ELECTRAUDIO

February 17, 2014

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
8888 University Drive
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440 Functional Specification for SoundSocket, an Innovative Audio Transmission Solution

Dear Dr. Rawicz,

The enclosed document contains the functional specification for SoundSocket, a product that uses power lines to transmit audio signals. The objective is to create a device that will provide quality audio transmission utilizing existing power lines, effectively eliminating the need to set up alternative wiring schemes or rely on wireless communication.

The functional specification breaks down our product into three primary components for analysis: system, hardware, and software requirements. Each section will explore the functionality that must be obtained and will assign a priority to each function based on whether it is essential for the main functioning of the product, desirable but not mandatory, or refinements for the finished product. This document will be utilized by our team in order to perform research and development and efficiently implement the product.

Electraudio was founded by five innovative and dedicated senior engineering students: Josh Ancill, Andy Cheng, Daman Dhillon, Kim Izmaylov, and Laura Wiggins. If there are any questions or concerns regarding the proposal, please feel free to contact us via email at kvi@sfu.ca.

Sincerely,

Kim Izmaylov

Kim Izmaylov
Electraudio

Enclosure: *Functional Specification for SoundSocket Power Line Audio System*

Functional Specification for **SoundSocket** Power Line Audio System

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Executive Summary

Today, more and more companies are using wireless technologies to reinvent existing products so as to empower them with portability. Conversely, the number of devices on the allowed frequency spectrums (2.4/5GHz) of home devices has increased tremendously [1]. This has a large and noticeable impact on performance in areas saturated with wireless devices, which one can sometimes easily notice in public WiFi networks or at home when a family member is streaming a high definition video, just to pull a few examples. Electraudio's SoundSocket Power Line Sound System provides a smart and elegant solution by providing an audio streaming or transmitting device which offers the portability of a wireless counterpart, and the stability and performance of a wired device by using the existing power lines in a building to transmit audio.

SoundSocket will feature a receiver and a transmitter, which should allow the transmission of audio if the pair is plugged into separate power outlets within a building. The user will be able to connect their audio device using a 3.5mm TRS cable to our transmitter, and playback the audio through a set of speakers connected to the receiver. They will also feature power ON/OFF buttons and the ability to control the volume on the receiver module.

The development cycle can be broken down into three main phases, as we have categorized every task into three priority levels. The first phase will be pushing out the highest priority items:

- The transmitter module is able to read audio input through a 3.5mm TRS cable, and output an OFDM modulated signal and couple it onto the power line
- The receiver module is able to receive and decouple/read the modulated signal sent by the transmitter
- The receiver can output the audio to a pair speakers through a 3.5mm TRS cable

After we are able to see that the transmitter and receiver are working in terms of being able to send and receive audio signals, we can focus on refining the performance of the design such as taking care of errors in transmission. This possibly involves implementing some sort of Forward Error Correction (FEC) in the modulation scheme, or dealing with synchronization issues with the OFDM module. As well, we would like to include an amplification circuit for the receiver and allow the user to control the volume through a variable switch (ex. Slider). Safety mechanisms and circuitry will also be a point of focus during this stage.

Finally, during the last phase of development, we want to see that our product looks, feels, and functions like a consumer product. That means further testing for reliability and correct functionality under intended and unintended use cases as well. In addition, we aim to design a custom case to house the components that make up the transmitter and receiver modules. This phase will end with us having a working final prototype by the beginning of April.

Table of Contents

List of Figures

Glossary

The definitions given here are given according to the context they are used in and are intended for clarity. They may differ slightly or be incomplete compared to lengthy official definitions.

ASIC “Application Specific Integrated Circuit”. A circuit that is built on a chip to perform a specific operation (as opposed to a programmable FPGA).

CSA “Canadian Standards Association”.

FPGA “Field Programmable Gate Array”. A circuit that contains programmable logic elements for implementation of desired functions

IEEE “Institute of Electrical and Electronics Engineers”. Among other duties, this organization is responsible for setting electrical engineering standards.

Line-level A signal power level standard; typical output power for use with ear phones.

Mains General purpose 120V household power lines.

OFDM **“**Orthogonal Frequency Division Multiplexing”. A modern, wideband digital communication method which encodes data on to different frequency carriers.

