LOW POWER EMBEDDED DESIGN
PROJECT UPDATE #3

Team Name : WearTech

Team Mates:

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Part Selection:

Battery : LIPO 785060, 2500 mAH
PMU IC : LT3008EDC
Processor : Blue gecko BGM121 module
As discussed, our project requires 2 Blue Gecko dev kits to act as devices in the mesh network.
Sensor : BMA280

Table 1: Energy modes vs Current Consumption of Blue Gecko:

Energy modes	Current Consumption	Frequency (MHz)	Total Current
EM0	130 uA/MHz	38.4	4.992mA
EM1	65 uA/MHz	38.4	2.496mA
EM2	3.3 uA	-	3.3uA
EM3	2.8 uA	-	2.8uA
EM4	1.1 uA	-	1.1uA

Table 2: Voltage and Current of all components:

Device	On Duty Cycle Current	Off Duty Cycle Current	Supply Voltage
Blue Gecko (MCU)	EM0: 130 uA /MHz	EM3: 2.8 uA	1.85 - 3.8 V
Accelerometer	130uA at 2kHz sample rate	129.73uA at 15.63Hz	1.62- 3.6 V Typical: 2.4
BLE Radio Communication	8.2 mA(0 db)	-	-

Calculations:

Accelerometer: Since we need the double tap/single tap to be sensed at lesser frequency in low power as compared to the data acquisition in higher frequency, We have assumed the Accelerometer to work at Low Power 2 mode while sensing double/single tap.

Specifications from BMA280 datasheet:
I_{DD} = 130uA
I_{DDSBM}= 62uA (suspend mode)

$$I_{DDlp2} \approx \frac{t_{sleep} \cdot I_{DDsbm} + t_{active} \cdot I_{DD}}{t_{sleep} + t_{active}}$$

$t_{active} = 4\ t_{ut} + t_{w,up1} - 0.9\ ms$ (or $t_{active} = 4\ t_{ut} + t_{w,up2} - 0.9\ ms$) (For <31.25Hz)

t_{ut} = 32ms
$t_{w,up2}$ = 1.2ms
t_{active} = (4*(32) + 1.2-0.9) = 125.9ms
I_{DDLp2} = ((0.5*62) + (125.9* 130))/(0.5+125.9) => 129.73uA
Normal Mode Current for 2kHz sample rate for unfiltered data is 130uA.

Duty cycle:

The worst case time-deduced from the Use Case model- to process a character is 300 ms. Considering an idle user , say a maximum of 50 commands and 200 characters per day is expected.

Total On time of the device = On time for commands(character) + On time for text(string)
= 300ms * 50 + 300 ms * 200
= (15/(60*60)) + (60/ 60 * 60)
= 0.0042 hrs + 0.02 hrs
= 0.0242 hrs

The device should be usable for 12 hrs in a day.
On duty cycle = 0.0242 /12 => 0.2 %

Hence, Off time of the device = 12 - 0.0242
= 11. 9758 hrs
Off duty cycle = 11. 9758/12 => 99.8 %

Determining the average weighted power out of battery using Blue Gecko:

On duty cycle:
Assuming that the blue gecko is given a input voltage of ~3.3v and ~2.5v is an output voltage.
Blue Gecko's efficiency at ~3.3v input to ~2.5v out is 2.5v/3.3v = 75.75%
Weighted average power out of battery = (On duty cycle * On time current * 2.5v) / 75.75%
= (0.2 * 13.322mA * 2.5v) / 75.75%
Weighted average power out of battery = 87.96 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
= 87.96 uW + 433.68 uW
= 521.64uW

Average energy the battery must provide on the use case:
= 12 hrs of use * 60 mins * 60 secs * 521.64uW
= **22.53J =>** 6259.68 uWh
=> 6.259 mWh

Battery:

As per our calculation, we need a battery with the following specifications:

- Average energy 22.53J
- Vout from the Battery is ≈ 3.3v
- Max current required 13.322mA (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% *13.322mA) + (99.8% * 0.133mA) = 15.938mA
15.938mA * 12 (->12 hours) = 191.26mAh

For rechargeable cells the battery nominal capacity should be 10x capacity
Thus total =>1912.6mAh (with 2.5v output) => 4.9025Wh=>

According to the above specifications we have chosen: (LIPO 785060)Lithium Ion Polymer Battery with 2500mAh & 3.7V output voltage
The discharge voltage is at 2.75v thus making a total of 6.875Wh which is within our needs for the battery.

