Low Power Embedded System Design Technologies

REMOTE WATER QUALITY ANALYSIS

FINAL PROJECT REPORT

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1. MOTIVATION:

With the ever increasing pollution and rise of the industrial age, water quality degradation is a major concern. Water quality analysis not only enables us to determine the quality of water for drinking but for sustenance of aquatic life and is useful for many other things.

There are some general parameters used to test the quality of water but the general techniques involved are often hard to set up and hence are done by some water treatment plants or industries.

This suggests a need of an equipment or a device which can be used by a normal user to get the quality of water remotely in a hassle free way on some simple and user friendly application. Such a device can enable the user to be assured of quality of water anywhere. Our aim is to develop a device that can the above issues effectively and be operable remotely so that we can monitor on the quality of water at regular intervals without any human intervention.

2. PROJECT OVERVIEW:

We are planning to come up with a device which can calculate some of the major water quality analysis parameters like temperature, pH and oxygen reduction potential. These parameters can help determine the quality of water to a certain degree and based on the reported parameters we can give suggestions about the proper and appropriate usage of water being tested. All the above mentioned parameters can be determined by using special sensors and probes.

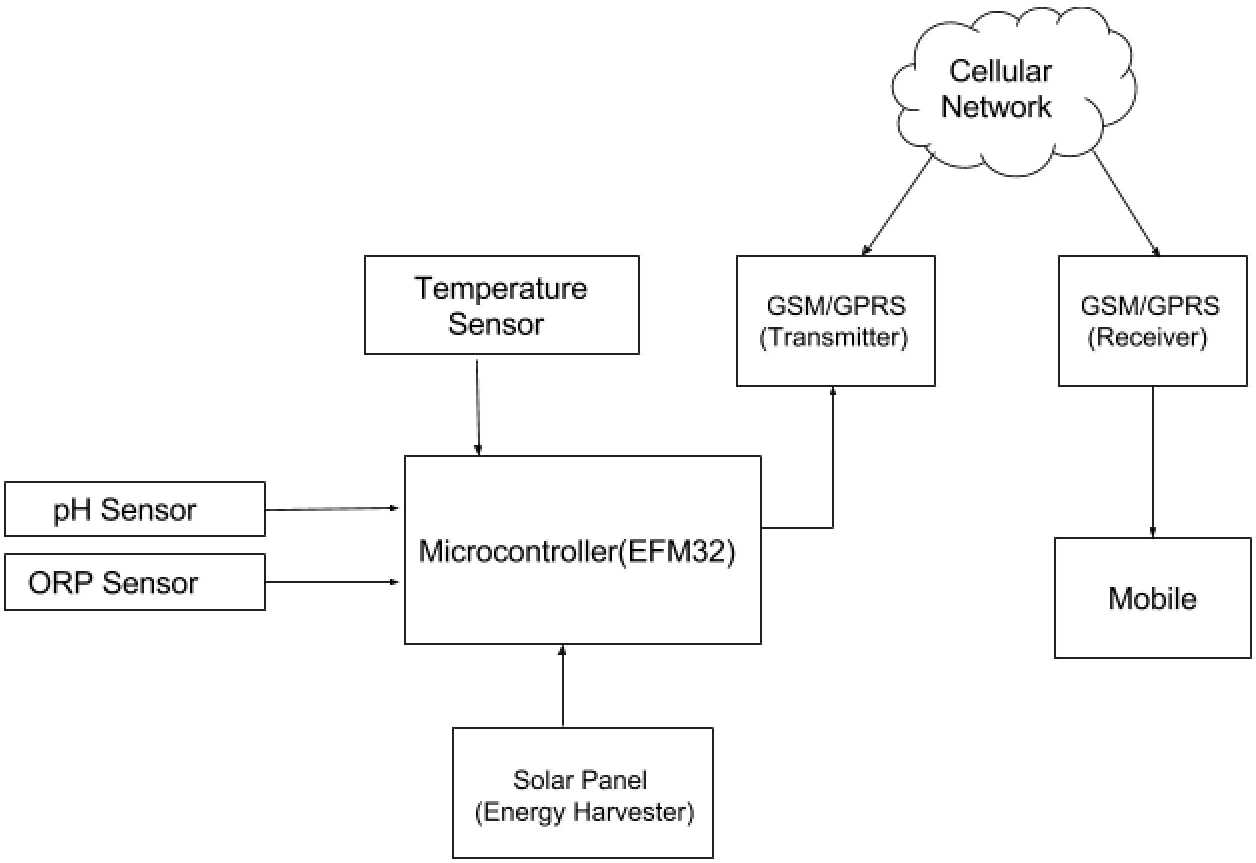
There are several other parameters that are associated with water quality as well such as conductivity,salinity, dissolved oxygen level, turbidity etc. Since our aim is to create a functioning model we have limited our scope to the three most important parameters in water quality analysis.

The idea is to create a device that will be operational remotely and can gather and send the required data at regular intervals of time without any human intervention. For this purpose we are using the SIM808 (GSM) module to send data from the device in the form of text.

The pH,ORP and the temperature sensor have specialized probes that will be dipped into the water body to perform computations and return the values. All the values are then sent to the SIM808 module which will transfers the data to the predefined number.

Since this will be a standalone device we will interface a solar panel to harvest energy and then charge the battery.

3. HARDWARE BLOCK DIAGRAM:



There are 3 probe based sensors - pH, ORP and water temperature sensor are used to measure the quality of the water. These reading are taken sequentially by the microcontroller and stored in a buffer. This buffer is then used to construct a text message which is then transmitted to the mobile phone in form of text message. The transmission is done using a GSM/GPRS module over the network. We are performing load power management in our system to conserve energy. The energy harvesting system in our design consists of the solar panel.The power management system works in such a way that if enough energy is available from the solar panel then current is not drawn from the battery. Once all the data is gathered from the sensors then the data is sent over a GSM network to the desired phone number.

4. COMPONENTS USED

- **MCU**
  Part: EFM32 Leopard Gecko
  Part Number : EFM32LG980F256G-E-QFP100-ND
  The EFM32LG Leopard Gecko is the ideal choice for demanding 8-, 16-, and 32-bit energy sensitive applications. With a broad selection of 5 energy modes supported by this MCU, and short wakeup time between 2 energy modes, applications can dynamically minimize energy consumption during program execution. It also has low energy interfaces and components (LE-UART,LE-TIMER ,etc) that further help to decrease the energy consumption

- **GSM Module**
  Part: SIM808
  The SIM808 module communicates with the microcontroller through the low energy UART communication line (LEUART). This module is suitable since it can be easily interfaced with a SIM card. It has different indicators for the network status and power status. The SIM module can be turned on and off using the powerkey as well.

