April 20, 2009

Mr. Patrick Leung
School of Engineering Science
Simon Fraser University
8888 University Drive
Burnaby, BC. V5A 1S6

Re: ENSC 440/305 Post Mortem for Electric Guitar Multi-Effects Device

Dear Mr. Leung,

The attached document, *Post Mortem for Electric Guitar Multi-Effects Device*, is the final installment in a series of documents related to InTune Innovation's ENSC 440/305 project. The product is a standalone device which creates live audio effects for the electric guitar. Users have the ability to adjust and save the sound of each effect as well as change (and save) the order in which the effects are processed, all in real time.

This document includes details regarding the final status of the project and a discussion of future possibilities with the product. Also included is a comparison of projected-versus-actual budget and timeline.

In Tune Innovations consists of four engineers, each in fourth-year: Kyle Balston, Tom Schultz, Scott Witzel and Michael Vogel. If there are any questions, feel free to contact us at **ensc440-intune@sfu.ca**.

Sincerely,

In Tune Innovations: Kyle Balston, Tom Schultz, Scott Witzel, Michael Vogel

Post Mortem

Electric Guitar Multi-Effects Device

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Submitted to: Patrick Leung: ENSC 440
Steve Whitmore: ENSC 305
School of Engineering Science
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1 Introduction

InTune Innovations has successfully developed its proposed electric guitar Multi-FX and FX-sequencing system. The device allows musicians to create unique guitar effects based on three main effect categories. Not only do users have the ability to create, save and adjust all effect settings, but users can also control the order in which the effects are processed.

The daunting mess of cables required to interconnect standalone effect pedals is largely eliminated with In Tune's Multi-FX solution. In fact, only two audio cables are necessary: the input cable and the output cable.

Users can create a live queue, or "playlist", of effect presets, enabling them to cycle through presets in a live environment. Users can therefore freely experiment with different effect combinations without having to change a single cable or turn a single knob.

1.1 Intended Audience

This document is intended as a final description of the results achieved over the past semester's work on this project. In Tune Innovations can return to this document in the future as a guide to new developments; however, the primary audience is the course instructors. Hopefully this document will fully complement any questions remaining after the project presentation.

2 Current State of Device

The device is fully functional according to functional and design specification. At the most basic level, the functionality of the device can be summarized as follows:

- **Three main effect categories**
  - Distortion, Tremolo, Auto-Wah
  - User can adjust, save, and restore effect settings/parameters (8 parameters in total)
  - Microcontroller sends control signals to digital potentiometers, which results in effect parameter changes
  - Each effect is built into single module (circuitboard)
- **User Interface**
  - Optical rotary encoder, buttons, LED displays, LCD screen and four footswitches comprise the user interface
  - Users can recall any saved parameters and sequences, and switch between presets in real-time using a footswitch
  - 7 segment LED display shows current effect sequence
- **Effect Routing**
  - Any permutation of effect ordering is possible (16 in total)
  - Analogue multiplexers route signal depending on user configuration
  - Bypass foot-switches allow the user to creatively experiment with the sequence in real-time

In Tune's device is powered by a single AC wall adapter. The device produces high quality audio, free of the hum and hiss that plague much existing guitar-FX equipment. The switching system is designed to be "true bypass," meaning that when an effect is removed from the current sequence, its circuitry is essentially "removed" from the sequence, so as not to cause unnecessary analogue signal loading and tone degradation.

Figures 2.1 through 2.5 present photographs of respective device modules. Description of each module is provided. Figure 2.1 presents a photograph of the completed device.

Figure 2.1: Complete Device, Assembled with Enclosure

The main user interface is placed on the horizontal plane of the device, summarized more clearly in figure 2.1.1.

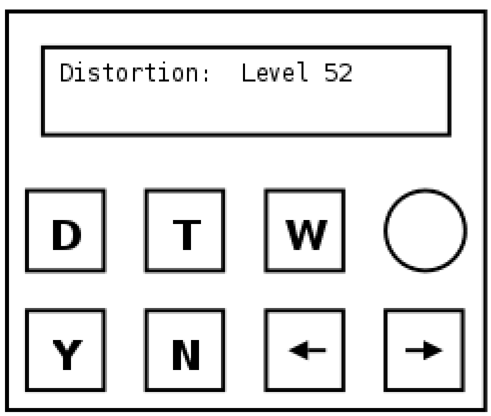

Figure 2.1.1: User Interface for the Multi-FX Device

While the device does come with initial “factory” presets users are encouraged to create their own effect sequences. In order to create a new preset the user navigates a shallow menu system using the button pad. First, the user selects the first effect to use in the chain. Then, using the rotary encoder, the user has the ability to adjust up to three effect parameters (for example *gain* and *depth*). After making all adjustments, the user then chooses the next effect and again has the ability to customize the sound.

