University of Colorado
Boulder

LOW POWER EMBEDDED DESIGN TECHNIQUES

FINAL REPORT

05/06/2020

CHILD SAVER

Engineers:
Srinath Shanmuganadhan
Tim Chien

Project proposal

What is the project?

This project is to take care of the safety of a child when the child rides a bike. This project helps to keep the parent notified about the child if in danger. We plan to use a GPS, LTE Module and Accelerometer sensor, whose usages are briefly explained below:

- GPS Module: This module is used to locate the child's location. We also plan to set a boundary, such that if the child crosses the boundary the parent can receive a notification regarding this. Thus, making sure of the safety of the child.
- Accelerometer: This sensor is used for fall detection of the child, if the child falls off from the cycle, the parent will be notified using the LTE module.
- LTE Module: This module is used to send notification to the parents.

What problem does the project solve? Or, what value does it provide?

Child safety is a big concern for every parent in this world. Every parent wants to make sure that their child is safe whenever he's outside. To alleviate the stress and tension of the parent, this device sends notification to the parent when the child is in danger. This device makes sure that whenever a child is out of their house, the parents can be aware of the child safety and about their whereabouts

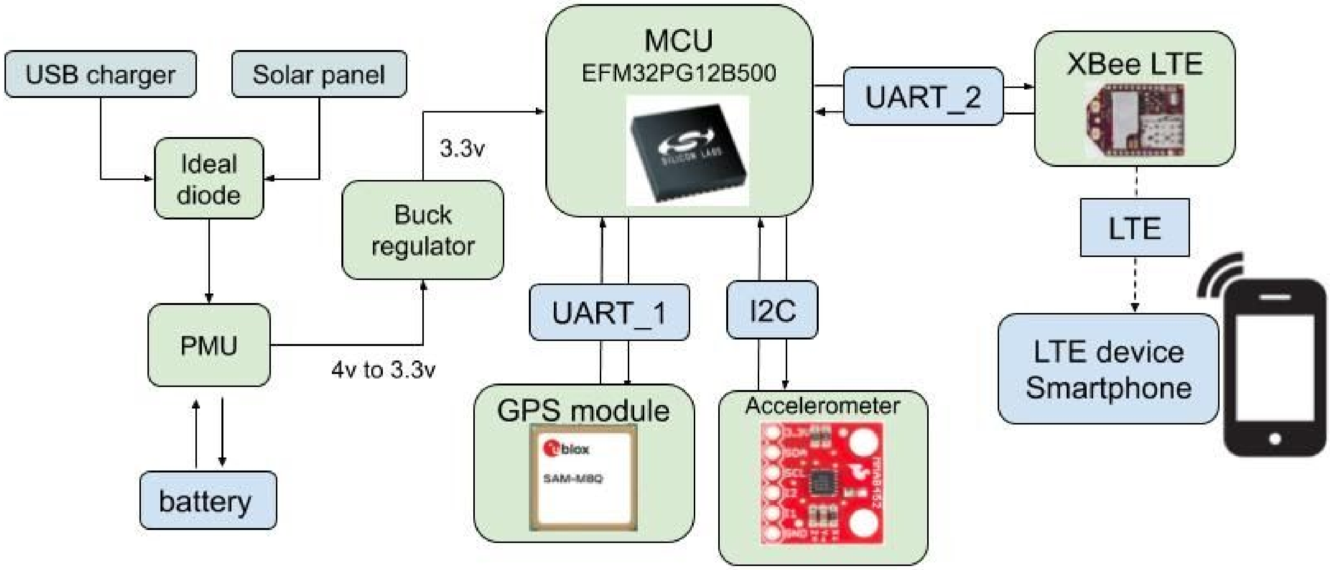
Features:

- MCU will control and communicate with all the peripheral chips and do the load power management to reach most efficient usage.
- GPS to collect location information in every 5 minutes, and transfer data to MCU with Low power UART
- Accelerometer to detect fall, and transfer data to MCU while children fall.
- LTE module to send notification to the parent
- Energy management IC to manage battery status and energy harvesting (Solar)

Specifications:

Dimensions: 80mmx60mm
Battery: rechargeable
Battery life time: 40 hr
Battery charge cycle: 5000 times
Temperature range: -10 °C ~ 40 °C
GPS Accuracy: 10~30 meters
Warranty: 1 Year

System Block Diagram



Component	Part Number	Function Description
MCU	**EFM32PG12B500F (EFM32 Pearl Gecko)**	This MCU is well suited for low power applications with multiple energy modes. It controls the flow diagram of the Child Saver, and communicates with peripheral chips to achieve the correct operation state.
Accelerometer	**MMA8452Q**	To detect the fall of the child. It will send an interrupt signal to MCU while detecting fall
GPS	**CAM-M8Q-0-10**	To get the positioning data of the device and track the child's whereabouts. Moreover, it has a geofence function for limiting child's activity area
LTE Module	**DIGI XBEE 3 Cellular LTE Cat 1 AT&T**	To send periodical notification to the user's cellular device every 5 minutes, and alert messages while child falls or crosses the boundary
Ideal diode	**TPS2111A**	It automatically switch USB charging power and solar panel power input, and output a power to PMU
PMU	**BQ24079**	To manage the battery charging and monitor the quality of the input power
Buck regulator	**TPS62822**	To convert an higher voltage unregulated power to a 3.3 volts regulated power
Battery	**LP103450JH 1s1p**	This battery can provide maximum discharging current 2C, with capacity 2000mAh
Solar panel	**SM141K10LV**	This solar panel can provide a 5 volts power to the system.

Hardware Design

Power Circuit Design

This section will explain how this circuit manages two power inputs and a rechargeable battery, and also how it provides a regulated voltage source to power the MCU and three peripheral chips.

The power circuit includes an ideal diode, a power management unit (PMU), a buck regulator, and their peripheral circuits.

- **Ideal diode and its peripheral circuit:** Reference: [TPS211xA datasheet]

  An ideal diode "TPS2111A" is used to manage two charge sources, a solar panel and a USB charger input. This Ideal diode enables seamless transition between two power supplies, each operating at 2.8 V to 5.5 V and delivering up to 1 A. It also includes extensive protection circuitry, including user-programmable current limiting, thermal protection, inrush current control, seamless supply transition, cross-conduction blocking, and reverse-conduction blocking.

  The peripheral circuit can be divided into 3 parts

  1. Current limiting: TPS211xA datasheet Page 4 & 17

     A resistor R_{ILIM} from I_{LIM} to GND sets the current limit to $500/R_{ILIM}$. While the value of R_{ILIM} is 400Ohm, the maximum current limit goes to 1.56A.

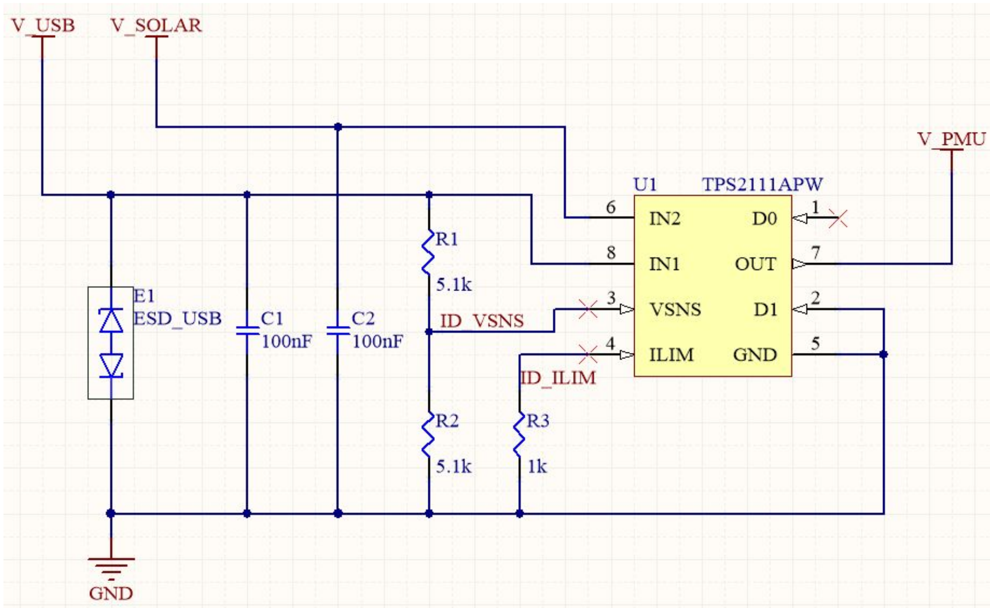
Current limit accuracy	TPS2111A	R_{ILIM} = 400 Ω	0.95	1.25	1.56	A
		R_{ILIM} = 700 Ω	0.47	0.71	0.99	

  2. Auto-switching mode TPS211xA datasheet Page 17

     While D0 is equal to logic "1" and D1 is equal to logic "0", the chip is configured as "auto-switching mode". In this mode, OUT connects to the first input source if the voltage level of VSNS pin is greater than 0.8v; otherwise, OUT connects to the higher of two input sources. Therefore, a voltage division circuit is used to provide an appropriate voltage to VSNS.

  3. RC circuit for input and output ports

     There are three places that need a filter circuit, two source input wires and the output wire. The component value selection of each input wire (a 0.1uF capacitor) and output wire (a simple RC filter: R: 50Ohm, C: 100pF) is followed in the datasheet.



- **PMU and its peripheral circuit:** Reference: [BQ2407x datasheet]
  A PMU “BQ24079” is selected to manage the battery charging process. The devices operate from either a USB port or an AC adapter and support charge currents up to 1.5 A.

