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

APEC PSMA Packaging Industry Session

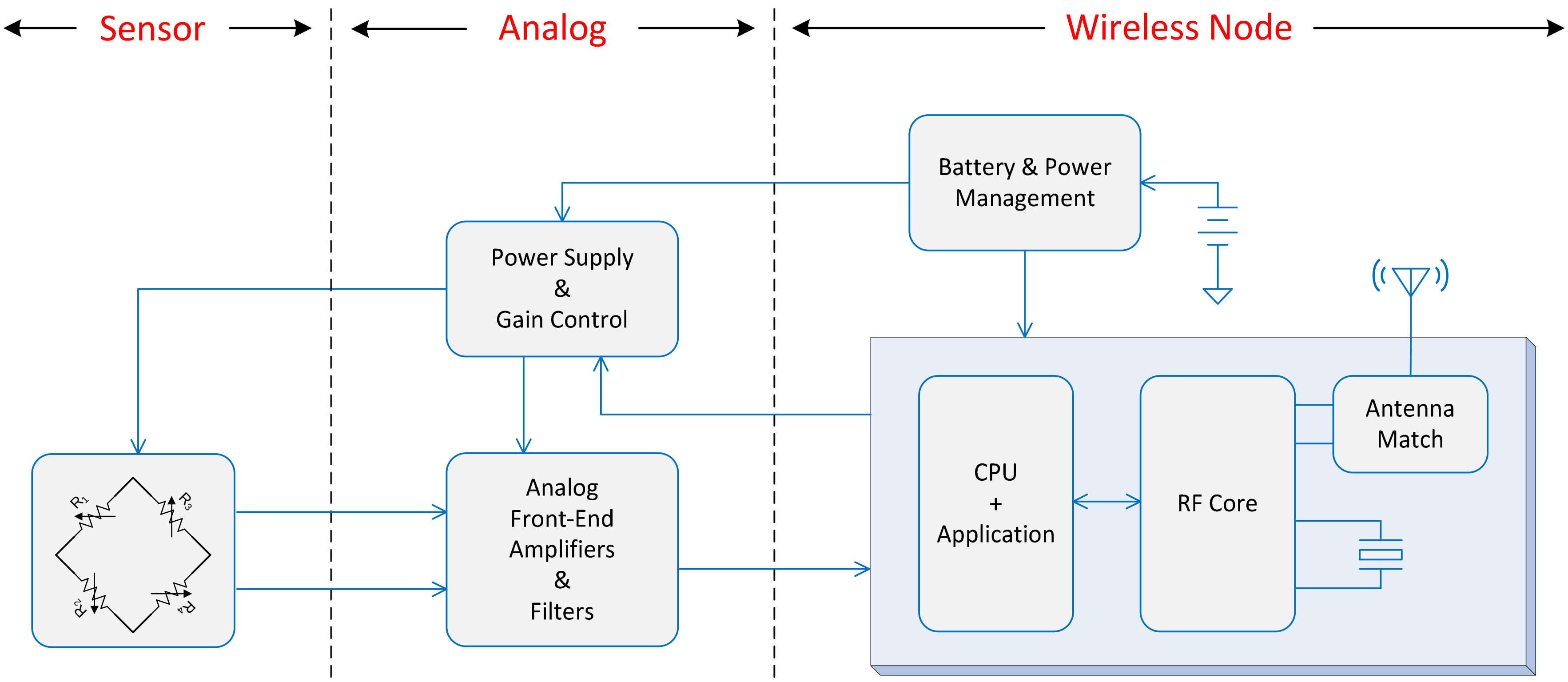
Ajinder Singh

Power Sources Manufacturers Association
The Multinational Power Electronics Association

