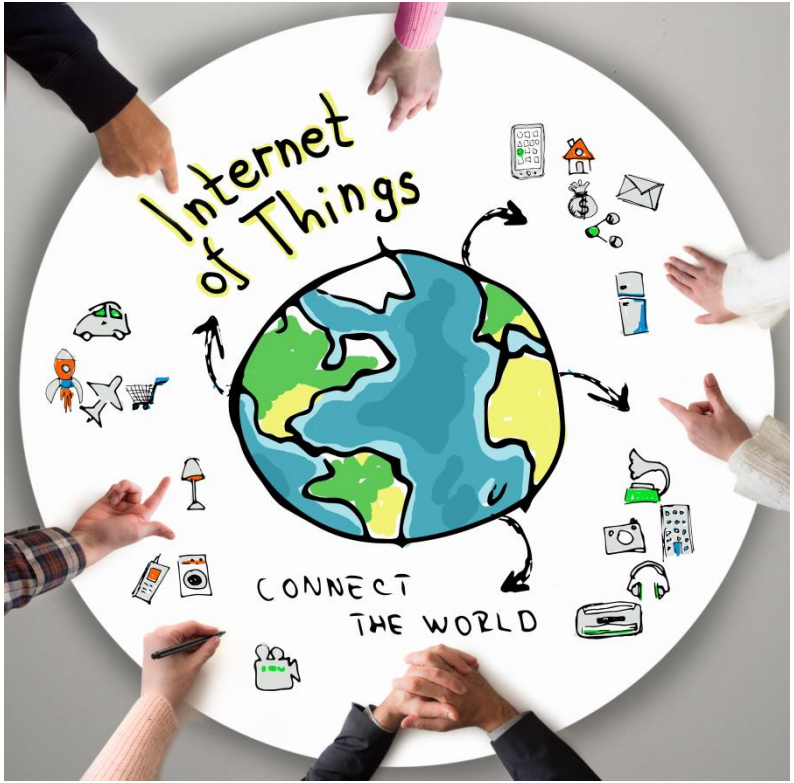
Energy Efficient Building Automation Solutions using Innovative Wireless Sensing and Predictive Maintenance

Miro Oljaca

Adam Yager

50 Billion Objects Connected by 2020



TI Information – Selective Disclosure

Sensors in Technology

Temperature

Temp. Sensors	Passive Infrared
Temperature & Humidity	

Current/Power

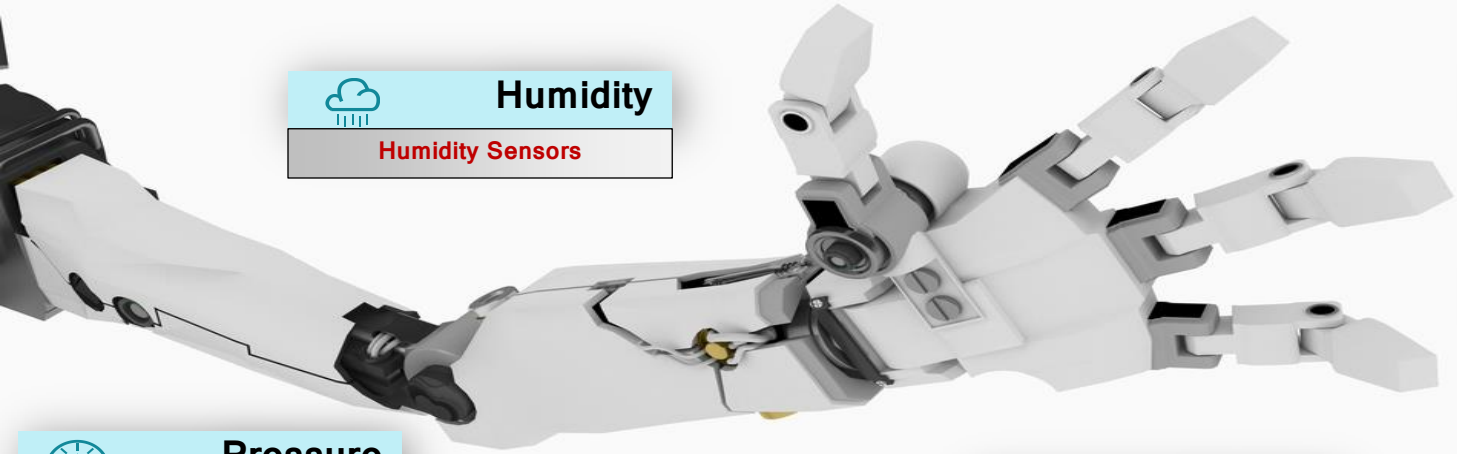
Current Shunt	Magnetic

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

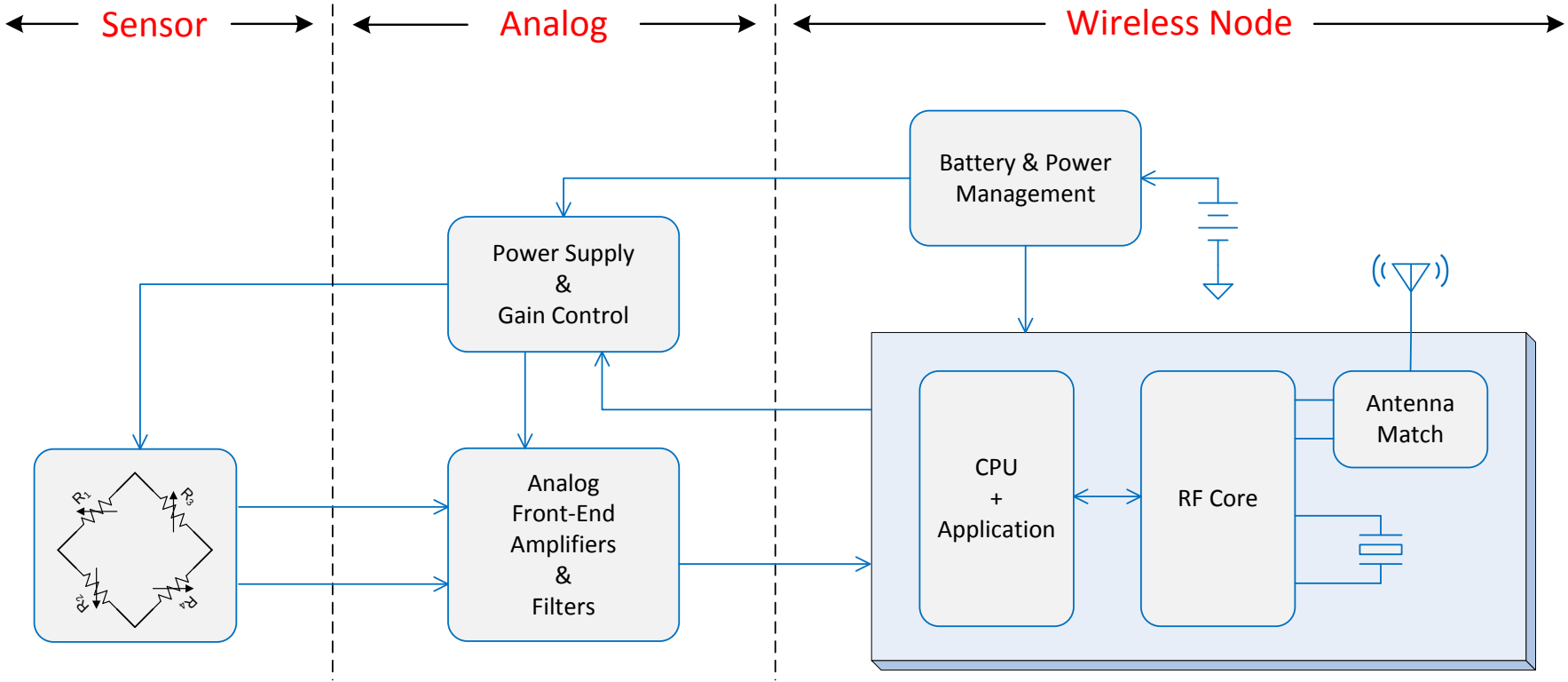
Position

Ultrasonic	Hall Effect
Inductive	Optical
Current Shunt	Capacitive

Biosensing

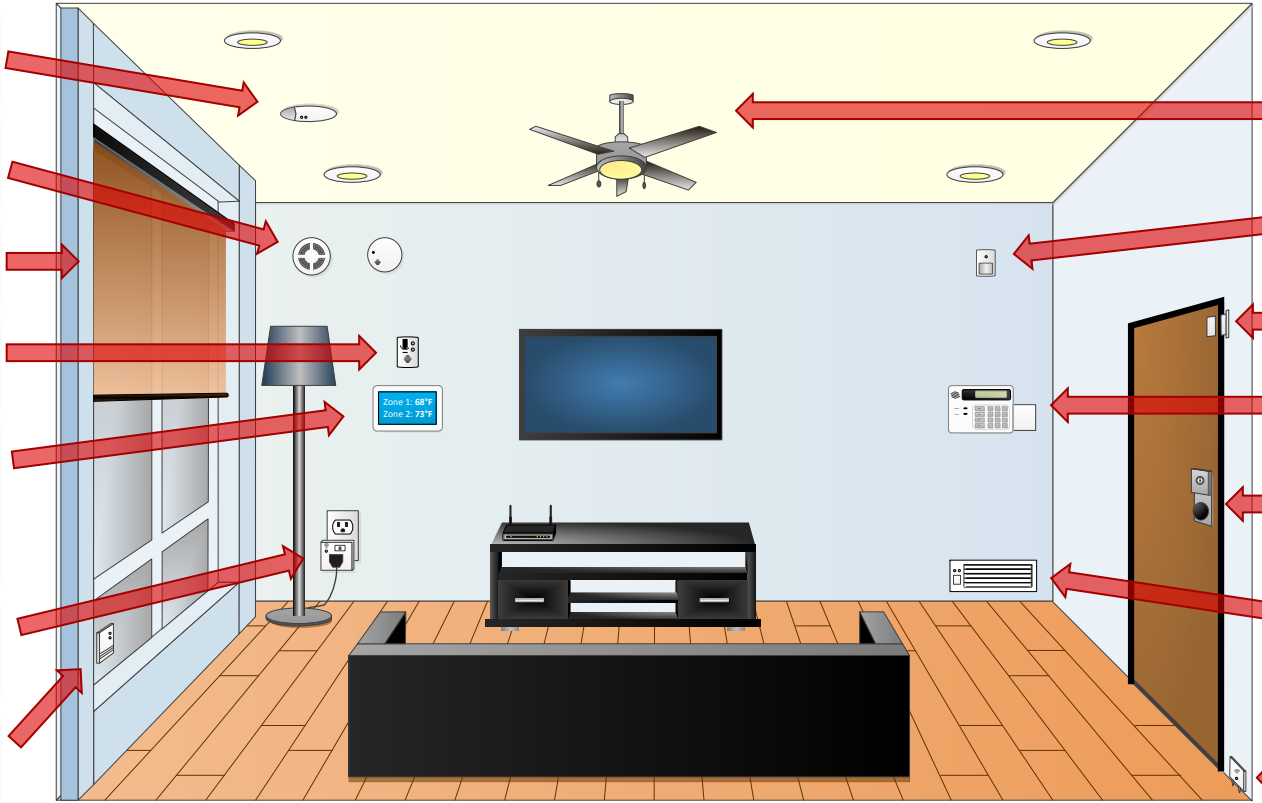
Pulse Rate	Pulse Oximetry
Body Composition	Bio Potential
Optical Scanning (DLP)	

