ECEN-5833

Low Power Embedded Design Techniques

Project Updates

Fitness Performance Tracking Vest

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Performance Tracker

The project aims to create and implement a fitness tracker specifically designed to measure key performance metrics across a wide range of sports activities. Whether engaging in a challenging scenic trek or participating in high-intensity sports games, usual walking, the fitness tracker will offer users valuable insights into their performance levels.

It will include the following statistics:

- Current Heart Rate
- Maximum Heart Rate
- Blood Oxygen
- Total Distance
- Altitude, Acceleration
- Max Speed
- No. of Laps/Sprints
- Calories.

Why this?

Performance tracking devices provide a level of individual performance analysis that far surpasses anything coaches and athletes from previous generations were familiar with. The advantages to early adopters of this technology are enormous. Individuals can keep track of their fitness and get an in-depth understanding of strengths and weaknesses. This knowledge, put together with the right training can do wonders.

Managing Workload

For emerging athletes, consistent and intelligent training is crucial for long-term success, particularly for those aspiring to college-level sports and beyond. Field sports like soccer, football, and baseball demand skill development through year-round, focused training. However, overtraining poses risks to athletes and teams. With performance-tracking technology, coaches can now make data-driven decisions to balance intensity and rest, ensuring peak performance on game days.

Injury Reduction

Injuries are a significant concern for athletes and teams, especially when they result from preventable factors, such as risky training practices. Performance tracking offers valuable insights into determining suitable training thresholds, preventing overexertion, and managing fatigue and stress during games and practices.

Hardware Block Diagram

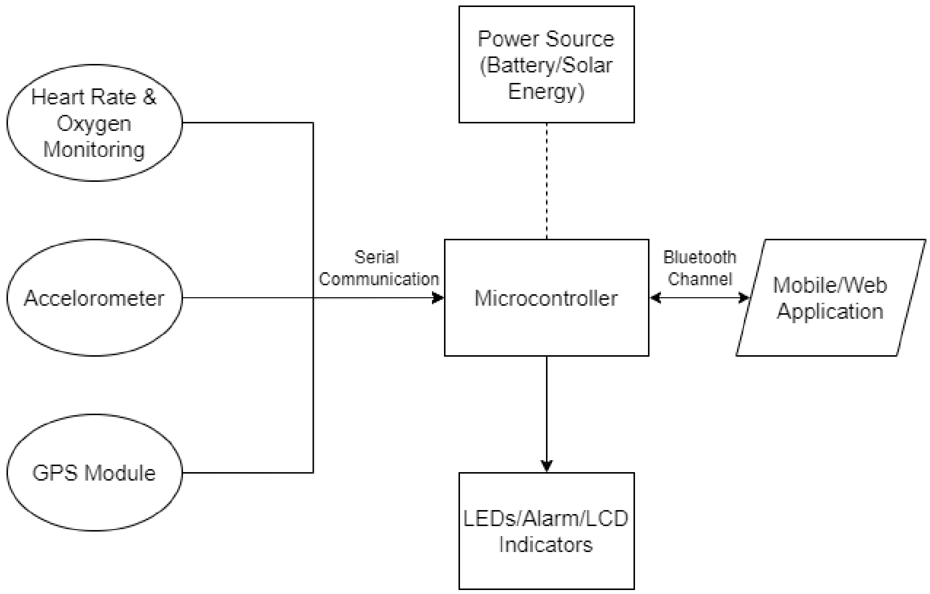

Figure 1: High-Level Hardware Block Diagram

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Data Flow Algorithm

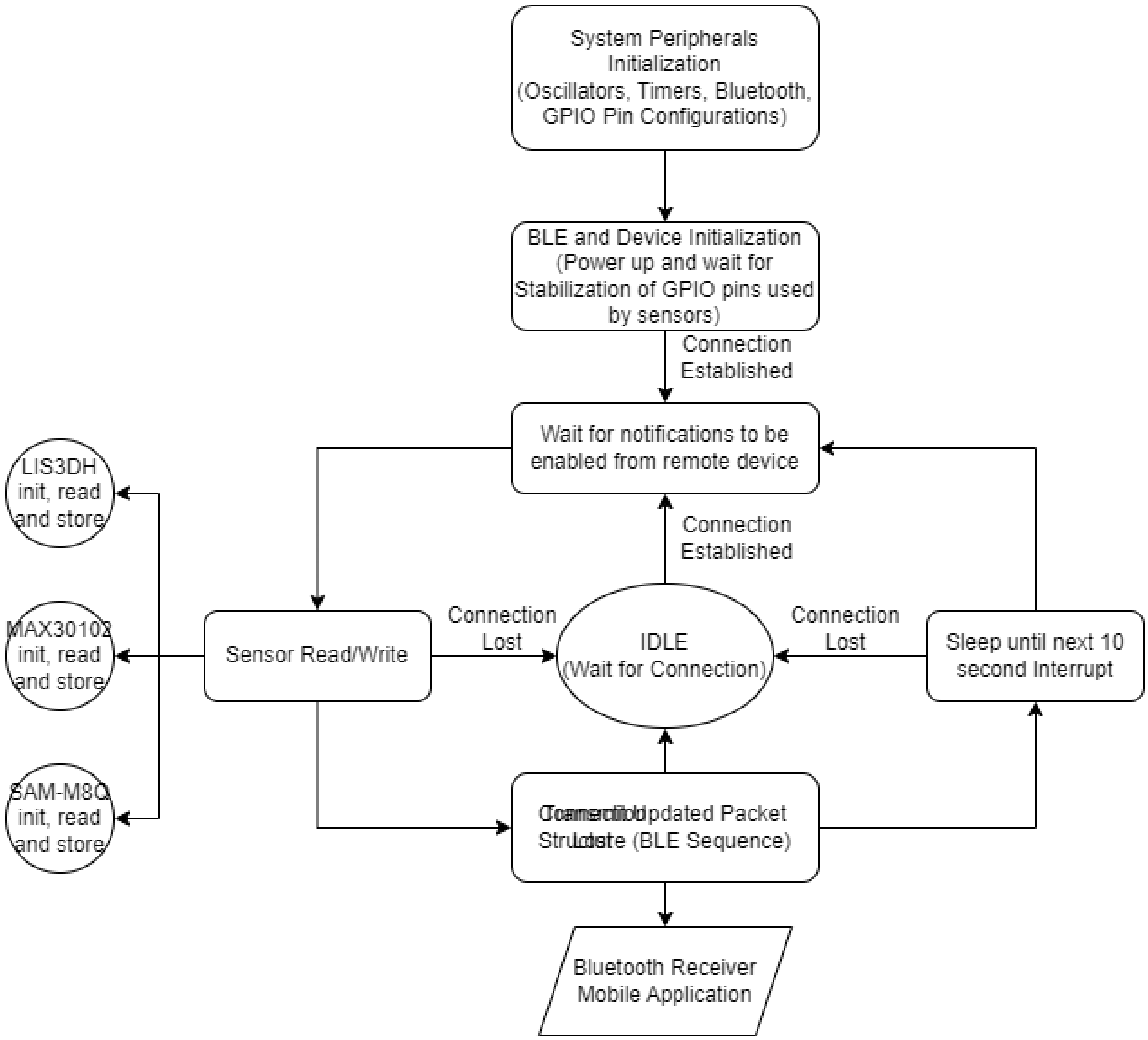


Figure 2 Data Flow Diagram

Microprocessor and Sensor Selection

EFR32 Blue Gecko

The EFR32 Blue Gecko is an ARM Cortex-M4-based family of wireless system-on-chip (SoC) devices used as an energy-efficient solution for wireless communication and IoT applications.

Operating Parameters	Range
Power Supply Voltage	1.8V – 3.8V
Wireless Connectivity	Bluetooth Low Energy (BLE), Zigbee, Thread
Peripherals	GPIO pins, UARTs, SPI, I2C, timers, and analog interfaces
Power Modes	active, sleep, deep sleep, and hibernate, (EM0 – EM3)
Operating Temperature Range	-40°C to +85°C

Heart Rate & Pulse Oximeter Sensor, *MAX30102*

The MAX30102 is used to measure both heart rate and oxygen saturation (SpO2). It works by emitting and detecting infrared light through the skin, measuring variations in light absorption due to blood flow, and using this information to calculate heart rate and SpO2 levels in wearable fitness devices. It plays a crucial role in monitoring the wearer's health and fitness parameters in real-time.

Operating Parameters	Range
Power Supply Voltage	3.3V – 5V
Communication Interface	I2C
Capability of heart rate measurement	30BPM – 200BPM
Oxygen Saturation Measurement	70% - 100%
Sampling Rate	50Hz – 1KHz

Operating Temperature Range	-40°C to +85°C

Accelerometer, LIS3DH Triple-Axis

The LIS3DH is a triple-axis accelerometer sensor used for motion sensing. Here are the working requirements and specifications of the LIS3DH Triple-Axis module:

Operating Parameters	**Range**
Power Supply Voltage	1.71V – 3.6V
Communication Interface	I2C/SPI
Measurement Axes	Three orthogonal axes: X, Y, and Z
Acceleration Range	70% - 100%
Operating Temperature Range	-40°C to +85°C

SAM-M8Q

- Initially, the NEO-6M GPS module was considered, but following thorough research, we opted for the SAM-M8Q GPS module due to its superior features and benefits compared to the former.

Parameters	SAM-M8Q	NE0-6M	MAX-M10S
Integrated Antenna	✓	×	×
Odometer	✓	×	✓
Tracking Channels	72	50	56
Dynamics	≤4 g	≤4 g	≤ 4 g
Altitude	50,000 m	50,000 m	80,000 m
Velocity	500 m/s	500 m/s	500 m/s
VCC Max	3.6	3.6	3.6

Product Features

- Free and easy to use Vest Mobile Application which enables the user to track the cardinal parameters related to human body (heartbeat rate and blood oxygen levels) and movement (speed, altitude, location) while performing any physical activity.
- Load power management would be implemented though software based on sensory data, such that, components consume as low power as possible.
- The device can run on rechargeable batteries, and it would also support charging over solar energy as a part of energy harvesting.
- If threshold values of heartbeat or oxygen levels are crossed above or below limits, the mobile app will support notifying the user with a warning.

Specs	Values
Dimensions	3.5in x 3.5in
Temperature	0 – 60 ˚C
Expected Wireless Range	10 meters (From EFRBG13)
Relative humidity	65 ± 20%
Warranty	~ 1.7 years

Table 1 Product Specifications.

Update 1: Week 3

Proposal Feedback Questions

1. I would like to know how often you plan on sampling your sensors and how often you are going to get GPS positioning?
    - We intend to sample each of the devices to ensure that new data becomes available every 10 seconds, aligning with our initial concept of transmitting data packets at this specific interval.

2. How are you going to implement load power management?
    - If the component under consideration supports low power or sleep mode with some condition/threshold, it will be incorporated for load power management, else the module's switching will be controlled by the software based on required conditions.

3. Under features, it's stated load power management will be implemented through software based on sensory data, but is there a low power mode on your GPS module?
    - Yes, SAM-M8Q has two low power modes out of which we will be using "Cyclic Tracking" mode which can sample data every 1 – 10 seconds.

4. Does your MAX30102 have a shutdown mode?
    - Yes, the MAX30102 sensor does have a shutdown mode. Its shutdown mode allows us to conserve power when the sensor is not actively needed, which is especially important in battery-operated devices.
    - In shutdown mode:
        - LEDs Turn Off: The MAX30102's LED drivers, which are used for emitting light into the skin to measure pulse and oxygen levels, are turned off. This significantly reduces power consumption as the LEDs are one of the most power-hungry components of the sensor.
        - Sensor Functions Pause: The sensor's data acquisition and processing functions are paused. It stops collecting and processing data, which further reduces power consumption.

- Registers Retain Data: The sensor retains its configuration settings and previous data in its registers during shutdown. This means that when you exit shutdown mode and power it up again, you can resume data collection with the same settings.
- To exit shutdown mode and bring the MAX30102 back into active operation, you typically need to write to the sensor's control registers to configure its mode of operation (e.g., heart rate or SpO2 mode) and start data acquisition.

5. How long do you expect your product to run (how long of a workout can it track before you need to charge it)?
   - As per initial estimations and design ideas, we plan to have battery that can keep the device up for at least 5 hours.
6. You mention an LCD in your indicators box, are you planning on implementing an LCD (think about your physical product specifications)?
   - The indication segment of the Block Diagram presented potential choices, but our current plan does not involve incorporating an LCD into the device. Instead, the device will feature status LED(s).

7. Also, please elaborate on your ideas for your mobile/web application (high level).
   - GUI Development Platform Considerations: Python/MIT App Inventor/Android Studio
   - App Features:

     Application will display following health, fitness & location parameters:

     - Heart rate
     - Blood Oxygen Level
     - Calories Burnt
     - Distance Covered
     - Location
     - Altitude
     - Motion Speed
     - Total activity time
     - Type of activity
   - User will have to set a profile during App initialization.
   - User Profile Parameters:
     - Profile name
     - Gender
     - Age
     - Height
     - Weight
   - App will be integrated with the fitness tracking vest through wireless communication protocol – Bluetooth.
   - Real-time data synchronization between the vest and the app

Past Week Progress

Sr. No.	Task	Date
1.	Sensor selection Verification	09/11/2023
2.	GPS sensor change based on specifications	09/12/2023
3.	Detailed study of sensor datasheets	09/14/2023
4.	Sensor working modes	09/14/2023
5.	Study and analysis of power consumption of each sensor and microcontroller	09/15/2023
6.	Load power management design	09/16/2023
7.	Storage element inclusion decision	09/16/2023

Plan for Next Week

Sr. No.	Task	Planned Date of completion
1.	Deciding basic process flow algorithm	09/18/2023
2.	Study: Basic Converters and Regulators	09/20/2023
3.	Study: PMIC and decide suitable one for our application	09/20/2023
4.	Components library creation in Altium	09/22/2023
5.	Study: App Development	09/23/2023
6.	Study: Health Parameters monitoring	09/24/2023

Gantt Chart

Please access the Gantt Chart here.

Support needed for following tasks/decisions

- Power Consumption Analysis
- Energy Harvesting Specifications
- Review of Process algorithm

Why these Sensors?

LIS3DH

- LIS3DH is a 3-axis accelerometer, measuring acceleration along the X, Y, and Z axes. The primary reasons to use this for our application are following:
  - Known for low power consumption, suitable for battery-powered devices and applications where power efficiency is critical and can help in load power management of our device.
  - Provides good resolution to capture a wide range of accelerations accurately.
  - Supports both I2C and SPI communication interfaces with transaction cycles in the range of microseconds and nanoseconds respectively.