  This PMU has several useful functionalities to manage the voltage and current for charging and discharging, moreover, a DPPM feature (Dynamic Power-Path Management) can help us control the source current between the system and battery charging and automatically reduces the charging current if the system load increases.
  Three special functions should be configured with specific hardware settings:
  BQ24079 datasheet Page 32

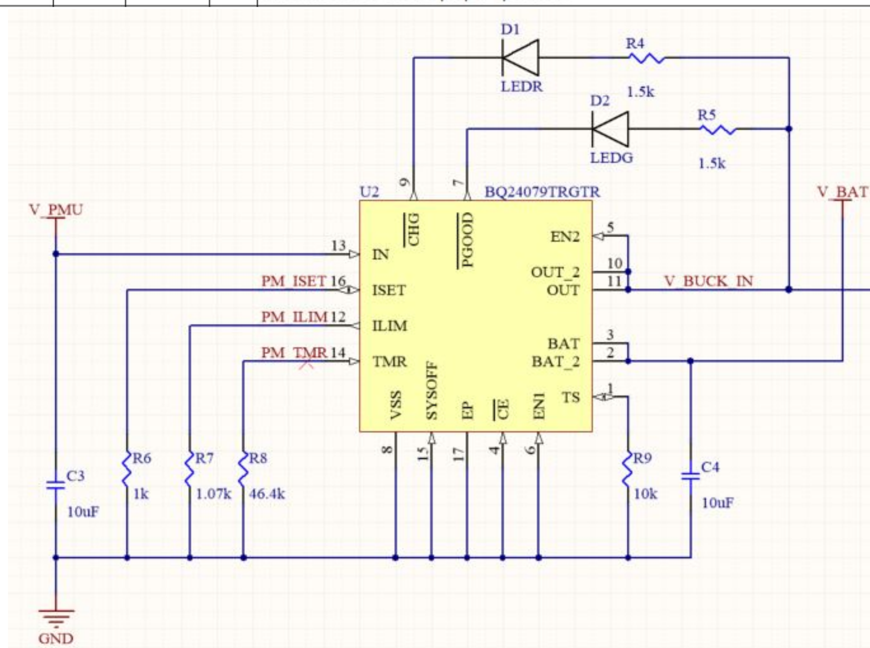
  1. Input current limit (ILIM)
     A resistor R_{ILIM} connected from ILIM to GND sets the input current limit to avoid the exceeded current breaking the circuit. The value of R_{ILIM} is selected with the allowable maximum current in our case. If the maximum current input is set as 1.5A, the value of R_{ILIM} should be 1033.3Ohm, and the closest value of resistor is 1.07kOhm, which can provide a 1.45A maximum current limit.

  2. Fast charge current (ISET)
     A resistor R_{ISET} connected from ISET to GND is used for limiting the charging current during the fast charging period. This maximum current should not exceed the maximum charging current of our battery, 960mA. Therefore, the maximum fast-charge current is set as 900mA, and the

value of R_{ISET} should be as close as possible to 989Ohm. A resistor with value 1kOhm is selected and provides a maximum current limit 890mA.

3. Fast-charge safety timer (TMR)
   A resistor R_{TMR} connected from TMR to GND controls the pre-charge and fast-charge phases to prevent potential damage to the battery and the system. The value of R_{TMR} is set as 46.8kOhm according to the datasheet to provide a 6.25 hours safety timer duration.
4. SYSOFF (connect to GND)

SYSOFF	–	–	15	I	System Enable Input. Connect SYSOFF high to turn off the FET connecting the battery to the system output. When an adapter is connected, charging is also disabled. Connect SYSOFF low for normal operation. SYSOFF is internally pulled up to V_{BAT} through a large resistor (approximately 5 MΩ). Do not leave SYSOFF unconnected to ensure proper operation.



- **Buck regulator and its peripheral circuit:** Reference:[TPS62822 datasheet]
  A buck converter "TPS62822" is used to convert an unregulated power source into 3.3v regulated power. This buck converter should provide enough current to the load system, especially the LTE module. It should be able to afford the current up to 1.5A, and its maximum current can be 2A.

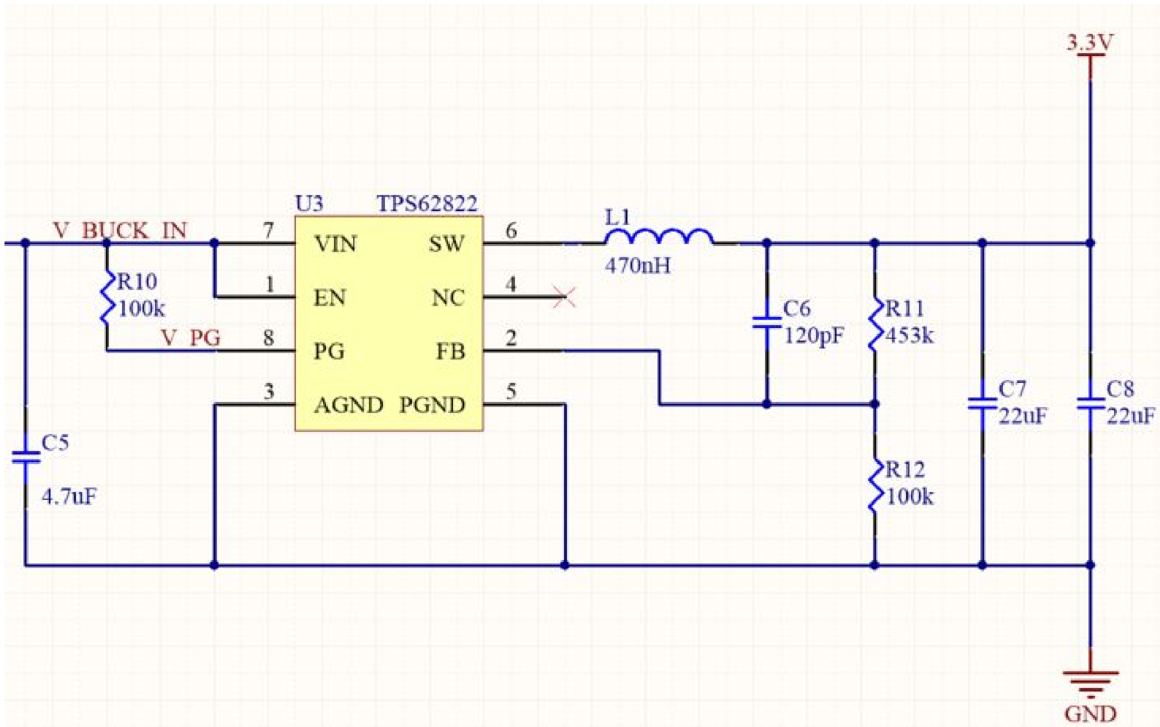
  Passive components selection: TPS62822 datasheet Page 10 to 14

  This chip also provides a voltage feedback feature to regulate the output voltage. A resistive voltage divider is connected to FB pin. The resistor values in this voltage divider should be low. Lower values of FB resistors achieve better noise immunity. The final voltage divider value is set as 453kOhm and 100kOhm.

  The bulk capacitor is very important to eliminate the ripple voltage on the load system. There is a ripple voltage specification in the LTE module, 75mV.

Therefore, the bulk capacitor is set as 22uF which will provide a 16mV ripple voltage, which is much smaller than that specification. The detail of bulk capacitor selection is shown in Appendix A.

Other passive components are selected according to the datasheet.



Central Circuit Design

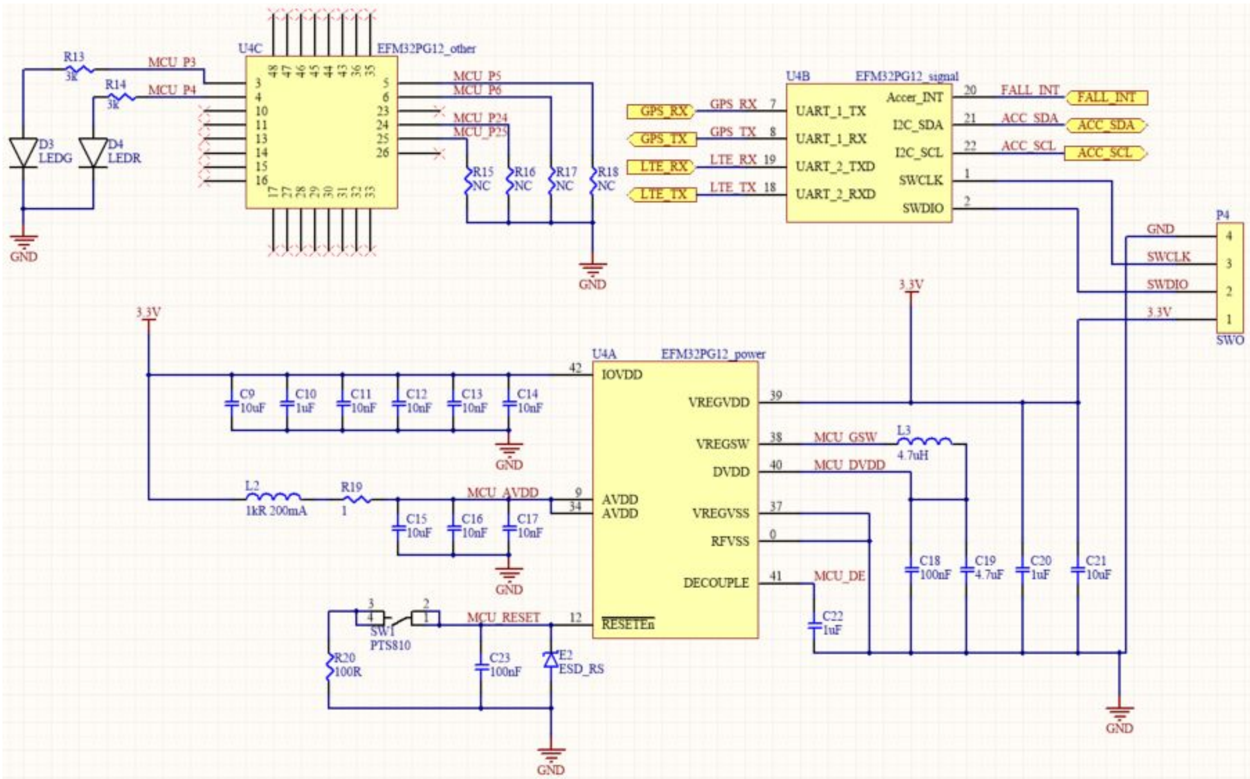
The central circuit includes a MCU "EFM32PG12" and its peripheral circuit. This section will show how we select those peripheral components and pins according to the "Pearl Gecko Development Kit" schematics.
This component is divided into two function parts, signal part and power part. The signal part includes GPIO pins for communication buses and bootloader function; and the power part consists of ground pins and power pins for MPC and GPIO operation