Example Sensor Nodes



TI Information – Selective Disclosure

Building Automation TI Designs Map



Daylight Harvester
TIDA-00488 TIDA-00100
TIDA-00758

Gas Detector
TIDA-00056 TIDM-1CHP-
TIDA-00756 TIDA-00378

Automated Window Blinds
TIDA-00757

Voice or Speech Recognition
TIDEP0066 CC2650RC
MSP-SR

Thermostat
TIDA-00751 KNX-TSTAT
FRAM-TSTAT TIDA-00754

Environmental Sensor
TIDA-00374 TIDA-00484

Smart Plug
TIDC-CC3200SMARTPLUG
TIDC-SMARTPLUG-WIFI

Glass Break Detector
TIDM-GBD-Robust

Gateway
TIEP-SMART-ENERGY-GATEWAY
TIDC-CHN

Automated Ceiling Fan
TIDA-00386
TIDA-00757

Motion detector
TIDA-00489
TIDA-00759

Door and Window Sensor
slyy058

Intrusion HMI Keypad
TIDEP0015 TIDA-00560
TIDA-00754 TIDA-00509

Electronic Lock
TIDA-00757

Wireless Vent / Damper
TIDA-00757
TIDA-00250

Water Leak Detector
<TIDA-00374>

TI Information – Selective Disclosure

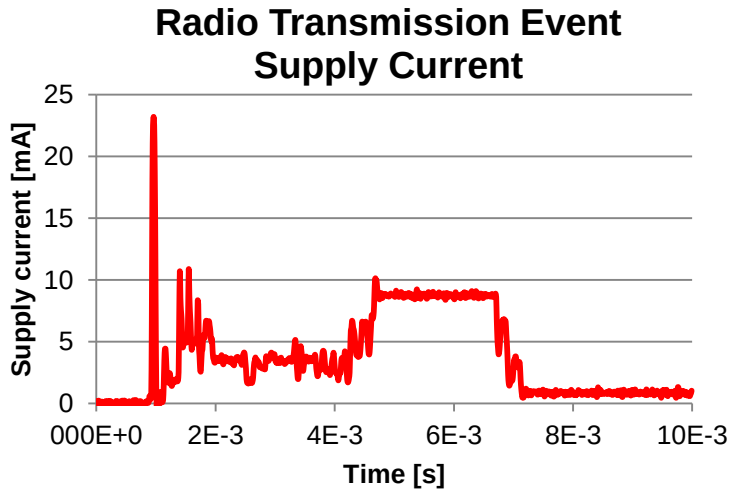
Battery Efficiency

- Wireless connectivity (2.4-GHz, Sub 1-GHz) will determine energy requirements from the energy source
- Obtaining a 10 year battery life requires careful consideration of analog and wireless design
- Energy harvesting can supplement and extend battery life. Solar harvesting is most commonly used as an additional energy source. TEG is another energy source that can be used as a supplement to battery life.
- Two types of sensor node designs can be distinguished depending on the application: always-on and interrupt-driven

TI Information – Selective Disclosure

Wireless Connectivity Power Requirements

		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



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:

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

TI Information – Selective Disclosure

10 Years on a Coin Cell Battery

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.

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**

10 Years on a AA battery

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.

<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**

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

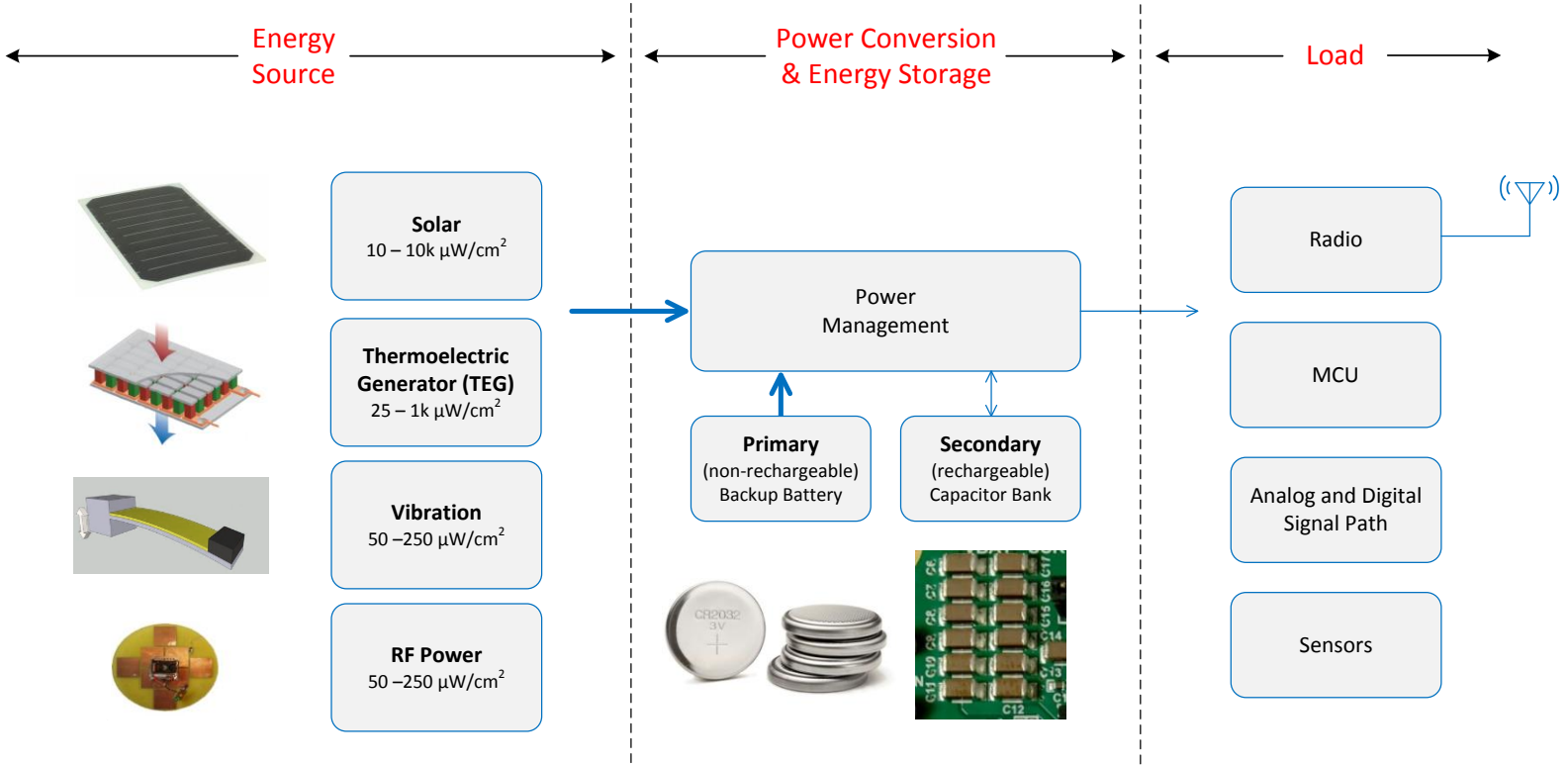
	Current	Voltage	Power	Time	Energy
Event	**mA**	**V**	**mW**	**ms**	**µW s**
Wake-up	32	3.1	99.2	0.2	19.9
Pre-Proc.	7.5	3.1	23.3	0.6	14.0
Rx	7.5	3.1	23.3	0.4	9.3
Tx	20	3.1	62	0.6	37.2
Processing	7.5	3.1	23.3	1.4	32.6
LED Blink	0.45	3.1	1.4	50	69.8
Sleep Mode	0.001	3.1	0.003	946.8	2.9
Total				**1,000.0**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

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

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

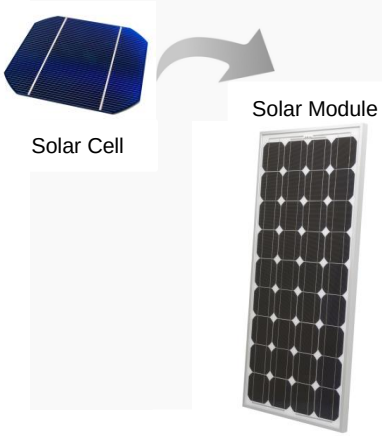
$$I_{AVG} = P_{AVG}/V = 186\ \mu W/3.1\ V = \mathbf{60\ \mu A}$$

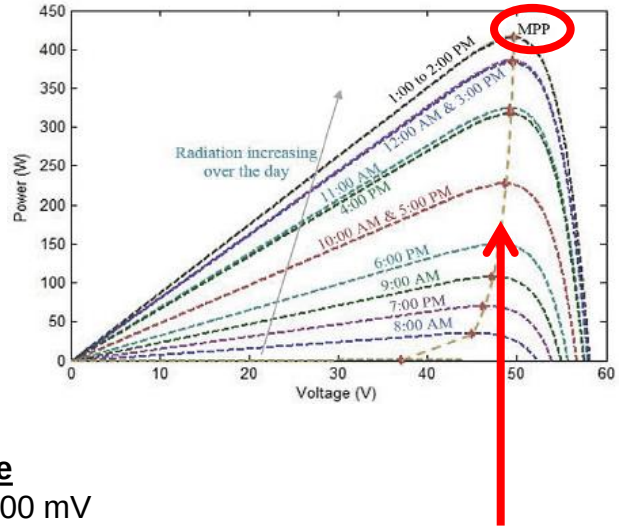
Supplementing Batteries with Energy Harvesting



