EEL 4924 Electrical Engineering Design
(Senior Design)

Final Design Report

April 19, 2011

Project Title:

Gator Distortionator

Team Name:

The Screamers

Team Members

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Project Abstract:

Our project consists of several analog music effect (distortion and compression) circuits with digital control. It allows a user to switch between several analog circuits in real time and control them from the same interface. Users are also be able to recall and save their favorite settings as presets, and automate or remotely control settings using MIDI commands.

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Project Features

- One analog compression effect stage first in the signal path
- Four switchable analog distortion effects second in the signal path
  - Three based on classic analog circuits
  - One designed from scratch
- Settings can be permanently saved as "patches" containing:
  - The current setting of the compression knobs (Sustain and Level)
  - Whether the compressor is active or bypassed
  - The current setting of the distortion knobs (Gain, Tone, Level)
  - Whether the distortion stage is active and, if so, which distortion circuit is selected
- Current settings are displayed on a large LCD screen.
- Each stage can be bypassed or activated by foot switches for added control while playing the guitar. Patches can also be scrolled by foot switches.
- All patch parameters are remote controllable and automatable by MIDI commands.
- A 9 V power output can power other guitar effect pedals.

Technical Objectives

The primary objective of this project is to create a digitally-controlled distortion effect with a completely analog audio signal path. There is also a power component of this project to create a power supply capable of delivering the necessary voltage levels needed. The digital, analog, and power components are detailed in the following sections along with the software component with a whole system block diagram pictured below in Figure 1.

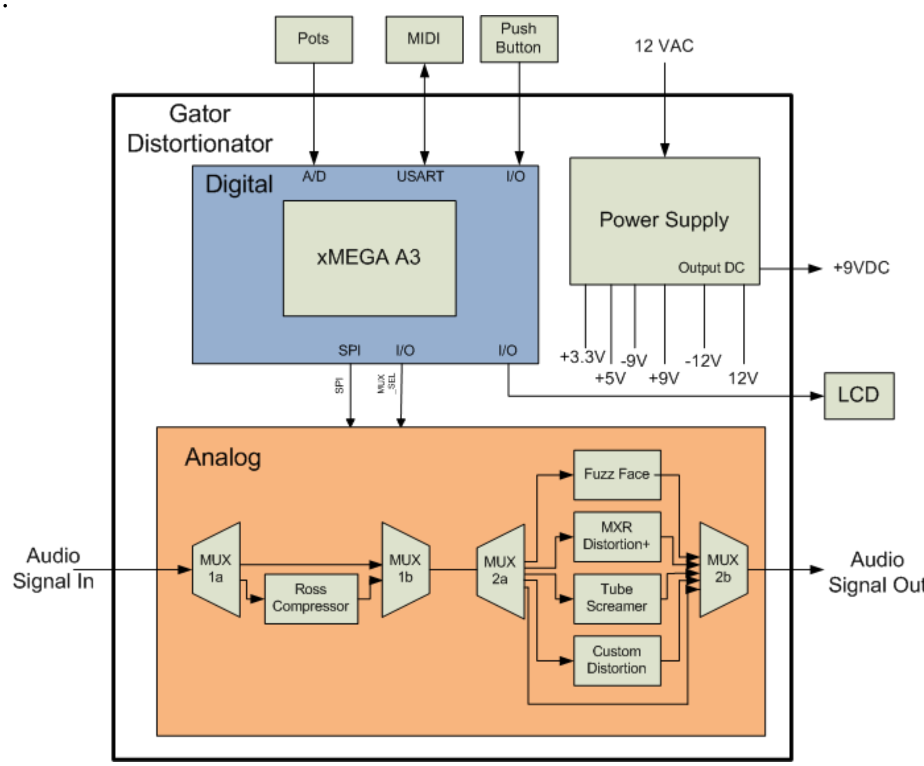


Figure 1 - High Level Block Diagram

Hardware Digital Component

The product is be controlled digitally by an Atmel XMEGA microcontroller. This microcontroller is used to capture inputs from push buttons and potentiometers wired to the analog to digital channels.