- Signal part:
  First of all, three communication buses are necessary to communicate with peripheral chips, one I2C, and two UART. Therefore, we use 2 GPIO pins for I2C, two GPIO pins for UART_1, and two GPIO pins for UART_2. The filter circuits will be designed in each peripheral sensor's schematics.
  A GPIO is set as an interrupt receiver to handle an interrupt signal from the accelerometer.
  Two special pins, SWDIO and SWCLK, are used as a bootloader and debugger.
  A SWD protocol is used for downloading the program into MCU

- Power part:

  This part can be divided into 5 different pinsets, ground, power for IO, power for processor, decoupling, and reset. All peripheral circuits in this section are designed according to the DK schematics.

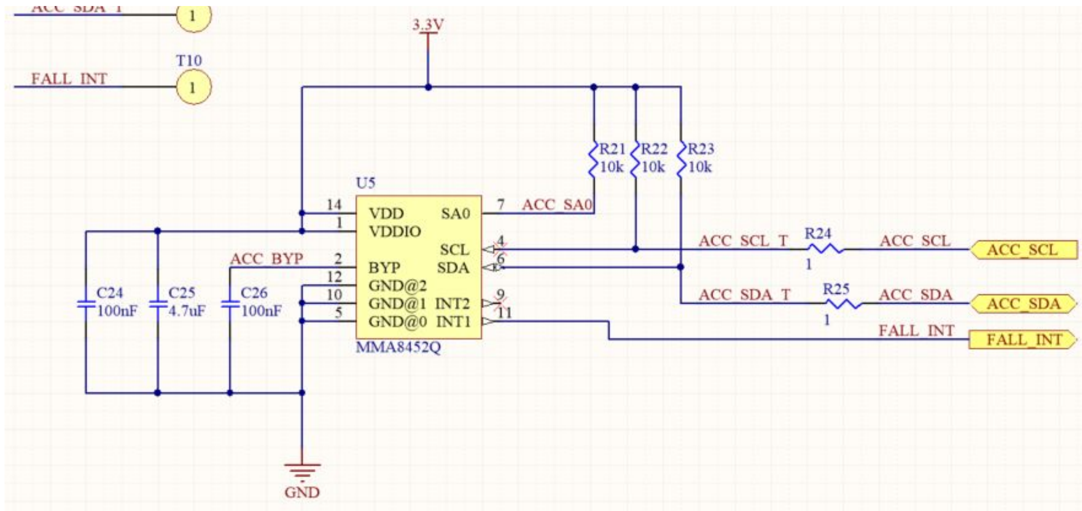
  The input voltage is a regulated 3.3V power from buck regulator IC. A reset circuit includes one button and a pair of RC.



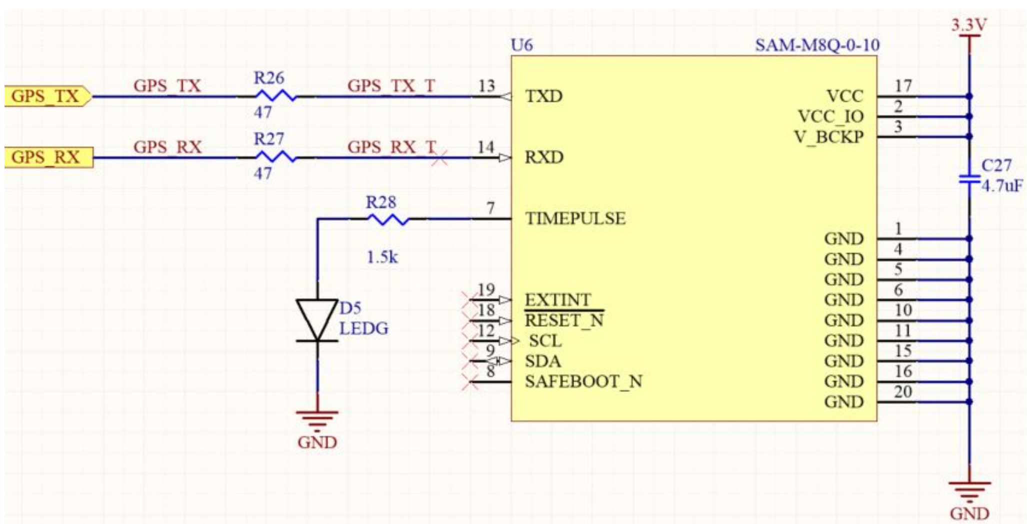
Peripheral Chip Circuits Design

Three peripheral chips with their peripheral circuits will be discussed individually in this section

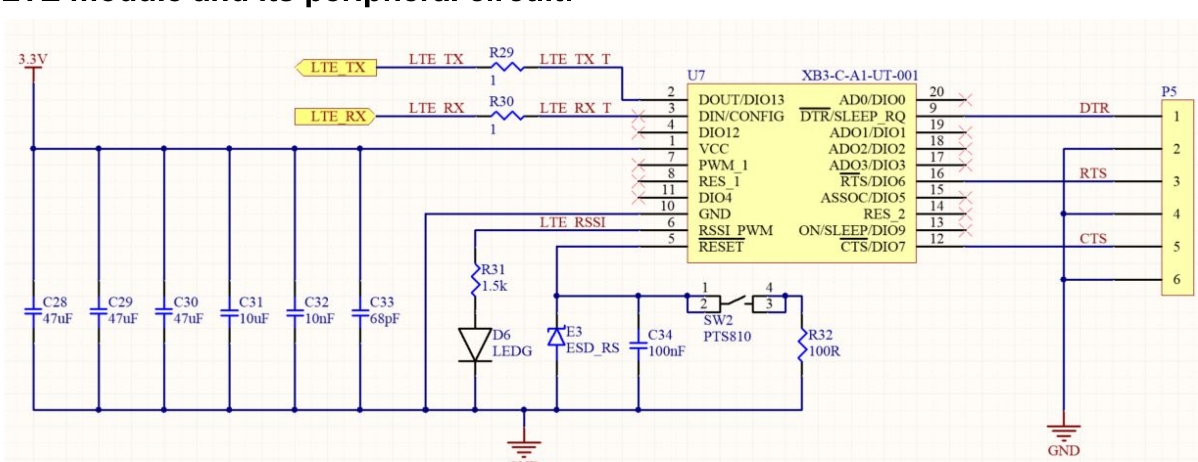
Accelerometer and its peripheral circuit:



GPS module and its peripheral circuit:



LTE module and its peripheral circuit:



