November 6, 2008

Dr. Andrew Rawicz
School of Engineering Science
Simon Fraser University
Burnaby, British Columbia
V5A 1S6

Re: ENSC 440 Design Specifications: Cyclic Technologies Anti-lock Braking System (ABS)

Dear Dr. Rawicz:

Attached with this letter is the *Design Specifications for Cyclic Technologies ABS System*. We are developing an ABS system for bicycles that would enable riders to maintain more control and stop faster during hard braking events. The ABS system will improve rider safety by enabling cyclists to maintain better control of their bicycles and avoid accidents.

This design specification outlines the requirements and goals of our product for both the proof-of-concept and production phases of development. The specification and test plans for individual modules are presented.

Cyclic Technologies consists of five dedicated, resourceful, and enthusiastic engineering students: Zack Blair, Amir Tavakoli, Rahm Lavon, Datis Danesh, and Milad Gougani. Our team brings together people with different skill sets and experience which will help Cyclic Technologies to achieve its goals.

Should you require additional information or would like to meet us in person, please feel free to contact us at cyclic-tech@sfu.ca.

Sincerely,

Cyclic Technologies

Enclosure: Functional Specifications for Cyclic Technologies Anti-lock Braking System

Design Specification

Bicycle Anti-lock Braking System

Submitted to:

Dr. Andrew Rawicz – ENSC 440

Mike Sjoerdsma – ENSC 305

School of Engineering Science

Simon Fraser University

11/06/08

Milad Gougani

Rahm Lavon

Datis Danesh

Amir Tavakoli

Zack Blair

Contact person: Amir Tavakoli

cyclic-tech@sfu.ca

Executive Summary

This design specification for Cyclic Technologies' ABS system outlines the design of the system and provides justification for our design choices. The system consists of three general subsystems, each of which we will describe in this document: data acquisition, Electronic Control Unit (ECU), and Hydraulic Control Unit (HCU).

The Data Acquisition module discusses the procedure of speed measurement and components used to achieve this purpose. The speed sensor consists of 12 permanent magnets, evenly spaced around the circumference of the brake disc, and a stationary pickup coil attached to the bicycle frame. As the bicycle wheel rotates, the magnets pass by the pickup coil, producing a series of pulses that are rectified by a comparator and processed by the ECU.

The ECU performs two functions: it provides a user interface via an LCD display, and it acquires data from the Data Acquisition module and controls the HCU accordingly to prevent wheel lockup. The ECU is analyzed in two sections: software, and electronics. The high-level design of the software platform is discussed along with a description of the digital and analog circuitry used in the ECU to achieve the brake modulation. The ECU is built around an Atmel AVR ATtiny2313 microcontroller, enabling it to respond and process information very quickly, having the capability of achieving up to 20 MIPS throughput, and enabling it to store configuration data on its on-chip EEPROM memory even if power to the ECU is lost.

HCU of the system involves mechanical analysis. Physical and Mechanical considerations of the system along with schematic of the unit is presented. The components used for the HC Unit are analyzed in detail and justification of the product choice is provided. Major components of the HCU are a valve and a pump. The Valve controls the oil flow in hydraulic system thereby reducing pressure on the calipers in an event of skidding. Once the ABS system is in full swing the oil in the system needs to be pumped back to the master cylinder to keep the brake system in function.

Along with the aforementioned detail analysis of the system, a description of test plans for the system and its subcomponents is provided at the end of the design specification. Cyclic Technologies' engineering team is determined to have a fully functional mock-up model of Bicycle ABS system, designed according to the Design Specifications, by the end of year 2008.

Table of Contents

List of Figures

List of Tables

Glossary

ECU	Electronic Control Unit
HCU	Hydraulic Control Unit
UI	User interface

1. Introduction

The Cyclic Technologies ABS system is a one-of-a-kind electromechanical braking system used on bicycles, making them safer, more reliable, and more practical than ever before. This ABS works on the same principle as conventional ABS systems currently available for automobiles and motorcycles. The system looks for acute deceleration during brake operation and regulates the force applied on brake caliper utilizing a 3 way valve and pump to prevent the wheels from skidding. This operation prevents wheel lock and minimizes the distance required to stop in an emergency.

1.1 Scope

This document outlines the design requirements that will be met by the today's ABS and how the design requirement relate to the functional specification outline in Functional Specifications for Cyclic Technologies ABS System[1]. Also, it provides information on system parameters, components and ratings. These set of requirements fully describe the proof of concept device and production procedures.

1.2 Intended Audience

The design specification document is intended for use of Cyclic Technologies members and employees. The design and quality control engineers should refer to this document's guideline in integration and testing stage of the ABS

2. System Specifications

The Bicycle ABS System is an added feature to the already popular hydraulic brakes. It has no interference on bicycles' regular operation and only operates when there is an event of skidding and wheel lockup. Cyclic Technologies' ABS system will operate in two main steps: First, it will detect the wheels skidding through an intelligent use of speed sensors. Second, once the skid event is detected, it will actuate the locally designed Hydraulic Unit to reduce the pressure on brake calipers and thereby avoiding wheel lock up.

In addition, Cyclic Technologies' ABS braking system provides the user with the ability to easily customize the braking system's performance using a menu-driven user interface on an LCD display.

3. Overall System Design

"The entire ABS system is considered to be a hard real-time system. The general working of the ABS system consists of an electronic unit, also known as ECU (electronic control unit), which collects data from the sensors and drives the hydraulic control unit (HCU), mainly consisting of the valves that regulate the braking pressure for the wheels" [2].

Hence, Cyclic Technologies overall ABS system design will be discussed and analyzed in the context of three main subsystems of Data Acquisition, Electronic Control Unit (ECU) and Hydraulic Control Unit (HCU) as presented in Figure 1. Design choices and detail analysis of subsections for the aforementioned subsystems will be presented along with figures and schematics.

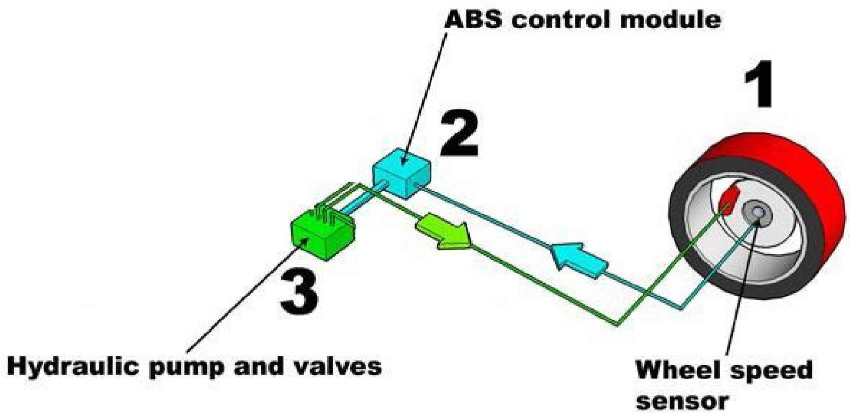

Figure 1 ABS Subsystems [1]

3.1 High level System Design

Cyclic Technologies ABS system is summarized as shown in Figure 2. The system has been divided into various subsections. The detail design and analysis of each subsection will be presented in this document.

