ECEN 5833: Low Power Embedded Design Techniques

# CUBIT

## Smart Measuring Instrument


Team Name: Cubit

Team Members: Rajat Chaple

Saloni Shah

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ECEN 5833: Low Power Embedded Design Techniques

# CUBIT

## Smart Measuring Instrument


Team Name: Cubit

Team Members: Rajat Chaple

Saloni Shah

## 1.1 Background

A measuring tape is used in a myriad of commercial businesses like construction, tailoring, warehouses as well as in day-to-day life. The first standard measuring tape was invented in 1850s and till now we have been using the same product. Although, since $18^{th}$ century the world has advanced in every possible way, we still use the same measurement technique. The conventional measuring tape has ample of drawbacks like taking and maintaining measurements is very tedious, also all the measurements taken are majorly single use. It is high time that we modernize our method of taking measurements and digitize the data which can be easily stored and accessed from anywhere.

## 1.2 Project Summary

For the course project, our team is designing a smart measuring instrument which will have the capability to take precise linear and angular measurements and transmit the data over to a mobile application using Bluetooth. Primarily, this device will have an encoder-wheel assembly which can be used to take measurements over a straight or curved surface very accurately. A high precision rotary encoder will be helpful in giving high resolution results. Moreover, we will also install an inertial measurement unit (IMU) sensor to take different angular and device orientation data. Both measurements can then be transmitted to a mobile app connected to the product using Bluetooth. This data will also be displayed on an LCD. This device will run on a small battery, and it will also contain an energy harvesting system using solar panel to recharge the battery. All these components will be interfaced with a single Blue Gecko board. The device will operate in low power mode by implementing load power management and utilizing minimum current for required peripherals.

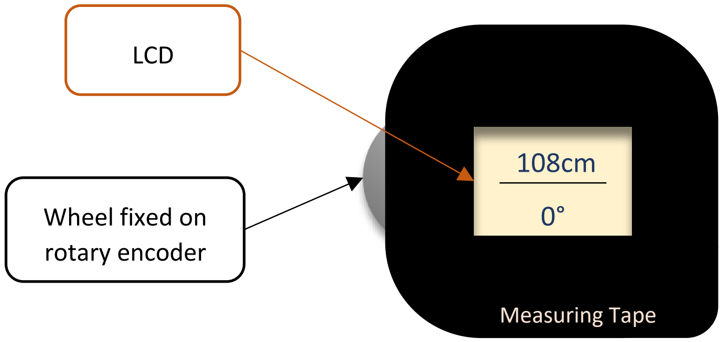


*Figure 1: Product Concept*

# 1.3 Product Application

- This product can be used to fulfill majority of measurement requirements like taking size data of a straight or uneven surface and taking angle measurements.
- This product can be used in small industries, construction sites, fashion companies and regular households.
- This product will eliminate the need to manually store measured data.
- This product will be low cost, low power consuming with energy harvesting mechanism.
- This product will use long lasting rechargeable batteries unlike single usage dry cells.

## 1.4 Block Diagram

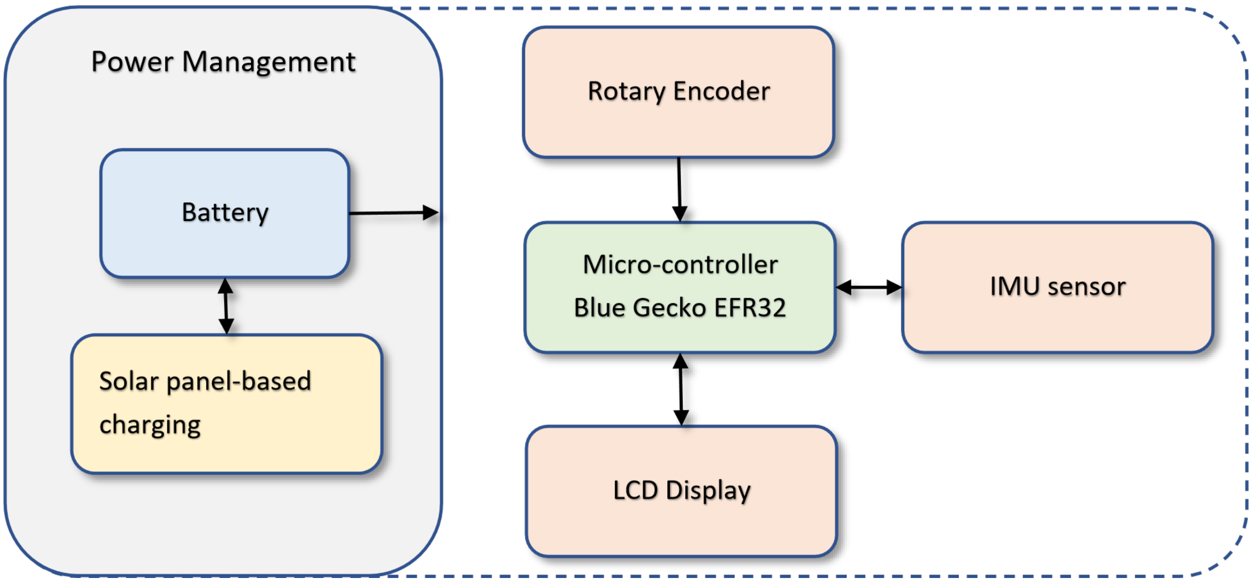


*Figure 2: Block Diagram*

## 1.5 Product Components

*Table 1: Components List*

| Component | | Part No. | Load Power Management |
|---|---|---|---|
| Microcontroller | Silicon Labs Blue Gecko | | |
| Radio | EFR32BG13 | | ✓ |
| | | | |
| Battery | Lithium Ion/Lithium Polymer | [LP802036JU+PCM+2 WIRES 50MM Jauch Quartz \| Batte Products \| DigiKey]() | |
| PMIC | BQ25570 | [BQ25570RGRT Texas Instruments \| Integrated Circuits (ICs) \| DigiKey]() | |

| | | | |
|---|---|---|---|
| Buck Converter | TPS62842<br>Or PMIC internal buck converter | TPS62842DGRR Texas Instruments \| Integrated Circuits (ICs) \| DigiKey | |
| Sensor | IMU sensor | BNO005 (To be acquired from Professor) | ✓ |
| | Rotary Encoder | Magnetic Rotary Encoder<br>Magnetic Wheel Assembly | ✓ |
| | Ultrasonic Sensor | Adafruit Ultrasonic Sensor | ✓ |
| HMI | LCD Display | Adafruit SHARP Memory Display Breakout - 1.3"<br>(Acquired from Professor) | ✓ |
| | Push Buttons | Available | |
| Energy Harvesting System | Solar cells | Monocrystalline solar cells | |

# 1.6 Proposed Product Demo

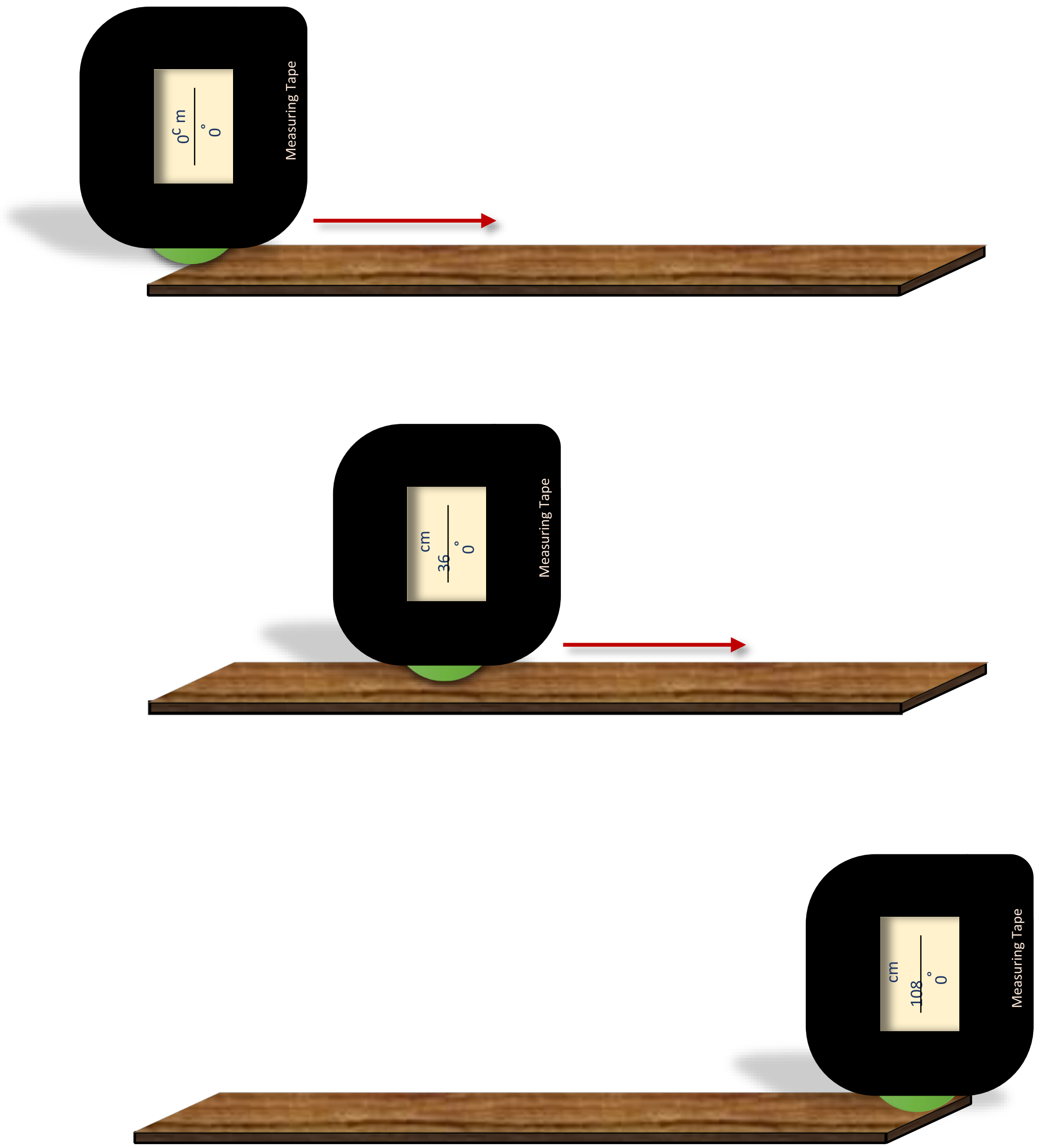


*Figure 3: Proposed Product Demo 1*

As shown in the above image, this measuring tape can be used to measure any surface. The wheel encoder assembly installed on the product can be slid over a flat or uneven surface to get size value accurately. This measuring tape will have a high resolution in centimeter because of the use of a precision Rotary encoder with large number of pulse detection in a single rotation.

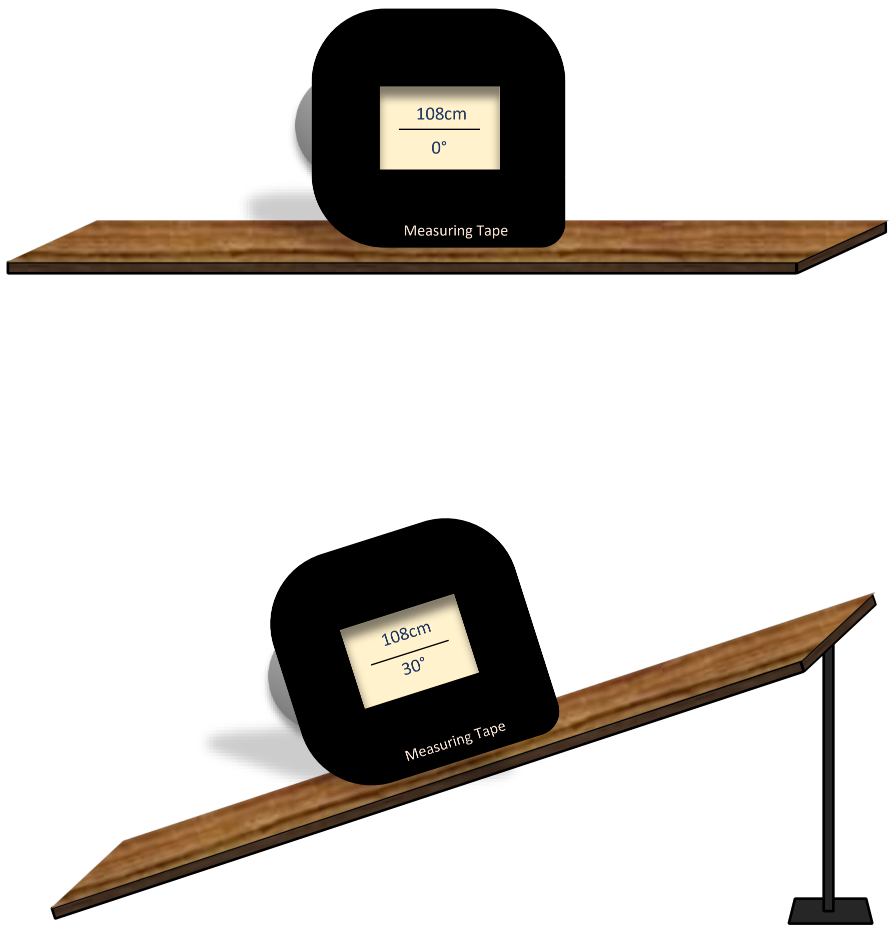


*Figure 4: Proposed Product Demo 2*

The above image shows how an angle measurement can be carried out using the product. This angle can be measured in any orientation of the device. The angle measurement will also be highly accurate due to the IMU sensor.

# 1.7 Product Features

- Free android app to store and manage measurement data
- Bluetooth connectivity of mobile phone with the device
- Rotary encoder-wheel assembly for linear measurement
- IMU sensor for accurate angle measurement
- LCD Display for better user experience
- Energy harvesting mechanism using solar panels
- Load power management by turning on only required peripherals
- Single rechargeable LiPo battery which can power the complete device

# 1.8 Product Specifications

- Dimensions: 80mm x 45mm
- Weight: 200g
- Wireless range: 100 m
- Size accuracy: ± 0.2 cm
- Angle accuracy: ± 1°
- Product Warranty: 2 years
- Operating Temperature: 0°C - 65°C
- Internal sensors and peripheral operating temperature:

*Table 2: Temperature specifications for sensors*

| Sensor | Operating Temperature Constraints |
|---|---|
| Blue Gecko | -40 to 85 °C |
| IMU | -40 to 85 °C |
| Rotary encoder | -40 to 150 °C |
| LCD Display | -40 to 70 °C |

Project Update 2

ECEN 5833: Low Power Embedded Design Techniques

# CUBIT

## Smart Measuring Instrument

Team Name: Cubit

Team Members: Rajat Chaple

Saloni Shah

Date: 01/29/2022

# 2.1 Activities accomplished in past week

- Studied mouse scroll-wheel encoder assemblies to decide the decide the mechanical assembly for final product. Disassembled 4 different optical mouses to explore different assemblies.

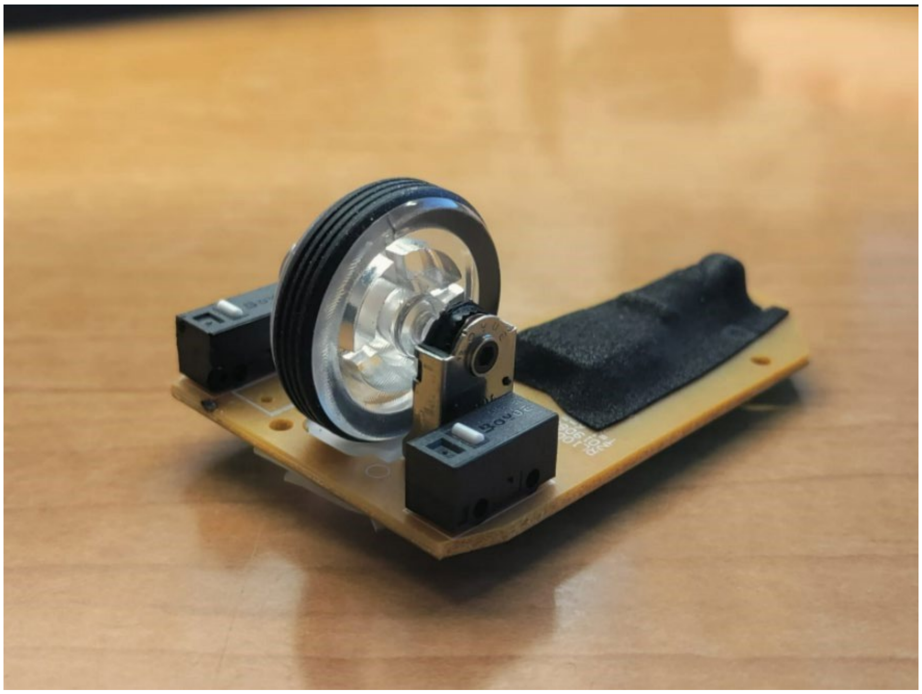

*Figure 5: Scroll wheel encoder assembly*

- Measured PPR(Pulse per rotation) of rotary encoder and circumference of wheel to estimate linear measurement resolution. ○ Finalized ultra-low power Graphic LCD display. ○ Estimated total power and energy consumption of the product.
- Worked on project planning and estimated timeline.

# 2.2 Activities for the coming week

- Finalize battery and solar panel based on energy consumption requirements. ○ Finalize Power management IC.
- Work on power supply circuit for the product.

# 2.3 Energy model for the product:

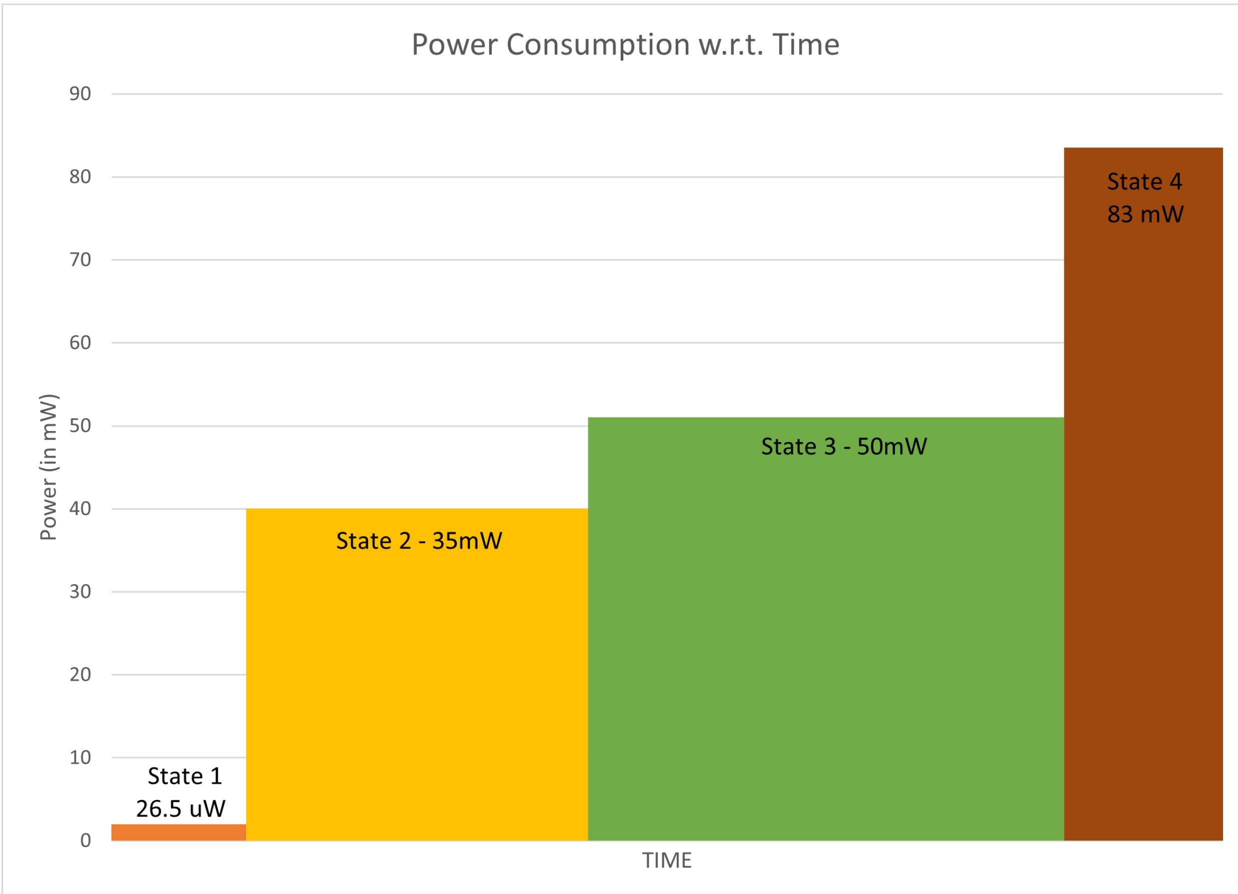


*Figure 6: Energy model*

# 2.4 Sensor selection:

### 2.4.1 IMU Sensor: BNO005

- This sensor works on I2C as well as UART.
- We will be interfacing the sensor using I2C as data transfer over UART communication takes longer and even though it consumes less energy, overall efficiency of UART decreases. Moreover, for transfer of larger data bytes I2C consumes the same amount of energy. (These assumptions were made using this reference.)
- This sensor will require external load switch as after start-up it only enters low power mode and suspend mode. (Even in suspend mode it consumes 40uA of current).

### 2.4.2 Rotary encoder

- This mechanical encoder has just 2 digital pins which can be wired directly as input to the controller. The encoder generated pulses gives the angular position of the axis and can then be converted to digital output.
- The encoder will also require external load switch as it does not have internal circuitry to turn power off.

Online Project Management using Monday.com

# 2.5 Program Flowchart:

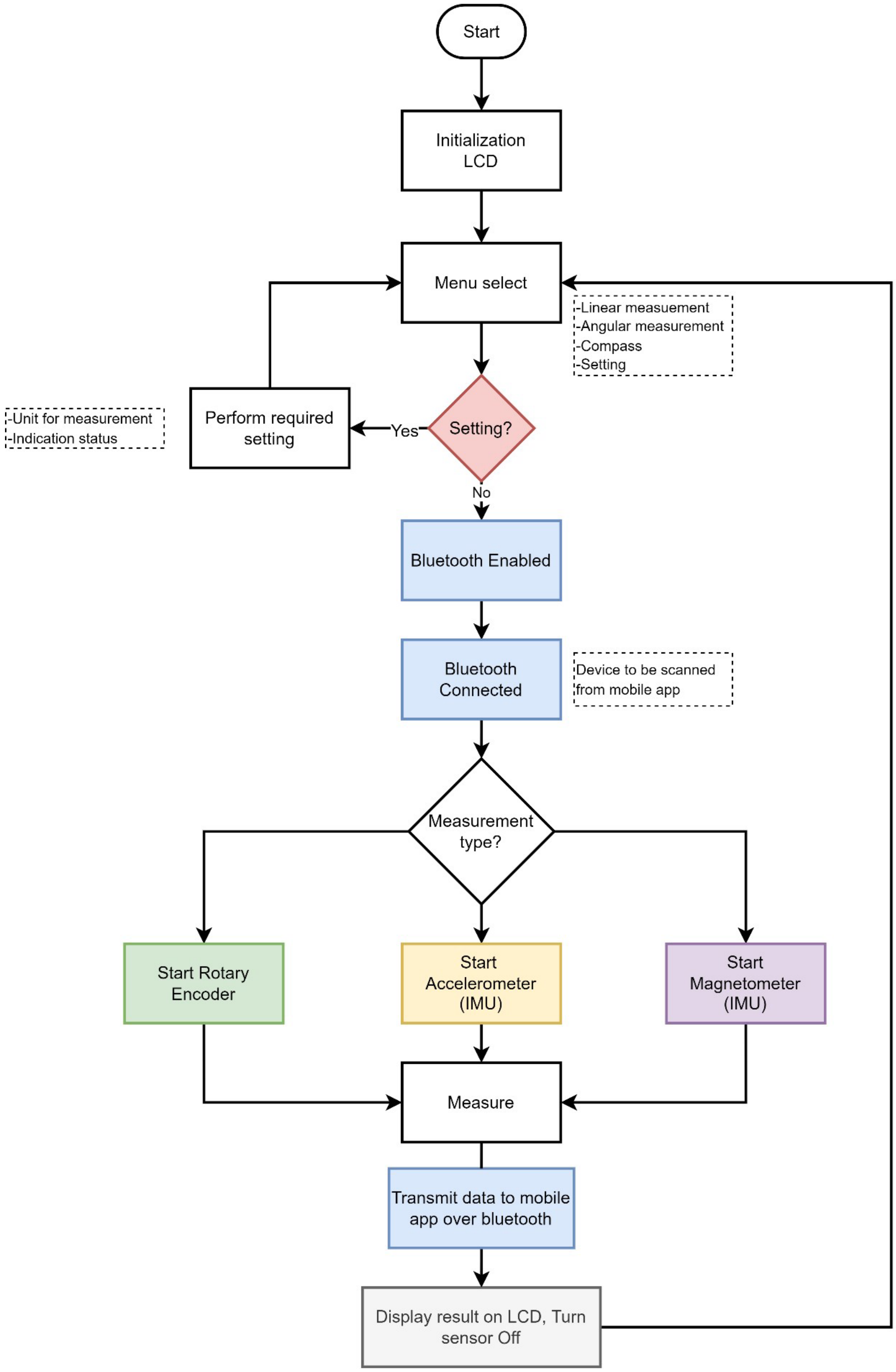


*Figure 7: Flowchart*

Project Update 3

ECEN 5833: Low Power Embedded Design Techniques

# CUBIT

## Smart Measuring Instrument

Team Name: Cubit

Team Members: Rajat Chaple

Saloni Shah

Date: 02/05/2022

## 3.1 Activities accomplished in past week:

- Finalized energy storage element (battery) based on energy consumption requirements.
- Finalized Power management IC and buck-converter IC.
- Practically implemented measurement system using mechanical rotary encoder, string-pulley assembly and interfaced it with Arduino. Found out that the rotary encoders have a limitation on how fast it can detect rotations i.e. it can only detect signals correctly at less than 160 rpm.

*Figure 8: Assembled rotary encoder with a string-pulley*


*Figure 9: Measuring the length of a ruler using the assembly*

Arduino serial monitor output with number of pulse counts and calculated length

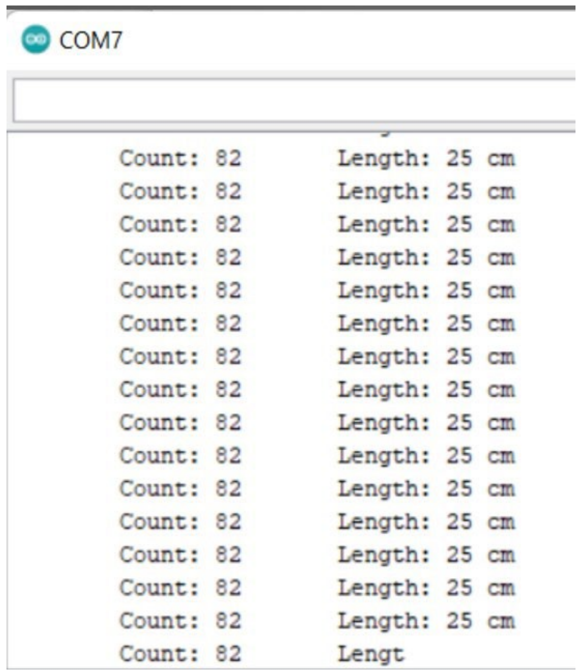


*Figure 10: Optical Rotary Encoder output*

- Changed the required rotary encoder from mechanical to magnetic due to speed constraints and higher chances of signal misses in the mechanical encoder.
- Finalized required magnetic rotary encoder and ultrasonic sensor for measurement applications.

## 3.2 Activities for the coming week

- Finalized energy harvesting element (solar panel) based on energy consumption requirements.
- Design product power supply circuit.
- Interface LCD display with Blue Gecko Evaluation Module.
- Finalize other required components for the product schematic design.

