Bike Buddy

Senior Design I

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Group 15

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1. Introduction

1.1 Executive Summary

Renewable and alternative energy sources are becoming more important to our society and future generations. Our design group wished to build something with energy as our focus. After a little brainstorming we decided to use the idea of harnessing the energy which could be produced from putting an electric generator on a bike. This isn't an original idea and in fact bike powered projects are quite common. Our group wished to design a unique system that could be used on the open road versus a stationary mechanism.

Our team's objectives are to efficiently store the energy created from the generator to power onboard devices which would enhance the user's bike riding experience. Data gathered from sensors and GPS satellites will be displayed on an LCD screen which rests on the bike's handle bars. This information includes the power being created from the generator, information about the rider's location (using a GPS module), as well as the ambient temperature. The Bike Buddy will also feature a USB connection for various devices such as iPods, cell phones, or digital cameras.

A small "bottle" shaped electric generator designed specifically for bikes was found on the internet. It works by hugging the tire of the bike to spin the induction mechanism of the generator. Four battery types were considered for the Bike Buddy, and lithium ion was chosen as the best solution. The Li-ion's high power-to-weight ratio, cycle durability, and charge/discharge efficiency makes it the most attractive choice for our application. Two 7.4 Volt lithium ion batteries will be used in our design. One will provide power to the onboard devices, while the other is being charged by the generator. When the battery powering the Bike Buddy reaches a critical discharge level, it will switch states with the other battery going into charge mode.

To switch the batteries, we designed a switching circuit that monitors the two batteries. There are two comparators connected to each of the batteries to monitor the voltage levels and compare them to a reference voltage of 3.5V. Once the battery supplying power to the main circuit reaches 3.5V, the comparator connected to that battery sends a signal to series of p-channel MOSFET switching the output to the other battery. Right after the switch, the drained battery is connected to the charger until the next switch cycle. Although the switching is done very quickly, the main board may experience voltage dips occasionally. Therefore, to prevent any intermittent power loss, a capacitor is connected to the output.

A microcontroller is used to collect data from the GPS module and temperature sensor and display this information on the LCD. The GPS and LCD both communicate using asynchronous serial data, which is handled by USART on the microcontroller. These devices will need a range of 3.3 to 6 Volts to power each. An adjustable switching regulator was chosen to regulate the batteries voltage to supply power to these

devices. The MAX608 had the required input and output voltage ranges for our design. Three MAX608 regulators are to be used in dividing up the power from the battery to each device.

There are many similar projects which have been built and documented on the internet. When doing research for the Bike Buddy many of these projects were studied to find the best design methods. Some were previous Electrical Engineering Senior design projects and others were independent studies. Both provided insightful information on the design process and parts that could be used.

1.2 Motivation

Bike Buddy is an efficient system designed to provide the bicycle rider with information about her trip. It was important to the group to make use of alternative energy sources to enhance a pleasant bike ride. The information provided to the rider includes the time of day, the outdoor temperature, cardinal direction, speed, and power generated by pedaling, amount of calories burned as a function of power. Figure 1.1 below illustrates this conversion between power output and the amount of calories burned.
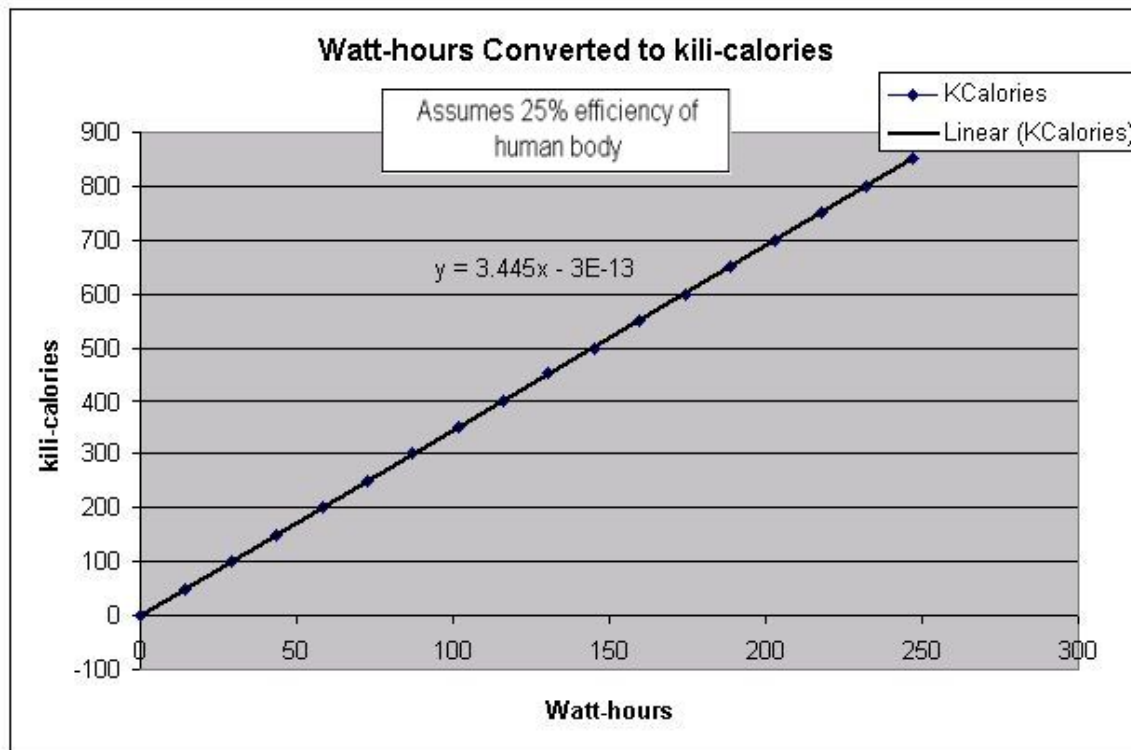
Figure 1.1 Watt-hours Converted to kili-calories (provided by scienceshareware.com, permissions pending)

The system can use the generated energy to power USB devices such as a portable fan or a cell phone. All of these features greatly facilitate long distance bike riding.

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The idea rose out of the group's interest in harnessing the energy used in pedaling a bicycle. Careful consideration was given to how this could be achieved in an efficient manner. In powering these devices we wanted a free energy source that would also be eco-friendly. The generator chosen would supply more than enough power for each item we wished to place on the bike. Instead of directly using the generators energy we wanted an intermediate source to harness its energy to avoid over powering the devices. The idea of using rechargeable batteries was what we came up with. Less waste would be created from being able to use the batteries for multiple charge and discharge cycles. Most of the battery types considered is also less toxic and when disposed of properly have less impact on the environment.

The Bike Buddy is a self-sustained, eco-friendly system which can be implemented on almost any bicycle. With alternative energy sources quickly on the rise, we felt this would be an interesting and motivational project for efficiently creating and harnessing power. We also wanted to be able to read how much power could be created by a human pedaling a bicycle. Questions arose like how long could they sustain generating a significant amount of power? And was this enough power for modern devices used for entertainment purposes. Not only would the Bike Buddy answer these questions, it would provide information on what types of applications could arise from human generated power sources.

1.3 Goals and Objectives

1.3.1   Features

The device enhances the common experience of riding a bicycle by providing useful information about the trip. A screen placed on the handlebar displays frequently updated data, including: the date and time of day, outdoor temperature, speed and cardinal direction, latitude and longitude minutes, and the amount of power generated by pedaling (expressed in watts). Also available to the user is a USB port, providing a way to charge and/or use portable USB devices, such as a cell phone.

1.3.2   Physical constraints

The system is 100% mobile in the spirit of the time-honored design of the bicycle. The self-contained display box is fastened securely to the handlebars with two clamps. A wire travels from this box along the body of the bicycle to an electrical generator attached to the rear wheel. The device is light-weight to minimize any additional work required to pedal the bicycle. To account for weather and various elements the rider is exposed to while riding outdoors, the device is water resistant.

1.3.3   Power efficiency

The system is entirely self-sufficient and is powered by a rider pedaling the bicycle. This is accomplished with a small bicycle generator attached to the rear wheel of the bike. This electrical energy generated by the rider is converted and stored in a battery as efficiently as possible. The battery is charged with a smart charger which monitors voltage, current and temperature levels. This power is then supplied to the other features in the device. A low-power display with controlled backlighting receives minimal updates to conserve power. The USB interface provides limited power to portable and chargeable USB devices.

1.4 Specifications

1.4.1   Electric generator

The 'bottle' generator chosen for the project has a marked output of 6 watts at 12 volts AC, shown in Table 1.1. This voltage is unregulated. It is attached to the bike frame near the rear wheel with a metal clamp. Its dimensions are 2.5″ in length with a diameter of 1.25″.

Voltage (V)	Current (mA)	Weight (lb)	Power (W)	Cost (USD)	Current Source
12V	500mA	1.2 lbs.	6W	$16.99	AC

Table 1.1: Specification for the electric generator.

1.4.2   Battery

Two 2-cell lithium ion battery packs are used in this project. The Lithium Ion module is made of 2 pieces of high quality 18500 rechargeable cells with a 2 Amp poly switch for full protection of over-heating. The cells are wrapped in transparent PVC shrink with external 22 AWG wire. This pack is installed with an internal IC chip to prevent over and under discharge situations. The specifications are listed below in Table 1.2.

Capacity	1400mAh
Voltage	7.4V (8.4V Maximum)
Dimensions	2.63in X 1.45in X 0.7in
Weight	3.5 oz

Max. Charge Current	2A
Max. Discharge Current	5A
Cut- off Voltage	4.8V

Table 1.2: Specification for the lithium ion battery.

1.4.3 Power supply

The power supply takes an AC input voltage from 0V to 50V that normally comes from a small generator and converts it to DC. Since the generator can only output a minimal voltage, there is no need to use a step-down transformer in the power supply; just a simple voltage regulator will suffice. Also, we don't want to step-down the voltage because we need to monitor the amount of energy that's being created by the generator. The DC conversion circuit will output a DC voltage with enough filtering to prevent transient noise. After that voltage is converted and regulated, that DC voltage is used to charge a rechargeable battery. That same voltage will also be used to power a switching circuit that'll decide which battery to use to power the system. The concrete specs are listed in Table 1.3 below.

Input Voltage	Full-Bridge Rectifier Output	Voltage Reg. Max. I/O	Bat. Charger Input Voltage	Output Voltages
12V AC	10.0V DC	67V / 10.0V	10.0V	3.3V / 5V / 6V

Table 1.3: Specification for the power supply circuit.

1.4.4 Display

A 128x64 pixel liquid crystal display was chosen for the project. The screen requires 6-7 V and has scalable LED backlighting. According to the datasheet, it draws approximately 220 milliamps with the backlight on. It is mounted on a daughterboard with the dimensions 2" x 2.45" and 0.75" deep, requiring four metal spacers to attach to the main circuit board. Connected to the screen is an intermediate 'backpack' circuit which provides serial communication and four pins: VCC, GND, Tx and Rx data lines. The Tx pin was included by the manufacturers for potential code revisions, so only the Rx pin will be used in the design. This pin is connected directly to an I/O pin on the microcontroller. The data is serial TTL at 115,200 baud (default).

1.4.5 Microcontroller

The ATmega128L meets the requirements for a powerful microcontroller with a variety of I/O features. It is powered by 3.3v and draws current in the range of milliamps. It features 53 multi-purpose I/O pins, an analog-to-digital converter, and 128KB of

programmable Flash memory. This microcontroller can drive a graphical display and handle multiple peripherals at once. It is a surface-mount device soldered to a daughterboard with standard 0.1 inch pitch headers intended for four 16-pin sockets (in the formation of a square). The board is 1.5 inches square, and each socket is 13/16" long with slightly more than 1/16" spacing between sockets.

1.4.6   GPS receiver

Bike Buddy requires a low-power GPS receiver with an embedded antenna to provide information including velocity, global position, and the time of day. The LS20031 receiver meets these needs. The daughterboard is roughly square with a dimension of 1 and 5/16 inch, and requires four metal spacers to attach to the main circuit board. Five bare pads on the underside of the chip can be soldered to (VCC, Tx, Rx, two redundant GND). The data line is serial with a default baud rate of 57,600bps. The software interface provided is in the form of an MTK packet, which encases standard NMEA sentences.

1.4.7   Temperature sensor

The temperature sensor that will be used in the project is called DS1625 made by Dallas Semiconductor. One of the benefits of this part is that doesn't require any other extra external component like other sensors. DS1625 can measure temperature from -55°C to +125°C in 0.5°C increments. In Fahrenheit, it is equivalent -67°F to 257°F in .9°F increments. This is very simple temperature sensor, it read as a 9-bit value. It will converts temperature to digital word in 500ms in max. The recommended DC operating conditions are listed in Table 1.4 below.

Parameter	Symbol	Min	Typ	Max	Units
Supply Voltage	V_{DD}	4.5	5.0	5.5	V

Table 1.4: Recommended DC operating conditions (Dallas Semiconductor. Permission pending)

Second temperature sensor is called DS18B20. It is higher technology, it has many other functions compare to DS1625 include basic temperature sensor function. It can measure temperature from -55°C to +125°C in 0.5°C increments. It has unique 1-wire interface, so it only need one port pint for communication.

Parameter	Symbol	Condition	Min	Typ	Max	Units
Supply Voltage	V_{DD}	Local Power	3.0	-	5.5	V
Pull-up Supply Voltage	V_{PU}	Parasite Power	3.0	-	5.5	V
		Local	3.0		VDD	

		Power				
Sink Current	I_L	VI/O =0.4V	4.0	-	-	mA
Standby Current	I_{DDS}	-	-	750	1000	nA
Active Current	I_{DD}	VDD=5V	-	1	1.5	mA
DQ Input Current	I_{DQ}	-	-	5	-	µA

Table 1.5: DS18B20 Operating Condition (Provided by Maxim, Permission pending)

VK011, Serial Temperature Sensor Interface can be used to test temperature sensor by itself. It requires 9-15V DC from adaptor or through the serial port. Currents will be 4mA@12vDC or 6mA@9vDC with LED disabled, but it will be 8mA@12vDC or 7mA@9vDC with LED power indicator. It is very easy fully assembled product; we can simply screw terminals for easy connection of up to four temperature sensor.

1.4.8   USB

USB is used for communication between devices and a host controller usually in personal computers; it can also be used as a power source. USB will be used as power source in the project for present, but also it has a potential as a data transferring function too. As for now, USB will mainly be discussed as power source. It provides a 5V supply on a single wire from USB devices that draw power. USB 2.0 released in April 2000, and it is very commonly used in every electronic devices. The specification provide 5V±5%, which is between 4.75 V and 5.25 V. This unit can load 100 mA, and maximum of 5 unit loads which is total 500 mA. For date transfer, it has maximum speed of 480Mbit/s.

Parameter	Requirement
DC voltage, high-power port	4.75V to 5.25V
DC voltage, low-power port	4.75V to 5.25V
Maximum quiescent current (low power, suspend mode)	500µA
Maximum quiescent current (high power, suspend mode)	2500µA
Maximum allowable Input capacitance (load side)	10µF
Minimum required output capacitance (host side)	120µF ±20%
Maximum allowable inrush charge Into load	50µC

Table 1.6: USB Specification.

2. Research

2.1 Electric generator

In the Bike Buddy one of our goals is to convert mechanical energy spent pedaling a bicycle into electric energy through a permanent magnet generator. The idea of using generators for electric power is a very common and a somewhat simple concept. Scientists such as Michael Faraday and Nikola Tesla revolutionized the capabilities of electromagnetic induction for power generation over one hundred years ago. Today we still use these basic concepts of electromagnetic induction to power entire cities, with populations exceeding one million people.

Electric generators vary widely in size and the amount of power they produce. Larger generators can be mechanically powered through a steam engine turbine. We will need only a small amount of power for our purposes, and our generator can be very small in comparison. Variables which determine a generators output voltage and current are mostly related to the geometry and materials of the device.

Our goal at first was to design an electric generator specific to our needs. This involved researching types of magnets, DC versus AC generator design, and Electromagnetic field theory and design. Because our generator needed to be small, durable, lightweight, and efficient in a dynamic environment we decided it would be in our best interests to purchase one on the market.

After doing some research, two designs for generators were considered. The first was a dynamo generator built to act as the axel of the bicycle wheel and the magnets would be spun through the rotation of the wheel. This required building a custom wheel (custom spokes) to house the generator. This proved to be a sleek and efficient design. The SRAM I-Light Dynamo 730 Front QR 36H Hub 3.0W is pictured below as Figure 2.1.

Figure 2.1: A Dynamo 730 Front Hub 3.0W Generator (Provided by Dynamo, Permissions Pending)

Product Specifications for the SRAM i-Light Dynamo 730 Front QR 36H Hub are as follows.

Voltage (volts)	Current (milliamps)	Weight (pounds)	Power (watts)	Cost (USD)	Current Source
6V	400mA	1.9 lbs.	2.4W	$63.70+s&h	AC

Table 2.1: Specification for the Dynamo 73 hub generator.

The second most common form of a bicycle generator is the friction-based 'bottle generator' pictured as Figure 2.2. This version comes with a bracket which easily clamps to almost any bicycle frame. The small black knob is positioned against the tire so that the tire spins the knob, powering the generator.

Figure 2.2: A 'bottle generator' attached to the rear wheel of a bicycle.

Our concern with this set-up was that if the tire were wet or there was any slippage between the tire and knob that there would be too much loss of power. However the specifications of the generator did not indicate this would be a problem, and are listed in Table 2.2 below.

Voltage (V)	Current (mA)	Weight (lb)	Power (W)	Cost (USD)	Current Source
12V	500mA	1.2 lbs.	6W	$16.99	AC

Table 2.2: Specification for a 'bottle generator'.

This second "bottle" generator was chosen based on price. It has higher current and voltage output, which can easily be regulated instead of needing to be amplified. The bottle design is cheaper, and won't require further construction of a custom wheel. We decided to purchase the "bottle generator," to test and verify its specifications. The two designs considered above, were chosen after extensively researching the development of our own generator, comparing types of generators which could be purchased on the market, and our own requirements for generating power to the Bike Buddy.

Safety

Electric generators tend to generate a lot of heat. The generator in our design will be mounted on the back wheel away from the rider. However precaution should be taken and a warning sticker should be placed on it to ward against human contact especially during use. Figure 2.3,below shows the heat characteristics of a generator during use.
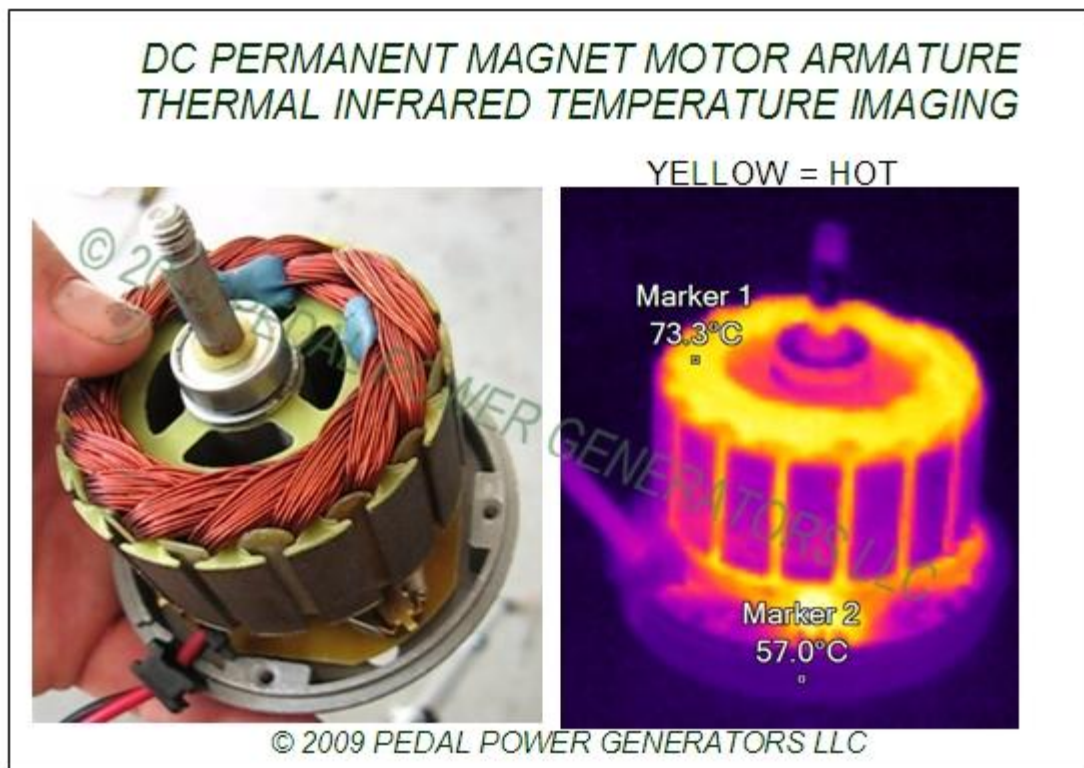
Figure 2.3 Thermal Infrared Temperature (Provided by Pedal Power Generators LLC. Permission pending)

There are many applications for designing a bike generator. Many will provide enough power to supply, laptop computers, television sets, house hold appliances, and even video game consoles! A simple setup for a bike generator powering a TV is depicted below in Figure 2.4
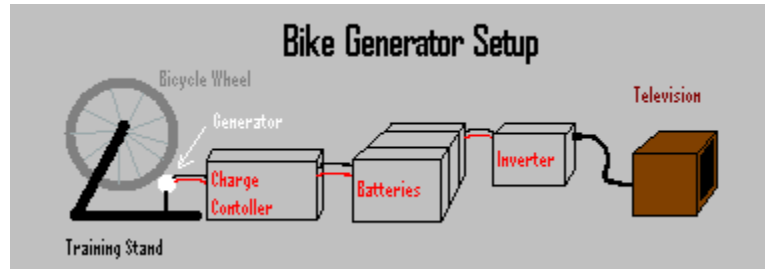
Figure 2.4:: Bike Generator Setup (Provided Pedal Power Station. Permission pending)

Wire Gauging

Another aspect that is really important for the project is the type and size of wire we use to connect the generator to the power supply. We need to connect the wire from the back wheel of a bike to the handlebar. A lot of power will be lost in the wire, so it is important that we select the right wire gauge for the amount of current generated by the generator. Table 2.3 below shows the different configuration and requirements at the different maximum current and power levels.

Wire Gauge and Current Limit Table

AWG gauge	Diameter Inches	Diameter mm	Ohms per 1000 ft	Ohms per km	Maximum amps for chassis wiring	Maximum amps for power transmission
0	0.325	8.2525	0.098	0.3224	245	150
1	0.289	7.3482	0.124	0.4064	211	119
4	0.204	5.1892	0.249	0.8151	135	60
6	0.162	4.1148	0.395	1.2959	101	37
8	0.129	3.2639	0.628	2.0605	73	24
10	0.102	2.5883	0.999	3.2764	55	15
12	0.081	2.0523	1.588	5.2086	41	9.3
14	0.064	1.6281	2.525	8.2820	32	5.9
16	0.051	1.2903	4.016	13.1725	22	3.7
18	0.040	1.0236	6.385	20.9428	16	2.3
20	0.032	0.8128	10.150	33.2920	11	1.5
22	0.025	0.6452	16.140	52.9392	7	0.92
24	0.020	0.5105	25.670	84.1976	3.5	0.577
26	0.016	0.4039	40.810	133.8568	2.2	0.361
28	0.013	0.3201	64.900	212.8720	1.4	0.226
30	0.010	0.2540	103.200	338.4960	0.86	0.142
**	***	***	***	***	***	***

Table 2.3: Wire gauge and current limit table (Courtesy of Cablesandconnectors.com, permission pending)

To power the onboard devices the electric generator is taking mechanical energy exerted by the rider into the bicycle and converting it into electricity. In turn the generators electricity is feeding a battery which will convert it into chemical energy to be stored. From this stored energy the devices such as GPS and the LCD will be powered by electrical energy converted from the batteries chemical potential. Figure 2.5 shows the energy cycle taking place.
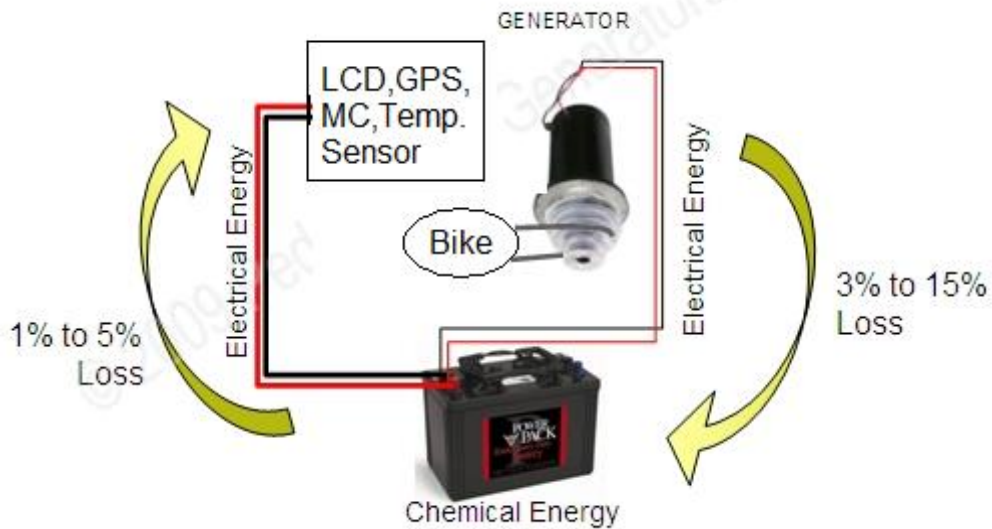
Figure 2.5: Basic depiction of the energy cycle for Bike Buddy. (Image provided by pedalpowergenerator.com, permission pending)

2.2 Power Supply

For a project like ours, power consumption is of the utmost importance. Since we are using a small generator to generate electricity, the less energy that is lost throughout the circuit, the better. Given those restraints, we decided to use energy efficient components wherever possible. One of the crucial sections of the design is the power supply, which will provide a stable voltage with enough current to the different sub-sections of the project. While researching how to best satisfy the requirements, we analyzed four different kinds of power supplies: linear, switched-mode, programmable, and voltage multiplier power supplies.

2.2.1 Linear Power supplies

A linear power supply takes an AC input voltage, typically from the wall socket, and lowers it to required specifications with a step-down transformer. Sometimes rectifiers are used to convert the AC signal to DC. Capacitors are used to smooth out the ripple in

the output. However, one of the crucial characteristics of a linear supply still remains: the output changes with the input. Such supply alone will not work for our project. The unstable output voltage does not meet the requirements of the subsections that rely on a constant DC voltage source. For many electronic devices, linear regulators are used to adjust the voltage and remove the ripple. Some of those configurations may be implemented in our design provided we make a few adjustments to meet our specifications.

2.2.2   Switched-mode power supplies

This type of supply does not use a transformer to step down an AC signal from the wall. It only uses a rectifier circuit to convert the AC to a DC output voltage. That voltage is then connected to a high-speed electronic switch that is then divided into different AC voltages at a maximum frequency of 1MHz. After that conversion is done, smaller step-down transformers are used with a rectifier circuit to again convert the AC signals to usable DC voltages. Switched mode power supplies like the one in Figure 2.6 are ubiquitous in computers because of their voltage level flexibility and they often have safety features to help protect the load device. As a safety precaution, they can shut down in the event of a short to prevent voltage spikes, which can damage the components. Although they are extremely popular, they have been known to have a very poor power factor. That's why many of the power supplies built within the last few years—such as the one shown below— have power factor corrections implemented into them.

Figure 2.6: An example of a switched-mode power supply. (Image falls under the GNU Free Documentation License for distribution.)

2.2.3   Programmable power supplies

Programmable power supplies are supplies whose voltage, current and frequency can be changed using a computer interface. Their physical designs are not that much different from other supplies because they fulfill the basic task of a power supply. They have added features that are useful to different applications for which they were designed. In automated equipment testing for example, being able to alter the voltage, current or frequency is extremely important for component stress testing. Many industrial machines used those power supplies to perform different tasks at different speeds. It would be inefficient to have to switch out a physical component to perform a different task on an assembly line. When selecting a programmable supply for applications that require AC, output voltage and accuracy, output frequency and output current are important features to note. In DC applications, the same is true with an added power characteristic. Although this type of supply seems very interesting as a project proposal, we don't think that it is necessary to implement all those features in our design. We're only using the power supply to power the device and then decide how to use that power efficiently with a microcontroller. Our supply will not be programmed but the subsystems will be using as little power as possible to maximize efficiency.

2.2.4   Voltage multiplier power supplies

Voltage multipliers are ubiquitous in portable electronics due to their small footprints and their current limiting feature. They are often used with relatively small batteries required in those applications to provide a voltage higher than the batteries can supply. They are what make many household devices operate efficiently. In a voltage multiplier, an AC input is converted to a higher DC voltage and current. Sometimes that DC output doubles, triples and even quadruples the input voltage to power a device that requires a high DC input. While this feature sounds very promising for a renewable energy project, there is a significant disadvantage to using a voltage multiplier. Given that the current is inversely proportional to the voltage any increase in the voltage will result in a substantial drop in current. But, if the application requires a low current with a high voltage, a voltage multiplier is the best option to implement. Some part of our power supply will require some implementation of a voltage multiplier in order to achieve the low current requirements for some of the components we plan to use.

2.3 Voltage regulator

Voltage regulators are extremely important in our design. After the AC voltage from the generator is converted to DC, we need to limit the voltage and current going into the main board. One of the possible ways to achieve that is to use voltage regulators. The first voltage regulator that we are using in the circuit must be able to output a 10V DC to the charger and the switching circuit. It must also be able to deliver a minimum current of 1A to the charger in order to charge the battery cells properly. During our research

we found several commonly used voltage regulators that cover some of the requirements of the project. Their specifications are noted below in Table 2.4. The famous LM317 voltage regulator chip is used in many applications, especially in power supply designs. It has the same configurations as the LM117HV. While the LM117HV is larger and used in large voltage applications, the LM317 is used in regulate voltages at reasonably low levels. Figure 2.4 below has a basic configuration that works for both the LM317 and its high voltage counterpart, the LM117HV.

	KA7810	LM117HV	NTE1932
Input Voltage	12.5V to 25V	1.2V to 57V	12.5V to 25V
Output Voltage	10V	10V	10V
Output Current	5mA to 1.5A	1.5A	1A
Temperature	0°C to 125 °C	-40°C to 125°C	0°C to 125 °C
Peak Current	2.2A	1.5A	2.2A
Package	TO-220	TO-220	TO-220

Table 2.4: Voltage regulators that meet some of the requirements for the project.

In many instances, diodes can be used as voltage regulators. Zener diodes have different voltage drop ratings across their reverse bias configuration provided that the voltage applied is greater than the breakdown voltage. They are sometimes used as reference voltages for amplifiers and comparators because of their low current ratings. In some applications with low current requirements, a zener diode can achieve the same result as a more expensive DC/DC voltage regulator.
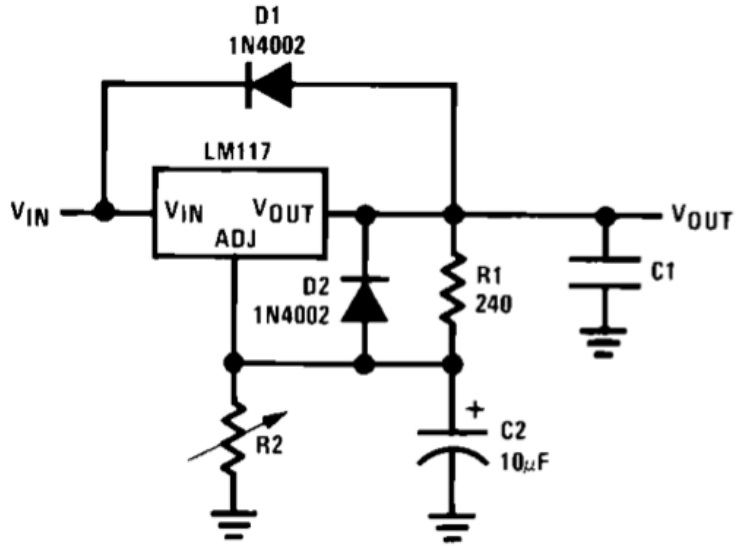
Figure 2.4. Schematic for the LM117and LM317 for an input of 25V. (Courtesy of National Semiconductor, permission pending).

For the voltage distribution, in considering voltage regulators to be used there were three limiting factors. The input voltage upper and lower limits, the amount of input and output current, as well as the output voltage required for each device. There are two general types of voltage regulators: linear and switching. For our design we decided to use the switching regulator for a few reasons. First, switching regulators are about 90% efficient whereas linear regulators are only about 50%. Switching regulators can also generate an output current higher than that of linear devices. They are also good for portable electronics applications with batteries. One quality that linear regulators have over switching however is less noise on the output voltage. Further testing will be required to see if the ripple in the output voltage will be a problem.

Switching regulators have many topologies. The three most common are buck (step down), boost (step up), and buck-boost (step up/step down). Our battery will be supplying anywhere from 3 to 8 Volts to loads which require a range of 3.3 to 6 Volts. Maxim has a voltage regulator which met these specifications. The MAX608 step-up converter is an adjustable regulator which works well with battery applications. The pin level diagram of this chip is pictured below in Figure 2.7.

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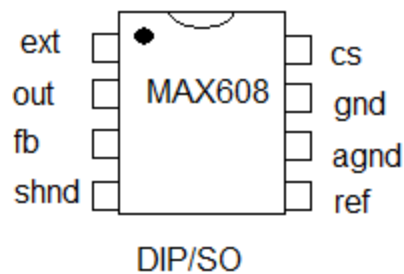
Figure 2.7: The pin layout for the MAX608 step-up converter.

Each pin will be connected to external circuitry listed below.

Pin 1 (EXT): Gate Drive for External N-Channel Power Transistor

Pin 2 (OUT): Power-Supply and Voltage-Sense Input. Always connect OUT to circuit output.

