

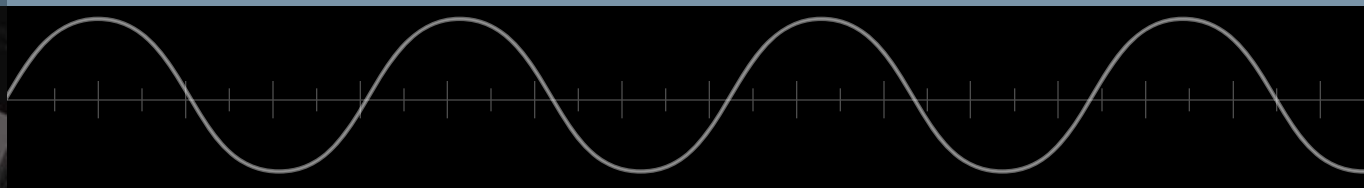
Small Footprint High Efficiency Designs for Energy Conversion

(Extend Battery Life with Harvested Energy)

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Energy Harvesting – where is it useful?

- Wireless Sensor Networks where maintenance is costly, inconvenient or hazardous
- Coupled with a primary battery to extend battery life
- Powering sensors/nodes where line power is not available

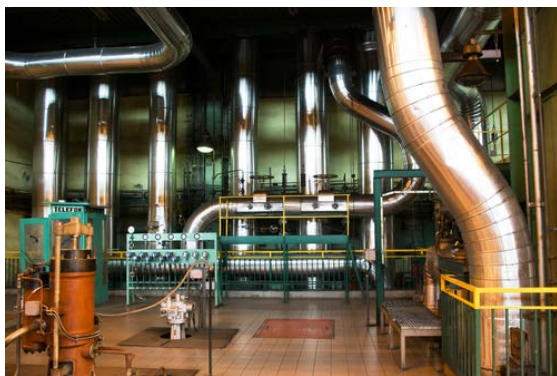
Asset Tracking/Monitoring



Data Center & Building Climate Control



Plant Automation

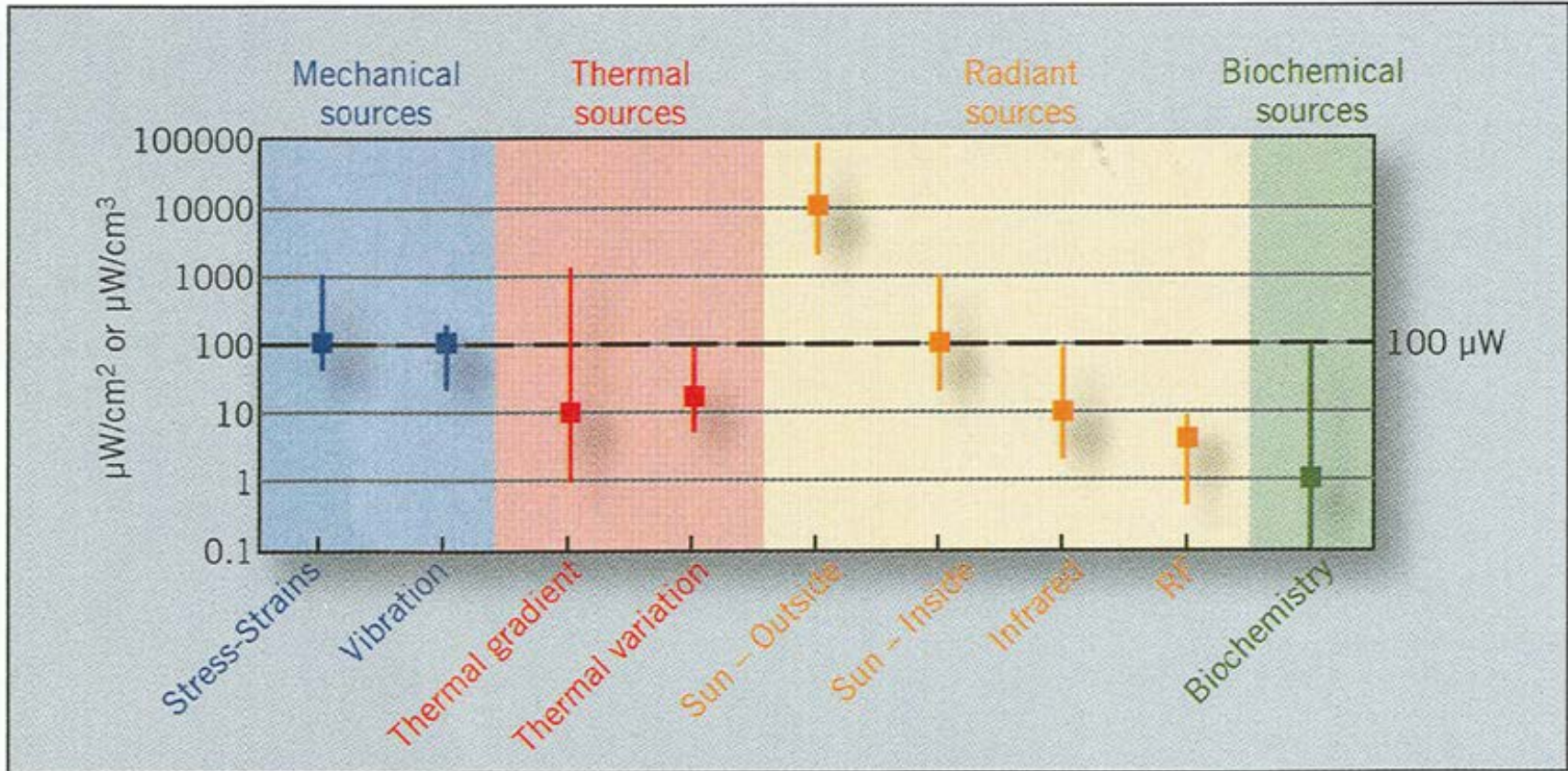


Remote Monitoring



Typical Application: Remote Wireless Sensors

How Much Power is Available?



A comparison of ambient energy sources (before conversion). (Source: CEA-Leti).

Ambient Energy is Only Part of the Story...

How Much Power is Available at the LOAD ?

Available LOAD power depends on:

- Energy source (needs to be quantified)
- Transducer (requires optimization)
- Power conversion efficiency (

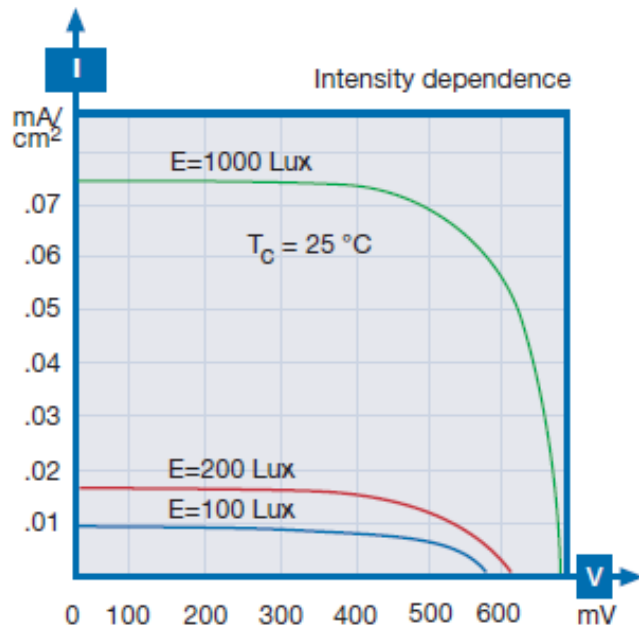
→ Each energy source

→ Each source transducer

→ Each source requires an optimized power manager

Solar Energy Considerations

[Light Source]		Sunlight	Fluorescent light	
Condition		Illuminance (lux)	Condition	Illuminance (lux)
Direct sun		100,000 to 120,000	Design stand (partially illuminated)	Around 1,000
Bright		50,000 to 100,000	Office/conference room	300 to 600
Cloudy		10,000 to 50,000	Restaurants/coffee shops	Below 200
Rain		5,000 to 20,000		