Power Storage Element Selection

- Expected runtime using supercapacitor = 1.36 hours
- Expected runtime using battery = 3 days (8 hours per day)[1]

### 3.2.1 Super Cap vs Battery

Required peak current: 25 mA

Average current consumption: 13.68 mA

Average Charge requirement for continuous 8 hours operation: 110mAh

Average Energy Required for 8 hours of operation: 328.4 uWh

Ambient Temperature Conditions: Room Temperature (about 25° C)

*Table 3: Super cap - Battery comparison*

| Super Cap | Battery |
|---|---|
| Steep discharge curve | Higher operating time |
| Large leakage current (30 uA) | Very less leakage current (2%/year) |
| Cannot handle required peak current | Can handle upto 1A peak current |
| Lower energy density | Higher energy density |
| Can operate in very low temperature | Dispenses less energy in low temperatures |
| Lower ESR power loss | Higher ESR power loss |

*Table 4: Supercap and battery specifications*

| Design Requirements | Super Cap (Tecate 100F) | Battery (Jauch 480mAh) |
|---|---|---|
| Useable Energy | 234.5J[2] - 18.6mAh | 480 mAh |
| Peak Discharge Current | | 1A |
| Recharge time | | 2 hours @ 0.5C |
| 2 years of use, 300 charges | 500,000 cycles | 300 cycles ~ 80% capacity usage |
| Leakage current or rate | 3 uA | Less than 2-3% |
| ESR | 210 mΩ | |
| Mechanical Dimensions | 12.5 x 25 mm | 38 x 20.5 mm |

[1] Refer attached spreadsheet for calculations

[2] Refer attached spreadsheet

# 3.3 Power Management Unit Selection

### 3.3.1 Determining the required voltage range for the product

- To decide the operating voltage range for the product, we looked at the input voltage range of the peripherals utilized in the system. The below table shows the minimum and maximum input voltage range of the sensors and MCU.

*Table 5: Voltage range for components[1]*

| Sensor | Vin(min) | Vin(max) | Current Consumption |
|---|---|---|---|
| Blue Gecko | 1.8V | 3.8V | 4uA |
| IMU | 2.4V | 3.6V | 12.3mA |
| Rotary encoder | 3V | 3.6V | 15mA |
| LCD Display | 3V | 5V | 4uA |

- Based on the above calculations, we decided to operate all the peripherals at 3.0V as to utilize maximum possible battery capacity and increase the operating time of the system.
- The approximate range of the supply voltage will be from 3.0-3.6V.

[1] IMU datasheet: BNO055 Datasheet (mouser.com)
Blue Gecko datasheet: EFR32BG13 Data Sheet: Blue Gecko Bluetooth® Low Energy SoC Family (silabs.com)
Magnetic Rotary Encoder datasheet: AS5147P-TS_EK_AB ams | Development Boards, Kits, Programmers | DigiKey LCD Display datasheet: Data+sheet.pdf (adafruit.com)

### 3.3.2 Determining the power management topology

- Considering that the power source battery gives maximum 3.7V and our required voltage supply for the peripherals is about 3.0V, which is always lower than supply voltage we decided to implement a buck converter to meet our power requirements.
- The primary reason for choosing a buck converter as opposed to a buck-boost is that most Lithium-Poly batteries have a plateau from 3.5-3.6V and very little charge below this plateau, limiting the usefulness of the buck-boost converter and its wide input voltage range2.
- Moreover, the buck-boost converter also has one additional MOSFET as compared to the buck converter which increases power loss and decreases efficiency of the converter.
- Keeping this in mind, we searched for a buck converter IC, with high efficiency, low quiescent current, low cost, and smaller footprint.
- All these requirements were successfully met by the buck converter TPS62840[3].

### 3.3.3 Determining Regulated or Unregulated Power Source

- While deciding whether to use regulated or unregulated power source, we carried out following calculations to understand efficiency of both topologies.

Assumed product usage of 60 minutes or 3600 seconds

Assumed number of measurements in 1 hour, average of 20 measurements

Assumed period for one measurement, average of 13 seconds

On duty cycle = (20 measurements * 13 seconds) / 3600 = 7.2% Off

duty cycle = 92.8%

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[2] EETimes - Buck-boost vs. buck converter: it's about battery life in portables

[3] TPS62840 datasheet: TPS62840 1.8-V to 6.5-V, 750-mA, 60-nA IQ Step-Down Converter datasheet (Rev. D) (ti.com)

TPS62840 Buck converter Efficiency Curve

- Off duty cycle = 0.015-0.020 mA
  Estimated 87.5% efficiency
- On duty cycle = 15-20 mA range
  Estimated 94% efficiency

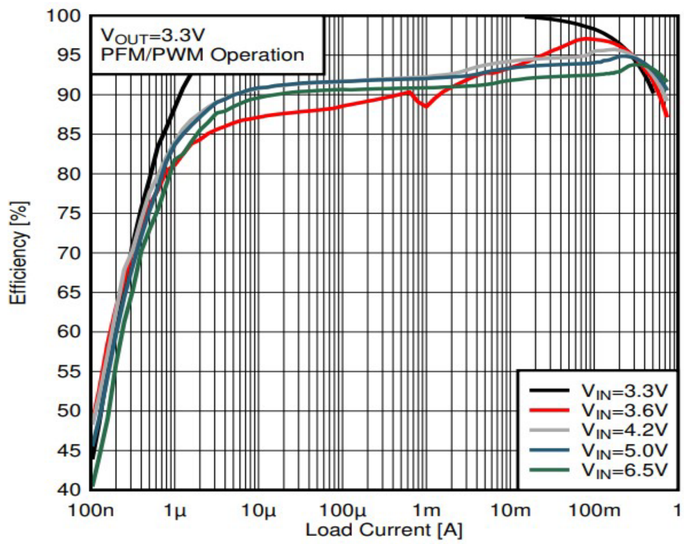



**Figure 19. Efficiency Power Save Mode**
**$V_{OUT}$ = 3.3 V**

For regulated power case (using TPS62840 buck converter):

- On duty cycle
  - TPS62840 efficiency ~3.6V input and 15,500uA is 94% + 0.06uA Iccq
  - Weighted avg power OOB = (On duty cycle * (15500 + 0.06) * 3.0V) / 94%
  - Weighted average power out of battery = 3561 uW ○ Off duty cycle
  - TPS62840 efficiency ~3.6V input and 20uA is 87.5% + 0.06uA Iccq

- Weighted avg power OOB = (Off duty cycle * (20 + 0.06) * 3.0V) / 87.5%
- Weighted average power out of battery = 63.8 uW ○ Total Average Power out
- Weighted on duty cycle average power + Weighted off duty cycle average power = 3561uW + 63.8uW = 3624.825 uW

<u>For unregulated power case (using Blue Gecko internal LDO):</u>

○ On duty cycle

- Gecko efficiency ~3.6V input and 15,500uA is 83.33%
- Weighted average power OOB = (On duty cycle * 15500 * 3.0V) / 83.33%
- Weighted average power out of battery = 4017.7 uW ○ Off duty cycle
- Gecko efficiency ~3.6V input and 20uA is 83.33%
- Weighted average power OOB = (Off duty cycle * 20 * 3.0V) / 83.33%
- Weighted average power out of battery = 66.81 uW ○ Total Average Power out
- Weighted on duty cycle average power + Weighted off duty cycle average power = 4017.7uW + 66.81uW = 4084.5 uW

Increase in battery life using regulated power = $1 - \frac{3624.825}{4084.5}$

= 11.25%

Based on above calculations, we decided to use a regulated power source since it provides longer battery life. Moreover, we have a higher on duty cycle, higher power on to power off ratio, higher efficiency at light load and low quiescent current which justifies the use of regulated power source.

### 3.4. Determining the Power Management IC

○ The primary criteria for selecting a PMIC were low minimum input voltage limit to support very low voltage from energy harvesting element (solar cell) and efficient boost converter. A simple and efficient circuitry for energy harvester is required which were available in PMIC BQ25570.

- The input voltage supported in this IC is 0.1-5.1V. Also, many typical solar cells have an output voltage of 0.1V.
- Another important criterion is to have a wide range of input voltage from battery to support lower battery power which is 2-5.5V in case of BQ25570.
- This IC also has higher charging current capacity (maximum 285mA) for fast charging from external charger or a USB charging port.
- BQ25570 also has internal Programmable Maximum Power Point Tracking (MPPT) circuitry for optimal energy extraction from energy harvester like solar panel.
- Moreover, BQ25570 has internal boost as well as buck converter to boost low input voltage from the energy harvester and simultaneously regulate the output voltage[4].

[4] BQ25570 internal buck converter vs external TPS62840 buck converter: The TPS62840 buck converter has higher efficiency at low current consumption than the internal buck converter.

Project Update 4

ECEN 5833: Low Power Embedded Design Techniques

# CUBIT

## Smart Measuring Instrument

Team Name: Cubit

Team Members: Rajat Chaple

Saloni Shah

Date: 02/12/2022

# 4.1 Activities accomplished in past week:

- Generated Altium components library for following parts

*Table 6: Components' library list*

| Sr. No | Part Description | Part Number | Footprint Name | Online SnapEDA/ Octopart Link |
|---|---|---|---|---|
| 1 | Blue Gecko | EFR32BG13P732F512GM48-D | 48-QFN_7x7 | N/A |
| 2 | PMIC | BQ25570RGRT | 21_QFN_35X35 | N/A |
| 3 | IMU Sensor | BNO055 | LGA28R50P4X10_380X520X100 | BNO055 SnapEDA |
| 4 | Magnetic Encoder | AS5147P-HTSM | 14-TSOP_5x4_4 | N/A |
| 5 | Resistor | RMCF0603FT1K00 | 2_Chip_0603_RMCF | N/A |
| 6 | Capacitor | CL10A475KP8NNNC | CAP_0603_1MM | N/A |
| 7 | Inductor | VLS3015CX-220M-1 | 2_IND_3x3 | N/A |
| 8 | LED (red) | 150060RS75000 | LED_0603_RED_WL-SMCW | N/A |
| 9 | LCD header | 3502 | LCD_SHARP_MEMORY_9_PIN | N/A |

### 4.1.1 Change in the Power management strategy

- With earlier update, plan was to use PMIC bq25570 and TPS62842 buck converter. Criterion for selection of external buck converter instead of one already integrated into bq25570 was Efficiency. However, considering ON duty cycle of the product operation, efficiency would no longer be a preliminary factor under consideration.
- Also, major concern where we cannot utilize most energy from the battery was resolved using following.
  - Entire circuit would work at 3.15v
  - Buck converters have dropout voltage. This limits battery's minimum usable voltage. As per datasheet, dropout voltage is maximum output current times the buck high side resistance.

Calculations:

Maximum output current: 35 mA

Maximum buck high side resistance: 200Ω

Dropout voltage: 35 x 200 = 0.7v

- Usable battery would be in the range of 3.7v down to 3.22v.

### 4.1.2 Tested battery power consumption from a sample project

- As a case study one of the sample projects was arranged. Though this project's objective is entirely different than that of CUBIT, similarities in functional blocks were identified. This project also contains solar energy harvesting, PMIC and a load.

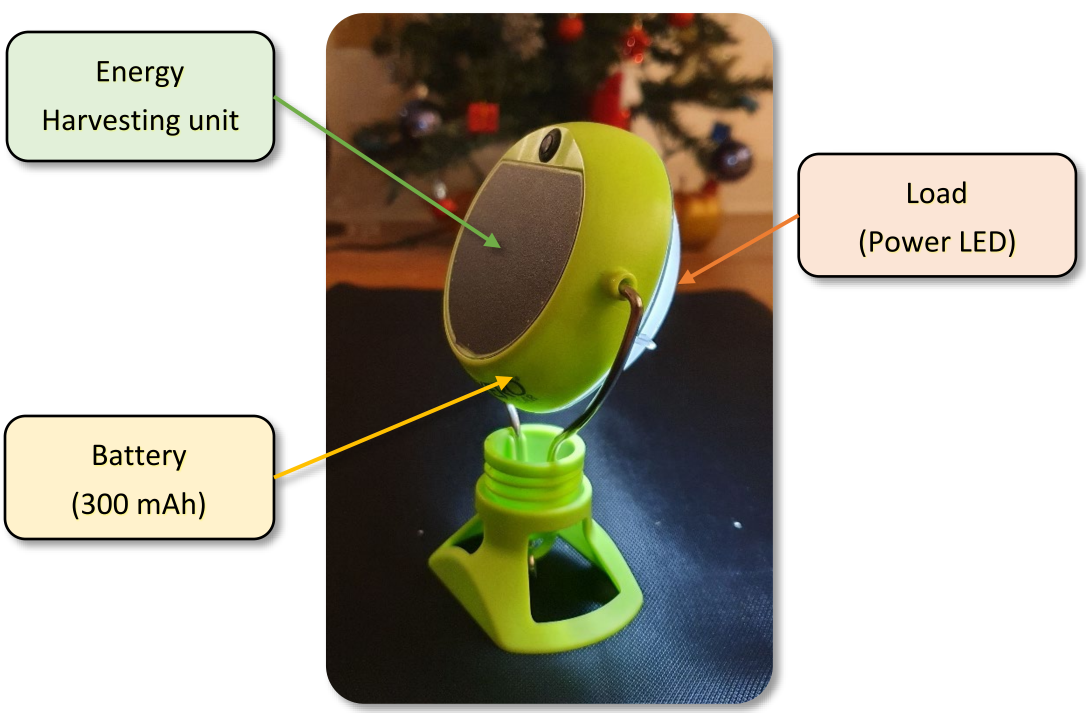
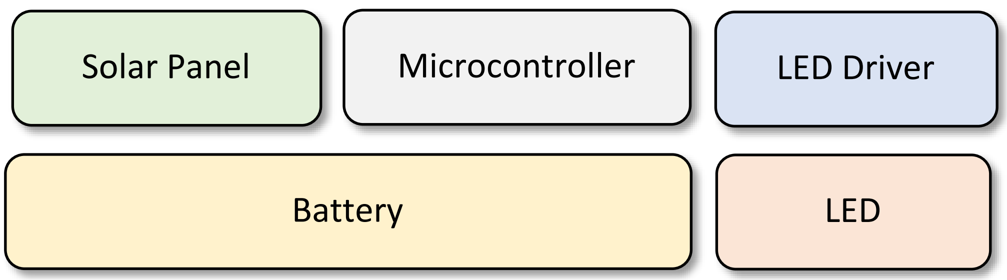



*Figure 11: Sample Product for case study*

Objective: Solar power lamp
Battery capacity = 500mAh
No of Solar cells = 7 (part number unknown)
LEDs: 1 power LED of typical current consumption of 50mA

## Sample Project Block Diagram




*Calculations:*

$$\text{Continuous current consumption by Power LED} = 55\ mA$$

$$Theoretical\ battery\ backup = \frac{Battery\ capacity(mAh)}{Continuous\ current\ consumption}$$

$$= \frac{500}{55} = 9.09\ Hrs$$

Practically measured battery backup: 9 hours
If current consumption was 18mA, we would get battery backup of ~27 Hrs

Outcome of the experiment:

Our calculation for CUBIT falls between this range where battery backup for 480 mh battery with 18mA avg current consumption is around 24 Hrs. This verifies calculations against practical measurements.

- Finalized solar cell unit

Calculations:

As per calculations in spreadsheet bq25570SolarAppDesign.xlsx,
Minimum solar panel area required is 8mW/cm$^2$
As per datasheet: solar cell (2994-KXOB25-12X1F-TB-ND), maximum peak power is 24.5mW per 1.54 cm$^2$
This implies power/cm$^2$ $= 24.5mW/1.54cm^2$
$= 15.90mW/cm^2$
Selected component satisfies this requirement of minimum 8mW/cm$^2$

### 4.1.3 Version tracking using GitHub

Updated previous updates, libraries and calculation documents to github rajatchaple/ecen5833_s22_lpedt_project (github.com)

### 4.1.4 Timing information

Following are the critical timing parameters per module.

*Table 7: Timing Information*

| Device | Parameter | Description | Min | Max |
|---|---|---|---|---|
| AS5147 (SPI) | tL | Time between CSn falling edge and CLK rising edge | 350 ns | |
| | tH | Time between last falling edge of CLK and rising edge of CSn | 50 ns | |
| | tMOSI | Data input valid to falling clock edge | | |
| BNO055 | fSCL | Clock frequency | | 400kHz |
| | fSUDAT | SDA Setup Time | 0.1 us | |
| | HDDAT | SDA Hold TIme | 0 us | |
| SHARP Memory LCD | fSCLK | Clock Frequency | | 1.1MHz |
| | tsSCS | SCS Setup time | 6 us | |
| | thSCS | SCS hold time | 2 us | |
| | tsSI | SI setup time | 250 ns | |
| | thSI | SI hold time | 350 ns | |

### 4.1.5 Calculations for PMIC IC

- Studied reference design in bq25570 user guide in order to understand PMIC circuitry for our application.
- Also, used calculator provided by TI on BQ25570 data sheet, product information and support | TI.com to calculate Resistor values.

### 4.1.6 Battery specifications

*Table 8: Battery specifications*

| **Parameter** | **Value** |
|---|---|
| Battery nominal Voltage | 3.7V |
| Typical capacity | 500mAh |
| Minimum capacity | 480mAh |
| Charge voltage | 4.2V |
| Standard current | 0.2C-100 mA |
| Max charging current | 0.5C – 250mA |
| Cut-off voltage | 3V |
| Max discharging current | 2C-1A |
| Power rating | 1.78Wh |

**Battery Tolerances**

*Table 9: Battery Tolerances*

| Parameter | Value |
|---|---|
| Overcharge voltage | 4.28 V ± 0.025 V |
| Overdischarge voltage | 3.00 V ± 0.05 V |
| Over current range | 1.0A to 4.0A |
| Charging operating temperature | +10°C to +45°C |
| Discharging operating temperature | -20°C to +25°C |

### 4.1.7 High risk elements:

- Magnetic interference of two sensors
  - IMU has a magnetometer which is to be used for compass and the rotary encoder is also based on magnetic pulse. These two components can interfere with each other and show incorrect reading. As a measure to mitigate this risk, we will be placing the two components physically as far as possible from each other on the board.
- EMI interference
  - Similar to the issue mentioned, the magnetic field from these components can also generate electromagnetic interference which can disrupt the functionality of other components on the board especially inverted F-antenna for Bluetooth connection (radio frequency can be disrupted due to electromagnetic interference). The potential solutions to overcome EMI are filtering, shielding, or grounding.
- Dual charging system (USB and Solar cell)
  - As a power storage component, we are using a rechargeable LiPo battery. To recharge this battery, we are planning on using energy harvesting component - solar cells. Apart from the solar cells, we also intend to have a 5V USB charging port on the board.
  - The major drawback in this design is the unavailability of a power management IC to efficiently switch between solar cells and USB port. Even if we interface a USB port, we have to have a circuit design such that reverse current does not flow from battery to our energy harvesting device and also to automatically switch between solar energy and USB input.
  - In this circuit design, we plan to use Schottky diodes for fast switching and low voltage drop. In case we are unable to successfully implement this design, we will be eliminating use of USB charging port and use the solar power as our primary recharge source.

### 4.1.8 Project Schedule:

*Table 10: Project Schedule*

| Task | Deadline |
|---|---|
| Altium Components Libraries | Feb 12, 2022 |
| Altium Product Schematic | Feb 26, 2022 |
| Altium Product Layout | March 5, 2022 |
| Product Final Layout for Fabrication | March 12, 2022 |
| Send PCCB board for fabrication | March 19, 2022 |

We are aligned with our project timelines except the task where our plan was to bring up LCD module last week. We will be achieving this task in upcoming week. Instead, this week we focused on our case study of sample project to verify our energy calculations.

## 4.2 Activities planned for the upcoming week:

- Finalizing Bulk capacitance
- Implement LCD driver
- Schematic of Power Management Unit

Project Update 5

ECEN 5833: Low Power Embedded Design Techniques

# CUBIT

## Smart Measuring Instrument

Team Name: Cubit

Team Members: Saloni Shah

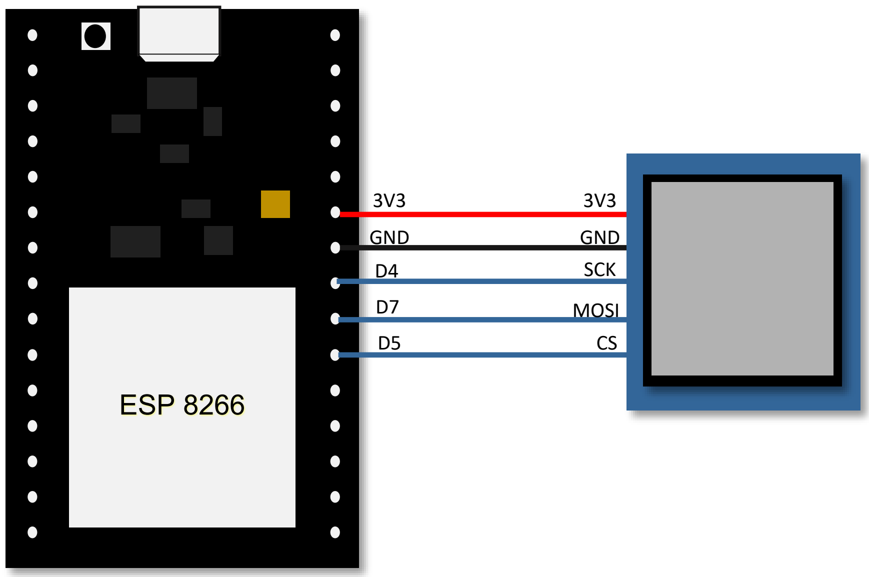
Rajat Chaple

Date: 02/18/2022

# 5.1 Activities accomplished in past week:

### 5.1.1 LCD Bringup

- LCD Interfacing with ESP8266
  - For quick test, LCD was interfaced with ESP 8266 using SPI protocol
  - Demo code was run from [Arduino Programming | Adafruit Sharp Memory Display Breakout | Adafruit Learning System]()



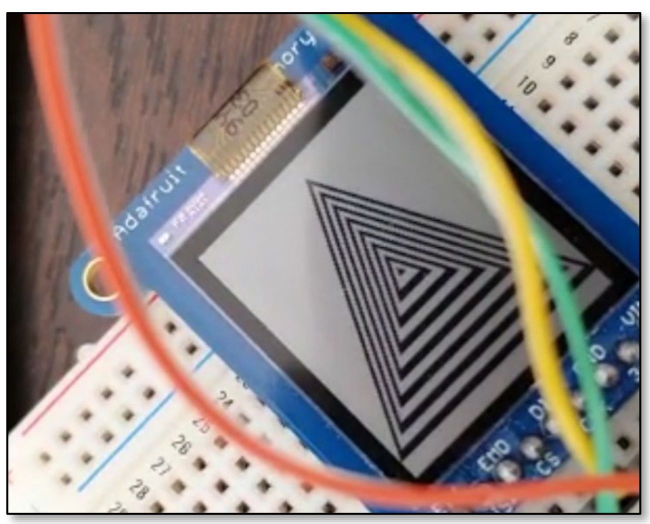
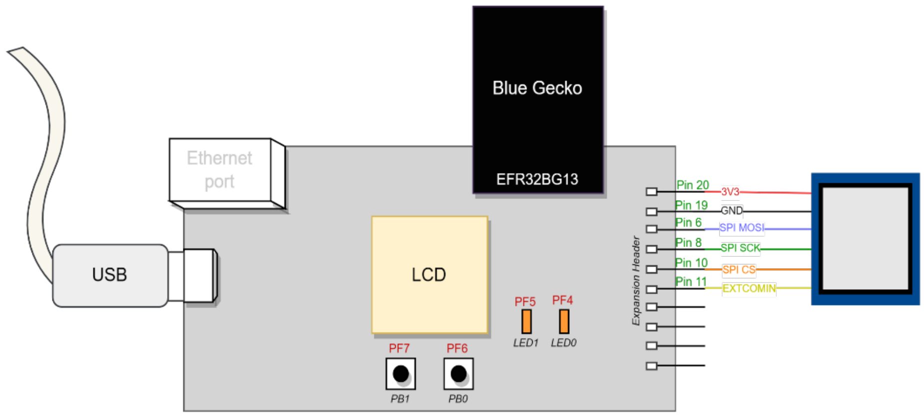



*Figure 12 LCD Interfacing with ESP8266*

- LCD Interfacing with Blue Gecko
  - Connections



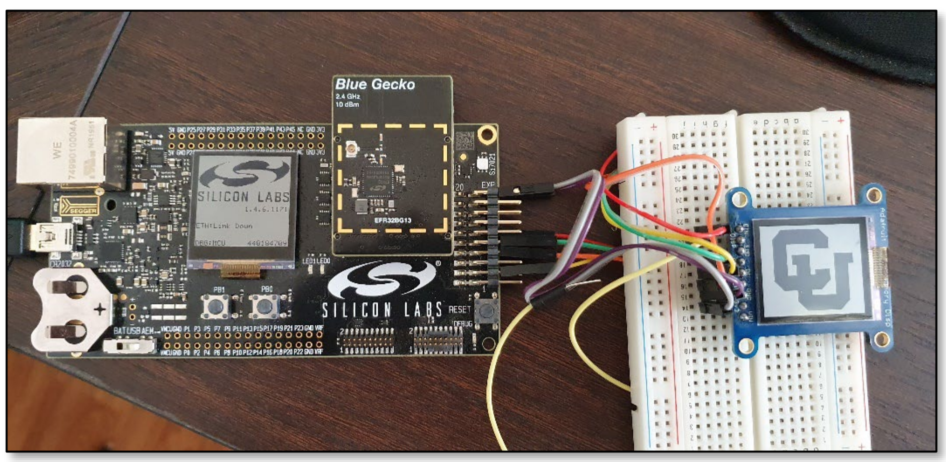




*Figure 13 LCD Interfacing with Blue Gecko*

  - Python Script for Image to binary
    - LCD requires array in binary format representing the graphics
    - Python script was written to convert any image into 168x144 graphics.
    - CU Logo was generated using this script.

- Findings

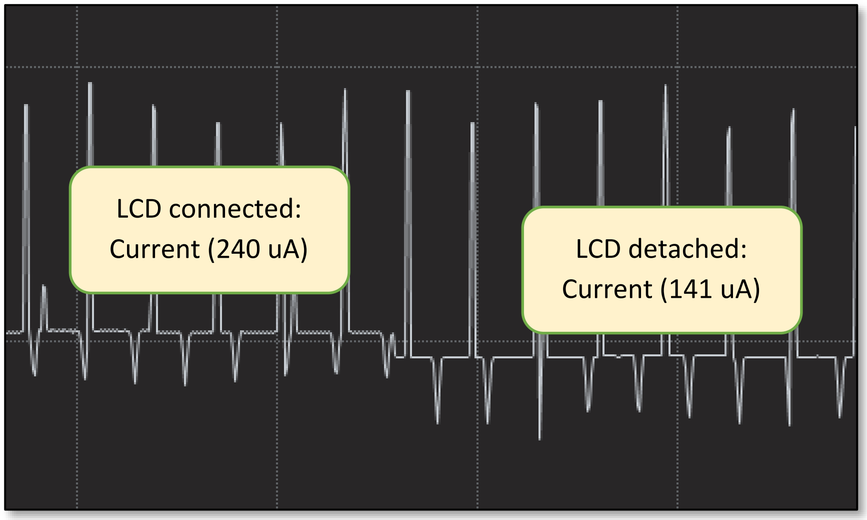
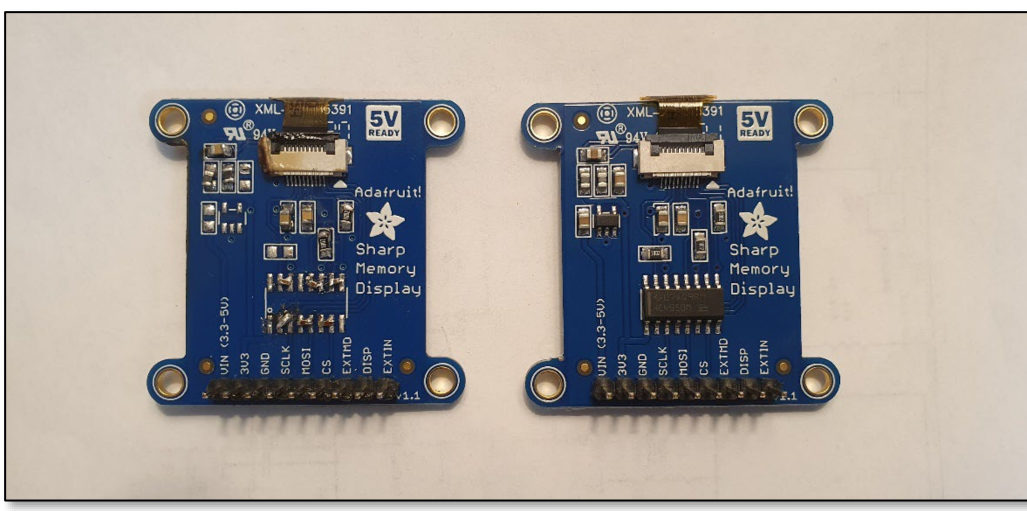



*Figure 14 Current consumption by LCD*

  - Current consumed by LCD is around 100uA

- Getting rid of additional components from the module




Removed Regulator and Logic level shifter

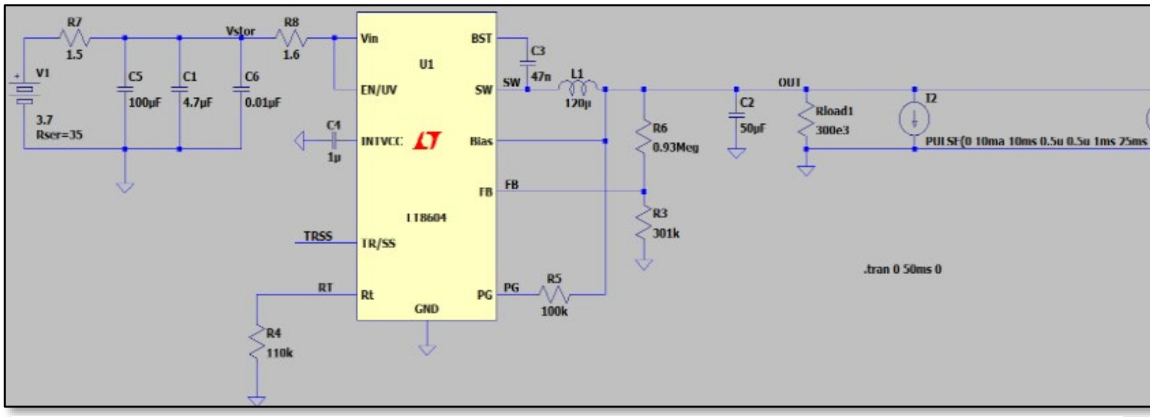
*Figure 15 LCD without a breakout module circuit*

Current consumption did not change even after removing these additional components

### 5.1.2 PMIC Simulation and Bulk capacitance

- In order to simulate Power management unit in LTSpice, we did not find the exact part number
- Combination of boost circuitry and LT8604 was used to simulate as these parts were matching with bq25570 specs.