MAX30102

- The selection between the MAX30101 and MAX30102 sensors was deliberated. In cases where exclusive heart rate monitoring suffices, the MAX30101 could be deemed adequate and economically advantageous. Nevertheless, for our application precise SpO2 measurements are necessitated for a broad spectrum of scenarios, the MAX30102 emerges as the favored option owing to its dual-LED configuration and enhanced accuracy.

SAM-M8Q

- Initially, the NEO-6M GPS module was considered, but following thorough research, we opted for the SAM-M8Q GPS module due to its superior features and benefits compared to the former.

Parameters	SAM-M8Q	NE0-6M	MAX-M10S
Integrated Antenna	✓	×	×
Odometer	✓	×	✓
Tracking Channels	72	50	56
Dynamics	≤4 g	≤4 g	≤ 4 g
Altitude	50,000 m	50,000 m	80,000 m
Velocity	500 m/s	500 m/s	500 m/s
VCC Max	3.6	3.6	3.6

Table 2: GPS module selection based on key specifications

Use Case Model

Power Consumption

The following data regarding current consumption at specific voltage levels as per datasheet was used to determine an estimate of total power usage and which energy modes would the device operate at any instant. All these values are based on specific operating environments from datasheets, and thus the actual consumption based on time periods (power on, stabilizing time, data transfer, sleep/wake) would vary once the measurements are made using the actual sensor and the microcontroller.

		Current (uA)	Voltage	Power (uW)
Interfaces	MAX30102 (HR and SpO2)			
	HR + SpO2 Mode	1200	5	6000
	HR Mode	1200	2	2400
	Standby Mode	0.7	1.7	1.19
	LIS3DH (Accelerometer)			
	Normal Mode @50 HZ ODR	11	2.5	27.5
	Normal Mode @1 HZ ODR	2	2.5	5
	Low Power Mode @50 HZ ODR	6	2.5	15
	SAM-M8Q (GPS)			
	Continuous Mode	23000	3	69000
	Cyclic Tracking (@ 1Hz)	9500	3	28500
	Max Supply Current (@1Hz)	67000	3	201000

Table 3: Power Consumption for Interfacing Devices

For the microcontroller, since it has an onboard Bluetooth module, and the radio would not work beyond EM1 mode, the following current consumption data is available from the datasheet:

Energy Modes	Typical Current Consumption (uA)	Voltage	Power (uW)
EM0	128	3.3	422.4
EM1 (all peripherals disabled)	76	3.3	250.8
EM1 (with Radio)	9500	3.3	31350
EM2	2.2	3.3	7.26
EM3	1.5	3.3	4.95
EM4	0.4	3.3	1.32
EM4 Sleep	0.08	3.3	0.264

Table 4: Power Consumption for Microcontroller

Energy Mode Analysis

According to the initial proposal and brainstorming, we plan to transmit the data packets every 10 seconds to the mobile application over Bluetooth. As per the reference manual of EFR32BG13, the device supports active radio transmission only until EM1 mode. Therefore, based on power consumptions, reference manual data and initial brainstormed sampling rate for data transfers, the device would always be in either **Active Mode, EM0 or EM1 energy modes**. But, with load power management, the current consumption at any instant can be lowered for the time when no new reading of sensory data is required or using sensor's internal low power feature.

Update 2: Week 4

Feedback Questions from Update 1

1. In your Gantt chart, I would recommend splitting your tasks into subsections for easier navigation. The Gantt chart should fill in the right side with colored cells where tasks are completed/planned. Please keep adding your updates to a growing document.

- Refer here.

2. For this week, you should have your proposal and then your update 1 as an additional section.

- Updated

3. Don't forget to add if you are on track and if not why.

- Added here.

4. Please pick your desired energy harvesting option. If you need help with this, reach out to me/Randy and the TA's.

- We plan to use solar panels/cells as our energy harvesting source as our device's primary application is sufficed outdoors. As the energy harvesting source would contribute to 10% of battery capacity, we would finalize the size/number of panels/cells once the energy source device is finalized.

5. In your energy mode breakdown, which sensors are running in which energy mode and for how long? There is an example of this energy chart given in the slide deck.

- In summary, all sensors need to be at least in EM1 energy mode to receive peripheral interrupts. The detailed explanation for energy mode using average & maximum current values and time period of one initialization, read and write cycle is provided in Energy Mode Breakdown and Use Case and Energy Storage Element Calculation sections.

6. Additionally, you need to tell me more about your design. How are you going to connect your sensors? Are they all on the same I2C bus? Are they split? If a sensor supports different serial protocols, which one are you picking and why?

- Refer here

Energy Mode Breakdown

To calculate the maximum power being drawn by the device and which energy state it falls under, following parameters were considered:

Device	Current (mA)	Voltage (V)	Power (mW)	Power(uW)
Deep Sleep	0.0013	3.3	0.00429	4.29
Microcontroller (Tx)	8.5	3.3	28.05	28050
GPS	67	3.3	221.1	221100
HR and SPO2	1.2	3.3	3.96	3960
Accelerometer	0.01	3.3	0.033	33
Total:	76.71			

Table 5: Voltage and Current Consumption Summary

Device States	Power (mW)
GPIO Init/ Startup	4.95
Sensor Init + Read	225.093
Transmit	80
Deep Sleep	0.00429

Referred from datasheet, 19dBm is 0.0794 Watts

Table 6: Power Consumption Summary for each State

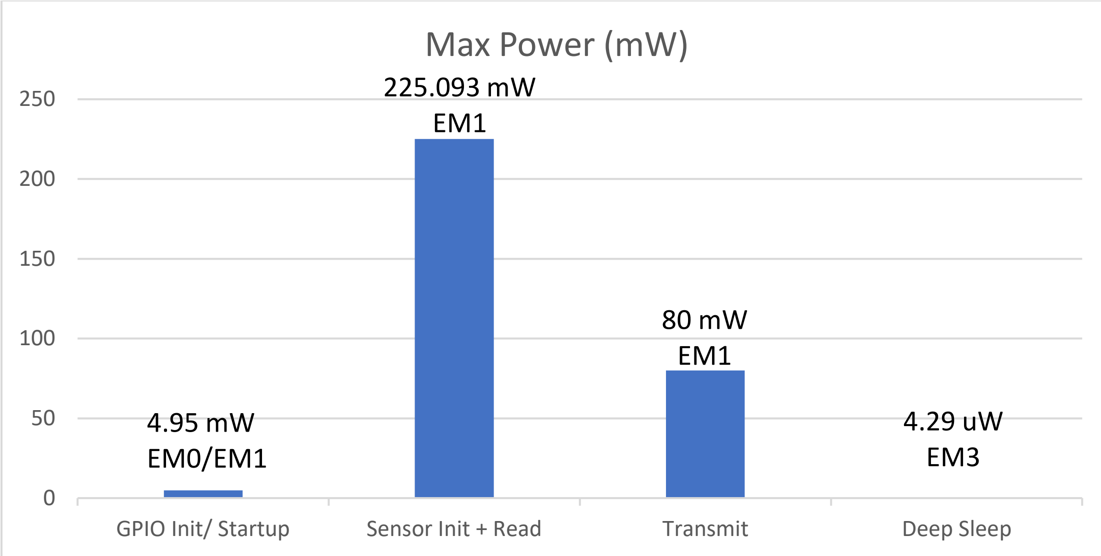


Figure 3 Energy Chart

The high-level design elaborating the timing, current and power consumption of each state is shown in the Use Case and Energy Storage Element Calculation section.

Past Week Progress

Sr. No.	Task	Planned Date of completion	Actual Date of Completion
1.	Deciding basic process flow algorithm	09/18/2023	Done (Refer here)
2.	Study: Basic Converters and Regulators	09/20/2023	Done
3.	Study: PMIC and decide suitable one for our application	09/20/2023	Done (Refer here)
4.	Components library creation in Altium	09/22/2023	Not started
5.	Study: App Development	09/23/2023	Not started

6.	Study: Health Parameters monitoring	09/24/2023	In progress

Plan for Next Week

Sr. No.	Task	Planned Date of completion
1.	Finish library creation of components to be used in the system.	09/29/2023
2.	Perform interfacing of all components using the development kits and verify the working.	09/29/2023

Gantt Chart

Please access the Gantt Chart here.

Progress Status

At this point, we've completed essential tasks, including the examination of fundamental regulators and the selection of a PMIC (Power Management Integrated Circuit). We have also determined the basic dataflow for the design. However, we realized that we underestimated our time for the completion of necessary tasks and planned other tasks such as studying app development and creating a component library. Unfortunately, due to other high-priority tasks such as energy management calculations and PMIC selection, we were unable to dedicate time to these tasks. Taking this phase of development into consideration, we are on schedule, except from verifying recharge time requirements for use cases and sizing storage based on the number of charge cycles required.

Support needed for following tasks/decisions

- Need help to precisely understand following two points and to verify if our analysis is right.
  1. Use-case recharge time requirements
  2. sizing storage based on use case number of charge cycles
- To figure out, calculation of total energy required between charging.
- Selection of energy harvesting component

Sensor Interfacing

Sr. No.	Sensor Name	Available communication Protocols	Selected communication protocol	Reason for selecting specific protocol
1.	MAX30102	I2C	I2C	Sensor supports only I2C
2.	LIS3DH	I2C, SPI	SPI	SPI is efficient in terms of power and time consumption
3.	SAM-M8Q	UART, DDC (I2C compliant)	UART	Less power consumption as compared to I2C

Though there are multiple pins available on EFR32BG13 to establish connections between the sensor protocol pins (I2C/SPI/UART) and the EFR32BG13 pins, the ultimate pin configurations will be determined during the schematic and layout design phase, taking into consideration design convenience and ease of implementation.

Use case and Energy Storage Element selection math

To calculate the amount of energy/charge for the battery following design has been taken into consideration:

State	State Name	Time Duration (sec)	Energy Mode
1	GPIO INIT	1	EM0/EM1
2	Sensor Setup and Read	4	EM1
3	Data Transmission	1	EM1
4	Idle	4	EM3/Deep Sleep

Table 7: Energy Mode and Duration for each state

The current consumed during the initialization of GPIO pins is calculated using the AEM current profiler in Simplicity Studio by enabling the GPIO pin for onboard temperature sensor, and for this use case of 3 sensors, it was found to be around 1.5mA. The states shown above would run periodically every 10 seconds. Apart from this, the maximum current, maximum average current and minimum average current values were calculated using following data from datasheets:

Device	Current (mA)	Voltage (V)	Power (mW)
Microcontroller Deep Sleep	0.0013	3.3	0.00429
Microcontroller (Tx)	8.5	3.3	28.05
GPS	67	3.3	221.1
HR and SPO2	1.2	3.3	3.96
Accelerometer	0.01	3.3	0.033

Table 8: Power Consumption Summary for each device

While using the above design as a reference, following average current and power consumption values were obtained:

Parameter	Min.	Max
Average Current (mA)	1.07091	14.52152
Average Power (mW)	3.304003	47.921016

Table 9 : Average Current and Power Consumption of System.

The average current and power values were calculated using the following use case assumptions from device datasheets:

Operation	**Worst Case Time (sec)**
GPIO Init	1
GPS	2
Accelerometer	1
HR and SPO2	1
Transmit	1
Sleep	4
Total	10

Table 10: Worst Case performance time summary

We have defined 3 battery selection options and they are as follows:

Case I: Assuming all sensors run continuously for 5 hours (Max Current Consumption)

Parameter	Value	Units
Voltage (V)	3.3	V
Current (I)	0.076	A
Duration (t)	5	h

Table 11: Calculated values for Max Current Consumption

From these input values, we get the following:

Resistance	43.42105263	Ohms	=V/I
Power:	0.2508	Watt	=V*I
Charge	0.38	Ah	=I*t
Energy (WattHour)	1.254	Wh	=P*t
Energy (Joule)	4514	J	=Wh*3600
Energy (Calorie)	1078.97	cal	=Wh*860.42065

Table 12: Electrical Parameters for Max Current Consumption

Thus, from the number of Joules, we can calculate the required mAH:

Energy (Joule)	4500	J
Voltage	4.2	V
Charge (= E/V/3.6)	297.62	mAh

Table 13: Required Charge Calculation for Max Current Consumption

Case II: Maximum Average Current Consumption

Parameter	Value	Units
Voltage (V)	3.3	V
Current (I)	0.014	A
Duration (t)	5	h

Table 14: Calculated values for Max Average Current Consumption

Resistance	235.714	Ohms	=V/I
Power:	0.0462	Watt	=V*I
Charge	0.07	Ah	=I*t
Energy (WattHour)	0.231	Wh	=P*t
Energy (Joule)	832	J	=Wh*3600

Energy (Calorie)	198.76	cal	=Wh*860.42065

Table 15: Electrical Parameters for Max Average Current Consumption

Energy (Joule)	1000	J
Voltage	4.2	V
Charge (= E/V/3.6)	66.14	mAh

Table 16: Required Charge Calculation for Max Average Current Consumption

Case III: Minimum Average Current Consumption

Parameter	**Value**	**Units**
Voltage (V)	3.3	V
Current (I)	0.001	A
Duration (t)	5	h

Table 17: Calculated values for Minimum Average Current Consumption

Resistance	3300	Ohms	=V/I
Power:	0.0033	Watt	=V*I
Charge	0.005	Ah	=I*t
Energy (WattHour)	0.0165	Wh	=P*t
Energy (Joule)	59	J	=Wh*3600
Energy (Calorie)	14.20	cal	=Wh*860.42065

Table 18: Electrical Parameters for Minimum Average Current Consumption

Energy (Joule)	100	J
Voltage	4.2	V
Charge (= E/V/3.6)	6.61	mAh

Table 19: Required Charge Calculation for Minimum Average Current Consumption

From the above 3 cases, we have an estimate of the minimum and maximum requirements of the system at any given instant and the data required to look for an energy storage element (Battery) that will suffice the energy requirements.

Energy Storage Element and PMU(s)

Energy Storage element: Battery (3898) Digi-Key Part No: 1528-2731-ND

Upon researching supercapacitors and batteries, it becomes evident that supercapacitors are used in situations requiring high or instantaneous power output in a short timeframe, prioritizing power density. Conversely, batteries are chosen when energy density is more important, typically when sustained energy supply is needed for extended periods, with less emphasis on immediate power demands. For our specific application, the primary requirement is an energy storage component with higher power density rather than energy density. Therefore, the optimal choice is a "**battery**."