The microcontroller is also used to drive a character LCD screen to provide user feedback on which compression and/or distortion circuit is selected.

The analog signal path is controlled by analog MUXes, which is controlled digitally through parallel I/O. These I/O lines are connected to GPIO pins on the microcontroller.

The analog circuitry also contains several digital potentiometers. They are controlled digitally through the SPI serial protocol. The data and clock lines are connected to a hardware SPI port on the microcontroller and the chip select lines are connected to GPIO pins on the microcontroller.

The onboard EEPROM in the microcontroller is used save user settings so that they can be preserved when the device is not powered.

In addition a UART port on the microcontroller is used to accept MIDI commands from a computer or other MIDI device.

A block diagram of the Digital Component is pictured below in Figure 2.

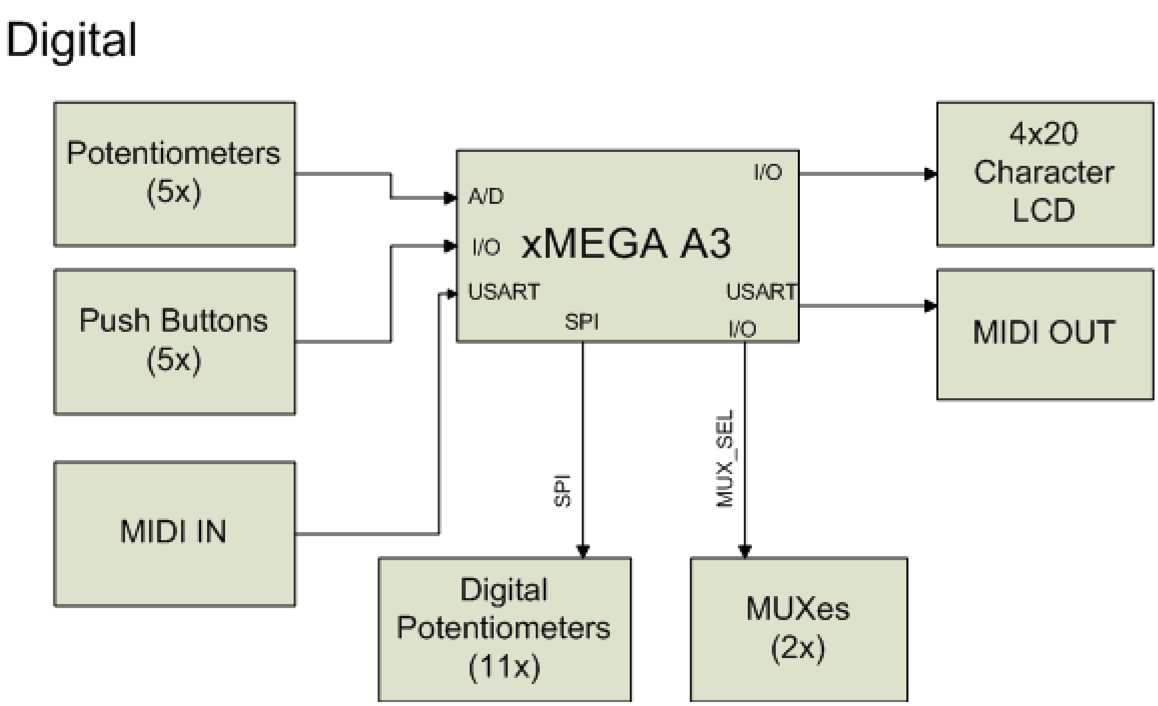


Figure 2 - Digital Block Diagram

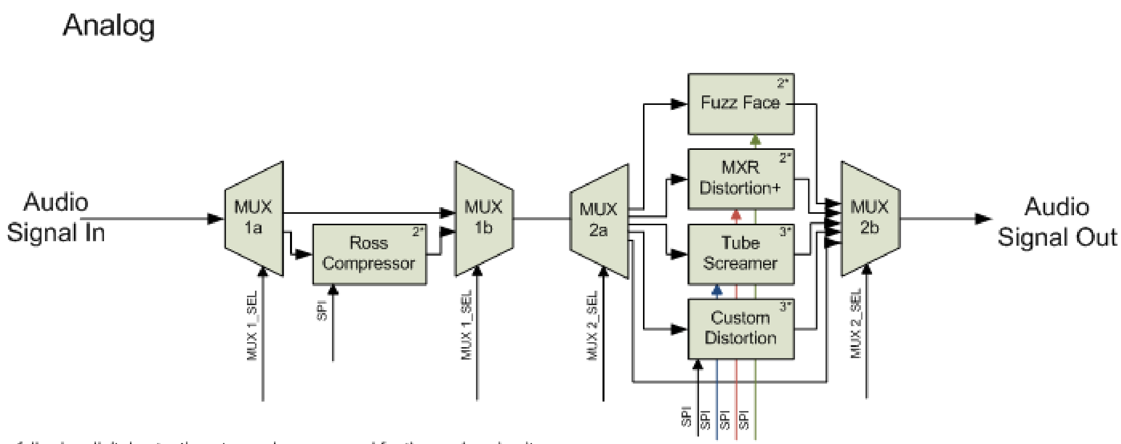
Hardware Analog Component

From the primary objective of having a purely analoug signal path, only analog distortion and compression circuits will be implemented. The signal path is pictured in a block diagram in Figure 3.

The design includes one compression circuit that may be bypassed followed one of four distortion circuits (or a bypass). The switching between distortion circuits will be accomplished by analog multiplexers (MUXes).