Verify C-Rate:

With 1C Capacity the battery discharges at 54mins with 2.5A as the current
2.75*(54/60)*2.5 = 6.1875J => 1.719Wh

For the total Wh we use in a day of (12 hourse use) => 4.9025Wh; meaning that we can use the device for almost 2 days without recharging, thus in 1.5 years of the use of the product the user can recharge the device 273 times in 1.5 years. The recharge cycles of the battery is 400, which comes within the limits of the
For a total ontime and offtime for

Above calculations (LIPO 785060) substantiates the choice of the Energy source to be Battery and not Super-Capacitor.
Batteries provide consistent voltage (3.3 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.

Item		Test Methods	Performance
4.1	0.2C Capacity	After standard charging, laying the battery 0.5h, discharging at 0.2C_5A to voltage 2.75V, recording discharging time.	then the ≥300min
4.2	1C Capacity	After standard charging, laying the battery 0.5h, discharging at 1C_5A to voltage 2.75V, recording the discharging time.	then ≥54min
4.3	Cycle Life	Constant current 0.5C_5A charge to 4.2V, then constant voltage charge to current declines to 0.05C stay 5min constant current 0.5C_5A discharge to 2.75V, stay 5min. Repeat above steps till continuously discharging time less than 36min.	≥400times
4.4	Capability of keeping electricity	20±5℃, After standard charging, laying the battery 28days, discharging at 0.2C_5A to voltage2.75V, recording discharging time.	the ≥240min

With the above info;
What is the C rate of the specified battery?
->0.5C discharge but with 1C discharge is the max, thus considering 1C
What is the peak discharge rate out of the battery?
->$1C_5$
Based on your lithium battery discharge curve, what is the lowest nominal voltage?
->With 1C, the discharge voltage is 2.75V
What will be the battery cut off voltage of your circuit?
-> The circuit needs at a min of 1.85 to max of 3.6V- Considering the Min-Max voltage and Max-Min Voltage, Thus we are considering an optimal/average of 2.75V
Will this nominal voltage require a buck only solution or buck boost?
-> We have 2.5 and 3.3 operable voltage ranges, if we are considering a 3.3V- we need a buck boost circuit. If we use 2.5V as output then the circuit will be simpler and we would not need a buck boost.
What is the voltage that will be programmed as the cut off voltage from the battery of the PMU circuit?
->3.3V /2.5V

Power Management Unit:

In our project, Blue Gecko MCU can be operated at 3.3 V which can in-return drive the sensors with the same 3.3V.
With LiPo Battery of 2500mAh and 3.7V (typical) we have

- Vin= 2.8V(min) to 3.9V(max)
- Vin (min) = 2.8 V as discharge current of the Battery is 2.75 V
- Vout = 3.3 V.

http://www.linear.com/solutions/ helps us choose PMU with the above specifications.

We have chosen "DC1388A - LT3008EDC Demo Board | 3uA Iq, 20mA Low Dropout Linear Regulators" as our PMU

Features

- Ultralow Quiescent Current: 3μA
- Input Voltage Range: 2.0V to 45V
- Output Current: 20mA
- Dropout Voltage: 300mV
- Adjustable Output (VADJ = VOUT(MIN) = 600mV)
- Fixed Output Voltages: 1.2V, 1.5V, 1.8V, 2.5V, 3.3V, 5V

- Output Tolerance: ±2% Over Load, Line and Temperature
- Stable with Low ESR, Ceramic Output Capacitors (2.2μF Minimum)
- Shutdown Current: <1μA n Current Limit Protection
- Reverse-Battery Protection
- Thermal Limit Protection
- TSOT-23 and 2mm × 2mm DFN Packages

More Info :
http://cds.linear.com/docs/en/datasheet/3008fc.pdf
http://www.linear.com/product/LT3008

The battery gives a range of 3.7 to 3.9 output voltage and the PMU gives fixed voltage at 1.2V, 1.5V, 1.8V, 2.5V, 3.3V, 5V at output.
The MCU is driven from the PMU and MCU further drives Accelerometer, & BLE.
The MCU,sensors,BLE can work in the max-min 1.85V to min-max-3.6V.
Our digital/analog portion does not require a fixed voltage range but we have chosen a 3.3 fixed output voltage from the PMU. If needed, going further we can reduce the voltage to 2.5V which is within voltage range of Blue Gecko and Accelerometer.
Thus accordingly, we presume the power supply to be a unregulated power supply.
We have not considered any capacitors because as per our calculations and the data sheet there is no current surge.