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

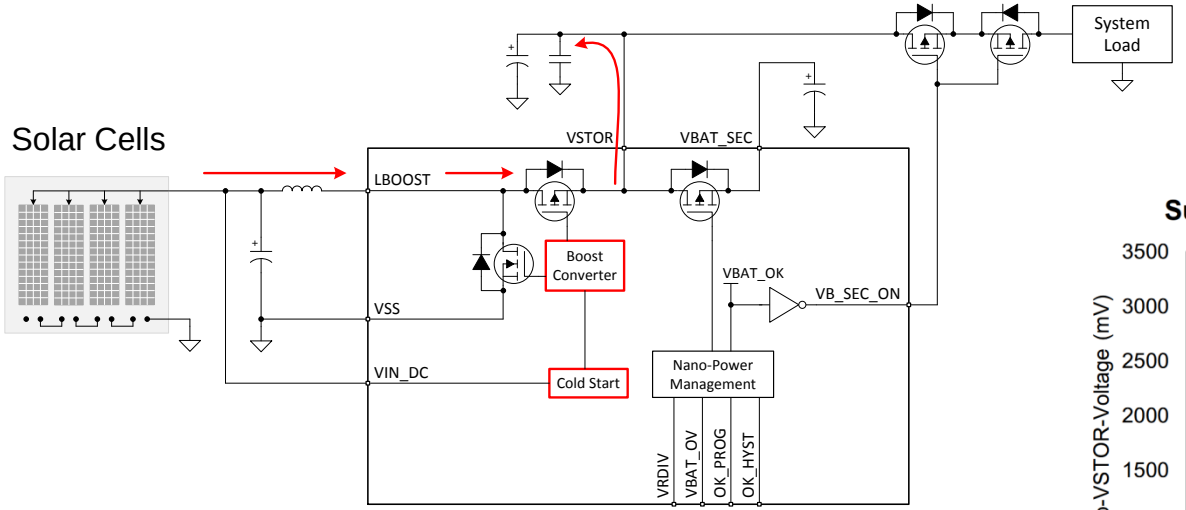
Open circuit voltage: ~600 mV

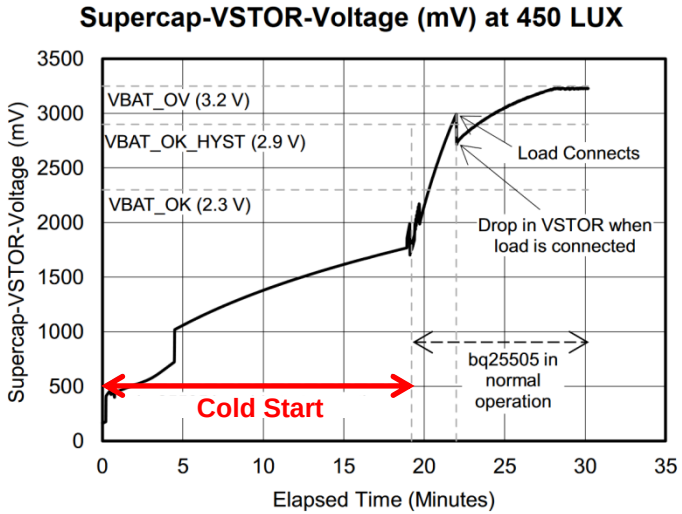
Maximum power voltage: ~500 mV

MPP tracking integrated in BQ25505

Energy Harvesting Process for Solar

Using BQ25505

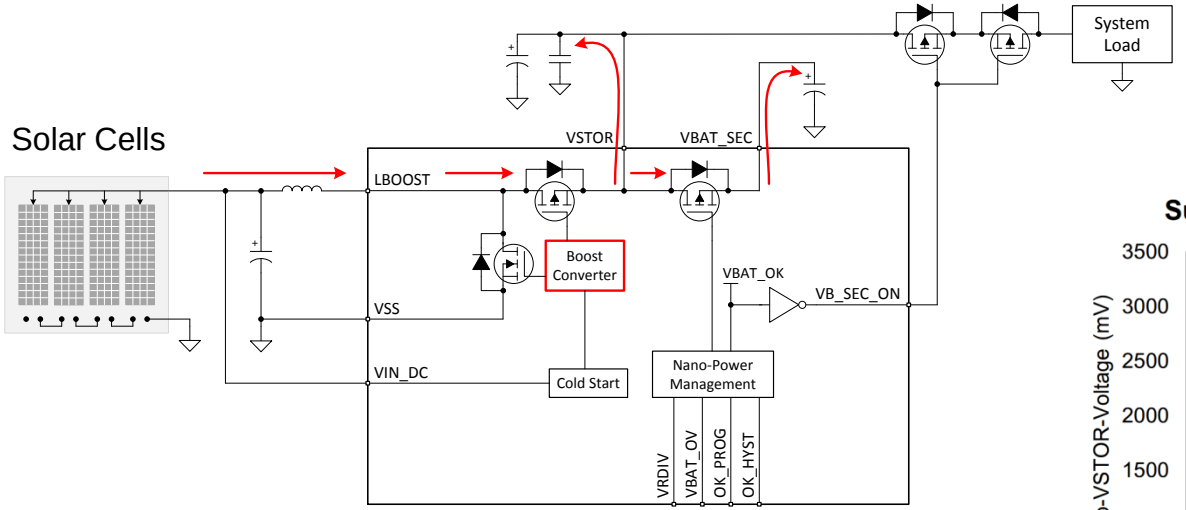


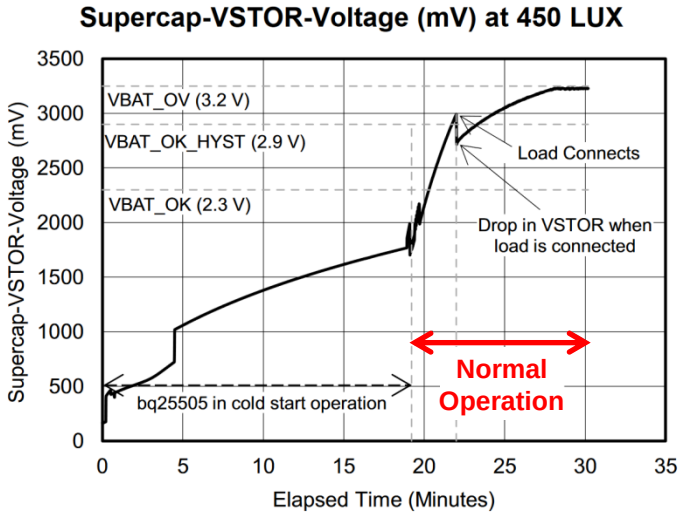


Cold Start: At startup, device runs in cold start mode until 1.8V.

Energy Harvesting Process for Solar

Using BQ25505

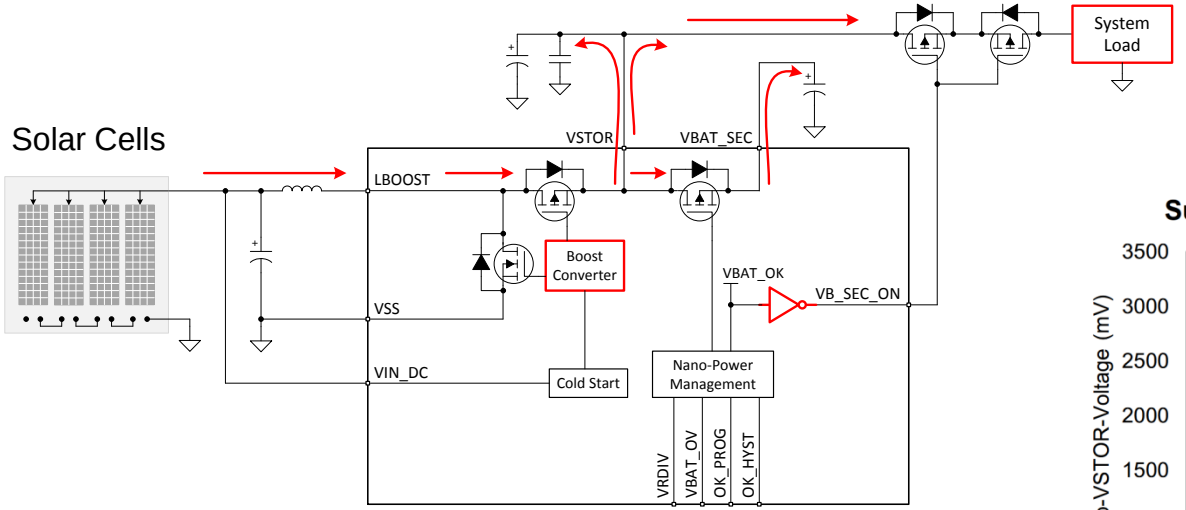


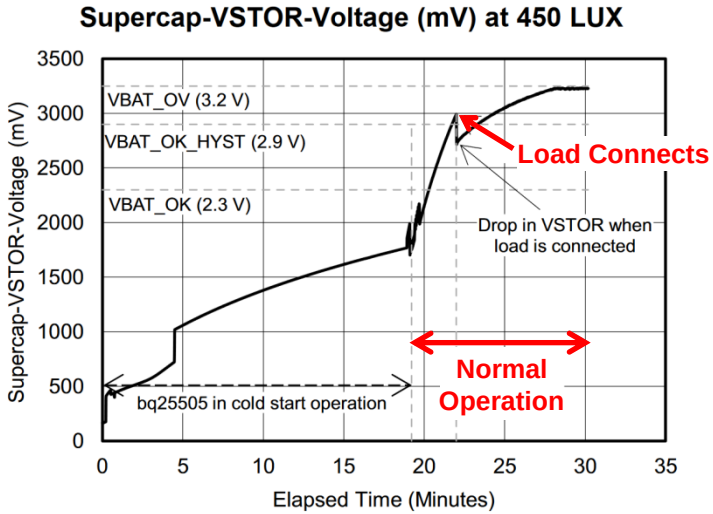


Normal Operation: After capacitor is at the 1.8V threshold, device enters normal boost operation.

