# 3. DESIGN APPROACH

The design approach represents the transition between a lower-level explanation of what The Blackbox does and a more in-depth description of the systems and components necessary to complete those tasks. To that end: in order to be able to take an input signal in, perform variable effects (FX) on the audio, control those operations via assignable foot pedals, and output that audio to an amplifier, The Blackbox uses a dual-system approach. Ultimately, using one microprocessor for control logic and other microprocessors for audio processing was deemed necessary, as either one of those options independently lacks the complexity and features critical to intended system design. Where design flexibility remains, then, is in the product UI and in the details of the interaction between the main and peripheral microprocessors. The section below details Alternative Instrumentation's decision-making process and a high-level description of the product approach that was chosen.

### 3.1.1 Design Options

The Blackbox's design is broken up into two primary approaches. Option 1 contains multiple smaller displays for information, both Analog and Digital FX, and a static-length FX chain. Meanwhile, Approach 2 focuses on a more nuanced UI containing a larger, programmed LCD, variable-length FX chain, and exclusively Digital FX. Moreover, in the interest of Design II, the second approach shows much more promise of increasing the scope of the design. Some of these include the length of the FX chain, the number of loadable FX, the location of the bypass switches, and the complexity of LCD implementation. Further, while it is true that some prefer the sound of and swear by analog components, interviews with the target audience have shown a neutral opinion on the sound quality differences between Digital FX and Analog FX. To build on that, the selected FX for The Blackbox includes distortion, delay, and EQ, where the choice to make any analog or digital lies in approaches 1 and 2 respectively.

Another notable difference between Option 1 and Option 2 is the number of displays demanded for the user interface. Option 1 creates a more complex hardware implementation due to the large peripheral count (multiple small LCDs, digital potentiometers, etc.), and analog EQ, but Approach 2 is much more involved in the software and programming side due to its all-digital implementation and a more complex LCD Display.

Alternative Instrumentation has selected the latter approach, largely due to the ease of subsystem integration and scalability for Design II, leading to a higher quality minimum viable product (MVP) within the limited time frame. Greater detail on each design option is expressed in Sections 3.1.2 and 3.1.3 and Tables 3.5 through 3.8 in the Appendix.

### 3.1.2 Design Option 1

Alternative Instrumentation's first choice for a version of The Blackbox lies in both an analog and digital (A&D) approach. Option 1 currently looks to implement analog distortion, digital delay, and analog EQ. However, an analog approach to these FX implementations has implications on the complexity of circuitry and further the UI of The Blackbox. In the interest of time and sticking to a more viable product, a digital implementation of the FX is much more desirable, more so because there is already a hefty amount of microprocessor coding regardless. As for multiple smaller displays, accomplishing such a UI would require a large number of pins on a microcontroller, or multiple smaller microcontrollers working together, which is not something Alternative Instrumentation has extensive experience in. Further information on nuances of analog versus digital approaches is listed in a visual form in Tables 3-5 and 3-6 in the Appendix.

Ultimately, The Blackbox is a musical tool made to serve the performer, a complex UI and circuitry required to make the analog components function along with the smaller LCD displays compromise qualities for the target audience.

### 3.1.3 Design Option 2

The second design option for The Blackbox includes an all-digital pedal library and FX-chain. Whereas Option 1 might only be able to string 3 FX pedals together digitally, Option 2 could chain up to five or even six FX pedals simultaneously. Additionally, with an increase in complexity, a larger LCD screen is needed to accompany The Blackbox.

As far as implementation of FX is concerned, an all-digital approach is more simplistic and universal across the 3 designated FX for The Blackbox. Moreover, a digital implementation provides a larger window given the time constraint placed on the team. This leads to less time spent on power regulation, datasheet reading for analog components, and general circuit building. Because of the universally digital implementation, there is potential for a web app to be used to substitute various digital FX pedals from the Internet to be loaded into The Blackbox.

With these considerations, a fully digital implementation and corresponding LCD display allows for Alternative Instrumentation to provide: the highest quality sound control for the user, the simplest UI, and the simplest mode of implementation given the constraints placed upon the team.

## 3.2 System Overview

On as basic of a level as possible, The Blackbox exists as a variable signal processor which, given power, takes in an audio signal, modifies it based on user input, and outputs a different audio signal. Figure 3-1 is a graphical example of this basic functionality in a Level 0 diagram of the system.

