5-2016

# Wireless voice amplification device for weak patients

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# Wireless Voice Amplification Device for Weak Patients

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**Departmental Honors Thesis**

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**Examination Date: 04/8/2016**

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***Abstract – One problem that nurses and doctors face when treating a very weak patient is difficulty of communication. Sometimes patients become so weak that they are barely able to speak above a whisper without completely exerting themselves. Often nurses will have to put their ear directly in front of a patient's mouth in order to hear what the patient is saying over the ambient noise in a hospital room. This becomes an even bigger problem when several patients are together in a single room and the ambient noise levels rise. One way to solve this problem would be to develop a wireless audio system to amplify the patient's voice so that the doctors and nurses are able to hear and understand a patient who is speaking just above a whisper. There currently exists no off-the-shelf solution tailored to this specific problem. Most wireless audio systems are designed for public speaking, karaoke, or telephony, and do not work well for the problem described above. There is no self-contained of-the-shelf solution that would solve the problem well enough to be implemented on a large scale. This paper examines the problem of wireless audio amplification in a hospital room setting and proposes a practical solution in the form of a self-contained wireless voice amplification system.***

**Table of Abbreviations**

| Abbreviation | Description |
|---|---|
| SoC | System on a Chip |
| IC | Integrated Circuit |
| TI | Texas Instruments |
| RF | Radio Frequency |
| CODEC | Coder/Decoder |
| PCB | Printed Circuit Board |
| JTAG | Joint Test Action Group – Interface used for programming debugging |
| DIP | Dual In-line Package |
| SMD | Surface Mount Device |
| USD | United States Dollar |

## Table of Contents

# I. Introduction

Sometimes a patient in a hospital becomes so weak that he or she can barely speak above a whisper. When a patient gets so weak that speaking loudly and clearly becomes impossible, communication with the patient becomes difficult. This can be difficult for doctors and nurses who need to communicate with the patient. When ambient noise levels in the hospital room rise, the inability of the patient to speak loudly becomes an even bigger problem. The difficulty of communication caused by the patient's weakness not only affects the caregivers, but also the patient himself and his/her loved ones who wish to communicate with the patient. This could frustrate the patient who is trying to express his/her feelings and also frustrate the family who is trying to listen to the patient. Prolonged inability to communicate could degrade the patient's mental health, causing stress or depression. Prolonged stress and depression can then reduce the patient's ability to fight the disease. [1] Thus, a system that could conveniently amplify the patient's voice and restore ease of communication would benefit all parties involved with the treatment of the patient.

There are several off-the-shelf products that function as voice-amplification devices, though most are designed for specific situations and would not provide a perfect solution for a weak patient in a hospital room. Any amplification system that was not wireless would be inconvenient for this situation because a wire would have to run from the patient's microphone to the amplifier and speaker. The microphone would need to be attached and then removed from the patient for every use, making it less convenient than just putting your ear up to the patient's mouth. Existing wireless audio amplification devices are designed for different situations, and are not well suited for use with a very weak patient. A typical wireless microphone used for music or public speaking is a relatively large device that needs to be held by the speaker. This would not work because the patient would likely be too weak to hold the microphone up himself, and if the other person had to get the microphone and hold it up to the patient’s mouth, the system would again be less convenient than putting his ear up to the patient’s mouth. Also most of these style microphones as well as lapel microphone systems designed for public speaking are designed to work with an existing audio amplification system, and therefore provide not only an inconvenient solution but an incomplete one.

This paper examines the problem of wireless audio amplification in a hospital room setting and proposes a practical solution in the form of a self-contained wireless voice amplification system. The system is designed to be self-contained, meaning that it provides a complete solution to the wireless voice amplification problem that does not require any other existing systems to be in place. The system consists of two parts, a small transmitter that is worn around the patient’s neck on a lanyard, and a small microphone such as a standard lapel mic used for public speaking or a throat mic designed for security guards, and a base-station that contains the wireless audio receiver, the audio power amplifier, and the speaker. The two halves of the system and their implementation are examined in the following parts of the paper.

## II. Problem Statement

Weak patients in hospitals sometimes become so weak that they cannot speak loudly and clearly. When ambient noise levels rise, communicating with a patient that can only speak very softly becomes difficult. This can be frustrating for the patients, the patient's family, as well as the doctors and nurses, and could impede that patient's medical care and even degrade that patient's mental health. This paper proposes a wireless voice amplification system designed specifically for this problem. The system will be self-contained, simple, and convenient for use in hospital rooms or hospice care with very weak patients who can only speak just above a whisper.

## III. System Overview

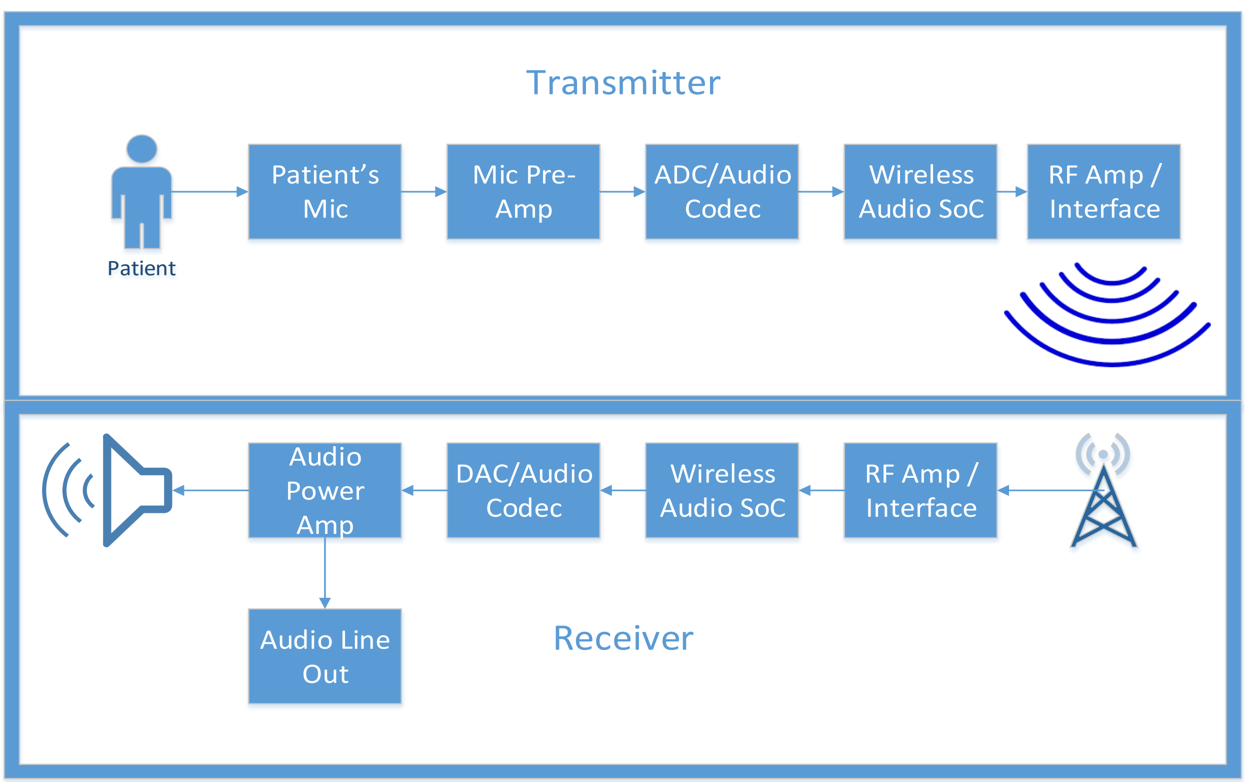


*Figure 1 - Wireless Voice Amplification System Overview*

## IV. Transmitter

The transmitter half of the system is shown in the upper portion of Figure 1. The figure shows some of the possible subsystems that may be necessary, though all of the subsystems may not be required for the overall system to function. For example, the microphone pre-amplifier circuit may not be necessary if the device is being used with a sufficiently sensitive microphone. Also, the radio frequency amplifier/antenna interface may not be needed if the desired range is only a few feet, and the antenna being used has sufficient gain. Also, Figure 1 only shows the circuits that are in the signal flow. Circuits that do not interact with the audio signal are not shown in Figure 1. For example, the power supply circuits for the transmitter and receiver are not shown in Figure 1, as they are not part of the signal flow.

For designing the prototype, the PurePath wireless headset development kit from Texas Instruments was used. [2] The PurePath Wireless Headset Development Kit is a development kit from Texas Instruments that demonstrates the functionality that can be achieved using the Texas Instruments CC8531 wireless audio system on a chip (SoC) [3]. The headset, like all CC85xx (CC8520, CC8521, CC8530, and CC8531) devices, can be configured using the PurePath configuration tool, which allows for easy manipulation of the device's firmware without writing any source code. This kit can be used for a number of different wireless audio situations and is designed to be versatile so that it can be useful for designing many different wireless audio systems. The PurePath wireless audio board is shown in Figure 2.

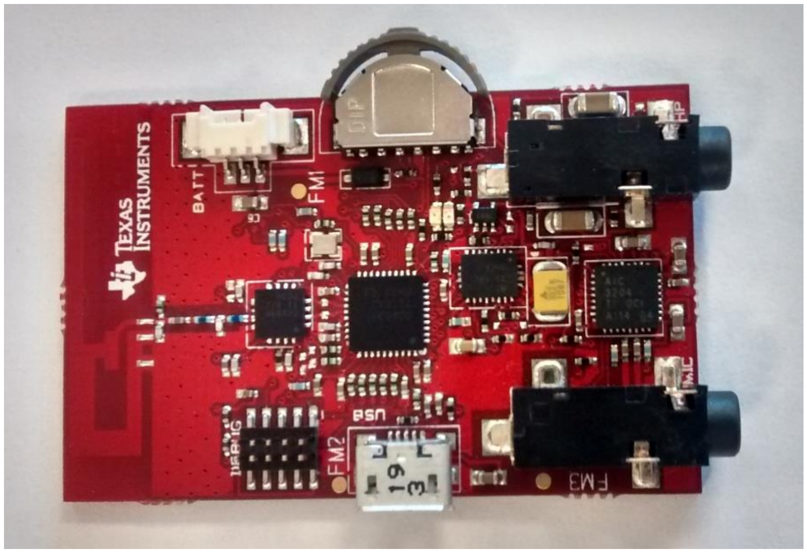


*Figure 2 - PurePath Wireless Headset Development Kit Board*

The PurePath kit is based around the following integrated circuits (IC) from Texas Instruments (TI). The PurePath kit includes the CC8531 wireless audio SoC, the CC2590 2.4 GHz RF interface [4], the TLV320AIC3204 ultra low power stereo audio codec [5], and the BQ25015 dual input battery charger with integrated adjustable-output synchronous buck converter [6]. Each of these IC's are produced by TI and are included in the reference design provided with the PurePath wireless headset development kit. The transmitter design is heavily based on the PurePath development kit, and is described in more detail below, though non-TI components were considered, and were included in the design of the circuits.