Energy Harvesting Process for Solar

Using BQ25505



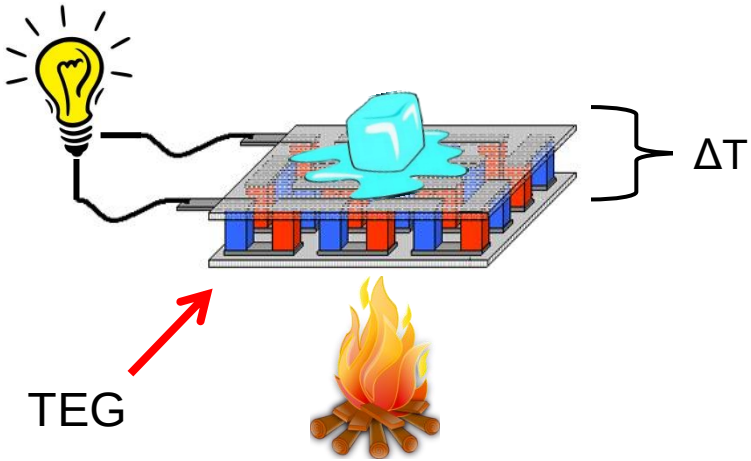


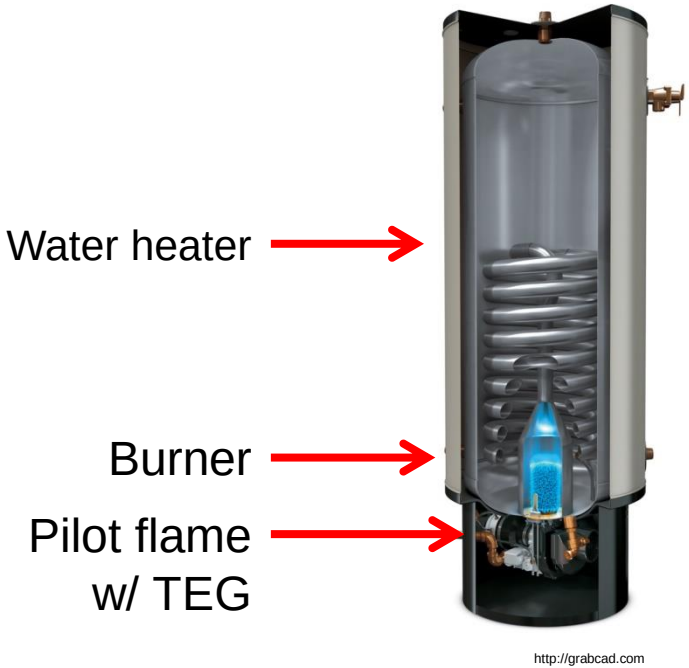
Load Connects: When the voltage reaches VBAT_OK_HYST at 2.9V (adjustable), the load connects and BLE beacon application begins.

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





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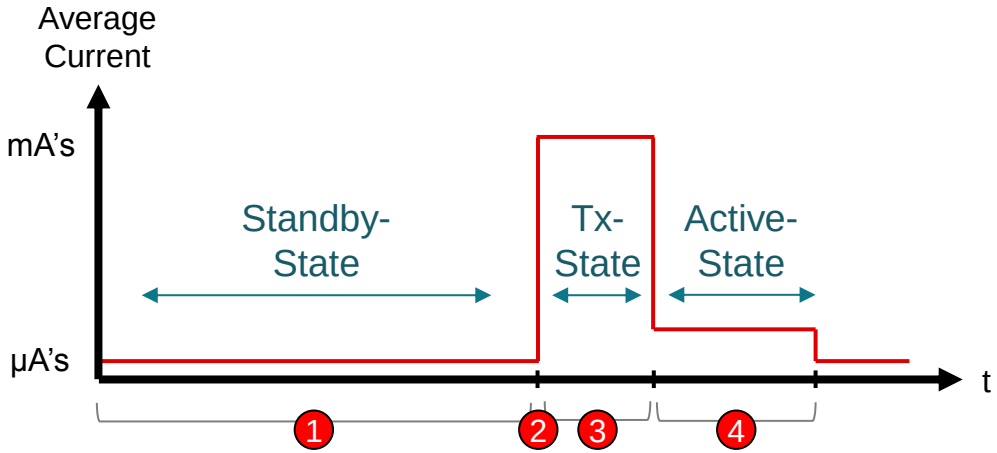
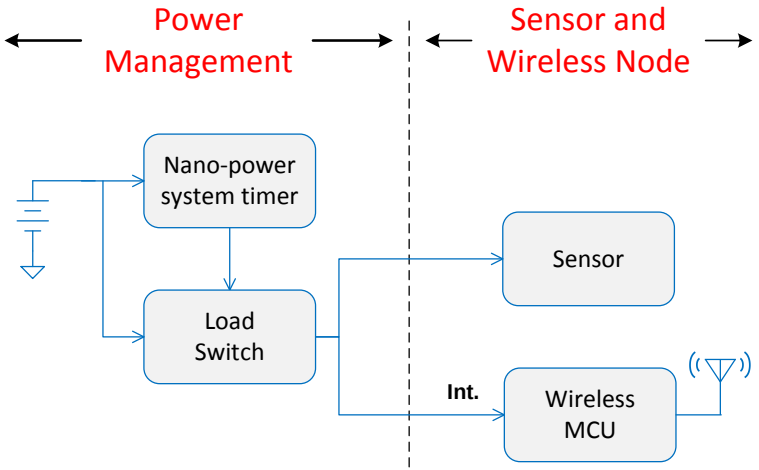
Analog System Requirements

Always-on Sensing





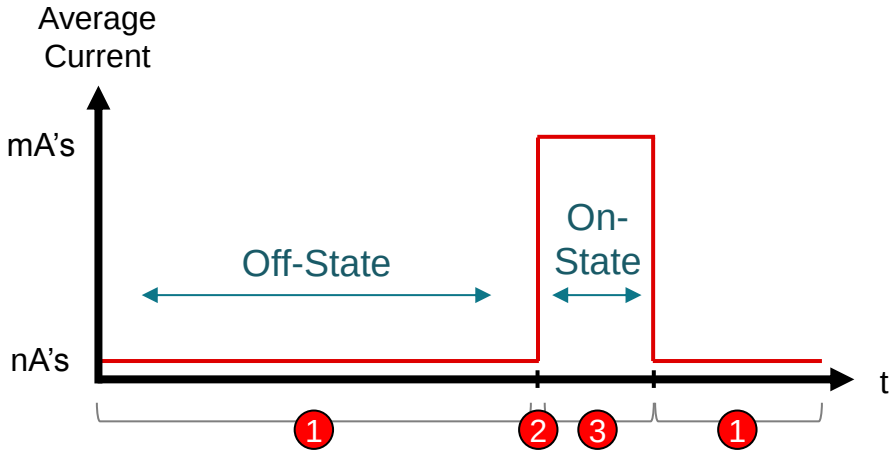
1. Radio hibernates, AFE monitors for an interrupt
2. During interrupt event, radio wakes up
3. Get sensing data, process, then transmits
4. Waits for inactivity, then go to sleep

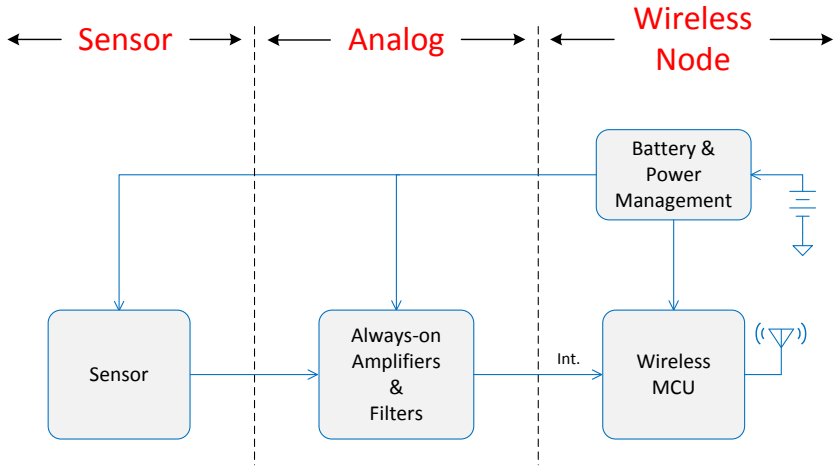
TI Information – Selective Disclosure

*Graph not to scale

Analog System 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

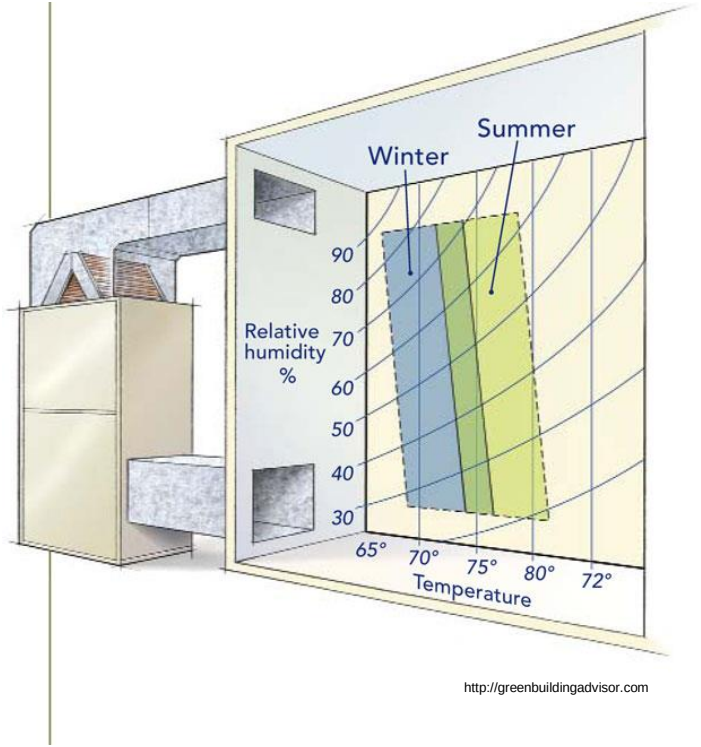
Texas Instruments

HVAC System Efficiency

- Comfort level depends on the combination of temperature and relative humidity
- For acceptable indoor air quality, minimum airflow per person needs to be maintained
- Information on the amount of people in a room anticipates the required supply for air flow
- Having temperature, relative humidity, and air flow will help run the HVAC system efficiently while keeping comfort level high

TI Information – Selective Disclosure

Building Comfort Level Sensing

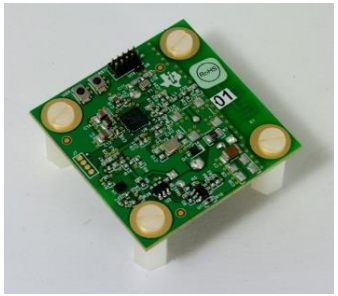


http://greenbuildingadvisor.com

An optimal comfort level is a function of **both** temperature and humidity parameters. To achieve this comfort level, measuring these parameters in each zone or room is vital.