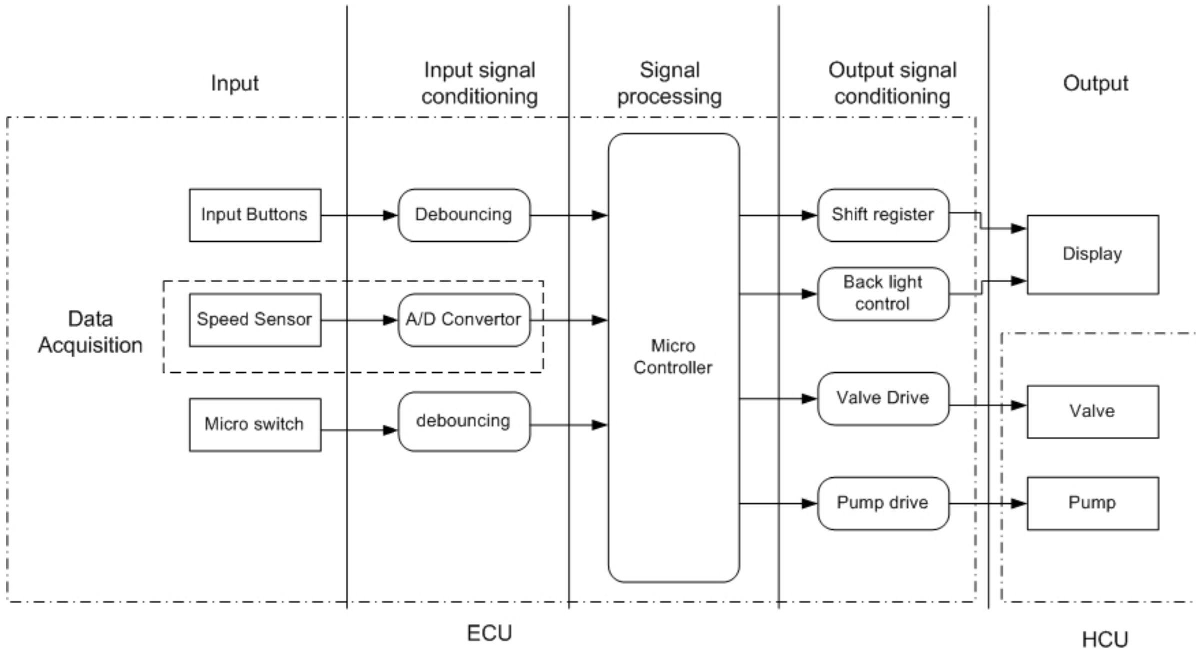

Figure 2 System Block Diagram

3.2 Data Acquisition

3.2.1 Speed Sensor Placement/Output

The Cyclic Technologies' ABS speed sensor is a low-power alternative to a Hall Effect sensor. Hall Effect sensors commonly used in industry require a current to run them, which unnecessarily puts strain on the power source. Conversely, our speed sensor an actually provide some power for our system.

Our speed sensor is composed of a stationary pickup coil attached to the bicycle frame, and 12 neodymium permanent magnets spaced evenly around the circumference of the disk brake at 30 degree intervals. Figure 3 shows the general configuration of the magnets and pickup coil on the rear wheel. The same system is also used on the front wheel.

Figure 3 Speed Sensor Placement

As the wheel turns, the magnets fly by the pickup coil, inducing a train of pulses in the pickup coil (see Figure 4). Using a Schmidt trigger stage, the induced pulses are converted into a digital signal that is appropriate for processing by the ECU.

.

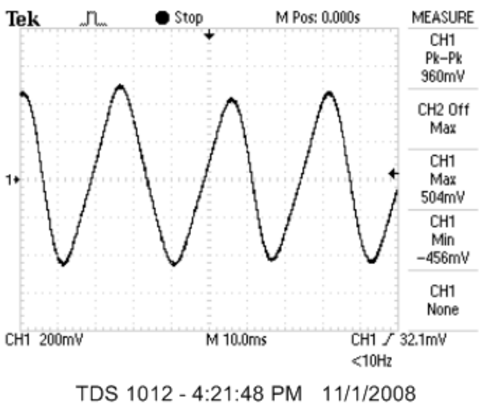

Figure 4 Speed Sensor Output Signal for 12 position magnets

Measuring the speed of each bicycle wheel is achieved by measuring the period between pulses from the wheel speed sensors. Every time a magnet on the wheel passes the pickup coil, a pulse will be sent to the microcontroller. Using the input capture feature of the microcontroller, the ECU is able to very accurately measure the time between successive pulses from the pickup coil by triggering an interrupt service routine every time it sees a rising edge.

Given an inter-pulse time of t_{pulse}, we can determine the frequency, at which the wheel is spinning using the formula,

$$f_{spin} = \frac{1}{N \times t_{pulse}}$$ Equation 1

Where *N* is the number of evenly-spaced magnets placed around the wheel.

Once we have f_{spin} , by knowing the circumference of the wheel, *C*, we can determine the speed of the wheel using the formula,

$$speed = C \times f_{spin}$$ Equation 2

In our system, we have 12 magnets evenly spaced around the wheel in $\frac{\pi}{6}$ (*rad)* increments. The circumference of our wheel is 26-inch diameter wheels is *C* =**2.07** (*m)* Therefore, once our ECU has measured the inter-pulse time between two pulses, t_{pulse}, it can calculate the speed of the wheel using the formula,

$$speed = \frac{0.17289}{t_{pulse}} \left(\frac{m}{s}\right)$$ Equation 3

3.2.2 Input Signal Conditioning (A/D Conversion)

As mentioned in the previous section, the output signal of the speed sensor needs to be converted to a square wave to be processed by the microcontroller. The conversion of the analog to digital signal can be done by utilizing a comparator. To achieve a more stable switching against rapid triggering by noise as the signal passes the trigger point, we chose to use a Schmitt Trigger as shown below in Figure 5.

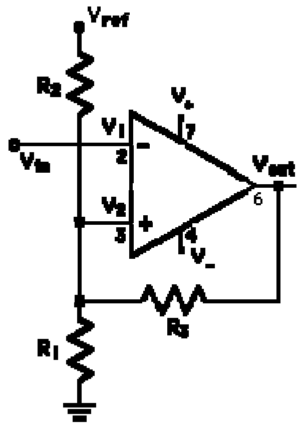

Figure 5 Schmitt Trigger

The circuit parameters summarized in Table 1 results in a clean 5V square wave to be processed by the microcontroller.

Table 1 Schmitt Triger Circuit Parameters

$V_{ref} = V_{CC}$	5 V
R1	1 KΩ
R2	100 KΩ
R3	100 KΩ
V2 (upper threshold)	100 mV
V2' (lower threshold)	0 V

3.3 Electronic Control Unit (ECU)

3.3.1 Hardware Overview

The ECU must perform several important functions:

- Monitor bicycle speed and actuate the brakes to prevent the wheels from slipping for a prolonged period when braking
- Provide an interactive UI that displays bicycle speed and other information in real time
- Store configuration data, even when power is removed

Additionally, it must do all of these things while consuming little power.

