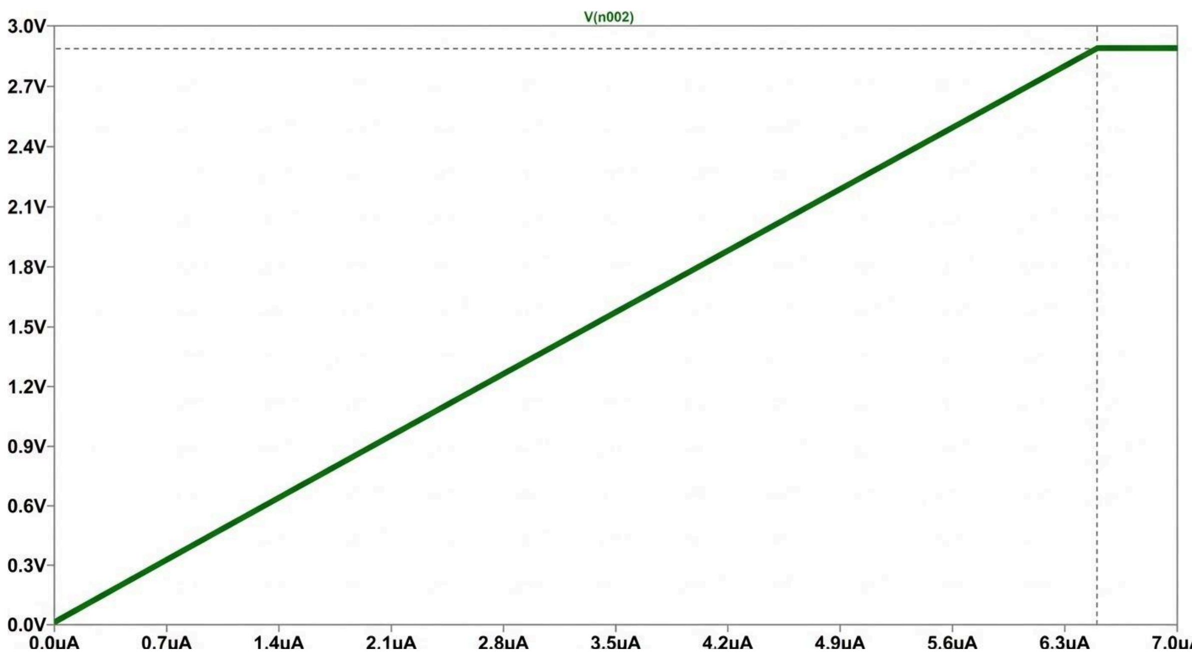

Figure C3: Output Voltage vs. Input Photocurrent simulation from circuit in Fig. C2

Figure C4: Step response of simulated circuit for 5 μA pulse. No overshoot, and settling time of 73 μs