The compression circuit and three distortion circuits are based on classic analog circuits. However all of the circuits have been modified to use digital potentiometers. The design does aim to closely matching the sound and performance of the original circuits.

The fourth distortion circuit is a unique design from scratch based around the values of the available digital potentiometers and have acceptable sound quality.



*The following digital potentiometers values are used for the analog circuits:
Ross Compressor: 2x 100k; Fuzz Face: 1x 100k, 1x 10k; Distortion+: 1x 100k, 1x 10k; Tube Screamer: 2x 100k, 1x 10k; Custom Circuit: 2x 100k, 1x 10k

Figure 3 - Analog Block Diagram

Hardware Power Supply Component

This project also has an onboard power supply capable of delivering the necessary voltage levels needed. A block diagram of the onboard power supply is shown in Figure 4.

The power supply is implemented by using an AC wall wart transformer to step down the voltage offboard. Then, using half-wave rectification, +/– 12 VDC are generated. From the +/- 12 V, linear regulators are used to step sown the voltage to +9 V, -9 V, +5.0 V and +3.3 V supplies. The +/- 12V levels are needed for the analog MUXes and digital pots. The +/- 9V levels are needed for the analog distortion circuits and the compression circuit. The +5.0 V level is needed for the MIDI interface, and the 3.3V level is used for the microcontroller.

The +9V supply and ground are routed to a power out jack to provide external power to any other components that the user might have that use +9V.

