Portable Bluetooth Amp for Home Speakers

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Table of Contents

1 Introduction

1.1 Objective

With our observations, we believe that there are no battery-powered amplifiers for regular home speakers on the market. Our objective is to create a device that allows people to repurpose their home speakers to become portable bluetooth speakers. We define portable as something that can be easily moved, for example by carrying it in your hands or storing it in a backpack. We want a user to be able to unplug their speakers and connect it to this device to bring their own speaker on the go. They would be able to connect it via bluetooth or a 3.5mm audio jack. As the device has its own battery, the user can use it anywhere, for example at the park or at a dance practice. Because speaker connections are common, the device gives the user the freedom to purchase their own speakers or use their existing home speaker system. As we plan to design the device to be usable with power from a DC power adapter, the user can also use the device as a standalone desktop amplifier. Therefore, if they want to use the device on the go all they must do is unplug the device.

1.2 Background

Bluetooth speakers are increasingly more common as people find convenience in a wireless and portable speaker [1]. However, the market lacks more powerful and affordable bluetooth speakers for those who need them for larger applications, such as theatrical and dance rehearsals. Large companies such as Bose and JBL have boombox style speakers, however their price point is over $300 [2][3]. As speakers have become more common in households in the past couple of decades we seek to create a portable bluetooth amp that can convert these household speakers into a bluetooth speaker. As users can repurpose their speakers, they can purchase our device to use with their own speakers rather than be locked into the speaker and amp all in one provided by other companies at a much cheaper price point. We expect the device to cost under $100 with our included requirements list in section 1.3.

1.3 High-level requirements list

- The device must be able to output at least 20 watts continuous for an 8 ohm speaker.
- The device must operate a minimum of 3 hours on battery with the amp outputting 20 watts continuous.
- The device must be small enough to be carried in a backpack or in one's hand.

2 Design

2.1 Block Diagram

The project consists of three blocks. There is the power unit, which handles the charging of the battery and supply of the voltages needed for the DAC, amp, and bluetooth module. The digital logic unit, which handles the initialization of the device's chips, bluetooth with the user's device, and volume control. Finally, the audio output unit accepts the audio signals from the bluetooth module or an external aux and outputs sound to an external speaker.

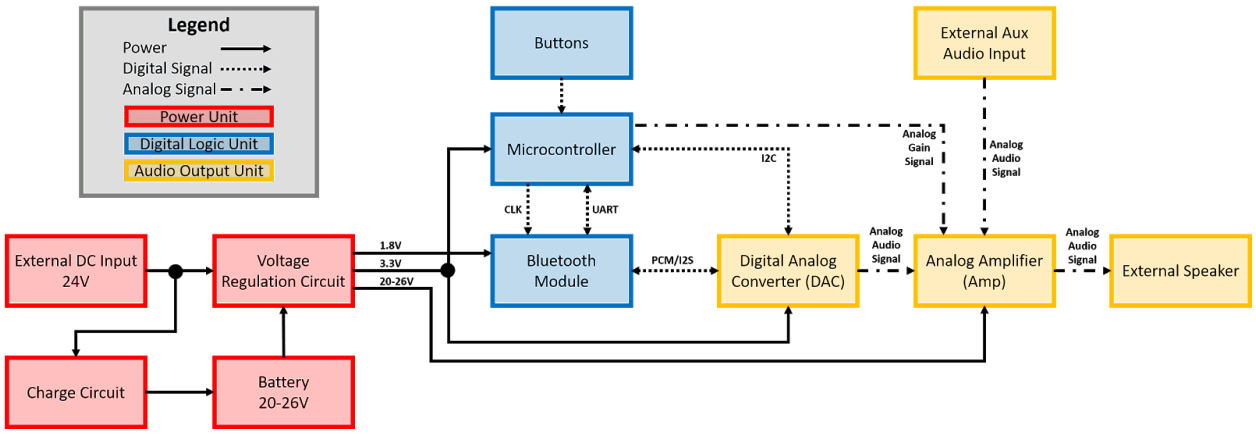

Figure 1. High-Level Block Diagram

2.2 Physical Design

The proposed physical format of the device consists of a rectangular box. The components are secured within the chassis. The rear of the box will house the banana plug connections for the speaker output, a 3.5mm audio input, and the DC power supply input. The front of the device will house the input buttons for easy accessibility. The size is planned to be smaller than a regular toolbox.

