

# **IoT – Power Challenge – How low can we go?**

## **APEC PSMA Packaging Industry Session**

**Ajinder Singh**

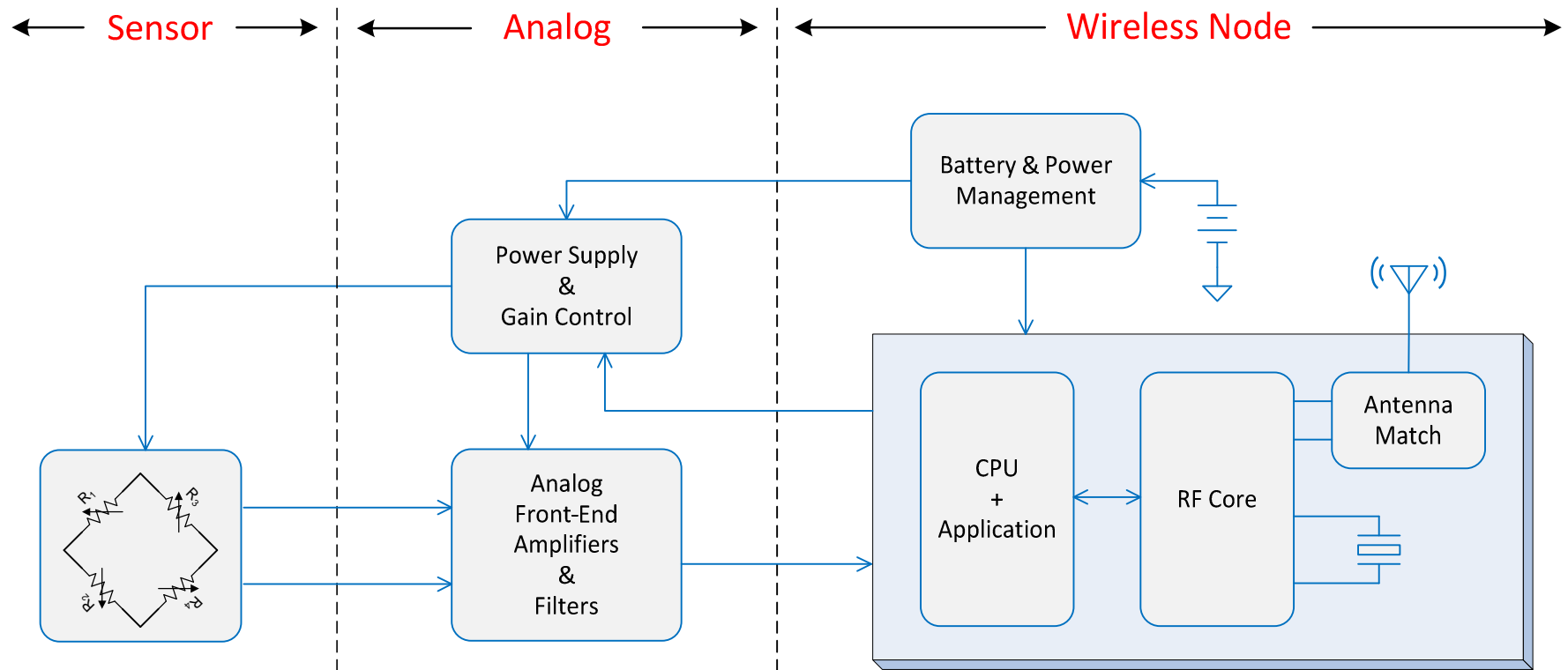
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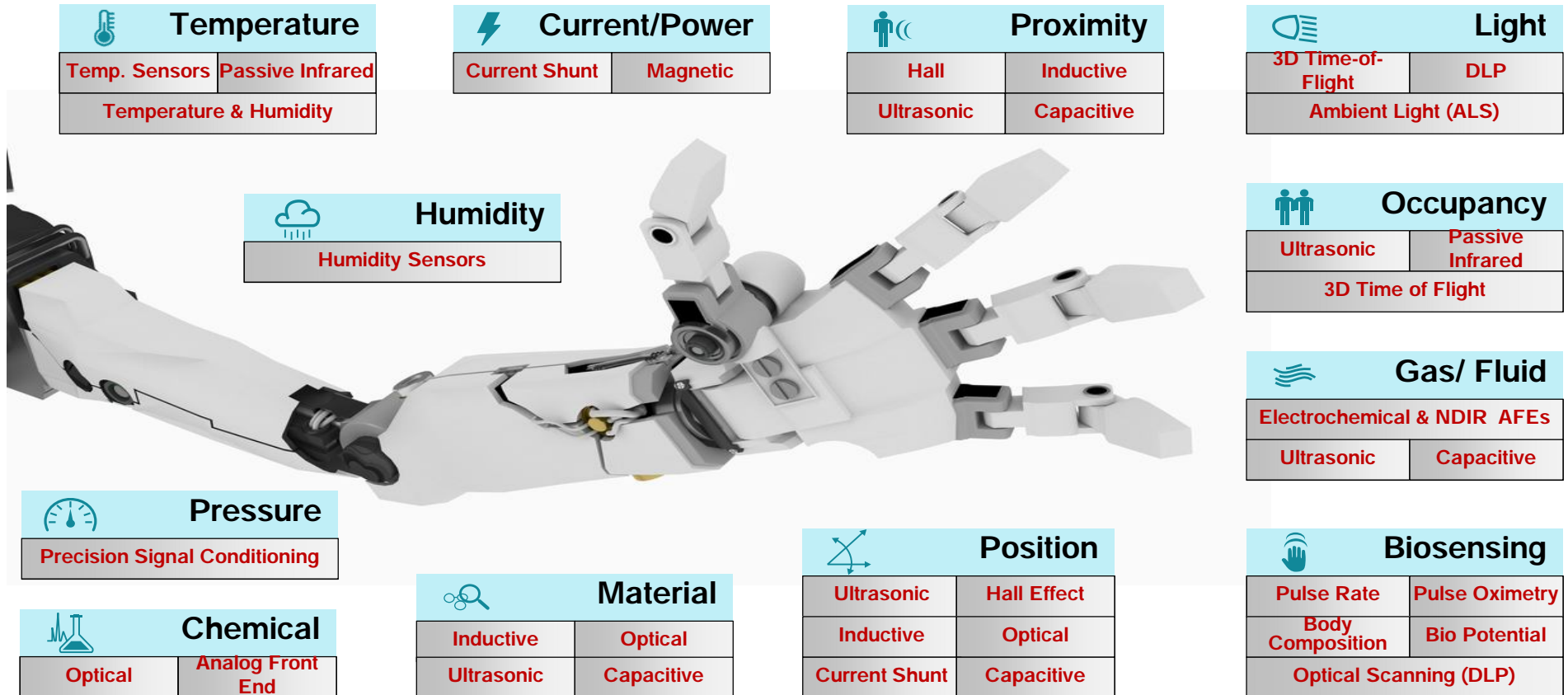
# 50 Billion Objects Connected by 2020



