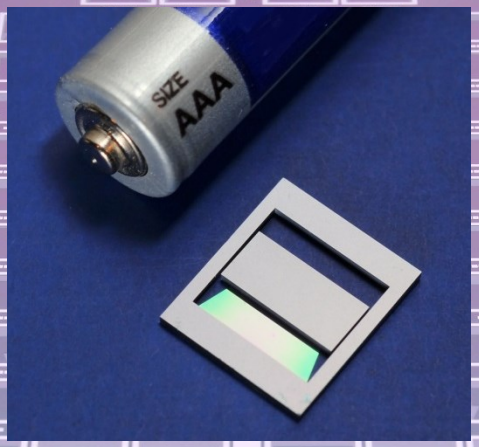
Design of MEMS Piezoelectric Vibrational Energy Harvesters for Industrial and Commercial Applications



Kathleen M. Vaeth, *Vice President of Engineering*

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MicroGen Systems Inc.: At a Glance

- **MicroGen Systems Inc. is developing MEMS piezoelectric vibrational energy harvesters.**
  - **Technology** developed at **University of Vermont** and **Cornell University**
  - **First prototypes validated** in **2011**
  - **Production:** X-FAB Semiconductor Foundries (Germany)

"Ten analog, MEMS and sensor startups to watch in 2014" EE Times (Jan 7, 2014)

2013 Winner
MEMS Tech Showcase® MEMS Industry Group
PRWEB (Nov 19, 2013)

2012 **EE Times' "Silicon 60"** Top 60 Emerging Companies in the World EE Times (Oct 4, 2012)

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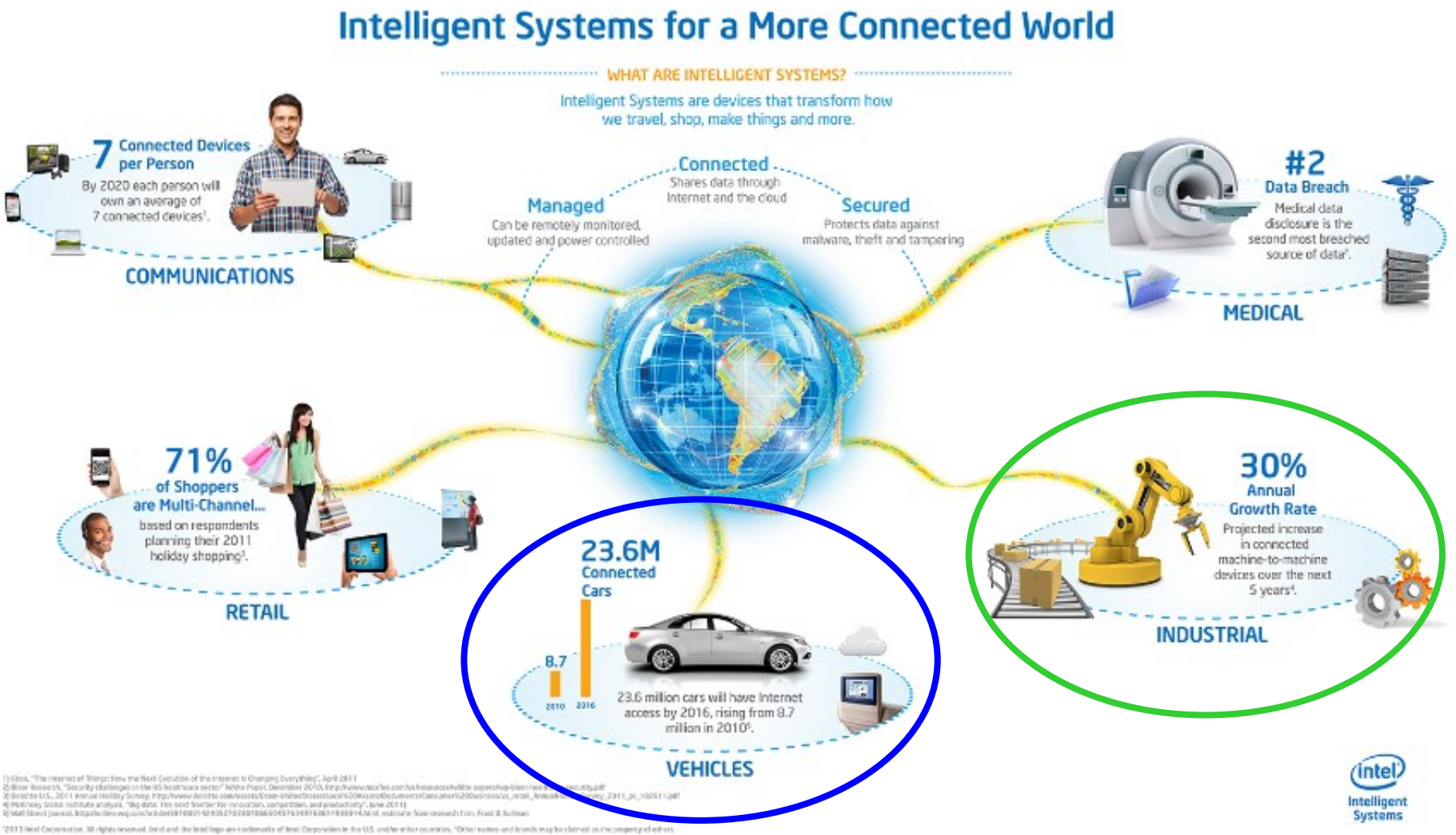
Internet of Things: Sensors Everywhere



There are predictions of one trillion sensors being produced per year by 2020

The all need power → Energy Harvesting

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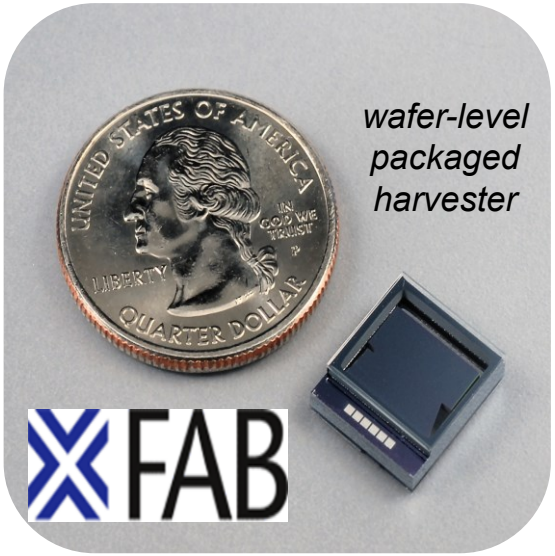
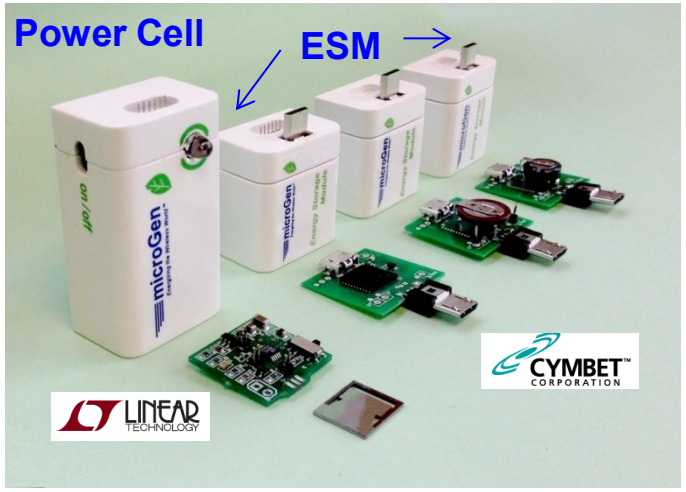
Solution: Micro-scale power source

