REALLY AWESOME DIGITALLY CONTROLLED ANALOG SYNTHESIS TOOL,

limited edition

(RADCASTle)

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Executive Summary

Classic analog synthesizers produced audio outputs with desirable traits of unpredictability and sonic imperfection. Later digital synthesizers offered several technical advantages in terms of convenience, ease of use, and a high degree of control. However, digital electronics could not faithfully replicate the imperfect sounds produced by older analog synthesizers. As a result, there has been a shift back to analog synthesis techniques.

The Really Awesome Digitally Controlled Analog Synthesis Tool, limited edition (RADCASTle) uses digital microcontrollers to support digital MIDI input and advanced signal routing. The RADCASTle employs classic analog audio synthesis hardware including a voltage-controlled oscillator, filter, and amplifier. The RADCASTle makes use of current microcontroller technology, low-cost components, and an innovative internal audio patching system to create an inexpensive alternative to existing digital/analog hybrid synthesizers.

The RADCASTle employs a MIDI input to create a monotonic analog audio output. There is a user interface on the device to allow precise control of analog filtering, audio synthesis, and internal signal routing.

The current state of the project has all its hardware components working. Software is working to some degree, but still needs to fully debuegged.

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1. Introduction

Within the domain of synthesizers, there has been a recent resurgence of interest in analog sounds, due to a cultural backlash against the perceived predictability of digital waveform generation [1]. Analog synthesis offers unique sounds by virtue of the inherent imperfections present in analog circuitry.

1.1 Objective

The purpose of the RADCASTle project is to integrate analog audio synthesis techniques with digital control circuitry in order to create a versatile synthesizer device. The RADCASTle will combine the technical and creative strengths of digital and analog audio synthesis for musicians and synthesizer enthusiasts.

1.2 Motivation

Musicians and synthesizer enthusiasts desire access to traditional analog sounds while maintaining the flexibility afforded by current digital synthesizer technologies such as ease and precision of control, as well as programmability through MIDI interfaces. The RADCASTle makes use of current microcontroller technology, low-cost components, and an innovative internal audio patching system to create an inexpensive alternative to existing digital/analog hybrid synthesizers.

1.3 Background

The first synthesizers of the 1960s and 1970s were purely analog. Manual patching had to be done between the various modules of the synthesizers, making them difficult to configure. This was especially arduous during live performances, where musicians had to patch their synthesizers between songs. With the advent of inexpensive microcontrollers, synthesizers were able to store patching information, easing the patching process for musicians. In the 1980s, digital sound synthesis technology became available, allowing synthesizers to digitally generate sound. This allowed the creation of more compact synthesizer designs which were able to generate very precise pitches. By the 1990s, musicians renewed their interest in the more traditional sound of analog synthesizers, due to the slight imperfections and quirks not available from digital synthesizers. This created a new market mixing traditional analog circuits with modern microcontroller technology.

Other designers have pursued creating analog synthesizers controlled by digital means. Some of the most popular models include the Oberheim OB-Mx, Moog Voyager, Little Phatty, and the Prophet 08 [1]. Much of the underlying analog circuitry, including the voltage controlled oscillator (VCO), filter (VCF), and amplifier (VCA) are based off older designs. The basic building blocks include premade circuit boards for the VCO, VCF, and VCA as well as microcontrollers to control these components.

2. Project Description and Goals

A digitally controlled monotonic analog synthesizer will be designed using several third party components. The sound synthesis will be performed using a VCO, VCF, and three

VCAs. The parameters of these components will be controlled using a custom Digital Control Board (DCB). A custom System Interface Board (SIB) bridges the DCB and analog boards.The patching itself will be controlled by a master microcontroller on the DCB interfaced with a routing control physical user interface. Filter and amplification parameters will be controlled by a microcontroller using a combination of user interface elements and MIDI input. These individual interface elements set separate parameters with rotary encoders and a dedicated slave microcontroller. The resulting synthesizer will be designed with the following goals.

- Generate a tone
- Allow configurable filtering of the tone
- Support MIDI pitch control input
- Support MIDI velocity/volume control input
- Audio mixing of various VCO/VCF outputs
- Dynamic patch routing
- Modular interface for VCF

The total materials cost of the RADCASTle will total between $200 and $300. The target users of the RADCASTle are musicians and synthesizer hobbyists.