# Example IoT Sensor Node

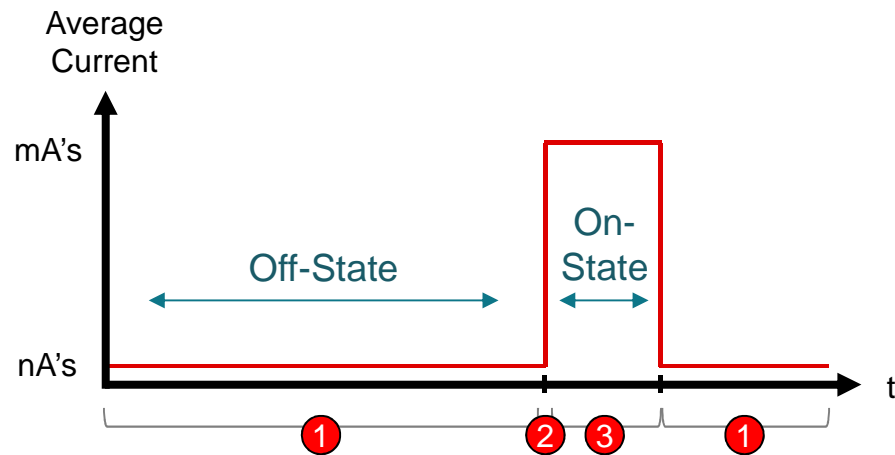


# Possible Sensing Functions

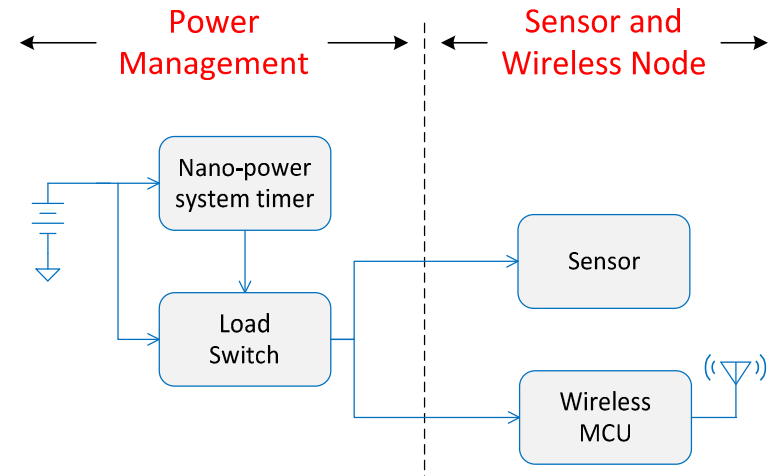


# IoT Sensing Node – Power Requirements

## Interrupt-driven Sensing

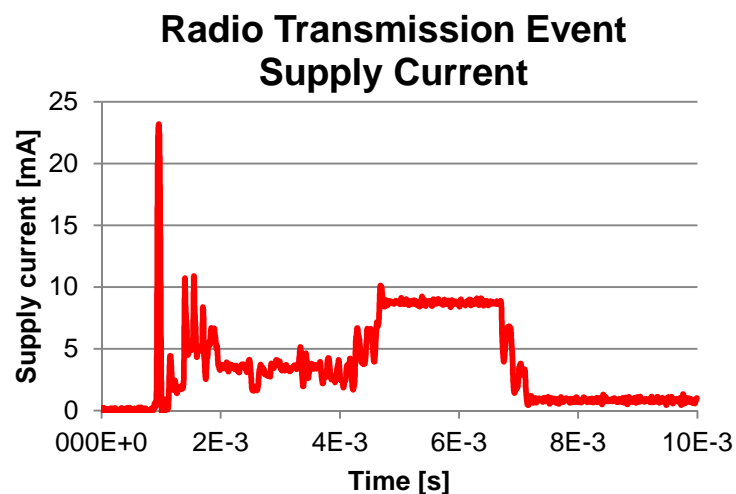


1. Sleep very efficiently
2. During interrupt event, radio wakes up
3. Get sensing data, process, transmits, then go to sleep



# Power Budget - Connectivity

		Supply Current		Transmission	
		Shutdown	Standby	Average	Duration
Sub-1GHz	CC1310	0.2 $\mu$ A	0.6 $\mu$ A	1.12 mA	104.1 ms
BLE	CC2650	0.1 $\mu$ A	1 $\mu$ A	1.57 mA	56.7 ms



TI Information – Selective Disclosure

## Sub-1GHz Example

### One event:

- Transmission for 104 ms
- Standby for 60 s

### Ten events per hour:

$$10 \times 1.12 \text{ mA} \times \frac{104.1 \text{ ms}}{3600 \text{ s}} = 0.32 \mu\text{A}$$

$$10 \times 0.4 \mu\text{A} \times \frac{60 \text{ s}}{3600 \text{ s}} = 0.07 \mu\text{A}$$

### Average current:

$$0.2 \mu\text{A} + 0.32 \mu\text{A} + 0.07 \mu\text{A} = \mathbf{0.6 \mu\text{A}}$$

# For 10 Years on a Coin Cell Battery – Budget for Rest



## System Power Budget:

- Wireless Connectivity (Sub-1GHz)

$$I_{AVG} = 0.6 \mu A$$

- Analog or Digital Signal Path

$$I_{AVG} = 2.1 - 0.6 \leq 1.5 \mu A$$

$$CR2032 \approx 220 \text{ mAh @ } 3 \text{ V}$$

$$1 \text{ year} = 8,765.8 \text{ h}$$

$$10 \text{ year} = 87,658.1 \text{ h}$$

$$I_{AVG} = \left( \frac{220 \text{ mAh}}{87,658.1 \text{ h}} \right) (0.85) = 2.1 \mu A$$



Including derating factor of 0.85 that accounts for self aging of the battery.