- **pH Sensor**
  Manufacturer: Atlas Scientific
  The pH sensor module consists of a pH circuit and a pH probe which can be dipped in water and measurements can be taken. The pH probe is a passive probe which consists of an electrode when dipped in a liquid produces a voltage based on the hydrogen ion activity in a liquid. The tip of the electrode has a glass membrane which permits hydrogen ions from the liquid being measured to diffuse into the outer layer of the glass. The communication between the controller and the pH circuit is through UART communication line. The pH circuit is connected to the pH probe through a BNC connector.

- **ORP Sensor**
  Manufacturer: Atlas Scientific
  The ORP sensor also works on the same principle as the pH sensor and includes a ORP circuit and a ORP probe with a different type of electrode. The ORP electrode is used to measure the electron activity instead of the hydrogen ion activity. The communication with the controller and the connection between the ORP circuit and the probe is done the same way as the pH sensor.

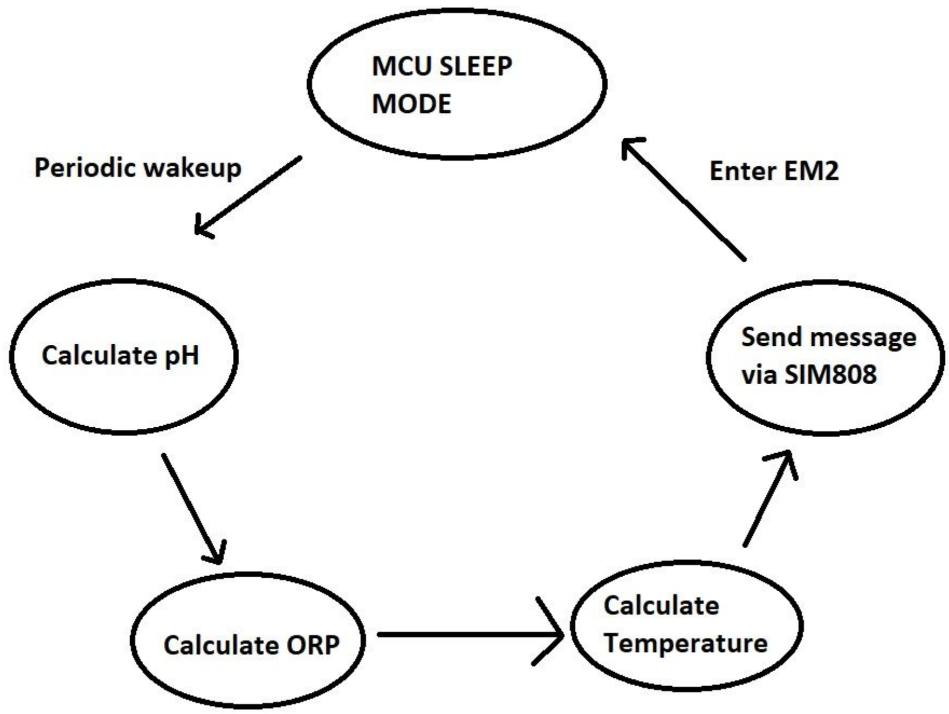
- **Water Temperature Sensor**
  Part Number:DS18B20
  The water temperature sensor runs on a one wire interface where just one wire is used to send and receive data to and from the controller. The temperature sensor has a sealed tip which allows us to measure temperature even in wet environments. The sensor has a 9 to 12 bit configurable temperature readings.

- **Energy Storage Device**
  Manufacturer: Adafruit
  In this project we are making use a rechargeable Lithium Ion battery of 1200mah. Based on the use case model of our project we feel the capacity of the battery is more than sufficient capacity and the battery will be used to power up the GSM module directly and is also connected to the PMIC. We are making use of load power management to limit the discharging of the battery.

- **Energy Harvesting Device**
  In our project we are making use of a solar panel as the energy harvesting device which produces a current of 0.3A at a regulated voltage 5.0V. The solar panel will be connected to the board through a micro USB connector. The PMIC is used to charge the Li-Po battery from the energy harvested from the solar panel.

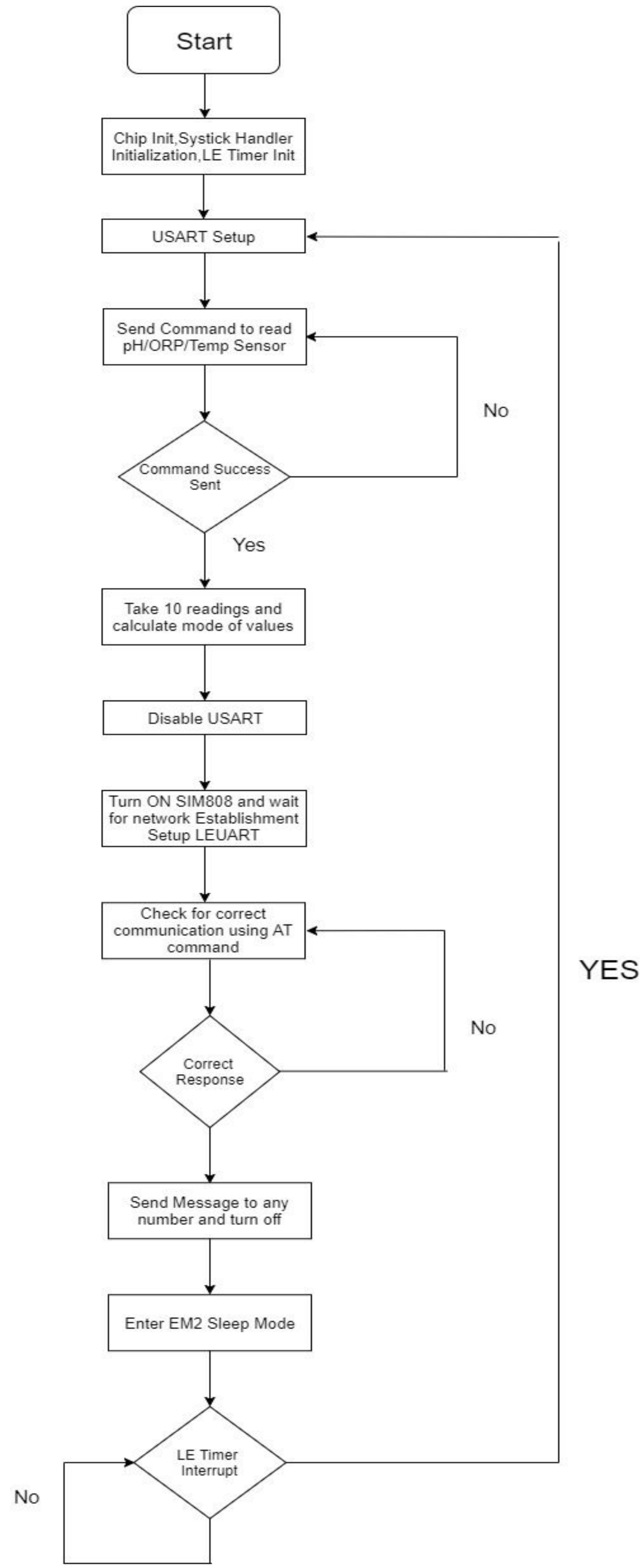
- **Power Management IC**
  Part: LTC 4160
  Manufacturer: Linear Technology
  The power management IC LTC 4160 are high efficiency power management and Li-Ion/Polymer battery charger IC's. It includes a bidirectional switching power path controller with automatic load prioritization, a battery charger and an ideal diode. The LTC4160's bidirectional switching regulator transfers nearly all of the power available from the USB port to the load with minimal loss and heat which eases thermal constraints in small spaces. These devices feature a precision input current limit for USB compatibility and Bat-Track output control for efficient charging. Also the LTC4160 has a 3.3V pin which can be used to power up the microcontroller.

