****** INSTRUCTIONS ******

Copy the tabular peak/average current draw table in here. Also include the relevant plots with a detailed description and label for each.

Heading 1 is for sections.
Heading 2 is for figure/table names so that they show up in the table of contents.

****** REMOVE BEFORE SUBMISSION ******

Power Characterization Report

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I. System Structure

Our system is comprised of three subsystems joined together by an MSP430: a power system, a sensing system, and a transmission system. For our first prototype, we are using a 3.7 V, 110 mAh lithium ion battery that is charged by a BQ25505 (or 25570) energy harvester, which uses a 2.52 V monocrystalline solar cell as a power source. Other components include the BQ27426 fuel gauge, the TPS62030 buck-boost converter, the HDC1080 temperature/humidity sensor, the Bluefruit bluetooth module, and an MSP430FR5994 Launchpad.

As a proof of concept, our prototype is capable of the following:

1. Charging a single cell battery with a solar cell.
2. Boosting the output of the charger to 3.3V to power the entire prototype.
3. Measuring the voltage across the battery and communicating it to the MSP430 to determine if transmission is viable.
4. Measuring ambient temperature and humidity.
5. Storing the temperature and humidity data in FRAM.
6. Transmitting the battery voltage and temperature/humidity data from FRAM to a phone via Bluetooth.

The system diagram for this is shown in ***Figure 1*** below.

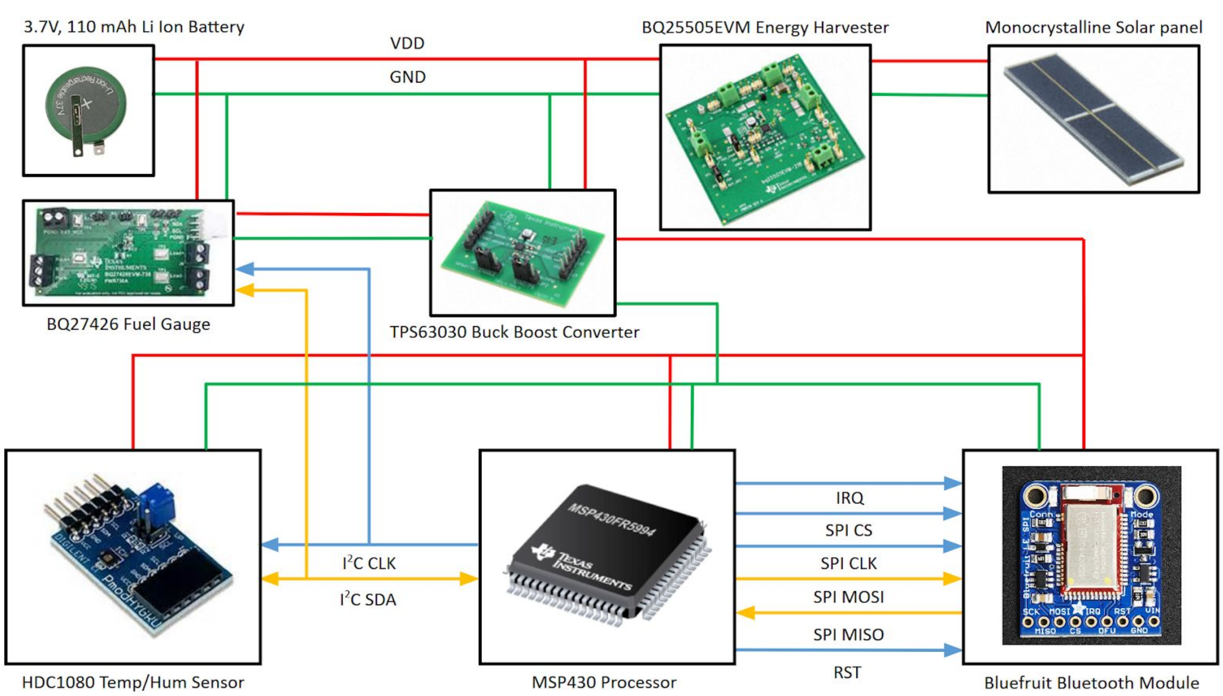

Figure 1: Prototype #1 system diagram

II. Solar Cell Performance

The key characteristics of potential solar cells are listed in **Table 1.** Upon testing, measured voltage and current values were approximately 75% the value of the datasheet. We decided to choose SLMD121H04L due to its power efficiency, size, and cost.