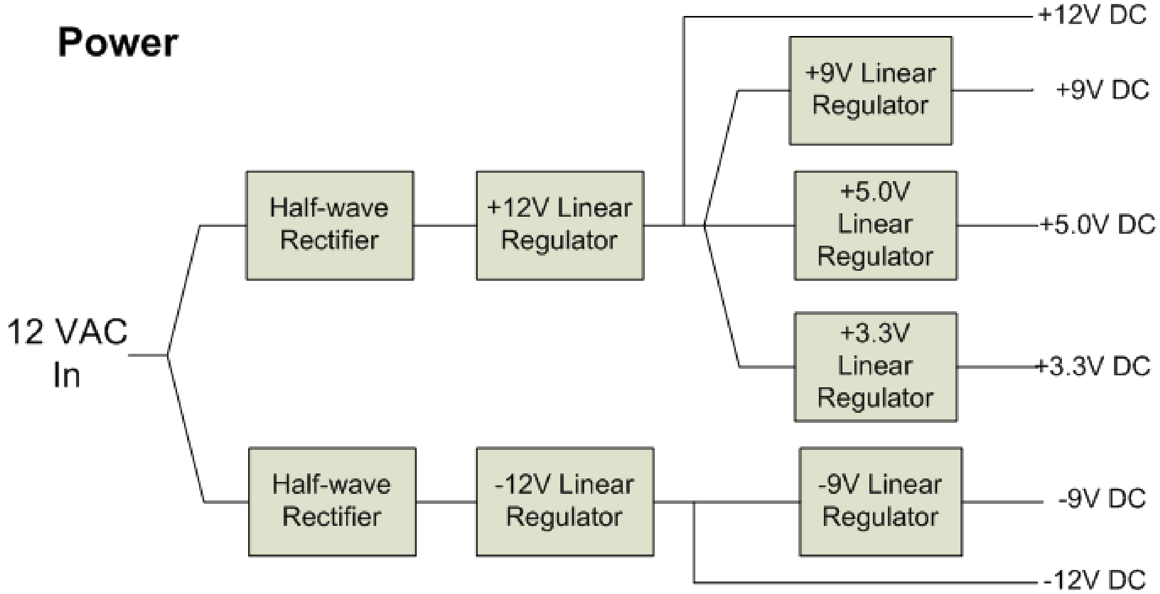


Figure 4 - Power System Block Diagram

Software Component

The project is designed to be user friendly with useful software. A flow chart of the current software is shown in Figure 5.The A/D channels are always be on to detect any change from a user and will update the digital pot to the new valve and output the change in real-time to the LCD.

Software also detects if a button has been pressed to save to current pot setting to memory. Another set of buttons control advancing to the next preset, advancing to the previous preset, bypassing the compression circuit, or bypassing the distortion circuit.

MIDI commands are accepted and interpreted to control the system remotely. The MIDI control codes are listed in.

Command	Byte 1	Byte 2	Byte 3
Compressor Bypass	0xB0	0x14	0x01 (On), 0x00 (Off)
Distortion Bypass	0xB0	0x15	0x01 (On), 0x00 (Off)
Left Scroll	0xB0	0x16	0x00
Right Scroll	0xB0	0x17	0x00
Compressor Sustain	0xB0	0x18	0x00-0x7F
Compressor Level	0xB0	0x19	0x00-0x7F
Distortion Gain	0xB0	0x20	0x00-0x7F
Distortion Tone	0xB0	0x21	0x00-0x7F
Distortion Level	0xB0	0x22	0x00-0x7F