Texas Instruments

50 Billion Objects Connected by 2020

Example IoT Sensor Node



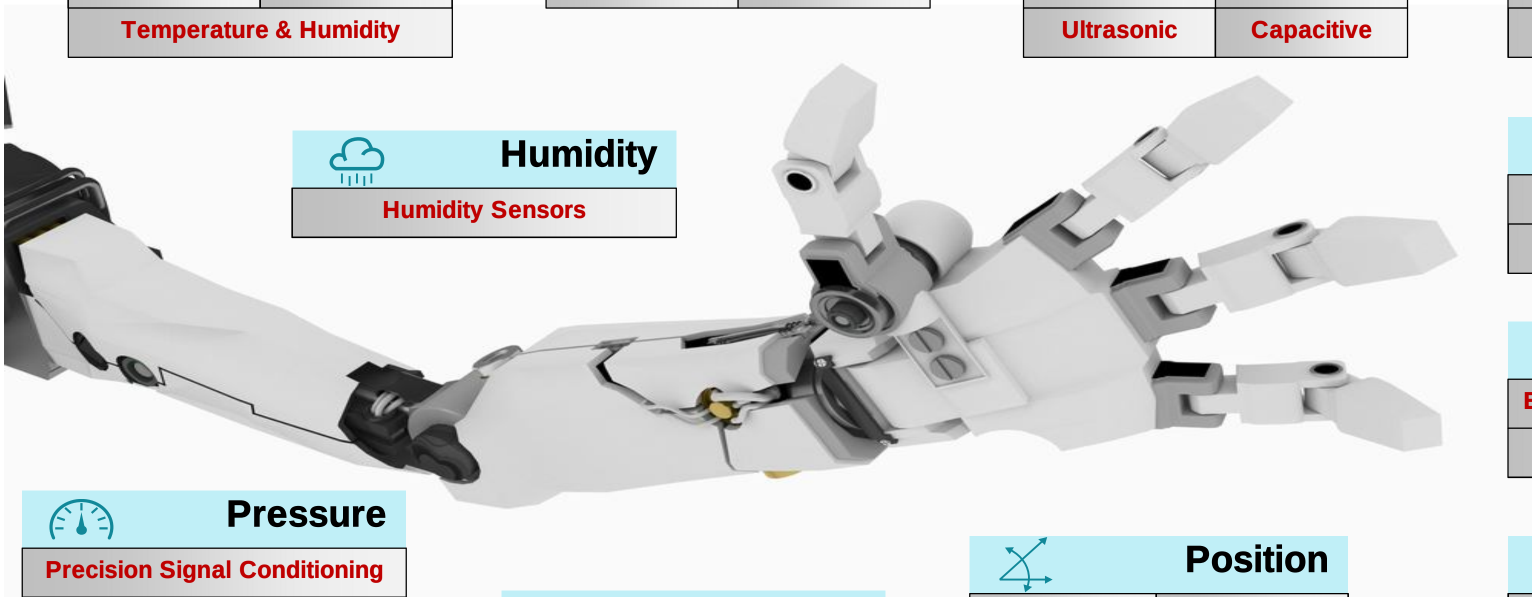
Possible Sensing Functions

Temperature
- Temp. Sensors
- Passive Infrared
- Temperature & Humidity

Current/Power
- Current Shunt
- Magnetic

Proximity
- Hall
- Inductive
- Ultrasonic
- Capacitive

Light
- 3D Time-of-Flight
- DLP
- Ambient Light (ALS)



Humidity
- Humidity Sensors

Occupancy
- Ultrasonic
- Passive Infrared
- 3D Time of Flight

Gas/ Fluid
- Electrochemical & NDIR AFEs
- Ultrasonic
- Capacitive

Pressure
- Precision Signal Conditioning

Chemical
- Optical
- Analog Front End

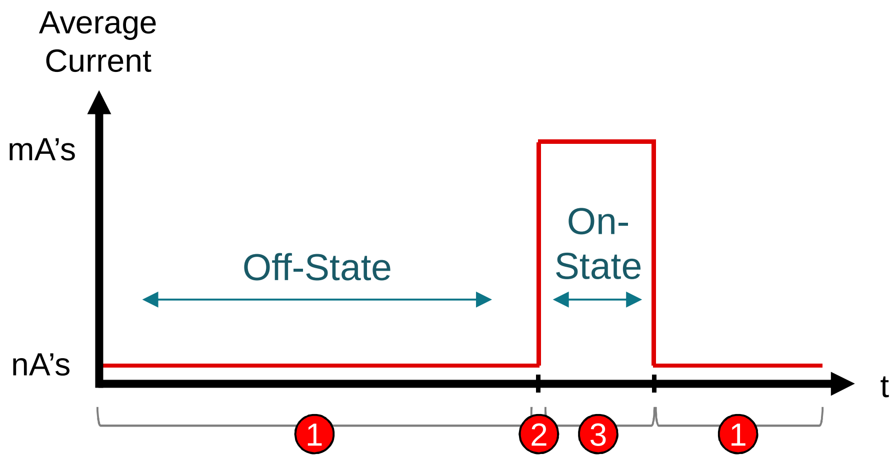
Material
- Inductive
- Optical
- Ultrasonic
- Capacitive

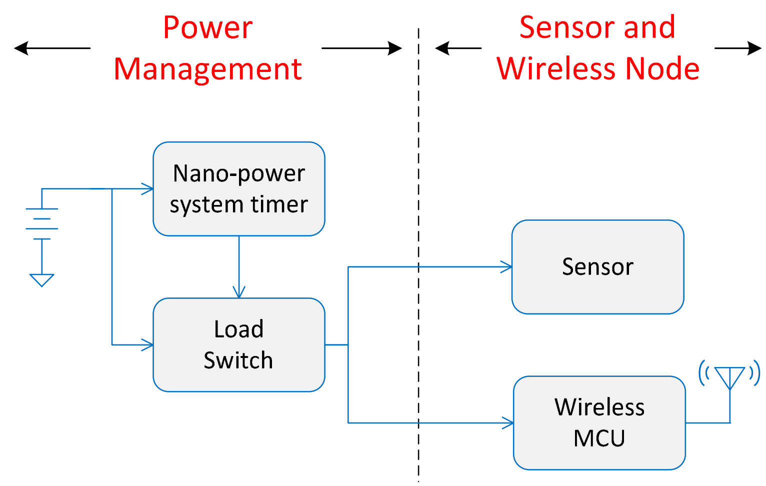
Position
- Ultrasonic
- Hall Effect
- Inductive
- Optical
- Current Shunt
- Capacitive

Biosensing
- Pulse Rate
- Pulse Oximetry
- Body Composition
- Bio Potential
- Optical Scanning (DLP)

IoT Sensing Node – Power Requirements

Interrupt-driven Sensing





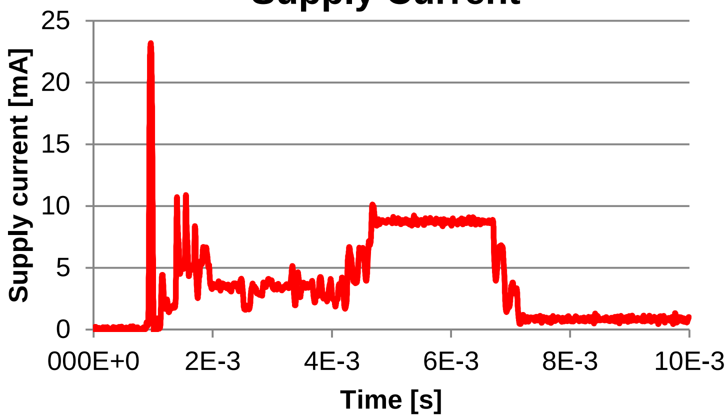
1. Sleep very efficiently
2. During interrupt event, radio wakes up
3. Get sensing data, process, transmits, then go to sleep

