

# LIVESTOCK TEMPERATURE MONITOR

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## Prefix A Table of Acronyms and Abbreviations

Acronym / Abbreviation	Meaning
ADC	Analog to Digital Converter
AWS	Amazon Web Services
CPU	Central Processing Unit
CRC	Cyclic Redundancy Check
DB	Database
DC	Direct Current
GUI	Graphical User Interface
ID	Identifier
ISM	Industrial, Scientific, and Medical
PCB	Printed Circuit Board
RAM	Random Access Memory
RF	Radio Frequency
RTC	Real-time Clock
Rx	Receive / Receiver
Tx	Transmit / Transmitter

# 1 Introduction

## 1.1 Objective and Background

Current methods of diagnosing sick animals are insufficient. The process is largely manual. We plan to change that by offering a solution to wirelessly monitor the core temperature of cattle.

According to the Wall Street Journal, “To monitor cattle health, feedlots typically rely on cowboys to ride through pens, watching for lethargic animals that are having trouble breathing.”[1] Because the process is labor intensive and the symptoms identifiable show up days after the onset of disease, the livestock industry suffers from a great deal of both false positive and false negative sickness. This results in a great deal of animal death, over medication of animals, unnecessary vet visits, and unnecessary loss of organic certification. This problem costs the cattle industry over 2 billion dollars in losses annually. As of 2016, there are about 92.0 million heads of cattle in the United States.[2] Of these cows, digestive and respiratory illness, mastitis, and other diseases kill approximately 1.5 million of them each year.[3]

We aim to fix these problems by creating a cow tag that will constantly measure the temperature of the animal and send it back to a receiver via RF 915MHz, known as the Industrial, Scientific, and Medical (ISM) band. We chose this band because it is unregulated in the United States and offers the best transmission range and bandwidth of the unregulated RF bands. The receiver would upload data via the internet and a GUI would alert the farmer of animals that are running fevers. This solution leads to less labor intensive, more accurate, and earlier diagnosis of sick animals. Because of the amount of money farmers lose to this problem, a working solution would be easily marketable -- buying our product would literally save them money.

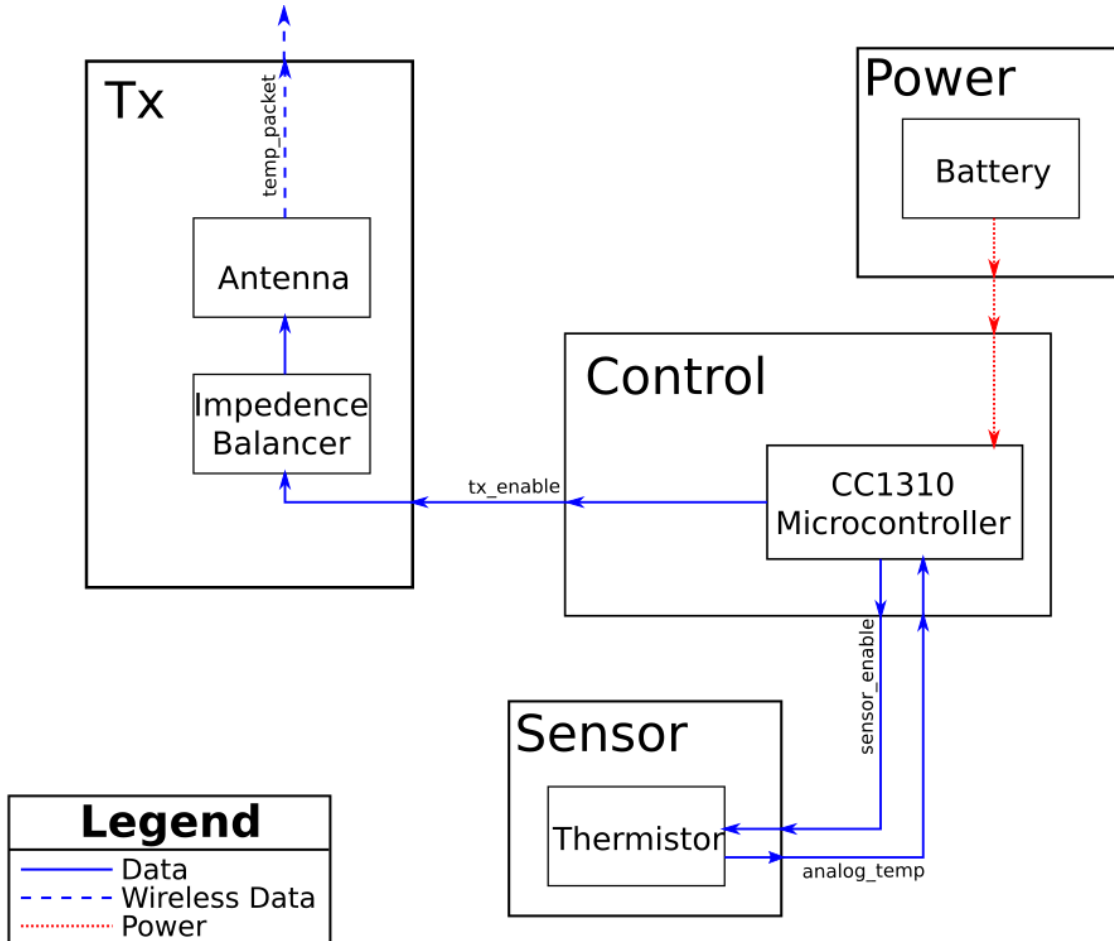
## 1.2 High Level Requirements

- Units must be durable enough and have a battery life long enough for the unit to last the entire lifespan of a beef cow (minimum 18 months).
- Units must transmit temperatures successfully every hour with a resolution of at least 0.2 degrees Celsius in order to detect a cow's fever within 12 hours.
- Units must have a bulk cost of less than \$10.

## 2 Design

### 2.1 Block Diagram

#### 2.1.1 Tag Block Diagram



**Figure 2.1: Block Diagram for Tag**

Refer to Appendix A for a schematic of the design.