Table 1 - MIDI Commands

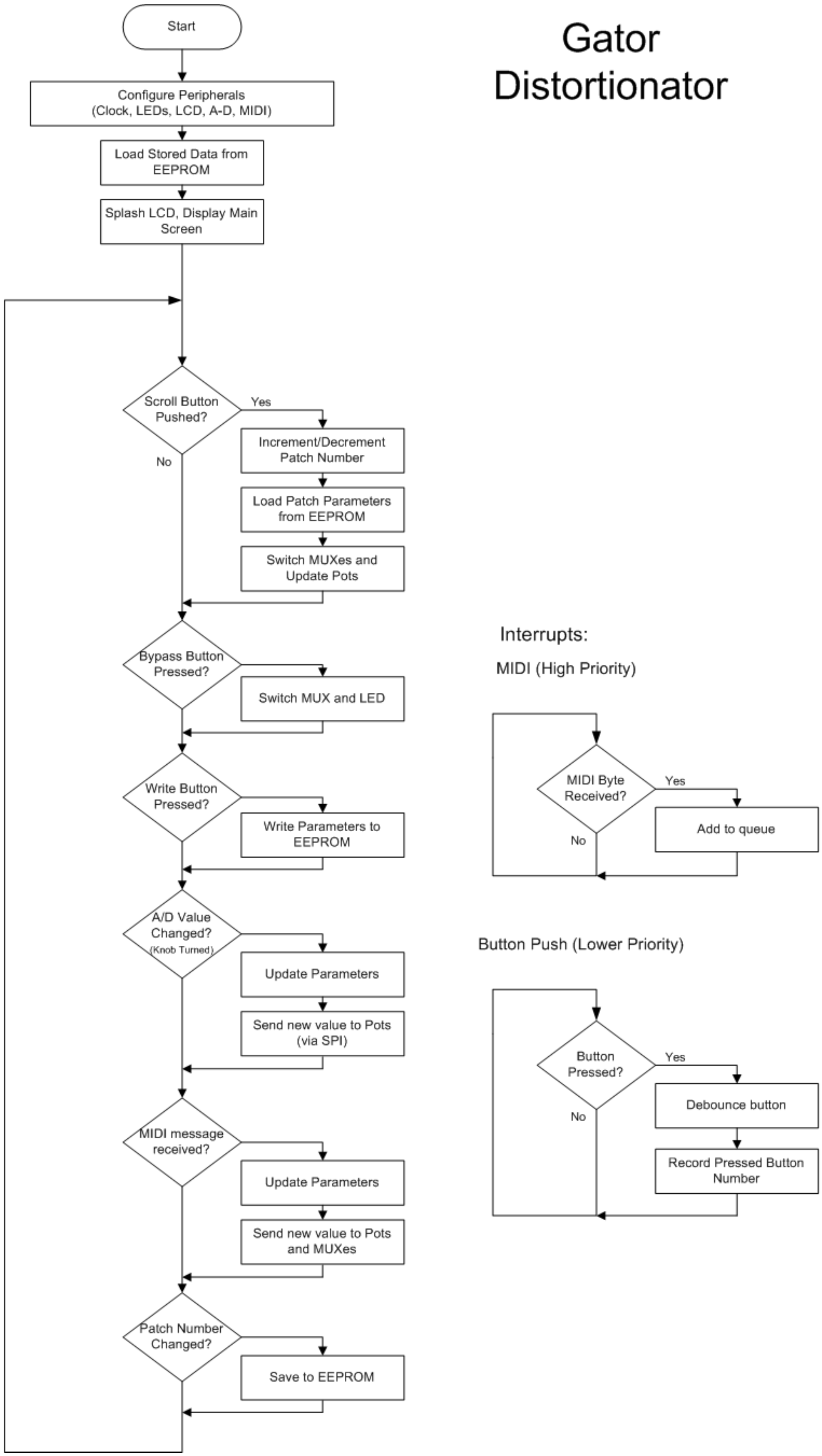


Figure 5 – Software Flow Chart

Cost Objectives

A main goal of integrating many analog circuits into one box is to reduce cost. In a distortion pedal, most of the cost is the PCB, assembly, enclosure, potentiometers, and jacks. From our previous experience, the cost to build one small analog distortion effect pedal is $50-$70. The actual price of one Gator Distortionator is about $235, not including the labor to assemble and test it. If a run of 10-25 units were made, a reasonable selling price might be $300 per unit. Table 2 shows the Bill of Materials for one unit. This cost of one unit does not reflect the overall development costs, which is and additional few hundred dollars.