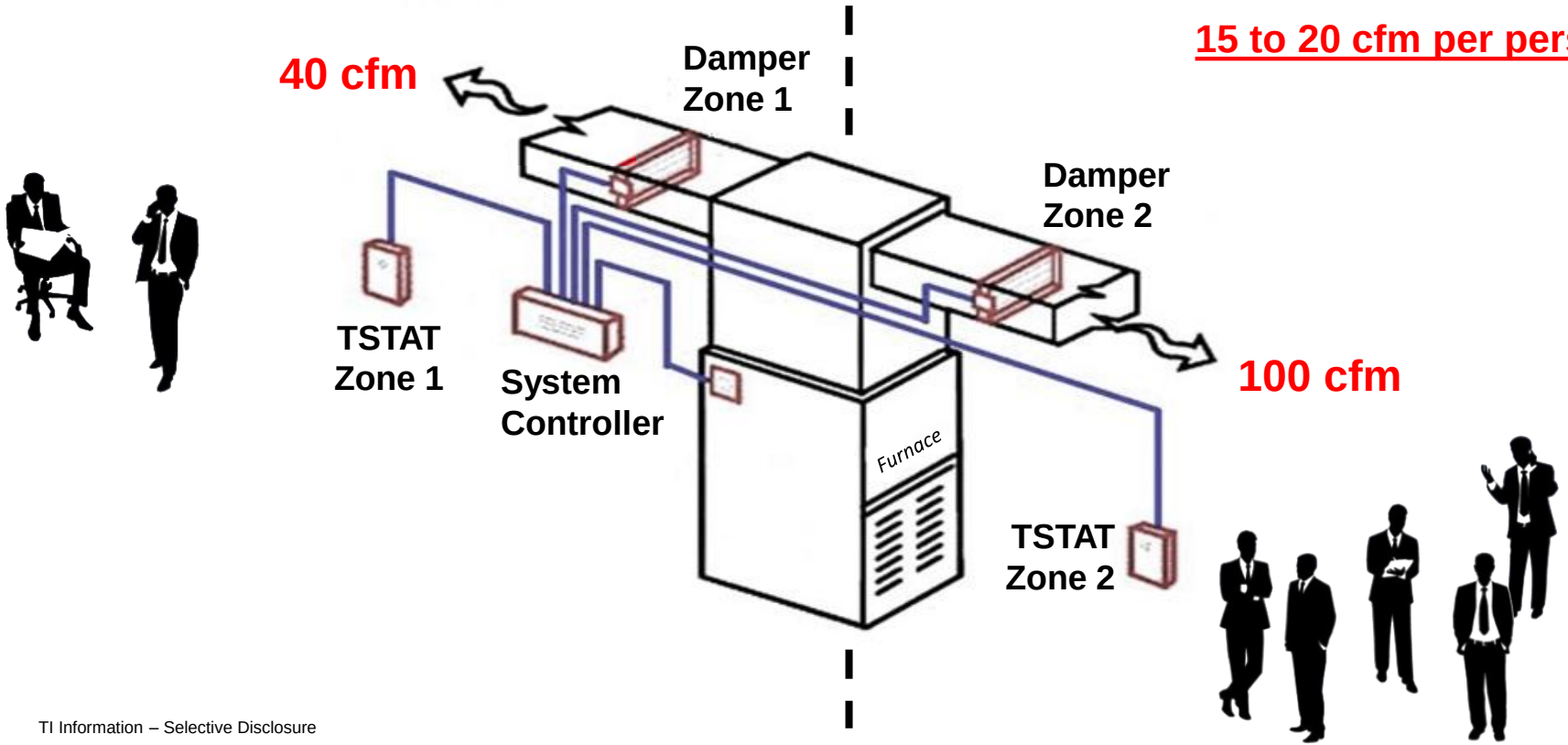
A humidity and temperature sensor node **TI Design** features:

- ±2% Relative Humidity Accuracy
- ±0.2% Temperature Accuracy
- 10+ year battery life from CR2032 based on interrupt-driven sensing
- Configurable system wakeup
- Wireless communication



TIDA-00374

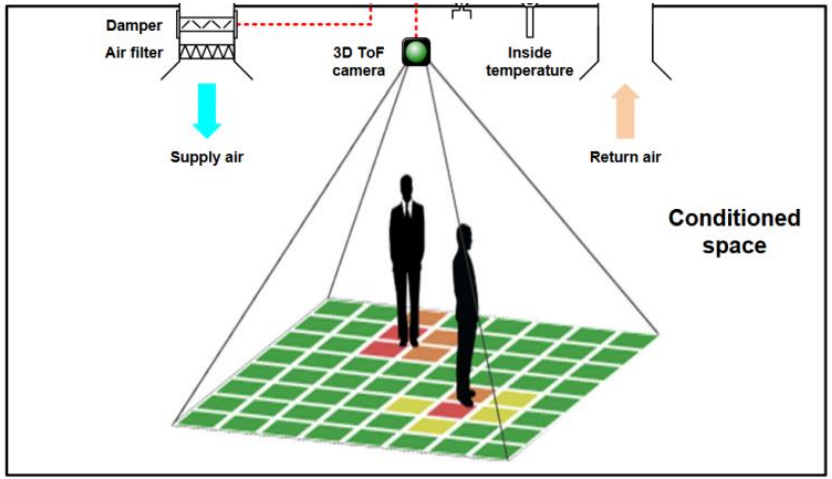
Air Flow Control using Zone Dampers

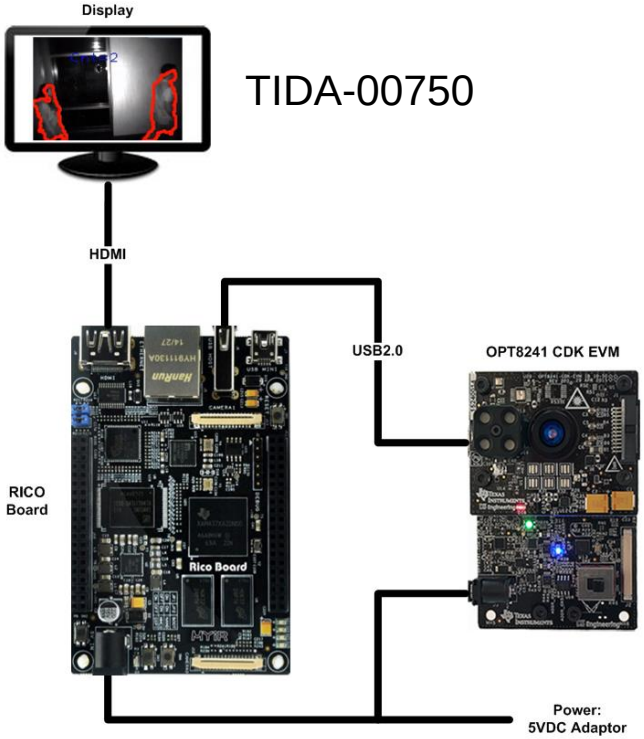


CFM: cubic feet per minute

People Counting Detector for DCV

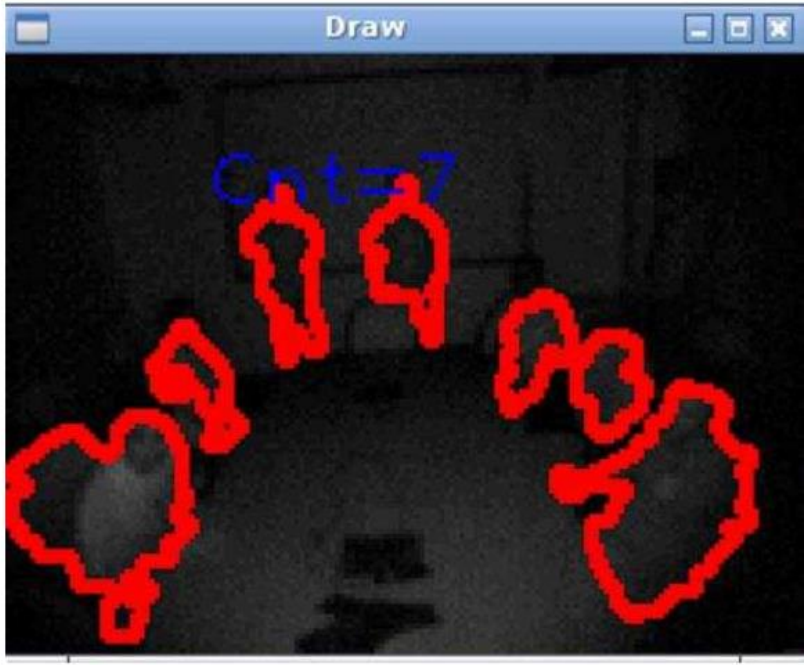
A demand controlled ventilation (DCV) system adjusts outside ventilation air based on the number of occupants rather than based on the max number of occupants





People Counting Detector for DCV measurement

Conference room with
6 people



Tracking algorithm output
from **TI Design**

TI Information – Selective Disclosure

Preventive Maintenance & Predictive Maintenance

- Preventive maintenance is the inspection, detection, and correction of developing failures either before they occur or before they develop into major defects

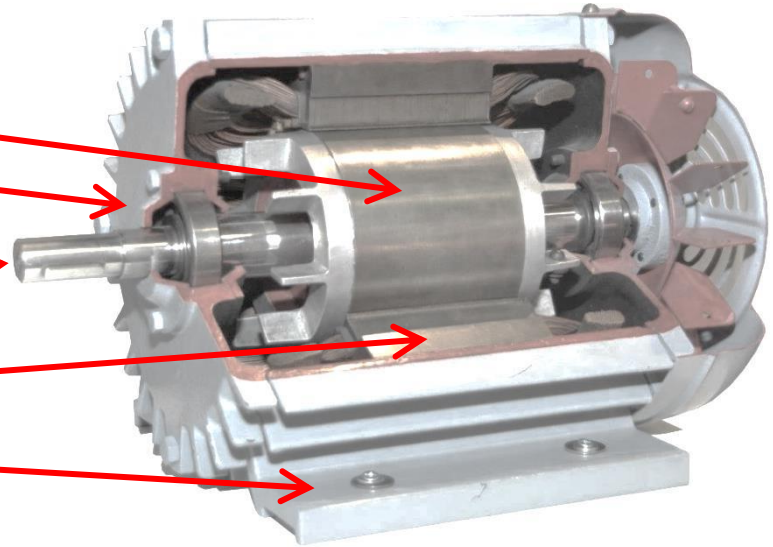
- To prevent equipment and machinery breakdown; tests, measurements, adjustments, parts replacement, and cleaning are specifically performed

- Smart ecosystem integration
  - Record Measurement data
  - Analyze trends
  - Diagnose problems
  - Anticipate future malfunction

Motor Drive Preventive Maintenance

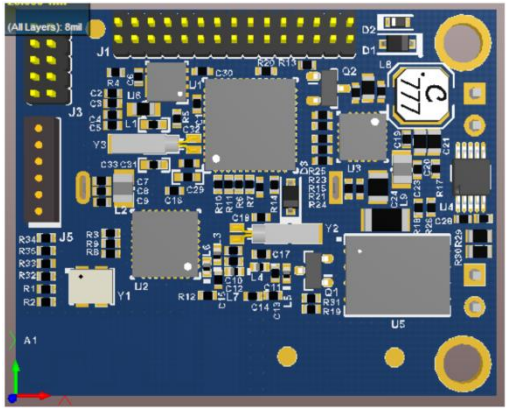
- Monitoring the health of the motor can help **prevent unplanned downtime** by detecting **early warning signs** of needed maintenance or replacement

- Source of motor problems:
  - Shorted rotor bars.
  - Damaged bearings.
  - Oil whirl and whip in bearings.
  - Motor unbalanced.
  - Eccentricity failure.
  - Bent or misaligned shaft.
  - Loose stator laminations.
  - Looseness of stator support.
  - Mechanical looseness.

