Wearable Unobtrusive Noise Canceling Vest

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Mobile and Ubiquitous Computing

ABSTRACT

This paper introduces a wearable noise-cancelling system for NASA astronauts onboard the International Space Station (ISS). Different from current headphone-based noise-cancelling solutions, our wearable vest is unobtrusive to astronauts’ regular activities and does not the block the ear. The power supply and anthropometry of the system are designed to accommodate ISS use context. To achieve active noise-cancellation, we apply adaptive noise cancellation algorithms on the noise samples acquired by reference microphones to generate anti-noise sound waves, and use speakers mounted on the vest for output. This research will be beneficial to ISS astronauts and other similar use cases.

Keywords

NASA; active noise-cancellation; wearable computing; acoustics.

INTRODUCTION

The International Space Station (ISS) has high amounts of ambient noise from all the pumps, fans, and machinery needed to support life on board. Astronauts are at risk of not only the annoyance of dealing with high levels of sound, but also permanent hearing damage if they do not have the proper protective equipment. There is a need for a protective active noise-canceling device that can actively mitigate sounds while not interfering with the daily activities and motion of the astronaut. Users also reported the desire to not simply wear headphones, as this interferes with communication on board.

Team Composition

For this project, we will continue working with NASA to develop a wearable unobtrusive noise-canceling vest. Each team member has been given a specific role that they will be responsible for the duration of the project. Riley Winton will be the Project Manager to keep communication between NASA and the team. Alan Dingtian Zhang and Haytham Abutair will both take the responsibility of a programmer specifically in algorithms. Katherine Kenna will be the industrial designer of the actual system. Taylor Powell will be the hardware specialist in designing the circuitry.

Related Work

Most existing research has been applied to headphone-based solutions, which is a logical approach since the ear and environment can be passively separated. Therefore, the ear-to-source distance remains constant and spatial effects of audio can be controlled. Unfortunately, this type of solution will not work for this project, as the client has requested an unobtrusive solution that doesn’t block the ear. Some research has been performed on open-ear and open-air solutions, with results usually including massive microphone and speaker arrays. We plan to apply those principles to the second phase of this project. Regrettably, little research has attempted to make a personal, body-mounted, active noise canceling system, and therefore this project will venture into unexplored areas.

Use Context

According to our NASA contact, the system would only be used during Intravehicular Activity (IVA), or inside the pressurized modules such as the current International Space Station, a future lunar/Mars habitat, or a long duration deep-space human vehicle. The conditions would be similar to that of Earth - that is 14.7 PSI, air atmosphere of 20% O_2 and 80% nitrogen. Future spacecraft and habitats may be 8.6 PSI at 32 % O_2 and 68% nitrogen. There is a constant noise level inside the International Space Station (ISS) of all of the life support systems, pumps, fans, water processes, etc. For example, one of the noisiest items is the exercise treadmill that the astronauts use constantly. Each astronaut has to exercise a couple of hours a day to mitigate the effects of zero gravity.

The astronauts will likely wear the system over a polo or t-shirt, with no additional headgear aside from a small communication headset. The vest would not be worn when in a flight suit, space suit, or while exercising. Regarding operating life, the estimated time would be 6-8 hours per day, 7 days per week. The astronauts do many experiments and maintenance tasks during the work in many parts of the ISS, and the noise canceling system would be beneficial for nearly all of these tasks.

PROTOTYPE DEVELOPMENT

Initially, we devised a basic vest to help determine the best placement for components and sketches of the next prototype for the wearable vest. This vest contains the location of the speakers, microphones, and control knobs.

In the second phase of this project, we developed housing for the speakers, wiring, and all additional system components through 3D printing.