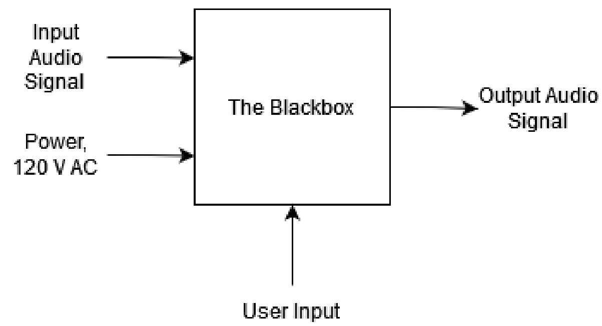


**Figure 3-1: The Blackbox Functionality Overview (Level 0)**

In slightly more complex terms, The Blackbox buffers its audio input before passing the signal through a series of user-assignable parametric effects, then buffers the signal again before outputting the signal via audio jack. Each effect, whether it be an analog or digital implementation, requires power as well—digital implementations using a microprocessor DSP typically use 3.3 V, but analog effects can vary in their implementation, potentially requiring many different voltages. Likewise, Figure 3-2 graphically demonstrates the Level 1 version of the system.

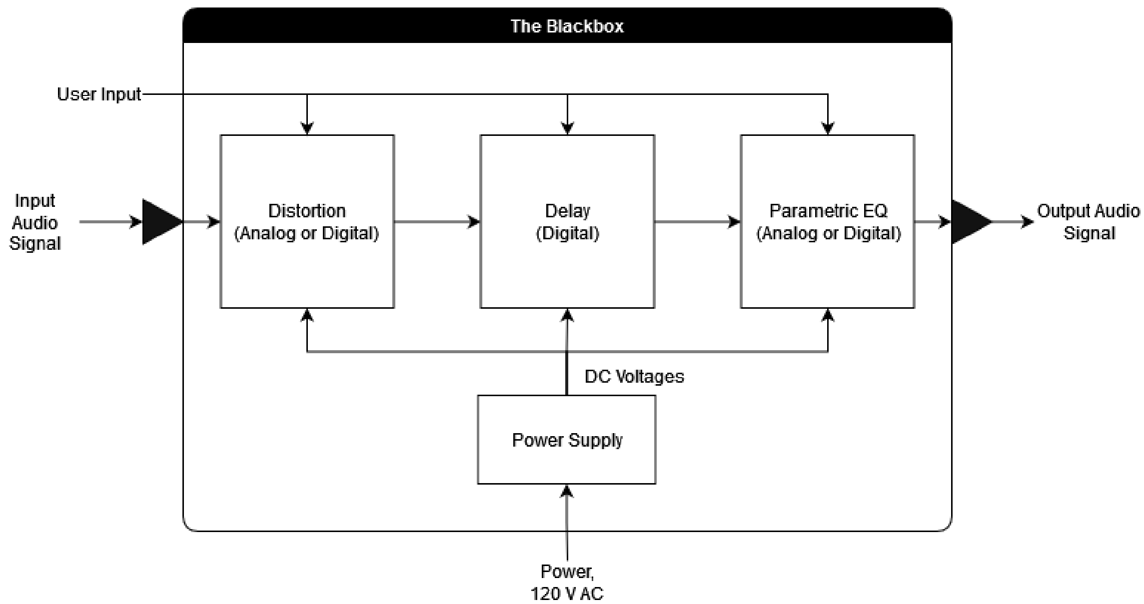


**Figure 3-2: The Blackbox Functionality Overview (Level 1)**

In terms of implementation, replication of the intended functionality requires microprocessors to perform the necessary effects and to control the logic, UI, and display LCDs. A more detailed version of the Level 1 diagram above, which includes information about power management, data flow, and microprocessor details, follows later in the document, in Section 3.4. Before that, though, an explanation of the microprocessor design and decision process, as well as those of the peripheral devices, is necessary.

### 3.2.1 Microcontroller

As mentioned before, The Blackbox uses multiple microcontrollers: one type to run the signal processing, and another to handle logic and controls. Alternative Instrumentation, then, had to make multiple choices regarding each microcontroller, taking into account ease of interaction and interfacing between the two types.

For The Blackbox's digital signal processing, the Spin Semiconductor FV-1 microcontroller was chosen to incorporate the numerous FX in the pedal's library.