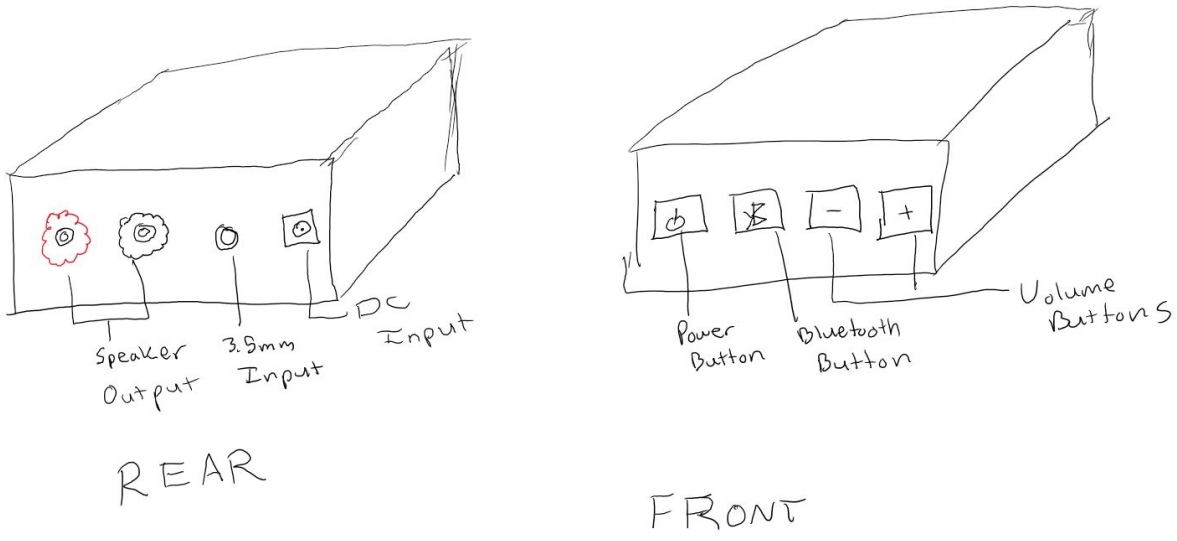

Figure 2. High-Level Physical Design

2.3 Overview and Requirements

2.3.1 Power Unit

This block consists of all the power management for the digital logic unit and audio output unit, including supplying 20-26V for the amplifier, 3.3V for the microcontroller and Bluetooth module, and 1.8V for the Bluetooth module. The external DC Input is used to charge the battery and supply power to the system, so as to not drain the battery while charging it. The power supply that is used will be removable so that the device is portable when not being charged. The battery will supply the power to the system when the external DC input is not connected. The charge circuit will charge the battery when the external DC input is connected. The voltage regulation circuit takes the 20-26V supplied from the battery, or the 24V supplied from the external DC input (if connected) and regulate the voltage to 3.3V and 1.8V for the microcontroller and Bluetooth module. It also passes the unregulated 20-26V (or 24V) supply to the amplifier.