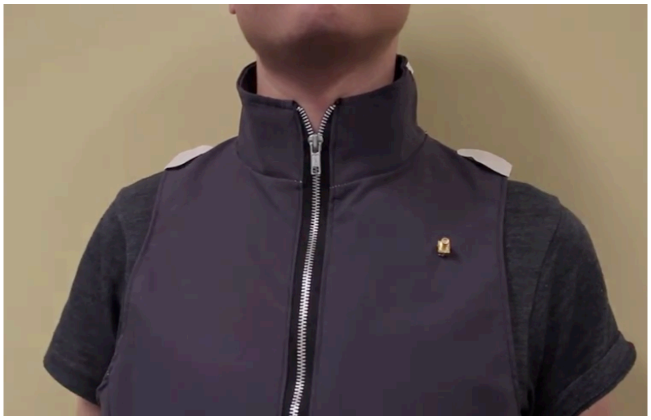

Figure 1. Prototype vest showing component placement.

Proof of Concept

Since NASA requested a proof of concept for the acoustic system - one that could show a small drop in noise levels to promote the feasibility of this idea, we developed a cost-effective test system using Max/MSP and a set of stereo desktop speakers. The rest of the system included a reference microphone (the built in microphone of a MacBook Pro), DSP from within Max/MSP, and a second computer speaker to play back our generated anti-noise. Finally, an iPhone running an SPL meter app simulated the error microphone that would be near the user's ear. This test setup mirrors the common block diagram of noise cancellation systems.

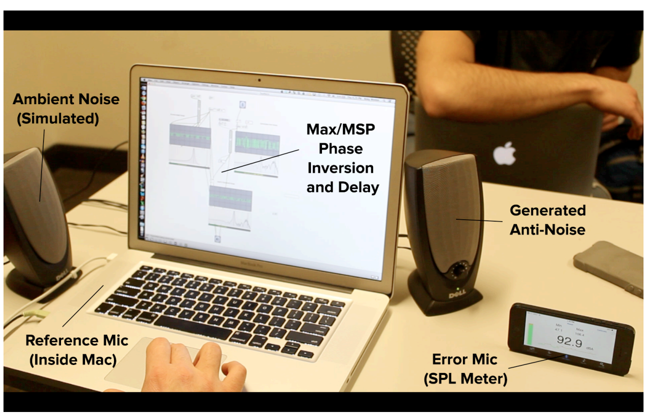

Figure 2. Proof of concept test setup and equipment.

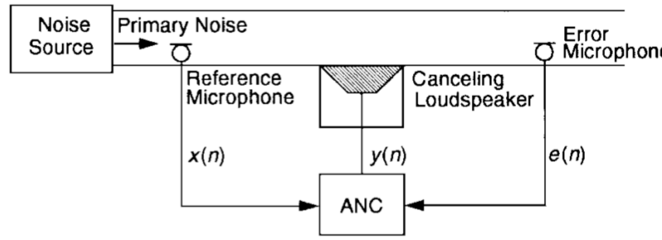

Figure 3. Block diagram of system operation.

One speaker was used to simulate ambient noise. In the International Space Station, this would be replaced by actual machinery and equipment noise. However, for our purposes we used two test stimuli: a sinusoid at 1 kHz and band-limited pink noise from 500 Hz - 2 kHz. This speaker was pointed towards the rest of the scene but very close to the reference microphone. This microphone captures the "ambient" noise and Max/MSP inverts the signal, as well as allows for the delay of the playback in the case of phase differences. The second speaker plays back this real-time signal and the user holds the SPL Meter near the ear to measure relative differences in A-weighted sound pressure levels.

Even with uncontrolled acoustic environments and simulated components, we were able to achieve drops in sound levels by over 10 dBA - a difference that represents less than half of the original signal amplitude. Even considering psychoacoustics, this reduced noise level would be perceived as approximately *half* of the original volume. While the test could easily be considered successful, we did become aware of several critical factors that will affect the ultimate result of this work.