MEMS Piezoelectric Vibrational Energy Harvesters and Power Cells



- Superior power generation from small form-factors
- Low cost, long life, high reliability and green energy

Power 50-200 µW DC



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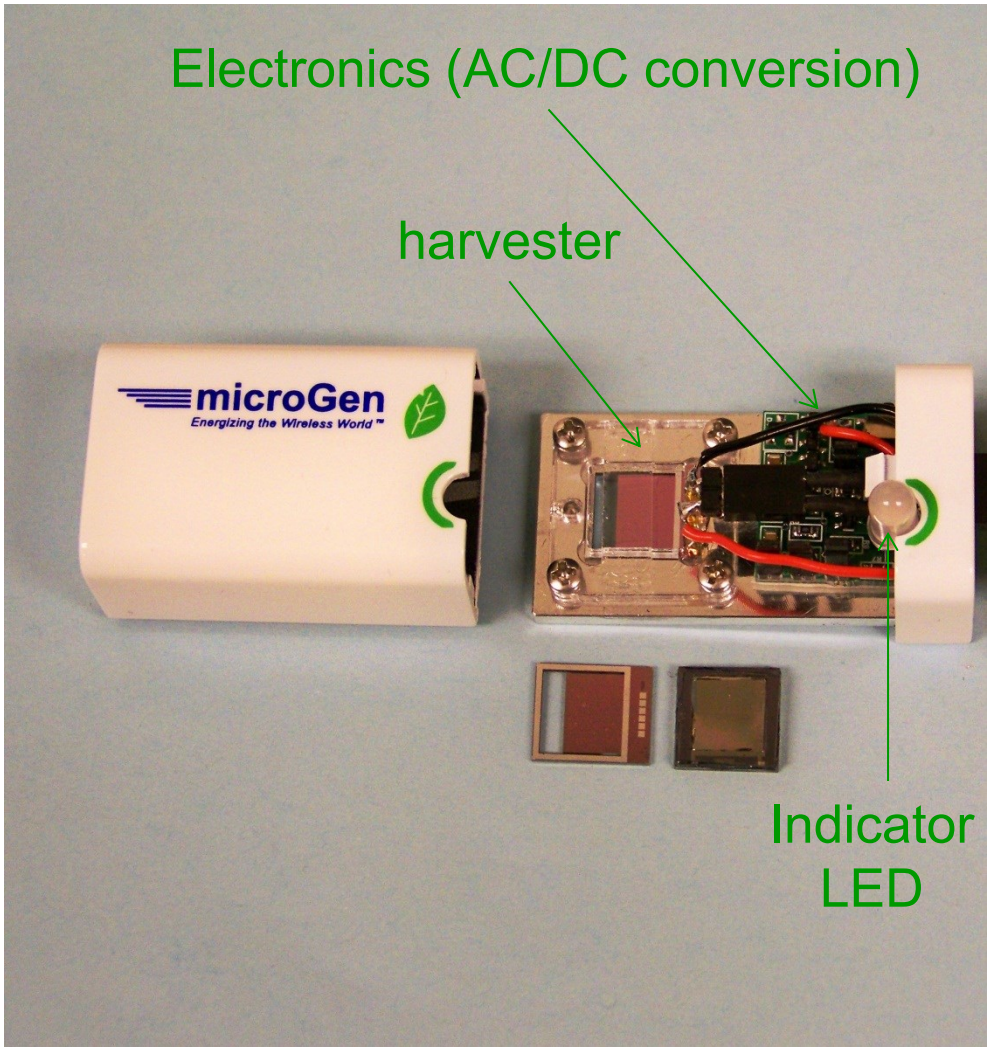
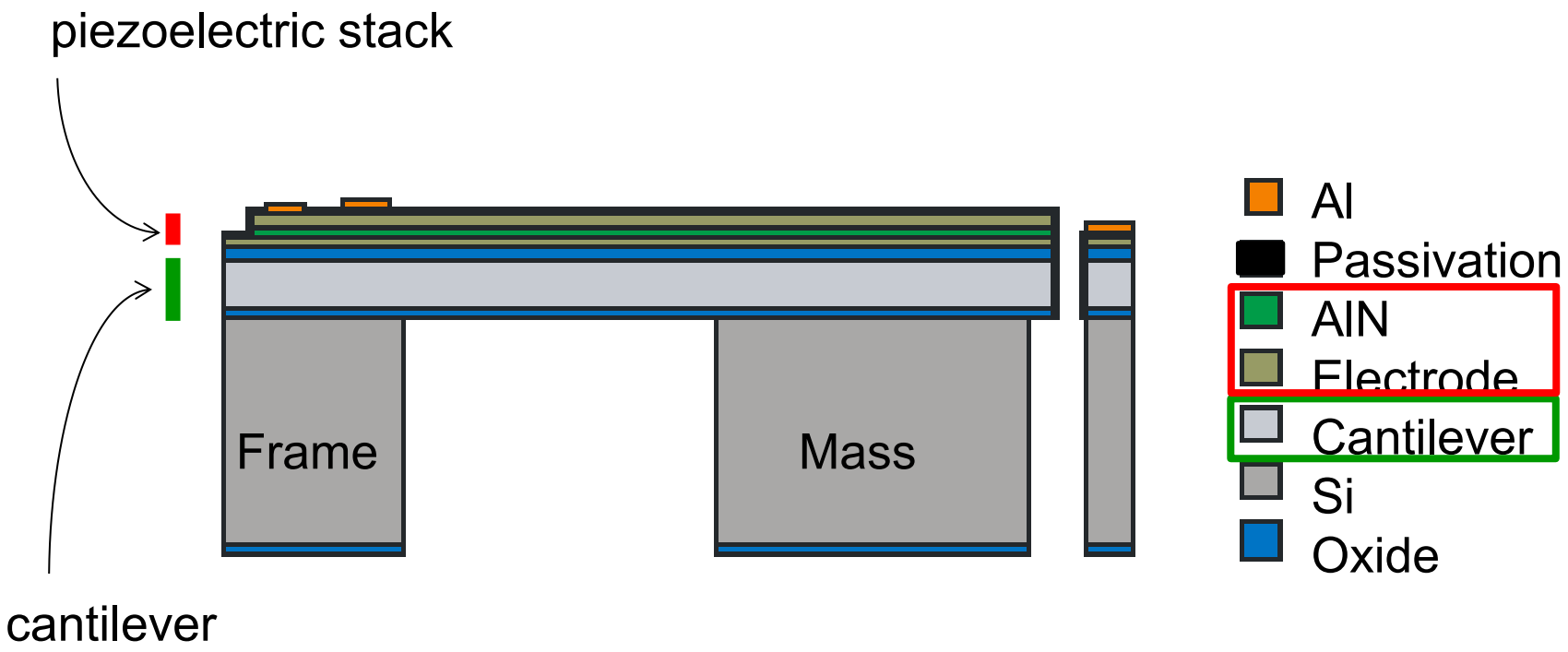
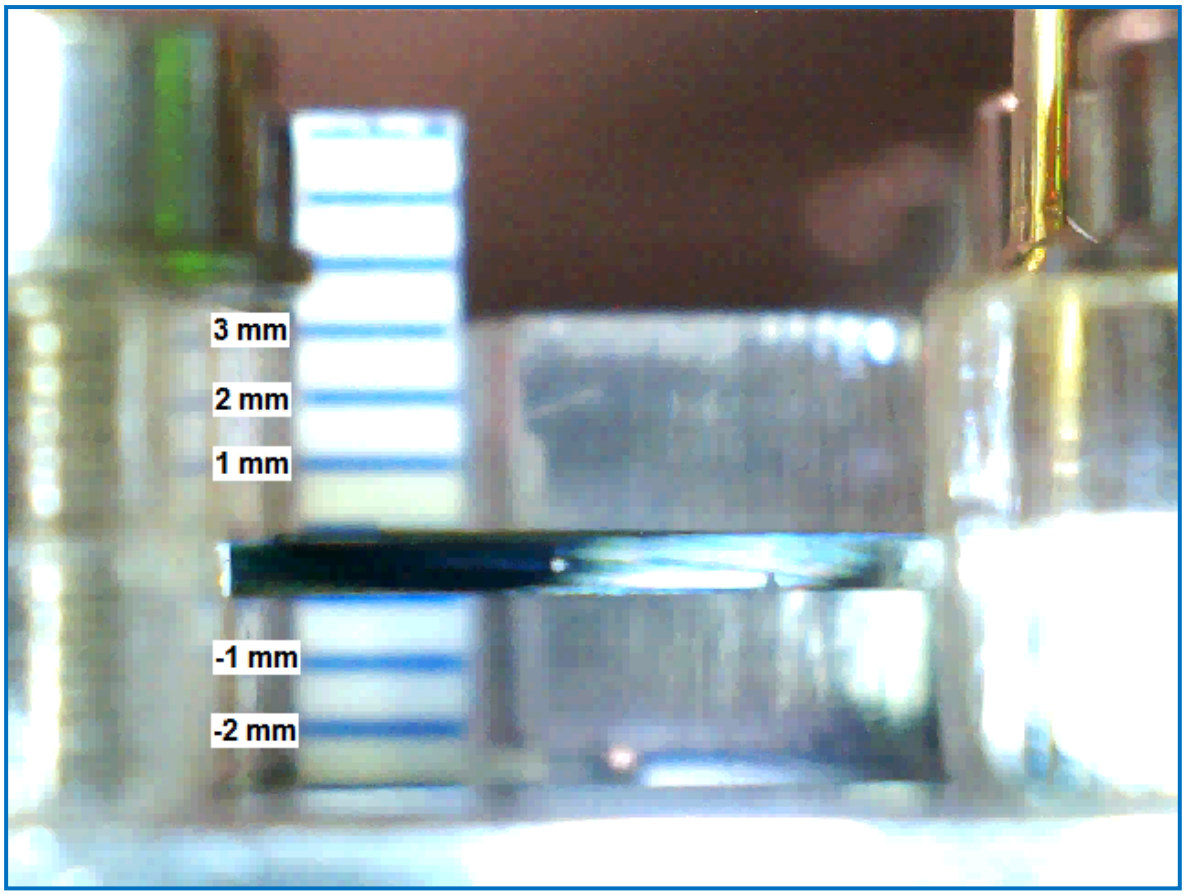
Power Cell