To achieve these goals, Cyclic Systems chose a powerful modern microcontroller, the Atmel ATtiny2313, as the heart of the ECU. The Atmel ATtiny2313 has RISC architecture and is able to achieve up to 20 *MIPS* throughput at 20 *MHz*. The EEPROM memory on-chip is for storing configuration data, and is able to enter low-power sleep modes to save power when not needed [3].

Below are some of its key parameters:

Table 2 ECU Key Parameters

Flash	2 Kbytes
EEPROM	0.125 Kbytes
SRAM	128 Bytes
Max I/O Pins	18
$f_{.max}$	20 MHz
V_{cc}(V)	1.8-5. V

Below is a schematic showing most of the ECU circuit.

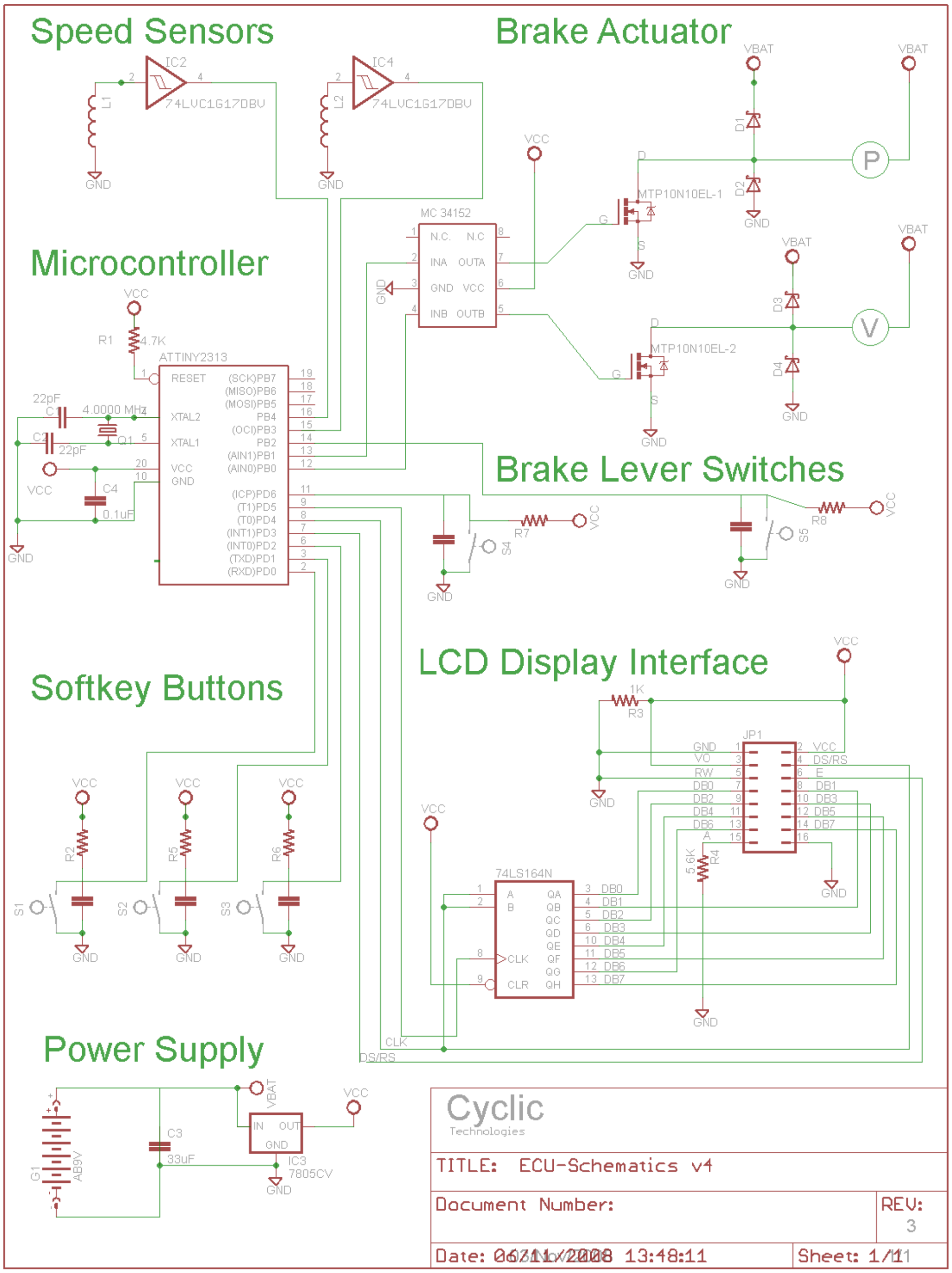

Figure 6 ECU circuit

3.3.2 Software development (Signal Processing)

3.3.2.1 ABS Control

When the bicycle is first put in motion, the induction generators and batteries inside the Electronic Control Unit (ECU) power the system and trigger it turn on. Wheel speed sensors read the pulses generated by the encoded generators, and send signals back to ECU module which continuously monitors wheel speeds for any abrupt deceleration or large disparity between the front and rear wheel speeds. When a brake is applied, pressure is increased in the calipers, forcing brake pads against the disks attached to each wheel, slowing the bicycle. If one or more wheels lose traction with the road surface, the wheel(s) will slow down quickly, indicating that they are close to locking. Hence, if a wheel's deceleration is abrupt and does not match the criteria stored in memory, the ABS system instantly responds by rapidly opening and closing valves to modulate the brake pressure applied by the rider. Overview of the system operation is summarized in Figure 7 System Flowchart

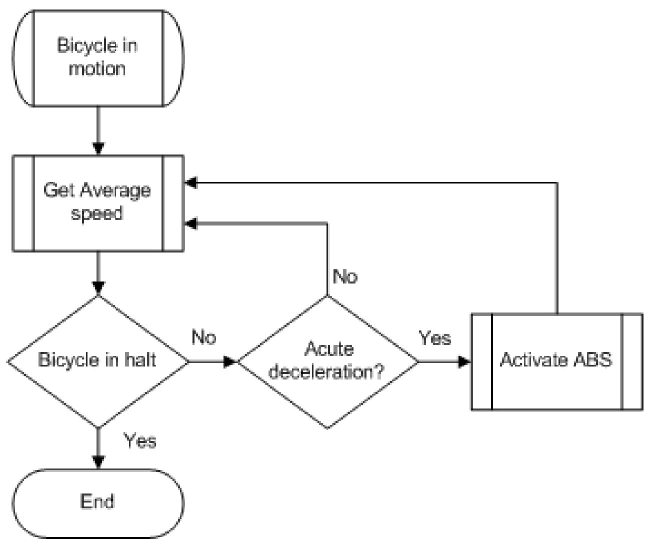

Figure 7 System Flowchart

3.3.2.2 User Interface

Our user interface (UI) is centered around an LCD display that presents to the user a menu-driven character-based interface. Below the LCD display are three press buttons: one on the left, one in the middle, and one on the right. The bottom row of text on the LCD display indicates the function of each push button by displaying a label above each one that is active. Therefore, each push button represents a "soft key" in that its function and label can change at runtime.

