Bluetooth 24-bits Headphone Adapter

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1 Introduction

1.1 Objective

With the progress of the semiconductor industry, people started to cut down the cord, ditch the heavy equipment, to pursue the freedom of portability. This is refining the way of how people consume music contents in daily life. Since we stepped into the era of LTE, the rich bandwidth of mobile network, the music industries have shifted their concentration onto a music streaming service. As streaming cost is aggressively cheaper than purchasing songs stand alone, people tend to compromise on the audio quality. Major streaming services are providing the users with 16-bits, 96 kbps for mobile low tier standard, 128 kbps for desktop standard. However, the base of the standard is raising up to 160 to 320 kbps for a premium audience [1]. Also, some Hi-Fi oriented services started streaming in 24-bits or even higher. It waves the flag of the next generation service in the market.

Yet, when we look at the popular peripherals, we know that for music enthusiasts, the top headphone sets are all using analog signal as input. Also, they play at a high impedance level. However, normal mobile devices won't be able to drive them. Now, from the observation, the number of mobile devices, which are taking the music quality into consideration, is increasing. The Bluetooth standard is coming to version 5.0. With the push from chipsets manufacturers, we can foresee a trend of public to have the investment onto the newer peripherals. 16-bits exists for a reason, and became a symbol of an era. However, innovators are not stopped and satisfied.

To follow this innovative movement, our goal is to make a Bluetooth headphone adapter that can transmit 24-bits audio data with a portable size and a longer battery life than the ones that are available on the market. The adapters on the market generally provide 16-bits audio data and last only for 9-15hours [2]. We aim to make ours to transmit 24-bits and 192kbps audio data while the battery last 40 to 50 hours.

1.2 Background

As an evidence of this innovative movement to provide better audio quality, LG came up with LG V20 last year with the support of playing 24-bits audio data [3]. The major music streaming services such as Spotify, Apple Music, Amazon Music Unlimited, Tidal, and Google Play Music started to provide the audio files with maximum of 256kbps to 1411kbps [1]. As the trend moves to the wireless audio devices, the necessity of a portable wireless device that can play the audio files as provided from those music streaming services will eventually increase.

1.3 High-Level Requirements

- Adapter must be able to produce audio quality of 24-bits and 192kbps; better than that (16-bits, 128kbps) of Bluetooth headphone adapters on the market
- Adapter must be able to operate longer time; ideally 20~30hrs battery power.
- Adapter must be small size as possible; to keep it portable.

2 Design

Adapter requires a total of 4 sections to make it a successful product: a Bluetooth module, a Digital-to-Analog module, a control module, and a power supply. The Bluetooth module will wirelessly receive audio data through Bluetooth receiver. Bluetooth A2DP protocol will send AAC audio data to ensure 24-bits and 192kbps. The Digital-to-Analog module will receive this 24-bits and 192kbps digital audio data and convert it to analog audio data. Then, the analog audio data get amplified before outputting through 3.5mm audio jack. The control module will allow the user to increase/decrease volume and mute/unmute the audio and indicate the status of battery, power on, or playing. This will be controlled by the microprocessor. The power supply will provide 3.3V or 5V appropriately for each module from the lithium-ion battery.