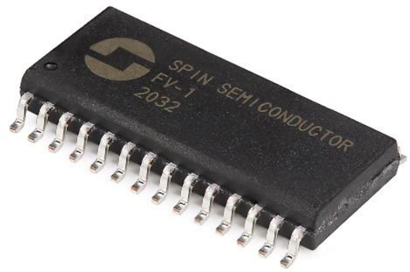


**Figure 3-3: Spin Semiconductor FV-1 microcontroller [1]**

The FV-1 was chosen in particular because of its focus in audio processing, low latency, extensive compatibility, and long history of use in guitar amps and FX equipment [2]. Table 3-1 shows the scores given to certain criteria for three different microcontrollers based on the intended purpose of handling guitar pedal FX, including the chosen microcontroller FV-1.

**Table 3-1: Decision Matrix for Microprocessor Selection (Pedal FX Micro)**

| Criteria | Micro 1 (FV – 1) | Micro 2 (STM32) | Micro 3 (PIC24) |
|---|---|---|---|
| **Performance (Speed)** | 4/5 | 5/5 | 3/5 |
| **Cost** | 5/5 | 3/5 | 5/5 |
| **Compatibility** | 5/5 | 4/5 | 3/5 |
| **Audio Processing** | 5/5 | 4/5 | 3/5 |
| **Latency** | 5/5 | 4/5 | 3/5 |
| **Memory/Storage** | 4/5 | 5/5 | 3/5 |
| **Total Score:** | 28/30 | 25/30 | 20/30 |

For the microcontroller needed to handle system logic and The Blackbox's display, it is vital it has enough input/output pins to accommodate all components and possesses high processing power. These necessities played a key factor in the decision to utilize the Arduino Mega.

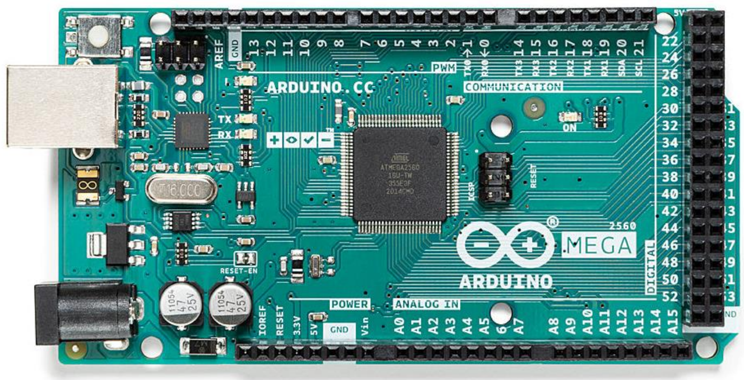


**Figure 3-4: Arduino Mega 2560 Rev3 microcontroller [3]**

The Arduino Mega was chosen as the primary microcontroller for logic due to its ability to meet several critical requirements. Its 54 digital I/O pins and 16 analog input pins provide sufficient capacity to interface with all intended components, such as the LCD display, potentiometers, switches, and additional peripherals. Additionally, the Arduino Mega offers ample storage for program code and processing capability in terms of flash memory, SRAM, and EEPROM. Table 3-2 summarizes the specifications of several microcontrollers considered during the selection process, including the Arduino Mega.

**Table 3-2: Decision Matrix for Microprocessor Selection (Logic Micro)**

| Criteria | Arduino Mega [3] | Arduino Uno [4] | ATmega128 [5] | LPC2106 [6] |
|---|---|---|---|---|
| **Input/Output pins** | 54 digital pins<br>16 analog pins | 14 digital pins<br>6 analog pins | 53 digital pins<br>8 analog pins | 32 digital pins<br>[None] |
| **Clock speed** | 16 MHz | 16 MHz | 16 MHz | 60 MHz |
| **Flash memory** | 256 KB | 32 KB | 128 KB | 128 KB |
| **SRAM** | 8 KB | 2 KB | 4 KB | 64 KB |
| **EEPROM** | 4 KB | 1 KB | 4 KB | N/A |

Together, the Spin Semiconductor FV-1 and the Arduino Mega provide a reliable and efficient platform to deliver high-quality audio processing and reliable system performance.

### 3.3 Subsystems

The Blackbox consists of four subsystems that each contribute valuably to the end goal of the product.

1. Digital FX Systems Design focuses on the design and implementation of software FX like delay and distortion.
2. Software Interface covers presets management, FX controls and ensures a responsive design.
3. User Interface ensures the ability of users to interact with the product through foot pedals, pushbuttons, and LCD screens.