# Humidity & Temp. Sensing Node for 2.4-GHz Star Networks Enabling 10+ Year Coin Cell Battery Life

TI Designs Number: TIDA-00374



## Solution Features

- Configurable System Wakeup Interval
- Extremely low off-state current (183 nA for 59.97 s)
- Ultra low on-state current due to low active processor and radio transmit currents (4.04 mA for 30 ms)
- $\pm 2\%$  Relative Humidity Accuracy
- $\pm 0.2^\circ\text{C}$  Temperature Accuracy
- Multi-standard 2.4 GHz radio

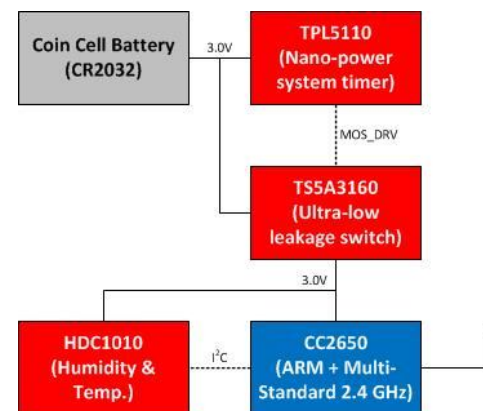
## Solution Benefits

- Use of Nano-Power System Timer to Duty-Cycle the System Results in 10+ year battery life from CR2032 coin cell
- Small, integrated solution size due to the integrated sensor and radio SoC

## Tools & Resources

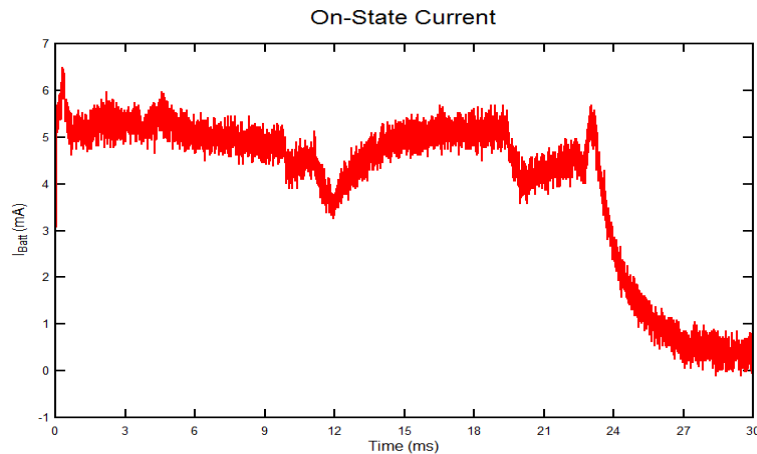


- [TIDA-00374 Tools Folder](#)
- [User Guide](#)
- [Device Datasheets:](#)
  - [HDC1010](#)
  - [TPL5110](#)
  - [TS5A3160](#)
  - [CC2650](#)

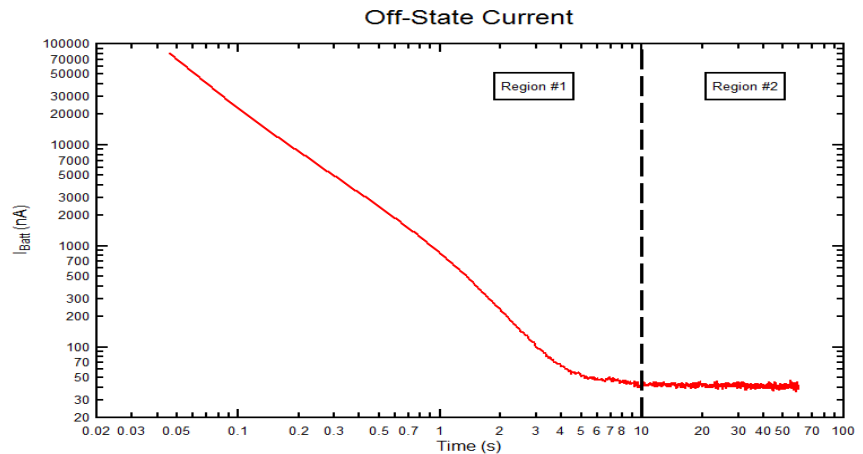




# TIDA-00374 Test Results: Power & Battery Life



On-State Duration: 30ms  
On-State Average Current: 4.04mA



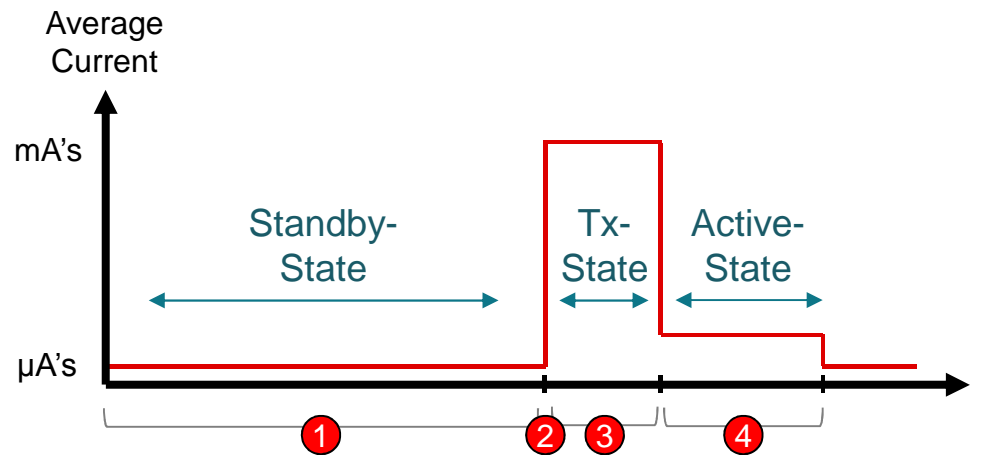
Off-State Duration: 59.970s  
Off-State Average Current: 183nA

$$Battery\ Life\ [years] = \frac{240\ [mAh]}{\left( \frac{4.038[mA] \cdot 0.030[s] + 183.01[nA] \cdot 59.970[s] \cdot 10^{-6}}{(0.030[s] + 59.970[s])} \right)} \cdot \frac{1\ [year]}{8760[hours]} \cdot 85\% = \mathbf{10.58\ years}$$

