Advancements in Energy Harvesting Transducers and the Challenges they Present for Power Management Solutions

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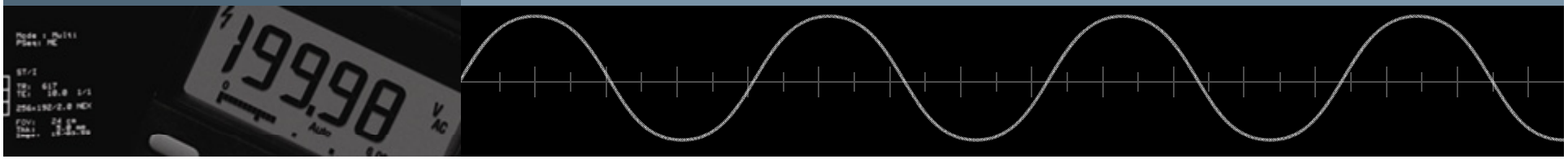


LINEAR TECHNOLOGY

Outline:

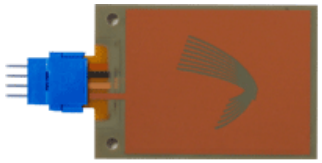
- **Transducers**
  - **Manufacturers (Advertised Products)**
  - **Market Challenges?**
  - **How Much Power is Available?**
  - **Power Management Challenges?**
- **Examples**
  - **Solar**
  - **TEG**
  - **Vibration**
- **If Energy Harvesting Alone is Not Enough…**
  - **Extending Battery Life with Energy Harvesting**

Energy Harvesting Transducers

Manufacturers (Advertised Product)

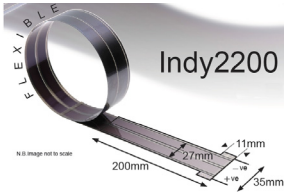
Thermoelectric Generator or Thermopile (Heat)

- Marlow Industries(EverGen), Micropelt(TE-Power),
- Perpetua (Power Puck), Nextreme(eTEG/WPG)



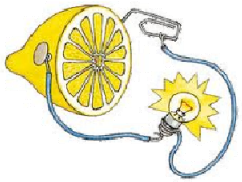
Piezoelectric (Motion / Vibration / Strain)

- Mide (Volture), PI Ceramics (*P-876*) , MicroGen (*BOLT™*),
- Smart Materials (*M8528P2,M8557P2, M8585P2*),
- T.M.S. AUTO PARTS CO LTD;alibaba.com (piezo bending generators)



Photovoltaic (Light)

- G24i(Indy,DOM,COM), Solar Print(SP5848 DSSC), Panasonic(Amorton)



Galvanic (Moisture)

- Components available to work with minimal voltages

Electromagnetic (Motion / Vibration / Induction)

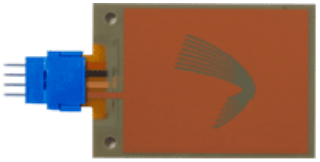
- Perpetuum(PMG FSH)

Energy Harvesting Transducers

Market Challenges

Thermoelectric Generator or Thermopile (Heat)

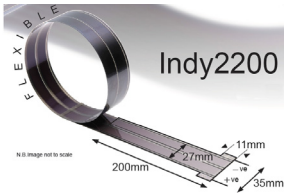
- Approvals from Field Trials



Piezoelectric (Motion / Vibration / Strain)

- High-Volume Application to Reduce Transducer Pricing

Photovoltaic (Light)



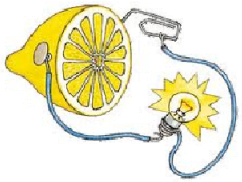
- None – Deployed in many applications

Galvanic (Moisture)

- None – Deployed in farming operations

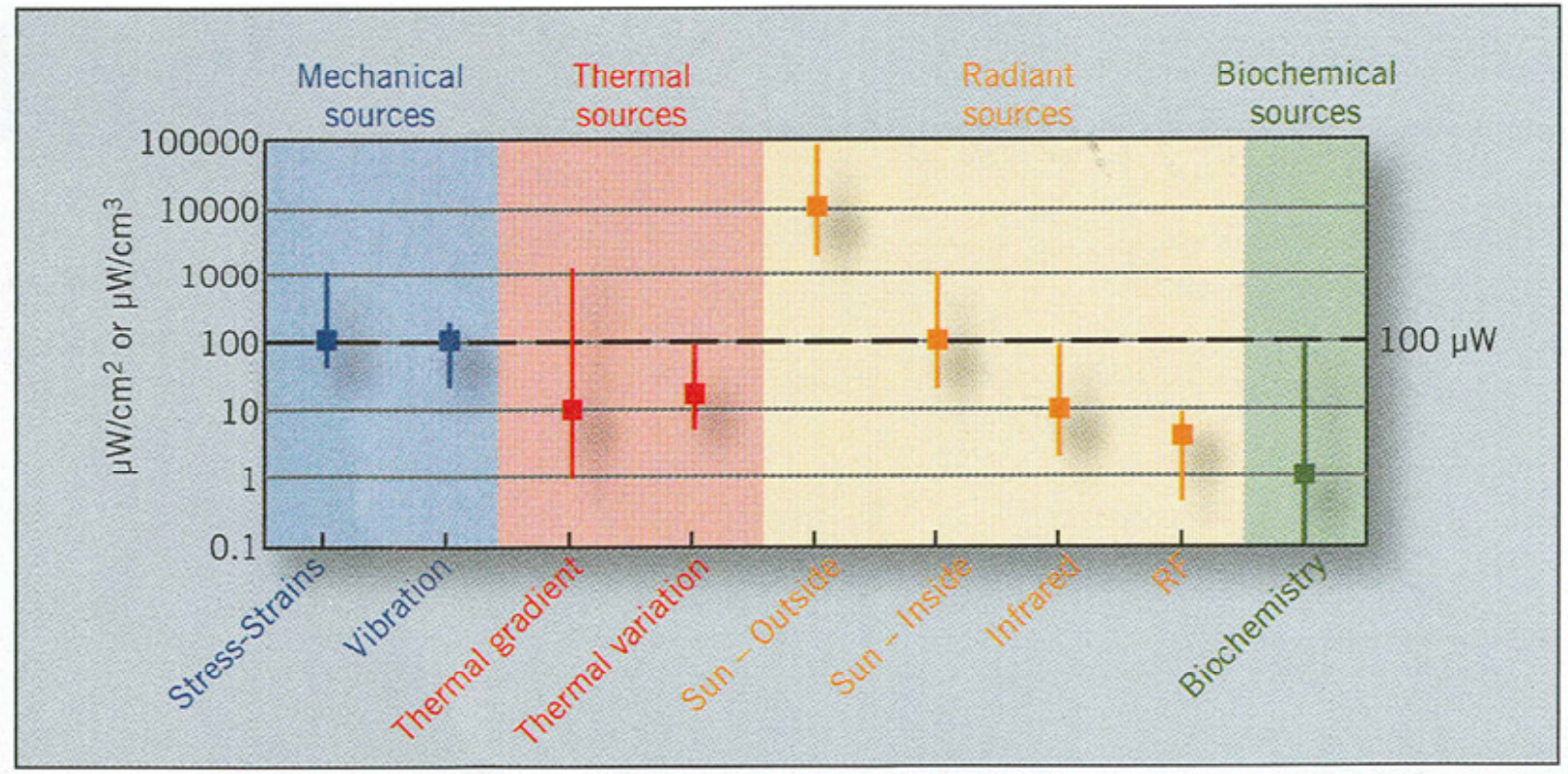
Electromagnetic (Motion / Vibration / Induction)

- Low-cost small disposable or re-usable transducer would enable large market in asset tracking.



Energy Harvesting Transducers

How Much Power is Available?



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

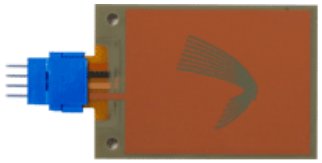
Ambient Energy is Only Part of the Story…

Energy Harvesting Transducers

Power Management Challenges

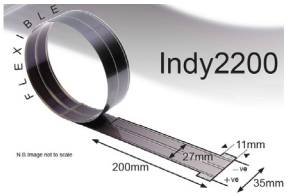
Thermoelectric Generator or Thermopile (Heat)

- Vin Dynamic Range(20mV-200mV),
- Low Impedances(3.5Ohms),
- Higher Impedance TEGs(150-300Ohms),
- *Thermal Impedance of TEG and System for desired DT*



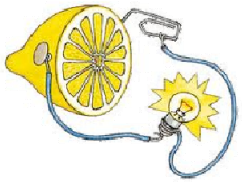
Piezoelectric (Motion / Vibration / Strain)

- AC Source Voltage, Vin Dynamic Range(4Vpp-200Vpp),
- High Source Impedance(80k-900kOhms)



Photovoltaic (Light)

- Maximum Power Point Operation



Galvanic (Moisture)

- Low Voltage, Low Impedance

Electromagnetic (Motion / Vibration / Induction)

- AC Source Voltage, Vin Dynamic Range(2Vpp-20Vpp),
- Source Impedance(4k-800kOhms)

LINEAR TECHNOLOGY

How Much Power is Available at the ***LOAD*** ?