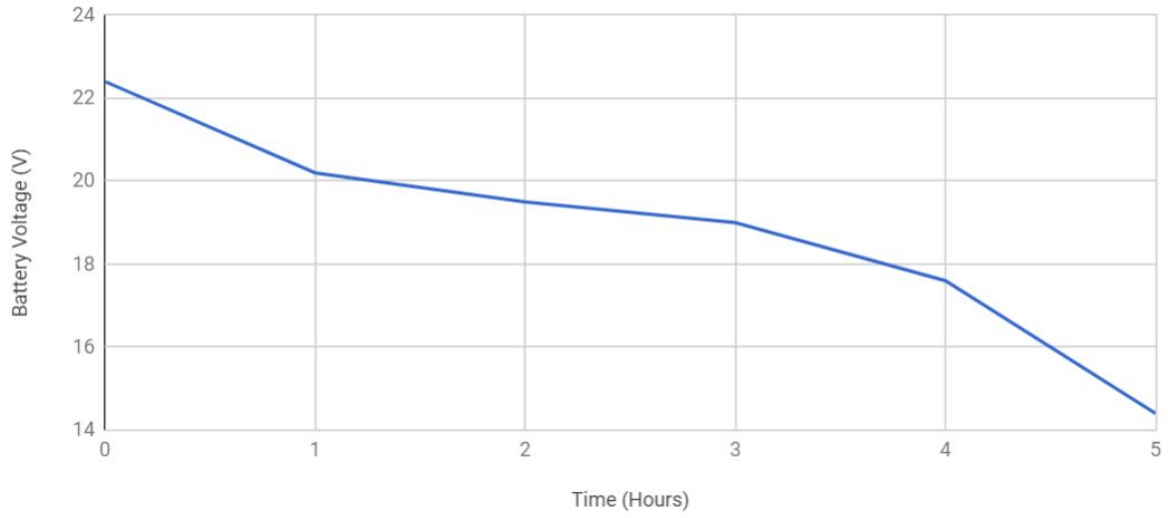

Figure 3: Battery Voltage Over Discharge Time Plot

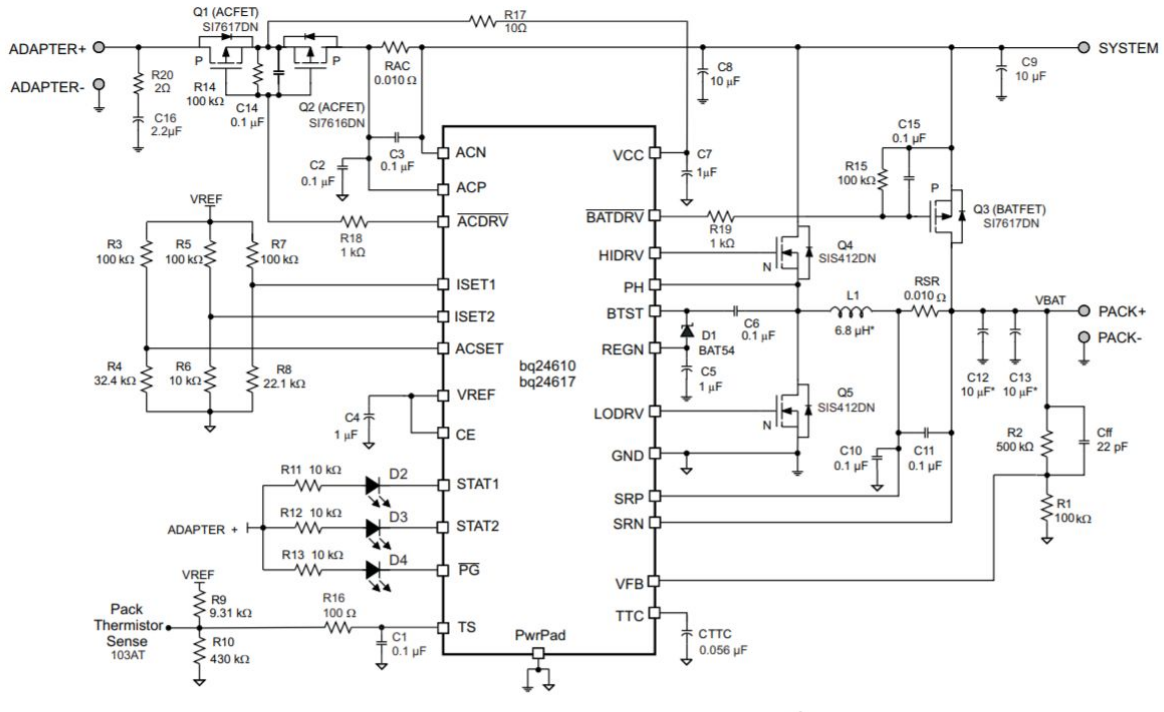

Figure 4: Battery Charging IC Schematic [6]

2.3.1.1 External DC Input

Requirements:	*Verification:*
1. Must be able to supply 24V to the charge circuit and to the voltage regulation circuit. 2. Must be removable from the system for portability.	1. Connect the output of the external supply to a resistive load of 1kΩ or less and measure the voltage using a multimeter to confirm that the voltage is between 23.0V and 26.0V. 2. Confirm that the output plug of the external supply is a common DC barrel jack.