5. SOFTWARE FUNCTIONAL BLOCK DIAGRAM



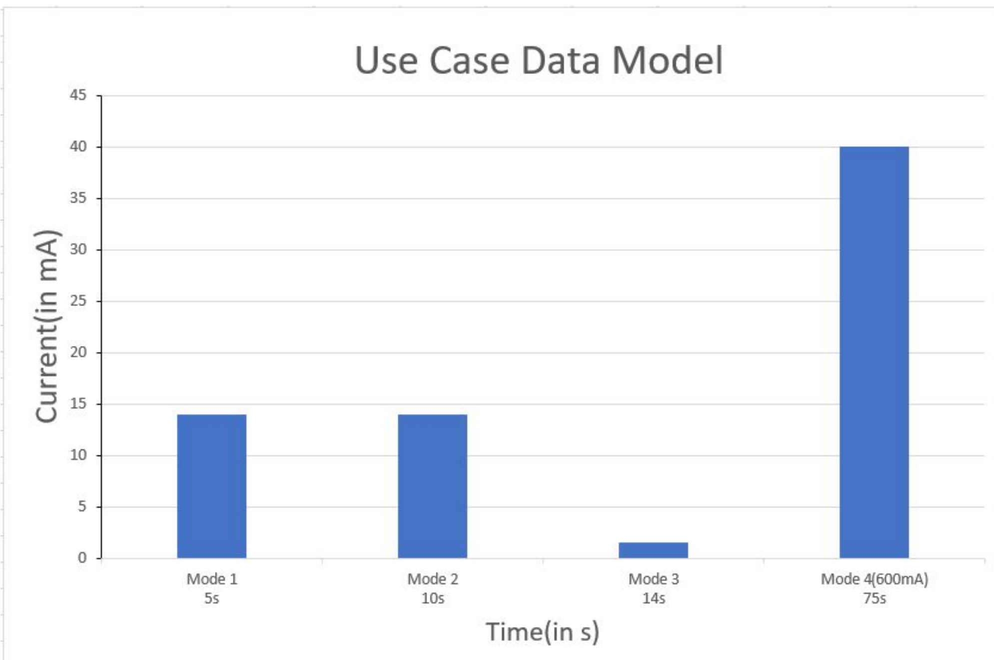
This system is going to run in a cyclic manner periodically 4 times a day based on a timer. The processor wakes up from the sleep, takes reading from all the 3 sensors and sends the message through the GPRS module and goes back to sleep. The cycle begins by first initializing the EFM32 controller first and setup the leuart. Then USART setup is done. First we initialize the pH sensor and run it for a cycle for 10 seconds for 10 readings. Next we run the ORP sensor for 10 seconds for 10 readings. Finally the temperature sensor is run for 10 iterations. In all the readings we take the mode of the value and then store the data. Now all the readings are transmitted via a cellular network using the SIM808 module. The message is sent to a predefined number. This entire cycle runs approximately for a period of one minute. After the data is sent the SIM808 module is turned off and the MCU enters EM2 mode. This is done to conserve energy and simultaneously the energy harvester will be charging the battery.

5.1 Initializing and Testing Sequence



6. ENERGY USE CASE MODEL

We basically divide the energy consumption rates into different modes. Once the MCU is turned on and the application begins the first mode is the powering up of the pH sensor in Mode1. Next the ORP sensor is turned on which runs in Mode 2. The energy consumption of both the pH and ORP sensor is the same. In the next mode the temperature sensor is turned on. In the last mode the GSM module is turned on and the data is sent to the designated cellphone. The use case model can be represented in terms of a graph as follows:



The above cycle runs four times a day at six hour intervals. Since each cycle lasts for about 75 seconds, the four cycles in total will add up to 300 seconds i.e 5 minutes in a day.

The energy harvesting device is out in the open all day and hence can gather and store energy as long as sunlight is available.

6.1 Energy calculations

The GSM module in our design consumes the highest amount of current i.e 2A current in bursts for a period of 500us until the network is established. We are making use of one battery for all our energy requirements. The battery is Li-Po rechargeable battery of a capacity of 1200mAH.