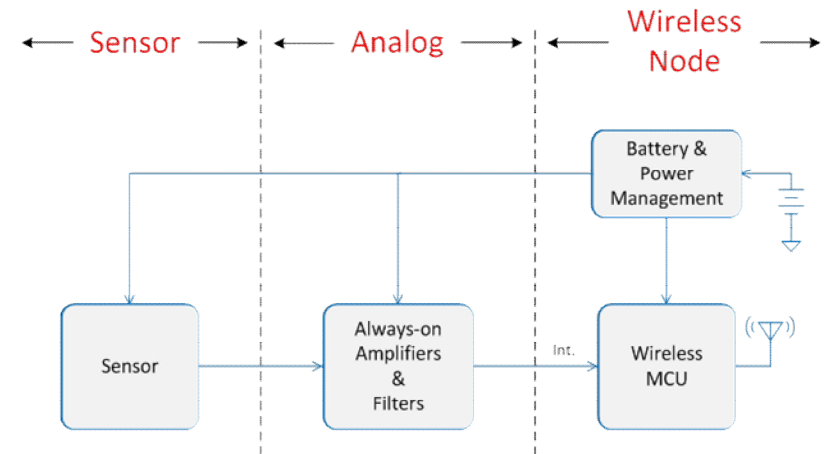
TI Information – Selective Disclosure

# IoT Sensing Node – Power Requirements

## Always-on Sensing



1. Radio hibernates, AFE monitors for an interrupt
2. During interrupt event, radio wakes up
3. Get sensing data, process, then transmits
4. Waits for inactivity, then go to sleep



# Low Power PIR Motion Detector with Wireless Connectivity Enabling 10 Year Coin Cell Battery Life

TI Designs Number: TIDA-00489



## Solution Features

- **Standby Current of 1.7- $\mu$ A typical** with active PIR sensor
  - Ultra-low Power Consumption Radio
    - 69- $\mu$ A / MHz ARM Cortex M3
    - Very low Rx / Tx current
  - Nanopower Op-amps and Comparators
- Interrupt driven Sub-1GHz wireless communication of motion for increased power savings
- **Sensitivity to >30-ft (~9-m)**

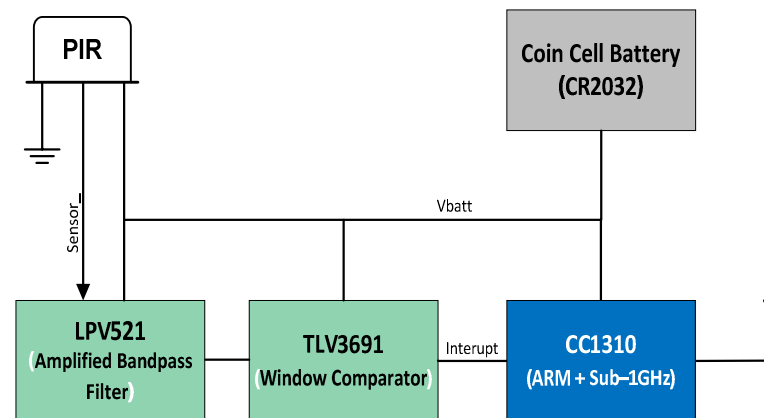
## Tools & Resources



- [TIDA-00489 Tools Folder](#)
- [User Guide](#)
- **Device Datasheets:**
  - [LPV521](#)
  - [TLV3691](#)
  - [CC1310](#)

## Solution Benefits

- Low Power design for **10+ year battery** lifetime from a single CR2032 coin cell (**<10 interrupts/hour**)
- Reduced cabling/installation cost and/or retrofit applications
- Saved building energy costs by cycling lighting based on occupancy



# TIDA-00489 – Measurement Results

- The table on the right shows the idle supply current
- The average expected battery life is shown on the table on the bottom right. This shows two active timer cases, 30 seconds and 60 seconds.
  - Case 1: Worst case of 10 motion events per hour
  - Case 2: Busy room in an office environment
  - Case 3: Intermittent motion during business hours

Circuit Path	Supply Current (Idle)	
	Nominal	Measured
Sensor	600nA	594nA
Comparators x 2	150nA	150nA
Divider	50nA	50nA
Opamp1	374nA	360nA
Opamp2	409nA	380nA
CC1310	100nA	120nA
<b>Total</b>	<b>1.683uA</b>	<b>1.654uA</b>

$$Lifetime = \frac{Battery\ Capacity}{Shutdown\ Current + Event\ Current} \times \frac{1}{8760\ hr/yr} \times Derating\ Factor$$

where  $Event\ Current$

$$= [(Delta\ Current \times Active\ Mode\ Duty\ Cycle) + (Radio\ Transmission\ Current \times Duty\ Cycle)] * Number\ of\ Events$$



	Active Timeout	
	Timer: 60 s	Timer: 30 s
Case 1	9.68 yrs	9.9 yrs
Case 2	12.12 yrs	12.12 yrs
Case 3	11.85 yrs	11.99 yrs
<b>Average</b>	<b>11.22 yrs</b>	<b>11.34 yrs</b>

# 10 Years on a AA battery



## System Power Budget:

- Wireless Connectivity (Sub-1GHz)

$$I_{AVG} = 0.6 \mu A$$

- Motor, Analog, or Digital Path

$$I_{AVG} = 26.2 - 0.6 \leq \mathbf{25.6 \mu A}$$

AA (alkaline)  $\approx 2,700 \text{ mAh @ } 1.5 \text{ V}$

$$1 \text{ year} = 8,765.8 \text{ h}$$

$$\mathbf{10 \text{ year}} = 87,658.1 \text{ h}$$

$$I_{AVG} = \left( \frac{2,700 \text{ mAh}}{87,658.1 \text{ h}} \right) (0.85) = 26.2 \mu A$$



Including derating factor of 0.85 that accounts for self aging of the battery.