Design

Our system prototype includes the vest, 3D printed housing for the speakers and microphones, circuitry for amplification of all audio signals, and the transducers themselves. Additionally, we outboarded the audio analog/digital conversion and processing to enable us to focus on the system design for prototyping purposes. We've focused on keeping the design as minimal as possible to not burden the user with unnecessary weight, while keeping the speakers as close as possible to the ear to constrain our phase relationships and keep the required speaker power consumption low.

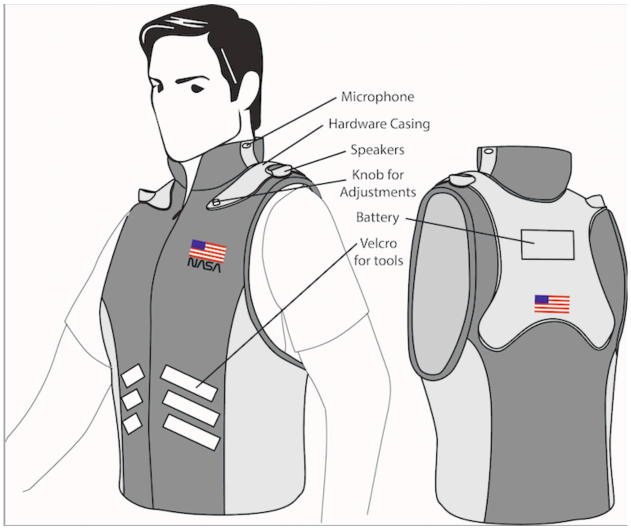

Figure 4. Design sketch of system.

Circuitry

The transducers and audio equipment are as follows:

- 4 x Microphones - Ringford CZ034 Electret Condenser
- 2 x Speakers - Dayton Audio CE30MB-16B 1-1/4" 16 Ohm Driver
- Audio Interface (A/D/A) - Focusrite Saffire Pro24 DSP

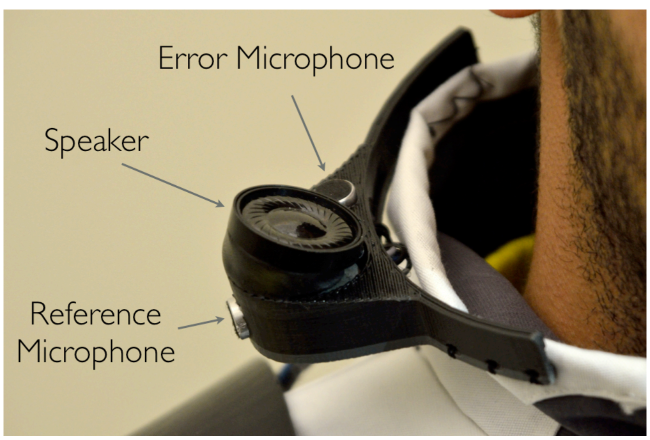

Figure 5. Close-up view of equipment.

Circuitry

The support circuitry involves a power amplifier for each speaker to provide the voltage and current for appropriate acoustic levels. These were based on the Texas Instruments LM380N audio amplifier. Each microphone also uses a pre-amplifier based on the Texas Instrument TL072 op-amp to provide correct polarization voltage and amplify the signal to appropriate levels for A/D and computation.

Originally, we laid out a circuit board design for milling, but unfortunately both campus circuit mills were broken for a majority of the semester. Therefore, we used RadioShack perfboard to lay out and assemble our circuits. Original schematics and layouts are in Appendix A. While the system eventually would require a battery-based power supply, we have designed it to work on a 12V single-ended power supply. At peak operating levels, we reached current consumption of ~110mA, and therefore a battery such as that in Appendix B could provide operating times of up to 10 hours while only adding minimal weight.