Mode 1:
pH + Microcontroller + GSM(sleep) = 80 + 0.6+ 4.4 = 85 mW
Energy = 85 * 5 = 425 mJ

Mode 2:
ORP + Microcontroller + GSM(sleep) = 80 + 0.6+ 4.4 = 85 mW
Energy = 85 * 5 = 425 mJ

Mode 3:
Water Temperature Sensor + Microcontroller + GSM(sleep) = 8.25 + 0.6+4.4= 13.25mW
Energy = 13.65 * 4 = 54.6 mJ

Mode 4:
Microcontroller(negligible) + GSM = 2.64W
Energy = 2.64 * 60 = 158.4 J

One Cycle(75 s):
Battery = 425*2 + 54.6 + 158.4*1000
= 159.3046
= 160 J (approx)

Four cycle in a day = 160 * 4 = 480 J

Sleep mode (86100s):
Total Power= 5mW
Battery = 380 + 52 = 432 J

Final Energy Consumption:
Battery = 432 + 480 = 912 J

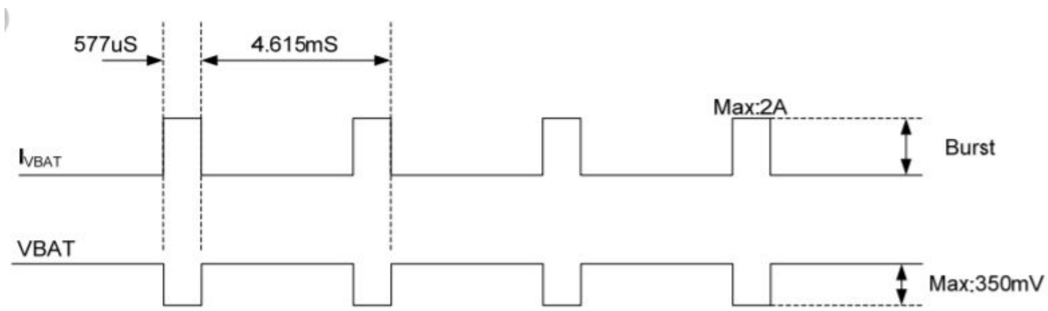
6.2 Storage element selection

Our energy storage element is a solar panel which we think will have a charge time of 9 hrs daily on average , but on rainy or snowy days there can be zero hours for charging. For the longer life of the batteries we want make sure that the batteries don't discharge less than 90% of its full capacity. Considering days with no sunlight we want batteries that have more capacity than 10 times the total energy it can draw in a day. Hence we keep it 15 times.

The maximum current requirements of various parts are as follows-
pH sensor- 16mA
Water sensor- 1.5mA
ORP sensor- 16mA
GSM module - 2A
Total Power Consumption = 912 * 15 = 13680 J

Hence based on the max current and energy requirements the final batteries chosen are-
Battery- Lithium Ion Polymer Battery 3.7V 1200mAh

6.3 C-rate calculations
LiPo battery configuration = 1200mAH, 3.7V, 1C
Peak current required by GSM module = 2A
Hence we need a capacitor to provide the 2A peak current.



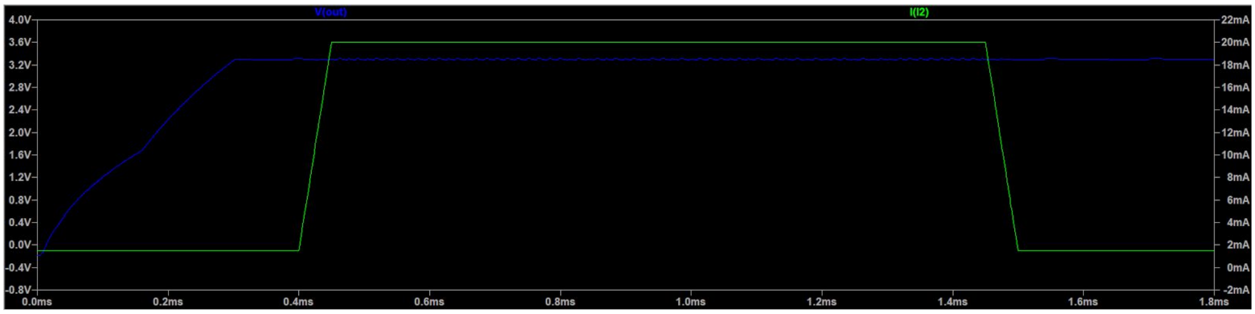
From the graph we can see that for the pulse:
dt= 577 usec, I = 2A, dV=3.7V- 3.5V(GSM voltage should not fall below 3.4V)= 0.2V
From the formula we have, $C = i*(dt/DV) = (2*577*10^{-6}) / 0.2$
$C = 6mF$
Hence we see that we should use a 6mF capacitor in parallel. But it is important to verify if the gap between pulse is enough to charge the capacitor back.

From the graph we can see that for the charging time:
dt= 4.6msec , dV= 0.2V, C= 6mF
I = (C*dV)/ dt = (6mF* 0.2V)/ 4.6ms = 0.26A
As the battery can give a max current of 1.2A hence this capacitor can be charged in the given time.

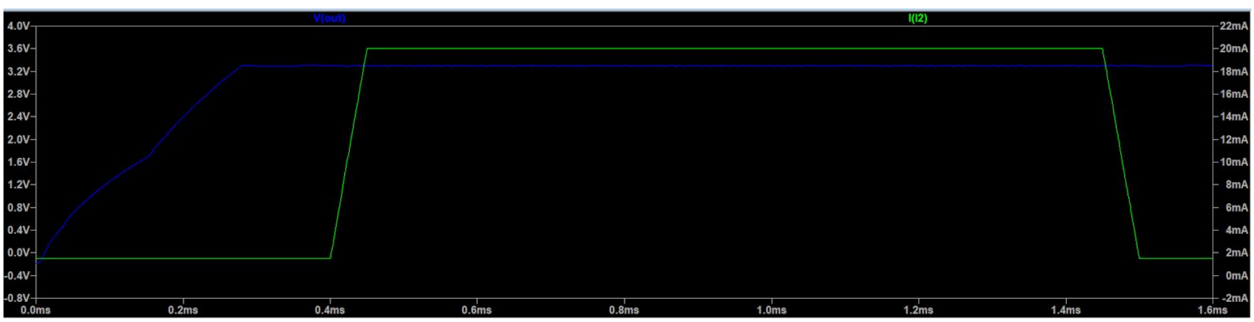
6.4 Power simulations

MCU simulations-

The current need of the MCU is minimum (20mA) and hence according to the simulation the voltage drop is minimal. And hence there is no need for any capacitance in this case.