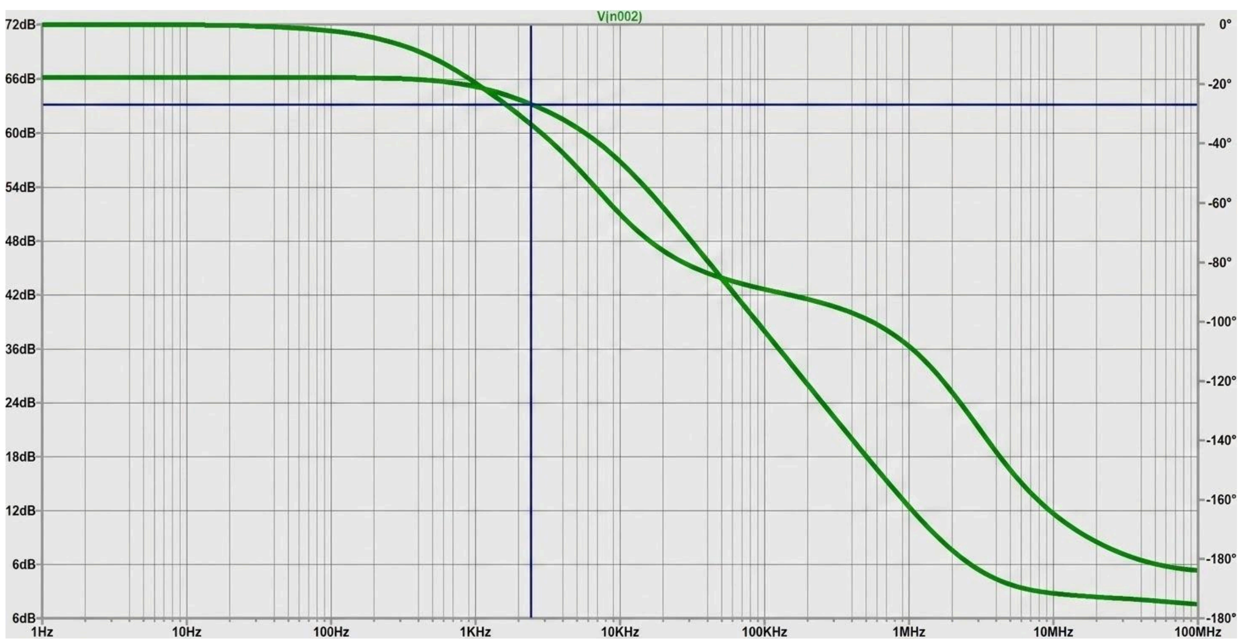

Figure C4: Bode plot overlay of magnitude and phase response. 3dB Bandwidth = 1.77 kHz