Figure 8 UI Soft Key

For instance, in the "Main Menu" screen, the label "Back" is associated with the leftmost push button, "Select" is associated with the middle push button, and "Next" is associated with the right push button. push buttons as SK1, SK2, and SK3, respectively.

Below is a storyboard for the LCD user interface. The Main Menu and Config ABS Menu are bound in boxes to indicate that the screens within them are part of a scrolling menu, and pressing the Next and Back soft keys results in scrolling down and up, respectively.

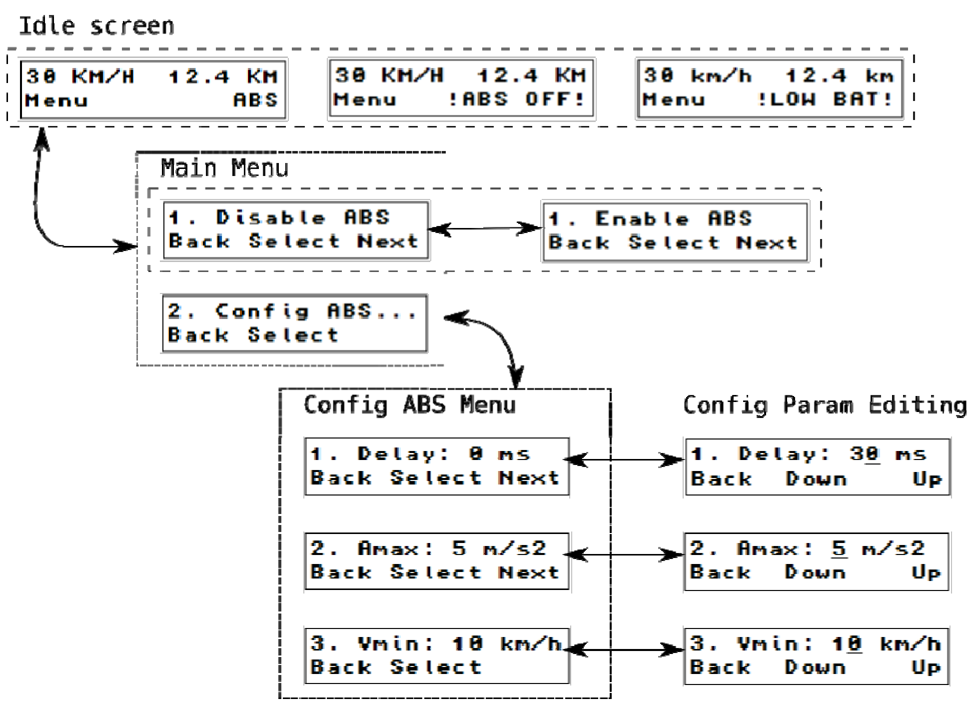

Figure 9 LCD user interface

3.3.3 Output Signal Conditioning

To drive both the valve and the pump, a power MOSFET will be utilized to apply 12 volts DC supplied by a AAA battery pack. According to the control signal form the microcontroller as shown in Figure 10. Due to the high capacitance at the input of the power MOSFET a driving circuit must be used to couple the micro controller to the MOSFET. This also reduces the power MOSFET slew rate. Furthermore, the valve and the pump are inductive loads so fly back diodes are utilized to mitigate the surges.

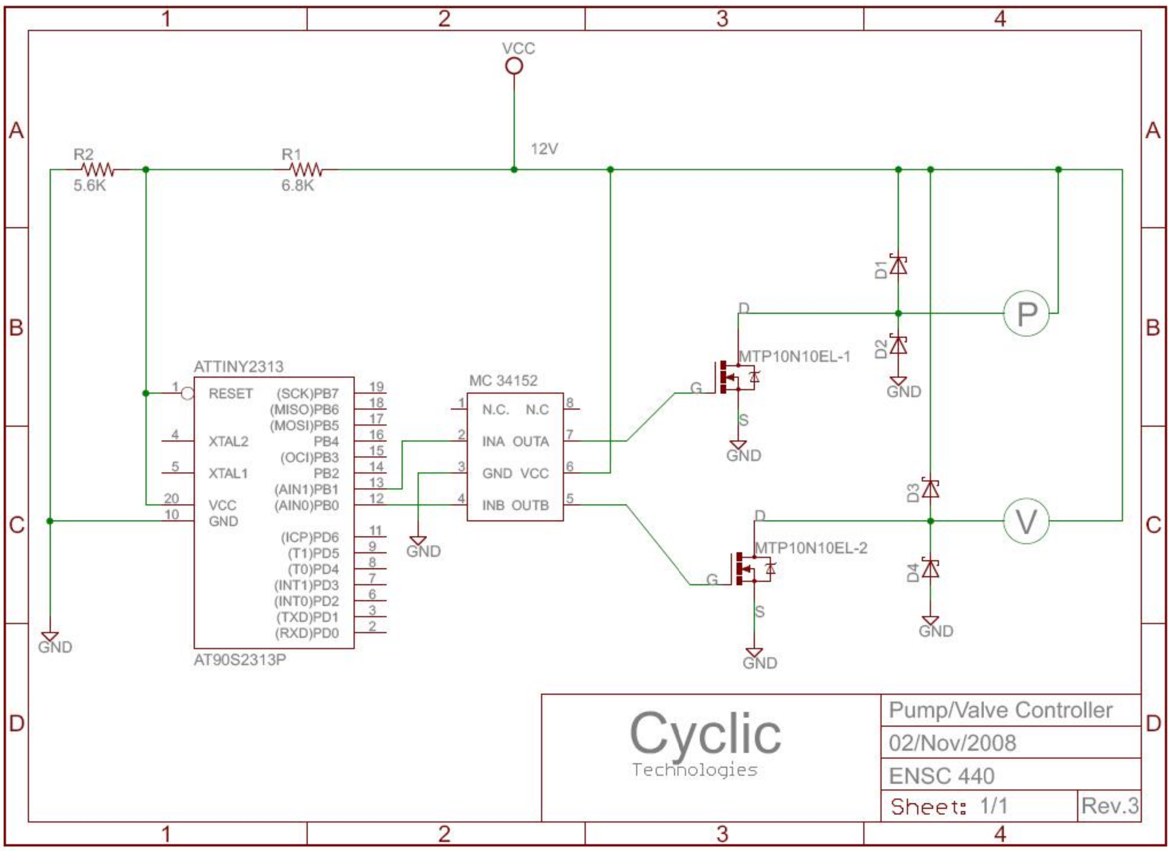

Figure 10 Controller Schematic Diagram

3.3.4 User Interface Unit

The user interface includes a 20 x 2 Char (5 x 8 dots) LCD module which is 3-wire interfaced to ATtiny2313 microcontroller, through 74LS164 shift register. As shown in figure below LCD connection pins are displayed with a jumper (JP1). The operations start with The E (enable pin) inactive, when microcontroller shifts out a byte into the shift register. This byte defines the status of pin DB0-DB7 of the shift register. Then, with E still inactive, the state of RS/DS (1: Register Select / 0: Data Select) is selected on the microcontroller pin, while the clock line (CLK) is not toggled. Finally, E line is pulsed to make the LCD module accept the byte [4, 5].

