LOW POWER EMBEDDED DESIGN
FINAL COURSE PROJECT PROPOSAL

Team Name: WearTech

<u>**Team Mates:**</u>

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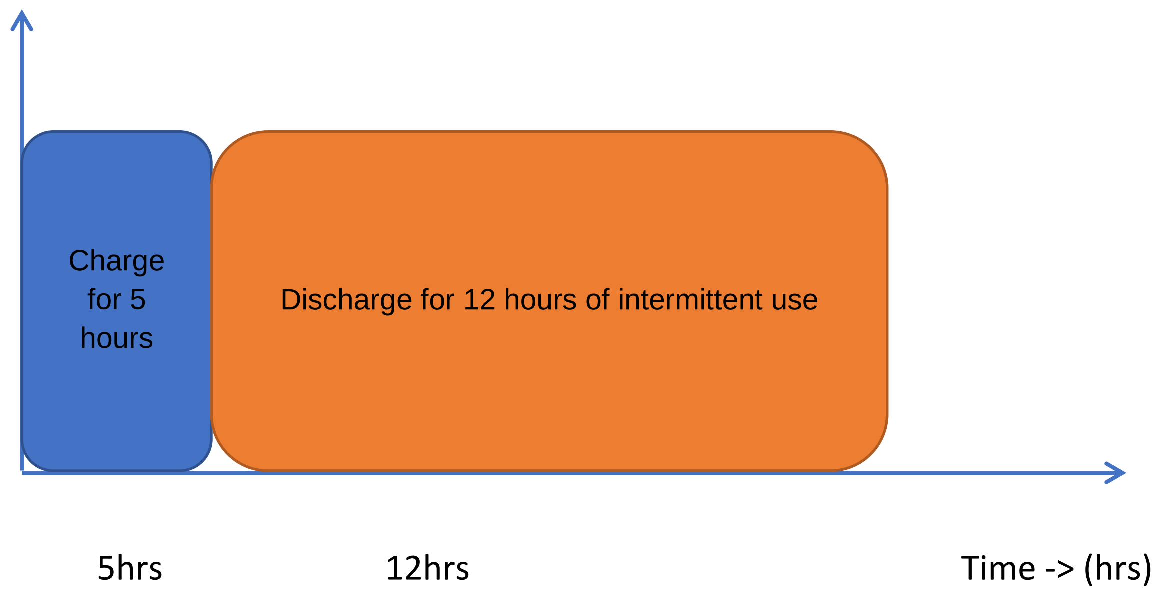
1. **What is the problem that this project is attempting to solve? How is this project going to solve this problem?**

   A wearable ring/cap which is used to take short notes and control other devices through the movements defined in the Mobile App.
   With the advent of technology, it is bane to open your mobile/laptop/book to take a note of something important that strikes you all of a sudden or take a phone number of someone you meet unexpectedly. Say you are in a harsh environment, What if you had a wearable device with you all the time as a look-out for such situations.
   In the Corporate world, say you are in a meeting and you need to take notes, rather than using notes/pens and disturbing others you can easily take notes of all the important points you need. Say in an unanticipated meeting, wouldn't you feel more secure,safe and confident with our device always at help.
   In the field of Software Development & maintenance, one can face a lot of issues/bugs to be fixed within due dates. And with that constantly in mind, Most of us get solutions to the same when we are involved in our day-to-day activities such as driving,eating,talking with a friend, etc. Hence we would end up looking for a pen & paper, if not we would waste time memorising the solution we had just found unless we have this device around which can keep a record of every thought that you want to be saved at any point of time.
   Now with the buzz of IoT we have seen a lot of devices which could communicate with our home appliances. We provide an integrated solution with the new Bluetooth Mesh Network, the Ring/Cap a single device which controls the home appliances and act as a note taker.
   The end-applications to such a device is enormous, it can be used to define the movement of a wheelchair, or used by old people/patients to communicate.

2. Use case described

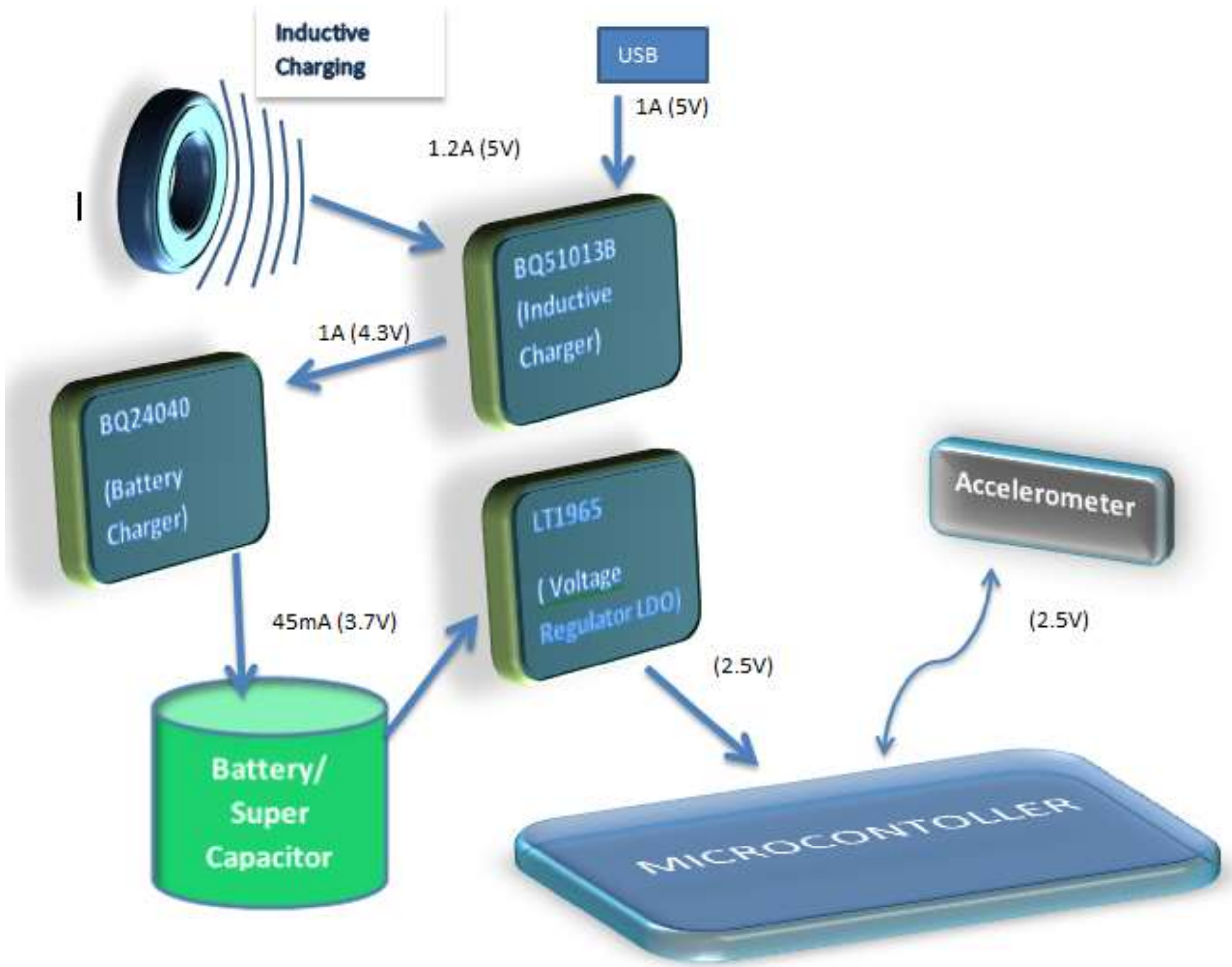
Use Case Model to charge energy storage device:



Stage 1: The battery is of .2C standard charge capacity, thus to charge fully it will take 5 hours

Stage 2: As per our use case, we need the device to be usable for at the most 12hrs.

3. Hardware functional block diagram



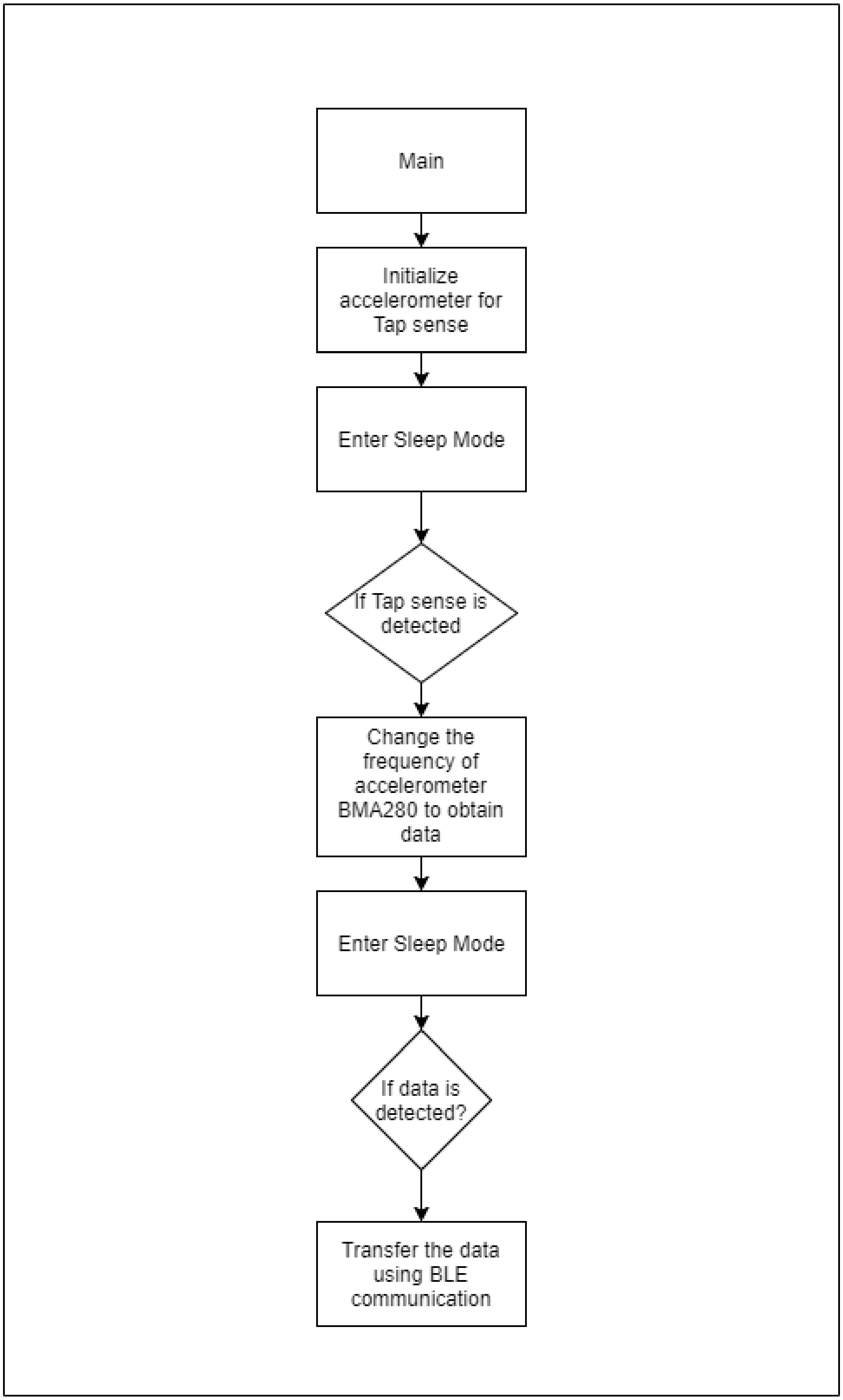
4. List of key hardware components to be used

Part Selection

Battery	**GMB401215-45mAh**
PMU IC	**LT1965**
Processor	**EFR32BG13– f1024**
Inductive Charging IC	**BQ5103B**
Battery Charger IC	**BQ24040**
Sensor	**BMA280**

As discussed, our project requires 2 Blue Gecko dev kits to act as devices in the mesh network.

5. Software functional block diagram



6. **What aspects of the project are considered high risk? How is this risk planned to be mitigated?**

Risk factors:

1. We might end up consuming more current because we are using accelerometer (BMA280) to both turn on the entire device and for data acquisition.
2. Our project involves inductive charging for the battery which is a new concept for us and we are not sure if we will be able to get the appropriate energy requirements from inductive charging as required by our application.
3. The issue with accelerometer data acquisition is that we might not know how much data is enough /less to compute the algorithm on the data and detect the pattern or the command
4. The Machine learning algorithms always need more information about the data to differentiate different patterns accurately. And for such high data handling it needs more high powered CPUs, which would help in computing the algorithms on the data in few milliseconds
5. The main problem is the time it takes to capture the data and send the data to either Phone/Cloud => process the data through FTT/any other algorithms to make sense out of the data and pass it through the pattern detector and predict a most accurate command. - All these have to happen within few miliseconds, if not the product can fail
6. The Bluetooth mesh network is a new technology which needs a lot of time to understand and troubleshoot the issue faced.