*Below simulation showed that there is need of 100uF bulk capacitor.*




*Addition of bulk capacitor restricts minimum voltage of the system at 3.15v. This satisfies requirements for all peripherals and the controller.*

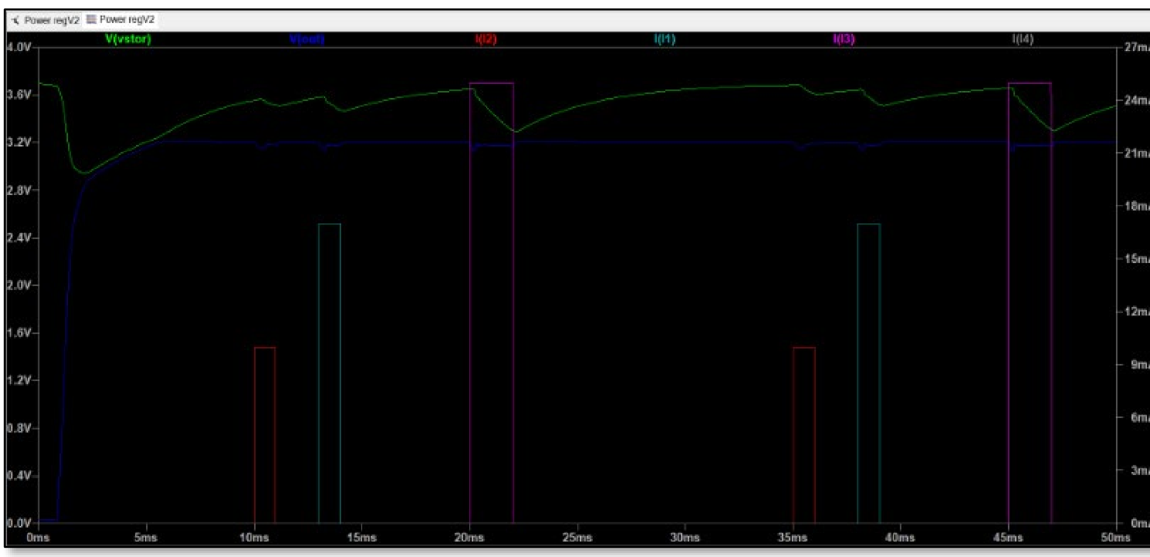



Figure 16 Calculating Bulk capacitor value

# 5.2 Activities planned for the upcoming week:

- Designing a schematic of Power Management unit and sensor interfacing
- Implement IMU sensor driver

# 5.3 Miscellaneous:

1. What features, components, will need to be added to your schematic to enable programming of your micro controller or SoC?
    a. 10 pin Debug connector would be added to the board schematic

| | | | |
|---|---|---|---|
| VAEM | 1 | 2 | GND |
| RST | 3 | 4 | VCOM_RX |
| VCOM_TX | 5 | 6 | SWO |
| SWDIO | 7 | 8 | SWCLK |
| PTI_FRAME | 9 | 10 | PTI_DATA |

**Figure 5.2. Mini Simplicity Connector Pin-Out**

**Table 5.1. Mini Simplicity Connector Pin Function**

| Pin # | Pin Name | Pin Function | EFR32 Functionality |
|---|---|---|---|
| 1 | VAEM | Target Advanced Energy Monitor Voltage Net | VDD |
| 2 | GND | Target Ground | VSS |
| 3 | RST | Target Reset (Active Low) | RESETn |
| 4 | VCOM_RX | Target Pass-through UART/Virtual COM Port Receive | US0_RX |
| 5 | VCOM_TX | Target Pass-through UART/Virtual COM Port Transmit | US0_TX |
| 6 | SWO | Target Serial Wire Output | SWO |
| 7 | SWDIO | Target Serial Wire Data Input/Output | SWDIO |
| 8 | SWCLK | Target Serial Wire Clock | SWCLK |
| 9 | PTI_FRAME | Target Packet Trace Interface Frame Signal | FRC_DFRAME |
| 10 | PTI_DATA | Target Packet Trace Interface Data Signal | FRC_DOUT |

*Figure 17 Debug connector pinout*

Source: [AN958: Debugging and Programming Interfaces for Custom Designs (silabs.com)]

Following features would be available with this debug port:

1) SWD (Serial Wire Debug)
2) AEM (Advanced Energy Monitoring)
3) PTI (Packet trace interface)
4) VCOM (Virtual COM port)
5) Virtual UART

The Debug In mode of the debugging would be used

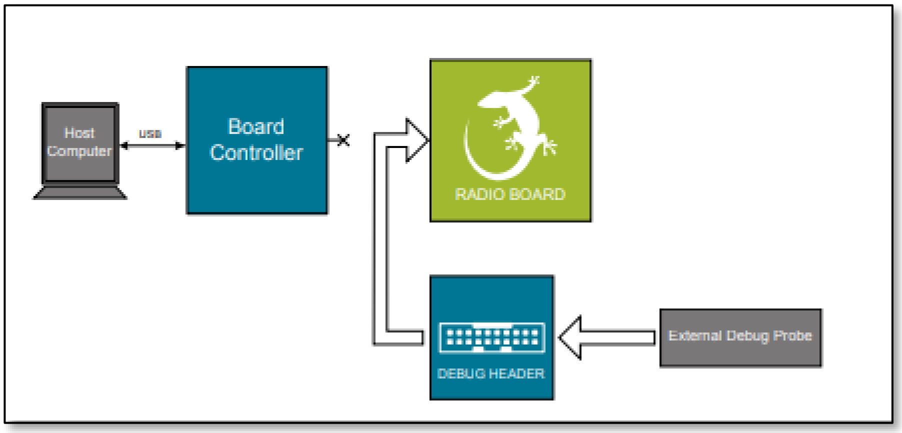



*Figure 18 Debug interface with Radio board*

Source: [UG279: EFR32BG13 Blue Gecko Bluetooth Starter Kit User's Guide (silabs.com)]

2. Describe the process of how you will compile and download code to your board, the target board
   1) Simplicity studio v5 would be used as a programming IDE during development.
      a. GNU ARM C compiler (cross compiler: arm-none-eabi-gcc) would be used to compile the code
      b. Simplicity Studio v5 also provides an option to select your development board. This in turn defines the memory map of the controller.

   2) Simplicity Commander would be used to download the code into target board
      Command line syntax: *commander [command] [options] [arguments]*
      Sequence of commands would be,
      a. Erase Flash
      b. Flash new code
      c. Verify written data
      d. Reset the microcontroller

3. Which signals will have test points?
    a. SPI port (For LCD and Magnetic Rotary Encoder)
        - SCLK
        - CS
        - MOSI
    b. I2C port (for IMU Sensor)
        - SCL
        - SDA
    c. UART pins (for Ultrasonic sensor)
        - RX/TX
    d. Power pins of each sensor
    e. PMIC Vout
    f. Energy Harvester Input
    g. USB Input
    h. Battery Storage input

4. Reset Circuit Description

    Reset would be controlled by 2 modes of operation

    a. Reset via Debugging Interface
        - Pin 3 on Mini debug connector
    b. On board reset switch
        - Pin 12 on EFR32BG13 is nReset
            - Active low
            - It's only required to drive this pin low externally
            - Internal pull-up pulls this pin high

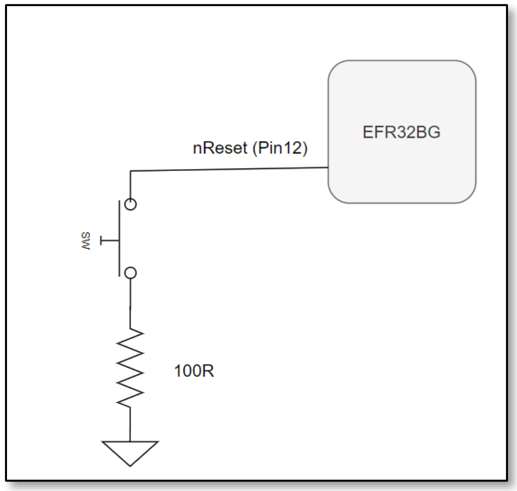



*Figure 19 Reset circuit*

## 5. Clock Generation Description

a. Both oscillators Low Frequency and High Frequency oscillators would be required:
   - High Frequency crystal (38 to 40 MHz): For Radio
   - Low Frequency crystal (32.768 kHz): For Low Energy modes operation

b. There are also other oscillators available for clock generation namely
   1) High Frequency RC oscillator
   2) Auxiliary high frequency RC oscillator
   3) Precision LF RC oscillator
   4) Low frequency RC oscillator
   5) Ultra-low frequency RC oscillator

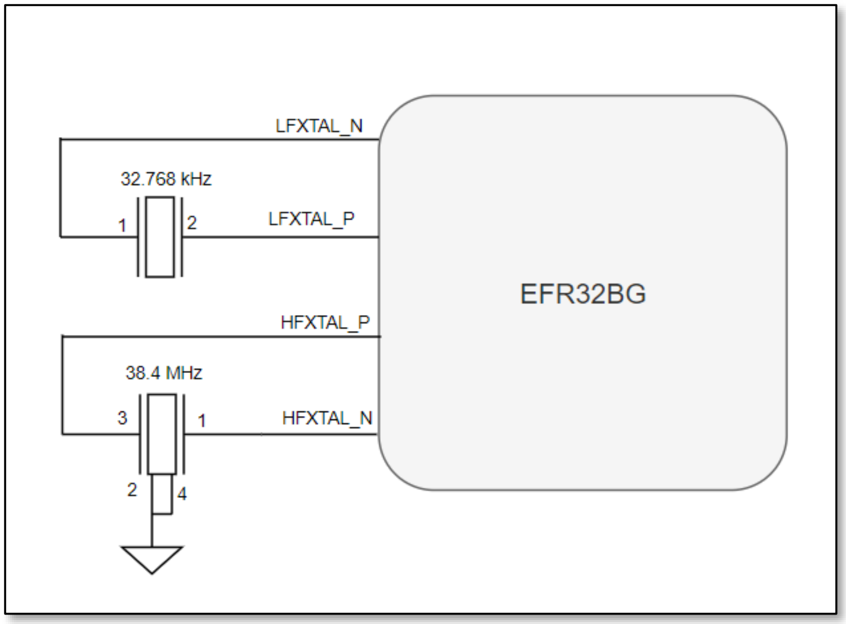



*Figure 20 Crystal oscillator connection diagram*

6. Provide alternative energy source other than the energy harvester

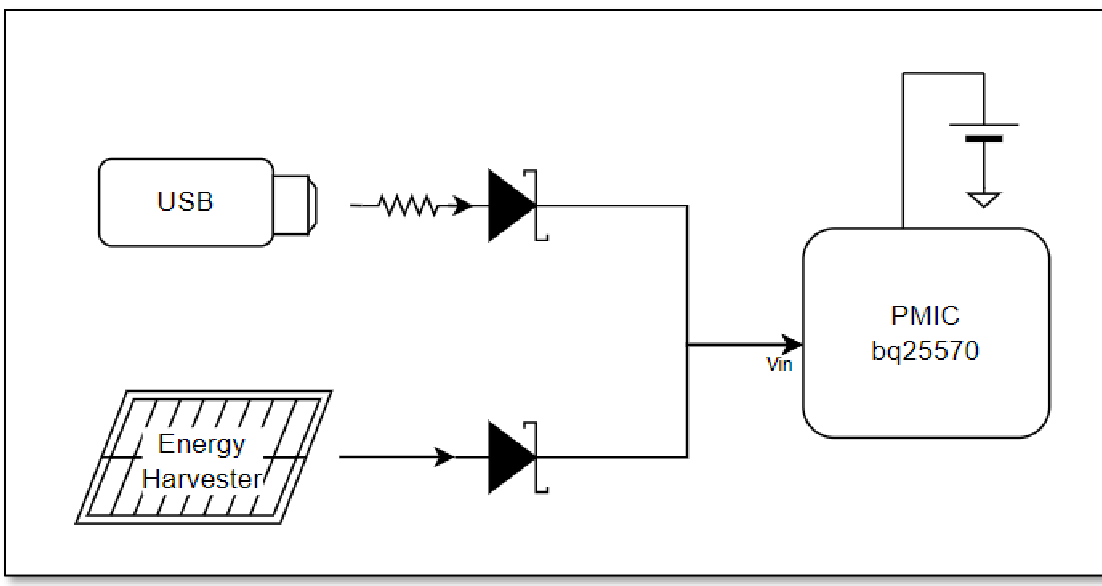



*Figure 21 Alternate energy sources for board*

There would be a provision of USB apart from Energy harvester unit as an alternative energy source.

- Schottky diodes would be used to allow both the energy sources to be connected at the same time.

- As VIN_DC is pulled to ground through a small resistance, USB supply would have a resistance in series to limit the current flow. This solves below problem,

**CAUTION**

If VIN_DC is higher than VSTOR and VSTOR is equal to VBAT_OV, the input VIN_DC is pulled to ground through a small resistance to stop further charging of the attached battery or capacitor. It is critical that if this case is expected, the impedance of the source attached to VIN_DC be higher than 20 Ω and not a low impedance source.

7. Jump Start method to charge the energy storage element in the event that the Energy Harvester circuity is not functional or takes too long.
    - Along with above circuit, there would be a provision to disconnect the battery from the embedded device and charge it using Lab power supply.
    - Battery would be charged at 235mA as 250 mA is the maximum charging current for the battery. Charge voltage would be set to 4.2V

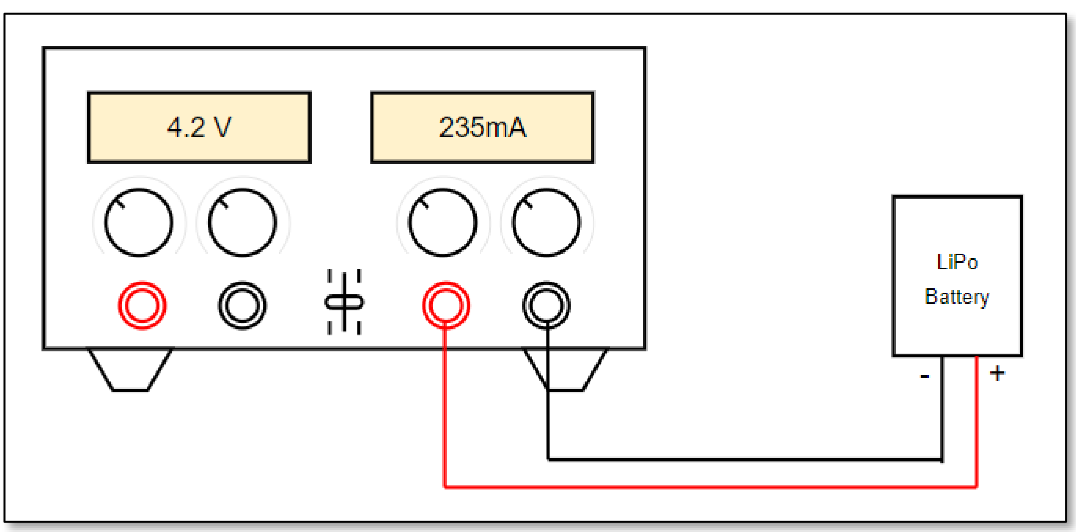



*Figure 22 Battery charging using power supply*

8. What is the maximum charging current allowed by the PMU circuitry?

   As per PMIC datasheet,

   - Typical charging current is 235mA and
   - Maximum charging current allowed by PMU is 285mA

9. What is the maximum charging current allowed by the energy storage unit specs?

   - Max charge current for the battery is 0.5C i.e. 250mA

10. What will the maximum current of the jump start power source be set to?

    - Maximum current for the jump start can be set to 250mA as supported by the battery.

11. Where will the jump start power and ground signals connect to?

    Following are the two options for the jump start,

    1) Disconnect battery and charge it using Lab power supply
    2) Charge battery using USB via PMIC

12. Ensuring that there is enough energy / current to program the flash of the MCU how much current will the programming of the MCU flash require?

    As per datasheet,

    - Current consumption during flash write is 3.5 mA and
    - Current consumption during Flash read is 2.0 mA

**4.1.13 Flash Memory Characteristics[1]**

**Table 4.44. Flash Memory Characteristics[1]**

| Parameter | Symbol | Test Condition | Min | Typ | Max | Unit |
|---|---|---|---|---|---|---|
| Flash erase cycles before failure | $EC_{FLASH}$ | | 10000 | — | — | cycles |
| Flash data retention | $RET_{FLASH}$ | T ≤ 85 °C | 10 | — | — | years |
| | | T ≤ 125 °C | 10 | — | — | years |
| Word (32-bit) programming time | $t_{W\_PROG}$ | Burst write, 128 words, average time per word | 20 | 26.3 | 30 | µs |
| | | Single word | 62 | 68.9 | 80 | µs |
| Page erase time[2] | $t_{PERASE}$ | | 20 | 29.5 | 40 | ms |
| Mass erase time[3] | $t_{MERASE}$ | | 20 | 30 | 40 | ms |
| Device erase time[4 5] | $t_{DERASE}$ | T ≤ 85 °C | — | 56.2 | 70 | ms |
| | | T ≤ 125 °C | — | 56.2 | 75 | ms |
| Erase current[6] | $I_{ERASE}$ | Page Erase | — | — | 2.0 | mA |
| Write current[6] | $I_{WRITE}$ | | — | — | 3.5 | mA |
| Supply voltage during flash erase and write | $V_{FLASH}$ | | 1.62 | — | 3.6 | V |

*Figure 23 Flash memory specs*

13. How much current will the energy storage element and the PMU be able to provide?

| Unit | Current |
|---|---|
| Energy storage element (Battery) | 1 A (2C) |
| PMU (bq25570) | 110 mA |

14. What are the connection points to enable external power to digital / MCU portion of the board?
    - USB as an input to the PMIC would be used to power digital/MCU portion of the board.
    - External lab power supply would be used to charge the battery.

Project Update 6

ECEN 5833: Low Power Embedded Design Techniques

# CUBIT

## Smart Measuring Instrument

Team Name: Cubit

Team Members: Saloni Shah

Rajat Chaple

Date: 02/25/2022

# 6.1 Activities accomplished in past week:

### 6.1.1 IMU Bring-up

- BNO055 interface with Blue Gecko
  - IMU Communicates with EFR32 radio board over I2C protocol.
  - BNO055 supports two configurable addresses, 0x29 and 0x28. 0x28 address was selected for the communication.
  - For bring-up, accelerometer values were read. This required following configuration
    - Set up config bits of IMU to turn on Accelerometer
    - Read lower byte of accelerometer

- Connection Diagram

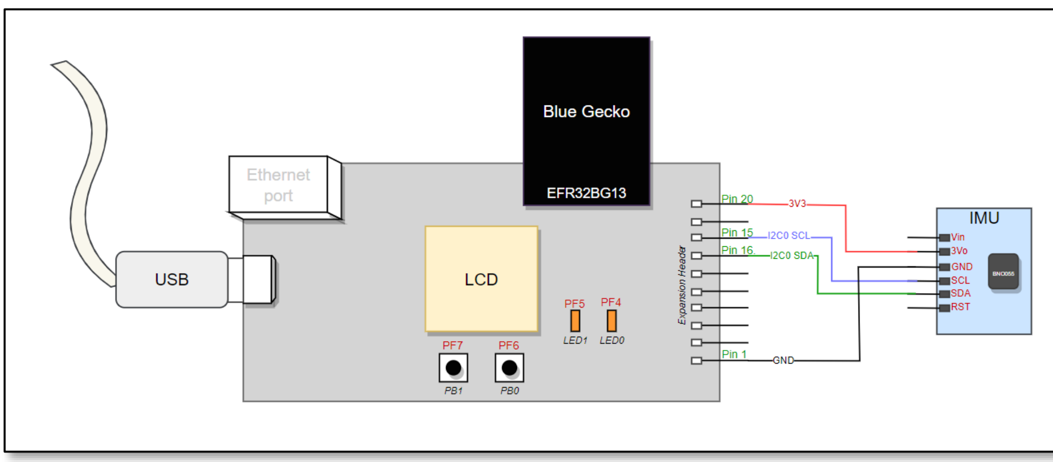



*Figure 24 IMU Interface with Blue Gecko*

  - Program was written for I2C_FREQ_STANDARD_MAX which is 92KHz data transfer.
  - Digilent's Analog Discovery 2 logic analyzer was used to monitor the I2C transaction
  - Hardware Interface and Logic analyzer trace is shown below.

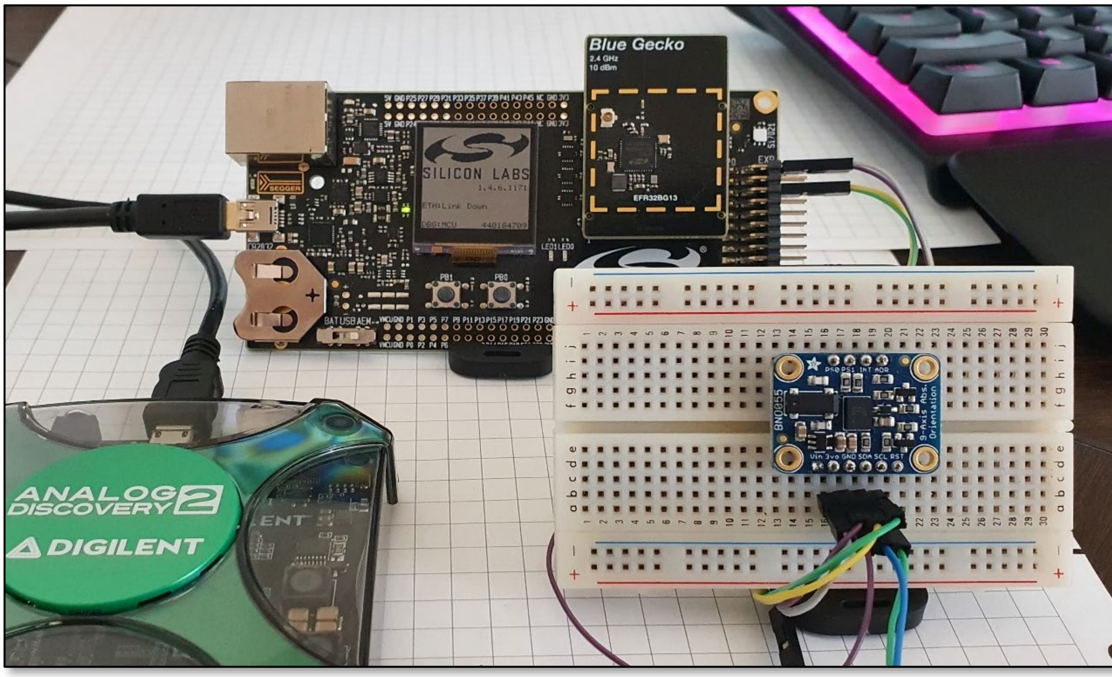



*Figure 25 Hardware: IMU with Blue Gecko*

- I2C Transactions
  - Accelerometer (x direction) lower byte data is stored in register 0x08 of BNO055.

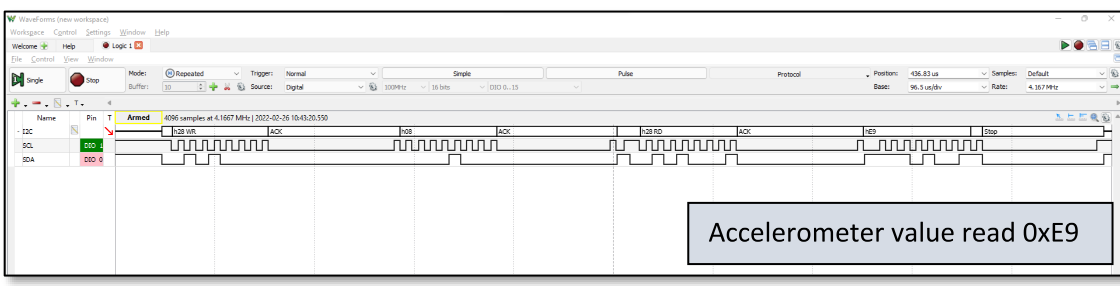



*Figure 26 Logic Analyzer trace for IMU*

  - Above activity was performed with different accelerations to verify change in values in register 0x08.
  - Next task for IMU would be writing down a wrapper functionality to receive
    - Angle using IMU fusion
    - Compass using Magnetometer

### 6.1.2 Magnetic Encoder Bring-up

- AS5147P Interfacing with Blue Gecko
  - Magnetic encoder uses Hall effect sensor AS5147 to detect change in magnetic field.
  - It supports SPI, ABI, UVW and PWM interfaces. ABI interface would be appropriate for our application as we can keep microcontroller in lowest possible energy mode whenever there's no activity.

