Post Mortem: **SoundSocket** Power Line Audio System

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1 Introduction

In recent years, wireless communications has expanded immensely and made its way into our lifestyles through consumer products such as wireless routers, TV and audio streaming devices, smartphones and now tablets. What hasn't kept up, however, is the physical bandwidth that allows these consumer devices to transmit data through radio waves: it is a fixed amount of bandwidth and many corporate, private, government and even military sectors also own portions of the frequency spectrum. What we are left with is a limited and quickly diminishing frequency slot to contain all the wireless transactions which occur nonstop in this wireless-centric era. As a result, signal interference has become a norm.

Electraudio recognizes a market where consumers want a reliable home audio system, unaffected by the interference posed by the sea of existing wireless devices. The way we solved this problem is by going to to a wired connection. The catch is, the consumer doesn't need to wire anything; the homes we live in is essentially a complex network of copper or aluminum wiring capable of transmitting data, such as audio, from one point to another as long as the wire is accessible. This provides the backbone to which we build our product, SoundSocket, on to give the user a solid audio experience that combines the benefits of both wired and wireless audio streaming solutions.

2 Product Overview

SoundSocket utilizes the existing network of wires in a building to transmit stereo quality audio through the use of a transmitter and receiver unit that simply plugs into the electrical outlets in the walls. Figure 1 depicts the setup of our power line audio system.

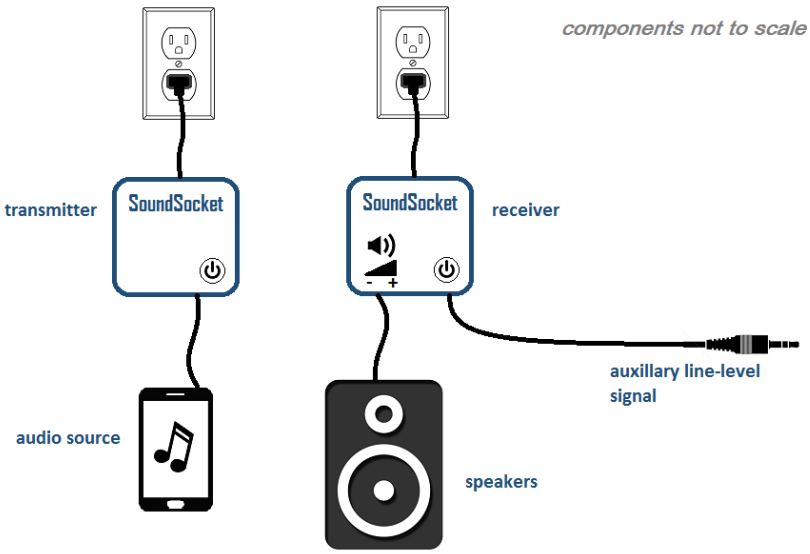

Figure 1: System Block Diagram

The user plugs in his or her audio source, usually an MP3 player or smartphone by using a standard 3.5mm audio jack into the SoundSocket transmitter. The transmitter, while plugged into the wall will transmit the signal across the entire power network. Meanwhile, the user can plug the SoundSocket receiver anywhere else in the house, which will play the audio source through a set of speakers.

3 System Overview

The diagram below describes the general (functional) process of what happens to the audio once it enters the transmitter. Essentially, analog audio is sampled and packetized, then encoded and modulated to an OFDM signal. RF modulation stage puts the signal onto a 7MHz carrier, which is then coupled onto the power lines where the receiver picks up the signal from another point in the power line network. There, the process is reversed to reproduce the original audio in stereo quality. Note that not all of this is implemented as we ran out of time before we could integrate the system.