Mitigation:

1. We are currently using accelerometer (BMA280) in low power 2 mode with 0.5 ms of sleep duration. So, we can considering reducing the current consumption either by increasing the sleep duration or using the accelerometer in a mode with lesser current than low power 2 mode.
2. We will focus on referring more documents and articles on inductive charging to get the required energy requirements. If we are beyond the

schedule and still not successful with inductive charging, then we will consider switching to an alternative power source such as USB charging.

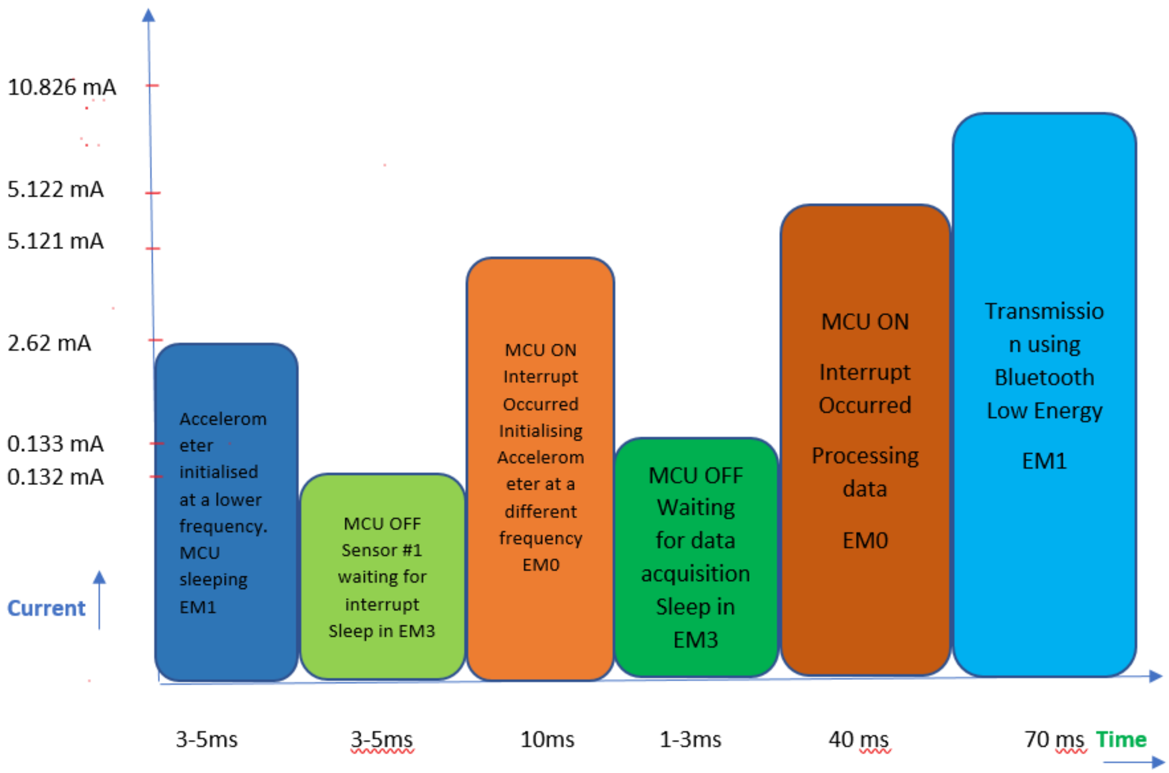
3. To know how much data is enough/ less from the accelerometer, we have found out a simple solution to configure a simple app from the mobile (all mobiles have a accelerometer and a gyroscope).

   We take the values of the mobile-accelerometer through a simple javascript application, populate the data to a csv-file/ populate the data in realtime to the algorithm we are generating. Thus before the firmware development we will have a clear idea on how much data would be required for acquisition.

4. We are trying to get a simpler lightweight Machine learning algorithm - which can run on a smartphone. If we cannot find the exact configuration we need, we will try dumping the data to any cloud platform to do the work for us - say AWS/IBM Watson etc..
5. Since it is considered as a prototype, even with a max delay to recognise the commands, the minimal success would be to achieve a command. Thus if the commands are recognised we can go ahead and start mitigating the delay.
6. We will focus on configuring only 1 or 2 devices with Bluetooth mesh network to make a simple network by referring documentations and receiving guidance from people who have worked on Bluetooth mesh network. If we are unable to achieve Bluetooth mesh network in the required time then we will consider using ZigBee/WiFi.

7. Project Update special topics:

7.1.1 Energy use mode model



Stage 1:

Configuring the Accelerometer for double tap sense (3-5ms)

State 2:

MCU is off, Sensor #1 i.e Accelerometer tap sense is On and it is waiting for an interrupt to switch on the entire device. The device stays in this state for about 3-5 ms after the user has used touch sense to switch on the device. It uses SPI serial port interface which works in EM3 for Blue Gecko and also, we wait for an interrupt in EM3 energy mode.

State 3: MCU becomes on when an interrupt occurs, hence it will be in EM0 mode. In the interrupt service routine (Accelerometer data acquisition) is switched on. This state will take about 10 ms to handle the interrupt and configure the Accelerometer to accept the Data acquisition at higher frequency.

State 4:

In this state, MCU is off while Accelerometer is waiting for an interrupt i.e it is waiting to receive data from the user. As use case considered is when user switches on the device and immediately writes the data, this state will approximately take 1-3 ms.

State 5:

In this state, MCU becomes on when an interrupt occurs i.e when data is received from the user and the data is processed. This state will approximately take 40 ms to handle the interrupt and process the data.

State 6:

In this state, the data is transmitted to the mobile phone using BLE and it is interpreted to display the character received. This will take about 70 ms and operates in EM1 for transmission.

7.1.2 Calculations to specify the Energy Storage Device

- **Average current / energy capacity calculation**

<u>Determining the average weighted power out of battery using Blue Gecko:</u>

On duty cycle:

Assuming that the blue gecko is given a input voltage of ~2.5v and ~1.9v is an output voltage.

