Datagoo Documentation

Release 1.0.0

Nathan Hall-Snyder, Ravi Sankar, Simon Ye

April 15, 2012

CONTENTS

Contents:

CHAPTER

ONE

QUICKSTART GUIDE

This guide is for installing a datagoo with hardware and firmware preinstalled. It details the steps for configuring and attaching the datagoo to a power supply, so that it is ready to send text notifications.

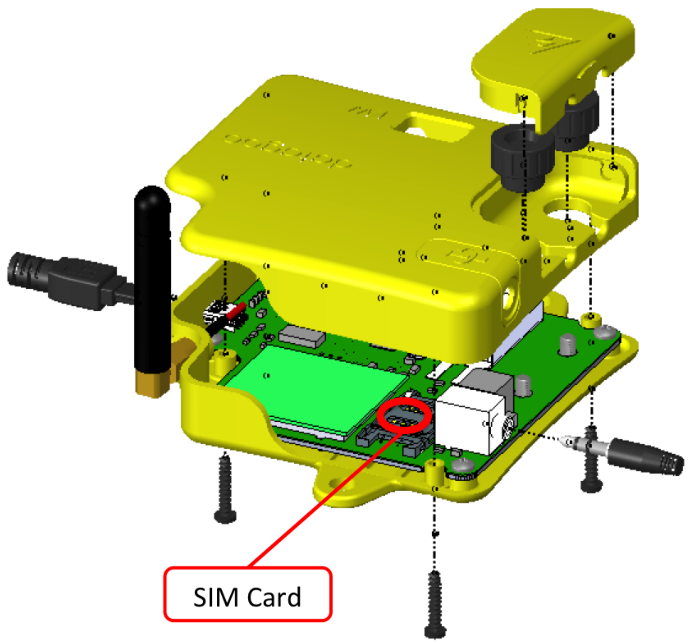
1.1 Required Materials

- Datagoo
- Current clamp
- Small philips screwdriver
- USB mini-b charger
- Activated SIM card with SMS plan (minimum 50 SMS per month)
- SD Card (minimum 16 MB)
- AC measurement cord
- Screws for mounting

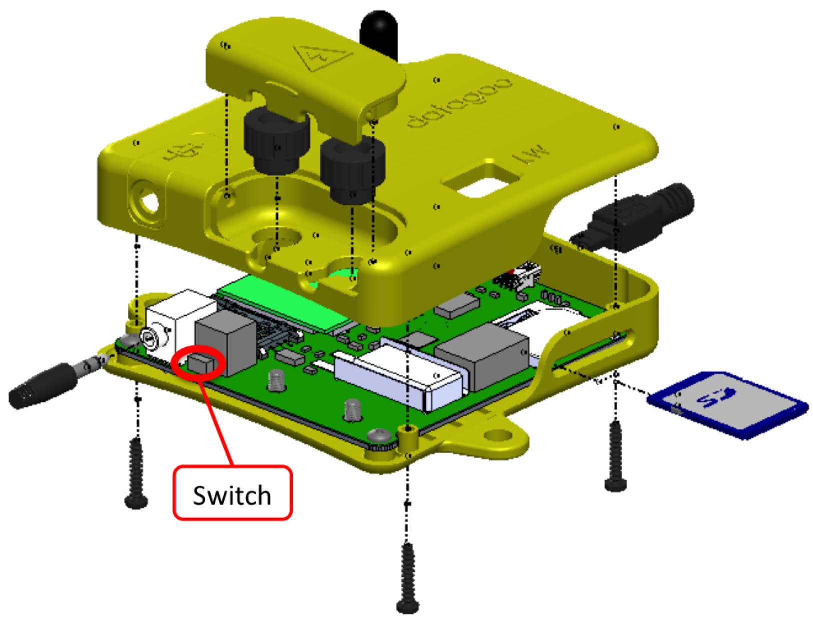
1.2 Installation

Warning: Make sure that all wires are disconnected from the device before removing the cover.

1. Remove the high voltage cover (may require a small tool) and the two plastic knobs.



2. Unscrew the four screws on the bottom of the device and remove the top case.
3. Place an activated SIM card in the SIM card holder. (Make sure that the SIM card is capable of sending text messages via a normal mobile phone before trying with the Datagoo)
4. Flip the ON/OFF switch to ON. You should see a small green light turn on.



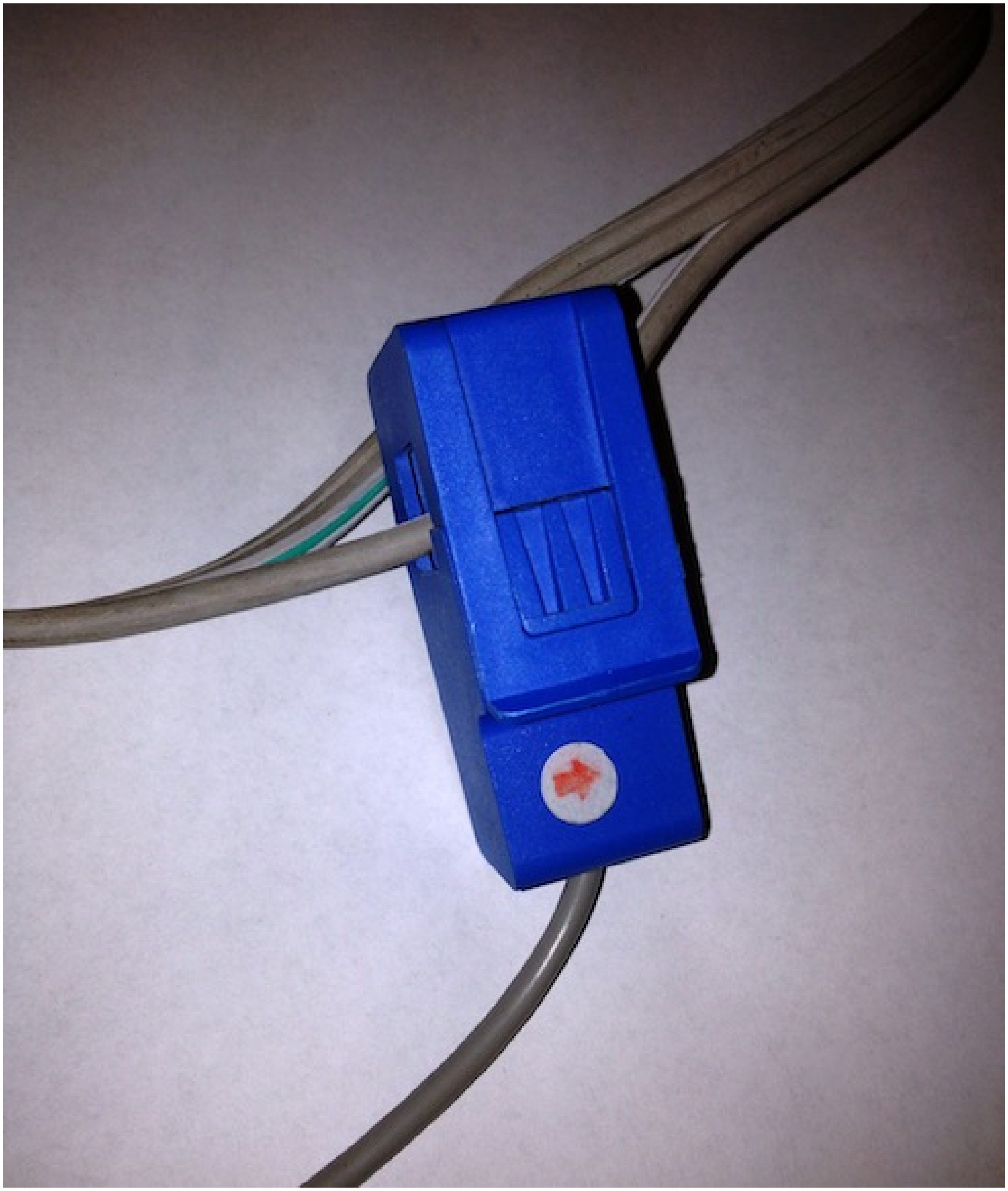
5. Put the top back on the device and screw in the four screws. Do not put knobs or high voltage cover back on.
6. Format an SD card to FAT16. (This is by default for SD cards, but please double check).
7. Create file `CELL.TXT` containing the mobile number to notify of power usage statistics and alerts. An example `CELL.TXT` file:

   ```
   5731921102
   ```

8. Place the SD card in the SD slot.
9. Plug in USB charger.

   > **Warning:** The USB charger should not be a computer. Plugging in the computer USB charger and line voltage to the voltage terminals at the same time will destroy both the datagoo and your computer.

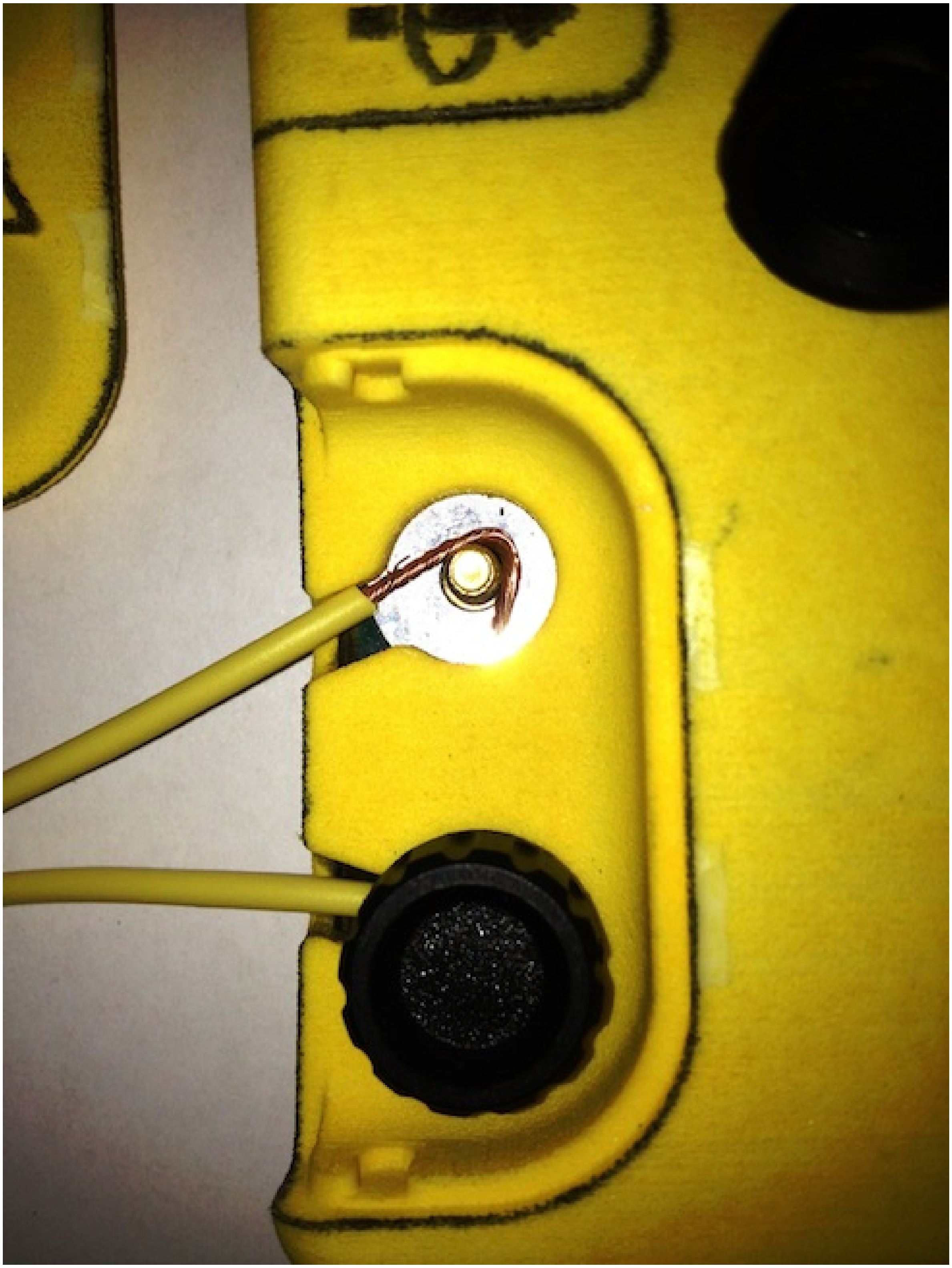
10. Connect current sensor. The current sensor should be clamped around only one wire.