Hardware Layout and Debugging Process

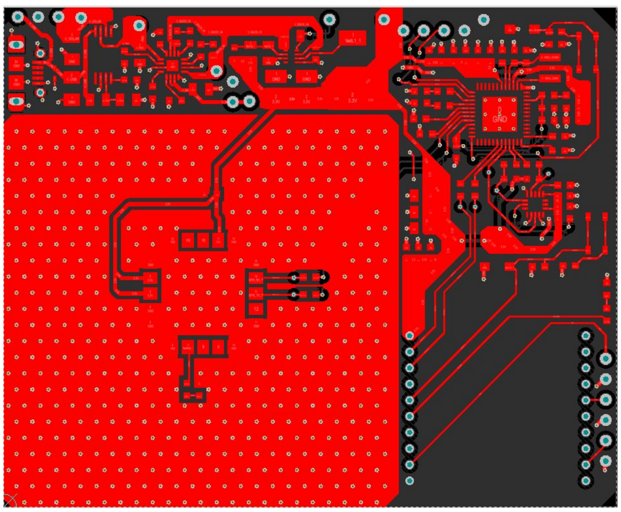
Layout and shortcut testing

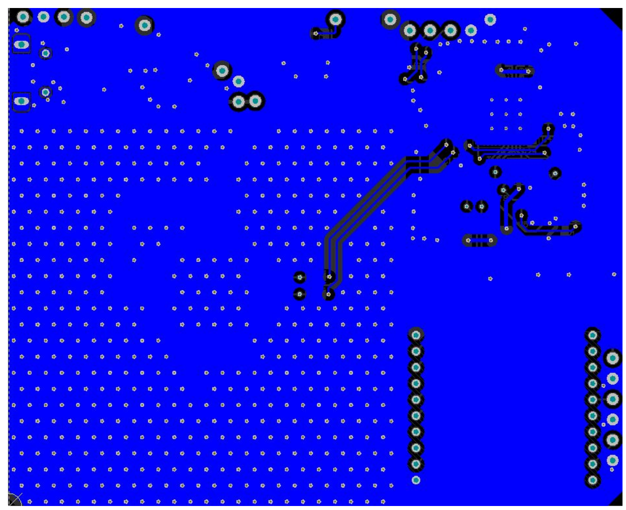
- **Layout:**

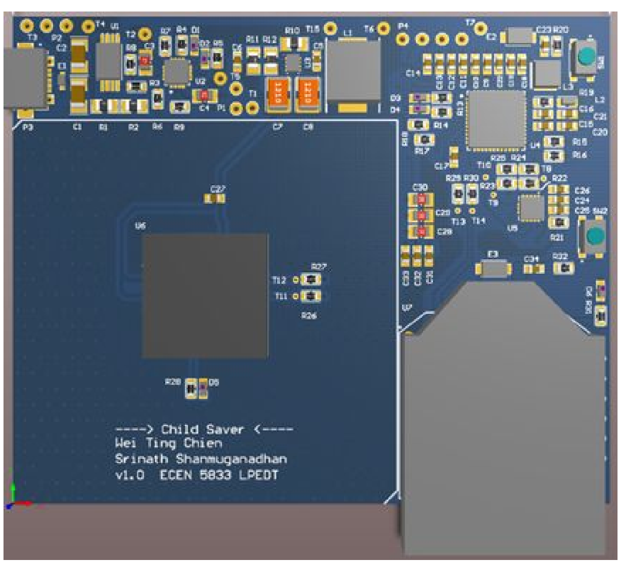
This is a 2 layers PCB layout. The bottom layer is a large ground panel, and with a few signal wires. And the top layer includes power pours and signal wires. One special point is the GPS needs a ground panel on the top layer as well, and it has a minimum size limit. Therefore, there is a large ground area for the GPS module on the top layer.

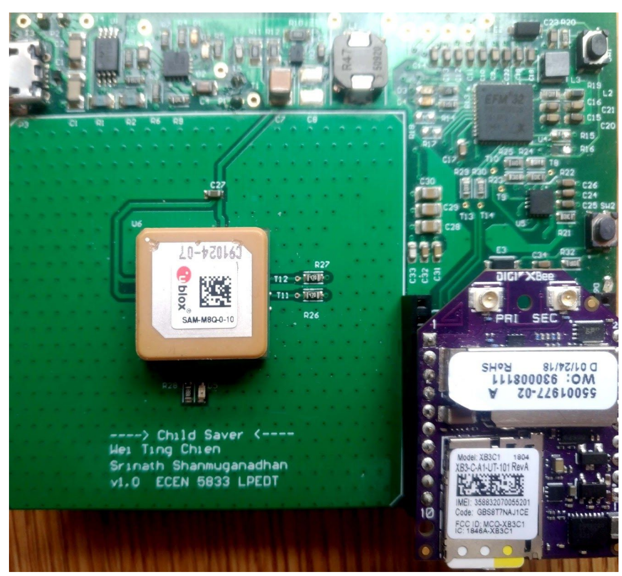
- **shortcut testing**

After the PCB fabrication, the PCBs should be tested for quality by the PCB shortcut testing before the soldering process.







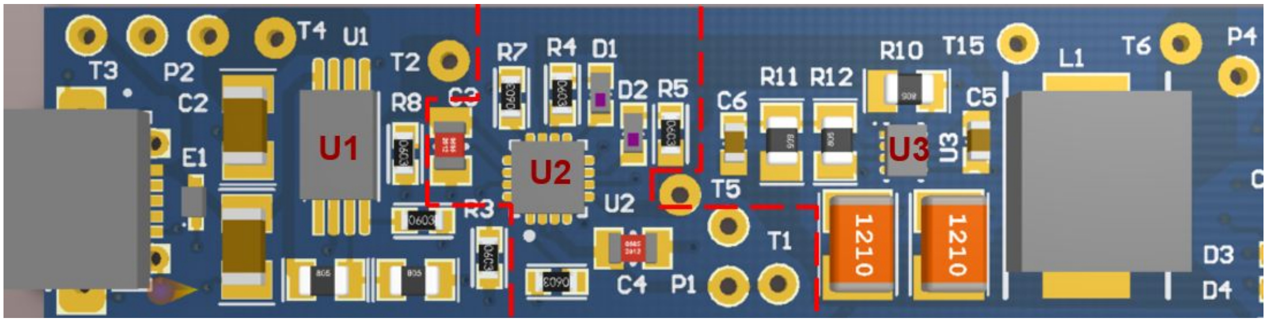


Power rail testing

After the soldering process, the power rail should be tested within the testing SOP and the test points set.

Test points set:

- **Ideal diode:** Solar power (T4), USB power (T3), PMU input-power (T2)
- **PMU:** BAT power (T1), Charging LED (D1), Power good LED (D2)
- **Buck regulator:** BUCK_IN power (T5), 3V3 power (T6), GND (T7)



Testing SOP:

- Power circuit (USB_CHARGING)

  CHG(D1) → 3V3 (T6) → V_BUCK_IN(T5) → V_PG(T15) → PGOOD(D2)

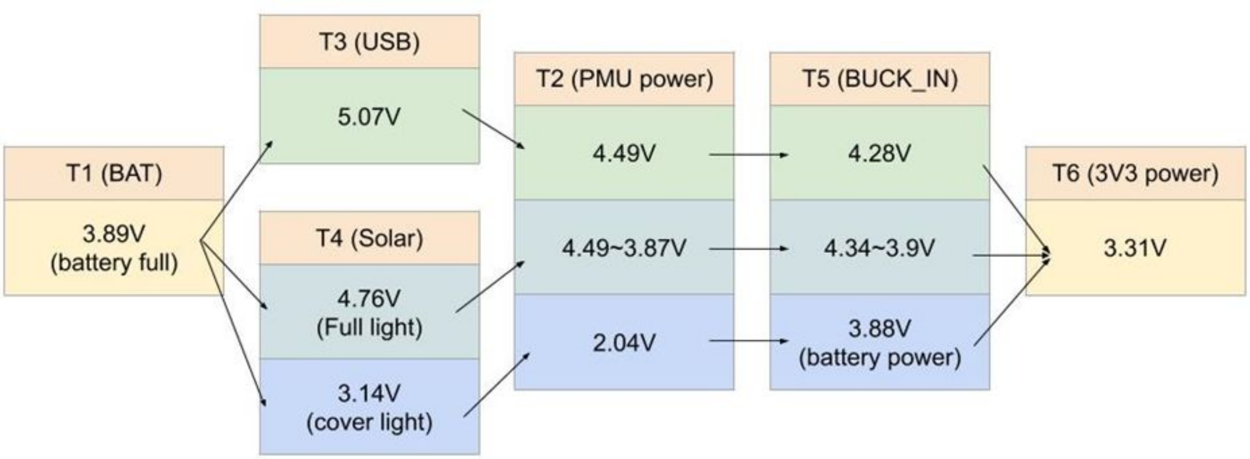
  → V_PMU(T2) → V_USB(T3)

- Power circuit (SOLAR)

  3V3 (T6) → V_BUCK_IN(T5) → V_PG(T15) → PGOOD(D2) → V_BAT(T1)

  → V_PMU(T2) → V_SOLAR(T4)

Power rail testing Result (Oscilloscope screenshots are in Appendix B)



Software:

Accelerometer:

The accelerometer has been configured for Fall detection. Whenever this sensor detects fall, it would trigger an interrupt in the MCU. The MCU will now send a message to the parents about the fall through LTE module.

GPS:

The GPS module will send the coordinates to the MCU, these coordinates will be sent to the parent mobile through LTE module.

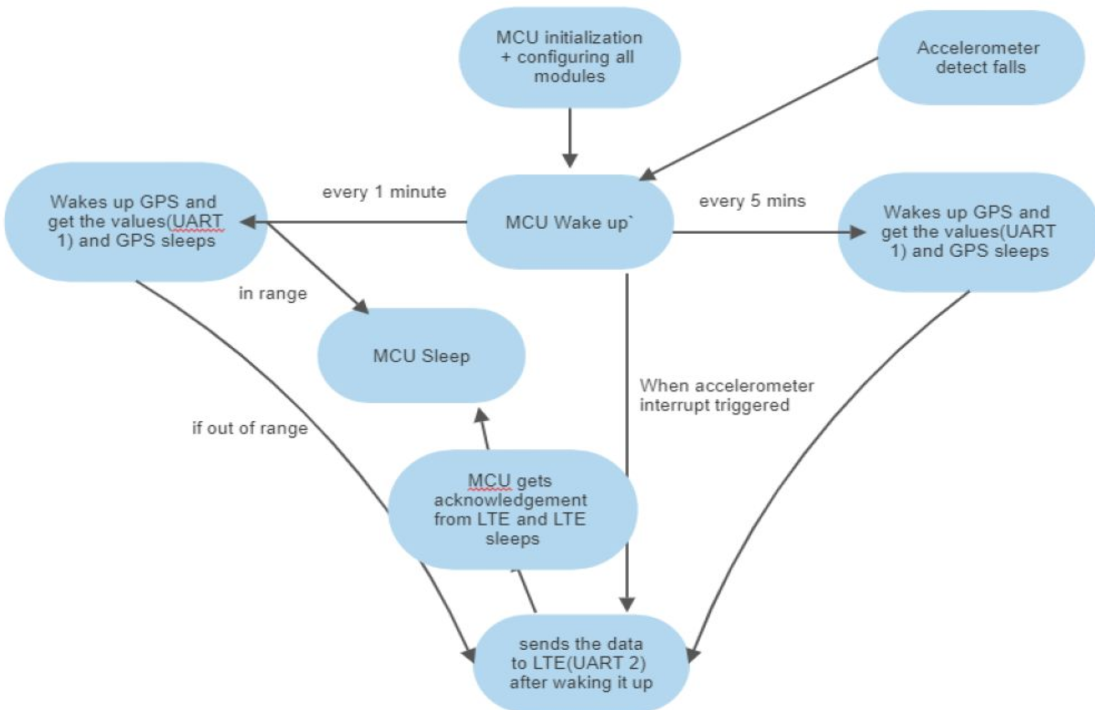
MCU:

The MCU sends commands over the LTE module whenever there is data given from any of the above sensors.