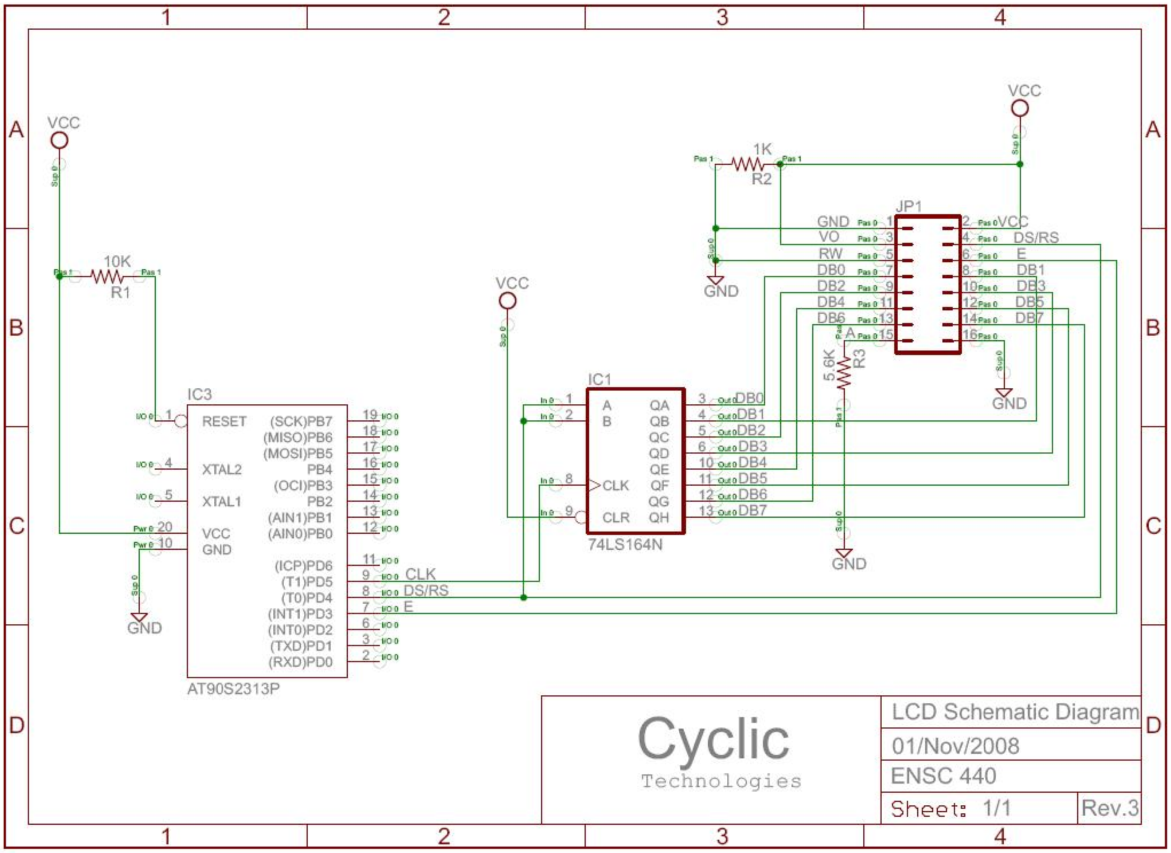

Figure 11 User Interface Schematic Diagram

3.4 Hydraulic Control Unit (HCU)

Cyclic Technologies ABS System will be implemented on a hydraulic platform rather than the traditional cable braking system. The reason for this choice is the significant difference in power requirements for pressure modulation in the braking calipers. Moreover the hydraulic technology has proven itself for compatibility with ABS systems in both automobile and motorcycle industries.

The Hydraulic Control Unit (HCU) contains a valve that disconnects the pressure feed to the calipers and a pump to release the existing pressure while forcing the oil back into the master cylinder. The unit will be controlled by the Controller Circuit presented in Figure 10. Valve and pump combinations are the most common method of implementing ABS systems in industry, and for good reasons. The power consumption is low, since forcing the fluid back to the master cylinder can be an ongoing process during the entire braking cycle. It also prevents the loss of fluid which may compromise the integrity of the braking system after numerous braking cycles.

3.4.1 Mechanical Design

As shown in Figure 12 below, the gear pump may be taken out of the oil path in normal operation. This redundancy allows for maximum reliability, as the system can always fall back to normal brake operation in the event of a failure.

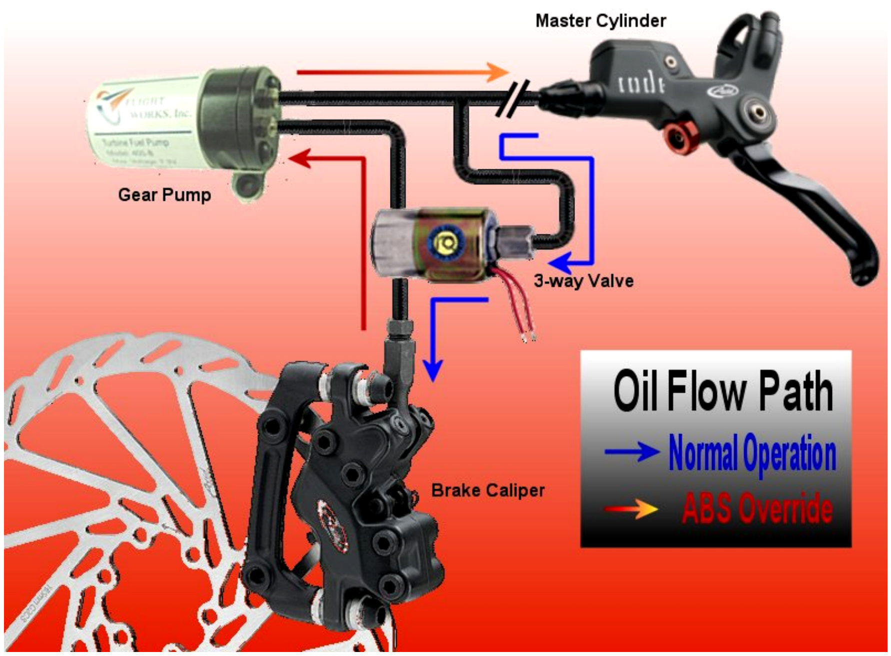

Figure 12 HCU Schematic

As can be seen in the above schematic, during normal operation the Master Cylinder is connected via the valve to the brake calipers. This allows oil pressure created by the operator's physical exertion of pressure on the lever to be transmitted to the calipers, forcing the caliper to squeeze on the brake pads, and effectively slow down the wheel. If this force exceeds the friction force available between the tire and the ground, this will eventually cause the wheel to lose adhesion with the ground and then a lockup becomes imminent. Before this situation occurs, it is detected by the ECU and the command is given to the HCU to disable the braking action until further notice. This causes the valve and the pump to activate immediately.