Overvoltage Voltage levels that exceed the allowable voltage levels on a circuit line/node.

Packet Unit of data with a set size, formatted with headers containing packet information and body containing actual payload data.

TVS “Transient Voltage Suppressor”. A general circuit element that is designed to react immediately to divert momentary overvoltages.

Zener diode A diode with specific reverse-voltage characteristics. The purpose is to divert the over-voltage on the line to ground when the voltage exceeds a certain threshold.

1 Introduction

SoundSocket, an innovative product from Electraudio, is an audio system which utilizes the concept of power line communication to transmit an audio signal, avoiding the need to rely on wireless technology or external wiring and the cumbersome setup associated with it. With SoundSocket, the user simply plugs the transmitter unit into a wall outlet and may utilize another outlet as both the audio and power source for the receiver unit. SoundSocket is a robust and reliable product that delivers CD quality audio.

1.1 Scope

This document describes the functional requirements and specifications that must be met by the product. The requirements have been prioritized with the highest priority requirements being essential to the main functionality and other requirements outlining refinements and addition of extra features. The document contains the functionality overview, software and hardware requirements as well as sustainability and safety issues.

1.2 Intended Audience

This documentation in intended for use by all Electraudio members for product development. It can be used throughout the research and product development stages as a reference to provide the overall view of the product. The hardware, software and design engineers can refer to the system requirements, hardware and software details contained in this document to aid in product development. Engineers performing quality assurance can focus on the sustainability and safety section of the report to ensure that safety concerns have been addressed and that the product meets all the goals and standards regarding its development and usage.

1.3 Classification

In this document, the following convention is used to number and prioritize the functional specifications:

[R#-p],

where **#** is the requirement numbers, and **p** is the priority of the functional specification defined as follows:

A – High priority: essential for the main function of the product. A proof-of-concept prototype must meet these requirements.
B – Medium priority: desirable features which do not affect main functionality. Implementation in prototype will depend on time constraints.
C – Low priority: refinements and finishing features that will only be present in a final product.

For example, **[R3-B]** would indicate the third requirement, with a medium priority.

2 System Requirements

2.1 System Overview

From the user's perspective, the functionality of the device is illustrated in Figure 1 below:

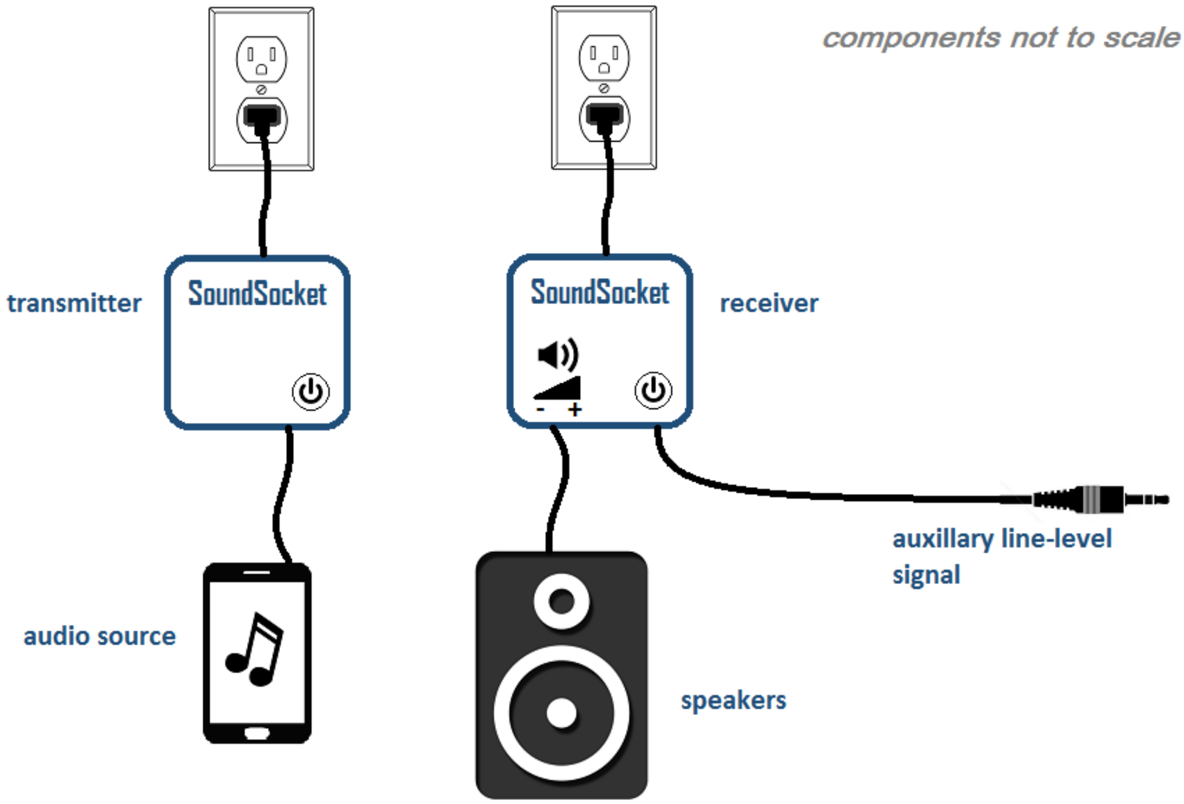

Figure 1: Model diagram

The transmitter will receive an audio signal from a line-level audio source via a regular 3.5mm audio cable. It will then broadcast the audio onto the power lines through a regular power cable. A receiver plugged into another socket on the same mains circuit would play the audio through the speaker, as well as provide the original signal at line level for other devices.

The SoundSocket audio transmission system can be modeled as shown in high-level functional block diagram (Figure 2):

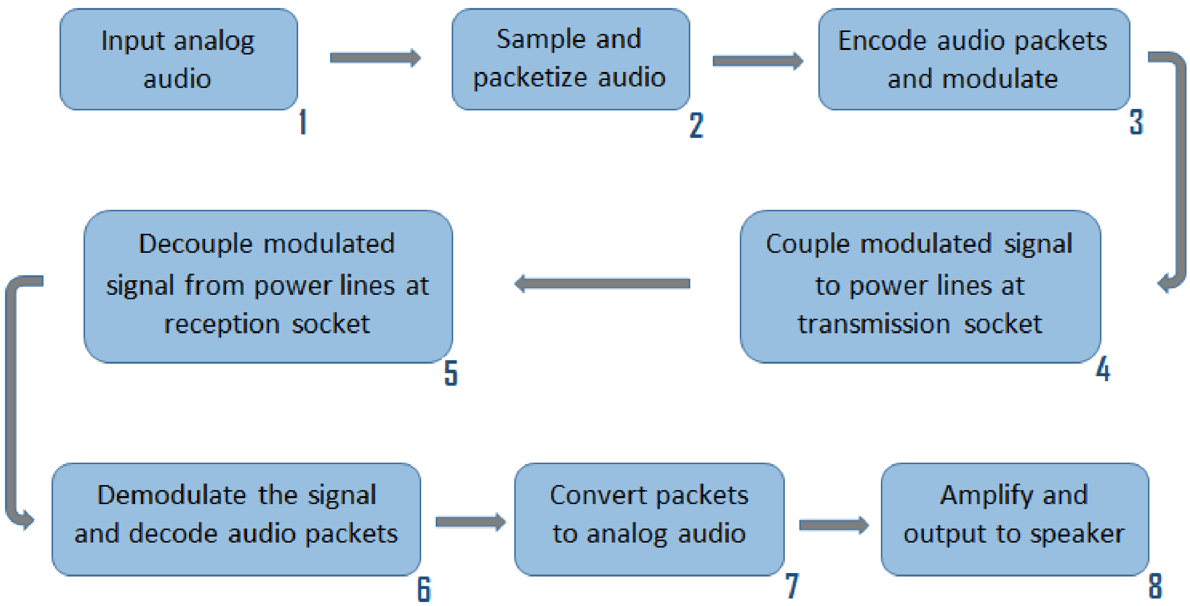

Figure 2: High-level functional block diagram

SoundSocket is a device that utilizes various digital and analog signal processing techniques to transmit audio through existing power lines (mains) inside a building. The purpose of the product is to allow the user to connect a standard consumer audio source to the device and enjoy CD quality audio from another device(s) connected into a different power outlet within the same mains circuit. As seen in Figure 2, there are 8 main stages of operation that SoundSocket performs at all times. The audio signal enters the system (1) and gets converted into a format that can be transmitted through the power lines (2, 3). Then the signal is coupled to the power lines (4), transmitted throughout the power circuit and decoupled at the receiver side (5). After that, the signal is converted back to analog format (6,7) and amplified for playback though the speakers (8).