# Smart Lock Reference Design Enabling 5+ Years of Life on 4x AA Batteries

TI Designs Number: TIDA-00757



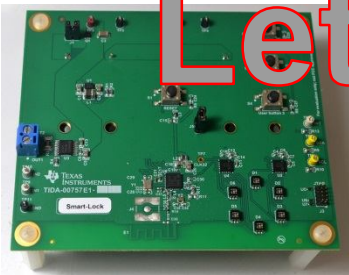
## Solution Features

- Low Power Consumption: 58  $\mu$ A average current consumption
  - Ultra-low Power Consumption Radio + MCU
    - 61- $\mu$ A / MHz ARM Cortex M3
    - Very low Rx / Tx current (6-mA / 9-mA)
  - Low  $R_{DS(on)}$  of 360m $\Omega$  from the Motor Driver
- Bluetooth Low Energy (BLE) radio enables seamless connectivity to smart mobile devices for lock/unlock events
- Battery polarity protection using P-ET

## Solution Benefits

- Over 5 years battery life using 4x AA batteries in series
  - 24 lock or unlock events per day
  - 500-ms BLE radio connection period
- 6 RGB LED's display power up, lock event, unlock event, and low battery status.
- Voltage based battery gas gauge, integrated in DC-DC converter
- BLE test using handheld BLE application

## Tools & Resources

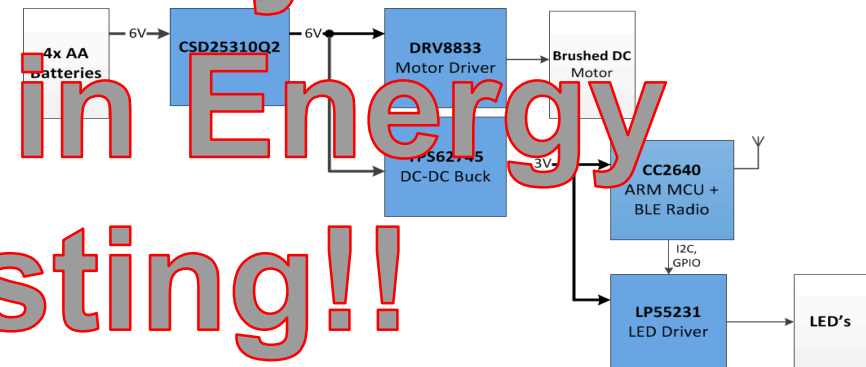


TI Information – Selective Disclosure

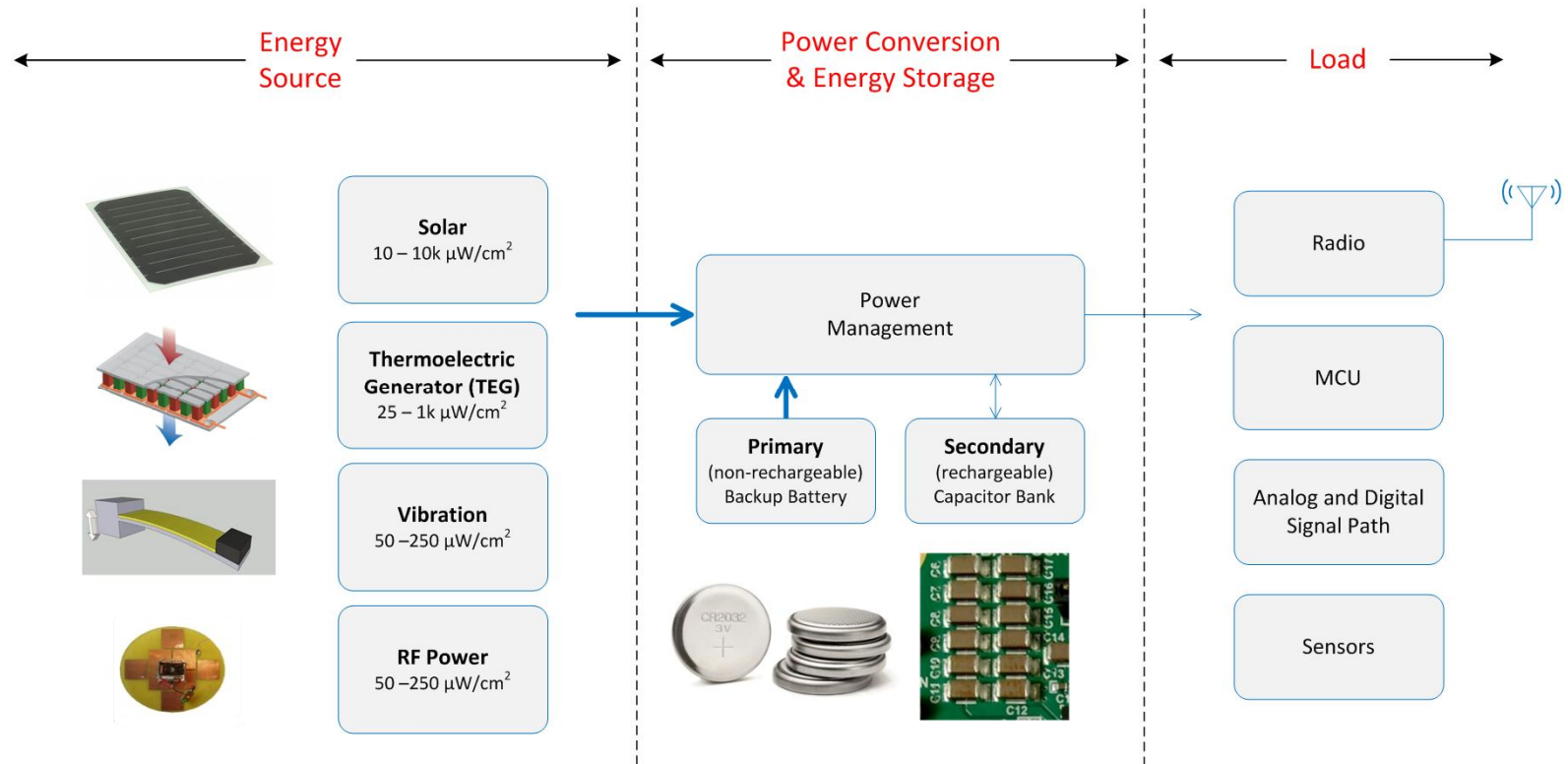
- TIDA-00757 Pin Configuration
- User Guide

### Device Datasheets:

- [TPS62745](#)
- [DRV8833](#)
- [CC2640](#)
- [LP55231](#)
- [CSD25310Q2](#)