- Connection diagram

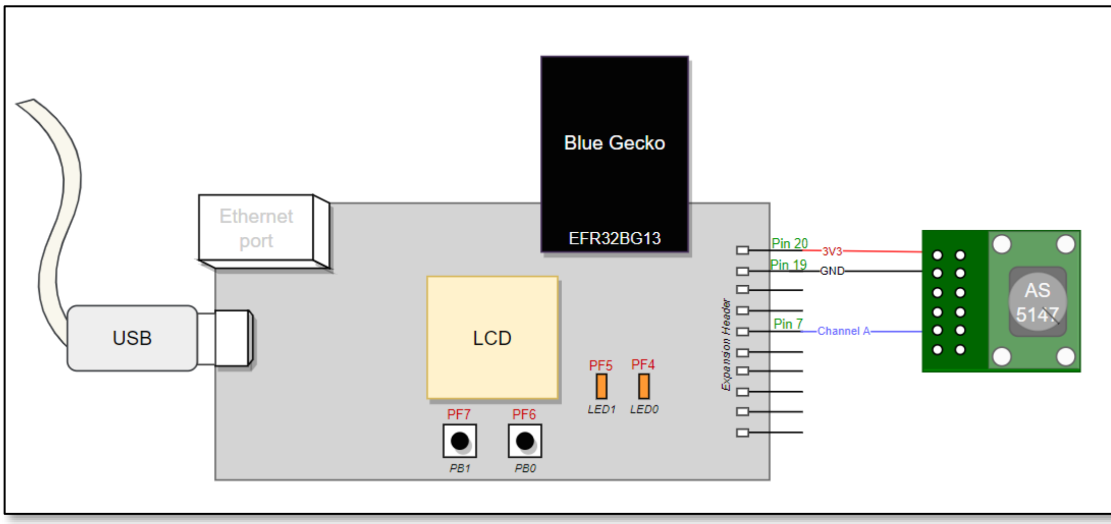



*Figure 27 Magnetic Encoder Interface with Blue Gecko*

  - Program was written to receive interrupts on GPIO pin and keep the count of pulses for channel A of Magnetic encoder. This count was printed over serial terminal.
  - Energy profiler was used to see variation in energy consumption as pulses were received.
  - With current configuration 1024 pulses are received per revolution.
  - It is configurable over SPI to receive 256 pulses per revolution
  - Hardware Interface and Energy profiler shown below

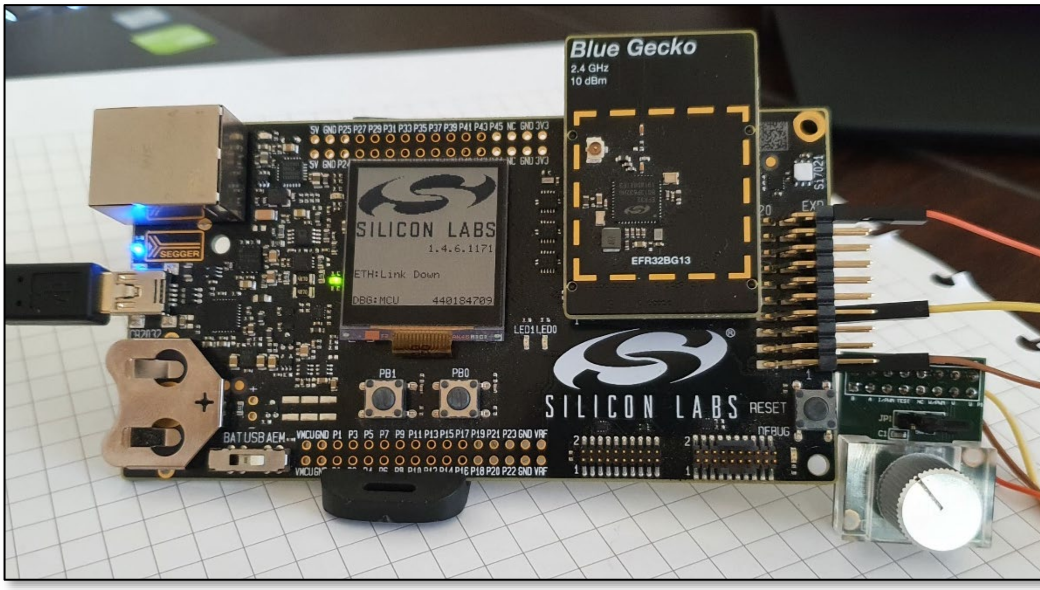



*Figure 28 Hardware: Magnetic Encoder with Blue Gecko*

- Energy profiler and Serial log
  - Energy profiler showed typical current Magnetic encoder is consuming which is around 900uA.
    Note: This measurement is only for 1 channel.
  - Program was setting EFR32 radio board in EM2 energy mode where Bluetooth is operational

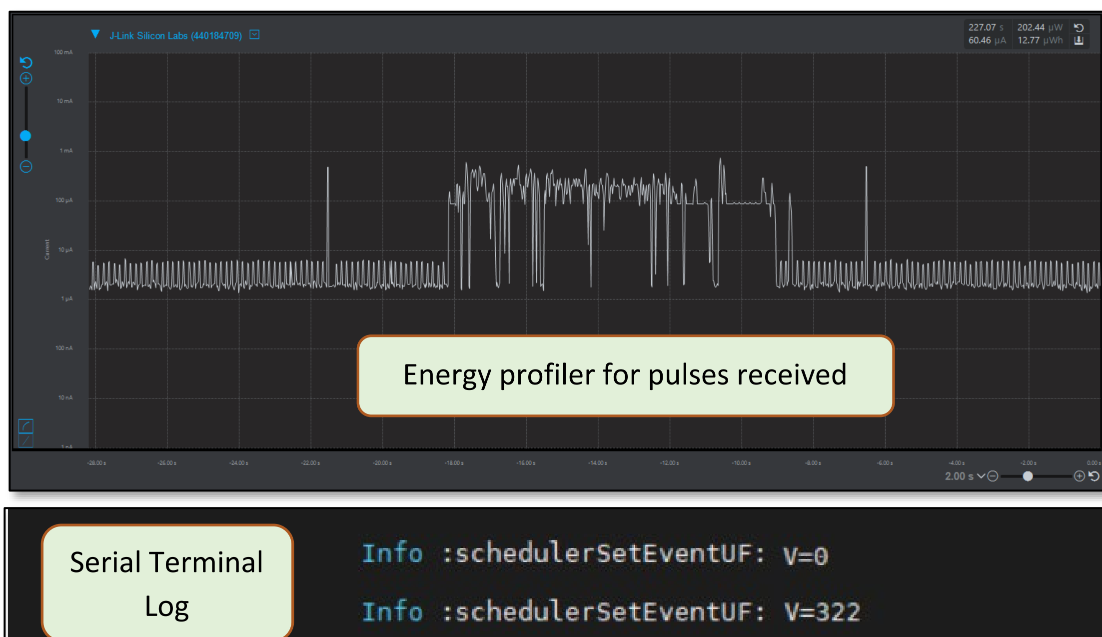



*Figure 29 Energy profile and Serial log for Magnetic Encoder*

- Challenges for magnetic encoder:
    - It's been observed that EFR32 for above operation is not able to handle 1024 pulses per revolution when wheel rotates faster. In fact, this much resolution is not required for this application.
    - In order to resolve this, plan is to use low power frequency divider to reduce pulses. Required number of pulses per revolution to maintain stated measurement resolution can be calculated as follows

Assumption: Wheel diameter = 3cm

Circumference of wheel = $\pi * d = 9.42\ cm$

In order to maintain minimum resolution of 0.5cm, around 20 pulses are required per resolution.

Magnetic encoder can be operated in 256 ppr mode with configuration bits and this further can be divided by 8 using external frequency divider. This would result in 32 pulses per revolution.

### 6.1.3 Actual Bulk capacitor value required (considering the DC bias)

- As per our bulk capacitor calculations, Cubit board requires 100uF capacitor.
- In order to find out equivalent capacitance that would give 100uF, simsurfing tool from murata was used.
  [SimSurfing: Multilayer Ceramic Capacitors - Murata Manufacturing]
- 220uF ([GRM32ER60J227ME05L Murata Electronics | Capacitors | DigiKey]) was selected based on following DC bias characteristic.
  - 3.2v is our operational voltage for the entire circuit
  - Effective bulk capacitor value @ 3.2v = 220 – 52.6% = 104.28uF

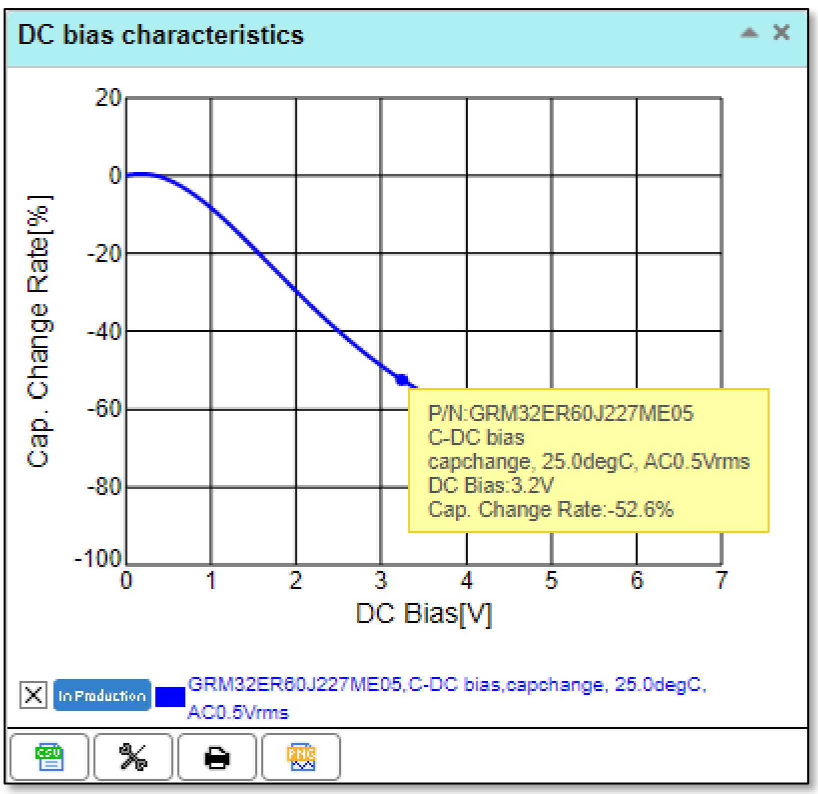



*Figure 30 DC bias characteristics for bulk capacitor*

### 6.1.4 IO Ports in design

- Buttons
  - Menu selection switches
- Switches
  - Operation Mode switch

| Modes | Description |
|---|---|
| All OFF | External supply to PMIC would be disconnected |
| Partial ON | Only PMIC, EFR32 radio board and LCD would be Turned ON |
| All ON | All components and required sensors would be turned ON |

- USB
  - To be used for fast charging of battery where energy from energy source would not be available.
- Battery connector
  - To be used for External Lipo battery

For above mentioned IO ports ESD protection would be required.

### 6.1.5 ESD protection

| IO Ports | ESD part |
|---|---|
| HMI pushbutton switches (4) | SP1001-04JTG |
| USB | SP1003 |
| Battery Connector | SP1003 |

- SP1003 part used for VBUS pin from USB connector and power pin from battery connector has clamping voltage of 12V which is closer to maximum allowable input voltage (5V) for PMIC BQ25570. Moreover, this part has low leakage current of 100nA (MAX) at 5V operation.
- SP1001 part used for ESD protection on push button switches satisfies the requirement of 4 I/O pins connection for 4 push-button switches.

# 6.2 Activities planned for the upcoming week:

- Incorporate changes in board schematic suggested in the review
- Designing a layout for the final board
- Interface ultrasonic sensor with Blue Gecko development board.

Project Update 7
ECEN 5833: Low Power Embedded Design Techniques

# CUBIT

## Smart Measuring Instrument

Team Name: Cubit

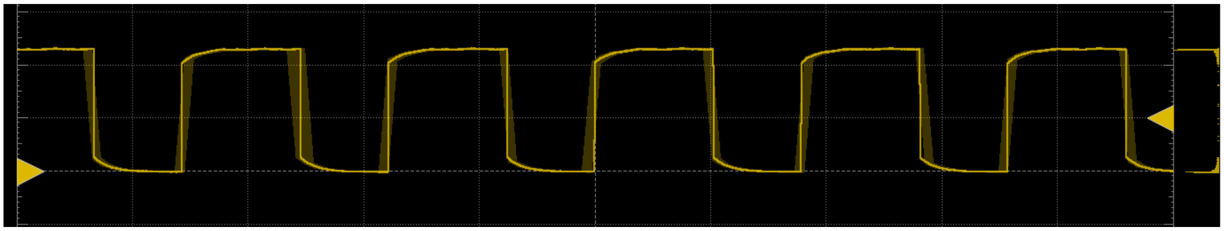
Team Members: Saloni Shah
Rajat Chaple

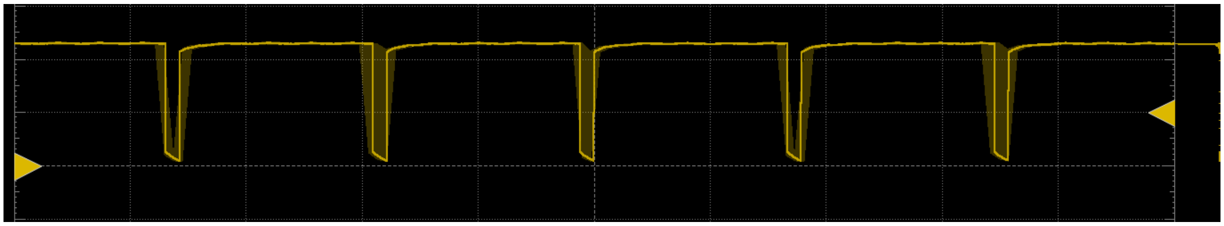
Date: 03/12/2022

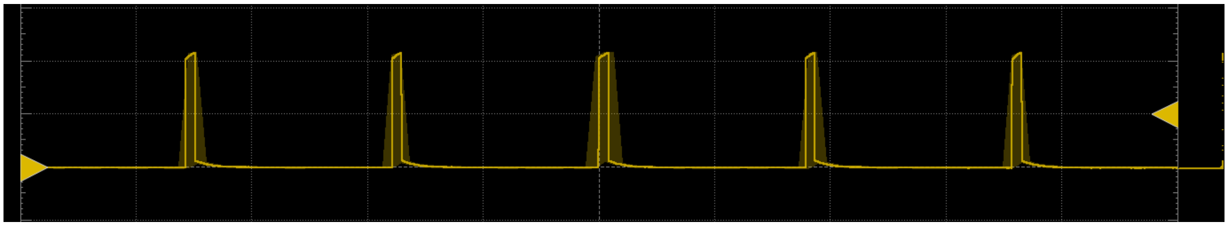
# 7.1 Activities accomplished in past week:

### 7.1.1 Testing of PWM output generation on Magnetic Encoder:

- The magnetic encoder gives output at the rate of minimum 256 pulses per rotation. Two different such output pulses must be interpreted by the controller to determine number of pulses generated and the direction of rotation.







### 7.1.2 Frequency divider for Magnetic Encoder output:

- The magnetic encoder gives output at the rate of minimum 256 pulses per rotation. Two different such output pulses must be interpreted by the controller to determine number of pulses generated and the direction of rotation.

- As per the challenges related to the encoder discussed in previous update, we monitored the pulses received on the controller at the rate of 12 rotations per second. As expected, while transitioning from lowest energy mode to a higher mode while receiving pulses, the controller missed some pulses due to time delay.
- For these reasons, we decided to include an additional frequency divider on the output of the encoder.
- CD74HC4520 is a high speed CMOS logic Dual Synchronous Counter. It is a dual binary up-counter which consists of two independent internally synchronous 4-state counters. The counter stages are D-flipflops to either increment on rising-edge or falling edge.
- The below image shows the timing diagram of 4-bit binary counter. In this component, we get the option of dividing the input by 1 (on Q0), by 2 (on Q1), by 4 (on Q2) and by 8 (on Q3). We will be using the Q3 output which divides the input by 8. This will reduce our magnetic encoder pulses to 32 pulses per rotation which will be computationally simpler for the controller.

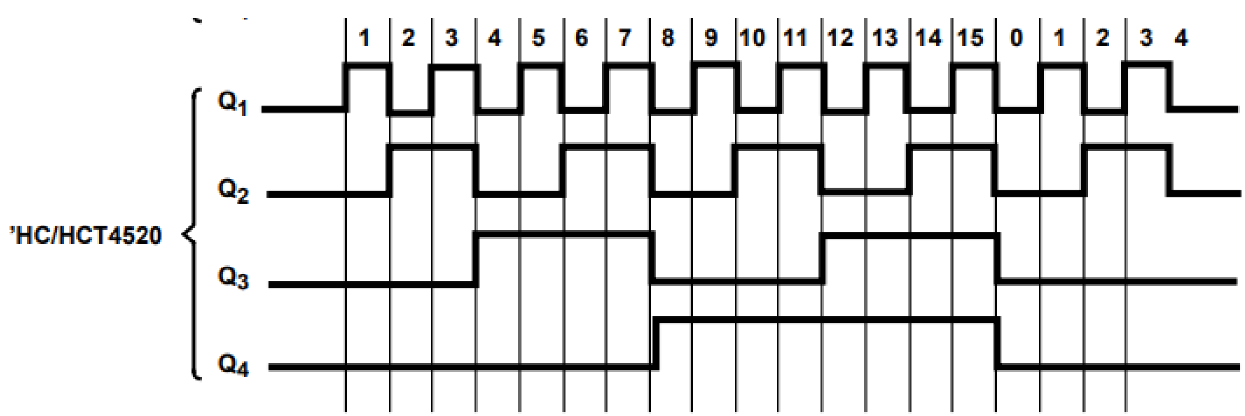
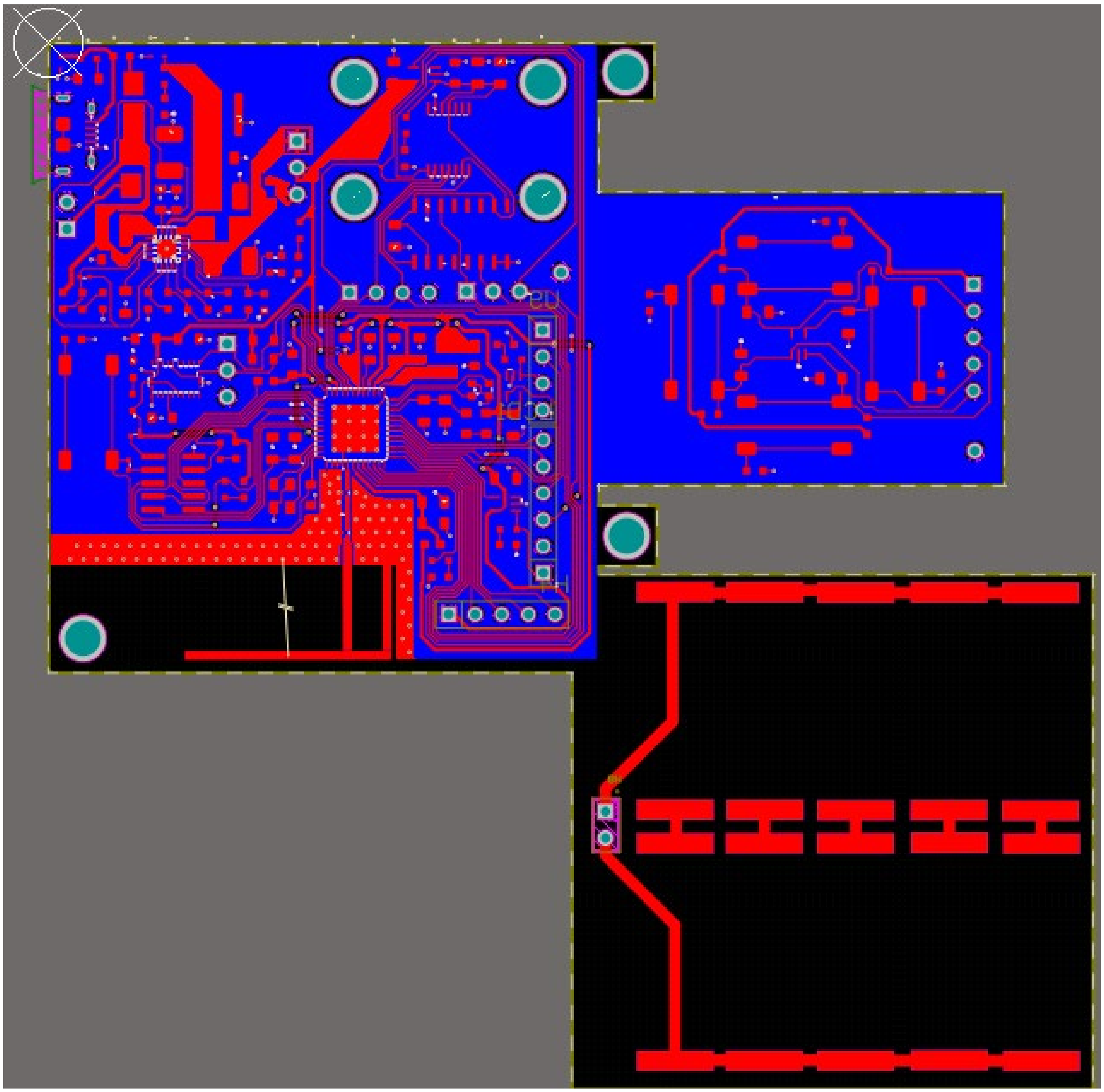



*Figure 31 Frequency division timing diagram in CD74HC4520*

### 7.1.3 Interfacing ultrasonic sensor with Blue Gecko development kit:

| | | | |
|---|---|---|---|
| (x)= array_buf[78] | char | 82 ('R') | 0x20001936 |
| (x)= array_buf[79] | char | 48 ('0') | 0x20001937 |
| (x)= array_buf[80] | char | 54 ('6') | 0x20001938 |
| (x)= array_buf[81] | char | 53 ('5') | 0x20001939 |
| (x)= array_buf[82] | char | 13 ('\r') | 0x2000193a |

### 7.1.4 Altium Board Layout:



# 7.2 Activities planned for the upcoming week:

- Incorporate changes in board layout suggested in the review
- Finalize board layout and place board fabrication order
- Complete the interfacing of ultrasonic sensor with Blue Gecko development board.
- Start working on configuring basic mobile application for the product.
- Development of initial software for the final board.

Project Update 8

ECEN 5833: Low Power Embedded Design Techniques

# CUBIT

## Smart Measuring Instrument

Team Name: Cubit

Team Members: Saloni Shah

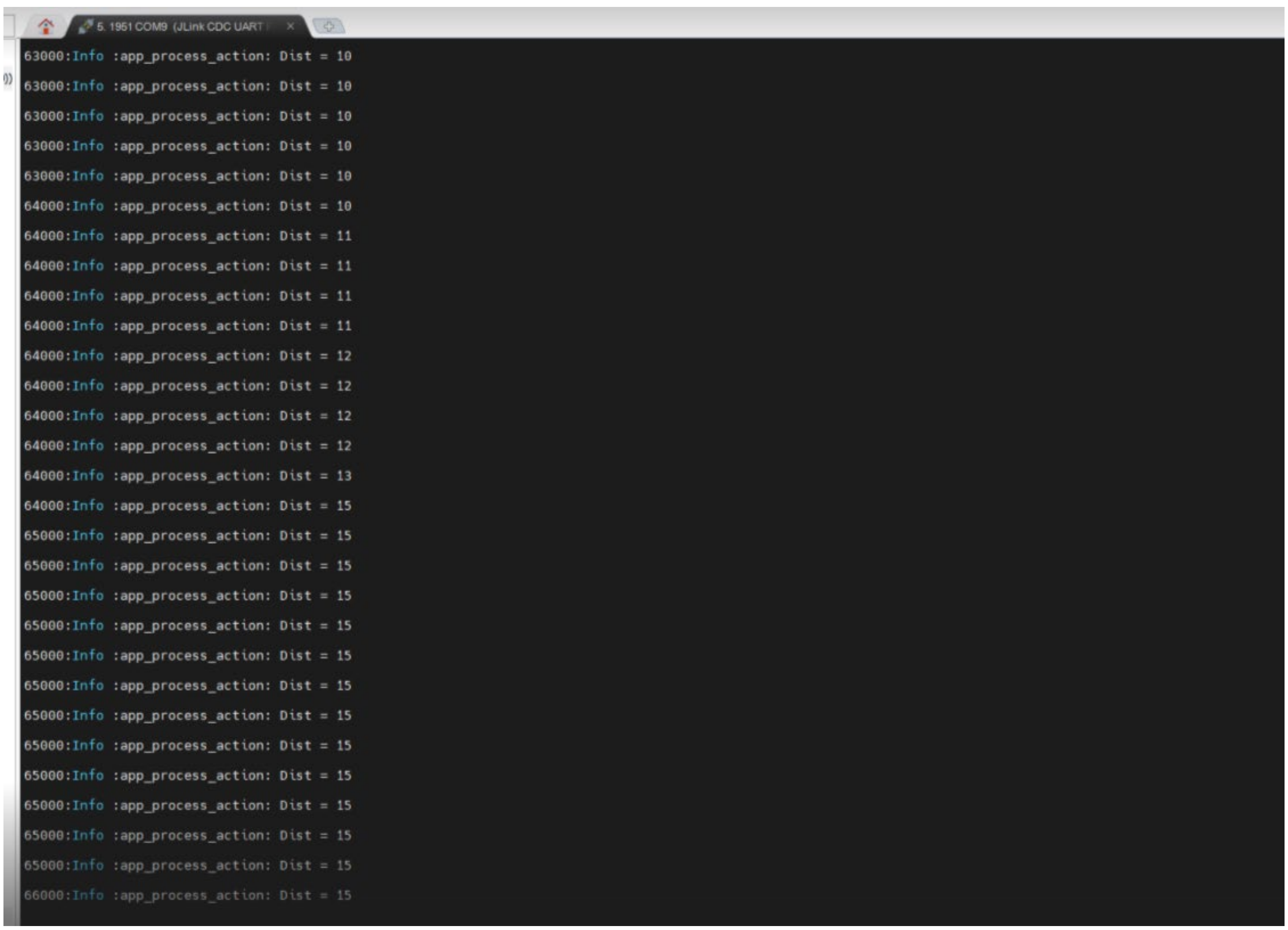
Rajat Chaple

Date: 04/02/2022

# 8.1 Activities accomplished in past week:

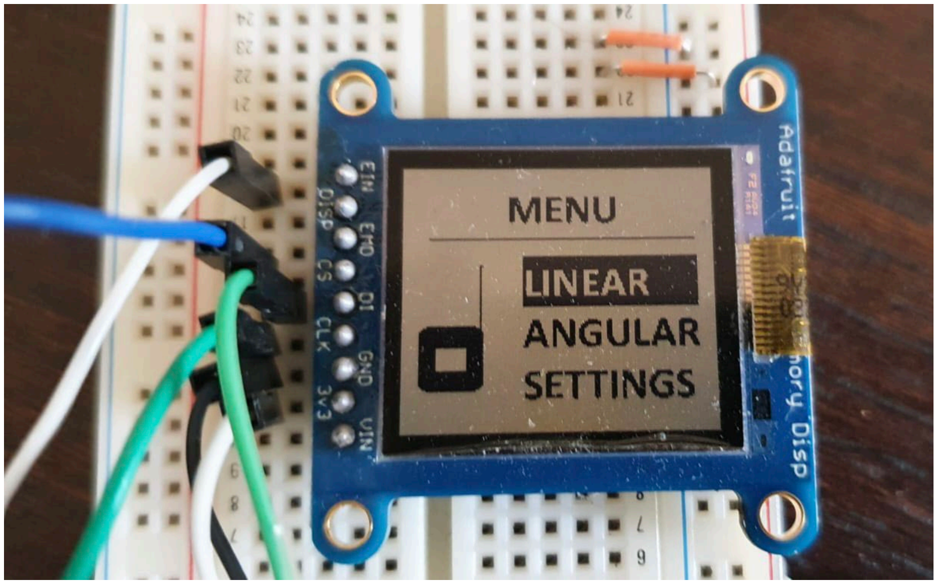
### 8.1.1 Completed interfacing of ultrasonic sensor:

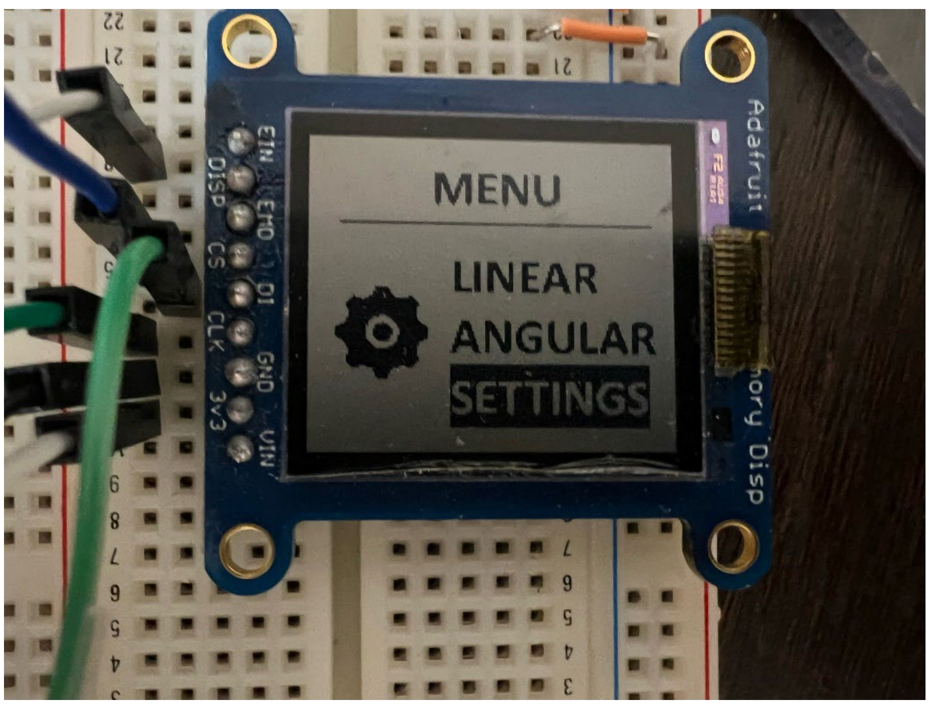
- Previously, data was being received over UART channel from ultrasonic sensor but could not be displayed accurately on UART communication port due to interference from UART communication taking place between Blue Gecko development board and the IDE.
- Previously, the UART RX pin used is the same pin used by VCOM for UART communication. This pin is then continuously enabled and disabled which caused the UART com port to display inaccurate values.
- Currently, we were successfully able to bypass that issue by changing to a different pin for UART receiving from ultrasonic sensor.