## A. Transmitter power supply and battery management

The transmitter must be battery powered in order to be useful. Also, to make using the product more convenient, the battery charger should be part of the system such that the user does not have to remove the battery and insert it into another circuit for charging. Also, the battery must be protected from over charging or over discharging to prolong the lifetime of the battery. Voltage regulation is needed to provide a stable voltage to the transmitter circuit while the battery voltage decreases over a cycle. The PurePath development kit uses the BQ25015 battery management IC to manage battery charging and voltage regulation. This IC has many features, including a programmable output synchronous buck converter, lithium polymer battery charging capability, and integrated load switching which allows the load to be powered while the battery is charging without any external circuitry. However, the BQ25015 was not chosen for the prototype, because some of the features were not necessary, and the price (4.55 USD in single quantities from Digikey) is high for a power management IC.

Instead of the BQ25015 from TI, the MCP73833 [7] from Microchip Technology was chosen. The MCP73833 has fewer features then the BQ25015 but is significantly less expensive (0.85 USD in single quantities from Digikey) than the BQ2015. The MCP73833 is a lithium polymer battery charger IC and does not have integrated load switching or voltage regulation. Though load switching would most likely not be necessary for this application, as the patient would mostly likely not be charging the transmitter and using it at the same time, it was still added to the power circuitry in the case that a user would want to charge and use the device at the same time. The load switching was accomplished by placing a P-channel MOSFET in series with the battery and the load, and tying the gate to the charging source voltage. When the charging voltage is applied, the MOSFET does not conduct, effectively removing the load from the battery. The load switching circuit was based on an application note from Microchip Technology [8]. Power is delivered to the load directly from the charging source voltage through a Schottky diode. The entire circuit is shown in in the appendix. Figure 3 shows the battery charger and load-switching circuit being tested on a breadboard. A light bulb was used as the load, so that the load switching could be seen as a visible change in brightness corresponding to the battery voltage (less than 4.2 V) or the charging source voltage (5 V or greater).

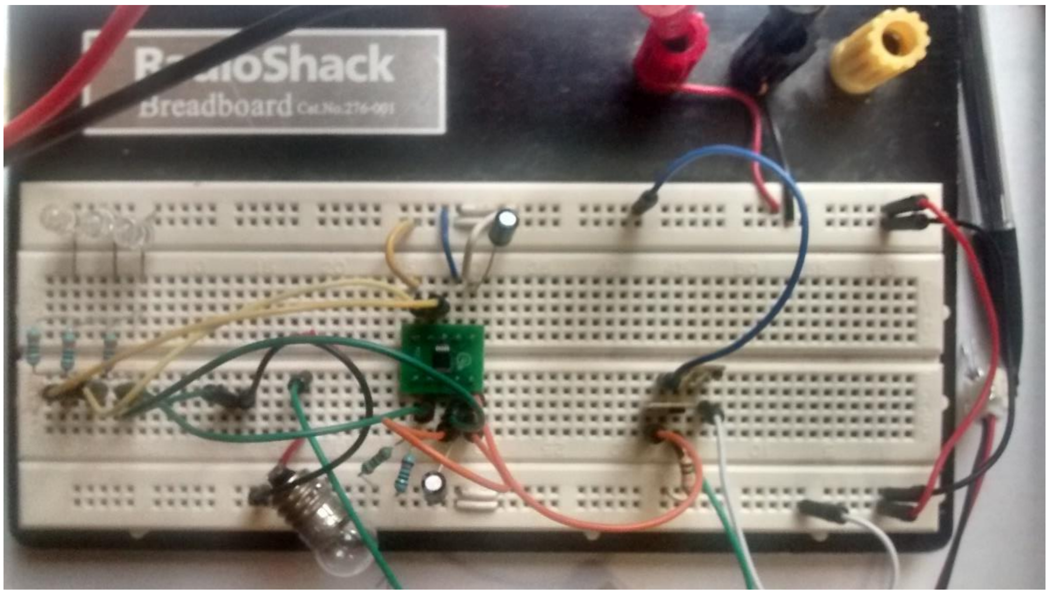

*Figure 3 - Prototyping Batter Charging Circuit with Load Switching*

The MCP73833 circuit uses three indicator LED's to indicate the status of the battery charging operation. The LED's are connected to the PG, STAT1, and STAT2 pins of the IC. When the PG LED is bright when the input voltage is greater than or equal to the minimum required voltage to charge the battery. The table below shows the status of each LED corresponding to the possible states of the battery charger circuit.

**Table 1 – LED Status Indication**

| State | STAT1 LED | STAT2 LED | PG LED |
|---|---|---|---|
| Shutdown | OFF | OFF | OFF |
| Standby | OFF | OFF | ON |
| Charge in Progress | ON | OFF | ON |
| Charge Complete | OFF | ON | ON |
| Temperature Fault | OFF | OFF | ON |
| Timer Fault | OFF | OFF | ON |
| System Test Mode | ON | ON | ON |

The MCP73833's maximum charging current can be programmed with a single resistor. The equation used to set the charging current is shown below, where $I_{reg}$ is in milliamperes and $R_{prog}$ is in kilo-ohms.

$$I_{reg} = \frac{1000}{R_{prog}}$$

The maximum charging current is 1A. The time is takes to charge a battery is directly proportional to the charging current as shown in the equation below.

$$Charging\ Time\ (hours) = \frac{Battery\ Capacity\ (milliamp * hours)}{Charging\ Current\ (milliamps)}$$

For example, if the battery capacity was 250 mAh, and the charging current was 1 A (1000 mA), then the charging time would be 15 minutes. For this design, $R_{prog}$ was picked to be 2 kOhms, such that the charging current was 500 mA, and the time to charge a 250 mAh battery was 30 minutes. Even though the USB ports on the receiver base station are rated 1 A output current, the battery charging current was set to 500 mA, so that the battery charger could be used with a computer USB port, which is typically limited to 500 mA output current.

The voltage regulation is achieved using the LT1763 low dropout linear regulator from Linear Technology [9]. The LT1763 is a 500 mA low dropout (300mV) linear regulator is available in several different fixed output voltages or an adjustable output voltage version. The circuit used the adjustable output voltage version with a switch to select between 3.3V and 1.8V to make the power supply demonstration circuit more versatile. The resistors for programming the output voltage were chosen using the following equation from the LT1763 datasheet.

$$V_{out} = 1.22\left(1 + \frac{R2}{R1}\right) + (I_{ADJ})(R2)$$

Choosing practical resistor values (E14 series):

Let $R1 = 10\ \mathrm{k\Omega}$,

$R2 = 16\ \mathrm{k\Omega}$ for $V_{out} = 3.17\ V$

$R2 = 4.7\ \mathrm{k\Omega}$ for $V_{out} = 1.79\ V$

The schematic and printed circuit board (PCB) layout were created using Altium Circuit Maker [10]. The schematic and PCB are shown in Figure 4 and Figure 5. The schematic was based on the typical application circuit shown in the MCP73833 datasheet with the load switching circuit added. The size of the PCB was chosen to be 1.5 by 1.5 inches for this demonstration board. In a commercial product, the size could be made much smaller by using smaller devices and pacing the components more closely. Also, all of the connectors except for the micro USB connector and the battery connector would not be required on a commercial product, as they are only used for measurement and testing.

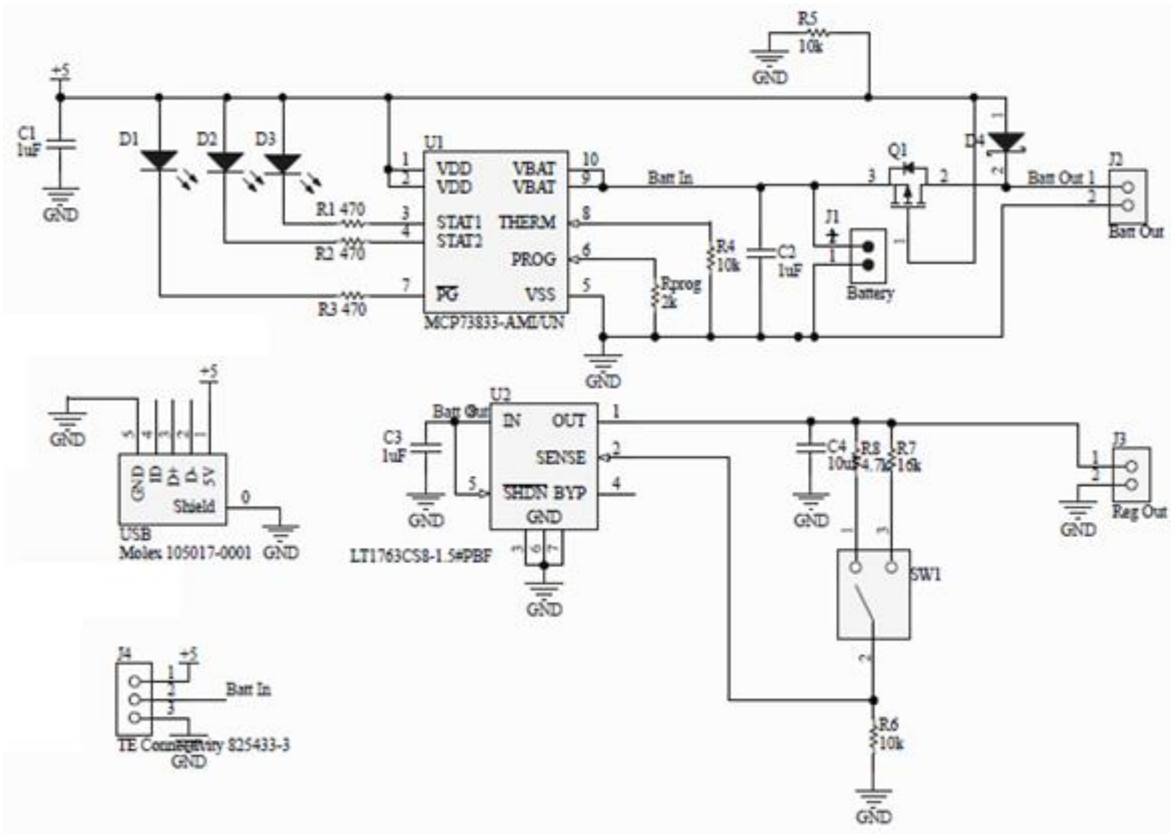


*Figure 4 – Battery Charger Circuit*

The PCB is shown in Figure 5 on the next page. The ground plane has been removed to show the routing on both layers. Notice that the high current traces are thicker than the signal traces. This is to prevent voltage drop and heat generation when the circuit is passing high currents. The highest possible current in the battery charger circuit is 500 mA. A general rule of thumb for trace thickness based on cross sectional area and rise in temperature is shown in the equation below taken from the Generic Standard on Printed Board Design (IPC-2221A) [11].

$$I = k\Delta T^{0.44}A^{0.725}\text{ , where } k = 0.048 \text{ for outer layers, and } k = 0.024 \text{ for inner layers.}$$

Assuming that the copper trace with is 1 mil thick lets A = 1*W in mils. Solving for a 10 degree Celsius increase in temperature for a 500 mA current, the minimum trace width was calculated to be 6.26 mil. Because board space was not a limitation, a trace width of 20 mils was chosen for the high-current traces.