4. Enclosure encompasses the durability of the product itself.

### 3.3.1 Subsystem 1: Digital FX Systems Design

Digital FX Systems Design focuses on applying digital FX (such as distortion or delay) and EQ to a guitar signal, incorporating op-amps to address an impedance mismatch, and fade-in FX intensity to avoid the infamous "pop" sound in the audio processing world [7]. Figure 3-5 shows the Op Amp the team is using for The Blackbox.

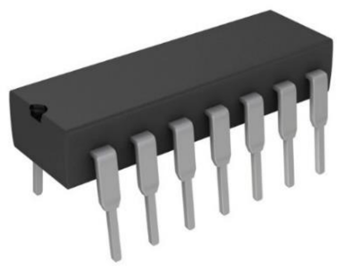

**Figure 3-5: Texas Instruments TL084CN Op Amp [8]**

This particular Op Amp was chosen because it possessed a unique combination of a 10 V supply span, 10 mA of current output, while also being a J-FET amplifier type [8].

The digital pedal's parameters can be manipulated by other subsystems such as the Software and User Interface. The FX themselves are being programmed on the FV-1s, and built using an open-source software called SpinCAD, providing the team with an opportunity to code using a GUI rather than assembly language. How distortion and delay FX operate is demonstrated in Figures 3-6 and 3-7.

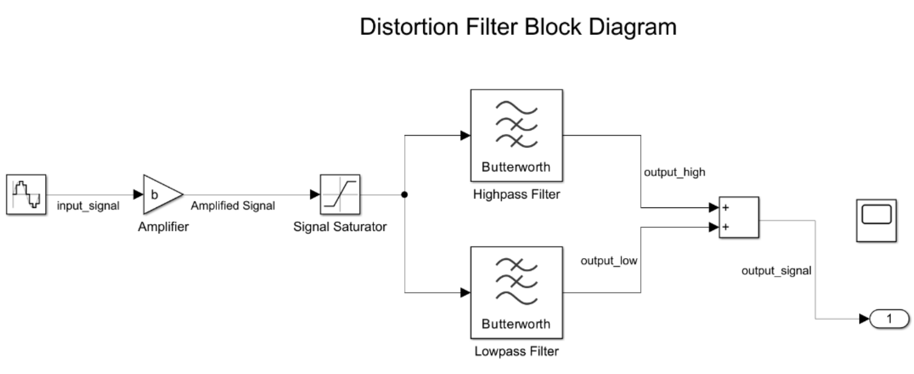


**Figure 3-6: Block diagram of digital distortion FX pedal**

Figure 3-6 demonstrates the steps needed to achieve distortion FX. The first step is amplification of the signal, ensuring it is powerful enough to survive the processing. After which, the signal passes through a saturator, which scales all frequencies in the signal to be confined into a “new number system.” Allowing the next phase of saturation to take place, which is audio clipping. The high waveforms peak and are cut off, split up into their high and low frequencies to eliminate redundancies and noise, before finally arriving at a mixer to combine the two signals [9].

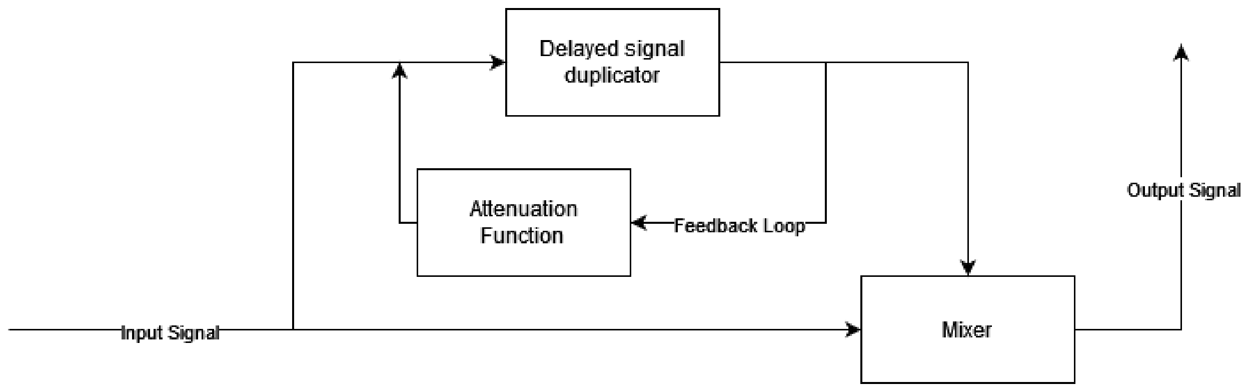


**Figure 3-7: Block diagram of digital delay FX pedal**

Figure 3-7 shows how the delay FX loops and how the feedback dies out. The attenuation function is an optimizer that binds the weights of a decaying mathematical function to a signal, which results in a particular number of repetitions [10].