*Graph not to scale

Power Budget - Connectivity

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

Radio Transmission Event Supply Current



Sub-1GHz Example

One event:

- Transmission for 104 ms
- Standby for 60 s

Ten events per hour:

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

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

Average current:

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

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

System Power Budget:

- Wireless Connectivity (Sub-1GHz)
  I_{AVG} = 0.6 µA
- Analog or Digital Signal Path
  I_{AVG} = 2.1 – 0.6 **≤ 1.5 µA**

CR2032 ≈ 220 mAh @ 3 V

1 year = 8,765.8 h
10 year = 87,658.1 h

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

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

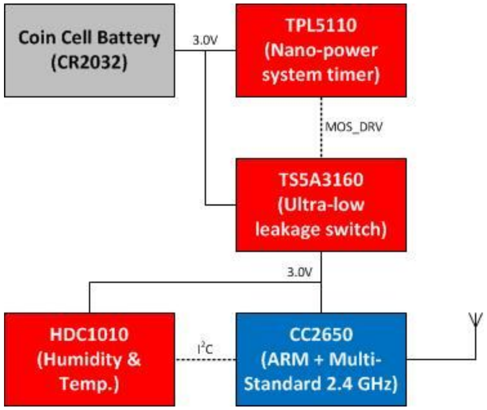
TI Designs Number: TIDA-00374

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)
- ±2% Relative Humidity Accuracy
- ±0.2°C Temperature Accuracy
- Multi-standard 2.4 GHz radio

Solution Benefits

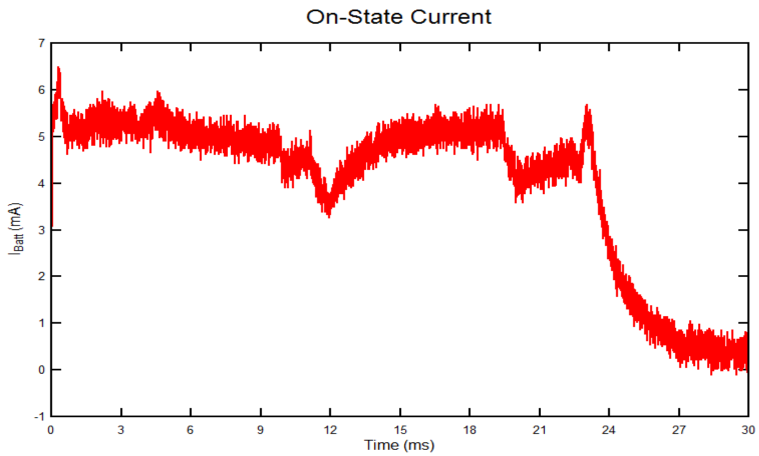
- Use of Nano-Power System Timer to Duty-Cycle the System Results in 10+ year battery life from CR2032 coin cell
- Small, integrated solution size due to the integrated sensor and radio SoC

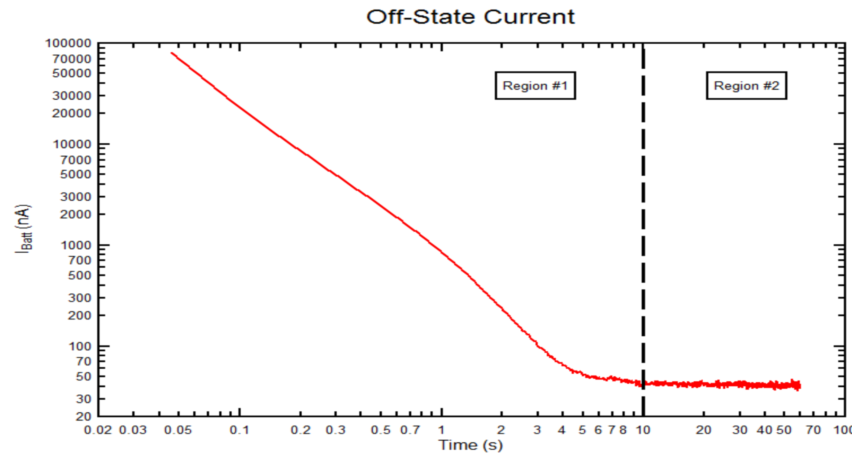


Tools & Resources

- **TIDA-00374 Tools Folder**
- **User Guide**
- **Device Datasheets**:
  - HDC1010
  - TPL5110
  - TS5A3160
  - CC2650