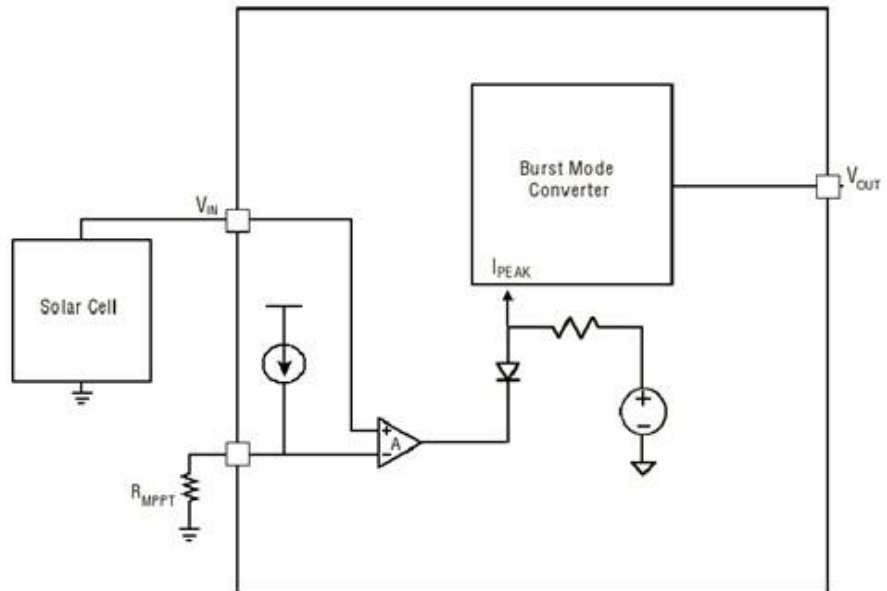
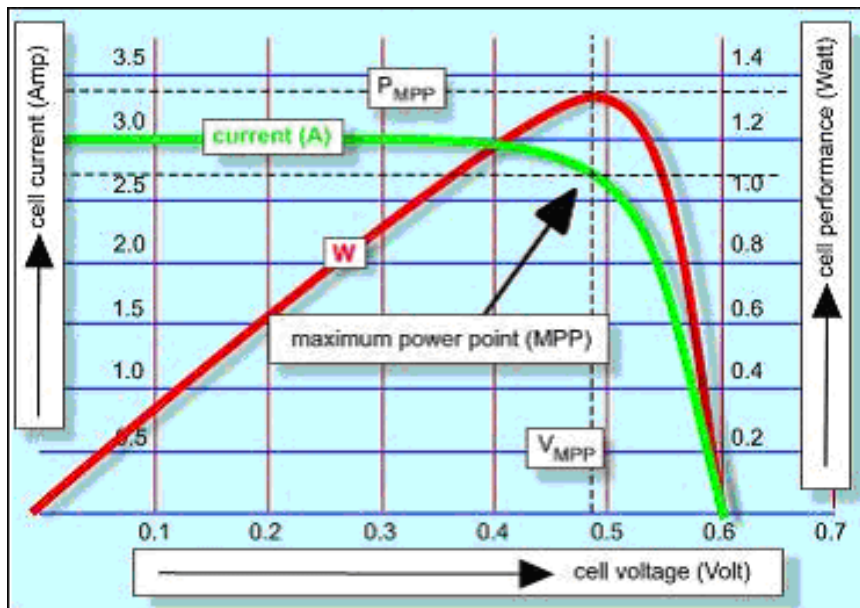


- Solar cell P_{OUT} depends on Lux (lumens / m²)
- Lux varies greatly from indoors to outdoors
- Lux easily measured with a light meter



Solar Power Management Considerations

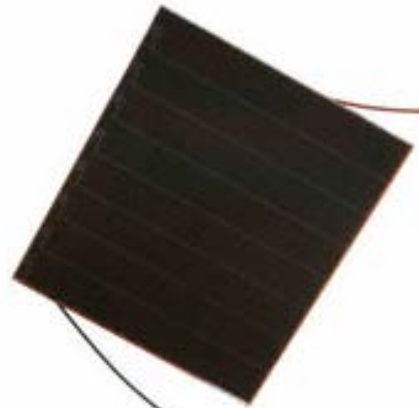
- Series / parallel combinations optimize panel voltages
- Maximum power point tracking / control optimizes energy transfer



Solar Example

Sanyo Amorton AM1815 Solar Cell

@200lux: $V_{oc}=4.9V$, $I_{sc}=47\mu A$



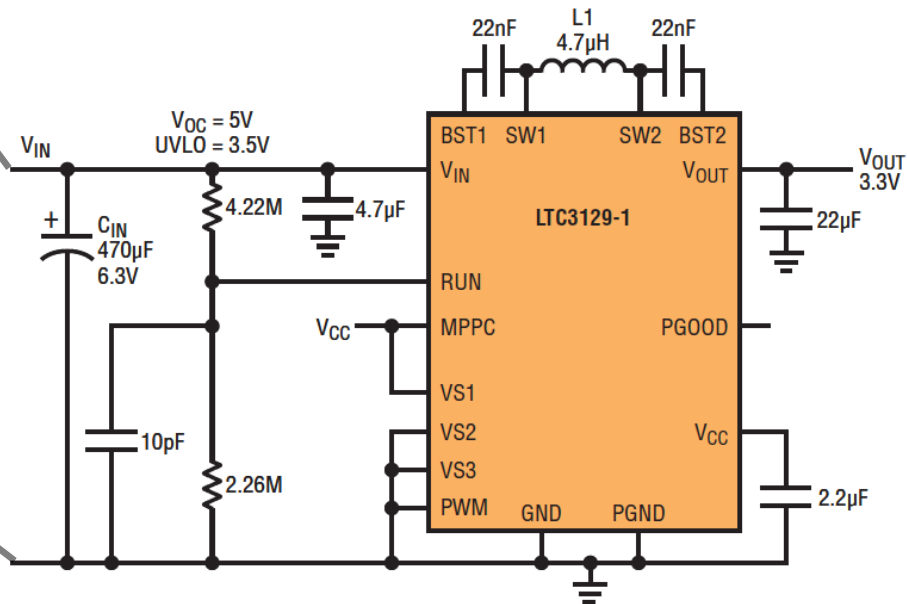
LTC3129 1.3uA Quiescent Buck-Boost Converter