### 8.1.2 Prototype software development for on-board LCD:

- Set up LCD screens for menu display which is controlled by push buttons.



# 8.2 Activities planned for the upcoming week:

- Assembly completion for final fabricated board
- Final completion of controlling LCD display using push buttons
- Designing sensor assembly on prototype board

# 8.3 Verification Plan:

- The following verification plan has been devised in order to check the correct functionality of the prototype.

| To be verified | Definition of passing | Date Test Performed | Tested By | Measured Value | Passed? |
|---|---|---|---|---|---|
| Voltage Vcc does not drop below minimum system specification | Minimum voltage during 10uA to 10mA at minimum battery voltage is above 3.0V | | | | |
| Voltage Vcc does not go above system specification | Maximum voltage during 25mA to 10uA step at maximum battery voltage (4.2V) is below 4.5V | | | | |
| Communication bus I2C | 1.IMU sensor data received accurately over the communication bus<br>2. The observed communication byte sequence on logic analyzer matches with the datasheet without I2C bus errors | | | | |
| Communication bus UART | 1. Ultrasonic sensor data is received over UART correctly<br>2. Sensor data is precisely displayed over UART com port | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Communication bus SPI | 1. Magnetic encoder can be programmed for variable output pulse frequency.<br>2. LCD display is properly updated | | | | |
| Energy Storage Element Charging | Upon reaching at low charge state (about 2.7V), the battery can be recharged using solar cells, USB connection or an external power source to reach a sufficient charge state to provide energy to system (about 3.2V) | | | | |
| Power Good signal on PMIC | The PMIC generates an output voltage of computed 3.2V which will turn on the LED connected to VBAT_OK pin of BQ25570 | | | | |
| System boot upon increase in charge of Energy Storage Element above required amount | When the battery charge is above 3.2V specification, the system can be booted successfully | | | | |
| System shut down upon decrease in charge of Energy Storage Element below required amount | When the battery charge is less than 3.2V, it will cause system shutdown. | | | | |
| Correct values from IMU sensor | The angle measurement value from accelerometer in BNO055 is within the range of -90° to +90° | | | | |
| Correct Value from Magnetic Encoder | Output from magnetic encoder after frequency | | | | |

| | | | | | |
|---|---|---|---|---|---|
| | division is 32 pulses per rotation. | | | | |
| Correct values from Ultrasonic Sensor | Ultrasonic sensor data value is in the range of 6-254 inches | | | | |
| Appropriate screen displays on LCD display | Required menu and sensor data is displayed on LCD upon controlling it with switch board | | | | |
| Bluetooth connection to host device | Successful Bluetooth connection is established between target board and mobile device | | | | |
| Data can be transmitted and received over Bluetooth connection | Sensor data values can be sent from target board and data indication/ notification can be controlled from the device | | | | |
| Energy Harvesting Unit can charge the battery | Battery charge can be increased from a low charge state using the solar cell board. The output voltage from the solar cell assembly is expected to be 1.12V and resultant current should be 275mA. | | | | |
| Energy Harvesting Unit can charge the battery to required use case specification | From a low charge state, the battery can be charged to at least 3.2V state to successfully boot the system. | | | | |
| Energy Harvesting unit can provide energy to the target board without being assisted by | From a low charge state, the battery can be charged to a higher charge of 3.2V to provide energy to the system without assistance of an external power source. | | | | |

| | | | | | |
|---|---|---|---|---|---|
| external power sources | | | | | |
| USB connection can be used to charge the battery | When the USB connector is connected, the battery can be charged from the USB bus. | | | | |
| Schottky Diode arrangement works correctly to use either USB connection or Energy Harvesting Unit to charge the battery | When USB is connected, the battery is charged through this connection and not from the solar cells. | | | | |
| USB bus voltage does not exceed maximum defined system specification | USB does not supply more than 5.1V which is specified maximum voltage for PMIC | | | | |
| Verification of functionality of PMIC BQ25570 | 1.VBAT_OV = 4.2V<br>2. VBAT_OK = 3.2V<br>3. VOUT = 3.2V<br>4. Charging of battery from solar cells or USB bus | | | | |
| Verification of functionality of MCU EFR32 | 1.Successful sensor interfacing over communication buses.<br>2. Low and High Frequency crystal oscillators generate specified frequency signal<br>3. Reset switch can be used to reset the MCU<br>4. GPIO pins can be used to control switch board and load switch for sensors | | | | |
| Verification of functionality of | Magnetic encoder output pulses which are 256 pulses per rotation are | | | | |

| | | | | | |
|---|---|---|---|---|---|
| Frequency Divider IC CD74HC4520 | divided by 8 and the final output to MCU is in the range of 32 pulses per rotation | | | | |
| Verification of functionality of Load Switches | Load switches can be controlled via MCU for regulate power supply to magnetic encoder, LCD display and ultrasonic sensor | | | | |
| Bulk Capacitance can maintain constant voltage as per specification | Bulk capacitance of 100uF on VSTOR of PMIC and output of PMIC keeps the voltage supply constant to 3.2V during abrupt changes in system power consumption | | | | |
| Switch Board can be used to control LCD display | 1.Up, down, back and go pushes on the button are detected by GPIO in the MCU.<br>2. Push buttons can be used to manage menu options on LCD display.<br>3. Selection of required menu option results in functionality to use corresponding sensor for measurement purposes. | | | | |
| Debug connector for programming Blue Gecko controller chip | EFR32 is successfully programmed and booted using Debug connector. | | | | |

Project Update 9

ECEN 5833: Low Power Embedded Design Techniques

# CUBIT

## Smart Measuring Instrument

Team Name: Cubit

Team Members: Saloni Shah

Rajat Chaple

Date: 04/09/2022

# 9.1 Activities accomplished in past week:

## 9.1.1 Fabricated Board Assembly:

- Successfully completed parts assembly for two fabricated boards.

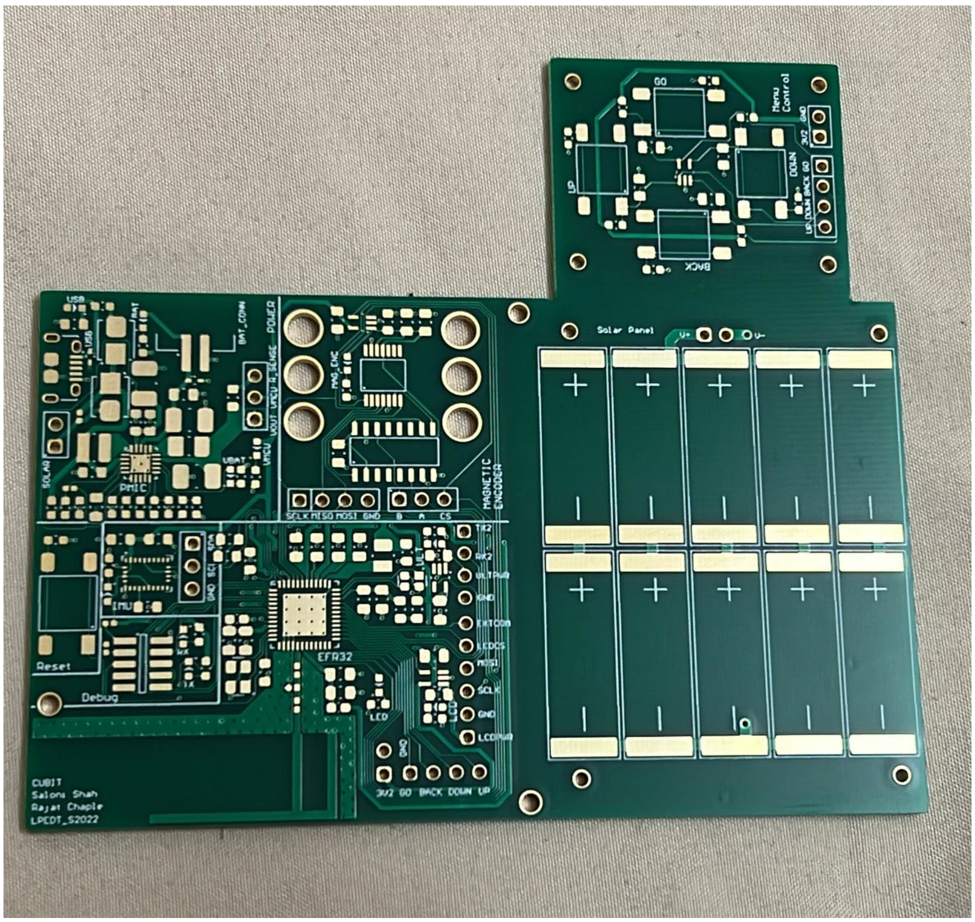



*Figure 32 Bare Fabricated Board*

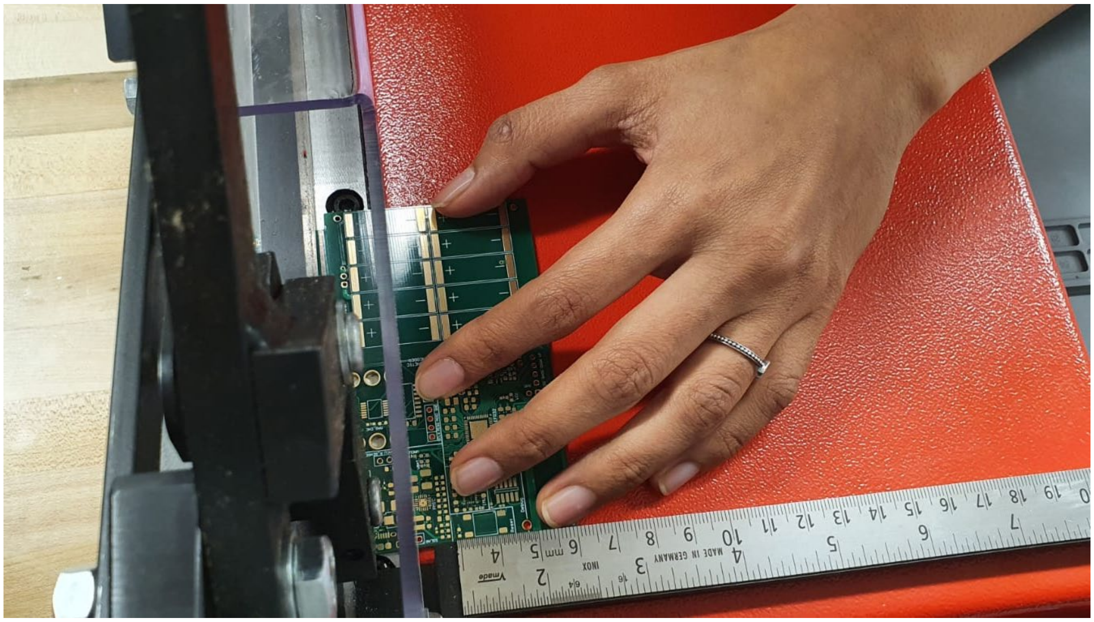


*Figure 33 Cutting the switch board from main board*

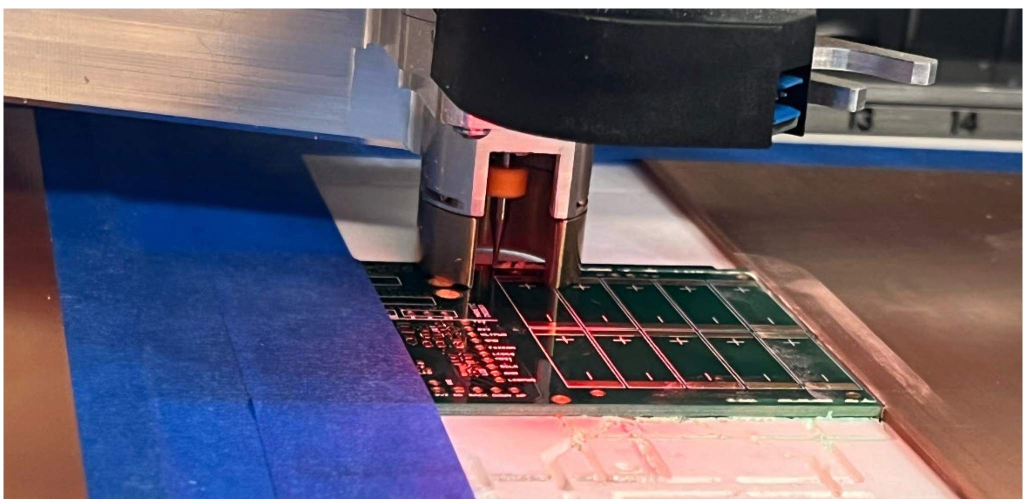


*Figure 34 Cutting solar panel board from main board using milling machine*

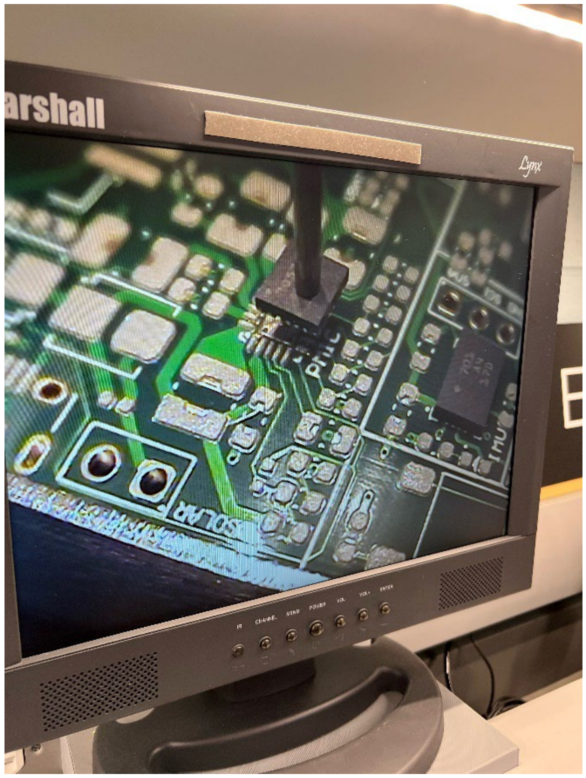



*Figure 35 Process of part placement using pick and place*

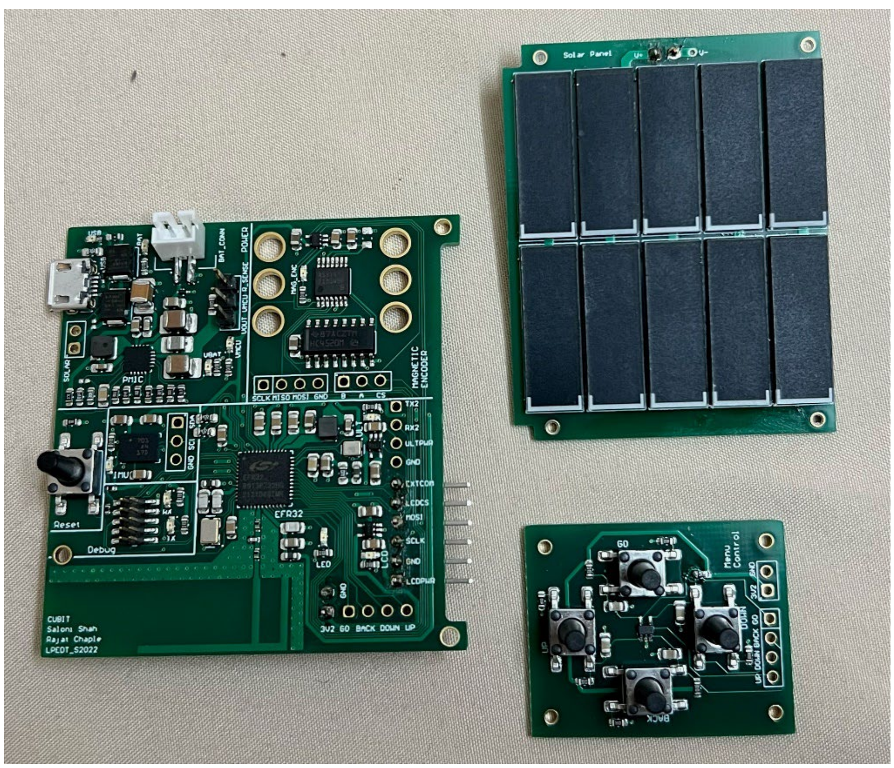



*Figure 36 Completely assembled boards*

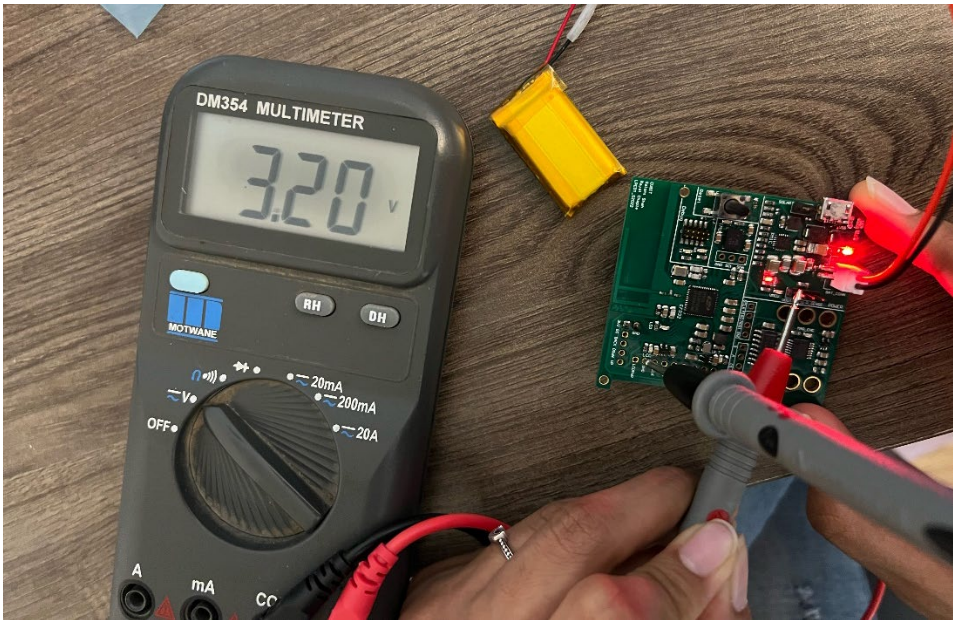



*Figure 37 Connecting battery to the power circuit. Verified 3.2V output from PMIC as expected*

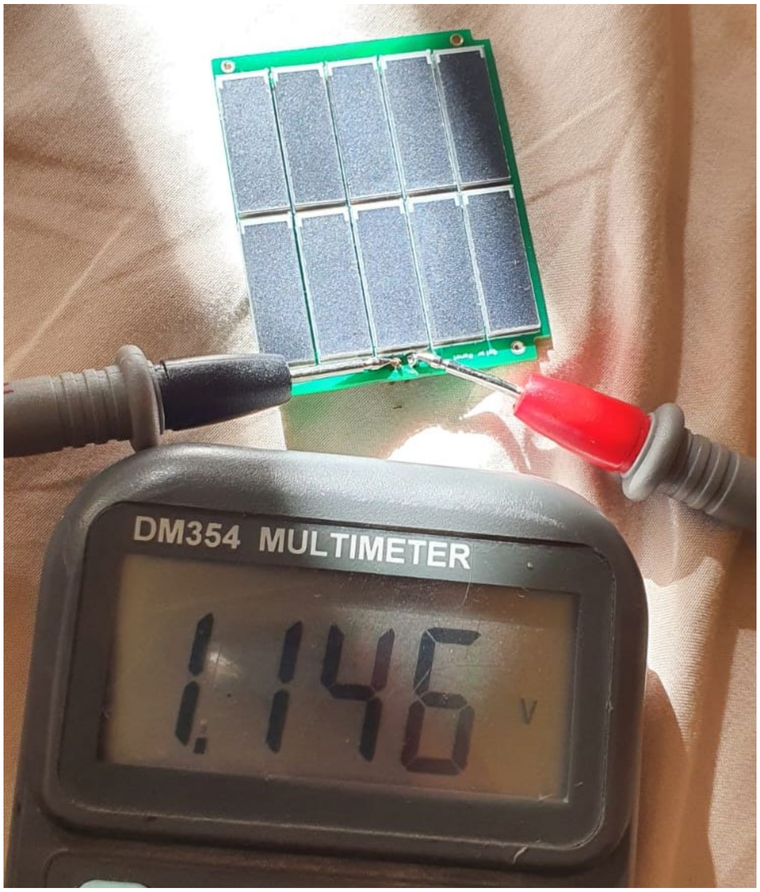



*Figure 38 Voltage output from solar panel board which will be used to charge the battery*

### 9.1.2 Programming target board using debug connector:

- During initial bring-up of the board, we successfully programmed EFR32 to run an LED blinking code.
- To program our target board, we used the simplicity commander tool provided by Simplicity Studio IDE.

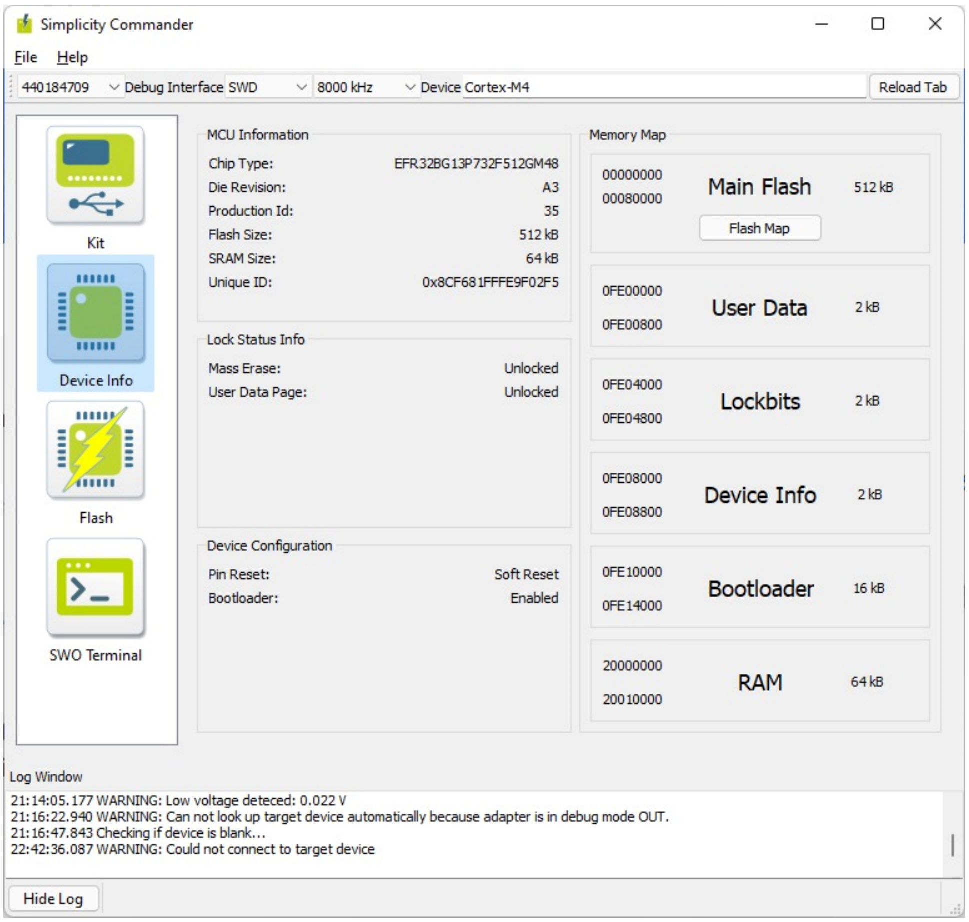



*Figure 39 Target board device information interpreted by Simplicity Commander*

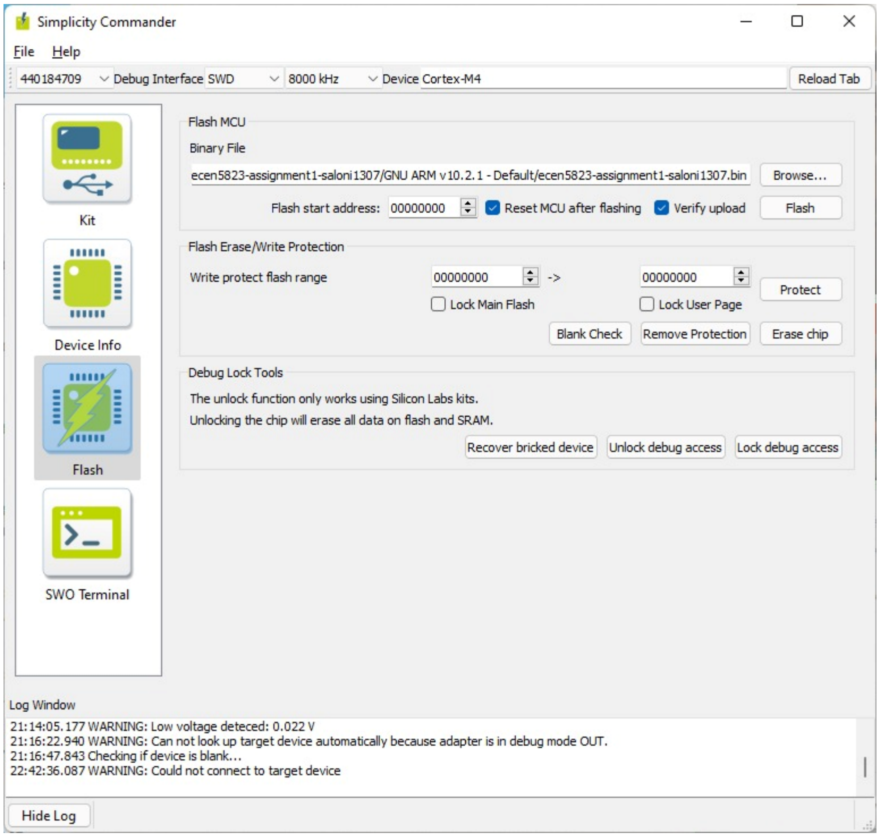



*Figure 40 Settings required for programming the target board*

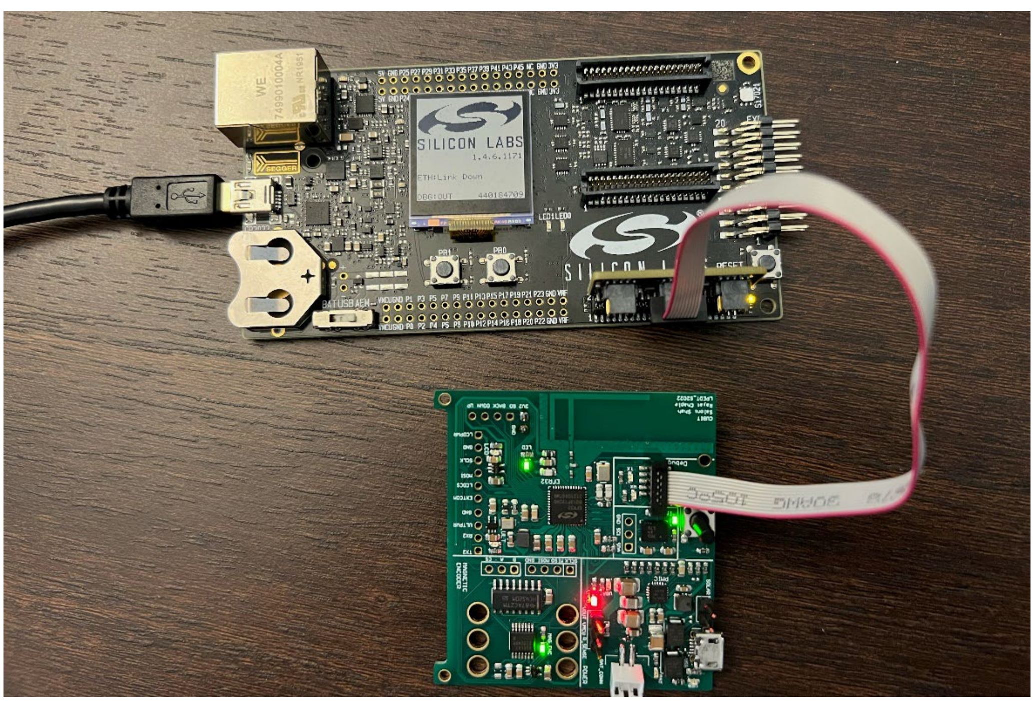



*Figure 41 Programming the target board using debug connector to run a simple LED blinking code*

