ECE 445

SENIOR DESIGN LABORATORY

FINAL REPORT

ZZZ-Mate: Pulse Driven White Noise Generator

Team #20

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Abstract

Our project is a multisystem white noise generator and wristband system that will synchronize the heart rate of the user with the output volume of the white noise generator. By measuring the heart rate and subsequently calculating the sleep stages of the individual, the white noise generator's output volume can be set for each respective stage of every cycle. This adaptive output level is more beneficial than a constant white noise as it will not be emitting a loud noise for extended periods of time, limiting hearing damage. This solution will also provide better sleep for the user, since the brain's auditory cortex is not overstimulated the entire night.

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1 Introduction

1.1 Problem

According to the CDC, about 70 million Americans suffer from sleep deprivation. Lack of sleep causes various issues in our daily lives such as tiredness, lack of concentration, memory issues, and high blood pressure. White noise machines have been a widely accepted tool for masking background noise, which many people use as a sleeping aid today. There are currently various white noise machines out in the market, however, all of these devices output a single, continuous signal. This constant output throughout the night can overstimulate one's auditory cortex while also exposing a user to prolonged and dangerous levels of noise.

1.2 Solution

White noise is typically beneficial during the earlier sleep stages, when people are more likely to be awoken by distracting noises or thoughts. However, rather than continuously playing background noise , our design aims to combat typical sleep deprivation issues by supporting users through all stages of their sleep cycle: wake, light sleep, deep sleep, REM, and repeat. The user will not be continuously exposed to dangerous decibel levels, as the white noise machine will only reach its highest volume levels during REM sleep.

We will take pulse rate measurements as an indicator of the user's current sleep stage and our sound generation device will adjust the volume of the white noise. A wristband with a photosensor will be used to detect the user's heart rate and will wirelessly relay the information to the white noise generator to adjust the volume as necessary.

1.3 Functionality

1.3.1 High-level Requirements List

- Average heart rate measurement (BPM) measured over the course of five minutes must be within ±5% tolerance against a third party pulse measurement device (i.e. fingertip pulse sensor, Apple Watch, FitBit, etc).
- The output volume maintains a linear relationship with the user's heart rate. The output will range from 0 to 46dB with ±5dB tolerance based on the user's current sleep stage identified using their real time heart rate outlined in our Sleep Stage to Volume Reference Table (Figure 8).
- Battery life of the wristband device must be at least 7.5 hours.

1.3.2 Overall Purpose

Our overall project relies on its ability to output a white noise signal that varies depending on the user's sleep stage as it changes through the entire night. Our high level requirements of accurate heart rate measurements and a linear relationship between the measured heart rates and the output volume make sure that our system is identifying the user's current sleep stage and adjusting the volume accordingly. The requirement of having a minimum battery life of 7.5 hours ensures that our system is functional for a full night's sleep.