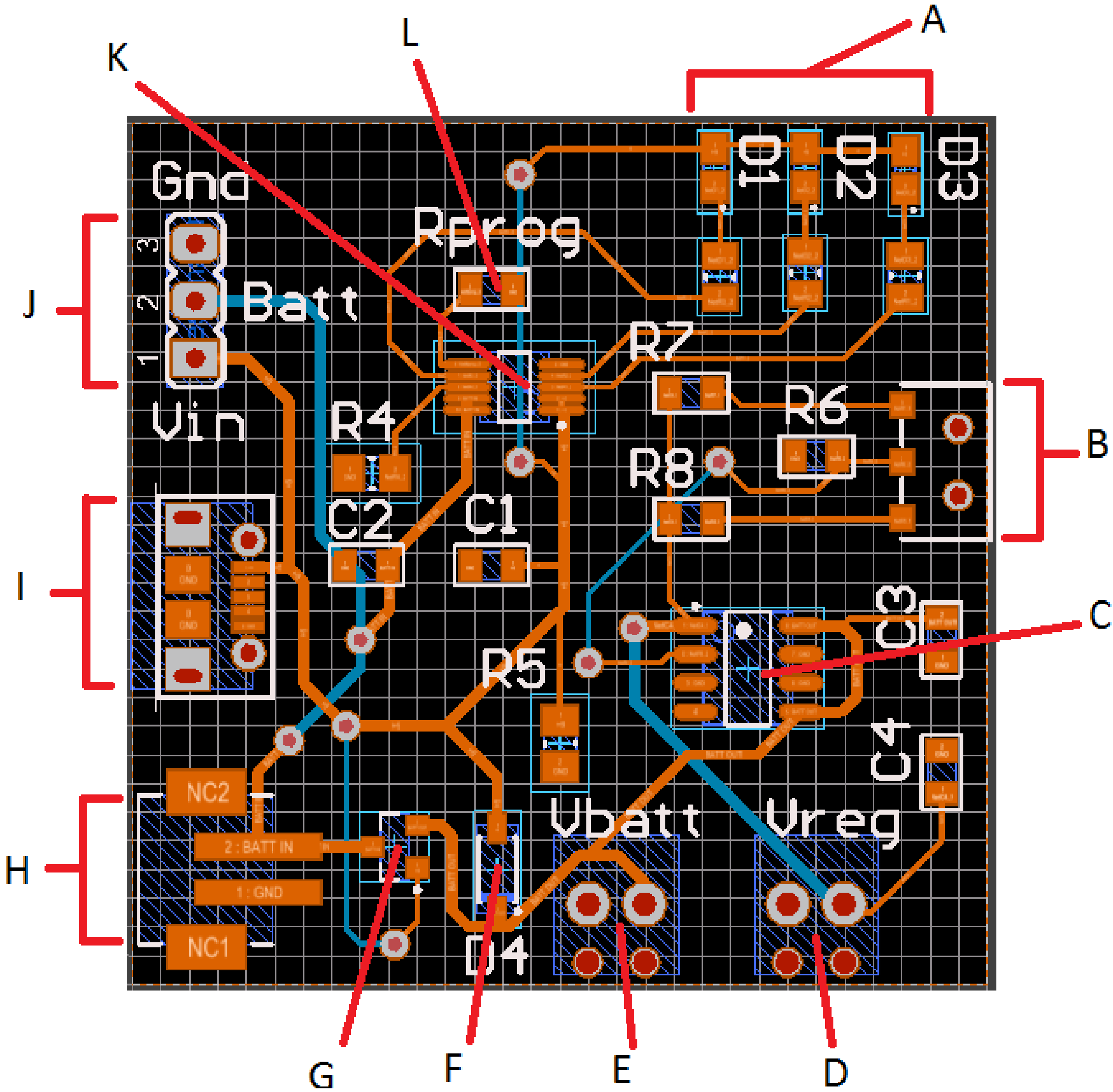


*Figure 5 - Battery Charger PCB*

A - Status LED's, B - voltage regular output selector switch, C – LT1763 voltage regulator, D – Output voltage screw terminal, E – Battery voltage screw terminal, F – Scottkey diode, G – P-channel MOSFET, H – battery connector, I – micro USB connector, J – test points, K - MCP73833, L – Charge current programming resistor.

## B. RF SoC Configuration

The firmware on the RF SoC used in the PurePath wireless headset development kit can be configured using the PurePath Wireless Configurator tool. This allows the SoC to be configured for several common scenarios without writing new firmware for the SoC. The PurePath configurator software connects to the SoC using the TI CC USB debugger over the SoC's JTAG interface. The CC debugger is shown in Figure 6 on the next page.


*Figure 6 – CC Debugger, USB to JTAG*

The PurePath configurator has several different prebuilt configuration options as well as the ability to create new configurations based on what supported external hardware is being used. Once supported hardware is selected or the behavior of other external hardware is specified, the CC85xx SoC's behavior can also be configured. For example, volume control can be disabled or enabled, depending on whether buttons are present in the circuit, and the increments can be changed. Similarly, the radio can be configured. Features such as pairing behavior and channels can be changed with the software. Once a configuration has been chosen or created, the PurePath software reprograms the SoC over USB using the CC debugger and the SoC's JTAG interface. The configuration used for this demonstration with the PurePath wireless development kit was a modified version of the demonstration program, with volume control disabled to prevent clipping, though this step is not always necessary. The power button function and pairing method were left default. Figure 7 shows a summary of the status LED functions as defined in the status identification section of the PurePath configurator settings.

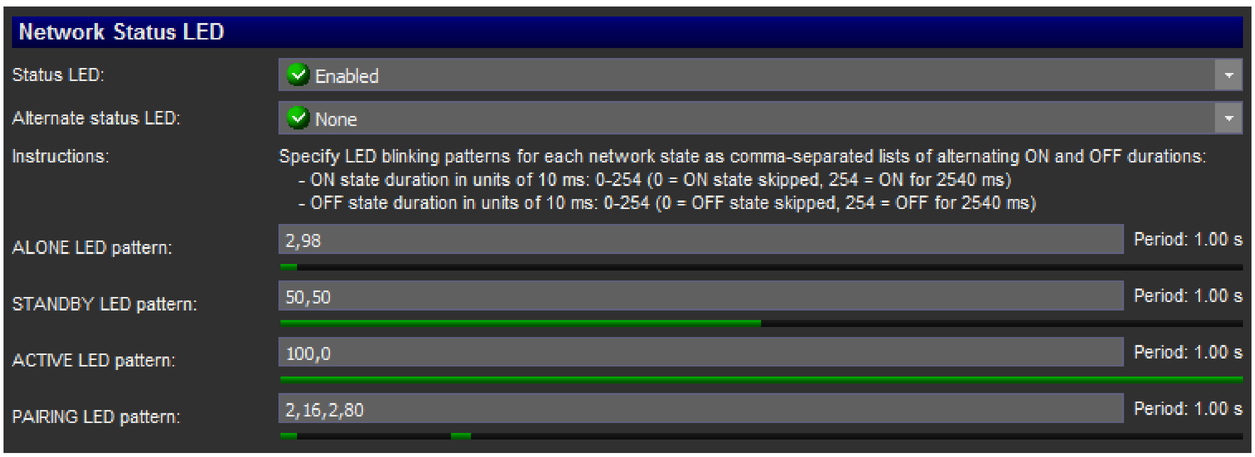

*Figure 7 – Status LED settings from PurePath configuration software*

## C. Range Testing

Range testing was performed using the PurePath wireless audio development kit. The PurePath wireless development kit uses the CC8531 wireless audio SoC, the CC2590 2.4 GHz RF interface, and an inverted F style PCB antenna [12]. Three different tests were performed to characterize the real-world performance of the PurePath wireless audio development kit.

### Indoor Range Test

The purpose of this test was to determine how well the wireless headset development kit functions when transmitting audio indoors. The headset was configured to analog cable replacement mode using the PurePath configuration tool. The master (transmitter) board was connected to a constant audio source, in this case, a laptop playing a test tone. The slave (receiver) board was paired with the master board and played the audio into headphones. The two devices were paired in the same room. The audio streamed uninterrupted within the entire room (about 120 square feet). The slave board was carried into an adjacent room and the door between the rooms was closed. The audio streamed throughout most of the second room, but there were some disruptions in the tone as the signal was interrupted. Moving to a third room broke the connection completely and no audio was streamed. Each room had drywall walls and wooden interior doors separating it from the adjacent rooms.

### Indoor Interference Test

The purpose of this test was to determine if a standard Wi-Fi router (in this case a Belkin F5D7234-4 G router) would interfere with the wireless headset development kit's ability to stream an audio signal. The master (transmitter) board was connected to a constant audio source, in this case, a laptop playing a test tone. The slave (receiver) board was paired with the master board and playing the tone into headphones. The two devices were paired and then the master board was placed within one foot of the Wi-Fi router. The experiment was conducted in a large room, and the slave board was carried away from the master board. The maximum usable distance, (with no interruption in the audio signal) was found to be a little over 15 feet.

After about 20 feet the signal was lost completely. It was concluded that the presence of the Wi-Fi router had no noticeable effect on the functionality of the wireless audio development board when transmitting indoors.