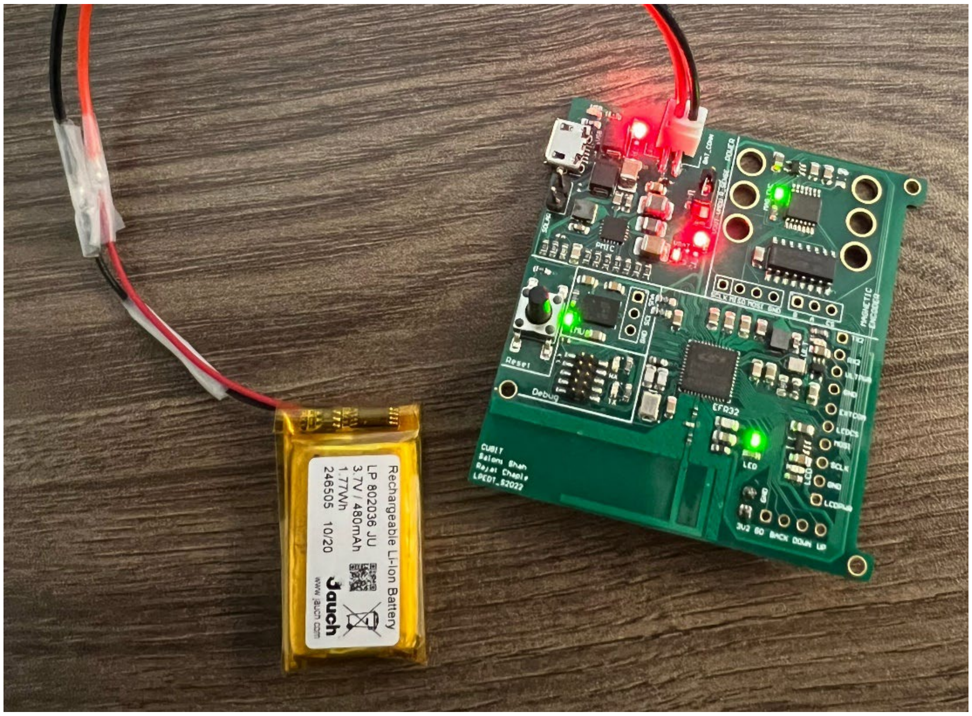



*Figure 42 Powering the digital circuit from the PMIC using a battery.*

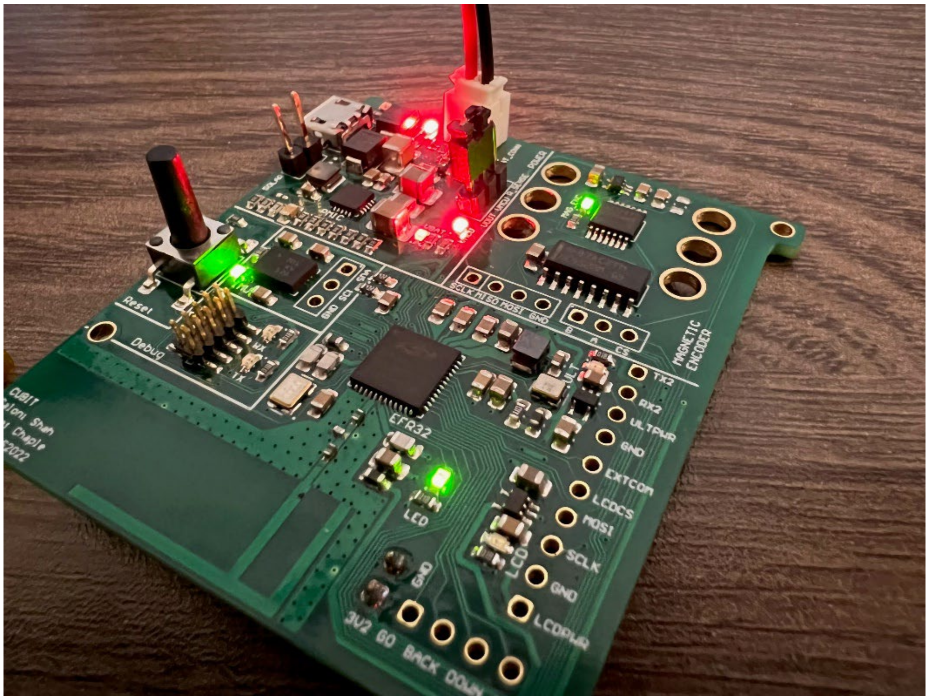



*Figure 43 Completely powered board using battery*

# 9.2 Activities planned for the upcoming week:

- Final completion of controlling LCD display using push buttons
- Programming magnetic encoder on target board

# 9.3 Verification Plan:

- Following verifications have been done on the target board:

| To be verified | Definition of passing | Date Test Performed | Tested By | Measured Value | Passed? |
|---|---|---|---|---|---|
| Power Good signal on PMIC | The PMIC generates an output voltage of computed 3.2V which will turn on the LED connected to VBAT_OK pin of BQ25570 | 4/8/22 | Rajat | 3.2V | Yes |
| System boot upon increase in charge of Energy Storage Element above required amount | When the battery charge is above 3.2V specification, the system can be booted successfully | 4/9/22 | Saloni | | Yes |
| Verification of functionality of PMIC BQ25570 | 1.VBAT_OV = 4.2V<br>2. VBAT_OK = 3.2V<br>3. VOUT = 3.2V<br>4. Charging of battery from solar cells or USB bus | 4/9/22 | Saloni | VBAT_OK = 3.2V<br>VOUT = 3.2V | Partly yes. Yet to test charging of battery |
| Verification of functionality of MCU EFR32 | 1.Successful sensor interfacing over communication buses.<br>2. Low and High Frequency crystal oscillators generate specified frequency signal | 4/9/22 | Rajat & Saloni | | Partly yes. Reset functionality working. |

| | | | | | |
|---|---|---|---|---|---|
| | 3. Reset switch can be used to reset the MCU<br>4. GPIO pins can be used to control switch board and load switch for sensors | | | | |
| Debug connector for programming Blue Gecko controller chip | EFR32 is successfully programmed and booted using Debug connector. | 4/9/22 | Rajat | | Yes |

Project Update 10

ECEN 5833: Low Power Embedded Design Techniques

# CUBIT

## Smart Measuring Instrument

Team Name: Cubit

Team Members: Saloni Shah

Rajat Chaple

Date: 04/23/2022

# 10.1 Activities accomplished in past week:

### 10.1.1 Design Changes for Magnetic Encoder Functionality:

- In the magnetic encoder, the output is given by 2 different digital pins which can be interpreted to determine the direction and distance covered.
- The digital output from the encoder is a PWM signal which are 50% phase shifted, the sequence of the digital output determines the direction of movement.

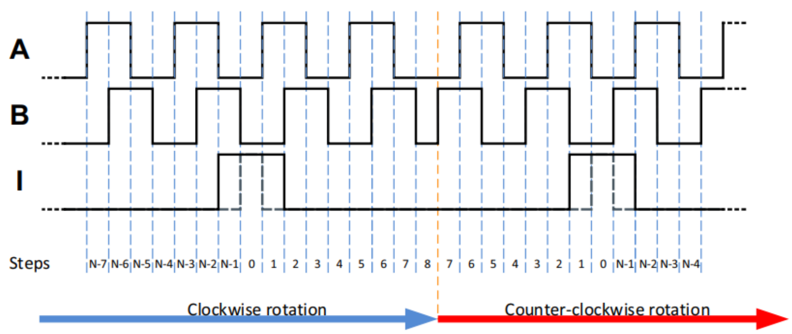
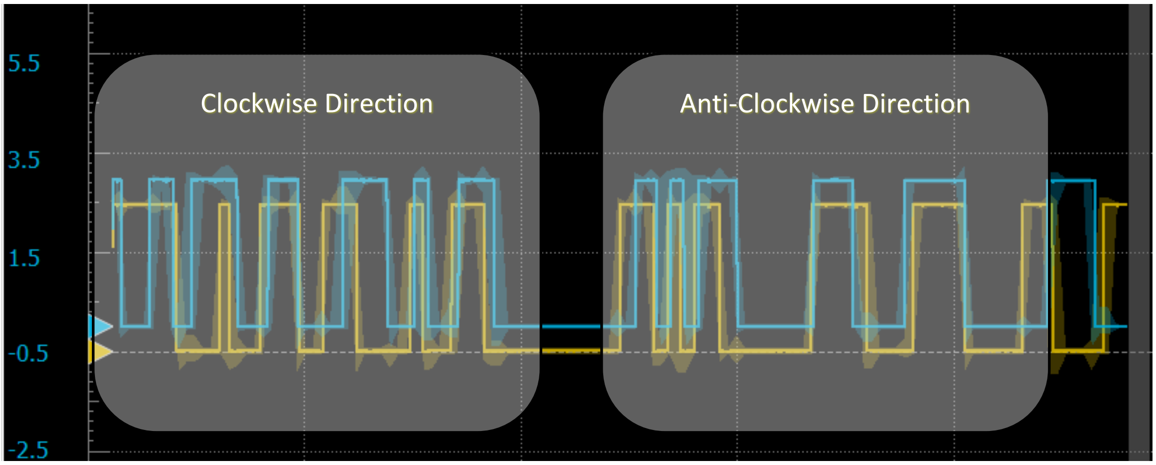
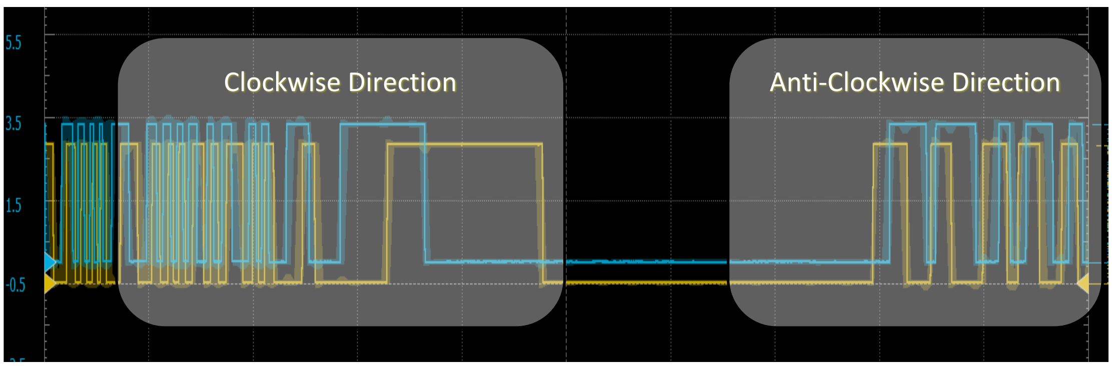



*Figure 44 Determining direction based on magnetic encoder output*

- However, upon passing through the frequency divider, the number of output signals per rotation are divided by 8. Moreover, the frequency divider only interprets the rising edge of the signals and hence the sequence of the two output signals is changed resulting in missing direction change.
- The below image shows the output signals from the frequency divider upon direction change.




- The below image shows the output signals directly from the magnetic encoder upon direction change.



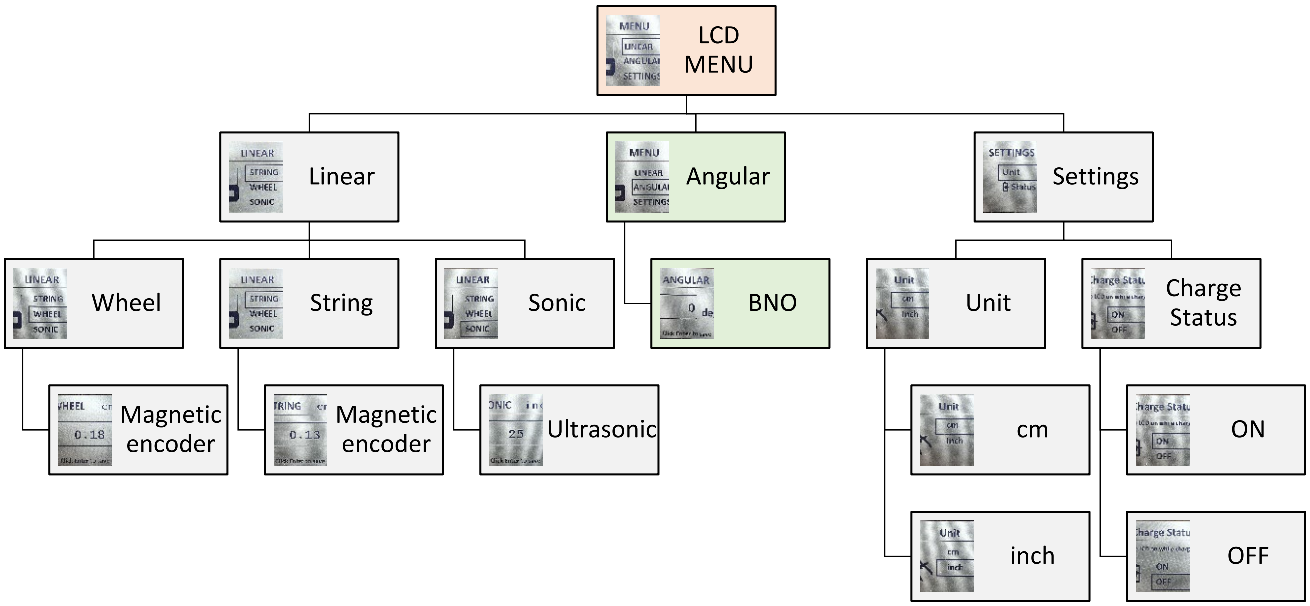

- In order to receive reduced pulses from the encoder, we programmed the magnetic encoder over SPI to output 256 pulses per rotation.

### 10.1.2 Design Changes for Low Frequency Crystal:

- Initially during schematic design, we used a low frequency crystal oscillator instead of a crystal which resulted in malfunctioning of low frequency clock of EFR32.
- Hence, we changed the part to a low frequency crystal. These changes are noted in the Altium schematic files.

### 10.1.3 Application code development for LCD:

- We designed different LCD screens for sensor selection on the board to carry out desired measurements.




### 10.1.4 Application code development for Magnetic Encoder:

- The magnetic encoder is utilized to carry out measurement using pulley assembly as well as wheel assembly.
- Upon placing different magnets on either side of the encoder, we can detect movement and determine distance using any of the assemblies.

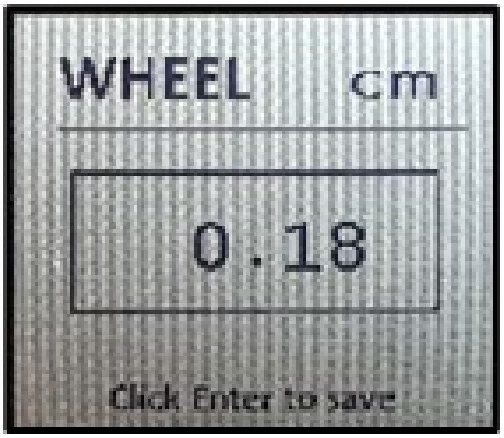



*Figure 45 Measurement value for wheel assembly*

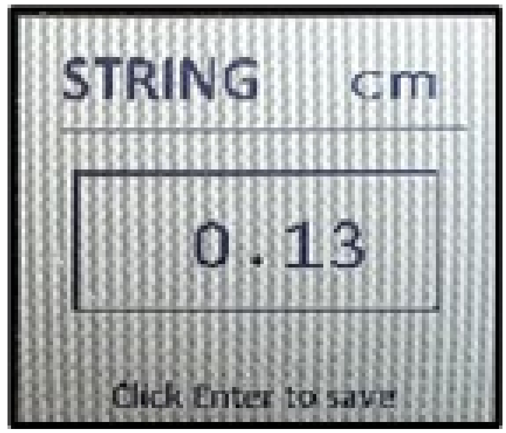



*Figure 46 Measurement value for pulley assembly*

### 10.1.5 Application code development for Ultrasonic Sensor:

- Ultrasonic sensor was successfully integrated with the board and measurements were carried out upon appropriate menu selection on the LCD.


*Figure 47 Measurement value for ultrasonic sensor*

### 10.1.6 Application code development for IMU Sensor:

- BNO055 was integrated with the target board to measure Euler Angle Yaw in order to determine the orientation of the measuring tape.
- Currently we are facing some issues in determining the angle accurately and with NACK signal received on the I2C bus.

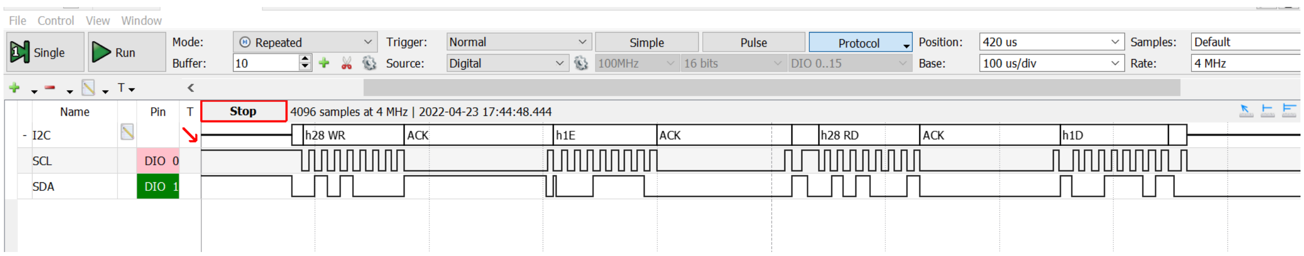



*Figure 48 I2C bus transaction*

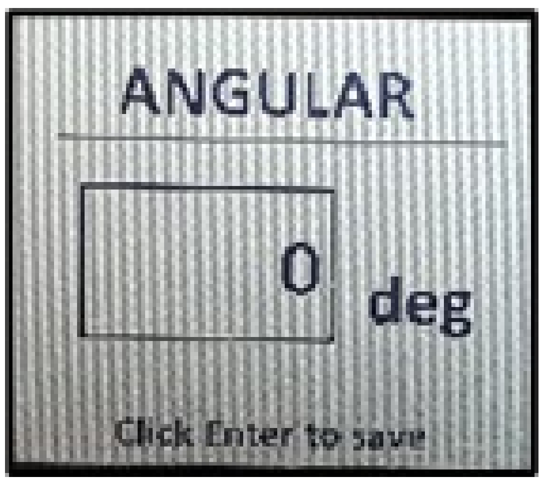



*Figure 49 IMU sensor Yaw angle measurement*

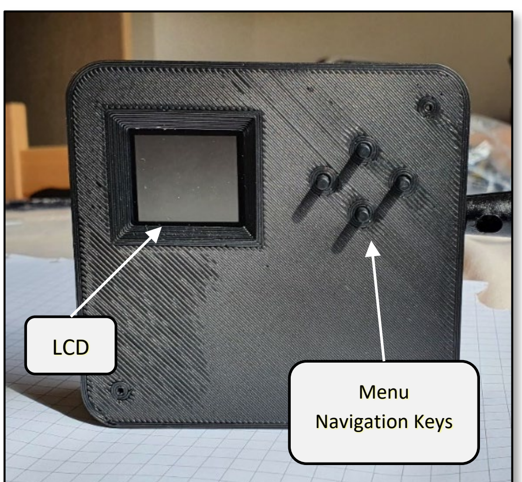
### 10.1.7 Complete board functioning using the USB connection:

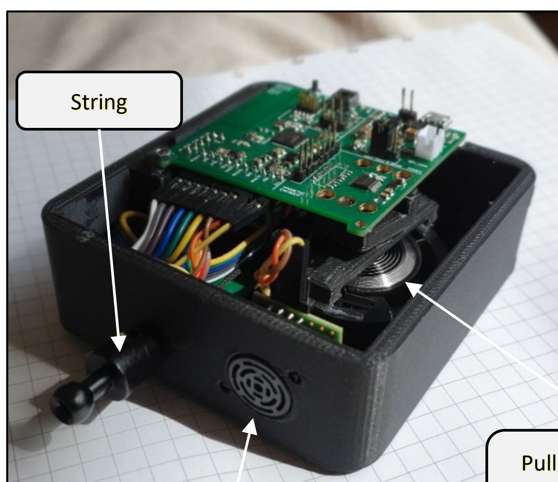
- When connected to USB input, we get a 4.15V on the battery in order to recharge the battery.
- Along with that, we observe a 3.2V output from the PMIC which will power the digital circuit and is used to carry out measurements.
- Hence, the complete product can also be operated and powered using a USB connection.

USB power operational

### 10.1.8 Mechanical Assembly Design for the product:

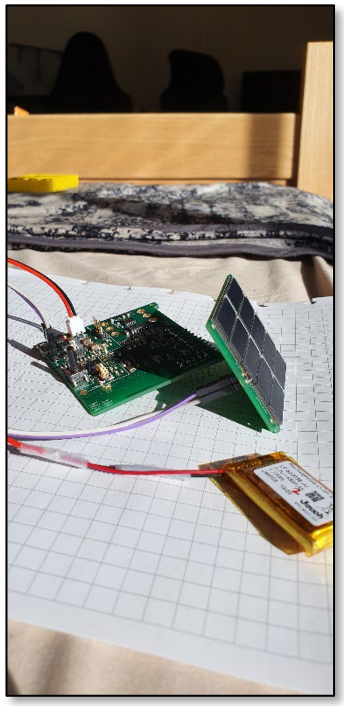
- CAD design for an outer casing and mechanical assembly for pulley and wheel was completed for the product and 3D printed.
- Below are the images of different parts of the assembly.

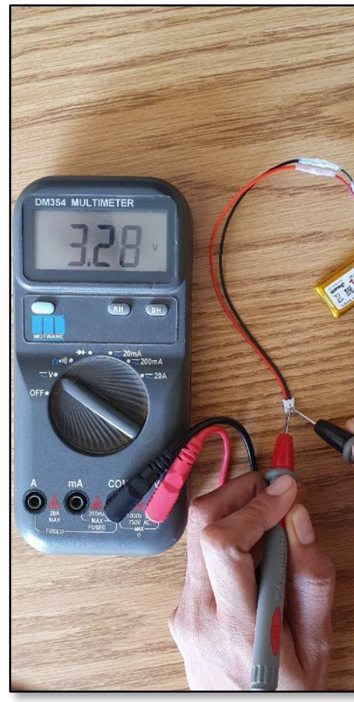


### 10.1.9 Battery charging using energy harvester:

Battery charging over Solar panel




Before charging

charging

After Charging

### 10.1.10 Bluetooth connection establishment and data transfer over Bluetooth between target board and EFR connect app:

- Successfully connected the board with EFR connect application over Bluetooth and transferred sensor data to the app for gatt custom characteristics.

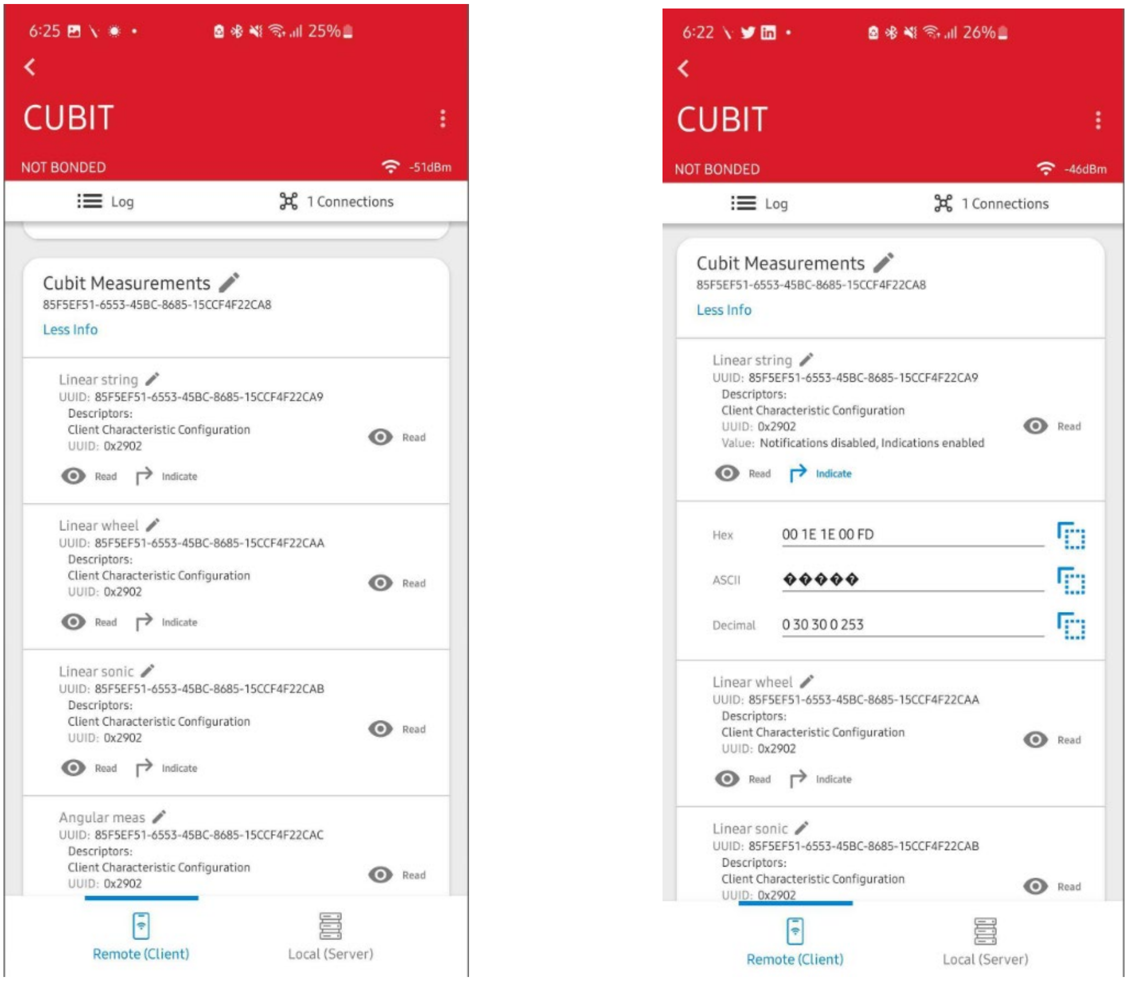



*Figure 50 Bluetooth Configurator Custom characteristics for different measurements*

## 10.2 Activities planned for the upcoming week:

- Mobile app development for CUBIT
- Second revision of mechanical assembly
- Prepare for final project demo