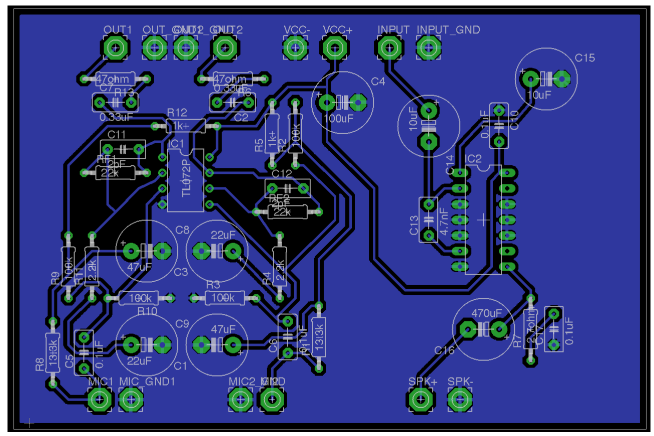

Figure 6. Eagle board design of circuitry for one ear.

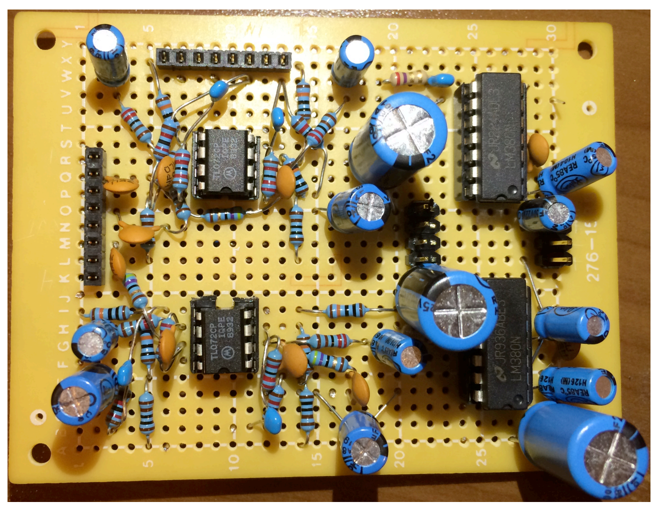

Figure 7. View of perfboard circuit for both ears.

Algorithm

The least-mean squares algorithm, while ideal as an adaptive noise cancellation algorithm, was not successful at operating in real time. To still prove the concept, we utilized Max/MSP, a software system based on C but engineered for real-time audio I/O and DSP. Here, we receive the signal from the microphones, filtered unwanted frequencies outside of our 500-2000 Hz range, invert the phase, and play it back an adjustable delay to compensate for differences in speaker-to-ear distances. This allowed us to continue prototyping with the goal that eventually, adaptive algorithms could be leveraged.

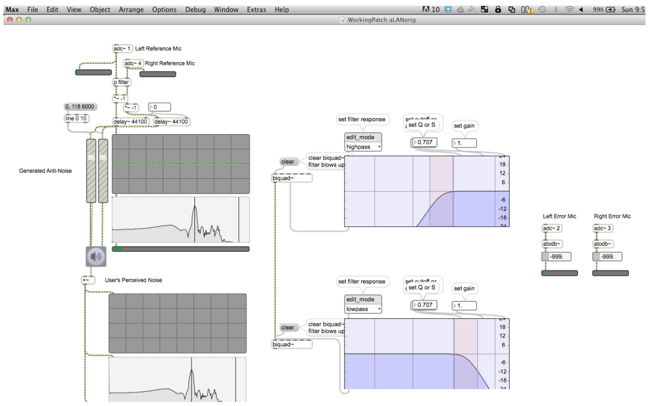

Figure 8. Screenshot of Max/MSP performing the phase inversion, filtering, and delay.

USABILITY TEST

We devised a pilot study to test the comfort and effectiveness of the design. Users would wear the vest while standing, complete a small set of Likert-scale subjective prompts, then sit and repeat the same questions. Additionally, users would be presented with 7 types of noise signals and allowed to control the playback level of the system. They would then respond with a 7-point Likert scale on how well they perceived any noise reduction. The entire test was conducted in a sound-attenuated chamber. For comfort and wearability questions, the Likert scale was as seen in Table 1.