3.5V

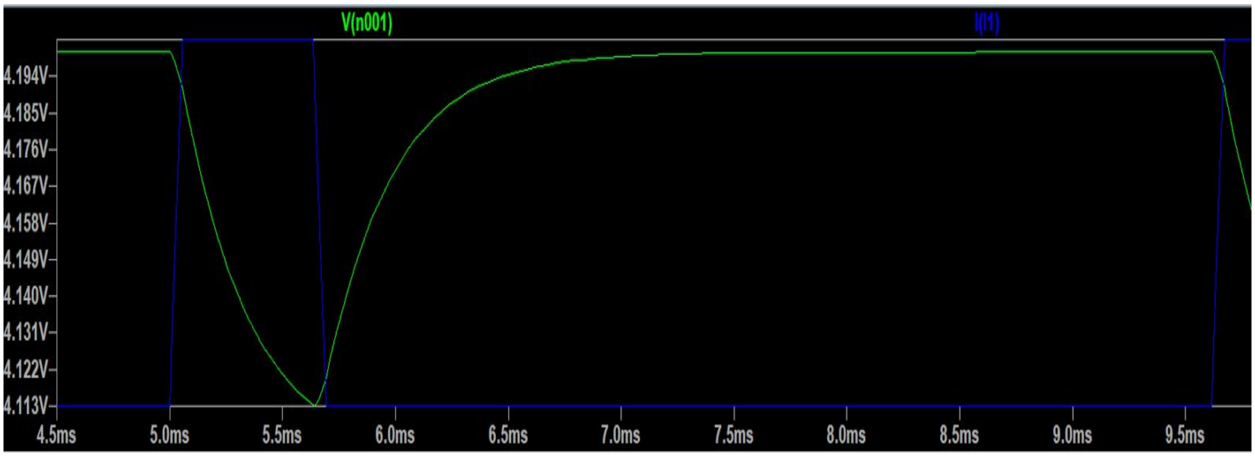


4.2V

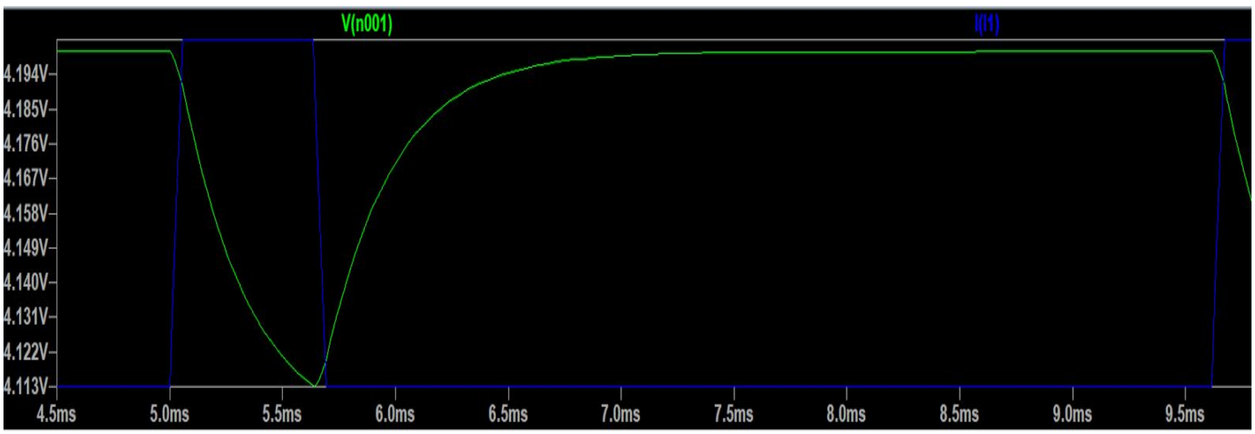
In both the cases for 3.5V and 4.2V it is clear than no voltage drop and hence it is sufficient for the MCU.

SIM808 simulations-

As the SIM808 requires a peak current 2A, hence we have to find a capacitor which can support this sudden increase in current and the system does not shut down. Based on the rate of change in voltage and the time for this current rise we find that the capacitance is 6mF. After selection of the capacitor we also performed simulations on LTspice to make sure if the voltage doesn’t fall below the specified voltage level of SIM808.



4.2V



3.5V

The above simulations are for the 3.5V and 4.2V which are extreme cases for the supplies.

6.5 Selection of capacitor

For our design we have chosen a capacitor of 6mF capacity. This capacitor is an electrolytic capacitor i.e a polarized capacitor.This capacitor has an operating voltage of -55 to 105 degree celsius. The rated DC bias voltage is 35V. The capacitor also has a low ESR and has a leakage current of 0.01CV where C is the nominal capacitance and V is the rated voltage. The lifetime of the capacitance is 5000 hours when operating at 105 degree celsius. This capacitor perfectly matches our design.

7. PLANNED DEVELOPMENT SCHEDULE

Task/Activity	**Planned Completion Date**	**When Completed**
Component Selection	8/5/2017	8/5/2017
Initial Firmware Setup	8/11/2017	8/11/2017
PMU Selection and Energy Calculations	8/20/2017	8/20/2017
Altium Project Schematic	9/15/2017	9/25/2017
Power Management Simulation	10/4/2017	10/4/2017
PCB Layout	10/30/2017	11/5/2017
Sensors Testing with Dev Kit	11/8/2017	11/8/2017
Board Assembly	11/15/2017	11/15/2017
Testing Board	11/25/2017	12/5/2017
Porting Firmware on PCB	12/5/2017	12/8/2017
Testing application with energy harvester	12/10/2017	12/12/2017