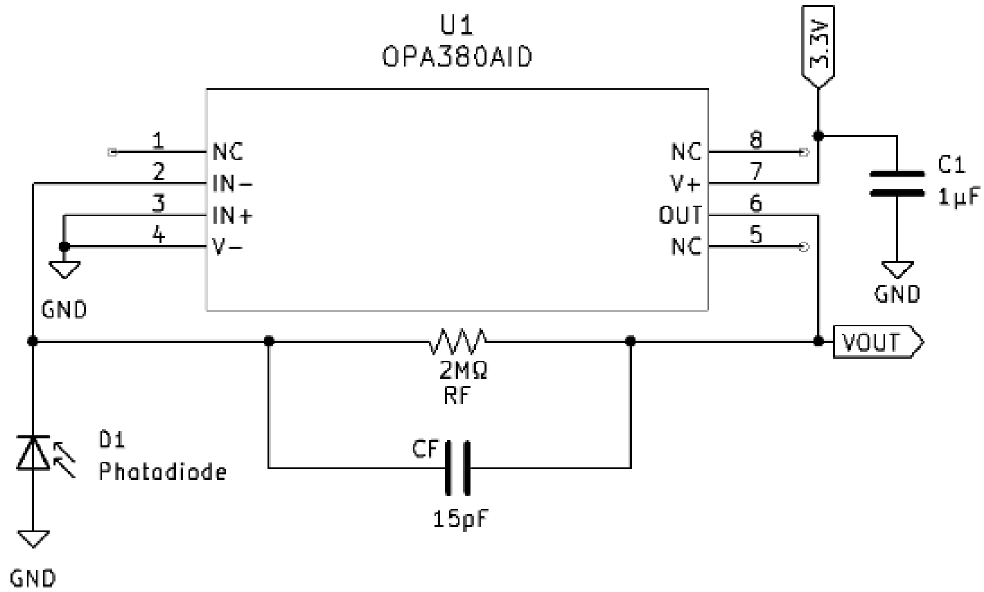

Figure C5: Final Design of Photodetector Schematic

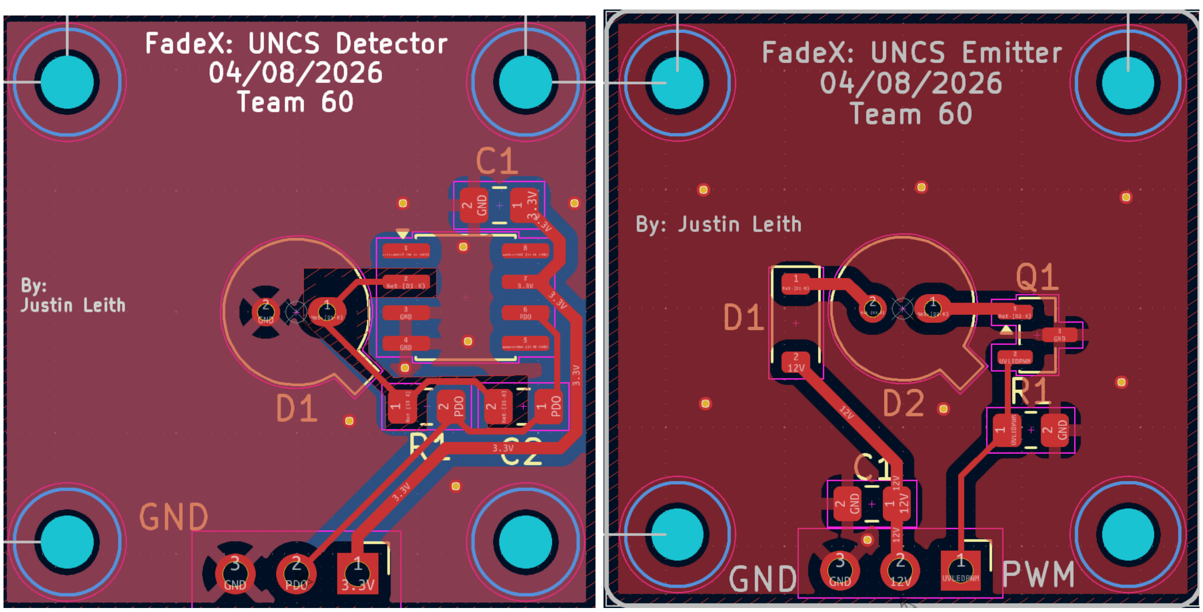

Figure C6: Photodetector PCB (left) and Light Emitter PCB (right)

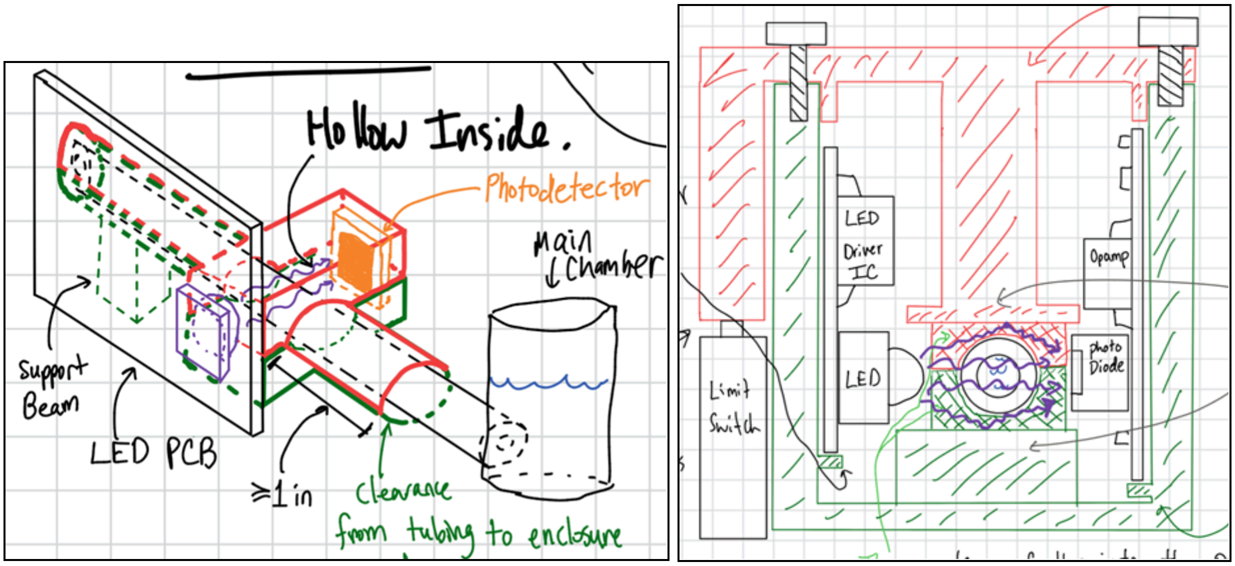

Figure C7: Rough sketches of UNCS enclosure (Left: 3D View; Right: Side View looking along tubing path axis)