Pin 3 (FB): Feedback Input for Adjustable-Output Operation. Connect to ground for fixed-output operation. Use a resistor divider network to adjust the output voltage.

Pin 4 (SHDN): Active-High TTL/CMOS Logic-Level Shutdown Input. In shutdown mode, VOUT is a diode drop below the input voltage (due to the DC path from the input voltage to the output). Connect to ground for normal operation.

Pin 5 (REF): 1.5V Reference Output that can source 100mA for external loads. Bypass to GND with 0.1mF. The reference is disabled in shutdown.

Pin 6 (AGND): Analog Ground

Pin 7 (GND): High-Current Ground Return for the Output Driver

Pin 8 (CS): Positive Input to the Current-Sense Amplifier. Connect the current-sense resistor between CS and AGND.

To adjust the output voltage an external voltage divider is required to accompany the Max608 chip. The input voltage is on the C2 node, and the output voltage is taken off of the C3 node. The output is automatically set to 5 Volts and may be adjusted by changing the component values in Figure 2.8 below. Resistors with a 1% tolerance should be used to achieve a 5% tolerance in the output voltage.
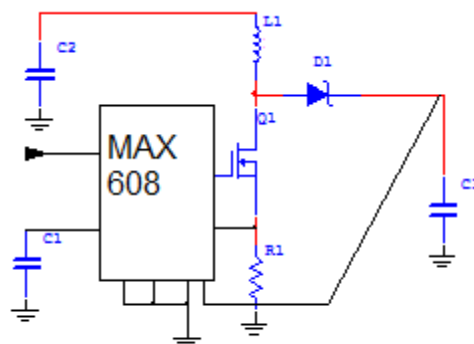
Figure 2.8: Schematic for the MAX608 voltage step-up converter.

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Two of our devices, the GPS and Microcontroller will be using a 3.3 V DC source. Another two, the USB and temperature sensor will be running on a 5 V DC source. Table 2.5 gives the design values for the components in Figure 2.8 to give these two output voltages.

	C1 (µF)	C2 (µF)	C3 (µF)	R1 (mΩ)	Q1	L1 (µH)	D1
5 V	0.1	150	0.1	50	NMMFT3055EL	22	1N5817
3.3 V	0.1	0.1	200	50	NSI6426	22	1N5817

Table 2.5: Component values for the schematic in Figure 2.8.

*Note: other components were added to the above topology to attain the correct output voltage.

Some of the relatively high voltage, regulators will require a heat sink. It is always recommended to include a heat sink on the regulator that is used in a power supply. The voltage levels are most of the times higher coming from a wall outlet and when those voltages are regulated, the regulator wastes a lot of energy shaking off that excess voltage and turns it to heat. So using a heat sink greatly reduces wear and tear and extends the life cycle of that particular voltage regulator. In Figure 2.5.5 we see a typical heat sink that is often attached to a voltage regulator to dissipate the heat created in the circuit.
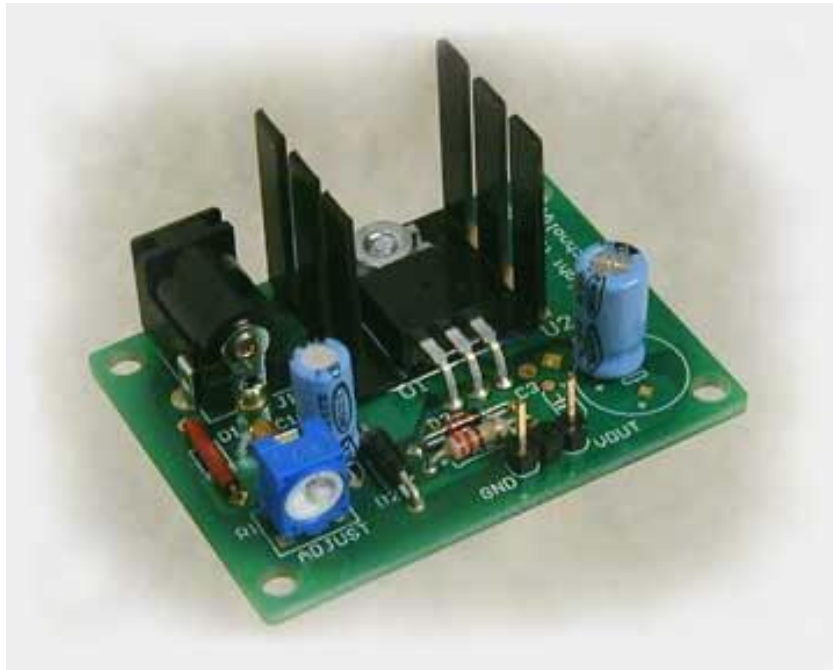
Figure 2.5.5. An example of a heat sink that that will be used for the LM317 voltage regulator. (Courtesy of electronicecircuits.com, permission pending).

2.4 Battery switcher

While thinking about the battery switching circuit that is needed to select a charged battery in the charger, we thought about implementing the switching behavior using a small microcontroller. Although that method may sound more efficient, we would still need to design a circuit to monitor the battery voltages and relay that information to the microcontroller which would in turn select a battery to power the system. Given that we are already using a microcontroller for the project, we wanted to experiment with an analog circuit design dilemma. Figure 2.9 below shows the general topology for two batteries being charged with a generator.
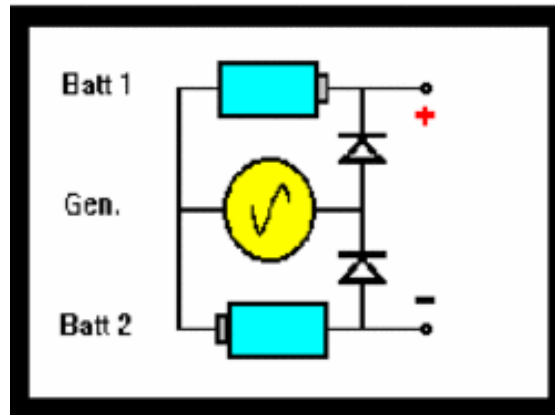
Figure 2.9: Two battery configuration. (Provided by Power stream. Permission pending)

Our design needed to switch between batteries, and a mechanism for switching needed to be developed. A simple relay switch like that pictured below in Figure 2.10 was our first attempt at solving this problem.
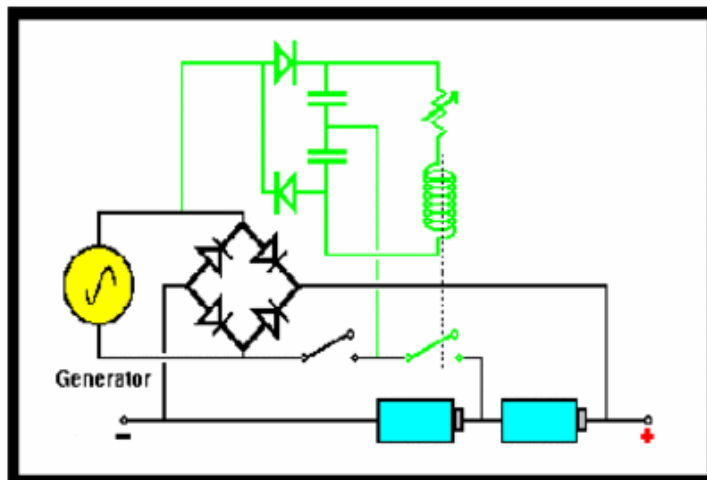
Figure 2.10: (Provided by Power stream. Permission pending)

However we needed a circuit that would create a smoother transient state between switching, so as to leave any connected components uninterrupted during this process. Needless to say, we were unable to find a battery switcher built in that method during our research. Therefore, we had no other choice but to design one from scratch.

What we did find were a few power source selector chips. Some of them were switching a battery source with an AC adapter source. The Maxim chip MAX1773 is one of those power selector chips. It incorporates two batteries with an AC adapter input. Figure 2.11 below shows a typical operating circuit that used the Maxim battery selector chip. Although it does some of the feature that we need for our design, its topology is too complicated and too demanding on our system. It is too complicated be interfaced with our charger given that we do not have enough power to drive its features efficiently.
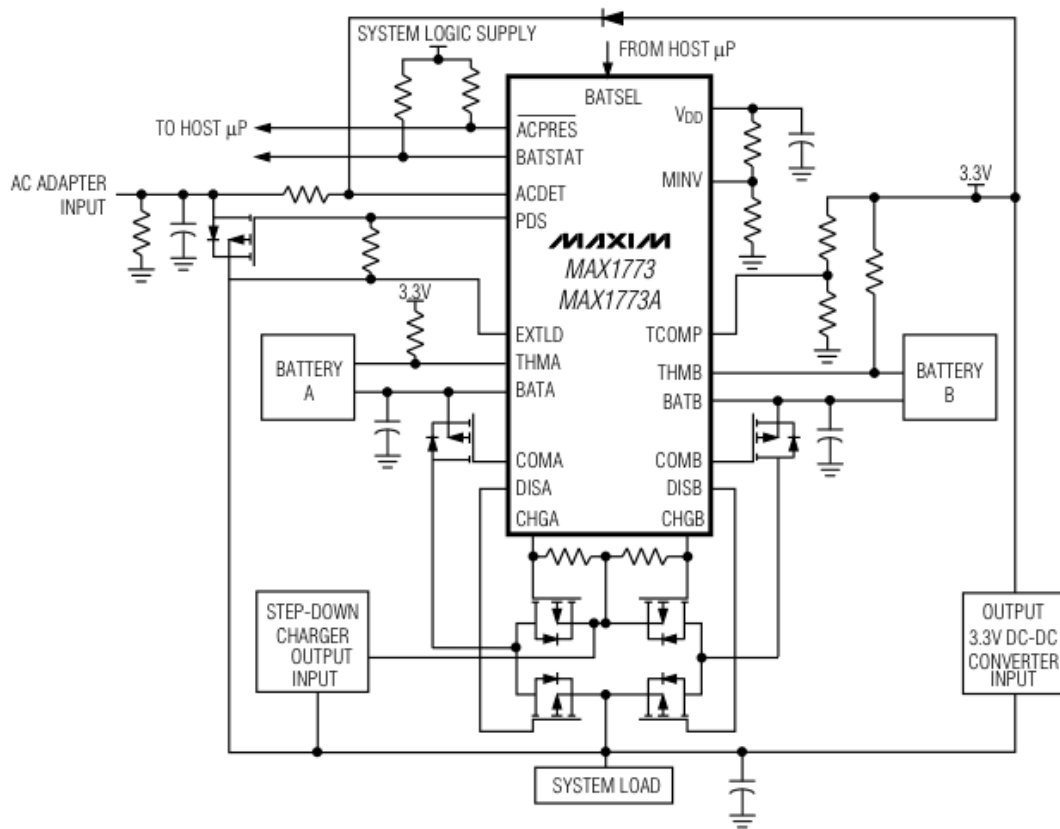
Figure 2.11: Schematic for a typical source selector circuit using the MAX1773 chip. (Provided by Maxim. Permission pending)

In designing the simple switcher that we want, we searched for similar design examples for efficient components to use. We first tried a design using NPN transistor to switch between the batteries. Given that transistors are driven by their base current and that that current also affects the emitter and collector current, Vce changes according to the resistor values on those terminals. Although the switch worked, the output voltage was only a fraction of the battery voltage. When we tried the design with PNP transistors,

the efficiency increases but since there's a small current leakage from emitter to base, the output was not as efficient as it could be. The whole notion of using resistors in the switcher did not sound efficient energy-wise since the maximum output current that should be achieved would be lower. So we went back to do some more research on how to drive a transistor without resistors. We noticed that the mosfets can be driven to saturation with a small voltage to their base terminal. So the next phase was to implement those mosfets to switch between the two batteries depending on their voltage levels. We wanted the load to decide when to switch the batteries, therefore we implemented the voltage reference level at the minimum required for the load so every time the source battery reaches that minimum, a switch would be initiated.

Given that we have to design the battery switcher from scratch, we search for low power comparators that would enable the efficiency in our choice. We found many chips that fit the profile of a low power comparator. The LTC6702 is a dual comparator chip manufactured by Linear Technology with a low supply voltage of 1.7V at the minimum. It has a low propagation delay of 500nS within a temperature of -40 degrees to 125 degrees. Since we need the switch to be as efficient as possible and as fast as possible, a 500nS would not require a large capacitor to compensate for the voltage drop on the output of the switcher. This particular chip was designed for battery powered system, threshold detectors, and automotive sensing control. A basic configuration of the comparator can be seen in Figure 2.12 below. Its setup may be different in the design of the switching circuit.
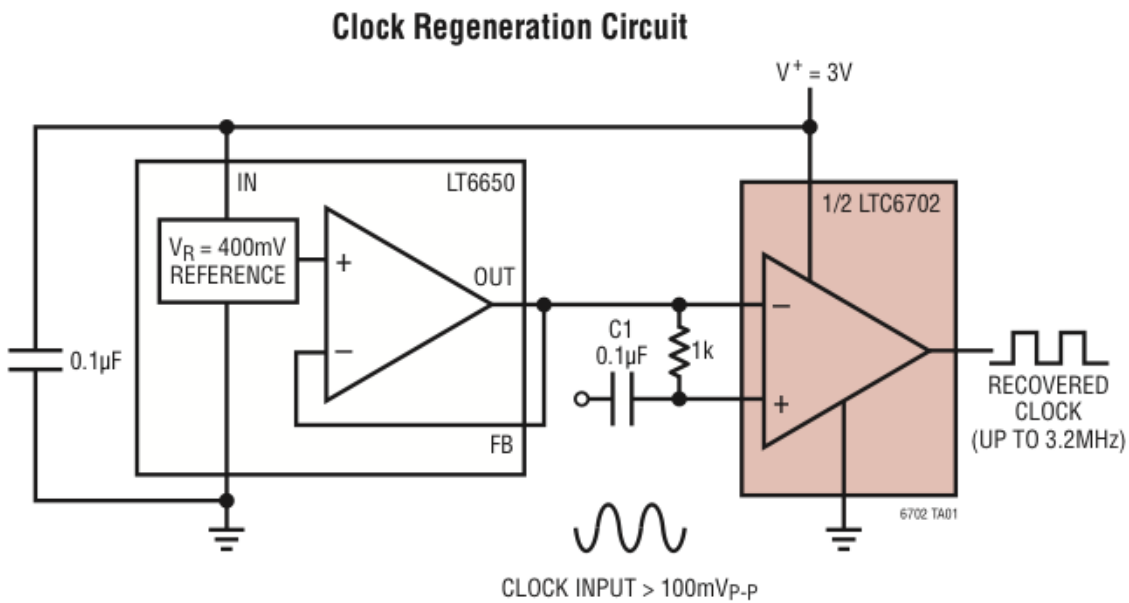
Figure 2.12: Schematic of a basic implementation of a comparator using the LTC7602 dual comparator. (Courtesy of Linear Technology, permission pending).

2.5 Power sensor

There are several ways to monitor the power on the generator. During our research, we found many analog and digital means to monitor the voltage levels from a dynamic power source such as the bicycle generator that we're using. The DS1231 chip manufactured by Dallas Semiconductor monitors the power level and can even warn the processor of impending power failure. This is important in certain applications where the processor may need to store non-volatile data that wouldn't survive power transients. It also provides enough time for an orderly shutdown. Sadly, it can only be used in very low voltage applications. It only accepts a maximum input voltage of 7.0V thus proving that it is better suited to monitor the input voltage on a microcontroller.

Linear Technology has a power-monitoring chip that does a great job at monitoring the voltage and current level of high power systems. The LT2940 can monitor a voltage up to 100V. Also, a current level is monitored to be multiply with the voltage inside the chip for a power level output. It can also indicated forward and reverse power flow given the right configurations. The MSOP package can handle a temperature up to 300 degree Celcius. In Figure 2.13 below, a configuration that monitor a voltage of 60v is shown with a load that can receive a current of up to 10A.
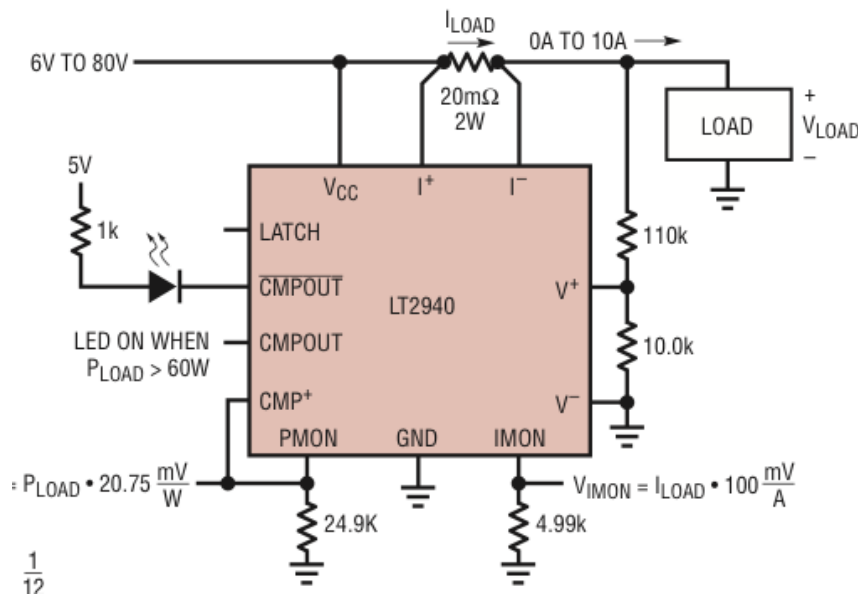
Figure 2.13: Basic schematic of a voltage monitoring system using the LT2940. (Courtesy of Linear Technology, permission pending).

The feature we want to add to our project is very simple. We only want to monitor the amount of voltage, more specifically DC voltage that is being generated. There are many complicated monitoring systems that are designed to monitor the mains voltage levels in a house. Our desired outcome can be achieved using our microcontroller and the A/D converter. We simply need to program the converted binary data and display it on the LCD.

2.6 Rechargeable battery

The battery selection plays a very important role in the design of our project. It will harness all the power created by the generator and supply it to our LCD screen, USB jack, GPS, and microcontroller. Because the battery or batteries are to be mounted on a bike which will be ridden outdoors; size, weight, and durability are important limitations to the project. The top candidates for research are the lead acid, lithium ion, nickel cadmium, and nickel-metal hydride batteries. Characteristics such as charging and discharging rates, energy density, energy-to-weight ratios, self discharge rate, and capacity which are important to the design are compared in Table 2.6 below.

Battery Characteristics	Lead Acid	Nickel Cadmium	Nickel Metal Hydride	Lithium Ion
Energy/Weight (Wh/kg)	30-40	40-60	30-80	100-160
Energy/Size (Wh/L)	60-75	50-150	140-300	250-360
Power/Weight (W/kg)	180	150	250-1000	250-340
Charge/Discharge Efficiency	50-92%	70-90%	66%	80-90%
Energy/Price (Wh/USD)	7(sld) - 18(fld)	—	2.75	2.8 - 5
Self-discharge Rate (per mo.)	3-20%	10%	30%	8% (21°C)
Time Durability	—	—	—	24-36 mo.
Cycle Durability	500-800	2,000	500-1,000	1,200
Nominal Cell Voltage	2.105V	1.24V	1.2V	3.6V
Nominal Capacity	7200 mAh	900 mAh	700 mAh	4800 mAh
Size	151x98x98mm	73x29x52mm	51x48x22mm	127x80x43mm
Weight	3940g	210g	135g	678g

Table 2.6: Characteristics of different battery technologies relevant to the project.

Each type of battery considered has its own unique charging methods. Most batteries have several methods in which they can be charged. The most efficient methods were researched with time and money considered as a ruling factor. A design goal for this project is to power the onboard electronics as efficiently as possible. This means using 'smart charging' circuits in the power supply. The battery type and method of charging chosen should efficiently charge and discharge the battery, as well as provide stable power to its loads.

The primary battery constraint of interest to a designer is usually the run time available under a specified load. While establishing actual run times in the product is important before the adoption of a design; battery screening and initial design are often performed using rated capacities. Designers should thoroughly understand the conditions under which a cell rating is established and the impact of differences in rating conditions on projected performance.

The standard cell rating, often abbreviated as C, is the capacity obtained from a new, but thoroughly conditioned cell subjected to a constant-current discharge at room temperature after being optimally charged. Because cell capacity varies inversely with the discharge rate, capacity ratings depend on the discharge rate used. The published C value may reflect either an average or minimum value for all cells. Typically nickel-cadmium cells are rated based on minimum values while nickel-metal hydride cells are rated on average values. The difference between the two values may be significant (~ 10 percent) depending on the variability in the manufacturing process.

2.6.1   Charge Termination Methods

The following chart summarizes the charge termination methods for the batteries we are considering. Charge termination is just as if not more important than the charge method used for each battery type. Table 2.7 below summarizes this process.

	Charge Termination Methods			
	SLA	Nicad	NiMH	Li-Ion
Slow Charge	Trickle OK	Tolerates Trickle	Timer	Voltage Limit
Fast Charge 1	Imin	NDV	dT/dt	Imin at Voltage Limit
Fast Charge 2	Delta TCO	dT/dt	dV/dt=0	
Back up Termination 1	Timer	TCO	TCO	TCO
Back up Termination 2	DeltaTCO	Timer	Timer	Timer

Table 2.7: Charge Termination Methods

TCO = Temperature Cut Off

Delta TCO = Temperature rise above ambient

I min = Minimum current

Depth of Discharge

There is an inverse relationship between the cycle life of a battery and the depth to which it is discharged to. The number of cycles yielded by a battery will increase

exponentially the lower the depth of discharge reaches. This law holds true for most battery chemistries. By restricting the depth of discharge one can drastically improve the life cycle of the battery. Using a cell with slightly more capacity than the required amount will also increase the cells life. By using a topping charge giving small pulses of current to the battery, the cells life can go up to 500,000 cycles. Figure 2.14 illustrates the depth of discharge vs life cycle.
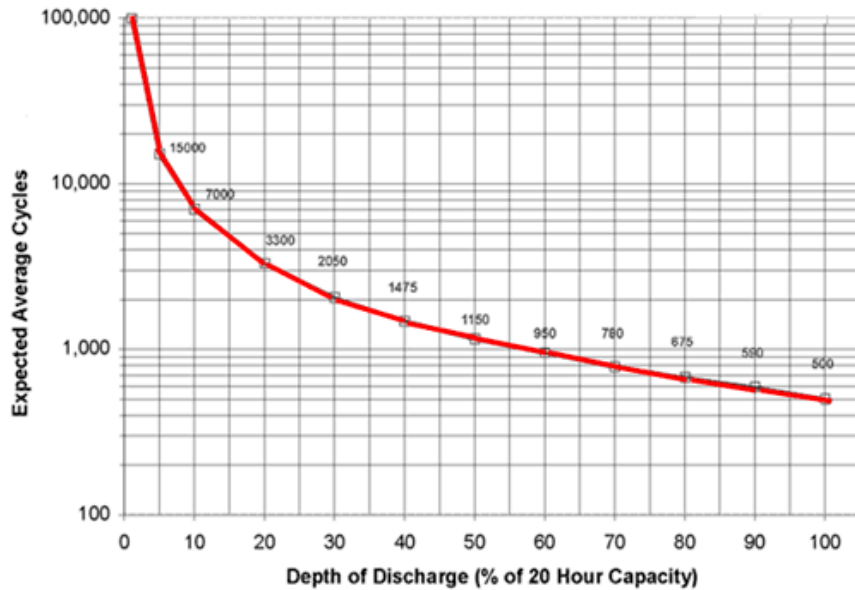
Figure 2.14 Depth of Discharge (Provided   permission pending)

Heat dissipation

The thermal capacity of an object defines its ability to absorb heat. For many years lead acid batteries have been the primary power source, especially for high power applications. Because of their size and weight temperature rise during use hasn't been a large problem. However their size and weight are their downfall for our applications in the Bike Buddy. As new technologies flourish with higher energy to weight ratios and energy densities, the unavoidable drawback is that the thermal capacity of the battery will go down.

2.6.2   Charging Lead-Acid

The charge efficiency for a rechargeable lead acid that can be recovered during discharging, also known as the coulometric efficiency as mentioned previously, is 70%. This means that you would have to put in 142 amp hours for every 100 amp hours you wish to retrieve. Figure 2.15 shows how much wattage from the generator will be required to charge a lead acid battery at a 100 amp hour rating.
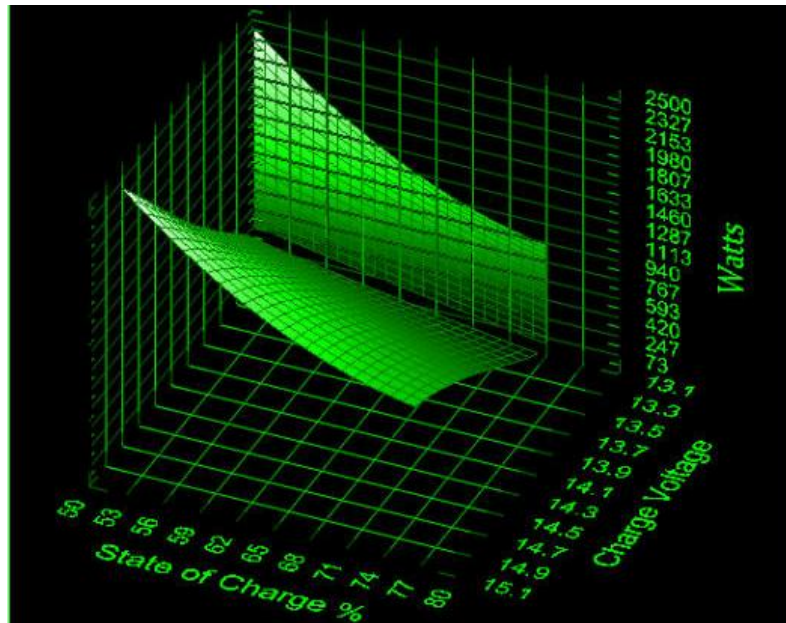
Figure 2.15: Typical wattage required of the bicycle generator vs. state of charge & charge voltage. (Image provided by Science Shareware .com, permission pending)

Lead-acid batteries come in different voltages depending on the number of cells they have. Typical chemistry for the lead acid battery has each cells potential at roughly 2.15 Volts. Any voltage higher than 2.15 applied to each cell will charge the battery. An upper limit of 2.35 Volts is set on the charging voltage, and this is known as the gassing voltage (a point which unwanted chemical reactions will occur). So the overall charging voltage of a six cell battery would lie between 12.9 and 14.1 Volts.

There are many methods for charging lead-acid batteries including: constant current charging, constant voltage charging, taper charging, soft charging, and quick charging amongst others. Because we are using an electric generator to charge the battery a voltage regulator and smart charging circuit are necessary to maintain the life of the battery.

Multi-stage charging techniques can be used to more efficiently charge a lead-acid battery through the use of a constant current charging method. Applying a constant current will initially raise the voltage to 70% of its charge. This could take anywhere from 3-5 hours. As the battery gets closer to its full capacity the current is reduced. Next is a topping charge where the battery is brought above its nominal voltage level for some time. If this were excluded the battery would lose its ability to be fully charged. The final stage is known as the float charge which compensates for the self discharge of the battery. Figure 2.16 illustrates the different stages of charging with respect to current and time.

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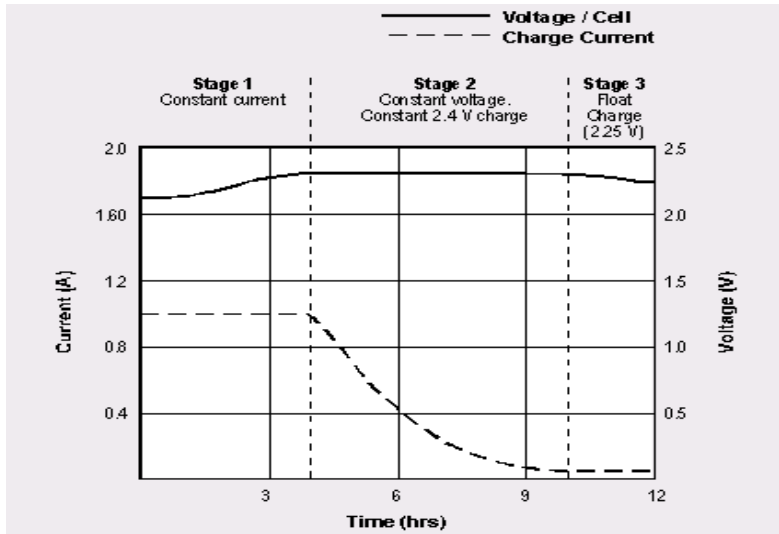
Figure 2.16: Three stage charging process of a lead-acid battery. Provided by Battery University, permissions pending.

The charging voltage is also a function of temperature. The Bike Buddy will be built for outdoor use, so a temperature sensor should be installed to regulate the charging voltage due to the ambient temperature. These charging voltages due to temperature are listed in Table 2.8 below.

Battery Temperature	Charge Voltage per cell	Charge Voltage for a 12 Volt battery	Gassing Voltage per cell	Gassing Voltage for a 12V battery
-20 °C *	2.67 to 2.76	16.02 to 16.56	2.97	17.82
-10 °C *	2.61 to 2.70	15.66 to 16.2	2.65	15.9
0 ° C *	2.55 to 2.65	15.3 to 15.9	2.54	15.24
10 °C	2.49 to 2.59	14.94 to 15.54	2.47	14.82
20 °C	2.43 to 2.53	14.58 to 15.18	2.415	14.49
25 °C	2.40 to 2.50	14.40 to 15.00	2.39	14.34
30 °C	2.37 to 2.47	14.22 to 14.82	2.365	14.19
40 °C	2.31 to 2.41	13.86 to 14.46	2.33	13.98
50 °C	2.25 to 2.35	13.5 to 14.10	2.30	13.8

Table 2.8: Voltage table for cyclic use charging. (Provided by Power Stream, permissions pending.)

Note that a fully discharged battery freezes solid at about 0°C, and a fully charged battery freezes about -40°C.

By setting a limit on the voltage you have to make a compromise. The battery wants to be fully charged to get its maximum capacity and avoid sulfation (when the sulfate begins to crystallize destroying the batteries potential) on the negative plate. However when the battery is being continually over saturated, the positive plate will begin to get corroded. Other phenomenon such as gassing will also occur, which results in loss of electrolytes. Table 2.9 illustrates some advantages and disadvantages of different peak voltage settings.

Voltage Limit	2.30V to 2.35V/cell	2.40V to 2.45V/cell
Advantage	Maximum service life; battery remains cool during charge; ambient charge temperature may exceed 30°C (86°F).	Faster charge times; good, consistent capacity readings; less inclined to sulfation.
Disadvantage	Slow charge time; capacity readings may be inconsistent and declining with each cycle. Sulfation can occur if no topping charge is applied.	Not suitable for charging at high room temperatures. A hot battery may fail to reach the voltage limit, causing severe over charge. Subject to corrosion.

Table 2.9: Voltage table for voltage level per cell.

Because the Bike Buddy will be operating in the outdoor heat, a lower charging voltage is important to the life of the battery. As shown in the table above the ambient charging temperature may exceed 86°F with a 2.30 to 2.35 V/cell limit.

Another disadvantage of the lead acid battery is that they cannot be fully charged as quickly as nickel or lithium batteries, and it takes about 5 times as long to recharge a lead-acid battery to the same level as it does to discharge. A typical bike ride may only last 30 minutes. This would hardly be enough time to even charge a lead acid battery to 50% of its potential. On nickel-based batteries, this ratio is about 1:1, and 1:2 on lithium-ion. In our design it will be important that the battery charge at a reasonable rate in order to power the onboard electronics in a timely fashion.

To get around long charging cycles, fast chargers can be used to speed up the process. Fast chargers are high powered devices designed to charge in less than 4 hours. They usually require advanced features such as active charge termination, battery test mode, bad battery recovery mode, and automatic maintenance. These fail safes will keep the battery from overcharging and other unwanted charging characteristics diminishing the batteries life.

2.6.3   Charging Nickel-Cadmium

The coulometric charge efficiency of Nickel-Cadmium based batteries is about 90% when fast charged (in an hour or less). These batteries accept charge very well and currents several times the Amp-hour rating may be applied up to 70% of the charge state. Fast chargers use this to their advantage to reach 70% potential within minutes. Past this the battery will lose its ability to accept charge as the pressure and temperature continue to increase. Below Figure 2.17 illustrates the relationship of cell voltage, pressure, and temperature as the battery is being charged.
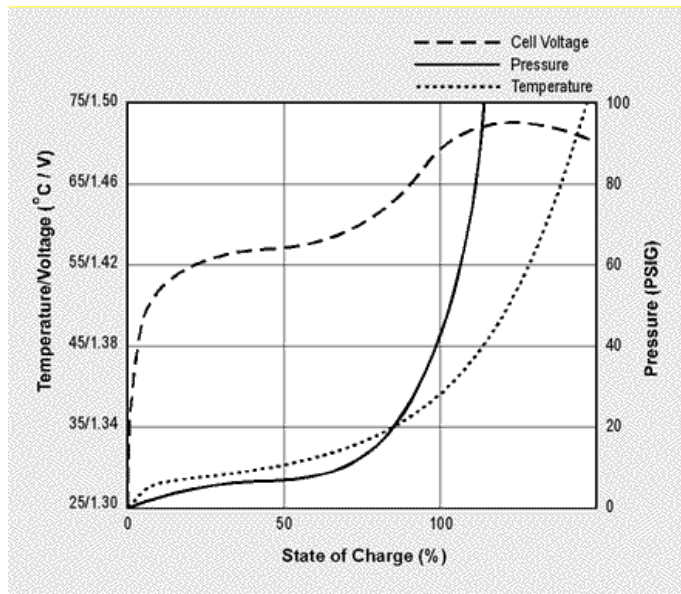
Figure 2.17: Temperature and charge relationship for a nickel-cadmium battery. (Provided by Battery University, Permissions Pending)

Although nickel-cadmium batteries are efficiently fast charged, they are amongst the hardest batteries to charge in comparison with lead acid and lithium ion. Fast charging was the only reasonable charging method for this battery type. All others required far too much time to reach a sufficient charge state. If a temperature or voltage monitor is used NiCad batteries can be charged up to 100% in 1.5 hours. More sophisticated algorithms are required for ultra-fast charging. These algorithms require constant monitoring of the voltage, temperature, and sometimes pressure, to actively determine the amount of current a battery can take without damage. Figure 2.18 shows a typical capacity loss of nickel cadmium cells over time.
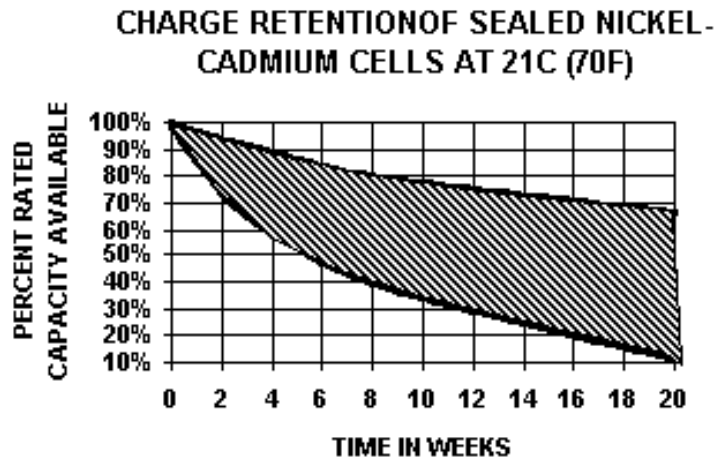
Figure 2.18: Typical capacity loss for a nickel-cadmium battery over time. (Image provided by Energizer, permission pending).