Blue Gecko's efficiency at ~2.5v input to ~1.9v out is 2.5v/1.9v = 75.75%

Since it cannot be a 75.75% ,

Weighted average power out of battery = (On duty cycle * On time current * 2.5v) / 75.75% = (0.2 * 10.826mA * 2.5v) / 75.75%

Weighted average power out of battery = 71.70 uW

Off duty cycle:

Blue Gecko efficiency at ~3.3 input to ~2.5v out is 2.5v/3.3v = 75.75%

Weighted average power out of battery = (Off duty cycle * Off time current* 2.5v) / 75.75% = (98.8 * 0.133mA * 2.5v) / 75.75%

Weighted average power out of battery = 433.68 uW

Total average power out = Weighted on duty cycle average power + Weighted off duty cycle average power

= 71.70 uW + 433.68 uW

= 505.38uW

Average energy the battery must provide on the use case:

= 12 hrs of use * 60 mins * 60 secs * 505.38uW

= 21.83J

▪ **Peak currents and Peak current step functions that will need to be considered**

BQ51013B has an inductive charging: the max current from the coil can be 1A
USB : the max current from the USB is 1A

The MAX current the BQ24040 (Battery Charger) & BQ51013B (Inductive charging) can handle is 1.245A

The Energy Harvester input doesn't require any current limiting circuit.

7.1.3 Engineering reasons why the particular Energy Storage Device has been selected

▪ **Number of recharge cycles**

▪ **Provide supporting documentation that the use case number of recharge cycles can be achieved.**

As per our calculation, we need a battery with the following specifications:
Average energy 21.83J
Vout from the Battery is ≈ 3.3v
Max current required 10.826mA (all on - MCU, Sensors, BLE)
If the product is targeted to be used for 1.5years , 5 days a week. We have 390 recharge cycles.
With weighted average power = (0.2% *10.826mA) + (99.8% * 0.133mA) = 15.439mA
15.439mA * 12 (->12 hours) = 1.83mAh
For rechargeable cells the battery nominal capacity should be 10x capacity.
Thus total =>18.3mAh

We need a battery with 18.3mAh and 21.83J
Thus selected: https://www.powerstream.com/lip/GMB401215-45mAh_With%20PCM_A0.pdf

Above calculations substantiates the choice of the Energy source to be Battery and not Super-Capacitor.
Batteries provide consistent voltage (3.7 V) - which is within the voltage range of the components we are using in our application. Since our application does not require any bursts of current and we need our device to discharge the power for a long time - we choose Battery.

7.1.4 Why is the particular MCU / SoC / Radio being proposed?

EFR32BG13 is chosen since it has the supported sdk for Bluetooth Mesh

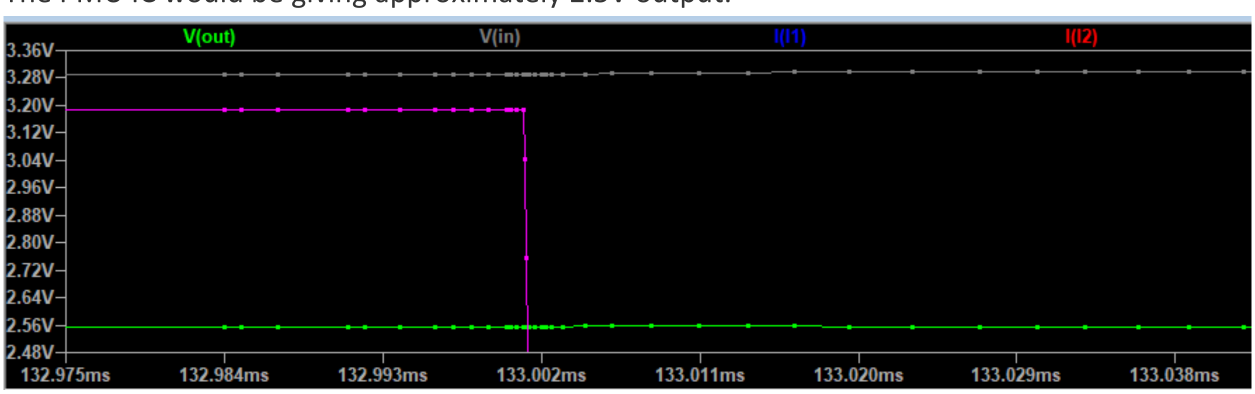
7.1.5 Why is the particular PMU solution being proposed?

We are researching for Inductive Charging, BQ51013B is the best available TI IC for inductive charging which also supports alternative USB charge mechanism.
BQ24040 is required to charge the LiPo battery from the BQ51013B.
LT1965 is chosen to regulate the voltage at 2.5V, which is provided to the MCU.

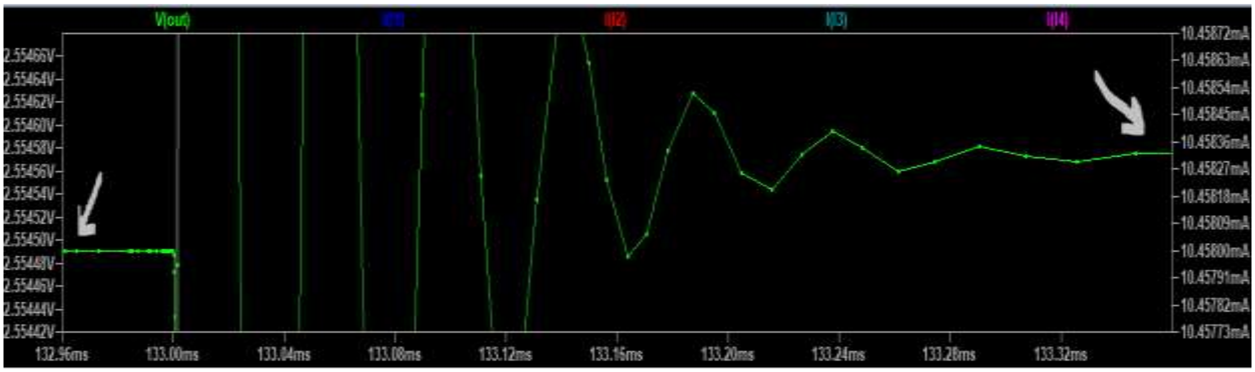
7.1.6 Supporting documentation that voltage droops due to possible current delta functions of this low energy mode device have been engineered not to result in a failure

