March 5, 2009

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

Re: ENSC 440/305 Design Specification for Electric Guitar Multi-FX Device

Dear Mr. Leung,

The attached document, *Design Specification for Electric Guitar Multi-FX Device*, provides a technical description of In Tune's ENSC 440/305 project. The product is a standalone unit which creates live audio effects based on an electric guitar input. Users will have the ability to adjust and save the sound of each effect as well as change the order in which the effects are processed, all in real time.

This document presents the technical aspects of the product's design. In other words, it describes the implementation of the functions detailed in the functional specification document.

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,

Thomas Schultz

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

In Tune Innovations

Design Specification

Electric Guitar Multi-FX Device

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Submitted to: Patrick Leung: ENSC 440
Steve Whitmore: ENSC 305
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Date: March 5, 2009
Version: 1.5

Executive Summary

The design specification of In Tune Innovation's electric guitar multi-FX device is a formal catalogue of the proposed implementation and design requirements for the proof-of-concept product. Whereas the functional specification discussed features in a hypothetical context, the design specification is largely a technical document. Background information is included where necessary, in order to give the reader a clear understanding of In Tune's design intentions.

All relevant information regarding the design process is included in this document. It is important to recognize that this specification is written approximately midway during the 13 week development cycle. As such, some features have already been implemented, whereas others have not. Where possible, the completed designs of certain features (such as some of the effect circuitry) are included. In Tune recognizes that implementation of features as described in this document are still subject to change prior to project completion. The designs discussed in this document (whether or not included in the final product) are copyright © 2009 In Tune Innovations, and may be reproduced only with permission of In Tune Innovations.

The team continues to follow the project timeline. Software and hardware components are being concurrently developed, and proof-of-concept project completion is on target for April 1st 2009.

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Glossary

Boost	To amplify or make louder. With respect to "treble boosting," high frequency signals are singled out and amplified.
Distortion	Effect which seeks to introduce inharmonics into guitar signal by reducing signal peaks. Also known as overdrive.
Effect Pedal	Footswitch-activated guitar effect, usually packaged to produce a single effect. Also known as a stomp switch.
Effect Sequence/ Daisy Chain	The order in which guitar FX are internally "chained." The order/sequence of this chain affects the resultant sound.
FX	Short for "effects".
JFET	Junction Field Effect Transistors.
LED	Light emitting diode.
Multi-FX	Multiple guitar effects integrated into a single standalone unit. In this document, refers to In Tune's Multi-FX device.
MUX	Multiplexer.
Overdrive	See "Distortion".
RoHS	*Restriction of Hazardous Substances Directive*. Electronic components meeting RoHS compliancy are more recyclable, and contain less environmentally unfriendly materials.
SPI	Serial Peripheral Interface.
Stomp Switch	See "Effect Pedal".
Tone	Refers to audible frequency spectrum. Musicians adjust tone to control volume of different frequency ranges (bass, treble).
Tremolo	Time based effect which changes signal volume over time, and at different frequencies.
User	In this document, the "user" is defined as an electric guitar musician (anywhere from beginner to professional), with basic understanding of the instrument.
UI	User Interface.
Wah (or Auto-Wah)	Frequency based effect which envelope filters a moving frequency range. Associated with the funk music genre.

1 Introduction

In Tune Innovation's Multi-FX device is a standalone hardware unit designed to create a variety of user programmable electric guitar effects. The user has exclusive control over the sound characteristics of each effect, and also has the ability to select the order in which the effects are processed. The programmable aspect of the device allows the user to cycle through different combinations of effects without having to change a single cable. This means that users can preset and store multiple versions of the effect at different settings, as well as store preset effect sequences. This allows for much more user-friendly musical experimentation than exists with products currently on the market.

The design specification provides in-depth description of the intended implementation of all features included in the proof-of-concept model.

1.1 Scope

This document contains the design specification for the completed proof-of-concept system, scheduled to be completed in April 2009. The design specification details the implementation of the requirements set out previously in the functional specification.

1.2 Intended Audience

The design specification is intended mainly as a record of the design guidelines and means of implementation for the Multi-FX device. This document has been made as detailed as possible in order to contain all relevant design specifications relating to the proof-of-concept model. In Tune's engineers will refer to this document during the development and integration stages as a checklist to ensure that design guidelines are being met, and that the product is being implemented as intended.

2 System Specifications

In Tune Innovations' Electric Guitar Multi-FX is an electronic device consisting of several built in electric guitar effects, as well an embedded sequencing system designed to control the internal effect chain. The user has electronic control over both the sound of each individual effect, as well as control over the sequence in which they are processed.

Any effect combination is possible, and not all effects need to be turned on at the same time. Users can simply use a single effect, or two, if desired. Footswitches activate the effects and presets, and intuitive buttons control the parameters of each effect and also control the user interface. The user does not need to rely on presets, however. The system functions in real time and the user can change the system settings at any time.

All features of the device are user-programmable. The user can store predefined effect sequences, and then retrieve any saved preset while still playing. Each of the three built-in effects (distortion, tremolo and auto-wah) can be fine tuned by the user, meaning a wide range of different sounds is possible within each effect type. The individual settings can be saved as presets and can be retrieved in a live setting.

The present effect sequence and current status of each effect (e.g. on/off) is visible above each effect footswitch, allowing for clear identification of the current settings. A LCD shows settings and presets.

3 Overall System Design

The purpose of this section is to provide a high level system overview of the entire Multi-FX Device. Low level details of each component (e.g. an effect) can be found in their respective sections.

3.1 High Level System Overview

Figure 1 shows a basic block diagram of the system with respect to inputs and outputs to the microcontroller.