# Supplementing Batteries with Energy Harvesting



# Types of Solar Cells for Energy Harvesting

- **Amorphous**

- Indoor light (300 to 600 nm)
- $\ll$  10% conversion efficiency

- **Dye-Sensitized**

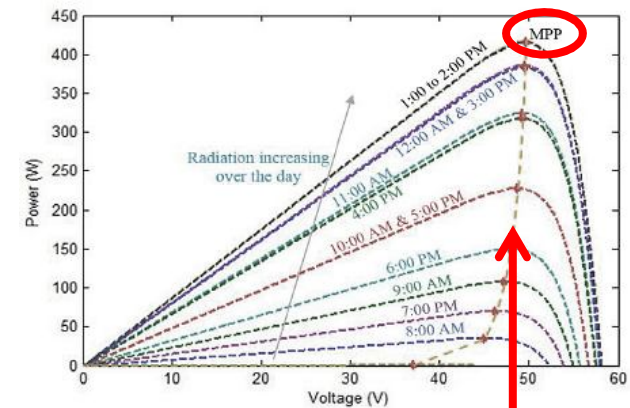
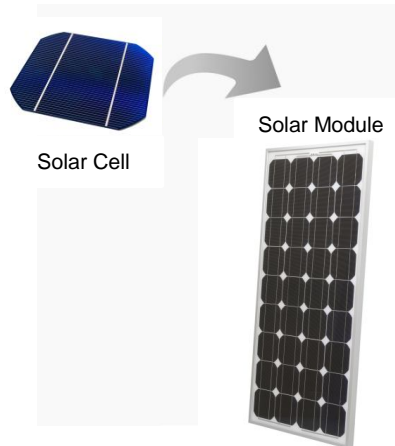
- Indoor light (tunable)
- 10% conversion efficiency