### 3.3.2 Subsystem 2: Software Interface

The Blackbox uses extensive programming to allow for an immediate response time when the user interacts with the product. It offers tone preset management to allow for the user to switch between delay and other presets in an instant. The product also has effect controls so that any effect can be chosen at will. Figure 3-8 outlines the logic of The Blackbox’s editing, saving, and pedal-selection systems.

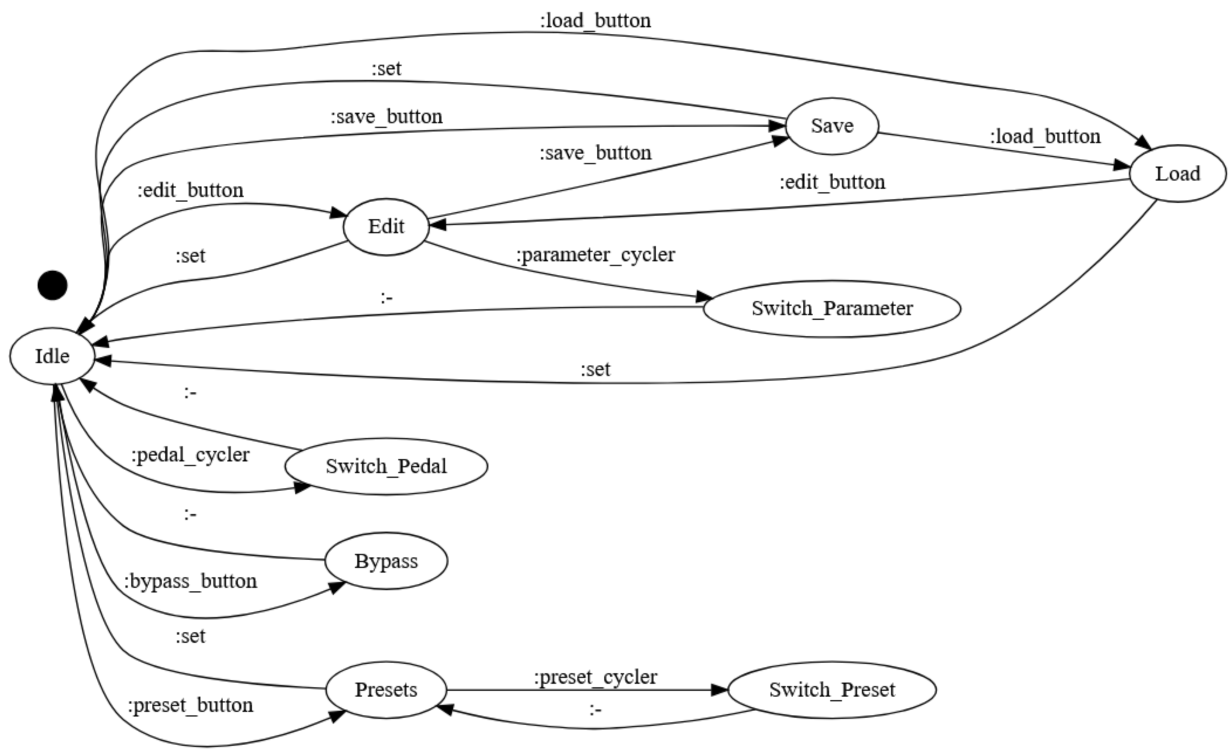


**Figure 3-8: FSM Logic Diagram**

Figure 3-8 depicts the outcome of specific user inputs given the current mode the user is in. This system allows the user to interact with The Blackbox and switch between different active modes in order to control the FX parameters accordingly.

### 3.3.3 Subsystem 3: User Interface

User Interface is the implementation of the controls of The Blackbox. The product allows the user to select from a range of effects using only the foot. There are no hands involved in the user interface. The Blackbox prototype uses 3D printed rocking foot pedals to simulate the final design. To save time the file for the 3D print is a publicly available file from thingverse.com.

**Figure 3-9: Images of 3D Printed Pedal [11]**

This 3D print allows for a full range of motion in conjunction with a potentiometer inside the main gear. This allows the pedal to act as an input for the FX activation.