Part of System		Manufacturer	Description	Quantity	Price Per Unit	Total Price
PCB		Advanced Circuits	2 layer PCB	1	$ 60.00	$ 60.00
Digital Control		Atmel	Xmega64A3	1	$ 7.17	$ 7.17
		Vishay Siliconix	16-Ch/Dual 8-Ch High-Performance CMOS Analog Multiplexers	2	$ 8.65	$ 17.30
		Analog Devices	Compact +30 V / ±15 V 256-Position Digital Potentiometer	12	$ 4.14	$ 49.68
			741 Op-Amp	1	$ 0.42	$ 0.42
			Various Passive Components (Resistors and Capacitors)	var	$ 1.00	$ 1.00
Physical Interface			Potentiometer	5	$ 0.80	$ 4.00
			Knobs	5	$ 0.60	$ 3.00
			Push button	1	$ 1.00	$ 1.00
			Foot Switches	4	$ 1.25	$ 5.00
		Newhaven Display	LCD - 4x20 Character	1	$ 21.27	$ 21.27
			LCD - Contrast Pot	1	$ 0.48	$ 0.48
			1/4in Audio Jacks	2	$ 1.02	$ 2.04
			2.1mm Power Jacks	2	$ 1.17	$ 2.34
			MIDI Jack	2	$ 1.51	$ 3.02
			Power Switch	1	$ 0.88	$ 0.88
			Enclosure	1	$ 22.53	$ 22.53
Power		Texas Instruments	Linear Regulators - Standard 3.3 V 500mA Fix Pos Voltage Regulat	1	$ 0.70	$ 0.70
		STMicroelectronics	Linear Regulators - Standard 12V 1.5A Negative	1	$ 0.70	$ 0.70
		ON Semiconductor	Linear Regulators - Standard 12V 1A Positive	1	$ 0.70	$ 0.70
		STMicroelectronics	Linear Regulators - Standard 9.0V 1.0A Positive	1	$ 0.70	$ 0.70
		Fairchild Semiconductor	Linear Regulators - Standard 9.0V 1.0A Negative	1	$ 0.70	$ 0.70
		Vishay	Rectifiers Vr/400V Io/1A	2	$ 0.02	$ 0.04
			Capacitors	4	$ 0.20	$ 0.80
		Triad Magnetics	Plug-In AC Adapters 120 to 12VAC 1.0A 17W	1	$ 8.30	$ 8.30
Analog Circuits						
	Fuzz Face		Matched 3AX31C Ge Transistor Pair	1	$ 9.60	$ 9.60
			Various Passive Components (Resistors and Capacitors)	var	$ 0.40	$ 0.40
	MXR Distortion +		741 Op-Amp	1	$ 0.42	$ 0.42
			1N270 Ge Diodes	2	$ 0.50	$ 1.00
			Various Passive Components (Resistors and Capacitors)	var	$ 0.50	$ 0.50
	Tube Screamer		2N3904 NPN Transistor	2	$ 0.02	$ 0.04
			RC4558 Op-Amp	1	$ 0.70	$ 0.70
			1N914 Signal Diode	2	$ 0.02	$ 0.04
			Various Passive Components (Resistors and Capacitors)	var	$ 0.80	$ 0.80
	Original Distortion		2N5088 NPN Transistor	5	$ 0.10	$ 0.50
			Various Passive Components (Resistors and Capacitors)	var	$ 1.50	$ 1.50
	Ross Compressor		2N5088 NPN Transistor	5	$ 0.10	$ 0.50
			CA3080 Operational Tranconductance Amplifier	1	$ 3.00	$ 3.00
			1N914 Diodes	2	$ 0.02	$ 0.04
			2kOhm Trimmer Potentiometer	1	$ 0.48	$ 0.48
			Various Passive Components (Resistors and Capacitors)	var	$ 1.00	$ 1.00
						$ 234.29

Table 2 - Bill of Materials

Technology Selection

Choice of analog circuits and components: The analog circuits were chosen because they represent several approaches to musical clipping with different levels of circuit complexity. Additionally, each of these circuits is highly sought after for its sound. Original components for the circuits were used where possible and when important to the performance of the circuit.

- The Fuzz Face was chosen as a simple circuit employing transistor clipping. It uses two germanium transistors, one of which is poorly biased, to clip the signal. We opted to purchase the original germanium parts because although germanium devices behave similarly to silicon in their linear region, they have a softer clipping characteristic.