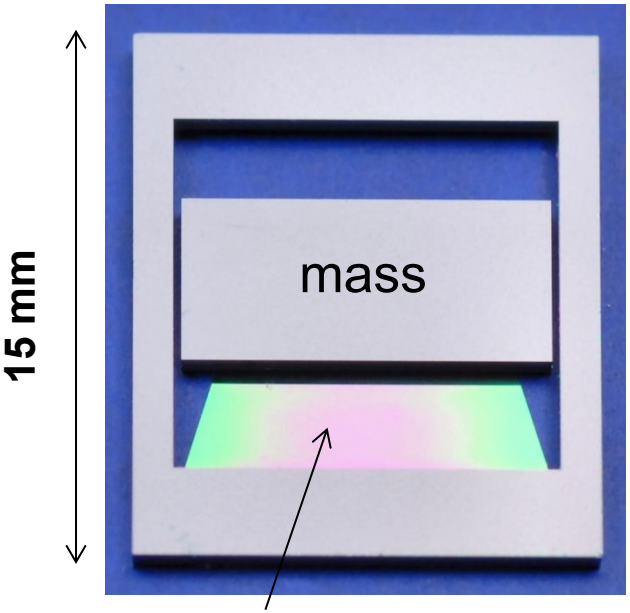
Harvester Cross-Section: MEMS



Resonant Mode Energy Harvesting



Bottom View



Cantilever coated with piezoelectric material

Deep cavity (~ 1-2 mm) packaging required, depending on frequency

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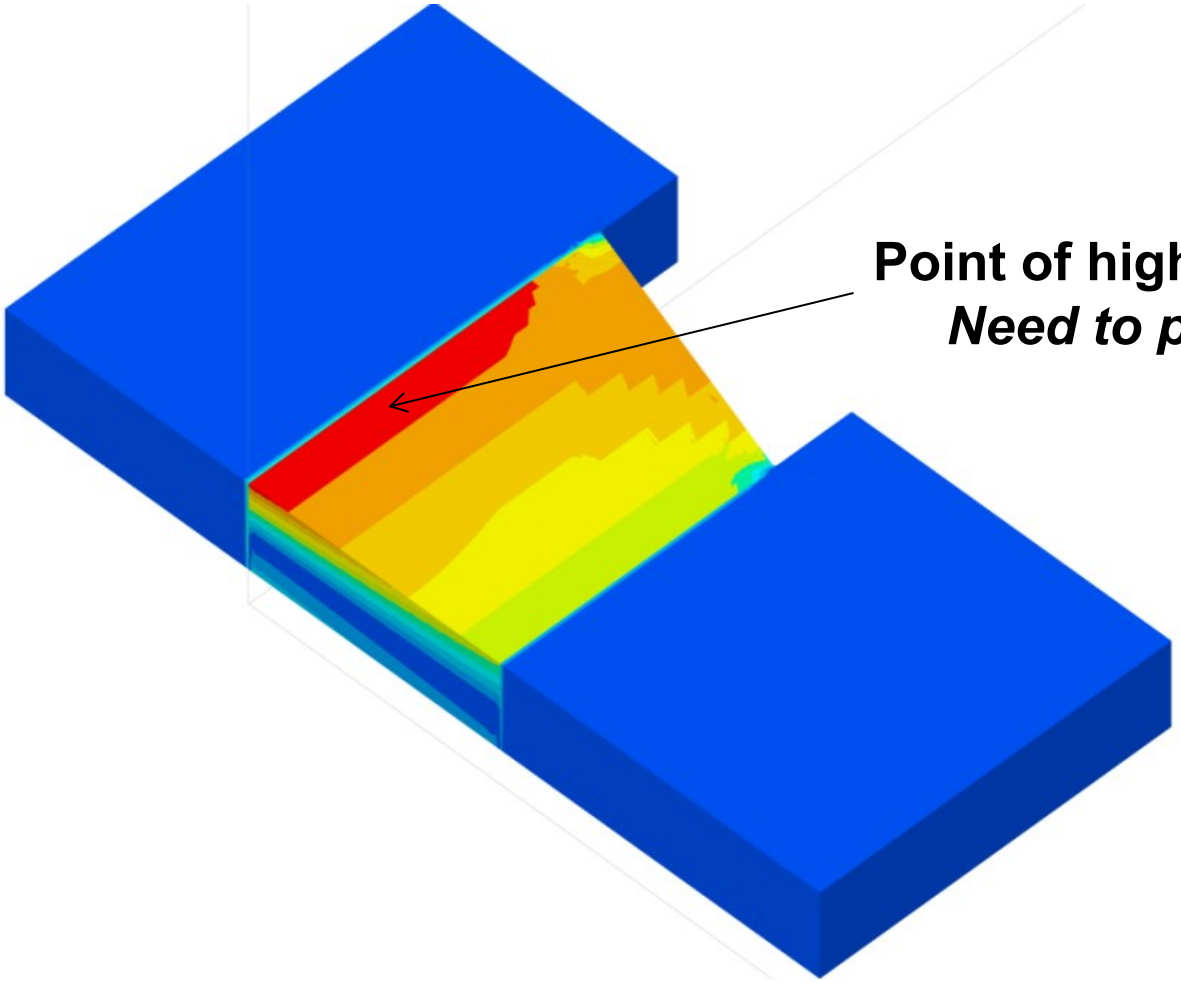
FEM Modeling for Stress Mapping