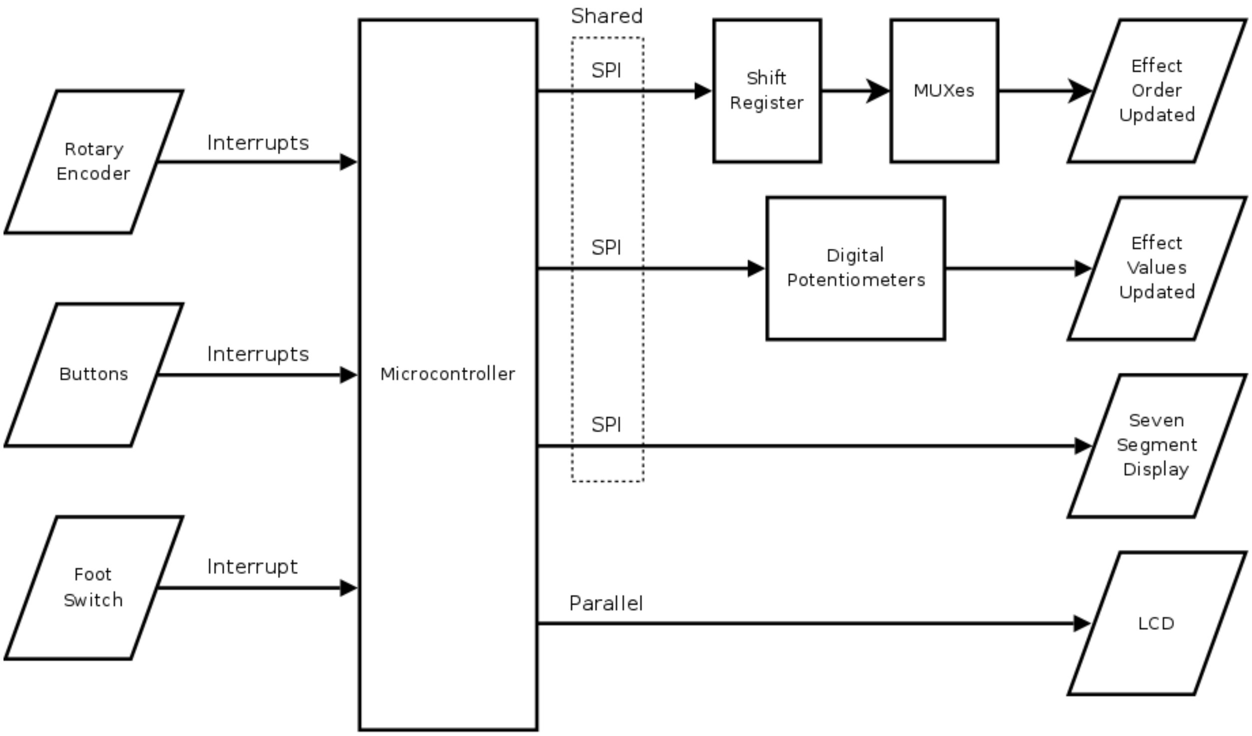

Figure 1: High Level Block Diagram

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.

3.2 Power Supply

The Multi-FX Device requires three different voltage levels in order to ensure that all electrical components are working properly. All operational amplifiers require 10V and -10V rails, as well as the analogue multiplexers used to switch the order of effects. The digital potentiometers and all digital logic IC’s require 5V, including the PIC. All voltages will be regulated in order to provide consistent voltage levels.

In order to conserve power, the current draw of the entire device is set to be at maximum 800 mA. However, considering the nature of the electrical components used in the device, we do not expect the device to draw more than 500 mA.

Power for the device will be provided from any North American household power outlet. Also, the use of a DC adapter is required to step down the voltage to a useable level. For the Multi-FX device, any DC voltage between 11 and 16 volts can be used.

3.3 Electrical System

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.

3.4 Mechanical Design

Two different kinds of stomp switches will be used, momentary and toggle. Momentary switches work by completing an electrical circuit for a brief period of time, while toggle switches alternate between predefined circuits. Double throw toggle switches will be used to alternate between the on and off setting for the individual effect board. When the stomp is set to off, the effect will be bypassed regardless of the effect order. A single momentary switch will be used to change preset effect orders.

3.5 Physical Design

The Multi-FX device will be housed in a metal enclosure to shield the device from radio signals and to significantly increase the durability, and thus lifetime, of the device. The enclosure will have one of the sides angled downward in order to afford stomping. An example of the case shape is seen in Figure 2.

Figure 2: Sample shape of product case **(source: http://www.hammondmfg.com/)**

The placement of electronic components will fall into three different locations:

1. Attached to the case walls (inside the unit).
2. On the upper plate.
3. On the sloped front plate.

Attached to the case walls

All internal circuitry shall be affixed to the walls of the case. This shall include the switching circuit, all effect circuits, and the voltage regulation circuit. The circuits shall be attached in such a way as to allow access to the board with the lid of the main case removed.

Upper Plate

The LCD display, button pad, and rotary encoder will be mounted on the upper plate. These electronics should be mounted in such a location as to minimize potential damage from missing a stomp pedal. They should also be mounted in a somewhat central location for easy viewing, and to minimize wiring distance to and from the circuit boards.

Sloped Front Plate

The sloped front plate shall be split into four zones, one for each foot pedal. The pedals should be spaced far enough apart such that activation of one stomp switch would not interfere with or touch a second switch. As previously mentioned, each stomp switch will control the activation or deactivation of an effect in the effect chain. If the effect is not in the effect chain the activation of the stomp switch will not turn it on. With each effect switch, there will be an LED that will be lit when the effect is active, as well as a 7 segment display that will show in which order that effect is currently operating. Both the LEDs and 7 segment displays will be located in such a way as to minimally interfere with the operation of the stomp switch.