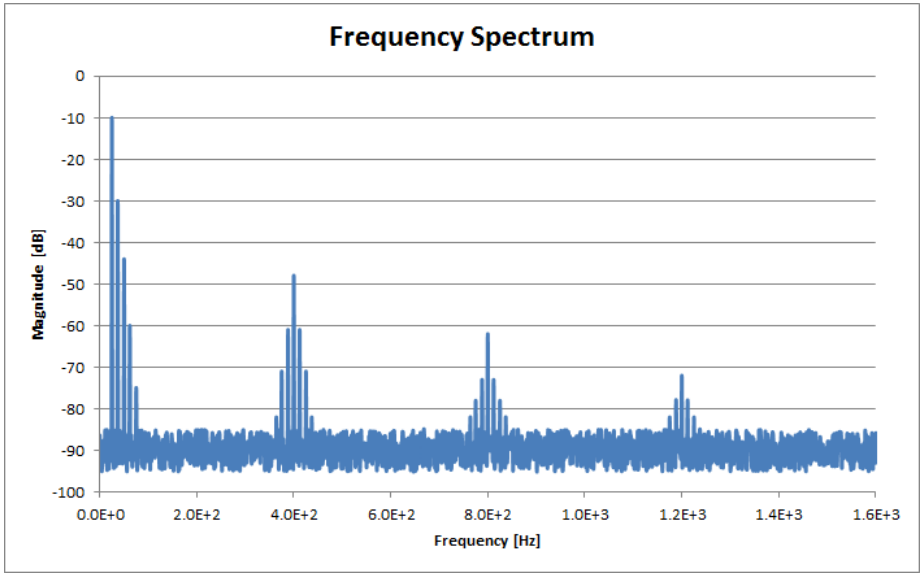


Motor Drive Vibration Measurements

Motor drive vibration measurement **TI Design** monitors the health of motors to accurately predict and schedule maintenance (or replacement) while minimizing costs and down time during industrial production.

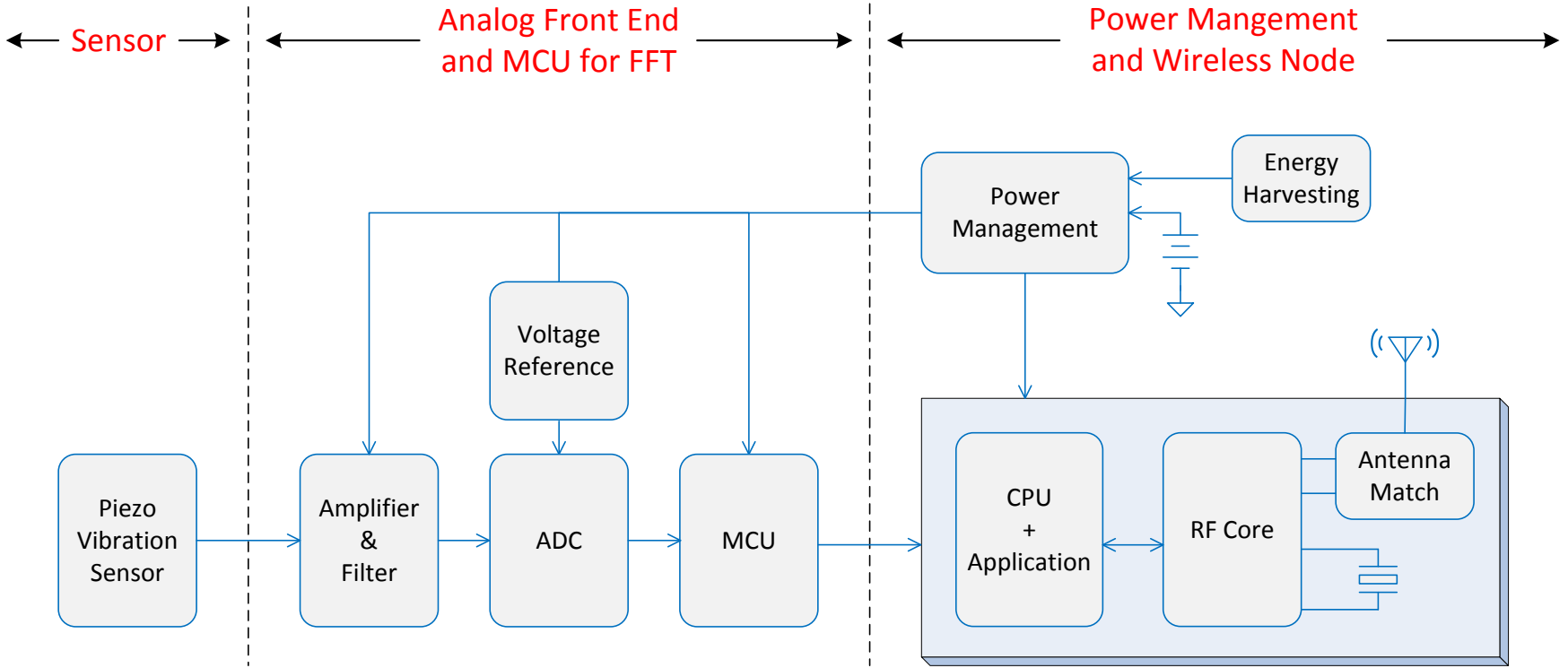


TIDesigns

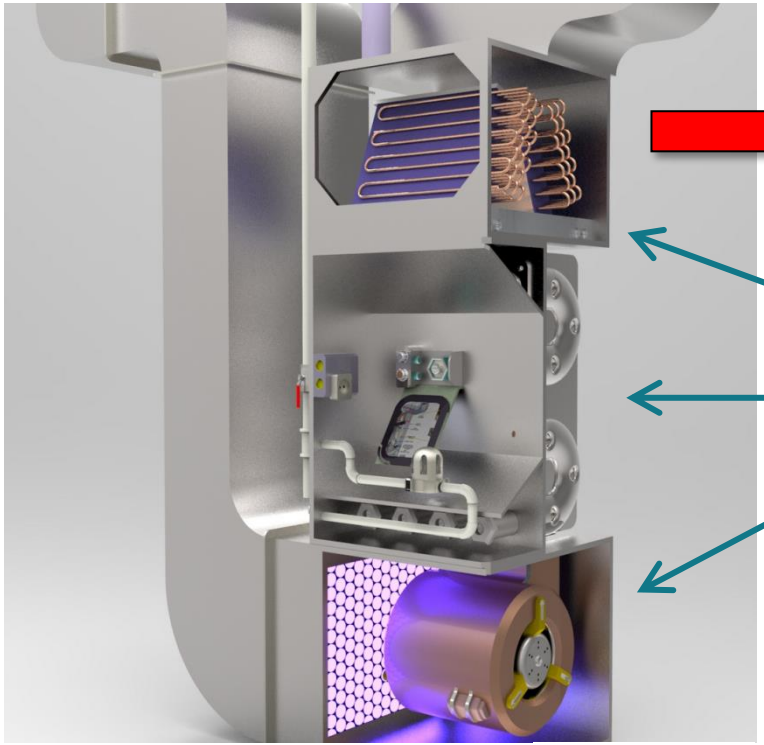


Texas Instruments

Motor Drive Vibration Measurements (cont.)



HVAC Evaporator Coil Preventive Maintenance



Coil

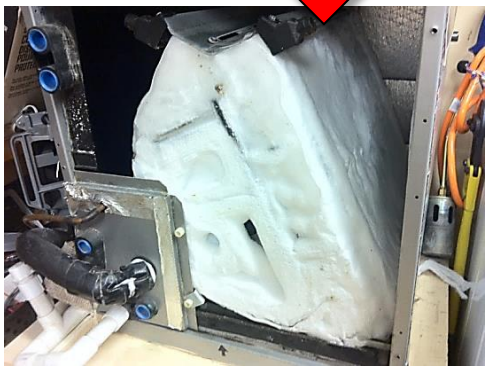
Heater

Blower

http://grabcad.com

Dirty Coil

Frozen Coil



http://imgur.com/Xb7z3.jpg

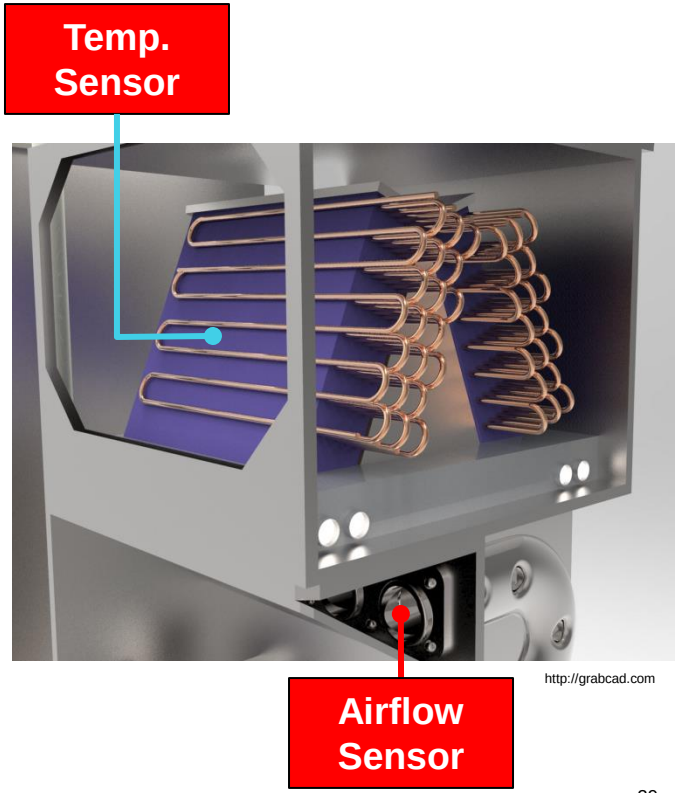
HVAC Evaporator Coil Health Measurements