### 2.1.2 Receiver Block Diagram

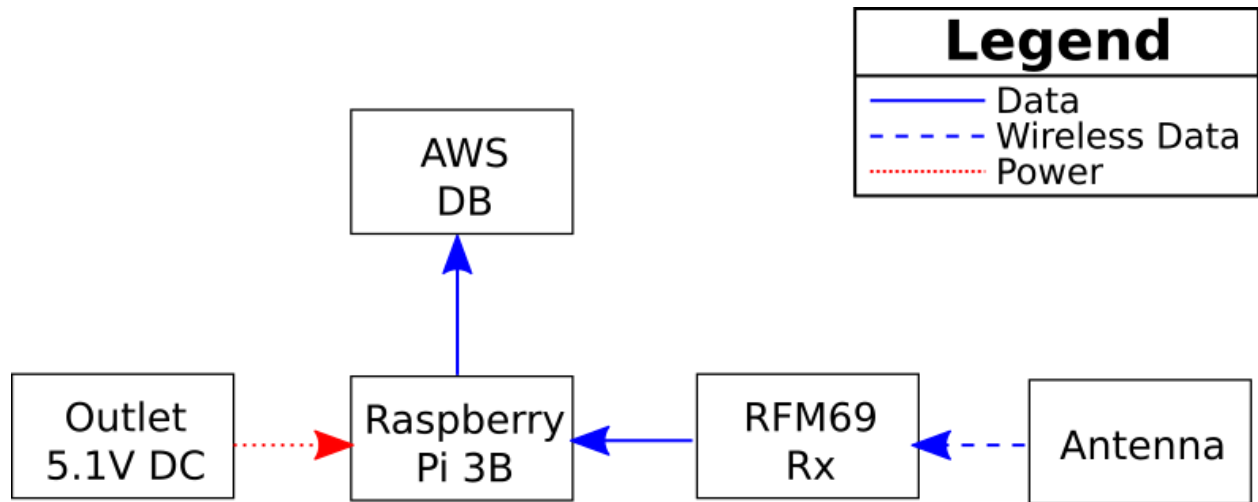


Figure 2.2: Block Diagram of Receiver

### 2.1.3 Physical Specifications

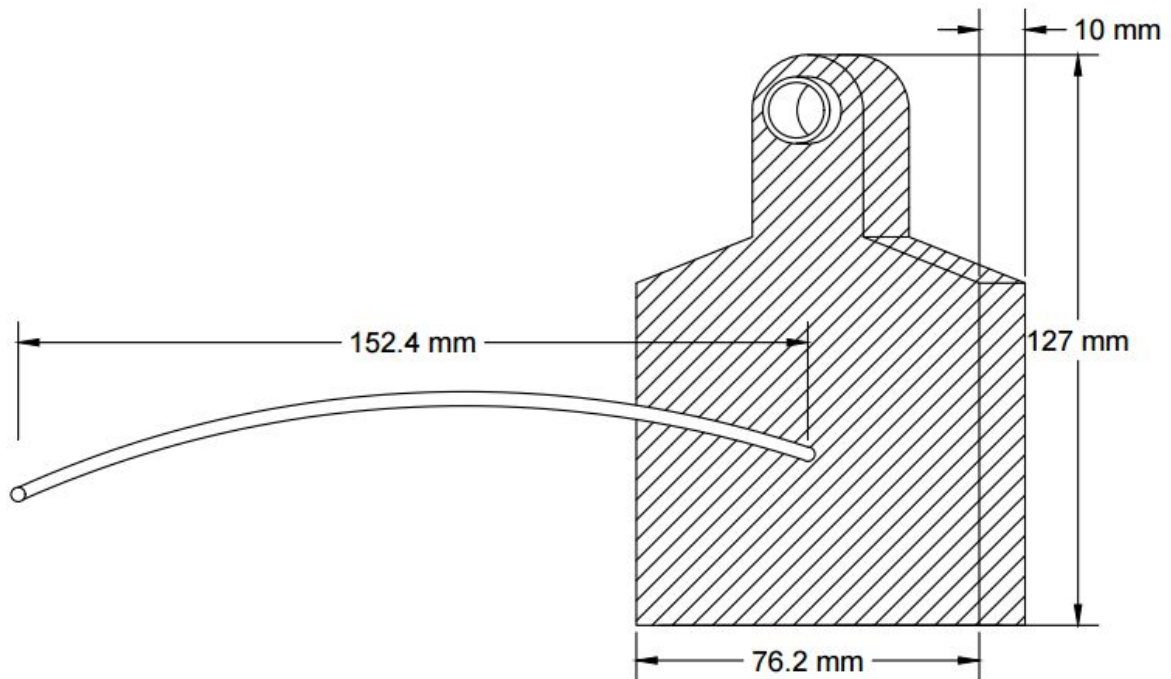


Figure 2.3: Physical CAD Drawing of Cow Tag

Figure 3 diagrams the physical dimensions of a cow tag thermometer. The tag will be a total of 5 inches tall, 3 inches wide, and 10mm deep. The thermistor will protrude out of the plastic housing 6 inches in order to reach the ear canal of the cow. The 10 mm deep is to have enough room for the ~2.5mm of board and be thick enough to protect the electronics. The hole at the top of the tag is for

the piercing that the cow receives. The piercer keeps the tag connected to the cow's ear.

## 2.2 Block Descriptions

### 2.2.1 Sensor Block

The sensor block is a thermistor and a regular resistor in series with each other. By reading the voltage between them, we can use that value to calculate the temperature the thermistor is currently sensing. The power input from the control block to the block is  $V_{cc}$ , which in this design is 3V, and the block will output a voltage that will depend on the temperature of the thermistor.

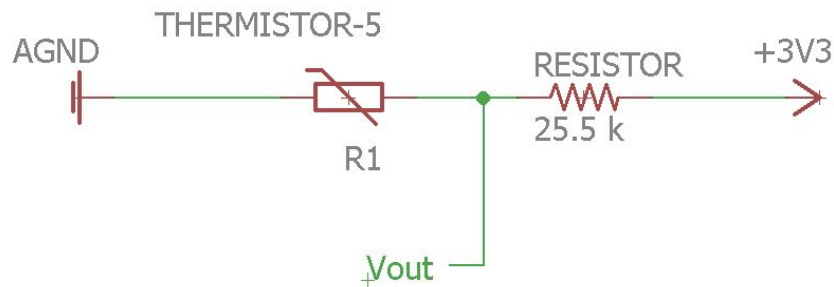


Figure 2.4: Sensor Block Schematic

#### 2.2.1.1 Thermistor

The circuit uses a NXFT15WB473FA2B150 thermistor made by Murata [4], with important specifications in the table below:

Table 2.1: Important Specifications of the Thermistor [4]

25 C Resistance	47 k $\Omega$
25 C B Value	4050 K
Tolerance	1%
Operating Temperature Range	-40 C to +125 C

The B value of a thermistor is based on the formula to calculate resistance from temperature, and is constant throughout the temperature range of the thermistor.