When finished, the new preset is saved and the user will be able to recall that preset when ever he/she wants.

Figure 2.2 presents a partial photograph of the power supply and signal switching module.

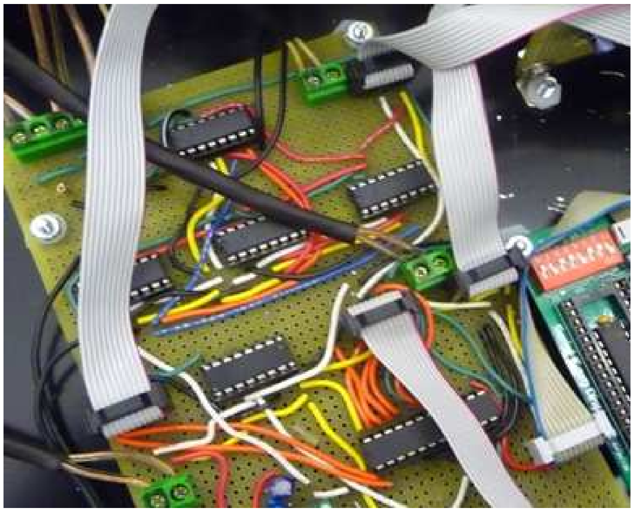

Figure 2.2: Power Supply and Signal Switching

The Multi-FX device uses three voltage levels, 10V, -10V, and 5V DC to power all of its components. In order for all electrical components to operate as expected, the internal power supply of the device will use voltage regulators to ensure that each component is powered by a consistent voltage.

The operational amplifiers and the multiplexers use both 10V and -10V. This is to ensure that all analogue signals are not being clipped or distorted in any detrimental way. While the same result could be achieved using a virtual ground, we decided that for the purpose of the proof of concept model it would be simpler to use the two separate rails. This will be considered for production models.

Finally, all digital components require 5V to operate. Digital components include a microcontroller, digital potentiometers, shift registers, inverters, and decoders.

Figure 2.3 shows the circuit boards for each of the three effects.

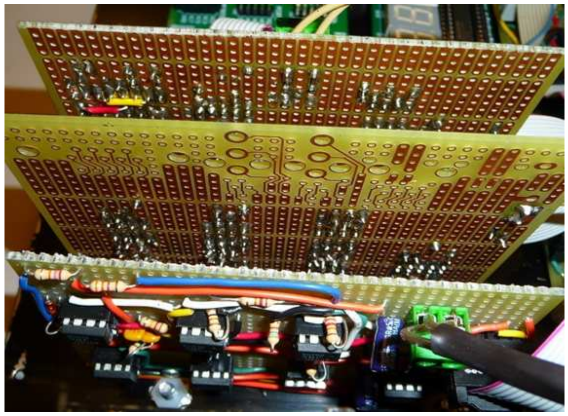

Figure 2.3: Three Effect Circuit Boards

As mentioned, the user has access to three electronic effects: distortion, tremolo and auto-wah. Distortion works partially via signal clipping, where inharmonic sounds are introduced by means of reducing signal peaks. The distortion circuit also includes a treble boosting stage which amplifies signals above 450 hertz. The user has control over the clarity, degree of treble boosting and output volume of the effect.

Tremolo is an amplitude modulation based effect. The user can control the volume, period and depth of the oscillating output signal. A wide variety of sound is possible; anything from slow volume swells to choppy helicopter blade-like sounds are easily attainable with this effect.

Auto-wah can be described as an automatically moveable low-pass filter. The result is a sound which mimics human speech ("wah"). The input signal is split – one segment is the guitar signal passed through the low pass filter, and the other is a control signal derived from the volume of the input. As the loudness of the input increases, the filter becomes more open, allowing higher frequencies to pass un-attenuated. This is achieved by using an envelope follower to ascertain the peak voltages of the input, and then use this information to control a selection of CMOS switches to control the low pass filter frequency cutoff.