Point of high stress:
Need to prevent overdeflection

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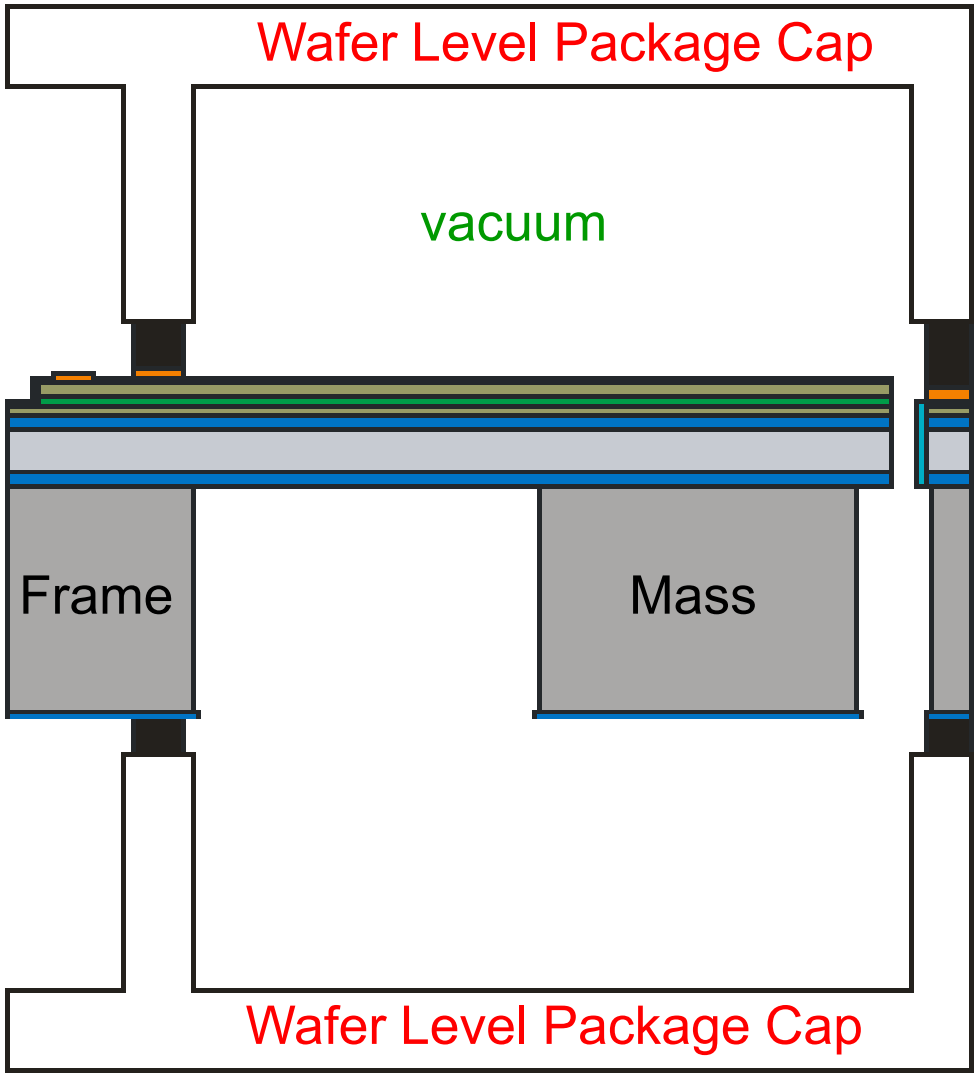
Harvester Cross-Section: Packaging



- Borofloat
- Glass Frit
- Al
- Passivation
- AlN
- Electrode
- Cantilever
- Si
- Oxide