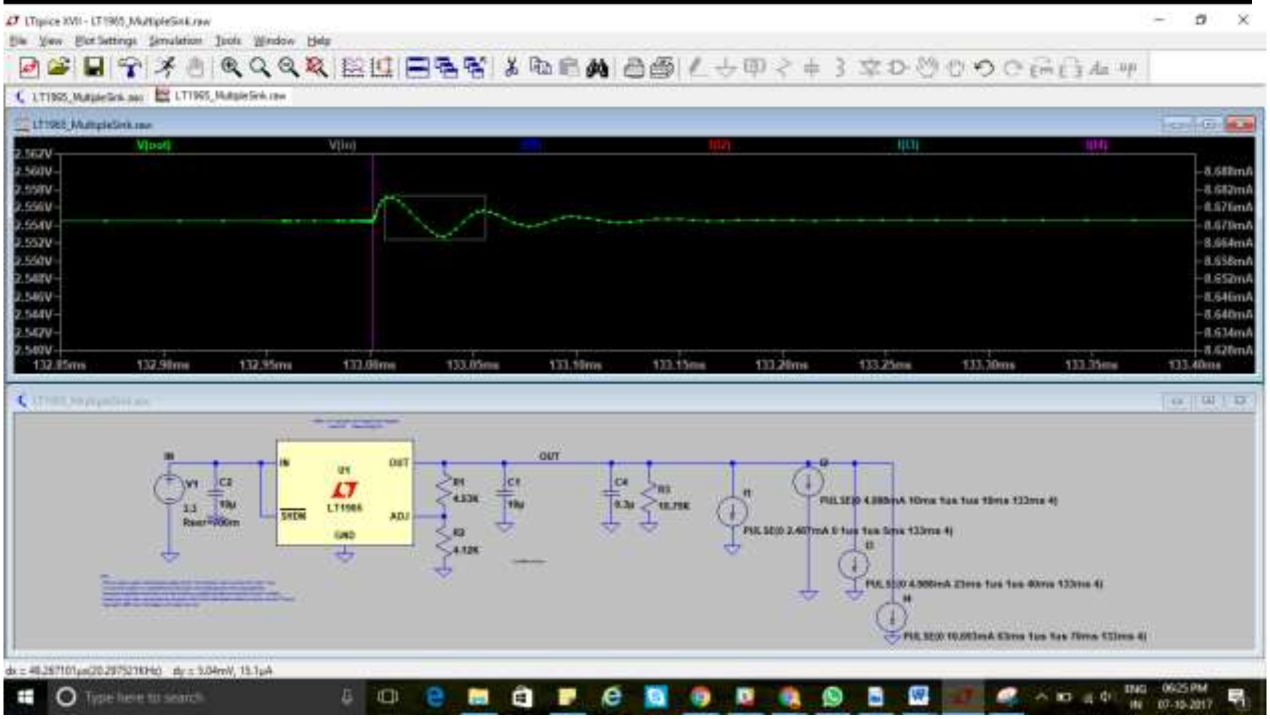
a. At Vin = min

Yes, the voltage was increased of about 0.1mV. The Supply Voltage was about 3.28V to the PMU IC from the battery.
The PMU IC would be giving approximately 2.5V output.



Note: The silver line indicates the stabilized voltage change





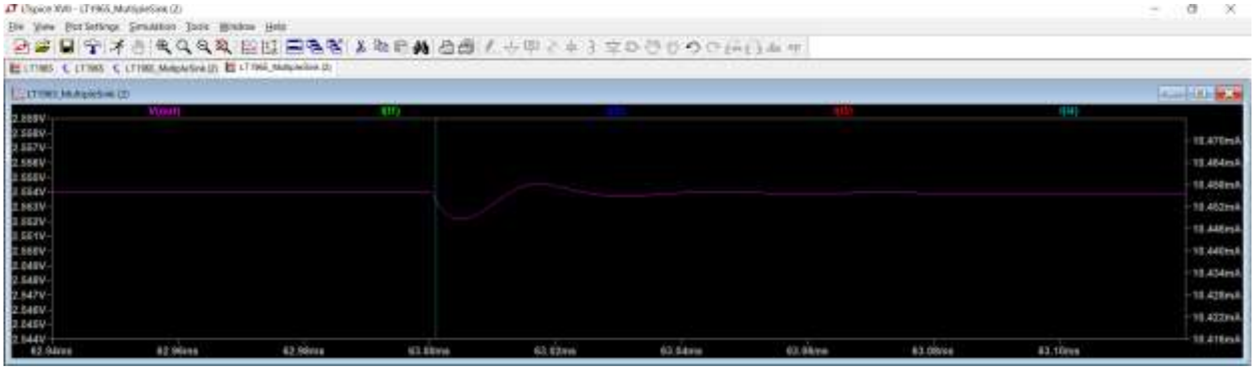
5mV is the ripple which is within the specifications of 0.5Vp-p

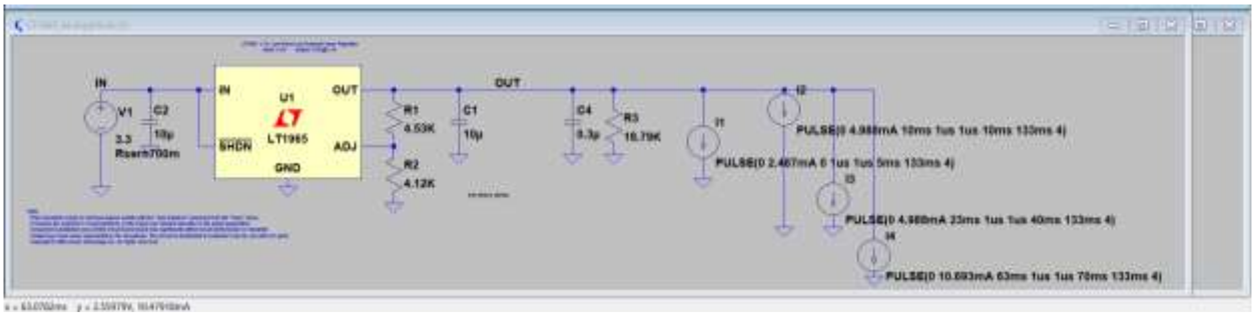
When the dynamic load is added there is a dip in the voltage, the min value is 2.553V, the appropriate voltage supplied by the battery is 3.296V
The Stabilized output voltage of the battery before the dynamic load was 2.5544V
Thus, there is a variation of 2.5544-2.553 = 0.0014V => 1.4mV which is within the specifications.

Dynamic current step up load:

Yes, there was a voltage dip with dynamic step up load.

Below screenshot shows the voltage dip when there is dynamic current step up load i.e when the load switches from EM0- Accelerometer interrupt to EM1-BLE transmission.