Output:

$$V_{OUT} = 3.3V$$

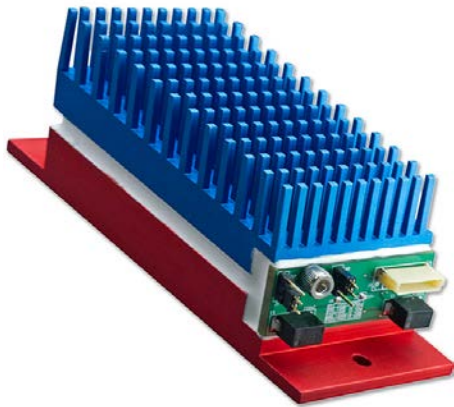
$$I_{OUT} = 38\mu A \quad @ \quad 200 \text{ lux}$$

$$I_{OUT} = 230\mu A \quad @ \quad 1000 \text{ lux}$$

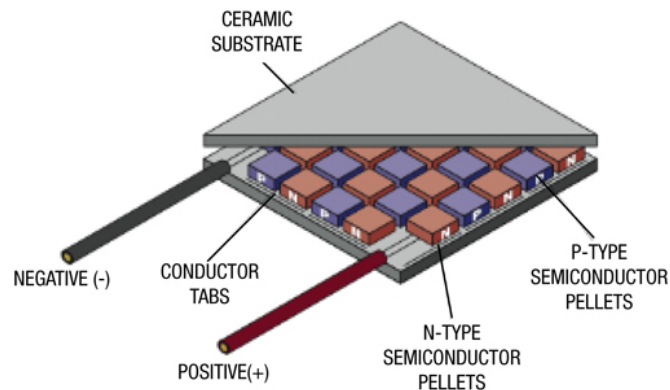


Thermal Energy Considerations

TEGs (Thermoelectric Generators)



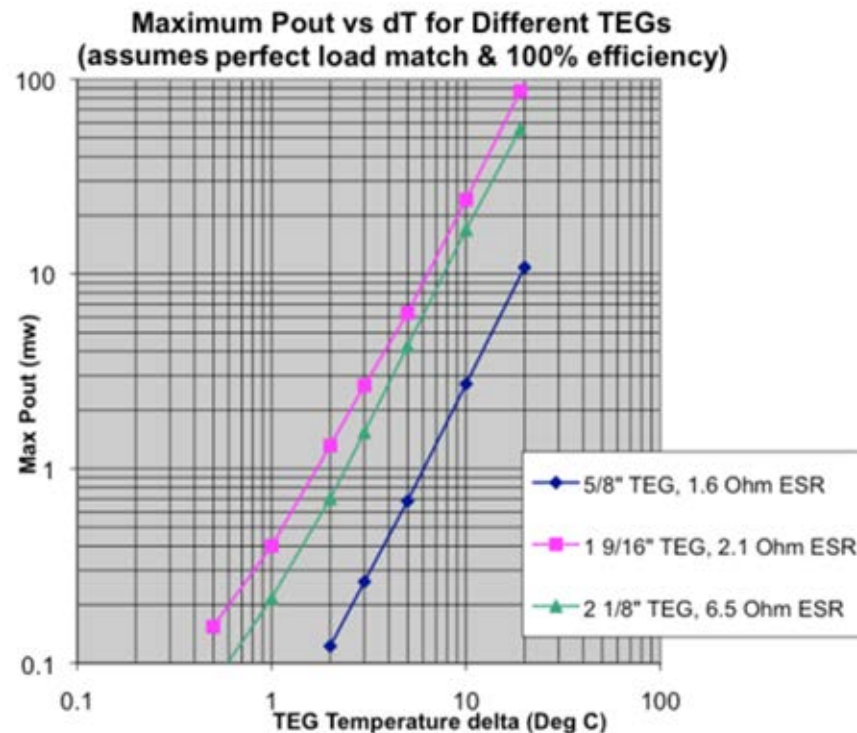
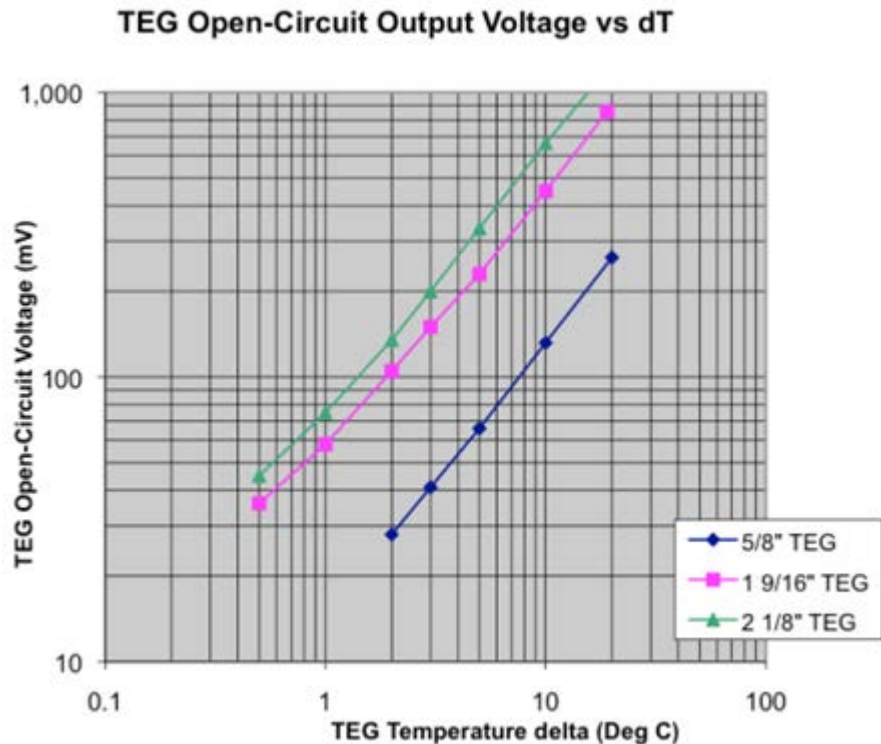
marlow industries, inc.[®]
Subsidiary of II-VI INCORPORATED



 **PERPETUA**[®]

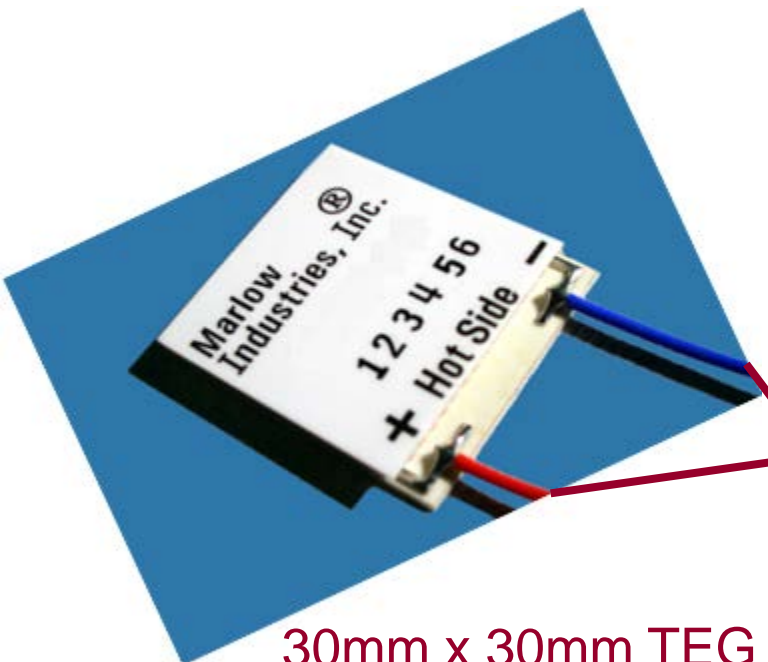
- **VOUT proportional to temperature differential**
- **Need to maintain a temperature gradient across TEG**
- **→ Heatsinks required**