2.3.1.2 Battery

Requirements:	*Verification:*
1. Must have a fuse between the battery and the rest of the circuit to prevent damage to the battery in the case of short-circuits. 2. Must supply 20-26V to the voltage regulators and to the amplifier. 3. Must have a capacity large enough for at least 3 hours of runtime.	1. Place a fuse with a voltage rating above 26V and current rating less than 80A immediately after the battery in the circuit. 2. Connect battery to the system. a. Play audio at a volume of 50% or greater and use a multimeter to measure the voltage of the battery (charged) to confirm the voltage is between 20.0V and 26.0V. 3. Connect battery to the system. a. Play audio at a volume of 50% or greater until the battery voltage drops to manufacturer recommended low voltage.

2.3.1.3 Charge Circuit

Requirement:	*Verification:*
1. Must be able to stop the battery from charging once the battery has reached full charge.	1. Connect the battery to the charge circuit and measure the current applied to the battery with a multimeter. Confirm that the amperage goes below 1mA when battery voltage is greater than or equal to the external supply voltage.

2.3.1.4 Voltage Regulation Circuit

Requirement:	*Verification:*
1. Must be able to supply 3.3V to the microcontroller and Bluetooth module. 2. Must be able to supply 1.8V to the Bluetooth module.	1. Apply a resistive load of 1kΩ or less to the output and measure the voltage using a multimeter to confirm that the voltage is between 3.0V and 3.6V. 2. Apply a resistive load of 1kΩ or less to the output and measure the voltage using a multimeter to confirm that the voltage is between 1.5V and 2.1V.

2.3.2 Digital Logic Unit

This block consists of a complete bluetooth module communicating with a compatible microcontroller via 4-wire UART transmission. The microcontroller will handle the initialization and shutdown the bluetooth module and the DAC. The bluetooth module will transmit incoming audio data directly to the DAC module via some form of pulse-code modulation (PCM) transmission such as I^2S. The microcontroller also receives user inputs via buttons for volume control, bluetooth connection, and power. The microcontroller will then send the appropriate signals to the bluetooth module, DAC, and amp.

2.3.2.1 Bluetooth Module

Requirement:	*Verification:*
1. Bluetooth module/stack must be Bluetooth qualified and must be compatible with the advanced audio distribution profile (A2DP) and audio/video remote control profile (AVRCP) [4]. 2. Bluetooth module must be able to transmit PCM data via I^2S. 3. Device should support a range of at least 20 feet in unobstructed sight. Passed maximum distance means constant interference/drop-out occurs; finite/unpredictable interference/drop-out is acceptable.	1. Find the necessary documentation to prove that the module we use is Bluetooth qualified and compatible with both profiles. 2. View the I^2S signal with an oscilloscope and verify that the frame matches the frame of a typical I^2S signal. 3. Connect to the device and play audio. a. Increase distance from the device until consistent interference or drop-out occurs. Measure distance.

2.3.2.2 Microcontroller

Requirement:	*Verification:*
1. The controller must be able to communicate through UART to initialize the bluetooth module. 2. The controller must be able to initialize and shutdown the device from a switch. 3. The controller must be able to adjust the gain of the amp via bluetooth UART and the physical volume buttons.	1. View the UART signal in an oscilloscope and verify that the signal frame matches the frame of a UART. 2. Initialize device and measure with multimeter current drawn from power source to each module. Shutdown device with switch and verify with multimeter that current to all modules is 0. 3. Probe the i/o pins to the gain control pins on the microcontroller. When the volume button is pressed, the oscilloscope should show a spike for increasing the gain.

2.3.2.3 Buttons

Requirement:	*Verification:*
1. Must be tactile for the user to input functions. 2. Must be momentary type buttons.	1. Press the button and confirm that there is physical feedback when the button is pressed. 2. Check the resistance across the button terminals when pressed and not pressed to confirm that the resistance is low (less than 10Ω) only when the button is pressed.

2.3.3 Audio Output Unit

This block consists of the DAC and amp. The block accepts two types of signals, a digital PCM data signal from the bluetooth module and an analog signal from a local 3.5mm connection. These two signals are the audio sources. The digital signal will be converted to analog via the DAC. A switch, for example a mux, will switch between the audio source depending on what the microcontroller signals it to.