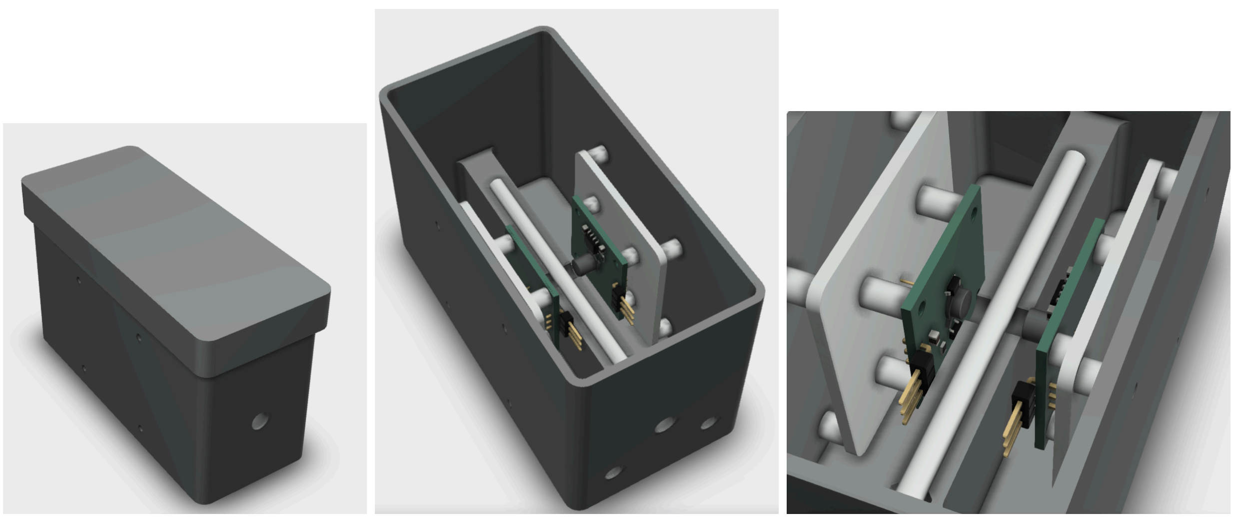

Figure C8: CAD rendering of the UNCS enclosure, showing tubing and PCBs with LED-to-Photodiode light path. Conceptual design and hand-sketches by Justin Leith; CAD implementation by Joshen Patel, Professional Mechanical Engineer (External Consultant).