# 10.3 Verification Plan:

- Following verifications have been done on the target board:

| To be verified | Definition of passing | Date Test Performed | Tested By | Measured Value | Passed? |
|---|---|---|---|---|---|
| Voltage Vcc does not drop below minimum system specification | Minimum voltage during 10uA to 10mA at minimum battery voltage is above 3.0V | 4/19/2022 | Rajat | 3.19V | Yes |
| Voltage Vcc does not go above system specification | Maximum voltage during 25mA to 10uA step at maximum battery voltage (4.2V) is below 4.5V | 4/19/2022 | Rajat | 3.2V | Yes |
| Communication bus I2C | 1.IMU sensor data received accurately over the communication bus<br>2. The observed communication byte sequence on logic analyzer matches with the datasheet without I2C bus errors | 4/18/2022 | Saloni | Receiving NACK signal from signal frequently | Partially |
| Communication bus UART | 1. Ultrasonic sensor data is received over UART correctly<br>2. Sensor data is precisely displayed over UART com port | 4/21/2022 | Rajat | | Yes |
| Communication bus SPI | 1. Magnetic encoder can be programmed for variable output pulse frequency.<br>2. LCD display is properly updated | 4/14/2022 | Rajat and Saloni | | Yes |

| | | | | | |
|---|---|---|---|---|---|
| Energy Storage Element Charging | Upon reaching at low charge state (about 2.7V), the battery can be recharged using solar cells, USB connection or an external power source to reach a sufficient charge state to provide energy to system (about 3.2V) | 4/15/2022 | Rajat and Saloni | Battery can be charged fully at 3.9V using solar cells as well as USB | Yes |
| Power Good signal on PMIC | The PMIC generates an output voltage of computed 3.2V which will turn on the LED connected to VBAT_OK pin of BQ25570 | 4/8/2022 | Rajat | 3.2V | Yes |
| System boot upon increase in charge of Energy Storage Element above required amount | When the battery charge is above 3.2V specification, the system can be booted successfully | 4/15/2022 | Saloni | 3.2V | Yes |
| System shut down upon decrease in charge of Energy Storage Element below required amount | When the battery charge is less than 3.2V, it will cause system shutdown. | 4/20/2022 | Rajat | Board still functional at 3V output from PMIC(Buck) when battery voltage is the same | No |
| Correct values from IMU sensor | The angle measurement value from accelerometer in BNO055 is within the range of -90° to +90° | 4/21/2022 | Saloni | Accurate angle measurement between 0° to 90° | Partially |

| | | | | | |
|---|---|---|---|---|---|
| Correct Value from Magnetic Encoder | Output from magnetic encoder after frequency division is 256 pulses per rotation. | 4/14/2022 | Saloni | 256 pulses per rotation | Yes |
| Correct values from Ultrasonic Sensor | Ultrasonic sensor data value is in the range of 6-254 inches | 4/21/2022 | Rajat | 6-254 inches | Yes |
| Appropriate screen displays on LCD display | Required menu and sensor data is displayed on LCD upon controlling it with switch board | 4/18/2022 | Saloni | | Yes |
| Bluetooth connection to host device | Successful Bluetooth connection is established between target board and mobile device | 4/22/2022 | Rajat | | Yes |
| Data can be transmitted and received over Bluetooth connection | Sensor data values can be sent from target board and data indication/ notification can be controlled from the device | 4/22/2022 | Saloni | | Yes |
| Energy Harvesting Unit can charge the battery | Battery charge can be increased from a low charge state using the solar cell board. The output voltage from the solar cell assembly is expected to be 1.12V and resultant current should be 275mA. | 4/16/2022 | Rajat | Solar cell output = 1.15V | Yes |
| Energy Harvesting Unit can charge the battery to | From a low charge state, the battery can be charged to at least 3.2V state to | 4/16/2022 | Saloni | Battery can be fully charged using solar cells | Yes |

| | | | | | |
|---|---|---|---|---|---|
| required use case specification | successfully boot the system. | | | | |
| Energy Harvesting unit can provide energy to the target board without being assisted by external power sources | From a low charge state, the battery can be charged to a higher charge of 3.2V to provide energy to the system without assistance of an external power source. | 4/16/2022 | Rajat | Battery can be fully charged using solar cells | Yes |
| USB connection can be used to charge the battery | When the USB connector is connected, the battery can be charged from the USB bus. | 4/23/2022 | Saloni | USB connection output = 4V which can charge the battery | Yes |
| Schottky Diode arrangement works correctly to use either USB connection or Energy Harvesting Unit to charge the battery | When USB is connected, the battery is charged through this connection and not from the solar cells. | | | | |
| USB bus voltage does not exceed maximum defined system specification | USB does not supply more than 5.1V which is specified maximum voltage for PMIC | 4/23/2022 | Rajat | USB connection output does not exceed 4.2V | Yes |
| Verification of functionality of PMIC BQ25570 | 1.VBAT_OV = 4.2V<br>2. VBAT_OK = 3.2V<br>3. VOUT = 3.2V<br>4. Charging of battery from solar cells or USB bus | 4/15/2022 | Saloni | VBAT_OV = 4.2V<br>VBAT_OK = 3.2V<br>VOUT = 3.2V | Yes |

| | | | | | |
|---|---|---|---|---|---|
| Verification of functionality of MCU EFR32 | 1.Successful sensor interfacing over communication buses.<br>2. Low and High Frequency crystal oscillators generate specified frequency signal<br>3. Reset switch can be used to reset the MCU<br>4. GPIO pins can be used to control switch board and load switch for sensors | 4/21/2022 | Rajat | | Yes |
| Verification of functionality of Frequency Divider IC CD74HC4520 | Magnetic encoder output pulses which are 256 pulses per rotation are divided by 8 and the final output to MCU is in the range of 32 pulses per rotation | 4/13/2022 | Saloni | Frequency divider removed for direction interpretation | Yes |
| Verification of functionality of Load Switches | Load switches can be controlled via MCU for regulate power supply to magnetic encoder, LCD display and ultrasonic sensor | 4/17/2022 | Rajat | | Yes |
| Bulk Capacitance can maintain constant voltage as per specification | Bulk capacitance of 100uF on VSTOR of PMIC and output of PMIC keeps the voltage supply constant to 3.2V during abrupt | 4/18/2022 | Saloni | Output constant 3.2V | Yes |

| | | | | | |
|---|---|---|---|---|---|
| | changes in system power consumption | | | | |
| Switch Board can be used to control LCD display | 1.Up, down, back and go pushes on the button are detected by GPIO in the MCU.<br>2. Push buttons can be used to manage menu options on LCD display.<br>3. Selection of required menu option results in functionality to use corresponding sensor for measurement purposes. | 4/14/2022 | Rajat | | Yes |
| Debug connector for programming Blue Gecko controller chip | EFR32 is successfully programmed and booted using Debug connector. | 4/9/2022 | Saloni | | Yes |

Final Project Report
ECEN 5833: Low Power Embedded Design Techniques

# CUBIT

## Smart Measuring Instrument

Team Name: Cubit

Team Members: Saloni Shah
Rajat Chaple

Date: 05/04/2022

# 11.1 Project Overview:

For the course project, our team designed a smart measuring instrument which has the capability to take precise linear and angular measurements and transmit the data over to a mobile application using Bluetooth. Primarily, this device has a string-pulley as well as wheel assembly which can be used to take measurements over a straight or curved surface very accurately. A high precision magnetic encoder is used in giving high resolution results. Moreover, we have also installed an inertial measurement unit (IMU) sensor to take different angular and device orientation data. There is an ultrasonic sensor mounted on the device to take long distance measurements. All these measurements are then transmitted to a mobile app connected to the product using Bluetooth. The mobile application is custom developed by us for the device functionality. This data can also be displayed on an LCD. All the features of the product can be navigated using a remote control. This device runs on a small battery, and it also contains an energy harvesting system using solar panel to recharge the battery. Moreover, the device can be powered as well as the battery can be charged using a USB port. All these components are interfaced with a single Blue Gecko board. The device operates in low power mode by implementing load power management and utilizing minimum current for required peripherals. The device runs in EM2 mode with only low power LCD display running and the appropriate sensor is turned on when the required measurement functionality is selected. Upon exiting the measurement functionality, the device falls back in EM2 mode again.

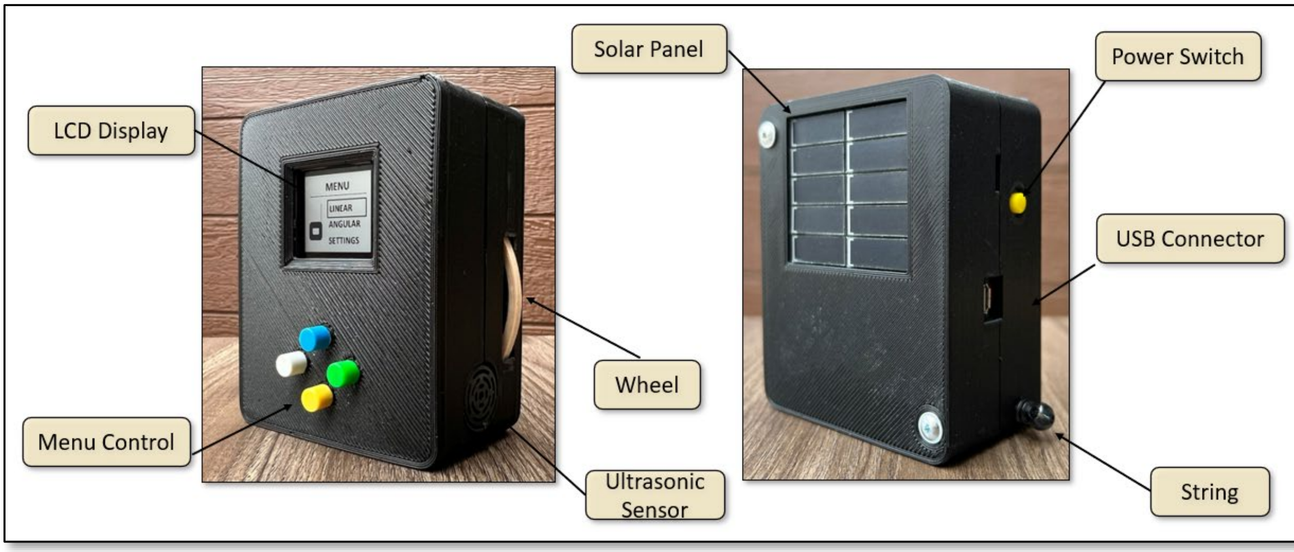



*Figure 51 Actual product design*

# 11.2 What problem does the project solve:

A measuring tape is used in a myriad of commercial businesses like construction, tailoring, warehouses as well as in day-to-day life. The first standard measuring tape was invented in 1850s and till now we have been using the same product. Although, since 18th century the world has advanced in every possible way, we still use the same measurement technique. The conventional measuring tape has ample of drawbacks like taking and maintaining measurements is very tedious, also all the measurements taken are majorly single use. Also, we need to use a different tape for body or fabric measurements which are small and flexible, the metal tape for commercial and household measurements are not flexible enough and we need a whole different tape for sonic measurement. It is high time that we modernize our method of taking measurements and digitize the data which can be easily stored and accessed from anywhere.

This product can be used to fulfill majority of measurement requirements like taking size data of a straight or uneven surface and taking angle measurements. This product can be used in small industries, construction sites, fashion companies and regular households. This product will eliminate the need to manually store measured data. This product is low cost, low power consuming with energy harvesting mechanism. This product uses long lasting rechargeable batteries unlike single usage dry cells.

# 11.3 Hardware Block Diagram:

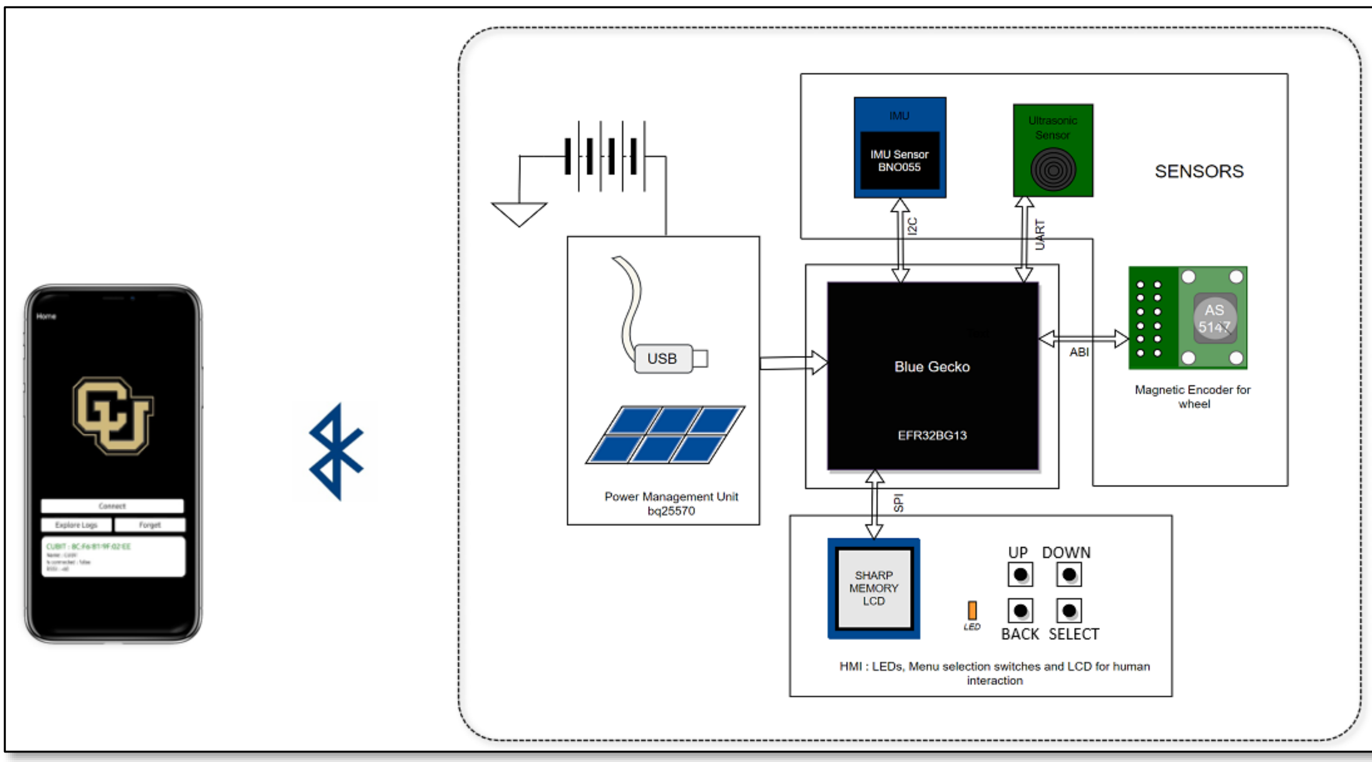



*Figure 52 System Block Diagram*

# 11.4 Key Components:

| Component | | Part No. | Load Power Management |
|---|---|---|---|
| Microcontroller | Silicon Labs Blue Gecko | | |

| | | | |
|---|---|---|---|
| Radio | EFR32BG13 | | ✓ |
| | | | |
| Battery | Lithium Ion/Lithium Polymer | LP802036JU+PCM+2 WIRES 50MM Jauch Quartz \| Batte Products \| DigiKey | |
| PMIC | BQ25570 | BQ25570RGRT Texas Instruments \| Integrated Circuits (ICs) \| DigiKey | |
| Sensor | IMU sensor | BNO005 (To be acquired from Professor) | ✓ |
| | Magnetic Encoder | Magnetic Rotary Encoder<br>Magnetic Wheel Assembly | ✓ |
| | Ultrasonic Sensor | Adafruit Ultrasonic Sensor | ✓ |
| HMI | LCD Display | Adafruit SHARP Memory Display Breakout - 1.3"<br>(Acquired from Professor) | ✓ |
| | Push Buttons | | |
| Energy Harvesting System | Solar cells | Monocrystalline solar cells | |
| USB Connector | | Micro-B USB | |

# 11.5 Software Flow Diagram:

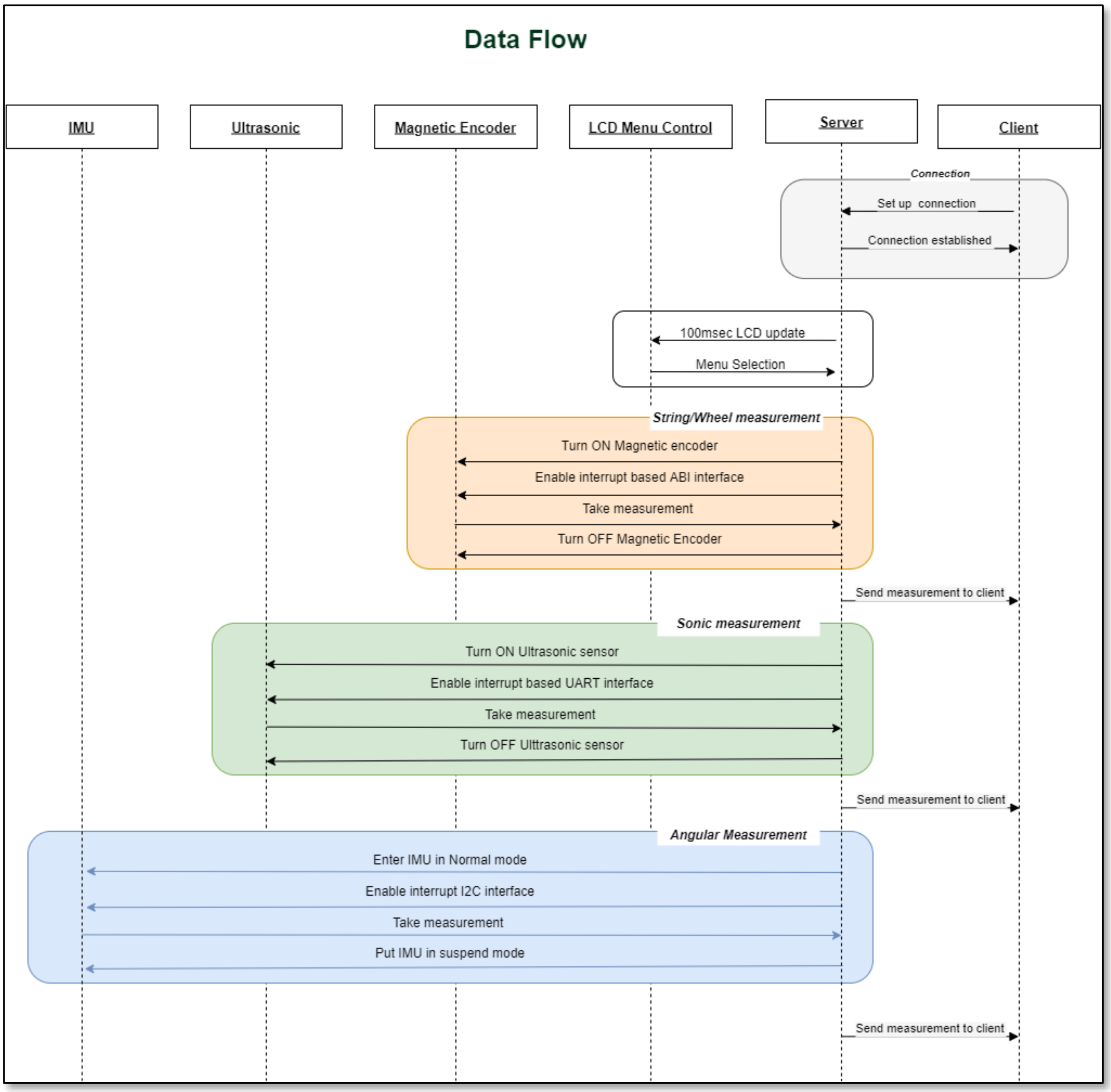



*Figure 53 Software Flow Diagram*

# 11.6 List of Commands:

Following is the list of commands used for BLE communication with app.

| BLE EVENT | Action |
| --- | --- |
| **System boot event**<br>sl_bt_evt_system_boot_id | **Start bluetooth advertising**<br>sl_bt_advertiser_create_set()<br>sl_bt_advertiser_set_timing()<br>sl_bt_advertiser_start()<br>sl_bt_system_get_identity_address()<br>sl_bt_sm_configure() |
| **BLE connection opened**<br>sl_bt_evt_connection_opened_id | **Stop advertising**<br>sl_bt_advertiser_stop()<br>sl_bt_connection_set_parameters() |
| **BLE connection closed**<br>sl_bt_evt_connection_closed_id | **Start advertising**<br>sl_bt_advertiser_start() |
| **Soft timer for LCD display update**<br>sl_bt_evt_system_soft_timer_id | displayUpdate() |
| Sensor data ready | Send data indication to mobile app |

# 11.7 How the target board is programmed:

- During initial bring-up of the board, we successfully programmed EFR32 to run an LED blinking code.
- To program our target board, we used the simplicity commander tool provided by Simplicity Studio IDE.

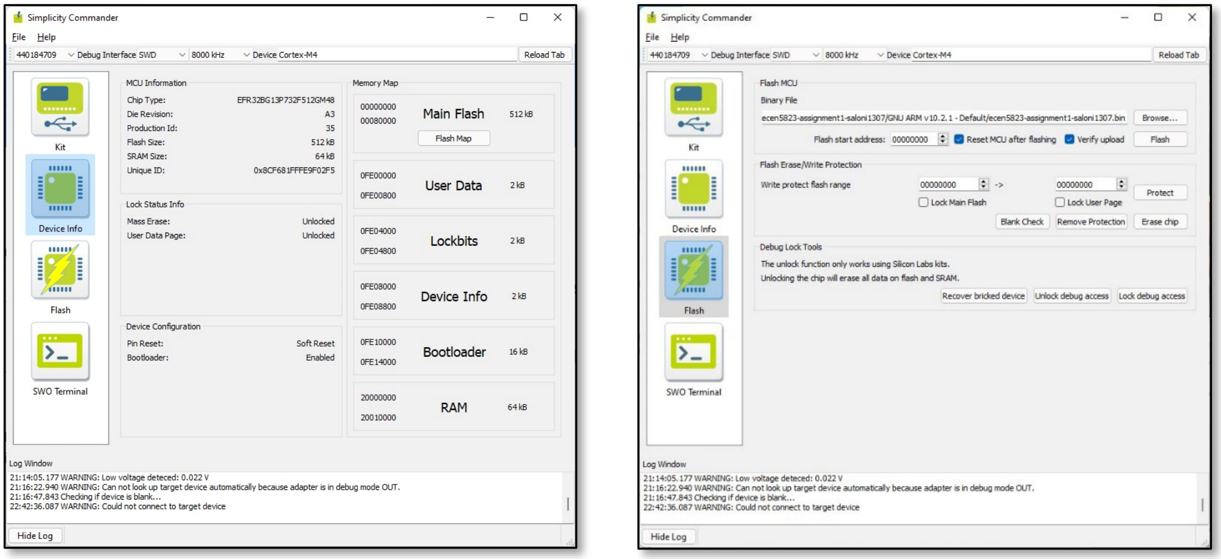



*Figure 54 Target board device information interpreted by Simplicity Commander*

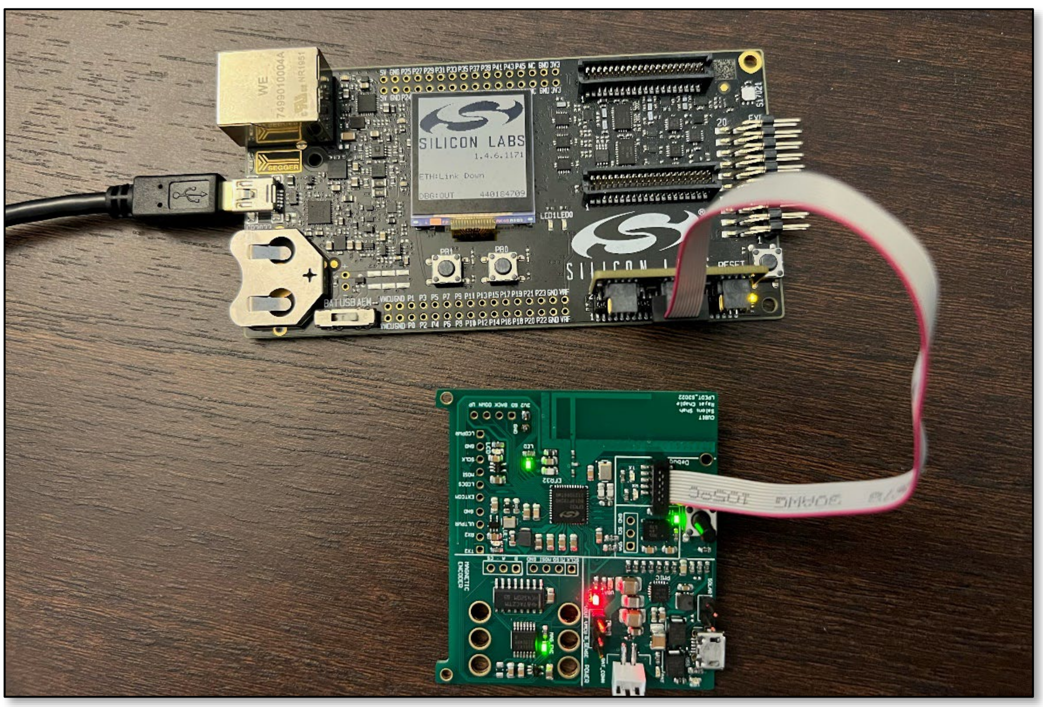



*Figure 55 Programming the target board using debug connector to run a simple LED blinking code*

- After the initial programming of the board, we can directly program the target MCU by flashing code from Simplicity Studio.

# 11.8 Current profile based on application usage:

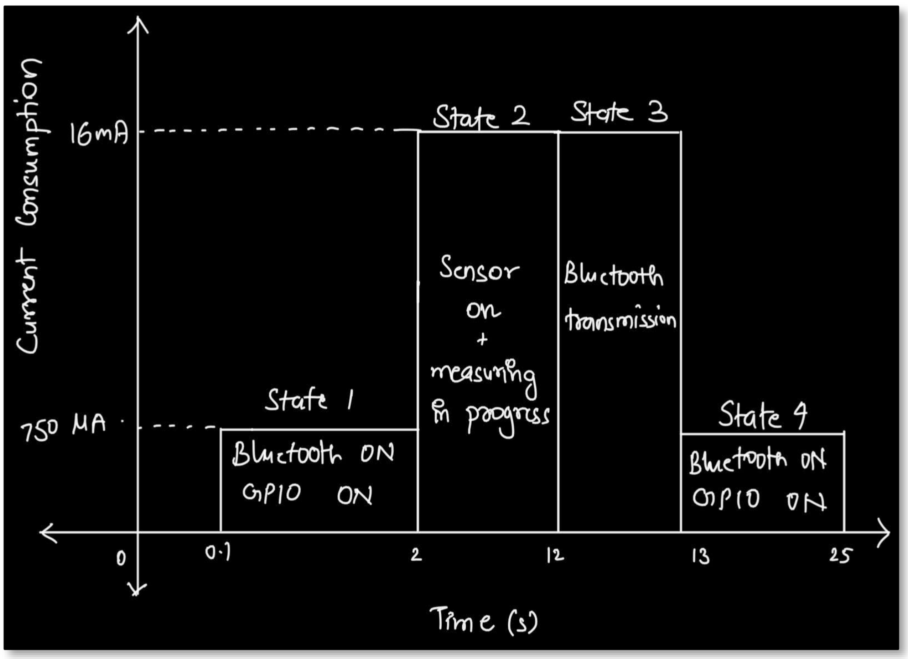



*Figure 56 Actual energy consumption profile of the device*

| | State 1 | State 2 | State 3 | | | State 4 |
|---|---|---|---|---|---|---|
| | | | State 3.1 | State 3.2 | State 3.3 | |
| Power Supply Quiescent | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Microcontroller EM2 mode | ✓ | ✓ | | | ✓ | ✓ |
| Microcontroller GPIO | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Magnetic Encoder | | | ✓ | | | |
| IMU sensor | | | | ✓ | | |
| Ultrasonic Sensor | | | | | ✓ | |
| LCD Display | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| Bluetooth Advertising | ✓ | | | | | |
| Bluetooth Connected | | ✓ | | | | ✓ |
| Bluetooth Transmission | | | ✓ | ✓ | ✓ | |
| Time Taken | 3000 | 1000 | 9000 | 9000 | 9000 | 12000 |
| Current Consumption (mA) | 0.78 | 0.75 | 16 | 11 | 4.3 | 0.75 |
| Percentage Time | 0.12 | 0.04 | 0.36 | 0.36 | 0.36 | 0.48 |

*Figure 57 Use Case Current Consumption*

Based on the above calculations, the average current consumption in one cycle is about 6.2mA.

# 11.9 Energy Storage Element selection:

### Considerations for choosing energy storage element:

- Continuous 8 hours of device usage
- Minimum 3-4 days of battery life without requiring a recharge

Based on the current consumption of device, for 8 hours of operation we require a 50mAh of battery charge. Before finalizing the energy storage element, we carried out analysis of super-capacitor and compared with the battery specifications. Below is the analysis of a reference super capacitor from Professor Graham's Project:

| **Super capacitor** | |
|---|---|
| Capacitance | 100 F |
| Vmax | 3.7 v |
| Vmin | 3 v |
| Average Supercap Voltage | 3.5 v |
| | |
| Energy (E) | 234.5 J |
| Charge | 18.61111 mAh |

$$Energy = \frac{1}{2}C({V_{max}}^2 - {V_{min}}^2)$$

Charge = (Energy) /(3.6 * average supercap voltage)

This charge is not even enough for 8 hrs of continuous usage

As required charge in this case is 50mAh

Considering the part cost, availability, and efficiency we chose a 480mAh LiPo battery with the following specifications:

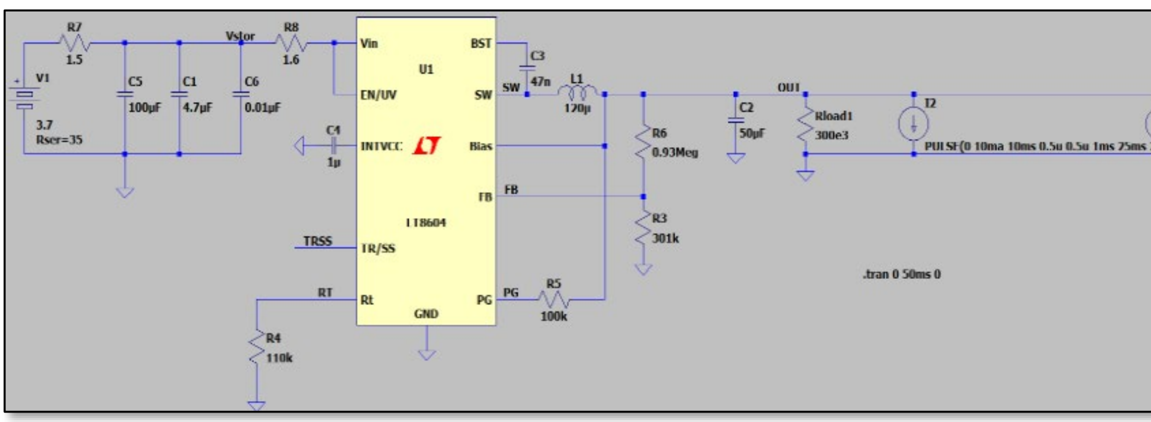
| Battery Specification | Value |
|---|---|
| Battery Capacity | 480 mAh |
| Nominal voltage | 3.7 V |
| Charge Voltage | 4.2 V |
| Cut-off Voltage | 3.0 V |
| Standard Current | 0.2 C |
| Maximum charging current | 0.5 C |
| Maximum discharge current | 2 C |

According to the battery specification and device requirement, ideally the battery can power the product for about 7 days before requiring recharging.