The formula to calculate the resistance from temperature using the B value is as follows [5]:



$$R = R_o e^{-B/T_o} e^{B/T} \quad (1)$$

Knowing that the average temperature of a cow is 38.6 C and goes up to 40 C in a fever [6], we can calculate the resistance range of the thermistor by putting those values into equation 1.

$$R_{min} = 47000\Omega \times e^{-4050K/298.15K} e^{4050K/313K} = 24672\Omega \quad (2)$$

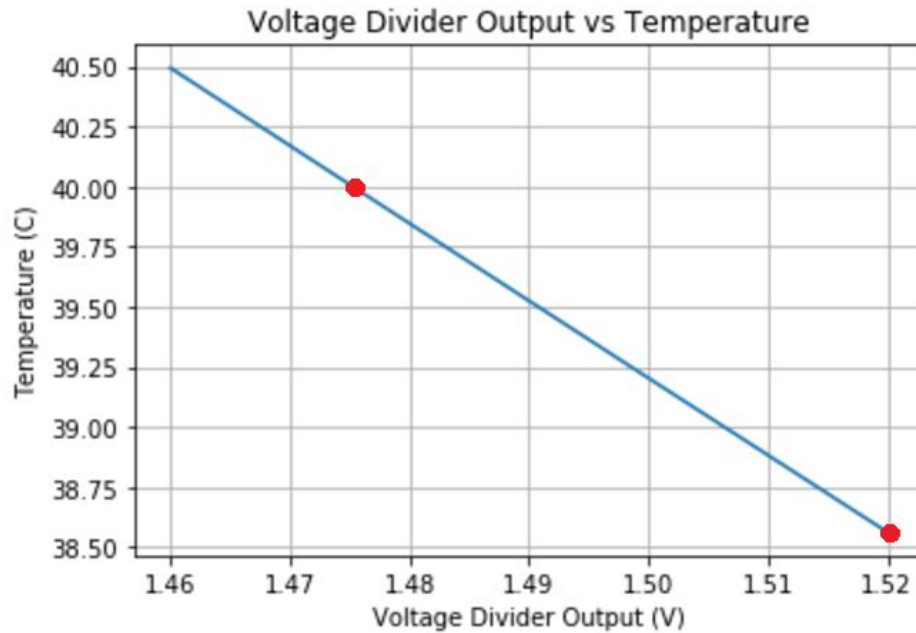
$$R_{max} = 47000\Omega \times e^{-4050K/298.15K} e^{4050K/311.6K} = 26149\Omega \quad (3)$$

That means the resistor in series with the thermistor should ideally be the average of the two calculated values above, so 25409. Unfortunately they do not make resistors that accurate so the design will settle with a 25.5k  $\Omega$  resistor.

We can then use the voltage divider rule along with the formula for temperature to generate a graph for the Temperature based on the voltage output from the voltage divider.

$$V_{out} = \frac{R}{R+25500} \quad (4)$$

$$T = \frac{B}{\ln(R/R_o) - B/T_o} \quad (5)$$



**Figure 2.5: Voltage Output vs Thermistor Temperature**

The graph generate above shows us that for the range of temperature we are interested, 38.6 C to 40 C, the voltage output from the voltage divider will lie between 1.45 V and 1.55 V.

### 2.2.2.2 Resistor

The resistor component is there simply so that we can measure voltage to eventually calculate the temperature of the thermistor. Its value has already been calculated above and actual value should be 25.5 k $\Omega$ .

### 2.2.2 Control Block

The control logic keeps track of time so that it knows when to power up the other components, and also controls how long the power and data is being sent to the other components. We also will have a 2 byte identifier value stored in the microchip upon programming for signal identification as well as another 2 byte identifier value for livestock identification. That value along with a 2 byte temperature and a 2 byte cyclic redundancy check (CRC) will be transmitted to the receiver (so the entire packet is a total of 8 bytes). The control block itself is built into a TI CC1310[7] chip, which is a microcontroller that features a built-in ISM band RF transceiver and 12-bit ADC. The control block gets 3V of power from the battery.

#### 2.2.2.1 Low Power Real-Time Clock

The RTC is also built into the CC1310 chip and allows scheduling of configurable periodic interrupts that will be used to schedule reading from the sensor block and transmitting the data. The RTC will be kept to a 32.8 kHz clock cycle which means that it needs to count to  $32800 * 60 \text{ seconds} / \text{minute} * 5 = 9840000$  in order to keep track of the 5 minute intervals between data transmission.

#### 2.2.2.2 Analog to Digital Converter

The analog to digital converter is also built into the CC1310 and receives the voltage output from the sensor module and reads it into the microcontroller. The CC1310 ADC is 12 bits, and taking into consideration the  $V_{cc}$  of 3V, leaves an error range of  $\pm 366\mu\text{V}$ , which is calculated later in the tolerance analysis.

### 2.2.3 Transmitter Block

The transmitter block is in charge of preparing the measurement for transmission, and eventually transmitting the measurement through the antenna. In the CC1310 chip, all the necessary components for transmission is already built in except for the antenna.

#### 2.3.3.1 RF Transmitter

The RF transmitter is built into the CC1310 chip. Among the variety of available frequencies that the CC1310 chip is able to transmit at, we chose 915 MHz because it is unregulated. The RF transmitter takes the output of the ADC, prepends a 2-byte magic number and a 2-byte ID as a header, and appends a 2-byte CRC to form the full 8-byte packet.

**Table 2.2 Packet Structure**

Bytes 0-1	Bytes 2-3	Bytes 4-5	Bytes 6-7
Magic Number	Tag ID Number	Temperature (in form of ADC block output)	2 byte CRC

(0xBEEF)			
----------	--	--	--

### 2.3.3.2 Antenna

Since we picked the transmission to be 915 MHz, the antenna will be a 915 MHz capable antenna. We will use a meandering monopole trace antenna because among trace antennas it boasts the best efficiency with the main tradeoff being area on the PCB [8]. Because our overall physical device will be significantly larger than the PCB needs to be, we have sufficient room for a large trace antenna.

### 2.2.4 Power Block

The power unit provides the necessary power to run all the components of the ear tag transmitter. It is essentially a battery that always powers the control unit but the control unit controls the power supply to the rest of the ear tag transmitter components. The power block needs to output a voltage of 3V at xmA that will last at least 2 years.

#### 2.2.4.1 Battery

This is the battery that provides power for the ear tag transmitter. It provides power to the control unit as well as the clock, and the control unit is in charge of sending power to all the other components of the transmitter.

The calculations for how much power is needed to power the transmitter unit for two years is as follows:

Microcontroller Specifications[7]:

- Wide Supply Voltage Range: 1.8 to 3.8 V
- RX: 5.4 mA
- TX at +10 dBm 868 MHz: 13.4 mA
- Active-Mode MCU 48 MHz Running Coremark: 2.5 mA (51  $\mu$ A/MHz)
- Active-Mode MCU: 48.5 CoreMark/mA
- Active-Mode Sensor Controller at 24 MHz: 0.4 mA + 8.2  $\mu$ A/MHz
- Sensor Controller, One Wakeup Every Second Performing One 12-Bit ADC Sampling: 0.95  $\mu$ A
- Standby: 0.7  $\mu$ A (RTC Running and RAM and CPU Retention)
- Shutdown: 185 nA (Wakeup on Extexternal Events)

Message is 10 bytes.