### Outdoor Range Test

The purpose of this test was to determine the maximum distance that the wireless headset development kit can stream audio with near ideal conditions. The headset was configured to analog cable replacement mode using the PurePath configuration tool. The master (transmitter) board was connected to a constant audio source, in this case, a laptop playing a test tone. The slave (receiver) board was paired with the master board and playing the tone into headphones. The two devices were paired and placed at the same height above level ground, approximately 4 feet. The slave board was carried away from the master board directly in the line-of-sight of the master board. The audio signal continued uninterrupted for about 75 feet. After 75 feet the audio signal was periodically interrupted, and could be lost completely by placing a hand around the board. At 85 feet the signal was lost completely. It was concluded that in near ideal conditions, the PurePath wireless headset development could stream an audio signal a much greater range than in typical indoor conditions.

### Range Testing Conclusions

The CC85xx with a PCB trace antenna, as used in the wireless headset development kit, is best suited for indoor use within one small room. Though it is possible to stream audio to an adjacent room, the results are not always perfect, and the audio signal can be interrupted. The device can be used in the presence of Wi-Fi, without any noticeable interference or difference in performance. The possibility of someone listening to an audio stream from a different room is real, and, therefore, sensitive information is unsecure, as there is no encryption used on the signal. Encryption could be added by writing custom firmware for the CC85xx, making the data more secure. If this product were to become a commercial product for use in hospitals, then encryption would need to be added, because transmitting a patient's voice over an unsecure channel during a medical conversation with a doctor could be considered a violation of the patient's right to confidentiality in medical ethics. For home use, however, an unencrypted audio stream would be acceptable.

## D. Microphone

The each board in the PurePath headset development kit has two 3.5mm audio jacks, one for input and one for output. Two microphones were tested, a standard lapel mic shown in Figure 8 and a throat mic shown in Figure 9. The throat mic that was used was the IASUS concepts NT3 Black OPS 2 Throat Mic System. Throat mics are typically designed for security guards or tactical sports (such as paintball, airsoft, etc.) and are designed to be worn around the neck and to be able to pick up low voices from the vibrations of the throat. When testing microphones, it is important to enable the volume control on both devices, as different microphones will have different input levels. This does allow clipping, however, as the device is amplifying the audio signal. The lapel mic performed well, but for very low voices, the lapel mic had to be positioned very close to the mouth. The throat mic that was tested did not work with the PurePath headset, presumably because the output was too low. A preamp circuit could be used, or a more sensitive throat mic could be used.

*Figure 8 – Lapel Mic*

*Figure 9 – Throat Mic*

The performance of the system was tested using a signal generator as the input source and measuring the voltage across the speaker terminals using an oscilloscope. The input source was set to a 1 kHz and the output was measured using the Fast Fourier Transform (FFT) function on the oscilloscope. Figure 10 shows the FFT output for $V_{in} = 20\ mV$, the first input voltage where the 1 kHz signal was above the noise floor.

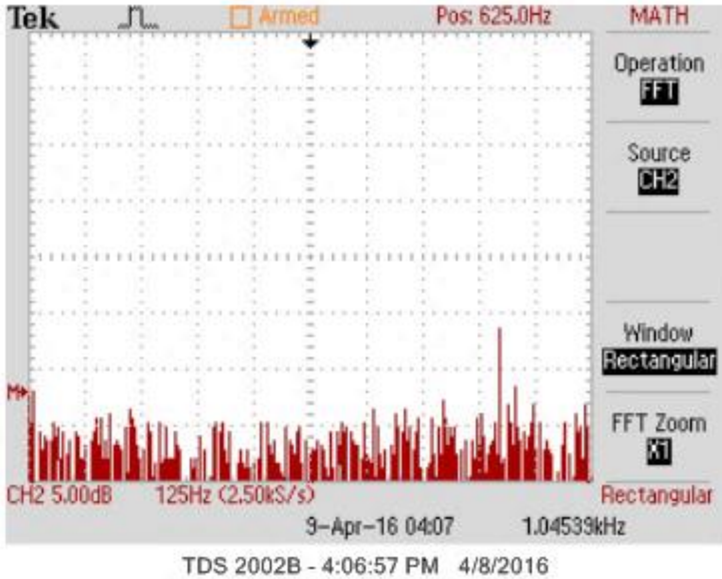


*Figure 10 – FFT of output signal for Vin = 20 mV*

The input voltage was varied from 5 mV to 400 mV, and the output was measured using the FFT function on the oscilloscope. A graph of the input voltage (in mV) vs the output voltage signal (measured in dBv over the noise floor) is shown in Figure 11. The volume of the output was set to about 75% of the maximum volume setting.

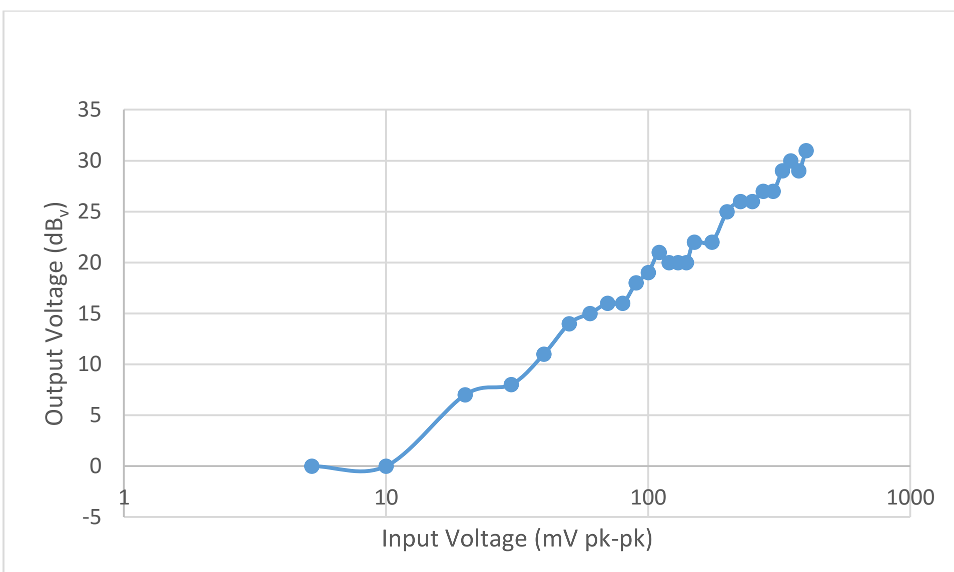


*Figure 11 - Input Voltage (mV pk-pk) vs Output Voltage (dBv above noise)*

The minimum input voltage that produced an audible output signal was 5.3 mV. The output was comfortably loud when the input signal was around 50 mV. After 100 mV the output signal was very loud. At the highest levels, the output signal began to distort. Figure 12 shows the FFT of the output signal when the input voltage was 400 mV. Notice the visible harmonics caused by the signal distortion.

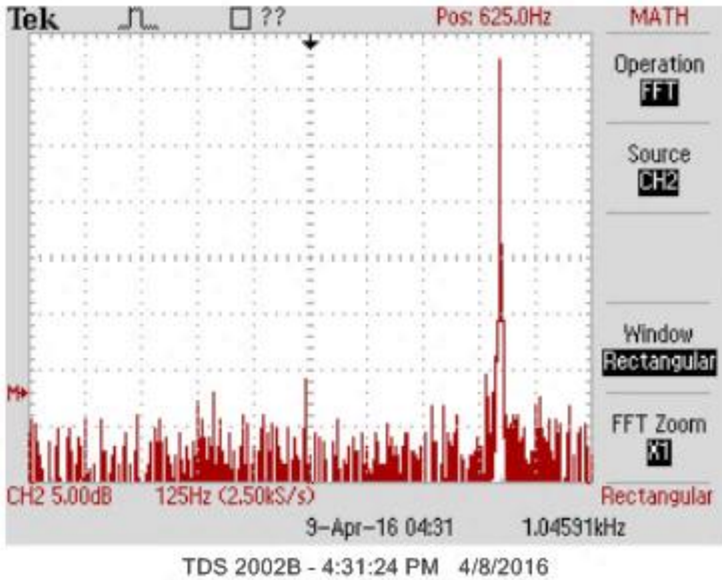


*Figure 12 – FFT for the output signal when* $V_{in} = 400\ mV$.

## V. Receiver Base Station

The receiving half of the system is referred to as the base station because it is intended to be left near the patient's bed and can remain stationary as part of the room, where as the transmitter can be moved around the room as long as it stays within the range of the base station. The receiver base station consists of three parts, the power supply, the RF SoC circuit (the PurePath wireless development kit was used in the prototype), and the audio power amplifier.

## A. Power Supply Board

The power supply circuit consists of two DC-DC converter modules and a linear voltage regulator powered by a 12V wall-wart style AC adapter. The two DC-DC converters provide two 5V rails for charging the transmitters over USB. The V7805-100R buck converter module from CUI systems was used [13]. The datasheet states that the module is rated for 1A output current and up to 97% efficiency. Graphs for the DC-DC converter's efficiency versus load current were given for best-case (Vin = 6.5 V) and worst-case scenarios (Vin = 32 V). The receiver base station will be operating with a 12V input, because 12 V is the minimum input voltage required by the audio amplifier circuit. The efficiency of this DC-DC converter was tested for a 12 V input voltage and varying loads using a 50 Ohm wire wound power potentiometer. The circuit was constructed using the recommended input and output capacitors from the datasheet. The test circuit shown in Figure 5 was used with $C_1 = 10\ \mu\mathrm{F}\ 50\ \mathrm{V}$ and $C_2 = 22\ \mu\mathrm{F}\ 16\ \mathrm{V}$. Both capacitors were TDK Corporation FK series ceramic capacitors [14]. The circuit was tested with an adjustable power supply set to 12 V, and with current meters at the input and output of the circuit. The meters used were the BK Precision Test Bench 390a multimeter [15] and the Fluke 77 IV multimeter [16]. The input and output voltages were measured at the terminals of the device so that multimeter burden voltage could be neglected.

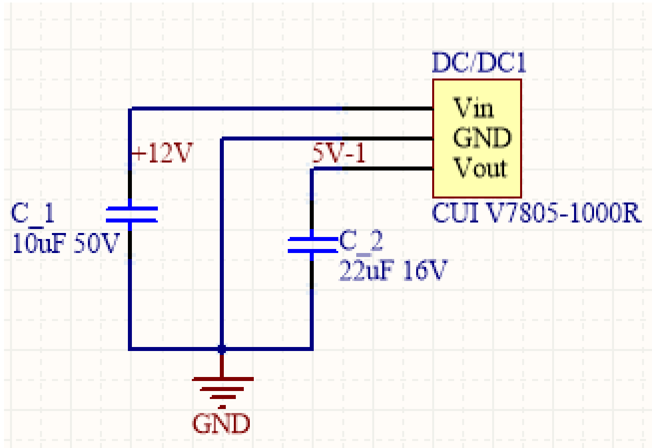


*Figure 13 – DC/DC converter test circuit*

The circuit shown in Figure 13 was constructed on a copper-clad board, and wires were attached for the input and output voltage, as shown in Figure 14.