1.4 Visual Aid

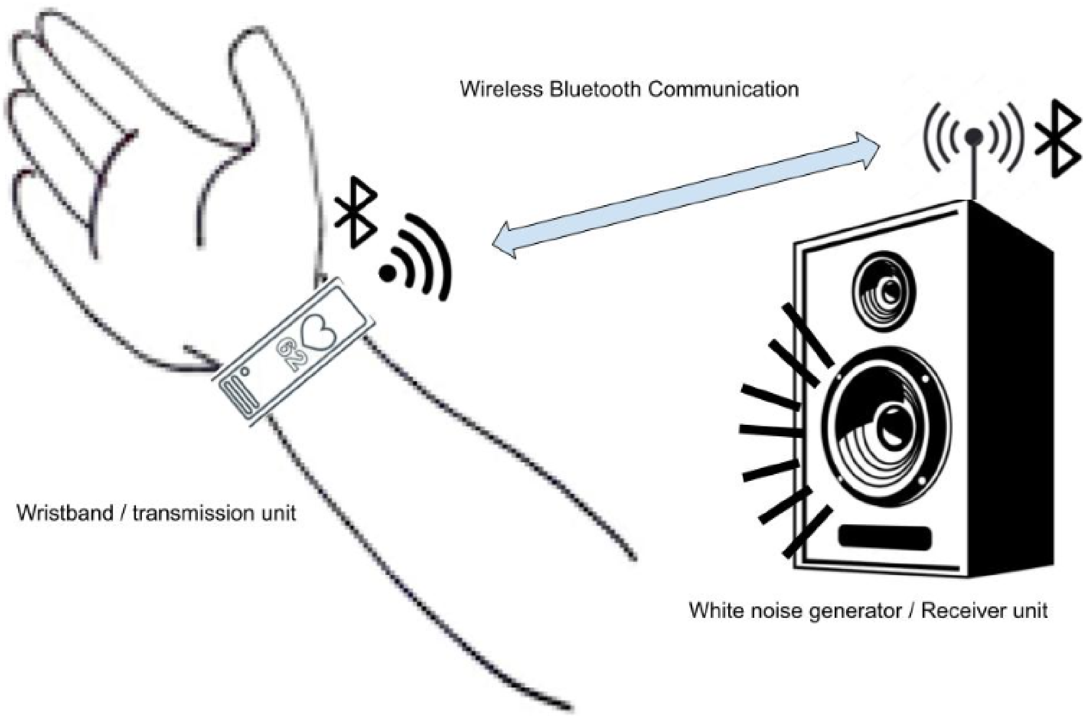

Figure 1: Visual Representation of System

1.4.1 Block Diagram

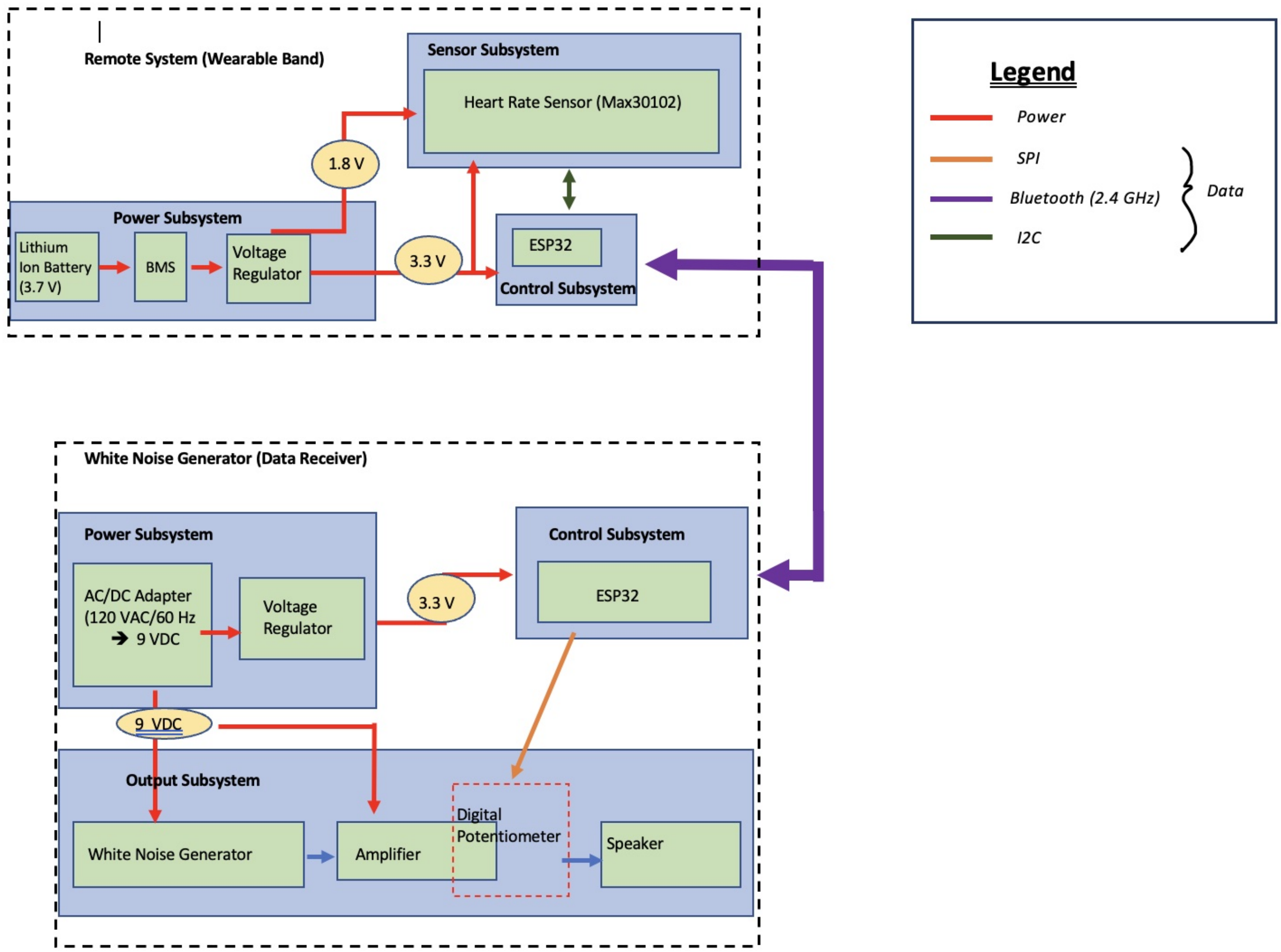

Figure 2: Block Diagram

2 Design

2.1 Subsystem Overview and Requirements

One of the two components of our system is the main white noise generator. This unit will contain one of the two microcontrollers, along with the main audio source, an amplifier, and a loudspeaker. The microcontroller will communicate wirelessly with the wearable wristband and process the provided heart rate information to determine the output audio level.

i. Power Subsystem

Overview

The main source of power to this unit will be provided via an AC to DC converter. This will be used to power the audio source as well as the power amplifier in the output subsystem. As the recommended operation condition for ESP32 microprocessor is rated for 3.3V at 500mA, a voltage regulator rated to output 3.3V at 500mA will also be incorporated to power the ESP32. The power amplifier system will dissipate at most 1.25W (per LM386 manual). Since the supply voltage will be rated for 9v, this will consume about 138mA (1.25/9). Summing all of these components, a supply current of 800mA will suffice the safe operational requirement of the overall system.

Requirements

Requirements	Verifications
1. Main 9V power net is supplying appropriate voltage when hooked up to the load.	a. Connect the load under the supply b. Probe across the power net and ground with voltmeter to verify the voltage reading of 9±0.3V
2. Regulated voltage net used for MPU power supply is outputting the proper voltage level for ESP32's recommended operational condition.	a. Probe across the 3.3V net (voltage regulator output) and ground with voltmeter to verify the proper voltage level of 3.3 ±0.2V

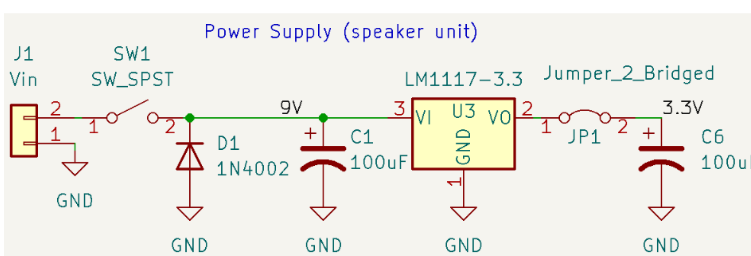

Figure 3: Power Supply Schematic

ii. Control Subsystem

Overview

This is the main interface of the entire system, where the ESP32 microcontroller will be utilized to receive the heart rate data from the wristband and apply appropriate change to the output noise level. Communication between the paired microcontrollers will be performed wirelessly via Bluetooth at 2.4GHz. The microcontroller will also be responsible for adjusting the output volume with the utilization of digital potentiometer via SPI communications.