3.4.2 Valve

The valve is responsible for disrupting the flow of oil from the master cylinder to the brake calipers. This action is required to disengage the brakes, since merely removing oil from the calipers allows addition oil from the cylinder to replace it. This cutoff must be nearly instantaneous, since up to 10 full ABS cycles may be encountered per second. For this reason as well as the high pressure considerations, we have decided to utilize the 3-way, normally open, Peter Paul Solenoid Valve. This valve is small, and typically switches within about 10 milliseconds, exceeding our physical requirements. In addition, power consumption is low, at nearly 10 watts, so the momentary valve action is tolerable for our power and battery considerations. One concern is that under extreme braking, oil pressure might rise beyond the valve's maximum operating characteristics. However, this situation is extremely unlikely, due to the valve's high maximum operating pressure differential, and the amount of force which must exerted on the brake lever to achieve this state. We will run extensive tests to ensure the safety and behavior of the valve during these circumstances.

The valve is to be placed in the oil path as close as possible to the brake calipers. The reason for this is that the expansion of the brake line contributes to the capacity of oil that must be modulated with each cycle of the ABS system, and reducing this decreases our response time, as well as the cycle recovery energy consumed by the pump to restore the normal braking state.

When activated, the valve accomplishes two functions simultaneously. First, it disconnects the pressure feed from the master cylinder. Second, it provides an alternate path for oil to leave the caliper.
This alternate path is usually closed to eliminate system hysteresis. An outline of the valve and a summary of its characteristics are given in the following Figure 13and Figure 14.

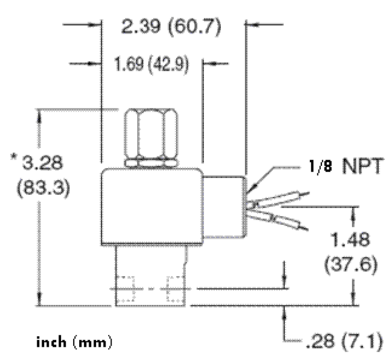

Figure 13 PETER PAUL series 20 - model 24 Solenoid Valve - Physical Dimensions [6]

OPERATING CONDITIONS
Media: DOT 5.1
Valve Temperature Range:
– 0°F (-18°C) to 104°F (40°C) ambient
Maximum Operating Pressure Differentials:
400 PSI
Burst Pressure: 5000 PSI
Leakage: Bubble tight for standard valves

ELECTRICAL CHARACTERISTICS
Coil Voltage: 1.8 to 265V DC
Nominal Power: 9.5 Watts
Coil Construction:
Non-molded Class A, Molded and potted Class F.
Typical Response Time on Air:
4 - 16 Milliseconds

MECHANICAL CHARACTERISTICS
Body: Stainless steel (standard)
Orifice Diameter: 1/32
Porting: 1/8 NPT
Housing: Grommet

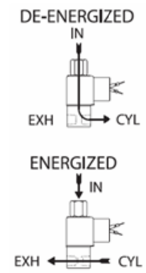

Figure 14 ETER PAUL series 20 - model 24 Solenoid - Characteristics

3.4.3 Pump

The valve is responsible for disrupting the flow of oil from the master cylinder to the brake calipers. This action is required to disengage the brakes, since merely removing oil from the calipers allows addition oil from the cylinder to replace it. This cutoff must be nearly instantaneous, since up to 10 full ABS cycles may be encountered per second. For this reason as well as the high pressure considerations, we have decided to utilize the 3-way, normally open, Peter Paul Solenoid Valve. This valve is small, and typically switches within about 10 milliseconds, exceeding our physical requirements. In addition, power consumption is low, at nearly 10 watts, so the momentary valve action is tolerable for our power and battery considerations. One concern is that under extreme braking, oil pressure might rise beyond the valve's maximum operating characteristics. However, this situation is extremely unlikely, due to the valve's high maximum operating pressure differential, and the amount of force which must exerted on the brake lever to achieve this state. We will run extensive tests to ensure the safety and behavior of the valve during these circumstances.

The valve is to be placed in the oil path as close as possible to the brake calipers. The reason for this is that the expansion of the brake line contributes to the capacity of oil that must be modulated with each cycle of the ABS system, and reducing this decreases our response time, as well as the cycle recovery energy consumed by the pump to restore the normal braking state.

When activated, the valve accomplishes two functions simultaneously. First, it disconnects the pressure feed from the master cylinder. Second, it provides an alternate path for oil to leave the caliper. This alternate path is usually closed to eliminate system hysteresis. An outline of the valve and a summary of its characteristics are given in the following Figure 15, and Figure 16.

Figure 15 Flight Works' Turbojet Fuel Pump Model 400-B - Photo[7]

Model 400-B CHARACTERISTICS
Weight: 60 g (2.1 oz)
Diameter: 24.0 mm
Length (not including barbed fittings): 44.4 mm
Bypass valve or regulator required: No
RF suppression included: Yes, PCB Installed
Mounting bracket included: Yes, Stainless steel
Pump gears: High precision stainless steel
Pump body: Hard anodized aluminum
Min. start voltage: 1.0 ± 0.15 Volts
Open flow rate: Approx. 1.0 l/min

Figure 16 Flight Works' Turbojet Fuel Pump Model 400-B - Characteristics

4. System Test Plan

4.1 Goals

Through comprehensive testing, we wish to verify that Cyclic Systems' ABS system is capable of preventing prolonged wheel lockup while stopping the bicycle quickly on a variety of surfaces:

1. dry pavement
2. wet pavement
3. loose gravel
4. grass
5. black ice

We also wish to verify that the system operates in a fail-safe manner, meaning that even if the ABS system fails or malfunctions, the braking system should continue to work at least as well as a non-ABS equipped braking system. Some specific failure modes and malfunctions we would test include:

- sudden and permanent loss of power (e.g because of a battery jiggling loose)
- momentary loss of power (e.g. because if a loose connection)
- sudden failure of wheel speed sensors (e.g. because of a rock bouncing up and severing an electrical connection or otherwise rendering the sensors inoperable)

4.2 Approach

Unit testing will be performed throughout the development process by the engineers working on each subsystem. Because unit testing will be performed by people with detailed knowledge of the subsystem under test, they will be able to use white-box testing methodologies to track down bugs quickly and find solutions for them. Thus, unit testing is an integral part of our development cycle and is very important for assuring a quality system. Subsystems that will be individually tested include:

- LCD display and user interface
- Electronic Control Unit (ECU)
- Wheel speed sensors
- Brake actuator

Integration testing will be performed after all unit tests have passed and the subsystems have been integrated into a complete system. All members will contribute to integration testing so that their insight into each subsystem can be leveraged for troubleshooting any problems that may arise.