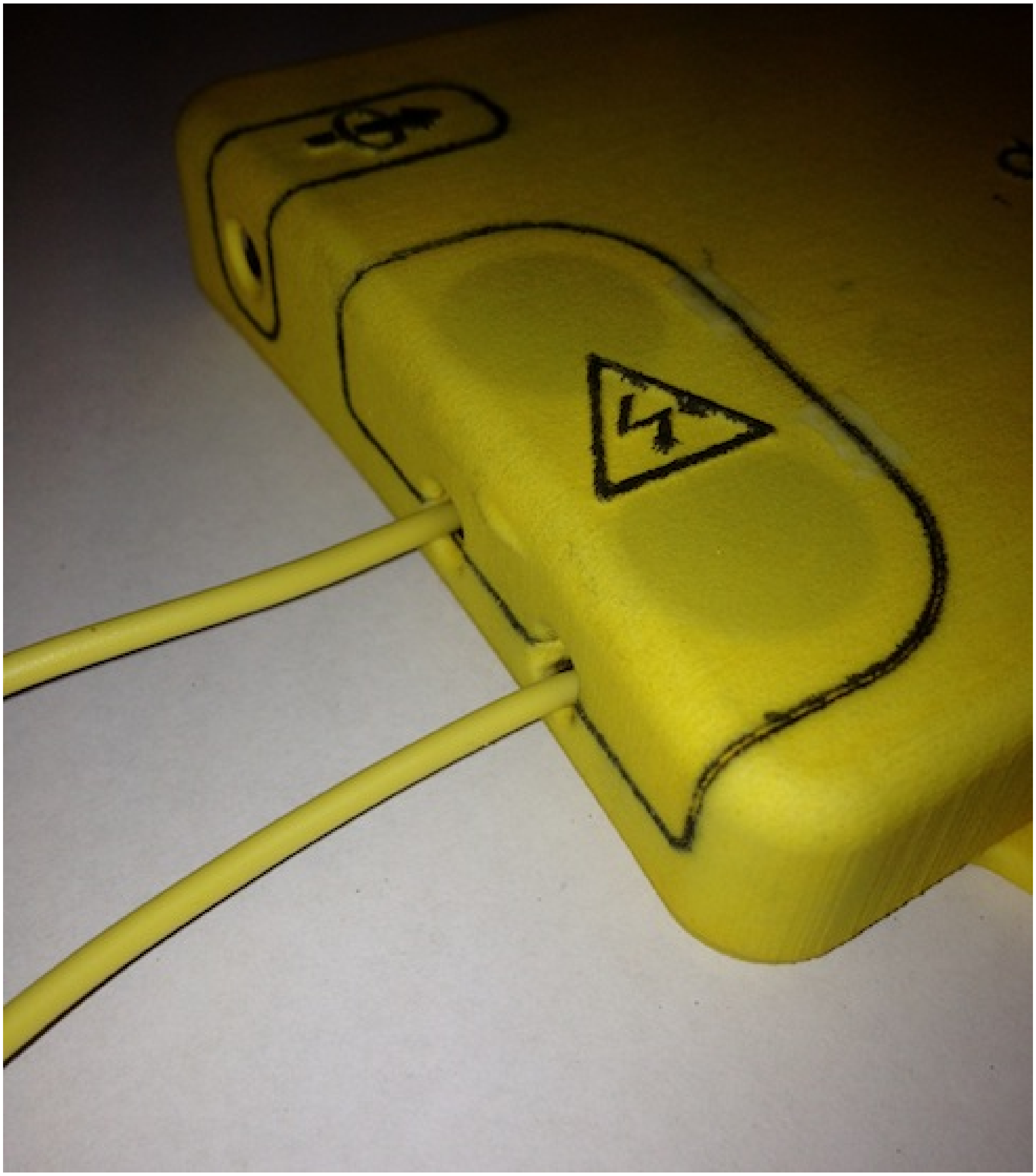
> **Warning:** Use extreme caution when working with high voltages. Stripping and connecting a live (plugged in) wire may cause electrocution to the user.

11. Strip two wires for the AC voltage signal. Make sure it is not plugged in!
12. Place one wire around the upper screw and screw down the plastic knob. Place the other wire on the lower screw and screw down the plastic knob. Give both wires a quick tug to make sure they are attached properly.


datagoo
kW
2GB



13. Replace the high voltage cover.



14. Plug the other end of the voltage wires to the power source.
15. The red display shows the number of kW currently being generated.
16. You're ready to go!

CHAPTER

TWO

PROJECT OVERVIEW

2.1 Alterna's Mission

Alterna on their mission:

> Alterna is a Center for Innovation and Entrepreneurship based in Quetzaltenango, Guatemala. Our mission is to develop technologies and build local businesses that satisfy basic needs and provide economic growth opportunities for the Guatemalan people in an environmentally sustainable way.

One of their major projects are micro-hydro plants in rural areas:

> Two million Guatemalans live without access to electricity. The vast majority of these people live in rural areas. Expansion of the national grid to the areas that are left unserved is increasingly difficult due to geographic constraints.
>
> Guatemala is also a country with great potential for utilization of hydroelectric power. The extensive rainfall and mountainous terrain of the country provide optimal conditions for generating electricity with water power.

http://www.alterna-la.org/en
http://www.alterna-la.org/en/projects/microhydro

2.2 Our Mission

Alterna currently has no good ways to monitor how much power these micro-hydro plants produce, because off-the-shelf systems designed for ultra-high current environments are expensive. Measuring power generation is useful both to understand the efficacy of these installations and because it is prerequisite to applying for carbon grants which can offset the costs of development. Therefore, we prototyped a circuit based on the open-source Arduino platform which measures single-phase AC power coming out of the installation, logs it to an SD card, and transmits daily SMS status updates over a GSM network. The circuit can handle household voltages (~240V), currents up to 100A, and costs around $200 (and as little as $100 when produced at scale).

2.2.1 Carbon Offsets

Becoming accredited to sell carbon offsets is not a trivial process and having information on kWh generated is only one part of it. Nevertheless, organizations like ClimateTrust exist to help organizations through the bureaucratic steps of the process, but they can't do anything without data, so we feel confident that this device will be an important part of offsetting micro-hydro costs with carbon offsets.

The U.S. Department of Energy Clean Energy Application Center authored a report on selling carbon offsets, which you can read here.

2.2.2 Specs In More Detail

Intended Purpose

- Easy to use power measurement device
- Cheap to make
- Able to monitor current and voltage on 1 phase system
- Logs data to an SD card
- GSM connectivity provides two functionality:
- Sends an SMS if the voltage drops for an extended period
- Sends a daily “power collected” SMS with the power generated during that day
- Flexible design allows for reprogramming and hacking

Intended Users

- Engineering graduates and other workers with basic technology fluency.
- Designed so that it can be manufactured *relatively* easily.

Power Measurement Specifications

- Nominal voltage is 220V. Maximum we’ve seen was 225, minimum 219. There may be brief moments (around half a second or less) when it is much lower, down to 150V, when an extra heavy load is switched on.
- Nominal frequency is 60 Hz. Minimum 59, maximum 62.5.
- Single Phase AC.
- Current varies significantly depending on the season (water flow). Max in the rainy season is approximately 55A. Right now it’s about 30A. Dry season production may drop down as low as 15A, but we aren’t sure on that yet.

CHAPTER

THREE

POWER MEASUREMENT THEORY

This page covers the mathematics behind calculating real power, apparent power, power factor, RMS voltage and RMS current from instantaneous Voltage and Current measurements of single phase AC electricity. Discrete time equations are detailed since the calculations are carried out in the Arduino in the digital domain. There are also code snippets of the equations included below:

Real Power

Real power (also known as active power) is defined as the power used by a device to produce useful work.

Mathematically it is the definite integral of voltage, $u(t)$, times current, $i(t)$, as follows:

$$P = \frac{1}{T} \int u(n) \times i(n) \, \mathrm{d}t$$

Equation 1. Real Power Definition.

U - Root-Mean-Square (RMS) voltage.

I - Root-Mean-Square (RMS) current.

$cos(\varphi)$ - Power factor.