Table 1: Key Solar Cell Specifications

Solar Cell	Area	Voc (V) Datasheet	Voc (V) Measured	Isc (mA) Datasheet	Isc (mA) Measured
KXOB22-12X1	7mm x 22mm	.63	.648	44.6	34
KXOB22-04X3F	7mm x 22mm	1.89	1.83	15	11
KXOB22-01X8F	7mm x 22mm	4.7	4.68	4.4	6
SLMD121H04L	43mm x 14mm	2.52	2.56	50	40
SLMD600H10L	35mm x 22mm	6.3	--	25	--
SLMD480H12L	35mm x 22mm	7.56	--	20	--

The power harvested by the SLMD121H04L in bright, cloudy, shaded, indoor, and optimal conditions is shown in ***Figure 2.*** Due to the many variables determining sunlight intensity, the curve for a typical day can fall anywhere between the 5 mW - 110 mW range. Power was defined as short circuit current times open circuit voltage for ease of comparison. In actuality, the maximum power point is generally 70% this value.

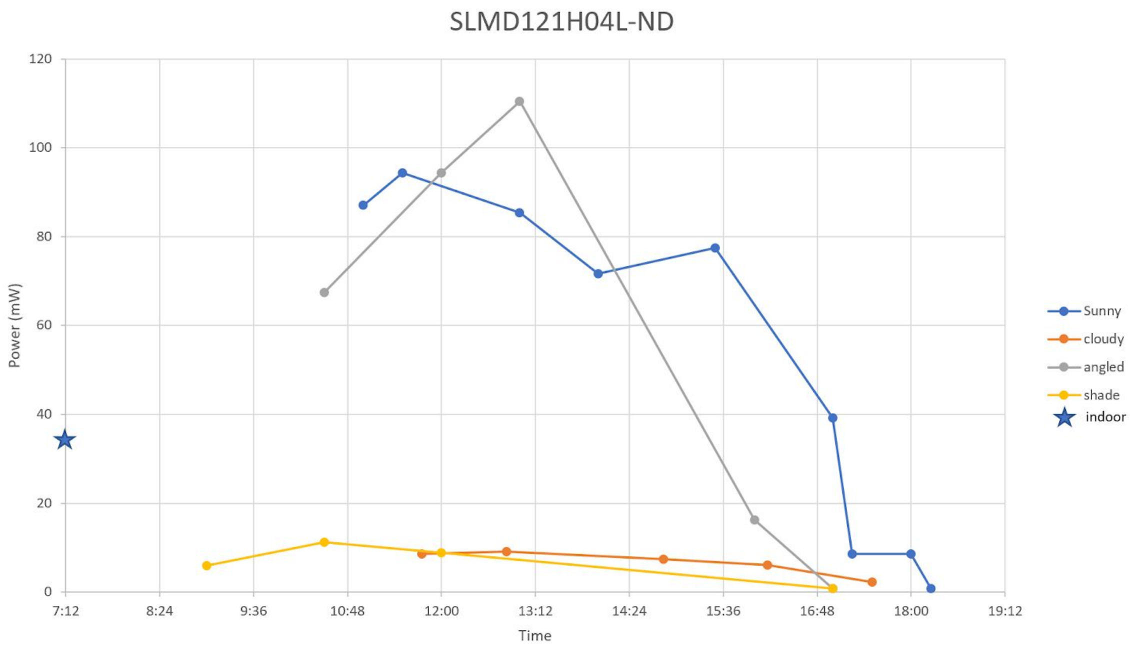

Figure 2: Solar Cell Power Across Various Conditions

III. Battery Performance

Our battery of choice is the RJD2430C1 by Illinois Capacitor, whose nominal performance is described below in ***Table 2***.

Capacity (mAh)		Charging Current (mA)	Discharge Current (mA)		Max Internal Resistance (mΩ)	Weight (g)	Max Diameter (mm)	Height (mm)
Nom	Min		Std	Max				
110	104	55	22	220	500	4.5	24.5	3.15

Table 2: Battery specifications as given by the RJD2430C1 datasheet.