In summary, figure 2.4 shows a high level block diagram of the system with respect to inputs and outputs to the microcontroller.

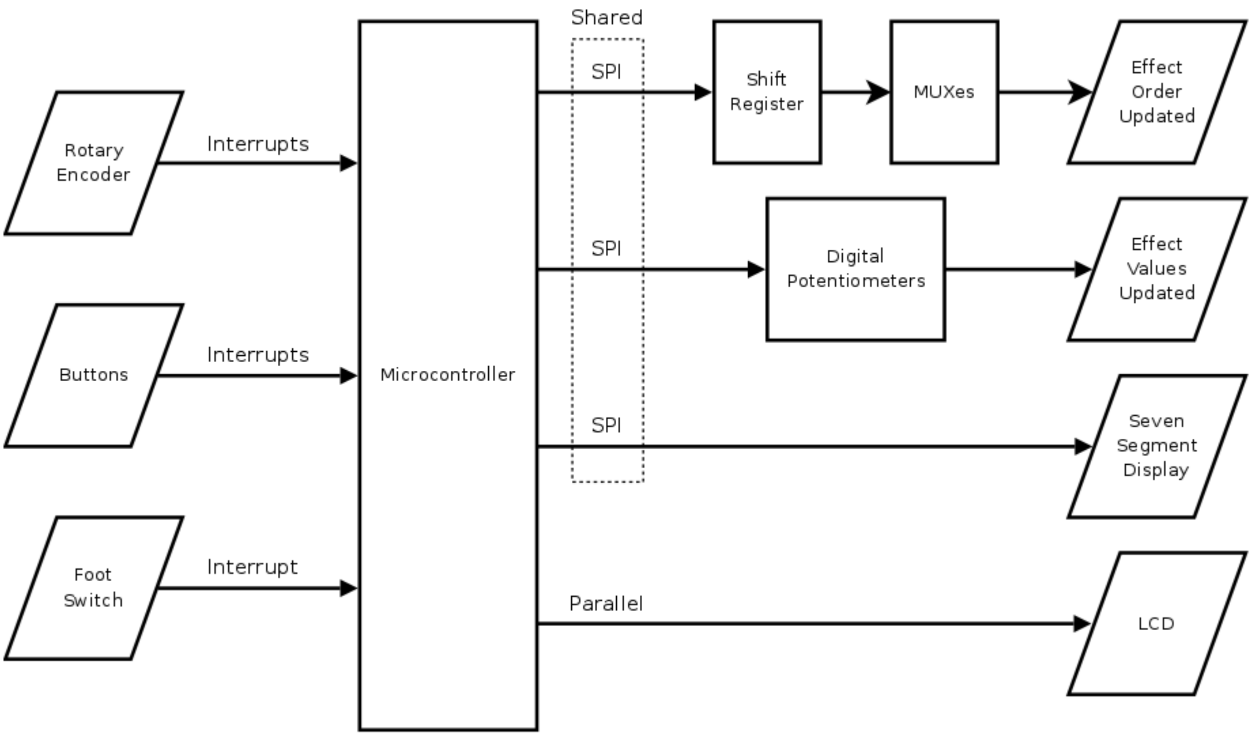

Figure 2.4: High Level Block Diagram

Objects represented as parallelograms are inputs from the user and outputs to the user, while objects in rectangles are devices necessary to perform the output.

The user interacts with the device through a stomp switch, push buttons and a single rotary encoder. Push buttons are used to navigate the menus while the encoder is used to adjust the settings of effects. The stomp switch allows the user to switch to the next preprogrammed preset.

The system outputs are shown to the user mainly through the LCD. The seven segment display is used to show the current effect order. This is done so that the user may easily see the effect order while playing.