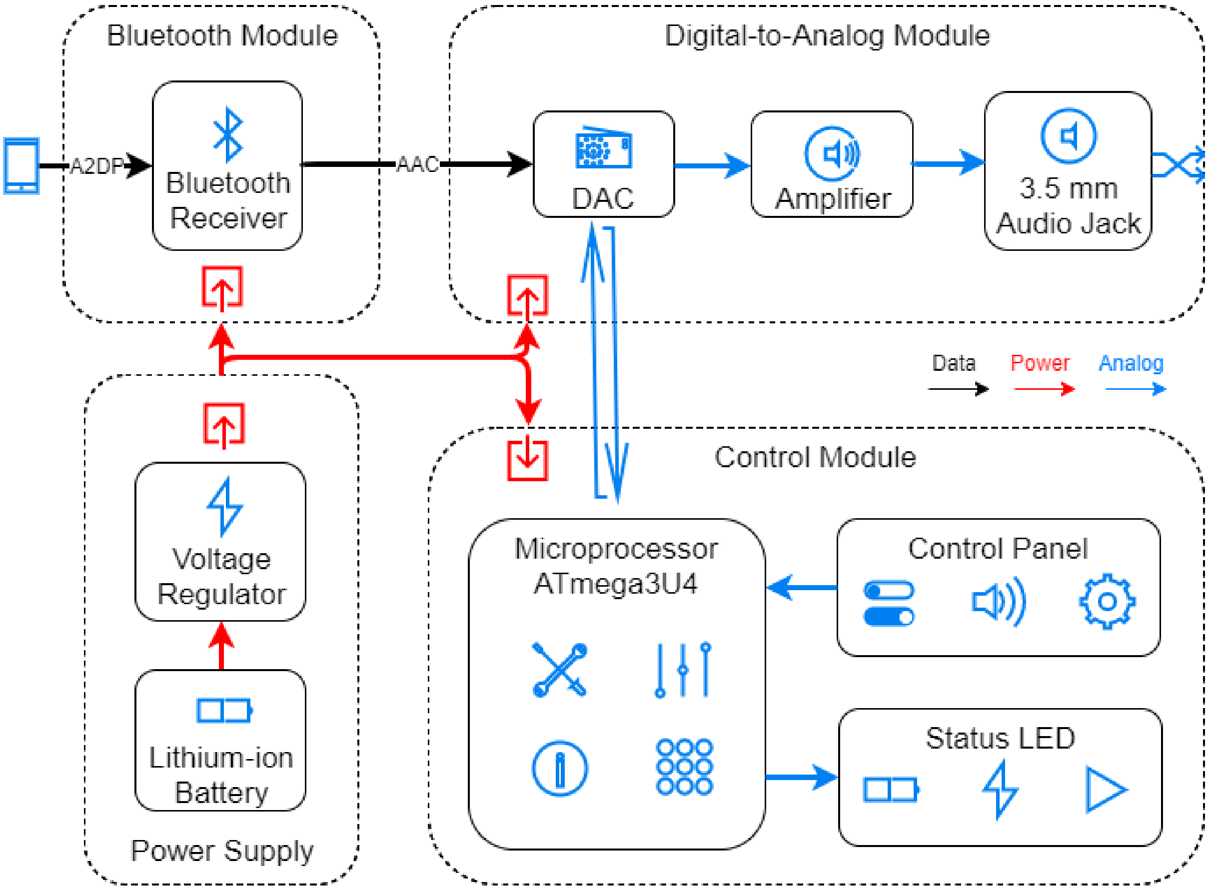


Figure 1 – Block Diagram

2.1 Bluetooth Module

For our design, the input has been designed as wireless transmission. Our unit has the ability to receive the audio content data via A2DP, Bluetooth 4.2 protocol, which ditches the cord transmission. Then, the Bluetooth receiving unit will be able to pass the signal into the AAC codec and then passes it into the amplifier and generates output analog signal.

2.1.1 Bluetooth Receiver

When it comes to the pick of the Bluetooth module, we prioritize the need of audio streaming specialty. After carefully checking, we decided to use BC127-HD chipset from BlueCreation, which has been certified by FCC. The BC127-HD has the following advantages:

1. Bluetooth 4.2 with LBE mode;

2. First several to support Qualcomm® aptX™ HD audio;
3. Providing an audio I/O digital interface at 24 bits/sample and 96,000 samples/s per second;
4. DSP has 24-bits digital audio support;
5. Chip operating at 120 MHz high speed;
6. Has 2 x Stereo I²S interface for added input/outputs.

With the features listed above, we can claim that BC127-HD from BlueCreation is definitely the right candidate for this product we are designing.

According to the data-sheet, the BC127-HD uses VBAT as the main power supply to the internal switch mode and the low-dropout regulators. This requires an input voltage from 2.80 to 4.25 volt from the lithium ion battery. Also, another 3.3V supply is required to power the UART along with other digital circuitry.