Charging Conditions	Charging Rate
Sunny	200-600 mV/hr
Cloudy	50 mV/hr
Shade	80 mV/hr
Cloudy w/ Shade	10 mV/hr

Indoor	250 mV/hr

Table 3: Average Charging Rate of Battery under various conditions.

IV. Bluetooth Low Energy Power Performance

The BLE module exhibits different power performance in each of the following states:

1) Idle before connection
2) Active transmission
3) Steady state idle while connected.

In addition, the BLE module has configurable transmit (TX) power levels to achieve different desired physical ranges. ***Table 4*** below describes the average current consumption for each TX power level for each of the states listed above. We see that the TX current draw does not change significantly with TX power level but the physical connection range does vary greatly with TX power level. Therefore, we decided to use TX level 4 and 0 for our system in order to achieve the greatest range.

TX Power Level (dB)	Initial Idle (mA)	Transmitting (mA)	Steady State Idle (mA)
4	47	33	25
0	43.5	32	27
-4	42.2	32	24.1
-8	43	34	24.2
-12	40	32	23.8
-16	39.5	32	24.1
-20	39	32	30.6
-40	37.7	32	27

Table 4: BLE Performance Summary

In ***Figure 3*** below, we see the Voltage vs. Time plot of the BlueFruit during the initial idle period before connecting. The scales are 3V/div and 400ms/div.

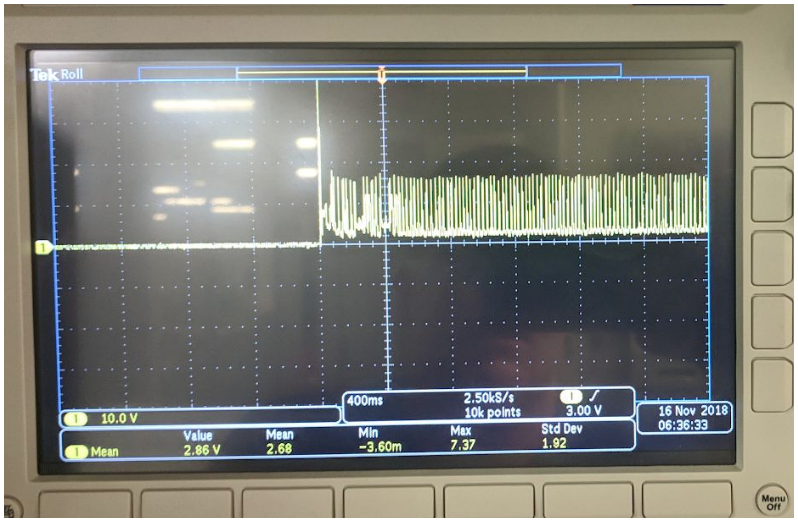

Figure 3: Voltage vs. Time for Initial Idle State

In ***Figure 4*** below, we see the Voltage vs. Time plot of the BlueFruit during transmission. Our code for this test was configured to transmit 4 data bytes per second. The scales are 3V/div and 400ms/div.

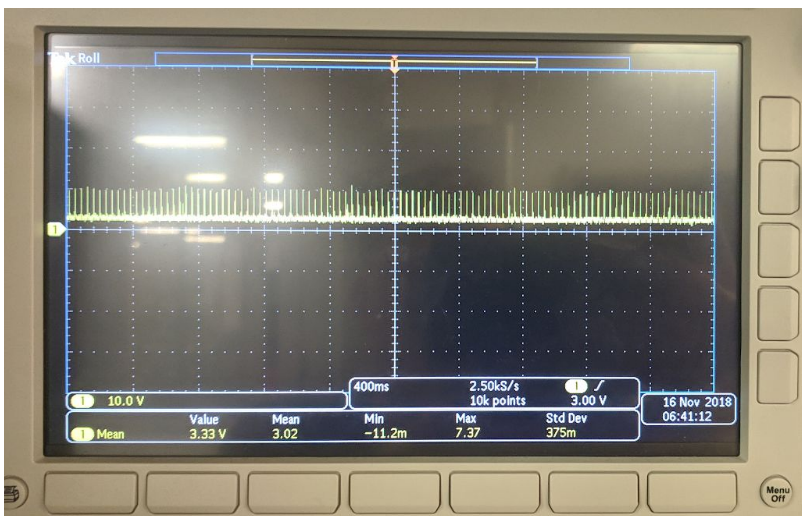

Figure 4: Voltage vs. Time for Transmission

In ***Figure 5*** below, we see the Voltage vs Time plot of the BlueFruit during the steady state idle period after transmission. The scales are 3V/div and 400ms/div.