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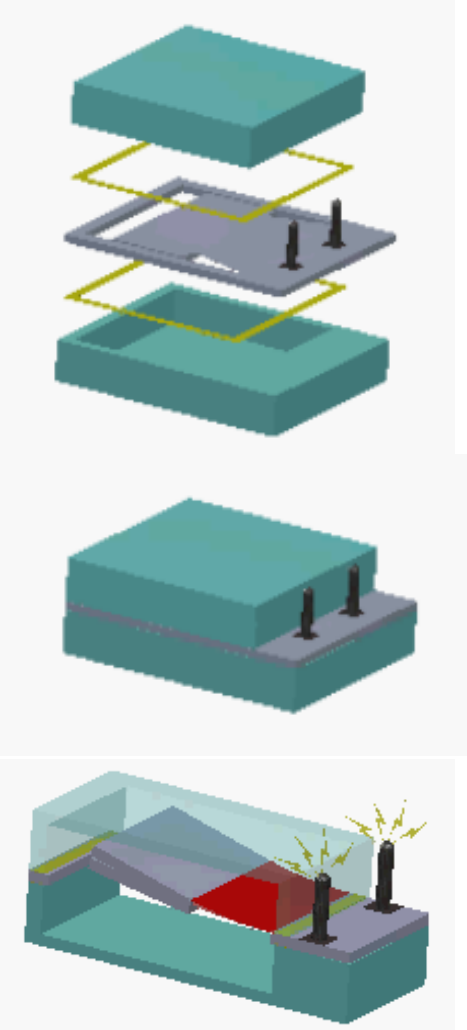
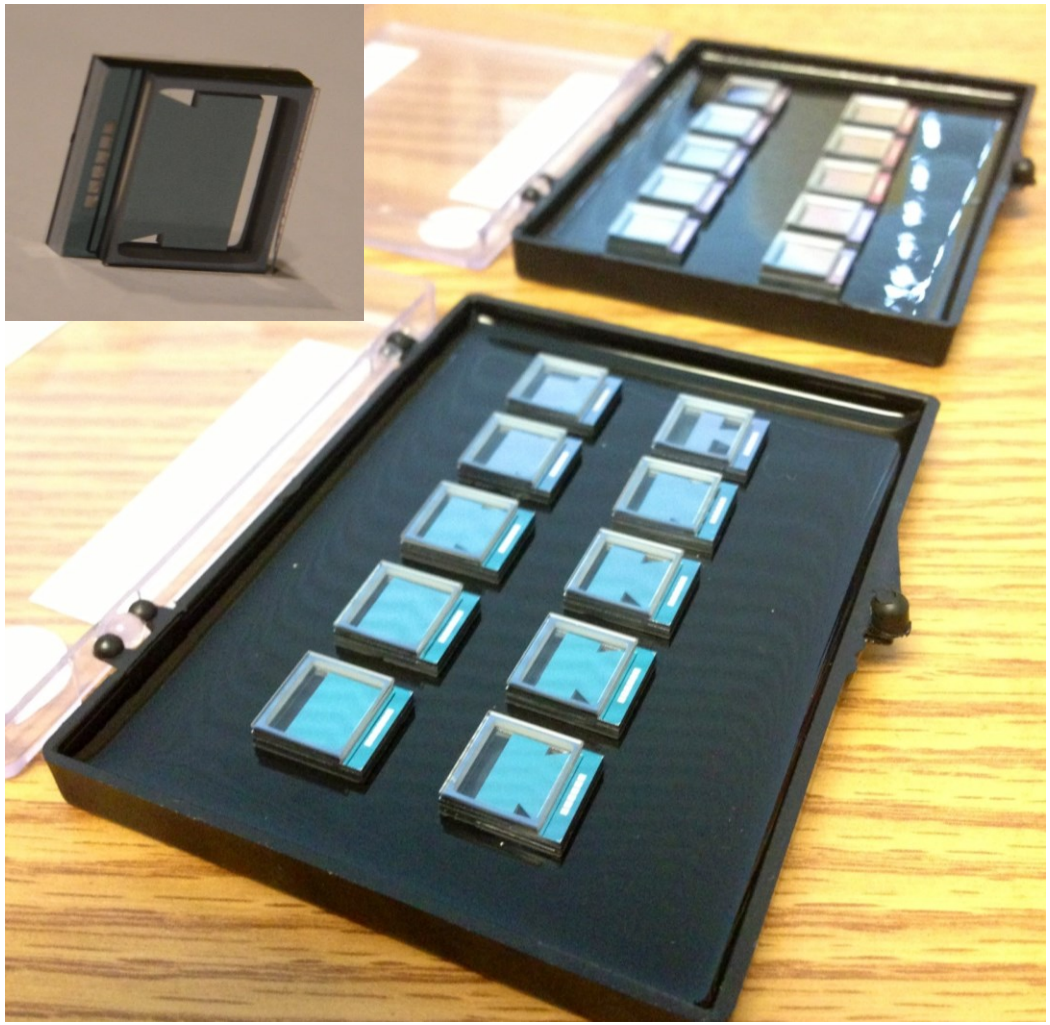
Wafer Level Packaged Devices

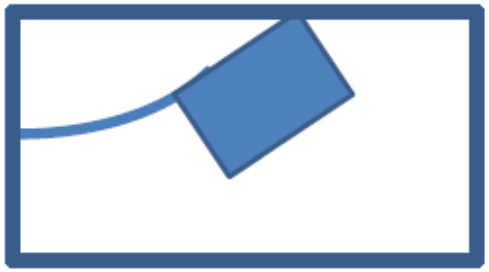




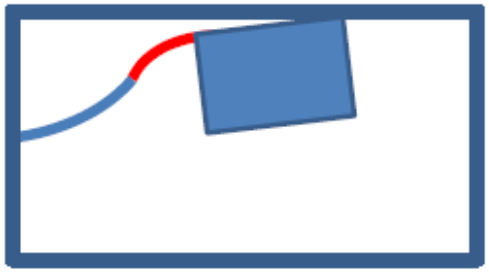
Energy Harvester Robustness

Enclosed packaging prevents overextension of the harvester, but control of the movement of the cantilever is still required in order to prevent breakage

desired

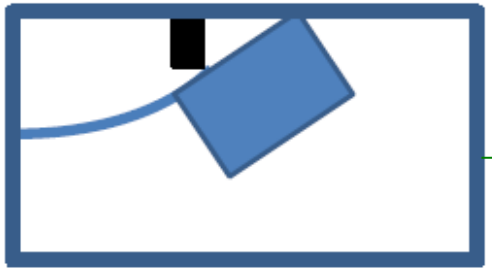


What is happening



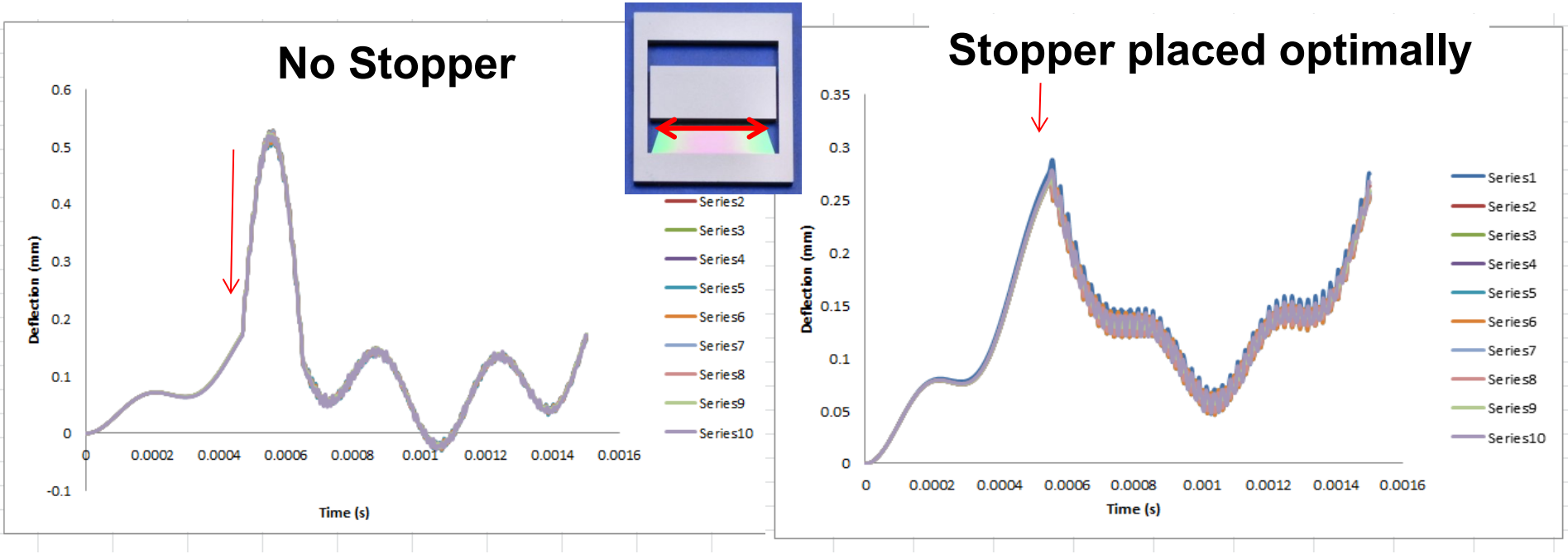
High strain causes fracture

Corrected with "stopper"