The discrete time equivalent is:

$$P = \frac{1}{T} \sum_{n=0}^{N-1} u(n) \times i(n)$$

Equation 2. Real Power Definition in Discrete Time.

$u(n)$ - sampled instance of $u(t)$

$i(n)$ - sampled instance of $i(t)$

N - number of samples.

Real power is calculated simply as the average of N voltage-current products. It can be shown that this method is valid for both sinusoidal and distorted waveforms.

Code example of equation 2:

```
for (n=0; n < numberOfSamples; n++)
{
    //instV and instI calculation from raw ADC input goes here.
    instP = instV * instI;
    sumP += instP;
}
realPower = sumP / numberOfSamples;
```

RMS Voltage and Current Measurement

An RMS value is defined as the square root of the mean value of the squares of the instantaneous values of a periodically varying quantity, averaged over one complete cycle. The discrete time equation for calculating voltage RMS is as follows:

$$U_{rms} = \sqrt{\frac{\sum_{n=0}^{N-1} u^2(n)}{N}}$$

Equation 3. Voltage RMS Calculation in Discrete Time Domain.

Current RMS is calculated using the same equation, only substituting voltage samples, $u(n)$, for current samples, $i(n)$.

Code example of equation 3:

```
for (n=0; n < numberOfSamples; n++)
{
    //instV calculation fsqV = instV * instV;
    sumV += sqV;
}
Vrms = sqrt(sumV / numberOfSamples);
```

Substitute V for I for current.

Apparent Power and Power Factor

$$P_{apparent} = V_{rms} \times I_{rms}$$

$$cos(\varphi) = \frac{P_{real}}{P_{apparent}}$$

Bringing it all together

The following snippet carries out all the measurements above:

```
for (n=0; n < numberOfSamples; n++)
{
    //instV and instI calculation from raw ADC input goes here.
    sqV = instV * instV;
    sumV += sqV;
    sqI = instI * instI;
    sumI += sqI;
    instP = instV * instI;
    sumP +=instP;
}
Vrms = sqrt(sumV / numberOfSamples);
Irms = sqrt(sumI / numberOfSamples);
realPower = sumP / numberOfSamples;
apparentPower = Vrms * Irms;
powerFactor = realPower / apparentPower;
```

Thats it, thats the core of single phase AC power measurment calculation.

This page is based on Atmel's AVR465 Application Note pp. 12-15 which can be found here.

Page referenced from OpenEnergyMonitor.

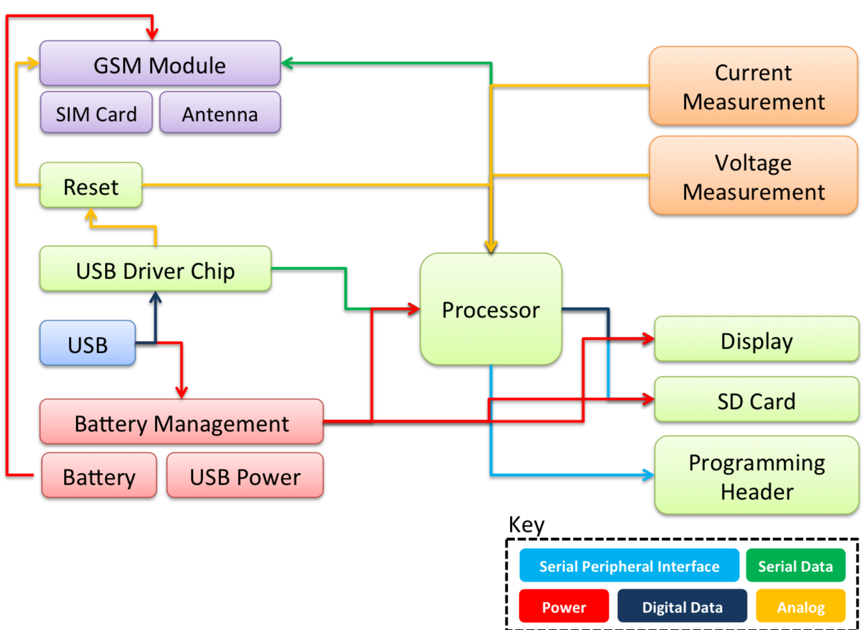
CHAPTER

FOUR

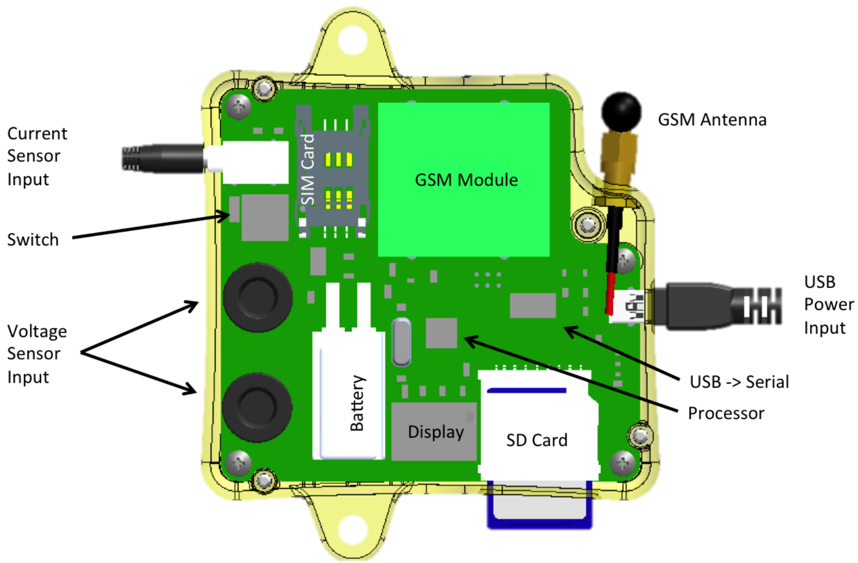
SYSTEMS DESIGN

4.1 Electrical Block Diagram

Datagoo is built around the ATMEGA328P, the same processor used by many hobbyists for a variety of Arduino designs. When coupled with an FTDI FT232RL USB-Serial circuit, the board can be programmed with any computer with a USB port. Other design decisions were made in the interest of cost and simplicty. Surface mount components were chosen for ease of manufacturing. The voltage and current measurement circuits were designed to utilize the ATMEGA328P's internal Analog-to-Digital converters, again reducing the component cost. The cell phone module was chosen for price - it is one of the cheapest GSM modules available. Also, all the components for which critical software needed to be written are avaiable in Arduino shield form, making testing custom applications more accessible.



4.2 Component Locations



4.3 Voltage Measurement System

The input voltage is rectified with a bridge rectifier. Then, a voltage divider reduces the voltage by a factor of 110. Then, the now 3.3V signal is run through an op-amp buffer for measurement accuracy. Finally, the signal is fed into the ATMEGA328P's Analog Input 1.