Requirements	**Verification**
1. Can pair up via Bluetooth 4.1+ protocol. 2. Can transmit audio signal under AAC/AptX-HD protocol. 3. Can send 24-bits signal with a sampling rate higher than 44.1kHz.	1. Connect to Windows laptop/TinkerBoard/Google Pixel 2XL/LG V20/ Google Pixel XL, under the device manager either via system report, or ADB over terminal, and check the LMP version. See if the value is 7 or 0x7 or above. 2. A) Under the Windows environment, launch Bluetooth Driver Stack provided by Microsoft, then pair up devices. Manually toggle in between AAC and Aptx HD and see if it will be okay to execute. B) Under Ubuntu or Debian environment, install the package bluez-hcidump, then run the command as sudo hcidump avdtp, and check the codec report. C) Under Android environment, with some devices that AptX HD enabled by default, once the device is paired up, there will be popped up notification indicating that "AptX HD device is connected". Then toggle the developer option, under the Networking→Bluetooth AVRCP, make sure the version is above 1.4, and check if able to toggle and register AptX-HD and AAC under Networking→Bluetooth Audio Codec. 3. A) We make a test audio sample file which is 24-bits coded with a

	sampling rate at 44.1 kHz. B) Under Windows environment, while streaming the sample file, check under the Bluetooth Driver Stack and check if the connection is under 24-bits mode and the maximum sampling rate is above 44.1kHz for the connection. C) Under Linux environment, check the AVDTP report while streaming, see if the connection is under 24-bits and Bluetooth maximum sampling rate is above 44.1 kHz. D) Under the Android environment, either check via ADB mode or under developer options, see if the Bluetooth codec is logging as 24-bits while receiving the audio, and the Bluetooth maximum sampling rate is above 44.1 kHz.

2.2 Digital-to-Analog Module

A digital-to-analog unit receives the digital audio data from a data input unit. This digital audio data is AAC codec with 24-bits and 192kbps. The analog audio data will go through amplifier to increase the gain, then output through 3.5mm phone connector.

2.2.1 Digital-to-Analog-Converter

We will use PCM1794A 24-bits Digital-to-Analog Converter chip to receive, convert digital data to analog audio data, then send out the analog audio data to the amplifier. The chip supports up to 192kbps, which is just enough for AAC codec that we are trying to process.

Requirements	Verification
1. DAC must be able to receive 24-bits audio data in both left and right channel 2. DAC resolution should be 2.98 e-7 V	1. A) Send in a digital 24 bits sample data separately for left and right channel, see on oscilloscope if each channel has output. 2. A) Send in 0x000000 and 0x000001 and oscillate to oscilloscope and measure the change in output voltage if it is 2.98 e-7V. $n-bit\ DAC\ resolution = \frac{V_{out}}{2^n} = \frac{5}{2^{24}}$

2.2.2 Amplifier

If we look at the output of the BC127-HD chip, the analog signal was provided as differential balanced audio output. In this case, each channel is generated as a differential pair of signals. In order to output to the peripherals, the headphone driver is required to have the ability to take the differential signals, combine them and convert into single-ended signal to drive the peripherals properly. Hence, we choose TI's TPA6138A2 module as the functionality provider. Upon investigation, we find out that the unit can offer 25mW with 32Ω. This is good enough for daily usage.

Requirements	Verification
1. Amplifier must be able to offer minimum of 25mW with 32 Ω. Gain setting of 2.0 for each channel.	1. A) Assemble Amplifier chip on PCB as specified in the datasheet as the basic application schematic B) Put load resistor of 32 Ω at the output and calculate to see that it provides 25mW

2.2.3 Audio Jack (3.5mm)

As the audio signal has been passed out from the BC127-HD and the amplifier module, the headphone driver unit which can pass the outgoing analog signal properly. The most common peripherals for consumers are stereo audio devices. Both the left and right channel will be dealing with ground-referenced signals.

2.3 Power Supply

A power supply will provide constant voltage of 3.3V/5V to keep the adapter running. Lithium-ion battery will be charged using USB-C port. We expect battery to provide enough power to run the device for 20~30hours. The power from the Lithium-ion battery will go through a step-down converter and a boost regulator to supply 3.3V/5V to the adapter system.

2.3.1 Lithium-Ion Battery

We will use a Lithium-Ion battery that outputs 3.7V at 1000mAh. We will charge the battery through a USB type C port. The 5V DC current first pass through Molex 105450-0101 USB type C connector and then enters BQ24090 lithium ion battery charger. The BQ24090 charger will connect to the lithium battery.