Requirements

Requirements	Verifications
1. WNG ESP32 can successfully send data to the digital potentiometer through SPI protocol	a. Confirmation is outputted onto the screen after decibel range transmission is completed i. Through SPI protocol, the host will receive a descriptor confirming the completion of the data transmission b. Using ohmmeter verify the proper change in resistance of wiper to ground connection
2. WNG ESP32 can successfully receive data wirelessly from the WB ESP32 chip via Bluetooth.	a. Confirmation of heart rate data reception by WNG ESP32 through Bluetooth is outputted onto the screen

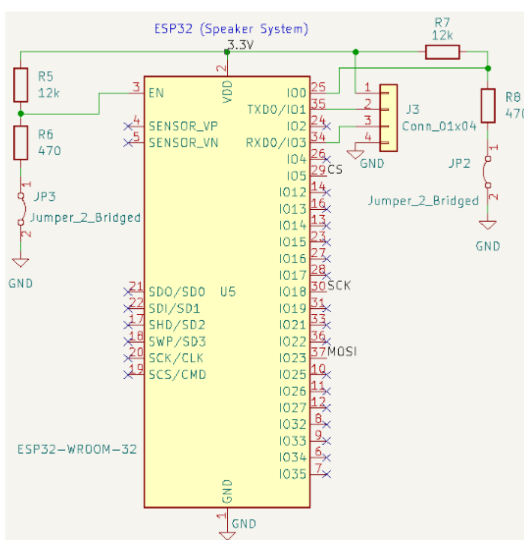

Figure 4: Primary microcontroller schematics

iii. Output Subsystem

Overview

This subsystem is responsible for generating the white noise and amplifying the signal up to an audible level for it to be outputted by a loudspeaker. The white noise generation circuit will be constructed with a general purpose NPN BJT transistor and a single opamp. The power amplifier section will be built around the LM386 audio power amplifier chip. This portion of the output system will interact with the control system to allow for a varying output level using digital potentiometer.

Requirements

Requirements	Verifications
1. Speaker output system has a range of 0-46 dB ± (as per the linear decibel relationship implemented)	a. Verify ambient noise level in decibels with decibel meter (with WNG speaker turned off). Decibel meter should be placed one foot away from the speaker for measurement taking. b. Verify noise level of testing environment in decibels with decibel meter. Verify that the maximum decibel level is 46 dB ± 5 dB. Decibel meter should be placed one foot away from the speaker for measurement taking.
2. Digital potentiometer properly responds to SPI protocol sent by WNG ESP32	a. Verify the change in the wiper position using ohmmeter as prompted by ESP32 b. Verify the change in the output volume

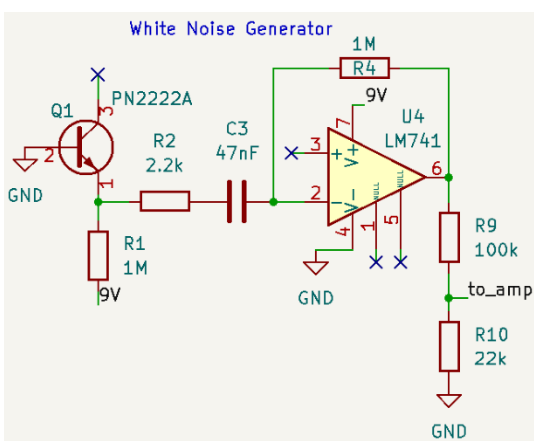

Figure 5: White noise generator schematics

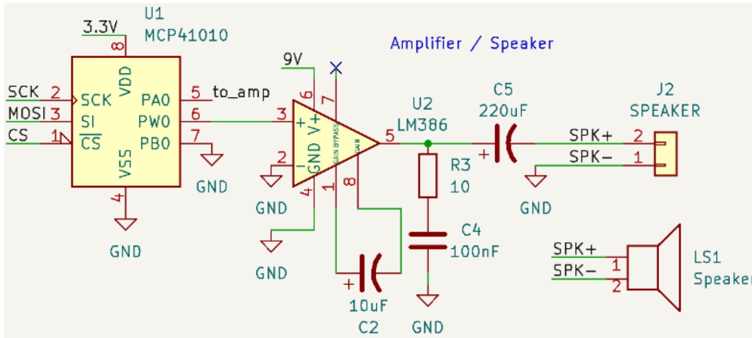

Figure 6: Amplifier/speaker unit schematics

The other major system of the ZZZ-Mate system is the wearable wristband. This device will be worn around the user's wrist to track the heart rate and transmit the collected data to the microprocessor in the white noise generator. The heart rate sensor will be utilized for data collection.

i. Power Subsystem

Overview

The main source of power for this unit will come from a lithium ion battery. A battery management system using AP9101, or a related chip, will be utilized for protection by detecting overcharge/overdischarge of voltage and current. As the ESP32 is recommended to be operated under 3.3V at 500mA, a voltage regulator will again be used to achieve the appropriate level. The MAX30102 heart rate sensor will also require a 3.3V source for LED, along with 1.8V for operating voltage. The MAX30102 manual specifies that the maximum supply current is rated at 1200 uA, along with LED current rated at 50mA. Summing all of these components, a supply current of 700mA will suffice the safe operational requirement of the overall system.