Worst case timing information on SPI communication bus based on Accelerometer on the SPI bus.

As per SPI information from Accelerometer(BMA280),

Table 22: SPI timing

Parameter	Symbol	Condition	Min	Max	Units
Clock Frequency	f_{SPI}	Max. Load on SDI or SDO = 25pF, $V_{DDIO} \geq 1.62V$		10	MHz
		$V_{DDIO} < 1.62V$		7.5	MHz
SCK Low Pulse	t_{SCKL}		20		ns
SCK High Pulse	t_{SCKH}		20		ns
SDI Setup Time	t_{SDI_setup}		20		ns
SDI Hold Time	t_{SDI_hold}		20		ns
SDO Output Delay	t_{SDO_OD}	Load = 25pF, $V_{DDIO} \geq 1.62V$		30	ns
		Load = 25pF, $V_{DDIO} < 1.62V$		50	ns
		Load = 250pF, $V_{DDIO} > 2.4V$		40	ns
CSB Setup Time	t_{CSB_setup}		20		ns
CSB Hold Time	t_{CSB_hold}		40		ns
Idle time between write accesses, normal mode, standby mode, low-power mode 2	$t_{IDLE\_wacc\_nm}$		2		µs
Idle time between write accesses, suspend mode, low-power mode 1	$t_{IDLE\_wacc\_sum}$		450		µs

The Maximum frequency at which SPI Clk for accelerometer works is 10 MHz because VDDIO for Accelerometer is >1.62 V.

Table 4.28. SPI Master Timing

Parameter	Symbol	Test Condition	Min	Typ	Max	Unit
SCLK period [1 2]	t_{SCLK}		2 * $t_{HFPERCLK}$	—	—	ns
CS to MOSI [1 2]	t_{CS_MO}		0	—	8	ns
SCLK to MOSI [1 2]	t_{SCLK_MO}		3	—	20	ns
MISO setup time [1 2]	t_{SU_MI}	IOVDD = 1.62 V	56	—	—	ns
		IOVDD = 3.0 V	37	—	—	ns
MISO hold time [1 2]	t_{H_MI}		6	—	—	ns

Note:

1. Applies for both CLKPHA = 0 and CLKPHA = 1 (figure only shows CLKPHA = 0)
2. Measurement done with 8 pF output loading at 10% and 90% of V_{DD} (figure shows 50% of V_{DD})

However, when considered the information of SPI Clk of Blue Gecko, The minimum Clk frequency is $1/t_{sclk}$, where tsclk = 2 * $t_{HFPERCLK}$.

$t_{HFPERCLK} = 1/f_{HFPERCLK}$ = 1/16 MHz

t_{sclk} = 2 * (1/16 MHz)

t_{sclk} = 125 ns

f_{sclk} = 1/125 ns = 8 MHz.

Hence considering the above 2 situations the Accelerometer can work at its maximum frequency of 10 MHz.

SPI doesn't use start or stop bits, so there is no 'wasted' signal time. There are only two symbols (high and low), so Baud rate = bit rate, measured in bit/s, kbit/s, Mbit/s, etc (not KBits/s). If the SPI clock is 10MHz, then the bit rate will be 10Mbit/s and if it has to be pre-scaled then it is divided by 2, 4, 8, 16, 32, 64, 128, 256, set by the 'Baud rate control bits.

Hence the worst frequency at which it will operate is 10 Mhz. It can be reduced further according to our convenience.