TEG Characteristics



- TEG open ckt voltages are very low
- TEG output impedance typically very low
- TEG's require highly specialized power management

Thermoelectric Example

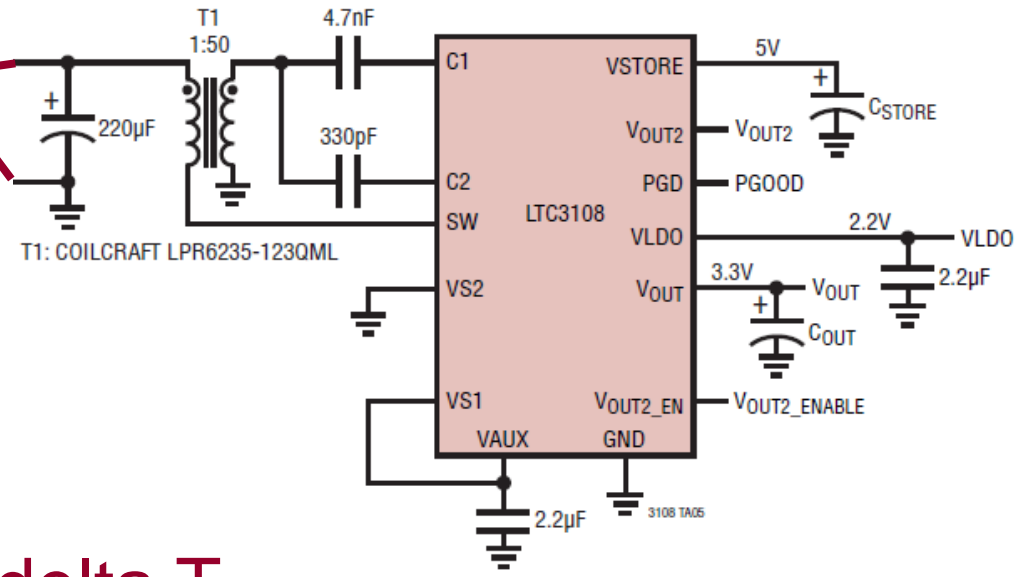


30mm x 30mm TEG

LTC3108

Ultralow Voltage Step-Up Converter
And Power Manager
(min $V_{IN} = 20mV$)

$V_{IN} \sim 20mV - 500mV$



LTC3108 Output:

$$V_{OUT} = 3.3V$$

$$I_{OUT} = 60\mu A \quad @ \quad 10^{\circ}C \text{ delta } T$$

$$I_{OUT} = 400\mu A \quad @ \quad 30^{\circ}C \text{ delta } T$$

Vibration Energy Considerations

What does the vibration source look like?

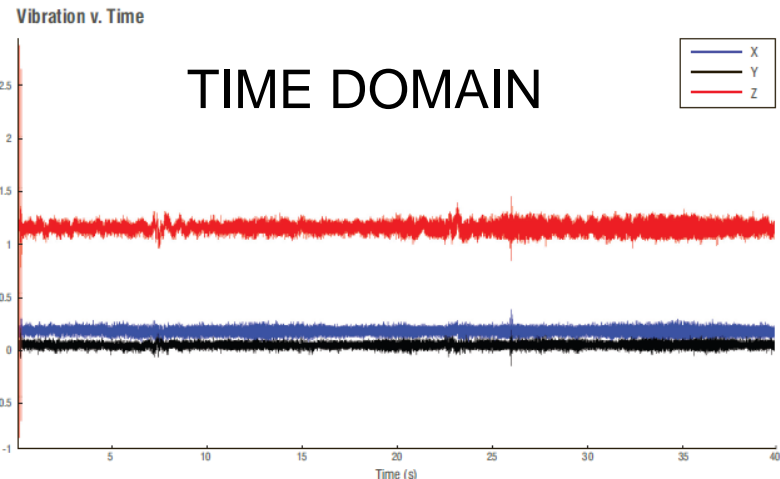
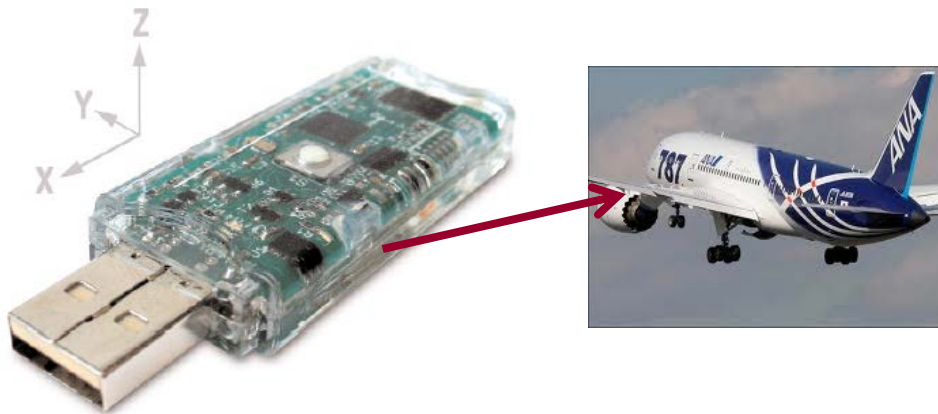


Figure 2: Time domain response of a commercial jumbo jet during taxiing.

→ FREQUENCY DOMAIN

SLAM-STICK™
HIGH SPEED • PORTABLE • RECHARGEABLE • DATA LOGGER

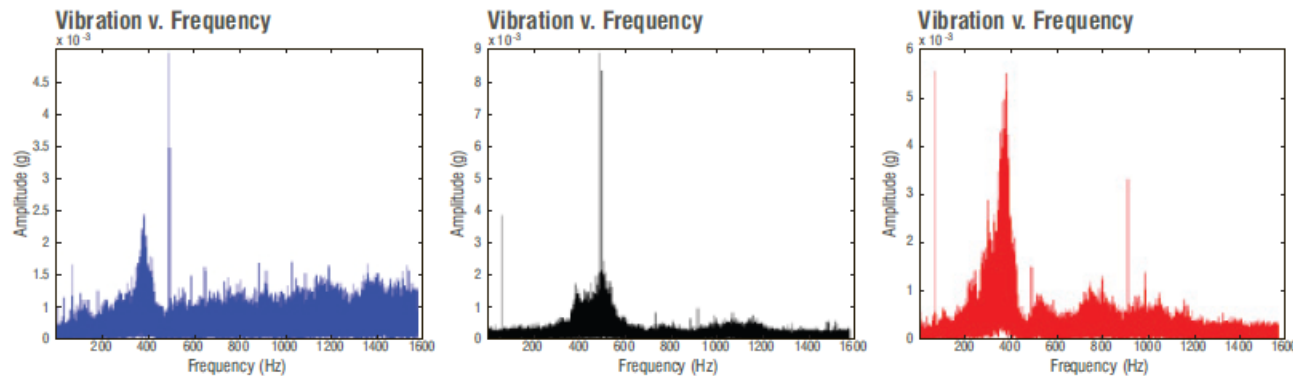
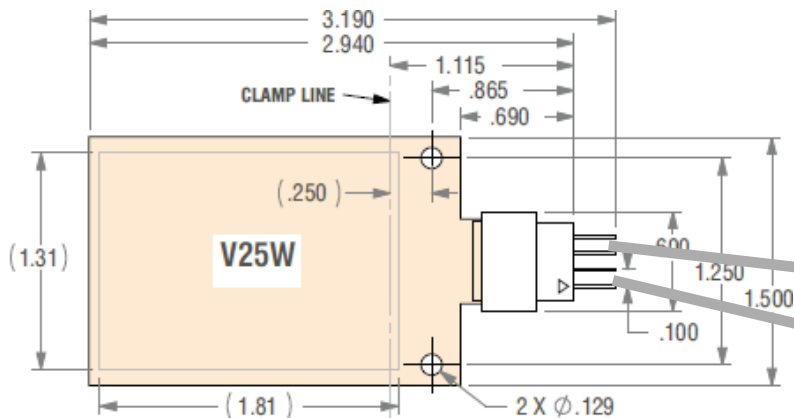