LTE:

This module acts in two modes: 1. Command mode 2. Transparent mode Initially all the configuration of the module is done is command mode like setting the baud rate, phone number of the receiver, to set the SMS protocol. Once these configurations are set, the module will be in transparent mode, where any message that is sent to this module will send it to the receiver phone. Desired messages for Fall detection and GPS are sent over transparent mode.

Software Flow Diagram:



Functionality:

We were able to get the LTE module and Accelerometer to detect Fall detection. Due to time constraints, the implementation of the GPS module to receive the coordinates was not completed. However, we did test the UART communication between MCU(Pearl Gecko) and GPS, the UART did work and we were receiving data from the GPS module. The LTE module was able to communicate with the cellular network. The communication of MCU to accelerometer was through I2C and communication from MCU to LTE module was done using UART. Whenever the accelerometer detect fall the information was sent through the receiver phone through UART

Difficulties Encountered:

Hardware:

1. Power rail components selection:
   It is hard to select all power management components to reach our product's specification. We need to learn how to select a suitable component with Digikey and how to read the components' datasheet. Moreover, we need to learn the fundamental knowledge to select the right components.

2. PCB layout:
   Getting a good layout is time-consuming. Several tries were made to get the desired layout which did cost us a lot of effort.

3. PCB assembly:
   Having to do our PCB assembly without a lab and without proper lab equipment was quite challenging, as we had to do PCB assembly with a fry pan and some simple tools.

Software:

1. GPS module: The communication to GPS module was using UBX protocol, the code to implement this module was complex as this was using a special protocol. Since the complexity was high we were not able to get the GPS module to work.

2. LTE module: The configuration of the LTE module was challenging as these were using special AT commands in order to configure the module. It was a bit hard to understand the working of this module using these commands.

Lessons Learnt:

Srinath:

1. Exposure to UBX protocol (special protocol) , which was used to configure the GPS module.
2. Understanding the working of LTE module and getting to learn about AT commands.
3. To keep track of your package after ordering the components, there are ways one's package would go missing if we do not track them.
4. It will be good to start your software process while your board is fabricated and not wait until the board arrives.
5. Always check your components if they are all available before you place your order, there are chances some of the components will be backordered during the time of purchase.

Tim:

1. Good practice in designing a product prototype from stretch
2. Well understand how to design a power circuit and the power chips selection
3. Good schematics practice
4. Good PCB layout practice
5. Good hands-on experience of soldering components
6. Good experience of hardware debugging

Appendix A Bulk capacitor selection

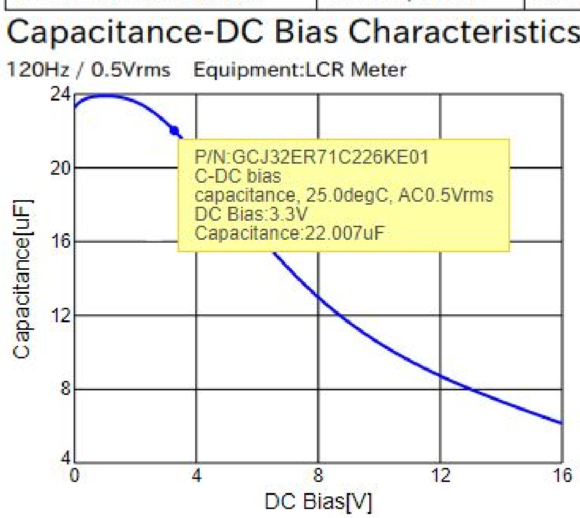
TI has provided simulation software for developers to simulate the current and voltage in specific cases. It is really useful when we use the TI buck regulator chip. A recommended simulation circuit is offered by TI webench, and we can use this circuit to choose suitable capacitance value of the bulk capacitor.

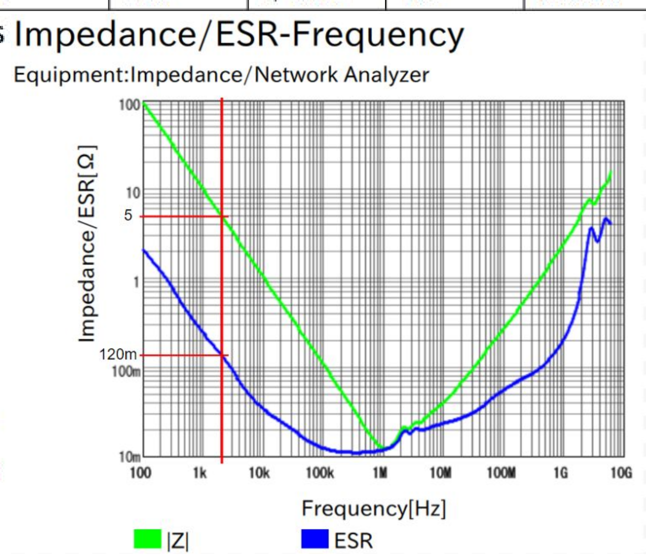
The most important point is the ripple voltage with different applied loads. To select a perfect bulk capacitor which can handle the worst case, following steps should be done:

1. Figure out the worst case:
   The largest load increase and decrease are in the moment that LTE module turns on and off, respectively. The worst current load is 1.5mA, and this current load will be applied when the LTE module turns on, and removed when LTE module turns off.
2. Simulate the worst case with TI webench, and analyze the ripple voltage and voltage dip:
   TI webench provides a simulation circuit with bulk capacitor and other passive components, and all these passive components can be changed in different settings.
3. Check the specific capacitance value can handle the worst case:
   The simulation result is great. A 22uF capacitance value for the bulk capacitor will generate 16mV ripple voltage, which is smaller than the LTE ripple voltage limit, 75mA.
4. Select a suitable capacitor with specific capacitance value and other capacitor characteristic parameters
   a. DC bias in 3.3V
   b. Good temperature characteristic (X7R is good enough)
   c. Capacitance tolerance (10~20% is acceptable)
   d. Low ESR
   e. Low ESL

According to the specifications listed above, a specific capacitor is picked. This capacitor can provide 22uF in 3.3V. Therefore, one this capacitor is enough to control the ripple voltage.

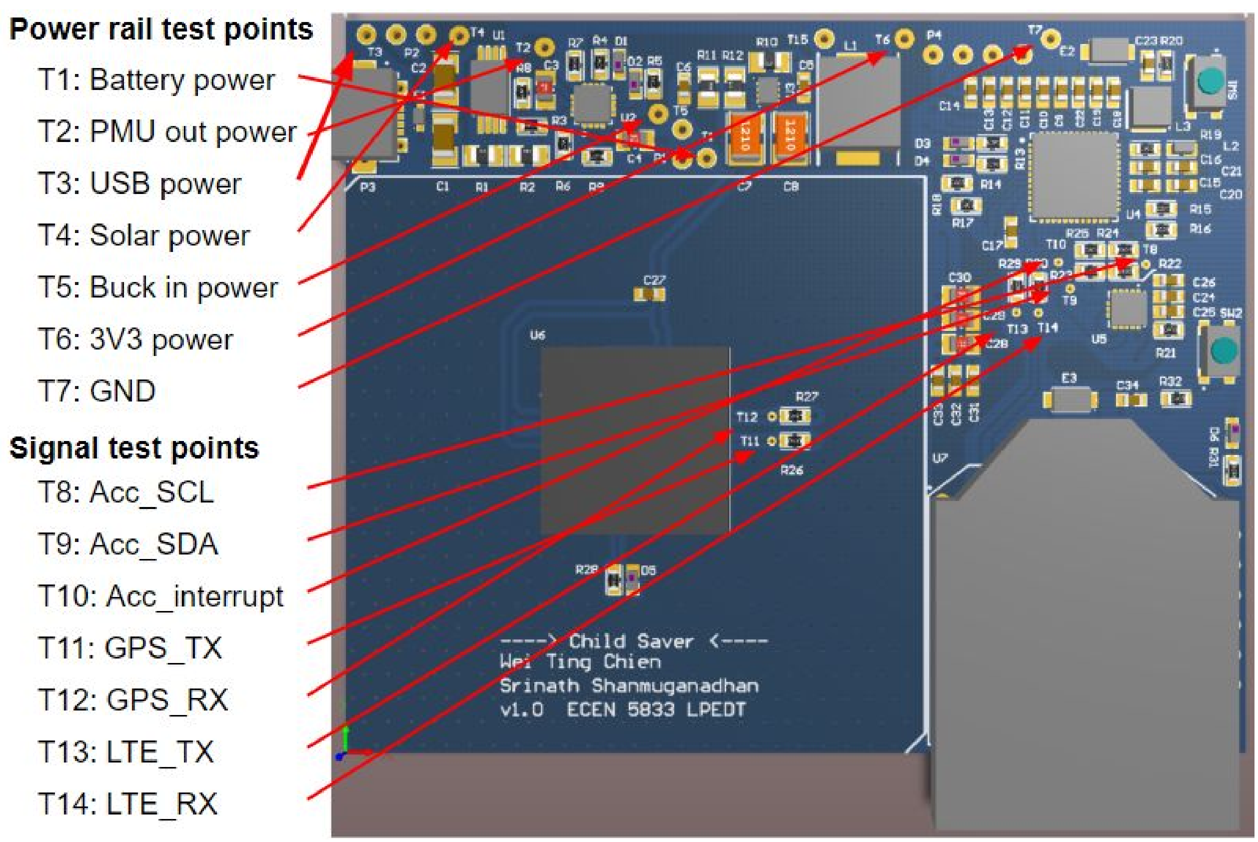
Murata Global Part No.	Size(mm/inch)	Temp.Chara.	Cap.Value	Cap.Tol	Volt.	Durability (%Rated Volt.)
GCJ32ER71C226KE01	3225M/1210	X7R	22uF	+/-10%	16V	150.0%