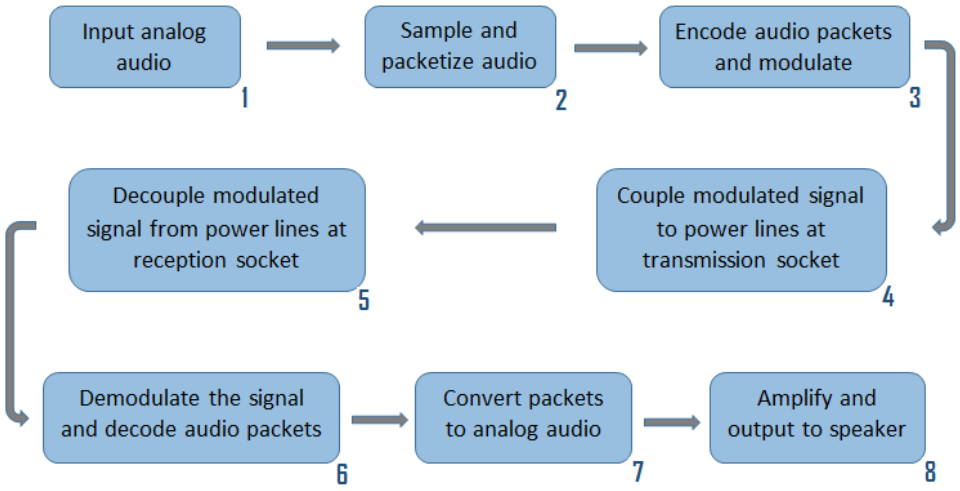

Figure 2: Functional Block Diagram

From a design point of view, the system is divided into 4 modules: Audio Processing, OFDM, RF and Isolation/Coupling modules, as illustrated in Figure 3:

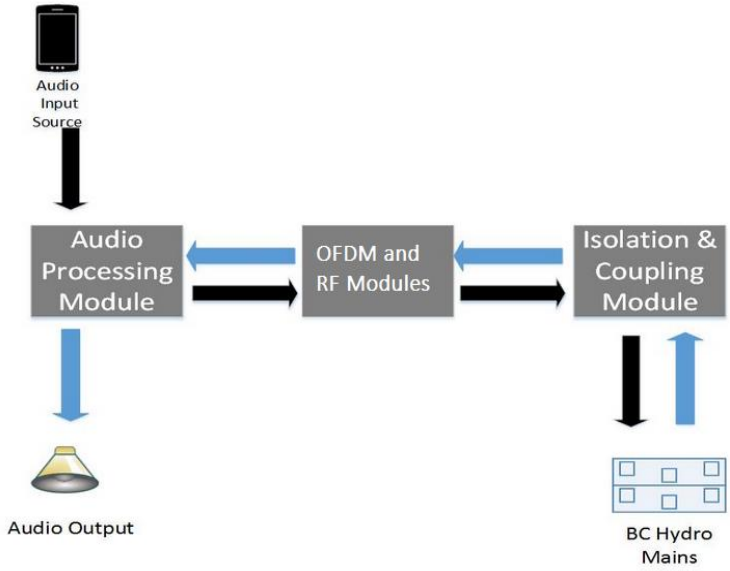

Figure 3: The 4 modules of SoundSocket

-The Audio Processing Module is responsible for sampling the analog audio, converting into digital packets and transmitting the audio data to the OFDM Module. This module is fully functional.
-The OFDM Module receives the digital data from the Audio Processing Module and performs Orthogonal Frequency Division Multiplexing; i.e. creates an encoded analog baseband signal (with multiple carriers) that represents the audio data. IT then passes the signal onto the RF stage. This module is also fully functional.
-The purpose of the RF Module is to take the baseband OFDM audio signal and modulate it onto a frequency of 7MHz for transmission through the power lines. This module is not fully functional as it adds a significant amount of noise to the audio signal.
-The Isolation and Coupling Module is designed to couple the incoming RF signal onto the power lines, while blocking the 60Hz 120V power signal from entering the device. This module is semi-functional, as the basic function of transmitting a high-frequency signal through the power-line model has been achieved. The power-line model consists of typical electrical wiring with 20V 60Hz signal (instead of the real 120V 60Hz power signal). Theory and simulations support the fact that the circuit should in fact work with real power lines, but that has not been tested.

The prototype utilizes two DE2-70 FPGA boards to implement the Audio Processing, OFDM and RF modules in our transmitter and receiver. We used an additional pair of DAC and ADC boards between the isolation and coupling circuitry (which is implemented with discreet components).