4.4 Current Measurement System

The Datagoo uses a "current transformer" to convert an AC signal into a readable value. A current transformer simply divides the current down. For our current transformer, a current of 100A will result in an output current of 33mA. The current is driven across a small resistor (33 ohms) to generate a voltage, which is then referenced against 1/2 * 3.3V, so both positive and negative currents can be sensed. The signal is then fed into the ATMEGA328P's Analog Input 0.

4.5 Battery Backup System

Datagoo uses a small lithium backup battery to keep the device on in the event of a power interruption. The battery is normally charged by the USB charger, and should be nominally at 4.2V. If the USB power is disconnected, the device switches to battery power and should last for ~30 minutes.

4.6 Display System

The display is a two digit, seven segment display that is used to show the amount of kilo-Watts currently being measured by the device. The display is multiplexed - only one segment is on at a time, hence the faint flicker.

4.7 SMS Cell System

A SM5100b GSM module is used to add cell network functionality to the Datagoo. Using the account information from a SIM card, it will send status text messages to the number written down in the configuration file. Since GSM network settings are specific to the country, make sure to change the right settings in the configuration file.

4.8 SD Card System

The Datagoo is capable of reading and writing files to a SD card. This is used to log the amount of power generated as well as any faults. The user must edit a configuration file in order to use the unit.

CHAPTER

FIVE

PARTS LIST

We chose to purchase components from a number of suppliers:

- GSM Module and Antenna: Sparkfun
- PCB: Sierra ProtoExpress
- Electrical Componentss: Digikey
- Battery: Batteryspace
- 3D Printing: Shapeways
- Mechanical Components: McMaster-Carr Supply
- Current Clamp: EpicTinker

Common components, such as a USB charger and hacked AC cable, were not purchased but salvaged.

5.1 Bill of Materials

Description	Designator	Library Part Name	Quantity	Supplier	Part Number
MOSFET N-CH 70V 3.8A SOT-223	Q2	NFET_ZXMN7A11GCT	1	Digikey	ZXMN7A11GCT-ND
CONN USB RECEPTACLE 5POS RT ANG	H1	CONN_USBMINIB_54819-0519	1	Digikey	WM17115-ND
RES 110K OHM 1/8W 1% 0805 SMD	R10, R11, R14, R15	RHM110KCRCT-ND	4	Digikey	RHM110KCRCT-ND
RES 33 OHM 1/10W 3900PPM 5% 0805	R7	P33CECT-ND	1	Digikey	P33CECT-ND

Continued on next page

Table 5.1 – continued from previous page

Description	Designator	Library Part Name	Quantity	Supplier	Part Number
RES 10K OHM 1/10W 1500PPM 5%0805	R1, R2, R5, R9, R28, R29, R30, R31, R32, R33, R34, R35	P10KCBCT-ND	12	Digikey	P10KCBCT-ND
IC OPAMP CMOS LOW-PWR MTP5	U2	OP_NJU7011F-TE1	1	Digikey	NJU7011F-TE1CT-ND
DIODE ZENER 5.1V 200MW SOD-523F	D1, D2, D3	ZENER_MM5Z5V1	3	Digikey	MM5Z5V1CT-ND
IC CONTROLLR LI-ION 4.2V SOT23-5	U8	LIION_MCP73837/8	1	Digikey	MCP73831T-2DCI/OTCT-ND
IC RECT BRIDGE 0.5A 600V 4SOIC	D7	BRIDGE_MB6S	1	Digikey	MB6SCT-ND
MOSFET P-CH 20V 2.6A SOT23	Q1, Q3, Q4	PFET_IRLML2246TRPBF	3	Digikey	IRLML2246TRPBFCT-ND
SWITCH DIP LOW PRO 1 POS GOLD	SW1	SWITCH_KAJ01SGGT	1	Digikey	EG4416-ND
3.5mm Audio Jack	J3	3.5mm Audio	1	Digikey	CP1-3533NS-ND
IC MCU AVR 32K FLASH 32TQFP	U6	MCU_ATMEGA328	1	Digikey	ATMEGA328-AU-ND
3.3v LDO up to 300 mA	U1	ADP122	1	Digikey	ADP122AUJZ-3.3-R7CT-ND
CONN SD CARD PUSH-PULL SMD	D9	SDCARD_2041021-4	1	Digikey	A101492CT-ND
8MHz 18pF 10ppm	X1	XTAL_8MHz-49US	1	Digikey	887-1233-ND
RES 1.0K OHM 1/8W 5% 0805 SMD	R26, R27	541-1.0KACT-ND	2	Digikey	541-1.0KACT-ND
CAP ALUM 100UF 35V 20% SMD	C1	AUTO_CAP_ALUM_100UF_35V_20%_SMD	1	Digikey	493-4471-1-ND
CAP CER 1UF 16V 10% X7R 0805	C3, C4, C5	CAP CER 1UF 16V 10% X7R 0805	3	Digikey	490-1691-1-ND
CAP CER 0.1UF 25V 10% X7R 0805	C2, C9, C10, C11, C12, C13	CAP CER 0.1UF 25V 10% X7R 0805	6	Digikey	478-3755-1-ND

Continued on next page

Table 5.1 – continued from previous page

Description	Designator	Library Part Name	Quantity	Supplier	Part Number
CAP CER 10UF 6.3V 10% X5R 0805	C6, C15, C16, C17	CAP CER 10UF 6.3V 10% X5R 0805	4	Digikey	478-1417-1-ND
CAP CER 4.7UF 6.3V 10% X5R 0805	C7	CAP CER 4.7UF 6.3V 10% X5R 0805	1	Digikey	478-1416-1-ND
CAP CER 18PF 50V 5% NP0 0805	C8, C14	CAP CER 18PF 50V 5% NP0 0805	2	Digikey	478-1307-1-ND
LED CHIPLED 570NM GREEN 0603 SMD	D5, D6, D8	LED_LG Q971-KN-1	3	Digikey	475-1409-1-ND
FERRITE CHIP 1500 OHM 500MA 0805	B1	FB_MMZ2012Y152B	1	Digikey	445-1560-1-ND
	C5	CAP CER 0.1UF 16V 10% X7R 0805	1	Digikey	399-1167-1-ND
CONN SM-CARD SIMLOCK W/ALIGN PINS	J4	SIM_C707_10M006_0492	1	Digikey	361-1021-1-ND
RES 470K OHM 1/8W 5% 0805 SMD	R4, R6	311-470KARCT-ND	2	Digikey	311-470KARCT-ND
RES 220 OHM 1/8W 5% 0805 SMD	R22, R25	311-220ARCT-ND	2	Digikey	311-220ARCT-ND
RES 160 OHM 1/8W 5% 0805 SMD	R8	311-160ARCT-ND	1	Digikey	311-160ARCT-ND
RES 100K OHM 1/8W 5% 0805 SMD	R12	311-100KARCT-ND	1	Digikey	311-100KARCT-ND
RES 75 OHM 1/8W 5% 0805 SMD	R17, R18, R19, R20, R21, R23, R24	311-75ARCT-ND	7	Digikey	311-75ARCT-ND
RES 8.20K OHM 1/8W 1% 0805 SMD	R16	311-8.20KCRCT-ND	1	Digikey	311-8.20KCRCT-ND
RES 2.0K OHM 1/8W 5% 0805 SMD	R3	311-2.0KARCT-ND	1	Digikey	311-2.0KARCT-ND
RES 1.0 OHM 1/8W 5% 0805 SMD	R13	311-1.0ARCT-ND	1	Digikey	311-1.0ARCT-ND
LED 7-SEG .40 2DGT SUPER RED CA	D4	7SEG_2DIG_LTD-4608JR	1	Digikey	160-1538-5-ND
IC USB FS SERIAL UART 28-SSOP	U3	USB->SERIAL	1	Digikey	768-1007-1-N
Polymer Li-Ion Cell:3.7V 210mAh	J5	LITHIUM_BATTERY		Batteryspace	PL-651628-2C