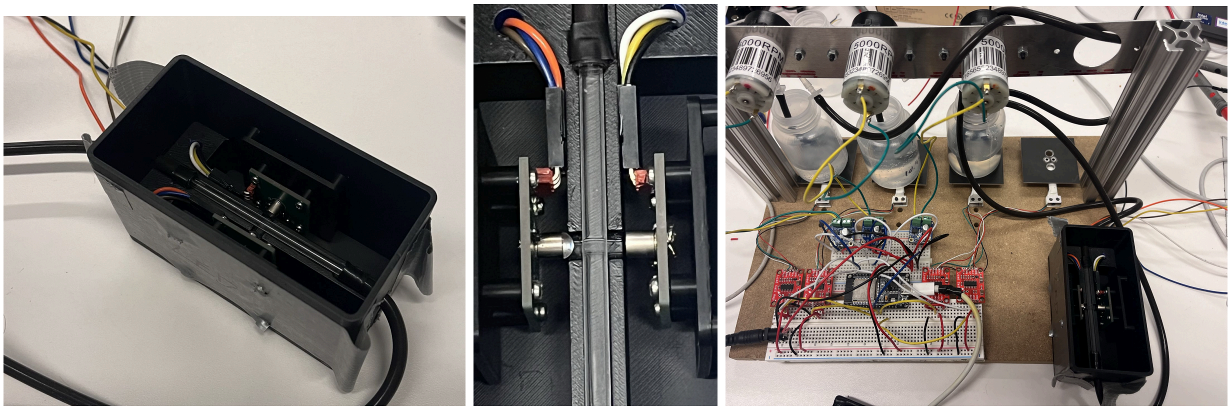

Figure C9: UNCS Assembly

Table C1: Initial UNCS testing

PWM Duty Cycle (% from ESP32 GPIO)	Output Voltage (V into ESP32 GPIO)
100	0.49
75	0.39
50	0.29
25	0.205
0	0.142