Requirements

ii. Control Subsystem

Overview

This is the interfacing portion of the wristband portion. Using I2C communication, The ESP32 microprocessor will receive data from the heart rate sensor and transmit the information wirelessly to the noise generator/receiver unit.

Requirements

Requirements	Verifications
1. Regulated voltage net used for MPU and LED power supply is outputting the proper voltage level for its recommended operational condition.	a. Probe across the 3.3V net (voltage regulator output) and ground with voltmeter to verify the proper voltage level of 3.3 ±0.2V
2. Regulated voltage net used for heart rate sensor power supply is outputting proper voltage level	a. Probe across the 1.8V net (voltage regulator output) and ground with voltmeter to verify the proper voltage level of 1.8 ±0.2V
3. Measured temperature outside of the enclosure is below safe level	a. Measure the external temperature using a thermometer heat gun. Verify that the measured temperature is below 20°C.

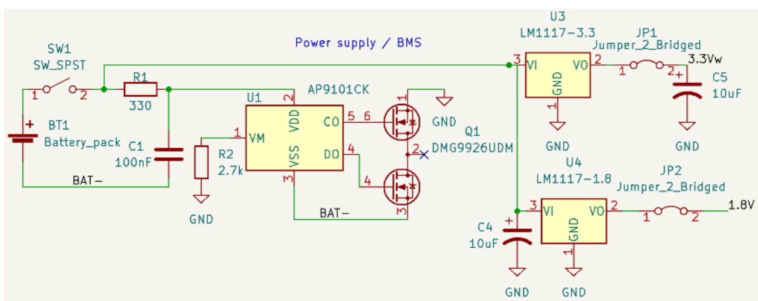

Figure 7: Power subsystem with BMS schematics

Requirements	Verifications
1. WB ESP32 can successfully send data wirelessly to the WNG ESP32 chip via Bluetooth	a. Confirmation of heart rate data transmission by WB ESP32 through Bluetooth is outputted to screen
2. WB ESP32 can successfully receive data from the heart rate sensor (MAX30102) through the I2C protocol	a. Confirmation of heart rate data reception by WB ESP32 is outputted to screen after I2C master provides the ACK bit
3. WB ESP32 and WNG ESP32 are properly programmed to determine the user's current sleep stage	a. Program ESP32s to output the heart rate data, sleep stage, and chosen decibel range to the screen and compare values against the Sleep Stage to Volume Reference table to check for accuracy

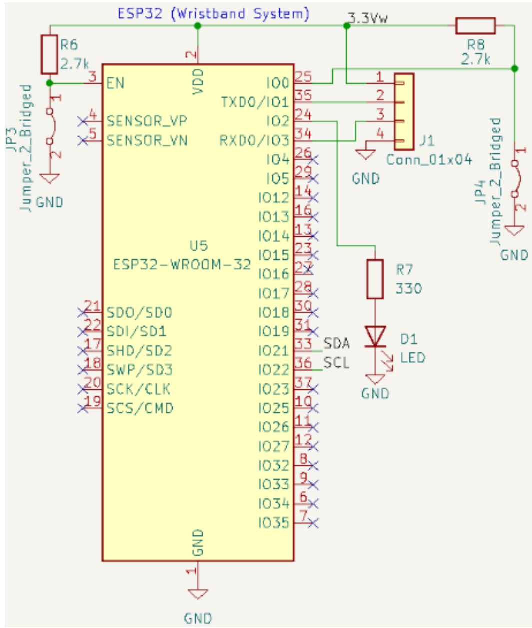

Figure 8: Secondary microprocessor schematics

iii. Sensor Subsystem

Overview

This is the main sensor module to be used to collect the heart rate information. MAX30102 oximeter sensor module will be used for this application to collect the data. The embedded LED will be emitted through the users' skin, and photodetector will measure the blood's absorbance of such lights. The MAX30102 module requires 3.3V and 1.8V for both chip power supply and LED. These will be provided through two voltage regulators and will be verified as discussed previously

Requirements

Requirements	Verifications
1. Measured heart rate within 5% tolerance when compared against a third party pulse measurement device	a. Attach the sensor module on a subject's arm along with another pulse sensing device (i.e. Apple Watch) or alternatively by taking a pulse with finger tip b. Subject will be timed to rest for five minutes c. Compare the measured results between the two devices

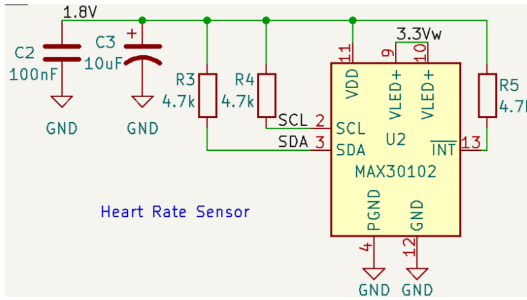

Figure 9: Heart rate sensor schematics

2.2 Design Alternatives

There were three main hardware issues encountered in the process of designing the ZZZ-Mate: Incorrect GPIO/SPI connections, absent enable and boot option switches, and an input over-voltage in the power amplifier circuit.