Send message every (s) seconds (s) = sec/msg

Standby in between messages

Wake up time is 174  $\mu$ s

Conservatively we are assuming a 1 ms wake up and set up time.

Standby power:

Conservatively it's constantly using standby power.  
 $(.7 \mu A)(2 \text{ years})(365 \text{ days})(24 \text{ hours}) = .0123 \text{ Ah}$  (6)

Message Transfer Power Usage:  
 $(10 \text{ bytes})/(50 \text{ kb/s}) = .002 \text{ seconds/message}$   
 $(.002 \text{ sec/msg})(13.4 \text{ mA}) = 26.8 \text{ uA/Msg}$   
 $(1/(s) \text{ msg/sec})(26.8 \text{ uA/Msg}) = 26.8/(s) \text{ uA}$   
 $(26.8/(s) \text{ uA/s})(2 \text{ years})(365 \text{ days})(24 \text{ hours}) = .470/(s) \text{ Ah}$  (7)

Wake up/Set up Time Power Consumption:  
Duty Cycle =  $(1 \text{ ms/msg})(1/(s) \text{ msg/s}) = .001/(s)$   
 $((.001/(s))(2.5 \text{ mA})) = 2.5/(s) \text{ uA}$   
 $(2.5/(s) \text{ uA/s})(2 \text{ years})(365 \text{ days})(24 \text{ hours}) = .0438/(s) \text{ Ah}$   
(8)

Active Power Usage:  
 $(1/(s) \text{ msg/s})(.00192 \text{ s/msg}) = .00192/(s) \text{ duty cycle}$   
 $(.00192/(s) \text{ duty cycle})(2.5 \text{ mA}) = 4.8/(s) \text{ uA}$   
 $(4.8/(s) \text{ uA})(2 \text{ years})(365 \text{ days})(24 \text{ hours}) = .0841/(s) \text{ Ah}$   
(9)

Thermistor Power Usage During Transfer:  
ohms =  $25.5 \text{ kohms (Thermistor)} + 25.5 \text{ kohms (Series Resistance)}$   
Voltage =  $3.3 \text{ V}$   
 $(3.3 \text{ V})/(51 \text{ kohms}) = 64.7 \text{ uA}$   
Duty Cycle =  $.00192/(s)$   
 $(.00192 \text{ duty cycle})(64.7 \text{ uA}) = 124.2 \text{ nA}$   
 $(124.2 \text{ nA/s})(2 \text{ years})(365 \text{ days})(24 \text{ hours}) = .002176/(s) \text{ Ah}$   
(10)

Total Amp-hours:  
Standby + Thermistor + Transfer + Setup + Active = Total Ah  
Total Ah =  $(6) + (10) + (7) + (8) + (9)$   
 $= .0123 \text{ Ah} + .002176/(s) \text{ Ah} + .470/(s) \text{ Ah} + .0438/(s) \text{ Ah} + .0841/(s) \text{ Ah}$   
 $= .0123 + .6001/(s) \text{ Ah}$   
(11)

Since we are planning on having the device transmit every 5 minutes, then (s) would be 300, so total power consumption in two years using equation 11 is:

$$.0123 + .6001/300 \text{ Ah} = 0.01430 \text{ Ah}$$

So the transmitter needs a battery that outputs 3V and has at least 14.30 mAh, and button batteries satisfy that condition. We chose the Panasonic CR2025 which has output of 3V and capacity of 165

mAh, it can be purchased for as cheap as 30 cents and widely available everywhere[9]. That particular button battery will allow the transmitter to theoretically run up to 20 years.

### **2.2.5 Receiver Unit**

The receiver unit is in charge of collecting data from all the various ear tag transmitters and process them to be present to the customer. It includes an antenna attached to a RF Receiver chip to receive signals, a Raspberry Pi 3 to process and store the data, and a surge protector connected to a conventional outlet for power.

#### **2.2.5.1 Raspberry Pi 3**

This is the calculating component of the receiver unit. It takes the measurement reading signals from the RF receiver and calculates the temperature that would cause those voltages. It can then store the data in its memory and later pass the data on through the built in USB adapter. Using the processed data, we can run a webserver on the Raspberry Pi 3 and also use the Wifi capability to transmit data to a bigger central database if needed. Since the receiver unit is plugged into a wall, this is always on and ready to receive new data.

#### **2.2.5.2 RF Receiver**

The RF receiver is always on and ready to receive new data from any of the ear transmitter's RF transmitters. The RF Receiver receives data from the antenna and any data it receives will be first processed by the RF Receiver and then sent to the raspberry pi unit for final conversion.

#### **2.2.5.3 Antenna**

The antenna takes the received signal and passes it to the RF Receiver chip. The transmitter antenna is already set at 915 MHz, so we will use the same one on the receiving end.

### **2.2.6 Tolerance Analysis**

For the tolerance analysis, we will analyze the margin of errors for the sensor block, which is the most crucial part of the whole design. If the initial measurement of the temperature is off, none of the other components matter since it'll all be wrong in the end.

Both the resistor and thermistor comes with 1% tolerance in resistance, and thermistor also has a 1% tolerance on the B value.

The ADC of the microcontroller is 12 bits and maps a voltage range of 0 to Vcc (3V). This means the distance between any two digital values is  $3/2^{12}$  volts. The maximum aliasing error occurs when an analog value is exactly halfway between two digital values. Thus, the conversion error is  $3/2^{13}$  volts, which evaluates to 366 uV.

Assuming that the ADC aliasing error is at max, and tolerance error is also at max, we can calculate the

temperature difference from the theoretical.