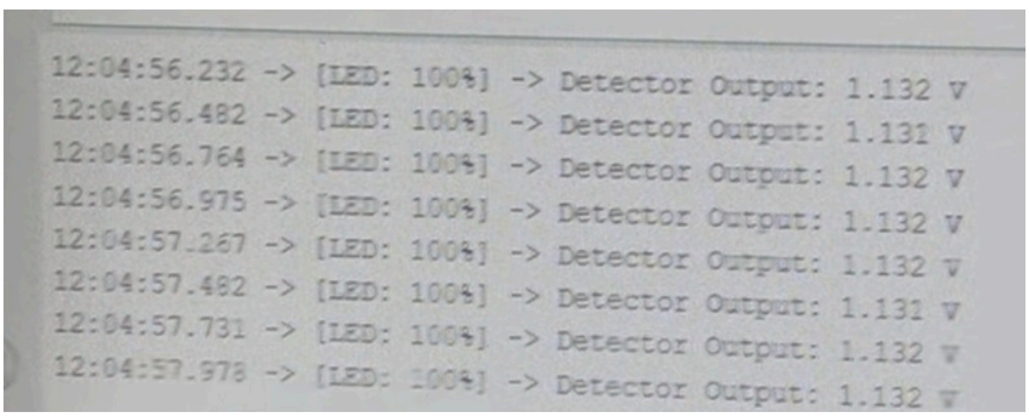

Figure C10: Measurement Verification of 1.13 V Blank Voltage

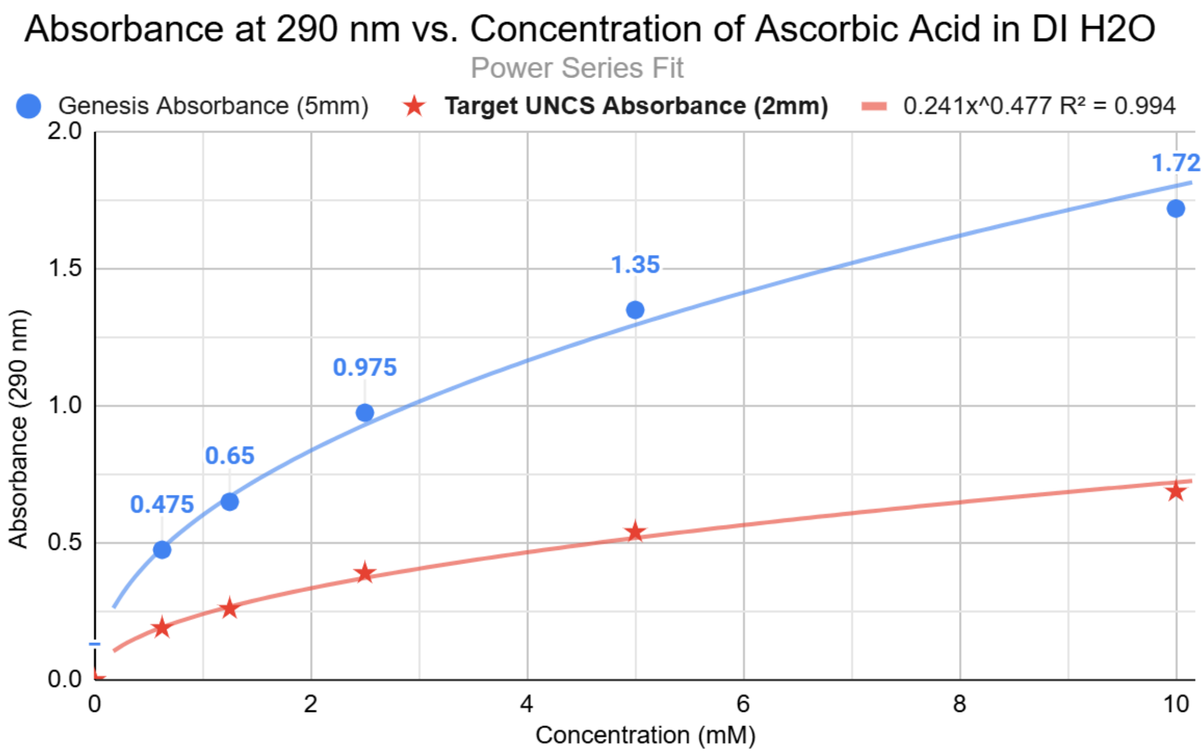

Figure C11: Calibration Curve for Ascorbic Acid

Step 1: Calculate Transmittance (T) Transmittance is the ratio of light that successfully passes through the sample compared to a pure water baseline, adjusted for the sensor's baseline dark noise.

Formula: T = (V_sample - V_dark) / (V_blank - V_dark) (C10)

Variables:

- V_sample = The voltage output when reading the current mixture.
- V_blank = The voltage output of pure DI water (the maximum light transmission).
- V_dark = The voltage output when the UV LED is completely turned off (the electronic noise floor).

Step 2: Calculate Absorbance (A) According to the Beer-Lambert Law, absorbance is the negative base-10 logarithm of the transmittance.

Formula: A = -log10(T)

Step 3: Calculate Concentration (C) Using the calibration curve derived from lab testing, the absorbance is converted to concentration (mM) using a power series trendline equation.

Formula: $A = 0.241 * c^{0.477}$ (C11)

Can relate Concentration to Output Voltage now and compare it to the calibration curve.