- The Distortion+ is an op-amp based circuit using shunt diode clipping. Here, we also chose to use the original 1n270 germanium diodes because of their different distortion character. Also, the germanium diodes clip at .3V vs. .7V for silicon, so using silicon diodes would lessen the amount of distortion unless the circuit were redesigned.

- The Tube Screamer is an op-amp based circuit that uses diodes in the op-amp feedback path. Unlike the previous two circuits, it also includes a tone control. This is implemented with an active filter.

- The most complex circuit is the Ross Compressor. It uses the CA3080 operational transcoductance amplifier to control the base current of a transistor to form a voltage controlled amplifier (VCA).

Floor-based form factor: We chose to incorporate all of the electronics into a box that operates like a large guitar effect pedal. This form factor has been the standard for guitar effects for over 50 years because it allows the guitarist control of the effect while playing guitar with both hands. This also allows guitarists to incorporate the device into their existing pedal boards.

Custom-designed bipolar power supply: We chose to design a custom power supply for several reasons. We wanted to use a +/- 12V supply to ensure that the digital potentiometers and analog MUXes would not distort the signal. Bipolar power supplies are not available as inexpenisive wall warts, so it is more practical to design a simple one from scratch using a 12 VAC wall wart.

Digital Potentiometers (AD5290): These are the only commonly available digital potentiometers that accept a supply over 5V. They are much more expensive than others, but redesigning the distortion circuits to use smaller supplies would dramatically change the sound (because of the op-amp performance, diodes clipping at a fixed voltage, etc.), which conflicts with our design objectives. These digital pots allow us to digitally control the circuits in the least invasive way possible.

Dual 8-to-1 Analog MUXes (DG407BDJ): We selected these MUXes because it was easy to obtain samples in DIP form and they offer very low on-state resistance. Like the potentiometers, they are capable of running on +/- 12 V supplies. They also help to minimize the number of I/O lines needed because they switch both MUXes in the package with the same select lines, switching the input and output of the effects in tandem. The main drawback of these components in a high price, so this selection is subject to change if we find a cheaper solution that will maintain high performance.

ATxMega Microcontroller: We chose the ATxMega192A3 microcontroller because we are familiar with it and find it easy to use. It has abundant parallel I/O for the MUXes and LCD, many A/D channels for the potentiometers, SPI for the digital potentiometers, UART for MIDI receive, and EEPROM to store the patches.

Future Work

There is an issue of some background noise in the analog circuitry, both compression and distortion, as well as some bleeding of digital noise into the analog signal path. Work has been preformed to remove as much noise as possible. However a new revision of the PCB will need to be designed and assembled to improve sound quality any further than the current performance.

A future revision of the PCB will include isolated digital and analog grounds, bypass capacitors on the digital potentiometers, and improved signal routing. A more robust power supply will also be implemented to cause less interference.

Several additional features can be implemented including: MIDI Out control, USB control, and more distortion circuits (up to 7 total).

Division of Labor

The division of labor for our project is detailed in the Member Responsibility Table located below.

Item	Quinn Martin	Jeff Caldwell
Redesign analog compression circuit for digital pots	100%	0%
Redesign 3 analog distortion circuits for digital pots	100%	0%
Design analog distortion circuit from scratch	100%	0%
Design power supply	100%	0%
Interface MIDI to uC	65%	35%
Analog schematic entry	100%	0%
Interface character LCD to uC	0%	100%
Interface potentiometers to uC A/D	0%	100%
Interface pushbuttons to uC	0%	100%
Interface MUXes and digital pots to uC	0%	100%
EEPROM Software	0%	100%
Digital schematic entry	0%	100%
Software design	50%	50%
PCB design	50%	50%
Mechanical design	50%	50%
Component selection	50%	50%