From the sensor block we have the formulas:

$$V_{out} = \frac{R}{R+25500} \quad (12)$$

$$T = \frac{B}{\ln(R/R_o) - B/T_o} \quad (13)$$

We can then vary the Vout and 25500 ohm resistor value in equation 12 along with the B value in equation 13 to find tolerances. Using python, we have the code for plotting in Matlab below:

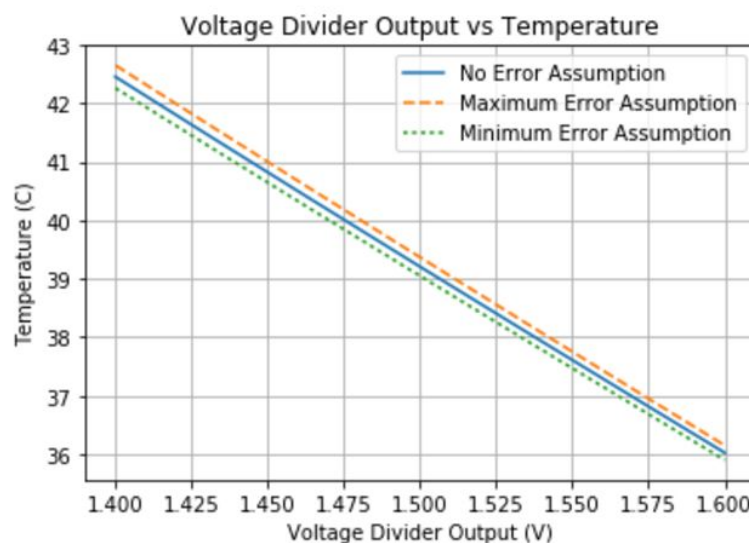
```
#Theoretical Values for No Tolerance Deviation
R = lambda v: 25500*v*1.0/(3-v)
T = lambda r: (4050.0/np.log(r*1.0/(47000*np.exp(-4050/298.15))))-273

#Theoretical Values for Max Tolerance Deviation in Negative Direction
Reu = lambda v: 25500*0.99*(v-0.000366)*1.0/(3-(v-0.000366))
Teu = lambda r: (4050.0*0.99/np.log(r*1.0/(47000*0.99*np.exp(-4050*0.99/298.15))))-273

#Theoretical Values for Max Tolerance Deviation in Positive Direction
Rel = lambda v: 25500*1.01*(v+0.000366)*1.0/(3-(v+0.000366))
Tel = lambda r: (4050.0*1.01/np.log(r*1.0/(47000*1.01*np.exp(-4050*1.01/298.15))))-273
```

**Figure 2.6: Tolerance Formulas for Tolerance Calculations**

In the code, R and T are the theoretical perfect values with no error in tolerance. Reu and Teu will give the maximum amount of Temperature that can result from all the errors combined, and Rel and Tel will give the minimum amount of Temperature that can result from all the errors combined. This code is then used to generate the following graph:



**Figure 2.7: Tolerance Comparison Graph**

We can see in the above figure that in the 38.6 C to 40 C range, the error range is pretty small.

We can also use the code in figure 2.6 to see the error range at specific voltage outputs.

```
At this voltage: 1.4 Theoretical: 42.4508769949 Upper: 42.6480628029 Lower: 42.2578351942
At this voltage: 1.42 Theoretical: 41.7946627699 Upper: 41.9843865314 Lower: 41.6089179007
At this voltage: 1.44 Theoretical: 41.142102621 Upper: 41.3244396777 Lower: 40.9635816151
At this voltage: 1.46 Theoretical: 40.4929349243 Upper: 40.6679570978 Lower: 40.3215681419
At this voltage: 1.48 Theoretical: 39.8469036728 Upper: 40.0146793865 Lower: 39.6826247832
At this voltage: 1.5 Theoretical: 39.2037578782 Upper: 39.3643522719 Lower: 39.0465037495
At this voltage: 1.52 Theoretical: 38.5632509968 Upper: 38.716726032 Lower: 38.412961594
At this voltage: 1.54 Theoretical: 37.925140374 Upper: 38.0715549317 Lower: 37.781758664
At this voltage: 1.56 Theoretical: 37.2891867056 Upper: 37.4285966764 Lower: 37.1526585702
At this voltage: 1.58 Theoretical: 36.655153512 Upper: 36.7876118795 Lower: 36.5254276675
At this voltage: 1.6 Theoretical: 36.0228066238 Upper: 36.1483635408 Lower: 35.899834547
```

**Figure 2.8: Tolerance Numbers at Certain Voltages**

Using the values calculated in figure 2.8, we can make a table to show the error ranges of temperature in the temperature range we want.

**Table 2.3 Tolerance Results**

Voltage (V)	Theoretical (deg C)	Upper Limit (deg C)	Lower Limit (deg C)
1.46	40.4929	40.6680	40.3216
1.48	39.8469	40.0147	39.6826
1.5	39.2038	39.3643	39.0465
1.52	38.5633	38.7167	38.4130

The above table shows us that within the range we want, 38.6 C to 40 C, the error range is at maximum  $\pm 0.15$ C around the theoretical value, which is within acceptable limits defined in the high level requirements of a resolution of 0.2 C.

## 2.3 Risk Analysis

We believe that the transmission/receiving module poses the greatest risk potential in our Livestock Temperature Monitor. It has the greatest risk potential because it is the most likely to fail and if it fails it will have a big impact on its function. The transmission module is the most complex portion of our design, and, therefore, it has more components, systems, etc. that can fail than any other module. Also, when the transmission module fails the signal can become amplitude shifted which will provide inaccurate data and cause wrong measurements.

To mitigate some of the risks of the transmission module, we will design the system to send multiple messages of the current value every time it is transmitting the data and to have parity bits within the

messages that we can check against for bit errors.

The tolerances of the transmission module are related to our first and second high level requirements. As for durability and battery, the module should be able to survive any temperature that a cow is expected to survive outdoors, 0-50 degrees Celsius. The module should also be able to survive any forces that a normal livestock tag can survive currently. The battery must not be drained by the module before the required time. As for requirement two, the tag must be within 0.2 degrees Celsius of the actual temperature, transmit up to 100m and report to the receiver once an hour. Following these tolerances can mitigate the risk of a failing transmission/receiving module.

If upon testing that it is discovered our methods of mitigation failed, we can also attempt to lower the value of the resistor attached to the thermistor in order to increase the voltage range of the output of the sensor module so that it is less affected by ADC error, or simply design an amplifier unit to further increase the voltage output range.



### 3. Design Requirements and Verification

#### 3.1 Sensor Module

**Table 2: Sensor Module Requirements and Verification**

Requirement	Verification
<ol style="list-style-type: none"><li>1. The Sensor output a voltage that is related to the sensed temperature.<ol style="list-style-type: none"><li>a. The Sensor shall output a voltage range of .1V, +/- .01V, linearly for the temperature range 38.6 C to 40 C respectively.</li></ol></li><li>2. The Sensor shall be able to reach into a cow's ear.<ol style="list-style-type: none"><li>a. The sensor shall be able to reach 150mm, +/- 10mm, from the ear tag.</li></ol></li></ol>	<ol style="list-style-type: none"><li>1. The sensor shall be able to accurately measure temperature.<ol style="list-style-type: none"><li>a. The sensor will be put in a temperature chamber. The chamber temperature will be varied from 38.6 C to 40 C over 4 hours, starting at 38.6 and increasing at a rate of .35 C/hour. We will use a multimeter to measure the output voltage. If the sensor outputs a range of .1V, +/- .01V, linearly over the temperature range it passes.</li></ol></li><li>2. The Sensor shall be able to reach into a cow's ear.<ol style="list-style-type: none"><li>a. We will use a tape measure to measure from the base of the sensor location on the board to the tip of the sensor. If the length is 150mm, +/- 10mm, it passes.</li></ol></li></ol>