2.6.4   Charging Nickel-Metal Hydride

Nickel based chemistries are amongst the hardest batteries to charge. Whereas with lithium ion and lead acid batteries you can control overcharge by setting a maximum charge voltage, the nickel based batteries don't have a "float charge" voltage. So the charging is based on forcing current through the battery. The voltage to do this is not fixed like it is for the other batteries. The nickel-metal hydride cell is more sensitive to charging conditions than the nickel-cadmium cell, however the techniques are similar. The increasing availability of charger integrated circuits has made it easier for the designer to effectively charge nickel-metal hydride batteries.

Several techniques have been developed for charging, the most effective is a general 3 stage process. First a fast charge state will bring the battery to 90% of its total capacity; this is followed by a timed charge which completes the charge to full capacity. Afterwards a trickle charge is applied to account for the self discharge of the battery. A temperature sensor will switch the charge state from the initial quick charge over to the intermediary charge. This method requires a more complex charging circuit, but will prolong the batteries life by reducing its exposure to overcharge. The coulometric charging efficiency of nickel metal hydride batteries is typically 66%, meaning that you must put 150 amp hours into the battery for every 100 amp hours you get out. The faster you charge the worse this gets.

When charging nickel metal hydride batteries the temperature and pressure continue to increase with the cell voltage. However when the battery gets close to its full potential the pressure begins to increase almost exponentially. This makes over charging these batteries somewhat dangerous. Most of today's batteries are equipped with a vent to allow for this pressure to escape. Without the vent the cells of the battery would receive enough physical damage to be ruined. Figure 2.19 illustrates the voltage, pressure, and temperature relationships when charging the battery.
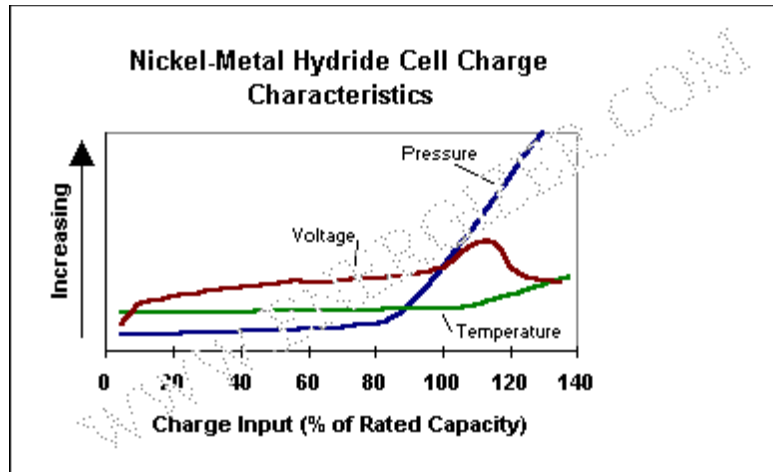
Figure 2.19: Charging characteristics of nickel-metal hydride. (Image provided by Energizer, permission pending.)

Voltage charging method

The charging voltage for nickel-metal hydride is between 1.4–1.6 V/cell. This voltage will vary depending on the discharge rate of the cell. A nickel-metal hydride charger can be used to charge nickel cadmium but not the other way around. According to Duracell and Energizer, the voltage charging method is the preferred method. A charger will measure the rate of change of the voltage of each cell. The cell or battery is then rapidly charged at a constant current of 1 C/h. The voltage charging method cannot be directly implemented, a 3 stage process is necessary as mentioned above. This is unlike a lead-acid cell for example, which can be more easily charged at a chosen constant voltage.

Trickle charging

This method uses a fixed low current state to charge the battery. This will result in continuous overcharging which is only acceptable at currents less than 0.1C/h. To maximize battery life, the preferred charge method of NiMH cells uses low duty cycle pulses of high current rather than continuous low current. This however is impractical for our applications and needs no further discussion.

Delta T charging method

This method works well for NiCad's, and is applied to NiMH as well. dT/dt measures the temperature rise at the end of charge. When a battery is fully charged new chemical reactions will begin to absorb the extra current. In nickel hydroxide chemistries this consists of generating and recombining oxygen. This will heat up the battery, and the sudden increase in temperature can be measured to disable the charge state.

When oxygen is generated it will slightly drop the voltage on the battery. If you can detect this voltage drop you can use the signal to terminate the charge. The best method for NiMH is the dT/dt method for two reasons. With the NiMH battery the voltage drop is smaller, and much harder to detect than with the NiCad battery. This ends up in overcharging the battery, which will limit the total number of charge/discharge cycles and hence the life of the battery. Also, a new NiMH battery has 'false peaks' early in the charge cycle, and so the charger will terminate too soon.

New ways to smart charge batteries are being used with micro processor technology. They implement a pulsing technique turning the charger on and off to do the voltage measurements. Cell capacity being uneven can create problems for this method. The dT/dt is still more reliable, especially for large battery packs.

Over-discharging

Completely discharging a cell can cause permanent damage and should be avoided. This situation can occur in the common arrangement of four AA cells in series in a digital camera, where one will be completely discharged before the others due to small differences in capacity among the cells. When this happens, the "good" cells will start to "drive" the discharged cell into reverse polarity. Devices such as cameras, GPS receivers and PDAs detect the safe end-of-discharge voltage of the series cells and go into an auto-shutdown mode, but devices like flashlights and some toys do not. This isn't a problem with a single cell system under a load because there are no other cells to reverse-charge it when it becomes discharged.

Safety

Batteries being over or undercharged can create safety hazards and certain safety measures should be taken into account. Using a resettable fuse in series with a cell is a good safety precaution when building a custom charging circuit. A bimetallic strip fuse will open if the cell gets too hot or builds up too much pressure. Overcharging NiMH causes a buildup of pressure, a risk inherent in the batteries electro-chemistry. Therefore cells have a vent from which hydrogen will be emitted in the event of serious overcharging. Some NiMH cell manufacturers provide an internal pressure switch within the cell. When the cell gets too much pressure it will disconnect from the charging current. This is also known as in cell charge control.

Modern NiMH cells contain catalysts to immediately deal with gases developed as a result of over-charging by turning them into water. However, this only works with overcharging currents of up to *0.1C*. As a result, the batteries will heat up quickly, marking the end of the charging process. Some quick chargers also have a fan to keep the batteries cool. A cooling fan for the Bike Buddy is strongly being considered. One concern is exposing our circuits to outdoor elements such as dirt and water. If a cooling fan is used a well designed venting system will be required.

Environmental impact

The cadmium in nickel cadmium batteries is a toxic element. The invention of nickel-metal hydride cells has made batteries more disposable with less impact on the environment.

Nickel-metal hydride batteries can directly replace alkaline for most purposes. Because they are able to be recharged and used many times over, far less waste is being created. In creating the Bike Buddy our motivation was to harness free energy to power the system. We also wish to minimize its effects on the environment. By using a rechargeable battery less waste is being created and the disposal of harmful toxins to the environment will be avoided.

Applications

NiMH cells are often used in portable electronic devices such as digital cameras, where they often vastly outperform primary batteries even on a single charge. Applications that require frequent replacement of the battery, such as video game controllers, also benefit from use of rechargeable batteries.

NiMH cells are particularly advantageous for high current drain applications, because of their low internal resistance. Alkaline batteries, which might have approximately 3000mAh capacity at low current demand, will have about 700mAh capacity with a 1000mA load. Digital cameras with LCDs and flashlights can draw over 1000mA, quickly depleting alkaline batteries. NiMH cells can handle these current levels and maintain their full capacity, a desirable characteristic for our Bike Buddy.

2.6.5   Charging Lithium Ion

Lithium-ion batteries have become very common in portable electronics, mostly because of their high energy-to-weight ratios and slow self-discharge rate when not being used. Common in laptop computers, cell phones, and many other products they are a front runner in the modern battery technologies. They are also being increasingly used in defense, the automotive, and the aerospace industries.

Li-Ion batteries have several advantages over other existing technologies which give them an edge. First they can be formed into many shapes and sizes tailoring to the devices needs. A large advantage they hold over lead-acid, nickel cadmium, and nickel-metal hydride is that they have a very high open circuit voltage in comparison. Their energy to weight ratio, discharge efficiency, and self discharge rate all make this battery type very attractive for our applications in the Bike Buddy. What looks like a self-discharge in these batteries is a permanent loss of capacity. On the other hand, "smart" Li-ion batteries do self-discharge, mainly due to the small constant drain of the built-in voltage monitoring circuit. We will make use of buffers in order to minimize these effects.

Shelf life

One large disadvantage in these cells is their cycle life. With each cycle deposits from inside the electrolyte that inhibit lithium ion transport, resulting in a diminishing cell capacity. The increase in internal resistance affects the cell's ability to deliver current, thus the problem is more pronounced in high-current applications. This means that a full charge in an older cell will not last as long in that of a new one. Capacity loss is a function of temperature and charge level. Table 2.10 illustrates the loss due to these parameters.

Temperature	40% charge level (recommended storage charge level)	100% charge level (typical user charge level)
0°C	98% after 1 year	94% after 1 year
25°C	96% after 1 year	80% after 1 year
40°C	85% after 1 year	65% after 1 year
60°C	60% after 1 year	60% after 3 months

Table 2.10: Lithium ion battery capacity loss due to age. (Information provided by Battery University, permission pending.)

High charge levels and elevated temperatures increase permanent capacity loss for lithium-ion batteries. The heat generated during a charge cycle is caused by the traditional carbon anode, which has been replaced with good results by lithium titanate. Lithium titanate has been experimentally shown to drastically reduce the degenerative effects associated with charging, including expansion and other factors.

At a 100% charge level, a typical Li-ion laptop battery at 25 °C or 77 °F will irreversibly lose about 20% of their capacity per year. However, a battery in a poorly ventilated environment may be subject to a prolonged exposure to much higher temperatures, which will significantly shorten its life. When stored at 40%–60% charge level, the capacity loss is reduced to 4% at 25 degrees Celsius. Maintaining the capacity of a lithium ion is the biggest challenge and downfall for using this battery type. Many factors go into the shelf life of these batteries besides how they are charged.

The voltage level to which the cells are charged also plays an important role to longevity. For safety reasons, most lithium-ion cannot exceed 4.20 volts per cell. While a higher voltage boosts capacity, the disadvantage is lower cycle life. Figure 2.20 shows the cycle life as a function of charge voltage.
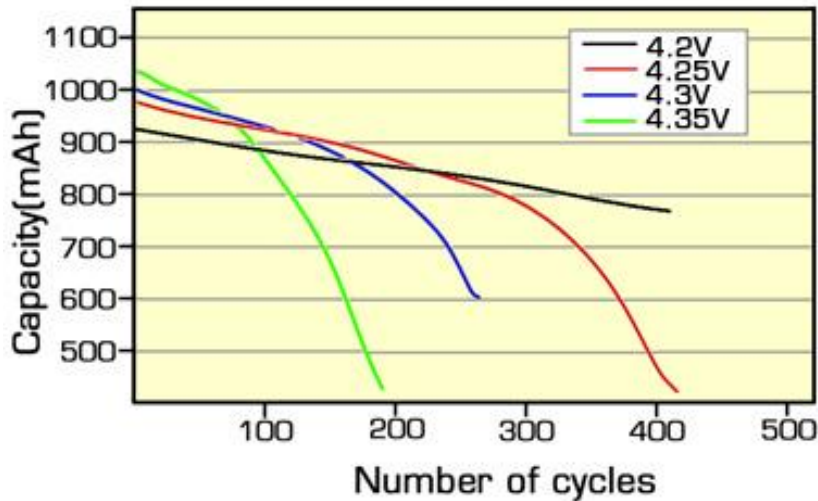
Figure 2.20: A higher voltage boosts capacity and lowers the Li-Ion battery's cycle life. (Provided by Battery University, permission pending.)

Internal resistance

Lithium Ion tends to have a higher internal resistance as compared to lead-acid and nickel based technologies. This increases with both charge cycling and age of the battery. Rising internal resistance causes the voltage at the terminals to drop under load, reducing the maximum current that can be drawn from them. Soon the terminals can no longer supply power to the device they are connected to.

High drain applications such as power tools may require the battery to be able to supply a current that would drain the battery in 1/15 hour if sustained; e.g. 22.5 A for a battery with a capacity of 1.5 A·h). Lower-power devices such as MP3 players, on the other hand, may draw low enough current to run for 10 hours on a charge (e.g. 150 mA for a battery with a capacity of 1500 mA·h). With similar battery technology, the MP3 player's battery will effectively last much longer, since it can tolerate a much higher internal resistance. To power larger devices, such as electric cars, it is much more efficient to connect many smaller batteries in a parallel circuit rather than using a single large battery.

Not only is it better to charge lithium-ion battery at a slower charge rate, high discharge rates also contribute the extra wear and tear. Figure 2.15 shows the cycle life as a function of charge and discharge rates. Observe the good performance if the battery is charged and discharged at 1C (A 0.5C charge and discharge would further improve this rating) in 5.
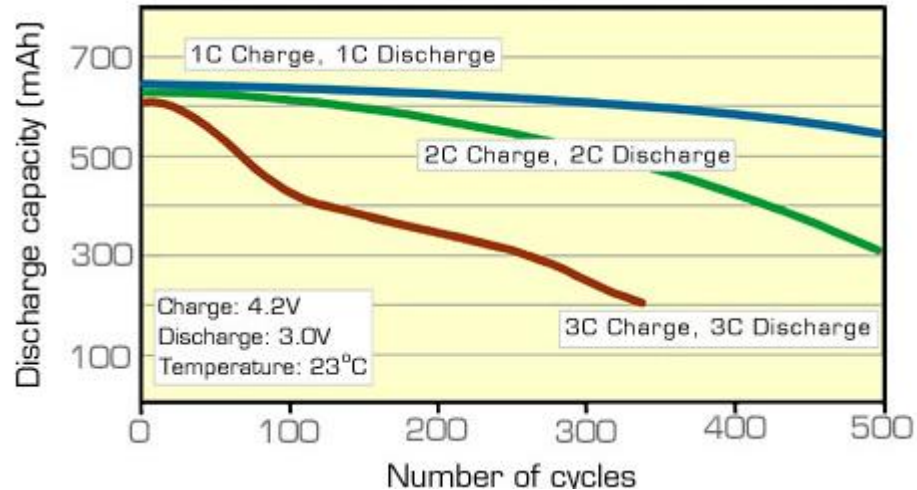
Figure 2.21: Cycle performance at various charge/discharge rates. (Provided by Battery University, permission pending.)

Safety requirements

Li-ion batteries are not as durable as nickel metal hydride or nickel-cadmium designs, and can be extremely dangerous if mistreated. They may explode if overheated or if charged to an excessively high voltage. Furthermore, they may be irreversibly damaged if discharged below a certain voltage. To reduce these risks, lithium-ion batteries generally contain a small circuit that shuts down the battery when it is discharged below about 3 V or charged above about 4.8 V. In normal use, the battery is therefore prevented from being deeply discharged. When stored for long periods, however, the small current drawn by the protection circuitry may drain the battery below the protection circuit's lower limit, in which case normal chargers are unable to recharge the battery. More sophisticated battery analyzers can recharge deeply discharged cells by slow-charging them.

Other safety features include but are not limited to: a shut-down separator (for over temperature), tear-away tab (for internal pressure build-up), venting (for pressure relief), and a thermal interrupt (for over current charging).

These devices occupy useful space inside the cells, and reduce their reliability; typically, they permanently and irreversibly disable the cell when activated. They are required because the anode produces heat during use, while the cathode may produce oxygen. Safety devices and recent and improved electrode designs greatly reduce or eliminate the risk of fire or explosion.

These safety features increase the cost of lithium-ion batteries compared to nickel metal hydride cells, which only require a hydrogen/oxygen recombination device (preventing damage due to mild overcharging) and a back-up pressure valve. Many types of lithium-ion cell cannot be charged safely below 0 °C.

Specifications and design

Because lithium-ion batteries can have a variety of cathode and anode materials, the energy density and voltage vary accordingly. Lithium-ion batteries with a lithium iron phosphate cathode and graphite anode have a nominal open-circuit voltage of 3.2 V and a typical charging voltage of 3.6 V. Lithium nickel manganese cobalt (NMC) oxide cathode with graphite anodes have a 3.7 V nominal voltage with a 4.2 V max charge. The charging procedure is performed at constant voltage with current-limiting circuitry (i.e., charging with constant current until a voltage of 4.2 V is reached in the cell and continuing with a constant voltage applied until the current drops close to zero). Typically, the charge is terminated at 7% of the initial charge current. In the past, lithium-ion batteries could not be fast-charged and typically needed at least two hours to fully charge. Current-generation cells can be fully charged in 45 minutes or less; some lithium-ion varieties can reach 90% in as little as 10 minutes.

General charging procedure

As with the previous battery types mentioned, the use of integrated circuits can be used to employ the correct charging procedure for Lithium-ion batteries. This is strongly recommended because of their volatile nature when under and over charged. Extreme precaution must be taken in considering designing a charging circuit for this battery type (which is why the above mentioned safety precautions were mentioned so extensively).). A general 3 step process is used in charging lithium ion batteries. First, a charging current is applied until the voltage limit in each cell is reached. A maximum cell voltage is applied until the current goes below 3% of the rated charge per cell. To keep the batteries potential to a maximum a periodic top-off voltage is applied every 500 hours. A diagram of this procedure is illustrated below in Figure 2.22.
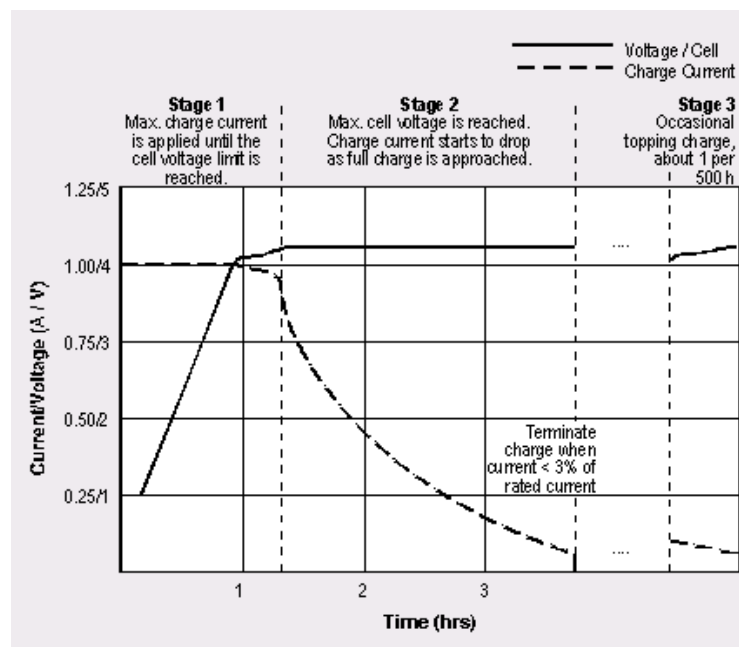
Figure 2.22: Three stage charging procedure for a Li-ion battery. (Permission to reprint by Battery University, pending)

The charge time is about three to five hours, depending upon the charger used. Generally, cell phone batteries can be charged at 1C and laptop-types at 0.8C, where C is the current that would discharge the battery in one hour. Charging is usually stopped when the current goes below 0.03C but it can be left indefinitely depending on desired charging time. Some fast chargers will skip stage 2 and claim the battery is ready at 70% charge. Some laptop battery chargers will "gamble", and try to charge up to 4.35v then disconnect battery. This helps to compensate internal resistance and charge up to 100% in short time. Top-off charging is recommended to begin when voltage goes below 4.05 V/cell.

Lithium-ion cells are charged with 4.2 ± 0.05 V/cell, except for military long-life cells where 3.92 V is used to extend battery life. Most protection circuits cut off if either 4.3 V or 90 °C is reached. If the voltage drops below 2.50 V per cell, the battery protection circuit may also render it un-chargeable with regular charging equipment. Most battery protection circuits stop at 2.7–3.0 V per cell. For safety reasons it is important to stay within the manufacturers stated voltage and current ratings during both charge and discharge cycles.

2.6.6 Battery selection

A great deal of information was evaluated in selecting a battery for the Bike Buddy. Four battery types were extensively researched to find the best candidate. The characteristics which became the biggest determining factors were qualities like energy to weight ratio, charging mechanisms and their difficulty to design, and overall efficiency. When these qualities were considered, the lithium ion battery proved to be the best choice.

Although lithium ion batteries require complex charging circuits, we were willing to make this a significant part of our design process. If we could construct an efficient method of charging and discharging this battery type the benefits outweighed the cost. The Bike Buddy doesn't require a lot of power to be run. The highest voltage needed was for the LCD screen at 6V DC. Our goal was to squeeze as much power as possible out of the battery being used without damaging it or the external circuitry.

Initially our design revolved around a 12V lithium ion as the source. We found a 6 cell pack from super circuits for about $90. This would supply an ample amount of power without any issues. Because we are trying to maximize efficiency and minimize cost, a 7.4 V two cell battery pack was also taken into consideration. After further evaluation the 7.4 Volt pack proved to be capable of providing enough power for our needs.

A charging circuit was designed to use two of these 7.4 V batteries (Figure 2.23) to supply power to the Bike Buddy. One battery will be charged while the other powers the LCD, GPS, microcontroller, and temperature sensor. The required current for these

devices are relatively low, especially the microcontroller. This made the implementation of the 7.4 V batteries possible.

Figure 2.23: 7.4 V Lithium Ion Battery Pack, Figure provided by Powergizer (permissions pending)

2.7 Battery Charger

Given the power constraints of our project, we wanted to find a charger that is efficient both in terms of power consumption and current output to the rechargeable battery. While many of the battery chargers charge the different kinds of rechargeable batteries available efficiently, almost all of them lack how to handle one of the basic features of our project: low AC input voltage. So, we set out to design a charger that is efficient and can accommodate a low input voltage. While searching for components that fit our requirements, we noticed that the Li-ion battery charger controllers are very flexible in terms of how the charging process can be controlled with an external circuitry. Some of them are explained in more details in the following subsections.

2.7.1   Battery Charger Controller – ADP3810

One of the chargers that we analyzed was the ADP3810 manufactured by Analog Devices.   It combines a programmable current limit with a battery voltage limit to provide a constant current, constant voltage to a Li-Ion battery. It has a very wide operating supply range from 2.7V to 16V. But that range changes according to the design requirements implemented in the external circuitry. This controller can monitor the voltage and current on the battery and limit the amount of current supplied to charge the battery. A resistor that is connected to the Voltage Sense pin decides the size of the battery the charger can charge. The current is also controlled through a Current Sense pin by connecting a voltage from 25mV to 300mV to its terminal. While charging, as the battery approaches its voltage limit, the voltage sense amplifier takes over to maintain a

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constant battery voltage. In Figure 2.24 below, the two amplifiers GM1 and GM2 that control the current and voltage to the battery are turned on at different states. When a battery starts charging, the Current Sense amplifier controls its charging cycle. When the battery reaches a maximum voltage, the Voltage Sense amplifier takes over to prevent overcharging.
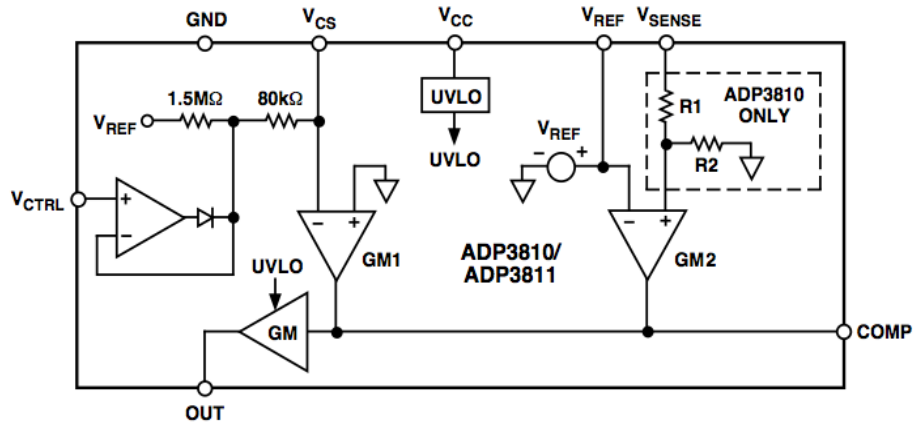
Figure 2.24: Block Diagram for ADP3810. (Analog Devices Permission Pending)

2.7.2   Switch-mode Li-Ion Battery Charger – MAX1758

Manufactured by Maxim, the MAX1758 offers a lot of control over the operation of the charger and batteries. The charging current can be programmed up to 1.5A while a timer can terminate the charging cycle one the programmed charging time has been reached. The temperature of the battery is monitored by an external thermistor and the charging can be terminated once it reaches a certain temperature level that is harmful to the battery and the surrounding circuitry. It has an input voltage range from 6V to 28V and its output can be set to charge Li-Ion batteries of up to 4 cells. The MAX1758 has an algorithm that selects the state at which a battery should be charged according to its charge level. As depicted in Figure 2.25, the charger starts at the Fast Charge state, the voltage increases while the current remains constant at maximum. But as soon as the voltage reaches at its peak, it remains there while the current drops to prevent overcharging or bleeding.

As indicated, the MAX1758 has two timers designed to terminate the charging process to ensure faulty batteries are not charged indefinitely. TIMER1 controls the maximum full time charge while TIMER2 only control the fast charge time. By using a 1nF capacitor on pins TIMER1 and TIMER2, the fast charge can be programmed for 90 minutes. All of the different states can be controlled with external capacitors. The states pins on the charger are monitor pins with can be connected to LEDs to indicate charging cycles and the state of the battery and charger.
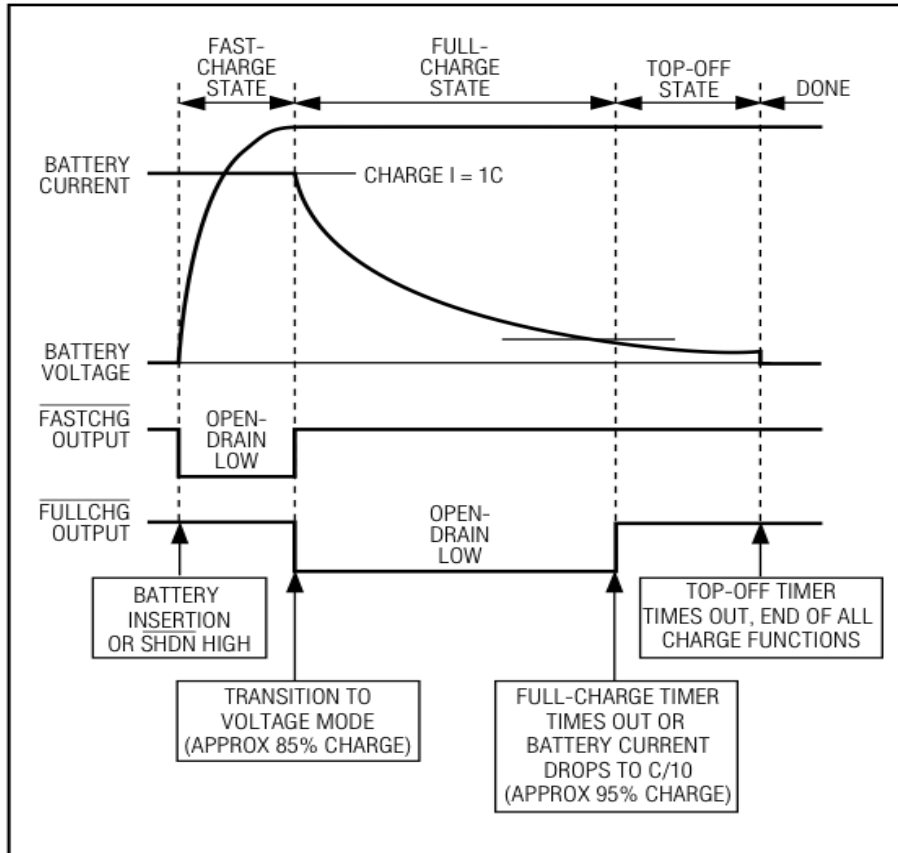
Figure 2.25: Charge state and indicator output timing for a typical charging sequence. (Provided by Maxim Permission Pending)

2.7.3 Advance Dual-Cell Li-Ion Charge Management Controller – MCP73842

The MCP73842 is a smart charger chip manufactured by Microchip. It is part of a highly advanced family of charge management controllers that are designed for space limited and cost-sensitive applications. This particular charger only works with dual-cell Lithium Ion or Lithium polymer battery packs of 8.2V or 8.4V maximum voltage. It requires an input voltage between 8.7V and 12V for proper operation. The MCP73842 provides fully functional, stand-alone charge management solutions with high accuracy, constant voltage and current regulations, cell temperature monitoring, safety timers, automatic charge terminations and charge status indications. The external circuitry is minimal given that the charger only has 10 pins that do not require many components to drive the features. The pins are used to program the charging current, the safety timers, preconditioning at the start of a charge cycle, end of charge control, charge status and automatic power down in case of emergency. The diagram in Figure 2.26 shows the typical charge cycles of the MCP73842.
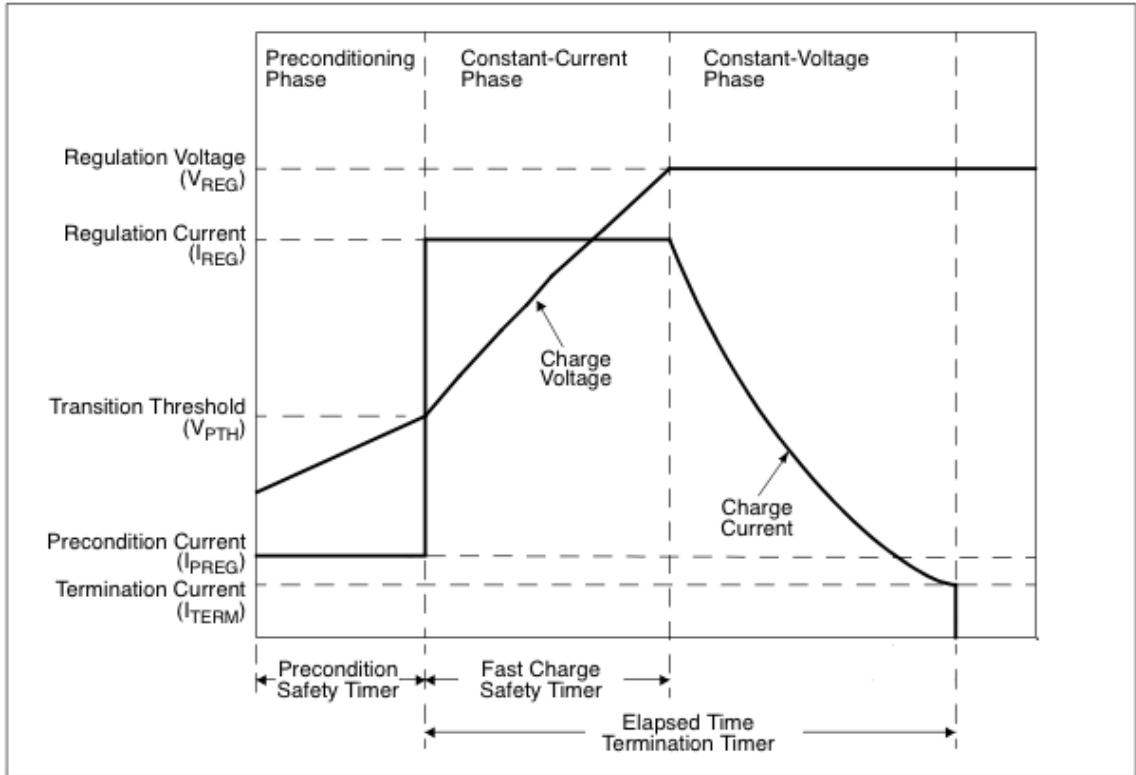
Figure 2.26: Charge profile for the MCP73842. (MicroChip Permission Pending)

During the preconditioning phase, the current supplied to the battery is very low while the voltage slowly increases. As the voltage approaches the lower transition voltage threshold, the current increases to maximum and allow the battery to charge at full capacity in normal speed mode. As the current reaches its peak, it stabilizes allowing the voltage to complete the charging process. The current then decreases to prevent overcharging and to allow the battery temperature to subside.