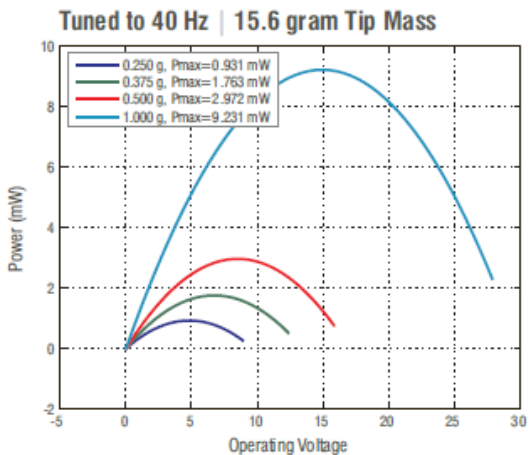
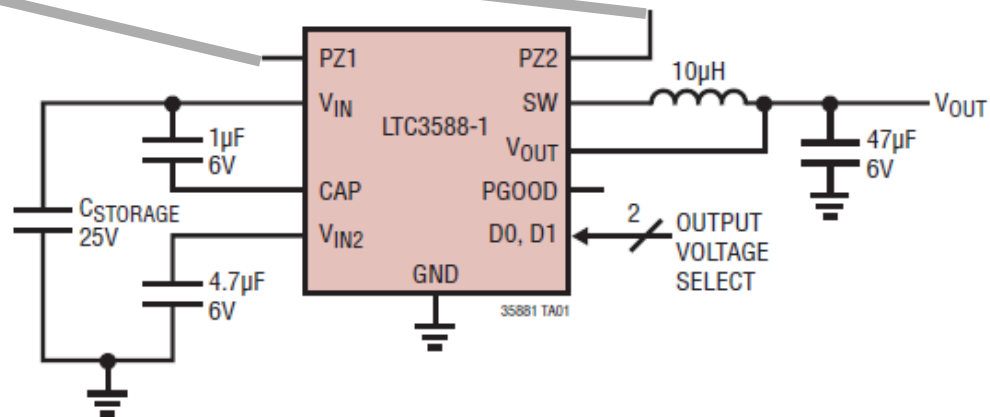
Figure 5: 1-D FFTs of vibration data during cruise

Vibration Source– Piezoelectric



LTC3588

Piezoelectric Energy Harvesting
Power Supply
($I_{CC} = 900nA$)



Output:

$$V_{OUT} = 3.3V$$

$$I_{OUT} = 200\mu A @ 0.25g / 40Hz$$

Energy Harvesting-Only Solutions



Energy source	Transducers	LTC Power Management ICs	Typical P_{OUT} @ $V_{OUT} = 3.3V$	Maximum P_{OUT} @ $V_{OUT} = 3.3V$
Indoor Solar (200lux – 1000lux)	Photovoltaic Cells (100cm ²)	LTC3129 LTC4071	100uW – 1mW	>100mW
Outdoor Solar (1000lux – 50000lux)	Photovoltaic Cells (100cm ²)	LTC3105 LTC3129 LTC3588	1mW – 100mW	>100mW
Thermal (10°C – 30°C dT)	TEGs (100cm ³)	LTC3108 LTC3109	200uW – 1.4mW	>10mW
Vibration (Piezo: 0.1g – 1g) (EM: 0.025g – 0.5g)	Piezoelectric (30cm ²) Electromechanical (200cm ³)	LTC3588	50uW – 500uW 500uW – 10mW	>100mW

Wireless Sensors Need 30uW – 500uW Avg Power

Why has EH adoption been slow?

- 1. Batteries already provide solution (with some limitations)**
- 2. Difficult to quantify how much EH power is available**
- 3. Systems need to operate even if harvested energy inadequate or unavailable**

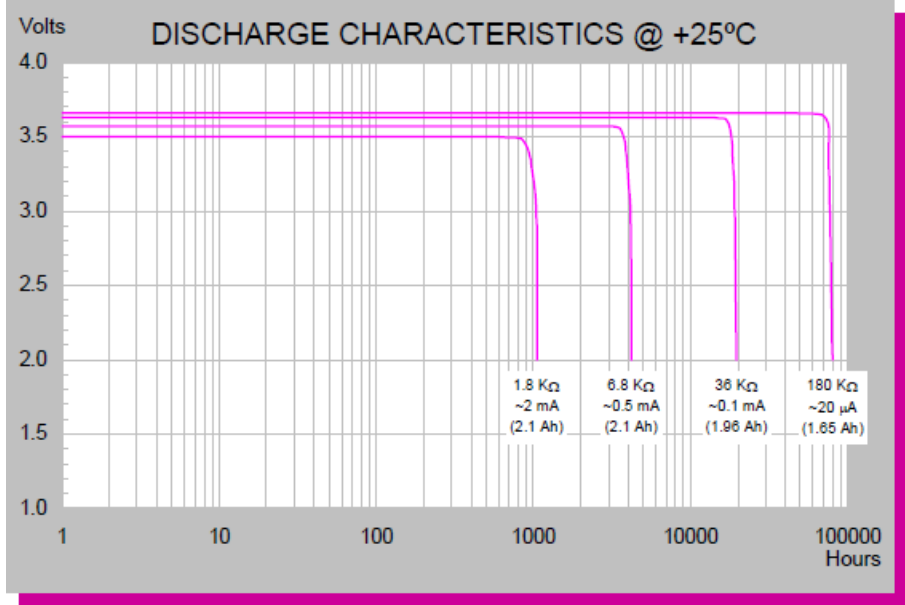
EH adds value despite these two issues

Battery Lifetime

TL-5104 AA (2.1A-hr)