The first option for the UI is a much more input heavy design. There are specific buttons for the save and load options. This design is seen in Figure 3-10 shown below.

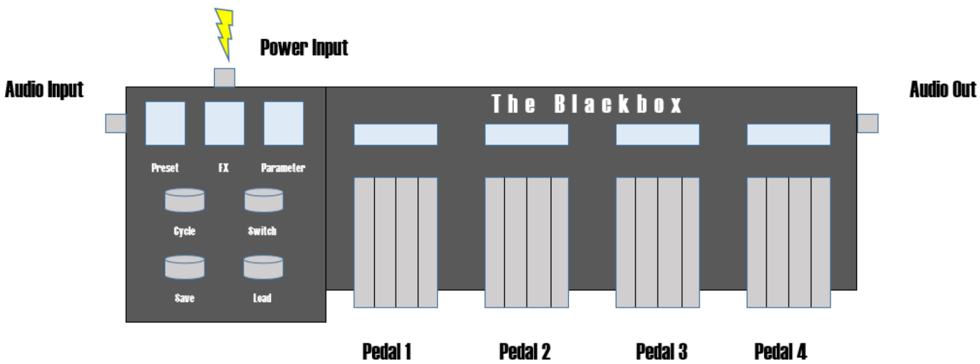


**Figure 3-10: Diagram of UI Option 1**

The approach functions as a hub of separate programmable expression pedals each connecting to a small LCD for visuals. The hub is connected to a separate pedal for programming which includes four pushbuttons: Cycle and Switch, which allow the user to select whether they are editing the Preset, FX, or Parameter values and select which value they want, and Save and Load, which handle the preset system by saving or loading the current pedal configuration (analog or digital). This system layout is demonstrated above in Figure 3-9. The placement of the smaller LCDs makes it awkward to include bypass switches as well.

The other option for the UI design is a more user-friendly design with a less complex range of controls shown below in Figure 3-11.

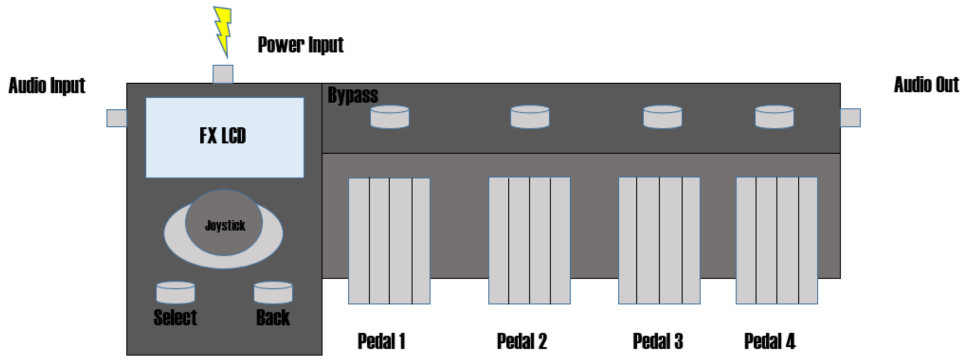


**Figure 3-11: Diagram of UI Option 2**

This option is intended to use a more compact and uniform design. This option involves the use of an effects hub with a large LCD screen for displaying the current effect. This hub is connected to a pedal that shifts in the desired direction, like a joystick on a controller. For the purposes of an MVP, the team's Design 1 product demo uses an implementation closer to a Directional Pad, which uses pushbuttons to replicate the up, down, left, and right inputs of a joystick. This approach is better suited for the design because a joystick offers 360 degrees worth of direction, which is not particularly needed for the design, which only utilizes four directions at most.

Also, a decision matrix helps determine which potentiometer works best for these microcontroller specifications. The potentiometer adjusts parameters such as tone, volume, and FX strength. Three potentiometers are compared using price, resistance value, and durability to help identify the most suitable option for the design as shown in Table 3-3.

**Table 3-3: Decision Matrix for Potentiometer**

| Criteria | CTS Control Pots | Bourns | Nobel |
|---|---|---|---|
| **Price** | $6.85 | $3.97 | $20 |
| **Resistance Value** | 250K | 25k-50k | 50k |
| **Durability** | Good | High | High |

The decision matrix favors Bourns because the product is cheaper with the perfect amount of resistance needed for the FV-1. This choice allows the potentiometer to interact seamlessly with the chip.