4 Initial and Final Cost

The end cost of our prototype proved much cheaper than what we originally planned for. This is in part due to a revision in our design which got rid of a critical component which was very expensive. In addition, we managed borrow some of the additional components used in the newly revised design which cut costs even further. The tables below shows the details of how our costs have changed from the beginning of the project.

Starting with the initial projection of prototype cost:

Table 1: Initial (anticipated) cost

Parts List	#	Cost
DE2-70 FPGA Board	2	$0 (ESSEF Parts Library)
AFE7225 Evaluation Module	2	$998
Miscellaneous	-	$100
Subtotal		$1098
Tax		$131.76
Total		$1229.76

This is cost of the actual prototype:

Table 2: Actual cost

Parts List	#	Cost
DE2-70 FPGA Board	2	$0 (ESSEF Parts Library)
ASLK Pro Boards*	2	$0 (Part of ENSC 425 Lab)
ADC/DAC Boards	2	$350.00
Miscellaneous Parts**	-	~$250.00
Subtotal		$600.00
Tax and Shipping		$100.00
Total		$700.00

*ASLK Pro Boards were not used in the final design
**Miscellaneous Parts include isolation and coupling module components, power line module components and last minute purchases

5 Problems and Challenges

One of the design challenges we faced in the very beginning was the fact that one of the components we needed was priced at a hefty $500. Not only that, we needed one in both the transmitter and receiver, quickly bringing our initial prototype cost to $1000. There were two problems associated with this situation: 1) We knew we wouldn't be able to get funding to cover just both of these parts, and they weren't the only components we needed and 2) Investing this much on just two components could prove to be problem if and when we decided to change our design and it is no longer necessary. In addition, the company wasn't interested in selling it to students and required signing of documents and a lengthy purchasing process. Luckily, we spent a little more time doing R&D and found an alternative design which didn't need these expensive components.

The biggest challenge and source of problems was the OFDM module. The OFDM is a modern and extremely powerful modulation technique, but it comes at a cost of high complexity even in the theory of operation. Getting it to work on the FPGA turned into a constant struggle and the progress was very slow and painful. In addition, the ADC/DAC boards we have purchased turned out to have high-pass characteristics (not indicated in the documentation) which caused the re-design on the whole RF module. This contributed to the lack of time to get it fully operational.

The isolation and coupling design depended on the nature of the signal provided by the OFDM and RF modules. We relied on the completion of these to finalize the initial circuitry (which was functional with some constraints). When it became clear that the RF module will not be completed in time, it was already too late to fully test and finalize an independent version of the isolation and coupling circuitry

that would provide 100% of functionality. Thus, the test plan became a guideline for implementing something that would satisfy some of the tests.

As the R&D was progressing, we came to a realization that with all the difficulties that came up, we should be aiming to achieve only the very basic functionality. This meant giving up on features such as error correction and multiple channels, although some designs were still implemented with those features in mind.

6 Timeline and deviations

The most prominent challenges caused deviations from the initially planned timeline given blow:

Task Name	Duration	Start	Finish
Primary Research	35 days	Fri 14-01-03	Thu 14-02-20
Proposal	6 days	Thu 14-01-16	Thu 14-01-23
Sourcing/Ordering Parts	26 days	Mon 14-01-20	Sun 14-02-23
Functional Specification	18 days	Thu 14-01-23	Mon 14-02-17
Design Specification	27 days	Sat 14-02-01	Mon 14-03-10
Assmebling and Testing Modules	21 days	Mon 14-02-10	Mon 14-03-10
Integration and Prototype Testing	21 days	Mon 14-03-03	Mon 14-03-31
Debugging	13 days	Thu 14-03-13	Mon 14-03-31