Requirements	Verification
1. The battery should output 3.7V. 2. The battery should be around 1000mAh.	1. Measure the open circuit voltage of the fully charged battery with voltmeter, ensure that the output is 3.7V. 2. Discharge the fully charged battery with a 40-ohm resistor for 10 hours. This will discharge the battery at around $I = \frac{V}{R} = \frac{3.7}{40} = 92.5(mA)$ and measure the battery's open circuit voltage, if it is still above 3V, then the battery is around 1000mAh.

2.3.2 Voltage Regulator

The step-down DC-DC converter LM3671 will be used to supply 3.3V to the most of the chips. Along with that, the boost converter TPS61222DCKR will be used to supply 5V to the DAC and amplifier chips to reduce the ripples as much as possible.

Requirements	Verification
1. Step-down converter provides 3.3V from a 3.7V Lithium-Ion battery output 2. Boost converter provides 5V from a 3.7V Lithium-Ion battery output 3. Operates at currents within 0-	A. Using the simple constant-current circuit to draw 600mA, connected to the output of step-down/boost converter. B. Measure the output voltage using voltmeter, ensure that the output

600mA	voltage is within 5% of 3.3V/5V.

2.4 Control Module

The audio data AAC codec will be sent from Bluetooth module to DAC chip, but the data flow needs to be controlled along with that. The microprocessor will be connected to DAC chip to control the audio data received or to be processed. The microcontroller will be connected to the control panel, which consists of physical buttons, and status LEDs to indicate the information.

2.4.1 Microprocessor

We will use ATmega32U4 to achieve three objectives. First objective is to activate the Bluetooth connection between the device and the Bluetooth receiver. Second objective is control the data flow between DAC module and Bluetooth module. Third objective is to control the data between DC volume control chip TPA2008D2 and LED array for volume indication.

Requirements	Verification
1. Can activate the Bluetooth connection between the device and Bluetooth receiver. 2. Can activate the audio data flow between Bluetooth receiver and DAC. 3. Can receive the volume information from TPA2008D2 and indicate on LED array.	1. ATmega32U4 is same microprocessor that is attached on Arduino Micro. Using Arduino Micro as a dev board, connect it to the Bluetooth receiver PCB and verify Bluetooth connection. 2. Similar to above, connect to DAC PCB and check if the signal is sent properly to DAC chip. 3. Similar to above, connect to DAC PCB (contains TPA2008D2) and get the volume information and send it to LED array.

2.4.2 Control Panel

Control panel consists of several buttons that triggers certain actions when pressed. There will be a power button to turn on the microprocessor, DAC, and Bluetooth chips. The volume controller button will be used to control the volume. The Bluetooth connection button will be used to connect the device and the adapter through Bluetooth transmission.

Requirements	Verification
1. Must be functioning when pressed	1. Button is pressed and the signal is sent through the button.

2.4.3 Status LEDs

The status LEDs will be connected through the microcontroller and indicates the following information: volume (through LED array), power on, Bluetooth status.

Requirements	Verification
1. Must be visible from at least 3m away with a drive current of 10mA	A) Using the simple constant current circuit with resistor, deliver 10mA to the load with supply voltage of 3.3V. B) Replace the load with LED position. C) Observe LEDs at least 3m away.