2.2 General Requirements

[R1-A] Transmitter and receiver must accept a standard 3.5mm TRS audio connector (male)

[R2-B] A prototype receiver must have an integrated amplifier and speakers

[R3-B] Transmitter and receiver must have a dedicated on/off switch

[R4-B] Receiver must have a volume control (for the speakers only)

[R5-C] The final product must have a set of standard audio outputs with the amplifier-speaker unit detachable and optional

[R6-C] The internal hardware of the product must consist of custom PCB assemblies and ASIC chip(s)

2.3 Physical Requirements

[R7-A] The product prototype must be in a basic enclosure or consist of enclosures mounted on a common base

[R8-A] Key voltage nodes, switches and buttons must be relatively easy to access for testing and debugging.

[R9-A] The prototype should not have unfastened components or loose wires

[R10-C] Final product must be aesthetically pleasing

[R11-C] All inputs, outputs and controls must be clearly labeled.

[R12-C] The product must be fully enclosed with only the inputs/outputs and controls available for the user.

[R13-C] The product must be reasonably stable on flat surfaces, with rubber standoffs for grip.

2.4 Performance Requirements

[R14-A] The transmitter must accept a line-level input signal

[R15-A] The receiver must output a line-level signal

[R16-A] The system must accept and output a stereo signal (i.e. 2 mono channels)

[R17-A] The system must provide CD-quality audio transmission

[R18-B] System must be capable of operating on different channels (for multiple systems to operate at the same time within the same power circuit)

[R19-B] A prototype receiver must be feeding amplified audio into speakers

[R20-B] Multiple receivers must be able to receive and playback audio broadcasted from only one transmitter

[R21-C] Amplifiers should be available in a variety of power ratings (50,100,500,1000W+) with appropriate speakers for each power rating

2.5 Electrical Requirements

[R22-A] System must operate over a physical model of BC Hydro power line; the model must have a 60Hz signal with an amplitude of 10-15V to imitate the 120V on real BC Hydro power lines.

[R23-A] All electrical connections must be soldered or made using appropriate interconnects

[R24-B] System must operate over existing BC Hydro power lines within the same mains circuit.

[R25-B] Transmitter must only require 1 power cable for operation (through which both data and power will be transferred).

[R26-B] The product must be compatible with the standard North American power outlet

2.6 Safety Requirements

[R27-A] All components must withstand operation temperature and currents

[R28-A] All hand-built circuitry must be properly isolated with no conducting surfaces permanently exposed to human body parts or other conductors

[R29-A] All hazardous hardware will be clearly labelled

[R30-A] Prior to using the mains as transmission lines, all voltage nodes and exposed conductors must be tested thoroughly for absence of unwanted voltages leaking from the mains transmission lines model

[R31-B] Prior to using the mains as transmission lines, the prototype must have an easily identifiable, accessible, large “off” switch to disconnect the power

[R32-B] Components that are likely to get hot must not be accessible to the user

[R33-C] The final product must not heat up the enclosure past comfortable temperatures

[R34-C] The final product must not resemble a toy

2.7 Standards

[R35-C] The product must be compliant to the following standards:

-IEEE 1901 (High speed power line communication) [2]

-CAS: IEC 60950, IEC 60065 and IEC 62368 (AV & Multimedia Devices) [3]

Our product is aimed at a main stream, non-specialized consumer. The general, physical and performance requirements are aimed collectively at giving the product the following qualities:

-Easy to use: functionality will be clear to the user and common audio standards will be followed.

-Competitive: the product will be aesthetically pleasing. It will also meet performance standards of similar non-power line devices.

-Easy to prototype and make changes, while in development.

The electrical requirements are aimed at gradually achieving the desired operation characteristics while in development. The safety requirements ensure that the device will not cause any accidents during the development, as well as during its operation as a final product.