#### 3.2 Power Module

**Table 3: Power Module Requirements and Verification**

Requirement	Verification
<ol style="list-style-type: none"><li>1. The power module shall provide power to the device at least 2 years in temperatures that cows can survive outside, as low as 0 C[10] and up to 50C.<ol style="list-style-type: none"><li>a. The power module shall provide 20mAh total, +/- 1mAh, over at least 2 years.</li><li>b. The power module shall be able to provide 13.4mA, +/- .1mA, and a constant 3V, +/- .1V. in temperatures 0 C to 50C.</li></ol></li></ol>	<ol style="list-style-type: none"><li>1. The power module shall power the device for no less than 2 years.<ol style="list-style-type: none"><li>a. We will run the power module, with a 225 ohm load, for 4 hours and measure the total Amp-hours used with a ammeter. If the device uses less than 4.57 uAh, +/- .2 uAh, then the module passes.</li><li>b. The power module, with a 225 ohm load, will be put in a temperature chamber that will vary the temperature from 0C to 50C over 4 hours, rate of 12.5</li></ol></li></ol>

	C/hour, and power measurement, with a wattmeter, will be taken. If the power module outputs 13.4mA and a constant 3V, +/- .1V, it passes.
--	---

### 3.3 Control Module

**Table 4: Control Module Requirements and Verification**

Requirement	Verification
<ol style="list-style-type: none"> <li>1. The control module software shall receive sensor data. <ol style="list-style-type: none"> <li>a. The control module software shall send an enable signal every 5 minutes, +/- 1 second.</li> <li>b. The control module software shall allow a 1ms, +/- .5ms, wake up time before each processing of sensor data.</li> <li>c. The control module software shall go into standby mode after transmission is finished.</li> </ol> </li> <li>2. The control module shall package the sensor data. <ol style="list-style-type: none"> <li>a. The control module software shall convert the analog thermistor voltage data into 4 bytes of digital data and append the voltage data onto the 4 byte ID data to make an 8 byte packet.</li> </ol> </li> <li>3. The controller module shall hold in memory a unique ID. <ol style="list-style-type: none"> <li>a. The controller module shall use memory to save a unique 4 byte ID.</li> </ol> </li> </ol>	<ol style="list-style-type: none"> <li>1. The control module shall receive sensor data. <ol style="list-style-type: none"> <li>a. Run the control module for 30 minutes and using an oscilloscope, track the input voltage and current. If we observe an enable signal every 5 minutes then it passes.</li> <li>b. Run the device for 30 minutes and using an oscilloscope, track the input voltage and current. If we observe a 1ms, +/- .5ms, active current draw, 2.5mA, before a transmitting current draw, 13.4mA, then it passes.</li> <li>c. Run the device for 30 minutes and using a oscilloscope track the current draw. If between the active/transmit cycle, every 5 minutes +/- 1 second, the current draw is the standby current, 0.7 <math>\mu</math>A, then it passes.</li> </ol> </li> <li>2. The control module shall package the sensor data. <ol style="list-style-type: none"> <li>a. Run the control module for 30 minutes and use an oscilloscope to track the "tx" output pin. If every 5 minutes, +/- 1 second, the "tx" output pin outputs an 8 byte packet, with the first 4 bytes as the digital data and the last 4 bytes as the ID data, it passes.</li> </ol> </li> <li>3. The controller shall hold in memory a unique ID. <ol style="list-style-type: none"> <li>a. Run the control module for 30 minutes and use an oscilloscope to track the "tx" output pin. If</li> </ol> </li> </ol>

	every 5 minutes, +/- 1 second, the “tx” outputs and the first 4 bytes are the unique ID it passes.
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### 3.4 Transmitter Module

**Table 5: Transmitter Module Requirements and Verification**

Requirement	Verification
<ol style="list-style-type: none"> <li>The transmitter module software shall transmit the packaged data. <ol style="list-style-type: none"> <li>The transmitter module software shall transmit the 8 byte packet at the 915Mhz ISM band at 10dBm, +/- 1dBm for at least 100m.</li> <li>The antenna shall be able to transmit data at least 100m on the 915MHz ISM band at 10dBm, +/- 1dBm.</li> </ol> </li> </ol>	<ol style="list-style-type: none"> <li>The transmitter module software shall transmit the packaged data. <ol style="list-style-type: none"> <li>Run the transmitter for 30 minutes and use an MXA signal analyzer to read signals on the 915MHz band. If an 8 byte packet is detected it passes.</li> <li>Run the transmitter for 30 minutes 100 meters away from the MXA signal analyzer that is reading signals on the 915MHz band. If an 8 byte packet is detected it passes.</li> </ol> </li> </ol>

### 3.5 Receiver Module

**Table 5: Receiver Module Requirements and Verification**

Requirement	Verification
<ol style="list-style-type: none"> <li>The receiver module shall receive the packaged data. <ol style="list-style-type: none"> <li>The antenna shall be able to receive data at least 100m on the 915MHz ISM band.</li> </ol> </li> <li>The receiver module software shall process the package into temperature and ID. <ol style="list-style-type: none"> <li>The raspberry pi software shall process the 8 byte data into the ID data and Temperature data.</li> </ol> </li> <li>The receiver module software shall convert the 4 byte temperature data into a temperature value. <ol style="list-style-type: none"> <li>The raspberry pi software</li> </ol> </li> </ol>	<ol style="list-style-type: none"> <li>The receiver module shall receive the packaged data. <ol style="list-style-type: none"> <li>Run a RF signal generator and push a signal to 915MHz 100m away from the receiver. If the receiver antenna pin outputs the transmitted data it passes.</li> </ol> </li> <li>The receiver module shall process the package into temperature values. <ol style="list-style-type: none"> <li>Send an 8 byte signal using a RF signal generator over the 915MHz band, and if the raspberry pi separates the signal into two 4 byte packages, first temperature then ID, it passes.</li> </ol> </li> <li>The receiver module software shall convert the 4 byte temperature data into a temperature value.</li> </ol>

shall process the 4 byte temperature data into a temperature value.	a. Input a 4 byte value into the raspberry pi and if the software converts the bytes into a temperature value it passes.
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## 4 Costs

### 4.1 Parts

**Table 4.1 Parts Costs - Tag Unit**

Manufacturer	Part Number	Part Type	Unit Px 100	Unit Px 5000	Supplier
Texas Instruments	CC1310F32RHBR	Microcontroller	\$3.740	\$2.200	TI Store
Panasonic	CR2025	Battery	\$0.222	\$0.159	Mouser
Linx	BAT-HLD-001	Battery Holder	\$0.233	\$0.183	Mouser
Murata	NXFT15WB473FA2B150	Thermistor	\$0.274	\$0.172	Mouser
Panasonic	ERJ-2RKF2552X	Resistor	\$0.006	\$0.003	Mouser
<b>Total</b>			<b>\$4.475</b>	<b>\$2.717</b>	