2.5 Circuit Schematics

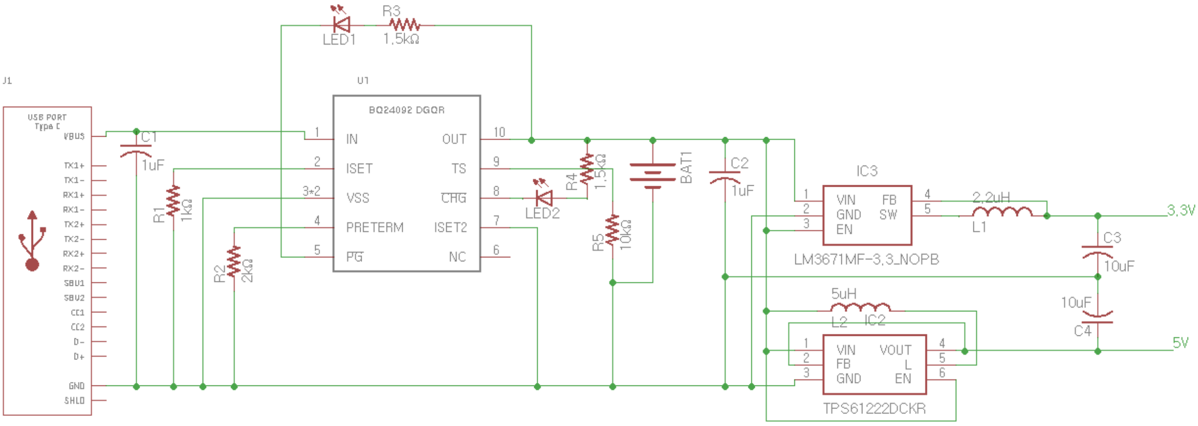


Figure 2 – Power Supply Schematic

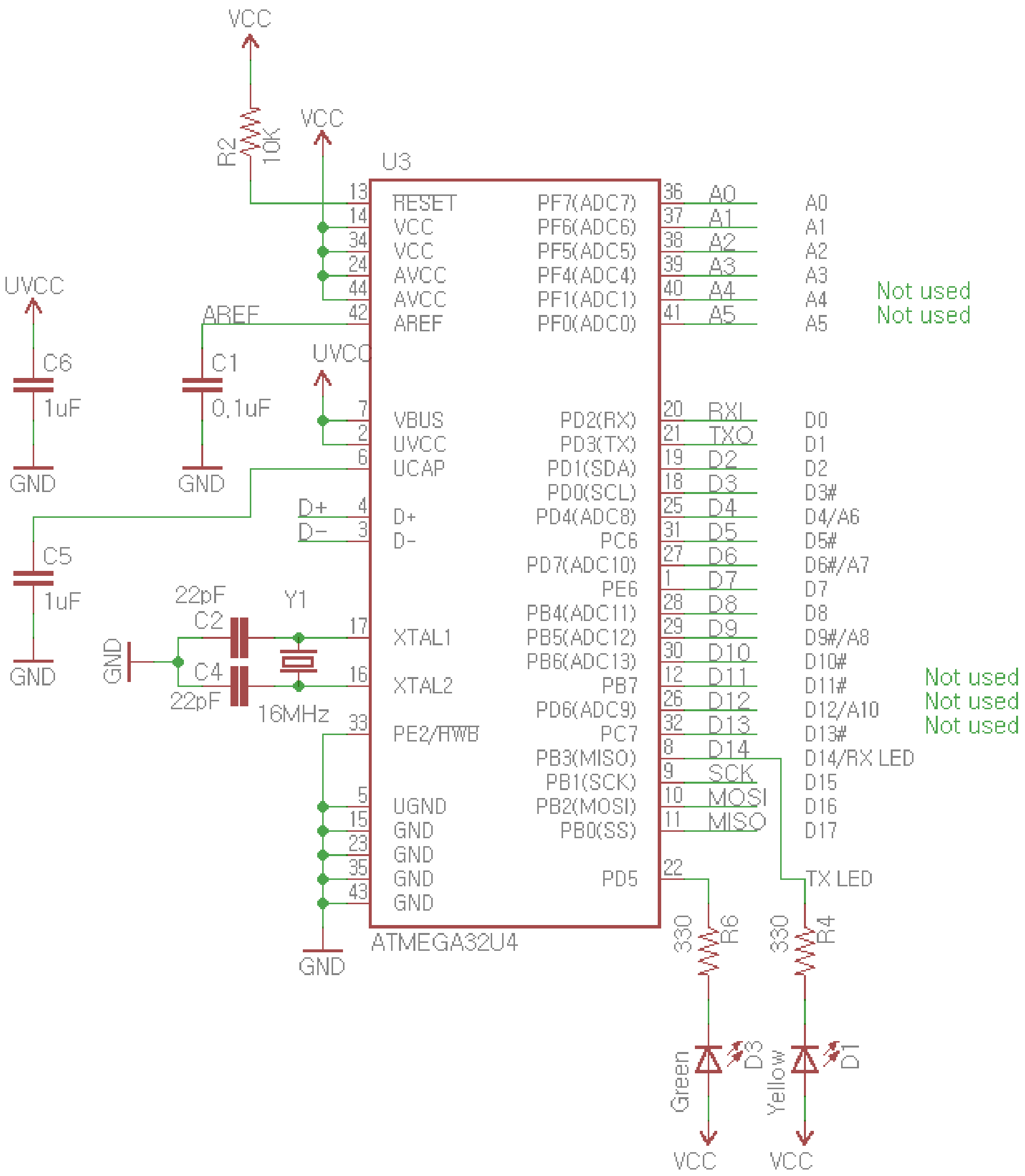


Figure 3 – Microprocessor Schematic

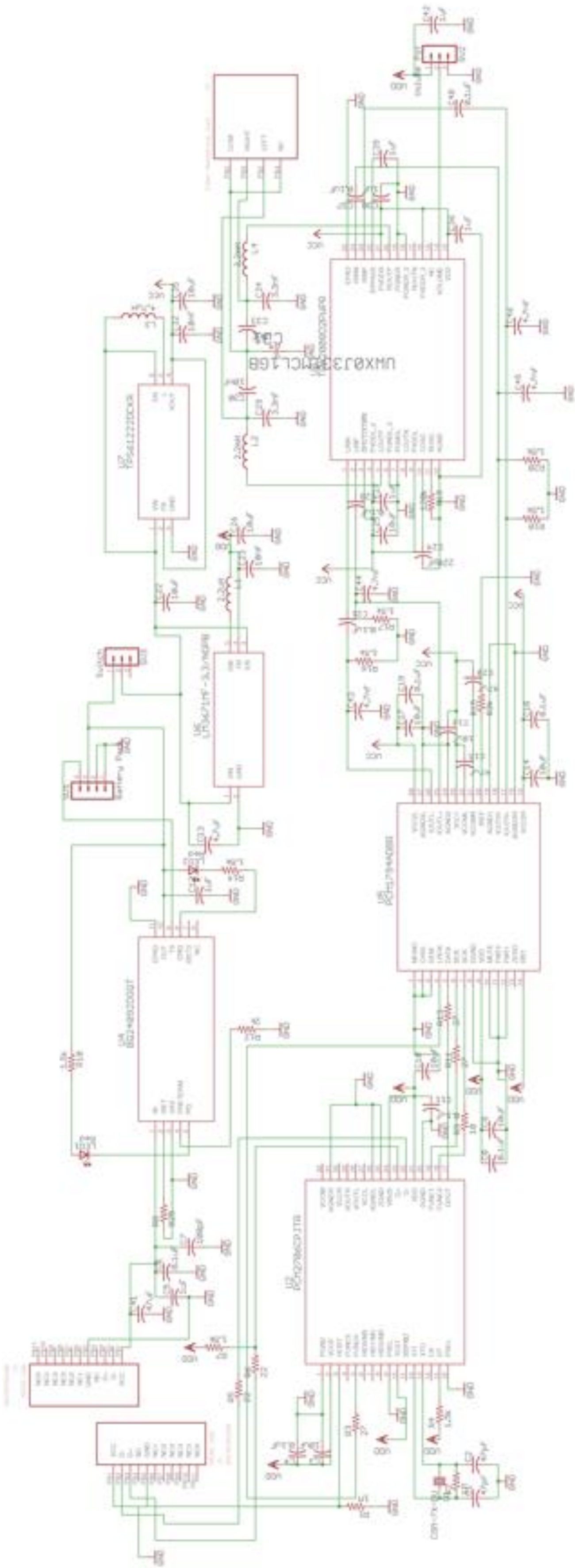


Figure 4 – Bluetooth, DAC, and Amplifier Schematics

Total of 3 PCBs will be used. Power supply PCB will supply 3.3V and 5V towards other two PCBs. Microprocessor PCB will get 5V and Bluetooth, DAC, and Amplifier PCB will get 3.3V and 5V.