3. Technical Specification

The original design called for the VCO, VCF, and VCA to be purchased from a third party vendor. Each will be soldered together by the project team and integrated onto a single motherboard. At least two microcontrollers will be used. The primary microcontroller (or set of microcontrollers) will interpret MIDI and user interface inputs and will be responsible for directly controlling the VCO, VCF, and VCA. In addition, routing microcontroller will manage the signal routing switches.

The final designed used a VCO, VCF, and six VCAs from a third party vendor. These analog boards are linked together and to the master microcontroller on the DCB through the SIB. A master microcontroller communicates with digital-to-analog converters to set the parameters on the analog boards. The master microcontroller also communicates with slave microcontrollers whose function is to transmit user input of these parameters.

The VCO will have a single logarithmic pitch input and will output rectangle, sawtooth, triangle, and sine waves to the signal router. The pitch input will be controlled by the primary microcontroller. Table 1 shows the specifications met by the VCO.

Table 1 – Specifications for the VCO

Input	**Target**	**Acutal**
Control voltage	1 V/octave control voltage	1 V/octave
Range	3 octave range	4 octave range
Output		
Waveforms	Rectangle, sawtooth, triangle, and sine waves	(same as target)
Power supply		
Supply voltage	+/- 15 V	+/- 12 V
Current draw	< 30 mA	~23 mA

The original designed had the VCF combining several filtering capabilities, including an HPF, LPF, and BPF. The purpose of the VCF was to take inputs from the VCO and filter them before reaching the VCA, although this behavior can be modified using the signal router. The filtering parameters will be managed by the primary microcontroller.

The final design uses the desired HPF, LPF, and BPF. Each output waveform first goes through its own VCA before being filtered. Table 2 shows the specifications met by the VCF.

Table 2 – Specifications for the VCF

	Target	**Actual**
Filter type	State variable - 12dB/octave	(same as target)
Available filters	High-pass, low-pass, and band pass	(same as target)
Resonance	Voltage controlled resonance (linear)	(same as target), Voltage controlled center frequency
Power supply	+/- 15 V	+/- 12 V

The original design had the VCA as the final stage of synthesis. The VCA would receive the analog signal from the signal router and amplify it according to a control voltage setting. This signal would then be outputted to a jack where speakers could be attached. The signal could also be fed back through the patching network.

The final design uses six VCAs. Each output of the VCO, a noise source, and the final output stage can be adjusted through its own VCA. The VCA will meet the specifications listed in Table 3.

Table 3 – Specifications for the VCA

	Target	**Actual**
Response	Log and linear to control voltage	Log control voltage
Power Supply	+/- 15 V	+/- 12 V
Effects	Ring modulation	no effects

The primary microcontroller will have a standard 5-pin MIDI input, which will be compatible with MIDI keyboards and other musical interface devices. The microcontroller will interpret note pitch, velocity, and volume MIDI commands in order to control the VCO and VCA. The microcontroller will manage the VCF by reading in several user interface elements, yet to be determined. Possible candidates are sliders, knobs, and capacitive touch sensors.

Finally, the signal routing/patching microcontroller will manage the analog signal paths between the VCO, VCF, and VCA using digitally controlled analog switches. The router will allow feedback loops. There may exist specially designated loops with non-linear circuit elements to expand the effects capability of the synthesizer. The signal router will have a physical user interface allowing on the fly selection of patch configurations, and saving and restoring of routing presets.

See the Appendix for further detail.

4. Design Approach and Details

4.1 Design Approach

The final design includes two main parts: the analog components and the digital components. The analog components include a VCO, VCF, and six VCAs (two VCAs per board) purchased from Ray Wilson of musicfromotuerspace.com. Each output waveform of the VCO proceeds to be amplified by its own VCA. This signal is filtered before being filtered by the VCF. Figure 1 shows a diagram of the analog signal flow.