**Table 4.2 Machining & Fabrication Costs - Tag Unit**

Part Type	Quote Description	Unit Px 100	Unit Px 5000	Supplier
PCB	50x40mm, 1.6mm thick, 6mil spacing	\$4.900	\$0.931	PCBWay
Housing	Plastic Case, 3D printed ABS	\$3.938*	\$3.938*	Illinois MakerLab
<b>Total</b>		<b>\$8.838</b>	<b>\$4.869</b>	

\*Estimate based on \$0.15/g \* 1.05g/cc \* 25cc until we have a CAD drawing and get a quote

**Table 4.3 Unit & Lot Costs - Tag Unit**

<b>Unit Price, 100</b>	\$13.313
<b>Unit Price, 5000</b>	\$7.586
<b>Lot Price, 100</b>	\$1,331.250
<b>Lot Price, 5000</b>	\$37,928.500

**Table 4.4 Parts Costs - Receiver Unit**

Manufacturer	Part Number	Part Type	Unit Px 1	Unit Px 100	Supplier
Raspberry Pi	Pi 3 Model B	Computer	\$39.950	\$39.950	Adafruit
Johanson	0915AT43A0026E	Antenna	\$1.280	\$0.574	Mouser
Kingston	SDC10/4GB	Micro SD Card	\$6.490	\$6.490	Amazon
CanaKit	Pi MicroUSB Supply	Power Supply	\$7.990	\$7.990	Amazon

Sparkfun	COM-13909	RF Transmitter	\$4.950	\$4.950	Mouser
<b>Total</b>			<b>\$60.66</b>	<b>\$59.954</b>	

**Table 4.5 Unit & Lot Costs - Receiver Unit**

<b>Unit Price, 1</b>	\$60.660
<b>Unit Price, 100</b>	\$59.954
<b>Lot Price, 100</b>	\$5,995.400

## 4.2 Labor

### 4.2.1 Research and Development

We have three team members doing research and development for approximately 20 hours per week for about 14 weeks.  $2.5 * 3 * 20 * 14 * \$45$  yields a research and development cost of approximately \$94,500.

### 4.2.2 Assembly

Assuming that each of us can assemble 15 tag units per hour, assembly adds \$3 ( $\$45/15$ ) to the unit cost. This changes the 5,000 lot unit price to \$10.586 per unit and the total lot price to \$52,930.

Assuming that each of us can assemble 3 receiver units per hour, assembly adds \$15 ( $\$45/3$ ) to the unit cost. This changes the 100 lot unit price to \$74.954 per unit and the total lot price to \$7,495.

## 4.3 Grand Total

The grand total cost to research, develop, order parts, and assemble a 5,000 lot of tag units and a 100 lot of receiver units is  $\$94,500 + \$52,930 + \$7,495$ , which comes out to a total of \$154,925.

## 5 Schedule

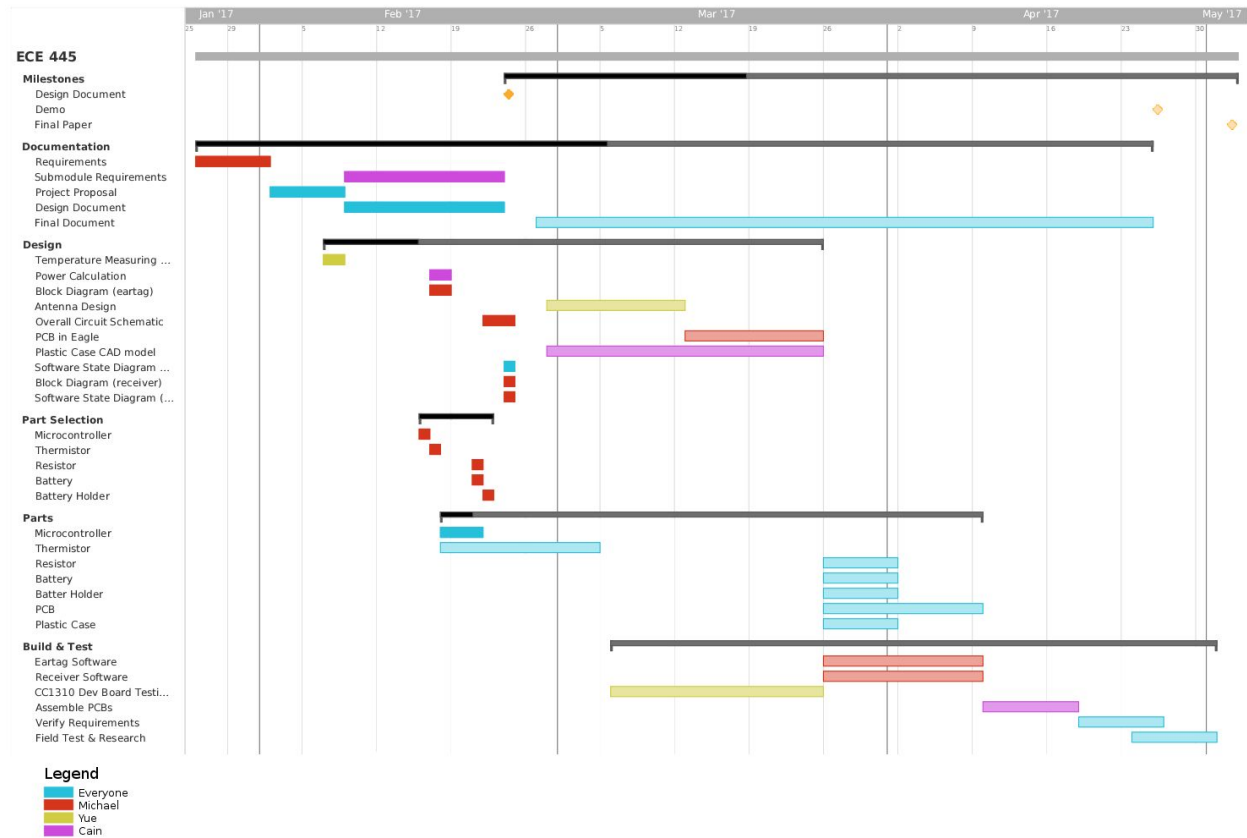


Figure 5.1: Schedule

\*Pale tasks are incomplete and dark tasks are complete.