Minimum out voltage is 2.552167 V
Therefore, voltage droop = 1.83 mV < 0.5Vp-p
Hence, this is within the IC specifications

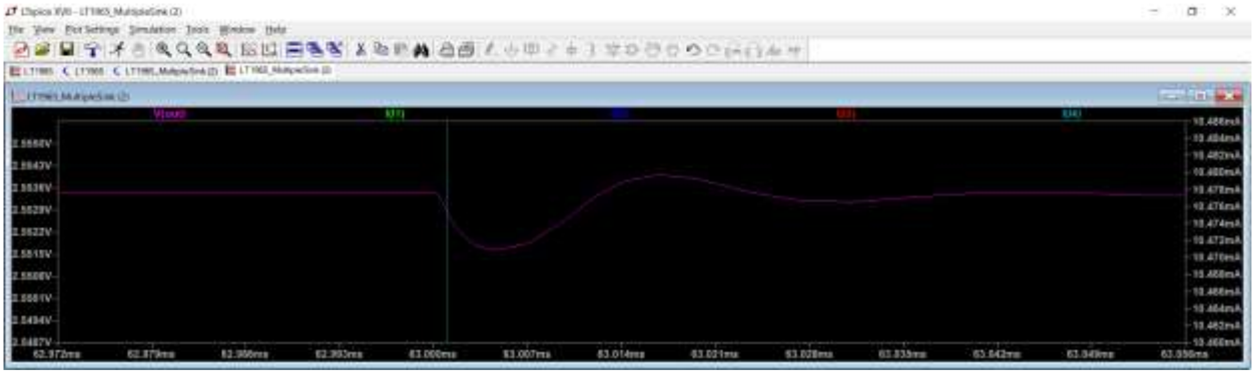
The stabilized voltage in EM0 before dynamic step up load = 2.55399 V
The stabilized voltage in EM1 after dynamic step up load = 2.55394 V

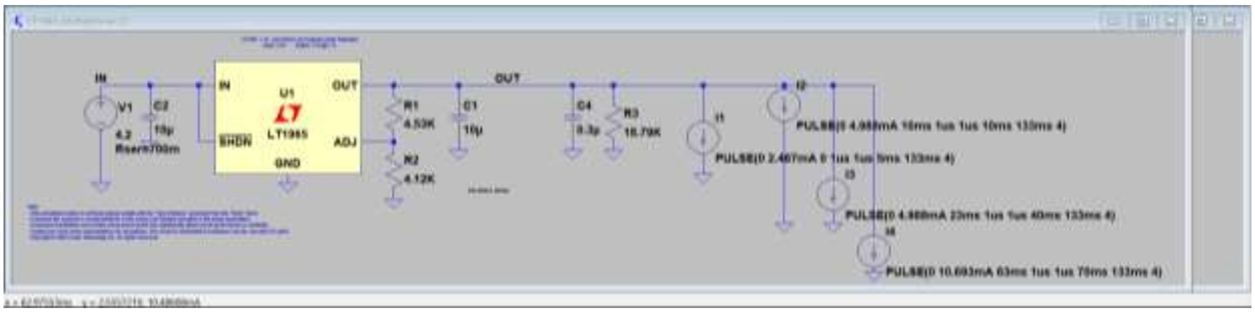
b. At Vin = max i.e Vin = 4.2 V

Dynamic current step up function load:

Yes, there was a voltage dip with dynamic step up load.

Below screenshot shows the voltage dip when there is dynamic current step up load i.ewhen the load switches from EM0- Accelerometer interrupt to EM1-BLE transmission.

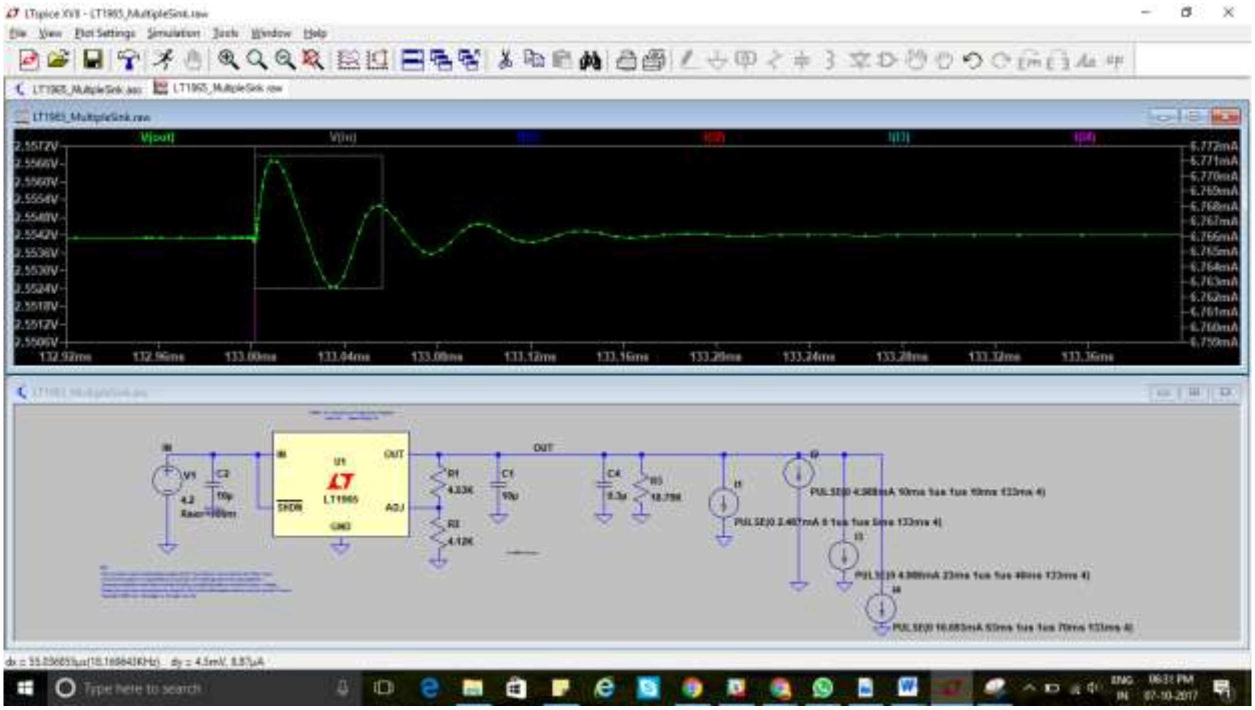




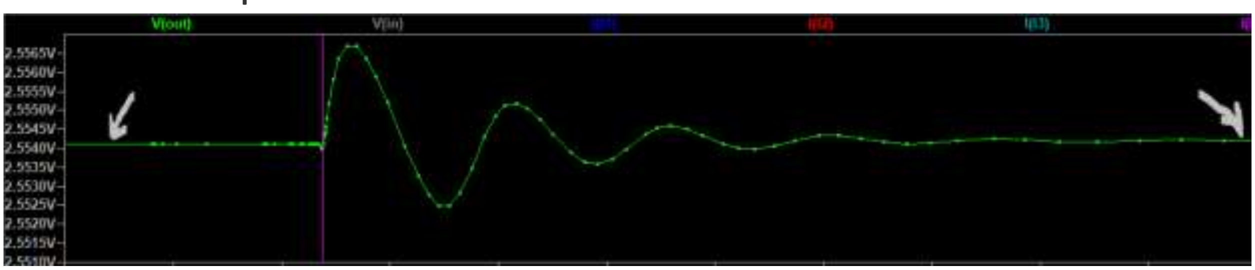
Minimum out voltage is 2.5516 V
Therefore, voltage droop = 1.8 mV < 0.5Vp-p
Hence, this is within the IC specifications