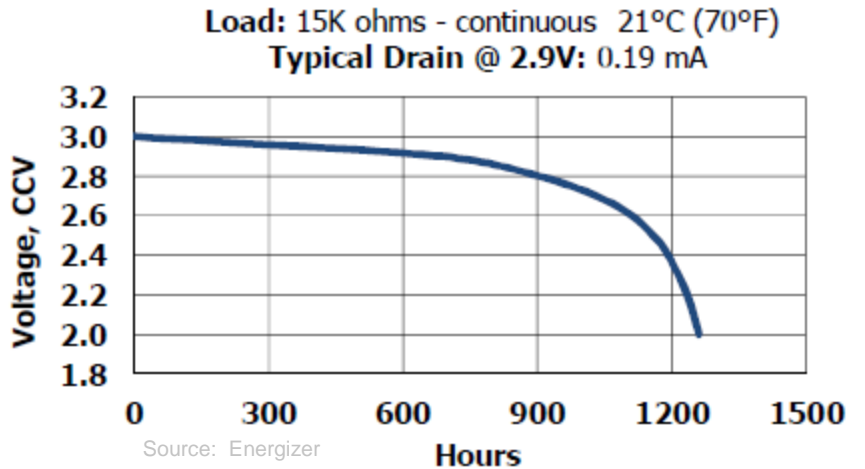
CR2032 (240mA-hr)



Source: Tadiran Batteries

<5 years of lifetime
with 50uA (180uW) load

Continuous Discharge Characteristics



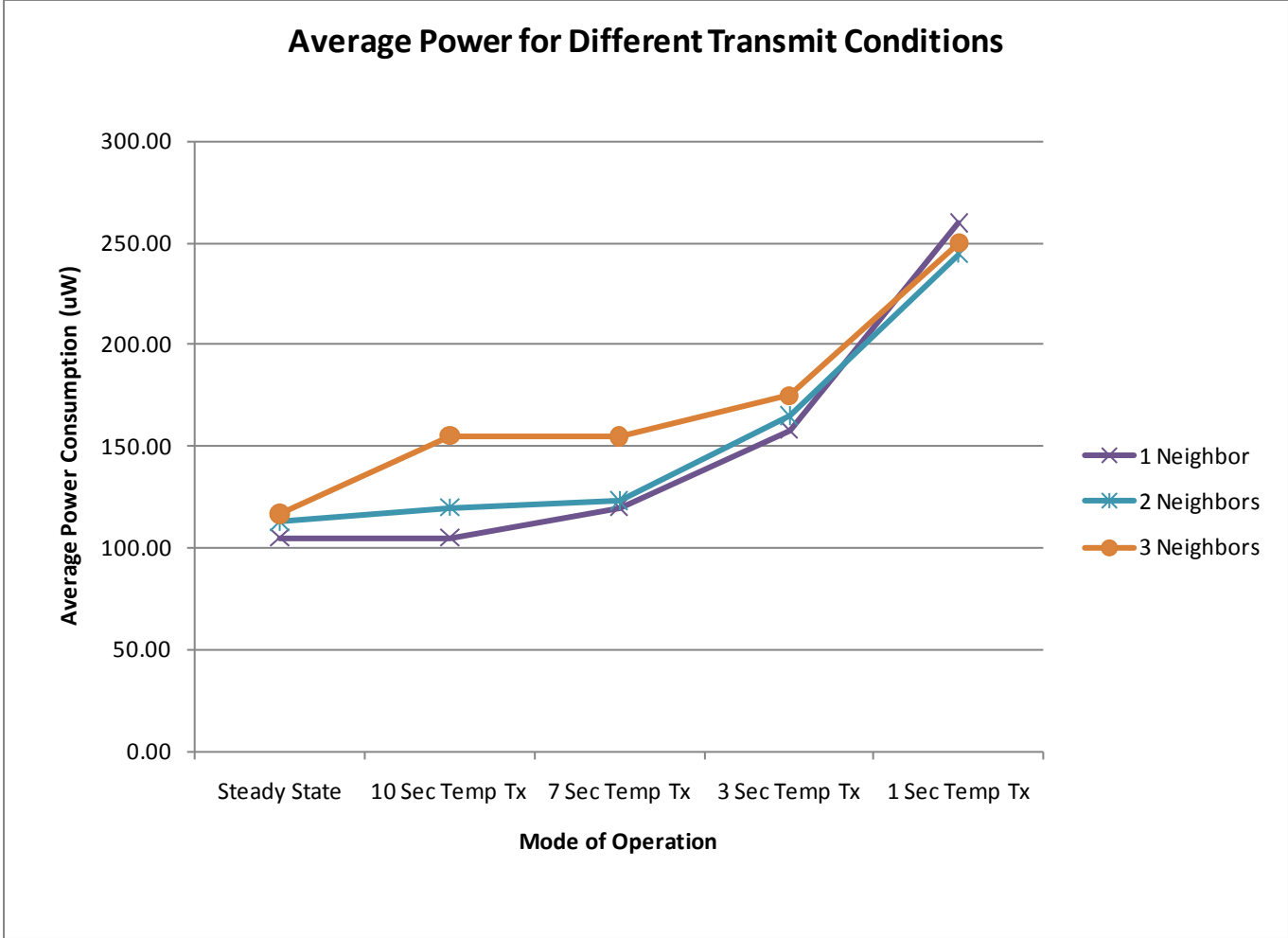
Source: Energizer

<1 year of lifetime
with 50uA (130uW) load

Where can Energy Harvesting Help?

- **Energy Harvesting to extend battery life**
 - **Harvested source prioritized**
 - **Always have reliable power source (i.e. battery)**
 - **Enables increased system functionality (i.e. more sensors, greater frequency of transmission, etc)**