- **PolyCrystalline**

- Outdoor light (500 to 1100 nm)
- 10 to 15% conversion efficiency

- **MonoCrystalline**

- Wide range (300 to 1000 nm)
- 20% conversion efficiency



## Single cell example

Nominal voltage: ~300 mV

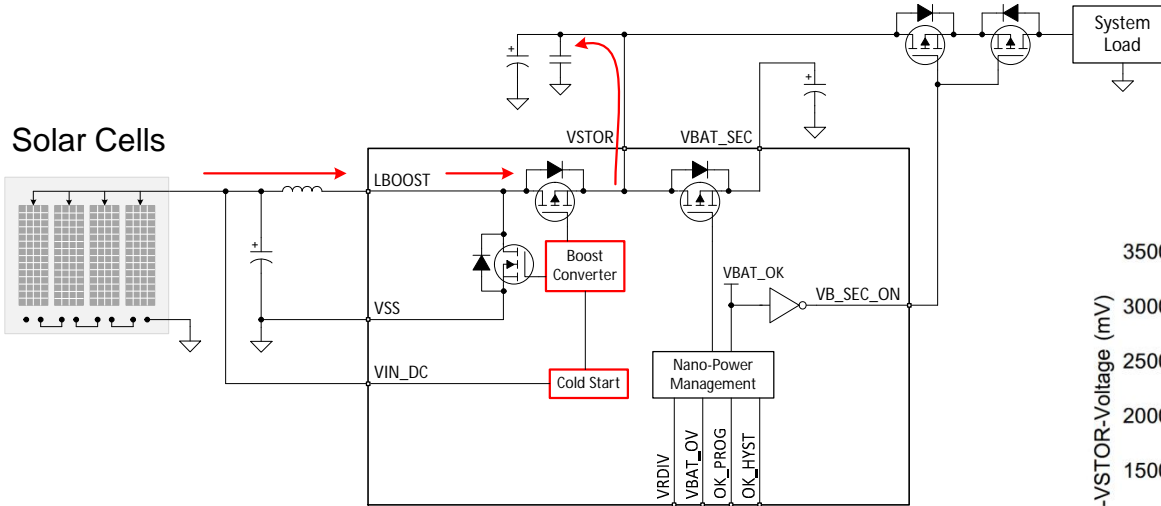
Open circuit voltage: ~600 mV

Maximum power voltage: ~500 mV

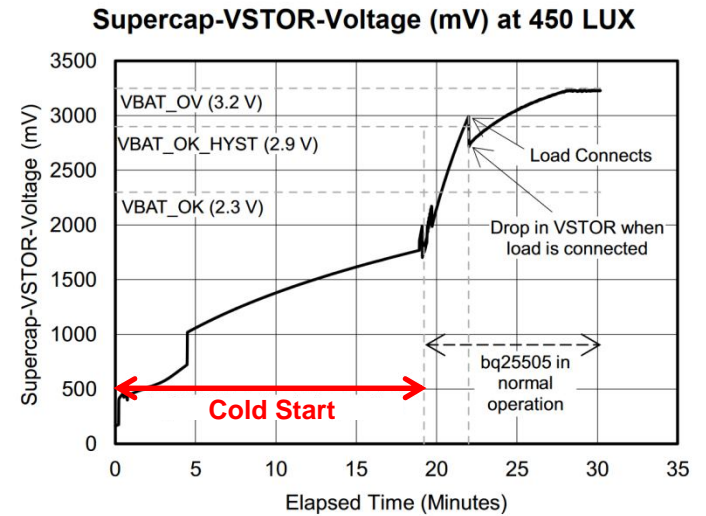
MPP tracking  
integrated in  
BQ25505



# Energy Harvesting Process for Solar Using BQ25505

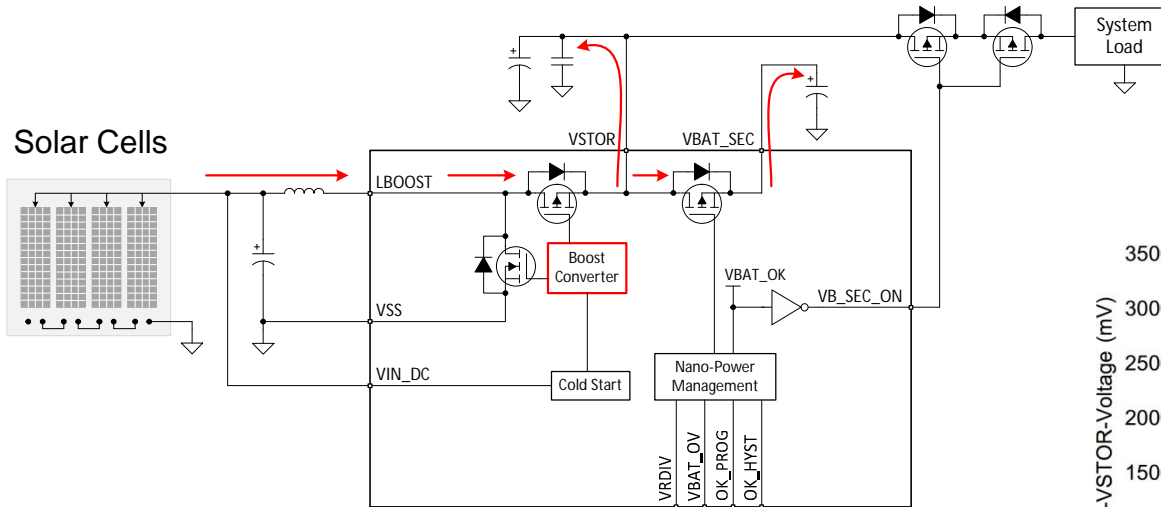


**Cold Start:** At startup, device runs in cold start mode until 1.8V.

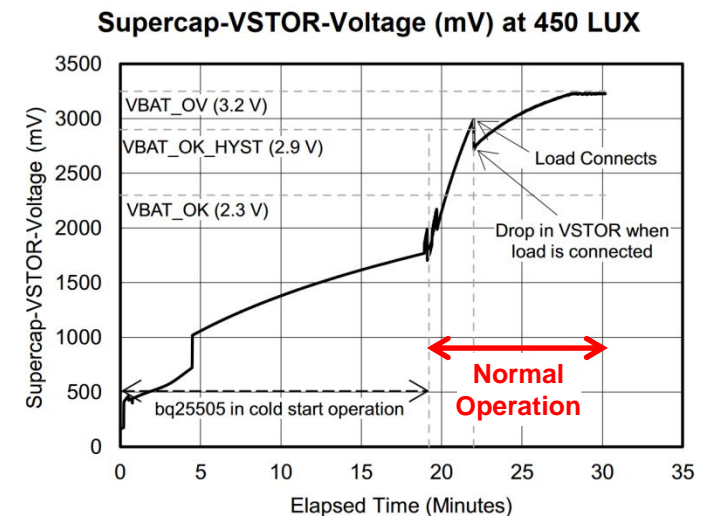


# Energy Harvesting Process for Solar

## Using BQ25505

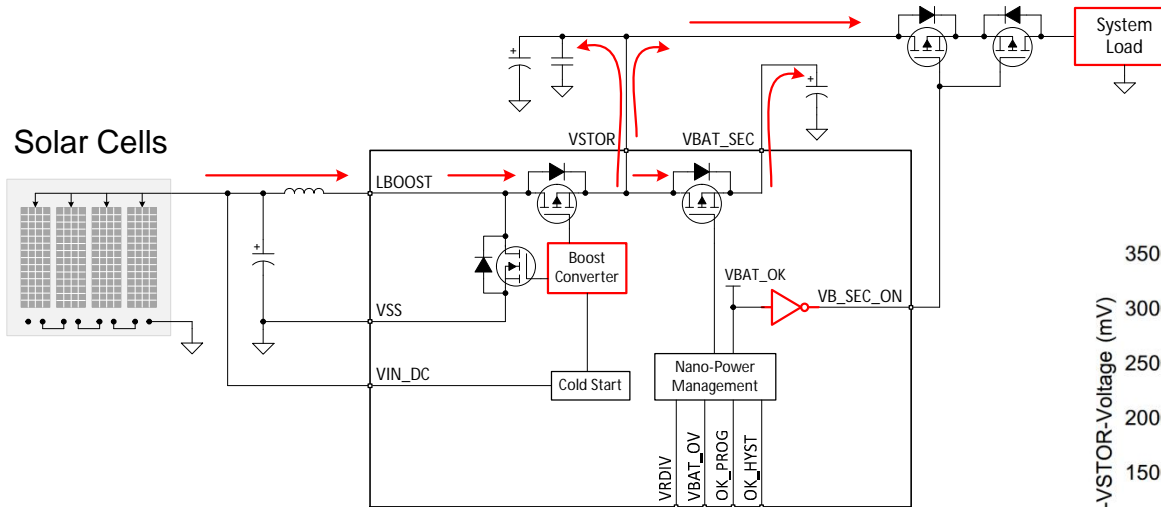


**Normal Operation:** After capacitor is at the 1.8V threshold, device enters normal boost operation.

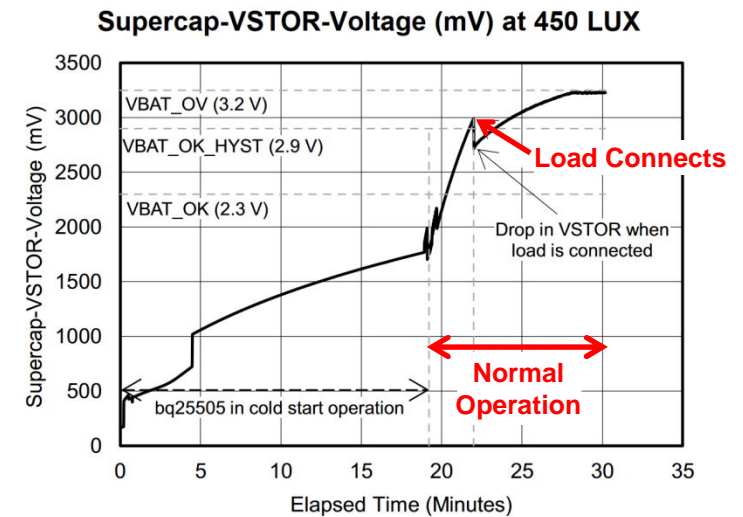


# Energy Harvesting Process for Solar

## Using BQ25505



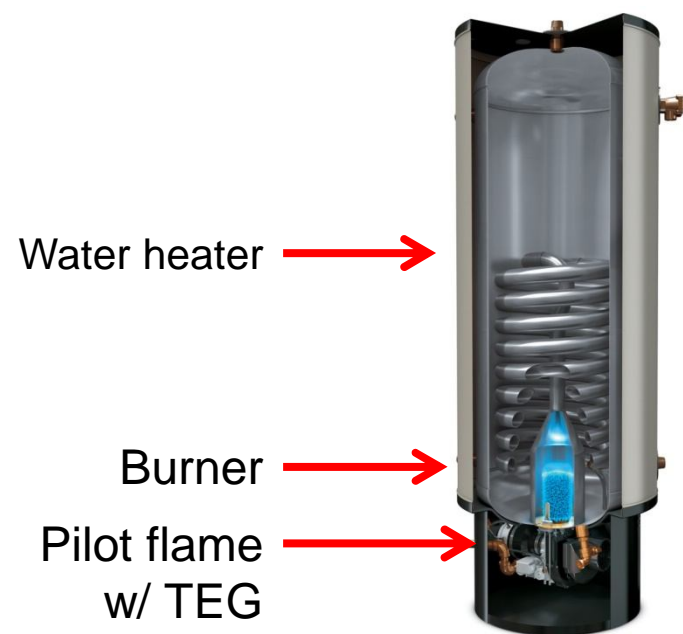
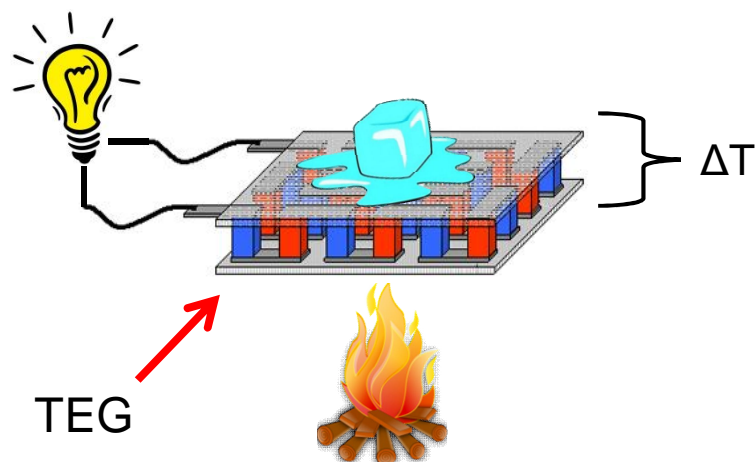
**Load Connects:** When the voltage reaches VBAT\_OK\_HYST at 2.9V (adjustable), the load connects and BLE beacon application begins.



# TEG Option for Energy Harvesting

A thermoelectric generator (TEG) converts a temperature differential into electrical energy

- One side has an applied heat source
- The opposite side maintains a lower temperature
- The temperature difference ( $\Delta T$ ) creates electricity



<http://grabcad.com>

# Energy Harvesting Requirements for BLE Beacon

## Required Energy Budget Calculation

- BLE Beacon transmitted **once a second**
- One heartbeat LED that blinks once every 2 seconds for 100 ms (equivalent to 50 ms blink per second)

## Design Options for Energy Harvesting

- **Larger solar cell form factor** enables shorter beacon intervals or a larger energy budget
- **Smaller solar cell form factor** requires a less frequent beacon interval or less energy budget