2.6 System Flowchart

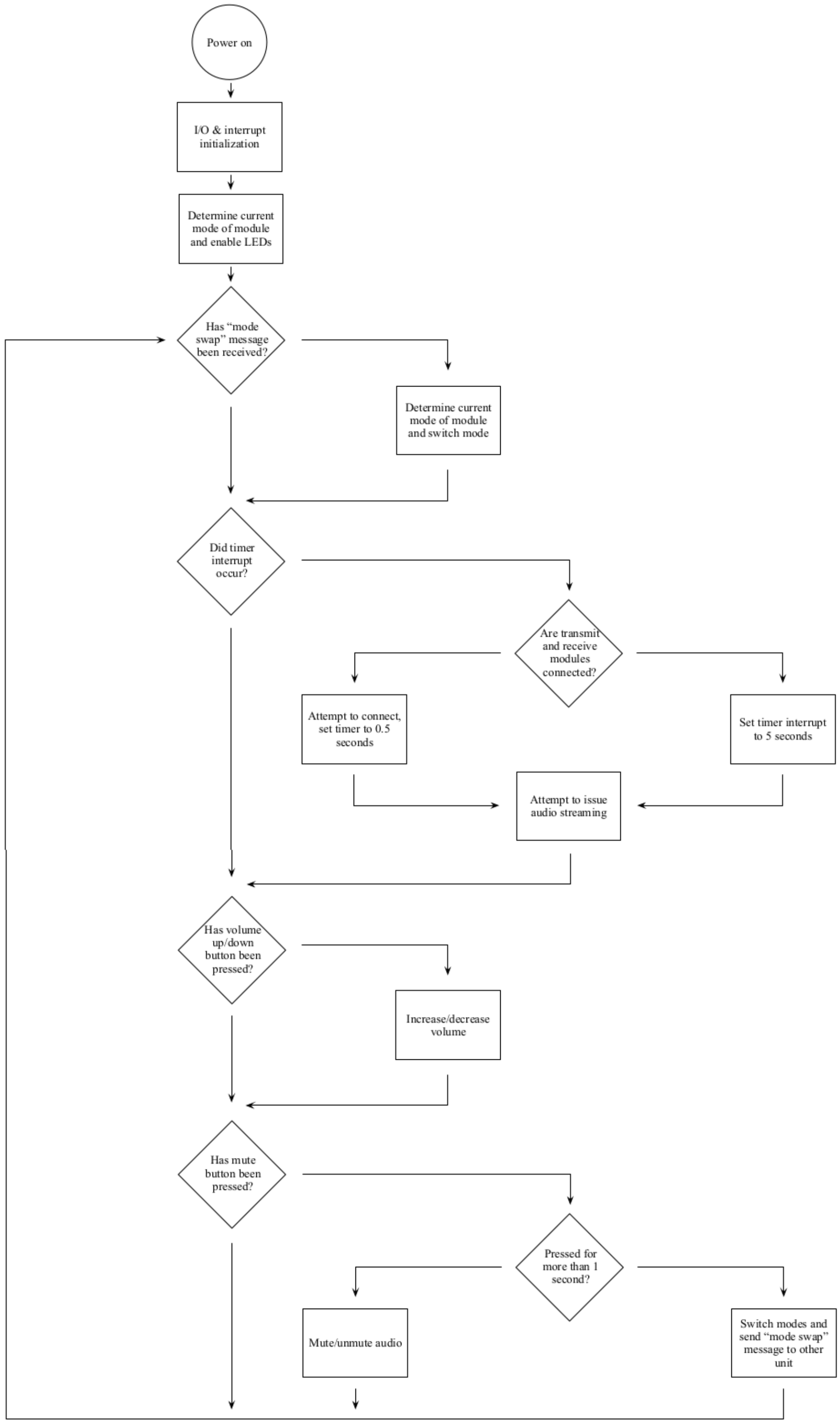


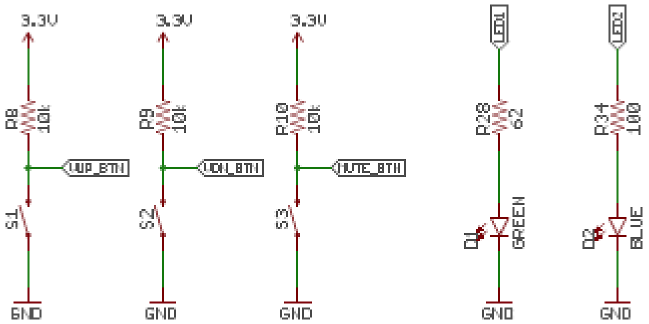
Figure 6 – Bluetooth Flowchart

2.7 Tolerance Analysis

According to the TPA6138A2 datasheet, the gain setting resistors are set to provide a gain of 2.0 for each channel. Input resistors and capacitors selected simply creates a high pass cutoff frequency of 10.6 kHz as shown from the calculation below.

$$R_{series} \approx \frac{3.3V - V_F}{I_F}$$

Assuming the voltage regulated to be 3.3V, along with the resistors that is connected in series as shown below:



This result with series of 15kOhms. Then using the equation below gives out the cutoff frequency of 10.6kHz.

$$f_{cIN} = \frac{1}{2\pi R_{IN} C_{IN}}$$
$$R_{IN} = 15\ k\Omega$$
$$C_{IN} = 1\ uF$$

The trans impedance from amplifier takes analog current and convert to analog voltage. It has a resistor connected to the ground. This produces a voltage to the DAC. It is designed to minimize the complexity, distortion, and power loss. Also, using a resistor connected to ground may be a better way to do it. Because the amplifier has such a large input impedance, we need to make sure loading won't make problems.