Appendix B Hardware Validation Plan

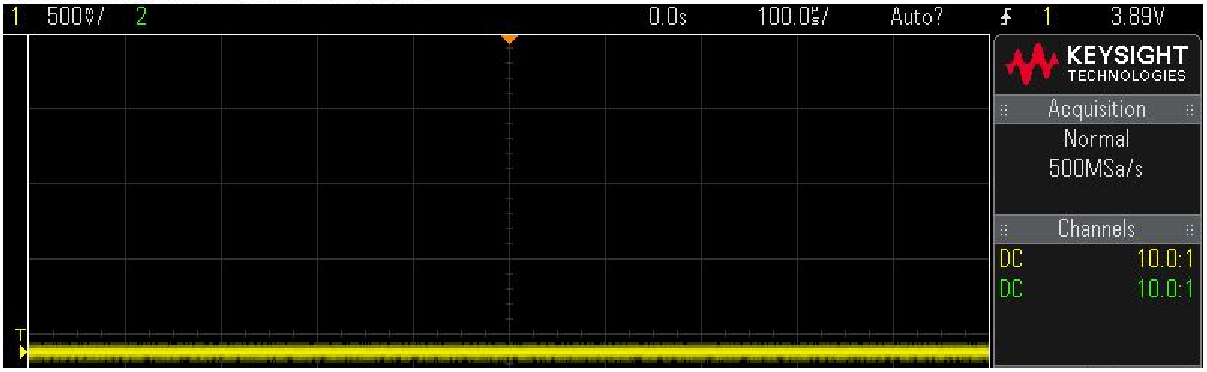
To be verified	Definition of passing	Date test performed	Tested by	Measured result	Passed?
Hardware testing					
Power rail testing while power on					
Buck regulator power output	T6: regulated 3V3 power	4/30/2020	Tim Chien	3.31V	Pass
Buck regulator power input	T5: 5V ~ 3V	4/30/2020	Tim Chien	4.28~3V	Pass
Battery power	T1: 4V~3V	4/30/2020	Tim Chien	3.87V	Pass
Power shut down while low power input	T6: 0V	4/30/2020	Tim Chien	0V	Pass
USB charging					
USB power input	T3: 5V	4/30/2020	Tim Chien	5.07V	Pass
PMU power input	T2: 5V	4/30/2020	Tim Chien	5.07V	Pass
Solar panel using					
Solar panel input	T4: 5V~0V	4/30/2020	Tim Chien	4.76~2.04V	Pass
PMU power input	T2: same as T4	4/30/2020	Tim Chien	4.49~2.04V	Pass
Charging performance					
USB charging	Full charge = 1.9hr T3: Voltage input 5V T3: Current input 0.5~1A	Not test yet			
Solar panel charging	Full charge = 35hr T4: Voltage input 5.5V T4:current input around 55mA	Not test yet			



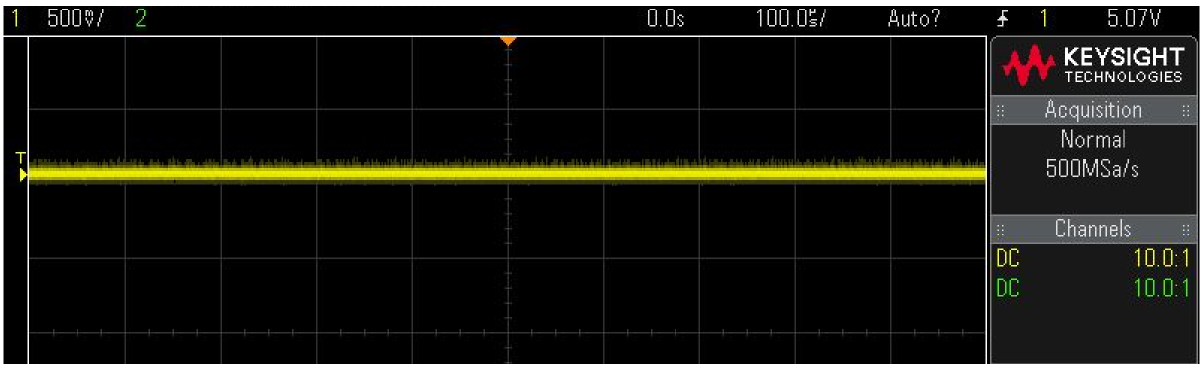
See Appendix C for detail testing result

Appendix C Power rail testing result (Screenshots)

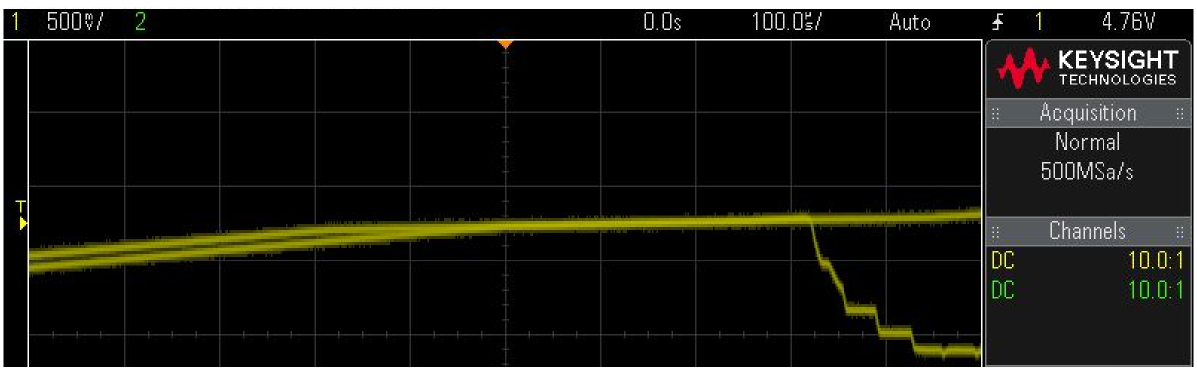
- **Battery power T1 : 3.89V (Full battery)**



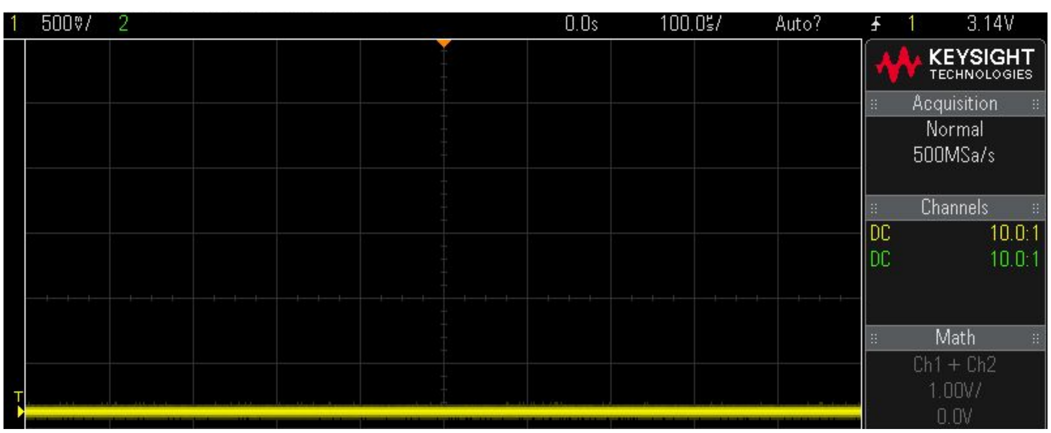
- **USB power T3 : 5.07V**



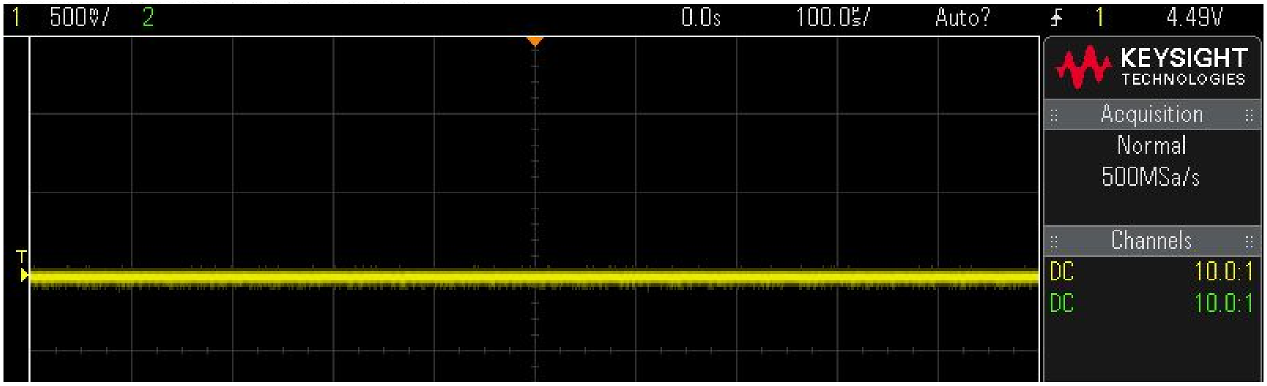
- **Solar power T4 : 4.76V (Full light)**