Use-case recharge time requirements

Assuming maximum average current consumption of the system mentioned above the recharge time requirements can be calculated as follows:

Battery Capacity = 400 mAH

Max. avg system current (power on + initialization + data acquisition + transmission) = 14.5 mA (Discharge rate)

$$\text{Next Battery Recharge Time (hours)} = \frac{\text{Battery Capacity (mAh)}}{\text{Max. Avg System Current (mA)}}$$

Plugging in the values:

$$\text{Next Battery Recharge Time (hours)} = \frac{400\,\text{mAh}}{14.5\,\text{mA}} = 27.5\ \text{hours} \approx 27\ \text{hours}$$

Table 20 Battery Recharge Duration

Sizing storage based on use case number of charge cycles (Warranty)

For the selected Battery charge cycles from the datasheet are as follows:

Cycle Life @25℃ - Cycle **life ≥ 500**

Discharge to 3.0V @0.2C, then 0.5c CCCV 0.01C charge to 4.2V, rest for 10 min. discharge @ 0.2C to 3.0V and rest for 10 min. Continue the charge/discharge cycles until discharge capacity lower than 70% of rated capacity.

Based on our calculations the battery will discharge at a rate of 0.03C which is nearly 15% less than the discharge rate considered in the datasheet. So, the warranty of product can be calculated as follows:

Recharge Time = 27 Hrs.

Number of hours to complete 500 cycles = 27 x 500 = 13500 Hrs.

Since the discharge current is 15% less than discharge current in datasheet adding 15% to Number of hours to complete 500 cycles = 13500 + 2025 = 15525 Hrs.

500 cycles in days = 15545/24 = 647 days

500 cycles in years ~= 1.7 yrs.

Note: These values are true considering the condition that there is no charging until and unless the battery discharges to discharge cut-off voltage of 3.0 V. But if the battery is charged and discharged at the same time using the energy harvesting element then the product warranty can be further improved based on the difference between charging and discharging rate.

Use-case PMIC selection

We have chosen the BQ25570, an Ultra-Low Power Harvester Power Management IC with a boost charger, and a Nano power Buck Converter, to serve as the Power Management IC (PMIC) for our product.

We have opted not to use an unregulated power supply since all sensors and the microcontroller in our system have a maximum voltage limit of 3.6 V, whereas the energy storage element supplies 3.7 V. As a result, we will require a regulator to step down and maintain a constant supply voltage of 3.3 V from the battery.

Considering the selected microcontroller and all attached sensors, it is clear that a 3.3 V voltage rail will be necessary for their operation, and this can be achieved using the chosen PMIC. Additionally, since the energy harvesting element is a solar cell/panel, we will need a boost converter to convert the solar output into power levels that are sufficient for our needs.

The component we have selected fulfills all these requirements as it provides both Buck and Boost converters, along with energy harvesting functionality.

Update 3: Week 5

Feedback from Update 2

1. Gantt Chart Modifications
- Refer here.
2. Find your solar panel's peak wattage and estimate how much sunlight you would get per day. This will give you the energy put into your battery (minus conversion losses).
- Based on the power consumption, PMIC's input voltage range and the maximum input current, we are exploring the solar panel options and would like to discuss with SA's on it.
3. With your GPS, try to verify functionality with UART. If you don't get that far before your boards are sent to fab, you can add both UART and I2C lines to your board.

- We will try interfacing and reading data from the GPS Module using UART and if there are any issues or for backup solution, we will also add I2C lines on our final design.

4. In your energy storage element selection math, how did you get to your time duration for each state?

- For calculating the time duration in each state, we took into consideration the maximum time taken by the sensor to setup and give out sensed data from datasheet. Along with the current and power values used to determine the energy state, we considered worst case time (in resolution of seconds for all sensors) in addition to the known parameters such as GPIO stabilization time from previous experience with EFR32BG13. Here is the summary of data we took into consideration to conclude a preliminary period based on Datasheet values (resolution: seconds) for each state:

Operation	Worst Case Time (sec)
GPIO Init	1
GPS	2
Accelerometer	1
HR and SPO2	1
Transmit	1
Sleep	4
Total	10

Upon combining these tasks into common states, here's the summarized state information:

State	State Name	Time Duration (sec)	Energy Mode
1	GPIO INIT	1	EM0/EM1
2	Sensor Setup and Read	4	EM1
3	Data Transmission	1	EM1
4	Idle	4	EM3/Deep Sleep

- The precise calculations for timing of each sensor with respect to the communication bus is elaborated here.

5. Please include your system's specs (dimensions, temp, expected wireless range, humidity range, warranty time).

Specs	Values
Dimensions	3.5in x 3.5in

Temperature	0 – 60 ˚C
Expected Wireless Range	10 meters (From EFRBG13)
Relative humidity	65 ± 20%
Warranty	~ 1.7 years

Sizing Storage based on recharge requirements

Based on current and recharge requirements of our system the storage sizing was calculated which is linked here. For deciding the storage element size three different cases were considered for different current consumptions of the system which can be found under Use case and Energy Storage Element selection math.

Finalization of storage size was done based on different supply voltages for all sensors and on supply voltage for the controller. Apart from this tolerance of battery was considered to make sure that it has sufficient power available to supply to the system.

C-Rate and Battery Solution

As per the datasheet for the selected battery solution Maximum Constant Charging Current is 400mA that is 1C and Maximum Continuous Discharging Current is 600mA (1.5C).

Based on Use case model and Energy Storage Element selection math for three different cases the discharging current in C is calculated as follows:

Assuming all sensors run continuously for 5 hours (Max Current Consumption)

Parameter	Value	Units
Current (I)	76	mA
Battery Size	400	mAH
Required Duration (t)	5	h
C Rate	**0.19**	**C**

Table 21 Worst case C rate.

Maximum Average Current Consumption

Parameter	Value	Units
Current (I)	14	mA
Battery Size	400	mAH
Required Duration (t)	5	h

C Rate	**0.0350**	**C**

Table 22 Normal case C rate.

Minimum Average Current Consumption

Parameter	Value	Units
Current (I)	1	mA
Battery Size	400	mAH
Required Duration (t)	5	h
C Rate	0.0025	C

Table 23 Best case C rate.

Hence it can be considered that even with the worst-case discharge rate of ~0.2C the system will work easily for 5hrs before needing a recharge.

Parameters	Value	Units
Nominal Voltage	3.7	V
Charging Cut-off voltage	4.2	V
Discharge Cut-off Voltage	3	V
PMU support a low battery discharge cut-off voltage	1.91	V

Table 24 Cut-off voltages of Battery.

As our system requires only two power supplies (3.3V and 1.8V) which are less that the nominal voltage of 3.7V, we would only require Buck-convertor.

PMU Solution

Features
Cold-Start Voltage: VIN ≥ 600 mV
Continuous Energy Harvesting From VIN as low as 100 mV
Battery Charging and Protection
Internally Set Undervoltage Level
User Programmable Overvoltage Levels

Programmable Step-Down Regulated Output
High Efficiency up to 93%
Supports Peak Output Current up to 110 mA (typical)

Additional features considered during selection of PMIC other than Use-case PMIC selection can be found here.

Apart from the PMIC, we will also use an LDO to limit the buck output to 1.8V as it is required by the MAX30102 sensor.

Past Week Progress

Sr. No.	Task	Planned Date of completion
1.	Component Library Creation	In-progress
2.	Worst Case timing analysis for sensor communication	09/30/2023
3.	Verification of Battery math	09/29/2023

Plan for next week

Sr. No.	Task	Date
1.	Component Library Creation + Schematic	10/07/2023
2.	Check Solar panel specifications	10/05/2023
3.	Bulk cap simulation	10/06/2023
4.	Spice analysis of power supplies	10/06/2023

Unplanned Tasks accomplished during past week

Sr. No.	Task	Date
1.	Studied Mini Debug Connector (AN958)	09/30/2023

Progress Status

We are on track as per the plan.

Support needed for following tasks

We found it difficult to gather enough information regarding the worst-case communication bus time for SAM-M8Q and only worst-case device response time was available for our analysis. Any leads on same would help us reach a concrete conclusion regarding timing parameters.

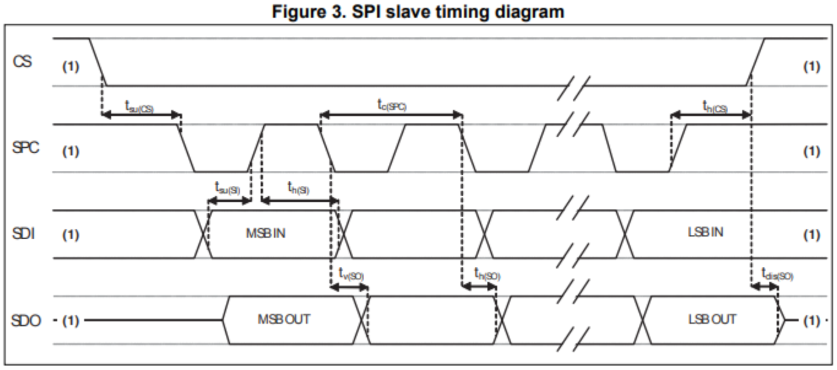
Worst case timing for communication bus

LIS3DH (SPI)

- Minimum Clock Cycle: 100ns
- Wait at least 5ms after powering up the sensor before reading/writing to the sensor.
- CS line takes minimum 5ns to change its state, should be held for at least 20ns.
- SDI line takes minimum of 5ns to change its state, should be held for at least 15ns.
- Valid output can be found on SDO line after a maximum of 50ns, can be held for at least 5ns before next clock pulse.
- The LSB of SDO will be available no later than 50ns after CS is pulled high.

Timing Diagram:

Figure 3. SPI slave timing diagram



1. When no communication is ongoing, data on SDO is driven by internal pull-up resistors.

Worst Case timing calculation based on datasheet:

LIS3DH		
Operation	**Cycles**	**Unit**

Read Operation	120	CLK cycles (16 CLK cycles per transaction x 6 read operations for 1 period)
Write Operation	96	CLK cycles (40 CLK cycles per transaction x 3 write operations for 1 period)
Total	216	CLK cycles

Timer Period for 1 CLK cycle	100	Nanoseconds

Worst Case time	21.6	Microseconds (total cycles x 1 CLK cycle period)

MAX30102 (I2C)

- Frequency: 0 to 400 KHz.
- There has to be 1.3us time between start and stop conditions over I2C channel.
- The setup time for Data line is 100ns.
- SDA/SCL Rise/Fall time: 300ns.

Timing Diagram:

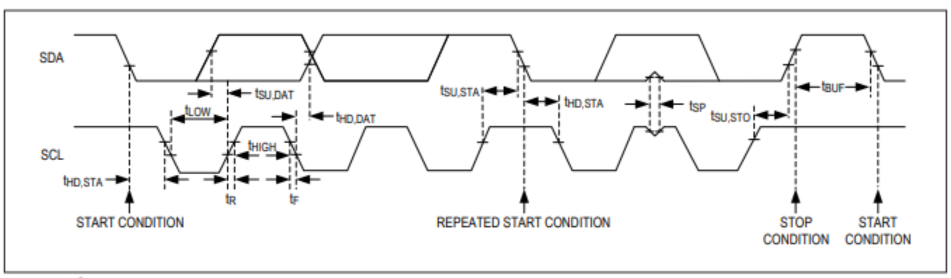


Figure 1. I²C-Compatible Interface Timing Diagram

Worst Case timing calculation based on datasheet:

MAX30102		
Operation	**Cycles**	**Unit**
Read Operation	102	CLK cycles (17 CLK cycles per transaction x 6 read operations for 1 period)
Write Operation	85	CLK cycles (17 CLK cycles per transaction x 5 write operations for 1 period)
Total	187	CLK cycles

Frequency	400	KHz
Timer Period for 1 CLK cycle	2500	Nanoseconds

Worst Case time	467.5	Microseconds (total cycles x 1 CLK cycle period)

SAM-M8Q (UART/I2C)

The documentation (datasheet and supporting document) available for SAM-M8Q enlists initialization steps and information relating the commands to be sent over UART. It does not have any timing related worst-case information and just provides supporting baud rates.

Possible UART Interface Configurations

Baud Rate	*Data Bits*	*Parity*	*Stop Bits*
4800	8	none	1
9600	8	none	1
19200	8	none	1
38400	8	none	1
57600	8	none	1
115200	8	none	1
230400	8	none	1
460800	8	none	1

High-risk development items and mitigation plans

- GPS Accuracy
  Ensuring accurate GPS data can be a challenge, especially in areas with poor satellite visibility (e.g., urban canyons or dense forests).
  To mitigate this risk, we are storing the most recent GPS data and the user's current direction of movement.

- Communication Failure
  Failure of sensor communication over the physical bus can be risky.
  To address this, we are incorporating test points for the communication lines of each sensor as a precautionary measure.

- Signal Integrity
  Signal noise has the potential to impact the reliability of sensor readings, potentially resulting in errors in the collected sensor data and consequently yielding inaccurate results. To address this concern, we are taking measures to minimize signal noise by placing decoupling capacitors in close proximity to the power pins.

Update 4: Week 6

Programming of Microcontroller

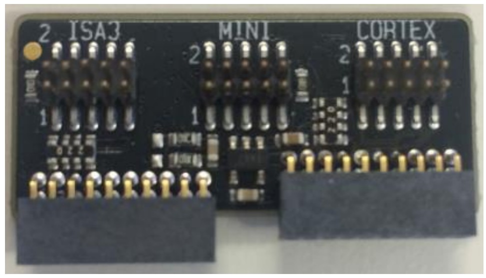


Figure 4 Simplicity Debug Adapter Board

We will be using the Simplicity Mini Connector on Debug Adapter Board to program the EFR32BG13 microcontroller. Here is the pinout of Simplicity Mini Connector:

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 5 Mini Connector Pinout

Compiling, Connecting, and Downloading Code to Target Board Design

The code generation, compilation, establishing serial connection and downloading the binary file to the target board would be done through Simplicity Studio IDE, a Gecko Development Board kit and the Mini Simplicity Connector.

Signal Test Points

The following signals will have test points for easy and fast debugging:

1. Power Lines: 3.3V and 1.8V
2. Oscillator Output
3. I2C: SCL and SDA Lines
4. SPI: SCK, MISO, MOSI and CS

5. UART: RX and TX
6. USB: Power Lines (Jump starting of battery charging)

Reset Circuit

The rest pin on EFR32BG13 must be pulled low for at least 100 nanoseconds in order to trigger Reset operation. The reset circuit consists of a tactile switch to reset the controller and a capacitor connected across it to avoid switch debouncing. As a result, if the controller is reset all peripherals connected to it will also get reset as the firmware will start from the beginning.