<table>
<tr><th>Comfort/Wearability</th><th>Noise Performance</th></tr>
<tr><td>Extremely Uncomfortable</td><td>No Reduction</td></tr>
<tr><td colspan="2">1
2
3
4
5
6
7</td></tr>
<tr><td>Extremely Comfortable</td><td>Perfect Reduction</td></tr>
</table>

Table 1. Likert scale structure for user test.

Figure 9. Image of usability study setup.

Results

From our initial pilot testing with 2 participants, the results were supportive of our expected results. Even during our uncontrolled studies, we were able to achieve SPL drops of up to 10 dBA for one participant, and up to 4.5 dBA for the second.

The comfort and wearability was also measured via subjective assessment. As seen in Figure 11, the system was overall perceived as extremely comfortable. The only negative impacts to wearability were long periods of sitting, mostly due to the large battery/component housing on the back of the vest. All responses were on a 7-point Likert scale.

Assessment	Standing	Sitting
Overall Comfort	7	7
Arm/Neck Movement Comfort	6.5	6.5
Long-term wearability	6	5.5
Perceived Burden	No	No

Table 2. Subjective responses to user test for comfort and wearability.

Noise Type	User Response	Relative Level (dB)
700 Hz Sine Wave	3.5	-3.9
1000 Hz Sine Wave	4	-4.5
1500 Hz Sine Wave	3	-2.4
2000 Hz Sine Wave	2.5	-1.4
White Noise	1.5	-1.2
Pink Noise	2	-1.6
Ambient Noise (Computer Fan)	2	-2.1

Table 3. Subjective responses to user test for noise performance.

FUTURE WORK

While the system prototype definitely supports the feasibility of this solution, there are several drawbacks and future action items for improving the design. Feedback is a primary concern - naturally when you feed a live microphone signal into a speaker, there are risks to be expected. To compensate for this, DSP could be employed to filter and prevent the feedback. This would likely allow the system to not only be safer, but also operate at higher levels and provide even greater degrees of noise cancellation. Currently, there is also a significant amount of crosstalk between each of the two speakers and the opposite ear. Software filtering could be utilized to help adjust this in the case that the user has two separate noise sources on each side of the head. There are many other types of advanced DSP that could be used to improve the design of the prototype including automatic phase adjustment depending on the frequency of cancellation. Additionally, we would look to expand the operating frequency range beyond the initial 500 - 2000 Hz band.

Ultimately, the goal of this project is to have a completely wearable and untethered experience. Therefore, miniaturizing the circuitry, bringing the A/D/A and algorithmic computation onboard, and powering it all with a battery represents the final goal of this project. At that point, users could likely use this is an actual use context and still benefit from the likely performance in noise reduction.