Available LOAD power depends on:

- **Energy source**
- **Transducer**
- **Power conversion efficiency**

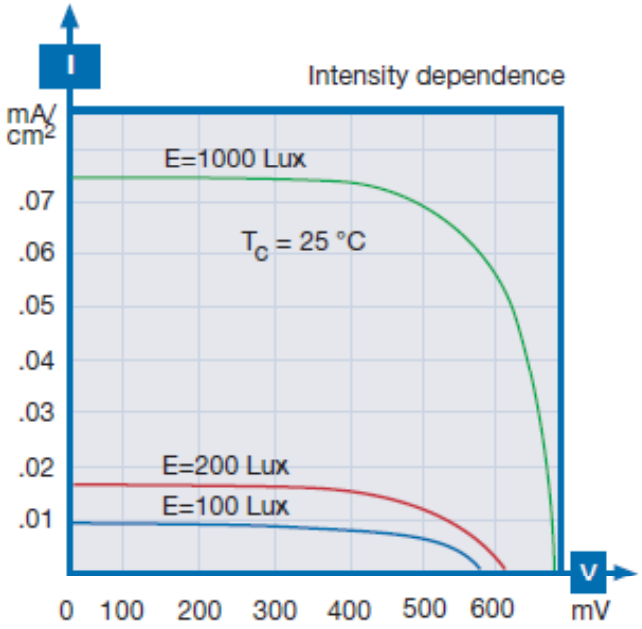
→ Each energy source needs to be quantified

→ Each source requires an optimized 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	1046mW / m^2
Bright	50,000 to 100,000	Office/conference room	300 to 600	
Cloudy	10,000 to 50,000	Restaurants/coffee shops	Below 200	<292mW / m^2
Rain	5,000 to 20,000			



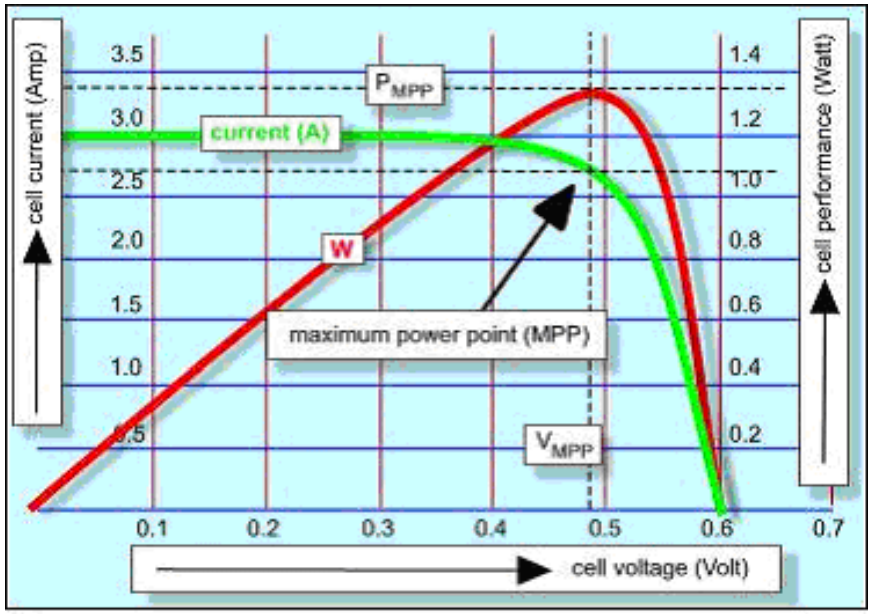
- **Solar cell P_{OUT} depends on Lux (lumens / m^2)**

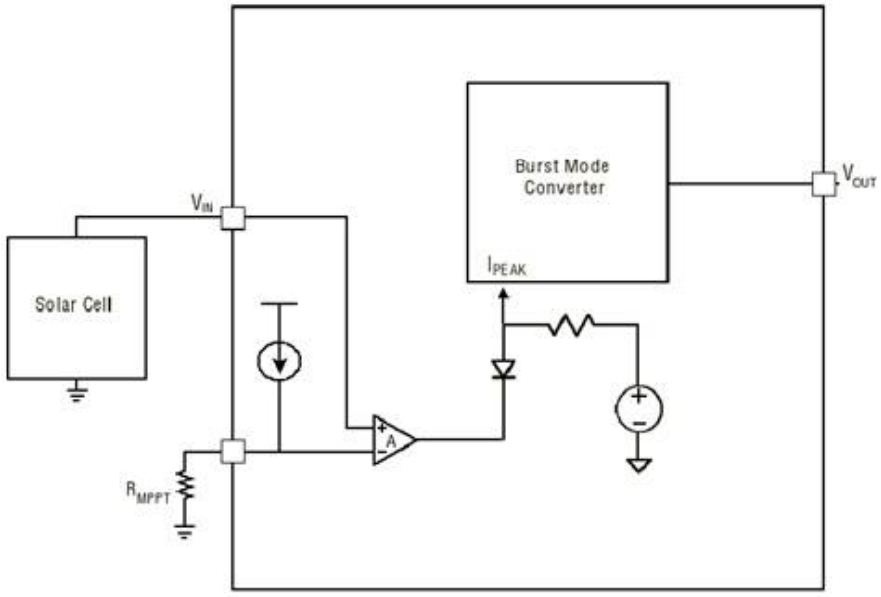
(1 lux = 1.46mW of EM power at 540 terahertz / m^2)

- **Lux varies greatly from indoors to outdoors**
- **Lux easily measured with a light meter**

Solar Power Management Considerations

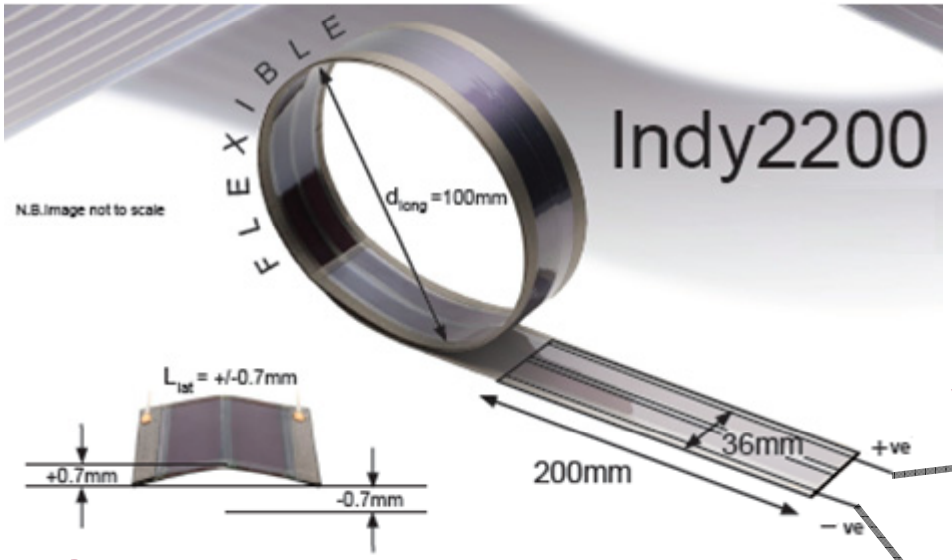
- **Series / parallel combinations optimize panel voltages**
- **Maximum power point tracking / control optimizes energy transfer**





Solar Example #1

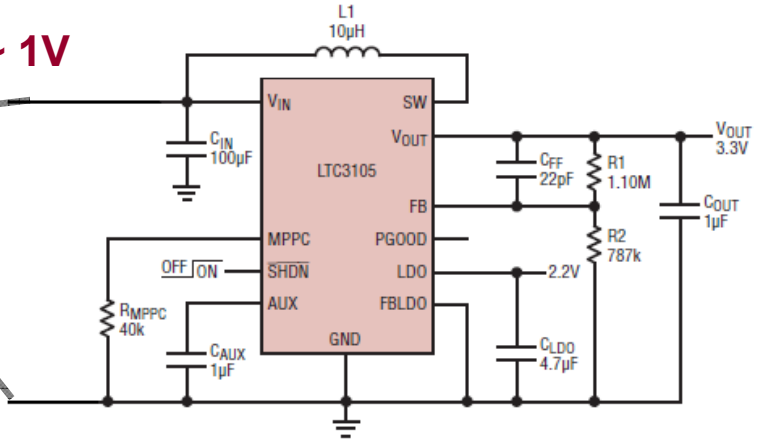
G24i Indoor Dye Sensitized Solar Cell (1 Volt Panel)



LTC3105

Low Voltage Boost Converter
with Maximum Power Point Control
(min V_{IN} 250mV)

V_{IN} ~ 1V



Output:

V_{OUT} = 3.3V

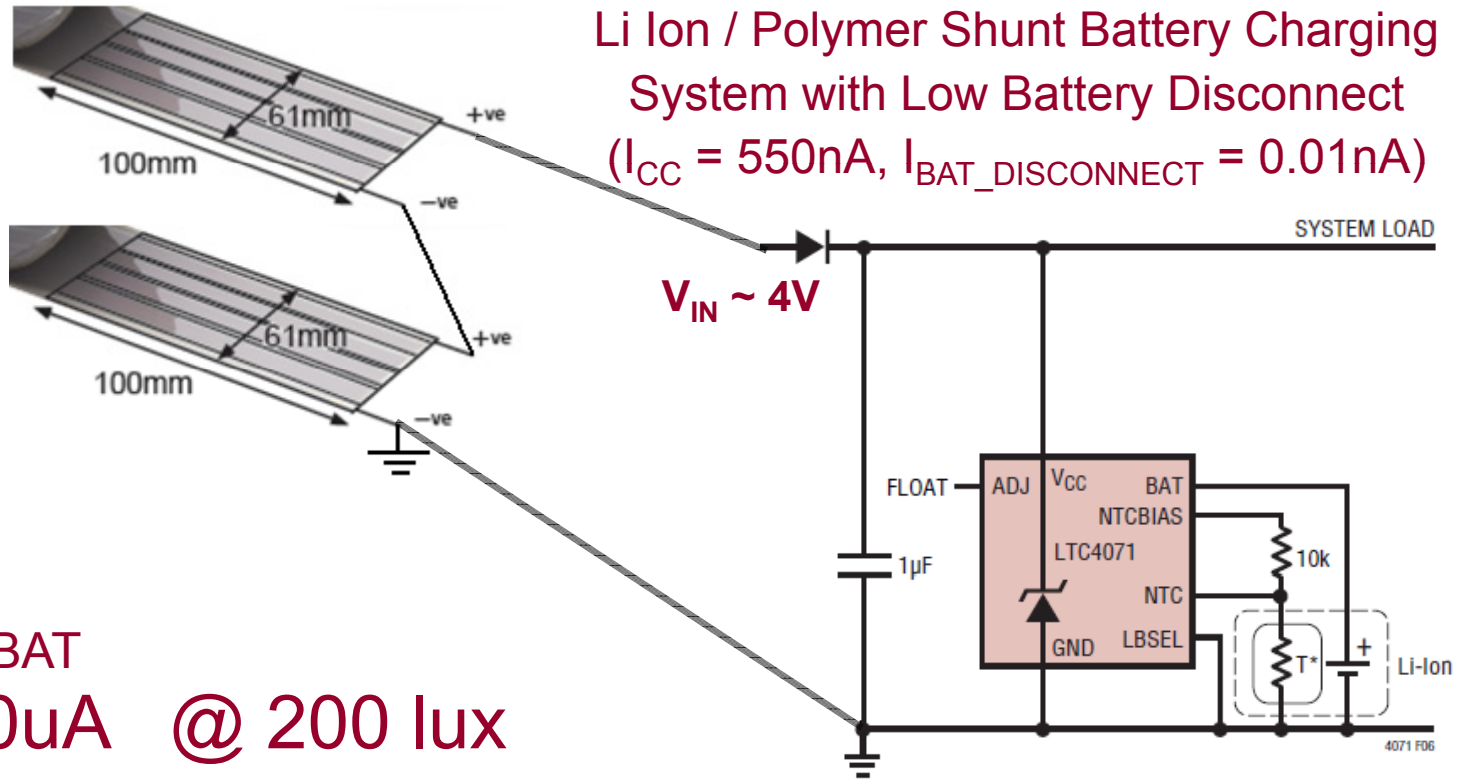
I_{OUT} = 20uA @ 200 lux

I_{OUT} = 200uA @ 1000 lux

Solar Example #2

Simple Method for Charging a Battery:

Indy4100



LTC4071

Li Ion / Polymer Shunt Battery Charging System with Low Battery Disconnect

(I_{CC} = 550nA, $I_{BAT\_DISCONNECT}$ = 0.01nA)

V_{IN} ~ 4V

"Output":

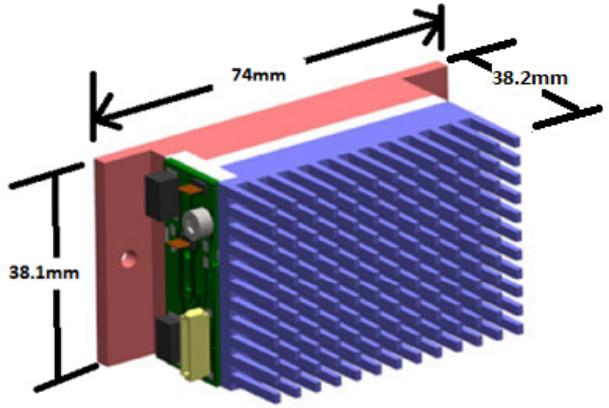
$V_{OUT} \sim V_{BAT}$

I_{CHG} ~ 90uA @ 200 lux

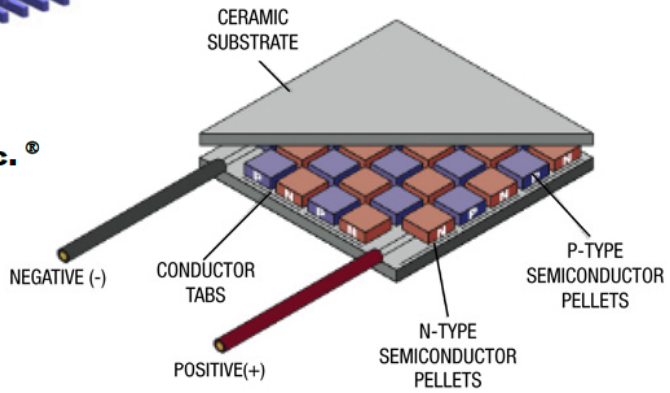
I_{CHG} ~ 450uA @ 1000 lux

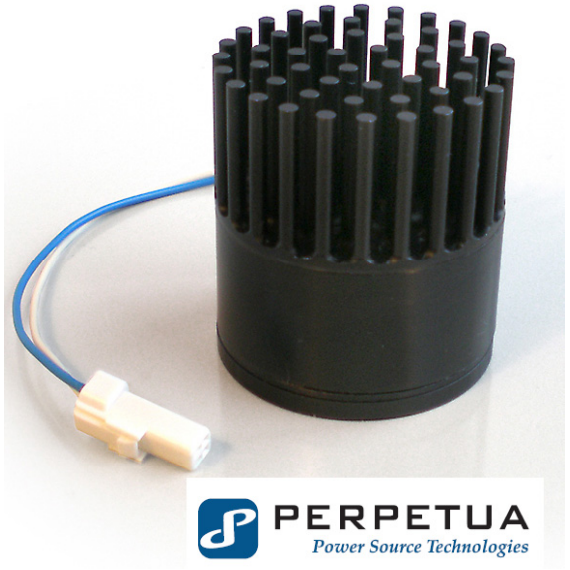
Thermal Energy Considerations

TEGs (Thermoelectric Generators)



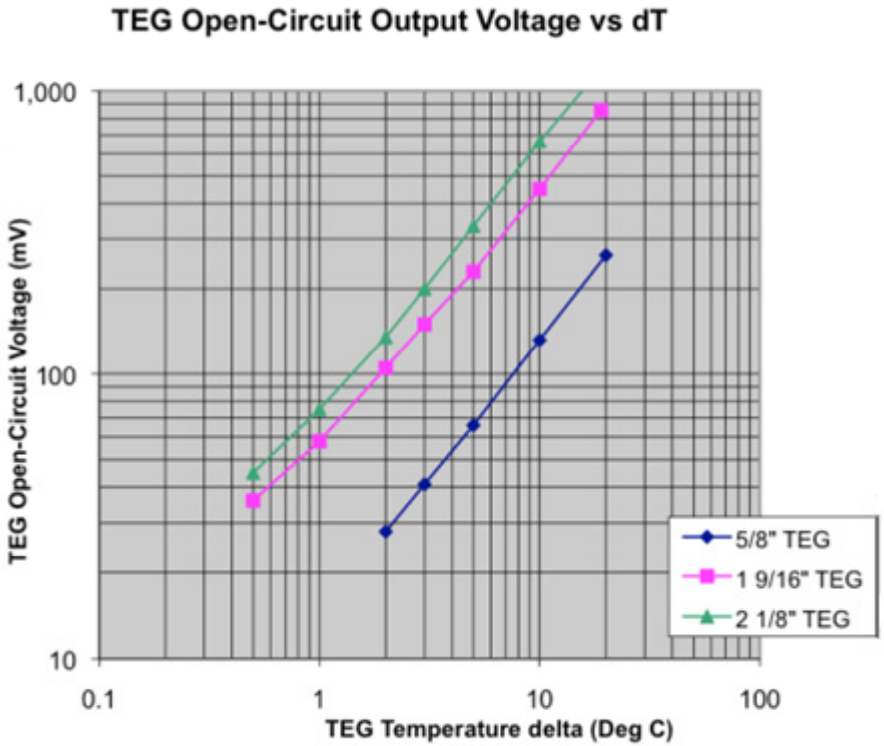
marlow industries, inc. ®
Subsidiary of II-VI INCORPORATED

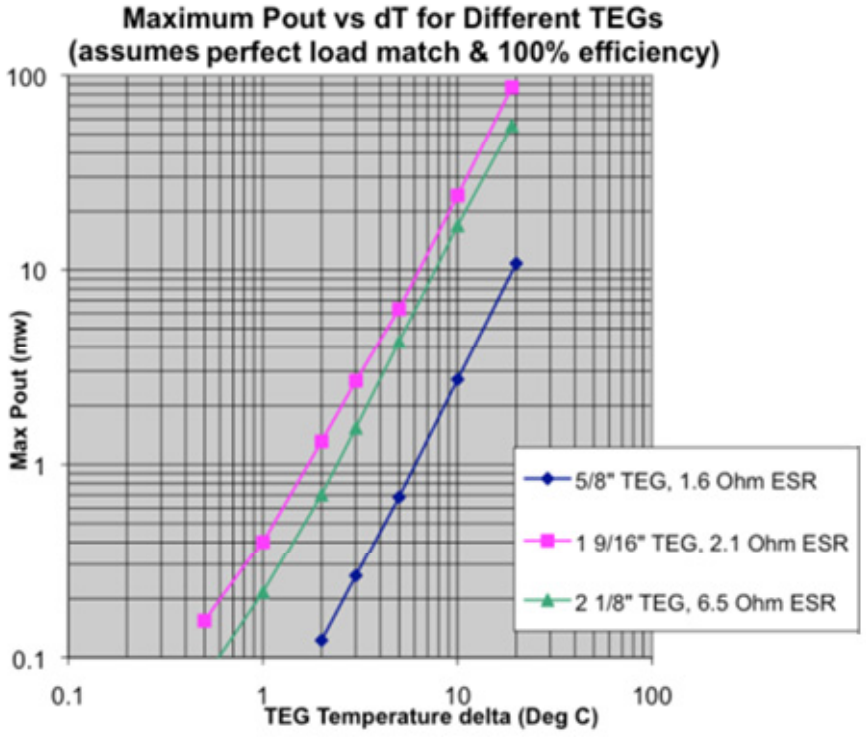




- VOUT proportional to temperature differential
- Need to maintain a temperature gradient across TEG
- → Heatsinks required