3 Hardware Requirements

3.1 Hardware Overview

SoundSocket is comprised of multiple independent modules which will be interconnected to form the complete device. The prototype will be built out of several major modules including the FPGA development board, the AD/DA board (Digital to analog conversion), analog front end for RF signal conditioning and an isolation module to couple the audio data to the power line. Figure 3 shows the hardware modules and the connections between them.

The FPGA will contain the microprocessor, OFDM modem and will interface with the audio codec IC on the DE2-70 FPGA board. The OFDM modem design is an open-source hardware design with modifications. [4] The OFDM modem will have its data inputs and outputs connected to the AD/DA board to convert the signals from the digital domain to the analog domain. In the prototype the AD/DA board will be connected to the separate analog front end modules which contains the necessary filters and frequency mixers to generate the final RF signal to be transmitted. Finally the conditioned RF signal will be coupled to the 'mains' power line through a coupling/isolation circuit.

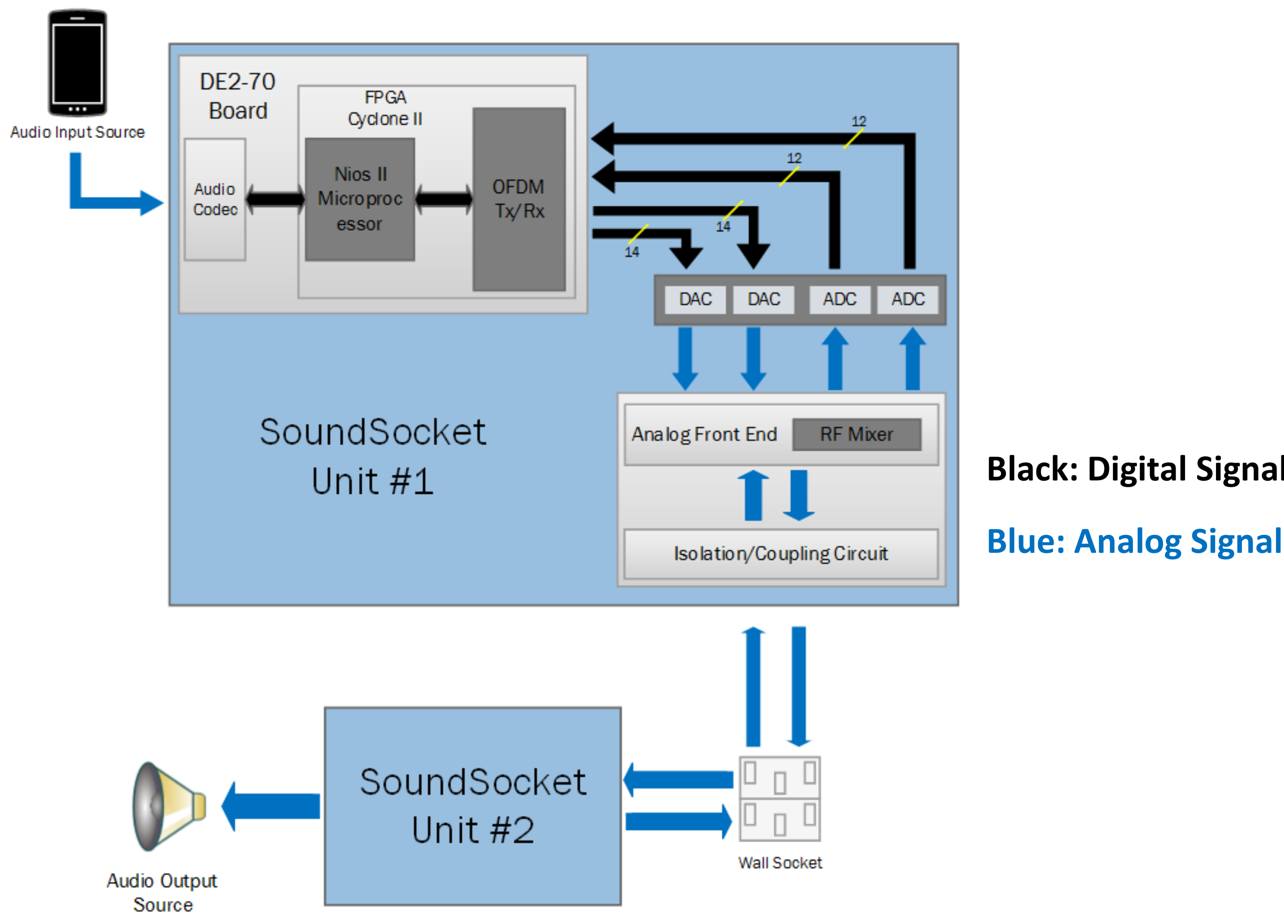

Figure 3: Hardware module connections

3.2 Processor Requirements

[R36-A] Processor must be implemented in FPGA for prototyping (Nios II)

[R37-A] Processor must run at sufficient speed to process all audio data without significant delay

[R38-A] Support serial communication with external peripherals

[R39-C] Processor will be implemented in custom IC for retail product

3.3 Audio Codec Requirements

[R40-A] Must sample audio at 48 kHz to sample the full human range of frequency sensitivity

[R41-A] Must accept at least one standard 3.5 mm audio jack input and at least one 3.5 mm audio jack output

[R42-A] Interface with processor over serial connection on same PCB

[R43-B] Adjustable sample rate configurable by the end user

[R44-C] Support multiple audio inputs allowing the user to switch inputs without having to unplug wires

3.4 Digital Modem Requirements

[R45-A] Support a data rate which can transmit lossless stereo CD quality audio with packet overhead over power lines

[R46-A] Use OFDM (Orthogonal Frequency Division Multiplexing) to obtain required data rates of at least 2 Mbps

[R47-A] Must recover transmitted data with minimal bit error rate

[R48-A] Synchronized transmitter with receiver for proper data recovery [5] [6]

[R49-B] Include error correction algorithms at hardware level to prevent incorrect data recovery

3.5 Analog Front End Requirements

[R50-A] Condition the signal for optimal transmit/receive characteristics

[R51-A] Must have high speed DAC (Digital to Analog converters) to convert digital modem signal to analog domain

[R52-A] Must have high speed ADC (Analog to Digital converters) to convert incoming analog signal to digital domain

[R53-A] Modulate signal to RF levels for transmittal over the power lines