The stabilized voltage in EM0 before dynamic step up load = 2.5534 V
The stabilized voltage in EM1 after dynamic step up load = 2.5533 V

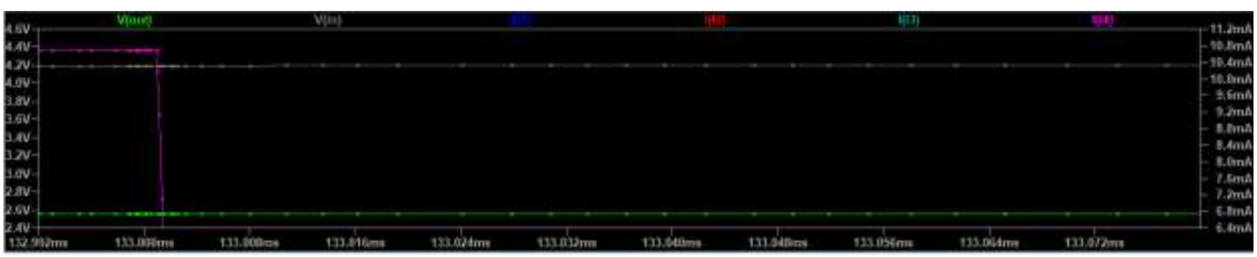
For Step Down Load: Vin: Max : 4.2V

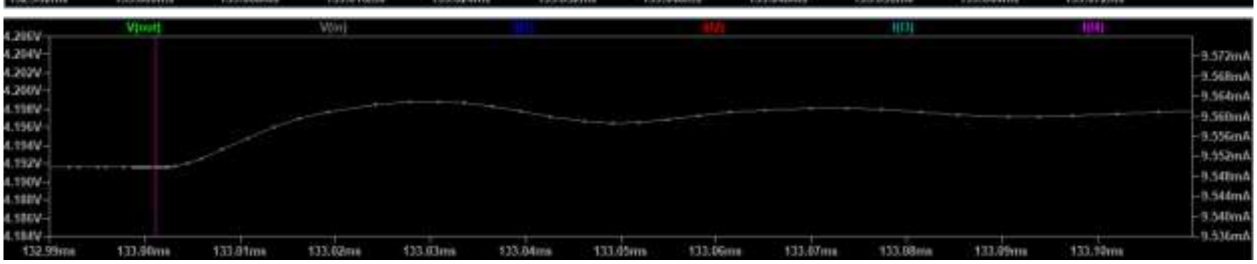


The ripple voltage is about 4.5mV, there is a voltage raise of about 1mV indicated by the arrows for step down function.



Vdd:





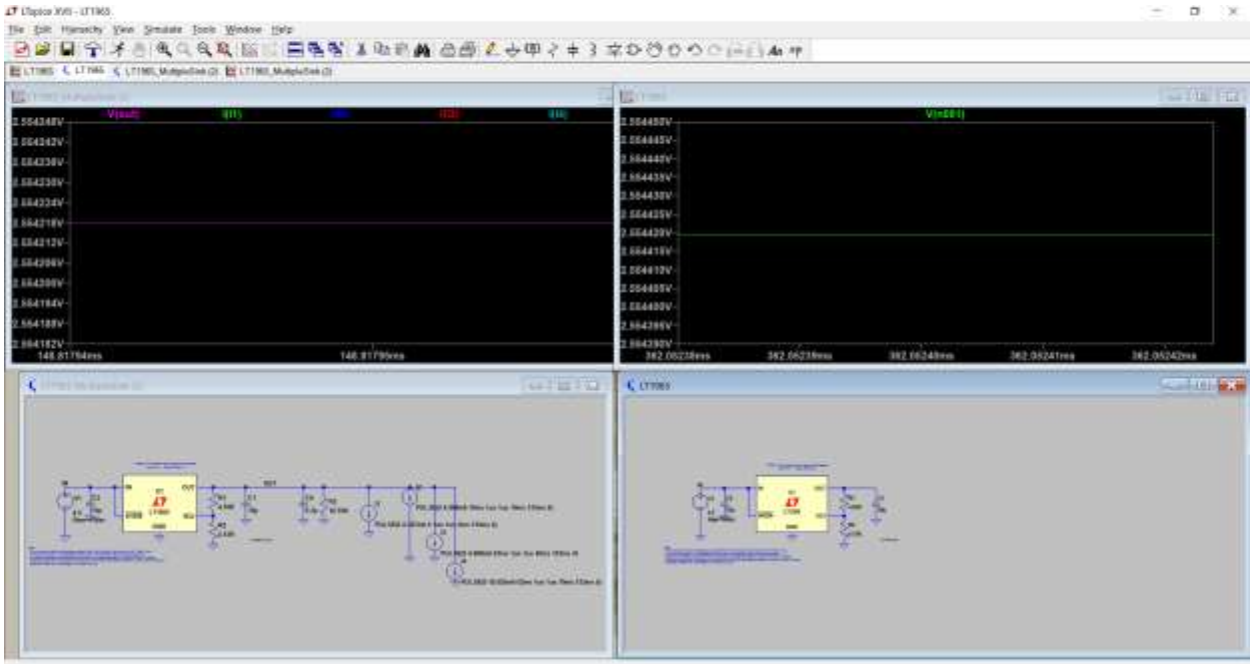
The Vdd was increased to about 5mV to 4.198v

When the dynamic load is added, a voltage dropped to about 2.5522V, the stabilised voltage before the variation was 2.55407V

The difference of about 1.87mV

Which is within the specifications of 0.5Vp-p ripple.