4 Digital Control

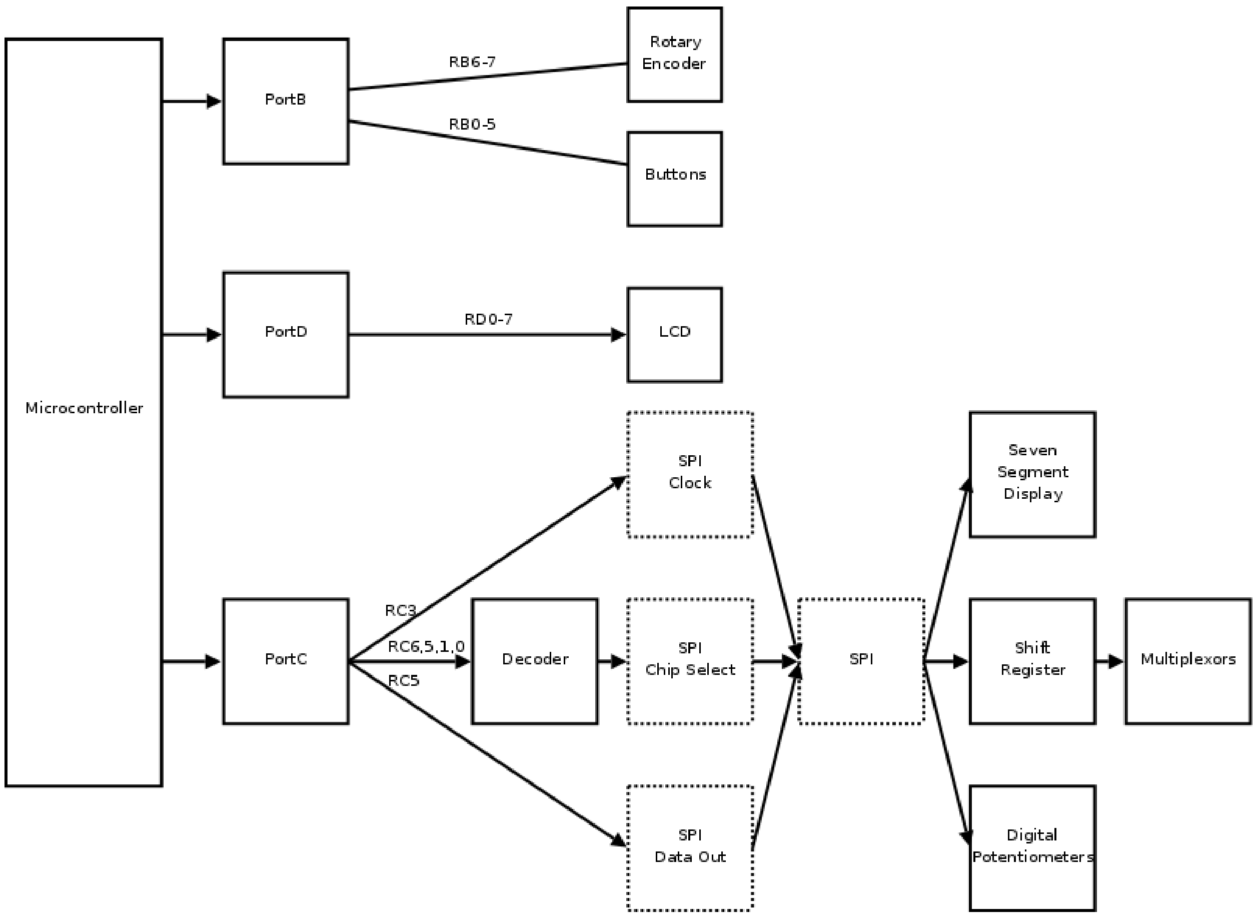

Figure 3: Digital Control Schematic

As seen above the user utilizes buttons and a rotary encoder to communicate with the microcontroller. The buttons are used to navigate a menu while the rotary encoder is used to change effect configurations. User feedback is provided from both the LCD and Seven segment displays. The details of these operations can be seen in the user interface section.

The order of the effects is changed using four analogue multiplexers and is controlled by the microcontroller via the SPI Bus, which consists of a clock, data, and multiple control signals. Chip select signals are used to select the peripheral that needs to be modified, while the clock and data signals are used to change the configuration of the peripheral. The analogue multiplexers are, however, not set up to use the SPI bus and thus we use a serial to parallel shift register to facilitate communication. Also, because we are using a shift register all multiplexers are updated using a single control signal.

Also connected to the SPI bus are the digital potentiometers used to change the configuration of the effects. Each potentiometer is used to adjust a specific part of an effect, like depth or frequency of oscillation for the tremolo effect. Thus, unlike the decoder, each potentiometer must have its own control signal. To maintain the efficiency of the SPI bus, a 4:16 decoder is used to select all chip select signals.

5 User Interface

As the Multi-FX device is programmable, a suitable user interface is required. Using tactile buttons, a rotary encoder, seven segment displays, and a LCD the user will be allowed to create their own presets as well as customize the sound of each effect. Figure 4 shows the layout for the UI of the Multi-FX Device.

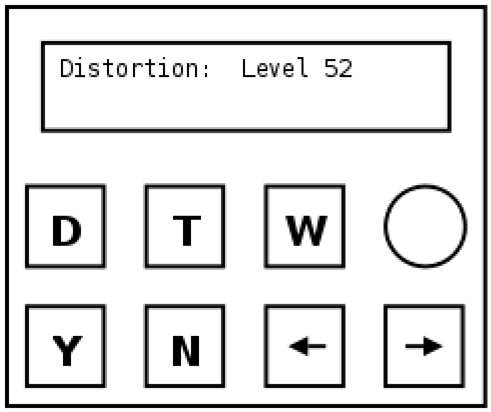

Figure 4: User Interface for the Multi-FX Device

While the device does come with initial, "factory" presets, the user is encouraged to create their own effect orders. In order to create a new preset the user will navigate 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 four parameters of the effect like tone 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.

When the user is playing the guitar, they no longer interface with the device though the buttons, encoder, and LCD. Instead, the user now uses the footswitch to cycle through the desired presets, which are chosen in a manner similar to adjusting the effect parameters. The order of effects of the active preset is shown via three seven segment displays. Each display is tied to a single effect and shows a "1", "2" or "3". This number corresponds to the position of the effect in the presets effect chain.

6 Guitar Effects

In Tune's Multi-FX will contain three categories of effects: distortion, tremolo and auto-wah. There are several design constraints to which all effects must adhere:

- Total system audio gain shall not exceed 20 dB.

This accounts for the device's ±10V power source. Assuming a maximum 1V AC guitar input, this requirement ensures that the output voltage will not exceed the power rail voltages. If it did, this would create undesired signal clipping and distortion.

- Each effect shall have a large (100 k – 1 M Ω) input impedance.

- No DC voltage shall enter/exit each effect, only AC.