TIDA-00374 Test Results: Power & Battery Life



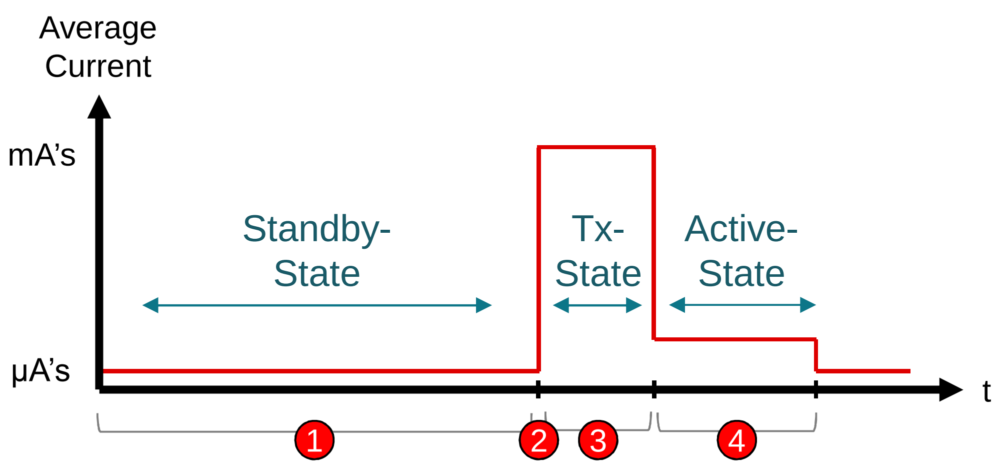


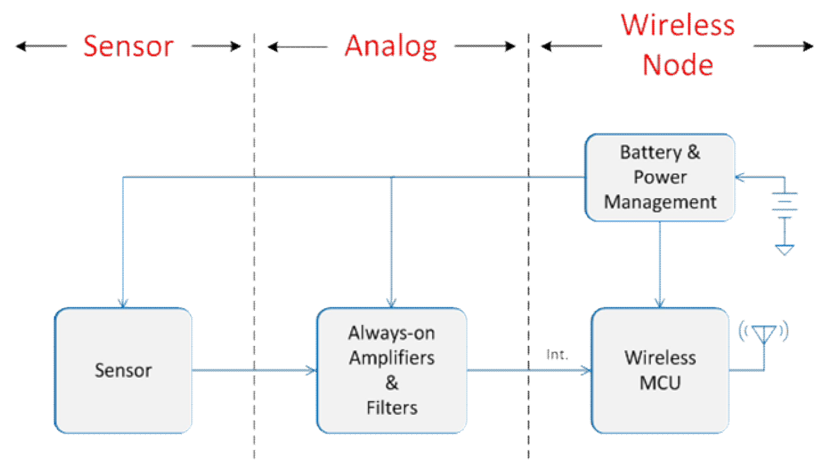
On-State Duration: 30ms
On-State Average Current: 4.04mA

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

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

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

*Graph not to scale

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

TI Designs Number: TIDA-00489

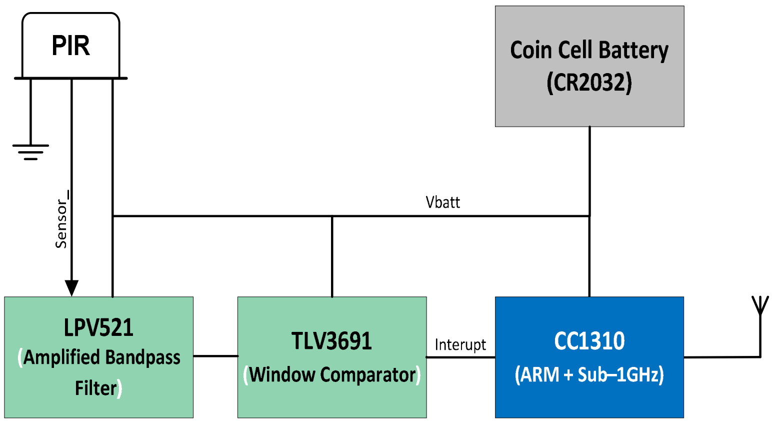
TIDesigns

Solution Features

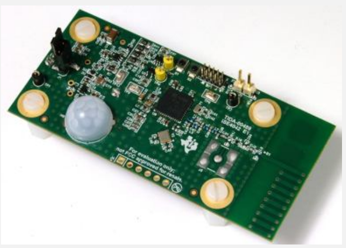
- **Standby Current of 1.7-µA typical** with active PIR sensor
  - Ultra-low Power Consumption Radio
    - 69-uA / MHz ARM Cortex M3
    - Very low Rx / Tx current
  - Nanopower Op-amps and Comparators
- Interrupt driven Sub-1GHz wireless communication of motion for increased power savings
- **Sensitivity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

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



Tools & Resources



- TIDA-00489 Tools Folder
- User Guide
- Device Datasheets:
  - LPV521
  - TLV3691
  - CC1310

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
Total	**1.683uA**	**1.654uA**

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

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

	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
Average	11.22 yrs	11.34 yrs

10 Years on a AA battery

<u>System Power Budget:</u>

- Wireless Connectivity (Sub-1GHz)
  I_{AVG} = 0.6 µA
- Motor, Analog, or Digital Path
  I_{AVG} = 26.2 – 0.6 **≤ 25.6 µA**

AA (alkaline) ≈ 2,700 mAh @ 1.5 V

1 year = 8,765.8 h
10 year = 87,658.1 h

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

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

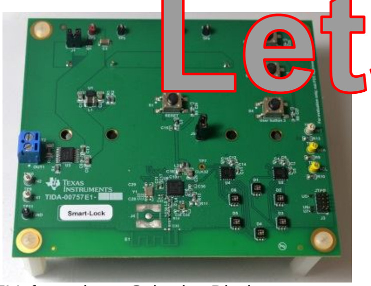
- Low Power Consumption: 58 µA average current consumption
  - Ultra-low Power Consumption Radio + MCU
    - 61-µA / MHz ARM Cortex M3
    - Very low Rx / Tx current (6-mA / 9-mA)
  - Low R_{DSON} of 360mΩ from the Motor Driver
- Bluetooth Low Energy (BLE) radio enables seamless connectivity to smart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

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 tested using the default BLE OAD application

Cant meet 10 years!