Continued on next page

Table 5.1 – continued from previous page

Description	Designator	Library Part Name	Quantity	Supplier	Part Number
Quad-band cellular antenna			1	Sparkfun	CEL-00675
SM5100B-D GSM/GPRS Module	J6	GSM MODULE		Sparkfun	CEL-09533
AVR Programming Header	None	CONN HEADER 6POS .100 STR 15A	1	Digikey	609-3210-ND
3D Printed Case Upper	None		1	Shapeways	N/A
3D Printed Case Lower	None		1	Shapeways	N/A
3D Printed Case High Voltage Cover	None		1	Shapeways	N/A
USB Charger	None		1	Any Supplier	
Power Cable	None		1	Dumpster	
Tri-P Phillips Thread-Forming Screw for Plastic, Black-Finish Zinc-Plated Steel, 4-20	None		4	Mcmaster-Carr	92295A106
Metric Nylon Fluted-Rim Knob, M4 X .7 Threaded Insert, 16 mm Diameter	None		2	Mcmaster-Carr	62935K15
Metric Pan Head Phillips Machine Screw, Zinc-Plated Steel, M3 Size, 5MM Length, .5MM Pitch	None		4	Mcmaster-Carr	92005A114
Metric Brass Pan Head Slotted Machine Screw, M4 Size, 6MM Length, 0.7MM Pitch, Packs of 25	None		2	Mcmaster-Carr	90928A327
Metric Brass Threaded Insert for Thermoplastc, Tapered, M3-.5 Internal Thread, 3.8MM Length	None		4	Mcmaster-Carr	94180A331
Current Clamp	None		1	Epictinker	SCT-013

CHAPTER

SIX

COST ESTIMATES

This page contains volume cost estimates for making more Datagoo Power Loggers:

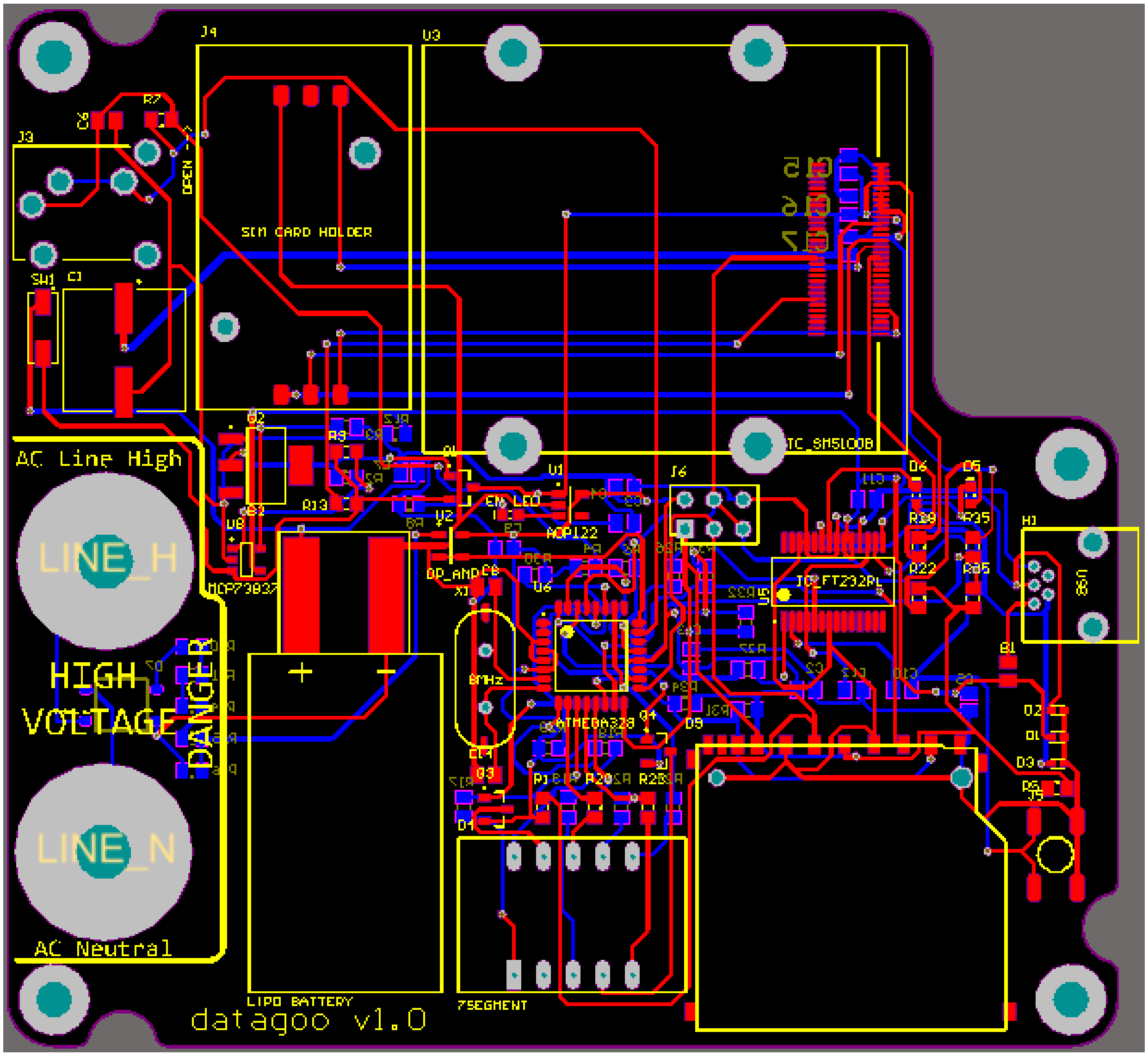
Item	1	10	50	100	Comments
PCB	$33	$24	$7.74	$4.50	Based on Sierra Protoexpress
Case	$82	$82	$82	$4	Tooling Required
Electronics	$50	$50	$35	$30	
GSM Module + Antenna	$60	$60	$60	$60	It’s likely that a lower price could be negotiated
Current Clamp	$11	$11	$11	$5	The 100 is a guestimate
Assembly	$0	$10	$5	$2	Again, estimates
Total	$236	$227	$196	$104	