The passive LC filter takes analog differential voltage. Then it outputs the filtered analog single ended voltage. It filters the switching noise from the amplifier switching mechanism. Then it converts 2 differential voltages to 2 single ended voltages for output peripherals.

Upon checking the data sheet for the TPA2008D2 chips, we discovered that for this type of chip, there is no output filter required if the leads to the speakers are less than 1inch long. This system expects long leads. Hence, the high frequency switching should not exist before it reaches the cables to whatever the output peripherals you have. Again, the filter filters out ripple current. This is to improve the efficiency and chance that high frequency components get transmitted to the output circuits.

We expect to use USB type-c port in this product for the charging the battery in the device. The battery charger chip BQ2409 expected to charge with 100mA input analog current. The battery management chip manages the 5V, then controls the current into the battery at 100mA and output 3.7 V. The chip also provides an option for a thermistor along with it for an extra layer of safety. If while charging, the battery operating temperature is higher than expected, the battery charger will be forced to shut off.

3 Costs

We expect the development cost to be $40 per hour, 8 hours per week for three people. We assume that we work about 10 weeks out of entire semester for this project.

$$3 \times \frac{\$40}{hr} \times \frac{8hr}{week} \times 10week \times 2.5 = \$24{,}000$$

Parts	**Cost**
USB C-type connector	$1.87
Single-Input Li-Ion Battery Charger (BQ24092DGQR)	$1.13
Lithium Ion Battery 1Ah	$9.95
3.7V to 5V boost converter (TPS61222DCKR)	$1.12
3.7V to 3.3V step-down converter (LM3671)	$1.43
Bluetooth receiver (BC127-HD)	$35.09
Microprocessor (ATmega3U4)	$6.95
24-bit and 192-kHz DAC (PCM1794ADB)	$17.42
Amplifier (TPA6138A2)	$0.91
3.5mm Phone connector female (SJ1-3535NG-GR)	$1.24
Total:	$77.41

Therefore, we would expect total of *$24077.11* to produce a single device.

4 Schedule

Week	**Sang Baek**	**Wayne**	**Noctis**
10/9	Start designing PCB	Prototype programming on Bluetooth connection	
10/16	Finalize the PCB schematics and board layout.	Continue working on Bluetooth connection and make them work	
10/23	First Round PCBway	Prototype programming on A2DP and AAC codec transmission	
10/30	Verify PCB and design 2nd version of PCB	Continue working on A2DP and AAC codec transmission and make them work	
11/6	Finish 2nd version PCB then order.	Prototype programming on microprocessor and the connection throughout the chips.	
11/13	Collect necessary analog signal data using the finalized PCB	Continue working on microprocessor and make them work.	
11/20 Thanksgiving	Bug fix time if there is any, start working the final report and presentation		
11/27	Prepare for the demo and continue working on final report	Bug fix for any software issue	
12/4	Continue working on final report and presentation.		

5 Ethics and Safety

In our project, one of the most important safety concern is the usage of Lithium batteries. Lithium batteries contain both cathode and fuel in a container. These two parts can react and cause fire or explode. An explosion can also be caused by overcharging or overheating the batteries. We will closely monitor the temperature of the battery to make sure that our battery stays within 0 °C to 45 °C during charging and disconnect the battery from the entire circuit if the temperature is abnormal to avoid further chemical reaction and potential fire hazard or explosion. We will also make sure that we disconnect the battery if the voltage is over 4.2V.

We will not make false claims about our project, according to the IEEE Code of Ethics, number 3: "to be honest and realistic in stating claims or estimates based on available data" [4]. We will make sure to provide 24-bits audio data through Bluetooth connection and DAC; even though the method for the users to check this is almost none at all.

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