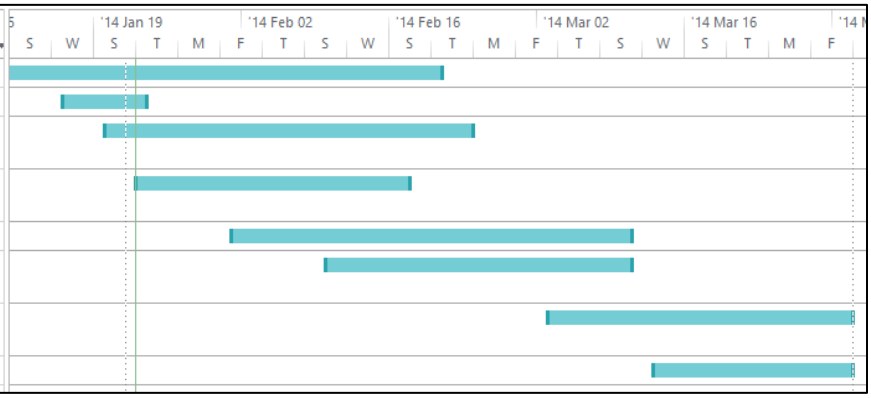

Figure 4: Original timeline

The R&D lasted well into March as we faced roadblocks outlined above and had to find ways to overcome these. For the same reason of trying to overcome unforeseen challenges, some parts were purchased as late as April. Thus, assembly of modules was ongoing up to the time of the demo on April 14th with integration starting early in April; it was not fully achieved.

7 Group Dynamics & Agenda

Our group consists of members with extremely similar course schedule. Thus, meetings occurred naturally and quite a lot of the work (both group and individual) was done physically at the same time and place. Keeping common minutes for such long and frequent meeting times proved to be ineffective as no-one used the first couple of minutes sets we wrote down. Tasks and responsibilities were assigned and recorded individually.

Online tools that eliminated the need for minutes are Google Drive and Google Hangout. The latter is a chat service that each one of us had installed on their laptops and smartphones. It enabled us to communicate to any member at any time or hold group chats and conferences if that was needed. Google Drive has a capability of keeping shared documents live, instantaneously updating any changes

made by any member. This gave us the ability to see the content produced by each individual at any time, when documents were being composed.

The luxury of seamless online communication services naturally eliminated the reason to hold formal meetings and keep written records.

Electraudio was split into the sub-teams responsible for each module with almost no cross-module work (meaning that everyone concentrated on their module only):

7.1 Workload Distribution

Audio Processing Module
Daman - Research and Development
Laura - Research and Development

OFDM Module
Josh - Research and Development
Andy - Research

RF Module
Josh – Research and Development
Kim – minor R&D of design that was abandoned due to ADC/DAC constraints

Isolation/Coupling Module
Kim - Research and Development

Financing/Budget tracking: Andy
Scheduling matters: Laura
Purchasing: Josh and Kim
Documentation: everyone, with Kim responsible for overlooking and finalizing the documents

8 Individual Learning

8.1 Kim Izmaylov:

Since I was responsible for isolation and coupling module, most of the technical knowledge that I've gained came from developing this module. Research of the power circuitry and wiring of the power line model network allowed me to grasp the basics of in-home mains power lines.
The task of coupling data to the existing power network is somewhat unusual. Because of this, I had to expand my thinking outside of typical "signal transmission" engineering mindset and consider things that aren't usually an issue in signal transmission. Some examples include overcoming the existing high(er) voltage on transmission lines and driving the signal in conditions with large unwanted loads present. It was definitely a good learning experience having to consider these unusual constraints and find a way to work around them. Also, simulating these "unusual" conditions in LTSpice has enhanced my skills and understanding of Spice modelling methods.

Some other technical skills that I have acquired or solidified are as follows:
-Galvanic isolation and better understanding of the notion of the circuit's "ground"
-Transformers: function, operation, hands-on experience
-Amplification of high frequency signals
-Unity gain operation of op-amps
-Filtering
-Prototyping using a protoboard

Besides the technical skills, I learned some lessons in project development and teamwork. The one that I'm likely to remember is to *always have a clear goal set.* This comes from the fact that after achieving some initial functionality of my isolation and coupling circuit, I left it hanging due to the fact that I needed the RF module to become functional to some extent to continue my development. This turned out to be a mistake because I ended up wasting time "cruising" until it became obvious that the RF module isn't likely to be ready in time. At that point it was too late to build my module as a fully operational unit, possibly unsuitable for a future RF module, but still a better proof of concept than what I have presented. In other words, I should have started the development regardless of the RF module progress, re-designing it in case RF module became operational.