2.7.4   LM3420-8.4 –Li-Ion Battery Charger Controller

This particular charger chip is in a class of its own. They compactly built integrated circuits designed for charging Li-Ion batteries at different voltage levels. They have an internal amplifier, a bandgap reference, an NPN output transistor, and voltage setting resistors. The amplifier's inverting input is externally accessible for loop frequency compensation. The output is an open emitter NPN transistor capable of driving up to 15 mA of output current into external circuitry. A typical setup configuration can be seen in Figure 2.27 below.
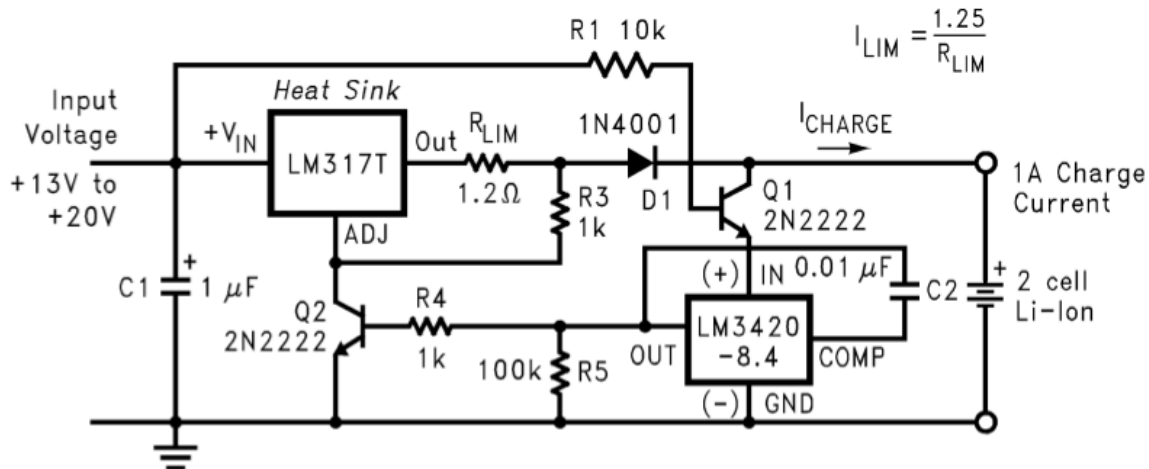
Figure 2.27: Typical Constant Current/Constant Voltage Li-Ion Battery Charger (National Semiconductors, permission pending)

This chip takes an input voltage from 13V to 20V and drives an 8.4 volt 2 cell Li-Ion battery. The LM317T voltage regulator is used to regulate the input voltage to a proper level for the battery. But, the charger itself is driven by a higher voltage. A capacitor is used on the input to stabilize the voltage. The chip regulates the charge voltage and current but doesn't change how the battery is charge. As compared to the other battery chargers, this chip does not limit the charge current; it only regulates the end process of a charge cycle.

2.7.5   Charger Comparison and Selection

All three of the chargers mentioned about have most of the basic required specs needed for this project. They can all manage an 8.4V Li-Ion battery without overcharging. They can monitor the charging current and voltage delivered to the battery. Also they can shut down on command in the event of an emergency. As for their implementation in the space available on the board, we must take a closer look at their extra features on Table 2.11 below that may heavily weigh on a final selection.

	ADP3810	MAX1758	MCP73842	LM3420-8.4
Input Vol. for 8.4V Li-Ion	-0.4V to 18V	-0.3V to 30V	-0.3V – 12V	20V
Max Charge Current	1.2A	1.5A	Resistor Select	1A
Operational Temperature	-40°C to +85°C	-40°C to +85°C	-40°C to +85°C	-40°C to +85°C
Max Power Dissipation	500mW	762mW	Resistor Select	300mW

Packaging/Pin Count	SO-8	28-Lead SSOP	8-Lead MSOP	5-Lead MSOP
Ext. Component Count	high	high	low	high

Table 2.11: Important features of the chargers for comparison.

Given the flexibility provided by the MCP73842 regarding the current charge and power dissipation, it seems to be best suited for an efficient charger design. Although its size and packaging may be problematic for manual soldering, it is the only one of the three that was manufactured with an 8.4V Li-Ion rechargeable battery in mind.

2.8 Display

Liquid crystal displays are a popular choice for handheld devices, and were considered by the group due to their abundance and affordable price range. One of the few disadvantages to choosing LCD technology for this project is in the power required to light the screen. Other technologies, such as electronic paper, were briefly considered as low-powered alternatives. While electronic paper is a promising new technology, to acquire a development kit would far exceed the project's budget.

In the embedded world there is a seemingly infinite variety of LCDs, all of which can be categorized as either segmented or graphic (pixel) displays. Among these are raw LCDs, "mid-range" parallel controlled LCDs, and serial graphic LCDs. Raw LCDs were not considered in order to reduce major design that would fall outside the scope of the project, which would include the task of interfacing to the microcontroller. With that said, choosing a microcontroller is an important consideration in choosing a screen, and effort was made to find an appropriate match. The most important deciding factors were in ease of programming, followed by appropriately small power consumption.

A segmented display was considered first. The SynchroChron LCD (Figure 2.28) has 160 segments amounting to 10 alphanumeric characters, 4 digits, and a radial dial/meter. It has no backlight and attractively low power consumption at ~20mA @ 3V. The constraint of having segments would simplify the task of drawing information to the screen; in addition there is a supplied function library and a font. The challenge would be in choosing how to display the required information inside of these constraints. Since there is more data to display than available space, one option would be to toggle between several different screen states. For example, temperature could be displayed on one screen along with energy produced, while another state (screen) would display position and velocity. A button or a timer could cycle these states.
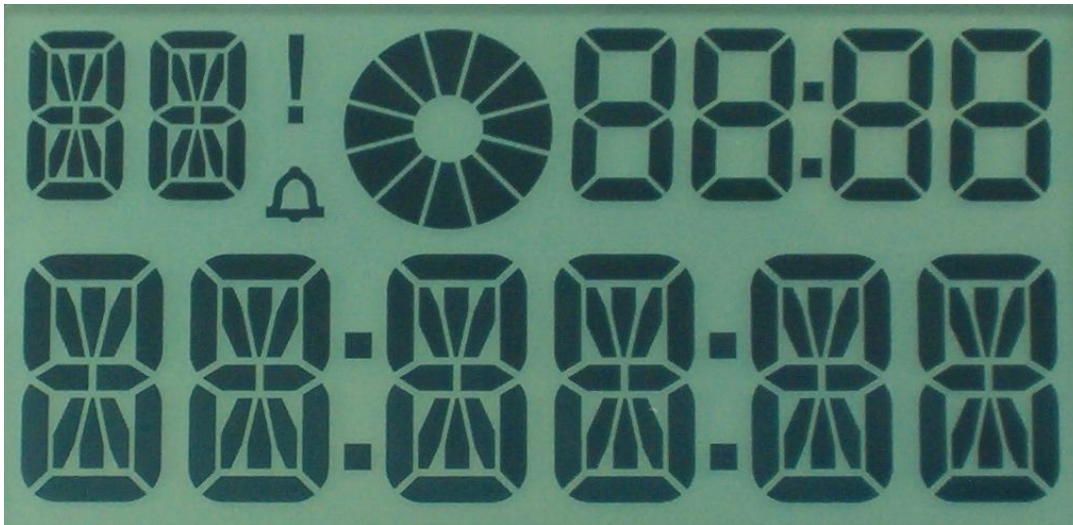
Figure 2.28: The 160-segment SynchroChron LCD. (SynchroSystems: permission pending).

The constraint of displaying information with segments was undesirable, so graphical LCDs were considered. These screens have built-in controller interfaces to handle the dirty work of displaying pixels. Among a variety of LCDs, several controllers were found in research, including the T6963 and KS0108 controllers. Several low-power screens designed for handheld applications were found, but featured anonymous controllers. Its manufacturers assured buyers that the LCD would ship with the code necessary to interface with it. Very little support was found online (for example, internet forums, manuals, and tutorials) for screens of this kind, so this approach was abandoned.

KS0108-controlled LCDs were found to be more common with a variety of support and documentation. They are designed very simply. The display address space is broken up into rows 8 pixels high, each column a single byte (Figure 2.29). This setup is ideal for displaying lines of alphanumerical characters, but provides a slight (but resolvable) challenge for drawing graphics. Further, the 128x64 screen we were considering turns out to be two side-by-side screens, each with its own controller. This complicates the task of having a continuous line of text or graphics from one edge of the screen to another. A KS0108 LCD would require extensive code to handle simple graphics and flexible text. Font libraries would need to be written or acquired. A slightly bigger screen at 160x128 was found with a T6963 controller. This controller appears to be a step up from the KS0108: pixels are addressed in an intuitive x, y format starting from the top-left corner of the screen. It also supports layering of text on graphics [ref]. This simplifies drawing considerably, compared to the row-based design in KS0108 screens.

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Left half **Right half**
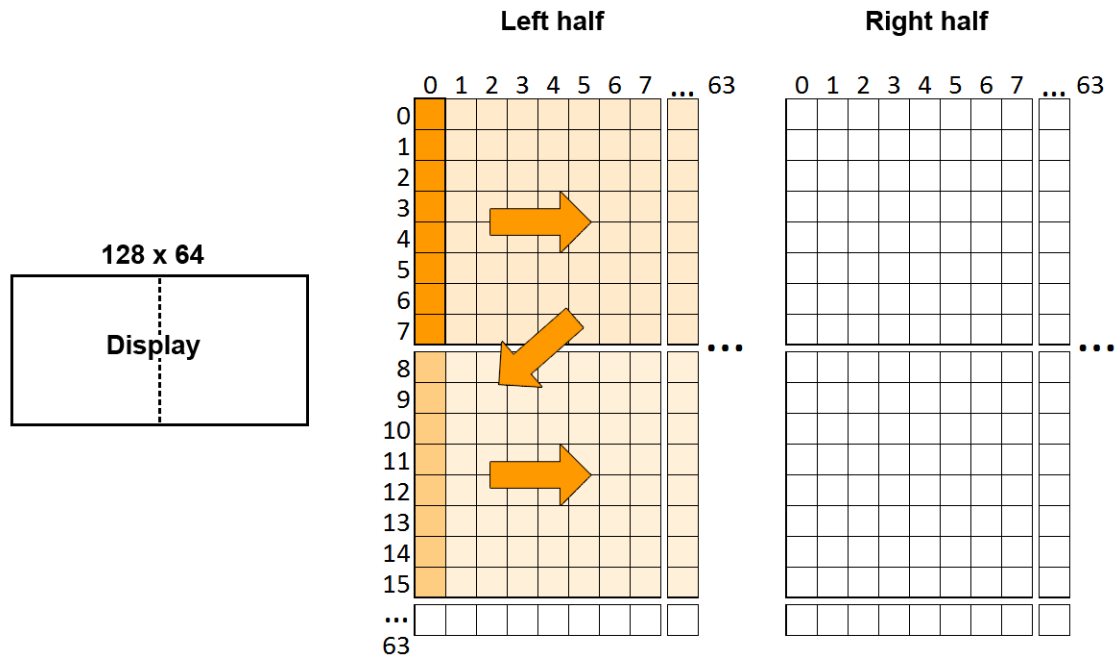
Figure 2.29: KS0108 LCD 128x64 pixel address space.

There exists a simple solution for the programmer, as there are LCDs that come fully packaged with a simplified serial interface. The 128x64 Serial Graphic LCD at Sparkfun consists of the KS0108 screen mentioned earlier and a 'backpack circuit' (pictured in red in Figure 2.30) designed by Sparkfun to provide serial communication with the screen. This higher-level controller is from the ATmega AVL family, which is the same that was chosen as the microcontroller for the project. The software for this controller is optionally available for downloading on the product description page. As part of the higher level serial interface, pixels are intuitively referenced starting from the bottom-left corner of the screen (Figure 2.31). Functions provided by sparkfun include drawing lines, circles and squares. There are built-in font libraries. There are four pins on the device (Vcc, GND, RX, TX).
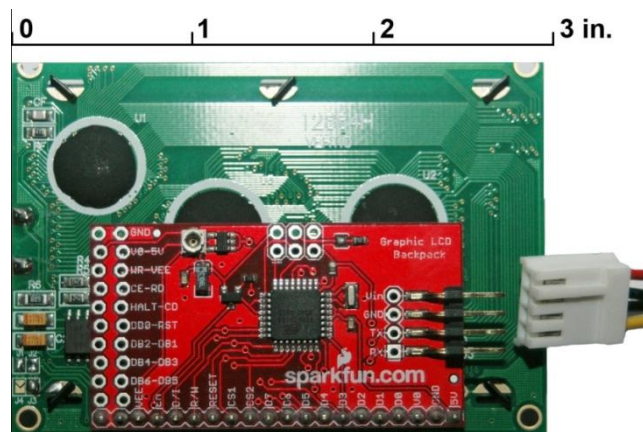
Figure 2.30: Serial Graphic LCD underside, displaying the backpack circuit and pins.

The serial graphic display was chosen in order to simplify the task of displaying lots of different information at once. This freedom comes with the cost of powering the device at ~220mA @ 6V when the screen is fully lit by the backlight. This is comparable to other backlit LCD screens, and is slightly higher. Power consumption can be reduced with careful use of the backlight and minimal updates to the display. Because of the requirements of a display unit in this project – and the potential difficulty in grappling with more primitive LCD controllers under the imposed time constraints – it was agreed to be a fair design decision.
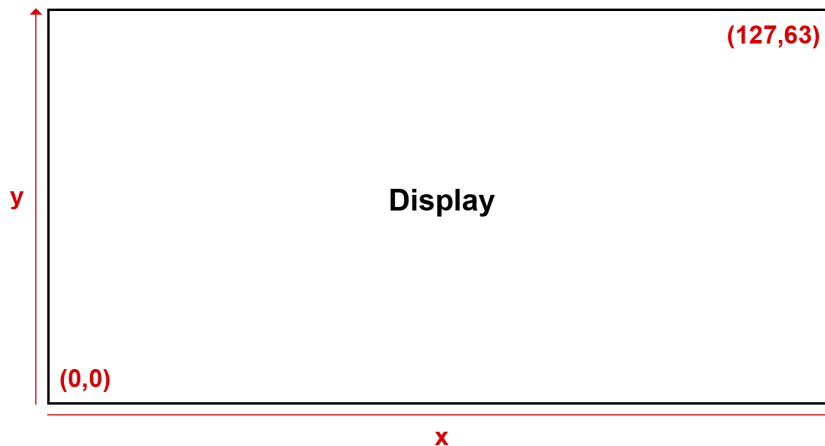
Figure 2.31: Serial Graphic LCD pixel layout.

2.9 Microcontroller

The role of the microcontroller is to collect, organize and display information to the user (via the display unit) with minimal power consumption. Other desirable features include ease of programmability and available support online. Three families of MCUs were considered: The PIC family, the TI MSP430 family, and the AVR ATmega 8-bit family. The group's first concern was in finding an MCU that would intuitively facilitate the use of an LCD. It was found that microcontrollers often come with simple LCD controller interfaces included. These are intended for simple segmented displays, typically having several lines of alphanumeric characters.

2.9.1 PIC10F200

We started looking at the PIC10F200 microcontroller from Microchip Technology for features we thought we wanted to implement in the project in the future. It is a very simple chip with only 33 single word instructions to learn just in case we wanted to program it in assembly. It has a 4MHz internal clock with 1uS instruction cycle. It is very low powered at 2.0V minimum input. It only has 4 I/O pins, 3 of whom with individual direction control and 1 designated as input-only. It has an 8-bit real time clock with an 8-bit programmable prescaler. The 204 and 206 versions each has 1

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comparator with internal absolute voltage reference with their output on one of the pins. They can be used separate from the chip. All of the microcontrollers in that class are available in different packages: 6-pin SOT-23, 8-pin PDIP and DFN.

2.9.2   MSP430

The MSP430 is one of the microcontroller families created by Texas Instruments. It was designed for a 16-bit CPU architecture to be used in low power applications for a very low cost. It is used extensively in low-powered wireless RF applications. The whole class has a frequency of 16MHz with a ram storage of 128B. The three latest versions in that class have a flash memory storage of 2KB. They all include 1 Watchdog or interval timer and 1 16-bit timer for internal clock use. Since most of them are very low powered at a range of 1.8V to 3.6V, they are available in small packages as picture in Figure 2.32 below. The whole MSP430 class is available in a 14PDIP, 14TSSOP and 16QFN.

Figure 2.32: Picture of the TinyBoard with one of the MSP430 class processors. (Provided by Siphec, permission pending).

One of the things we focused on during our research was the design examples using some of the chips that we learned about during research. For the MSP430, we looked for implementations and C libraries that would be useful to our design. We quickly notice the lack of support there are online for the MSP430 as compared to the other chips, not because that other chips were better or had more features but only because most people use them for DIY projects.

2.9.3   Microcontroller selection

Some basic PICs were considered, but did not appear to have a robust support environment for development. The TI family of microcontrollers was very appealing in their low-power consumption and their use by hobbyists and engineers alike. The MSP430 family operates in mere microamps. Some downsides to using the MSP430 are in development costs. It was found that obtaining a programmer and a development board would cost in the range of 200 dollars. Another concern was in a relative lack of online support from hobbyists. An important design consideration is in choosing an MCU that has been popular with design projects similar to ours.

The AVR family satisfied this concern for online support in development, mainly through the independently-operated AVR Freaks website. It is a popular choice for hobbyists building hand-held, battery-powered devices. The ATmega series boasts a number of features similar to the TI family, including analog-to-digital converters needed for sensor data. They appear to be relatively more powerful with faster clock rates and significantly more FLASH program memory. They consume relatively more power than the MSP430 chips, but it's still quite low compared to some of the peripherals required by design.

2.9.4   ATmega128L

Serial Peripheral Interface (SPI)

AVR has support for SPI, which provides an interface for communicating serially with peripherals or sensors. The ATmega128L provides SPI with full-duplex, three-wire synchronous data transfer. This is dependent upon an external clock which synchronizes read/write transmission. SPI utilizes a master/slave relationship with each device, allowing for multiple slave peripherals to be connected to a master controller. As in Table 2.12, when SPI is configured and enabled, the following pins are over-ridden:

Pin	Direction, Master SPI	Direction, Slave SPI
MOSI	User Defined	Input
MISO	Input	User Defined
SCK	User Defined	Input
$\overline{SS}$	User Defined	Input

Table 2.12: SPI pin overrides. Information provided by the ATmega128L datasheet. (Permission pending)

The problem with SPI is that it's irrelevant to the project, which will likely have peripherals configured for asynchronous data transmission. Systems like these have already been seen in GPS receivers and LCD screens. UART will be used to communicate with these peripherals instead.

Universal Asynchronous serial Receiver and Transmitter (UART)

The UART transmission system provided by the ATmega128L allows the microcontroller to send and receive serial data to other microcontrollers or peripherals. Asynchronous serial communication is advantageous because it relies on a fixed data rate instead of a clock signal, which reduces the number of wires required to three (Rx, Tx, GND). The data is sampled at regular intervals based on the baud rate agreed upon between the microcontroller and the peripheral. UART is very sensitive to timing. The UART clock is based on the system clock; because of this, the system clock of the microcontroller must be stable to reduce read/write errors. A great deal of attention must be given to timing in order to design a UART system. A value (referred to as the UBRR value) is kept in the USART Baud Rate Register (Table 2.13), and is used (with the system clock) to determine the baud rate. This value can be calculated according to Table 2.14. Some example values are also conveniently displayed in Table 2.16 for a given frequency of 1.0 MHz.

Bit	15	14	13	12	11	10	9	8	
	–	–	–	–	UBRRn[11:8]				UBRRnH
	UBRRn[7:0]								UBRRnL
	7	6	5	4	3	2	1	0	
Read/Write	R	R	R	R	R/W	R/W	R/W	R/W	
	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	

Table 2.13: The USART Baud Rate Register. Information provided by the ATmega128L datasheet. (Permission pending)

Operating Mode	Equation for Calculating Baud Rate	Equation for Calculating UBRR Value
Asynchronous Normal Mode (U2X = 0)	$BAUD = \dfrac{f_{osc}}{16 \cdot (UBRR + 1)}$	$UBRR = \dfrac{f_{osc}}{16 \cdot BAUD} - 1$
Asynchronous Double Speed Mode (U2X = 1)	$BAUD = \dfrac{f_{osc}}{8 \cdot (UBRR + 1)}$	$UBRR = \dfrac{f_{osc}}{8 \cdot BAUD} - 1$
Synchronous Master Mode	$BAUD = \dfrac{f_{osc}}{2 \cdot (UBRR + 1)}$	$UBRR = \dfrac{f_{osc}}{2 \cdot BAUD} - 1$

BAUD   Baud rate (bits per second)

f_{osc} System Oscillator clock frequency

UBRR   Contents of the UBRRH and UBRRL Registers, (0 – 4095)

Table 2.14: Equations for calculating baud rate register setting (UBRR). Information provided by the ATmega128L datasheet. (Permission pending)

The default clock for the ATmega128L is an internal RC oscillator configured at 1.0 MHz. This oscillator can be set to other frequencies by modifying the CKSEL register, as shown in Table 2.15; however, these frequencies are not optimal, as is shown in Table 2.16. This table shows example baud rates and UBRR values for the given frequency (1.0 MHz). As illustrated, there are significant errors for baud rates higher than 9600bps. According to the AVR datasheet, an error margin of +/- 2% is acceptable. An optimal frequency (to produce 0.0% data errors) is found to be 1.8432 MHz (and multiples thereof), as listed in the datasheet.

CKSEL3..0	Nominal Frequency (MHz)
0001	1.0
0010	2.0
0011	4.0
0100	8.0

Table 2.15: Internal calibrated RC oscillator operating modes. Information provided by the ATmega128L datasheet. (Permission pending)

Baud rate (bps)	f_{osc} = 1.0000 MHz			
	U2X = 0		U2X = 1	
	UBRR	Error	UBRR	Error
2400	25	0.2%	51	0.2%
4800	12	0.2%	25	0.2%
9600	6	-7.0%	12	0.2%
14.4k	3	8.5%	8	-3.5%
28.4k	1	8.5%	3	8.5%
...				
115.2k	—	—	0	8.5%
Max	62.5 kbps		125 kbps	

Table 2.16: Examples of UBRR settings for a 1 MHz oscillator freq. Information provided by the ATmega128L datasheet. (Permission pending)

STK300 development board

An affordable development board package for the ATmega128L was found with a USB programmer and coding environment included, ideal for our ease-of-development concerns. Manufactured by Kanda, the board (model number STK300) provides ISP and JTAG interfaces, two RS232 ports, and standard 0.1 inch spaced pins for easy access to the microcontroller's 51 input/output pins. It also features 8 LEDs and 8 buttons for development purposes. Software included with the bundle consists of the WinAVR C compiler, sample code, and the Atmel AVRStudio 4 IDE with assembler and simulator. Also included are several books on embedded C development, AVR datasheets, documentation, schematics and sample files. Of these, the WinAVR C compiler will primarily be used for development. Included with the board is the ATmega128L (a surface-mount device) specially mounted on a daughterboard with standard 0.1 inch pitch headers.

2.10 GPS receiver

A GPS module provides a number of features to the project, including accurate time, velocity (speed and cardinal direction), and global positioning coordinates. These coordinates are displayed as numerical minutes, which can be useful in describing your exact position if lost on an off-road bicycle trip, or used in a Geo Cache hunt. All of this data is sent at a rate usually between 1 and 5Hz in the form of NMEA sentences (Figure 2.33). These packets can be intercepted by the MCU, trimmed, formatted, and then displayed.
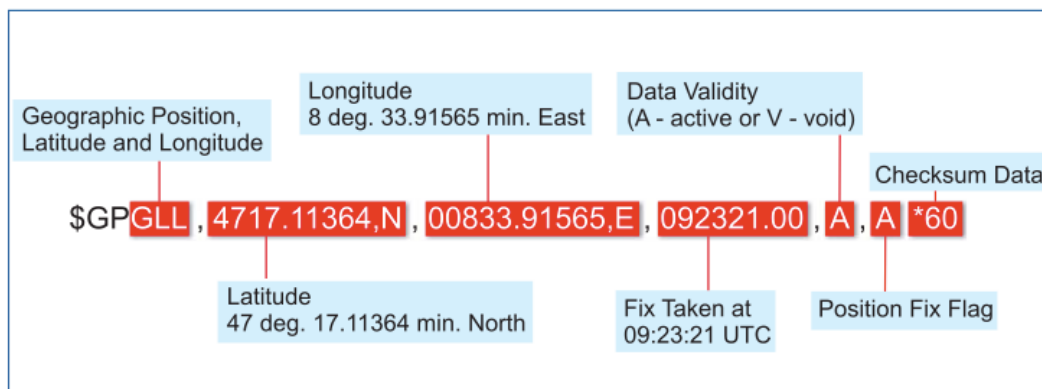
Figure 2.33: An example of a complete NMEA string generated by a GPS receiver. (Courtesy of MikroElektronika, permission pending)

The largest deciding factor in a GPS module is a simplified interface with the MCU. Any module will satisfy the basic feature requirements for speed, cardinal direction and coordinates. The second most important factor is power consumption and scalable update rates. Because the bicycle won't be moving as fast as a car, the microcontroller requires less frequent updates from the GPS, saving power. One last consideration is the antenna. An external antenna provides more freedom for some applications of GPS

where signal strength might be questionable or variable, however for this project the orientation of the GPS module remains fixed to the device and outdoors. An embedded antenna with sufficient signal strength suits the project's needs, and simplifies external package considerations.

2.10.1   LEA-5X series GPS and GALILEO modules

One of the GPS modules we analyzed was the LEA-5 series module manufactured by U-blox. The LEA-5 pictured below in Figure 2.11, works with the American system and European system, respectively, GPS and GALILEO. It features an high performace 50-channel u-blox 5 technology which provides excellent performance and flexibility at an economical price. It also has a 32-channel acquisition engine with over one million effective correlators capble of parallel searches. The whole LEA-5X series has the same compact size of 17.0 x 22.4 nm. The series has been designed with backwards compatibility in mind, enabling ease of upgrade while reducing engineering and design cost. It has a very low TTFF (Time To Find First) of <1sec and the best-in-class acquisition and tracking sensity by their calculations. With a maximum navigation update rate of 4Hz, its velocity is accurate to 0.1 meters per second.

The LEA-5 series are designed to be used with passive and active antennas. An optional antenna supervisor is available for some models in the series. In the default operation mode, the antenna supervisor is activated and enables the receiver to detect short circuits to the active antenna by checking the bias voltage level and can even shut down the voltage bias immediately. The chip, shown below Figure 2.34, can be configured to work at different UART Baud rate. NMEA data can be transferred at rate of 9600 or 38400 baud. For the UBX data protocol, the transfer rate is 4800 an 57600 baud.

Figure 2.34: Picture of the LEA-5X GPS and GALILEO module. (Courtesy of u-blox, permission pending).

This LEA-5X class can be implemented with almost any microcontroller on the market provided that they have the necessary input data ports. The Figure 2.35 below shows an implementation using one of the GPS module from that class. It is obvious that in order

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to drive the information from the module to a microcontroller, two transistors are used to amplifier the transfer signal for accuracy. Not only that, the received signal also trigger an output to the microcontroller like an interrupt would. The power management feature on the u-blox chips is very impressive. They can operated in two different power modes: maximum performance and eco-mode. In both cases, the receiver is operated in continuous mode. The difference lies in the how the data acquisition is implemented. The maximum performance mode freely uses the acquisition engine for best possible data reception at weak signals. With the eco mode however, the use of the acquisitition engine is optimized to perform at low current setting.

Those modules have I2C compliant interface to connect an extra optional serial memory storage chip. They can be used for precise time measurements with sub-microsecond resolution using the available external interrupt. They are rated at a maximum input voltage of 3.6V. The battery backup voltage also can up at a maximum of 3.6V but the antenna bias voltage is up to 6V for better signal receptions.
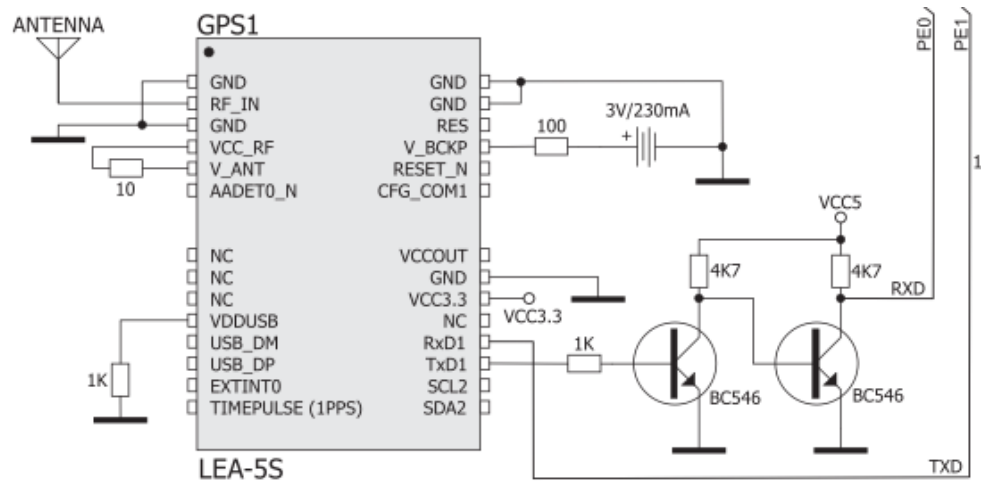
Figure 2.35. An implementation of the LEA-5S GPS and GALILEO module. (Courtesy of u-blox, permission pending).

2.10.2 The LS20031 GPS module

The LS20031 module is a 32 channel super-sensitive receiver that updates each second and consumes low power. There is an embedded antenna on the chip that must be oriented facing up towards the sky. The data line is 3.3v TTL serial at a scalable baud rate, allowing for direct USART connection to the serial pins on the MCU. Other models were found to have an RS-232 interface which is undesirable; additional parts would be required to handle the RS-232 signal and convert it to the MC's 3.3v logic. Referring to Figure 2.36, the LS20031 has five bare contacts (Tx, Rx, Vcc, two redundant GRND) to which wire can be soldered.
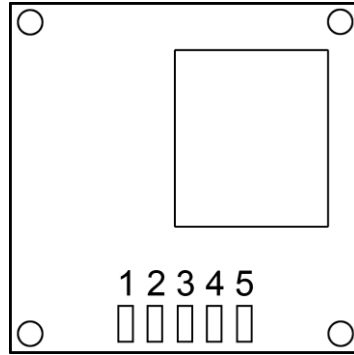
Figure 2.36: GPS receiver LS20031 under-side.

2.11 Temperature sensor

Early in the project, the group was going to add heart rate sensor that can display the heart rate graph of the bike rider on the LCD screen every second. We thought this will be useful when people ride the bike and check their heart rate to promote the exercise. Very first time that was considered was Digital Heart Beat Rate Sensor. It has digital heart rate detector IC chip, and it needs to be clamped on earlobe. However, it has to Connect to heart beat receivers such as exercising equipments, heart beat watches, blood pressure monitors which will cost a lot. Also clamping on earlobe might disturb the bike rider. Other one was Mini Digital Heart Beat Detector. It has many functions such as alarms and clock, which is not related to our project .The most important reason that we lost in interest in this product was it was powered by 2 AA batteries. It does not have to be powered by our battery. It was a product that is already made to use for portable, which makes this was not a good part to buy to use in our project. Because one of the purposes of this project is that how much we can use our knowledge to in practical items in real life. We try to avoid any items that are already built in. After many discussions, we decide to use thermal sensor instead of heart rate sensor. There are a few reasons we have decide to remove and change it to something else. First of all, having a earlobe heart rate sensor or finger heart rate sensor while riding a bike could be dangerous and unsafe. Comparing to gym bike, the bike rider is actually riding the bike on the road, not like riding on the stand bike. Also, heart rate will be changing every second, and that will makes the rider keep check on the heart rate like in gym. Eventually it will be disturbing the rider, and it could cause the accident.

We decide to use temperature sensor. For safety issue, we don't need to wear anything on our body like heart rate sensor so it won't bother us while riding a bike. Also the outside temperature won't change frequently, so that the rider does not bother to check every few second like bio-feedback sensor. We will be able to check the temperature, and display on LCD screen. We have found many different thermal sensors during the research.

One of the thermal sensors we found was Maxim Integrated Products has introduced MAX6638, a ±1.0 degree Celsius accurate thermal sensor with two independent SMBus

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(TM) serial ports. The two SM bus interface can be used by GmPU card controller and a CPU board controller. It also monitors its own internal temperature. The combination of high accuracy and multiple temperature monitoring makes the MAX6638 ideal for our project. Packaged in a 16-pin TQFN, the MAX6638 operates over the 3.0V to 5.5V supply-voltage range, while consuming only 500 micro amps of supply current, one of the best requirement for our project. Also the MAX6638 device is specified over the -40 degrees Celsius (-40 degrees Fahrenheit) to +125 degrees Celsius (257 degrees Fahrenheit) temperature range.
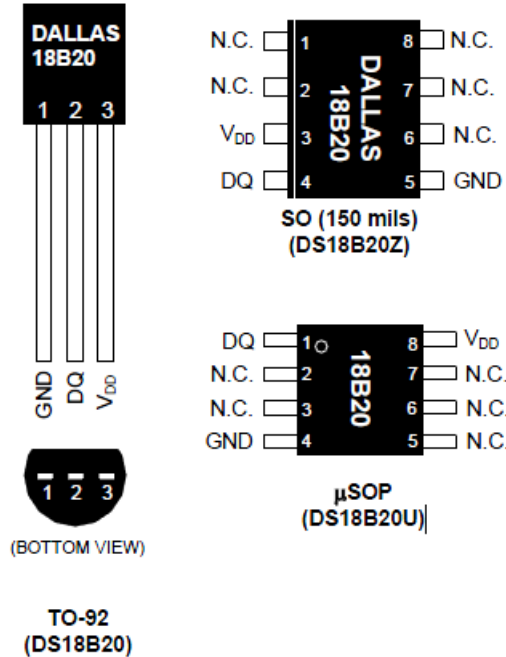
Figure 2.37: DS18B20 Pin Configuration. (Provided by Maxim. Permission pending)

The one we decided in the beginning was DS18B20, which is one-wire digital temperature sensor. While researching, we found out that this temperature sensor has been used in many places. It was used not only in many people's individual project, but also it was used in many school or company projects in the world. There are so many website, document, schematic and other information that will be really useful information for this project. It is very famous and user-friendly product. This was latest DS18B20 wire digital temperature sensor from Maxim IC. Maxim is very famous company in Engineers and it delivers innovative analog and mixed-signal engineering products. So we started to research on this temperature sensor. First of all, this is a digital sensor, so the microcontroller can read and display it on screen easily. This was latest DS18B20 wire digital temperature sensor from Maxim IC. It is known as 9 to 12-bit precision, and the range is from negative 55 degrees Celsius to +125 degrees Celsius. And it has ±0.5°C accuracy from –10°C to +85°C. It can be powered from data line. Power supply range is 3.0V to 5.5V. This device will convert temperature to 12-bit digital word in 750ms (max). This could be the best part we can get. Price was only around few

dollars, and it is digital, good accuracy with wild range of temperature sensor. These 1-wire temperature sensors have become really popular, because they are inexpensive and easy to use, and giving calibrated digital temperature readings directly to us.