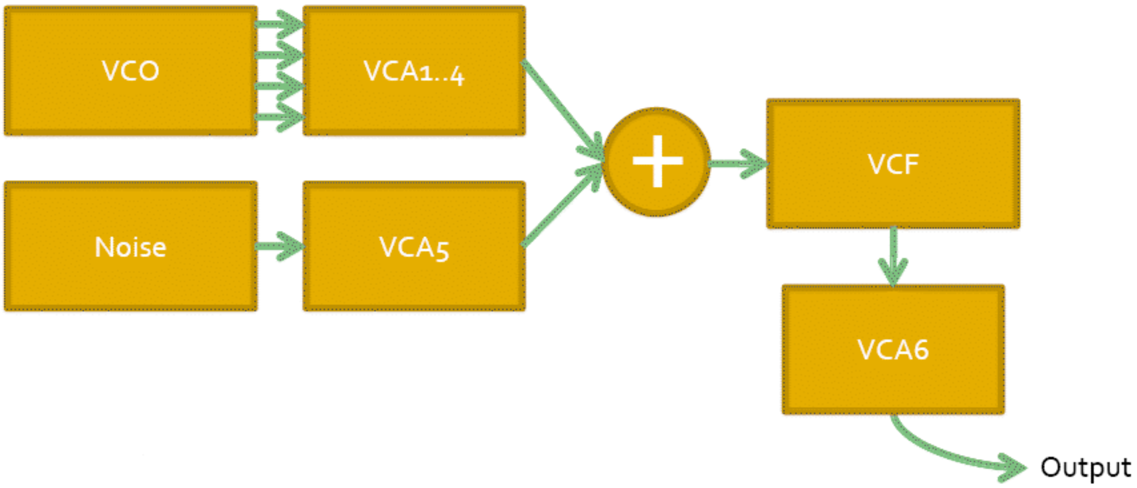

Figure 1. Analog signal flow.

The digital control board (DCB) houses the master microcontroller. This master microcontroller communicates with separate user interface boards. These boards house a slave microcontroller that reads user input via a rotary encoder and communicates this setting back to the master microcontroller. Based on these setting, the microcontroller can communicate appropriate voltage settings the various analog boards. The DCB also reads in input data from a MIDI controller. This data sets the pitch and velocity of a note that is relayed to the VCO. A debug port was also added to help in debugging the system. Figure 2 shows the digital control scheme.

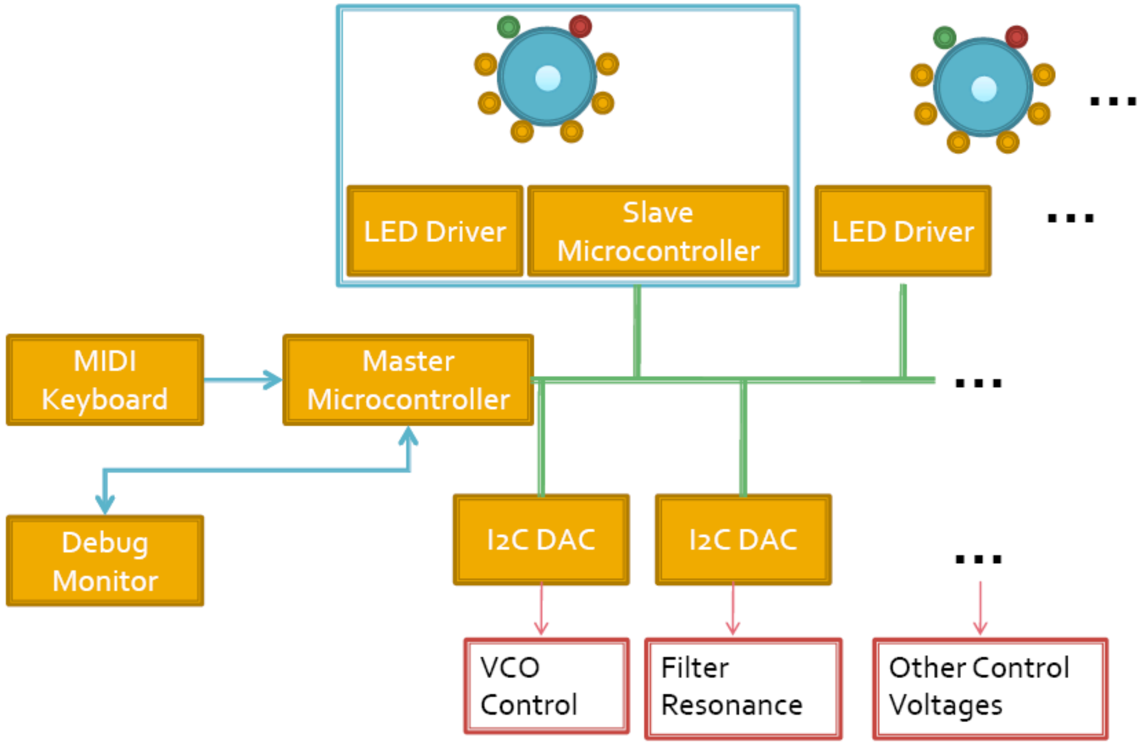

Figure 2. Digital control scheme.