[R54-B] Allow modulation onto multiple different carriers to allow multiple transmitting devices to operate simultaneously

[R55-B] Use as little bandwidth as possible while maintaining other requirements

3.6 Isolation Circuitry Requirements

[R56-A] The isolation circuitry must de/couple signals to and from transmission lines while blocking the mains power from entering the signal path

[R57-A] The circuitry isolating the low voltage signal processing from the 120V mains should be protected thoroughly and redundantly by fuses, zener diodes, spark gaps and other necessary circuit protection components

[R58-A] The analog isolation circuitry must be designed in such a way that in the case of a component failure, no mains voltage appears on the lines which were not designed for it. In cases where leakage due to failure cannot be prevented, fuses and TVS components must be installed to immediately divert the high voltage to earth and break the circuit

3.7 Wiring Requirements

[R59-A] Prototype will have coaxial cables connecting the analog signals to and from the analog front end to the digital modem

[R60-B] Power circuits will be on separate boards for both safety and modular design

[R61-B] Device will have only one power connection for all components

[R62-C] Retail product will have all non-power supplying parts on a single PCB

4 Software Requirements

4.1 Software Overview

The primary function of the software portion of this product includes processing the analog audio signal in order to transmit it through power lines. There is no interaction between the user and the software. The input signal will be processed by the Wolfson WM8731 24-bit sigma-delta audio codec on the DE2-70 development board, which will digitize the signal on the transmitter side, creating a bit stream for transmission. On the receiver side, the bit stream is processed and converted back to an analog audio signal.

The digital signal output by the audio codec will be processed using a Nios II embedded microprocessor. The data will be grouped into appropriately sized packets and passed to the OFDM transmitter. The packetizing of the data on the transmitter side, using the Nios II processor, is part of the software implementation of the product. Each packet will include the sampled data along with an added header which includes some additional information about the given packet. On the receiver side, the signal is processed using a Nios II microprocessor on another DE2-70 development board, which is another part of the software implementation of the product. Unpacking the data will generate a bit stream which will be passed to the audio codec to generate the analog output signal. The information in the headers will be used for communication between the various components of the system. If a packet is lost or corrupted, the information provided in the header can be used to retransmit and retrieve the lost packet to maintain the desired signal quality.