8. VERIFICATION PLAN

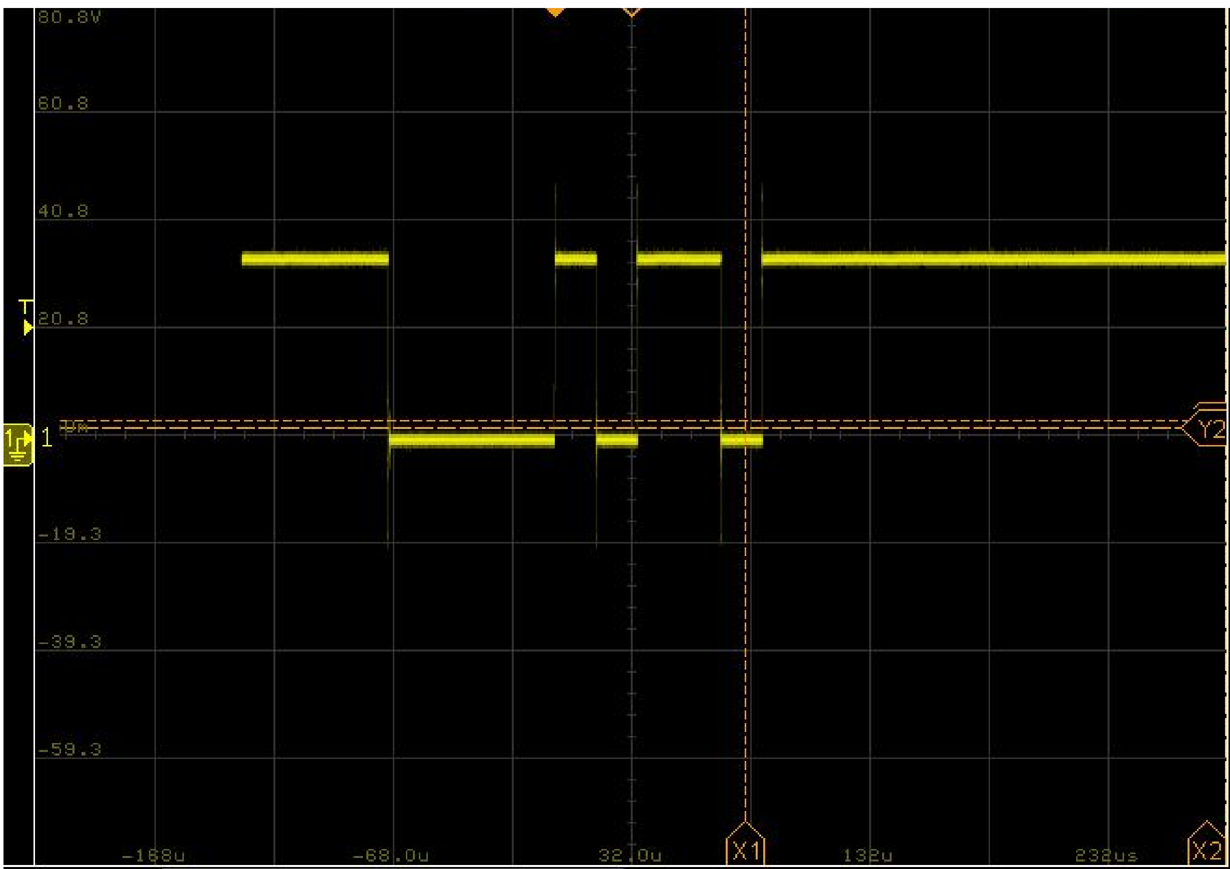
Following is the verification plan:

To be Verified	Definition of Passing	Date test performed	Tested by	Measured Result	Passed
Power Supply Voltage (min and maximum)	Minimum voltage = 3.5V Maximum Volatge= 4.2V	21-Nov	Shreyas	Getting accurate voltage	PASSED
Signal Quality of UART communication line	Check correct signal level transition on oscilloscope	25-Nov	Omkar,Shreyas	Verified on ossiloscope and also by connecting RX,TX on Realterm	PASSED
Energy Harvesting Element Charging	Checking 300mA current at 5V regulated output at the VBUS test point	2-Dec	Omkar, Shreyas	Getting required current and voltage and power LED on PMIC also turns ON	PASSED
Energy Storage Element Charging	Check on the BAT_CHG test point for current of 300mA at 3.5V	2-Dec	Omkar, Shreyas	Getting 4.2V which enough for charging and charging LED also turns ON	PASSED
Booting up of power as energy storage element goes from low to high voltage	Check whether the voltage level at LDO3v3 pin is 3.3V and also the voltage at VOUT signal is at a minimum of 3.7V	2-Dec	Omkar, Shreyas	Correct voltage tested	PASSED AFTER CORRECTION
Shutting down of power as energy storage element goes from high to low voltage	Check for the dropping down of voltage level to zero at LDO3V3 and at VOUT	2-Dec	Omkar, Shreyas	Correct voltage tested	PASSED AFTER CORRECTION
Sensors providing correct values to MCU	Check on the leopard gecko development board for correct operation	8-Dec	Omkar	Able to read expected values , compared with the reading of serial to USB converter	PASSED
Antenna to transmit and receive signals	Check the NETSTATUS LED once SIM808 is powered up	5-Dec	Omkar, Shreyas	The chance in frequency of blinking of the net-status LED verifies that module registers on the network and hence antenna works	PASSED
Booting up of the system without the energy storage element	Check whether the voltage level at LDO3v3 pin is 3.3V and also the voltage at VOUT signal is at a minimum of 3.7V	11-Dec	Omkar, Shreyas	Tested for correct voltages and also correct operation of SIM808 and MCU	PASSED AFTER CORRECTION
Load Capacitor functioning	Check for 2mA peak current at VBAT pin	5-Dec	Omkar, Shreyas	Correct current supply during network establisment. Verified on ossiloscope	PASSED
Funtioning of SIM808	Check STATUS LED after providing VBAT accurately	21-Nov	Omkar,Shreyas	Led turned ON and getting 2.8V at VDD_EXT	PASSED
Monitoring of Battery voltage on the MCUs GPIO	Correct handling and reading of the battery voltage at GPIO pin	4-Dec	Omkar,Shreyas	Failed as GPIO of MCU couldnot handle 3.7V voltage	FAILED
Programming of Leopard Gecko	Check if the program is getting uploaded and Debugged	4-Dec	Omkar,Shreyas	Uploaded a sample code for GPIO toggling and verified that it is working	PASSED