This requirement is met by incorporating some type of high impedance input buffer with a capacitor (an op-amp buffer would suffice). Given that the system is dealing with analogue audio signals, this high impedance minimizes unnecessary signal degradation. The small output impedance of a buffer produces a similar effect, and will be included as the final component in each effect.

The most important factor with respect to effect design is that it, at the most basic level, must be aurally appealing. This means, for instance, that should two methods exist for creating a particular effect, the one with the "best" sound wins out. This cannot always be explained mathematically. Preliminary testing has already confirmed this. An example the reader may find interesting is In Tune's component selection process for "distortion".

Plenty of electrical components can distort an input signal. To an objective listener and non mathematician, this distortion can be described according to the behavior of the electronic component when forced into an overdriven/distorted state. Op-amps clip ungracefully, transistors less so, and diodes clip very gracefully – yet they *all* produce distortion as per the mathematical idea of signal clipping. Thus, the creative design process doesn't always align with the scientific engineering process – especially when dealing with audio design.

The design process is comparable to heuristic development. At the time of this writing, there is still more than a month remaining in the project timeline (and thus all is not complete). Because of this, the effects presently are in various stages of creative development and, although complete on paper, are still subject to potential modifications based on the collective performance of the effects.

6.1 Distortion Effect

Distortion first emerged as an electronic guitar effect in the 1960s. Prior to this, distortion was ingenuously achieved by the shredding of a guitar amplifier's speaker cone. 1960s musicians eventually figured out that they could create a smoother distortion/overdrive sound by forcing the volume knob up to the 11/10 position, thus creating the first signal clipping based distortion. With the emergence of transistors, diodes and operational amplifiers, the spectrum of possible clipping/distortion effects has greatly broadened.

In formulating the circuitry for distortion, In Tune Innovations experimented with a variety of electronic components used in audio circuitry. Germanium diode clip appear to clip most similarly to the sound produced by vintage tube distortion. Silicon diodes clip slightly more harshly than their germanium counterparts, and LEDs produce the most clipping of the types of diodes tested.

It may be a surprise that, on average, the harshness of guitar distortion in popular music has been steadily increasing each decade since its birth. Take any late 1990s to present rock music and compare it with the guitar sounds of any late 1960s or 1970s rock song. A trained ear is not necessary to hear the difference.

In Tune's lab research has netted a preference for creating distortion via silicon diodes used in an asymmetrical op-amp feedback configuration. As will be described, this configuration allows for the greatest variety of sound.

Figure 5, on the following page, presents the proposed design schematic for distortion.

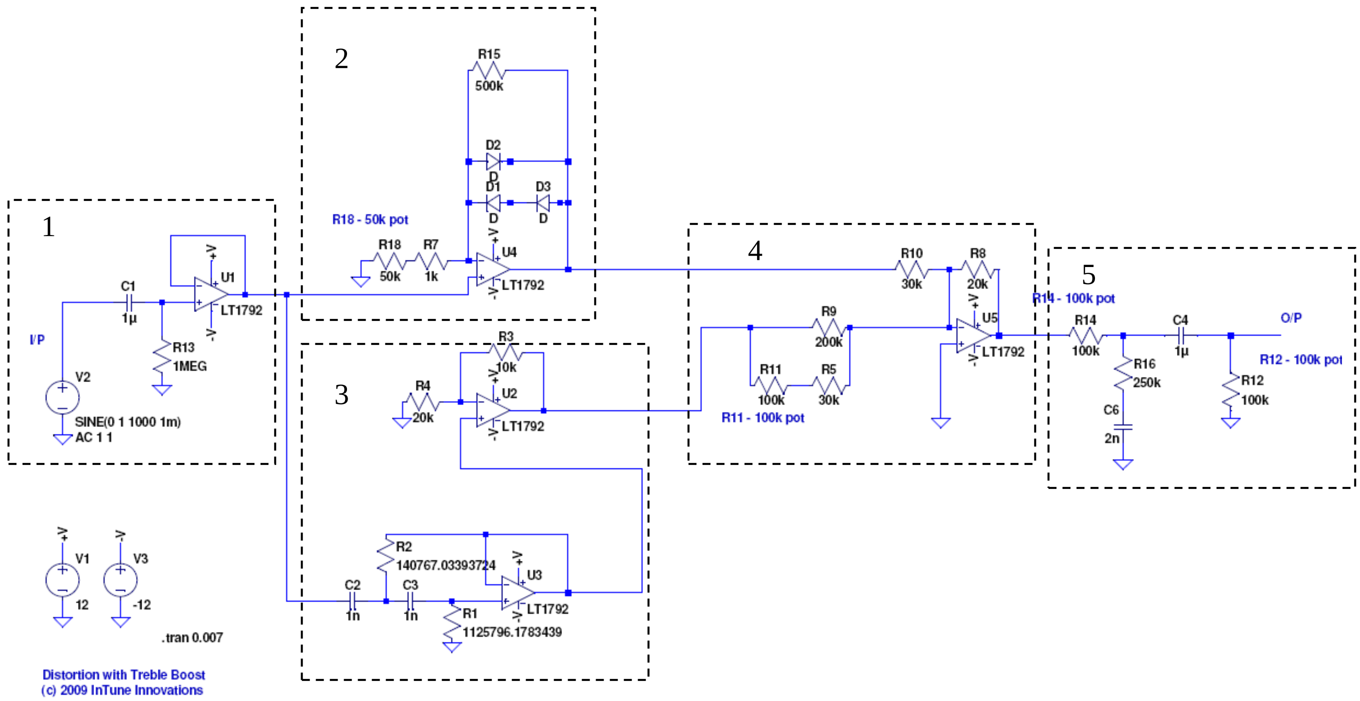

Figure 5: Distortion Effect at block level, with proposed circuitry included

The distortion “blocks” are as follows:

1. Input buffer.
2. Asymmetrical distortion & distortion gain control.
3. Treble frequency boosting (of clean signal).
4. Signal Mixing (distortion & treble).
5. Tone and output volume control, and DC offset removal.

In Tune’s goal for the distortion effect is to produce a “soft” distortion sound along with a boost in treble frequencies, in order to create “bright” fuzz. We feel that this can mimic the famously popular sound of British rock band *Queen*, exemplified by lead guitarist Brian May.