ACKNOWLEDGMENTS

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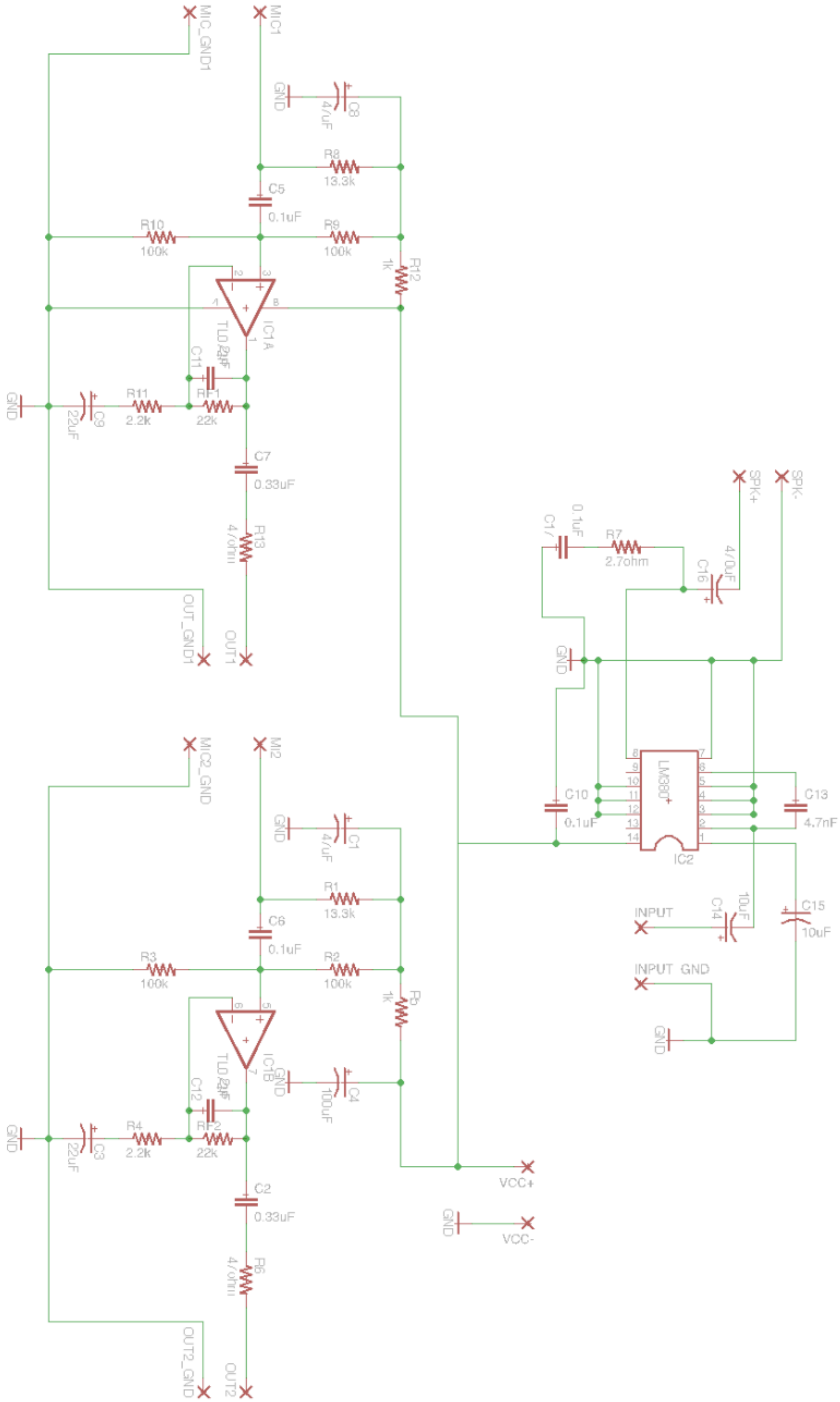