3 Problems Encountered

This project was an excellent learning experience in product development. A few interesting problems we overcame include:

- Switching from a perforated board to a “vector” board for circuit prototyping
    - Vector board is much quicker to prototype and debug. After realizing we should prototype all boards using this material, we remade our first effect using this method
- Analogue circuit debugging
    - Analogue circuit debugging can get frustrating, especially when problems are not always repeatable. We developed an iterative approach, testing module by module, in order to pinpoint problematic circuitry.
- Power supply current limiting
    - At the onset, it was difficult to predict current requirements (especially of the entire device). Late in the semester, we altered the power supply circuitry to encompass a higher current limit (able to sink up to 1.5 A), which more than met our final requirement of 500 mA.
- LCD screen blankly lit up
    - When first testing our product, the LCD screen frequently would power on, but not show any content. The reason for this was eventually traced to the power-spike caused by the bench power supply – the PIC board included voltage overload protection. This problem disappeared when we moved to a more stable DC adapter supply.
- Audio noise
    - Occasionally we encountered ambiguous hiss or hum from the effects. We eventually discovered circuit grounding issues (ground looping), which explained the introduction of these audio artifacts.

3.1 Future Work

We fully met our specifications for the proof-of-concept model. Our product's design is very modular and expandable; with very little modification, four or more effects can be incorporated into a future model. Some areas for future work with the Multi-FX system include:

- Design PCB layouts for all effects (speeds up production time)
- Design additional effects (possibilities include delay and chorus effects)
- Implement a "motherboard" style system, where users could theoretically purchase effect "cards" and plug them into a custom unit.
- Examine alternate layouts or different case selection

4 Budget and Timeline Analysis

When we originally created our timeline and budget, we didn't have a complete grasp on what our project would entail, or even all the fine details of what goes into the project, and how much that costs. Now that the project is completed, we have compare our original estimate of time and money investiture with the realized amounts. We made all attempts to keep to the budget and timeline, but as our project evolved, deviations did occur.

4.1 Time Line Comparison

We compare the realized timeline with the timeline that we had originally proposed back in January. The comparison of the two timelines are shown in Figure 4.1