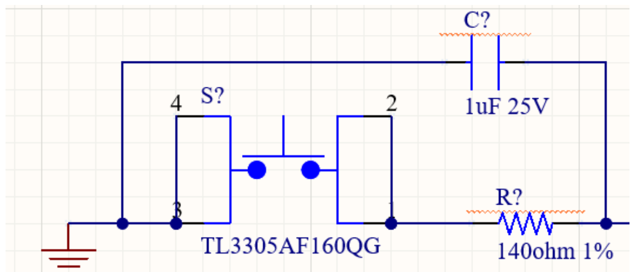


Figure 6 Reset Circuit

10.3.5 RESETn Pin Reset

The pin reset on EFR32xG13 Wireless Gecko can be configured to be either hard or soft. By default, pin reset is configured as a soft reset source. To configure it as a hard reset, clear the PINRESETSOFT bit in CLW0 in the Lock bit page, see 8.3.2 Lock Bits (LB) Page Description for details. Forcing the RESETn pin low generates a reset of the EFR32xG13 Wireless Gecko. The RESETn pin includes an on-chip pull-up resistor, and can therefore be left unconnected if no external reset source is needed. Also connected to the RESETn line is a filter which prevents glitches from resetting the EFR32xG13 Wireless Gecko.

Clock Generation

The clock signal requirement on EFR32BG13 is sufficed by either selecting one of the oscillators and configuring it in accordance with the requirements of the design to generate a clock pulse or by supplying an external clock signal into the microcontroller. For our current design requirements, the external peripherals use CLK signals only for serial communication and no component needs a high frequency clock for operational efficiency.

From the list of available clock sources (integrated oscillators), we plan to use **HFXO** and **LFXO** as our primary oscillator sources for all the processing. HFXO is used because the device needs to have this oscillator when using the RF utility, or the hardware (Radio Controller) automatically takes up this oscillator when using RF application. It is important to note that LFXO is available up to EM2 energy mode so for our low energy requirements it can meet the requirements. Also, when the state machine will put the device in SLEEP state, we can configure it to select the same oscillator once it wakes up upon completion of decided sleep period. This is important because, after each wake up event, the oscillator must be enabled else no clock source would be provided to the peripherals.

Oscillator	Frequency Range
HFXO	38 – 40 MHz[1] or 4 to 50 MHz[2]
HFRCO	1 – 38 MHz[1] or 72 MHz[2]
AUXHFRCO	1 – 38[1] MHz or 1 – 50 MHz[2]
USHFRCO	1 – 50 MHz[2]
LFXO	32768 Hz
LFRCO	32768 Hz
ULFRCO	1000 Hz

Note:
1. EFM32xG1 and EFR32xG1/xG12/xG13
2. Giant Gecko Series 1 only

Figure 7 Frequency range for Oscillators

Oscillator	Energy Mode					
	EM0	EM1	EM2	EM3	EM4H	EM4S
HFXO	Available	Available	—	—	—	—
HFRCO	Available	Available	—	—	—	—
AUXHFRCO	Available	Available	On demand[1]	On demand[1]	—	—
USHFRCO	Available	Available	—	—	—	—
DPLL	Available	Available	—	—	—	—
LFXO	Available	Available	Available	—	Available[2]	Available[2]
LFRCO	Available	Available	Available	—	Available[3]	Available[3]
ULFRCO	On	On	On	On	On	Available[4]

Note:
1. In response to an asynchronous ADC trigger from the PRS.
2. If retained by the RETAINLFXO bit in EMU_EM4CTRL.
3. If retained by the RETAINLFRCO bit in EMU_EM4CTRL.
4. If retained by the RETAINULFRCO bit in EMU_EM4CTRL.

Figure 8 Oscillator availability for Energy Modes

Alternative energy source apart from energy harvester?

Apart from energy harvesting element, we plan to use USB-C to supply power and jump start the PMIC. We will also have provision to select a source for PMIC.i.e. Energy harvesting element or USB-C.

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

PMU can supply a maximum charge current of 285 mA. (as per the datasheet)

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

Energy storage element can sustain maximum charging constant current up to 400 mA .i.e. 1C.

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

Maximum current of the jump start power source will be set to 10mA based on following graphs present in the datasheet:

1. **Charger Efficiency vs Input Voltage**
2. **Charger Efficiency vs Input Current**

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

Power (voltage) will be connected to a selector switch to select input source either energy harvesting element or USB-C and ground signals will be connected to common ground of the board.

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?

Based on the memory characteristics of flash memory on EFR32BG13, it takes a maximum of **3mA** current for:

Burst Write: *40 microseconds x Number of words to be written*

Single Word Write: *82 microseconds x Number of words to be written*

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	40	μs
		Single word	57	68	82	μs
Page erase time[4]	t_{PERASE}		20	27	40	ms
Mass erase time[1]	t_{MERASE}		20	27	40	ms
Device erase time[2 3]	t_{DERASE}	T ≤ 85 °C	—	60	74	ms
		T ≤ 125 °C	—	60	78	ms
Erase current[6]	I_{ERASE}	Page Erase	—	—	3	mA
		Mass or Device Erase	—	—	5	mA
Write current[6]	I_{WRITE}		—	—	3	mA

Figure 9 Memory Characteristics for EFR32BG13 Flash Memory

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

The energy storage element along with the PMU will be able to supply nearly 110 mA current to the system load (based on BQ25570 datasheet).

What are the connection points to enable external power to digital / MCU portion of the board?

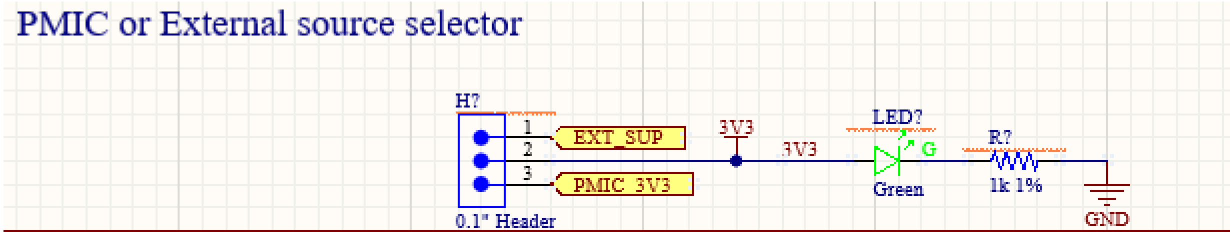


Figure 10 Source Selector Circuit

We plan to use the above circuitry to control the POWER selection when PMIC does not work. Alternatively, an external lab supply can be used in such situations using the source selector.

Past Week Progress

Sr. No.	Task	Planned Date of completion	Actual Date of Completion
1	Component Library Creation + Schematic	10/07/2023	10/07/2023
2	Check Solar panel specifications	10/05/2023	Not Started
3	Bulk cap simulation	10/06/2023	10/08/2023
4	Spice analysis of power supplies	10/06/2023	10/08/2023

Plan for Next Week

Sr. No.	Task	Planned Date of completion
1	Sensor Header Port soldering	10/08/2023
2	Sensor Interfacing and reading registers	10/18/2023
3	Altium Component Placement	10/13/2023

Gantt Chart

Please access the Gantt Chart here.

Progress Status

We are on track as per the schedule.

Support needed for following tasks/decisions

- Though the RM mentions using HFXO for RF applications, from previous coursework experience we have used EFR32BG with LFXO for Bluetooth application involving RF utility. Does it override the oscillator configuration by the user when using RF or there is a catch in this selection?

Update 5: Week 7

Feedback Questions

1. Are you planning on using all the COMs and PTI signals from the debug connector?

➔ Yes, all pins of debug connector are currently interfaced with the microcontroller as we have GPIO pins available after connecting all other components.

2. The linked Gantt chart only has 7 lines of activities. Did you link the wrong chart?

➔ Yes, we attached the link to previous version of Gantt Chart, here is the updated link for updated chart.

Bulk Capacitance requirement for power voltages

As outlined in the analysis of Bulk Capacitance Simulation, we have determined that there is no need for a bulk capacitor, since all the ICs meet their voltage requirements in both dip and spike conditions. Regardless of this analysis, we have added a capacitor footprint next to the battery as a backup option so that any discrepancies or modifications with respect to the design can be taken care of even after boards are back from fabrication.

I/O Ports

PMIC

For the PMIC, we plan to read the VBAT_OK digital signal through the I/O pin on Gecko Board to monitor the battery status (voltage levels) and control the power consumption by Gecko peripherals accordingly. The VBAT_OK signal will be read on gecko board's PORTD (Pin 15).

Debug Connector

The Simplicity Mini debug connector will be used for programming the microcontroller and debugging. It will occupy 7 I/O pins on PORTF (PF0-PF6). These pins have the necessary pin mux configuration available to implement the required functionality.

Sensors

The sensors (MAX30102, LIS3DH, SAM-M8Q) will occupy I/O pins on Gecko for serial communication and interrupt signal implementation. Following is the summary of pins used by the sensors:

1. MAX30102: PORTD [Pins – 10 (SDA), 11 (SCL), 12 (Interrupt)]
2. LIS3DH: PORTA [Pins- 0 (Interrupt 2), 1 (Interrupt 1), 2 (MISO), 3 (MOSI), 4 (CLK), 5 (CS)]
3. SAM-M8Q: PORTC [Pins- 6 (Reset), 7 (Interrupt), 10 (TX), 11 (RX)]

Low Frequency Oscillator

The 32.768 KHz oscillator is used by the Gecko Board for its low power consumption design. It is connected to the Gecko Board using PORT B (Pins 14,15) as no other pin supports low frequency oscillator signal input for EFR32BG13.

ESD Protection

To protect I/O pins from ESD events, the following TVS diode has been interfaced with ICs and mechanical components including USB connector, Energy Harvester output, Source Selection switch and Communication Line Test points.

Digikey Part Number: F4088CT-ND
Description: 12V (Typ) Clamp 7A (8/20µs) Ipp Tvs Diode Surface Mount SOD-882, Datasheet

Figure 11 TVS Diode

This part was selected as it supresses ESD if any down to 5V which can be sustained by all the parts used in the circuit.

Past Week Progress

Sr. No.	Task	Planned Date of completion	Actual Date of Completion
1	Sensor Header Port soldering	10/08/2023	10/08/2023
2	Sensor Interfacing and reading registers	10/18/2023	In Progress
3	Altium Component Placement	10/13/2023	10/14/2023

Plan for Next Week

Sr. No.	Task	Planned Date of completion
1	Altium Component Routing	10/21/2023
2	MAX30102 Interfacing	10/16/2023

Gantt Chart

Please access the Gantt Chart here.

Progress Status

We are on track as per the schedule.

Update 6: Week 8

Feedback Questions

1. Your selection of the SP1003 part is fine, but the SOD882 package is quite small. The Part is about 1mm by 0.6mm and having the pads not exposed on the bottom will force you to use hot air to rework the part. The SOD723 is small as well, but the pins are exposed so you can use a soldering iron and steady hands to rework this part.

➔ We are using SP1003-DTG which has exposed leads, and we plan to reflow the pins using the soldering iron.

Layout Status

The layout review was completed on October 24th 2023, with no major modifications required. We are implementing the minor suggestions/modifications from the SAs mentioned below:

➔ Trace width settings for power signals.
➔ Avoid using 90 degrees of angle on any trace.
➔ Stitching the ground layer for serial communication signals.
➔ Minimizing GND plane discontinuity.
➔ Add more vias for F-antenna.

Overall, we are currently good with layout progress and do not see any hindrances. We required some feedback for efficient GPS routing which was provided by Prof Randy Spalding and we have incorporated his suggestions in our design.

Gantt Chart

Please access the Gantt Chart here.

Progress Status

We are on track as per the schedule.

Update 7:

Verification Plan

Please access the verification plan here.

Gantt Chart

Please access the Gantt Chart here.

Progress Status

We are waiting for the board to be delivered and start assembly and verification next week. We are also working on application/firmware development.

Update 8:

Progress Status

Board Bring-Up, Initial Software Testing and App Development

- All three boards assembled successfully.
- Primary unit testing was done using software demo code and verified that all three boards are completely functional, no hard errors.
- Mobile application: Initial application running where we can see bluetooth device listed, connect, and read characteristic data.

Lessons learnt during the board bring-up:

- The polarities of the components should be double-checked before soldering. We reversed the polarities of the TVS diode.
- Make sure designators are in sync between schematic and final PCB layout.

Next Steps

- Perform thorough hardware verification.
- Integrate firmware for all three sensors and develop final code.
- Add storage capability to mobile application.
- Integrate various API to mobile application. (For ex: Maps)
- Test final integrated code and verify functionality.
- Test mobile application.

Gantt Chart

Please access the Gantt Chart here.

Progress Status

As of now we are on schedule, and everything is going as planned.

Vaishnavi Patekar Devang Boradhara Aneesh Deshpande

Final Report

Project Overview

What problem does the project solve?