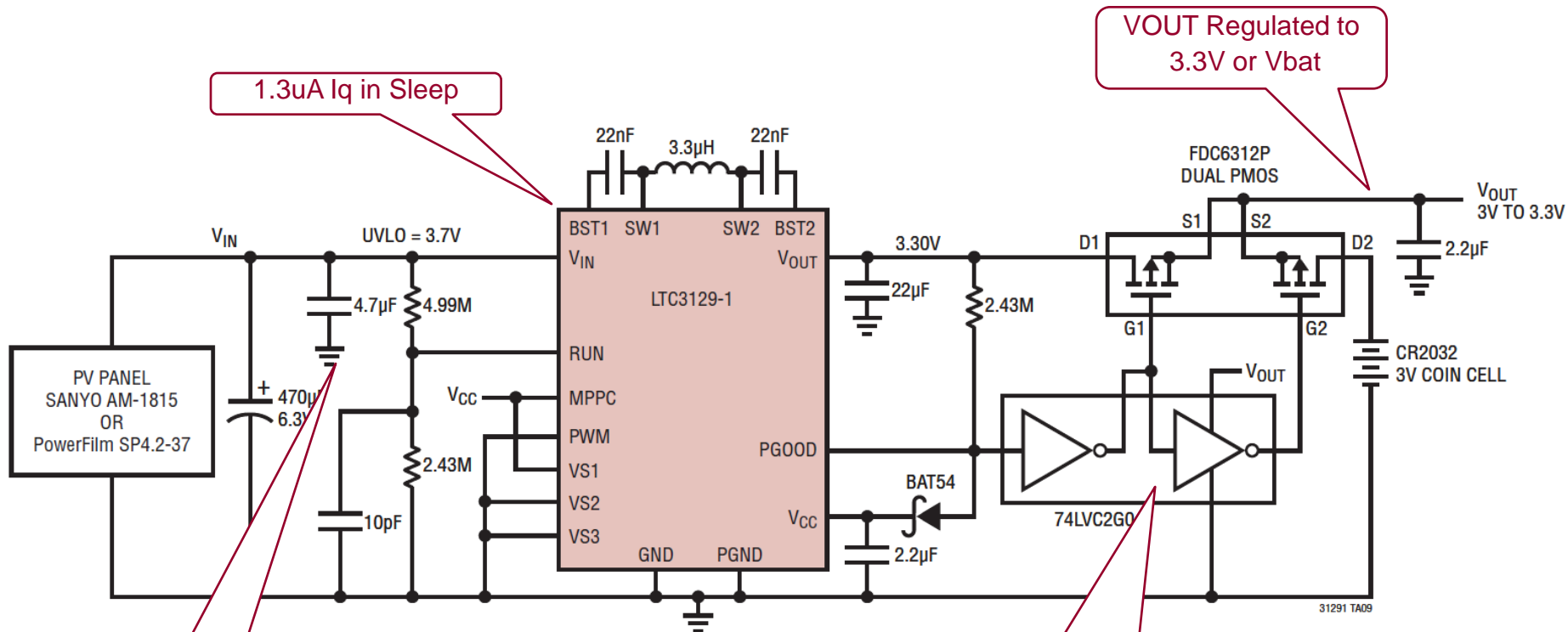
Wireless Sensor Node Example



Data collected from Linear Technology's Eterna Evaluation Module using integrated temperature sensor only



Solar Application to Extend Battery Life



1.3uA Iq in Sleep

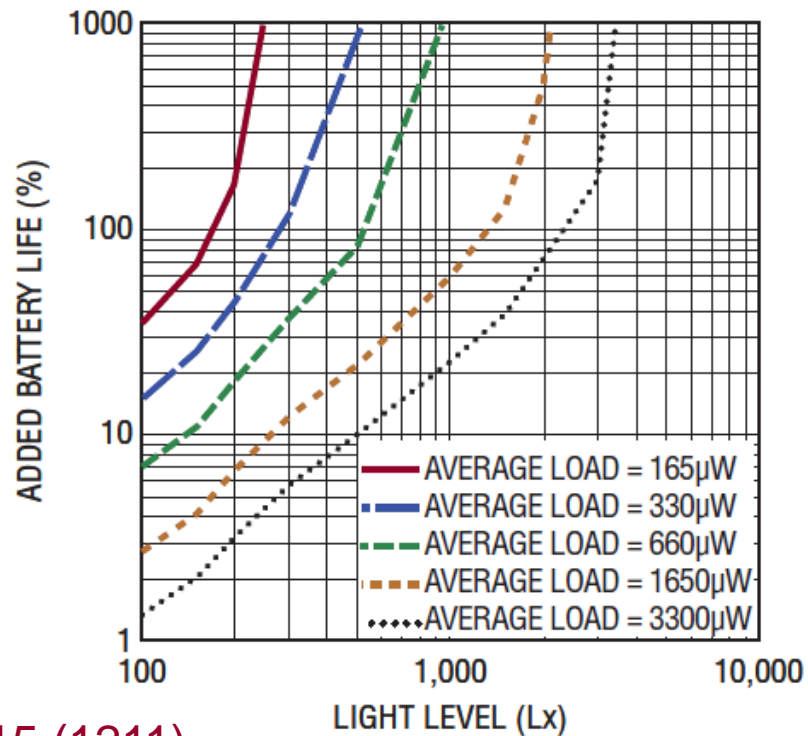
VOUT Regulated to 3.3V or Vbat

Extract Max Power from Solar Source

Pgood Drives External to SwitchOver to Battery only when necessary

Extending Battery Life w/ EH

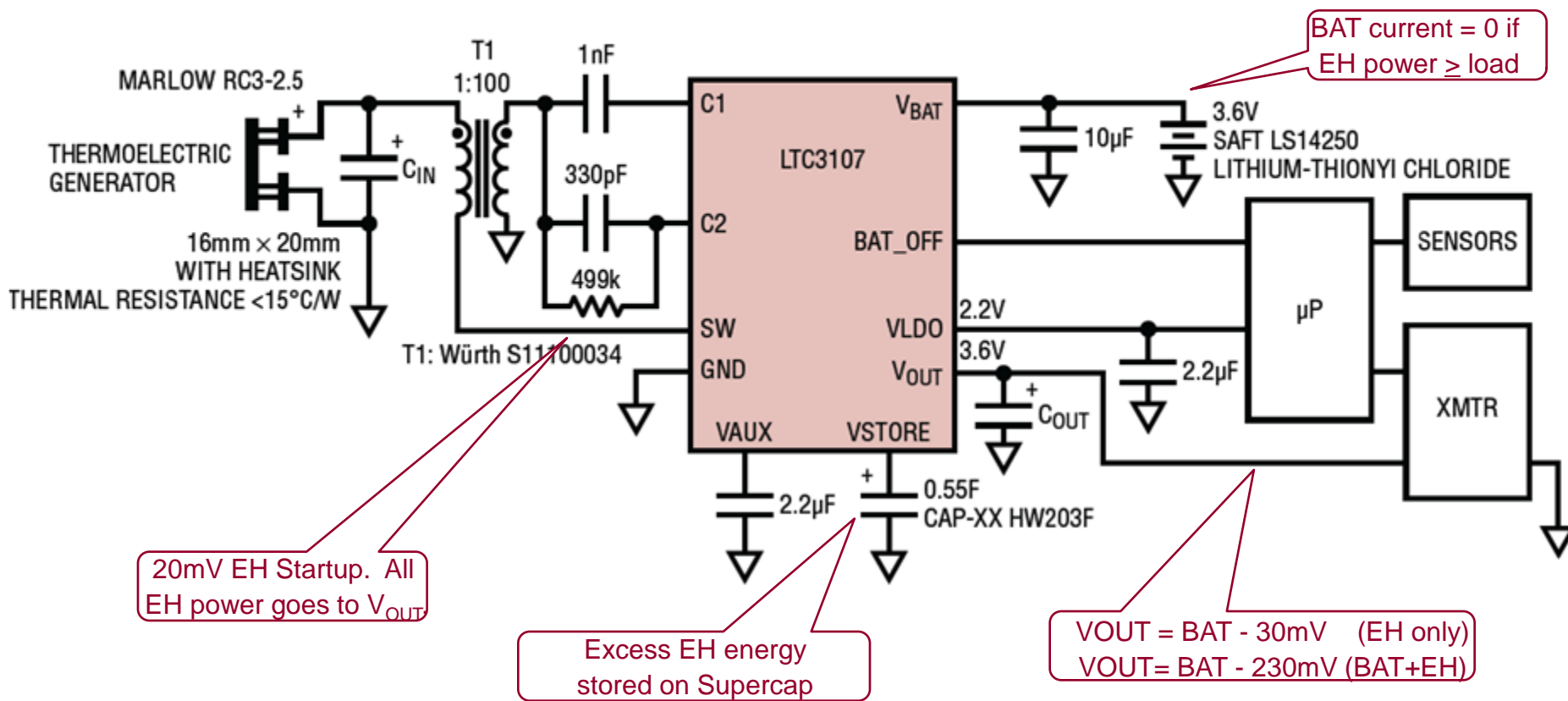
Percentage of Added Battery Life vs Light Level and Load (PowerFilm SP4.2-37, 30sq cm Panel)