Input Buffer

The capacitor and resistor form a high pass filter. The resistor R13 and capacitor C1 form a high pass filter. Their values are set accordingly to remove any DC offset, as well as pass all audible frequencies.

Asymmetrical distortion & distortion gain control

Asymmetrical distortion refers to that, although both positive and negative signal peaks are clipped, one peak is clipped slightly less. From our testing, it is apparent that the result is a cleaner sound with less harsh sounding distortion. This is because more signal amplitude is passed before clipping takes place. Figure 6 shows an example of asymmetrical clipping performed on a sine wave.

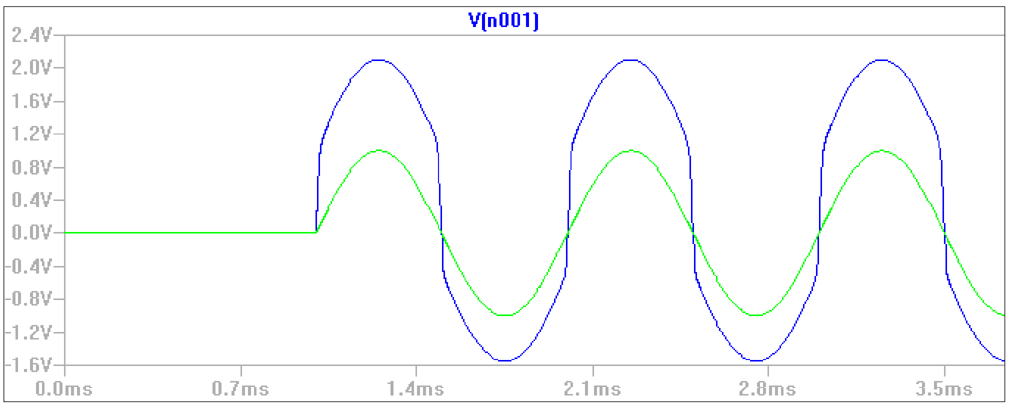

Figure 6: Asymmetrical signal clipping. Blue: Output clipped signal. Green: Input sine wave.

The reader may ignore the difference in signal gain for now; it will be explained shortly. As shown in Figure 6, the positive peak amplitude is 2.0V, while the negative peak amplitude is 1.6V. If the clipping was symmetrical, these two amplitudes would be identical. As shown in Figure 5, the high positive peak is created by the addition of an extra diode in the feedback path.

The clipping is created as the diodes conduct. Notice that the clipping is “soft”, meaning that the peaks are not horizontal. Flat peaks constitute the harsh clipping described earlier.

If the gain of the distortion stage is relatively low, less clipping (or no clipping) will occur. Utilizing a non-inverting op-amp configuration allows the user to change the gain. The non-inverting configuration also ensures that a gain of less than unity is not possible, as shown by the equation

$$\text{Gain} = 1 + R2/R1 \qquad (1)$$

Where R2 is the output feedback resistor and R1 is the resistor connected between the inverting terminal and ground. When either R2 is small (<<R1), or R1 is large (>>R2), then the *R2/R1* ratio is approximately zero. In an inverting gain configuration, the *1* constant disappears from equation 1. This is not desirable, because this would prevent the user from lowering the distortion level without significantly affecting the audio level.

Treble frequency boosting (of clean signal)

The "tone" of guitar can be loosely personified as the enunciation of the guitar's sound. Boosting the treble frequencies of a clean signal allows the upper level harmonics to be reintroduced into the distorted sound. Emphasizing the treble frequencies creates a less muddy sounding distortion (which is highly sought after by musicians).

The fundamental frequency range of the electric guitar is in the 80-1200 Hz range. In Tune's distortion effect has set a threshold of 450 Hz as the lower limit frequency for treble boosting. As shown in the third block in Figure 5, an active Butterworth high-pass in a Sallen-Key configuration can.

A second order filter has a sufficiently steep decibel roll-off (-12 dB/oct) to effectively mute frequencies below 450 Hz. The audible range of guitar is quite narrow, and passive filtering only slightly fades out low frequencies in the 100-450 Hz range. It is not an effective attenuator in an application where precision is necessary.

Signal Mixing (distortion & treble)

In Tune allows the user control over the degree of treble boosting heard in the output signal. This means that the effect can be used solely as distortion if desired, solely as a treble booster, or mutually. The mixing stage controls the percentage of treble and distortion signals able to pass through to the output stage.

Tone and Output Volume Control, and DC offset removal

DC offset removal is necessary for all effects; amplifiers cannot accept DC input and, in the case of poorly built amplifiers, can cause permanent damage. The same high pass filtering used in the input buffer stage easily meets this requirement. Tone and output volume control are included to give the user to make fine tune adjustments to the final sound of the effect.

6.2 Tremolo Effect

Tremolo effect is a low frequency oscillation of output volume. This will be obtained by multiplying the input signal by a periodic oscillatory signal. The majority of the user adjustability will come from the oscillatory signal. While this signal would optimally be a sine wave, it was decided to go with a triangle wave pattern. The reason for this change was that triangle wave generation requires a much simpler circuit using components that are more durable with a longer usage life. Many sinusoid wave generator circuits rely upon a small lamp and light intensity sensor, and it was felt that over time with use, the lamp's resistance would change, and ultimately the lamp would burn out or fail.

The tremolo circuit has been designed and a prototype has been satisfactorily tested. Figure 7 presents the proposed design schematic for Tremolo. All the component values have not been added as they remain to be determined. The circuit has been divided into functional blocks one to four for functional description.