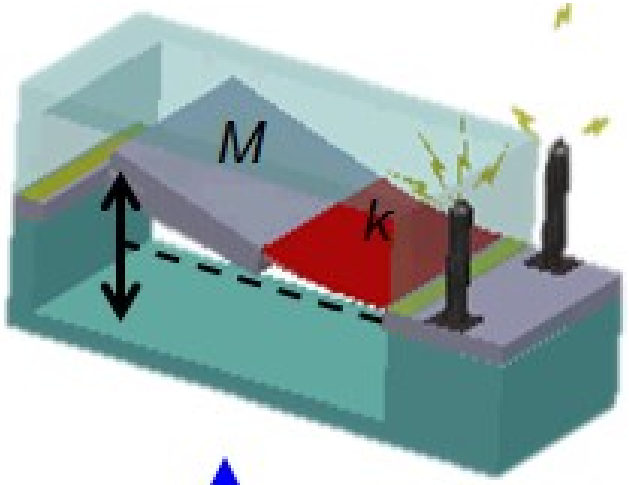
Where should the stopper be placed?

Cantilever Deflection Near Mass with Time

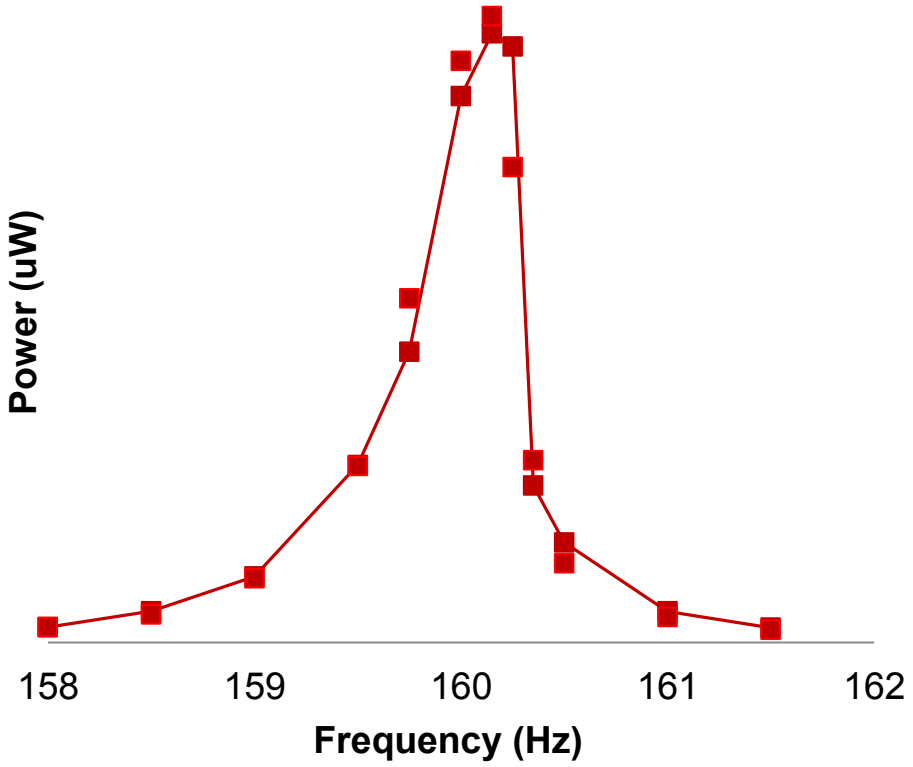


- Stabilization of cantilever movement achieved by incorporation of a stopper on the top and bottom WLP caps.

"Resonant mode" Operation: *MicroGen's BOLT™ Product Line*



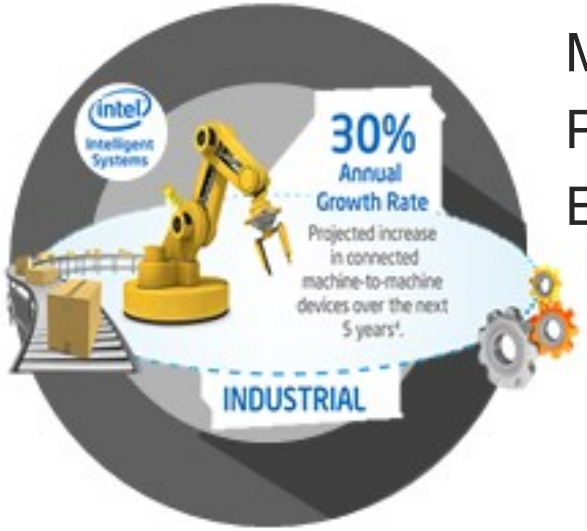
external vibration at a constant frequency



$$\text{Resonant frequency } f_1 \sim \left[\frac{k}{M}\right]^{\frac{1}{2}}$$

Q factor > 250

Industrial, Building, and Smart Infrastructure



Machine to machine (M2M) connectivity

Process automation (e.g. oil & gas industry)

Equipment preventative maintenance

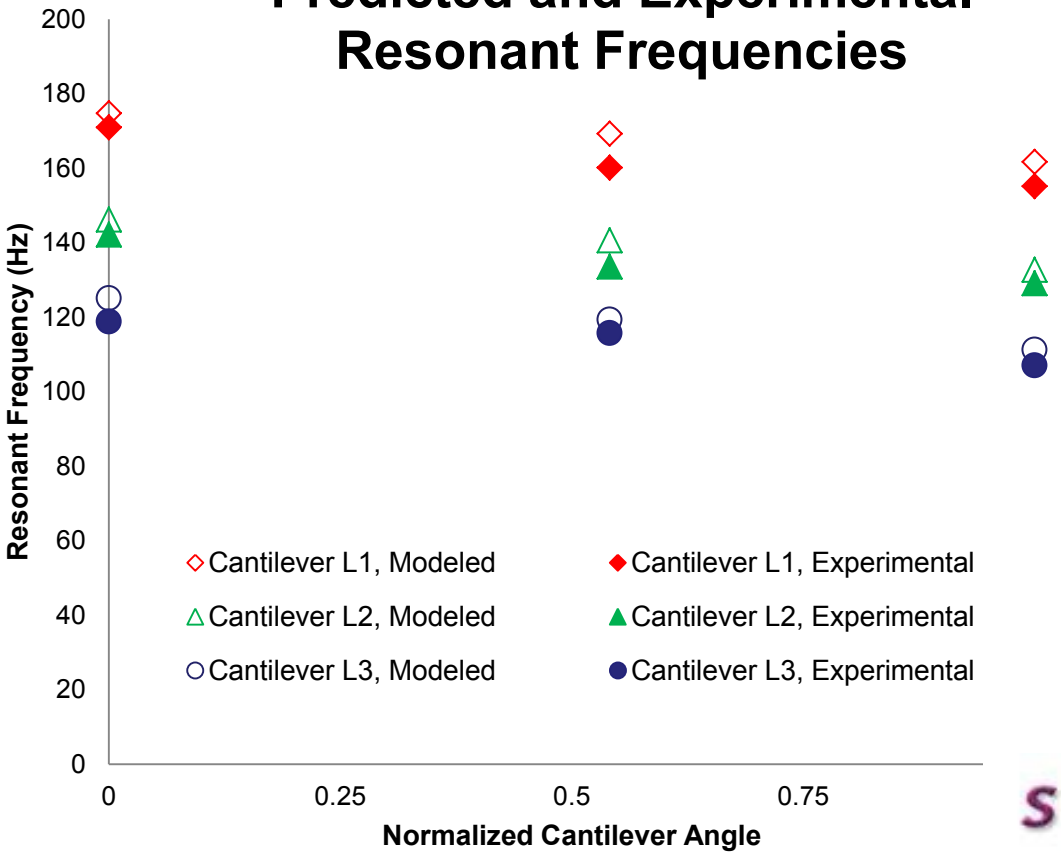
Constant Commissioning (Smart Buildings)