To bridge the connection between the analog and digital portions of the synthesizer, a system interface board was used. Here a one-to-one signal flow matches the signals generated by the master microcontroller to the analog boards. Figure 3 shows the overall system design.

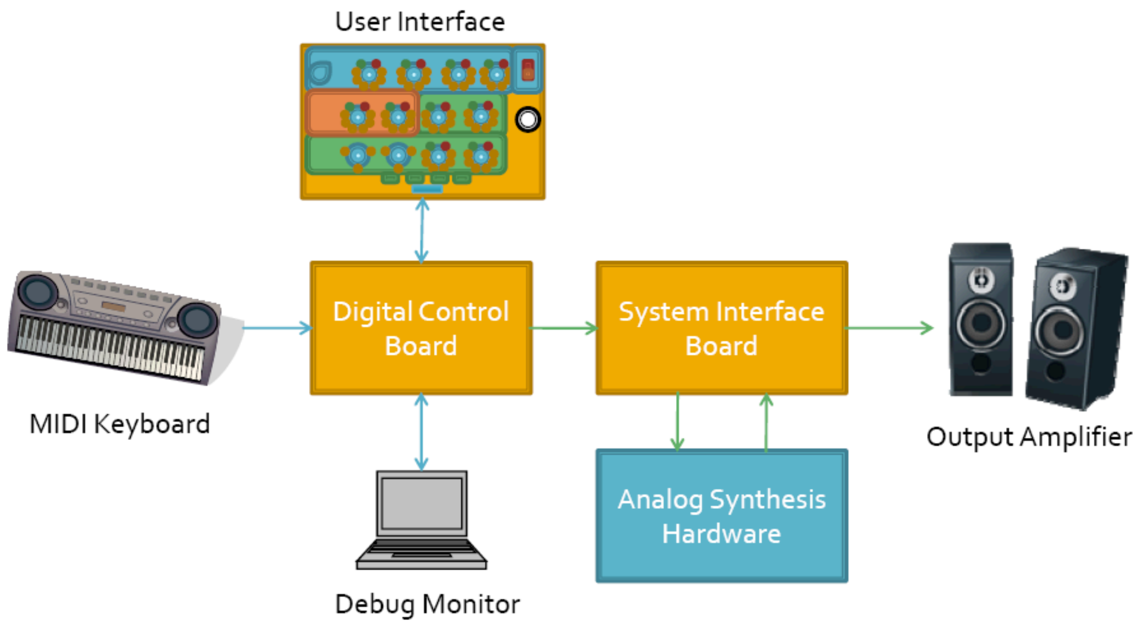

Figure 3. System design overview.

4.2 Codes and Standards

The synthesizer will respond to a small subset of the MIDI protocol, which will be received over a standard 5-pin MIDI cable interface. In addition, a raw audio input (bypassing the VCO) will be supported over a standard ¼” TRS-connector input jack. Output will be produced through the same type of jack. Power will be supplied through a standard wall socket and a third-party power supply, supporting the U.S. standard 120V at 60Hz AC input. Audio signals within the synthesizer itself will be limited to ±12V, as limited by the voltage controlled components. Digital circuitry will be run at TTL levels.

4.3 Constraints, Alternatives, and Tradeoffs

Possible alternatives to the third-party voltage controlled components of the synthesizer include construction directly from schematics available online. The choice of the third-party components was made to minimize risk and to expedite development of the synthesizer.

The decision to use microcontrollers rather than a dedicated embedded computer was made in order to increase modularity, simplicity, and availability of GPIOs while decreasing cost and risk during possible design regression.

MIDI is a current and widely-implemented standard created specifically for music synthesis. The parameters provided by the MIDI protocol can control various aspects of the synthesizer hardware with far more convenience than could be achieved using manual control of pitch and volume parameters. Regular MIDI has a very simple hardware protocol, allowing simple interpretation by the on-board microcontrollers. MIDI-over-USB, while providing a versatile hardware layer and data protocol, also increases complexity of implementation with the addition of the USB protocol layer. For these reasons, regular 5-pin MIDI was chosen over an impractical manual control scheme or the more modern, yet complex, MIDI-over-USB protocol.

5. Schedule, Tasks, and Milestones

The project will be divided into phases. For each task, one person is primarily responsible to ensure completeness. To ensure completion of tasks, weekly group meetings are planned. The task schedule, including degree of difficult and responsible person for each task, is shown in Table 4.