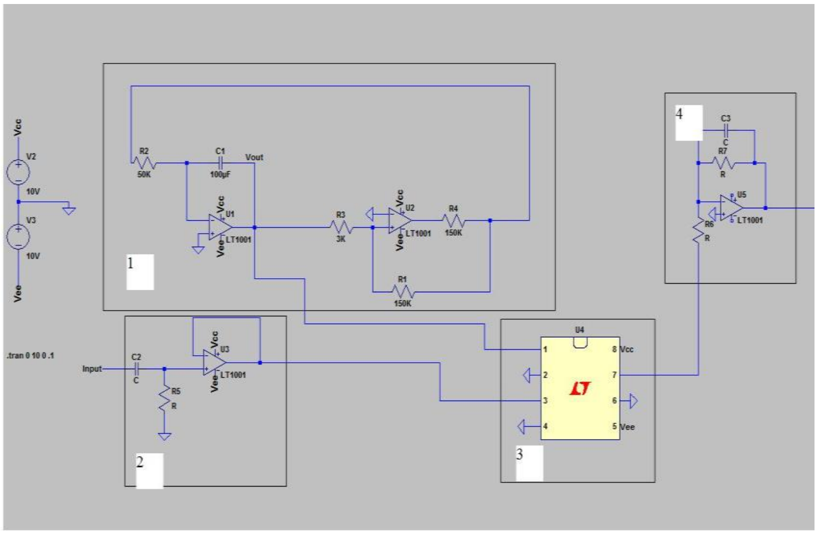

Figure 7: Tremolo Effect at block level, with proposed circuitry included

The Tremolo "blocks" are as follows:

1. Triangle Wave Generation.
2. Input Buffering.
3. Multiplication of Signals.
4. Output amplification and noise filtering.

In Tune's goal for the tremolo effect is to have an audible oscillation of output volume. The user will be able to adjust the oscillatory frequency and depth, as well as the ultimate gain of the circuit.

Triangle wave generation

A good sounding tremolo effect is somewhat personal so the triangle wave should be as user adjustable as possible while still outputting a noticeable effect. Too low a frequency makes the effect indistinguishable, whereas too high a frequency results in helicopter style choppiness. Therefore, after much sound testing, it was determined that the frequency must be able to be adjusted between 0.5 and 30 Hertz.

For a good auditory distinction in output volume, it was determined that the output should pass through zero (muting). To do this, the triangle wave should be a 0V ± depth waveform. Other baseline multiplication values were tested, but the zero volts sounded the best to our test engineers.

Based on a zero voltage baseline, it was determined that the peak of the triangle wave should be adjustable between 0.75 and 2.0 volts. These values represent a suitable range of depth, while still maintaining an audible output.

Input Buffering

The capacitor and resistor form a low pass filter that is intended to filter out any noise that may have crept into the input signal. Additionally, the capacitor eliminates any DC offset, leaving a pure AC signal.

Multiplication of input and triangle signal

The whole effect is based on the principle of superposition of the input signal onto a low frequency carrier wave. Although a multiplication circuit was originally designed from op-amps and transistors, it was a very large and complex circuit. It was decided to go with an IC multiplier. As both signals are AC signals, a four quadrant multiplier is needed. The AD633 was chosen for its simplicity, size and price. As this multiplier also divides by a factor of 10, an amplification stage will have to be included on the output.

Output multiplication and noise filtering

As mentioned with the multiplier, post multiplication amplification is needed. It was determined that the user should have control over the amount of amplification to satisfy their personal tastes and desires. Included in this stage is another low pass filter. This is set to remove any noise that may be due to the tremolo circuit.

6.3 Auto-Wah Effect (Envelope follower)

The quintessential sound of funk music is directly attributed to the effect known as Wah. "Wah" is, in fact, onomatopoeia for the sound it produces (*wah-wah*).

Traditionally this effect is created with a moving low pass or band-pass filter. A potentiometer connected to a pivoting (rocker) foot pedal would control the cutoff frequency of the filter, causing a vocal-like "wah" sound. The main drawback of this design is that the effect only works while the musician moves the position of the pedal. This is neither always desirable nor efficient, especially when playing at high speeds.

In the 1980s, automatic wah effects began to emerge, seeking to remove the mechanical reliance of the wah pedal. Various types exist, although one popular method used an oscillator to continually move the filter's cutoff frequency. The drawback with this design is that the user has no direct control over the filter position with this implementation.

In Tune Innovations is designing an automatic wah based on an envelope follower used in conjunction with a moveable low pass filter. The purpose of the envelope follower is to ascribe a DC voltage based on the amplitude (volume) of the input signal, and then adjust the filter accordingly. At high volumes, the filter "opens," passing the entire frequency range. Thus, the user controls the filter by means of strumming intensity.

Figure 8 presents the frequency response of a low pass filter with a -3dB frequency of approximately 300 Hz.

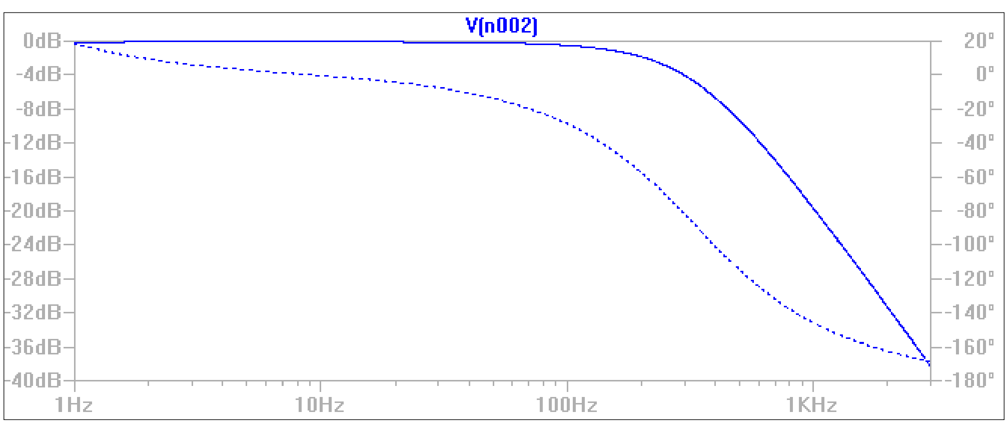

Figure 8: Frequency response of low pass filter, with -3dB frequency of approximately 300 Hz

In Tune's wah effect will use a Chebyshev low pass filter with a variable cutoff frequency between 200-1200 Hz (encompassing the audible range of guitar). Chebyshev filters include a passband ripple slightly before the cutoff frequency. This ripple provides a volume/gain boost at the cutoff frequency, enhancing the essence of the effect.