Real-time monitoring for structural integrity

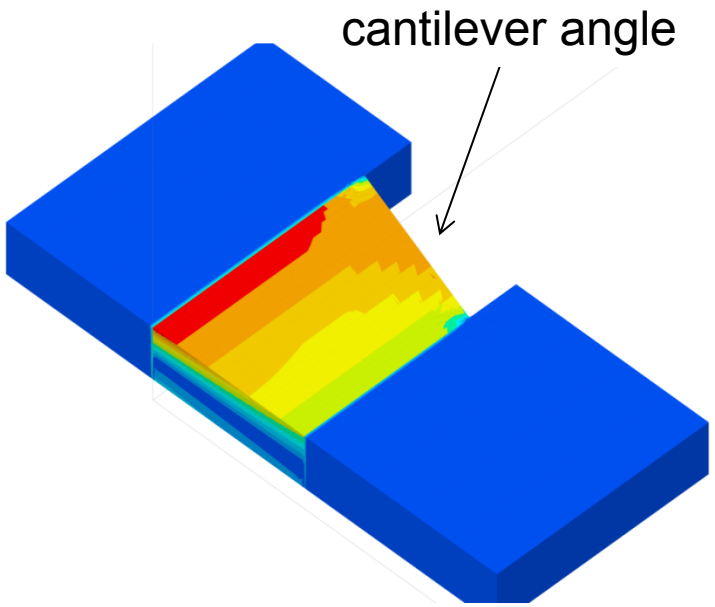
Design Parameters: Low G and Frequency, Specifically Tuned Frequency

Design for Frequency Tuning

Predicted and Experimental Resonant Frequencies



FEM Modeling



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open engineering

Modeled Frequency is within 5% of experimental observations
Frequencies from 100 – 1500 Hz typical

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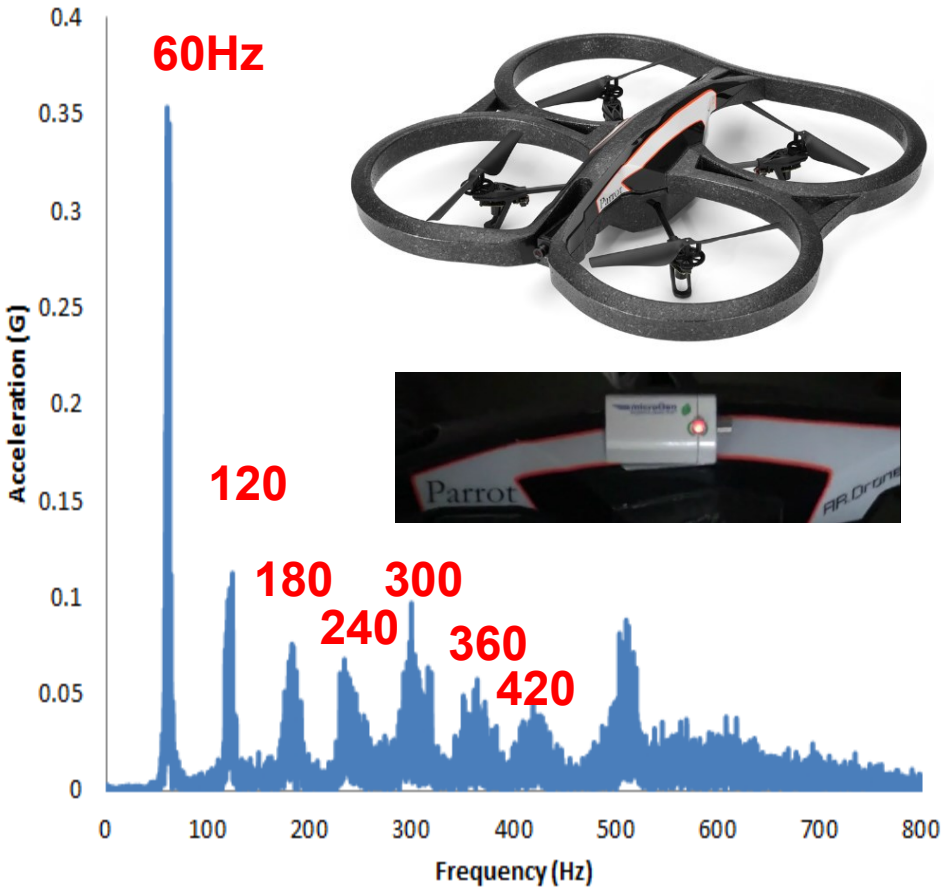
Demos

Powering off of real devices @ 120 Hz



video

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Examples

Powering off of real devices @ 120 Hz

Motor of fish pump

Fan

Building heater fan

Vacuum Pump

Microwave

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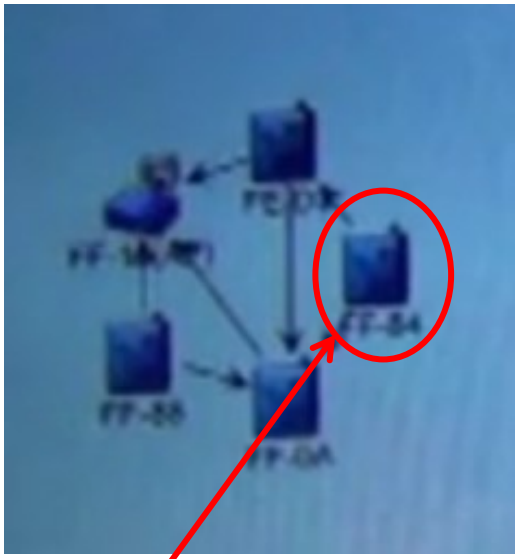
Powering a LTC DC9003A-B SmartMesh™ IP Mote