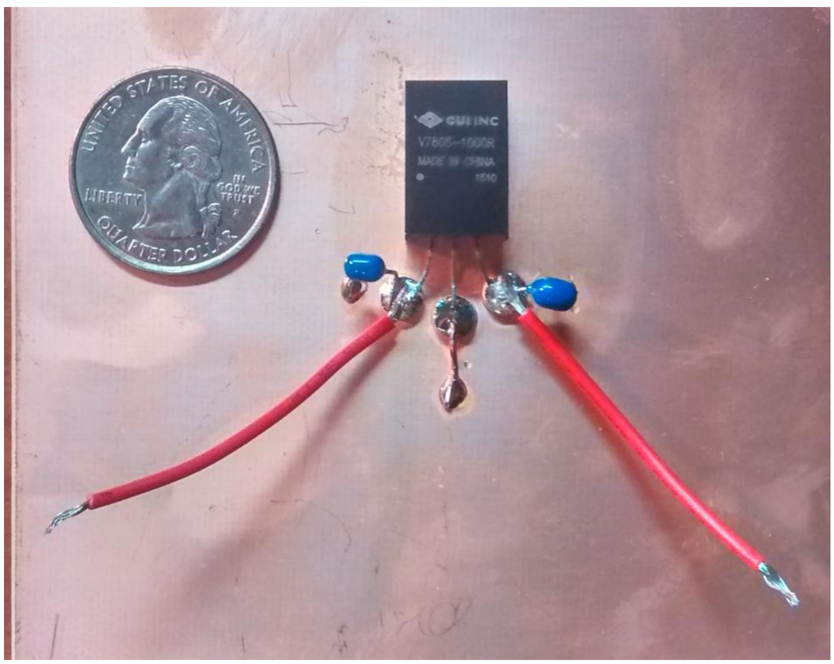


*Figure 14 – DC-DC converter board constructed on copper-clad board.*

Efficiency was tested by measuring the input voltage and current and the output voltage and current for varying loads within the current rating of the device. The efficiency vs load curve for a 12V input voltage is shown in Figure 15.

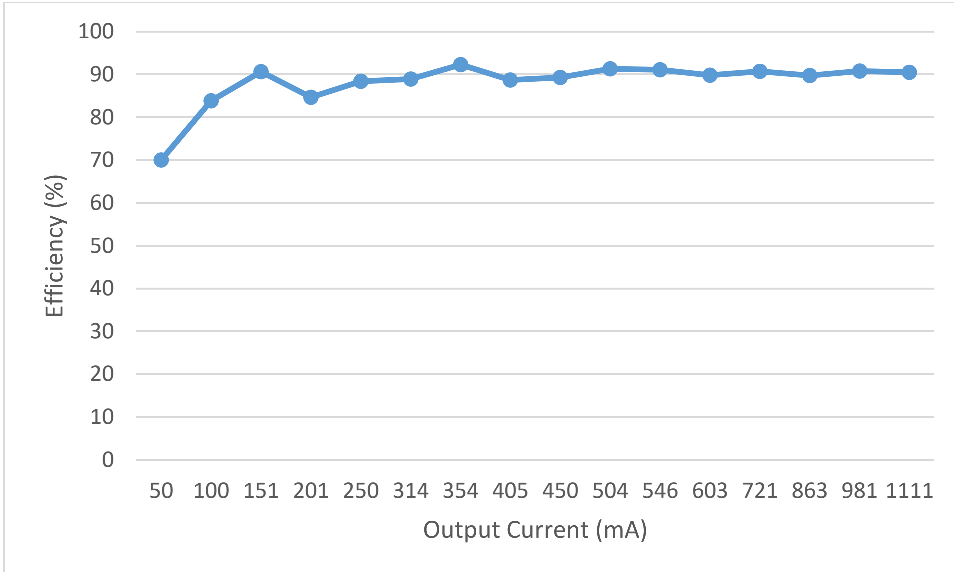


*Figure 15 – Efficiency versus load for the DC-DC converter module with* $V_{in} = 12\ V$

The peak efficiency was 92% which occurred when the load was 350 mA. The average efficiency was 80%. The peak efficiency claimed in the datasheet was 97% at 6.5V, the best-case input voltage. The efficiency versus load curve from the datasheet for the best-case input voltage is shown in Figure 16. The average efficiency of 80%, and the efficiency of 90% at 1 A load is much better than a linear voltage regulator could achieve. An LM7805 operating at 1A with a 12V input would be dropping 7 volts and dissipating 7W, and therefore operating at only 41% efficiency. The wasted power would be dissipated as heat, and the regulators would require large heatsinks or fans to keep from overheating. An efficient DC-DC converter wastes very little power, and therefor generates very little heat. In this regard, DC-DC converters perform better than linear regulators, though linear regulators do have advantages over switching converters, such as noise performance. In this case, the DC-DC converters were used to power the lithium battery charging circuit, which does not require the noise performance advantages that might be achieved using a linear regulator. For this reason an efficient DC-DC converter was chosen.

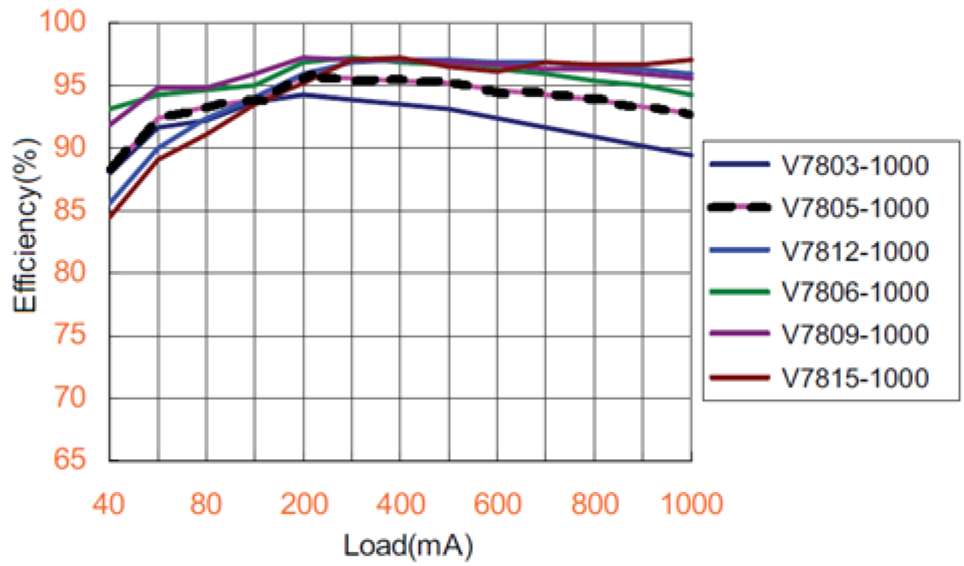


*Figure 16 – Efficiency vs Load at* $V_{in} = 6.5\ V$ *taken from datasheet*

The power supply board for the receiver base station consists of two DC-DC modules which provide two 5V rails rated at 1A each for and a linear voltage regulator providing a 1.8V rail at 500 mA to power the receiver circuitry. The power supply circuit schematic and PCB layout were created using Altium Circuit Maker. The power supply circuit and the board layout is shown in the appendix.

## B. RF SoC Configuration

The PurePath wireless development board was used in the prototype. The RF SoC on the PurePath wireless development board was configured to be in slave (receiver) mode, with the same settings as the transmitter board. The volume control was disabled to prevent clipping, though this is not a strictly necessary step, as the on-board digital amplifier can be used to increase the volume of the signal.

## C. Audio Power Amplifier

The audio power amplifier circuit was designed around the LM384 5W audio amplifier IC based on the reference circuit from the datasheet [17]. The LM384 is a 5W audio amplifier IC with a fixed gain of 34 dB. The LM384 is designed such that it uses ground-referenced input signals, allowing for convenient volume control using a voltage divider. If more gain is needed the circuit can be wired with a negative feedback loop, though this was not done as the output from the digital to analog converter in the audio codec used in the PurePath wireless headset development signal was sufficient to be used without an extra feedback loop. If more than 5W output power is needed, two LM384 IC's can be connected a bridge configuration to provide 10W of output power.

The full schematic and the board layout are shown in the appendix. In the schematic, R1 and C1 on the input signal are optional. Resistor R1 provides a fixed attenuation if one is required and can be jumpered (short-circuited with solder) or a zero ohm resistor if not required. Capacitor C1 AC couples the input signal to the amplifier and can also be jumpered or a zero ohm resistor if not required. The volume is controlled with a logarithmic potentiometer wired as a voltage divider that attenuates the input signal. The LM384 can be powered with an input voltage of 12-24 volts. This is why the minimum input voltage for the entire base station was chosen to be 12 V, the minimum input voltage for the LM384. The audio board drives an 8 Ohm speaker as recommended by the datasheet. The audio circuit was tested using a retail 8 Ohm four-inch car speaker from Boss (Boss Audio BRS40) purchased from Amazon, as well as an inexpensive 8 Ohm speaker from CUI INC [18] purchased from Digikey. Both speakers performed similarly, with no noticeable difference in audio quality or power consumption by the amplifier.

The LM384 datasheet recommends using a heat sink when driving large loads. A clip-on heatsink [19] for a 14 DIP IC was used with the LM384, though the IC never got warm even when driving the 8 Ohm speaker for several minutes at a large volume. If a lower impedance speaker such as a 6 Ohm or 4 Ohm speaker were used, the heatsink might become more necessary.

## VI. Design Improvements

There are several improvements that should be made to the wireless voice audio system before the system could be made into a product that is ready for production. First, the PurePath development kit cannot be used in a commercial product, because it is licensed for development and testing purposes only. The development kit does come with detailed reference designs that could be adapted into another circuit card that would be in the receiver base station, along with the power supply board and the audio amplifier board described in this paper. The three boards would be mounted vertically using standoffs. This would greatly reduce cost as the PurePath development kit, which includes two boards, a programmer/debugger, the configurator software, and a reference design is significantly more expensive than the sum of its components. A nearly identical circuit could be used for the transmitter as well, though the size of the transmitter circuit board would need to be minimized so that the user could wear the transmitter around his/her neck on a lanyard.