There are two ways to get power for the DS18B20 temperature sensor. One way is by external supply on the VDD pin, or it can operate in parasite power mode, which allows the DS18B20 to function without an external battery supply. Parasite power is useful for applications that require remote temperature sensing or that is very space constrained. Here, the diagram for the DS18B20 (Figure 2.38) shows that it is parasite power control circuitry, which steals power from the 1-Wire bus via the DQ pin when the bus is high.
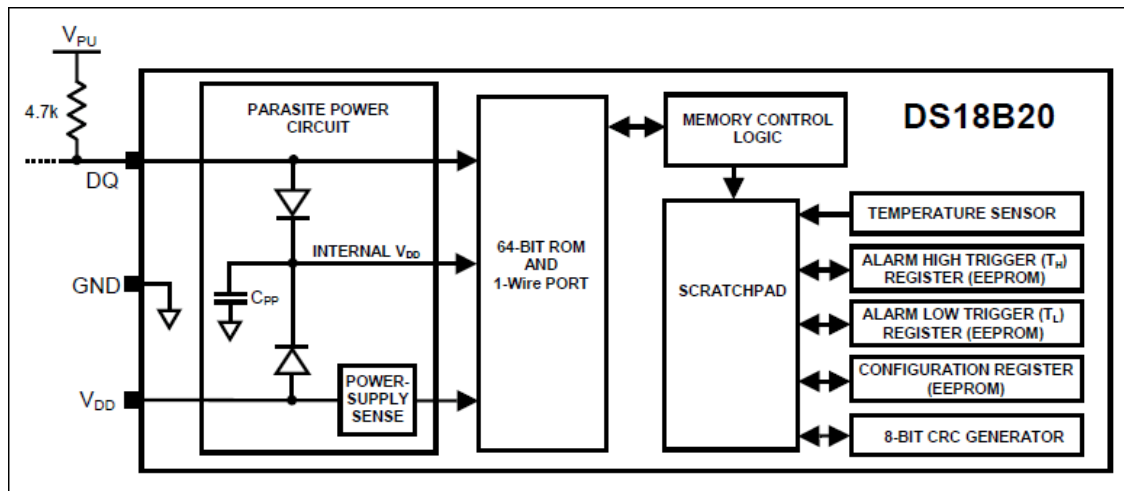
Figure 2.38: Diagram of DS18B20 (Provided by Maxim. Permission pending)

To operate in parasite power mode, there will be two requirements; we need one data line and a ground. 4.7K pull-up resistor has to be connected to the 1-wire bus. This is very important because when the line is in a "high" mode, the device will pull current and it will charge the internal capacitor. This current will be is generally very small, but it could be as high as 1.5 mA when it converts the temperature or writes EEPROM. When a slave device is performing one these operations, the bus master must keep the bus pulled high to provide power until the operation completes; a delay of 750ms is required for a DS18S20 temperature conversion. The master can't do anything during this time, like issuing commands to other devices, or polling for the slave's operation to be completed. To support this, the One Wire library makes it possible to have the bus held high after the data is written.

For the Normal (external supply) mode, with an external supply, three wires are required: the bus wire, ground, and power. The 4.7k pull-up resistor is still required on the bus wire. As the bus is free for data transfer, the microcontroller can continually poll the state of a device doing a conversion. This way, a conversion request can finish as

soon as the device reports being done, as opposed to having to wait 750ms in "parasite" power mode.

The use of parasite power is not recommended for temperatures above +100°C becuase the DS18B20 won't be able to maintain communications due to the higher leakage currents that will exist at those high temperatures. For our project, there will be no case that it will be above +100°C, so it wouldn't matter. But for applications that can be reach as high as +100°C, it will be a bad idea using DS18B20 with power mode of parasite. It should be powered by an external power supply.

Measuring temperature using DS18B20, it is user-configurable to 9,10, 11 or 12 bits, corresponding to increments of 0.5°C, 0.25°C, 0.0625°C, respectively. It is at power-up at 12 bit in default mode. To initiate a temperature measurement, the master has to issue a Convert T[44h] command. DS18B20 output temperature data is calibrated in degree Celsius. The data will be stored as a 16-bit sign-extended two's complement number in the temperature register as shown in Table 2.17.

	BIT 7	BIT 6	BIT 5	BIT 4	BIT 3	BIT 2	BIT 1	BIT 0
LSB	2^3	2^2	2^1	2^0	2^{-1}	2^{-2}	2^{-3}	2^{-4}
	BIT 15	BIT 14	BIT 13	BIT 12	BIT 11	BIT 10	BIT 9	BIT 8
MSB	Sign	Sign	Sign	Sign	Sign	2^6	2^5	2^4

Table 2.17: Temperature Register Format DS18B20 (Provided by Maxim, Permission pending)

The sign bits shows if the temperature is positive or negative, 0 for positive, 1 for negative. In 12-bit resolution, all bits in the register will contain valid data. For 11-bit resolution, bit 0 is undefined, for 10-bit resolution, bit 1 and 0 are undefined and for 9-bit resolution, bit 2, 1 and 0 will be undefined. Here is a example of temperature representation in below Table 2.18

Temperature (°C)	Digital Output (Binary)	Digital Output (Hex)
+125	0000 0111 1101 0000	07D0h
+85	0000 0101 0101 0000	055h
+25.0625	0000 0001 1001 0001	0191h
+10.125	0000 0000 1010 0010	00A2h
+0.5	0000 0000 0000 1000	0008h
0	0000 0000 0000 0000	0000h
-0.5	1111 1111 1111 1000	FFF8h
-10.125	1111 1111 0101 1110	FF5Eh
-25.0625	1111 1110 0110 1111	FE6Fh
-55	1111 1100 1001 0000	FC90h

Table 2.18: DS18B20 temperature/data relationship example. (Provided by Maxim. Permission pending)

In DS18B20 Configuration register, shown in Table 2.19, there are bytes 4 of the scratchpad memory. The user can set the conversion resolution of the DS18B20 using the R0 and R1 bit in this register as shown in Table 2.20. There is a direct trade of between resolution and conversion time. Bit 7 and bit 0 to 4 in the configuration register are reserved for internal use by the device and con not be overwritten.

Bit 7	Bit 6	Bit 5	Bit 4	Bit 3	Bit 2	Bit 1	Bit 0
0	R1	R0	1	1	1	1	1

Table 2.19: Configuration Register (Provided by Maxim, Permission pending)

R1	R0	Resolution (bits)	Max Conversion time
0	0	9	93.75ms
0	1	10	187.5ms
1	0	11	375ms
1	1	12	750ms

Table 2.20: Thermometer Resolution Configuration (Provided by Maxim, Permission pending)

We can calculate the total delay of a loop cycle easily: adding all these instruction clock cycles but taking care of just one thing: brne is normally true (it uses 2 cycles), except in the last loop, when brne condition is false, so it takes only 1 cycle and L15 is not executed as the code continues with the next instruction. This means we have to subtract 2 cycles from the total (1 from nop and 1 from brne).

Therefore, the total delay of this loop is: (8 cycles * number of loops) – 2 cycles

Instruction	Clock Cycles
Idi	1
Idi	1
rjmp	2
Total Cycles	4
Nop	1
Sbiw	2
Idi	1
Cpi	1
Cpc	1
Brne	2 if ture, 1 if false

Table 2.21: Instrution Clock Cycles (Provided by Maxim, Permission pending)

4 cycles (initialization) + ((8 cycles * number of loops) – 2 cycles) =(8 cycles * number of loops) + 2 cycles

Considering that at 8Mhz each cycle takes 0.125us, the final delay in µs will be:

(8 * 0.125µs * number of loops) + 2 * 0.125µs = (1µs*number of loops) + 0.25µs =

(number of loops)µs + 0.25µs

After many research, I have found existent of DS18S20. DS18S20 is replacement of old DS1820 and it has more information and devices that supports. It is similar, even the name of the product is a letter different. So we decide to see the differences. The DS18B20 and DS18S20 1-Wire devices are both famous and excellent choices as digital temperature sensor. As we can see from the name of the product, both devices has the same resolution, requirement and accuracy. The only different point is how the data is accessible to us. The DS1820 used a dual-oscillator technology to do a temperature conversion. The DS18S20 was designed to be replacement for the original DS1820. ADC in the DS18S20 is designed to always perform 12-bit conversions and the 12-bit will be rounded to a 9 bit value and stored in the register of temperature. If you want more than 9-bit resolution, the value of count remain register need to be calculated. However, DS18B20 is different from the DS18S20. We will be able to pick the resolution that we need by using configuration register. This makes this DS18B20 flexible to many people to reduce the ADC conversion time, and also it will save power for higher resolution. Table 2.22 shows the temperature conversion time and LSB for each possible resolution setting.

Resolution	9 bit	10 bit	11 bit	12 bit
Conversion Time (ms)	93.75	187.5	375	750
LSB (°C)	0.5	0.25	0.125	0.0625

Table 2.22 DS18B20 Conversion Times and Resolution Settings (Provided by Maxim, permission Pending)

The temperature registers of the DS18B20 and DS18S20 will be different. The temperature register in the DS18S20 will be suitable toDS1820 which it provides 12 bits resolution. However DS18B20 is smarter chip. It removes the part to perform an additional calculation, which is required in DS18S20. The default power up state of the temperature register in both devices is +85°C. Here is the list of the Temperature of Register format for each part.

	bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0
LSB	2^6	2^5	2^4	2^3	2^2	2^1	2^0	2^{-1}
MSB	Sign	Sign	Sign	Sign	Sign	Sign	Sign	Sign

Table 2.23: DS18S20 Temperature Register Format (Provided by Maxim, permission Pending)

	bit 7	bit 6	bit 5	bit 4	bit 3	bit 2	bit 1	bit 0
LSB	2^3	2^2	2^1	2^0	2^{-1}	2^{-2}	2^{-3}	2^{-4}
MSB	Sign	Sign	Sign	Sign	Sign	2^6	2^5	2^4

Table 2.24: DS18B20 Temperature Register Format (Provided by Maxim, permission Pending)

The scratchpad memory are also different. The DS18S20 don't have the configuration register that allows the DS18B20 to change resolution. The DS18S20 has two additional registers that will be used if greater than 9 bits of resolution are required. Last, the 8 bit family code are different each other. The family code for the DS18B20 is 28h when the DS18S20 has the same code the original DS1820 has, which is 10h.

	DS18S20	DS18B20
byte 0	Temperature LSB (AAh)	Temperature LSB (50h)
byte 1	Temperature MSB (00h)	Temperature MSB (05h)
byte 2	TH Register	TH Register
byte 3	TL Register	TL Register
byte 4	Reserved (FFh)	Configuration Register
byte 5	Reserved (FFh)	Reserved (FFh)
byte 6	Count Remain (0Ch)	Reserved
byte 7	Count Per °C (10h)	Reserved (10h)
byte 8	CRC	CRC

Table 2.25: Scratchpad Memory Map Comparison

The DS18S20 is only recommended for an application that is currently using the original DS1820. Used as a drop-in replacement, the DS18S20 will hopefully save the designer from having to make changes to existing firmware or software. Some code changes may be required, nonetheless, because the DS18S20 has a longer conversion time (750ms) than the DS1820 (500ms). The DS18B20 is recommended for any application that requires 9 to 12 bits of temperature resolution. This device offers much more flexibility and is easier to use than the DS18S20.

After large amount of research, we figure that the DS18B20 has too many functions that that we won't use in the project, we needed to find replace part that is simpler and it can fit well in the project instead of DS18B20.DS18B20 will be also tested but we wanted to find second choice. DS1625, digital thermometer made by Dallas Semiconductor is simple temperature measurements that require no external components, and it provides 9-bit temperature readings which indicate the temperature of the device. This is actually older technology than DS18B20. The data will be read from and also will be written via 2-wire serial interface. Figure 2.39 shows a block diagram how the DS1625 measures temperature through its on-board proprietary temperature measurement technique.
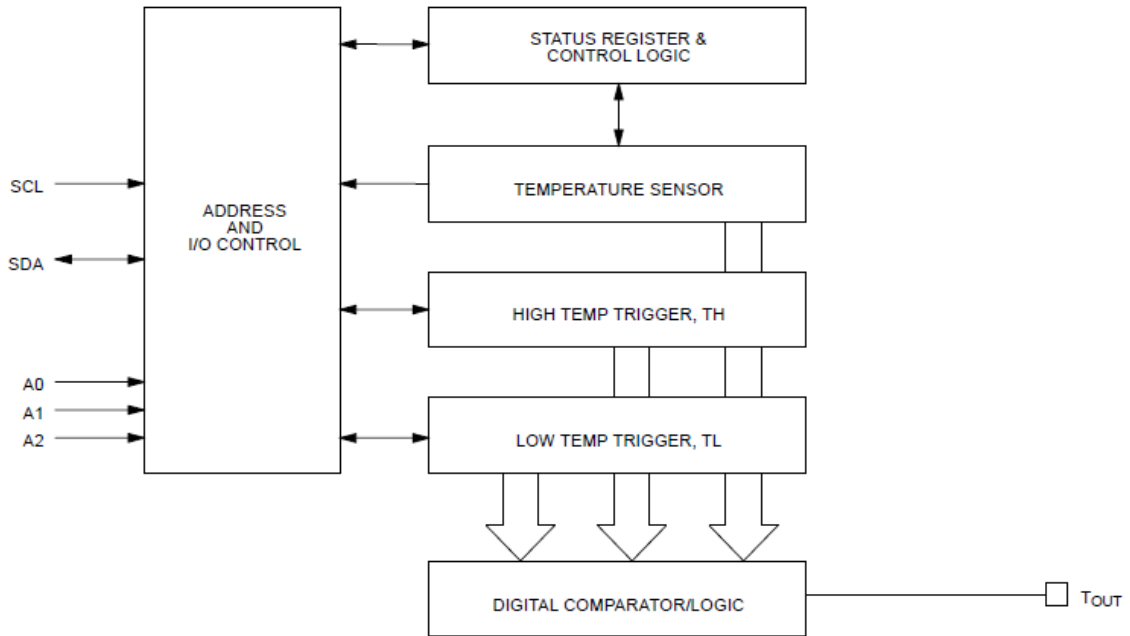
Figure 2.39: Functional Block Diagram (Provide by Dallas Semiconductor, Permission pending.)

DS1625 measures temperature using counting the number of clock cycles that an oscillator with a low temperature coefficient goes through during a gate period determined by high temperature coefficient oscillator. The counter is preset as a base count which is -55°C. When the counter become 0 before the gate period is over, the temperature register, that is also preset as -55°C, is incremented, signify that the temperature become higher than --55°C. Simultaneously, the counter is preset with a value that is determined by the slope accumulator circuitry as shown in Figure 2.40.
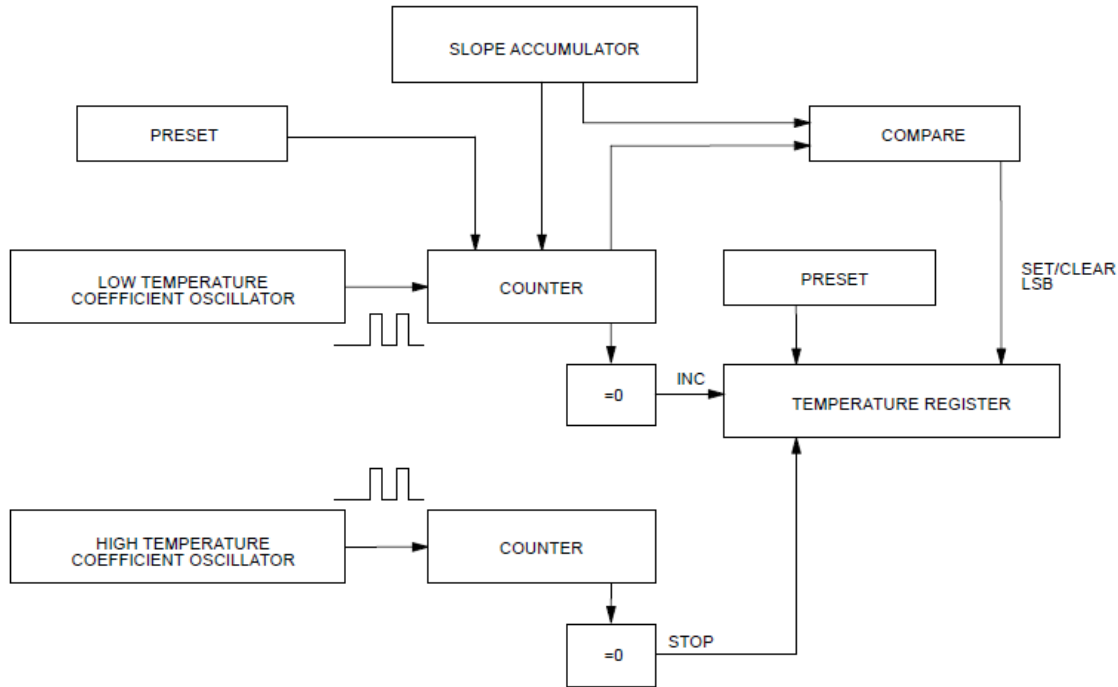
Figure 2.40: Temperature Measuring Circuitry (Provided by Dallas Semiconductor, permission pending)

The circuitry is needed to compensate over the temperature, the counter is going to be clocked until it becomes 0, and it will repeat the processes until the gate period is done. The slope accumulator is for compensating the nonlinear behavior of the oscillators over temperature by changing the number of counts needs to go through for every incremental degree in temperature.

As briefly describe in the specification of temperature section, this sensor has 0.5°C resolution and its reading is in a 9-bit, two's complement by issuing the read temperature command. The read temperature command will read the last converted temperature value from the temperature resister. Table 2.26 shows relationship between output data and measured temperature. First, the data will be transmitted serially through the 2-wire serial interface, MSB first, in range of -55°C to +125°C in 0.5°C increments.

Temperature	Digital Output (Binary)	Digital output (Hex)
+125°C	01111101 00000000	7B00h
+25°C	00011001 00000000	1900h
+1/2°C	00000000 10000000	0080h
+0°C	00000000 00000000	007Fh
-1/2°C	11111111 10000000	FF80h
-25°C	11100111 00000000	E700h

-55°C	11001001 00000000	C900h

Table 2.26: Temperature/Data relationships (Provided by Dallas Semiconductor. Permission pending)

The temperature data has to read from the DS1625 as either a single byte with temperature resolution of 1°C, or as two bytes, the second byte containing the value of the least significant bit of the temperature reading which represent 0.5°C . Remaining of 7 bits of LSB will be appear as 0 as it is shown in Table 2.26.

Table 2.27 represents the temperature in terms of a 1/2°C LSB, 9 bits format. MSB represent -25 and first bit of LSB represent 0.5°C. The temperature will be represented in terms of a 0.5°C LSB.

MSB									LSB							
1	1	1	0	0	1	1	1		0	0	0	0	0	0	0	0

Table 2.27: Example format when T is at -25°C

TEMP_READ higher resolution can receive the value by reading the temperature. Count remain value is left in the counter that can be read after READ COUNTER command. Counter per Clock value after READ SLOPE command. After obtain all of the data, temperature can be calculated as following :

Temperature = TEMP_READ -.25 +(Count per clock-count remain)/count per clock

This DS1625 supports a bi-directional 2-wire bus and data transmission protocol. "Master" is the device that controls the message, and the devices that are controlled by the master are "slaves". Master device will manage the bus by generating serials clock (SCL) and controlling the bus access. It will eventually generate the START and STOP condition. SDA and SCL are the connection to the bus made with the open-drain I/O lines. There will be few conditions that have been defined. When the Bus is not busy, both data and clock lines will remain as High. When it starts to data transfer, there will be a change in the state of the data line, from high to low. While the clock is high, it defines a start condition. If Stop data transfer occurs, there will be a change in the state of the data line, but this time from low to high, the clock line will be high and defines the stop condition. The state of the data line represents valid data if the data line is stable during of the high period of the clock signal after a Start condition.

2.12 USB

The Universal Serial Bus, USB, became really popular nowadays to connect computer peripherals. As a Data source, the original USB 1.1 specification limited data rates to about 12Mbits/sec. USB 2.0, which has been using lately, the rates are up to 480Mbit/sec. Not only the data transfer, but it also provide DC power to the peripheral devices. Very large amount of electronic devices supports USB power as their power sources, such as mp3 players, portable fan, vacuum cleaner, all kind of lights, and even coffee maker.

Also USB is less expensive than FireWire because it doesn't require a controller ship set like FireWire need one. Even though FireWire works better than USB in general, but USB has its own benefits. It is easy to use, it is cheaper, and simpler. A USB controller require to power one unit load, which is around 100mA. It can possibly power up to 5 units. It could be used to power up little devices such as keyboard, and for more, it could be used to power up and charge the batteries of mp3 players and other devices batteries. It seems the spec is silent about intermediate loads, so we assume that the sources deal with just the two cases, either a load is low power (100mA), or higher power (500mA). This is the reason that we decide to add USB port for the project.

2.12.1   Types of USB

There are different types of USB connectors. Type A, Type B, Mini-A and Mini-B are common types of USB. Type A is the most famous type of the USB these days. This Standard type A USB plug is rectangle looking and it carries both data and power. Type-B is square shape, and it delivers power in addition to carrying data, even some devices, it has no data connection, but only receive power from the upstream devices. This two-connector type, type A and B is usually designed in one cable to prevent a person from creating dangerous electrical loop. Also there are mini and micro USB types. Those are made for cell phones, digital cameras, portable game player, PDAs or other portable devices. The cellular phone company groups have recently endorsed micro-USB as the standard connect for cellular phone data transfer and power on. Of course USB-A receptacle can be plug in USB-A only, and same for USB-B, mini-B, micro-A and micro -B, except Micro-A receptacle can be plug in to Micro-B plug. Female part of Type A will be used in the project to power the devices since Type A is the most common type of USB.
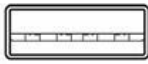
Type	Port Image	Connector Image
Type A	4.5mm x 12.0mm	
Type B	7.3mm x 8.5mm	
Mini-A	3.0mm x 6.8mm	
Mini-B	3.0mm x 6.8mm	

Table 2.28: USB Types (Provided by Intel, permission pending)

2.12.2   USB Power

Idea of installing USB on the bike didn't come out in the beginning of the project. Our group was brainstorming what devices we can use in the project. We had considered using speaker and mp3 player on the bike, or having a Fan. Also we thought about lighting for protection and notify other cars or pedestrians. After a few discussions, we have found many disadvantage of having a mp3 players and speaker system on the bike. If we mount the mp3 player, it loose its mobility function. The mp3 player and speaker that will be mounted on the bike could get wet, therefore it might not give us good quality sound or more possibility that it gets break. Also it wasn't a safe idea that having a sound system on the bike, it could disrupt the bike rider by confusing the rider if the sound if coming from the speaker or surround area. Using a earphone would be better idea than having an speaker on the bike. Also there are many other devices that we wanted to add, however, we need to change our design every time we add new devices on the bike.

Because of all these little issue, we try to look for another idea that could replace the mp3 player and other devices. While we were discussing about the mp3 player, we notice the USB charger for mp3 player. We could use any devices without any problems by using USB power source. As it is mentioned previously, there are numerous devices that use USB power source these days. It is like having a 110V outlet on the bike. We started to research what we could do with USB power source.

There are numerous devices that can be powered by USB. Portable Fan, mp3 player, speaker, cell phone, neon light are some of these devices that use USB power. We could install a neon light on the bike really easily by plugging in the USB power. Also a detachable fan can be easily install on the bike by plugging in. This Bike Buddy project is generating the power from the pedaling, and it charges on the batteries and that batteries is what we are using it as a power source. Since we have USB port is available, we can also not operating the devices, but also charge the devices or battery. Most cell phone has its own USB data cable that can transfer and/or charge the cell phone batteries. Using the USB cable comes with most of cell phones will let us charge the battery using USB port. This will be really useful riding a bike when the cell phone battery is out.
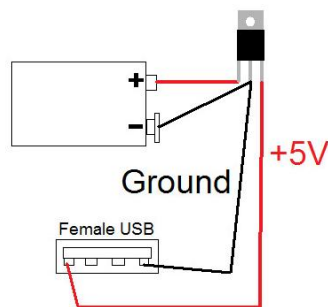
Figure 2.41: USB with 9V battery.

This picture, Figure 2.41 is USB power using 9V and voltage regulator (5V), COM-00107. Because USB power is 5V, we need something more than 5V from the battery since there are no 5V batteries out there. We can use 4AA/AAA batteries (which is around 5 V). For better result, we need to have a voltage that produces exactly 5V witt voltage regulator. The regular will take a voltage into a steady 5V. This can be handled by the battery parts. From the research, one of the examples was that if we get a 9V battery, we will need a resistor greater than 100ohm and flat female USB connector which mates with the device's USB cable. Connect the positive side from the battery go the resistor and then it connect with positive side of USB and diode. The other side of diode will be connected with negative side of battery and USB. Polarity matters on the diodes so we had to make sure which way it goes. This is the simple way to make USB from 9V battery. Battery could be different depends on our project. As long as it is higher than 5V, and it will be, using this design will give us 5 V USB power source to use electronic devices.

2.12.3   USB Charger

From the research, we have found that charging or operating device with USB cable that is provided by the device has no problem. We worried about over-charging the batteries and it will break the devices. Also we worried if the current changes depends on the status of device, whether it is on or off. Most of the high developed electronic devices such as mp3 players, cellular phone or others, it's charging cable has smart chip to prevent over charging, and also the device itself has one too.

We found a experiment about charging the Li-Ion battery. Li-Ion batty cells provide very stable operation from around +5°C to +45. Outside this temperature range charge current needs to be significantly reduced or suspended by the battery manufactures.
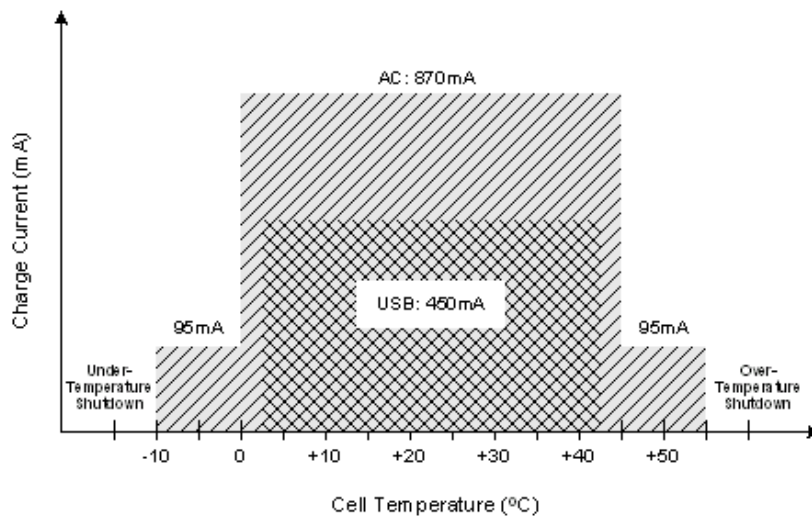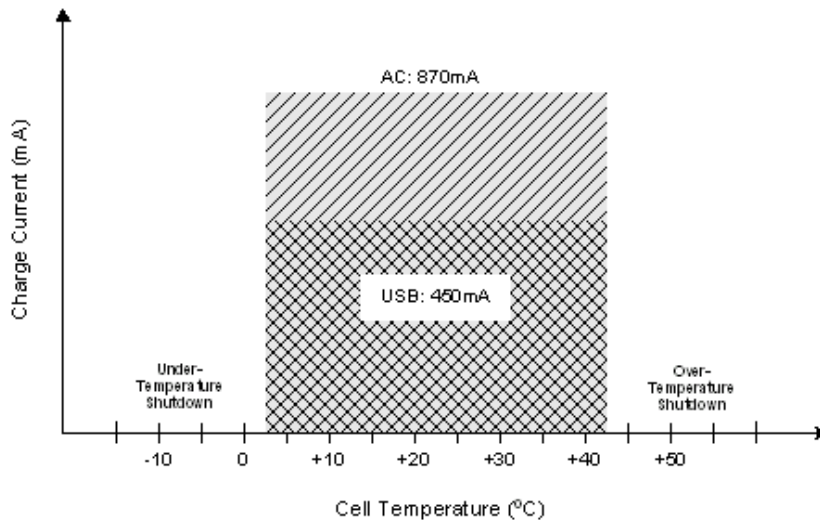
Figure 2.42: Examples of Charge Current Settings Based on Cell Temperature and Power Source (provided by powermanagementdesignline.com, permission pending)

The two temperature-based charging profiles are described in Figure 2.42. First graph represents a sophisticated method. It allows higher average charge current while ensuring battery cell safety. The temperature-based charging current profile can also be different depending on power source type, AC wall wart or USB port. The second graph represents a traditional implementation with a single charging profile and over-/under-temperature monitoring. Here is a one important parameter for a USB charger, the accuracy of the fast charge current. The more precise the charge current level, the less headroom is required by the design to guarantee that the USB current limit is not violated. Drawing as much current as possible from the USB port is the point, but without causing the port voltage to drop and the USB host to shut down the port for safety reasons.

While researching, we have found some example experiment about USB battery charger. He tested with 4 2300 mA NiMH cells that were fully discharged. Eventually it will takes 10 hours to charge with USB, but it will takes 18 hours in normal way assuming 135mA/cell, which is about right assuming a 90% charge rate efficiency. 18 hours is too long to charge compare to 10 hours. This shows how efficient the USB charger is.

Here is another experiment that had been done with USB charger. This Charger is little different. It stops charging when the battery temperature reaches 33°C. So it is really important that two batteries have to have same level of discharge. Procedure is easy. We will plug it into a USB port and insert the two batteries into the charger. It should have LED or some kind of signification to tell when the battery is fully charged. Approximate charge times are shown below Table 2.29.

Cell Type	Charge Time
700mAh NiCd	1.5h
1100mAh NiCd	2.5h
1600mAh NiMH	3.5h
2000mAh NiMH	4.5h
2500mAh NiMH	5.5h

Table 2.29: Charging Time (Provided by Stefanv. Permission pending)

It is possible that AAA can be charged in the same location of the AA charger. Only one thing that is need to be careful is that the battery has to be modern AAA with capacity of 700mAh or more.

2.12.4   USB Data

USB can be as a power source and a data source. Compare to the power source USB design, it has data+ and data- cable. It has USB Vcc, data+, data- and GND. USB Port Color Codes are Red = +5V, Green = Data+ (+D), White = Data- (-D), Black = Ground (GND). Connecting the Data+ and Data- line to the microcontroller, we should be able to get the data from the USB sources to microcontroller shown below Figure 2.43.
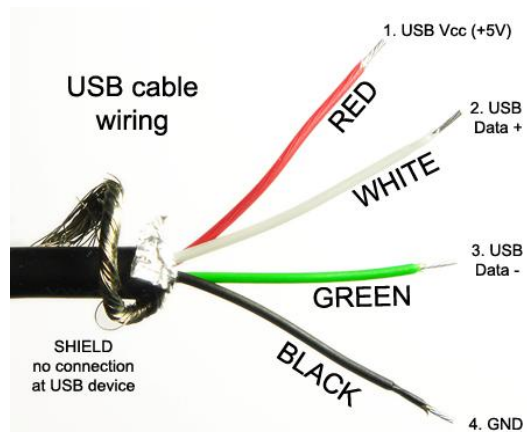
Figure 2.43: USB Pins (Provided by bealecorner.org, permission pending)

3. Design

3.1 Explicit Design Summary

As it was introduced in previous sections, Bike Buddy utilizes a bicycle generator to charge a lithium ion battery. This battery supplies current to a subsystem responsible for displaying sensor information. These include a temperature sensor, a GPS receiver, a system for monitoring power generated, and a charge monitoring system for the battery. The battery also supplies current to a female USB port. A top-down block diagram of Bike Buddy can be seen below in Figure 3.1:
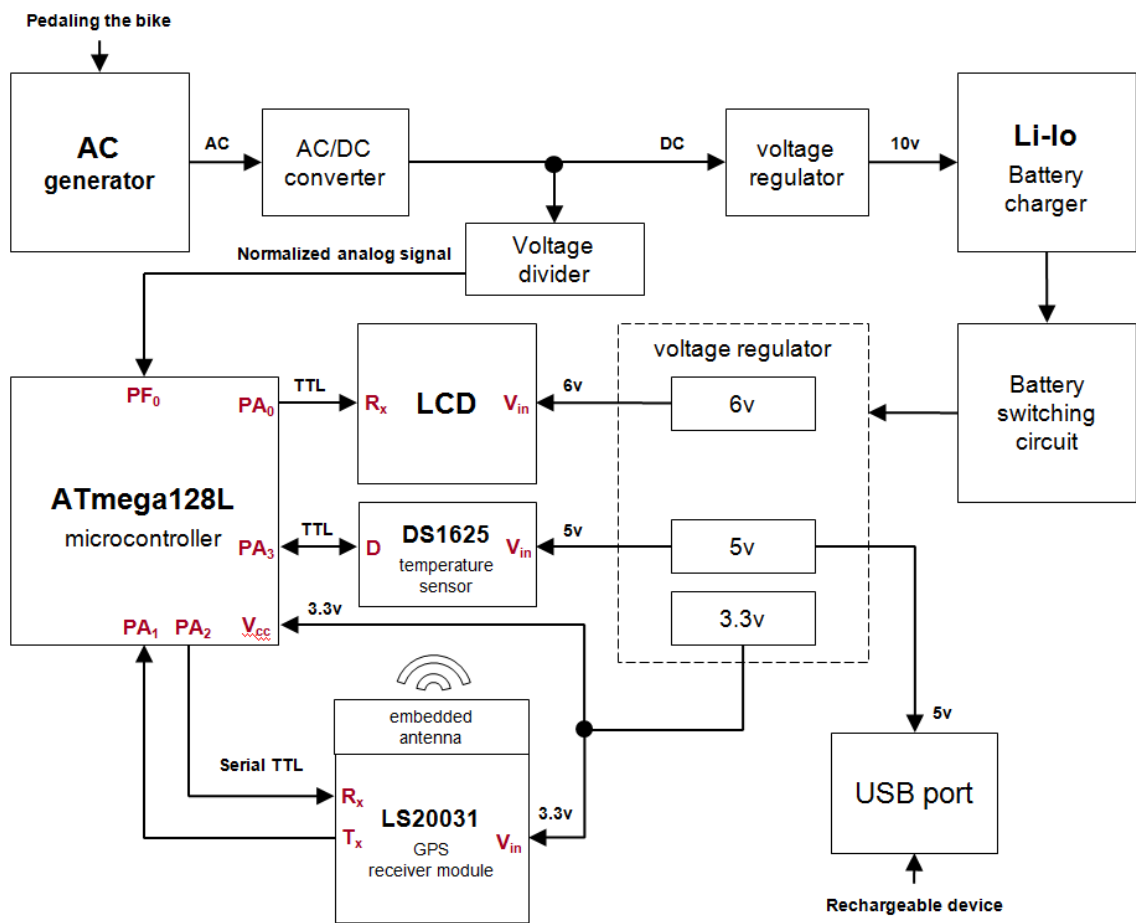
Figure 3.1: Top-down block diagram for Bike Buddy.