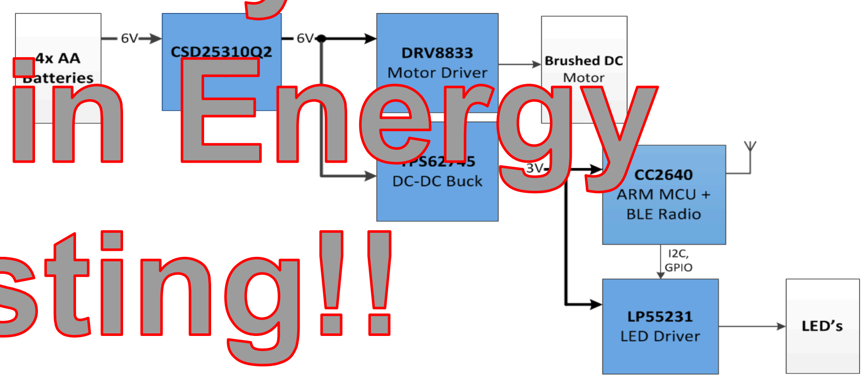
Tools & Resources



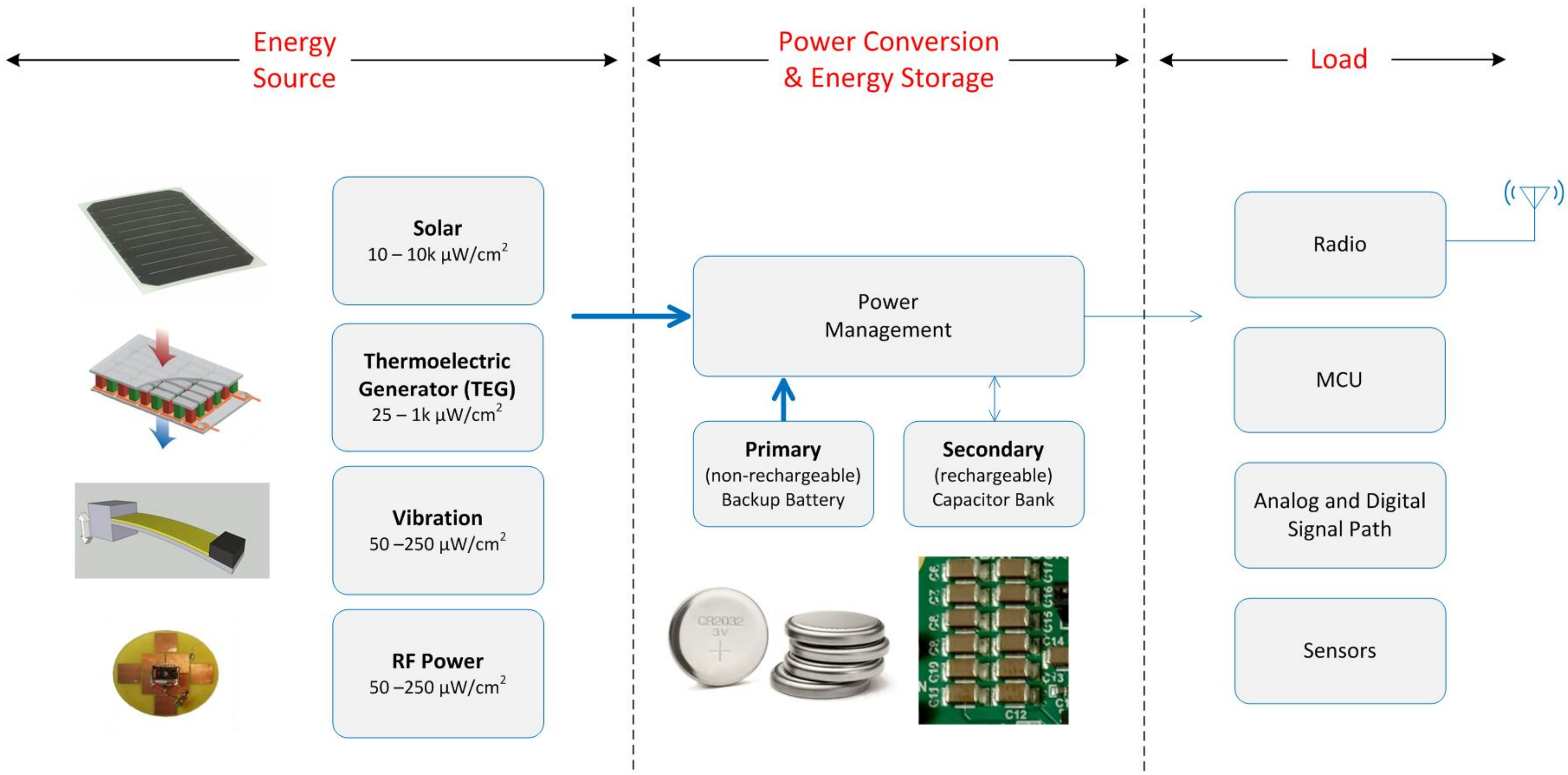
TI Information – Selective Disclosure

- **TIDA-00757 Tool Folder**
- **User Guide**
- **Device Datasheets:**
  - TPS62745
  - DRV8833
  - CC2640
  - LP55231
  - CSD25310Q2

Lets bring in Energy Harvesting!!