In the initial design, the ESP32 pin connections were not properly configured for SPI/I2C protocols. The white noise generator was revised to make a corresponding connection from the MCP41010 digital potentiometer to the ESP32 in VSPI configuration: SCK pin to CLK (GPIO18), SI to MOSI (GPIO23), and CS to CS (GPIO5). In the wristband PCB, I2C interfacing between the MAX30102 heart rate sensor and the ESP32 was revised to connect GPIO21 to SDA and GPIO22 to SCL.

The ESP32s were modified to include enable and boot options that correspond to an spst switch/pull up resistor network that users can push during the programming process. These options were implemented by placing a pull-up resistor along with pin header/jumper jackets. Pin headers act as a open SPST switch when not jumped, and close the circuit and set the pin to logic low when jumped.

Our last issue involved the potentiometer attenuating the volume down to no noise level at a certain point rather than increasing it as expected. This was caused by the high input voltage transmitted from the white noise generator to the LM386 chip. Though the datasheet specified the maximum input voltage level to be at 0.4VDC, the digital multimeter showed that the white noise generator was outputting a voltage of 2VDC. To attenuate the input voltage going into the amplifier, we implemented a voltage divider using two resistors to lower the level down to 0.33VDC. This allowed the unit to consistently output an appropriate level of white noise across the full wiper position range of the potentiometer.

2.3 Design Description and Justification

The first subsection within the white noise generator module is the power subsystem. The main power to the module will be supplied by a AC/DC converter capable of supplying 9VDC at 1A. This will be used to power the audio source, the amplifier, circuit, along with the microcontroller (ESP32). The ESP32 chip requires a minimum of 500mA to be supplied per datasheet [1]. As with the power amplifier, datasheet for the TI's LM386-3 specifies that for a source voltage of 9V and load (speaker) impedance of 8 ohms, typical output power is at 700mW [2]. As power = current*voltage, the dissipated current for this configuration will be 78mA (700mW/9V). Prior to the PCB assembly, the entire white noise generator/amplifier section was breadboarded and tested using a 9V supply at 100mA and was verified as operational without issues. The rough estimate of the total current is 578mA. ESP32's average operating current per manual, is also at 80mA. Therefore, 1A supply was determined to be a sufficient amount for the entire white noise generator system. A voltage regulator will be stepping down the voltage for the microprocessor supply voltage at 3.3V, and a component capable of handling 950mA output current were sourced (LM1117) for this application. 1N400X series diode is also placed in a reverse bias manner as a way to protect the unit in case of reverse voltage polarity. This is so that in case the users accidentally use a center negative power supply instead of the center positive, it will short circuit itself and minimizes the hardware damage along with securing the user safety. Finally, an SPST switch will be incorporated here to turn the device on and off.

Second subsystem in the white noise generator is the control subsystem which serves as the main interface between the two modules. ESP32 was selected for its Bluetooth connectivity along with various serial protocol capability. In the cases of white noise generator, this was configured for VSPI protocol to interface with the digital potentiometer. 1x4 pin headers are also implemented for the programming of the microprocessor through FTDI programmer, where the pins corresponds to Vcc (3.3V), RX, TX, and finally GND.

The output subsystem is responsible for generating the white noise and amplifying the signal up to an audible level for it to be outputted by a loudspeaker. The first component of this subsystem is the white noise generator itself, which is constructed from NPN BJT transistor (2N2222) and a single operational amplifier (opamp) (LM741). The schematic for the white noise generator was directly sourced from an online resource [3]. This schematic was used mainly for its simplicity and the availability of the necessary components. This circuit operates with zener shot noise, which is produced in situations where a "reverse -biased diodes and transistor base-emitter junctions exhibit a Zener effect when they break down" [4] in Zener or Avalanche configuration. This source is then amplified to an audible level using an opamp in a non-inverting configuration. Output of the opamp was then fed directly into the LM386 power amplifier chip through digital potentiometer. The power amplifier schematic was sourced from TI's LM386 datasheet [2] which listed examples of schematics including such circuits for achieving a gain of 200. This chip again was chosen for its availability to allow for testing and affordability during the design and development process. As a result, all of the components excluding ESP32 in the white noise generator module were made using through hole devices. The simplicity of the overall circuit also made the PCB compact enough to allow larger THT packages to be used without sizing concerns.

A lithium ion battery pack was chosen as the main source of its power to allow the wristband unit to operate wirelessly. A 1100mAh battery was chosen to allow the device to run for a prolonged duration of users' sleeping time. A battery management system using an AP9101C chip along with dual MOSFET was also implemented for circuit protection as shown in AP9101 datasheet [5]. There was an option to use AP9221 to omit the use of external MOSFET, however KiCAD did not have the appropriate footprint. SnapEDA version of the footprint/symbol was also not supported by the current KiCAD version. This idea was discarded as a result of time constraints and the design was left to use the separate parts for the BMS. Two voltage regulators were also included to stepping the voltage down to 3.3VDC and 1.8VDC respectively. 3.3V voltage net will be used to power the ESP32 as well as the internal LEDs of the MAX30102 heart rate sensor chip, while the 1.8V is the power supply for the MAX30102 chip itself. A latching type SPST switch is again used for this system to turn the unit on and off. In comparison to the white noise generator, this is more important as it is used to conserve and maintain the battery life when the unit is not in use.

The control subsystem for the wristband unit is relatively identical to the white noise generator unit aside from the GPIO connections which was discussed previously in the Design Alternatives.

The last subsystem involves the MAX30102 pulse oximeter and heart rate sensor chip, which will collect the user heart rate data. The internal LEDs of the chip will emit red and IR lights through the subjects' skin and the embedded photodetector will measure the reflected light to collect the measurement. Supply power for both internal LEDs and the IC itself will be 1.8V and 3.3V as previously discussed. Schematic design was again, referenced from the Analog Device's datasheet [6]. Lastly, all components on the entire wristband module are SMD devices to achieve the compact board design for physical user interface. The heart rate sensor chip will be soldered on the underside of the PCB to have a direct contact against the users' skin surface.