Table 3 - Member Responsibility Table

Project Timeline

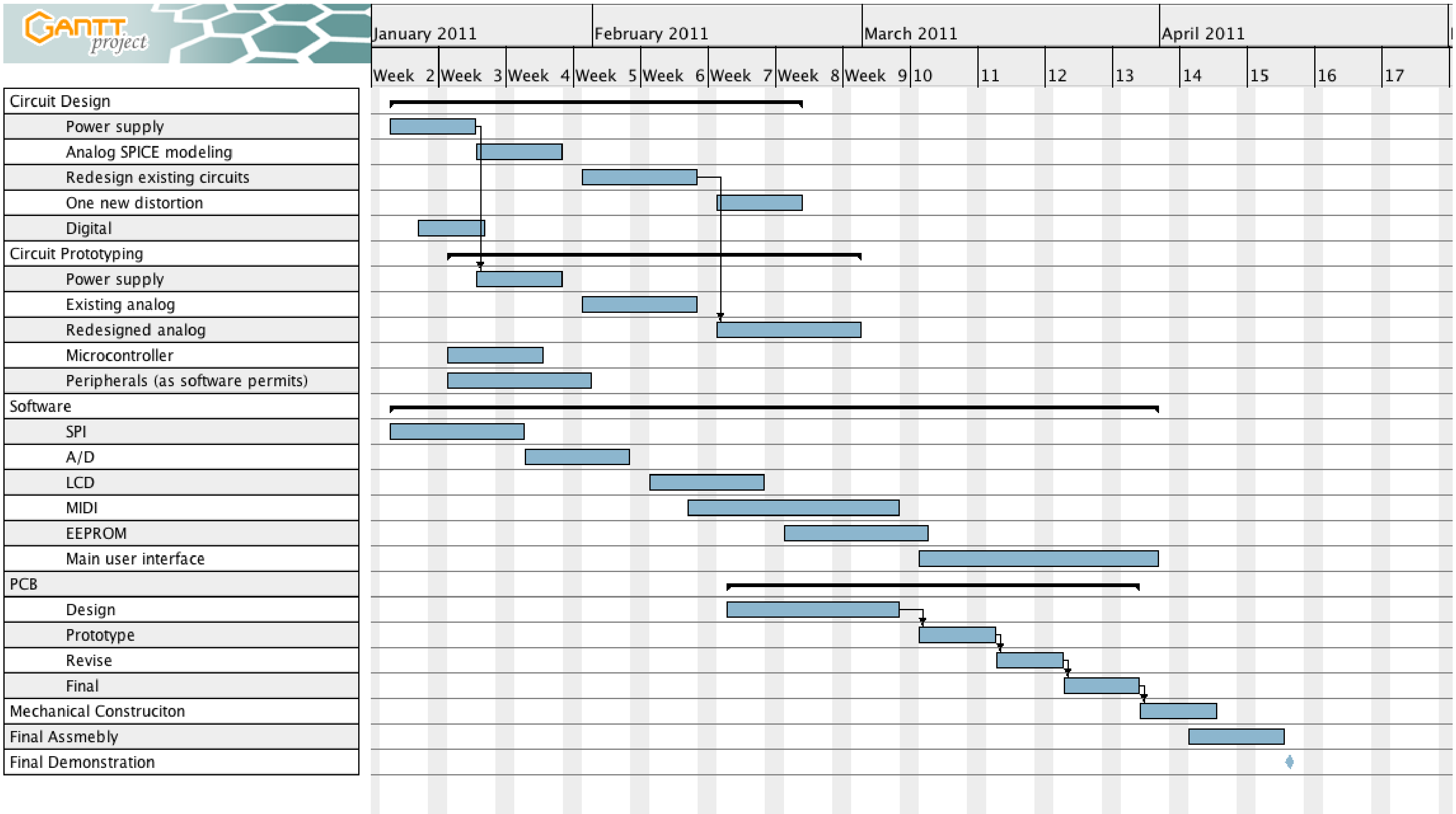


Figure 6 - Gantt Project Timeline

Appendix - PCB Layout