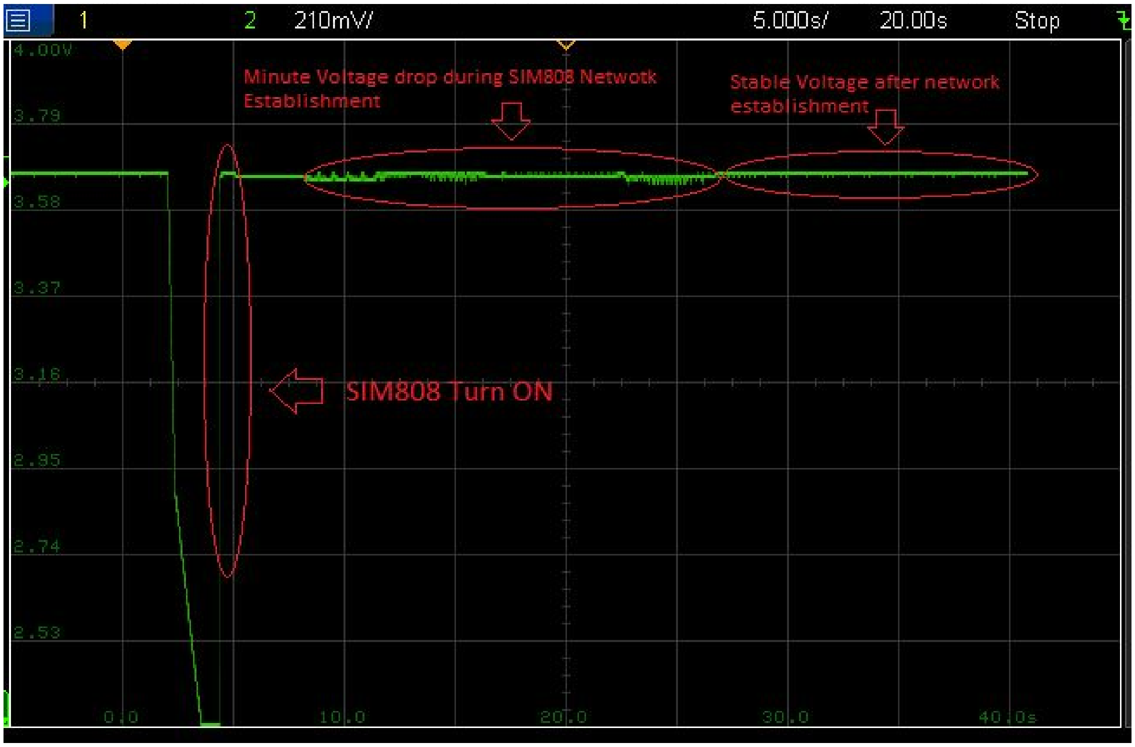
Funtioning of LTC4160	Check for the CHRG active low pin and functioning of LED	2-Dec	Omkar,Shreyas	LEDs turning ON correctly	PASSED
VDD pin for SimCard Holder	Check for the VDD before placing the simcard holder	8-Dec	Omkar	Worked but only after placing SIM	PASSED BUT OT AS EXPECTED
Power Up signal for GSM from the MCU	Probe on PWRKEY test point	10-Dec	Omkar,Shreyas	Worked partially but had to change resistor values	PARTIALLY PASSED
Power supply to sensors from MCU	Probe on the GPIO power pin of respective sensors for voltage of 3.3V	5-Dec	Omkar, Shreyas	Required voltage is supplied	PASSED

Important screenshots taken during verification plan:

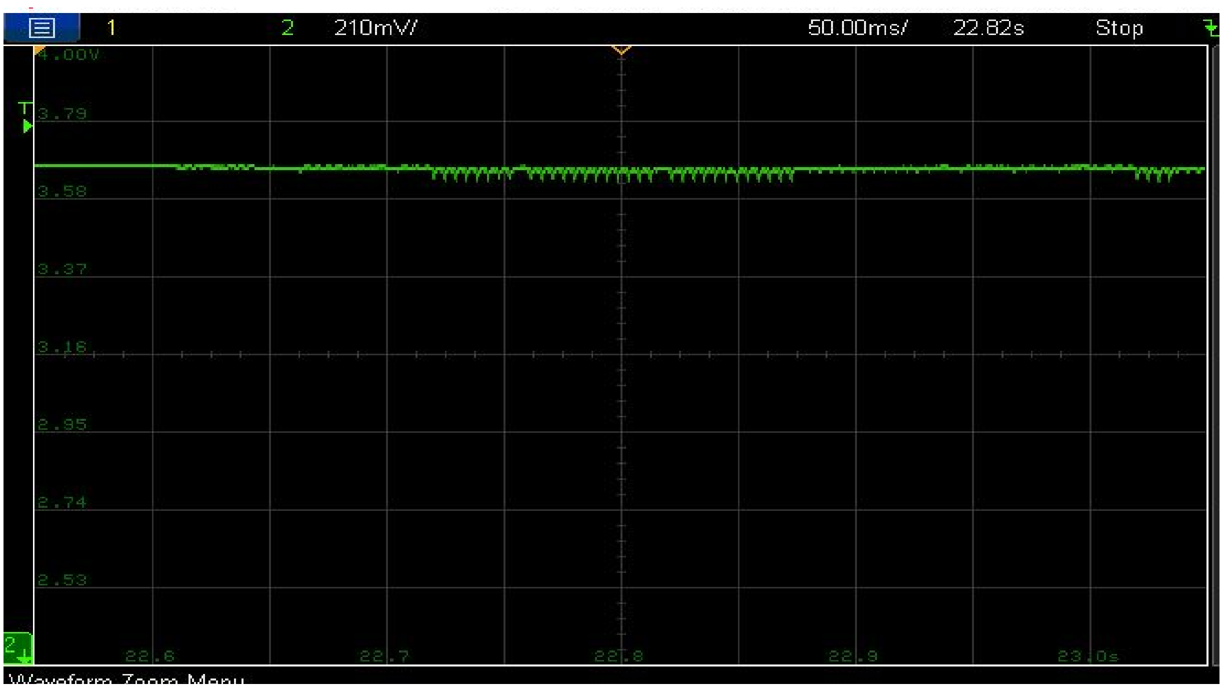
1) USART and UART lines checked for correct voltage level shifts. In the screenshot of character 0xA being transmitted in UART line is shown.



2) Voltage drop testing for SIM808 with the load capacitance



3)The voltage drop at the supply of SIM808 is minimal, which proves our load capacitor selection is correct



9. GENERAL ISSUES FACED

1) **Problem:** Initially we had decided to use a turbidity sensor and the current requirement of the turbidity sensor was quite high. We needed to make use a different battery for this turbidity sensor.
   Solution: Instead of using the turbidity sensor we decided to make use of an ORP sensor that has a much lesser current requirement. After making this change only a single battery was sufficient for our energy requirement.

2) **Problem:** We forgot to include the high frequency crystal HFXO in our design which is required to run the USART peripheral
   Solution: We decided to make use of the internal high frequency crystal HFRCO of the MCU.

3) **Problem:** We faced issues in generating footprints and some of the mappings between the pins of component and the signals were wrong.
   Solution: We should have taken care and verified the mappings between the pins and the signals to make sure the traces are right on the board. We had to cut the traces on the board and make external connections using wire.