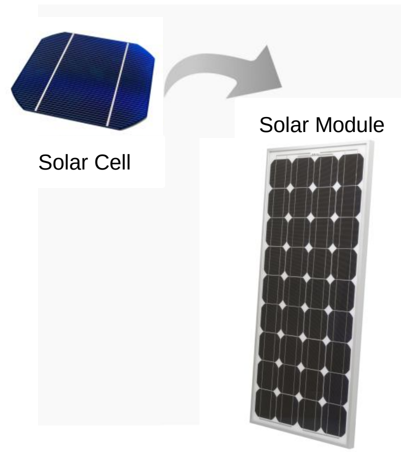


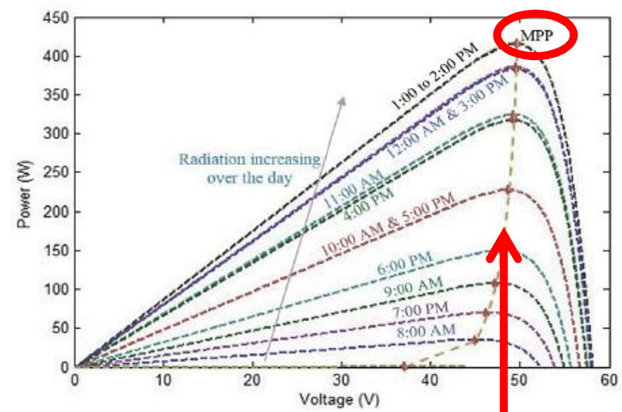
Supplementing Batteries with Energy Harvesting



Types of Solar Cells for Energy Harvesting

- **Amorphous**
  - Indoor light (300 to 600 nm)
  - << 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



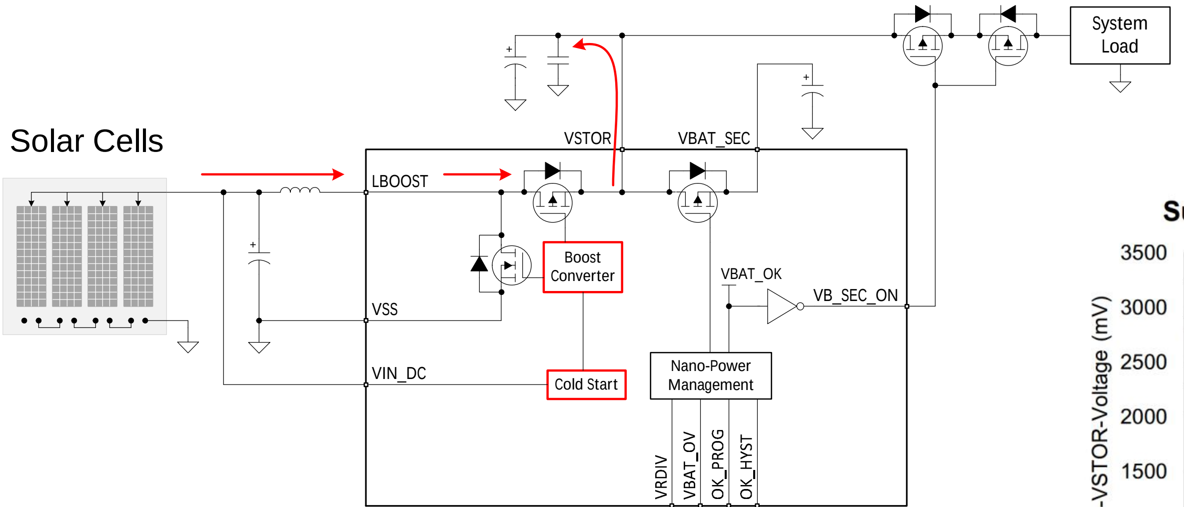


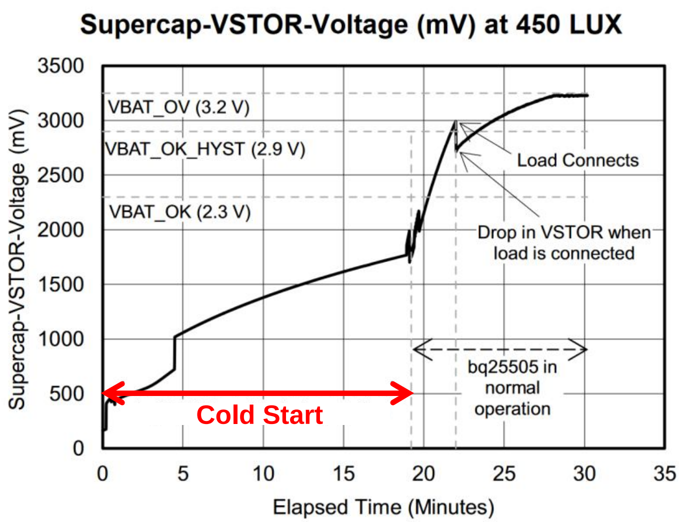
Single cell example
Nominal voltage: ~300 mV
Open circuit voltage: ~600 mV
Maximum power voltage: ~500 mV