Simulation for with & without Dynamic load:



The circuits as shown above:

Voltage when there is no dynamic load: 2.5542 V (Image on the right)

Voltage when there is dynamic load: 2.5542 V (Image on the left)

Hence there is no change in the voltage when a dynamic load is added to the circuit.

The min voltage when the power supply is drooping is 2.53 V which is within the specifications of the IC.

7.1.7 Proper engineering selection of the required bulk or PMU ceramic load capacitance

The value of Decoupling Cap is calculated as the project's circuit doesn't require any Bulk load capacitance (Thus not taken into consideration)

Decoupling capacitors:

Blue Gecko: According to hardware considerations, we have considered a decoupling capacitor (ceramic capacitor) of value 0.1 uF

Ref:https://www.silabs.com/documents/public/application-notes/an0002.1-efr32-efm32-series-1-hardware-design-considerations.pdf

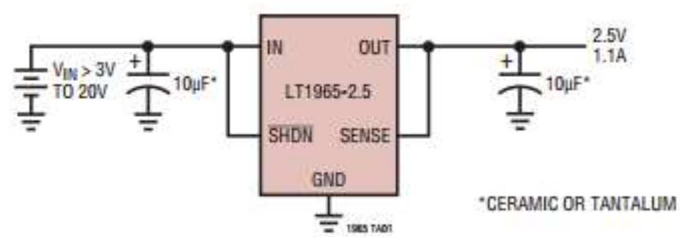
BMA280: We have considered a decoupling two capacitors of 100 nF(0.1 Uf each).
Ref: http://www.mouser.com/ds/2/783/BST-BMA280-DS000-11_published-786496.pdf

Hence total capacitance = 0.3 uF

Thus, the capacitance for the power plane is the same value as the decoupling capacitor of 0.3uF.

According to the Data sheet of LT1965:

3.3V to 2.5V Regulator



OUT (Pins 1, 2 / 1, 2 / 4 / 4): Output. This pin supplies power to the load. Use a minimum output capacitor of 10µF to prevent oscillations. Large load transient applica-

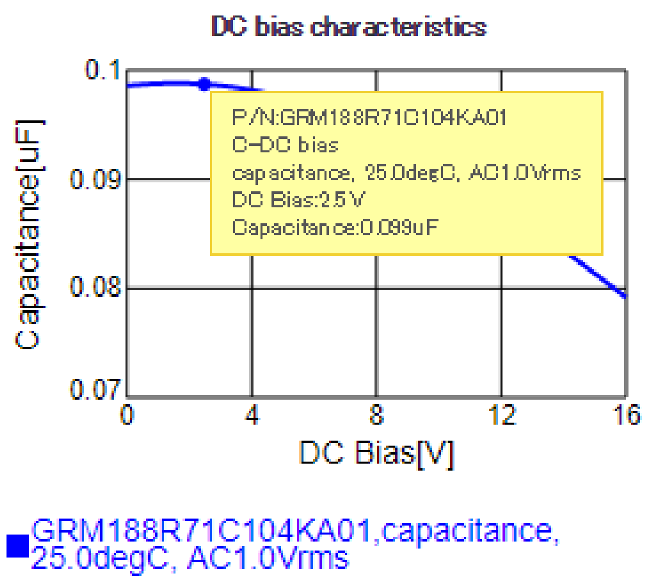
And also ceramic capacitor of type X5R is preferred according to the data sheet of PMU and for the decoupling capacitors for MCU and accelerometer sensor.
Ref: https://www.silabs.com/documents/public/application-notes/an0002.1-efr32-efm32-series-1-hardware-design-considerations.pdf
http://cds.linear.com/docs/en/datasheet/1965fb.pdf

Considering the DC-Bias characteristics, we have selected the below part-number for the load capactior which would suffice with the condition given in the datasheet (min of 10uF for the load capacitor)

We have a decoupling capacitor of 0.3 uF. Considering the DC-Bias characteristics, we have selected the below part-number for the load capactior which would suffice the requirement.

We have a decoupling capacitor of 0.1 uF each at each volatage terminal of BMA280 and PMU.

Selected part number to give a capacitance of 0.1UF at 2.5V which is our working voltage is : http://psearch.en.murata.com/capacitor/product/GRM188R71C104KA01%23.html



Ref: http://cds.linear.com/docs/en/datasheet/1965fb.pdf

7.1.8 ESD protection has been engineered on these user accessible lines to ensure a long-life product

A TVS DIODE 5VWM 12.5VC SC88 is selected for the power lines from the USB, the inductive charging does not need any ESD diodes. Since the BMA 280 is on the board, we do not need any ESD diodes for the communication.

7.1.9 Verification plan

To be verified	Definition of passing	Date test performed	Tested by	Measured result	Passed ?
Supply voltage to the MCU should be within the minimum and maximum specification	The voltage should be within 1.8V to 3.3 V				
Supply voltage to the BMA280 sensor using SPI interface should be within the minimum and maximum specifications	The voltage should be within 1.2V to 3.6 V				
Signal quality of SPI communication line	Check correct signal level transition on the oscilloscope				
Firmware Block of BMA280 using SPI interface: The MCUis receiving correct data from the sensor	The interrupt should get triggered whenever the sensor senses data. The MCU is receiving the correct accelerometer reading from the sensor- verify clock too. Verify Chip Select of SPI goes low while transferring data				
The radio is transmitting data correctly	Verify at the receiver's end the data received				
Supply voltage	The voltage				

from the USB	should be within 4.3 to 5 V				
Supply current from the Inductive coil	50mA to 1A				
The Current out from the Inductive Charger – BQ51013B	1.1 to 1.2A				
The Current input to the BQ24040	1.1 to 1.245 A				
The Voltage at the RECT pin	Must be within 4.3 to 5V				
The voltage at the BAT Pin/VOUT from BQ24040	3.5 to 4.2V				
The current at the BAT Pin/VOUT BQ24040	45mA +/- 10%				
The voltage input to the LDO LT1965	1.8 to 20 V				
The voltage output from the LDO to MCU	2.5V exact				

References

1. https://datascience.stackexchange.com/questions/8732/algorithm-for-gesture-classification-in-a-wearable
2. https://powerbyproxi.com/wireless-charging/
3. https://www.youtube.com/watch?v=mRAWrXePAw0
4. https://www.technologyreview.com/s/601461/wireless-charging-is-actually-charging-ahead/
5. Bluetooth Mesh Networking/ An Introduction to Developers by Martin Woolley
6. **http://www.lipolbattery.com/lithium%20polymer%20battery.html**
7. **https://milliamps-watts.appspot.com/**