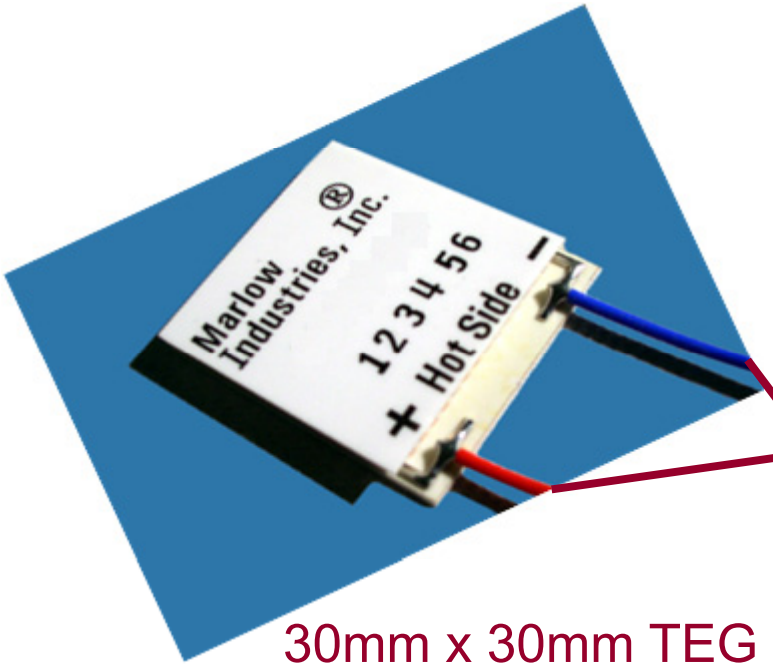
TEG Characteristics





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

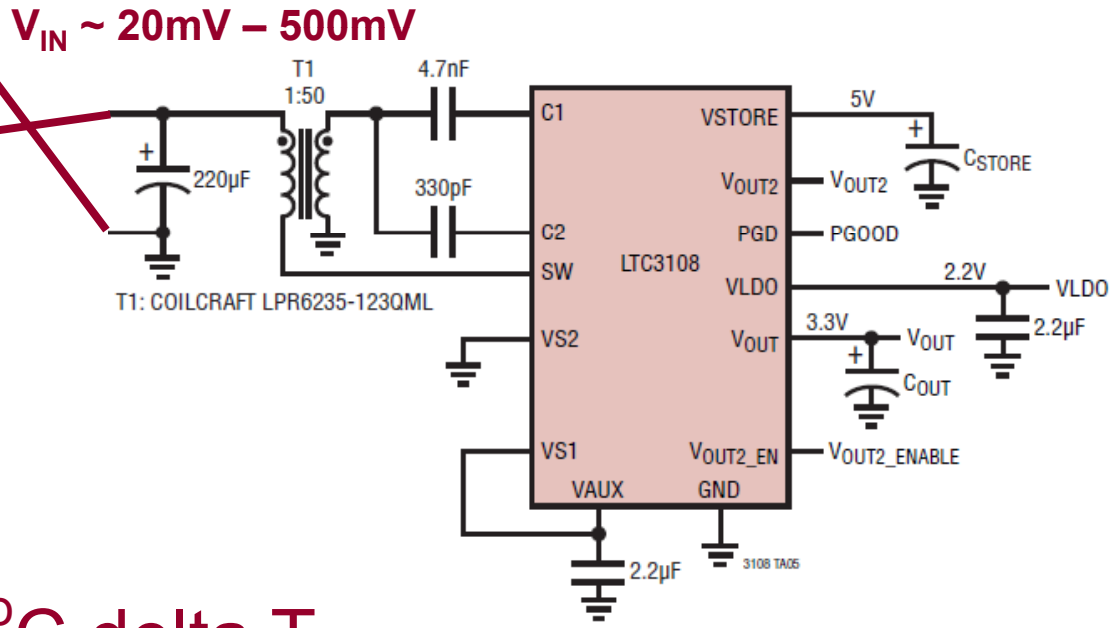
Thermoelectric Example #1



30mm x 30mm TEG

LTC3108

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



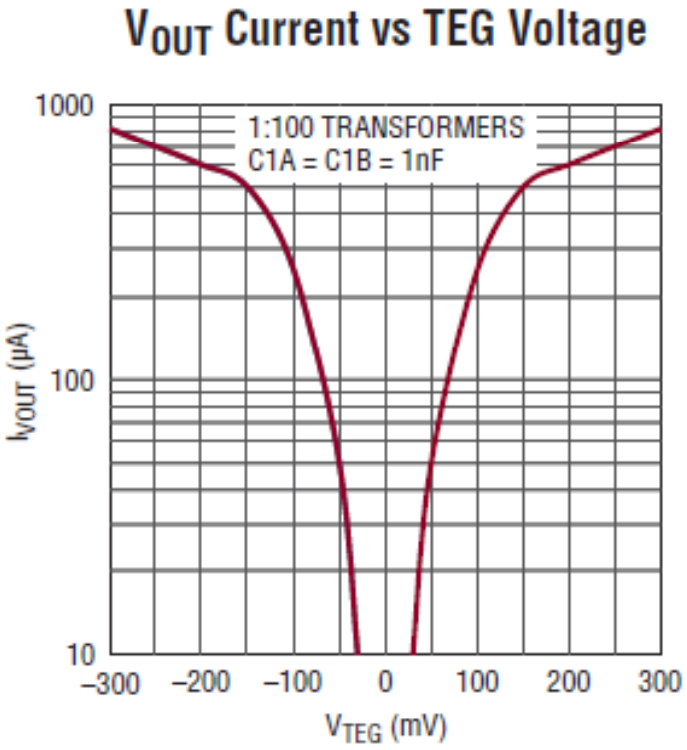
Output:

V_{OUT} = 3.3V

I_{OUT} = 60uA @ 10°C delta T

I_{OUT} = 400uA @ 30°C delta T

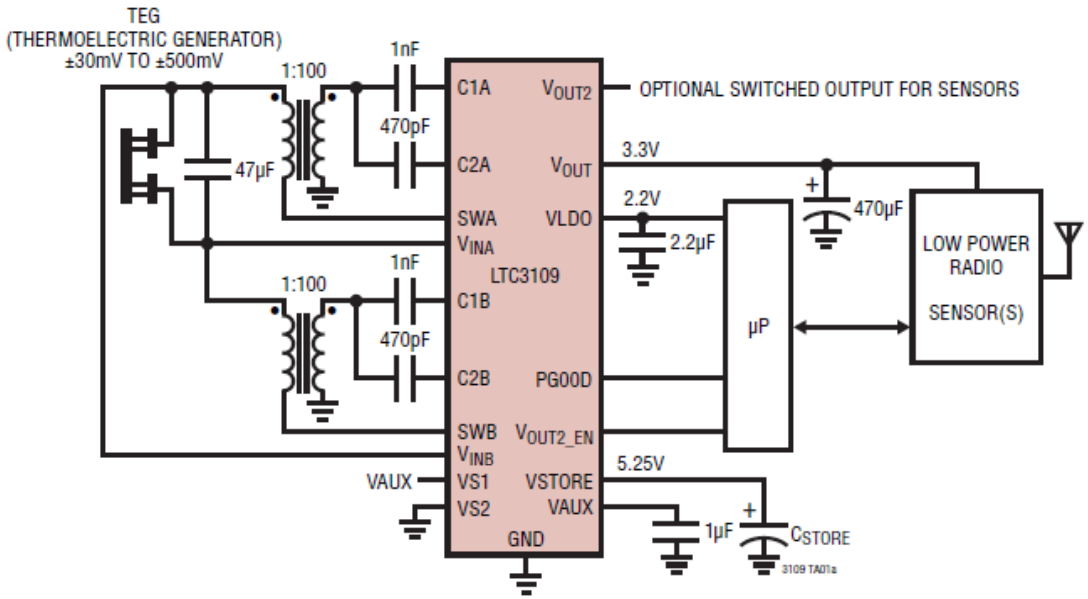
Thermoelectric Example #2



LTC3109

Auto-Polarity, Ultralow Voltage Step-Up Converter And Power Manager

(min V_{IN} = +/-30mV)



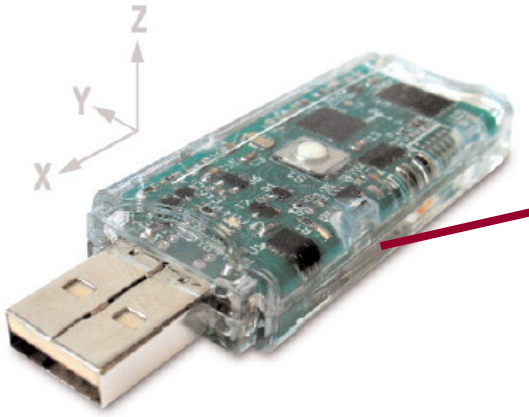
Output:

V_{OUT} = 3.3V

I_{OUT} = 60uA @ +/- 10°C delta T

Vibration Energy Considerations

What does the vibration source look like?



TIME DOMAIN

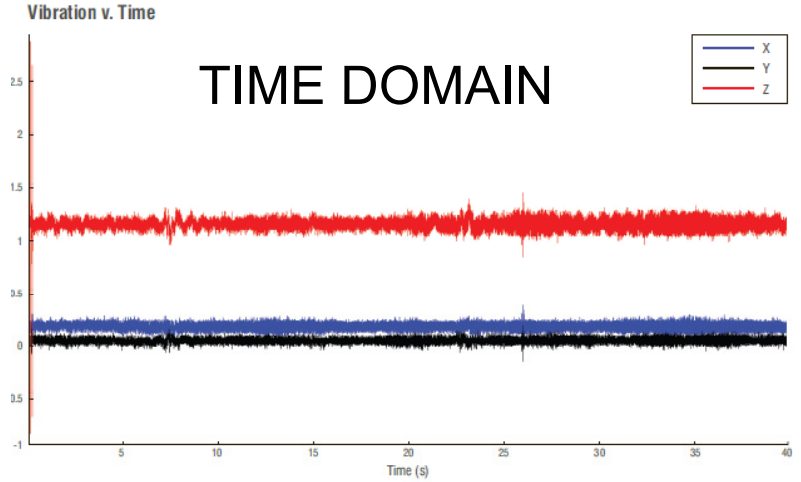


Figure 2: Time domain response of a commercial jumbo jet during taxiing.