# 11.10 PMU simulation summary:

- In order to simulate Power management unit in LTSpice, we did not find the exact part number
- Combination of boost circuitry and LT8604 was used to simulate as these parts were matching with bq25570 specs.

*Below simulation showed that there is need of 100uF bulk capacitor.*



*Addition of bulk capacitor restricts minimum voltage of the system at 3.15v. This satisfies requirements for all peripherals and the controller.*

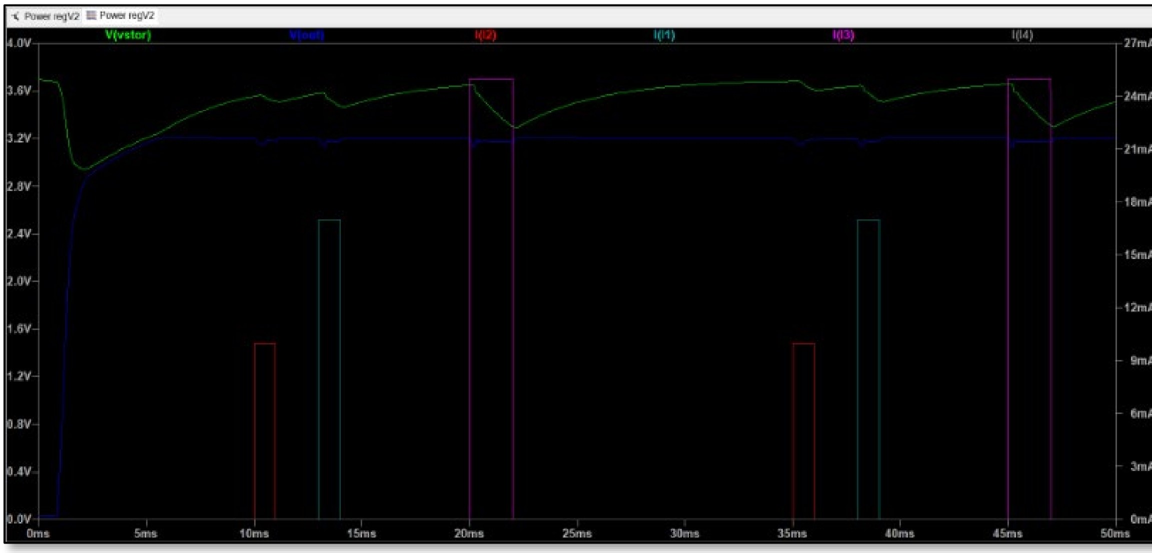



*Figure 58 PMIC Simulation using system load*

# 11.11 Bulk capacitor selection summary:

- As per our bulk capacitor calculations, Cubit board requires 100uF capacitor.
- In order to find out equivalent capacitance that would give 100uF, simsurfing tool from murata was used.
  [SimSurfing: Multilayer Ceramic Capacitors - Murata Manufacturing]
- 220uF ([GRM32ER60J227ME05L Murata Electronics | Capacitors | DigiKey]) was selected based on following DC bias characteristic.
  - 3.2v is our operational voltage for the entire circuit
  - Effective bulk capacitor value @ 3.2v = 220 – 52.6% = 104.28uF

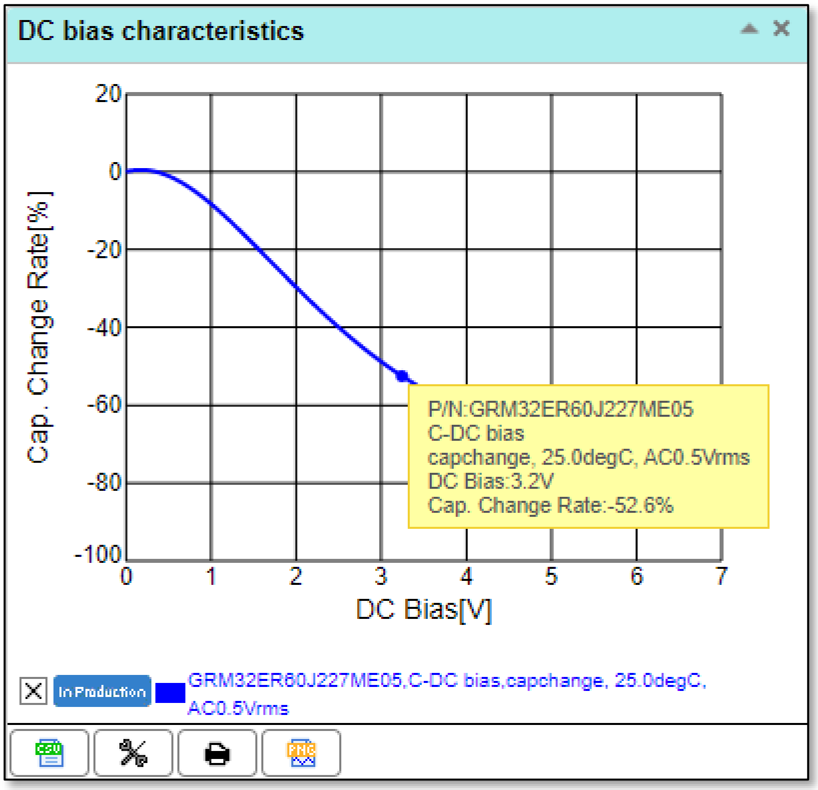



*Figure 59 DC bias characteristics for bulk capacitor*

# 11.12 External Energy source requirement for MCU:

- The complete device can run off the battery or using a USB connection.
- While reconnecting the battery to the board, it needs an initial voltage boost from energy harvester since according to the PMIC BQ25570 specifications, for initial start-up.

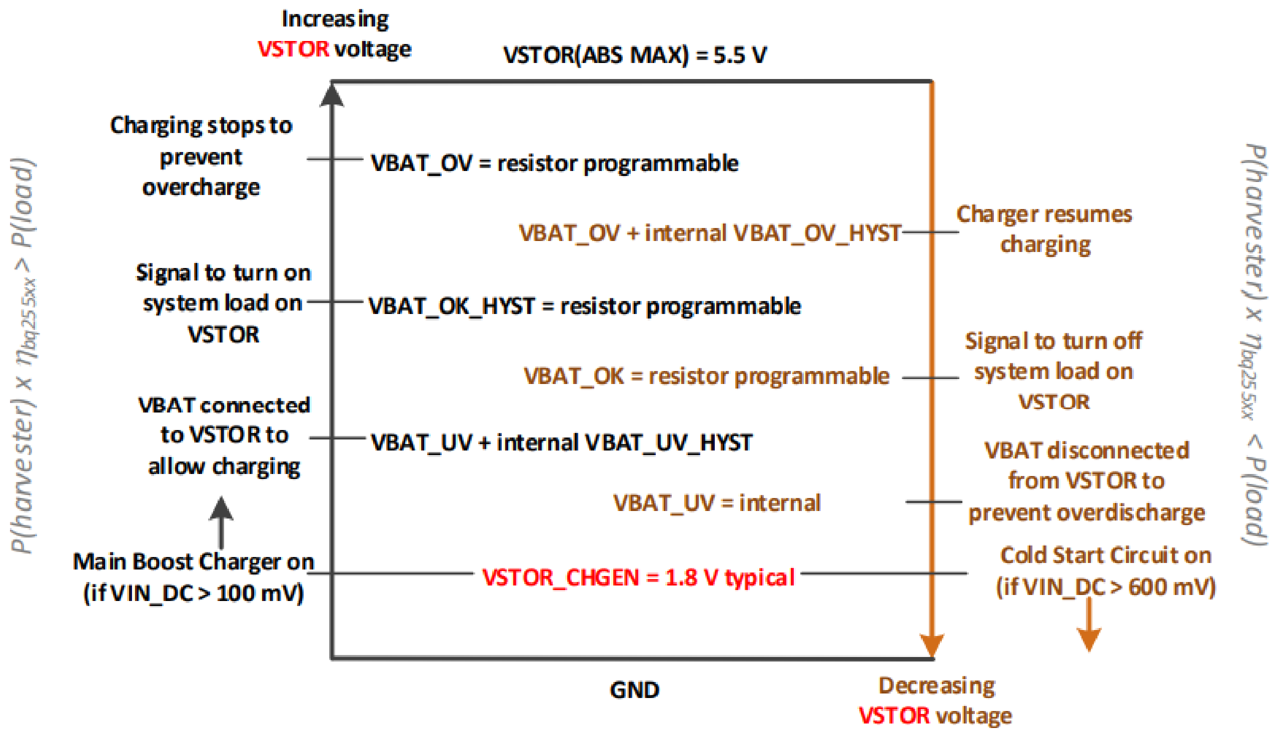



**Figure 21. Summary of VSTOR Threshold Voltages**

# 11.13 Test Points:

In the final board design, we had test points for I2C lines, SPI bus and ABI digital signal output of magnetic encoder. The I2C lines test points helped us in analyzing I2C transfer between MCU and BNO055 using a logic analyzer. While initial interfacing of BNO, we received multiple I2C bus errors during data transaction. By connecting a logic analyzer on the test points, we were able to rectify the error and resolve the issue. The test point on SPI bus helped us in successfully programming the magnetic encoder IC to output a smaller number of pulses for every rotation. The test points on magnetic encoder IC helped us in analyzing the number of A and B digital output pulses from encoder and determining direction of rotation of the pulley and wheel. Based on the digital signal received upon change in direction of rotation, we were able to program an algorithm to precisely estimate distance covered.

Moreover, we had through-hole connections for PMIC output and solar panel output which enabled us to analyze the BQ25570 output, load current and voltage analysis, disconnecting power circuit output from digital part of the board, analyzing battery input voltage.

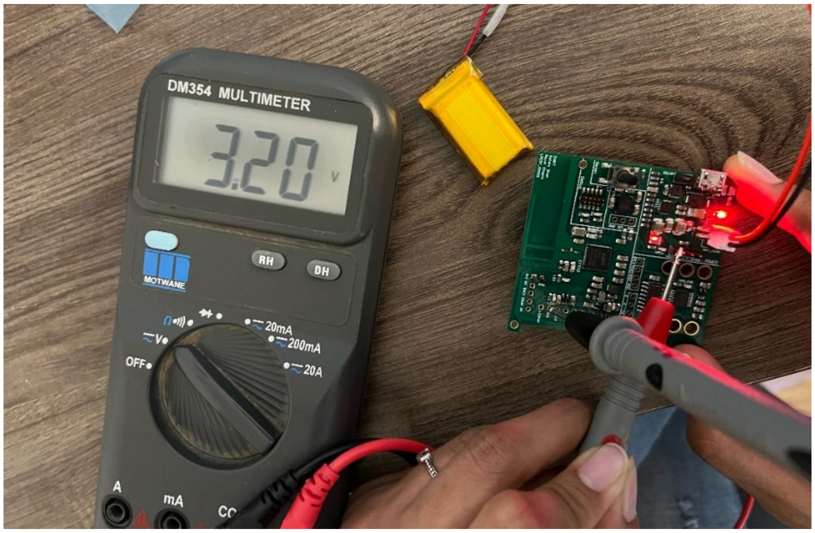



*Figure 60 Connecting battery to the power circuit. Verified 3.2V output from PMIC as expected*

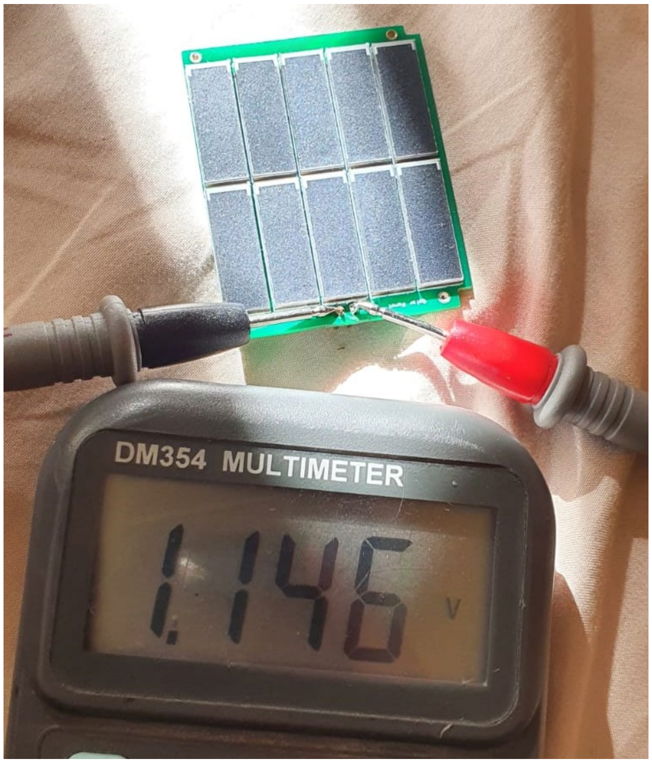
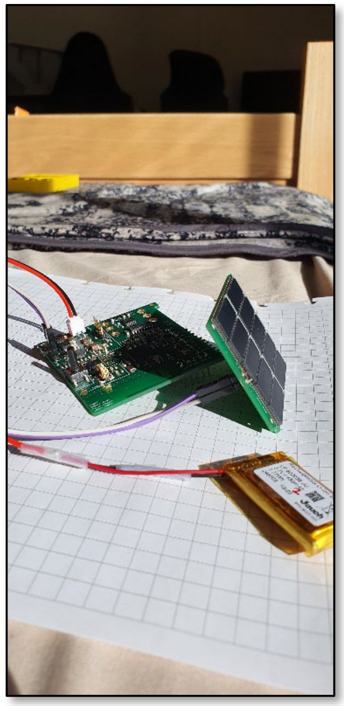


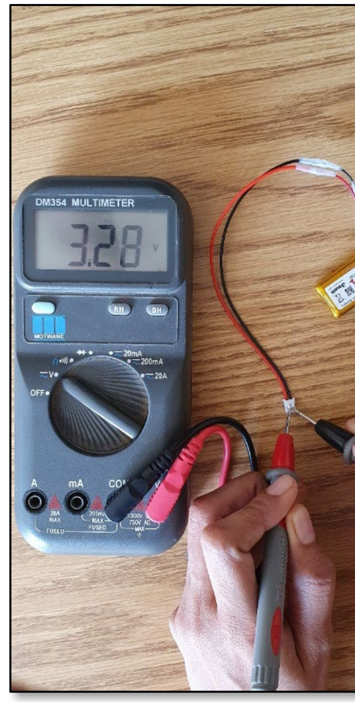

*Figure 61 Voltage output from solar panel board which will be used to charge the battery*

Battery charging over Solar panel after 4-5 hours of charging


Before charging



charging




After Charging

# 11.14 Assembled Board:

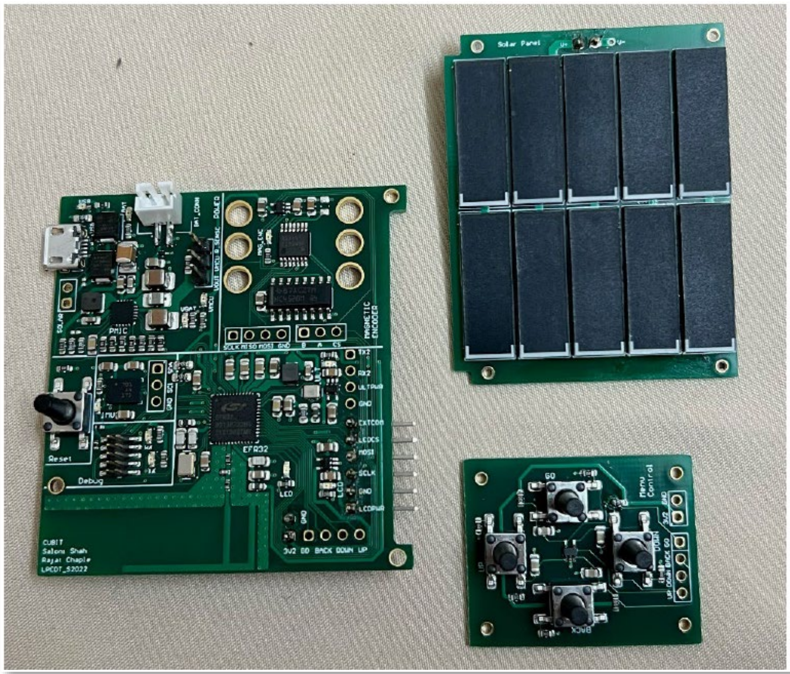



*Figure 62 Assembled Board*

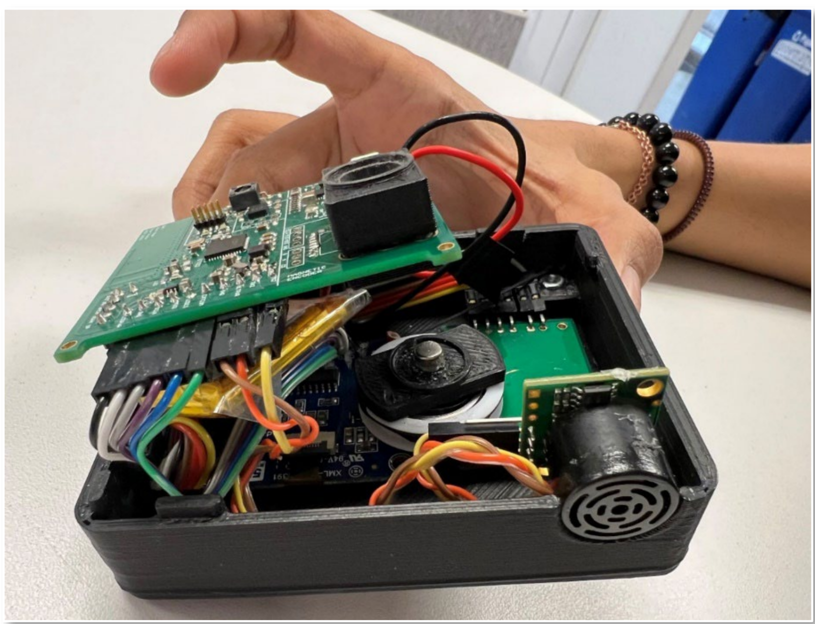
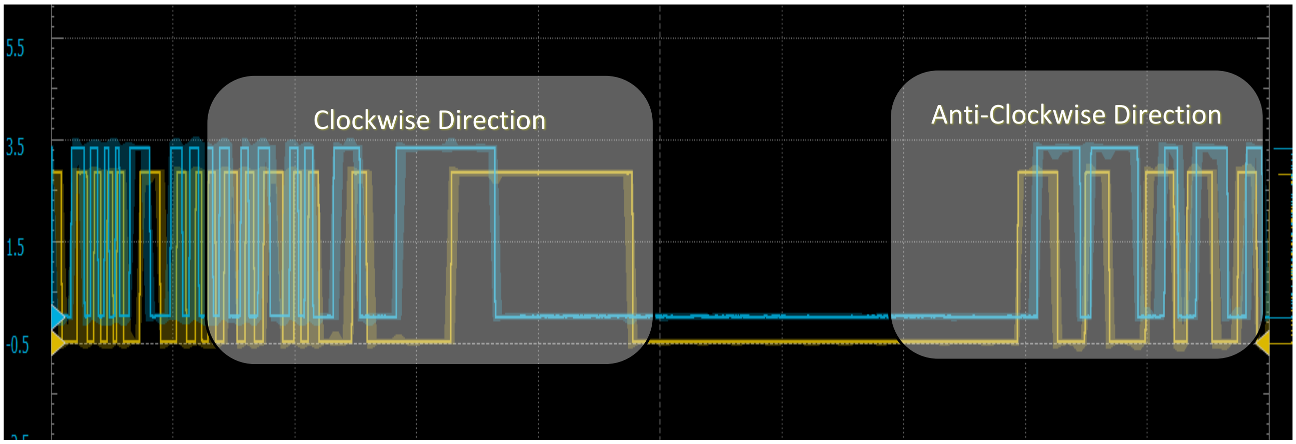


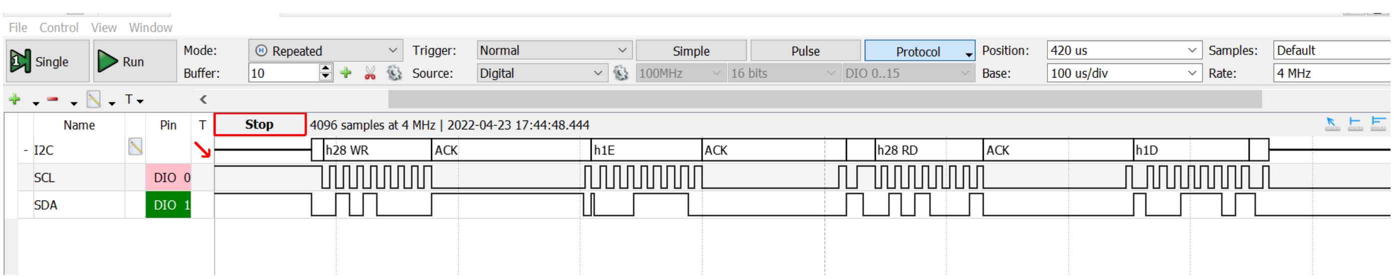
*Figure 63 Final product bring up on mechanical assembly*

# 11.15 Signal Quality Analysis:

- Magnetic Encoder ABI interface output signals




- I2C bus transaction




# 11.16 Difficulties encountered in project development:

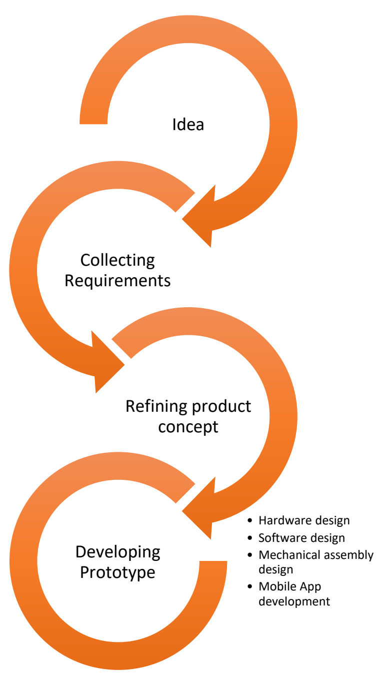
- Due to the use of incorrect low frequency crystal, LFXO clock was not working which prevented the MCU from going into low power mode. This error was later rectified and resolved.

- Frequency divider on the output of magnetic encoder was not helpful, instead it created problems in determining the direction of wheel rotation. This issue was later resolved by bypassing the frequency divider.
- Microcontroller was not going in low power mode as UART peripheral was automatically setting the MCU in EM1 mode instead of staying in EM2 mode.
- We faced quite a few challenges in designing and executing mechanical assembly for the product since a form-factored final device required precise measurements.

# 11.17 Product Development Cycle:

Since this course is completely project based, we decided to go through product development cycle and acted accordingly. Following elaborates our stages of the developed product

Product development cycle: (until prototype development)

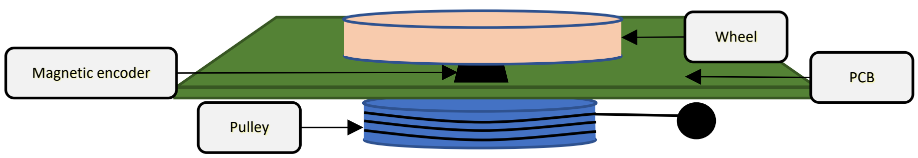


1) Idea / Brainstorming
    a. We had two ideas in mind
        i. <u>CUBIT</u>: Smart measurement tape that would be charged over solar panel. This tape would have multiple mechanisms of measurement linear measurement, angular measurement with various sensors: rotary encoder, IMU, Ultrasonic measurement.
        ii. <u>Harvesting blinds</u>: Solar panel on window blinds. These blinds would continuously adjust themselves to be perpendicular to Solar rays serving two purposes. 1) Restricting light into the house 2) Harvesting maximum energy. Harvested energy was planned to be used for home automation

    We decided to go with the first idea (CUBIT)

2) Requirements on high level
    a. Microcontroller + BLE (or both integrated into one chip) that should handle reading data from sensors, process data and send it over Bluetooth.
    b. Power Management Unit design: Power management unit would have following purposes
        i. Constant voltage supply
        ii. Shall provide enough current to manage load sensors
        iii. Shall be able to regulate battery output
        iv. Shall be able to harvest energy from solar panel and charge a battery
        v. Shall be capable of using alternative source of energy like USB charging
    c. Sensors
        i. Rotary encoder: Shall provide linear measurement
        ii. Ultrasonic sensor: Shall provide aerial distance measurement
        iii. IMU sensor: Shall provide angular measurement

3) Scoping and refining the product concept
    a. For easy handling, product shall have menu control this would consist of LCD and control keys
    b. While going through appropriate modes, only respective sensors would be turned on in order to reduce overall energy consumption from the battery.
    c. Linear measurement using Magnetic encoder can be performed in two ways using single sensor (Magic of mechanical assembly). Wheel based measurement can be mounted on top of the magnetic encoder and string-based assembly on the bottom. Following diagram represents the concept




4) Prototyping
    a. PCB design
        i. PCB was designed using Altium designer. This was a 2 layer board with continuous ground plane as a second layer. BOM was created and components were purchased mostly on digikey.
        ii. Component assembly was done with the help of pick-n-place machine and reflow oven.

    b. Software design
        i. Software Architecture was developed as per requirement.
        ii. Since this is a battery-operated device, software architecture was designed to keep microcontroller to lowest energy mode possible.
        iii. Sensors were interfaced using ABI, UART and I2C interface. LCD was interfaced using SPI interface.

c. Mechanical Assembly design
    i. Casing and assembly was designed using CATIA and Solidworks CAD software.
    ii. Design files were fed to 3D printer

d. Android app development
    i. React native was used to develop an android app. React native is an open source UI software framework created by Meta platforms.

We developed two stages for prototype development from mechanical assembly point of view. Flaws in 1st prototype was rectified in 2nd prototype.

# 11.18 Final Project Functionality Summary:

- Free android app to store and manage measurement data
- Bluetooth connectivity of mobile phone with the device
- Magnetic encoder-wheel assembly and string-pulley assembly for linear measurement
- IMU sensor for accurate angle measurement
- Ultrasonic sensor for long distance measurement
- LCD Display for better user experience
- Push button switches for menu control and functionality navigation on device
- Energy harvesting mechanism using solar panels to recharge the battery
- USB connection which can power the board as well as recharge the battery
- Load power management by turning on only required peripherals
- Single rechargeable LiPo battery which can power the complete device

# 11.19 Lessons Learned - Rajat:

- Understood how sensors can still be powered from other digital signals or communication lines even after disconnecting power from VMCU signal which can affect load power management.
- Understood the importance of how selecting a part and package is critical. Changing a part at times could be a challenge. We had to replace a 4-pin oscillator with a 2-pin crystal.
- How indicator LEDs are useful for debugging. This was the lesson learnt when initially choosing EFR32BG13P732 part number from project properties was still compiling for EFR32BG13P632. At this point the blinking code was not working.
- Datasheets are primary source of information. BQ25570 does not give output when only battery is connected. It needs an initial voltage boost from energy harvester input.
- Detailed planning is the primary requirement. Execution of this plan is also equally important.

# 11.20 Lessons Learned - Saloni:

- Calculative decisions need to be made while putting the microcontroller into sleep mode. Multiple and frequent interrupts do not allow sufficient time for sleep and wake transition for MCU.
- Spending significant amount on time during design process of the project i.e., layout and schematic is the key to successful project execution.
- Debugging is an art. We had multiple issues with the board as mentioned earlier. Hence, debugging in the right direction is critical for solving these issues.
- There should be a backup plan in your circuit design. It is always better to have a mechanism to isolate non-working part of the circuit. It was a good fix where we eliminated frequency divider altogether from our circuit.
- Altium is useful and powerful tool for circuit and PCB designing. It was a good learning experience for me: footprint/schematic design tool, placement of

components for signal integrity, antenna design, error checking and design violation checks.

One of the most important lessons hat we both learnt was understanding project/product development cycle. Right from product planning, time management, hardware design (PCB design and assembly), software architecture, application software, testing, mechanical assembly design, 3D printing and mobile application design which was fun and a challenge at the same time.