2.4 Equations and Simulations

The most crucial bottleneck to this project derives from the fact that everyone has different resting and sleeping heart rates. Determination of the sleep stages is also very vague and arbitrary. To compensate for these differences, we calculated each sleep stage to be associated with a heart rate range personalized for the user's baseline resting heart rate.

Based on studies conducted by the Bio-Medical Engineering Laboratory in the Electrical Engineering Department at the University of Texas in Austin, the average decrease in heart rate between each sleep stage from wake to deep sleep is measured to be around 10% (around 5-7 bpm). When the individual enters the REM stage their heart rate increases again until it is similar to the individual's resting heart rate and the cycle starts over.

We are able to divide a subject's sleep cycle into five distinct categories, each associated with a specific range of heart rates. We do this by first establishing the subject's baseline heart rate using the following equation, where m represents the number of buffer lengths being used, n represents the maximum number of samples that can be stored represented in one buffer length (16 with the MAX30100), and x represents each measured heart rate (in bpm).

$$Baseline\ Heart\ Rate\ (BHR) = \frac{1}{mn}\sum_{i=1}^{mn} x_i \quad where\ m = 2$$

After the BHR is calculated, we are able to calculate the starting range value for the REM/Wake stage (Stage 1) by obtaining the lower floor value when dividing by 5. The upper end of the range is calculated by adding 5 to the HRF value, and the subsequent stage calculations are demonstrated in Figure 9.

$$Heart\ Rate\ Floor\ (HRF) = ((int)\,\frac{BHR}{5}\,) \times 5$$

To identify which stage the subject is currently in, and which volume range to set the white noise generator at as a result, a current heart rate is continuously calculated every time the FIFO buffer is filled up (every 16 measured heart rate values). The algorithm will then use the established heart ranges calculated using the BHR to identify which sleep stage the CHR falls into, and set the volume range to the appropriate dB range, as demonstrated in the Figure 9.

$$Current\ Heart\ Rate\ (CHR) = \frac{1}{mn}\sum_{i=1}^{mn} x_i \quad where\ m = 1$$

Volume Range (dB)	**Sleep Stage**	**Heart Rate Range (bpm)**
≈ 46	REM/Wake (1)	HRF – (HRF + 5)
≈ 29 – 45	REM/Wake or N1/N2 (1.5)	(HRF - 5) – (HRF)
≈ 14 – 29	N1/N2 (2)	(HRF - 10) – (HRF - 5)
≈ 0 – 14	N1/N2 or Deep Sleep (2.5)	(HRF - 15) – (HRF - 10)
≈ 0	Deep Sleep (3)	(HRF - 20) – (HRF - 15)

Figure 10: Sleep Stage-to-Volume Reference Table

To account for discrepancies in the heart rate sensor's readings as well as the subject's actual heart rate cycles during sleep, we included intermediate sleep stages (Stages 1.5 and 2.5), where it is harder to pinpoint what stage exactly the subject may currently be in. Having an intermediate volume range in between stages helps create a more gradual change in volume.

Output volume range can now be assigned to these heart rate ranges. This will be done by dividing up the minimum and maximum output level of the speaker system. The implemented power amplifier will follow the provided schematic in TI's datasheet for LM386 [2] to achieve a gain of 200. This gain is then verified with the following equation:

$$A_v = \frac{V_{OUT}}{V_{IN}}$$

Decibel change could then be calculated using the following equation:

$$dB = 20\,log_{10}\,(A_v)$$
$$dB = 20\,log_{10}\,(200) \approx 46$$

If we assign the output volume to be minimum at heart rate of 60bpm and maximum at the heart rate of 75, we could assign the following:

$$\Delta dB \;\; per \;\; bpm = dB \;\; range/(Max \;\; bpm - min \;\; bpm)$$
$$= 46 \;\; dB/(75 \;\; bpm - 60 \;\; bpm) \approx 3\,dB \;\; per \;\; bpm$$

Therefore, volume range should change approximately by 15dB per each sleep stage (3dB/bpm * 5bpm). The tolerance of ±5dB will be applied to this.

3 Results

3.1 White Noise Generator System

3.1.1 Power Subsystem

The 9VDC power net was measured with DMM to be supplying the 9.124VDC, which clears our 9±0.3VDC tolerance level. The 3.3V voltage net from the output of the LM1117-3.3 was also verified to be supplying 3.3±0.2VDC (measured at 3.273VDC).

3.1.2 Control Subsystem

The white noise generator ESP32 was not able to successfully send data to the digital potentiometer due to a stack overflow error. This error can likely be attributed to an infinite loop or an address error. The white noise generator was not able to communicate with the simulated wristband ESP32 due to a "brownout detector trigger error." This error means that the system voltage was below the required threshold voltage, which could be attributed to faulty programmer wires.

3.1.3 Output Subsystem

The speaker output system was able to adequately fulfill the 0-46 dB ± 5 dB requirement that we set. It is worth noting, however, that the ambient noise level of the testing requirement must be very quiet in order to view the full range of the output volume.

3.2 Wristband System

3.2.1 Power Subsystem

The 3.3V voltage requirement was able to be met, measuring at 3.303VDC. The regulated voltage net for the heart rate sensor suffered a hardware failure with the dual channel mosfet in the power subsystem, so no voltage was able to be supplied. The measured temperature requirement was also not able to be fulfilled because the PCB was unfunctional, so no relevant temperature could be taken to make sure nothing was overheating.