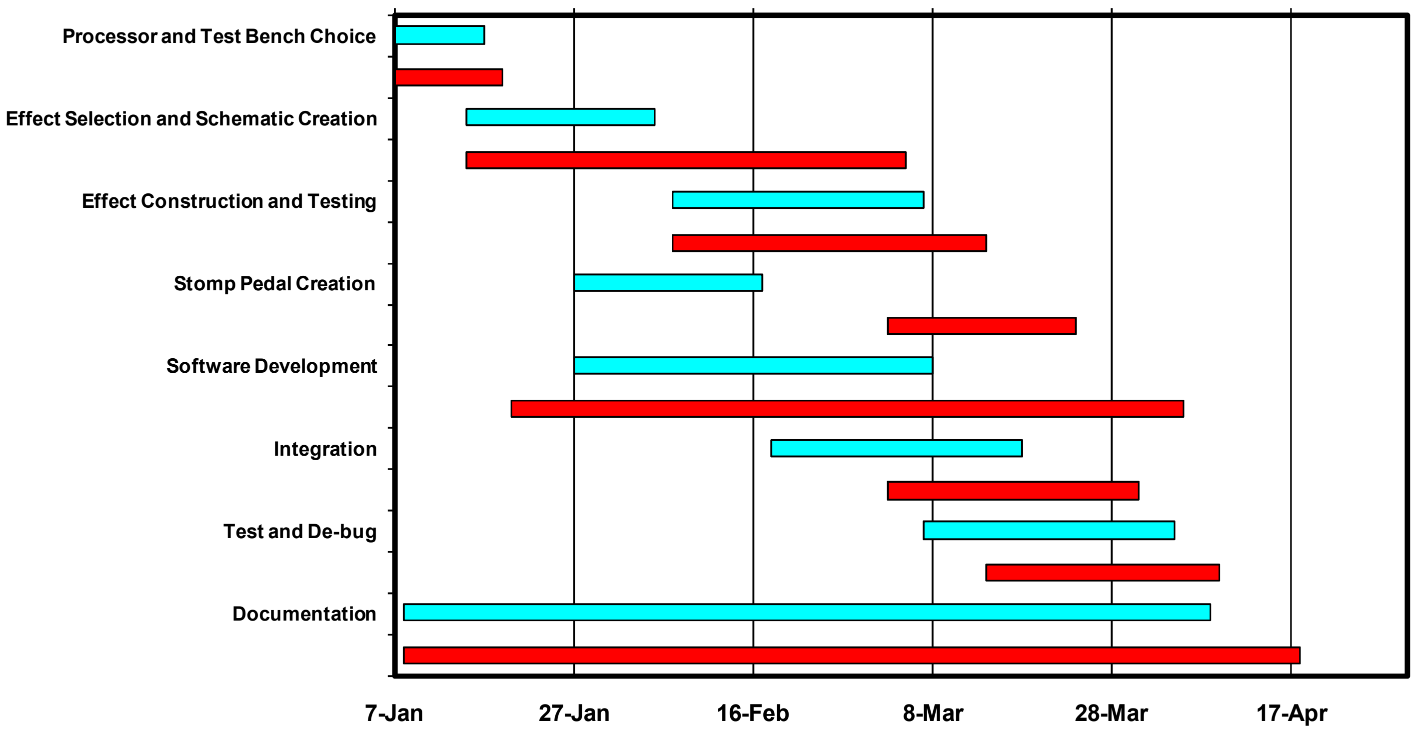

Figure 4.1: Comparison of proposed (blue) vs. realized (red) timelines.

As seen, we managed to keep to the timeline relatively closer. Each step seemed to creep a few days late, which led to a later integration than planned. However, during integration, we tested after each successive step, which led to a quicker debugging period than if we had fully integrated then attempted to debug. If you only change one variable and the system no longer works as expected, then it's easier to figure out than if you had introduced a multitude of new variables.

The effect schematic creation went well overtime as we created the schematic then realized the circuit of one effect prior to creating the schematic for the final effect. This resulted in the final schematic not being finalized until the end of February, although at that point all other effects were already built. That is why we were able to recoup time on the creation dates.

The stomp pedal creation timeline ended up changing completely. The reason for this was that we had originally intended on creating our own stomp pedal. After analyzing a few designs, we decided to go with the pedal that is used on all stomp effects. So, the timeline really reflects the integration of the stomp pedal into our circuitry, and to finalize the wiring required.

The software development started earlier than expected and continued on well after the anticipated end point. The reason for this is that originally it was unknown how much programming would be required. As it turned out, the majority of the project involved programming the PIC. Therefore, our programmer was kept busy all semester. He also started earlier than expected, as he was exploring how to program the PIC to control our peripherals well before we had anything substantial on the project for him to do.

4.2 Budget Comparison

When started back in January, we only had a slight idea as to what our project would entail, and how much it would cost. As it turned out, we were very close on our estimate. As seen in Figure 4.2, we were overbudget by only slightly more that $100.

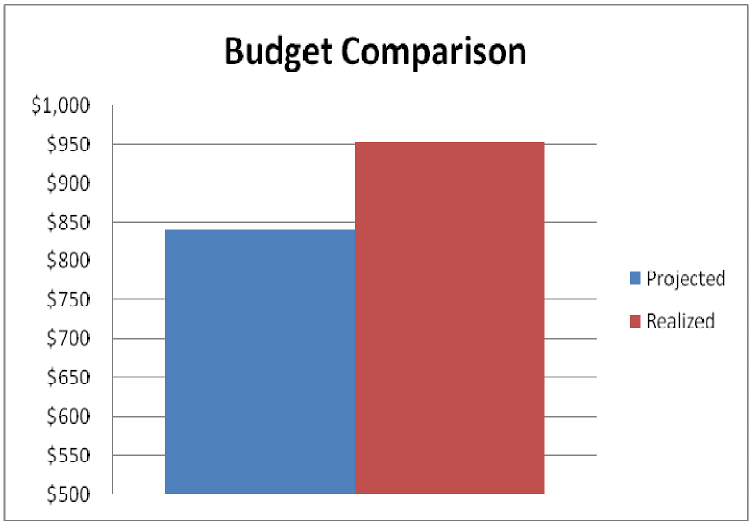

Figure 4.2: Comparison of projected vs. realized budget.

As seen, our actual expenses were $952.53, as compared to the $840.91 that we had originally intended on spending. There were several key areas or expenditures that can be identified as major contributors to where and why we went over budget. One of the major expenses and cost overruns was our initial order. We ended up doubling our order to save on future shipping and delivery time, should a part fail and we need a replacement. In addition to doubling our original cost, the shipping on that order was very expensive. Getting items shipped internationally in a time guaranteed manner with other people to do the legal paperwork, and paying the proper duties came out to be in excess of $100 for a shipment cost of $400. This was well above any budgeted amount.