Figure 5: Voltage vs. Time for Steady State Idle

V. Temperature & Humidity Sensor Power Performance

The overall power performance of the temperature and humidity sensor is described below in ***Table 5***, the results of which are consistent with the estimates provided by the HDC1080 datasheet.

	Typical (Temp+Hum, read @1Hz)	Peak
Current	1.66 µA	3.21 µA
Voltage	3V	

Table 5: Sensor Performance Summary

This data was generated using an oscilloscope voltage measured across the 1M Ω resistor of the transimpedence amplifier circuit shown below in ***Figure 6***. The current draw was calculated by $I = \frac{V_{cc} - V_{Out}}{R}$.

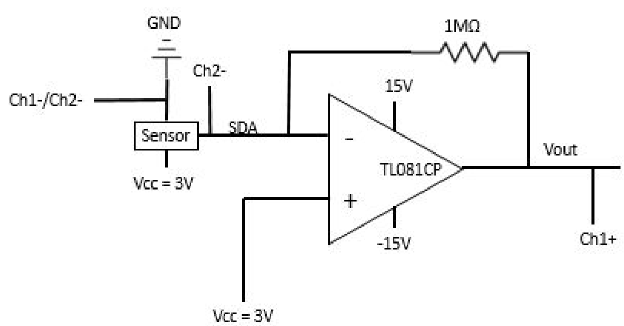

Figure 6: Voltage measurement circuit for temp/humidity sensor

The exact oscilloscope readings are shown in ***Figure 7*** over a 120ms range.

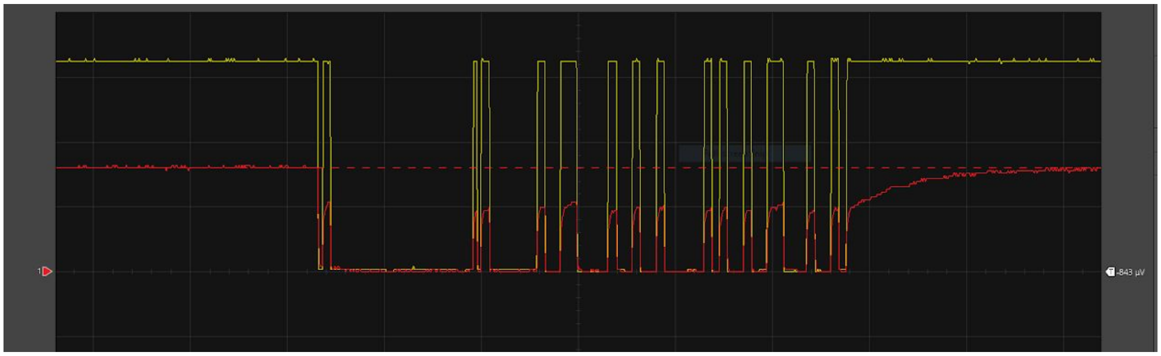

Figure 7: I2C data (yellow, Ch1) and corresponding voltage V_{out} (red, Ch2), 20ms time/div

VI. Prototype #2 Structure & Power Considerations

These power considerations for prototype 1 are an important reference for future iterations of our product. In prototype 2, we plan to add a few more components to our design, including an external oscillator for a precise low-frequency clock, and an LDO to clean up the power line to our sensor. We plan to add transistors to the power lines for the sensor and Bluetooth module in order to minimize current leakage when the system is asleep. Furthermore, we plan to reconfigure our fuel gauge to monitor the state of charge of the battery (as a percentage), as opposed to the voltage across the battery. Having a more precise idea of battery availability along with an understanding of the data described in this document will help us to create an optimized measurement and transmission schedule to reduce power consumption.