3.2.2 Control Subsystem

The requirement of successfully bluetooth data transmission was able to be partially fulfilled, due to our use of a breadboard to simulate the wristband system. Using both the ESP32 and MAX30102 developer kits, we were able to send the heart rate data and calculated decibel range to a phone device to make sure the correct sleep stages were identified. This simulated breadboard also fulfilled the requirements to send and receive heart rate data. The ESP32 was also able to properly determine the user's sleep stage and output it to a phone screen.

3.2.3 Sensor Subsystem

The requirement for the sensor subsystem was to have an accurate heart rate measurement that would be within 5% of a competing heart rate measurement device. The PCB implementation of this subsystem was completely non-functional due to a hardware failure of the dual channel mosfet in the power subsystem. Despite this, a breadboarded heart rate sensor developer kit (for the same chip, MAX30102) was used to simulate this function in order to test our software implementation. The developer kit sensor took measurements from the user's finger, whereas our third party device took them from the wrist, so this measurement was unable to be met as we used a lower quality sensor.

4 Conclusion

4.1 Accomplishments

We were able to successfully reach our requirements for white noise output, heart rate data collection, Bluetooth connection between the wristband ESP32 and a cellphone, and software design implementation.

The white noise generator was implemented on our printed circuit board as planned and was able to output volume at a variable range of 0 - 46 dB. This output could be adjusted accordingly using the digital potentiometer. We were also able to collect live heart rate data using a MAX30102 sensor implemented on a breadboard version of our wristband subsystem. This system also included an ESP32 which was able to process the heart rate measurements and communicate the data to a smartphone device via Bluetooth. We were also able to successfully implement our software design using this connection by programming the wristband ESP32 with our sleep stage identification algorithm so that the smartphone would output the current measured heart rate as well as the decibel range instruction that would be sent to the white noise generator.

4.2 Uncertainties

The white noise generator (WNG) subsystem was unable to successfully work with its ESP32 chip to communicate with the digital potentiometer or establish serial connection through Bluetooth.

To test the communication between the ESP32 and the speaker, the chip was programmed to adjust the potentiometer to adjust the speaker's decibel output from 46 dB to 0 dB, then 0 dB to 46dB in 10 seconds. Rather than fluctuating in volume as expected, the speaker outputted a constant volume at the max range of 46 dB for the whole duration of time. By examining the output logs of our program we deduced that the issue was caused by a stack overflow error, indicating that our setup functionality was stuck in an infinite loop. This is most likely due to our input and output wires being incorrectly identified or connected based on SPI protocol.

The ESP32 chip on the WNG system was also unable to establish a Bluetooth connection with any device. The Arduino output logs indicated that this was caused by a "brownout error" which results from a device receiving insufficient voltage. A supply current of 800 mA was required to operate the WNG system, and it received less as a result of the unreliable connection wires that came with the FTDI programmer. This programmer was used to flash code to the chip as well as power the system during testing, but was connected to the board externally using dangling wires. Continuity between the programmer and the PCB was unstable when verified with DMM.

4.3 Future Work

Our first step for future work is to integrate all our components successfully onto the two printed circuit boards (PCB) as planned. This includes creating enclosures to make the wristband component wearable on the wrist and coupling the white noise generator PCB and its speaker inside one white noise device.

Another step to improve upon our design would be to add more metrics to support our sleep stage identification process. This includes adding motion sensors and microphones on the white noise generator to detect user motion and background noise that could indicate disturbances in sleep and alert the device to output a greater volume.

5 Cost and Schedule

5.1 Cost Analysis

The cost breakdown of our design will be made up of our labor wages and electronic parts. Based on the average starting salaries for ECE graduates from UIUC, we calculated our wages to be $35/hour and we estimate our workload for this project to be an average of ten hours a week for the next ten weeks until our final demo.

5.1.1 Labor

$$Cost_{labor} = \$/hour \times 2.5 \times hours/week \times number\,of\,weeks \times team\,members$$

$$Cost_{labor} = \$35/hour \times 2.5 \times 10\ hours/week \times 10\ weeks \times 3 = \textbf{\$26,250}$$

5.1.2 Electronic Parts

PART	Manufacturer	Qty	Cost
ESP32 WROOM32	Espressif	2	$3 / pc
Switch	Linkstyle	2	$2.60 / pc
LD1117V33	STMicroelectronics	1	$0.77 / pc
LDI1117-3.3H	Diotec Semiconductor	1	$1.87 / pc
LM1117MPX-18NOPB	Onsemi	1	$0.69 / pc
100uF/16VDC E.Cap (THT)	Wurth Elektronik	2	$0.16 / pc
10uF/16VDC E.Cap (THT)	Panasonic	1	$0.29 / pc
220uF/16VDC E.Cap (THT)	Wurth Elektronik	1	$0.16 / pc
MCP41010	Microchip	1	$1.39 / pc
2N2222A	Diotec Semiconductor	1	$0.61 / pc
LM741	Texas Instruments	1	$0.90 / pc
LM386-3	Texas Instruments	1	$1.49 / pc
47nF Film Capacitor	Kemet	1	$0.08 / pc
100nF Film Capacitor	Kemet	1	$0.08 / pc
1/4W/1% Metal Film Resistor (THT)	Royal OHM	10	$0.02 / pc
Jumper Jacket	SparkFun	4	$0.36 / pc
9VDC AC/DC adapter	Maxinbuy Power	1	$7.49 / pc
ASR00008	TinyCircuits	1	$7.47 / pc
AP9101CK	Diodes Incorporated	1	$0.52 / pc
DMG9926UDM	Diodes Incorporated	1	$0.55 / pc
MAX30102	Analog Devices	1	$13.82 / pc
SMT resistors, 0805 package	Panasonic	7	$0.20 / pc
SMT 10uF capacitors, 0805	Samsung	3	$0.10 / pc
SMT100nF capacitors, 0805	Samsung	2	$0.10 / pc
PCB (Prototype pricing)	PCBWay	2	$1 / pc