Solution

- Airflow sensor attached to bottom of coil measures air velocity into coil fins
- Temperature sensor located above coil fins
- In a **TI Design**, compressor cut-off switch based on sensor output prevents freezing

Benefits

- Potentially save money on filters if your system is infrequently utilized
- Customer knows when coil is becoming obstructed, increasing issue awareness
- Energy saving focused design
- Easy AC tech diagnosis based on MCU output

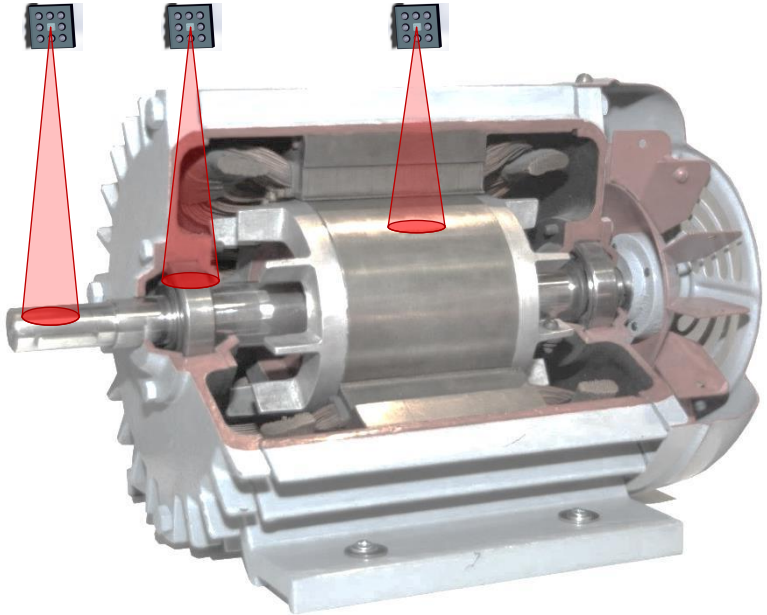


http://grabcad.com

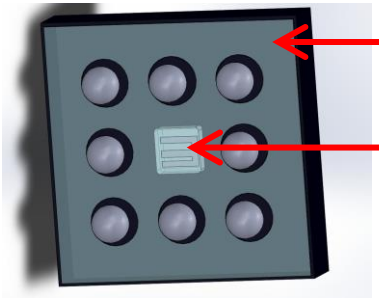
TI Information – Selective Disclosure

Non-Contact Temperature Measurement

Monitoring the health of the motor can help **prevent unplanned downtime** by detecting **early warning signs** of needed maintenance or replacement. Rotor and stator temperature are of concern in both **short-term machine protection** and in **long-term condition monitoring**. As stator temperature is easy to measure, rotor bearings and shaft temperature is more difficult to measure.



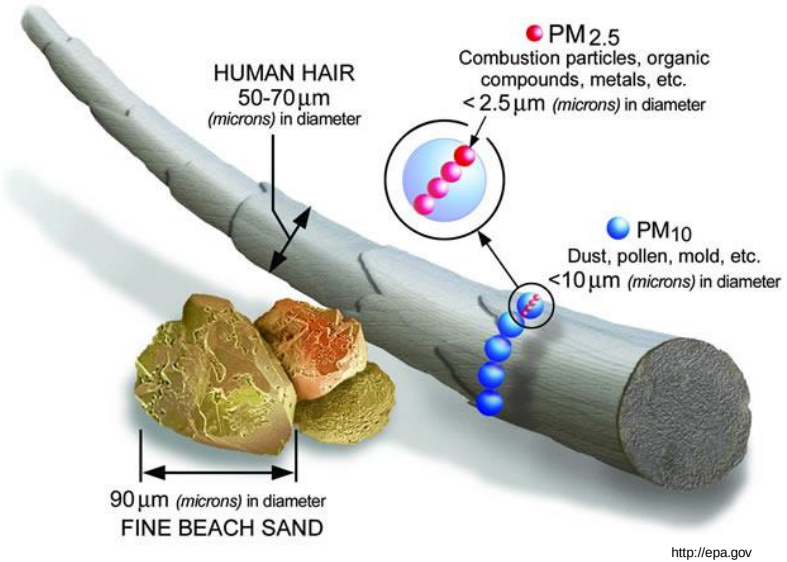
TMP007



Die body is the cold junction

Thermal piles absorb **IR** (sensor area is 330 um x 330 um)

Air Quality Index (AQI) and Particle Pollution



http://epa.gov

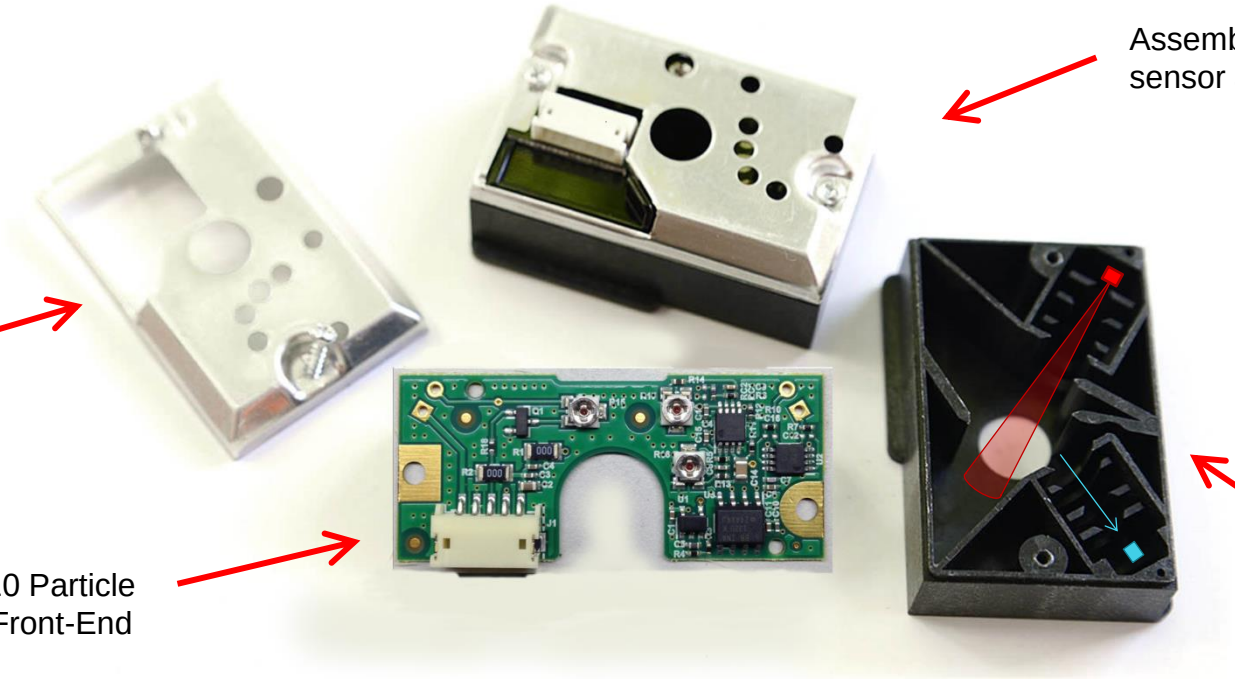
An air quality index (AQI) is a number used by government agencies to communicate to the public current and future air pollution levels.

Based on eight pollutants (**PM10**, **PM2.5**, NO2, SO2, CO, O3, NH3, and Pb).

AQI	$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	Air Quality Descriptor
0–50	0.0–15.4	0–54	Good
51–100	15.5–40.4	55–154	Moderate
101–150	40.5–65.4	155–254	Unhealthy for Sensitive Groups
151–200	65.5–150.4	255–354	Unhealthy
201–300	150.5–250.4	355–424	Very unhealthy

http://spacemath.gsfc.nasa.gov

AQI and Particle Pollution Sensor Design



Assembled
sensor and chamber

Chamber
cover

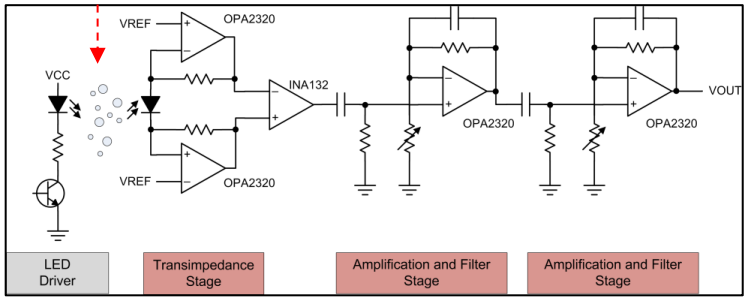
PM2.5 and PM10 Particle
Sensor Analog Front-End
TI Design

Chamber with
LED and optical
detector

TI Information – Selective Disclosure

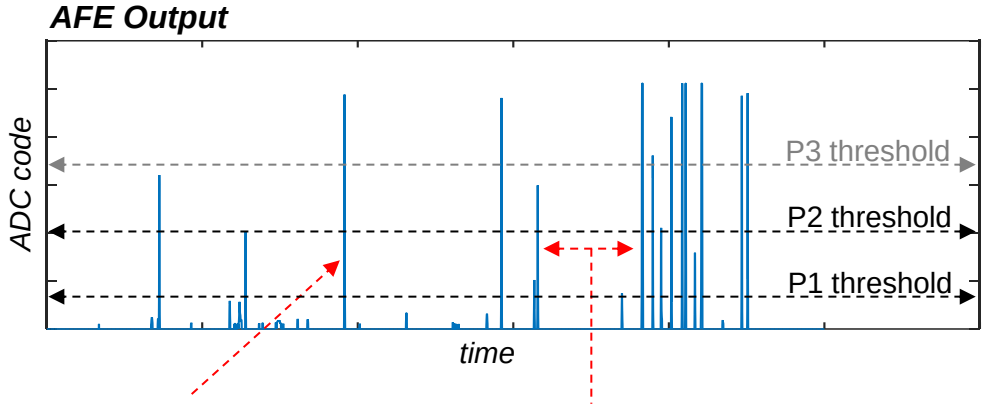
AQI and Particle Pollution Analog Front End