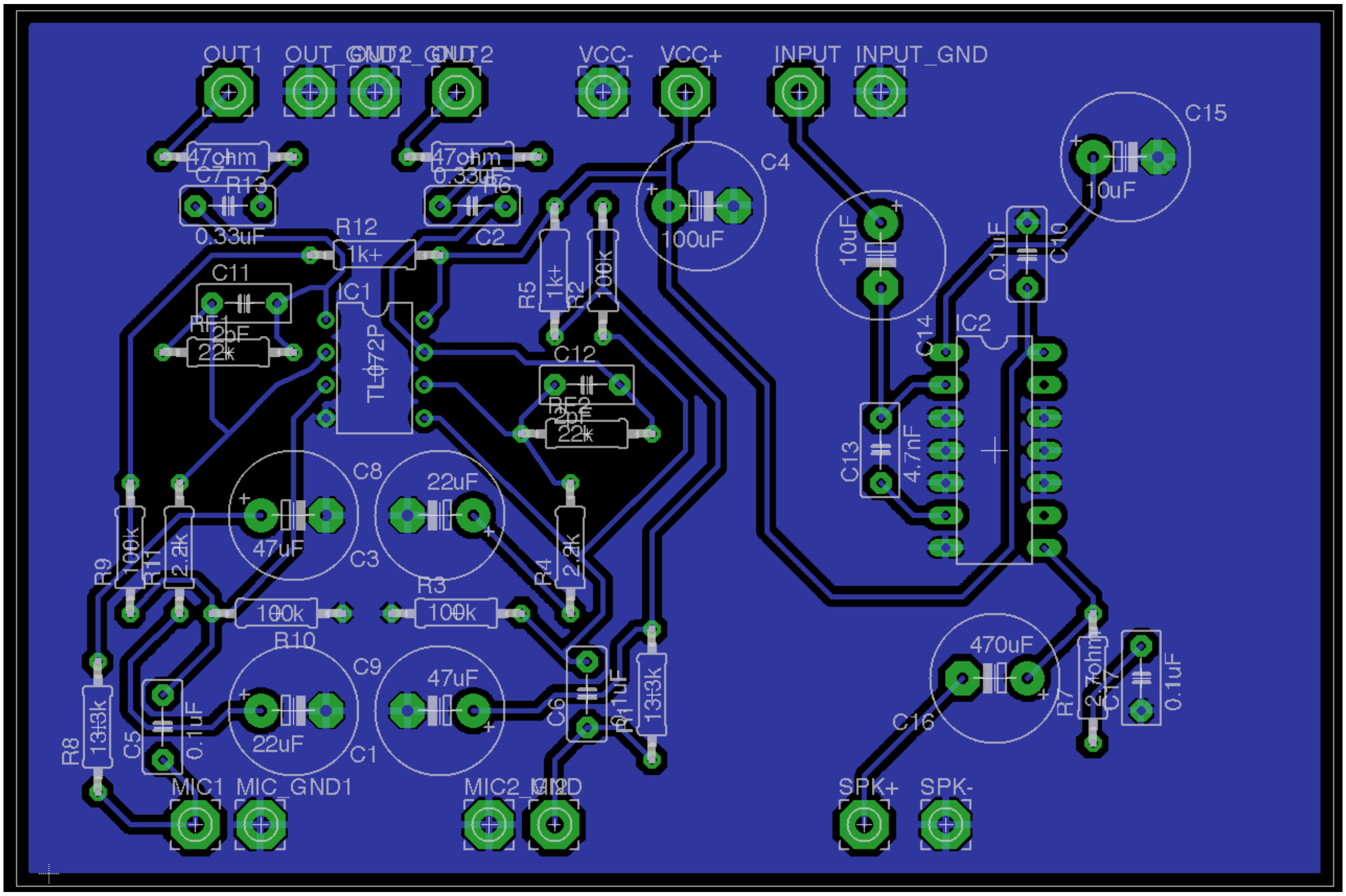
Appendix A: Circuit Schematics and Board Designs