I have also solidified my experience in keeping personal feelings separated from work. I was able to isolate strictly personal matters and operate based on professional and result-driven principles as much as possible. Oddly enough, this eased off some of the personal concerns since work was getting done where confrontations seemed very likely.

Finally, I have come to realization that in a project like this, it's better to stay engaged continuously and work in smaller steps, rather than have large, discreet design sessions for the following reasons:
-Potentially, bugs are found earlier
-Easier to handle as problems come in small chunks
-Easier to stay excited and emotionally attached to the project in a positive way, which is very important
-Somehow you feel more confident when there is a relaxed but constant flow of work
As a result, I was doing and feeling much better when small things were accomplished day by day in the beginning of the project, as opposed to when I've achieved a bigger task, but after was has been the my most stressful day/night at SFU.

8.2 Laura Wiggins

I was well suited to undertake the role of firmware and software engineer. I am very comfortable working in VHDL and I have implemented software in C on soft processor cores before. I also took on the scheduling role. My previous experiences provided the foundation upon which I was able to continue to build my knowledge as the project progressed.

I worked alongside Daman to implement the audio processing module. Working as a team facilitates a discussion of the design choices that are being made and can essentially prevent much time wasted exploring futile solutions or getting hung up on minor errors. Development of this module was primarily done as a team, and the most effective progress was made working together. Additional research was primarily done individually as it was deemed necessary. There were also various tasks that we each did individually as the need arose. Essentially, we primarily did development as a team with various additional tasks assigned individually as needed. I found this method of development to be very effective, and it enabled us to work very well together to implement the audio processing module.

The schedules of most team members were fairly similar which enabled us to regularly spend time working in the same location together. This proved to be an invaluable tool for development. All of the time spent together facilitated design discussion and ensured that everyone was aware of the current state of the project. Physically working together with other people can dramatically increase the efficiency of implementation. For integration and synchronization of the modules, I found this to be absolutely crucial. Constant and effective communication between team members is an indispensable tool for project development.

Although my primary responsibility was the development of the audio processing module, I took every opportunity I was presented with to offer my assistance wherever it was needed. Whether this involved assistance debugging, or design discussion, or a trip to Home Depot, I was always glad to help whenever I could. This flexibility afforded me the opportunity to learn a great deal about the various technical aspects of the project.

My knowledge of the intricacies of communication systems is less developed than I am content with as I have not yet taken any of the courses dedicated to the subject. However, working through the design of this project and assisting with the debugging of the OFDM module has provided me with an opportunity to learn quite a bit about it this material. It seems to be a very interesting and useful topic and it definitely warrants some further investigation in the future.

If I was given the opportunity to go back and do things differently, I would have started working on this project much earlier and perhaps taken a lighter course load for the semester. We started forming our group near the end of the previous semester, recruited through the break, and added an additional member a few weeks in. Even so, given the complexity of the project, we should have started project planning and development significantly earlier. The various issues that we encountered arose only as we delved deeper into development. We could not have foreseen all of the challenges that we encountered and, had we allotted more time, we may have been able to more effectively combat the various challenges that we faced.

Although it proved to be extremely challenging, it has been a very enjoyable course. Throughout the semester I have had many exceptional experiences and I have gained a considerable amount of knowledge. I am proud of what we were able to accomplish.