MPP tracking integrated in BQ25505

Energy Harvesting Process for Solar

Using BQ25505



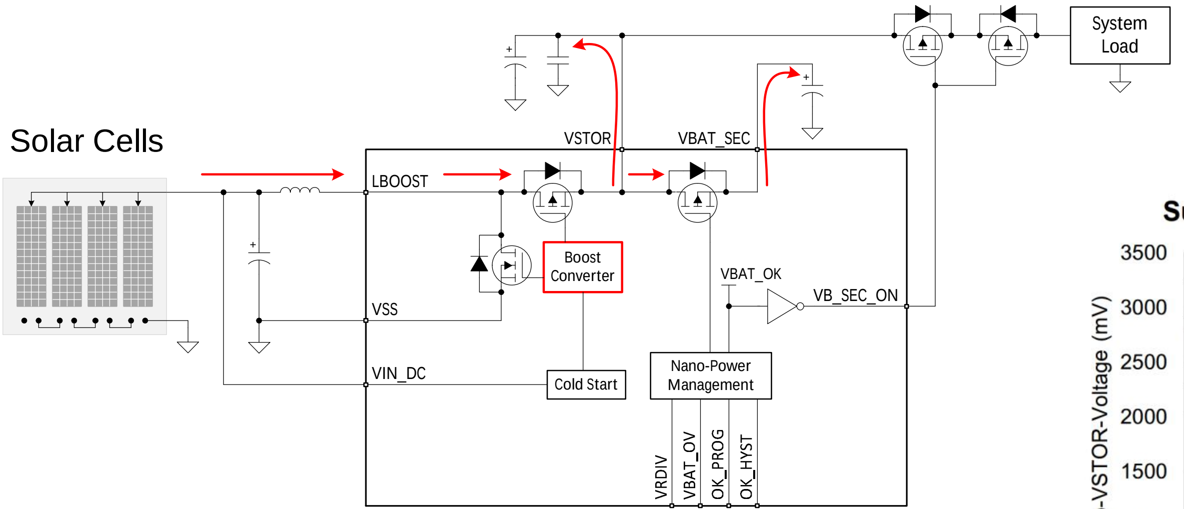


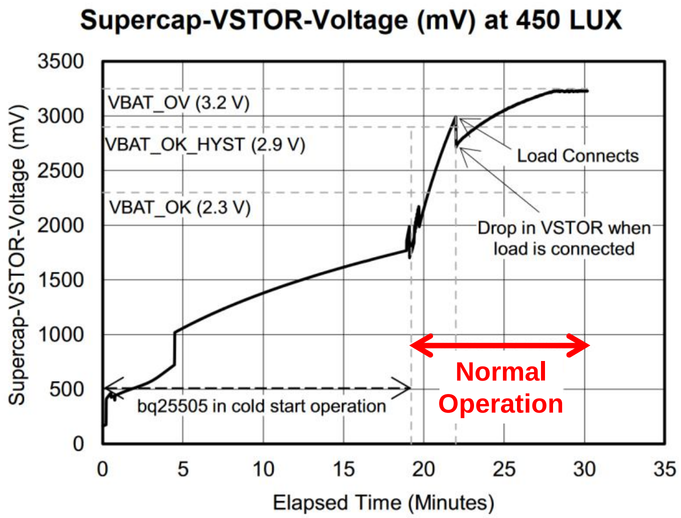
Cold Start: At startup, device runs in cold start mode until 1.8V.