Table 4 – Project Schedule, Tasks, and Milestones

Task Name	Duration	Start	Finish	Difficulty	Responsible Person
Design					
Motherboard PCB layout	3 days	11/5/2008	9/20/2008	Medium	Logan
UI panel for filter control and signal routing	3 days	9/30/2008	9/19/2008	Medium	Robert
Design chassis	2 day	12/9/2008	12/10/2008	Easy	Toan
Order					
Voltage controlled components from Ray Wilson	3 wks	9/15/2008	9/30/2008	N/A	Greg
Microcontrollers from Microchip	2 wks	9/16/2008	9/25/2008	N/A	Robert
UI elements	2 wks	9/22/2008	10/2/2008	N/A	Toan
Miscellaneous parts and signal routing components	2 wks	9/22/2008	10/2/2008	N/A	Logan
Motherboard PCB	2 wks	11/15/2008	11/19/2008	N/A	Logan
Chassis	2 day	12/9/2008	12/10/2008	N/A	Toan
Program					
Microcontroller code for MIDI interpretation	1 wk	11/24/2008	12/1/2008	Medium	Robert
Signal routing microcontroller code	1 wk	11/24/2008	12/1//2008	Hard	Robert
MIDI filter control code	1 wk	11/24/2008	12/1/2008	Medium	Robert
Assembly					
Voltage controlled components	3 days	11/1/2008	11/4/2008	Medium	Greg
UI to VCO and VCA for testing	1 day	11/3/2008	11/3/2008	Medium	Robert
Able to create tone	*0 days*	*11/24/2008*	*11/24/2008*	*Milestone*	
Signal routing UI panel	3 days	10/3/2008	10/7/2008	Hard	Logan
UI for VCF	2 days	10/3/2008	10/6/2008	Medium	Toan
Integration					
Components on motherboard with direct signal connections	1 day	12/1/2008	12/2/2008	Medium	Greg
Primary microcontroller, controlling VCO and VCA	2 days	12/5/2008	12/7/2008	Medium	Robert
MIDI control	*0 days*	*12/7/2008*	*12/7/2008*	*Milestone*	
Signal routing, initially with straight-through connections	1 day	11/8/2008	11/8/2008	Easy	Logan
Signal router microcontroller	4 days	12/2/2008	12/6/2008	Hard	Robert
Functionally complete	*0 days*	*12/11/2008*	*10/14/2008*	*Milestone*	
Motherboard and UI into chassis	1 day	12/11/2008	12/11/2008	Easy	Toan

The complete Gantt chart is shown in Appendix A.

6. Project Demonstration

The demonstration of the final synthesizer is straightforward. The separate components must be hooked up correctly (i.e. analog components hooked up to the SIB, the SIB hooked up to the DCB, the MIDI controller attached to the DCB, etc.). Once these connections have been made, the user can play the MIDI controller and create different notes. The user can also adjust different parameters of the synthesizer, including center frequency of the filer, an ADSR envelope, etc. Sound generated and shaped according to user input confirms a working project. The hardware thus far is performing as expected. Software bugs are being worked out for the demonstration.

7. Marketing and Cost Analysis

7.1 Marketing Analysis

The analog modular synthesizer market consists of both hobbyists and musicians. Although digital synthesis has captured the majority of the synthesizer market due to its versatility and ease-of-use, a steady interest in the sounds of the sixties and seventies has kept the market growing. Many in this market are independent of large financial backing. Therefore, the market has evolved to cater to DIY construction of pre-designed modules. The companies that pursue such a business model are able to offer inexpensive modules and heavily integrated support for their clients. To reproduce the full modular synthesizer experience, however, some musicians are willing to spend ten's of thousands of dollars for vintage equipment or modern mimics. Some manufacturers meet this want by providing large synthesizers chassis with an array of modules pre-built into the system.

The DIY manufactures cater to the low cost and educational market. The RADCASTle harnesses the low cost module technology of this sector. The Cat Girl Modular Synthesizer by Ken Stone offers many standard modules from $5.00 to $30.00 [2]. For instance, users of this system may purchase the printed circuit boards for VCAs, waveshapers, sequencers, and digitally controlled switch matrices. Users may then populate the boards and integrate them into their own modular synthesizers.