Opting to implement the data packetization in software allows a simple means to format the packets based on the specific requirements of the system. Another justification for choosing a software implementation for signal processing is the ease over the hardware approach to achieve the same results.

4.2 General Requirements

[R63-A] Must be able to read a 768 kbps bit stream created by the audio codec of the DE2-70 board

[R64-A] Must be able to create a unique header for each packet of data which will be utilized by the receiver to decode the data

[R65-A] Must have enough memory present in the embedded Nios II system to store sampled data

[R66-A] The frequency utilized to create and store the packets in memory must be greater than or equal to the packet transmission frequency

[R67-B] Must be able to read two 768 kbps bit streams for stereo created by the audio codec of the DE2-70 board

[R68-B] The packet headers must contain sufficient information to enable easy decoding and tracing of the data on the receiver side for better data transmission

[R69-B] Must be able to retransmit a lost, corrupted, or missing packet from the receiver side

[R70-C] Will be able to handle multiple audio data sampling rates

[R71-C] Will be able to handle multiple bit depths for audio data

5 Sustainability and Safety

At Electraudio, we want to develop an end product for consumers which is high quality, yet sustainable and safe to use. To achieve this, we started by pushing our high standards from the very beginning of the development cycle, during the inception of our prototype design.

Our product, SoundSocket, draws power from the power-lines and uses them to transmit data at the same time. As with any device that connects to the 120V sockets, we are aware of the dangers of a device with a poorly thought-out power safety mechanism, and will closely follow the regulations set by the CSA. We believe that not only should our product work the way we intended, but also provide a safety for scenarios where the consumer may try to use it for purposes outside our specification. In addition, we are aware that SoundSocket is classified as a “Broadband over Power line System” by the FCC, and will adhere to the rules as an unintentional radiator (due to RF energy leak from unshielded power lines) as per Part 15.611 and 15.615 of the rules.

Another aspect of SoundSocket relevant to safety is the modularity of our prototype. During the initial phase of development, there will be problems with components malfunctioning, or becoming obsolete due to a change in the overall design. However, being a modular system, we can easily keep track of and isolate problems where they occur to guarantee safety of the individual operation of each component before integration as a whole unit. Additionally, by making sure the inputs and outputs of each block is completely safe, we reduce the risk of damaging and possibly creating unnecessary waste of components.

When selecting components, we made sure to use ones which were sustainable and reusable, which is why we went with DE2-70 FPGA boards which were also RoHS compliant, meaning they do not contain materials immediately hazardous to the environment upon disposal. Another reason we chose to use FPGAs in our prototype design was due to their reprogrammable feature, thus making our development a lot more flexible down the line. In addition, these boards can also be reused for other purposes or donated to the school which would make it sustainable in an educational sense as well. The ASLK PRO boards along with any other PCB or chip/modules we is and also will be RoHS compliant.

6 Conclusion

In this functional specification report, Electraudio has presented an overview of the main objectives we want to achieve during the first critical phase of development: that is, getting the main “must-have” functionality down. We further provided details on the specific tasks for each of the three phases by separating them into priority levels A, B, and C, where A is the highest priority. By doing so, we can make sure we stay focused on what’s most important at any point in the development cycle. To reiterate, we want to have a fully functioning transmitter and receiver that allows us to transmit audio and play it through a set of speakers through the receiver. Only after this phase will we look to adding and implementing complementary features such as volume control and additional safety designs. We at Electraudio believe that the detail provided in this report demonstrates that we have a clear view of our main goal and understand the priorities to deliver the final working prototype by the beginning of April.

7 References

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[3] C. Group, "Audio, Video & Multimedia Devices," Canadian Standards Association, [Online]. Available: http://www.csagroup.org/ca/en/industries/it-av-technology/audio-video-multimedia-devices. [Accessed February 2014].

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[5] Darmstadt University of Technology; Institute of Microelectronic Systems, "OFDM Basics for Wireless Communications".

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