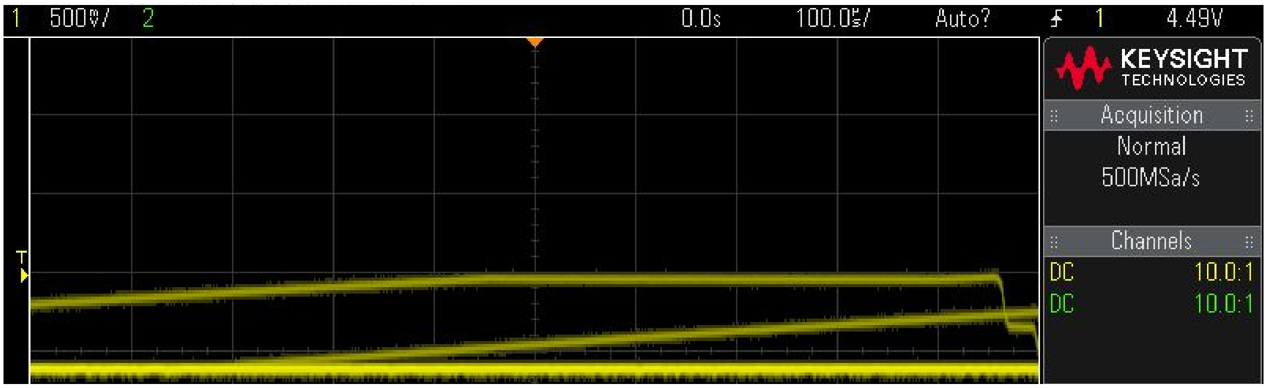
- **Solar power T4 : 3.14V (Covered light)**



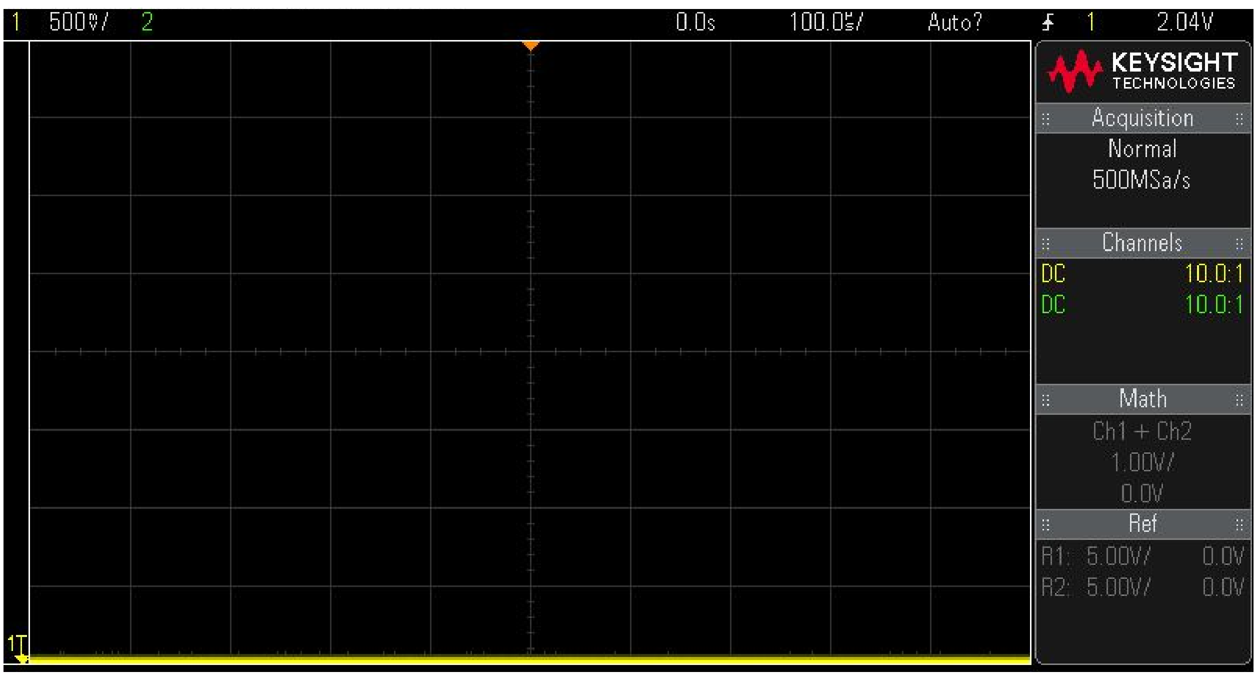
- **PMU output power T2 : 4.49V (USB connecting)**



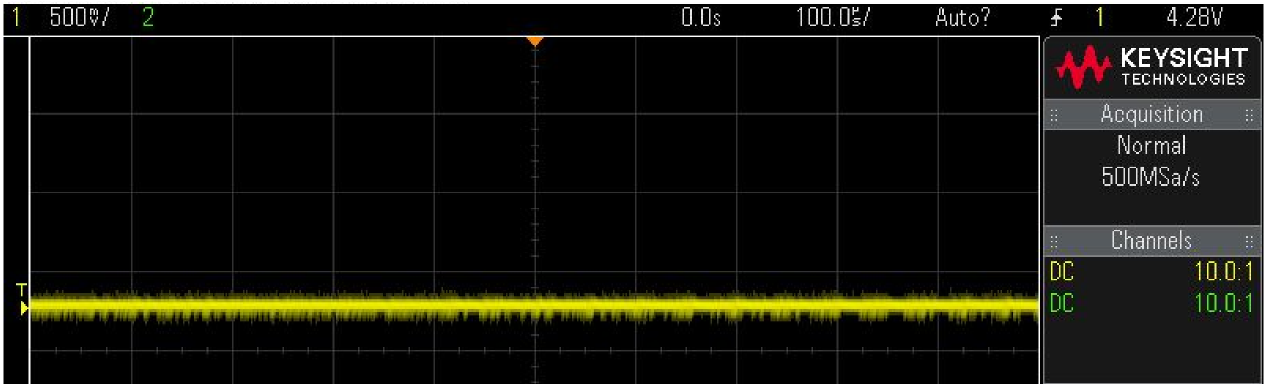
- **PMU output power T2 : 4.49~3.87V (Solar Full light)**



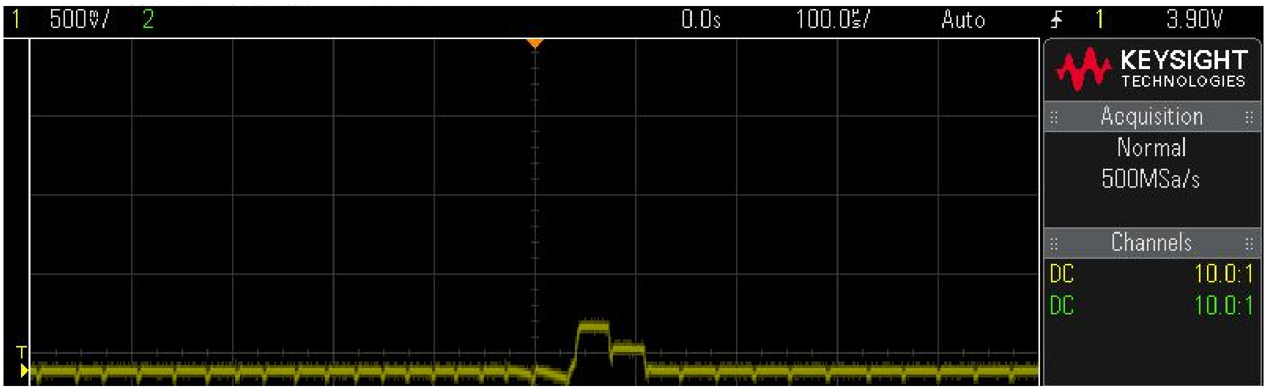
- **PMU output power T2 : 2.04V (Solar Covered light)**



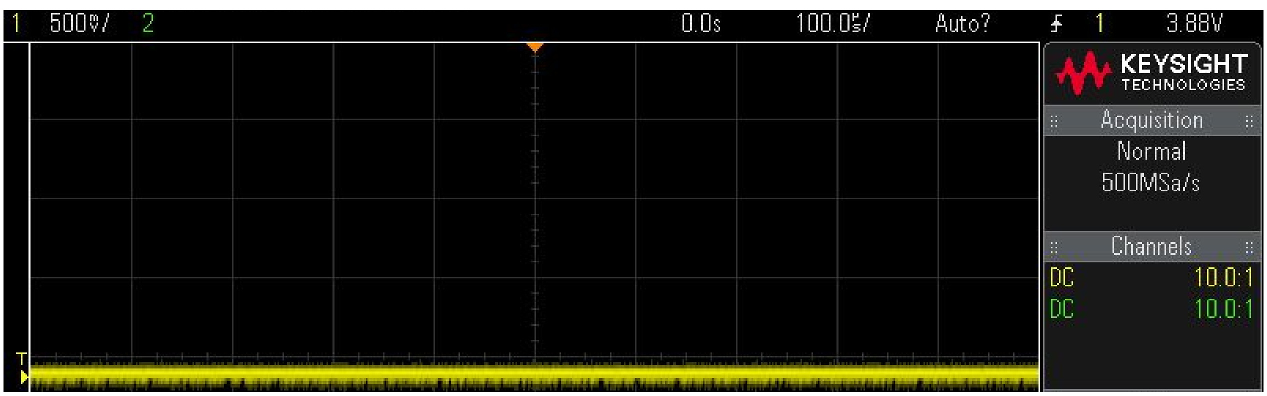
- **Buck input power T5 : 4.28V (USB connecting)**