HDR100IMP40M-G-V-TH	Chip Quik	1	$0.58 / pc
FR 8 JS - 8 Ohm	Visaton	1	$11.31 / pc

Figure 11: Total Cost of Electronic Parts

$$Electronic\ \ Parts = \$68.72$$

$$Grand\ \ Total\ \ Cost = \textbf{\$26,318.72}$$

5.2 Schedule

Week	Task	Sanjana	Haruya	Vakaris
September 18 - 24	Design doc initialization Order parts	Design doc (Collect heart rate data samples, heart rate/sleep stage connection algorithm)	Design doc (subsystem requirement fix, physical design)	Design (Design and ethics) Research heart rate / sleep stages
September 25 - October 1	9/26 Design Document Check 9/29 Design Document Submission 9/30 Soldering Assignment due	- Collect heart rate data during sleep - Start developing heart rate monitoring algorithm to identify sleep stages - Set up ESP-IDF	- Circuit schematic design - PCB design - Breadboard the circuit - Design doc	Design doc PCB Design
October 2 - October 8	Design Review 10/4 PCB Board Review	- Finish developing heart rate monitoring algorithm - Test ESP-IDF with physical ESP32	- Further testing with acquired components - Tolerance test for the components	- Enclosure design - Tolerance test for the components
October 9 - October 15	10/11 PCB order 10/12 Teamwork Evaluation	- Research/Understand ESP-IDF + bluetooth interface - Evaluate partners	- Evaluate partners - Digi-pot implementation	Evaluate partners

October 16 - October 22	- Work on subsystems	- Translate algorithm into Python code to use in ESP-IDF	- ESP assistant - PCB design - interface - Test correlation between heart rate and device output	- Test correlation between heart rate and device output
October 23 - October 29	- Test and refine subsystems	- Wifi interface - Test correlation between heart rate and device output	- ESP assistant - PCB design	- Test correlation between heart rate and device output
October 30 - November 5	10/31 Second Round PCB Order 11/1 Individual Progress Reports	- Work on Bluetooth connection - Refine algorithm - Progress report	- Order PCB - Progress report - Meetup with Machine shop for enclosure	- Progress report
November 6 - November 12	- Prepare for mock demo	- Prepare for mock demo	- Prepare for mock demo	- Prepare for mock demo
November 13 - November 19	Mock demo	- Prepare for mock demo	- Prepare for mock demo	- Prepare for mock demo
November 20 - November 26	Revision, further testing, etc	- Final Demo Preparation	- Final Demo Preparation	- Final Demo Preparation
November 27 - Dec 3	Final Demo	- Final Paper	- Final Paper	- Final Paper
Dec 4 - 9	Final Presentation Dec 7 - Final Papers due Dec 8 - Lab Notebooks due, Final Peer Evaluation	Party Teamwork Evaluation	- Teamwork Evaluation - party	Party Teamwork Evaluation

Figure 12: Group Work Schedule

6 Ethics and Safety

6.1 Ethics and Safety

6.1.1 Ethics and Safety

Our team will strive to uphold the standards of ethics and safety outlined by IEEE and will take precautions ”to hold paramount the safety, health, and welfare of the public, to strive to comply with ethical design and sustainable development practices.” [7] The overall design of ZZZ-Mate will be constructed upon a relatively low voltage and power level, minimizing the potential physical hazard. In terms of circuit protection, various components will be added, such as a reverse polarity protection diode for the main DC source in the noise generator unit. Another concern for potential physical hazard includes the wristband device, whose circuitry could be harmful if any external contents come into contact with the PCB. The PCB can be encased in a housing to prevent any damage to the device, as well as protect the user. The PCB will be encased in a housing to prevent any circuitry exposure, to protect the user as well as the device. As the voltage regulators will be emitting dangerous temperatures when stepping down the voltage, temperature is a serious concern with regards to the safety of the user. By taking the mounting style of the PCB into account, sufficient clearance will be provided for the voltage regulators. The enclosure for the wristband system will be sourced with temperature and burn ratings in mind.

Another potential hazard for the ZZZ-Mate is the audio level of the white noise generator. Since the user will be exposed to speaker sounds for a prolonged period of time, these decibel levels cannot exceed dangerous levels. According to the CDC, volume above 70 dB for a prolonged period of time, or above 120 db for any amount of time is harmful for hearing, and according to our design. [8] To uphold the safety standards of the IEEE we will make sure the maximum volume capabilities are limited to safe levels in time and volume.

6.1.2 Data Privacy

Our design includes collection of personal health data in the form of the user’s continuous heart rate throughout the night. This information is very sensitive as it could also be used to calculate a person’s heart rate variability (HRV), which has been known to be used to identify a variety of diseases affecting the heart, lungs, and mental health. [9] In addition to ensuring that the data is only used to calculate the appropriate volume of our white noise generator, we are responsible for protecting the data and its owner’s privacy. According to the ACM code of conduct, we must take “precautions to prevent re-identification of anonymized data or unauthorized data collection, ensuring the accuracy of data, understanding the provenance of the data, and protecting it from unauthorized access and accidental disclosure.” [10] We will take extra precautions not to attach any identifying information to a user’s heart rate data and make sure that the data is not being accessed by any outside entities.

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