4) **Problem:** We were testing our sensors on the development kit and the sensors were giving an undervoltage message because the voltage present on the GPIO pin on the MCU in high drive mode was less than the required voltage. Same problem persisted on the our PCB but the values it was reading were correct
   Solution: We implemented a software solution for this problem in which we filtered the Under voltage message that was sent by the sensor.

10. HARDWARE ISSUES FACED

1) **Problem:** The major difficulty we faced was resolving the shorts on the board between 3.3V and GND.
   Solution: First we had a look at our design to make sure there were no inherent flaws in the design. Since all the components are surface mount we made a list of all the components along the 3.3V trace and assigned priority to them trying to figure out the short. First we removed the decoupling capacitors connected to the 3.3V pin of the MCU and GND.Then we removed the resistors and inductors along the 3.3V.Both these steps did not resolve the issue. So then we decided to remove all the components along the path including any ESD diodes connected between 3.3V and GND. Finally we had to remove the MCU to resolve the short.

2) **Problem:** We replaced the MCU on one of the boards and once we made a connection between the battery supply and 3.3V supply pin of the MCU the short was introduced again.
   Solution: There was a flaw in our layout design. We had kept a connection between the GPIO pin of the MCU and the battery supply voltage to monitor the voltage level of the battery. This was at 3.7V and the maximum the MCU could handle was 3.3V. When we made the power connection between 3.3V and the MCU pin the MCU started heating up. We removed the jumper making the connection between the 3.3V pin and the MCU pin but still the MCU was heating up. Finally we traced all the connections from the battery supply throughout the board and eventually cut the trace between the battery supply and the MCU pin.

3) **Problem:** The connections of the USB connector were not right. The mapping for VCC and GND were swapped between the connection on the component and the component pin description.
   Solution: We had to cut out these traces and then make external connections through wires.

4) **Problem:** One of our PMIC’s got damaged because of the wrong connections we had made in the USB connector.
   Solution: We had to replace the PMIC’s on one of our board.

5) **Problem:** The terminals of the PMOSFET that was connected to the PMIC were wrong.
   Solution: This PMOSFET was an optional element added to the PMIC hence we decided to remove the PMOSFET.

6) **Problem:**Choice of the ESD diodes were incorrect. Even though the clamping voltage was enough. There were some reasons that they were conducting below the clamping voltage.
   Solution: Hence we decided to remove the ESD diodes.

7) **Problem:** The PWRKEY of the SIM808 module was not working right.
   Solution: The voltage divider circuit was not correct then we replaced the value of the resistor connected between GND and the PWRKEY.

11. SUMMARY

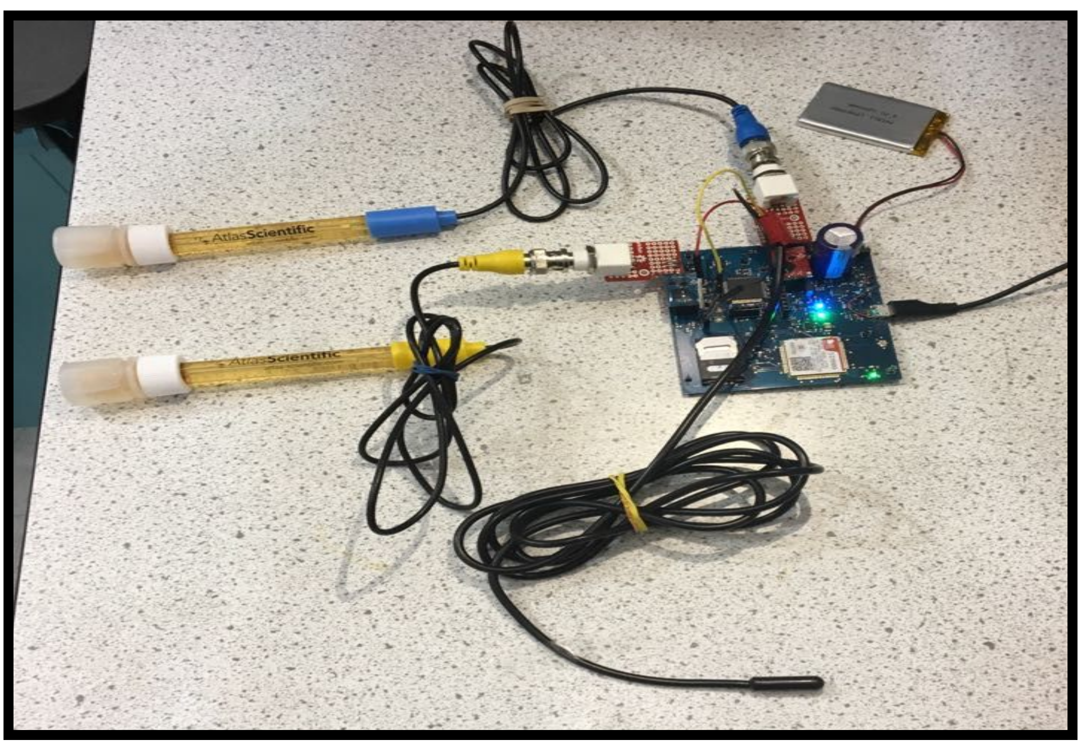
The functionality of the project can be summarized as follows:

1) The power management IC is functioning properly. The input voltage available from the battery is 3.7V. The voltage available from the energy harvester(solar panel) in direct sunlight is 5.1V. The LDO3V3 pin of the IC is also supplying regulated 3.3V to the MCU. The supply to the SIM808 module from the PMIC is also working fine which is at 3.7V.

2) The MCU is working fine with the pH sensor. The sensor is taking ten readings at the rate of one reading per second. The ORP sensor is also working fine with the MCU. This sensor also samples at the same rate as the pH sensor. Once all this data is gathered, it is sent to the SIM808 module.

3) The SIM808 is able to establish network properly and then send the data over the cellular network to the desired telephone number.

4) All these parts on the PCB are working fine together and based on the timer set in the MCU, periodically MCU can wake up. After waking up it can read the sensors and perform processing on it and send it to SIM808. And finally the SIM808 can send data read to any phone number. In form of text message.



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9) https://cdn-shop.adafruit.com/datasheets/SIM808_Hardware+Design_V1.00.pdf