Hardware Block Diagram

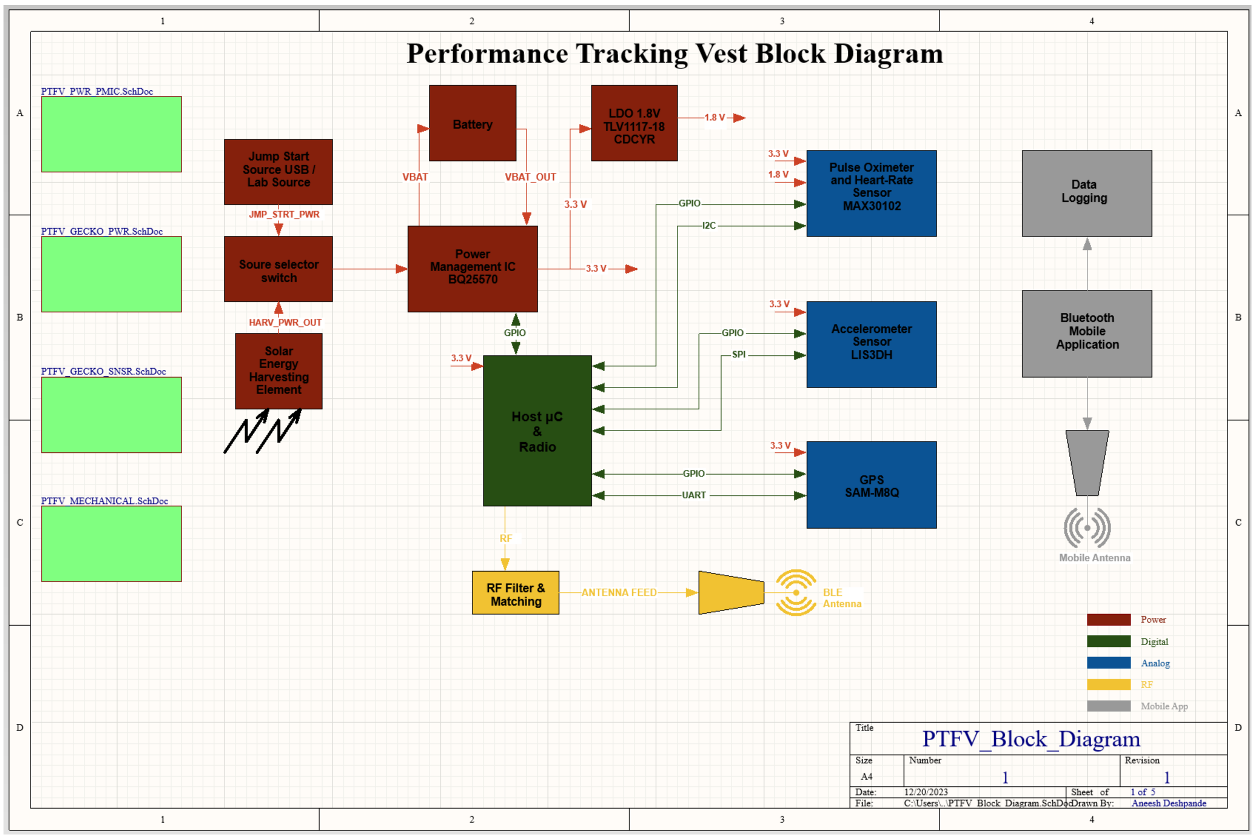


Figure 12: Hardware Block Diagram

Key components

1. EFR32BG13 Microcontroller
2. MAX30102 Hear Rate and SpO_2
3. LIS3DH Accelerometer
4. SAM-M8Q GPS Module
5. BQ255 PMIC

Software Flow Diagram

List of commands

All configurations and mode settings are handled in the code that will be flashed into the SoC. Alternatively, the GPS module can be configured using commands over UART without the onboard SoC if the RX and TX pins are accessible. Below is the list of commands used to configure the SAM-M8Q GPS Module

1. UBX-CFG-GNSS
   {0xB5, 0x62, 0x06, 0x3E, 0x0C, 0x00, 0x00, 0x00, 0x20, 0x01, 0x00, 0x08, 0x10, 0x00, 0x01, 0x00, 0x01, 0x01, 0x8C, 0x92}; GPS with L1C/A minimum 8 channel max 16 channels
2. UBX-CFG-GNSS
   {0xB5, 0x62, 0x06, 0x3E, 0x0C, 0x00, 0x00, 0x00, 0x20, 0x01, 0x00, 0x10, 0x20, 0x00, 0x01, 0x00, 0x01, 0x01, 0xA4, 0x2A}; GPS with L1C/A minimum 16 channel max 32 channels
3. UBX-CFG-NMEA
   {0xB5, 0x62, 0x06, 0x17, 0x14, 0x00, 0x00, 0x23, 0x00, 0x02, 0x00, 0x00, 0x00, 0x00, 0x00, 0x01, 0x01, 0x01, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x00, 0x59, 0x32}; GP NMEA data only

Planned development schedule and when tasks were completed

Gantt Chart

How the target microcontroller/SoC will be programmed?

Current profile over time based on expected application usage

Lowest Possible Current Consumption

Figure 13: Lowest Current Consumption Profile

The above scope shows current profiling when the GPS is set to its lowest mode of operation, i.e. it consumes the least amount of energy. The device consumes approximately 25mA while operating in this mode for a specific amount of time. For the final application code, this mode is not used due to irregular intervals of data reception from the GPS module.

Average Current consumption based on expected application usage

Figure 14: Average Current Consumption Profile

The above scope shows current profiling when the GPS is set to cyclic mode where it refreshes data over 20 second intervals. The device consumes approximately 35mA constantly while operating in this mode. For the final application code, this mode is used to calculate the battery power consumption and estimated life.

Energy Storage Element selected and selection documentation

PMU simulation results

PMIC Input Voltage

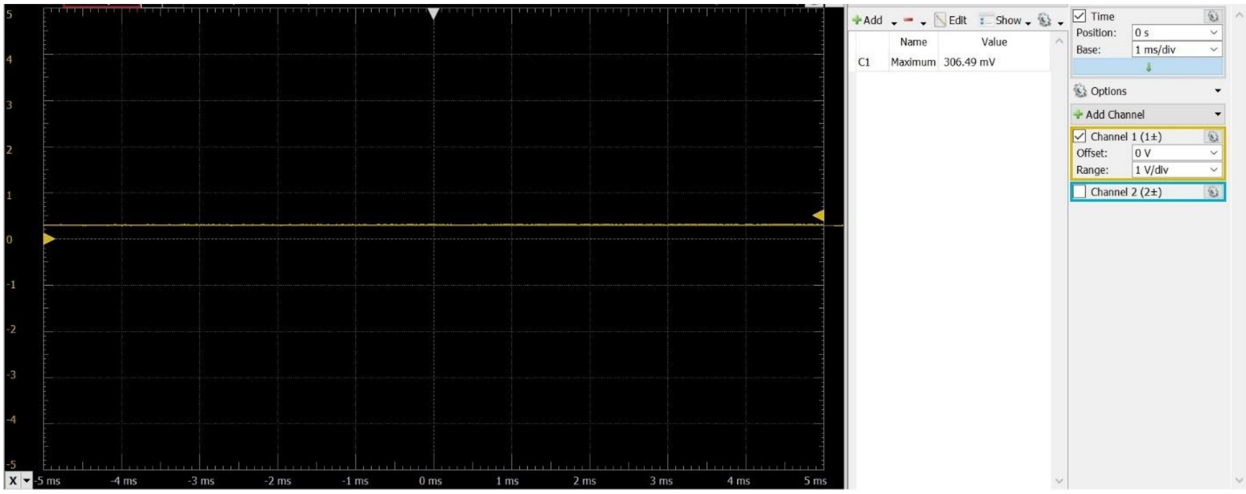


Figure 15: PMIC Input Voltage

The picture above shows minimum input voltage present at PMIC input at any given point which according to datasheet should not fall below -0.3 V.

PMIC Output Voltage

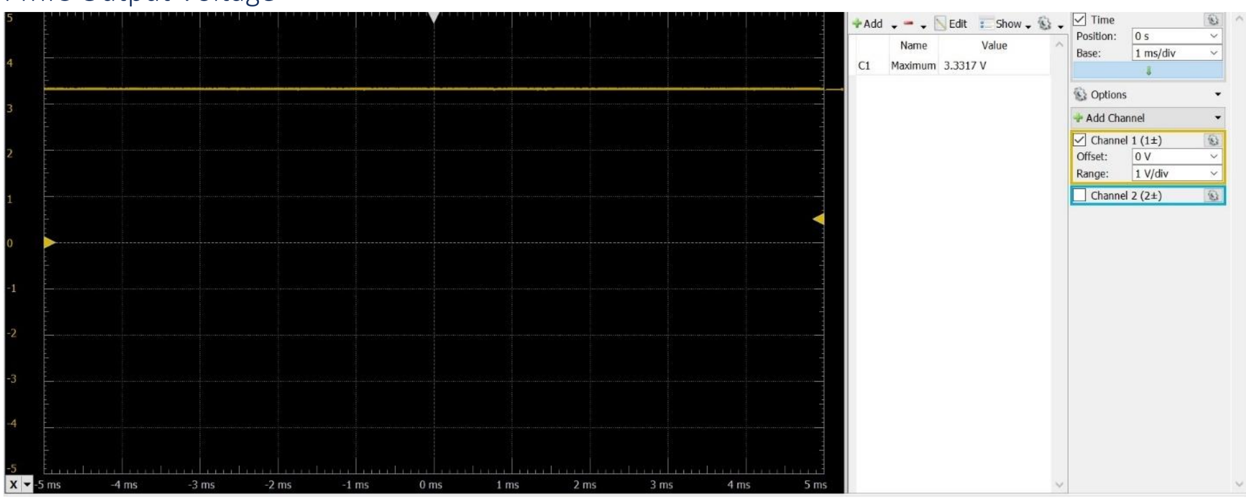


Figure 16: PMIC Output Voltage

PMIC VBATOK Signal

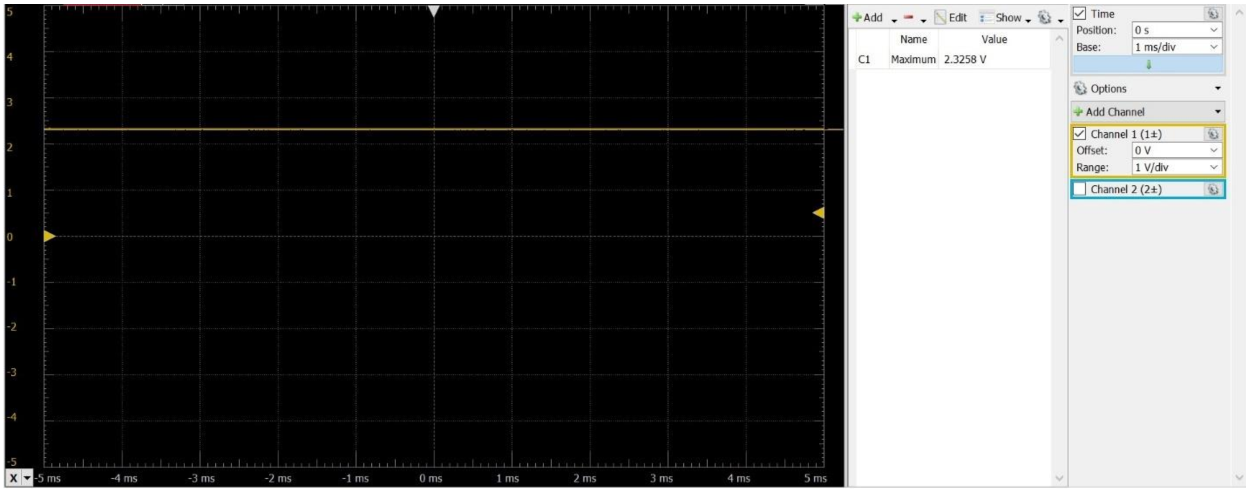


Figure 17: PMIC VBATOK Signal

USB Input Voltage

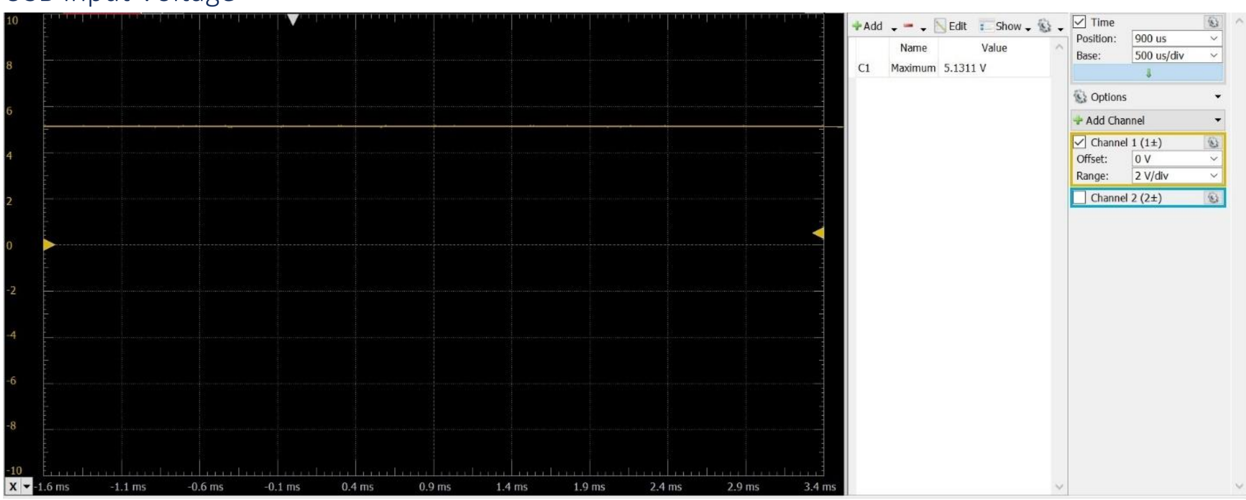


Figure 18: USB Input Voltage

LDO Input Voltage

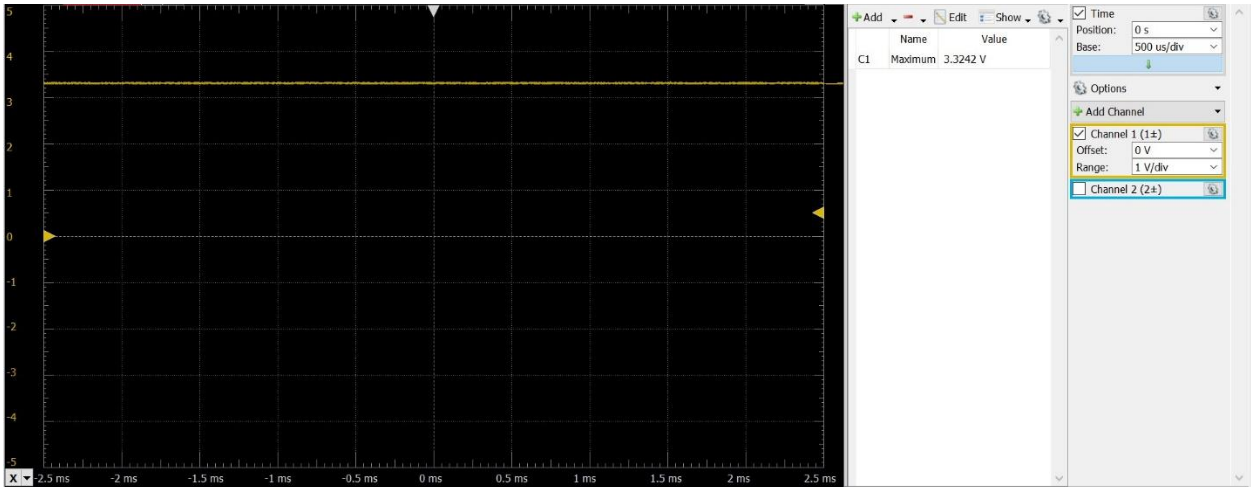


Figure 19: LDO Input Voltage

LDO Output Voltage

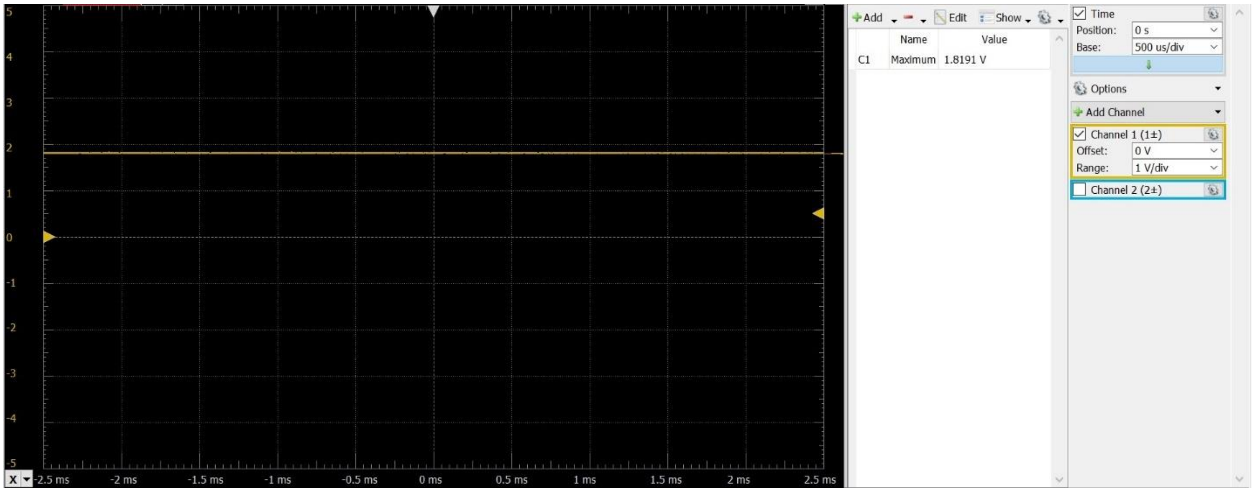


Figure 20: LDO Output Voltage

Bulk or large decoupling capacitor selection and back up data

Based on LTSpice Simulation of the electrical parameters of our system and the selected PMIC, a bulk or large decoupling capacitor was not necessary.