OUT1
OUT_GND1
OUT2_GND
OUT2
VCC-
VCC+
INPUT
INPUT_GND
C15
10uF
C4
100uF
47ohm
C7
R13
0.33uF
0.33uF
R6
C2
R12
1k+
C11
IC1
TL072P
RF1
2pF
22k
R5
1k+
R2
100k
10uF
0.1uF
C10
C14
IC2
C12
RF2
2pF
22k
C13
4.7nF
C8
22uF
47uF
C3
R9
100k
R11
2.2k
R4
2.2k
R3
100k
100k
R10
C9
47uF
22uF
C1
C6
0.1uF
R1
13.3k
R8
13.3k
C5
0.1uF
470uF
C16
R7
2.7ohm
C17
0.1uF
MIC1
MIC_GND1
MIC2_GND
SPK+
SPK-

Appendix B: Recommended Battery Specifications

SB BATTERY

SP1.2-12 *(12V 1.2AH)*

MAINTENANCE-FREE RECHARGEABLE BATTERY

Specification

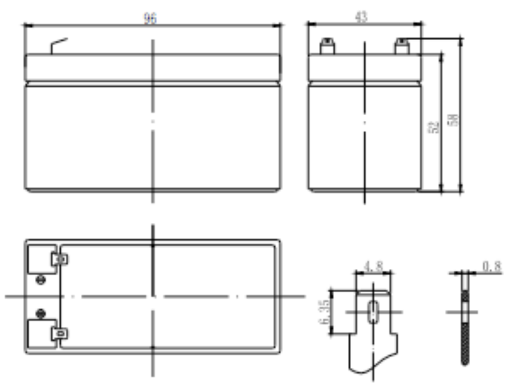
Nominal Voltage	12V
Number of cell	6
Design Life	3~5 years
Nominal Capacity 77ºF(25ºC)	
20 hour rate (0.04A, 10.5V)	1.2Ah
10 hour rate (0.12A, 10.5V)	1.25Ah
5 hour rate (0.24A, 10.5V)	1.19Ah
1 hour rate (0.884A, 9.6V)	0.88Ah
Internal Resistance	
Fully Charged battery 77ºF(25ºC)	95mOhms
Self-Discharge	
3% of capacity declined per month at 20ºC(average)	
Operating Temperature Range	
Discharge	-20~60ºC
Charge	-10~60ºC
Storage	-20~60ºC
Max. Discharge Current 77ºF(25ºC)	19.5A(5s)
Short Circuit Current	65A
Charge Methods: Constant Voltage Charge 77ºF(25ºC)	
Cycle use	14.5-14.9V
Maximum charging current	0.39A
Temperature compensation	-30mV/ºC
Standby use	13.6-13.8V
Temperature compensation	-20mV/ºC

General Features

- Absorbent Glass Mat (AGM) technology for efficient gas recombination of up to 99% and freedom from electrolyte maintenance or water adding.
- Not restricted for air transport-complies with IATA/ICAO Special Provision A67.
- UL-recognized component.
- Can be mounted in any orientation.
- Computer designed lead, calcium tin alloy grid for high power density.
- Long service life, float or cyclic applications.
- Maintenance-free operation.
- Low self discharge.

Dimensions and Weight

Length(mm / inch)	96 / 3.82
Width(mm / inch)	43 / 1.69
Height(mm / inch)	52 / 2.05
Total Height(mm / inch)	58 / 2.28
Approx. Weight(Kg / lbs)	0.61 / 1.34
Standard Terminal	F1



Discharge Constant Current (Amperes at 77ºF25ºC)

End Point Volts/Cell	5min	10min	15min	30min	1h	3h	5h	10h	20h
1.60V	5.20	3.50	2.43	1.35	0.81	0.35	0.24	0.126	0.06
1.65V	4.93	3.33	2.32	1.30	0.78	0.34	0.23	0.123	0.06
1.70V	4.65	3.16	2.21	1.24	0.75	0.33	0.23	0.118	0.06
1.75V	4.36	2.98	2.10	1.18	0.72	0.31	0.22	0.115	0.06
1.80V	4.07	2.80	1.98	1.12	0.69	0.30	0.21	0.113	0.06

Discharge Constant Power (Watts at 77ºF25ºC)

End Point Volts/Cell	5min	10min	15min	30min	45min	1h	2h	3h	5h
1.60V	9.00	5.67	4.67	2.67	2.07	1.63	0.88	0.66	0.48
1.65V	8.44	5.34	4.41	2.53	1.97	1.56	0.85	0.65	0.47
1.70V	7.88	5.01	4.16	2.40	1.87	1.49	0.81	0.63	0.46
1.75V	7.33	4.68	3.90	2.26	1.77	1.42	0.76	0.61	0.45
1.80V	6.79	4.35	3.64	2.12	1.67	1.34	0.71	0.60	0.44