- Sanyo AM-1815 (1211)
- CR2032, 3V Lithium

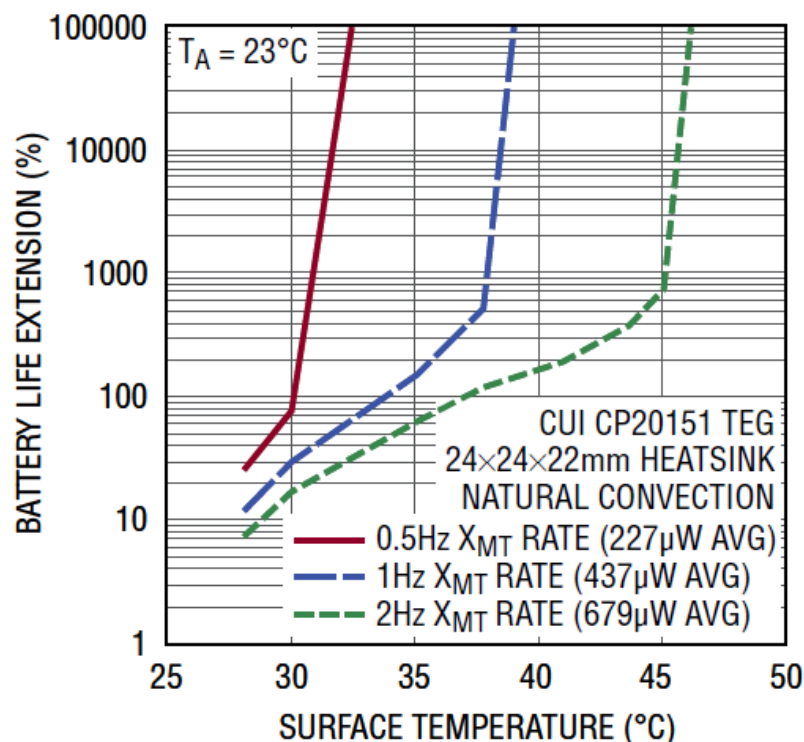
Thermal Energy Harvesting DC-DC Battery Life Extender

Remote Sensor Application Using Thermal Energy Harvesting to Extend Primary Battery Life



How much battery life extension?

**Percentage of Added Battery Life
vs TEG Surface Temperature**



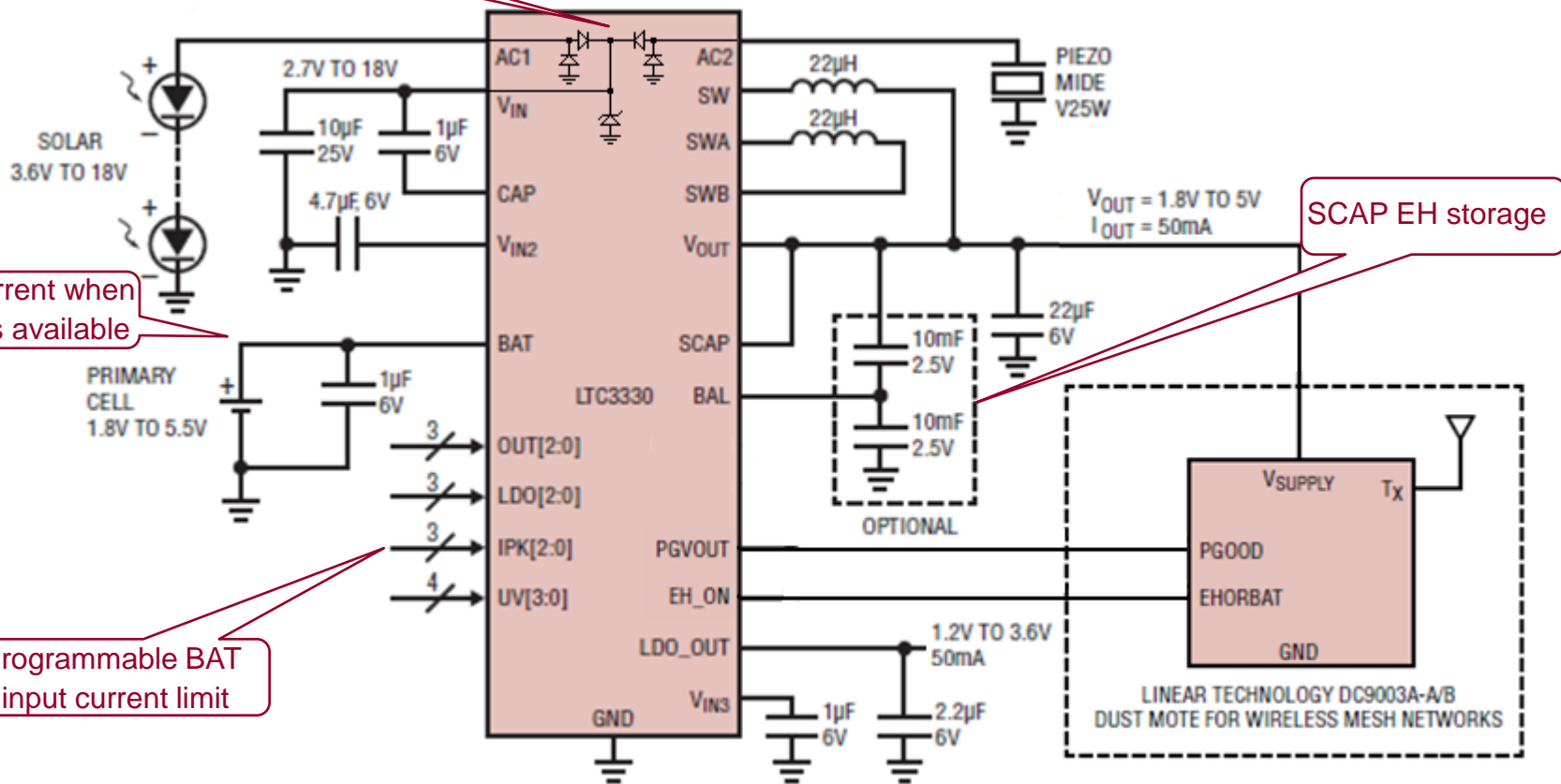
Indefinitely extend battery life with 15C surface to ambient differential

EH Nanopower Buck-Boost DC-DC with Battery Life Extender

AC or DC EH sources >4V.
EH gets priority over BAT

Zero BAT current when
EH source is available

Programmable BAT
input current limit



Battery Life Extender Solutions

Energy source	Transducers	LTC Power Management ICs	Typical P_{OUT} @ $V_{OUT} = 3.3V$	Maximum P_{OUT} @ $V_{OUT} = 3.3V$
Solar (200lux – 1000lux)	Photovoltaic Cells (100cm ²)	LTC3330 LTC3331 LTC3129	100uW – 1mW	>100mW
Thermal (10°C – 30°C dT)	TEGs (100cm ³)	LTC3107	200uW – 1.4mW	>10mW
Vibration (Piezo: 0.1g – 1g) (EM: 0.025g – 0.5g)	Piezoelectric (30cm ²) Electromechanical (200cm ³)	LTC3330 LTC3331	50uW – 500uW 500uW – 10mW	>100mW

Summary

1. Existing Energy Harvesting IC's and transducers can provide more than enough power for many applications
2. Applications unable to eliminate batteries can benefit from Energy Harvesting to extend battery lifetime and delay replacement costs
3. New products available to use EH specifically to extend the life of a battery

Thank You!