CHAPTER

SEVEN

ELECTRICAL

Warning: Before trying to have the PCB manufactured, please contact nhallsny@stanford.edu for the correct settings. For components and designators, check out the Bill of Materials



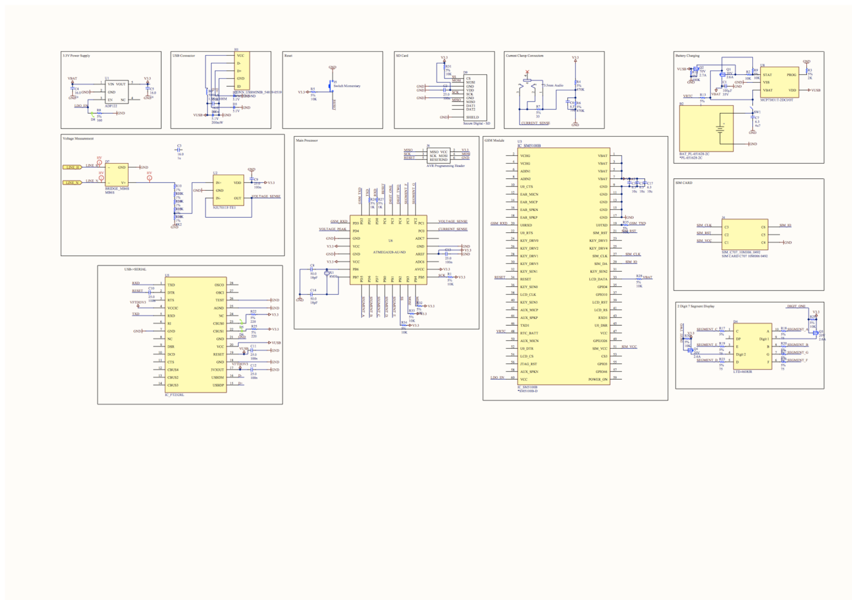
7.1 Description

For a description of how each sub-system works, consult the Systems Design

7.2 Schematic

Note: See below for known bugs before using these designs.

`Download Electrical Schematic.`



Electrical Schematics (generated in Altium):

7.3 Design Errors

1. If the device is completely discharged, and is recharged with a USB charger, the reset button needs to be pressed in order to reset the device.
2. The voltage measurement is not isolated. While we made this decision for cost reasons, for safety and ease of hacking the design should be updated with an isolation transformer.

7.4 Schematic Errors

There are no known errors in the below schematic.

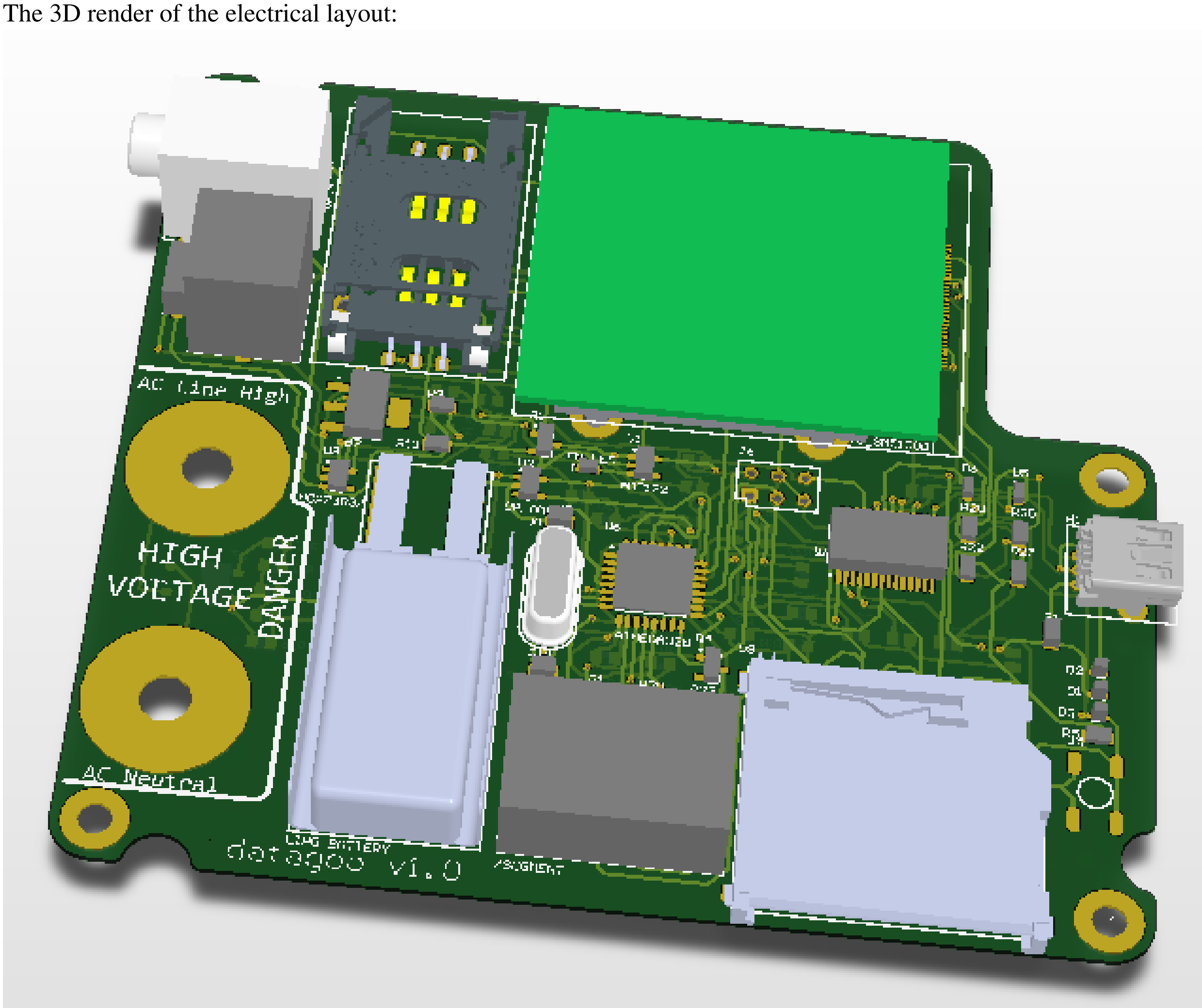
7.5 Layout Errors

There are several known errors in the layout:

1. The LDO_EN is not connected from the GSM Module
2. The GSM_TXD is not connected to the GSM Module
3. The MOSI pin on the AVR programming header is RST, and should be MOSI
4. The Zener diode footprint does not have a direction indicator
5. The LED footprint does not have a clear direction indicator
6. The footprint for SW1 is incorrect, but hackable
7. The large 100uF capacitor doesn't have a polarity marking
8. The same net is connected to two of the seven segment display pins
9. The pullup for the reset net is not connected to 3.3V