As the voltage on the generator fluctuates between a positive and a negative value, the bridge rectifier in the AC/DC converter inverts all the negative sections of the wave. As the inversion happens, the frequency of the signal doubles due to the full-wave rectifier circuit and then filtered through the 10uF capacitor as pictured in Figure 3.3 below. At

this point the output voltage still has some ripple which needs to be filtered through a voltage regulator. We regulate the 10V that is required for the charger with the LM317 voltage regulator chip. That voltage is used as the input of the charger to charge the Li-Ion 7.4V batteries (8.4V Max). The charger keeps track of the level of the battery being charged to prevent overcharging. As pictured in Figure 3.2 below, the charging process begins with a low current while the voltage increases for the preconditioning phase. After six minutes, the process enters the fast-charge phase with a constant current while the voltage continues to increase. After fifteen minutes, the voltage is at maximum and the current decreases to prevent overcharging. The charger remains in the constant voltage phase at low current until the battery is removed or switched with the switcher.
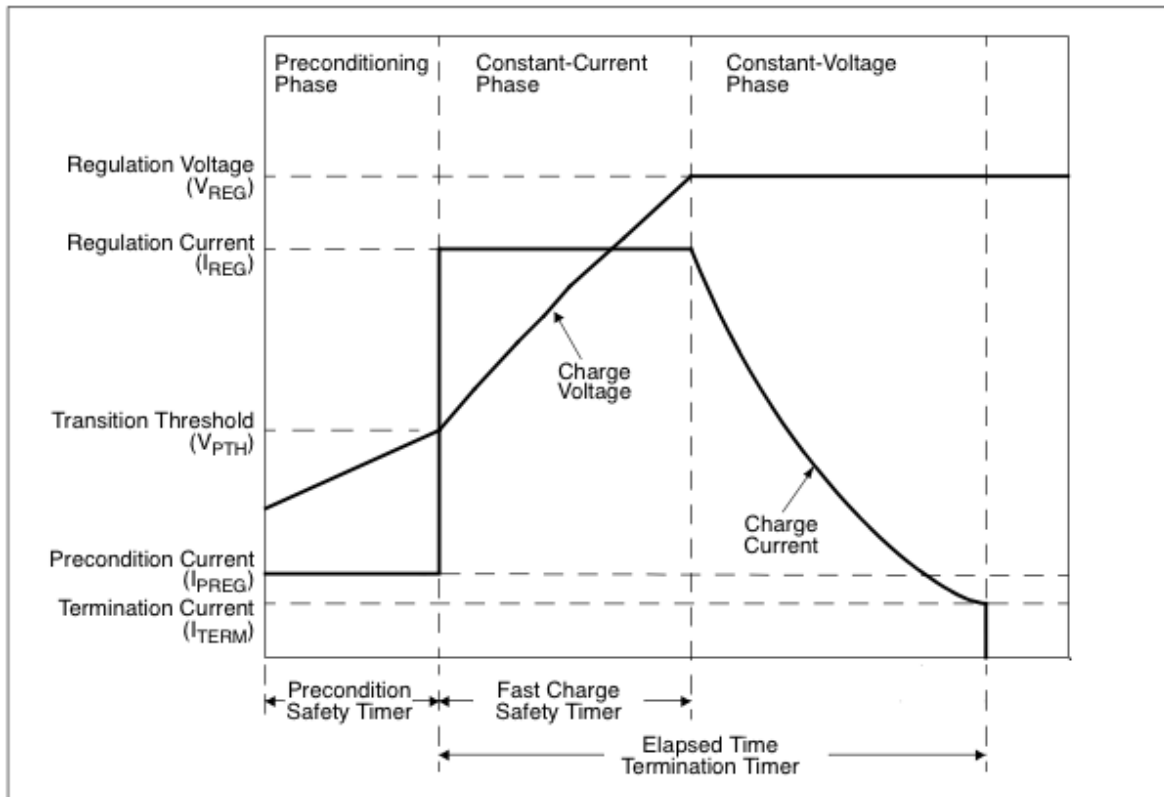
Figure 3.2: Charge profile for the MCP73842. (MicroChip – Permission Pending).

All of the functionalities of the power supply at this point are geared towards charging one Li-Ion battery, but we are switching between the two batteries that consecutively power the main board. In order to achieve this feat, a switching circuit is implemented using 6 p-channel mosfets, 3 zener diodes and 2 comparators. The design schematic for the switching mechanism is shown in Figure 3.6 on page 77. The voltage divider subsection on the block diagram will regulate the DC voltages from the generator and the two batteries to suitable levels for the Analog to Digital converter in the microprocessor. The analog to digital converter will sample the voltages and store their corresponding binary representation in a data register. That data is then read and scaled

accordingly to display the voltage levels and amount of power generated and burned by the system.

In addition to processing the power generated and the battery levels from the circuits detailed above, the role of the ATmega128L microcontroller is to organize the information obtained from the LS20031 GPS module and to display it with the Graphical LCD. Both of these devices transmit asynchronous serial data, which is shared between two lines on each device: a TX line and an RX line. The LCD requires only the RX line, although a TX line is included for development purposes. The baud rate for each device is programmable, and both are established to transmit 9600bps. The ATmega128L handles communication with these two devices using its two USART subsystems.

Software for the ATmega128L is written in C. Libraries for the AVR microcontroller are provided with a software package included in the STK300 development board. Sensor data is read and stored much more slowly than it's received, and updated roughly every 1/6 of a second to the LCD. Commands for drawing to the LCD are detailed in Table 3.1. A layout for the screen (with lines to differentiate information) is initially drawn, and updates are made to smaller information fields only when necessary.

Command	Byte	Argument	Description
Set X Coordinate	0x18	0:127d	Moves cursor for text generator.
Set Y Coordinate	0x19	0:63d	Moves cursor for text generator.
Set/Reset Pixel	0x10	x, y, 0:1d	0: set (x,y) pixel, 1: reset (x,y) pixel
Draw Line	0x02	x1, y1, x2, y2, 0:1d	(x1,y1) to (x2,y2), 0: draw, 1: erase
Draw Circle	0x07	x, y, r, 0:1d	(x,y) center, r: radius, 0: draw, 1: erase
Draw Box	0x0F	x1, y1, x2, y2, 0:1d	(x1,y1) to (x2,y2), 0: draw, 1: erase
Erase Block	0x05	x1, y1, x2, y2	Entire box is erased.

Table 3.1: A set of commands for drawing to the LCD.

The GPS module sends packets in the form of NMEA sentences at a frequency of once per second (scalable up to 5 Hz). These packets are transmitted through USART1 and read only several times per second. When a packet read, it is stored in memory and later parsed by a function which takes only the desired values (UTC time, date, latitude, longitude, speed over ground, and course over ground) and stores them in memory. When the screen is ready to be updated, a print function is called for each datum. This function sends the "Erase Block" command with the statically defined coordinate space for each particular datum, sets the X, Y coordinates for the text generator accordingly, and sends the byte sequence to the LCD as an ASCII string.

USB is used as power source in this project. +5V pin and ground Pin of USB parts will be connected to the battery and ground. The battery is already regulated and it will give

5V to USB port. From this USB port, other devices will be used to power up. Originally, this USB port was design to replace the mp3 player and speaker system. After more research we considered having a data line connected to the microcontroller. However, USB power could be used in so many devices; it is already letting us use many devices without any hard process. It is like a having an 110V electrical outlet on the bike since there is huge number of devices that can use USB as power source. USB port signifies that more devices are available for the bike instead of redesigning the project such as the voltage divider and the voltage regulator.

There will be two temperature sensors that will be tested. DS18B20 which is latest version of temperature sensor from Maxim IC, and DS1626 which is old version of temperature sensor from Dallas Semiconductor are these. DS18B20 has 3 pins that will be connected to microcontroller, ground and battery. The line that is connected to microcontroller is called DQ, and it has unique one-wire interface that requires only one port pin for communication. It measure temperature with user-configurable bit of 9,10, 11 or 12 corresponding to increments of 0.5°C, 0.25°C, 0.0625°C, respectively. And this will convert temperature to 12 bit digital word in 750ms. Programming tool C will be used to design and test the temperature sensor. DS1625 is a second choice of temperature sensor. It has 8 pins. SDA and SCL, the w-wire serial data input/output, and 2- wire serial clock will be connecting to the microcontroller. This sensor will measure the temperature by counting the number of clock cycles. This temperature will be read as 9-bit value, and this will convert temperature to digital word in 500ms.

3.2 Power supply

3.2.1   AC/DC Converter

The generator is supplying an AC signal that needs to be converted to DC to meet the required specs of our project. In Figure 3.3 below, the bridge rectifier can have a minimum voltage drop of 0.8V if built with schottky diodes. The 10uF capacitor is used to filter out the ripple in the output. The configuration is to be connected to a voltage regulator for more filtering.
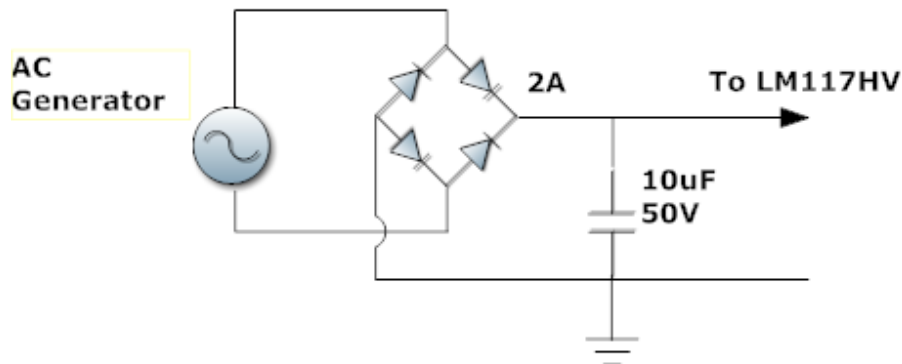
Figure 3.3: Schematic for the bridge rectifier circuit to convert AC to DC.

To calculate the DC voltage output at a particular AC input from the generator, we need to take into account the fact that we're using a full-bridge rectifier in the configuration.

At 12V AC from the generator: Vdc = Vpeak – Vr(p-p)/2 = 12(sqrt(2) = 16.9V

After the voltage is converted, a 10V regulator is applied to further remove the ripple and keep the output at the constant 10V for the charger and the switcher. The LM317 pictured below on Figure 3.4 has the same configuration as the LM117HV; the only difference is, the LM117HV has a better input voltage range. The voltage regulator has an input to output voltage difference of 3V to 40V. So if the output is 10V, the input can be between 13V and 50V. At maximum speed, the generator's DC output fall within that range.
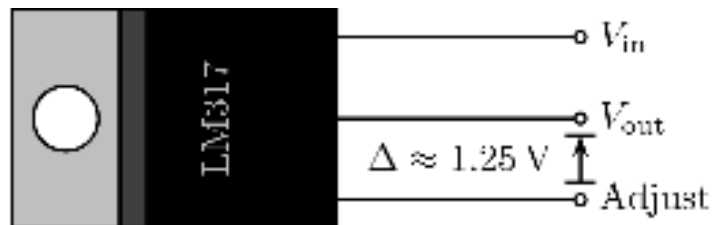
Figure 3.4: Configuration for the LM317 voltage regulator used in this project. (Courtesy of Datasheetreference, permission pending)

3.2.2   Battery Charger

To charge an 8.4V Li-ion battery, we selected the MCP73842 smart charger chip. The design configurations in Figure 3.5 were provided by Microchip on the datasheet of the charger chip. This particular configuration below works well with a 2-cell battery like the one we using, we only need to find the external parts for our desired voltage and current.

The resistor between pins 1 and 2 is used to monitor the current level. It is calculated by dividing the voltage difference on the two input pins by the desired charge current. The voltage difference is 120mV per the datasheet, and the desire current is 2A for the 8.4V battery we are using. Therefore,

R_{SENSE} = 120mV / 2A = 60mΩ

Power dissipation = 60mΩ x 2A² = 120mW

The gate to source threshold voltage and the resistance from drain to source of the external P-channel mosfet must be taken into consideration. They both must be low enough as their configurations affect the performance of the charger. The maximum allowable threshold voltage and is computed below:

$V_{GS} = V_{DRVMAX} - (V_{DDMIN} - V_{FCSMAX}) = 1.0V - (8.7V - 0.120V) = -7.58$ V, this is a worst-case scenario. The resistance from drain to source must be low enough to accommodate this gate voltage. All of this can be avoided by selecting the right p-channel mosfet such as the Fairchild NDS8434, which has a very low gate to drain internal resistance.
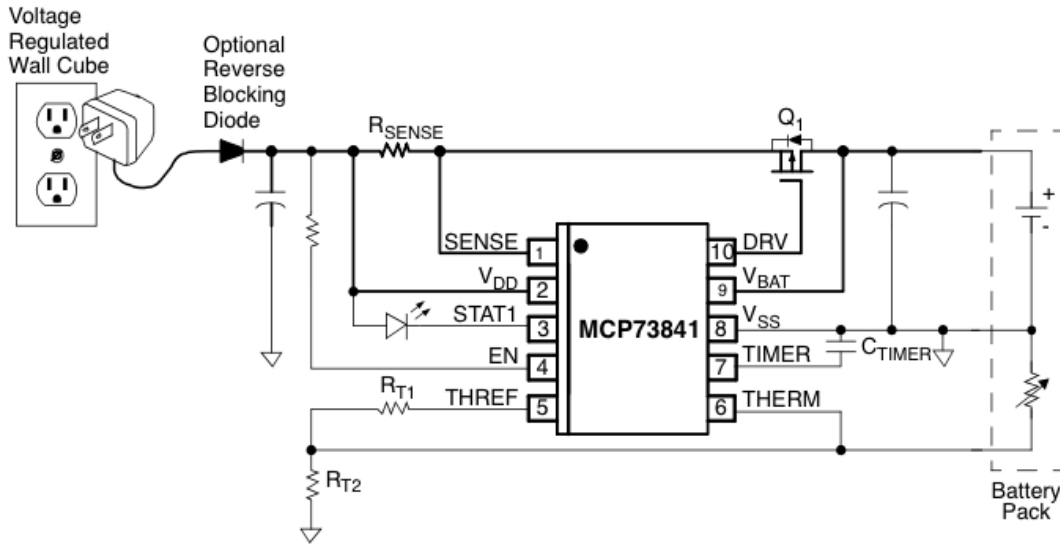
Figure 3.5: Schematic for the smart Li-Ion battery charger. (Provided by Microchip, permission pending)

As soon a battery is connected, the MCP73842 will check the quality of the charge on the battery, the temperature, voltage and current for safe operation. Resistors R_{T1} and R_{T2} regulate the low and high temperature threshold levels. To find those resistor values we need to use the formulas provided in the datasheet for PTC thermistors.

$R_{T1} = 2(R_{COLD})(R_{HOT}) / (R_{HOT} - R_{COLD})$

$R_{T2} = 2(R_{COLD})(R_{HOT}) / (R_{HOT} - 3R_{COLD})$

If $R_{COLD} = 33$ (degrees Fahrenheit), and $R_{HOT} = 100$ (degrees Fahrenheit)

$R_{T1} = 98.5\Omega$

$R_{T2} = 6.6K\Omega$

The first resistor can be about 6.1k given that the input voltage is about 10V. We want to limit the current going inside the chip to between 1 and 2mA. Ctimer capacitor determines the amount of time for each of the three stages in the figure. Each of the stages occur at 1.5 hour intervals, so the capacitor simply need to find the time for the preconditioning and all of the other time threshold will be set. These configurations will be implemented in the charger's circuitry, they will be calibrated during the testing phase of the design.

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Tprecon = (Ctimer)(1.0 Hour)/ 0.1uF

At Ctimer = 0.01uF , Tprecon = 6 minutes

Therefore, a battery will take 6 minutes for preconditioning, 9 minutes for fast charge, and 18 minutes for termination period. That's a total of 33mimutes. The battery charge time will take longer that, those time limits are for transitioning between stages. The amount of time to charge the battery will be determined by the current and voltage level on the battery itself. Remember that the charger also regulates the charge current and the temperature. So any changes on those fronts will terminate the charging process.

3.2.3   Battery Switcher

For the battery switcher, the design is very comprehensive given the concept and behavior we want to achieve. We simply want the power source to alternate between the two batteries A and B.   To be sure that the switch is efficient, we need one of the batteries to decide when to switch to the other. Given that we need the output voltage to be at least 3.5V, the switch has to happen when the battery connected to the output reaches 3.5V. In Figure 3.6, as battery A is being charged, battery B is sourcing the circuit.   Once battery B falls below Vref at 3.5V, the output on comparator C1 is grounded thus turning off the p-channel mosfets M2, M3, and M5. M2 connects battery A to the output while M3 connects battery B to the charger. Once comparator C2 notices the higher voltage on Battery A, its output is at 4.7V biasing the p-channel mosfets M1, M4 and M6. M1 disconnects battery A from the charger, M4 disconnects battery B from the output, and M6 breaks the circuit to prevent the output from reaching comparator C1. M5 also prevents the output voltage from reaching comparator C2 while battery B is in use. The 100uF capacitor on the output prevents voltage dips while the batteries switch.
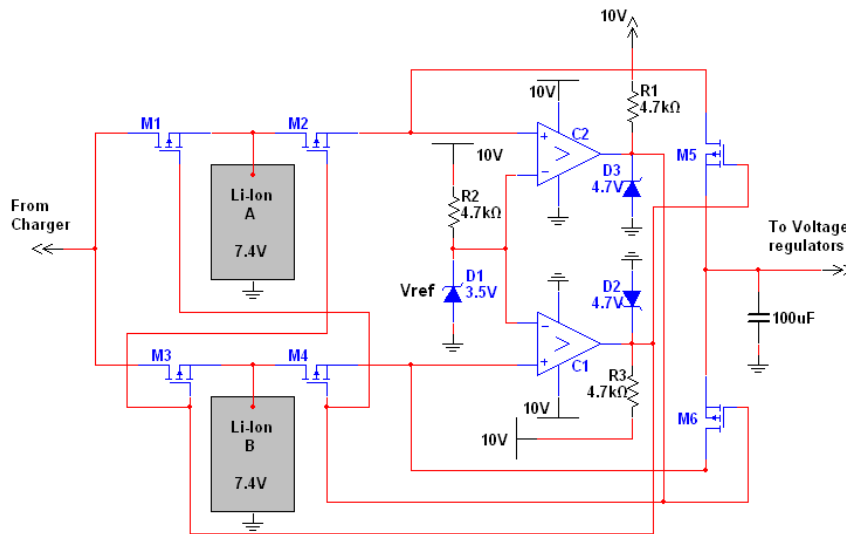
Figure 3.6: Schematic for the stand-alone automatic battery switcher.

The two comparators require 10V DC at the positive bias terminals. Due to the behavior of comparators, and output DC source needs to be connected to ensure that the output of the comparators goes high when Vin- is greater than Vin+. The 4.7V diodes were chosen to ensure the right voltage biasing levels and that that level doesn't fluctuate with the DC input. Diode D1 limits Vref at 3.5V. That setup is more efficient than a voltage divider that would certainly change with the input. It eliminates noises that may affect how the comparators' reference voltage and how low the batteries are drained.

We were careful to ensure that this circuit is as efficient as possible. There are no resistors or any other passive components between the batteries and the output. The p-channel mosfets are very sensitive and highly efficient. Each of them only has a voltage drop V_{DS} of about 50mV. Therefore, with an 8.4V battery as source, the output of the switcher is about 8.3V.

$$V_0 = V_{bat} - 2V_{DS}$$

$$V_0 = 8.4 - .1 = 8.3V$$

This setup will not affect the charger's behavior because the charger will only notice a battery connected to its output. However, it will be charging the batteries more frequently given that a discharged battery will be connected every time the switch is activated.

3.2.4   Voltage divider For ADC on MCU

To monitor the DC voltage on the generator, we need a voltage divider to convert a higher voltage to a relatively lower voltage for the AD converter section of the Atmega128L MCU. The design schematic in Figure 3.7 shows how the connections are made.
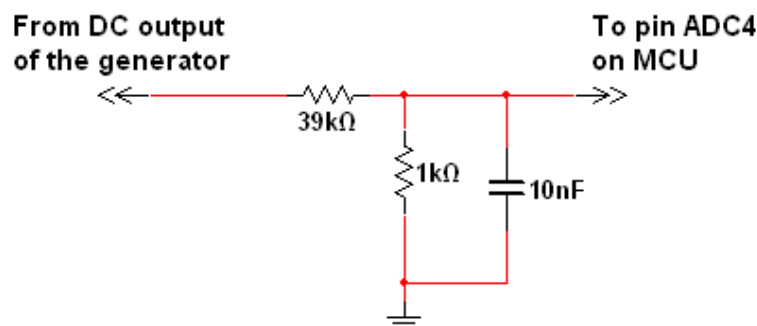
Figure 3.7: Schematic for the voltage divider from the Generator to A/D Converter on the Atmega128L.

The ADC pins on the Atmega128L microcontroller have a voltage range of 0 to 5V. But given that the internal reference voltage is 2.56V, our input voltage must not reach that

level for accurate conversions. So, in order to achieve that limit, we set up a voltage divider that would keep the attempted maximum voltage from the generator within 2.56V on the ADC pins.

Once a voltage reaches an input pin, it is then converted to a binary value that is stored into that pin's corresponding data register. Given that the internal reference voltage 2.56V and that the date register can hold a maximum binary value of $2^{10} - 1$, or 1023, we need to find out the voltage intervals at which a binary data is recorded.

Voltage interval = 2.56V / 1023 = 0.0025V

At every 2.5mV increment on the input pins, a binary data is recorded in the data register. Since we want the voltage recorded from the generator to be accurate to the 1/10 of a volt, we need to select resistor values that would increment the stored binary data at every 1/10 volt from the generator.

0.0025 = (1/10)(R2/(R2+R1))

1/40 = R2/(R1+R2)

R1 = 39K, R2 = 1K

Using these two resistors above, the ADC can monitor a voltage up to (1/10)(1023) = 102.3V. We are well within the boundaries since our small generator only reaches about 50V at maximum speed.

A similar process can be used to monitor the battery voltages also. But given that we don't want to affect the circuitry where the batteries are connected, we need to add a buffer to prevent the current from moving back to the main circuit. Figure 3.8 illustrates the design procedure used in this project. One battery will be connected to pin ADC5 while the other will use pin ADC6. We didn't use pins ADC0 to ADC3 because they are internally connected to an amplifier circuit and we don't need that feature for what we want to achieve. If our signal inputs were too small or lower than 2.5mV, we would have to use the internal amplifier to monitor their levels.
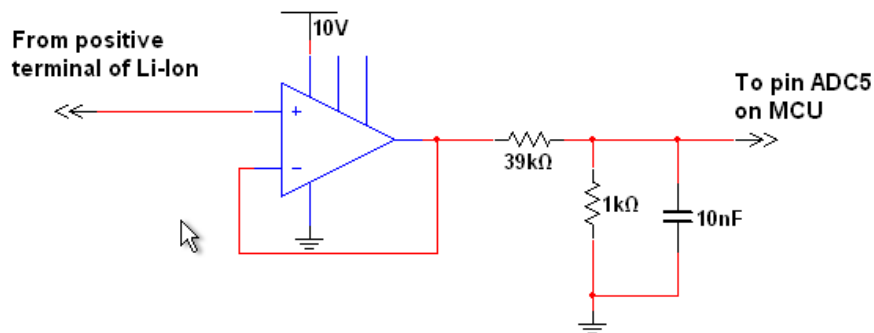
Figure 3.8: Schematic for the battery monitoring signal interfaced with the Atmega128L ADC input pins.

3.2.5   Voltage Regulator

The Max 608 adjustable voltage regulator can be implemented for voltage regulation on each of our devices in the Bike Buddy. It is a BiCMOS step-up power supply controller with preset and adjustable output options. It uses the advantages of pulse-frequency modulation and pulse width modulation to give a high efficiency over a large range of current. The external sense resistor and power transistor allow for the user to change the output current for each unique application. Refer to Figure 3.9 for the design procedure for setting a specific output voltage on the MAX 608 chip. The design requires that R2 be between 10k and 500k, and Vref=1.5 V. The following equation is used to determine R1 for a desired Vout.

R2=R1(Vout/Vref-1).

For a 6V output; R1=10k and R2=30k.
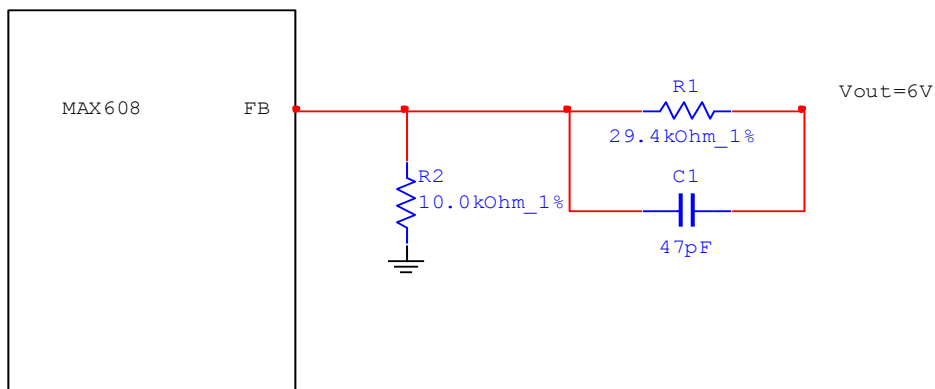
Figure 3.9: Schematic for 6V output on the Max 608 regulator.

Next is the schematic for setting an output voltage of 3.3V on the same MAX608 chip. Several components are added to enhance efficiency and minimize power loss. Using the smallest capacitance values possible will ensure circuit stability; higher capacitance values may degrade line regulation. In order to achieve the highest accuracy possible in the output voltage, resistors with a 1% tolerance should be used in order to achieve a 5% deviation. Using N-FET transistors will allow for a higher efficiency as well because they don't draw any DC gate-drive current during operation.

80
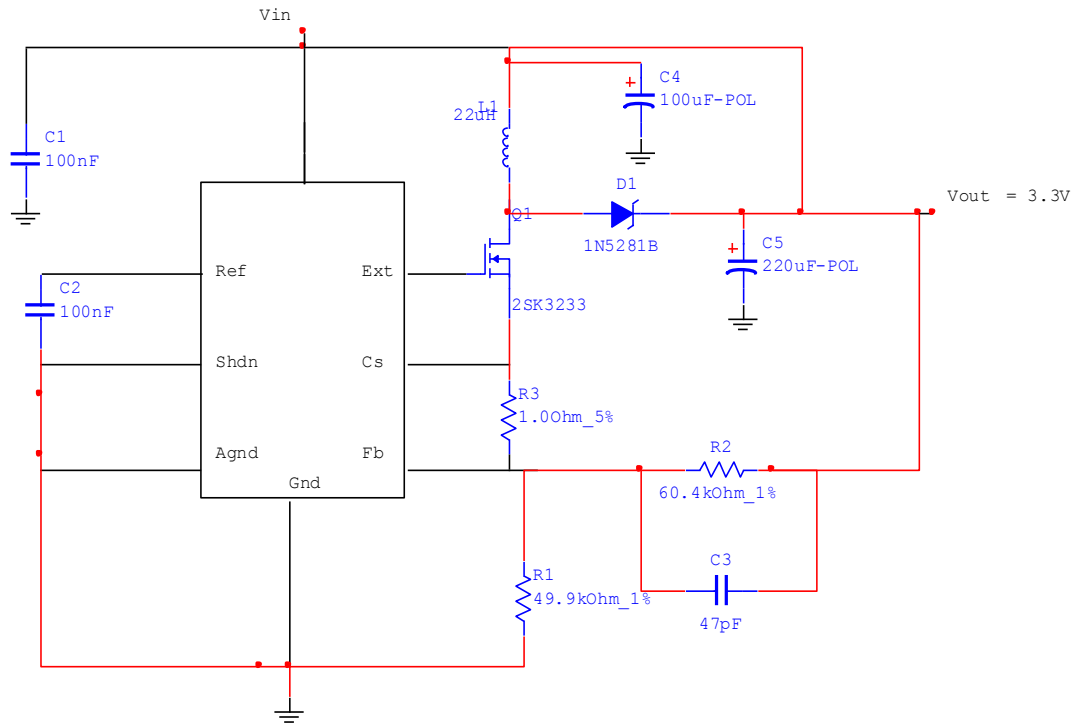
Figure 3.10: Schematic for 3.3V output on the Max 608 regulator.

Figure 3.11 below shows the circuit topology required for a 5V output. The MAX608 chip is preset with the output of 5V, so no changes had to be made to the external circuit topology presented in the data sheet. The MAX608 also features a low input voltage start-up oscillator. This will guarantee start up under no load with voltages down to 1.8 Volts. This will ensure proper regulation should the battery drop below the minimum charging voltage.
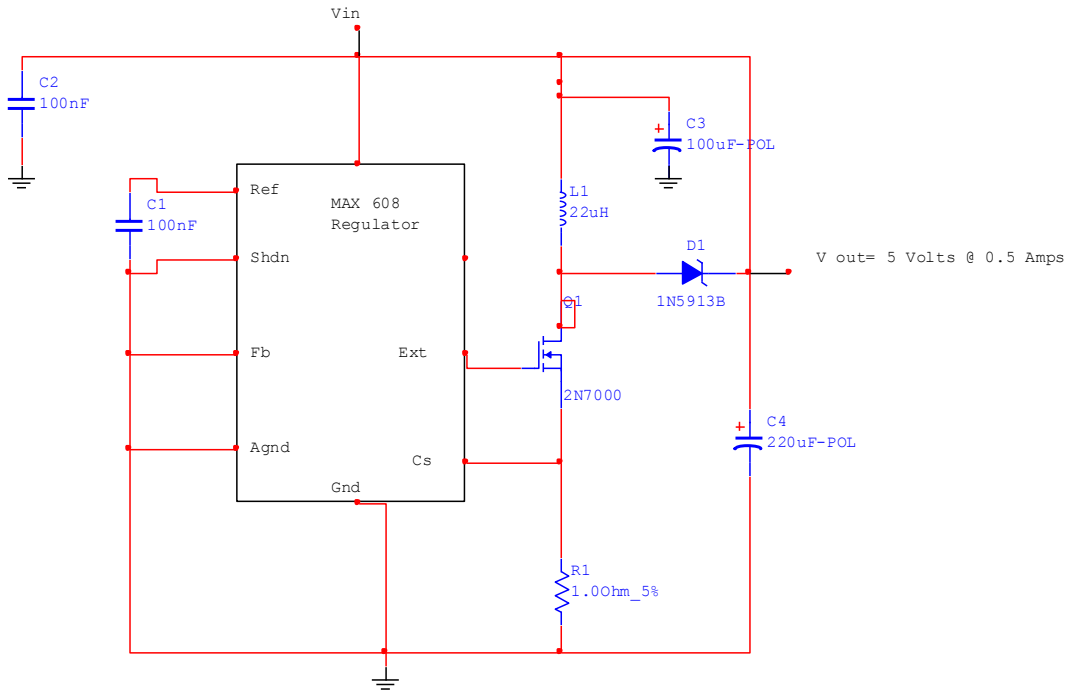
Figure 3.11: Schematic for 5V output on Max 608 regulator.