Figure 9 presents the proposed design schematic for Wah. Note that block 4 is not yet designed at the time of this writing.

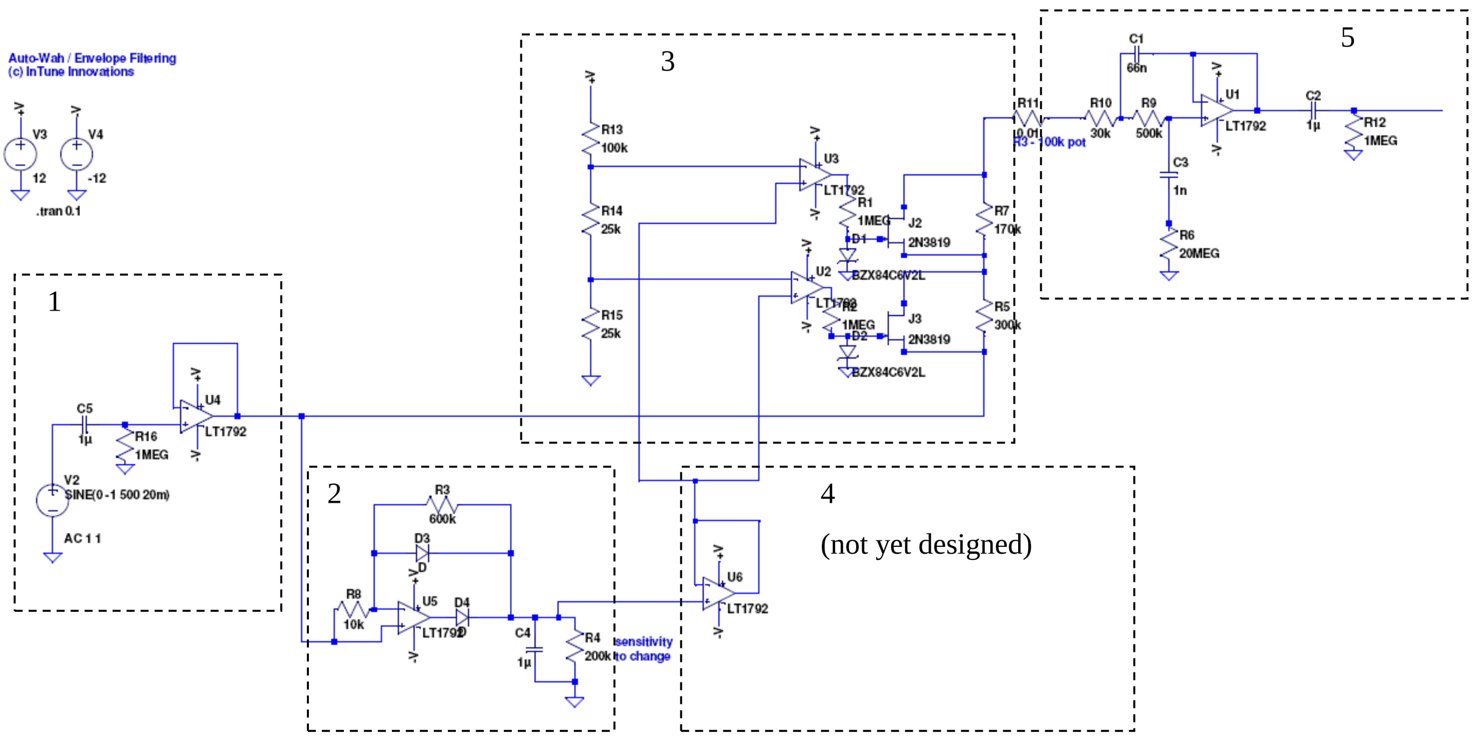

Figure 9: Auto-Wah Effect at block level, with proposed circuitry included

The Auto-Wah "blocks" are as follows:

1. Input buffer.
2. Envelope follower.
3. Low pass filter cutoff frequency controller.
4. Filter sensitivity controller.
5. Chebyshev (or equivalent) Low pass filter.

Input Buffer

The capacitor and resistor form a high pass filter. Resistor R16 and capacitor C5 form a high pass filter. Their values are set accordingly to remove any DC offset, as well as pass all audible guitar frequencies.

Envelope follower

The envelope follower creates an outline, or envelope, connecting signal peaks. The sensitivity can be adjusted to be slow or quick to change. Figure 10 shows envelope following (blue line) of an input signal created by the circuitry showing in block two, Figure 9.

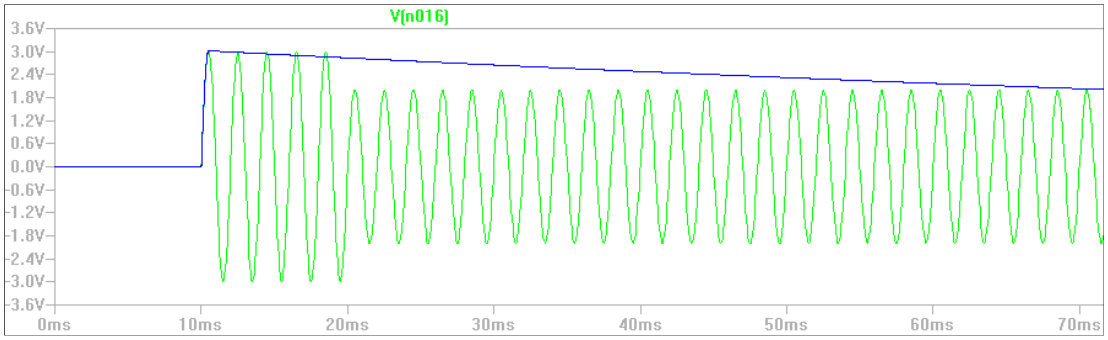

Figure 10: Envelope follower (blue), creating envelope of AC input (green)

At a lower sensitivity, the envelope follower yields a DC voltage based on an AC input. This voltage corresponds to the peak amplitude of the input audio signal – the volume, in other words. The DC voltage will then be used to control the position of the low pass filter – mimicking the effect of the original Wah's foot rocker pedal. At high volumes, the filter "opens," passing the entire frequency range. Thus, the user controls the filter according to strumming intensity.