Energy Harvesting Process for Solar

Using BQ25505

Solar Cells

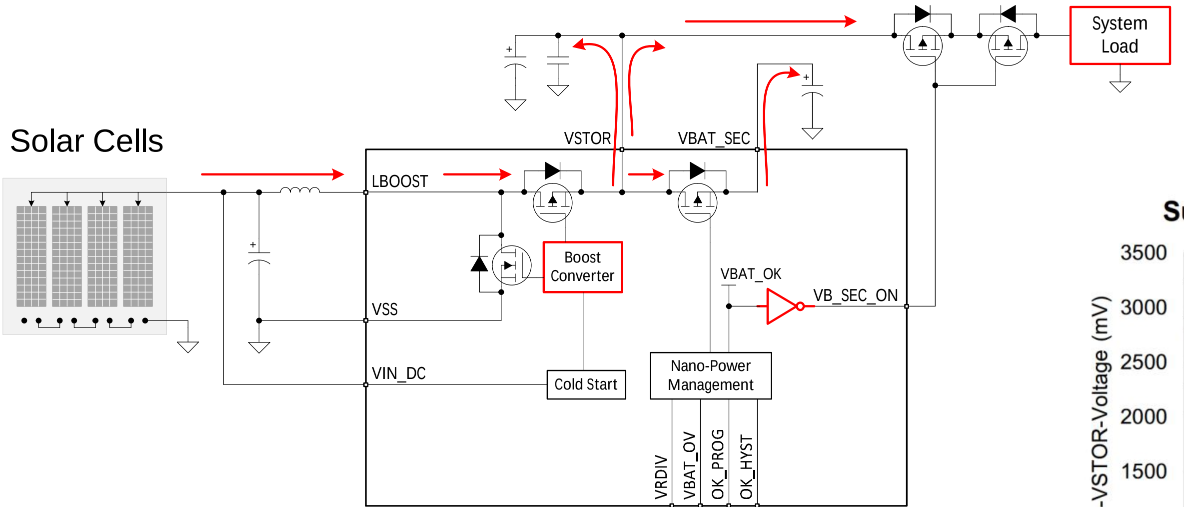


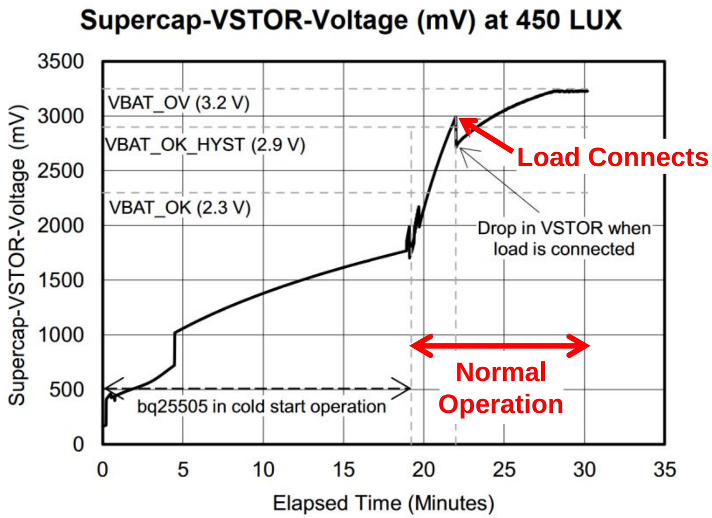


Normal Operation: After capacitor is at the 1.8V threshold, device enters normal boost operation.

Energy Harvesting Process for Solar

Using BQ25505



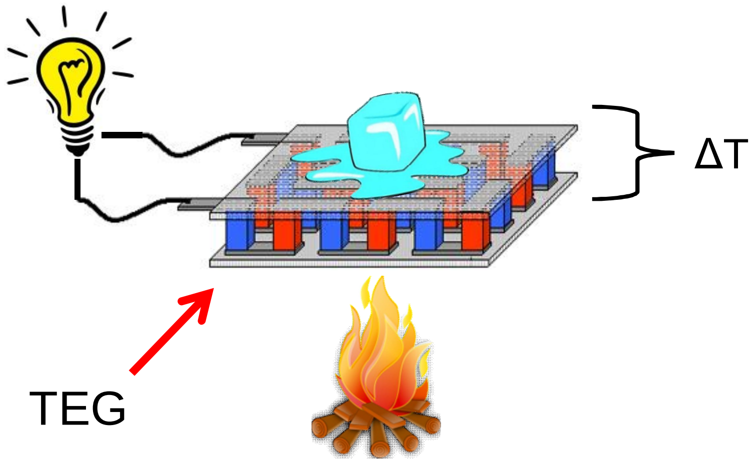


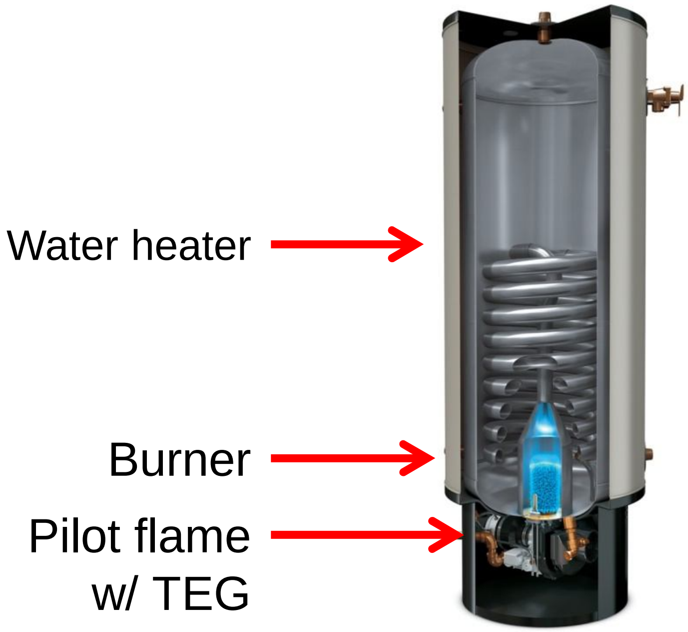
Load Connects: When the voltage reaches VBAT_OK_HYST at 2.9V (adjustable), the load connects and BLE beacon application begins.

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 (ΔT) 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
Total				**1,000.0**	**185.7**

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

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

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

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

TI Designs Number: TIDA-00488

TIDesigns

Solution Features

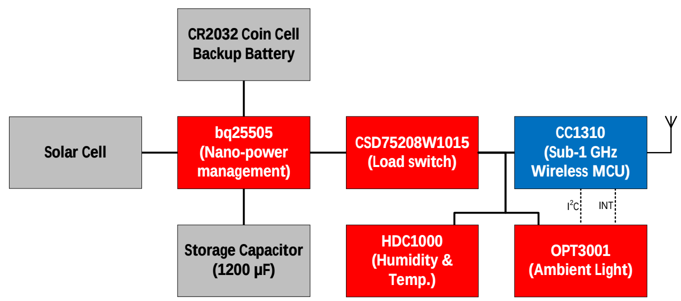
- Runs entirely from solar energy when LUX level is sufficient
- Supports interrupt mode triggered by indoor LUX levels
- Precision Optical Filtering to Match Human Eye (±0.01 Lux Light Accuracy)
- ±2% Relative Humidity Accuracy
- ±0.2°C Temperature Accuracy

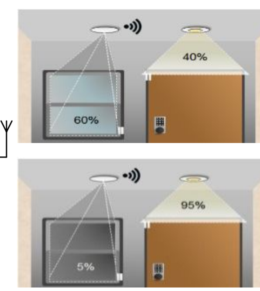
Solution Benefits

- 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

Tools & Resources

- **TIDA-00488 Tools Folder**
- **User Guide**
- **Device Datasheets**:
  - BQ25505
  - OPT3001
  - HDC1010
  - CC1310
  - CSD75208W1015





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