2.3.3.1 Digital Analog Converter (DAC)

Requirement:	*Verification:*
1. The DAC must be able to receive and convert PCM data via I^2S to an analog signal.	1. Connect the *I^2S from the bluetooth module to the DAC and verify that audio playing on the bluetooth module can output from the DAC to the amp.*

2.3.3.2 Analog Amplifier (Amp)

Requirement:	*Verification:*
1. The amp must be able to playback audio from either the analog 3.5mm input, or the digital bluetooth signal. 2. The amp must be able to adjust the gain via the microcontroller's signal. 3. The amp must be able to output at least 20 watts continuous for an 8 ohm speaker.	1. Verify that the amp can output an audio signal to the speakers from the DAC. 2. Measure the output of the amplifier over a resistive load and increase the gain by incrementing the microcontroller's gain value. The Vrms should increase with higher gains. 3. Generate a 1kHz sine wave through an 8Ω resistive load and measure the voltage drop over the load. Input the voltage into V^2/8 and verify it is over 20 watts. a. Note: Due to the amplifier having a bridge-tied load output, you must use a differential probe.

2.3.3.3 External Aux Audio Input

Requirement:	*Verification:*
1. Input jack must be a 3.5mm (⅛") headphone port.	1. Connect a 3.5mm connector from the device to a phone. Ensure that the ring and tip pins on the jack are receiving a signal by probing the pins with an oscilloscope.

2.3.3.4 External Speaker

Requirement:	*Verification:*
1. The impedance of the speaker must be 8 ohms. 2. The speaker recommended output power must be at least 20W.	1. Measure the resistance between the two terminals of the speaker with an ohm meter and verify that it is near 8 ohms. a. You should also verify on the datasheet of the speaker that it is 8 ohms. 2. Verify on the speaker's datasheet that it's continuous or recommended operating wattage is equal or greater than 20 watts.

2.4 Total Harmonic Distortion

As with any audio device, we must achieve a minimum audio quality that is reasonable for the quality of materials we use. One aspect that we can minimize is fundamental total harmonic distortion, calculated by the equation:

$$THD = \frac{\sqrt{\sum_{n=2}^{\infty} V_{n\_rms}^2}}{V_{fund\_rms}} \qquad eq.1$$

2.5 Risk Analysis

Building a battery-driven device implies taking crucial safety measures in order to finish the product on time while guaranteeing safety. An electrical short in the relatively expensive battery could destroy it and potentially other components in the circuit, deducting from us time and money. In order to prevent this from occurring, we plan to develop the digital logic unit and the audio output unit without the battery and simply use a lab power supply instead. When the power management unit is stable, only then will we integrate the three systems.

3 Ethics and Safety

The user's safety and the safety of his/her belongings are of great importance to us; the user trusts our product to boost an audio signal to a safe level for an external speaker for hours at a time. We intend to follow rule #1 of the IEEE Code of Ethics [5] by assuring that the boosted audio signal cannot damage the user's property by limiting the amount of achievable gain, and more importantly by implementing a fuse between the battery the rest of the circuit to minimize the damage of a short in the battery.

Working with lithium batteries is inherently dangerous, especially during prototyping. We must keep in mind the danger of batteries and the possibility of shorting. While not in use, the battery will be kept in a safe storage location away from people so as to prevent any injury of others [5]. When the battery is in use, we will ensure that it is protected against damage and kept at a safe distance away from any person.

Being a Bluetooth device, there are several regulations that it must adhere to in order to maintain safety and legality. The Bluetooth module and stack must be qualified with Bluetooth SIG; however, a qualified, unmodified module can be used, which is what we plan to do [4]. Also, the Bluetooth module (and hence the device as a whole), must be using the correct "Bluetooth SIG"-approved profiles, namely the advanced audio distribution profile and the audio/video remote control profile.

Although every engineer should remember to cite sources and credit contributors properly [5], this project requires some software, so we especially must remember to check if any code we use or modify has been trademarked or requires licensing or appropriate credit. So far, the bluetooth module we are considering using comes with royalty-free stack software for specific microcontrollers. We will continue to thoroughly examine the terms of use for any software or hardware we use and meaningfully credit any contributions to our project.

References

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[4] Bluetooth SIG, “Product Qualification and Declaration”. Available: https://www.bluetooth.com/develop-with-bluetooth/qualification-listing. [Accessed 8-Feb-2018]

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[6] Texas Instruments, “bq24610 Datasheet”. Available: http://www.ti.com/lit/ds/symlink/bq24610.pdf. [Accessed 13-Feb-2018]