# Conclusions

This paper examines the problem of wireless audio amplification in a hospital room setting and proposes a practical solution in the form of a self-contained wireless voice amplification system. A system was designed and tested using the PurePath wireless headset development kit from Texas Instruments, which features a CC8531 wireless audio SoC. A prototype system was constructed using the PurePath wireless headset kit, an LM384 audio amplifier circuit, am MCP73833 battery charger circuit, and a DC-DC converter circuit. The prototype was tested to demonstrate its functionality as a voice amplification device for use in hospital rooms with very weak patients who can only speak softly. The prototype is receiver base station is shown in Figure 12.

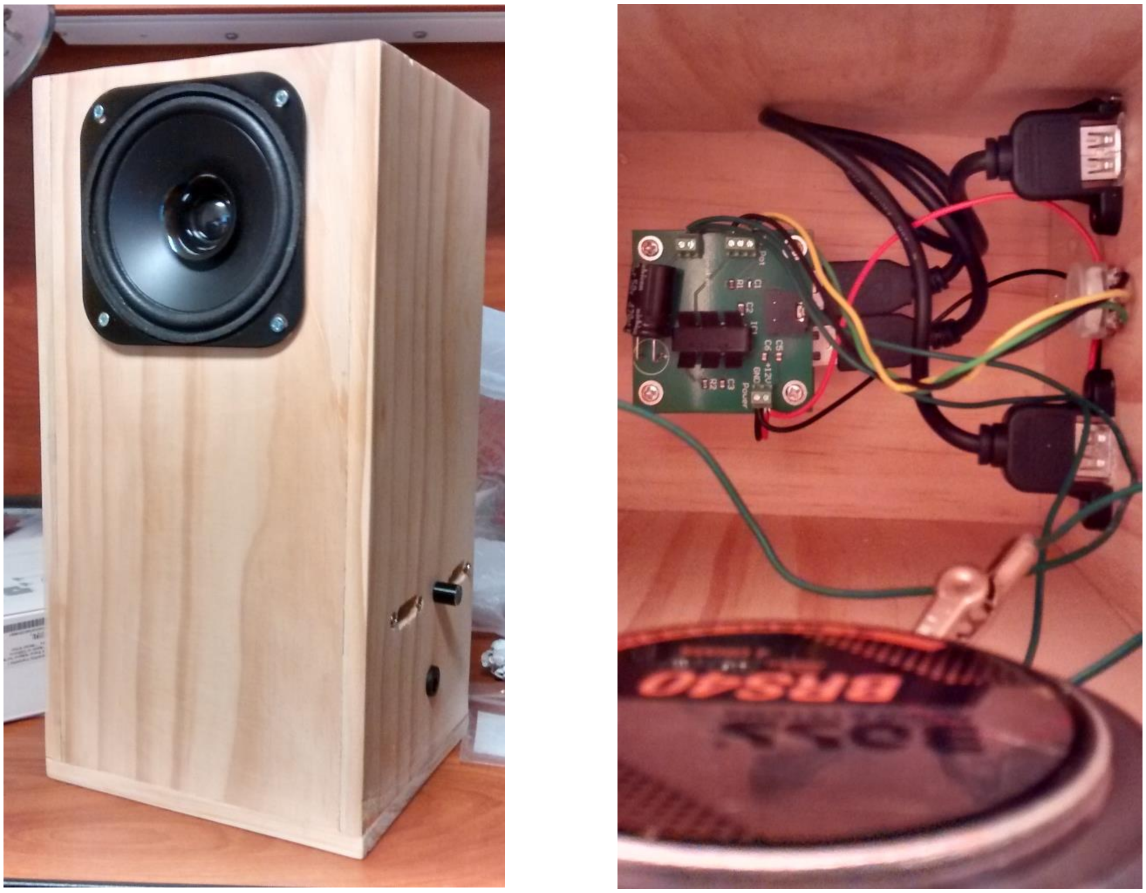

*Figure 17 – Receiver base station prototype (left) Top-down view of receiver electronics (right)*

## Acknowledgements

I would like to acknowledge Ms. Marlena Russel for bringing the idea of a wireless voice amplification system to Dr. Ofoli and for providing funding for the parts that were used to develop the prototype. Thanks to Dr. Loveless, Dr. Reising, and Dr. Clark for sitting on the review committee and providing feedback on the project. Many thanks to Dr. Ofoli for providing direction for the project and helping me along the way.

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# Appendix A

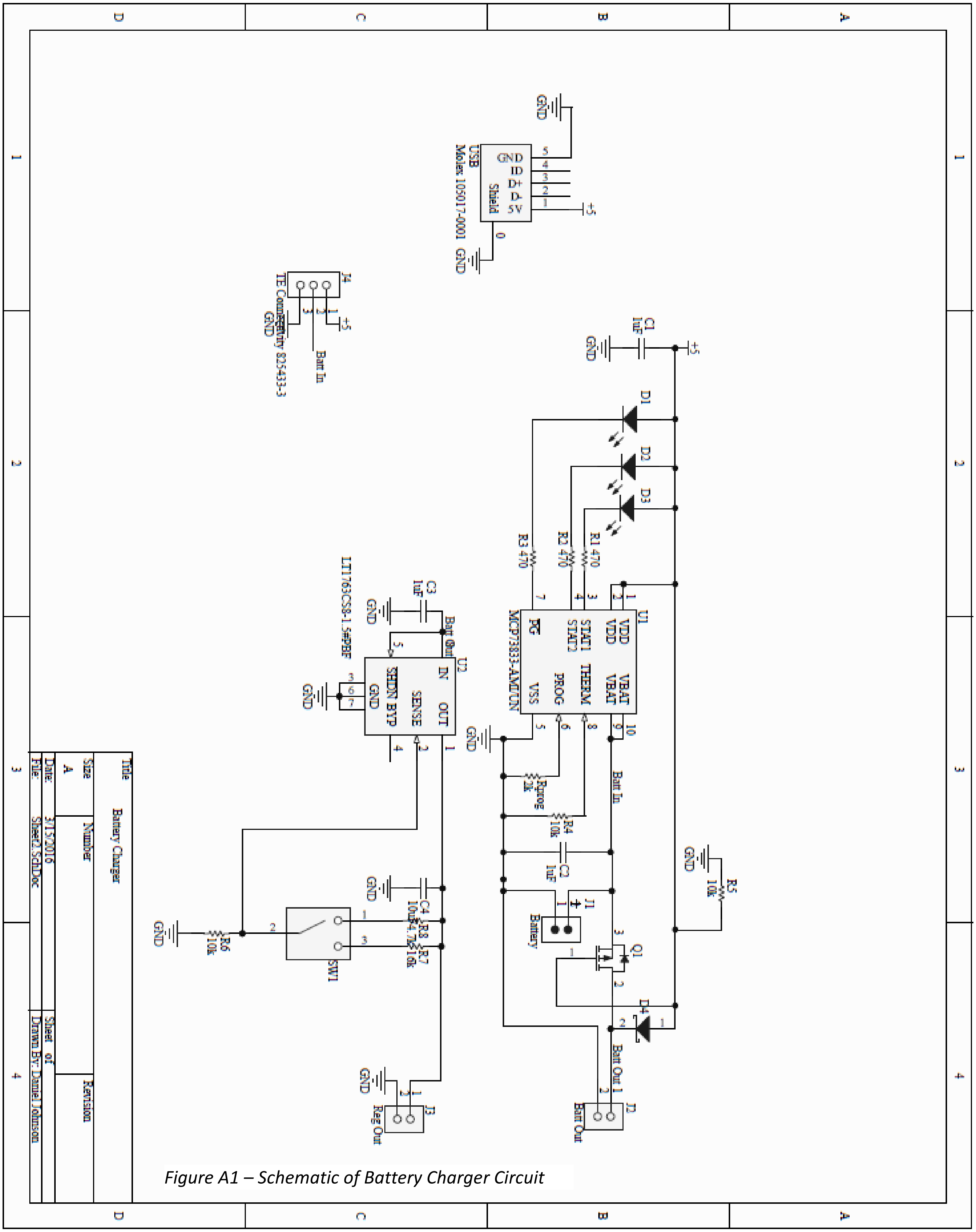


*Figure A1 – Schematic of Battery Charger Circuit*

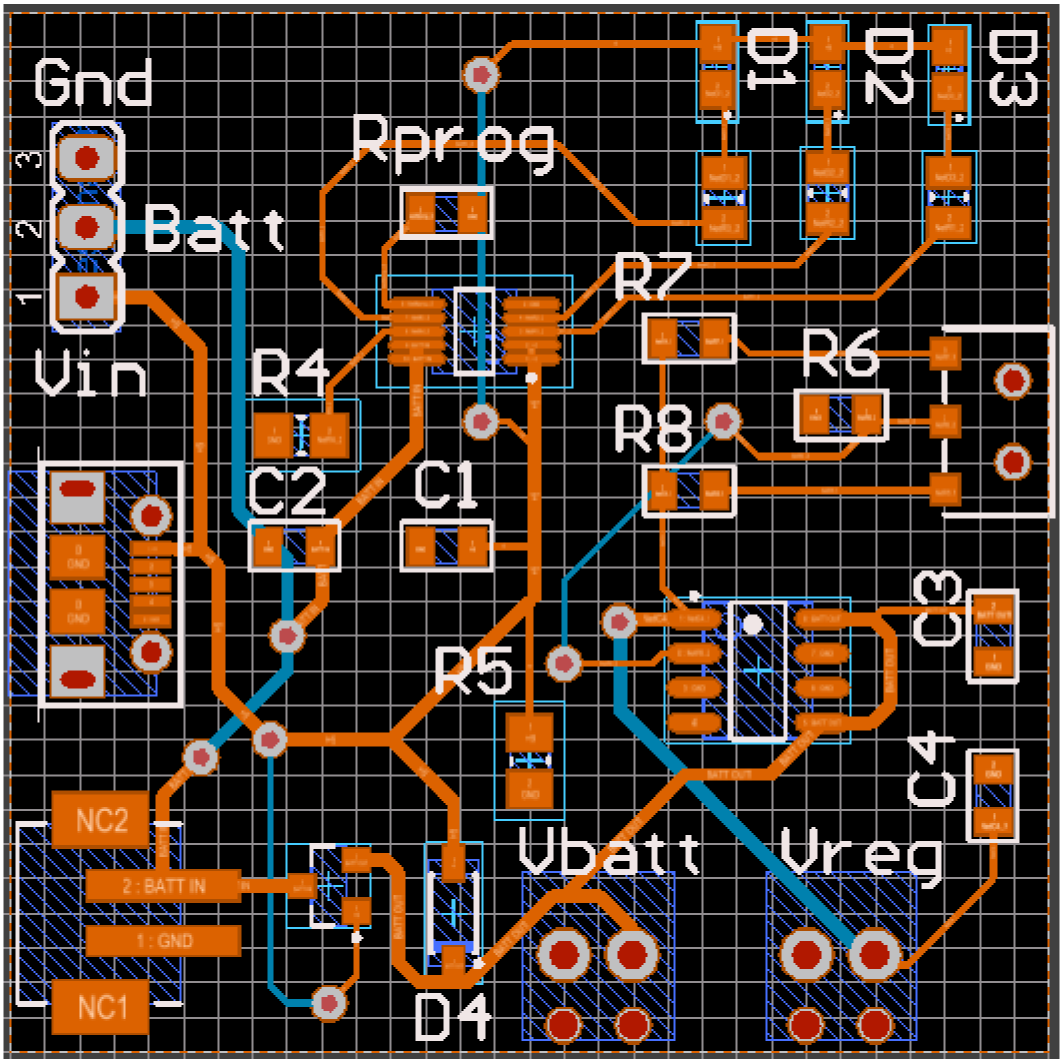


*Figure A2 – PCB Layout for battery charger circuit. The ground planes have been removed to show the routing on both layers.*