Furthermore, as mentioned in the time line section, we ended up going with prefabricated bypass stomp switches instead of developing our own. This added to the cost as we did not budget for those items, and also ended up replacing them all once. They were $15 each, so that was also an unexpected cost of $100.

Overall however, we felt we did budget relatively well given our general knowledge at the time. Now that we have a better idea as to shipping costs and the cost of cases, we feel that we could cut some costs in additional projects.

5 Group Dynamics

Our group worked efficiently both as individuals and as a team. Because of the modular design of the project, we often worked independently as designers and then integrated and debugged together as a team. Especially given the analogue circuitry aspect of the project, we became very efficient at tandem circuit debugging.

We held meetings frequently during the first part of the semester in order to create a shared vision of the end product. In retrospect, this was important because it allowed us to focus more on design later on rather than on proposed functionality.

For collaboration, we made use of the online collaboration tool *Zoho*. This helped us track individual milestones and module deadlines, and it also served as a tool to group together ideas for the functional specification document.

6 What to do differently

If we were to repeat this same project *again*, meaning reproduce this project in its entirety, we would definitely design and fabricate PCBs for all circuitry. For the proof of concept model, however, the perforated vector board that we used has been more than valuable as a tool for circuit debugging and tweaking.

After simulating circuitry using LTspice, we built and tested circuits on a solderless breadboard. In retrospect, we should have included digital potentiometers in the breadboard test as well. We assumed that they would function identically to analogue potentiometers, although this assumption was slightly off.

We unintentionally neglected the small parasitic capacitance associated with digital potentiometers. Normally this would not have been a problem, except that several of our effect circuits depended on precise capacitances. Thus, the effect of the stray capacitance was accounted for once we were in the construction phase, and not the design phase. This added a small delay to the system integration.

Another recommendation for ourselves is to order the enclosure/case as early as possible. Factory lead times and stocking issues resulted in a minor scramble during March in our search for a proper device enclosure. Telephone discussions with sales reps for various distributors eventually lead to us speaking to a Digi-Key technical service representative, who helped us locate a suitable enclosure which was in stock (and available for same-week delivery).

7 Individual Reflections

7.1 Kyle Balston

I think our group did a great job working together to create a fantastic product. A few key things helped us along the way, some on purpose, some not quite as much. When we started in December we didn't have too much of an idea of how much effort goes into designing a device, even a small relatively uncomplicated one such as ours. I think we all learned a lot and going into a second project would be both more skilled and more confident with our abilities.

Our modular design allowed us all to work concurrently while minimizing the amount of integration time required because we knew what the expected outputs and inputs from our functional blocks were supposed to be. In the future, standardizing other aspects of our design would be a very good idea. The next step would be to standardize the input and output locations on the board as well as have a board template that would allow easier access to components when mounted in our case. Related to that, a more cohesive case and mounting plan would have helped as well. As electrical engineers we were more concerned about the functions of our device and didn't fully realize some of the repercussions of our layouts in terms of mounting and ease of servicing.

I was responsible for the microcontroller programming and worked most closely with Tom who designed and implemented the digital control logic. A project of any greater size would have required two programmers, greatly increasing the complexity and planning required. It would have forced us to have a much more rigorous design process stressing upfront API and interface development. As I have already experienced this in my computer science project class this was a welcome change. It gave me more freedom and responsibility during development, allowing me to focus more on feature milestones that were appreciable externally. This allowed me to frequently demo my work and get constant feedback which really helped increase the intuitiveness, ease of use and functionality of our product.

I would definitely work with this group again! I think we all did a great job and, most importantly, obtained a lot of real world experience.

7.2 Thomas Schultz

I really enjoyed working with this group on our Multi-FX device. Even in the upper years I have found it difficult to find a group where I can completely rely on my partners to get their part of the job done. Not true in this case. All members of the team were able to do what they said they'd do and, with few exceptions, have it done when they said they would. I consider this aspect of our group dynamic to be the most valuable.

The results of our project more than meet what I had expected at the beginning at the semester. Back in December when we started I wasn't confident about designing our own analogue effect circuits, but as our demo showed, we managed to create some great sounding effects. My only complaint is that not all of our effect chain combinations sound amazing, although I must admit I'm not the most musical person in the group.