→ FREQUENCY DOMAIN

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

MIDE

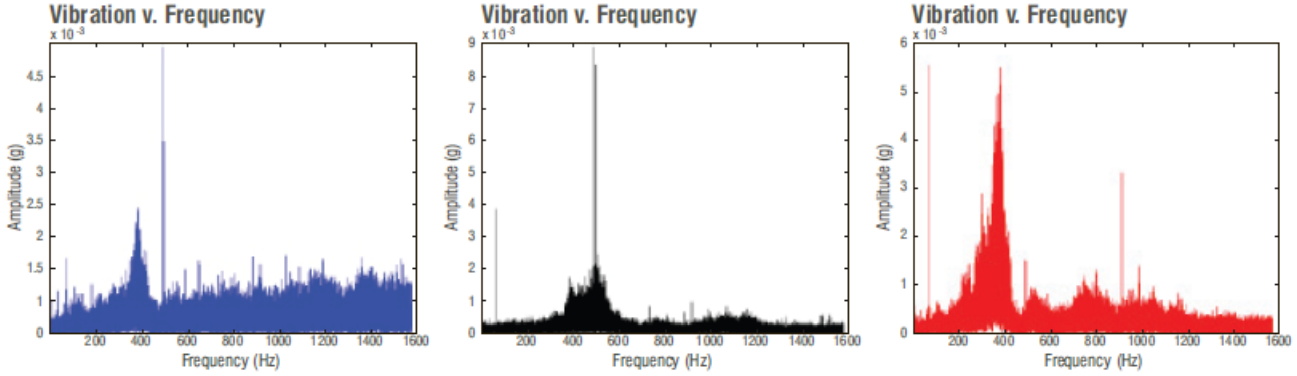


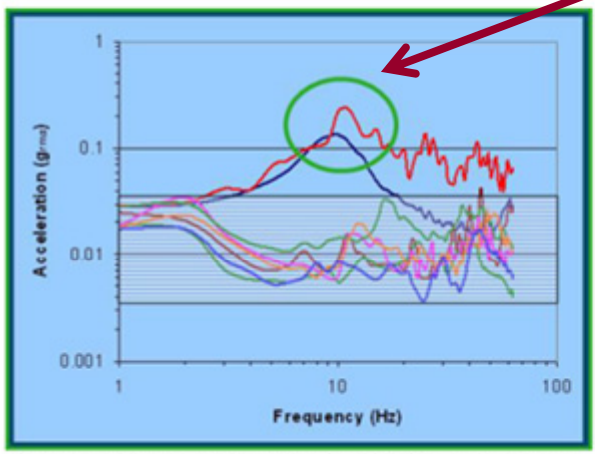
Figure 5: 1-D FFTs of vibration data during cruise

LINEAR TECHNOLOGY

Vibration Transducers

Frequency response must match or power falls off quickly

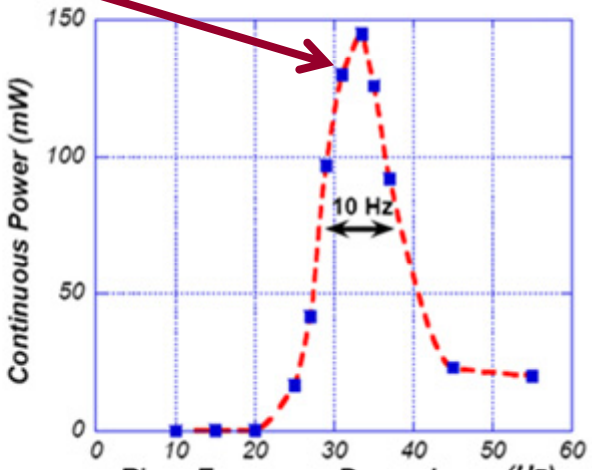
Source



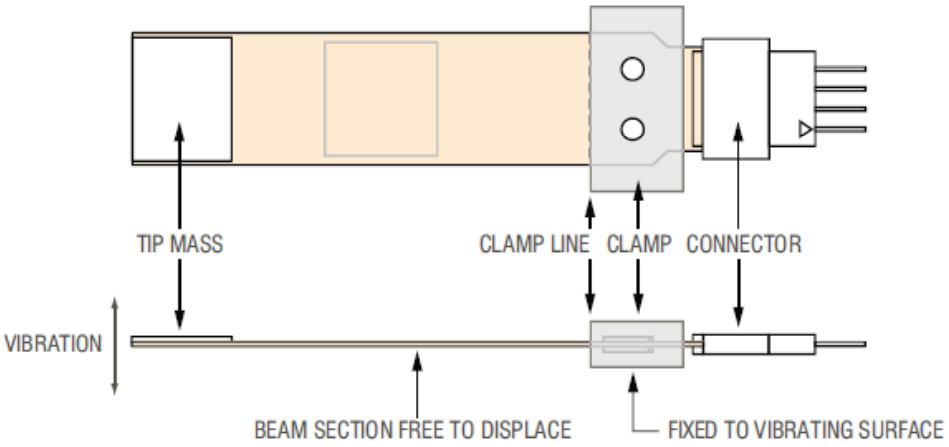
Interior and exterior vehicle vibration data on automobiles, trucks and minivans.

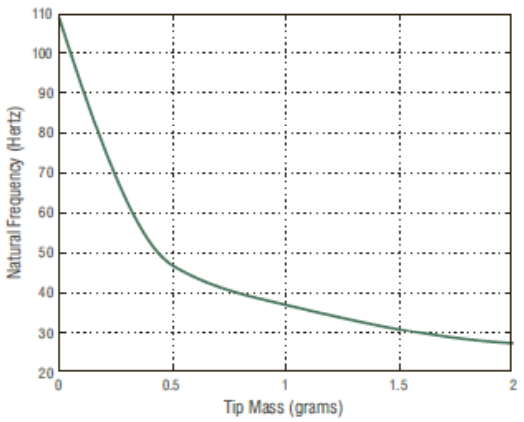
Source: Adaptive Energy Corporation

Transducer

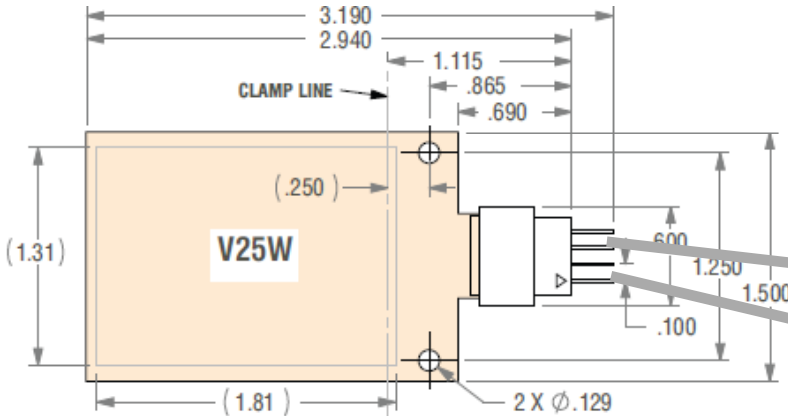


Source: Advanced Cerametrics Corporation





Vibration Source #1 – Piezoelectric



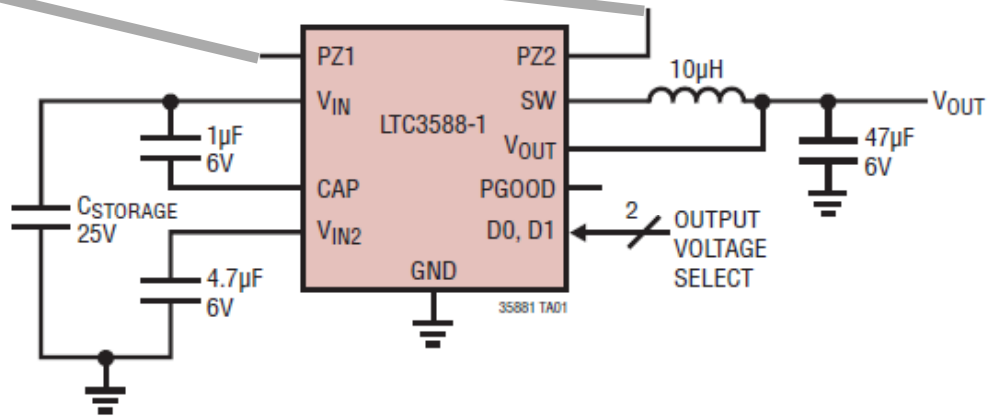
MIDE

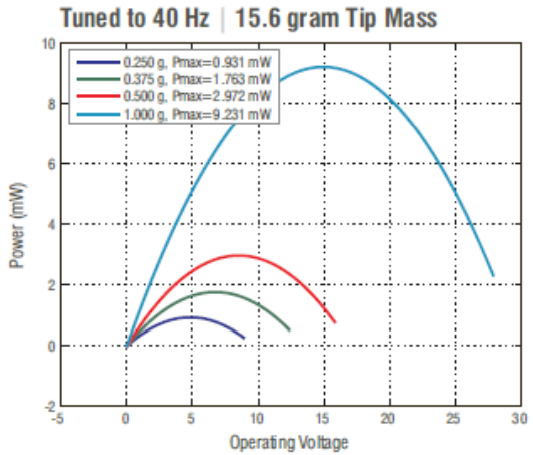
Volture™

LTC3588

Piezoelectric Energy Harvesting Power Supply

(I_{CC} = 900nA)





Output:

V_{OUT} = 3.3V

I_{OUT} = 200uA @ 0.25g / 40Hz

LINEAR TECHNOLOGY

Vibration Source #2 – Electromechanical

perpetuum

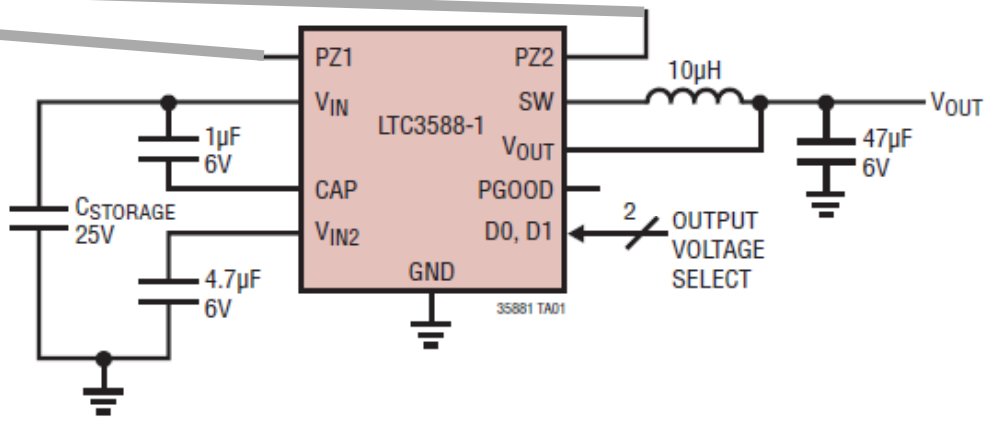
PMG FSH

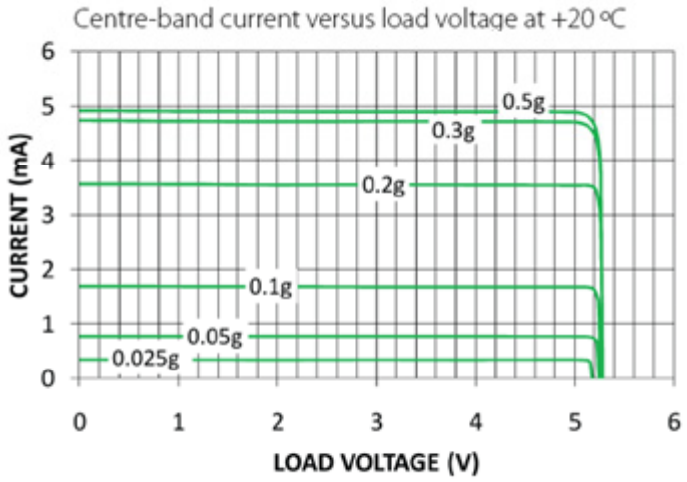
LTC3588

Piezoelectric Energy Harvesting Power Supply

(Eff ~ 90% @ V_{IN} ~ 5V)