Will an external energy source be required to program the MCU?

If programming the MCU via the Simplicity Mini Connector, no other external energy source is necessary for uploading the code. If the code is flashed using only serial communication pins of mini connector, then the MCU needs power either from Battery or external source.

Planned Test Points

We added following test points in our design:

Signal	Did it work?
3.3 V for peripherals and EFR32BG13	Yes
1.8V for MAX30102	Yes
Current Sense Resistor (Inrush Current)	Yes
I2C SDA	Yes
I2C SCL	Yes
SPI SCK	Yes
SPI MOSI	Yes
SPI MISO	Yes
UART TX	Yes
UART RX	Yes

Should there have been more test points?

We included test points for all aspects controlled by our software, except for the CS line in SPI communication. While we didn't encounter any problems due to the absence of this CS test point, having it on board would have been beneficial especially when there are changes or additions to functionality or hardware utilizing SPI.

Photos of Assembled Board

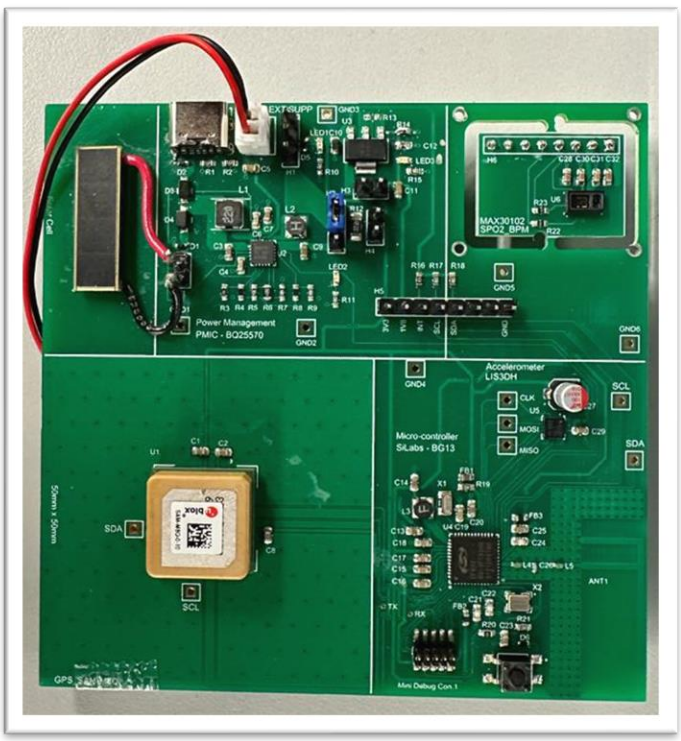


Figure 21: Assembled Board Front View

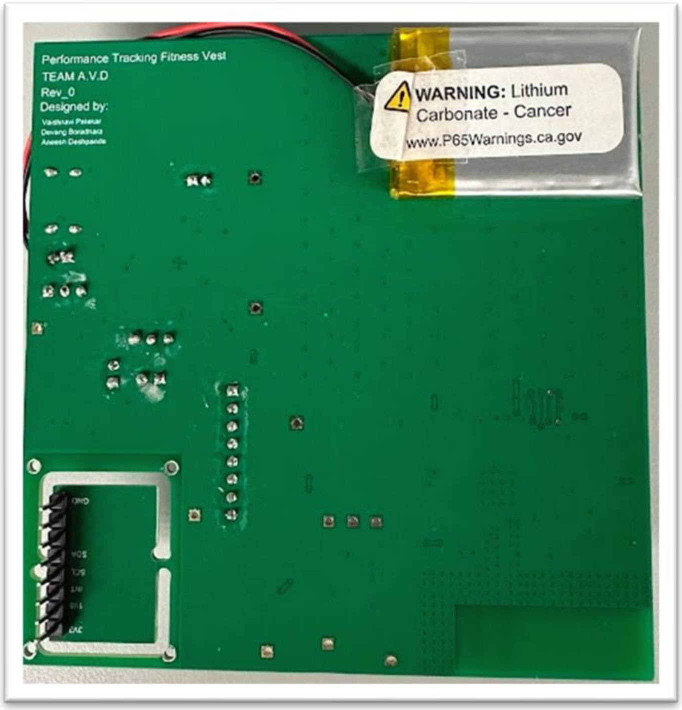


Figure 22: Assembled Board Back View

Complete Detailed Verification Report

[Verification Report]

Signal Quality analysis of Key Signals

Current Sense Resistor (Inrush Current)

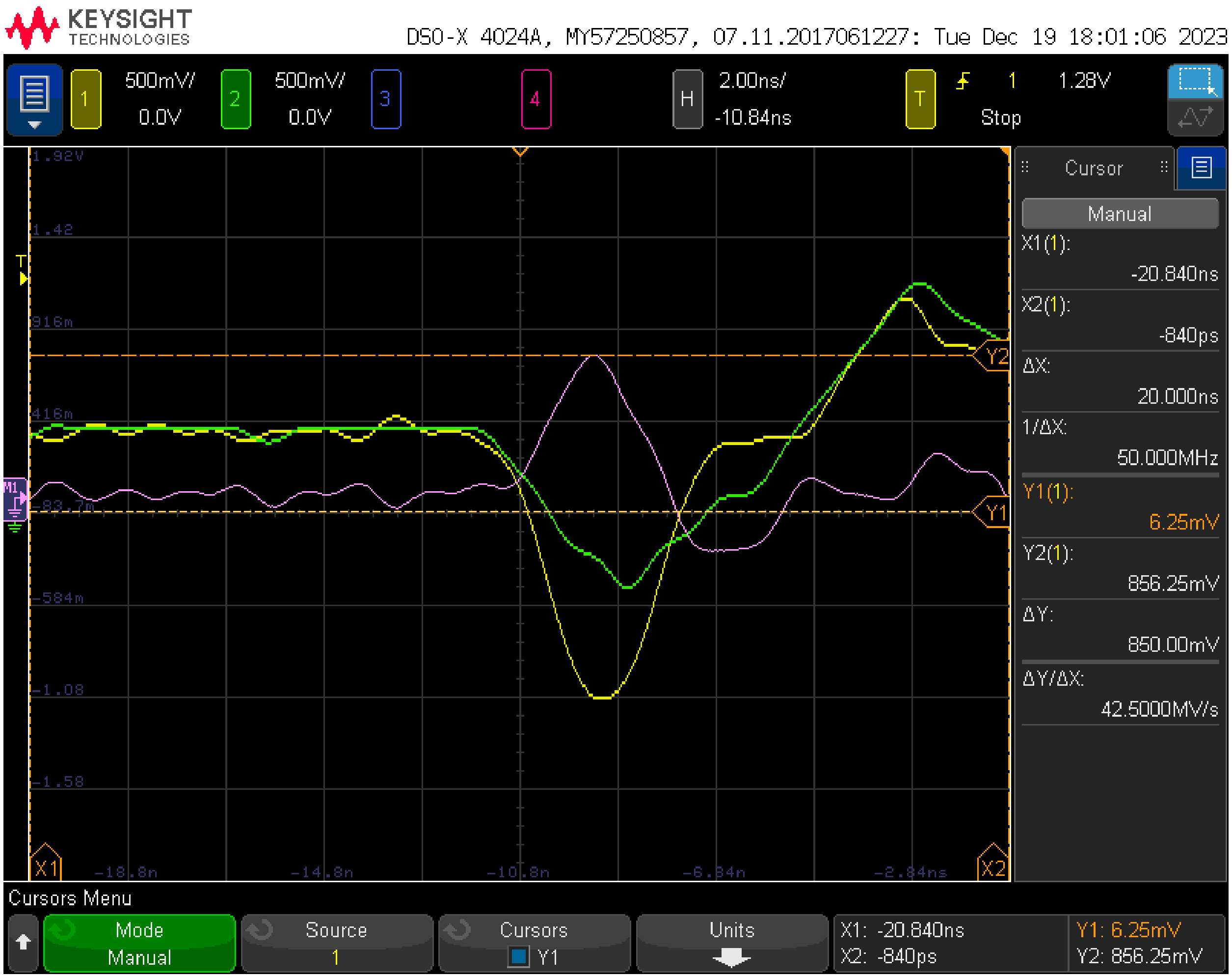


Figure 23:Measuring Inrush Current using Current Sense Resistor

Channel 1 = Voltage at low end of sense resistor (yellow)

Channel 2 = Voltage at high end of sense resistor (green)

V = 850 mv (Voltage at high end of sense resistor - Voltage at low end of sense resistor (channel 4))

R = 500m Ohms

Inrush current = V/R_{sense}

= 1.7 A

I2C Signals (SCL and SDA during Read/Write Cycles)

Writing device address on SDA: 0xAE

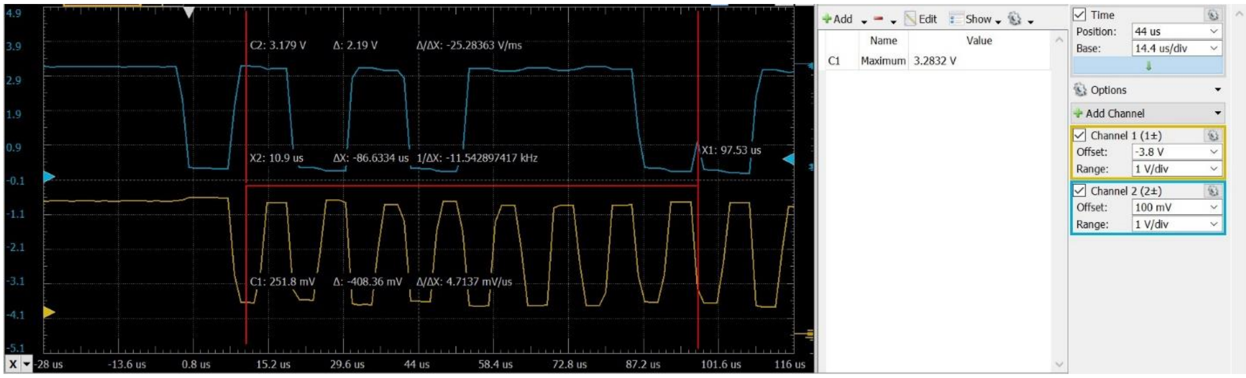


Figure 24: I2C Write Cycle for Address 0xAE

Writing register address on SDA: 0xFF

Figure 25: I2C Write Cycle for Address 0xFF

Reading register value on SDA: 0x15

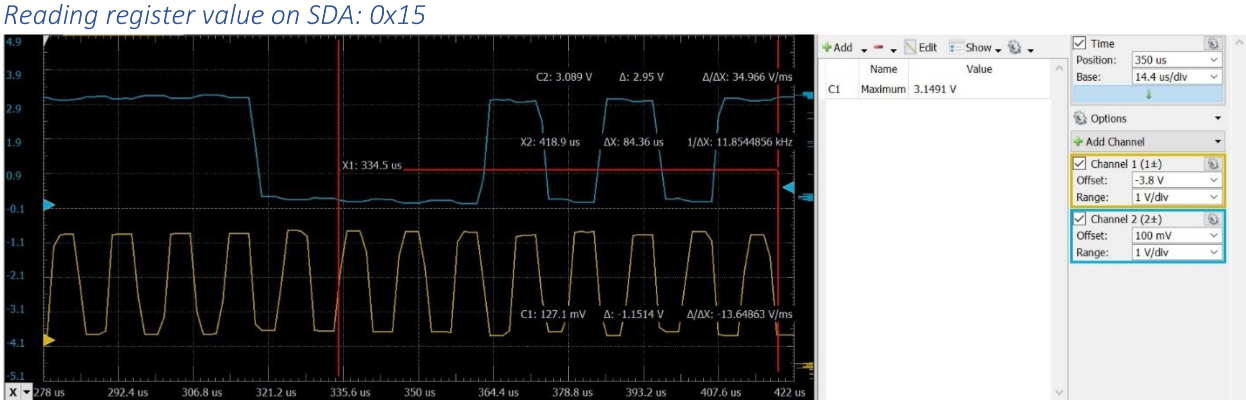


Figure 26: I2C Read Cycle for Value:0x15

SPI Signals (SCK, MOSI, MISO and CS during Read/Write Cycles)

Writing Register Address on MOSI:0x8F and Reading Value on MISO:0x33

Figure 27: SPI Signals (MOSI, MISO, SCK and CS)

UART Signals (TX and RX)