From this project I will take away some much needed experience in the design of an entire product. I now especially know the importance of standardization across an entire product, especially if the design is supposed to be modular. I was also fortunate enough to design my first power supply circuit. This is something I've wanted to do since my first Co-op experience when I first realized the complexity of just powering the product correctly.

I really enjoyed this course, and all the people associated with it. I feel that now I have definitive proof that I have what it takes to be an engineer.

7.3 Michael Vogel

I am very proud of the results we achieved as a group this semester. Not only do we have a fully functional device, but also the quality of the audio and the user interface is comparable to that of a commercial product.

My role in the project was working on part of the electronic effects design. One important thing I learned is that analogue circuits can require a significant amount of debugging effort, especially upon integration. Before this semester, I'd really only prototyped circuits on breadboards, and not on soldered circuit boards.

This semester, I learned an incredible amount about guitar effect design. Back in January, the design task seemed rather daunting; however, we quickly developed an iterative process towards effects design that made the process quite efficient. As an effect designer, the first step is to research and describe exactly what "sound" the effect should create. Next, the designer needs to split the functionality into blocks (e.g. clipping stage, volume gain stage, tone control stage), and then iteratively develop a schematic for each stage. The most important step is to simulate the circuit (e.g. LTspice) *prior* to building it. Debugging is much quicker if the designer knows exactly how the physical circuit should behave based on simulation.

I very much enjoyed working with Kyle, Tom and Scott this semester. Over the course of the semester, we have become even greater friends than before, and it made working on this project a lot of fun.

7.4 Scott Witzel

When first starting the project, I was quite apprehensive about my actual abilities to create something. All coursework to date has been very theoretical, and the labs have been quite focused. For once we had complete control over what we wanted to accomplish and total flexibility in how we do it. I was very, very afraid.

Luckily we had a very diverse group; there always seemed to be someone who could do what was needed. Kyle and Tom were essential for the coding and all the logic control. Mike was the tireless workhorse that kept us going, starting all the documentation early, and kept us all motivated with his unwavering commitment. They are all truly great people to work with, and I would work with any of them again without question. At times when things got a little frustrating, I would think ‘to hell with this project’, but I would get back to the trouble shooting because I didn’t want to disappoint any of my team mates. It was the people who kept me going, not the product.

So we forged on, designing and creating. When it came time to move my circuit from breadboard to soldered circuit, I froze again. A soldered board is so permanent (or so it seemed at the time), and I didn’t want to create a substandard product. I caused a bit of a delay in our timeline while I was afraid to commit by putting solder iron to vector board. I finally did, and loved it. Also, I made several alterations to the design after the first go around. So it wasn’t permanent at all.

There were many things about the project that we could do better a second time around. Standardize the boards, make sure everyone has the same concept of product, what it’ll do, and what all it entails. Those were just some of the lessons learnt. Some of the things we did well, either consciously or subconsciously was to have a lead in each area whose decision was the answer, follow through with what you say you’ll do, and take the time to keep group dynamics positive. I guess that was the benefit of the project, it opened our eyes towards project management. I was just glad that it was a smaller project (13 weeks isn’t that long after all), so some of our mistakes or omissions didn’t end up sinking us. A day spent planning is worth at least a week of hard work.

All in all, I couldn’t have been happier with how the course went. There were no major arguments, we are better friends now than before, we completed on time and relatively on budget, and I think our product is far superior to what I had originally thought we'd produce. I can easily see how this project can be the hell course, but luckily we seemed to have avoided most of those pitfalls (thankfully).

8 Conclusion

In Tune Innovations is exceedingly proud of its accomplishments this semester. In 13 weeks, the team has successfully researched, designed and built a working, performance quality, electric guitar multi-effects system. The finished product represents what was an excellent learning experience for the team. All four members have gained invaluable insight into product development, team dynamics, iterative design, electronics design and the merit of hard work.

Planning a budget and timeline early on helped the team focus on development goals, and regular team meetings allowed for us to develop a unified vision of our end product. We are more than satisfied with the results.

This project is definitely a stepping stone for future efforts in electronics music engineering. The system design is intuitive enough to be used in its present state by live musicians. Guitarists who have tested the device thus far are equally impressed with the results. The modular design of the project allows for future models to incorporate more, or different, effects based on what customers prefer, as well as tweaks to the user interface based on user feedback.