Appendix D FadeX Tapering Algorithm

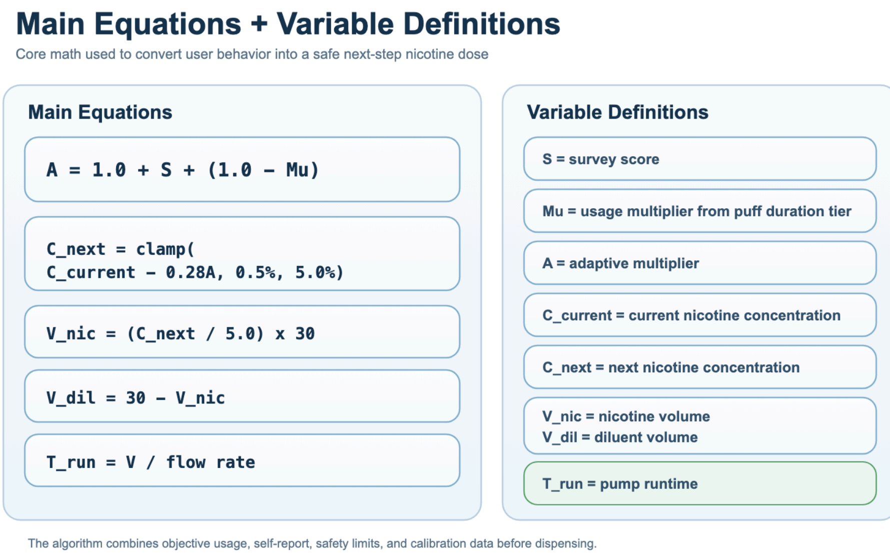

Figure D1: Main Equations & Variable Definitions

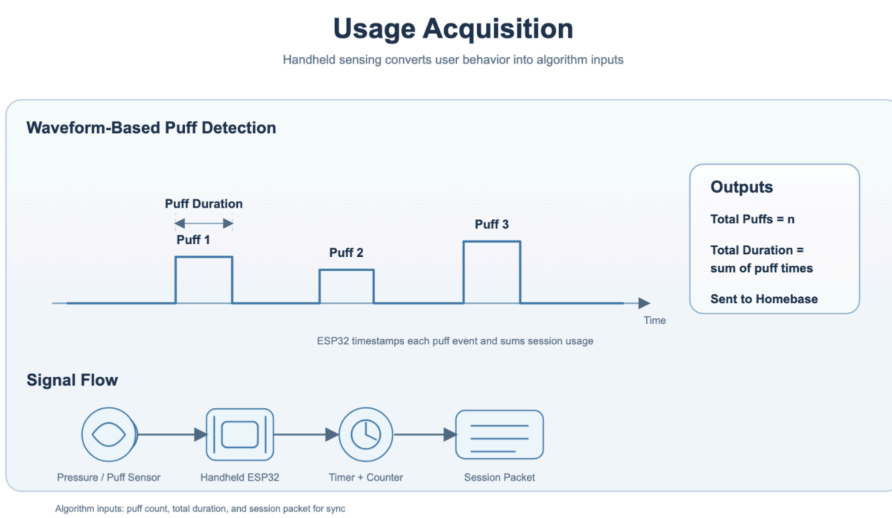

Figure D2: Usage Data Based off Puff Count & Duration

Stage 2: Scenario Drop Rates

Adaptive decision logic maps usage severity and survey score into a scenario-specific taper rate

Scenario Matrix Summary

A = 1.0 + S + (1.0 - Mu)

ID	Usage (Mu)	Survey (S)	Multiplier (A)	Weekly % (3 Mo)	Weekly % (4 Mo)	Weekly % (6 Mo)	Clinical Description
G1	0.9	0.5	1.6	0.60	0.45	0.30	PATIENT EXCELLENCE: High self-efficacy and low dependency.
G2	0.9	0	1.1	0.41	0.31	0.21	EFFICIENT PROGRESS: Physical usage low, patient is stable.
G3	0.9	-0.5	0.6	0.23	0.17	0.11	MENTAL FATIGUE OVERRIDE: Prioritizes mental stability.
G4	0.9	-1	0.1	0.04	0.03	0.02	PSYCHOLOGICAL PLATEAU: 90% slow-down to prevent relapse.
G5	1.0	0.5	1.5	0.56	0.42	0.28	CONFIDENCE BOOST: On-track usage with high morale.
G6	1.0	0	1.0	0.38	0.28	0.19	THE LINEAR ANCHOR: Perfect alignment; standard baseline.
G7	1.0	-0.5	0.5	0.19	0.14	0.09	CAUTIOUS DAMPENING: Cuts speed in half for adjustment.
G8	1.0	-1	0	0	0	0	SAFETY HOLD: Taper paused to provide consistent nicotine.
S1	1.1	0.5	1.4	0.53	0.39	0.27	COMPENSATORY OFFSET: Progress while usage is rising.
S2	1.1	0	0.9	0.34	0.25	0.17	MILD RESISTANCE: Slight 10% safety buffer introduced.
S3	1.1	-0.5	0.4	0.15	0.11	0.08	WITHDRAWAL WARNING: Taper shifts to micro-step.
S4	1.1	-1	-0.1	-0.04	-0.03	-0.02	RECOVERY STEP (MINOR): Slight nicotine increase for relapse.
S5	1.3	0.5	1.2	0.45	0.34	0.23	HEAVY COMPENSATORY OFFSET: Restricted pace for heavy usage.
S6	1.3	0	0.7	0.26	0.20	0.13	HEAVY DEPENDENCE DEFENSE: Forces significant slow-down.
S7	1.3	-0.5	0.2	0.08	0.06	0.04	CRITICAL MICRO-STEP: Minimal progress to maintain habit.
S8	1.3	-1	-0.3	-0.11	-0.08	-0.06	RESCUE STABILIZATION: Emergency brake; stabilization dose.