## 6 Ethical Considerations

### 6.1 Relevant IEEE Ethics Guide Provisions[11]:

1) to accept responsibility in making decisions consistent with the safety, health, and welfare of the public, and to disclose promptly factors that might endanger the public or the environment;

This ethic guideline is important to us because what we are working on is very tightly related to public health. Catching sick cows before they are used for meat or milk produce is an important part of our society.

3) to be honest and realistic in stating claims or estimates based on available data;

It is important for us to not make any false or inaccurate claims in the design, research and testing that we do for our project. These will only hurt us and other engineers around us.

6) to maintain and improve our technical competence and to undertake technological tasks for others only if qualified by training or experience, or after full disclosure of pertinent limitations;

This project is aimed at improving all of our technical competence and knowledge to better our understanding of our field.

7) to seek, accept, and offer honest criticism of technical work, to acknowledge and correct errors, and to credit properly the contributions of others;

Throughout our design process we will be asking for honest criticism of our work by peers, TAs and professors. We must be able to accept criticism of our work even if we do not agree. Looking at our project from multiple points of view will help in the growth of our technical and business skills.

10) to assist colleagues and co-workers in their professional development and to support them in following this code of ethics.

During the duration of the design process it is very important for us to assist and support each other in our work. We are here to improve our technical and general engineering skills and we can do that better by working together as a team.

### 6.2 Safety Guidelines

We adhered to strict guidelines. We had all values double checked, verified that all vendors sourced their materials legally, that all planned construction and machine shop work was to be done by certified professionals. On top of this, we repeatedly accepted criticism and implemented changes. All group members contributed equally and were not subject to any form of discrimination including but not limited to on the basis of sex, orientation, age, national orientation, or religion.

### 6.3 IACUC Policy [12]

- All research, teaching, and outreach activities at the University of Illinois involving vertebrate animals must be approved by the Institutional Animal Care and Use Committee (IACUC) before the activity begins.
- Once the activity begins, any proposed changes must be submitted to the IACUC as a major or minor amendment to the protocol. Changes must be reviewed and approved by the IACUC before they are implemented.
- The approval is for a 3-year period; the IACUC conducts mandatory annual reviews.
- If the approved use of animals is expected to continue beyond three years, a new Proposal for Activities Involving Animals must be submitted to the IACUC, reviewed, and approved before the active protocol expires.



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Appendix A      Circuit Schematic and PCB Drawing

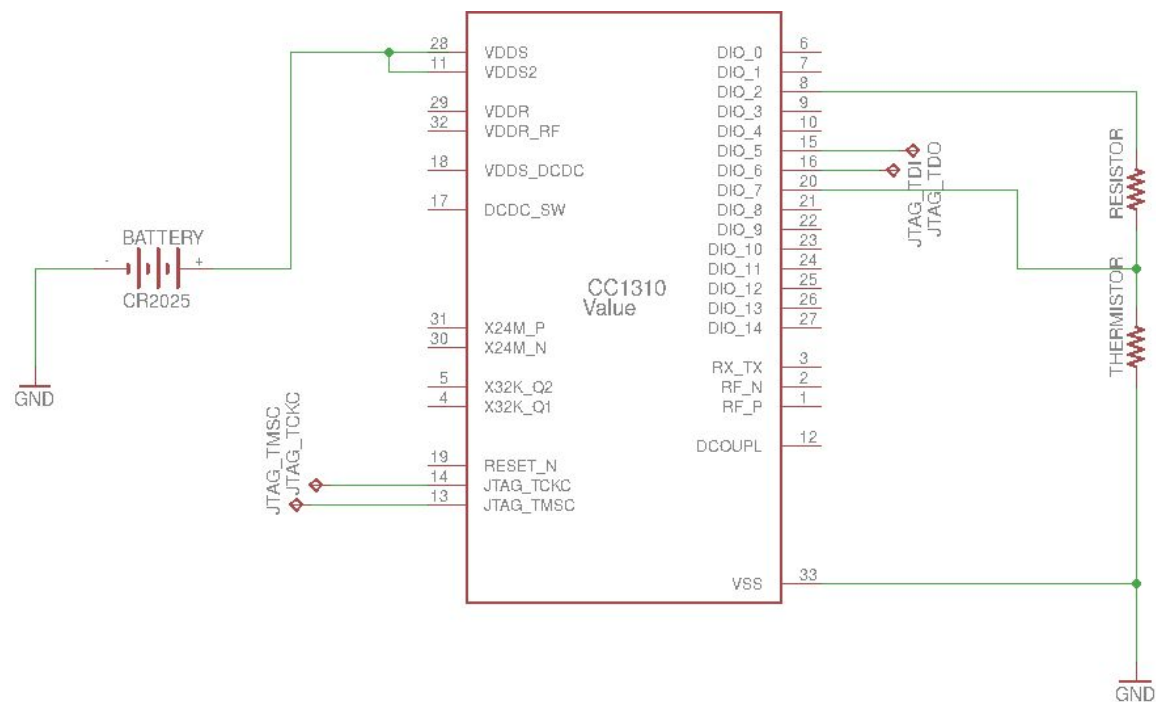


Figure 1: Circuit Schematic

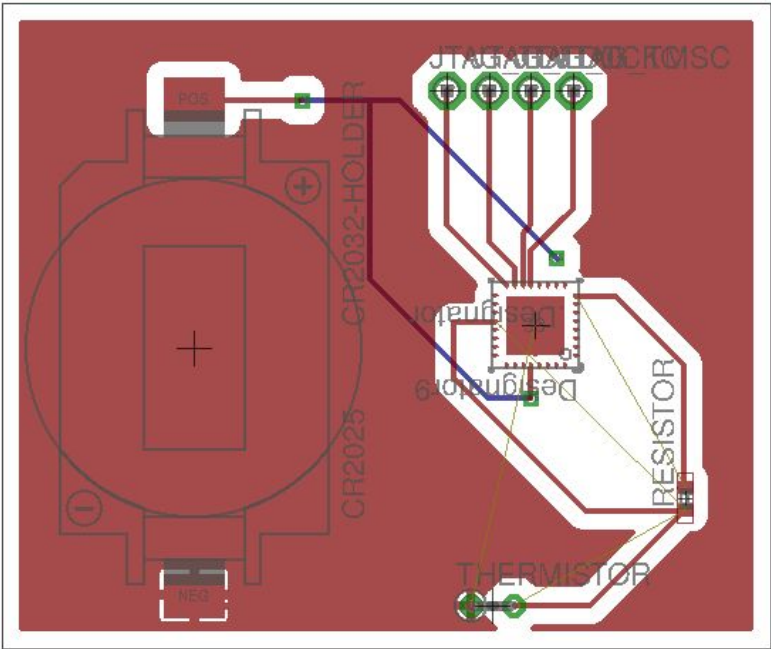


Figure 2: PCB Drawing