Low pass filter cutoff frequency controller

Several designs of this feature were drafted before deciding on the implementation shown in Figure 9. Fundamentally, this portion of the circuit needs to control the cutoff frequency of the low pass filter. Mathematically, this depends on the capacitors and resistors in the low pass circuit.

JFETs can be used as electronically variable resistors, allowing for several MΩ resistance when not conducting, and variable between zero and few hundred ohms when operated in the ohmic region. Incorporating a JFET as a variable resistor in the low pass circuit is possible; however the corresponding capacitor values required to create the filter become impractical because of the 200-1200 Hz filter range requirement.

The use of FETs as switches brings us to the current implementation of this feature. At the most basic level, several op-amp comparators are used to control FET switching – which in turn control a resistor in the filter circuit. Each FET is connected in parallel with a several hundred KΩ resistor; when the parallel FET is switched on, the effective resistance becomes zero (essentially removing the resistor from the circuit). This change in resistance affects the location of the filter's cutoff frequency. The comparator/FET switching is controlled by an input voltage from stage four, which is essentially a sensitivity controller of the envelope follower circuit.

Filter sensitivity controller

This section is not yet fully designed, however the intent of this section is to receive input from the envelope follower, and output a corresponding output DC voltage to be received by the comparators in stage three. In other words, this circuitry will determine how "loud" a signal is – ultimately controlling the sensitivity of the filter. The guitar input level can vary up to 3 V depending on gains from previous stages. If the user is playing quietly (< 1V peak-to-peak), this would otherwise mean that the filter would remain "closed". A configurable logarithm amplifier would satisfy this requirement. Logarithmic control can map the signal envelope to a larger voltage range in order for the comparator/FET switching to control the filter.

Chebyshev (or equivalent) Low pass filter

As mentioned above, In Tune's wah effect will use a Chebyshev low pass filter with a variable cutoff frequency between 200-1200 Hz (encompassing the audible range of guitar). Chebyshev filters differ from other conventional filters in that they typically contain a passband ripple slightly before the cutoff frequency. This ripple provides a volume/gain boost at the cutoff frequency, which in the case of Wah enhances the emphasis of the effect (in our opinion). As mentioned, the sectional blocks discussed above control the position of the filter's cutoff frequency.

7 System Test Plan

Individual modules will be tested prior to system integration. Upon completion, the device will operate as fulfilled by the functional specification. The proof of concept unit will undergo a more rigorous testing regime than successive production units because the effects are intended to be of performance quality. When building production quality units, we can safely assume that the effects are still functional as intended, and testing will be reserved to completed units, and not on individual modules. Test cases are listed below; the test cases encompass the design requirements of the proof-of-concept device.

7.1 System Power-on

User Input: The user enables the power switch.

Conditions: Device is plugged in and initially turned off.

Expected Observations: Device powers on (LCD on / text displayed). Effect Preset 1 is automatically selected.

7.2 System Power-off

User Input: The user flips off the power switch.

Conditions: Device is plugged in and initially turned on.

Expected Observations: Device turns off and guitar signal ceases flowing from device output.

7.3 Using Effects

User Input: The user tries all three effects, and tests them at different parameter values.

Conditions: Device is on.

Expected Observations: User can select and change the parameters of any effect in real time.

7.4 Effects Switching

User Input: User selects a switching sequence for one to three effects.

Conditions: User first enters switching mode.

Expected Observations: New sequence is created and displayed to the user. User can still make adjustments to FX settings if desired.

7.5 Loading Effects Presets

User Input: User selects a preset via the system menu.

Conditions: Device is on.

Expected Observations: Effect sequence and/or settings are updated.

7.6 Saving Effects Presets

User Input: User saves a preset (e.g. preset 5) via the system menu

Conditions: Device is on.

Expected Observations: Effect sequence and/or settings are saved in the correct preset location.

7.7 Audio Quality test

User Input: User turns on all effects and sets system to full volume.

Conditions: Guitar is connected directly to system.

Expected Observations: When compared to system bypass (e.g. guitar connected directly to amplifier with settings unchanged, volume gain of Multi-FX is no less than unity, and any signal degradation is non-obvious.

7.8 Mean Time to Failure Test

User Input: Audio Quality Test settings, input via function generator.

Conditions: Device is on, input and output monitored through oscilloscope

Expected Observations: The satisfactory output signal should not degrade over time. A maximal degradation of 5% should be observed over a five hour period of continual operation. This test should be left running until 5% degradation in signal is observed, and this time period should be reported out. The results of this test will also help us determine our mean time to failure.

7.9 Durability Test

User Input: User stomps on stomp pedal.

Conditions: A hydraulic ram is used to simulate stomping of various forces.

Expected Observations: The unit must tolerate a minimum of 50 repetitive "stomps" of hard force without deformation of the case. Deformation is defined as a bending or breaking of the case from its original shape.

8 Environmental Concerns

In Tune Innovations is commited to helping protect the environemt in what ever way we can. As such, the Multi-FX device will follow the cradle to cradle design philosophy as closely as possible. The cradle to cradle approach ensures that at the end of the products life cycle most of the components, or technical nutrients, are not simply thrown away. Where possible components will be recycled, and in the event that recycling is not an option the materials will be disposed of in an apropriate fashion.

Additionally, In Tune Innovations plan on developing the Multi-FX unit into a modular system in which the user can easily change out the effect circuits with other In Tune effects boards. This will ultimately minimize the amount of materials going into production as each user would only need to have one FX kit instead of the multitude of pedals that most guitar hobbyists currently own.

9 Conclusion

This design specification clearly defines the intended implementation of In Tune's Multi-FX unit. Functionality of the proof of concept model was outlined in the functional specification, and its requirements remain unchanged. In Tune will follow the functional specification as well as the design specification as closely as possible in order to develop a final product analogous to what has been described in this document.

In Tune Innovations is dedicated to producing performance-quality musical electronics. In Tune's Multi-FX system enhances the inherent versatility of the electric guitar, while greatly simplifying the task of preparing effect sequences for musical performance.

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