7.6 3D Layout

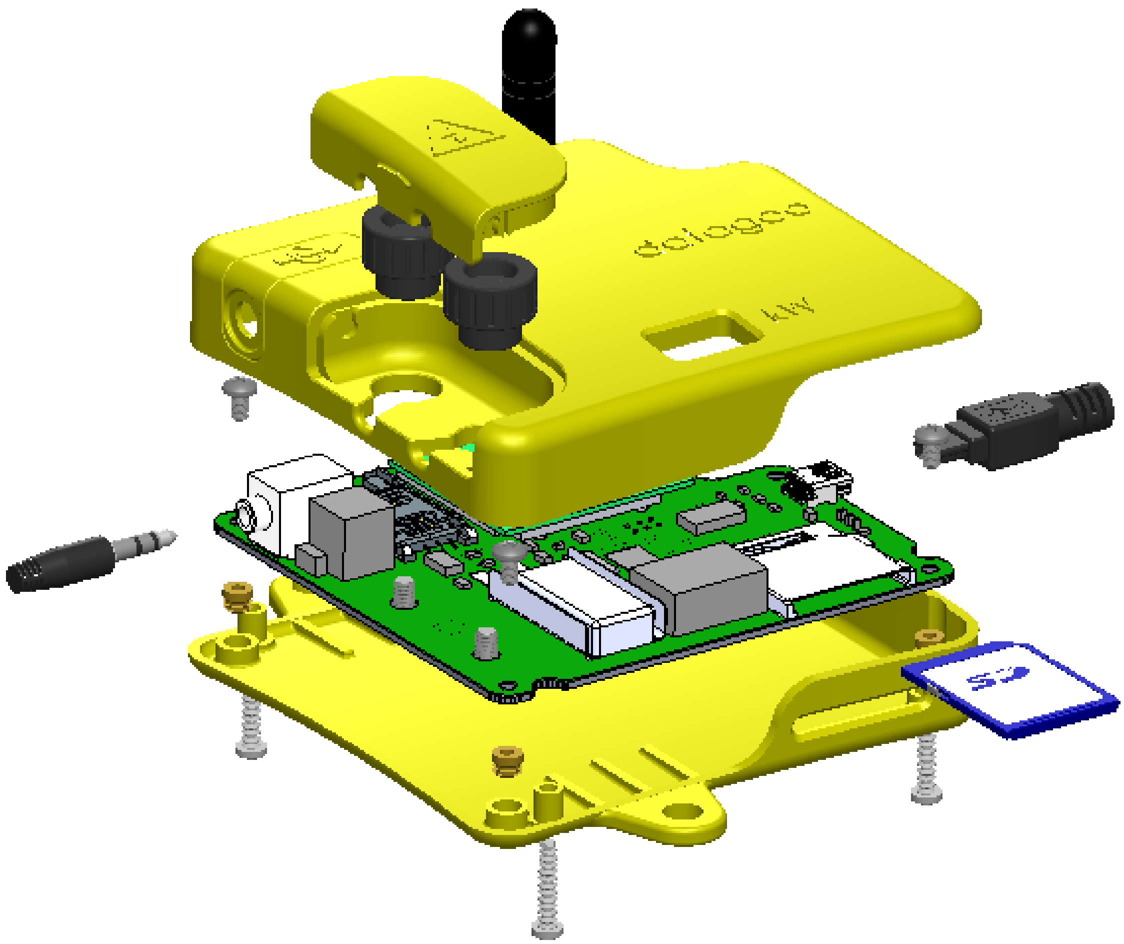
The 3D render of the electrical layout:



CHAPTER

EIGHT

MECHANICAL



8.1 3D Printing the Datagoo Case

The files below can be sent to any 3D printing company for fabrication. I would suggest Shapeways, for price. Our first prototype was completed by ZoomRP. Use these links to order your own copy:

Shapeways Permalinks

Upper Case: http://shpws.me/4lcv $33.74

Lower Case: http://shpws.me/4lcx $37.51

Cover: http://shpws.me/4ldY $6.22

The three files that constitute the case are the Cover, the Lower Body and the Upper Body. The .stl (stereolithography) file is used by most common 3d printing companies.

If there are needed changes to the solid files, the original Solidworks files still exist. Please email nhallsny@stanford.edu with any requests.

8.2 Known Errors

No known errors.

CHAPTER

NINE

SOFTWARE

9.1 Downloading the Firmware

DataGoo's firmware is open-source and can be downloaded from GitHub: https://github.com/yesimon/datagoo. Feel free to send a pull request if you want to contribute changes either to the source code or the documentation.

For write access to the repository, please contact Simon at sye737+github@gmail.com.

9.2 Building with Arduino IDE

Download the required external libraries (see *Software Libraries*) and place them in the Arduino `libraries/` directory. Open `datagoo.ino`, compile and upload using the GUI.

9.3 Software Libraries

9.3.1 External Libraries

EmonLib

A significant portion of our code is based on the OpenEnergyMonitor project, which is building an open source energy monitoring solution targeted at homes in the UK/Europe (and to a lesser extent the US). Their library does much of the heavy lifting for us in converting the raw voltage and current inputs coming into the DataGoo device into power measurements.

We forked their code base primarily because we needed to output our readings over GSM and to an SD logger, rather than over a custom (low-power) RF system which OpenEMon uses to transmit their data.

Open Energy Monitor website
GitHub (up-to-date code) for the library

9.3.2 Cell Phone Communication

There isn't exactly a library for communicating with the GSM module; instead, it presents itself as a Serial device which can read and write messages.

GSM Module Documentation
In particular, see the AT command set.

Also, see this tutorial for some example code using the GSM module.

9.3.3 Standard Arduino Libraries

SD Library

The library to write text to SD cards is part of the Arduino standard library. It lets us write to the SD card just by creating a file and then calling file.print().

SD Library

SoftwareSerial Library

This library is also part of the Arduino standard library and emulates a Serial port over software, which is especially critical for interfacing with the GSM module (which takes input and provides output over Serial).

SoftwareSerial Library

CHAPTER

TEN

TEAM

Nathan - nhallsny@stanford.edu

Ravi - sankarr@stanford.edu

Simon - sye@stanford.edu

CHAPTER

ELEVEN

PROJECT DESCRIPTION

DataGoo is an open-source device designed to measure power generation or consumption from small-scale electrical installations–cheaply. We designed it to be initially deployed in microhydro plants run by Alterna in Guatemala.

DataGoo builds heavily on a similar, open-source device called the OpenEnergyMonitor (emon). The emon system involves a transmitting device, a receiving device, and display software and is targeted for in-home deployment. Our device is designed for deployment in the field, so it uses a simpler output interface: text messages over GSM and logging to an SD card.

CHAPTER

TWELVE

INDICES AND TABLES

- *genindex*
- *search*