The RADCASTle system has the potential to be lucrative to hobbyists due to its low cost relative to other “complete” modular synthesizer packages. A key difference between the RADCASTle system and the DIY systems is the vast use of digital control. Digital control is utilized in modular synthesizers to perform MIDI interfacing, sequencing, and limited signal routing. The proposed system allows all signals to be routed via digital control, simultaneously eliminating the need for manual patch cables and creating a new method of playing a modular analog synthesizer. This allows for rapidly changing the signal routing paths as opposed to adjusting one signal path. This system's unique emphasis on swapping configurations as part of the musical composition defines a new niche in this market.

Musicians seeking the retro sounds without wallowing in electronics provide the market for the high end analog modular synthesizer packages. The Buchla & Associates 200e Electric Music Box and the Synthesizers.com systems exemplify both the sound and look of an original modular synthesizer [3]. These systems are built into walnut chassis, can contain hundreds of different control variables (knobs, sliders, etc), and support similar digital control schemes to the DIY modular synthesizers. Individual modules for these systems can run from $50 to $500, with total costs of a full system priced at well over $10,000. However, in an effort to be faithful to retro designs, these systems utilize patch cable routing for inter-module connections.

The RADCASTle system proposes to standardize module connections with digitally controlled analog switches and to be produced at far less cost than the larger “complete” systems. For musicians seeking easy and unique analog sounds, the RADCASTle system is a complete solution. The proposed synthesizer may not be as lucrative to clients who wish to have “replica” systems, however.

Both the DIY and replica markets may be reached through the internet. This business model has several advantages. Firstly, the market for analog modular synthesizers is scattered all over the world. The inherent ability of the internet to reach various interest markets is well known. Marketing of the product could be pursued via message boards, video demonstrations posted in public access sites such as YouTube, the product's own web page, and word-of-mouth. Strong integration with the DIY community for educational purposes has the potential to generate a loyal and enthusiastic fan base. The low cost of the device coupled with its “out of the box” functionality could lure some musicians away from the high cost systems in favor of recreating retro sounds without the need for perfect recreation of older devices.

7.2 Cost Analysis

Engineering costs consist of design hours, meeting hours, report hours, construction hours, and testing hours. Table 5 shows the expected hours and associated costs.

Table 5 – Costs of Engineering Time

Engineering Time	Quantity	Unit Price	Price
Greg's Time	136	$25.00	$3,400.00
Logan's Time	136	$25.00	$3,400.00
Robert's Time	136	$25.00	$3,400.00
Toan's Time	136	$25.00	$3,400.00

Total time is calculated assuming 16 total class hours, an average of 6 hours per week for 15 weeks of general work time, and an extra 30 hours for report writing and weekend work.

Table 6 shows the costs of constructing the full synthesizer. The digital control board, system interface board, and interface knobs cost includes construction and component costs.

Table 6 – Costs of Manufacturing

Item	Quantity	Unit Price	Total Price
VCO	1	$18.00	$18.00
VCA	3	$15.00	$45.00
VCF	1	$17.00	$17.00
Noise Source	1	$15.00	$15.00
Digital Control Board	2	$30.00	$60.00
System Interface Board	3	$20.00	$60.00
Interface Knobs	12	$6.00	$72.00
Shipping	3	$30.00	$90.00

The total price of the complete item is $550.00. This value has been calculated assuming that 500 would be sold over a five year period. Manufacturing would be made up of part time technicians, and thus no fringe benefits would be assessed. All parts are assumed to have been purchased at the same time and stored. Overhead would include the cost of running an advertising and ordering website, which is assumed to be $30 per month. All taxes and shipping charges are passed on to the customer and do not factor into this calculation. As a final simplifying assumption, inflation is assumed to be 0.

With this scenario, the expected profit is $48,600, which yields a 19% profit. This sum would be lower in practice due to inflation rates.

8. Summary

The various hardware components, including custom designed PCBs, are working as expected. The software is working to a certain degree, but is still being debugged. The overall system design has changed from the original design. The major changes including using separate VCAs for each output waveform of the VCO and using a dedicated slave microcontroller for each rotary encoder. Also, a system interface board was added to separate the digital and analog components of the project. Although significant progress had been made, further testing should be done before a full scale production phase is initiated.

9. References

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[2] CGS - Ken Stone's Modular Synthesizer, “Modular Synth,” *Ken Stone’s Modular Synthesizer*, 2008. [Online]. Available: http://www.cgs.synth.net/. [Accessed Sept. 16, 2008].

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[4] Synthesizers.com, “Modular Analog Synthesizer for Electronic Music,” *Synthesizers.com*, 2008. [Online]. Available: http://www.synthesizers.com. [Accessed Sept. 16, 2008].

Appendix A