Reference:

https://electronics.stackexchange.com/questions/260004/spi-how-calculate-baud-rate-through-clock-and-bit-rates

https://www.silabs.com/documents/login/data-sheets/bgm12x-datasheet.pdf

For Accelerometer:

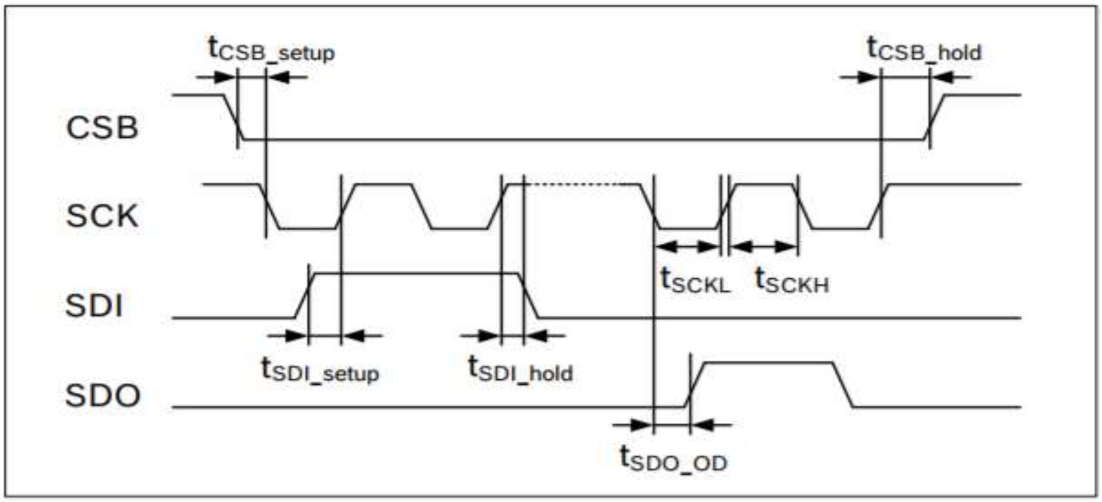

Figure 13: SPI timing diagram

SDI Hold time: 20 ns(Min)
SDI Setup time: 20 ns (Min)
SDO Output Delay: 40 ns (Min)

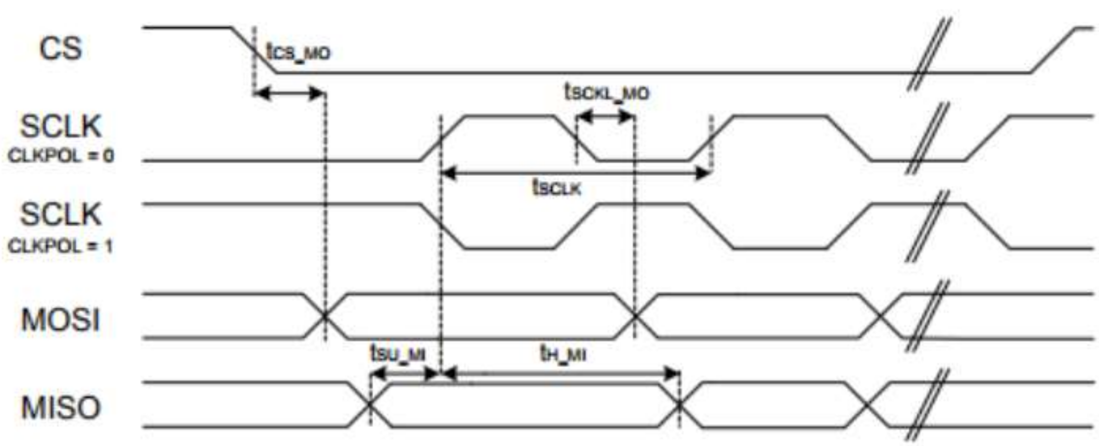

Figure 4.1. SPI Master Timing Diagram

SPI interface in master mode in Blue Gecko:
MISO setup time: 37 ns(Min)
MISO hold time: 6 ns(Min)

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.

Accomplishments:

- We are on schedule for the project.
- We have recalculated the energy profile -current in each mode of operation and its functionality.
- We have completed parts selection for energy storage device and power management unit.
- We have re-calculated the peak current and the amount of energy that has to be supplied to the circuit from the battery.
- We have decided on unregulated power supply
- Worked on the Machine Learning Algorithms to see which would be a good fit for data extraction and prediction.

Next week:

- Schematics design for the circuit
- Energy spiked calculation
- Simulation of Voltage droop
- We need to work on Bluetooth Mesh
- Keep the work going on with the Algorithm for the Machine Learning

Reference:

http://www.lipolbattery.com/lithium%20polymer%20battery.html
https://milliamps-watts.appspot.com/