Sending Commands over TX pin

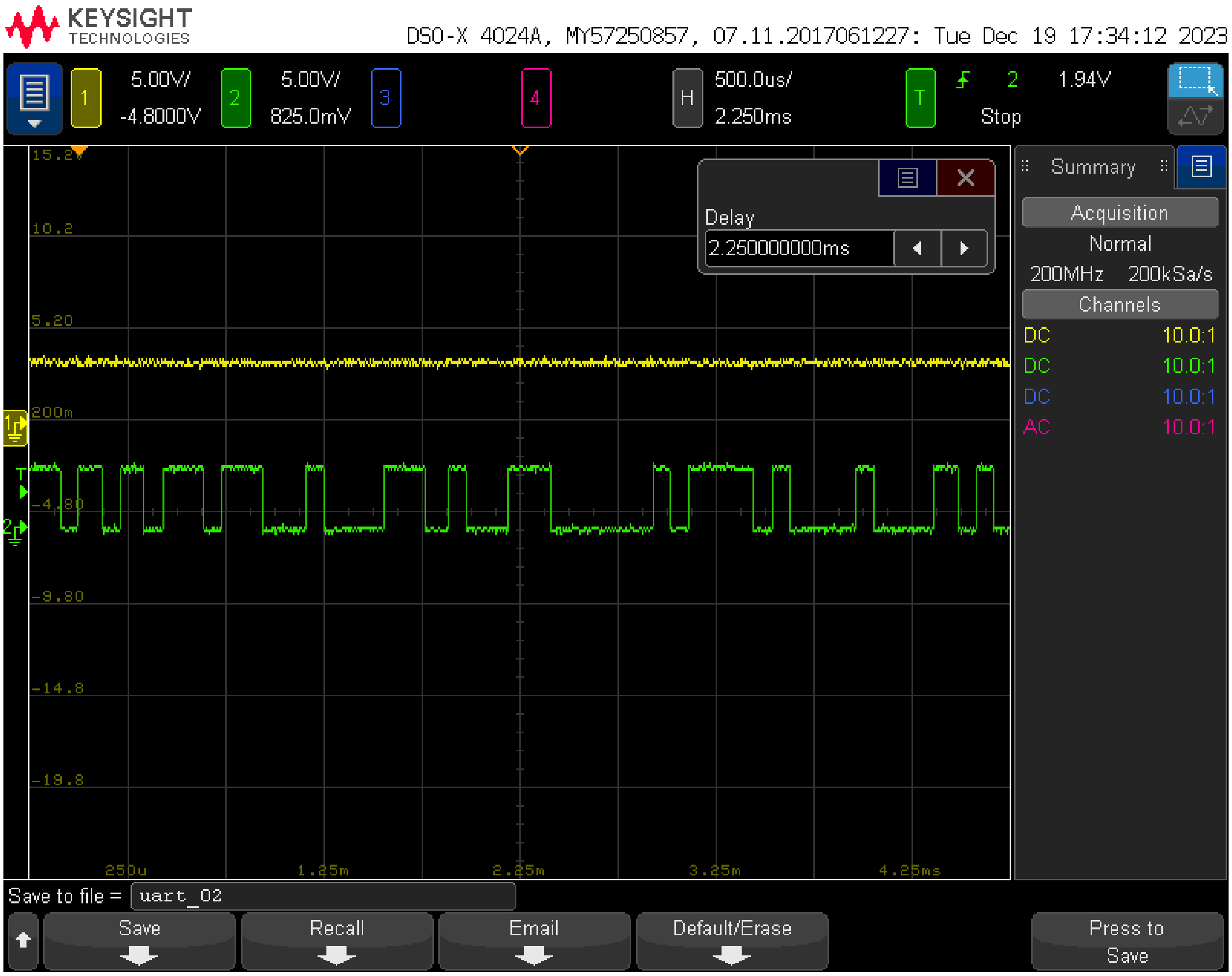


Figure 28: UART TX Signal Transitions

Receiving Data over RX pin

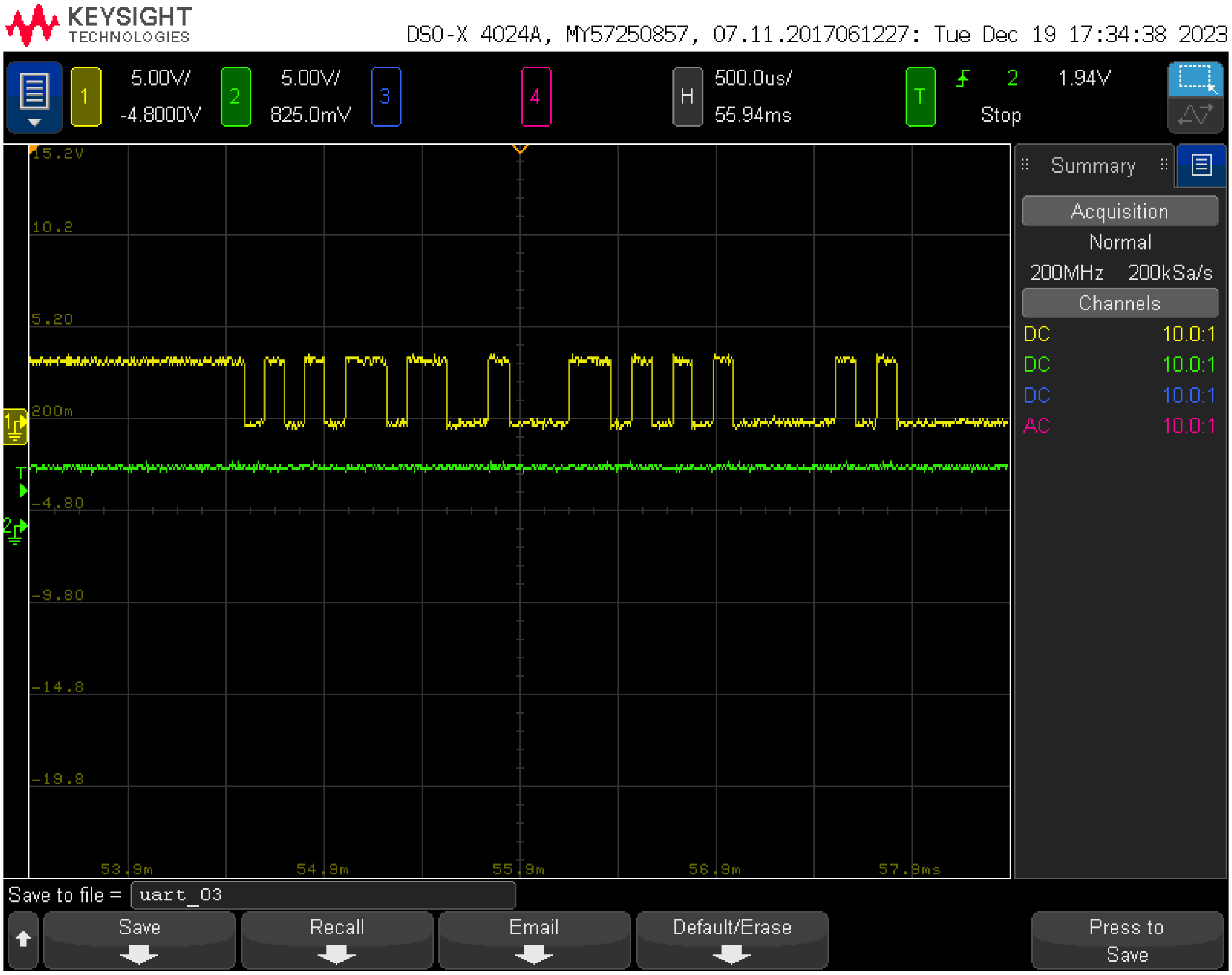


Figure 29: UART RX Signal Transitions

ACK signals from UART peripheral device

Figure 30: RX Line Receiving ACK from Peripheral Device

Reset Signal (EFR32BG13)