V_{IN} ~ 5V





Output:

V_{OUT} = 3.3V

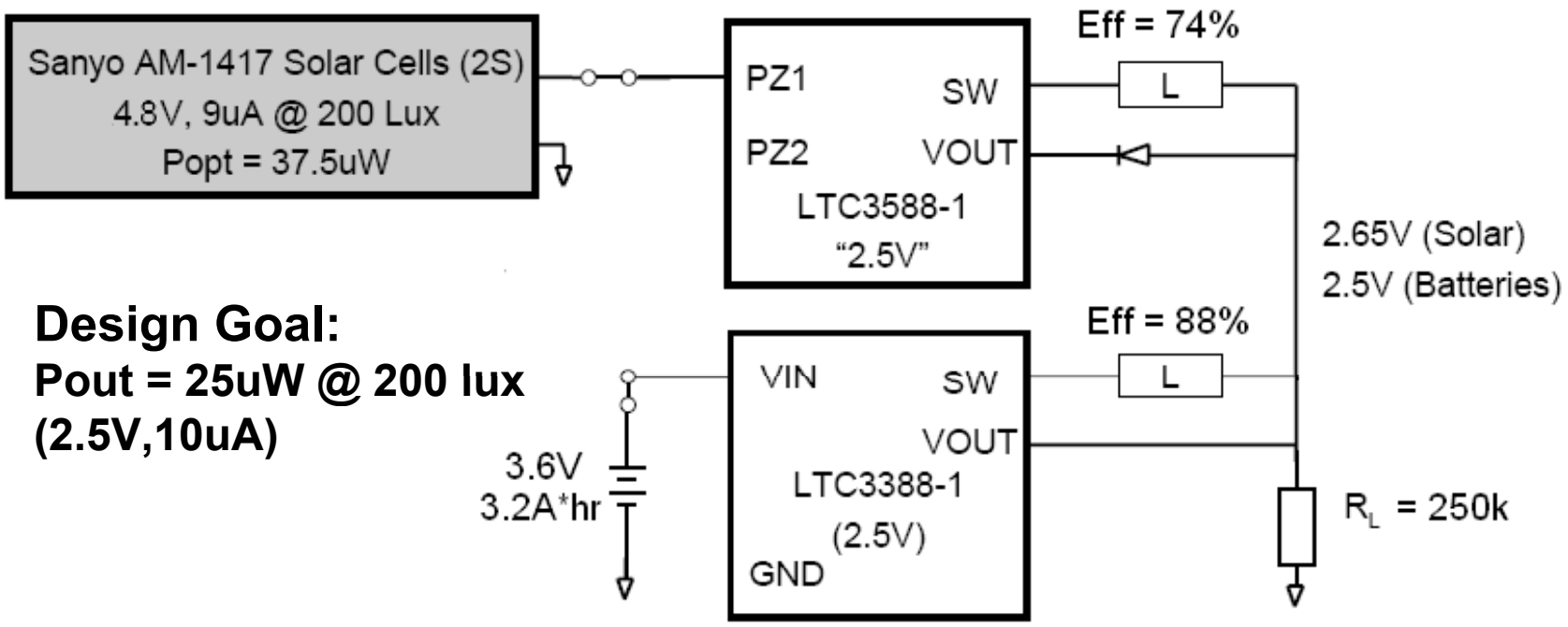
I_{OUT} = 400uA @ **0.025g !!!**

LINEAR TECHNOLOGY

If Energy Harvesting Alone is Not Enough…

Use Energy Harvesting to Extend Battery Life:

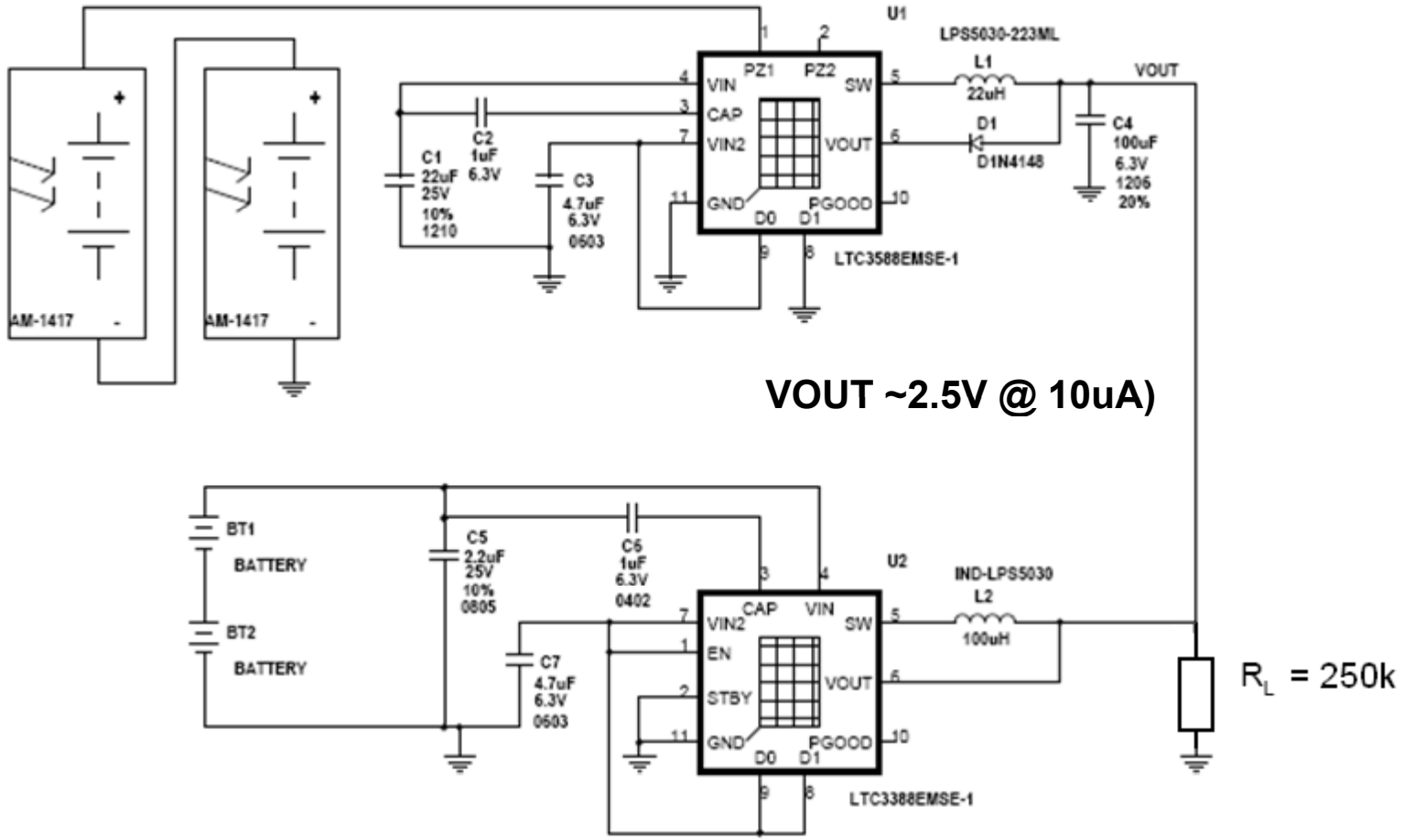
Load gets power from either indoor solar or
Li primary cells (0.66% / year self discharge)



Design Goal:
Pout = 25uW @ 200 lux
(2.5V,10uA)