3.2.6 Cooling Fan circuit

The Bike Buddy will be housed in a single circuit box located at the front of the bike. Several components such as voltage regulators, and charging circuits will be dissipating a lot of heat. A cooling fan may be necessary to avoid overheating any of our circuitry. Figure 3.12 is a design we might consider using to cool off our circuit box.
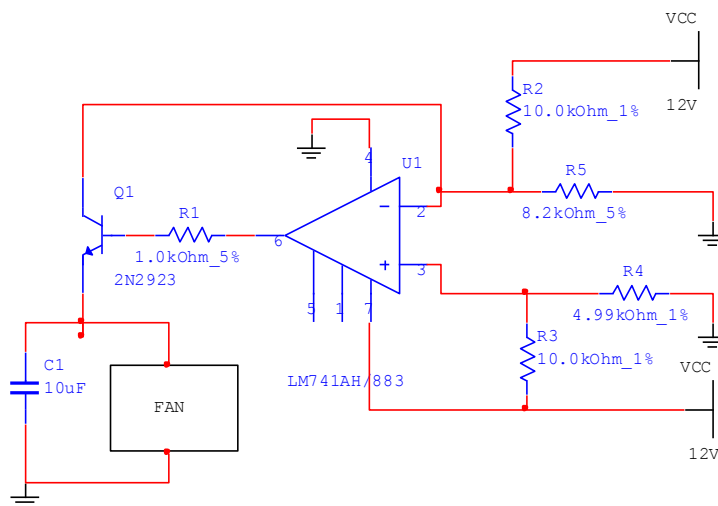
Figure 3.12: Schematic for the cooling fan.

3.3 Microcontroller

3.3.1 Hardware

As illustrated in Figure 3.13, the ATmega128L is mounted on a daughterboard with standard 0.1 inch pitch headers intended for four 16-pin sockets (in the formation of a square). The board is 1.5 inches square, and each socket is 13/16″ long with slightly more than 1/16″ spacing between sockets. It's supplied 3.3 volts.
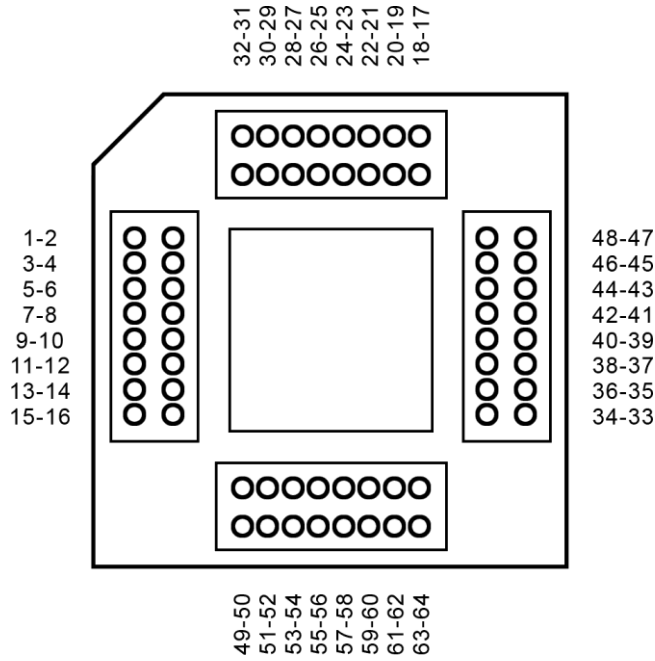
Figure 3.13: Underside of the ATmega128L daughterboard.

Pin	Label	Peripheral	Periph. Pin
53	GND	—	GND
52	VCC	3.3v regulator	—
51	PA0	LCD	Rx
50	PA1	LS20031 (GPS)	Rx
49	PA2	LS20031 (GPS)	Tx
48	PA3	DS1625 (Temp)	SDA

Table 3.2: Pin assignments for the ATmega128L.

Clock

The ATmega128 ships with settings CKSEL = "0001" and SUT = "10", leaving the default clock source the Internal RC Oscillator at 1 MHz with the longest startup time (65ms). This is slow and insufficient for many reasons; USART requires a more accurate clock, and this can easily be changed. An external RC oscillator must be chosen and set according to Table 3.3. The oscillator is hooked up to pin XTAL1 as shown in Figure 3.14. Using the AVR programmer that ships with the STK300 development board, an external clock source is chosen in the Fuse menu. Then in the STK300 programmer under the "board" tab, the board's target clock can be specified.

CKSEL3..0	Frequency Range (MHz)
0101	0.1 – 0.9
0110	0.9 – 3.0
0111	3.0 – 8.0
1000	8.0 – 12.0

Table 3.3: External RC oscillator operating modes.
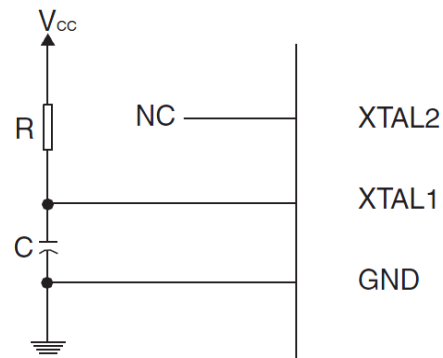
Figure 3.14: External RC oscillator configuration.

Analog-to-Digital Converter

The A/D converter on the microcontroller is used to monitor the power created by the generator and the charge levels of the two batteries. To turn on that configuration in the hardware, we have to power the A/D converter by connection the AVcc pin to 3.3V, same as the Vcc. In Figure 3.15 below, we use a 10uH inductor between the Vcc and the AVcc pins to filter out any noise that may affect each of the input pins. Since we want to use the internal 2.56V reference voltage with the AD converter, we have to ground the Aref pin using a 0.1uF capacitor in the design configuration below.
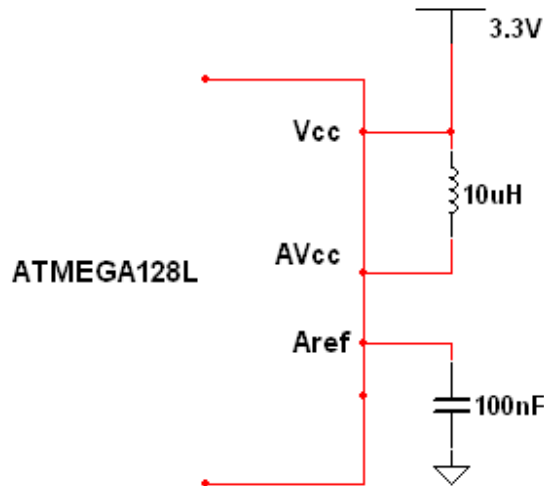
Figure 3.15: Schematic for turning on the ADC on the Atmega128L.

3.3.2 Software

USART interface

There are two USARTs on the ATmega128L, each of which are referred to in this document as USART0 (n=0) and USART1 (n=1). Asynchronous serial transfer in the ATmega128 is highly time sensitive. Shown in Table 3.4, the optimal system clock rate for using UART is a multiple of 1.8432 MHz. This multiple is given in the ATmega128L datasheet, and yields a 0.0% error rate for data transfer. A clock rate of 7.3728 MHz was chosen for the design, with baud rates for the devices set to 9600bpm. This gives us a UBRR value of 47, since we are not doubling the transmission rate (U2X=0 on the table).

| Baud rate (bps) | f_{osc} = 7.3728 MHz | | | |
| | U2X = 0 | | U2X = 1 | |
	UBRR	Error	UBRR	Error
2400	191	0.0%	383	0.0%
4800	95	0.0%	191	0.0%
9600	**47**	**0.0%**	**95**	**0.0%**
14.4k	31	0.0%	63	0.0%
28.4k	15	0.0%	31	0.0%
...				
115.2k	3	0.0%	7	0.0%
Max	62.5 kbps		125 kbps	

Table 3.4: Example of UBRR settings for an oscillator frequency of 7.3728.

To initialize UART on the ATmega128L, several bits in the control register B (UCSRnB, shown in Figure 3.16) must be set to enable the transmission lines. When set, the bits 4 (RXENn) and 3 (TXENn) enable the transmitter and receiver lines for UART. Using USART0 as an example, this is accomplished with the following single line of code: `UCSR0B |= (1<<RXEN0)|(1<<TXEN0);` Also required for initializing UART is the size and format of the frames to be transmitted. This is kept in control register UCSRnC in the bits UCSZn1:0 (the most significant bit, UCSZn2, is kept in UCSRnB). Both USART devices use 8-bit frames, so a value of `011` is written to these bits.

Bit	7	6	5	4	3	2	1	0	
	RXCIEn	TXCIEn	UDRIEn	RXENn	TXENn	UCSZn2	RXB8n	TXB8n	UCSRnB
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Bit	7	6	5	4	3	2	1	0	
	–	UMSELn	UPMn1	UPMn0	USBSn	UCSZn1	UCSZn0	UCPOLn	UCSRnC
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	1	1	0	

Figure 3.16: The control and status registers, UCSRn, for the ATmega128L's USART.

Once these data lines are functioning, USART must be configured for the specific baud rate chosen above (9600bpm). According to Table 3.4, the UBRR value needed is 47. This value is stored in the baud rate register UBRRn, shown in Figure 3.17.

Bit	15	14	13	12	11	10	9	8	
	–	–	–	–		UBRRn[11:8]			UBRRnH
				UBRRn[7:0]					UBRRnL
	7	6	5	4	3	2	1	0	
Read/Write	R	R	R	R	R/W	R/W	R/W	R/W	
	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	
	0	0	0	0	0	0	0	0	

Figure 3.17: The baud rate register, UBRRn, for the ATmega128L's USART.

Analog-to-Digital

To use the Analog to Digital converter on the Atmega128, we have to turn on it by writing a 1 to the ADEN bit on the ADC status register. The prescaler, aided by the MCU's internal clock, will generate a clock to drive the data that is stored in the data register into the microcontroller. The prescaler will continue to run as long as the ADEN bit is set. Figure 3.18 below shows how the ADC is initialized so it can be called on later for stored binary data. The ADSC bit is set to initiate a conversion. And after each

conversion, a data string is written to the ADC data registers and the ADIF pin on the ADCSRA is set to indicate that an input data is ready to be transferred. In single conversion mode, after each conversion, the ADSC bit is reset. But if the ADC is setup in "free running mode" a new conversion starts immediately after while the ADSC remains high. Any converted data that exceeds the maximum allowable for 10-bit binary will result in codes close to 0x3FF (1024).

```
void adc_init(void)

{

//select reference voltage

//AVCC with external capacitor at AREF pin

ADMUX|=(0<<REFS1)|(1<<REFS0);

//set prescaller and enable ADC

ADCSRA|=(1<<ADEN)|(1<<ADIE);//enable ADC with dummy conversion

//set sleep mode for ADC noise reduction conversion

set_sleep_mode(SLEEP_MODE_ADC);

}
```

Figure 3.18: Example of C code to initialize the ADC on Atmega128. (Courtesy of scienceprog.com, permission pending)

3.4 Display

3.4.1 Hardware

This 128x64 pixel liquid crystal display is mounted to a daughterboard that is 2" x 2.45" with a depth of 0.75". It is supplied 6V from the power circuit and draws approximately 220 milliamps with the backlight fully on. There is an intermediate 'backpack' circuit which provides four pins (refer to Table 3.5). The Tx output data pin was included by the manufacturers for potential code revisions, so only the Rx input pin is used in the design. This pin is connected directly to an I/O pin on the ATmega128L. The data is serial TTL at 115,200 baud (default).

Pin	Peripheral	Periph. Pin
Vin	6v regulator	—
GND	—	GND
Tx	—	GND
Rx	ATmega128L	PA0

Table 3.5: Pin assignments for the LCD.

The screen is part of a larger circuit which will be attached directly to the packaging with a rectangular hole in the top with dimensions 1¾" x 2 15/16". This circuit is connected to the main circuit by way of standard 0.1 inch separated pins, as shown on the right in Figure 3.19.
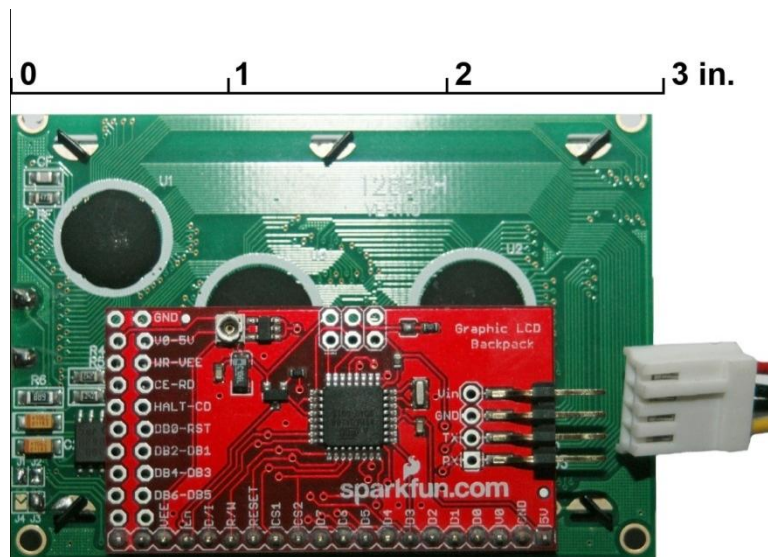
Figure 3.19: Underside of the LCD.

3.4.2   Software

Initialization

Controlling the screen is made simple by the backpack circuit that is integrated with this LCD. The circuit features an ATmega168 controller with a basic set of commands and a built-in font for ASCII characters. Pixels are referenced to with (0, 0) being the bottom-left corner of the screen and (127, 63) being the top-right corner. Every command is preceded with the character "|" (pipe), or ASCII 0x7C. Table 3.6 details some of the commands for configuring the display.

Command	Byte	Argument	Description
Clear Screen	0x00	—	Clears all written pixels.
Reverse Mode	0x12	—	Green-on-black pixel display.
Splash Screen	0x13	—	Toggles sparkfun logo at boot.
Set Backlight	0x02	0:100d	The number is decimal.
Set Baud Rate	0x07	"1:6"	Retained during power cycling.

Baud rate	
"1"	4,800bps
"2"	9,600bps
"3"	19,200bps
"4"	38,400bps
"5"	57,600bps
"6"	115,200bps

Table 3.6: Commands for configuring the LCD.

Note: the 'argument' for Set Baud Rate is assumed to be an ASCII decimal value, i.e., 0x30 is "0".

The screen ships with a default baud rate of 115,200bps. This will be stepped down to 9,600bps by sending the command <0x7C 0x07 0x32>. After the command is sent, the lower rate will be retained even after being powered down. If at any time the baud rate cannot be determined, a packet sent at 115,200bps on startup will automatically reset it. The smaller rate (9,600bps) is chosen to communicate with the microcontroller via UART at a safe rate. The screen's start-up splash screen—displaying Sparkfun's company logo—will be disabled with the command <0x7C 0x13>. Pixels are initially displayed "normally", black on a green background, and can be reversed. This reduces visibility and contrast in direct sunlight, and won't be used. The LCD backlight will require adjusting in the interest of reducing the screen's overall power consumption. Testing will be done outdoors to determine the best viewing conditions. The software provides a range of 0 to 100 to set the backlight, given by the command <0x7C 0x02 0x32> (in this example, the command sets the backlight to 50 decimal).

Drawing

Any message sent without the pipe "|" precursor is assumed to be an ASCII string. Text is drawn to the screen in the form of 6x8 pixel ASCII characters. The placement of a text stream is based on two variables, x_offset and y_offset. These settings specify the top-left bit of a character, and allow the programmer to write text anywhere on the

screen. Characters will automatically print left to right, top to bottom without adjusting these settings. If these offsets are too close to the right edge or the bottom of the screen, the text generator will correct itself by reverting to the next logical line that allows it to print a whole character. Character information is limited to a 416-byte input buffer on the chip. The commands for setting offsets and other drawing commands are listed in Table 3.7.

Command	Byte	Argument	Description
Set X Coordinate	0x18	0:127d	Moves cursor for text generator.
Set Y Coordinate	0x19	0:63d	Moves cursor for text generator.
Set/Reset Pixel	0x10	x, y, 0:1d	0: set (x,y) pixel, 1: reset (x,y) pixel
Draw Line	0x02	x1, y1, x2, y2, 0:1d	(x1,y1) to (x2,y2), 0: draw, 1: erase
Draw Circle	0x07	x, y, r, 0:1d	(x,y) center, r: radius, 0: draw, 1: erase
Draw Box	0x0F	x1, y1, x2, y2, 0:1d	(x1,y1) to (x2,y2), 0: draw, 1: erase
Erase Block	0x05	x1, y1, x2, y2	Entire box is erased.

Table 3.7: Drawing commands for the LCD.

Shapes are drawn quite simply given a few beginning/ending coordinates and a signal bit specifying whether to 'draw' or 'erase' the shape. Circles can be drawn outside of the screen space, but only the pixels inside the screen space are stored. Setting individual pixels yields different results depending on which pixel display mode the screen is in currently. In normal mode setting a pixel writes a 1 to the location specified, however in reverse mode it clears the pixel. Resetting a pixel has the opposite effect, setting it to the 'background' (depending on the display mode).

Updates to the screen are handled by the microcontroller. The layout of the screen will be sent upon start-up, consisting of boxes and lines to distinguish the different data. Cursor positions for various text fields in the screen layout will be stored in variables. A print function will be written to update/display a string to a particular point on the screen. This routine has two phases: (1) erasing the text by sending the Erase Block command, and (2) setting the x, y coordinates and sending the string message. The print function will be called as part of the larger 'screen update' routine that is called every 1/6 second.

3.5 GPS receiver

3.5.1 Hardware

The LS20031 package consists of a 32 channel GPS receiver with embedded smart antenna, and a small battery for storing system data for rapid satellite acquisition. There are five bare pads 1.2 mm apart on the underside of the LS20031 (please refer to Figure

3.20 below). Wire can be easily soldered to these pads. The pin assignment is shown in Table 3.8. The Vcc pin will have 3.3v from the power supply circuit. Both input and output data lines will connect directly to two I/O pins on Port A of the microcontroller. The unit needs to face the open sky to operate effectively. The package is 30 sq mm and 5.8 mm thick, with a 1 mm hole in each corner. This will be attached to the perforated main board with four metal spacers.
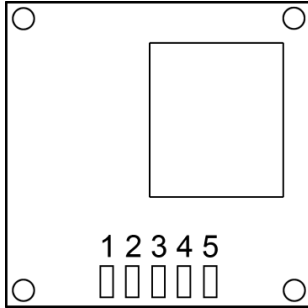
Figure 3.20: The bottom of the LS20031.

Pin	Label	Peripheral	Periph. Pin
1	VCC	6v regulator	—
2	RX	ATmega128L	PA1
3	TX	ATmega128L	PA2
4	GND	—	GND
5	GND	—	GND

Table 3.8: Pin assignments for the LS20031.

3.5.2   Software

The receiver is configured by default to transmit serially at 57,600 baud, 8 bit word, no parity, 1 stop bit (8N1). The data output is in the form of an NMEA sentence that contains six records. These records are updated via satellite at a rate of 1 Hz. The initialization software block on the microcontroller will instruct the module of which NMEA records to transmit and how fast. The only NMEA record used in the design is the Recommended Minimum Specific GNSS Data (RMC), which provides UTC time, date, latitude, longitude, speed over ground, and course over ground. The full record is shown , with the following example:

```
$GPRMC,053740.000,A,2503.6319,N,12136.0099,E,2.69,79.65,100106,,,A*53
```

Name	Example	Units	Description
Message ID	$GPRMC		RMC protocol header
UTC Time	053740.000		hhmmss.sss
Status	A		A = data valid or V=data not valid
Latitude	2503.6319		ddmm.mmmm
N/S Indicator	N		N=north or S=south

Longitude	12136.0099		dddmm.mmmm
E/W Indicator	E		E=east or W=west
Speed over ground	2.69	Knots	True
Course over ground	79.65	Degrees	
Date	100106		ddmmyy
Magnetic variation		Degrees	
Variation sense			E=east or W=west (not shown)
Mode	A		A=autonomous, D=DGPS, E=DR
Checksum	*53		
<CR><LF>			End of message termination

Table 3.9: The full Recommended Minimum (RMC) Specific GNSS Data. The example is provided by LOCOSYS in the LS20031 datasheet (permission pending).

The unit is controlled by sending MTK packets on the input line at the same agreed-upon rate as the output. The packet is built according to Table 3.10, and is restricted to a length of 255 bytes. For example, the packet which adjusts the baud rate to 9,600 is `$PMTK251,9600*[...]<CR><LF>`.

Preamble	TalkerID	PktType	DataField	*	CHK1	CHK2	CR	LF

Preamble	1B character '$'	Start of the packet	
TalkerID	4B character string "PMTK"		
PktType	3B character string "000:999"	Identifier used to decode the packet.	
DataField	Variable length; comma separated fields		
*	1B character '*'	Used to mark the end of a DataField.	
CHK1, CHK2	2B character string	Checksum of data between Preamble and '*'	
CR, LF	2B binary data	Signifies end of the packet.	

Table 3.10: MTK packet structure.

A more concrete example using a sample code in Figure 3.21 below can be implemented for this project accordingly. Given the display is connected to PORTE of the microcontroller in the right manner, The code can be implemented to initialize the 128X64 LCD used to display the informations provided by the Atmega128.

```
char GLCD_DataPort at PORTA;
char GLCD_DataPort_Direction at DDRA;

sbit GLCD_CS1 at PORTE.B2;
sbit GLCD_CS2 at PORTE.B3;
sbit GLCD_RS  at PORTE.B4;
sbit GLCD_RW  at PORTE.B5;
sbit GLCD_EN  at PORTE.B6;
sbit GLCD_RST at PORTE.B7;

sbit GLCD_CS1_Direction at DDRE.B2;
sbit GLCD_CS2_Direction at DDRE.B3;
sbit GLCD_RS_Direction  at DDRE.B4;
sbit GLCD_RW_Direction  at DDRE.B5;
sbit GLCD_EN_Direction  at DDRE.B6;
sbit GLCD_RST_Direction at DDRE.B7;
// End Glcd module connections

char txt[768];
signed int latitude, longitude;
char *string;
int i;
unsigned short ready;
extern const unsigned short world_bmp[1024];

void Timer1Overflow_ISR() org IVT_ADDR_TIMER1_OVF {  // if interrupt is generated
by TMR1IF
  TCCR1B = 0;          // Stop Timer 1
  ready = 1;           // set data ready
  i = 0;               // reset array counter
}

void UART_Rd_ISR() org IVT_ADDR_USART0__RX {  // if interrupt is generated by RCIF
  txt[i++] = UART1_Read();
  if (txt[i-1] == 0)
    i = 0;
  if (i == 768) i = 0;
  //Stop Timer 1:
  TCCR1B = 0;
  //Timer1 starts counting from 15536:
  TCNT1L = 0xB0;
  TCNT1H = 0x3C;
  TCCR1B = 1;                 // No prescaler
  RXC0_bit = 0;               // Set RXC0_bit to 0
}
```
.

Figure 3.21: Code example to initalize and LCD module. (Provided by MikroElectronika, permission pending)

3.6 USB

The Universal Serial Bus (USB) has already become a standard interface in today's consumer devices. It is very easy to plug and play, and its high data transfer rates have resulted in a wide adoption among all kind of electronics such as computer, digital camera, mp3 players and even cellophanes. It also has bidirectional communication, and it offer great power source to charge for many devices. Using USB port as a power source for battery charging or to power up devices do not show significant challenges to the design.

3.6.1   Specification of USB

Figure 3.22 shows demention and materials of female part of USB. It is most common type of USB, and it is rectangle shape. As it shown, it is small, it can be installed without limitation of space. USB port will be installed in the front side of the bike. This female part of USB will be covered with non-metalic materials to avoid any major or minor problems that could be occuer, and also protect it from outside circumstance.

Figure 3.22: Specification of USB (Provide by 4UCON Tech Inc. Permission pending)

Table 3.11 shows pins with its signal and color. Pin 1 and pin 4 wil be used to get the power. There will be no need to connect pin2 and pin3 to the microconroller becuase we are not transferring any data. Pin 1 only needs to connet to the batteries which is 5 V by using regular, and pin 4 will be grounded.

Pin No.	Signal	Cable Color
1	+ VCC	Red
2	Data -	White
3	Data +	Green
4	GND	Black

Table 3.11: Pin assignment for USB.

3.7 Temperature Sensor

DS1625, Digital thermometer sensor has 8pins, shown in Figure 3.23 below.
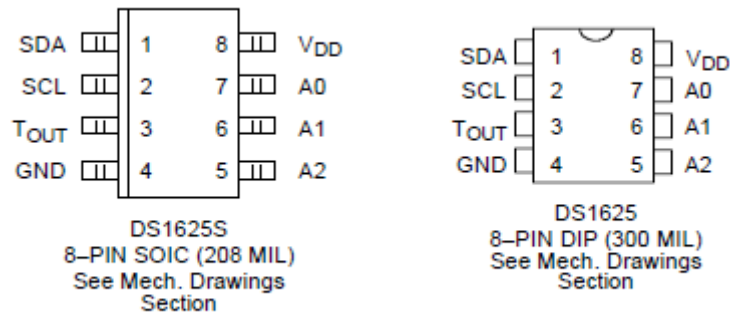
Figure 3.23: Detailed Pin Description. (Dallas Semiconductor. Permission pending)

Pin 1	**SDA**	Data input/output pin for 2-wire serial communication port
Pin 2	**SCL**	Clock input/output pin for 2-wire serial communication port
Pin 3	**T$_{out}$**	Thermostat output. Active when temperature exceeds TH; will reset when temperature falls below TL

Pin 4	**GND**	Ground pin
Pin 5	**A2**	Address input pin
Pin 6	**A1**	Address input pin
Pin 7	**A0**	Address input pin
Pin 8	**V_{DD}**	Supply voltage 5V input power pin

Table 3.12: Pin assignment for DS1625 temperature sensor.

V_{DD} pin will be connecting to supply voltage of 5V input power. Pin 1 and 2 will be connecting to the microcontroller to communicate with. Pin 3 will be connected to LED light that indicate exceeds temperature. Pin 4 will be grounded. Pin 5 to Pin 7 are address input pins, it will read the temperature. Pin 8 is V_{DD}, it will be connected to the power source coming from batteries.

DS1625 have to have temperature settings resident in the TH and TL registers to operate. A configuration/status register will be used to determine the method of operation and also to indicate the status of the temperature conversion operation. The configuration /status register and its descriptions are listed in following Table 3.13.

Done	THF	TLF	NVB	1	0	POL	1SHOT

Done	a conversion done bit. 1 = Conversion complete 0 =Conversion in progress
THF	Temperature High Flag. 1 = Temperature is greater than or equal to the value of TH, Stay remain until 0. 0 = Power is removed, or reset
TLF	Temperature Low Flag. 1 = Temperature is less than or equal to the value of TL, stay remain until 0. 0 = Power is removed, or reset
NVB	Nonvolatile memory 1 = Write to an E^2 memory cell in progress 0 = nonvolatile memory is not busy.
POL	Output Polarity Bit 1 = active high 0 = active low
1SHOT	One shot Mode 1 = DS1625 will perform one temperature conversion upon reception of the Start Convert T protocol 0 = DS1625 continuously perform temperature conversions

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Table 3.13: Configuration Register and Description (Source from Dallas semiconductor. Permission pending)

The DS18B20 sensor, sensor can come in three different packages: TO-92, SO-8 and µSOP-8. It doesn't matter which types of sensor we use, we will choose the most convenient types and it will operates and give us same result. The schematic is shown below for each package type.
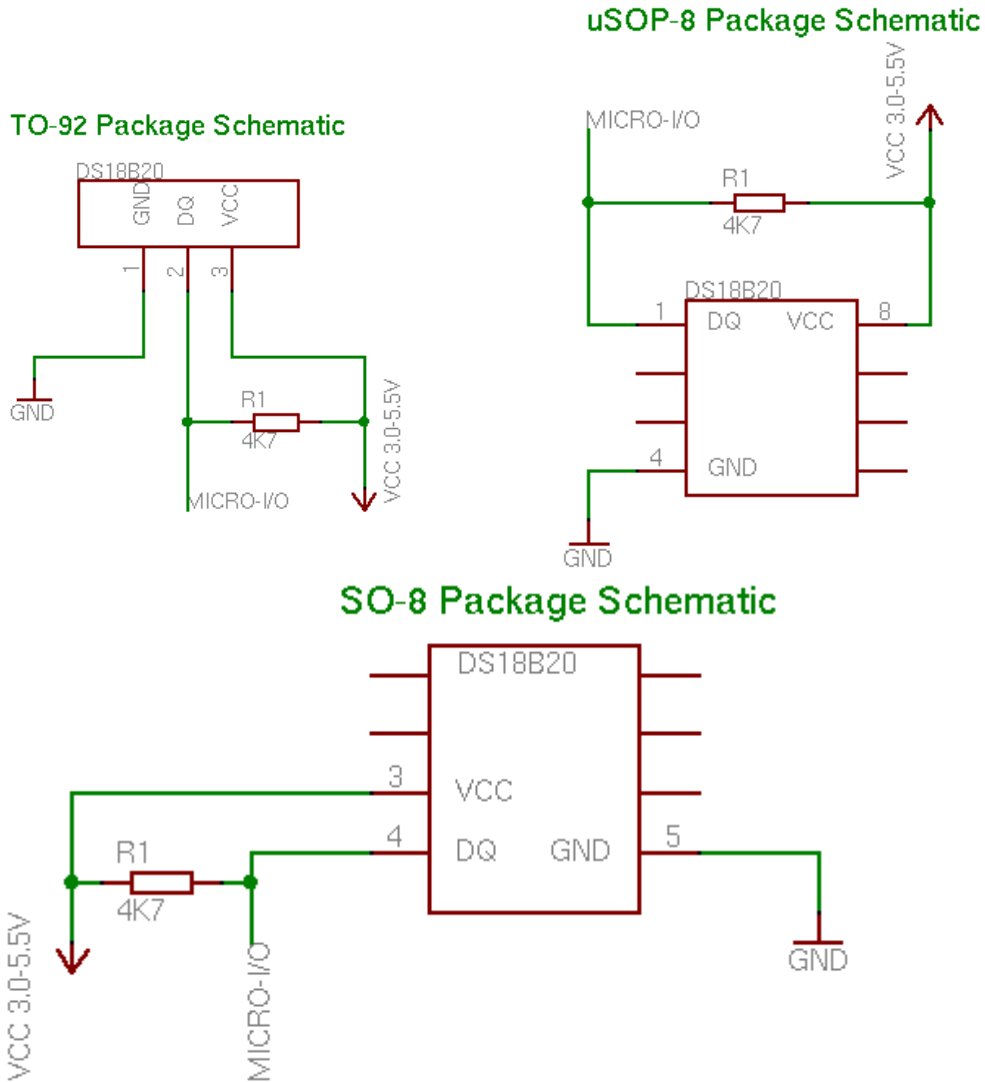
Figure 3.24 Schematic For DS18B20

V_{DD} pin will be connecting to the power source which is coming from battery. In case of using parasite power mode, it needs to be grounded. For DQ connection we can choose any of the microcontroller's I/O pin. In the project it will connect to the microcontroller

pin number 48, PA3 to send and receive data. Also DQ pin ill let the device power on in parasite power mode. All Pins description is listed below Table 3.14.

PIN			NAME	FUNCTION
SO	μSOP	TO-92		
1,2,6, 7,8	2,3,5,6, 7	-	N.C	No Connection
3	8	3	V_{DD}	Optional V_{DD}. V_{DD} must be ground for opertion in parasite power mode.
4	1	2	DQ	Data Input/Output.Open-drain 1-Wire interface pin. Also provides power to the devie when used in parasite power mode
5	4	1	GND	Ground

Table 3.14: DS18B20 Pin Description(Provided by Maxim, Permission pending)

4. Prototype

4.1 Parts acquisition

The systems/components mentioned below are interfaced with passive components to be purchased online through DigiKey or Mouser. All active devices have been listed in the tables below. All Resistors, Capacitors, and Inductors will be ordered in bulk.

Part/Component	Vendor
ATmega128L dev board (STK300)	Kanda.com
Serial graphic LCD 128x64	Sparkfun.com
Bike generator 12V 6W	Bike World USA
LS20031 GPS receiver	Sparkfun.com
2-cell 7.4V Li-Ion Battery packsx2	Powerizer.com
DS1625 Temperature Sensor	Dallas Semiconductor
DS18B20 Temperature Sensor	Maxim
Power Supply	
Schottky Diodes x4	Mouser/DigiKey
Zener Diodes x5	Mouser/DigiKey
LM317 Regulator	National Semiconductor
MCP73841 Smart Charger IC	Microchip
PMOS x8	Mouser/DigiKey
Comparator x2	Mouser/DigiKey
Max608 Regulator	Maxim

Table 4.2 The suppliers and parts required for Bike Buddy.

4.2 Equipment & Facilities

Testing and assembly will be carried out by the group members either in lab on campus or at a group member's residence. One of our members has an oscilloscope, digital multi-meter, variable DC power supply, and a breadboard with various components. With these items we plan to test and debug most of our circuits. We will need the on campus laboratories to use a logic analyzer and a function generator to test and debug anything which we cannot achieve with our privately owned equipment. Simulation

programs such as PSpice and MultiSim will be used to verify our results. Due to the small nature of modern circuitry, some items such as our printed circuit board will be sent to a private merchant to be professionally built.

4.3 Building

4.3.1 Assembling subsystems

Before construction of the circuits, each sub-system will be simulated in MultiSim or PSpice to guarantee it is functioning correctly. Once each subsystem is verified an entire circuit diagram will be simulated to ensure it is functioning correctly as well.

Each system inside Bike Buddy will be assembled separately on its own perforated board for testing in the senior design lab. Only when each individual system is debugged and is known to be working correctly will they be interfaced as a whole. Attaining the transfer function of each part will be necessary in ensuring proper construction. If one part isn't working correctly it could damage subsequent components, and this should be avoided at all costs.

The individual systems to be built are the power supply and voltage regulation circuits. Other devices such as GPS and temperature sensor will be interfaced one at a time to ensure proper functionality. First the power supply circuit will be constructed on its own perforated board. Voltage and current reading will be taken to acquire the transfer function of the circuit. The LCD screen and microcontroller are the next parts to be interfaced. This is done because they will be able to tell us if our circuit is working correctly on the data transfer level which will be required for the subsequent devices to be interfaced.