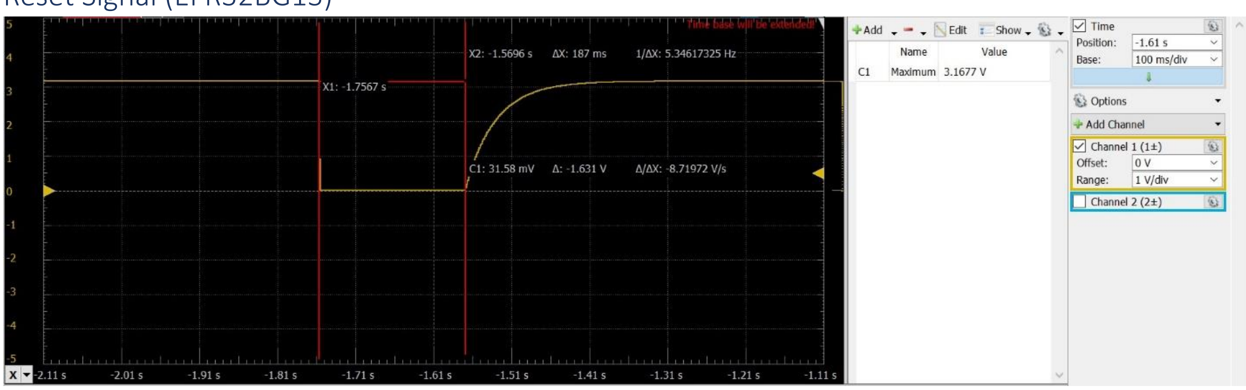


Figure 31: Reset Signal from EFR32BG13

Vdd Signals for Peripheral Devices

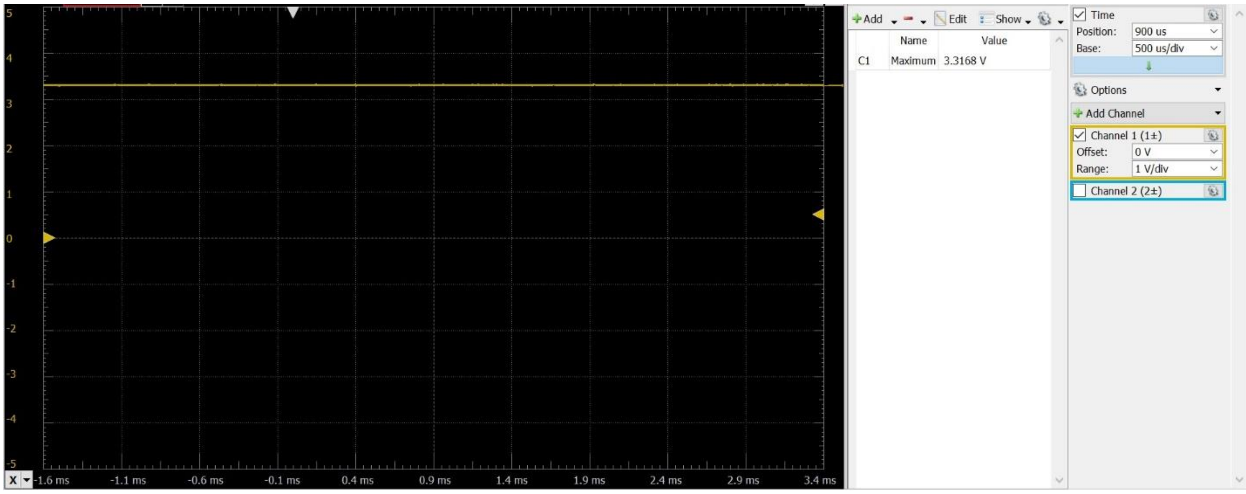


Figure 32: VDD Supply for EFR32BG13

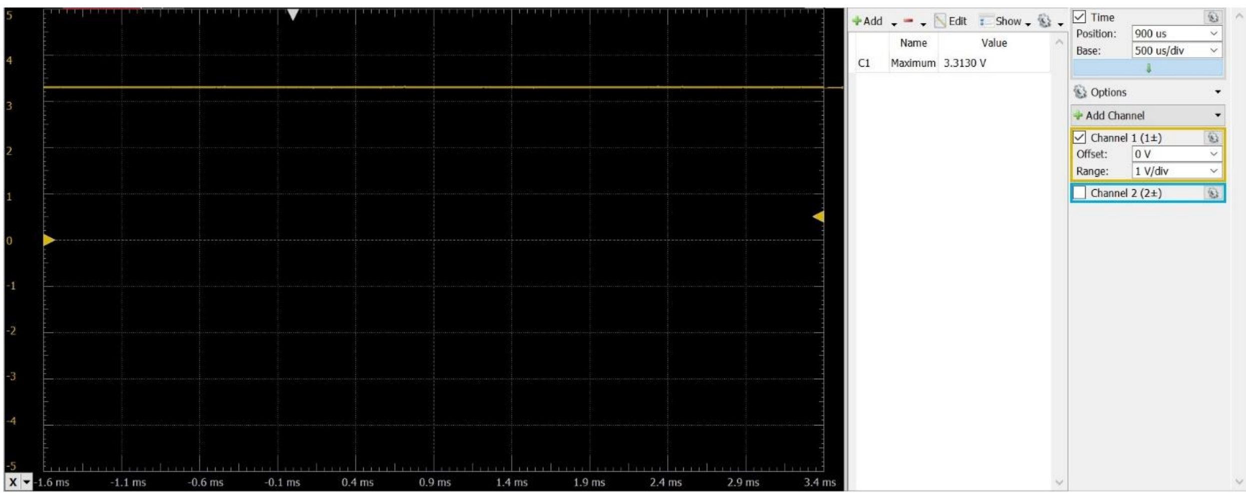


Figure 33: VDD Supply for LIS3DH

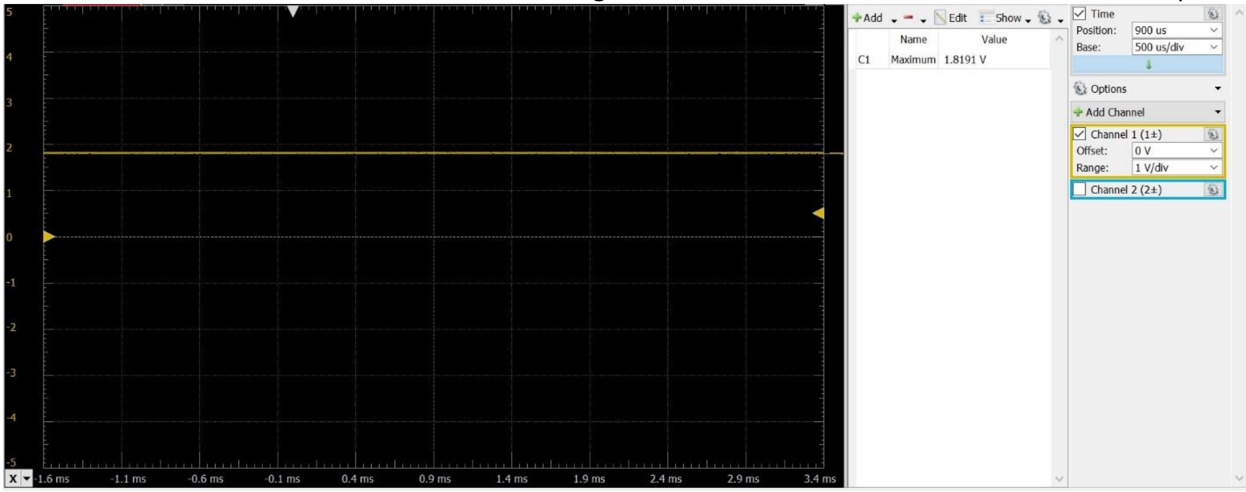


Figure 34: VDD Supply for MAX30102

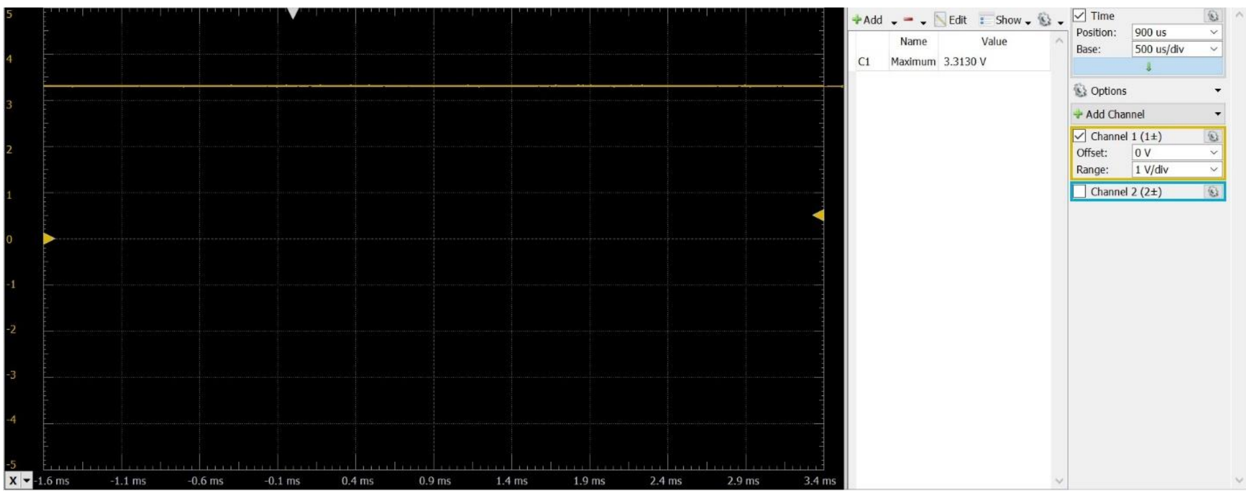


Figure 35: VLED+ (1.8V) for MAX30102

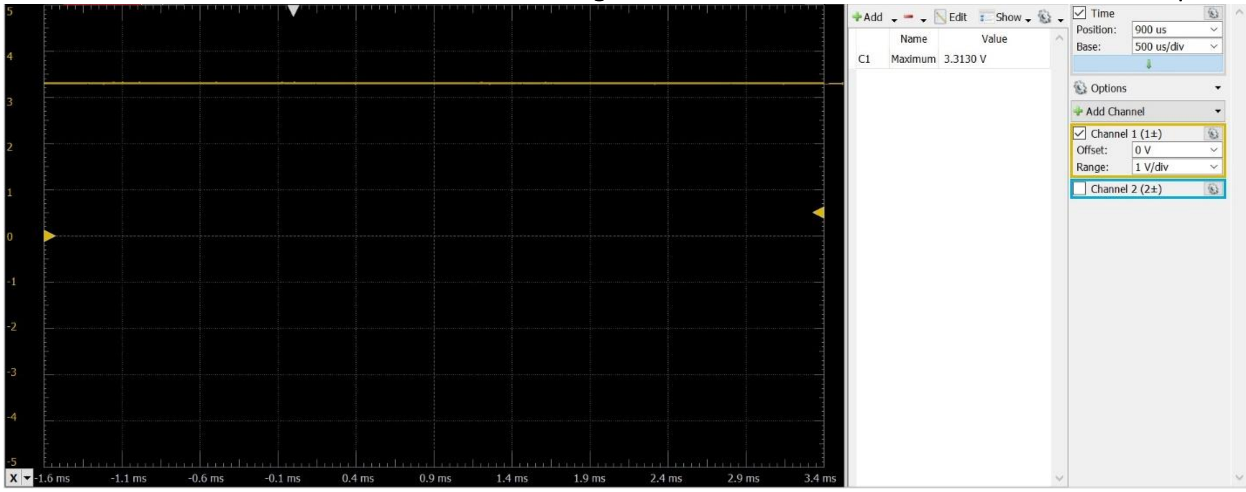


Figure 36: VDD Supply for SAM-M8Q

What were the difficulties encountered on the project?

- Troubleshooting assembly errors to get correct LDO output. We placed diodes with polarities reversed which resulted in our device not functioning. This was fixed later, and we got the output according to our specifications.
- We spent a lot of time to fix the driver issue for one of our sensors using SPI bus. The hardware was working as it should have but we had to tweak software a little bit to get required data.
- Using SAM-M8Q over UART was a very difficult and extenuating task because of irregular SLCP configuration of Silicon Labs IDE to use VCOM to visualise the data coming from SAM-M8Q over UART.
- Even though we were able to establish successful communication between SoC and MAX30102, we faced difficulties in converting raw RED Led and IR Led Data into medically precise heart rate and blood oxygen levels.

Summary of functionality

The project achieved successful integration of raw data acquired from the heart rate and Oximeter sensor (MAX302) with the accelerometer data and the latest GPS information, including coordinates, direction, and time. The system demonstrated its capability to effectively transmit this consolidated data via a Bluetooth application shown below.

Please refer to the demo video linked below for the detailed understanding of the system functionality: PTFV_Demo_Video

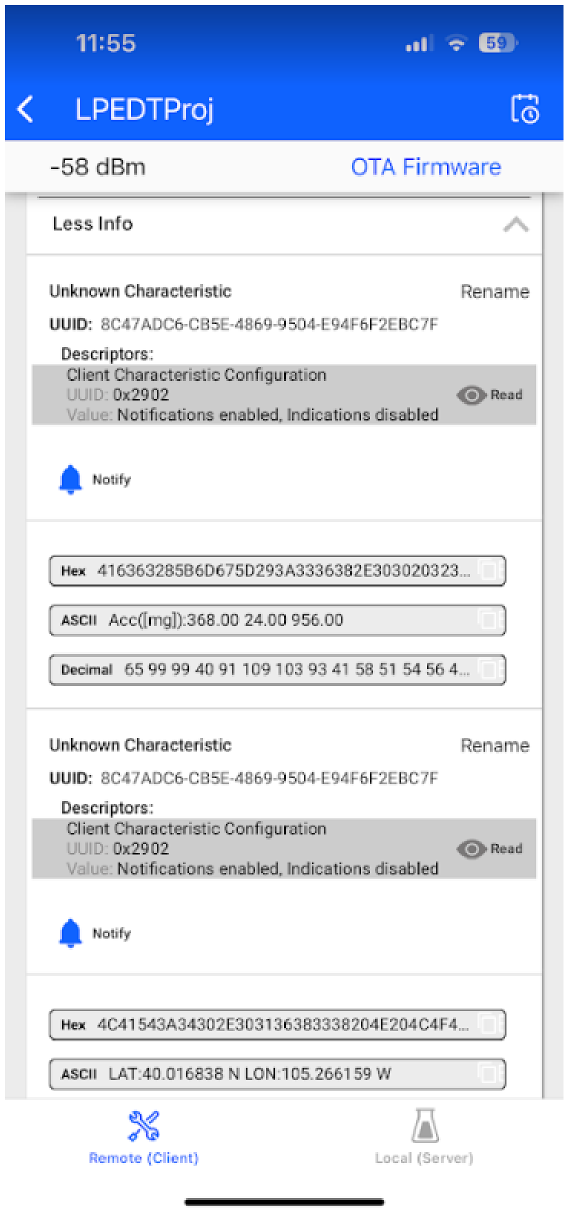


Figure 37: BLE App Screen from Silicon Labs

Lessons Learned

Aneesh

1. Learned implementation of PMICs in a project from scratch including layout, passive value selections and external factors that contribute to change in behavior of power lines of the system.
2. Exposure to UBX communication protocol used in SAM-M8Q helped me learn the intricacies of communication while dealing with GPS devices. We spent a lot of time on this aspect, but it was a great learning curve.
3. To lower our current consumption though software, I spent a great amount of time to explore RTOS on our system and verify the difference. During the project timeline, I learnt a new skill of FreeRTOS which can drastically reduce the current drawn. We did not use it in our final code due to time constraints, but it is added as a future scope.
4. Bluetooth Low Energy Topology. I used lessons from another class to implement the Bluetooth Services and Characteristics for our sensor data and show it on the android app.
5. While exploring ways to reduce current consumption on our board, we spent some time learning about LEUART and LETIMER from EFR32BG13, the peripherals which have low current consumption and work on very low frequencies, proving to be extremely efficient for Low Power Embedded System Design.

Devang

1. **NMEA Protocol for GPS Devices**. Working on this project exposed me to configuration, reading and writing using NMEA sentences used over UART communication. We wrote software to listen for type of NMEA sentences we want and decode each of them to get meaningful data.
2. Learned about fine details of SPI communication and minute difference in implementations in devices based on half duplex and full duplex modes which can affect the software driver development.
3. Implementing software with custom **Scheduler and State Machine Driven approach**. This project gave me the opportunity to practically use the lessons learned in another class, especially Event Driven Software for Embedded Systems to lower power consumption through software.
4. Estimation of power consumption helped me consider a lot of factors which broadened my scope of understanding a system's total power consumption. This involved counting clock cycles used in Serial Communication and having the best possible rough estimate.
5. **Android App Development**. We planned to create a Custom App to show our data, even though we did not accomplish that due to the timeline, working on the initial version of the app which connects to our board and shows data from one characteristic helped me learn the design and development of Android App using **Android Studio** and **MIT App Inventor Tool**.

Vaishnavi

1. Code design strategies such as incorporating **atomic functions** aiming to minimize power consumption ensuring that the software components are designed to operate with minimal power requirements.
2. Acquired a knowledge of **data processing** of the raw ADC values acquired by the MAX30102 to convert into standard heart rate and blood oxygen levels.
3. Gained knowledge in **signal processing methods** to effectively obtain the desired target data.

4. Learned to **design a PT1 filter to minimize hysteresis losses** in sensor values, ensuring more stable and reliable results.
5. Learned to create a **Python script** for reading data from a serial terminal, processing it, and presenting it visually (using matplotlib) in either an application or a web page.
6. Reading datasheets thoroughly at the early stage of the project is more beneficial than doing so during the later phases of development.

References

[1] U-blox-Receiver-Description, https://content.u-blox.com/sites/default/files/products/documents/u-blox8-M8_ReceiverDescrProtSpec_UBX-13003221.pdf (accessed Sep. 16, 2023).

[2] SAM-M8Q Hardware Integration Manual, https://content.u-blox.com/sites/default/files/SAM-M8Q_HardwareIntegrationManual_%28UBX-16018358%29.pdf (accessed Sep. 16, 2023).

[3] SAM-M8Q Power Management Application Note, https://content.u-blox.com/sites/default/files/products/documents/PowerManagement_AppNote_%28UBX-13005162%29.pdf?hash=undefined (accessed Sep. 16, 2023).

[4] Accelerometer LIS3DH Datasheet, https://cdn-learn.adafruit.com/assets/assets/000/085/846/original/lis3dh.pdf?1576396666 (accessed Sep. 16, 2023).

[5] MAX30102 high-sensitivity pulse oximeter an ... - analog devices, https://www.analog.com/media/en/technical-documentation/data-sheets/MAX30102.pdf (accessed Sep. 16, 2023).

[6] EFR32BG1 data sheet: Blue Gecko Bluetooth® low Energy Soc Family, https://www.silabs.com/documents/public/data-sheets/efr32bg1-datasheet.pdf (accessed Sep. 16, 2023).

[7] Recommended configurations and operating profiles for MAX30101/MAX30102 ..., https://www.analog.com/media/en/technical-documentation/user-guides/max3010x-ev-kits-recommended-configurations-and-operating-profiles.pdf (accessed Sep. 16, 2023).

[8] S. Biswas, "How do smartwatches measure calories: Tech," knowledge, https://www.vertexknowledge.com/post/how-do-smartwatches-measure-calories-tech-knowledge#:~:text=Smartwatches%20use%20their%20inbuilt%20accelerometer,calories%20to%20fuel%20their%20contractions (accessed Sep. 16, 2023).

[9] BQ25570. BQ25570 data sheet, product information and support | TI.com. (n.d.). https://www.ti.com/product/BQ25570

[10] Li-polymerbatterytechnologyspecification - Adafruit Industries. (n.d.-a). https://cdn-shop.adafruit.com/product-files/3898/3898_specsheet_LP801735_400mAh_3.7V_20161129.pdf

[11] The major differences between supercapacitors and batteries - Eaton. (n.d.-b). https://www.eaton.com/content/dam/eaton/products/electronic-components/resources/brochure/eaton-supercapacitor-vs-batteries-white-paper-elx1150-en.pdf

[12] AN958: Debugging and Programming Interfaces for Custom Designs | Silicon Labs
https://www.silabs.com/documents/public/application-notes/an958-mcu-stk-wstk-guide.pdf

[13] API library for Oximeter 5 Click driver
https://github.com/MikroElektronika/mikrosdk_click_v2/tree/master/clicks/oximeter5

[14] Documentation for GNSS evaluation and visualization tool
https://content.u-blox.com/sites/default/files/u-center_Userguide_UBX-13005250.pdf

[15] Driver Library for MAX30102
https://github.com/libdriver/max30102/tree/master/project/stm32f407

[16] Research paper on energy expenditure from heart rate monitoring during submaximal exercise
Keytel LR, Goedecke JH, Noakes TD, Hiiloskorpi H, Laukkanen R, van der Merwe L, Lambert EV. Prediction of energy expenditure from heart rate monitoring during submaximal exercise. J Sports Sci. 2005 Mar;23(3):289-97