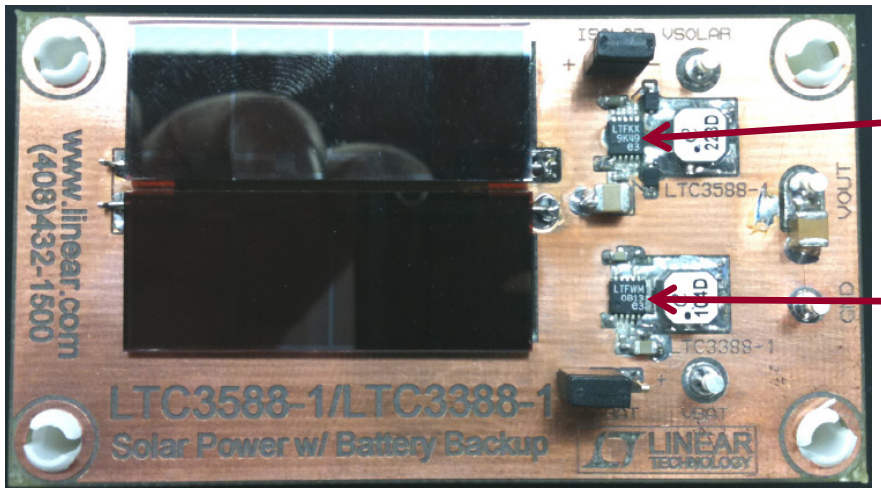
Battery Life Extender

Solar Powered Thermostat with Battery Backup



Low Power EH + Battery Solutions

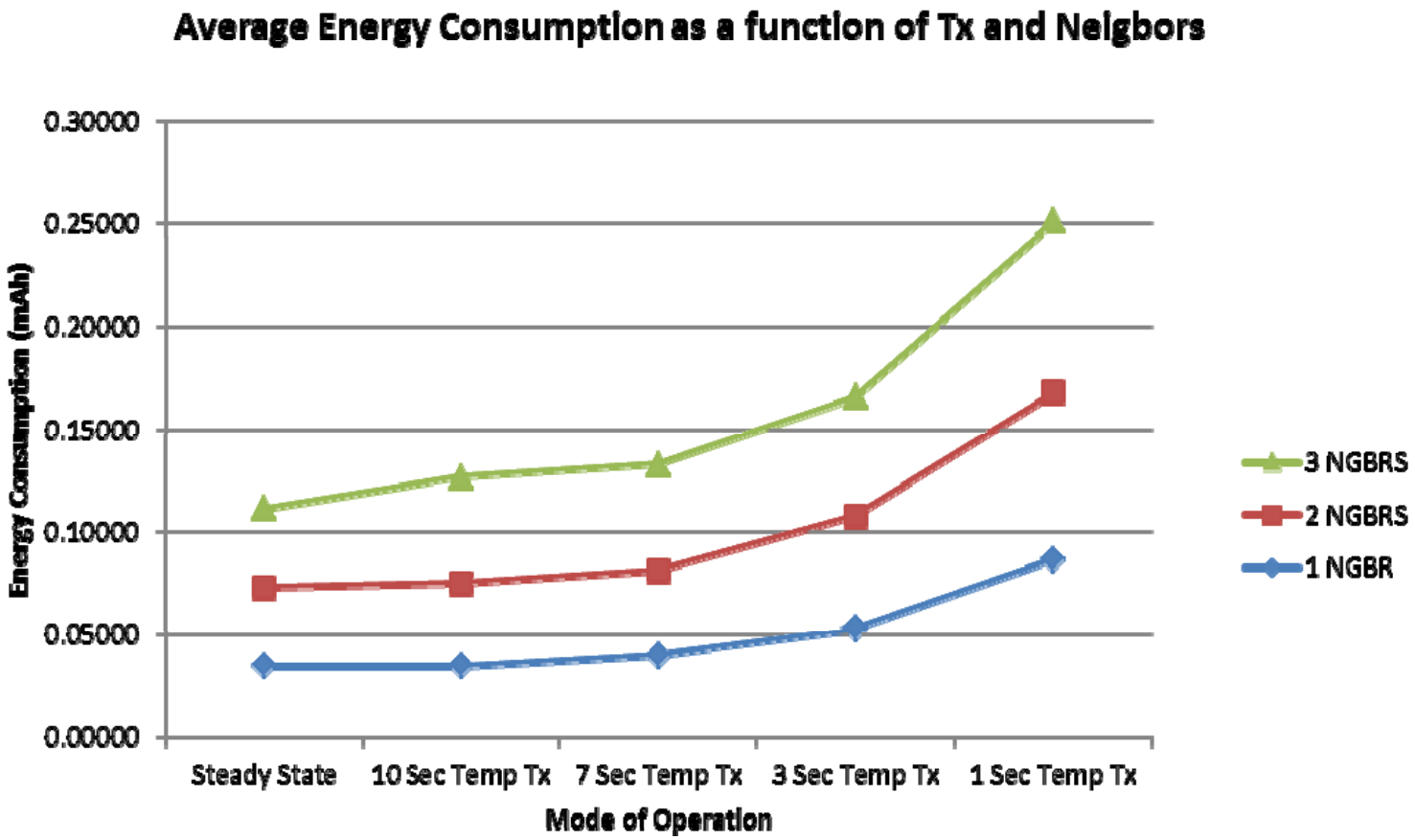
Solar Powered Thermostat with Battery Backup



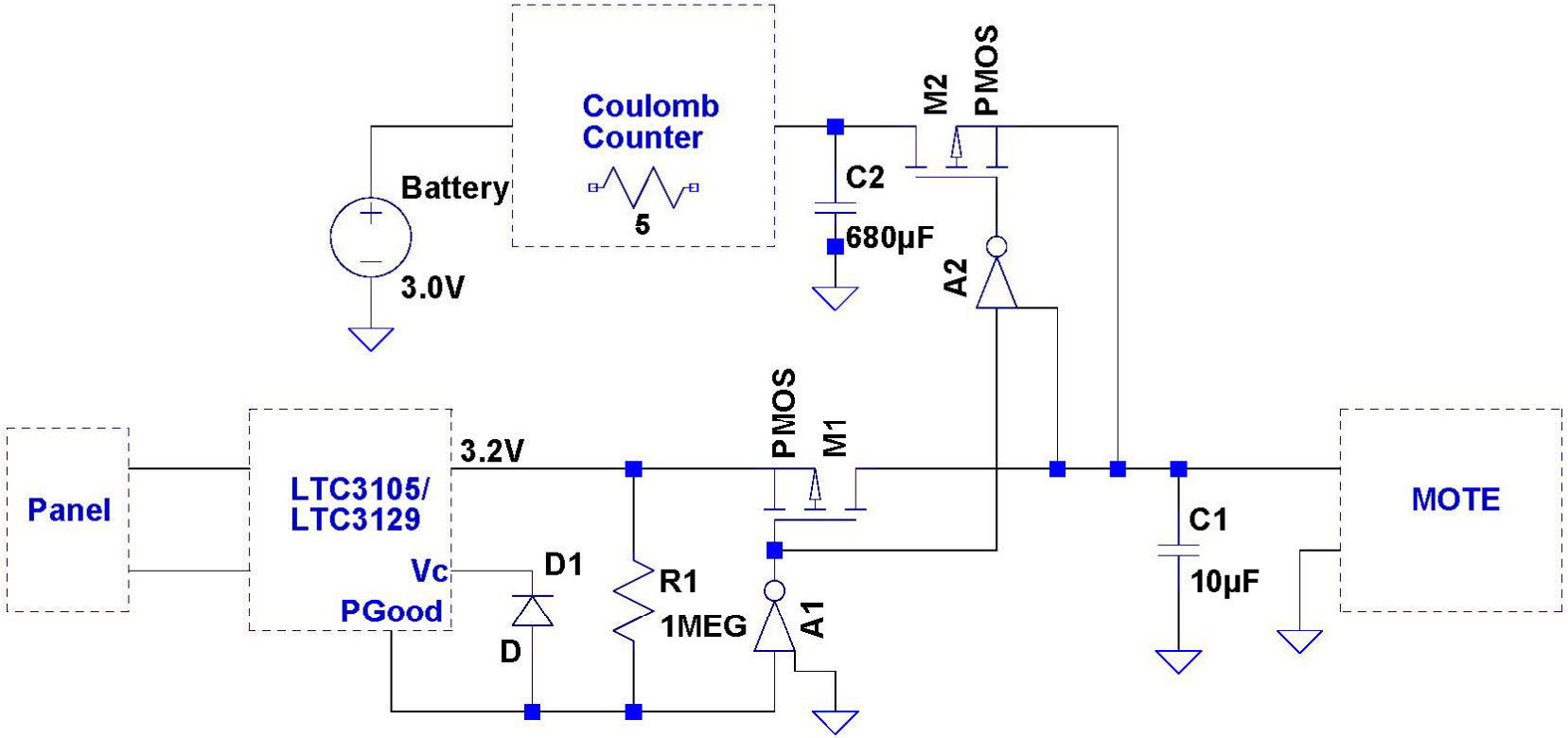
Available Output Power:
25uW @ 200 lux
V_{OUT} = 2.5V, I_{OUT} = 10uA

Batteries take over when light source is gone

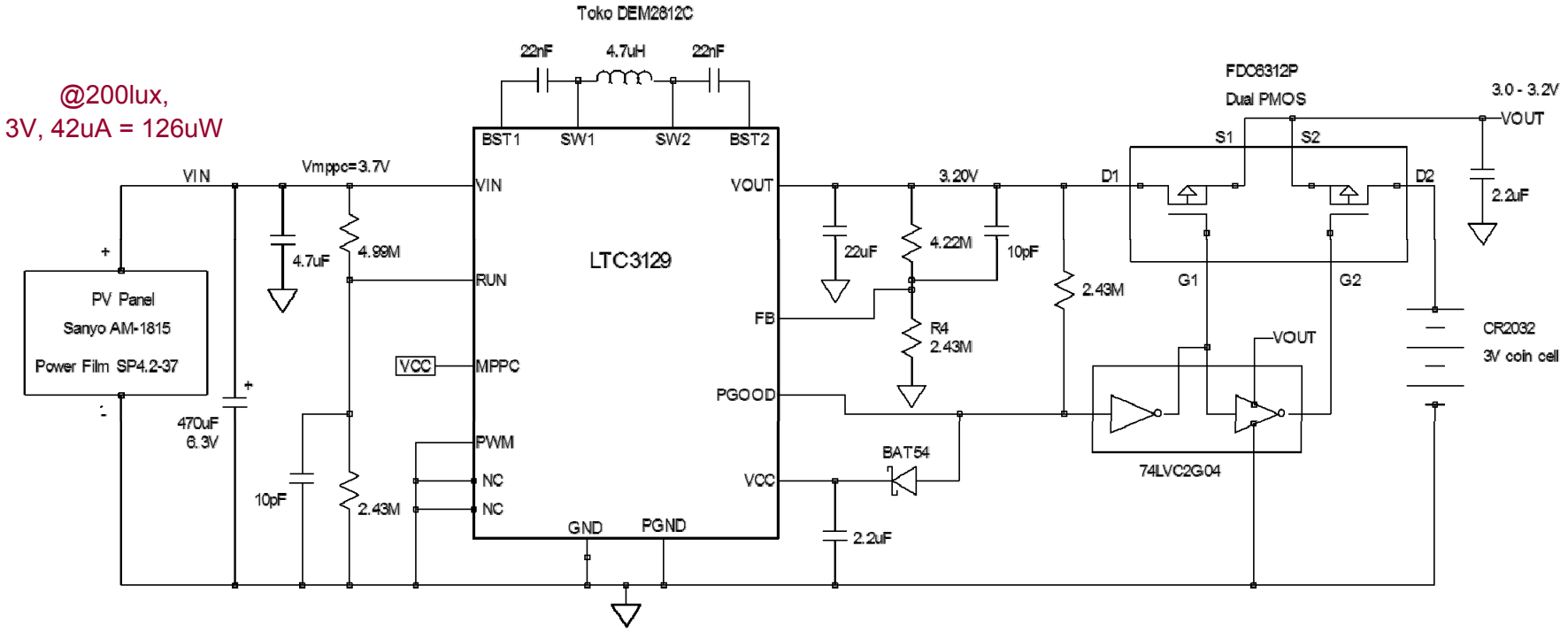
Wireless MESH Network Example –
Energy Requirement as a function of TX and Neighbors