8.3 Josh Ancill

In the past four months I have learned a great number of things and have acquired numerous skills ranging from technical to interpersonal skills. This project has allowed me to hone my knowledge of VHDL by learning to read a previously created design and expanding the functionality to serve our purposes. I have learned over the course of the semester how to use a simulator to assist in the initial design stage of digital designs using ModelSim. Learning the various glitches/bugs/annoyances from using the Altera Quartus II software on both Windows 7 and Windows 8/8.1 was at times quite trying as dealing with such issues often resulted in a low amount of work being successfully completed on days where those kinds of problems were encountered. As my strengths involve solving miscellaneous computer issues (something I have been doing my whole life) I often found myself in a troubleshooting role for the group when technical problems were encountered. The actual VHDL modifications made in our design often required the careful analysis of state machines and a background in OFDM theory. I found myself reading countless articles, journals and webpages looking for the best, simplest

explanation of the theory I was trying to implement. In additional to the digital design skills I also learned about picking, ordering and assembling parts for our project and although it was simple, really enjoyed building our "model power network" for doing the isolation/coupling tests on. Learning some of the finer details when it comes power circuits was something I found significant as well and some of the tips and tricks learned in this project may save my life at some point (keeping ones left hand in ones pocket for safety, for example).

I also learned a great deal of interpersonal skills when it comes to team management, time management and the overall handling of the work load I had to undertake over the past four months. I had one of my busiest semesters ever at SFU and by the end I could really feel the toll it had taken on my whole life. I feel like this project has better prepared me for dealing with such situations in the future. I learned the importance of getting as much work done earlier in the semester as possible before the work load increases for all classes and it becomes harder to accomplish any single task. I also learned the importance of teamwork as our project was too massive for any single person to have done all modules. The success we did have was only possible due to multiple people working together on different tasks and working together to ensure those individual tasks worked in unison with each other. I would have liked to work more closely with my other group members on my responsibilities as at times I felt like I was the only one who really know what I was trying to accomplish which caused difficulties when I would encounter a problem, as I was unable to ask my fellow group members for help without occupying a large amount of their precious time. In all I wish we had more time to have worked on the project and that I had worked more closely with the rest of the group. I feel like although we picked a lofty goal when starting down the path we choose, it was an achievable goal, however, as things did not go as planned over the semester it became harder and harder to meet those original goals.

In all I learned a great deal from my team and although we did not fully meet our original goals I feel good about what we did achieve over the semester and I wish the rest of my team the best of luck in the years to come.

8.4 Andy Cheng

During the past three and a half months, I learned a lot about what it was like to research, develop, and integrate a product. It was not simply a project where we had to follow example designs and worked within just one category of engineering, but instead brought several technologies of various fields together to build a product with a very specific function. This introduced a lot of challenges in a technical sense, but also brought about a challenging side to group dynamics. By dividing our members between the core modules, I saw that it sometimes distorted our scheduling since the amount of work and difficulty of each were not equal.

For myself, I joined the group roughly two weeks after the course had started, however project work and research had already started. I found that although the initial integration into the group was relatively smooth, it became hard to catch up as I would always be trying to catch up in learning the theory while the other member was ahead with implementation. However, this is also due to the lack of communication from my end. I definitely should have been more proactive in seeking out the other members of the group who were working on tasks related to what I was learning about, instead of staying quiet and trying to figure it out myself. Doing so resulted in me always being a few steps behind.

In terms of technical knowledge learned, I gained a lot reading about OFDM theory and analyzing an open IP core that performed this modulation scheme. In addition, I found that having to write such a

detailed functional and design specification really forced you to question whether you truly understand enough of the end product as well. In the beginning I did not really question why we used OFDM to modulate the signal as there are other modulation techniques that exist, but as I began to write the documentation I was able to learn why it was necessary and what advantages it held against other techniques as to convince the reader that we were making a reasonable design choice.

9 Conclusion

Throughout the three and a half months from the inception of our product idea, to the research and development, to the physical implementation of the modules and finally, the partial integration into a working prototype has been quite the experience. We learned first hand the process of bringing an idea to life as a startup company. Throughout the semester, we questioned our design many times which lead to ongoing changes in it. However, in the end we were able to capture most of the functionality of what we wanted our product to be: a simple plug and play audio streaming system that kept the reliability of a wired connection, but also the portability of wireless. With the main reason for lack of integration being the time constraints, we have plans to finalize and improve the modules that are not fully functional at the moment.