USB port will be installed in the front side of the bike. This port will be used as power source as we describe in previous section. It will be used to power on devices such as mp3 players, portable fan or others, and also it will charge the battey of the devices such as cellular phone or even AA/AAA batteries. This sigifiy that the bike is generating the power to charge the battery, and at the same time we can use a portion of the battery to manage other devices that use USB power sources. This will makes user to be more convinence when new devices need to be installed.

Once the microcontroller and LCD are working correctly we will be able to display information coming from the GPS module, temperature sensor, and power being generated in the power supply. This will be accomplished with some testing routines written in AVR C (refer to the Testing section).

4.3.2 Attaching to the bicycle

The PCB and the LCD screen will be placed in a ventilated plastic housing on the front handlebars of the bicycle. It will have the main power switch and an LED indicating

whether it is on or off. The LCD screen will be housed so that it is flush with the top of the housing. Everything inside this housing will be protected from the elements since it will be exposed to the outdoor environment on a constant basis. The house will have to protect the circuitry from water, dirt, and even strong wind gusts. The basic design and dimensions are pictured below in Figure 4.1. One side of the box will be ventilated to allow access heat to be dissipated. The front will have a main power switch to power the entire circuit. One or two LED's will be used to indicate power state.
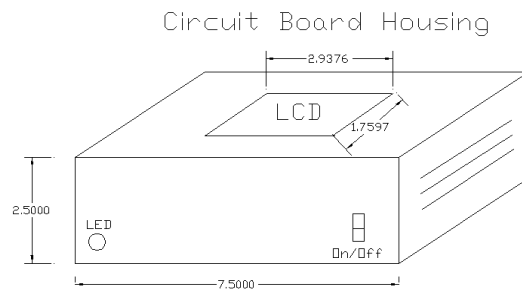
Figure 4.1: CAD of the total system packaging.

The Bike Buddy housing will be attached to the handlebars using two clamps as pictured in Figure 4.2. Prior to mounting the circuit board inside the housing, the clamps will be properly attached to the box with four screws. The clamps can easily be mounted on any apparatus with the same size. They can easily be adjusted for a better viewing angle. Given that the power cable runs from the circuit board housing to the generator, it will be attached to the underside of the main truss with clamps and enough girth in the front allowing the bike to turn freely. It can also be filled inside a flexible tube to prevent wear and tear or for a more aesthetic display of the Bike Buddy.

Figure 4.2: These two clamps on the bike provide a surface to attach our device to.

5. Testing

Testing is a very important procedure in the step of the project. The unit is built based on the research and design, and testing will confirm every section of them. Before combine everything together, each parts need to be tested. For some of the devices, it can be tested by itself, however, others may not. Parts like power supply or generator need additional machines or other equipment such as voltage meter or oscilloscope. Parts such as microcontroller or GPS will need to use programming tool to test it out. It will also need the display screen to see the result. Such as USB, it will need other sample devices to be connected together to test the current and voltages.

5.1 Generator

To test the generator we used a digital multi-meter to read its voltage output at various speeds when attached to the rear tire. We ended up getting a maximum voltage output of 50 Volts when the rear tire (the tire with the generator on it) was propped in the air and the bike was pedaled as fast as possible for a period of 10 seconds. With no resistance on the tire we knew that a person actually riding the bike wouldn't exceed this voltage.

The generator will also be tested for stress and noise that may be created from contact with the tire. It may respond differently under different weather conditions. The generator will be best tested for RPM accuracy on a wet, dry, and sandy tire. Under normal conditions the more load that the generator will be supplying, the more resistive to rotate it becomes. Under our loads this should go somewhat unnoticed by the rider. Because of tire wear, it will be stressed tested to see how much power loss due to friction might occur.

5.2 Power supply

Because of the many different stages that are in the power supply, the testing will be done on each subsection. The AC/DC will be tested in a simulation such as the one below on Figure 5.1. A test on the real components will be done in the lab using a function generator and an oscilloscope to read the output. The voltage regulator will be tested for accuracy in the range of input voltages it can handle. All of this will be done without connecting it to the charger. It will run for a few minutes to test the amount of power dissipated in the chip with a heat sink. Two different heat sinks will be tested for best performance in heat dissipation using a thermometer.

The design box will be tested for heat since the power supply will be part of the whole design circuit in a small box. Although it will be separated by a thermal pad and be on the underside of the board, we will measure the heat generated by the power supply with a thermometer inside the box while the other systems are turned off. Normally with proper heat sinks, ventilated properly, the heat shouldn't be an issue. But we will know for sure during the testing phase.
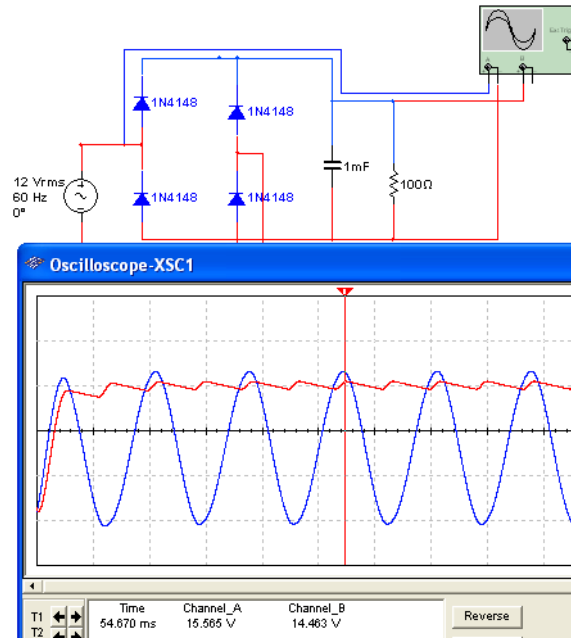
Figure 5.1: Testing simulation for the AC/DC subsection of the power supply.

After the voltage is tested on the regulator, the charger will be probed for accuracy using a multimeter. The maximum charge voltage must not exceed 8.4V. Given the configuration of the charger chip we are using, the output current will be tested at different stages of the charging process. For the switching circuit, there will be a switch between each one of the batteries and the output. Once the switch is off on one of the batteries, the other should switch to output. The threshold voltage will be tested with a power supply in the lab for accuracy. During simulations, the p-channel mosfets had a drain to source voltage drop of 10mV. But that level will be measure in the lab during testing to see how much power that is being lost in the switcher. After all of the subsections have been tested, an overall power supply test will be done with the generator connected and the output monitored for a voltage between 8V to 7V.

Battery charge threshold

The batteries can hold a maximum of 8.4Volts but there's an internal circuitry in the battery packs that may prevent the voltage from reaching that level. A test will be done to find the maximum allowable charge on the batteries. They will be tested for heat dissipation in the charger with the thermister that is already implemented in the charger. The exact current level will be tested in the lab with a load connected to them. They'll be tested at the maximum load of the system to match the battery life calculated at maximum load.

5.3 Microcontroller

The development board for the ATmega128L provides excellent tools for programming and testing software on the chip. It connects to a personal computer via USB, and comes with the WinAVR development studio. According to the datasheet, the chip's Flash memory can be written to an average of 10,000 times before failing. The first testing sequence is to verify that the chip can be successfully programmed with these facilities. Simple programs are included with the development board which light up the LEDs and demonstrate the use of switches. Programming the ATmega128L with this provided software (each of which are verified to work correctly) will demonstrate the success of the AVR USB Programmer. The next testing phase is to initialize USART with software, and to attempt serial communication with the LCD or the GPS receiver module.

Testing the Display

The LCD circuit is designed to communicate at a default baud rate of 115,200 bps. Once USART0 is configured at a baud rate of 115.2kbps, an initial packet is sent to change the baud rate to 9600bps. Then, the command to display a factory demonstration is sent at 9600bps, which will verify the new baud rate and a successful transmission. This is the hardest step because attempting to correctly configure USART may present difficulties. Once communication is established, the next phase of testing includes drawing text and shapes using the built-in commands. Software will be written to handle the update frequency of the screen, and these delays will need to be tested.

Testing the GPS receiver

USART will have to be configured on the uC before initializing communication with the LS20031 GPS module, which is outlined in the design chapter. In addition, to simplify this testing procedure, the LCD and its software system will be fully functioning in order to display the information collected by the GPS receiver. Once a baud rate of 57,600 baud is established for USART1, a packet will be sent to the module to change the baud rate to 9600bps. After this is done, a simple software routine will listen for a packet (NMEA) from the module and attempt to parse its contents. The values obtained from this packet will include global position coordinates, the time of day, and the date, which can each be verified. This will indicate a successful transmission from the GPS satellites, as well as successful communication with the ATmega128L's USART1 hardware.

5.4 USB

First of all, we can start with simple voltage test. This USB power source has two lines: for +5V and GND. From the specification, and what we designed, the voltage between line 1 (+5V) and line 4 (GND) needs to be 5V from the battery. To check this, simply we can use voltage meter to see if it read 5V. The female USB port will be connected directly with battery, we can't guess the result yet, but it needs to be 5V. After this simple check, the devices that use power from USB will be used. However, the devices will not be connected to the USB to see it power up for not. To be more careful, we can build a light .

To test the power using devices, we will load each souce at 100mA and 500mA to check if the voltage remains in spec. Secondly, we will test each load for current draw. Last, we will build a simple test adaptor out of a USB extension cable such a diagram below.
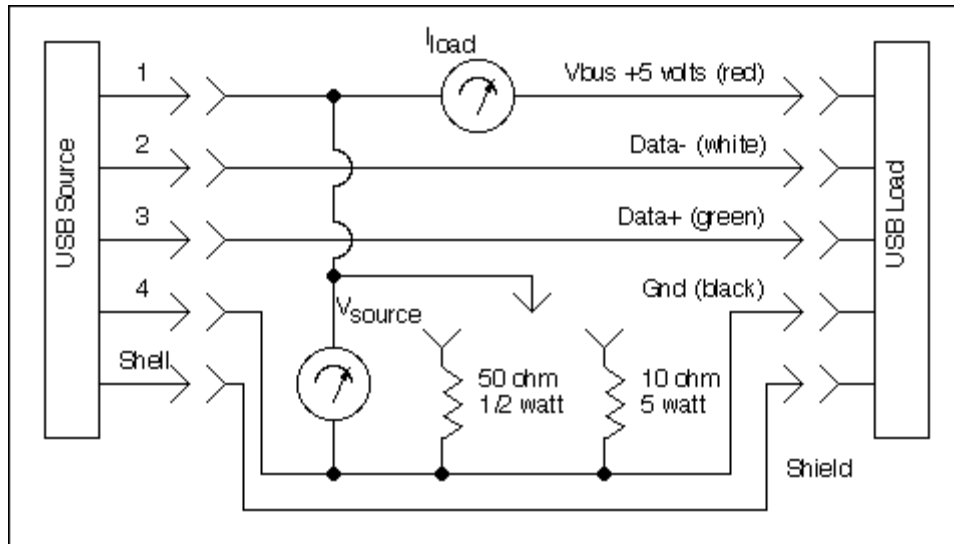
Figure 5.2: USB extension Test (Provided by Girr . Permission Pending)

The USB extension cable is cut and spliced to reconnect the ground and shield and data lines as above. The line 1, which is Vbus+5volt, is interrupted so that a regular current meter can be inserted. Second volt meter will be used to check the source voltage as Vsource. 50ohms and 10ohms resisteros act as the test loads at 100mA or 500mA, which is low or high. The clip lead will be used to connect one resistor or the other one. The test will be seperated in two, source voltage test and load current test.

During Source Voltage Tests, the USB load will not be used neither is the current meter. The test cable is connected to the source and the voltmeter is connected. There will be try trail. One for not loading anything neither resistor connected. Second trial is one at low load with 47 to 51 ohm resistor connected. Last trial will be the one at high load with 10 ohm resistor connected. The voltage of each device will be compared to the spec voltage which is 4.75 volt to 5.25volt. 4.4 volt to 5.25 volt will be used for lower power devices. If the voltage is out of spec, it determines that particular items are not suitable. We will check every devices voltage and check if they are in spec. If we see higher voltage, it will cause fewer problems, but if we see low voltage, it will be a huge problem. Fortunately, may high developed devices such as cellular phone, PDAs, or other will have Smart IC chip, which protect it from accepting out of spec power source coming to the devices. Also some USB charger that comes with the devices has its own protection chip embedded these days.

The second test is load current tests. In this test, the voltmeter and the load resistors will not be used. The test cable simply serves to let the place to insert a current meter between the source and the load. The load should work properly with a low current

source or high current source if the current measured was less than 100 mA or 500 mA, respectively.

The source varied from test to test, but it was always an in-spec high power source so that it should not impact the current drawn by the load to any great extent. In this test, there will be 4 trials for each device depends on states of the devices, charging or discharging for charging states, and running or sleeping for device states. The testing result will be written in the format of below Table 5.1.

Devices	State of Initial Charge	State of Devices	Load Current (mA)	Load Type	Comments
	charged	running		Low or High	
		sleeping			
	discharged	running			
		sleeping			

Table 5.1 Testing Format for Load Current Test.

Test will be performed with as many as devices. Highest load current should be appear when the devices is fully discharged and running so that the device will run and charged at the same time.

5.5 Temperature Sensor
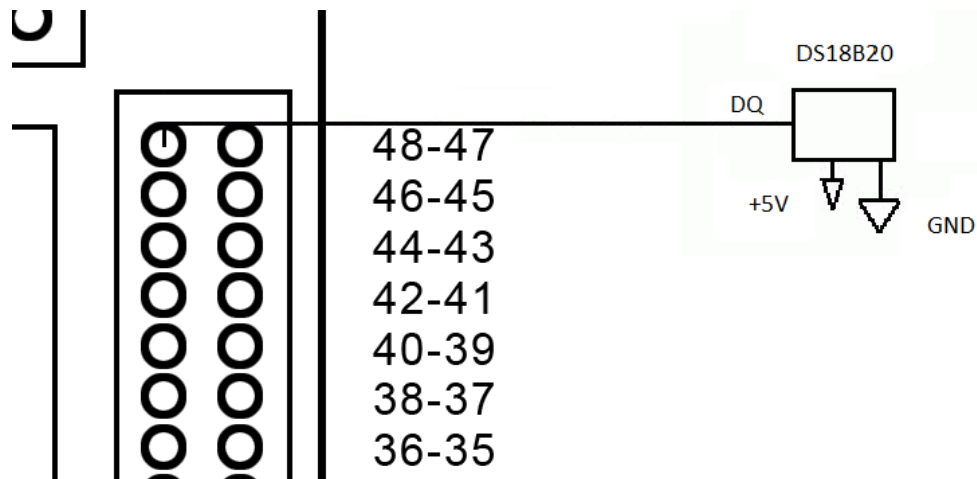
Figure 5.3: Connecting Microcontroller and DS18B20

DS18B20 will be working with AVR microcontroller with LCD screen. Atmega128L is excellent AVR microcontroller. DQ will be connected to the 48 pin of microcontroller, and other 2 pins will be connected to +5V and GND shown in Figure 5.3. Of course

microcontroller will be connected to the LCD screen to see display the temperature. After connecting everything, we need to write a code to test it out. Some sample code to test out is listed in Appendices in program code. It can be used in CCS, PIC, C or PCM.
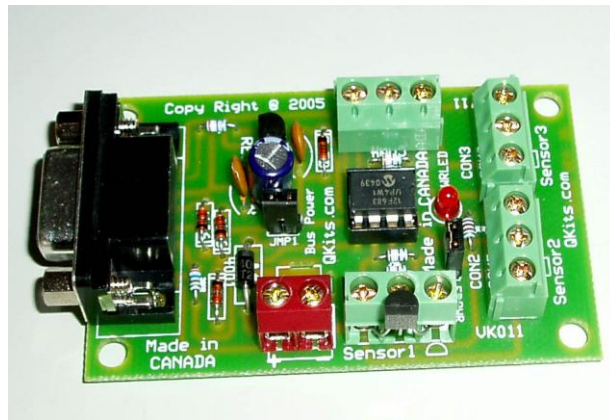
Figure 5.4: VK011 a serial temperature sensor interfaces. (Provide by Qualitykits. Permission pending)

Another way to test it out is individually with computer. VK011, shown in Figure 5.4, is a serial temperature sensor interfacing that can support up to 4 Dallas DS18 B20. This is a fully assembled product. This would be one of the best ways to test the temperature by itself without using our own microcontroller. This will allow the temperature sensor to be displayed in its own window with assignable colors for over under temperature conditions. Celsius or Fahrenheit can be selected by user and the number of digits for precision can be chosen by user too. It requires .NET framework Version 2. The result should come out shown in Figure 5.5.
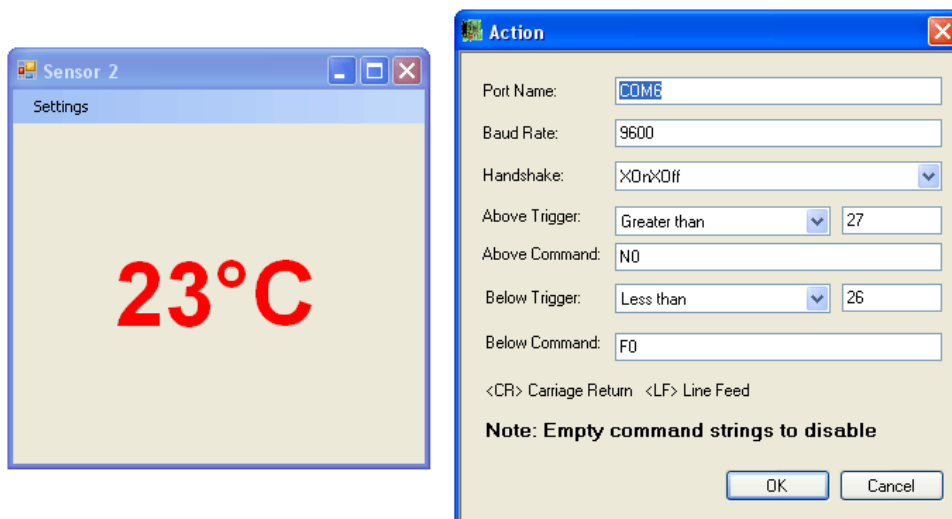
Figure 5.5: Individual Test with VK011 (Provide by Qualitykits. Permission pending)

6. Project Management

6.1 Milestones

Figure 6.1 shows the Milestones for the project briefly.

	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr
Research	■	■	■		■	■			
Parts Acquisition			■	■	■	■	■		
Prototype				■	■	■	■		■
Test: Parts				■	■	■	■		
Software Design			■	■	■				
Implementation						■	■	■	■
Integration							■	■	■
Documentation	■	■	■	■			■	■	■
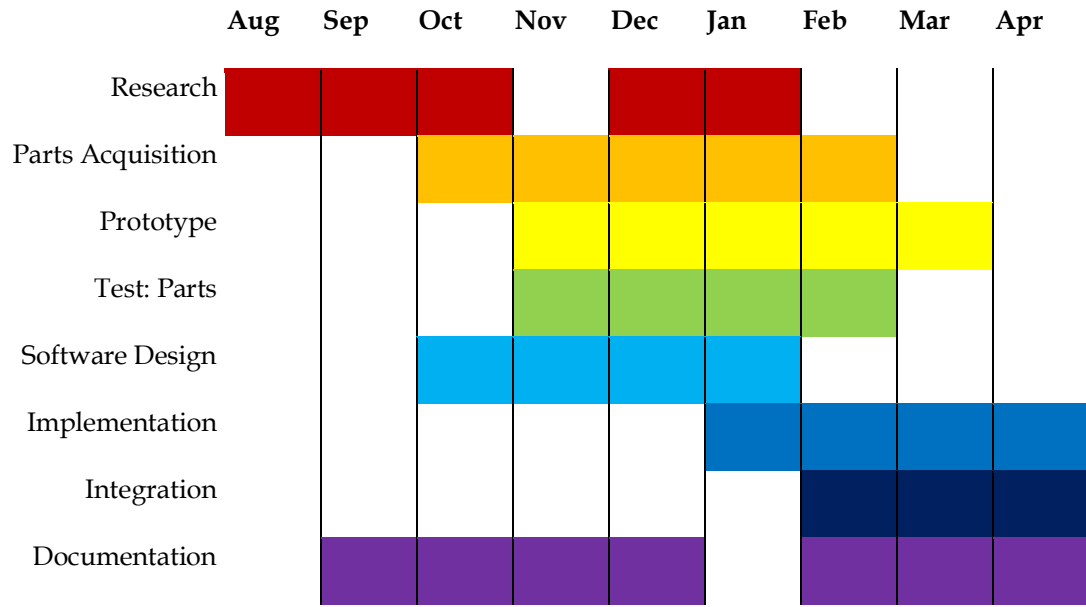
Table 6.1: Project milestone chart.

First Semester

- September 30th, Solidify project goals and objectives
- October 7th, 2009: Start discussing about designing display, power generator, biofeedback system, battery monitoring circuit, radio and MCU, Finish preliminary research
- October 9th, 2009: Discuss about LCD, building or buying a generator, having a mp3 player, deciding adding GPS
- October 7th, 2009: October 21st, 2009: Decide on micro-controller to be utilized
- November 4th, 2009: Finish design of all sub-systems
- November 18th, 2009: Complete interfacing of systems to work as a whole
- November 23rd, 2009: Finish outline document each section
- November 28th, 2009: Finish charging circuit, power supply, and LCD outline
- December 2nd, 2009: Finish any unresolved issues and order parts
- December 9th, 2009: Finish documentation
- **December 14th, 2009: Final Documentation Due**

Second Semester

- January 13th, 2010: Test each part, re-order if necessary

- January 25th, 2010: Have working prototypes of each system
- February 10th, 2010: Have every system tested individually
- February 24th, 2010: Finalize software design, test microcontroller in custom socket
- February 30th, 2010: Have assembled subsystems for testing – revise hardware decisions
- March 12th, 2010: Testing and debugging software/hardware
- March 24th, 2010: Finalize system
- April 3rd, 2010: Have a finished, semi-working prototype of Bike Buddy – Final testing phase
- April 17th, 2010: Finish the document
- April 21st, 2010: Final execution
- **May 3rd, 2010: Last Day of School**

6.2 Budget and financing

The project is tentatively sponsored by Progress Energy. During the first semester, project expenses have been split between the four group members. Table 6.2 shows past and anticipated expenses:

Product/Part	Vendor/Service	Cost
ATmega128L dev board (STK300)	Kanda.com	$104.00
Serial graphic LCD 128x64	Sparkfun.com	$43.83
Bike generator 12V 6W	Bike World USA	$24.48
LS20031 GPS receiver	Sparkfun.com	~$70.00
2x 2-cell Li-Ion Battery packs	Powerizer.com	~$40.00
DS1625 Temperature sensor IC	Digikey	$3.27
DS18B20 Temperature sensor IC	Sparkfun.com	$4.25
USB port (female)	Sparkfun.com	$4.00
Power supply circuit	Digikey/Mouser	~$50.00
Battery charger circuit	Digikey/Mouser	~$40.00
Battery switching circuit	Digikey/Mouser	~$40.00
Packaging/Misc. Hardware	Skycraft, …	~$100.00
Printed circuit board		~$150.00
Printing design document	Kinko's	$50.00
Additional printing/presentation costs	Kinko's	~$150.00
Total		**$823.83**

Table 6.2: Project budget.

6.3 Group organization

The design of the project was distributed between three electrical engineering majors and one computer engineering major. Two of the members (EE) focused on choosing an electrical generator, choosing a battery, charging the battery, and distributing power to the rest of the circuit. The computer engineer was responsible for collecting and displaying sensor data to the screen, including design related to the microcontroller, GPS and LCD. The fourth member was responsible for collecting and displaying temperature data and designing the USB interface.

During the research phase of development, the group communicated frequently using Google Groups bulletin software. This service provides tools for group discussion, collaborative web page editing and file sharing. Group documents, images, discussions, and summaries of meetings were all centrally stored on the website. A page was dedicated to each major component of the preliminary design where research was written. In these pages specific parts were found, detailed and evaluated based on their usefulness to the project. Meetings were held after Senior Design lecture on Mondays and Wednesdays to review updates made to these pages, and to discuss which parts would be used in the final design.

The group agreed to meet three times a week in the senior design computer lab in Engineering 1. A Google Calendar was made for the project to keep everyone informed about meetings and agreed deadlines. During the design phase, one of the members received an invite to the Google Wave Beta. Wave is a new technology designed for collaborative online discussion, similar to a message board in real time. Additional meetings were held online using this service, improving the group's productivity considerably.

The final document template was created in Microsoft Word 2007 months in advance with correct styles, formatting and section headings. This was done to anticipate frequent edits over the coming months. Updates were made to this document iteratively and shared online. Changes were added using Word's 'merge document' features. These choices have simplified the process of four individuals collaboratively authoring a single design document.

6.4 Research and design methods

In our current day in age the World Wide Web has become a primary source for information. Instead of spending hours in a library looking up different texts in a card catalog, one can simply type what they are looking for into an online search engine and get thousands of results. Information has become accessible on a global scale at the tip of your fingers. Projects and documents anywhere from ten years to ten minutes ago may be researched online.

When doing research online it is important to recognize the difference between professional documents, and those that are amateur in nature. One must be able to

recognize reputable sources that will have merit in being studied. Internet sites that have .edu or .gov domains are usually the most reputable for citing sources and doing research. Because of the nature of an engineering senior design project, cold hard facts and not opinions are the only information which should be considered.

Our research revolved around previous projects that were similar to our own, as well as technical documents that included our parts and technologies we implemented. One such project is Bike Buddy from WindStream Power LLC. Figure 6.1 below is a picture of their final product.

Figure 6.1: Bike Buddy (Figure provided by Windstream Power LLC, permissions pending)

This was designed to charge a 12 V deep cycle battery or a 12 V system. Our design needed similar power and voltage ratings, so some of these products features were studied as general guidelines for the direction we should take our own project. Similar goals entailed reading the amount of power one could generate from pedaling such a device, as well as being able to power electronics to be interfaced with its power source.

Another project which was researched gave insightful information on problem questions and design goals that we paid heavy attention to. PedalPowerGenerator.com was a "does it yourself" type project. It offered free bike generator plans and design goals such as:

1. Generator efficiency. (Determined by power out / power in x 100)

2. How to mount the generator to a solid structure so it will not move during power generation.

3. A way to store energy from the generator (Battery, Capacitor, compressed air, water pumped to a high up tank, high speed flywheel)

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4. How to use that energy, in our case: GPS, LCD, MC, and a temperature sensor.

5. Picking a generator that will last a long time. (Brush vs. Brushless, ball bearing vs. brash bushing bearing).

6. Designing a safe system for a mobile bicycle.

Our design is unique in the aspect that it is mobile. Most other projects researched were stationary systems like the one pictured below in Figure 6.2

Figure 6.2: Pedal a watt (Provided Convergence Tech Inc. Permission pending)

Although these stationary models can generate a little more power, they are limited in the applications. By mounting the generator on a stationary housing only a few extra Watts were generated in this project when compared to the Bike Buddy. By studying previous attempts at bicycle power generation, we were able to ask ourselves the important design questions at the beginning of our research. Knowing where others had failed gave us certain areas to concentrate on in creating a working design of our own.

7. Final Summary

The idea of the Bike Buddy was a collaborative effort in designing a product that would be fun to use and a challenge to design. Alternative and renewable energy sources were at the heart of our motivation for this project. Using an electric generator to supply power to the bikes features remained a constant throughout the design process. While the methods of transferring and storing that energy were debated and redesigned numerous times.

The onboard devices the Bike Buddy would feature were also changed and reinvented throughout the course of the semester. Several items which ended up be excluded from the design were: a speaker system that would play music from an IPod or Mp3 player, a USB download function that would record paths traveled and other information which needed memory, and a heart rate sensor to measure burned calories and other dietary information.

As the research for designing these items continued, we quickly realized that we didn't have enough time to effectively implement them into our design. Had more time been available one of our goals was to interface the LCD with the GPS to display information such as frequent routes traveled and different distances of each. All of this information would be handy to bike enthusiasts looking for a good workout routine. The idea of adding speakers to the bike was also dropped considering most people would probably wear headphones anyways. The heart rate sensor was excluded for safety reasons. It would be a distraction to the biker, heart rate sensors are generally for stationary workout machines.

The items we decided to include were a GPS module, temperature sensor, and a USB jack. These would still give information on location, speed, etc. but wouldn't require memory and a log of ongoing data. The USB jack would replace the speakers and could also be used for items such as a phone, fan, or Mp3 player. This USB port signify that we can use any other devices that use USB power source without redesigning other parts such as voltage divider or voltage regulator. It gives user to use other devices easily. These devices could be more easily interfaced with one another, and still provided the user with interesting information involving their bike ride.

Due to current limitations only a certain number of features could be included on the Bike Buddy. One of our design goals is to efficiently use all of the power sent to the circuit to power each device. Working with tight constraints in current and voltage made for an exciting and challenging project. An initial assumption was that generating power would be the biggest problem. It turned out that the generator we selected would provide an ample amount to our circuit. Storing and transferring the energy proved to be a bigger challenge.

Most projects involving pedal power generations were stationary in nature. What made our project unique is that fact that the user can bike anywhere they want and have all sorts of devices being powered as they ride. The closest implementation of our project

was a generator that simply powers a light for your bike. The Bike Buddy would be useful for all age groups, whether implemented for purely exercise purposes, or just to charge an Mp3 player. It is very versatile and is designed to work in hot and cold conditions.

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8.2 Permissions

To Power Stream Electronics, Battery University.com, Science Shareware.com, Energizer, Sparkfun Electronics, Encoder

My name is Nick Quinlan, I am a Senior Electrical Engineering student at the University of Central Florida. I am currently working on a senior design project which we will be using Lithium Ion batteries and developing our own smart charger. I am writing you this letter to ask your permission in using some of your information including tables and graphs from your website in my paper. All of my work will be cited if granted permission in using this information.   I thank you for your consideration.

Sincerely,

Nick Quinlan

To Maxim,Dallas Semiconductor

My name is Nowook Park, I am a Senior Electrical Engineering student at the University of Central Florida. I am currently working on a senior design project which we will be using DS18b20, DS1625 with microcontroller. I am writing you this letter to ask your permission in using some of your information including tables and graphs from your website in my paper. All of my work will be cited if granted permission in using this information.   I thank you for your consideration.

Sincerely,

Nowook Park

To bobhobby, beyondlogic, phanderson

My name is Nowook Park, I am a Senior Electrical Engineering student at the University of Central Florida. I am currently working on a senior design project

 which we will be using pictures and information for our project. I am writing you this letter to ask your permission in using some of your information including tables and graphs from your website in my paper. All of my work will be cited if granted permission in using this information.   I thank you for your consideration.

Sincerely,

Nowook Park

Atmel Corporation

2325 Orchard Parkway

San Jose, CA 95131

USA

To Atmel:

Hi, my name is Ethan Pemble. I'm a senior computer engineering student at the University of Central Florida. I'm using your AVR ATmega128 product in my senior design project, and would like to ask for permission to reprint a few tables and figures from its datasheet. This will be part of my project's design document, detailing the research and design work I've done. It will aid in explaining certain details of the ATmega128 architecture (such as certain register diagrams). Each figure will be properly cited.

Thanks for your time.

Ethan

LOCOSYS Technology, Inc.

20F.-13, No.79, Sec. 1, Xintai 5th Rd.,

Xizhi City, Taipei Country 221, Taiwan

www.locosystech.com

To LOCOSYS:

Hi, my name is Ethan Pemble. I'm a senior computer engineering student at the University of Central Florida. I'm using your LS20031 GPS receiver module in my senior design project, and would like to ask for permission to reprint a few tables and figures from its datasheet. This will be part of my project's design document, detailing the research and design work I've done. It will aid in explaining certain details of the LS20031 software interface (such as packet structure and record contents). Each figure will be properly cited.

Thanks for your time.

Ethan

Hello, Ari -

Yes, you have permission to incorporate the materials into your documentation.

A4

From: Ari N. [mailto:anacius@gmail.com]
Sent: Monday, December 14, 2009 7:11 AM
To: Taleoadmin
Subject: Permission Request

Analog Devices
Corporate Headquarters
One Technology Way
P. O. Box 9106
Norwood, MA 02062-9106
(781) 329-4700 / 1-800-262-5643

To Whom It May Concern:
Hi, my name is Ari Nacius. I am a senior at the University of Central Florida. I am currently working on a renewable energy project and requesting permission to reprint some of the design examples in the ADP3810/ADP3811 Charger and datasheet in my documentation. They will help me explain some of the design choices which I've made. Each figure will be cited accordingly.

Thank you for your understanding,

Ari.

Hello Ari,
If each figure is cited appropriately, you have permission to use them.

Regards,
Drew

From: Ari N. [mailto:anacius@gmail.com]
Sent: Monday, December 14, 2009 4:06 AM
To: Paresh Maniar
Subject: Permission Request

Maxim Integrated Products, Inc.
120 San Gabriel Dr
Sunnyvale, CA 94086-5125 USA

To Whom It May Concern:

Hi, my name is Ari Nacius. I am a senior at the University of Central Florida. I am currently working on a renewable energy project and requesting permission to reprint some of the design examples in the MAX1758 and MAX1773 Charger and and Source Selector datasheets in my documentation. They will help me explain some of the design choices which I've made. Each figure will be cited accordingly.

Thank you for your understanding,
Ari.

Hi Ari:

You should be fine as long as you reference the datasheets that you pulled the schematics or other information from in your documentation.

Regards,

Marc McComb

Academic Program Sales Engineer

office: 480-792-4391

mobile: 480-478-5676

From: "Ari N." <anacius@gmail.com>@MICROCHIP
Sent: Monday, December 14, 2009 4:57 AM
To: University
Subject: Permission Request

Corporate Headquarters
Microchip Technology Inc.
2355 West Chandler Blvd.

A6

Chandler, Arizona, USA 85224-6199
(480) 792-7200

Hi, my name is Ari Nacius. I am a senior at the University of Central Florida. I am currently working on a renewable energy project and I am requesting permission to reprint some of the design examples in the MCP73842 charger chip datasheet in my documentation. They will help me explain some of the design choices which I've made. Each figure will be cited accordingly.

Thank you for your understanding,

Ari.