1. As particles flow through sensor, scattered light gets picked up by photodiode.



2. AFE converts photodiode output current to voltage, amplifies signal, and filters signal.

3. Microprocessor digitizes AFE analog signal. AFE output looks like series of pulses.



4. Pulse amplitude is related to particle size. Amplitude thresholds used to detect different particle sizes.

5. Pulse spacing (frequency) is related to particle concentration.

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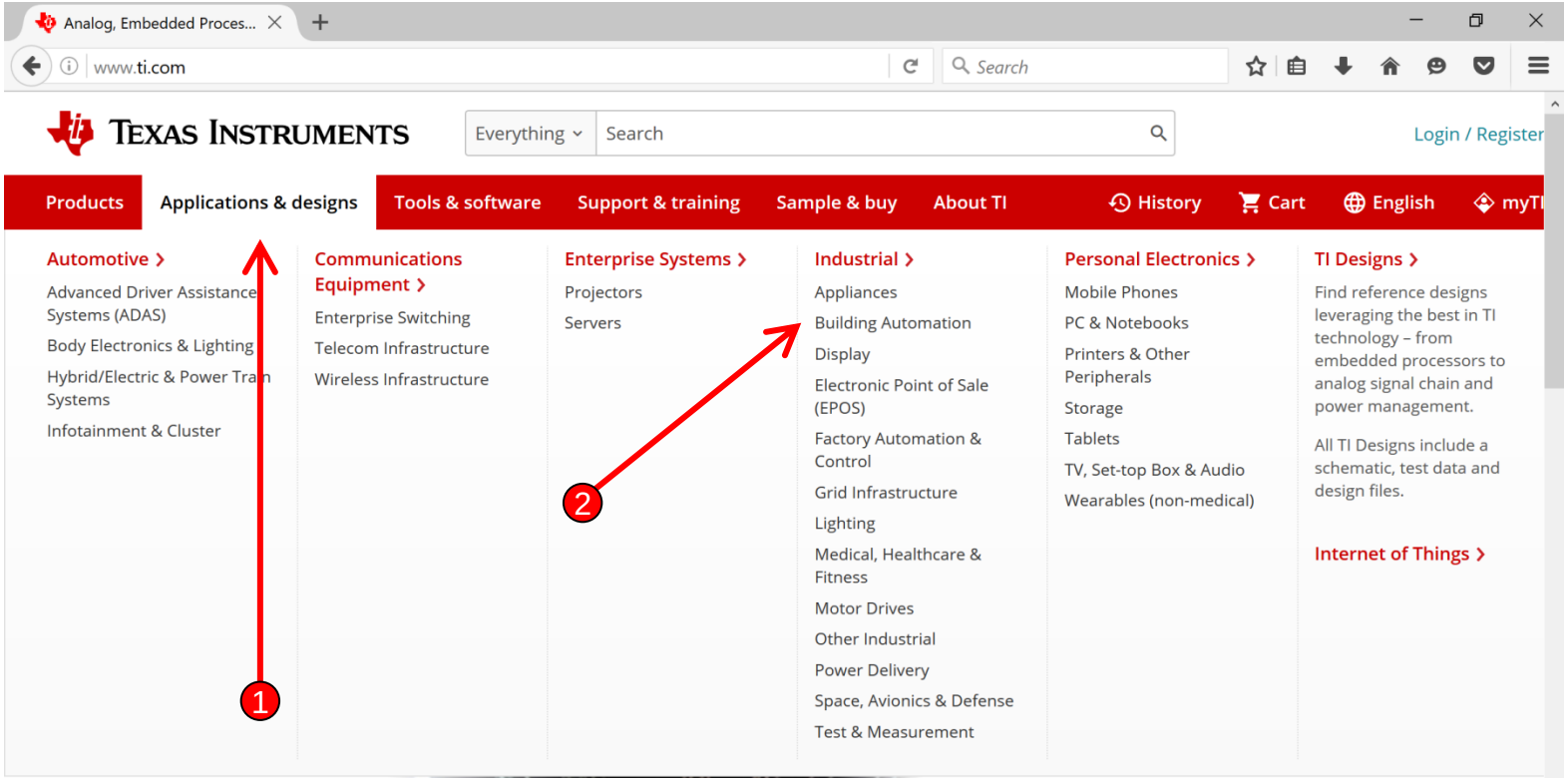

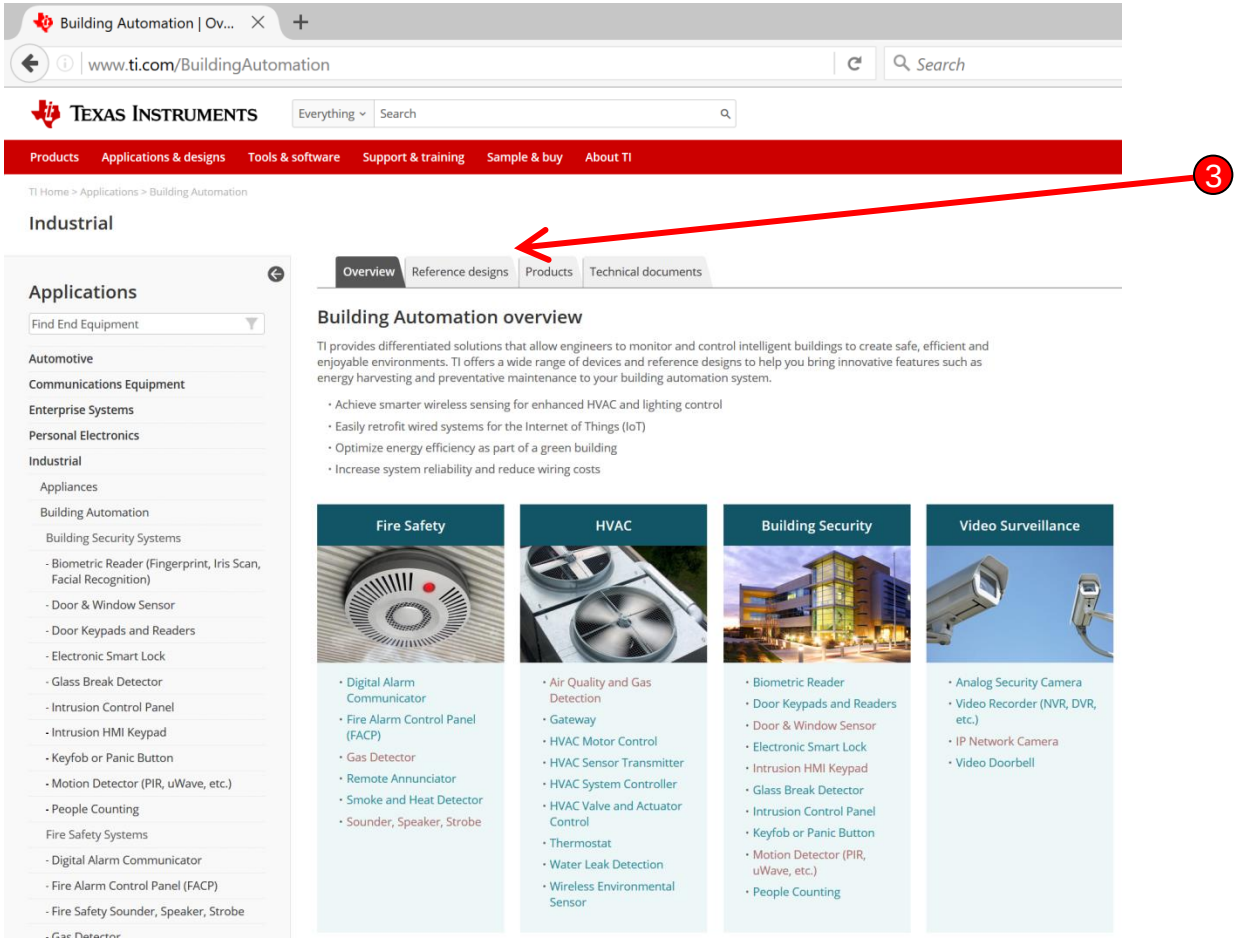
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Building Security Systems
- Biometric Reader (Fingerprint, Iris Scan, Facial Recognition)
- Door & Window Sensor
- Door Keypads and Readers
- Electronic Smart Lock
- Glass Break Detector
- Intrusion Control Panel
- Intrusion HMI Keypad
- Keyfob or Panic Button
- Motion Detector (PIR, uWave, etc.)
- People Counting
Fire Safety Systems
- Digital Alarm Communicator
- Fire Alarm Control Panel (FACP)
- Fire Safety Sounder, Speaker, Strobe
Overview
Reference designs
Products
Technical documents
Building Automation overview
TI provides differentiated solutions that allow engineers to monitor and control intelligent buildings to create safe, efficient and enjoyable environments. TI offers a wide range of devices and reference designs to help you bring innovative features such as energy harvesting and preventative maintenance to your building automation system.
• Achieve smarter wireless sensing for enhanced HVAC and lighting control
• Easily retrofit wired systems for the Internet of Things (IoT)
• Optimize energy efficiency as part of a green building
• Increase system reliability and reduce wiring costs
Fire Safety
• Digital Alarm Communicator
• Fire Alarm Control Panel (FACP)
• Gas Detector
• Remote Annunciator
• Smoke and Heat Detector
• Sounder, Speaker, Strobe
HVAC
• Air Quality and Gas Detection
• Gateway
• HVAC Motor Control
• HVAC Sensor Transmitter
• HVAC System Controller
• HVAC Valve and Actuator Control
• Thermostat
• Water Leak Detection
• Wireless Environmental Sensor
Building Security
• Biometric Reader
• Door Keypads and Readers
• Door & Window Sensor
• Electronic Smart Lock
• Intrusion HMI Keypad
• Glass Break Detector
• Intrusion Control Panel
• Keyfob or Panic Button
• Motion Detector (PIR, uWave, etc.)
• People Counting
Video Surveillance
• Analog Security Camera
• Video Recorder (NVR, DVR, etc.)
• IP Network Camera
• Video Doorbell

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Building Automation reference designs

Signal Conditioning | Power | Embedded Processing | View All Building Automation TI Designs ›

TIDesigns

Signal Conditioning

Humidity and Temp Sensor Node for Star Networks Enabling 10+ Year Coin Cell Battery Life

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Wireless PIR Motion Detector Enabling 10 year coin cell battery life

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Smart Lock Reference Design Enabling 5+ Years Battery Life

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Power

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

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Universal 85VAC-264VAC Input, 24V 1A Output, PSR Flyback

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Isolated Fly-Buck Power Module for PoE Application

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