**Table A1 – Battery Charger Bill of Materials**

| Description | Designator | Quantity |
|---|---|---|
| CAP CER 1UF 25V 10% X7R 0805 | C1, C2, C3 | 3 |
| CAP CER 10UF 25V 10% X7R 0805 | C4 | 1 |
| LED SUPER RED CLR THIN 0603 SMD | D1, D2, D3 | 3 |
| 1.0 A Surface Mount Schottky Barrier Rectifier, 40 V, -65 to 125 deg IIC, 2-Pin SOD-123 Package, RoHS, Tape and Reel | D4 | 1 |
| PH Series 2 Position 2 mm Pitch Surface Mount Top Entry Shrouded Header | J1 | 1 |
| CONN TERM BLOCK 2.54MM 2POS | J2 | 1 |
| CONN TERM BLOCK 2.54MM 2POS | J3 | 1 |
| Pin header; pin strips; AMPMODU MOD II; male; PIN: 3; straight | J4 | 1 |
| P-Channel 20 V 38 mO 9.1 nC SMT Enhancement Mode Mosfet - SOT-23 | Q1 | 1 |
| RES SMD 470 OHM 1% 1/8W 0805 | R1, R2, R3 | 3 |
| Res Thick Film 0805 10K Ohm 1% 0.125W(1/8W) ±100ppm/C Molded SMD Automotive Paper T/R | R4, R5, R6 | 3 |
| RES SMD 16K OHM 1% 1/8W 0805 | R7 | 1 |
| RES SMD 4.7K OHM 1% 1/8W 0805 | R8 | 1 |
| RES SMD 2K OHM 1% 1/8W 0805 | Rprog | 1 |
| Switch Slide ON ON SPDT Side Slide 0.1A 12VDC 1.2VA 10000Cycles Gull Wing SMD T/R | SW1 | 1 |
| Stand-Alone Linear Li-Ion/Li-Polymer Charge Management Controller with Power-Good Output, 4.2V, 10-Pin MSOP, Industrial Temperature | U1 | 1 |
| 500 mA, Low Noise, LDO Micropower Regulator, 1.8 to 20 V Vin, 1.5 V Vout, 8-pin SOIC (S8-8), -40 to 125 degC, Pb-Free | U2 | 1 |
| CONN RCPT MICRO USB R/A SMD | USB | 1 |

# Appendix B

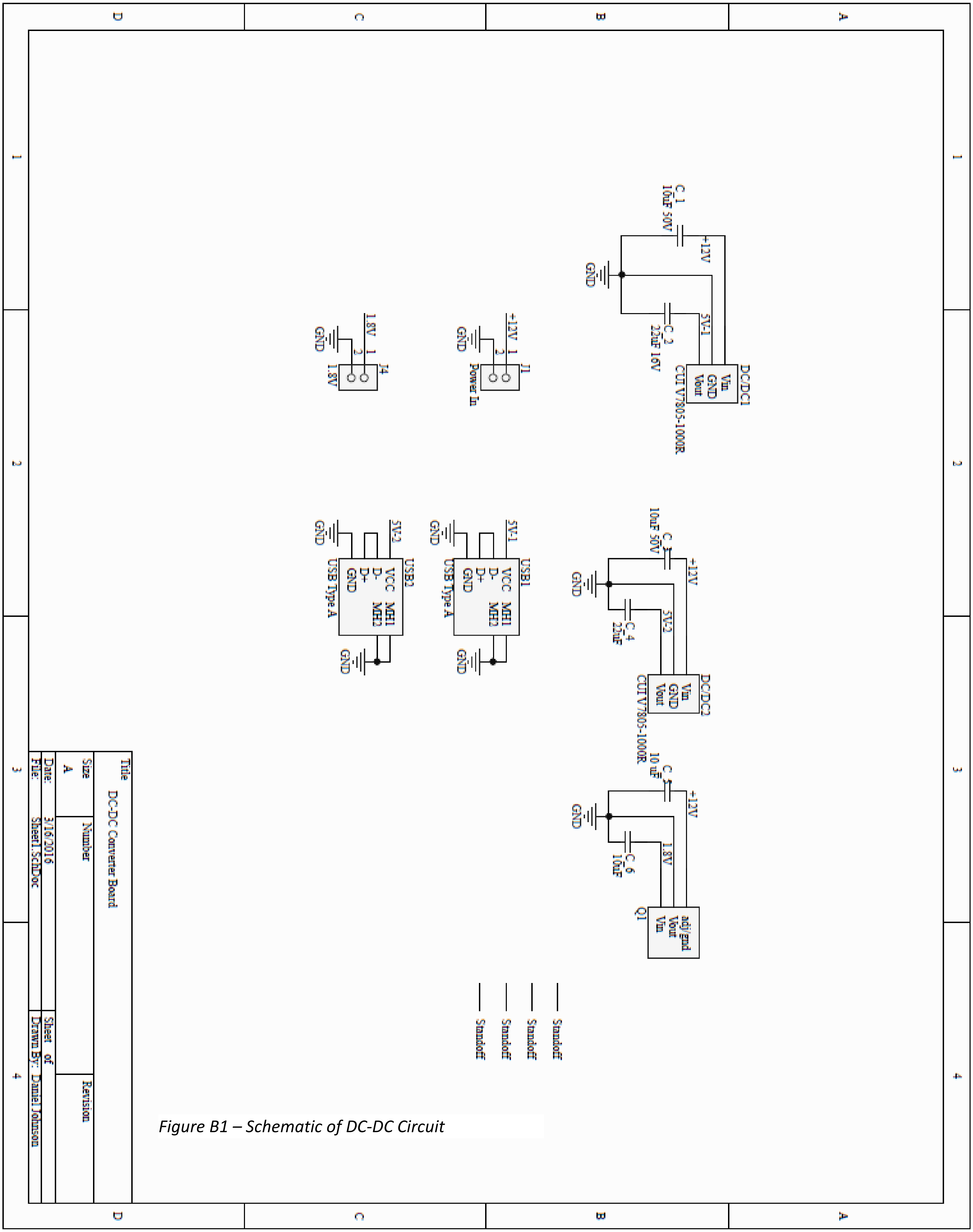


*Figure B1 – Schematic of DC-DC Circuit*

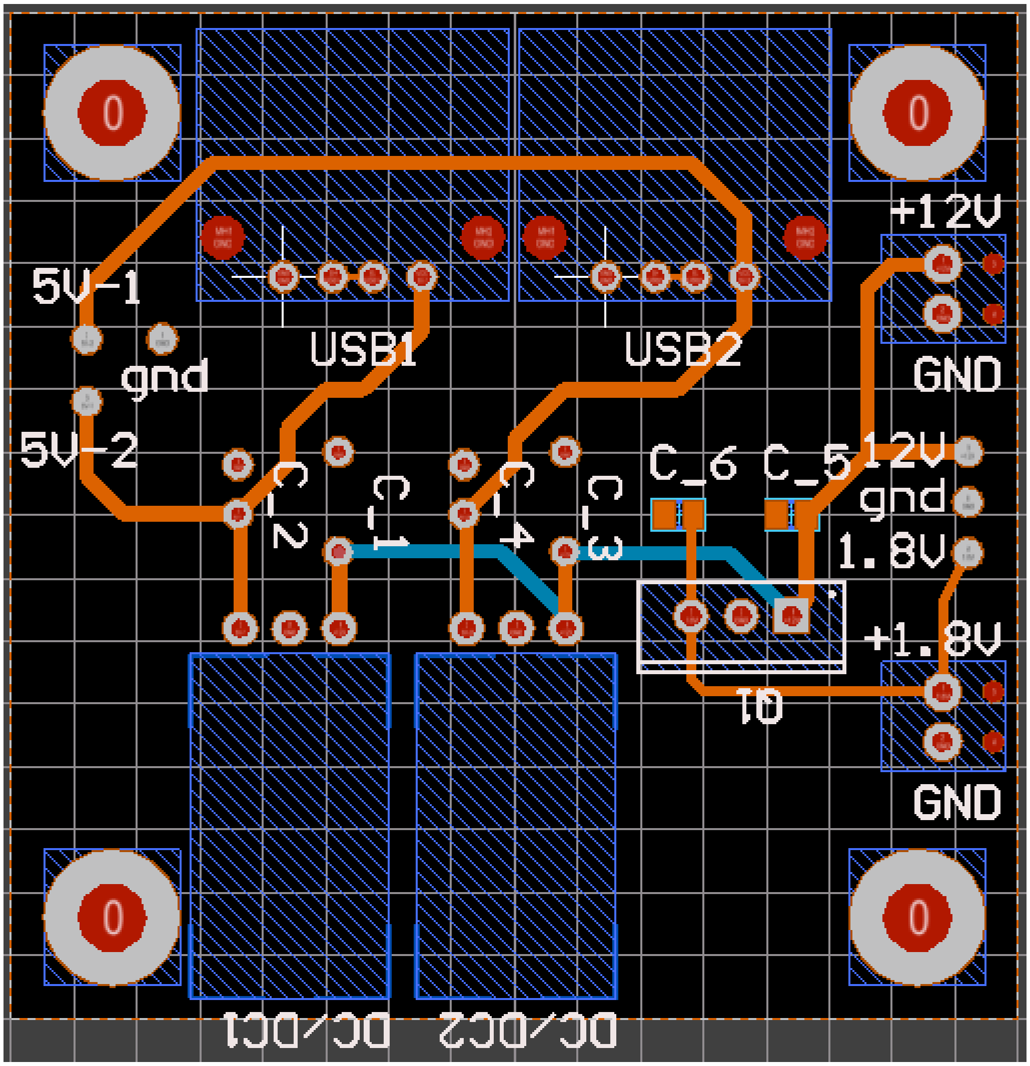


*Figure B2 - DC-DC converter board layout. Ground plane in the top layer has been removed to show the routing on both layers.*