**Figure 3-12: KAISH Soft-click Switch [12]**

Figure 3-12 displays a switch that can be fully operated by the user's foot to engage or disengage FX's being used at that moment. It is designed with the purpose of longevity and high use, which aligns with the team's target audience

**Figure 3-13: Switchcraft Audio Jack [13]**

Figure 3-13 shows the type of audio jack being used by The Blackbox. This product helps pass the audio signals to and from the pedals.

### 3.3.4 Subsystem 4: Enclosure

Most parts inside of The Blackbox are extremely delicate and require care and shielding to maintain over a long time. One of The Blackbox's main goals is offering extreme lifetime value to the product through the Enclosure subsystem. A performer is not going to be especially concerned with the amount of force that is being applied to a guitar pedal amid performance. The Enclosure subsystem ensures that the exterior of The Blackbox is rigid and durable enough to withstand the weight and pressure of a person stomping on it.

The Blackbox meets IP-55 water and dustproof standards. This quality allows for The Blackbox to be used in different situations including the rain, which also means it is impervious to spills. Some of the ways to make a circuit water resistant are the following:

1. Potting (encasing entire circuit in resin)
2. Conformal coating for the PCB
3. Gaskets on switch mounts
4. Enclosures around guitar jack mounts
5. Plates of cork along the bottom to soak up any possible internal leaking [14]

These innovations are not within the scope of Design I and is instead something intended for Design II.

## 3.4 Level 2 Prototype Design

The end goal for The Blackbox's implementation includes an aluminum casing (waterproofed using cork boards and gaskets), professional-grade foot pedals, and a large database of digital FX to place into a similarly large potential FX chain. In the pursuit of a minimum viable product, however, the team's Design I prototype integrates a less-complex version of many of these features; The Blackbox uses a 3D printed casing and foot pedals, incorporating each of the FX, UI, and implementation subsystems in isolation; though a more complete prototype could run a larger FX chain, the prototype possesses three slots, with 3 adjustable parameters for each.

### 3.4.1 Level 2 Diagram

The prototype functionality overview is shown below in Figure 3-13. The different types of arrows in the diagram correspond with different types of connections, as described in the legend: solid lines represent audio data, which passes into The Blackbox using a buffer, passes through each of the Spin FV-1 DSPs in sequence, and passes out through another buffer; power (dotted line) passes from a standard power outlet at 120 V AC, into a wall wart that converts it to 12 V DC, and into the Arduino Mega, which has 5 V and 3.3 V output power pins to power the FV-1s and LCD Display; control lines pass from the user input into the Mega as well, and out into each of the FV-1s (to control parameter select and potentiometer pins) and the LCD (with display data) as shown in Figure 3-13.