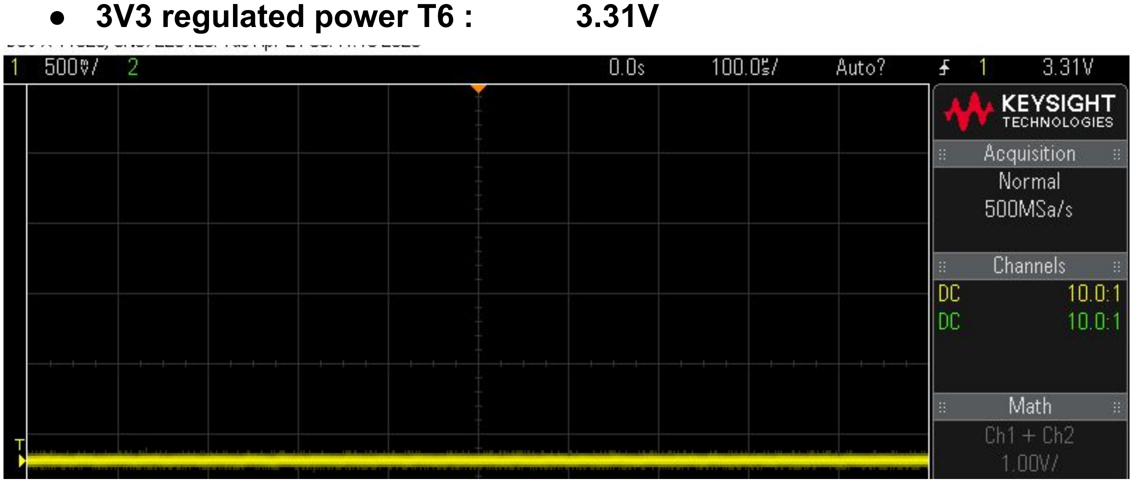
- **Buck input power T5 : 4.34~3.9V (Solar Full light)**



- **Buck input power T5 : 3V (Solar Covered light ⇒ battery power)**



- **3V3 regulated power T6 : 3.31V**



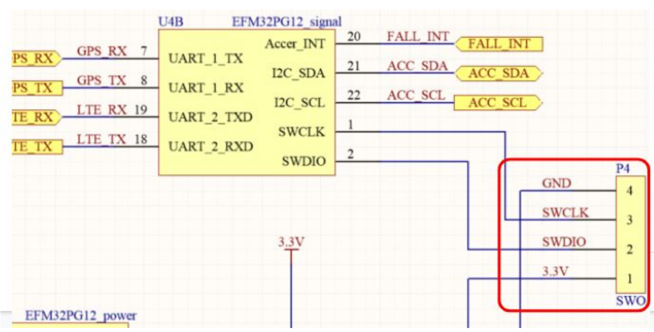
Appendix D SWO Programming process

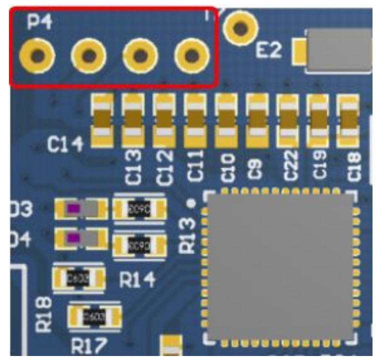
In order to download the program to our own target PCB, we selected a SWO protocol with 4 pinouts, SWDIO, SWCLK, V_target, GND, and planed to use the EFM32 development kit as the adapter and the Simplicity Studio software to download the program. In this section, I will explain the programming progress in three steps, the PCB design, the hardware connection, and the software setup.

PCB design

It is easy to use the default programming protocol to set up the MCU.The SWO protocol is one of the programming protocols in our MCU. There are six pins defined in this protocol, SWCLK, SWDIO, SWO, reset, V_target and GND. In my design, only four pins are used, SWDIO, SWCLK, V_target and GND.

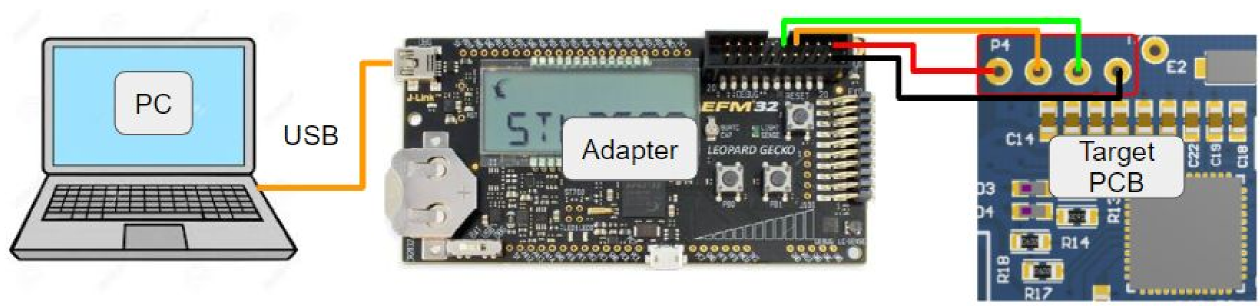
1. SWDIO, SWCLK: Transmit the program data with data and clock reference lines.
2. V_target: Provide the adapter (development kit) the voltage level of the target
3. GND Ground reference





Hardware connection

The connection is very easy. We used a USB cable to connect the computer and the development kit, and four jumper wires to connect the development kit and our target PCB.



Software setup

1. Set the development kit as an adapter.
   - Set the development kit's mode to "OUT" in Simplicity Studio, and the Debug LED on the development kit will turn on
2. Use the connection tool "Simplicity Commander" in Simplicity Studio Launcher to check the adapter and target MCU connection.
   - Simplicity Studio can recognize the target MCU with SWO protocol and the power level with V_target pin
3. Download and debug the program

Appendix E Hardware & Documentation Schedule

ACTIVITY	Lead	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE	Comments
Project proposal 1							
Hardware diagram	Tim	12	1	12	1	100%	
POC on project ideas	Both	9	5	9	7	100%	
Project Update 2	Both	14	5	14	5	100%	
MCU Selection	Tim	14	1	14	1	100%	
Radio module Selection	Tim	15	1	15	1	100%	
Accelerometer Selection	Srinath	15	1	16	1	100%	
GPS module Selection	Srinath	17	3	17	3	100%	
Reasons for Module selection	Both	15	3	16	3	100%	
System level requirements	Both	17	1	17	1	100%	
Power mode chart	Tim	17	1	17	1	100%	
Project Update 3	Both	21	7	21	7	100%	
Energy storage element Selection	Both	21	2	21	2	100%	
Battery management module Selection	Both	22	3	22	3	100%	
Dive deeper on all the modules	Both	24	2	24	6	33%	
Check the usability of two sensors (if we ge	Tim	23	5			0%	
Setting up MCU development environment	Srinath	23	5	23	2	80%	
System power consumption measuerment	Tim	23	3	24	2	100%	
Project Update 4	Both						
Communication protocol review	Tim	31	5	33	3	100%	
Battery analysis	Srinath	33	3	33	3	100%	
Project Update 5							
Power supple Component selections	Both	39	3	39	3	100%	
Bulk Capacitor simulations	Both	38	5	38	5	100%	
Bulk Capacitor selection	Tim	42	1	42	1	100%	
Project Update 6							
Schematics ver. 1.0 freezed	Tim	44	1	48	3	100%	
Schematics ver. 1.0 documentation	Tim	44	3	45	3	33%	
Power circuit design	Tim	42	3	44	3	100%	
Power circuit design review	Srinath	47	1	54	6	100%	
Embedded software design	Srinath	45	4	45		30%	
Project Update 7							
ESD analysis	Both	58	1	58	1	100%	
Schematics review #2	Both	59	4	61	2	50%	
Schematic							
MCU & LTE module schematic and footprin	Tim	31	2	31	2	100%	
GPS & Accelerometer schematic and footpr	Tim	33	2	33	2	100%	
Power system Component schematic and fo	Tim	41	3	41	4	100%	
Schematic layout	Tim	40	4	43	4	100%	
Schematic documentation	Tim	44	2	45	47	100%	
Schematic review #1	Tim	44	3	54	5	100%	
Schematic review #2	Tim	52	4	62	3	100%	
PCB layout							
MCU & LTE module	Tim	50	4	50	2	100%	
GPS module & Acceleromenter	Tim	50	4	52	2	100%	
Power circuit	Tim	54	2	54	2	100%	
PCB layout review	Tim	56	4	65	4	100%	
PCB layout review	Tim	60	4	70	4	100%	
PCB processing and Debug							Component delivery delay
PCB Assembly	Tim	60	1	97	1	100%	
PCB Debugging (Power rail)	Tim	62	2	100	2	100%	

Gantt chart google sheet link