Battery Life Extender - Basic System Block Diagram



Buck-Boost with Battery Switch-Over Circuit

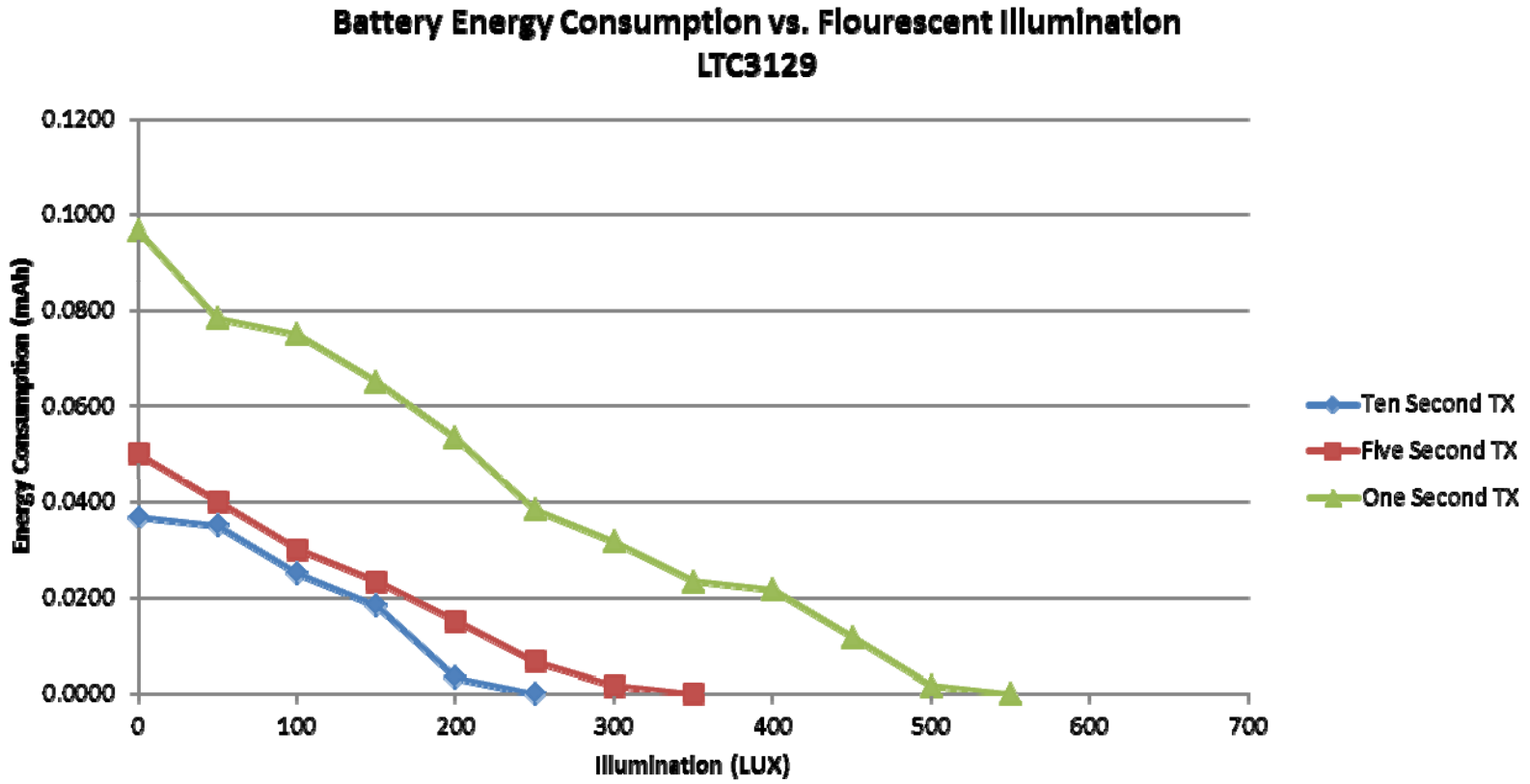


- 3129 switch-over circuit switches between Battery and Solar

Buck-Boost with Battery Switchover

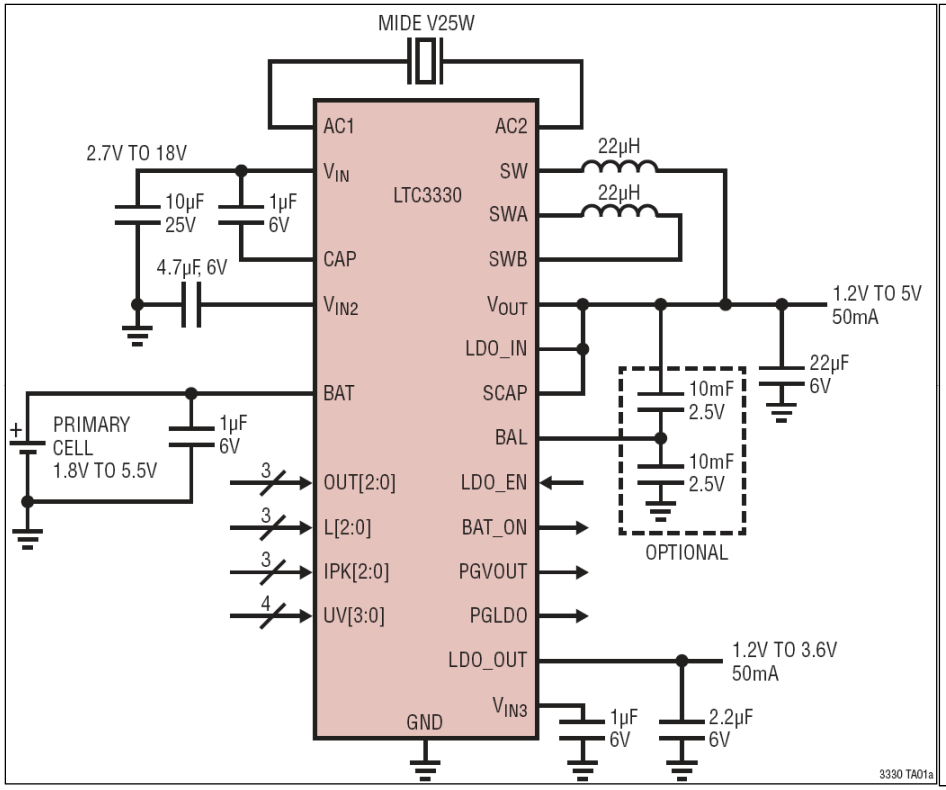
- Here solar is barely able to supply load, As Vin drops, it hits RUN threshold, part stops switching, runs off Vbat

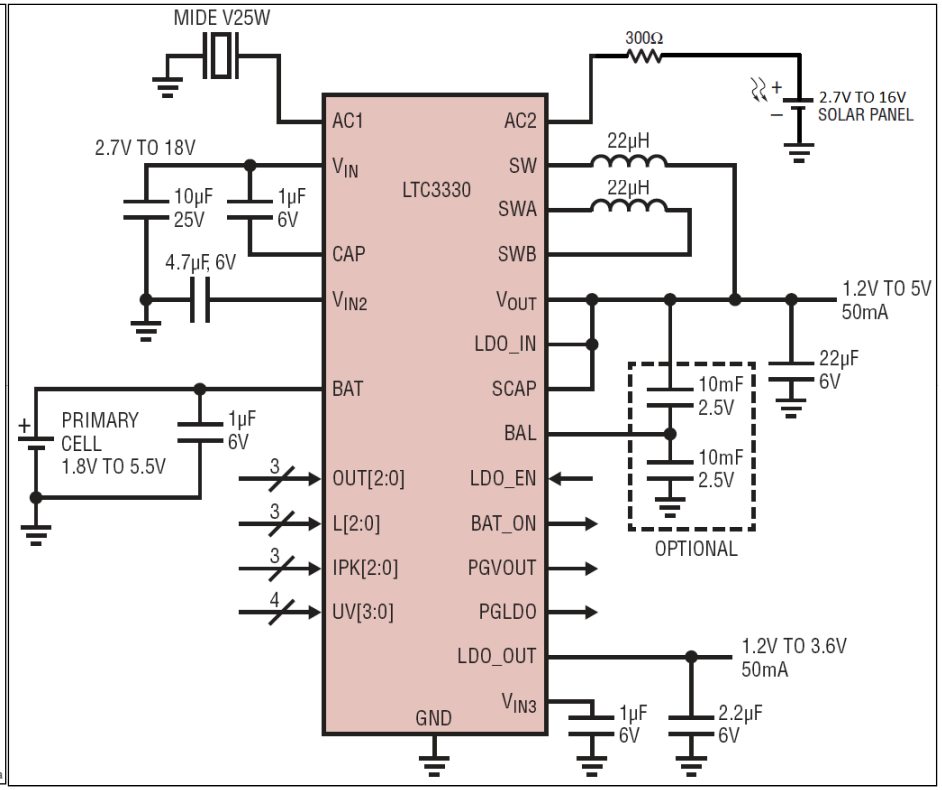
Extending Battery Life with Energy Harvesting



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

Use Energy Harvesting to Extend Battery Life





- Piezoelectric and
- Primary Cell Battery

- Piezoelectric, Solar and
- Primary Cell Battery

- AC1 and or AC2 to VOUT = BUCK
- BAT to VOUT = Buck-Boost

Advancements in Energy Harvesting Transducers and the Challenges they Present for Power Management Solutions

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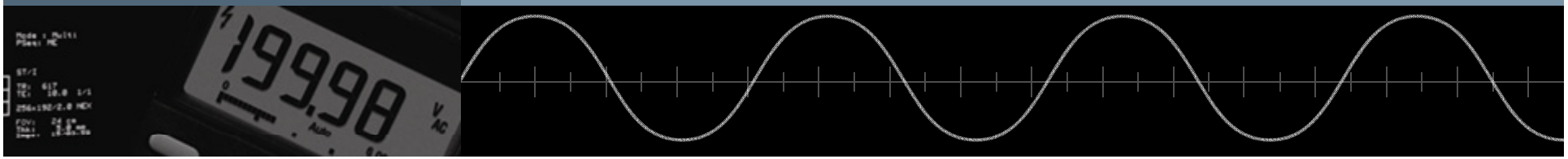

Thank You

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Energy Harvesting 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)	**LTC3105** **LTC4071** **LTC3129** **LTC3459** LTC3330	100uW – 1mW	>100mW
Outdoor Solar (1000lux – 50000lux)	Photovoltaic Cells (100cm^2)	**LTC3105** **LTC3588** **LTC3129** LTC3330	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** **LTC3129** **LTC3459** LTC3330	50uW – 500uW 500uW – 10mW	>100mW

Thank You

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