Acceptance testing will be performed last; after all other tests have passed. All Cyclic Systems' team members, as well as some of their friends and family, will participate in acceptance testing. Acceptance testing will primarily involve using a Cyclic Systems' ABS equipped bicycle for short trips and some demanding rides and noting any deficiencies or possible improvements on the system. Thus, acceptance testing will be primarily black-box testing, where the systems performance is tested without detailed knowledge of its inner workings, and outsider feedback is solicited to further identify any issues with the product.

4.3 Unit Test

4.3.1 LCD display and User Interface

4.3.1.1 Home Screen Content

Steps:

1. Turn on the ECU and attached LCD

Expected Result:

- The "Home" screen is shown, which shows the current speed and distance travelled at the top.
- On the bottom row, there is a soft key for "Menu" and an indicator that ABS is enabled, as shown below.

```
30 KM/H   12.4 KM
Menu          ABS
```

```
30 KM/H   12.4 KM
Menu    !ABS OFF!
```

4.3.1.2 Menu Screen Content

Steps:

1. Turn on the ECU and attached LCD
2. When at the "Home" screen, press the left soft-key (corresponding to "Menu")

Expected Result:

- The "Menu" screen is shown with the first item ("1. Disable ABS" if ABS is enabled or "1. Enable ABS" if ABS is disabled) shown and three soft key labels shown on the bottom row: Back, Select, and Next.

```
1. Disable ABS
Back Select Next
```

```
1. Enable ABS
Back Select Next
```

4.3.1.3 Return to Home Screen Timeout

Steps:

1. Navigate to the various screens in the UI
2. Don't press any keys for 1 minute

Expected Result:

- After 1 minute of not pressing any keys, the UI returns to the "Home" screen automatically. If the user was in the middle of editing a field, their changes are not saved.

4.3.1.4 Low Battery Indicator

Steps:

1. Run the ECU with attached LCD with the battery very low (at least 1 hour before it cannot power the device reliably)
2. Replace or recharge the battery

Expected Result:

- The "Home" screen shows a low battery indication "!LOW BAT!".

```
30 km/h   12.4 km
Menu     !LOW BAT!
```

- After replacing or recharging the battery, the "Home" screen does not show "!LOW BAT!".

4.3.1.5 ABS Status Indicators

Steps:

1. Turn on the ECU and attached LCD
2. Note the ABS status indicated on the bottom right corner of the "Home" screen: "ABS" indicates it's enabled, and "!ABS OFF!" indicates it's disabled
3. Press the soft key labeled "Menu"

Expected Result:

- Verify that if the "Home" screen shows "ABS", the first item in the "Menu" screen is "1. Disable ABS", and if the "Home" screen shows "!ABS OFF!", the first "Menu" screen item is "1. Enable ABS".

```
30 KM/H   12.4 KM    →    1. Disable ABS
Menu          ABS         Back Select Next

30 KM/H   12.4 KM    →    1. Enable ABS
Menu     !ABS OFF!        Back Select Next
```

4.3.1.6 Disabling ABS

Steps:

1. Navigate to the "Home" screen
2. Verify that the "Home" screen indicates ABS is enabled by showing "ABS" on the bottom right corner
3. Press the "Menu" soft key to navigate to the "Menu" screen
4. Verify that the first item is "1. Disable ABS"
5. With the first item in view, press the "Select" soft key

Expected Result:

- After pressing the "Select" soft key with the first item in the "Menu" screen selected, the device returns to the "Home" screen.
- After pressing the "Select soft key, the "Home" screen shows "!ABS OFF!".

4.3.1.7 Enabling ABS

Steps:

1. Navigate to the "Home" screen
2. Verify that the "Home" screen indicates ABS is disabled by showing "!ABS OFF!" on the bottom right corner.
3. Press the "Menu" soft key to navigate to the "Menu" screen.
4. Verify that the first item is "1. Enable ABS"
5. With the first item in view, press the "Select" soft key

Expected Result:

- After pressing the "Select" soft key with the first item in the "Menu" screen selected, the device returns to the "Home" screen.
- After pressing the "Select" soft key, the "Home" screen shows "ABS".

4.3.1.8 Menu Screen Scrolling

Steps:

1. Navigate to the "Menu" screen
2. Press the "Next" soft key until you reach the bottom of the list
3. Press the right-most soft key once more.
4. Press the "Back" soft key until you reach the top of the list
5. Press the "Back" soft key once more

Expected Result:

- Except for the last item in the list, pressing the "Next" soft key moves down in the list.
- Except for the first item in the list, pressing the "Back" soft key moves up in the list.
- When the last item in the list is shown, the "Next" soft key label is not shown, and pressing the "Next" soft key has no effect.
- When the first item in the list is shown, the "Back" soft key navigates back to the "Home" screen.

4.3.1.9 Configuration Parameter Editing

Steps:

1. Navigate to the "Menu" screen
2. Select "Config ABS..."
3. Select "1. Delay"
4. Adjust the delay up and down using the "Up" and "Down" soft keys
5. Press "Back" once you are done editing the field
6. Repeat steps 3-5 for "2. A_{max}" and "3. V_{min}"

Expected Result:

- The cursor is positioned on the selected parameter number.
- The "Up" and "Down" soft keys increase and decrease the selected parameter, respectively.
- After you press "Back", the cursor no longer appears beneath the selected parameter number, your changes are preserved, and the "Up" and "Down" soft keys are replaced with "Select" and "Next" soft keys, respectively.

4.3.2 Electronic Control Unit (ECU)

4.3.2.1 Hardware Damage Immunity to Source Voltage Reversal

Steps:

1. Insert battery backwards in the battery holder

Expected Result:

- The system does not turn on
- The system is not damaged, and does turn on if the battery is reinserted with the correct orientation

4.3.2.2 Low-Power Mode and Wakeup

Steps:

1. Leave the ECU on for 10 minutes without applying any input to it (wheel speed is zero, no buttons are pressed, brakes are not applied)
2. Press a button, move the bicycle wheel, or apply the brakes

Expected Result:

- The system places itself into a low-power mode, turning off the LCD screen
- When a button is pressed, the bicycle starts moving, or the brakes are applied, the system turns on again and the LCD screen shows the "Home" screen.

4.3.2.3 Hardware Under-Voltage Operation

Steps:

1. Use the ABS system as the battery gets so low that it is unable to reliably power the system
2. While the battery is low, provide the ECU with signals indicating a locked up wheel with the brakes applied, simulating the situation where a user is moving and skidding because of a hard brake

Expected Result:

- The ECU should operate correctly, and then when the battery gets too low, it should turn off. It should not operate in an unreliable state.

4.3.2.4 Software Recovery from Intermittent Power

Steps:

1. Cycle the device power on and off quickly to simulate the effect of a loose power connection or battery

Expected Result:

- The system does not enter a dangerous state and once power is reapplied, the ECU recovers to correct operation. If the system does enter an undefined state as a result of the brief power loss, it should automatically reboot itself and recover to a good state within 0.5 seconds.