**Table C1 – DC-DC Converter Bill of Materials**

| **Description** | Designator | Quantity |
|---|---|---|
| Cap Ceramic 10uF 50V X7S 10% Radial 5mm 125C | C_1, C_3 | 2 |
| Cap Ceramic 22uF 16V X7R 20% Radial 2.5mm 125°C | C_2 | 1 |
| Cap Ceramic 22uF 16V X7R 20% Radial 2.5mm 125°C | C_4 | 1 |
| CAP CER 10UF 16V 10% X5R 0805 | C_5 | 1 |
| CAP CER 10UF 16V 10% X5R 0805 | C_6 | 1 |
| V78-1000 Series 5 W Single Output 5 V R/A Non Isolated Switching Regulator-SIP-3 | DC/DC1, DC/DC2 | 2 |
| CONN TERM BLOCK 2.54MM 2POS | J1 | 1 |
| CONN TERM BLOCK 2.54MM 2POS | J4 | 1 |
| 1.5 A adjustable and fixed low drop positive voltage regulator | Q1 | 1 |
| Threaded Aluminum Female Hex Standoff 6 - 32 Thread Length .5 inch | S1, S2, S3, S4 | 4 |
| Conn USB Type A RCP 4 POS Solder RA Thru-Hole 4 Terminal 1 Port | USB1, USB2 | 2 |

# Appendix C

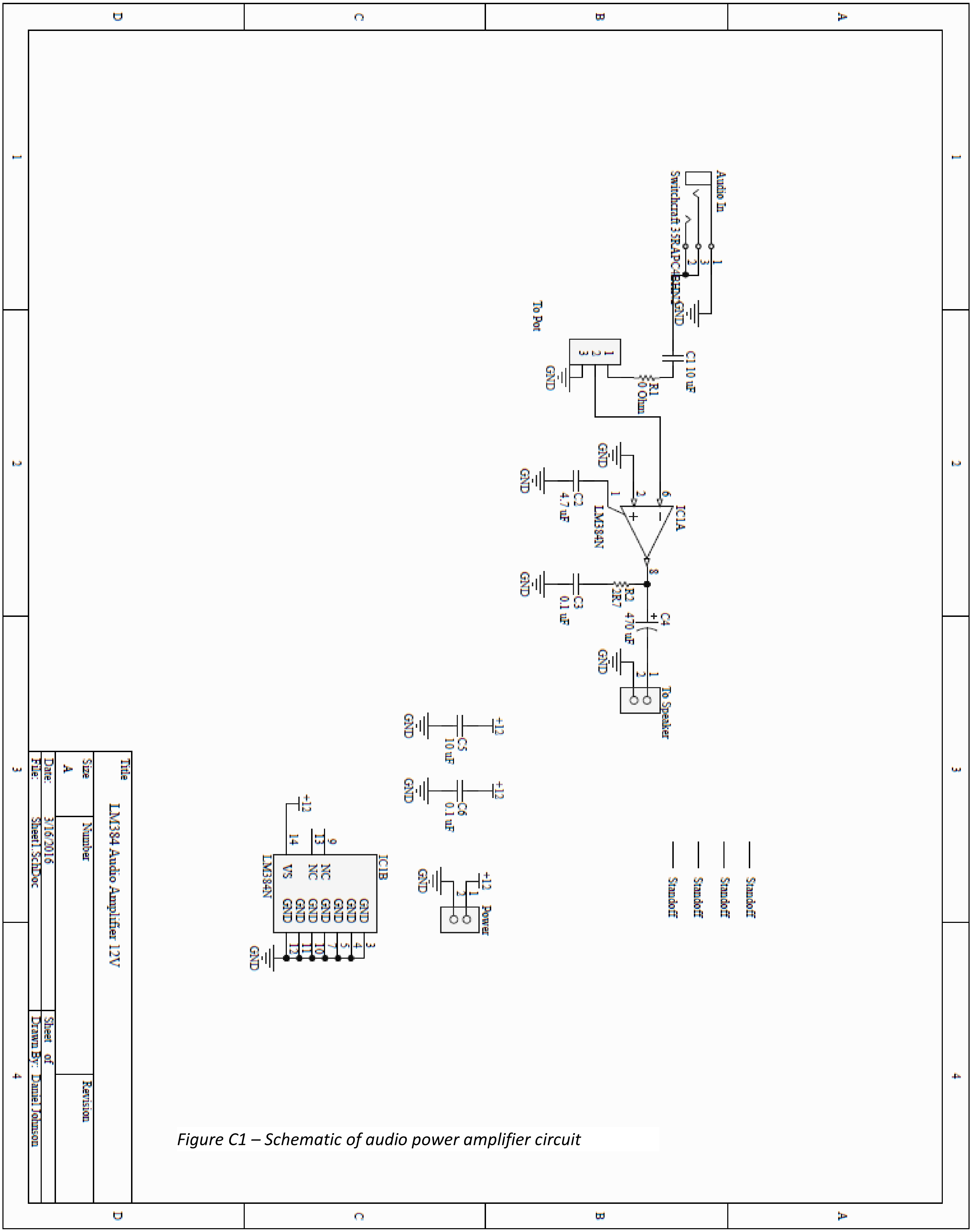


*Figure C1 – Schematic of audio power amplifier circuit*

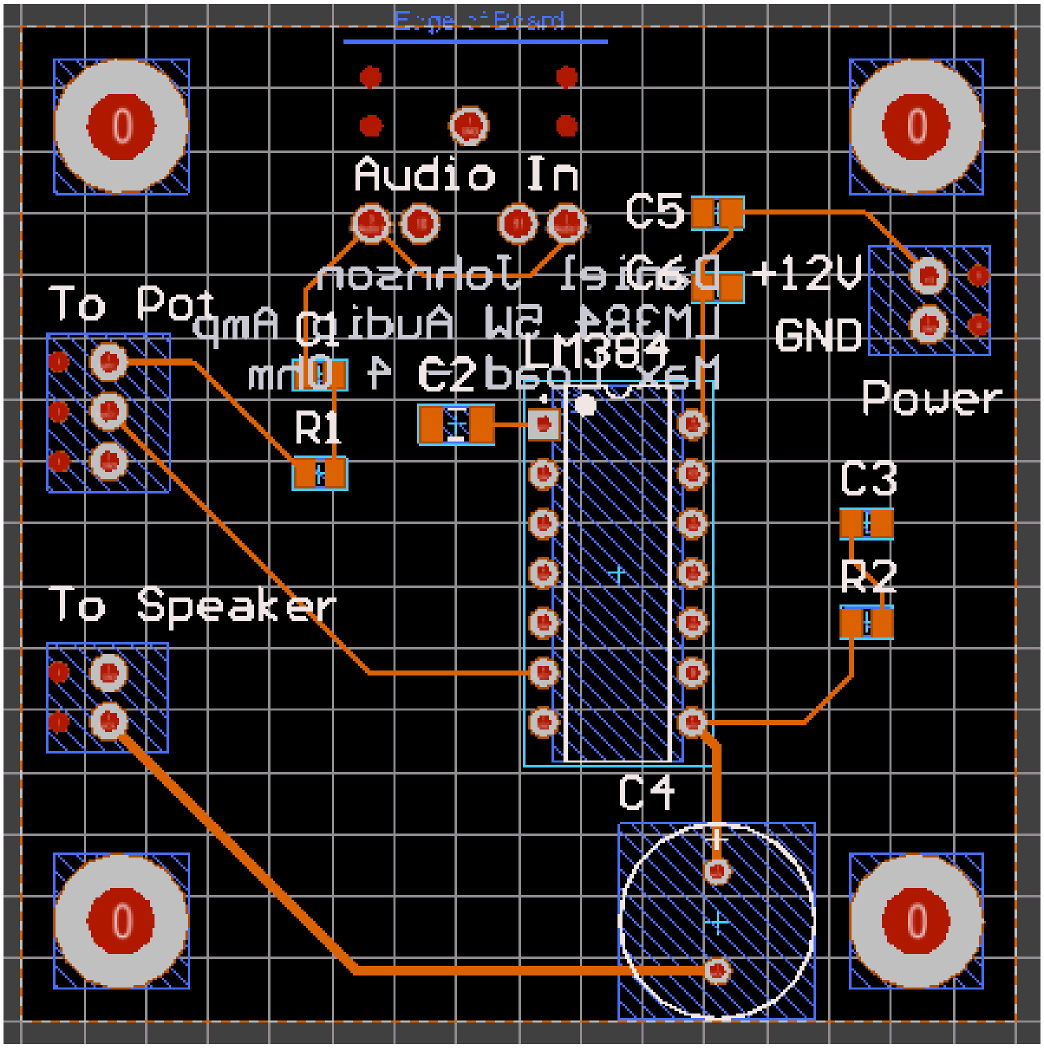


*Figure C2 - Audio amplifier board layout. Ground plane in the top layer has been removed to show the routing on both layers.*

**Table C1 – Audio Power Amplifier Bill of Materials**

| Description | Designator | Quantity |
|---|---|---|
| CONN JACK STEREO 3.5MM HORIZON | Audio In | 1 |
| CAP CER 10UF 10V Y5V 0805 | C1, C5 | 2 |
| CAP CER 4.7UF 25V 10% X5R 1206 | C2 | 1 |
| CAP CER 0.1UF 25V Y5V 0805 | C3, C6 | 2 |
| Cap Aluminum Lytic 470uF 35V 20% (10 X 20mm) Radial 5mm 1220mA 3000h 105Ø¢°C Automotive Bulk | C4 | 1 |
| 5 W Audio Power Amplifier, 0 to 70 deg C, 14-pin DIP (NFF14) | IC1 | 1 |
| CONN TERM BLOCK 2.54MM 2POS | Power, To Speaker | 2 |
| Thick Film Resistors - SMD 0805 0 ohms 1% Tol | R1 | 1 |
| Thick Film Resistors - SMD 0805 2.7ohms 1% Tol | R2 | 1 |
| Threaded Aluminum Female Hex Standoff 6 - 32 Thread Length .5 inch | ST1, ST2, ST3, ST4 | 4 |
| 3 Way 2.54mm Pitch 6A PCB Header PCB Phoenix Connector A phoenix connector that mounts to a through-hole PCB connection. | To Pot | 1 |