## Beacon Energy Requirement

	Current	Voltage	Power	Time	Energy
Event	mA	V	mW	ms	μW s
Wake-up	32	3.1	99.2	0.2	19.9
Pre-Proc.	7.5	3.1	23.3	0.6	14.0
Rx	7.5	3.1	23.3	0.4	9.3
Tx	20	3.1	62	0.6	37.2
Processing	7.5	3.1	23.3	1.4	32.6
LED Blink	0.45	3.1	1.4	50	69.8
Sleep Mode	0.001	3.1	0.003	946.8	2.9
<b>Total</b>				<b>1,000.0</b>	<b>185.7</b>

Note: Using CC2541 from TIDA-00100  
Solar panel is 58.1 x 56.7 mm  
250 lux generates **200 μW**

$$P_{AVG} = E/t = 186 \mu Ws/1 s = 186 \mu W$$

$$I_{AVG} = P_{AVG}/V = 186 \mu W/3.1 V = \mathbf{60 \mu A}$$

# Energy Harvesting Ambient Light and Environmental Sensor Node for Sub-1GHz Networks

TI Designs Number: TIDA-00488



## Solution Features

- Runs entirely from solar energy when LUX level is sufficient
- Supports interrupt mode triggered by indoor LUX levels
- Precision Optical Filtering to Match Human Eye ( $\pm 0.01$  Lux Light Accuracy)
- $\pm 2\%$  Relative Humidity Accuracy
- $\pm 0.2^{\circ}\text{C}$  Temperature Accuracy

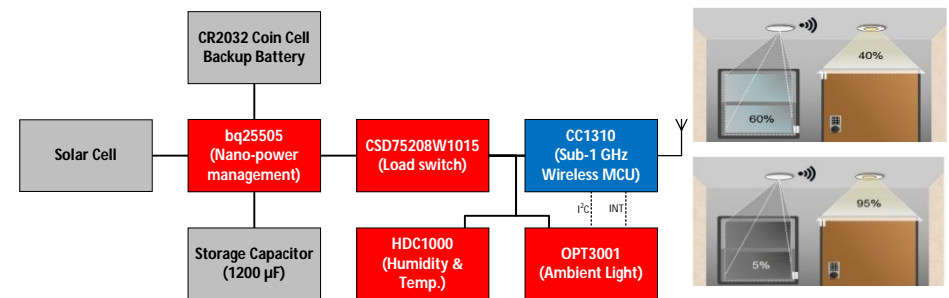
## Tools & Resources



- [TIDA-00488 Tools Folder](#)
- [User Guide](#)
- [Device Datasheets:](#)
  - [BQ25505](#)
  - [OPT3001](#)
  - [HDC1010](#)
  - [CC1310](#)
  - [CSD75208W1015](#)

## Solution Benefits

- Save building energy and maintenance costs depending on natural ambient light level and adjusting artificial light level
- Retrofit applications with wireless communications with no power wiring required
- Little-to-no maintenance
- Long battery backup life (up to 10 years) during periods of low LUX level



# Summary

- Wireless sensing nodes are expected to be truly wireless – without power cord
- Expectation is do more – complex computations with less – that is smaller and smaller battery
- Solving long battery life should be looked at entire systems point of view and is not just the power management chip function

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