4.3.3 Wheel speed sensors

Wheel speed sensors will be tested with the bicycle in a stationary position and allowing the wheels to rotate. Cables may be tethered temporarily from a wire harness near the sensors to a test bench. From there, signal analysis may be performed to detect whether the speed sensors are working.

4.3.4 Brake actuators

The brake actuators will be tested by manually applying the control signal to the actuator whilst applying the brakes. If the brake actuator is functioning properly, the brakes will be released and the lever will not drop until the actuator is released.

The pump will be tested by rotating the wheel during this procedure and the lever should rise above the 1/2 way point.

4.3.5 Integration Test

4.3.5.1 Anti-lock Braking On Various Surfaces

Steps:

1. Perform steps 2-7 for various surfaces: dry pavement, wet pavement, loose gravel, grass
2. Ride the bicycle at 20 km/h (or well above the V_{min} configured)
3. Suddenly apply the rear brakes fully
4. Ride the bicycle at 20 km/h (or well above the V_{min} configured)
5. Suddenly apply the front brakes fully
6. Ride the bicycle at 20 km/h (or well above the V_{min} configured)
7. Suddenly apply both the front and rear brakes fully

Expected Result:

- In each situation, the ABS system modulates the applied brake(s) to avoid prolonged skidding at a rate of 7 Hz or greater.

4.3.5.2 Appropriate Brake Modulated

Steps:

1. Ride the bicycle at 20 km/h (or well above the V_{min} configured)
2. Apply the front brakes lightly and the rear brakes fully to skid the rear wheel only
3. Apply the front brakes fully and the rear brakes lightly to skid the front wheel only

Expected Result:

- When the rear brake is fully applied, it is modulated while the front brake is NOT modulated.
- When the front brake is fully applied, it is modulated while the rear brake is NOT modulated.

4.3.5.3 System Deactivation When Speed is Less Than V_{min}

Steps:

1. Ride the bicycle at 5 km/h (or below the V_{min} configured)
2. Suddenly apply the rear brakes fully
3. Ride the bicycle at 5 km/h (or below the V_{min} configured)
4. Suddenly apply the front brakes fully
5. Ride the bicycle at 5 km/h (or below the V_{min} configured)
6. Suddenly apply both the front and rear brakes fully

Expected Result:

- In each situation, the ABS system should not modulate the brakes because the speed is below V_{min}.

4.3.5.4 System Can Be Disabled and Enabled

Steps:

1. In the UI, select "Menu->Disable ABS" to disable the ABS system
2. Ride the bicycle at 20 km/h (or well above the V_{min} configured)
3. Fully apply each brake separately, and then both brakes together
4. In the UI, select "Menu->Enable ABS" to re-enable the ABS system
5. Ride the bicycle at 20 km/h (or well above the V_{min} configured)
6. Fully apply each brake separately, and then both brakes together

Expected Result:

- After disabling the ABS system, the brakes are not modulated during a hard stop and the bicycle is allowed to skid.
- After enabling the ABS system, the brakes are modulated during a hard stop and the bicycle is not allowed to skid.

4.3.5.5 System Under-Voltage Operation

Steps:

1. Use the ABS system as the battery gets so low that it is unable to reliably power the system

2. While the battery is low, and the ABS system is enabled, ride at 20 km/h (or well above the V_{min} configured)
3. Apply both brakes fully

Expected Result:

- The ABS system should operate correctly, modulating the brakes to prevent a prolonged skid.

4.3.5.6 UI Load Does Not Interfere with ABS

Steps:

1. Ride the bicycle at 20 km/h (or well above the V_{min} configured)
2. Slam on the brakes while rapidly pressing random soft key buttons on the LCD screen

Expected Result:

- The ABS system should operate correctly, without abnormal delay, modulating the brakes to prevent a prolonged skid.
- The UI should not hang or act unexpectedly.

4.3.6 Acceptance Test

4.3.7 General Acceptance Tests

Steps:

1. Ride the bicycle, according to typical usage patterns (e.g. bicycling around town, through parks, etc)

Expected Result:

- The ABS system should meet or exceed the users' expectations.

5. Conclusion

The proposed design specifications of Cyclic Technologies' ABS system are presented in this document to address the design challenges in our project. The actual development of our system has already begun and we are experimenting with the speed sensor in parallel with valve and motor controller circuitry. With our comprehensive system test plan we will make sure that all the functionalities of our system are viable and reliable. Furthermore, we are confident that our final prototype model will satisfy the essential requirements laid out in the proposed design specifications document.

6. Appendix

Below is a photograph of our LCD module displaying "Cyclic System" during testing. The backlight provides riders with the ability to read the screen, even during nighttime riding.

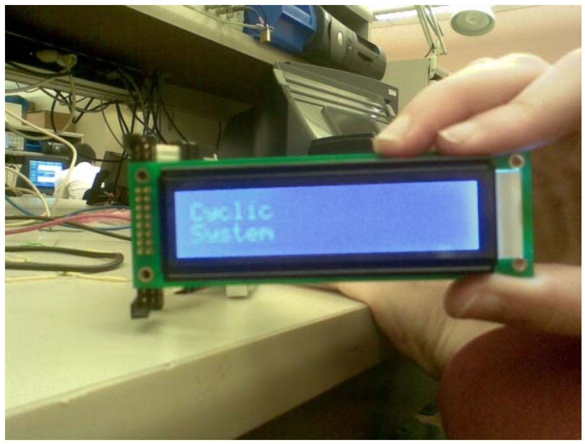

Figure 17 working LCD

7. References

[1] Cyclic Technologies, "Functional Specifications for Cyclic Technologies ABS System", Simon Fraser University, Burnaby, BC, Canada, October 2008

[2]“Anti-lock Braking System” in Wikipedia, History, Sept. 18, 2008. [Online]. Available: http://en.wikipedia.org/wiki/Anti-lock_braking_system [Accessed: Sept. 21, 2008].

[3] 8-bit AVR Microcontroller, “ATtiny2313/V data sheet”. AVR [Online]. Available: http://www.avr.com [Accessed: November 06, 2008].

[4] M. Carrick,"Home page - Micah Carrick," Feb. 2006. [Online]. Available: http://www.comm.pdx.edu/faculty/Sussman/sussmanpage.htm [Accessed: Nov. 03, 2008].

[5] S. Heinzmann, "How to control a HD44780-based Character-LCD," sec. 5.3, Jun. 15, 2006. [Online]. Available: http://home.iae.nl/users/pouweha/lcd/lcd_examp.shtml#_3. [Accessed: Nov. 3, 2008].

[6] Peter Paul Solenoid Valve, “Series 20 – Model 24 Solenoid Valve data sheet”. PETER PAUL [Online]. Available: http://www.peterpaul.com [Accessed: November 06, 2008].

[7] Flight Works Inc., “Model 400-B Turbojet Fuel Pump data sheet”. FLIGHT WORKS, INC. [Online]. Available: http://shopping.netsuite.com/s.nl/c.ACCT103531/sc.2/.f [Accessed: November 06, 2008].