Figure D3: Scenario Codes

Stage 3: Dispensing and Safety

Homebase hardware converts the algorithm output into a physically mixed nicotine dose

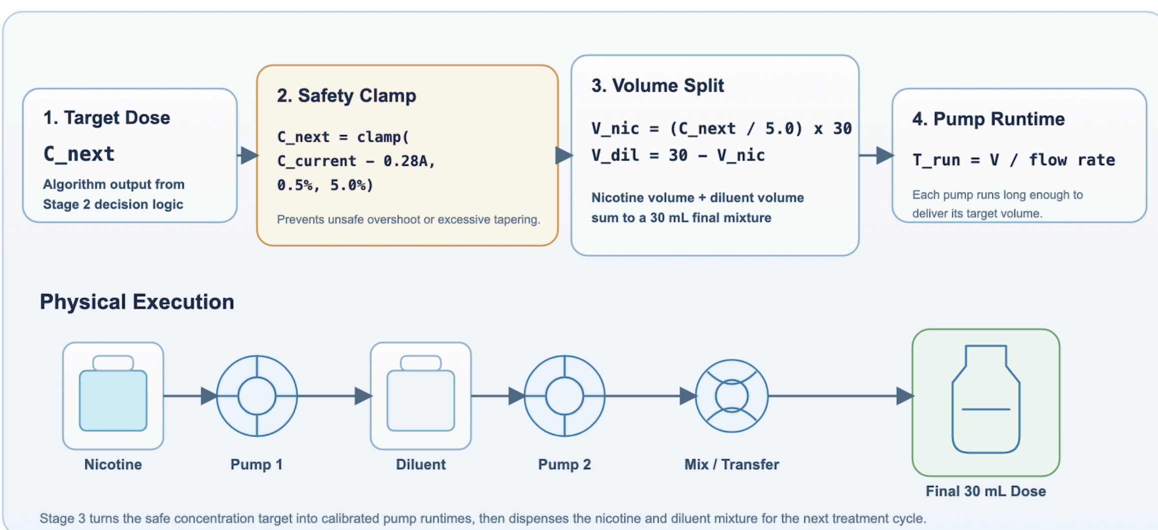

Figure D4: Dispensing and Safety

Table D1: Nicotine Dilution Schedule Example

Timeframe (6 Months)	Target Concentration	Target Molarity (mol/L)	Final Batch Volume	50mg/mL Concentrate Stock Needed	PG/VG Diluent Needed
Weeks 1-2	50.0 mg/mL	0.308	10.0 mL	10.00 mL	0.00 mL
Weeks 3-4	45.0 mg/mL	0.277	10.0 mL	9.00 mL	1.00 mL
Weeks 5-6	40.0 mg/mL	0.247	10.0 mL	8.00 mL	2.00 mL
Weeks 7-8	35.0 mg/mL	0.216	10.0 mL	7.00 mL	3.00 mL
Weeks 9-10	30.0 mg/mL	0.185	10.0 mL	6.00 mL	4.00 mL
Weeks 11-12	25.0 mg/mL	0.154	10.0 mL	5.00 mL	5.00 mL
Weeks 13-14	20.0 mg/mL	0.123	10.0 mL	4.00 mL	6.00 mL
Weeks 15-16	15.0 mg/mL	0.092	10.0 mL	3.00 mL	7.00 mL
Weeks 17-18	10.0 mg/mL	0.062	10.0 mL	2.00 mL	8.00 mL
Weeks 19-20	5.0 mg/mL	0.031	10.0 mL	1.00 mL	9.00 mL
Weeks 21-22	2.5 mg/mL	0.015	10.0 mL	0.50 mL	9.50 mL
Weeks 23-24	0.0 mg/mL	0.000	10.0 mL	0.00 mL	10.00 mL