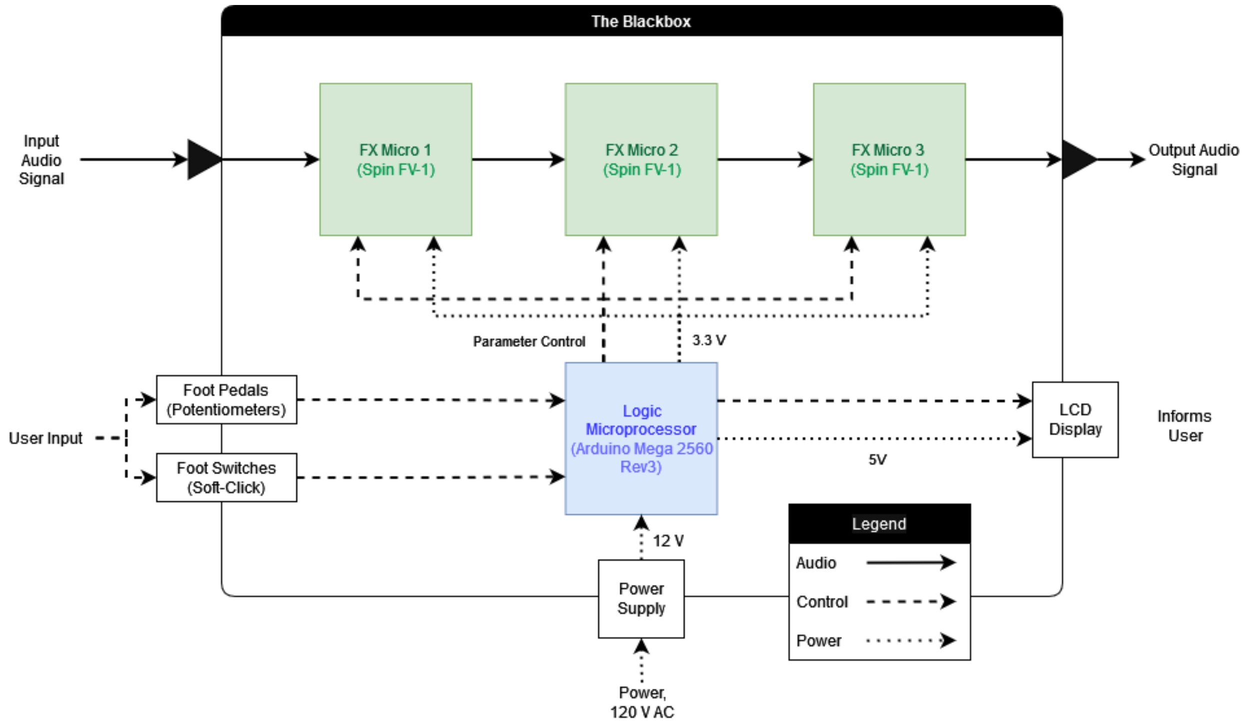


**Figure 3-14: Level 2 Diagram of The Blackbox**

Figure 3-14 displays how The Blackbox takes in and sends out information. It also shows the power required to make each section of The Blackbox function.

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## 3.6 APPENDIX

**Table 3-5: Trade-off Table of Analog Versus Digital Distortion**

| Analog Distortion | | Digital Distortion | |
|---|---|---|---|
| **Pros** | **Cons** | **Pros** | **Cons** |
| • Simpler effect execution as chips can be bought<br>• Iconic sound | • Complex circuit layout<br>• Less effect variation<br>• Simulation is more difficult<br>• Preset implementation becomes much more difficult<br>• Can introduce more noise from components | • Simpler circuit layout<br>• Much larger effect variation<br>• Simulation and testing are automatic given its a digital filter<br>• Preset logic system follows naturally | • More challenging implementation<br>• Limited by the microcontroller used to implement it<br>• Somewhat controversial sound |

**Table 3-6: Trade-off Table of Analog Versus Digital EQ**

| Analog EQ | | Digital EQ | |
|---|---|---|---|
| **Pros** | Cons | Pros | Cons |
| • Smoother, more musical sound | • More susceptible to noise and distortion from components<br>• Higher precision components drive up price | • Higher precision of parameters<br>• Consistent Implementation | • More structured sound |

**Table 3-7: Decision Matrix for FX Pedal Selection**

| FX pedals | Average # of parameters | Analog or Digital | Simplicity of implementation | How commonly is it used? | Total score |
|---|---|---|---|---|---|
| **Overdrive** | 4 | Both | 3/5 | 5/5 | 7 |
| **Distortion** | 4 | Both | 4/5 | 5/5 | 8 |
| **Fuzz** | 2 | Both | 3/5 | 3/5 | 6 |
| **Chorus** | 3 | Both | 3/5 | 3/5 | 6 |
| **Tremolo** | 3 | Both | 5/5 | 2/5 | 7 |
| **Compressor** | 3 | Both | 3/5 | 1/5 | 4 |
| **Delay** | 4 | Digital | 5/5 | 4/5 | 9 |
| **Reverb** | 4 | Digital | 5/5 | 3.5/5 | 8.5 |
| **Tuner** | 1 | Digital | 2/5 | 5/5 | 7 |
| **WAH** | 1 | Both | 4/5 | 2/5 | 6 |
| **Parametric EQ** | 5 | Both | 3/5 | 5/5 | 8 |

**T3.1.1able 3-8: “Venn” Diagram of Design Option 1 and Design Option 2**

| Design Options for The Blackbox | | |
|---|---|---|
| **Design Option 1:** | **Common Between Designs:** | **Design Option 2:** |
| • Multiple small LCD displays and LEDs to indicate menu options<br>• 3-length FX chain, any longer would compromise UI design<br>• Options for both analog and digital<br>• Smaller FX pedal library<br>• "Cycle and Switch” Foot-Button-Based UI | • LCD Screen(s)<br>• 3 Expression Inputs<br>• Preset Options<br>• Same microcontrollers<br>• The FX implemented are Distortion, Delay, and EQ | • Singular Large LCD display<br>• Not limited to the length of the FX chain<br>• Much larger FX pedal library, leading to an entirely digital implementation being necessary<br>• Joystick-Based UI |