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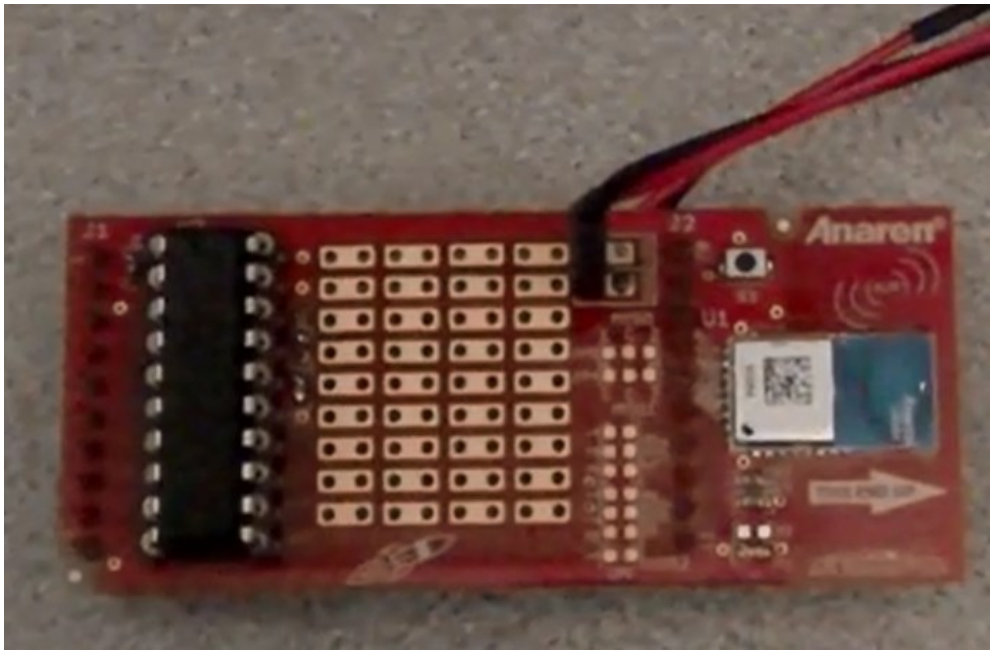
Powering an Anaren Temperature Sensing Mote and LCD Display

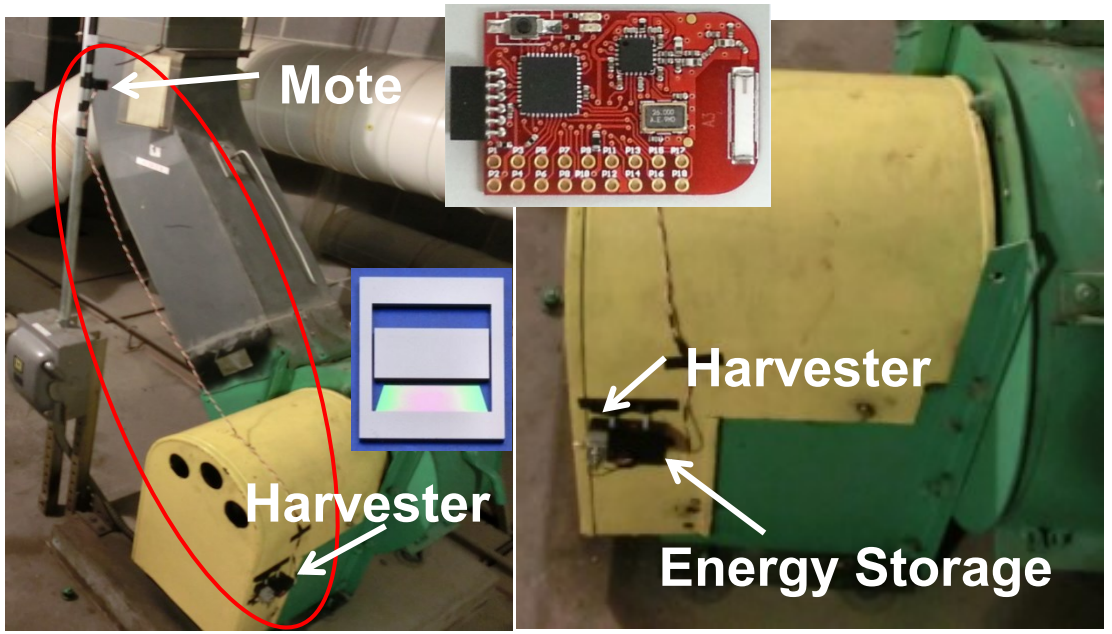
Sharp Memory LCD Display

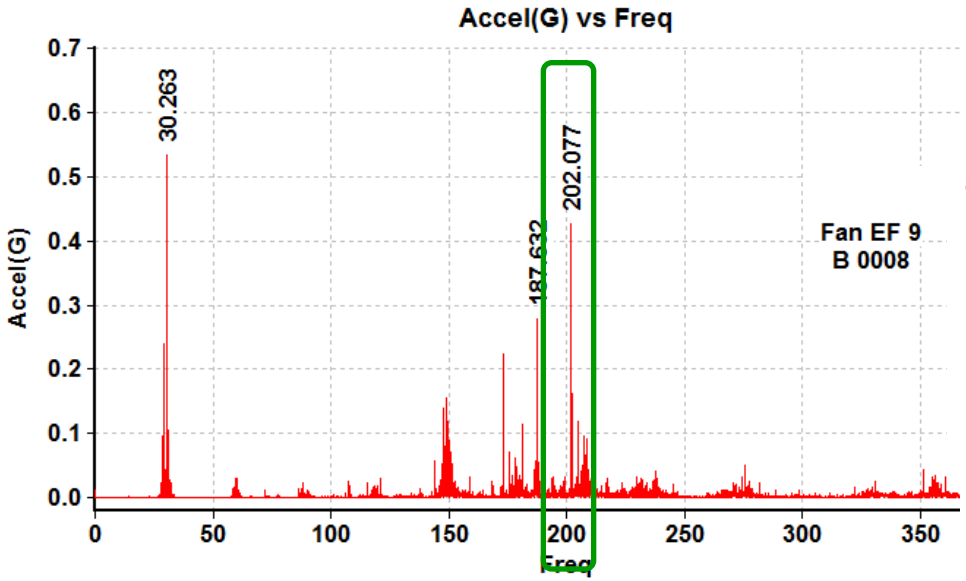
CC110L AIR Module

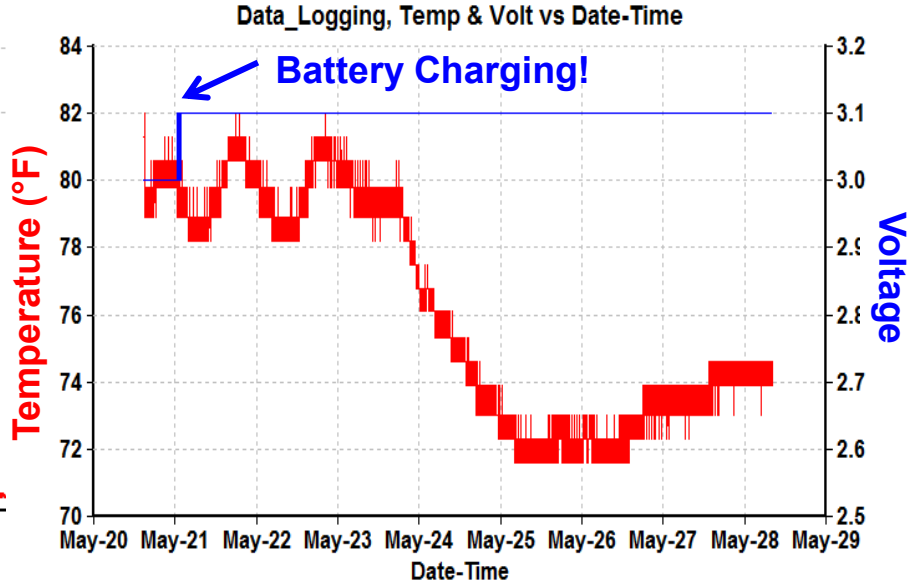


Anaren

Harvesting from Building Air Handling System







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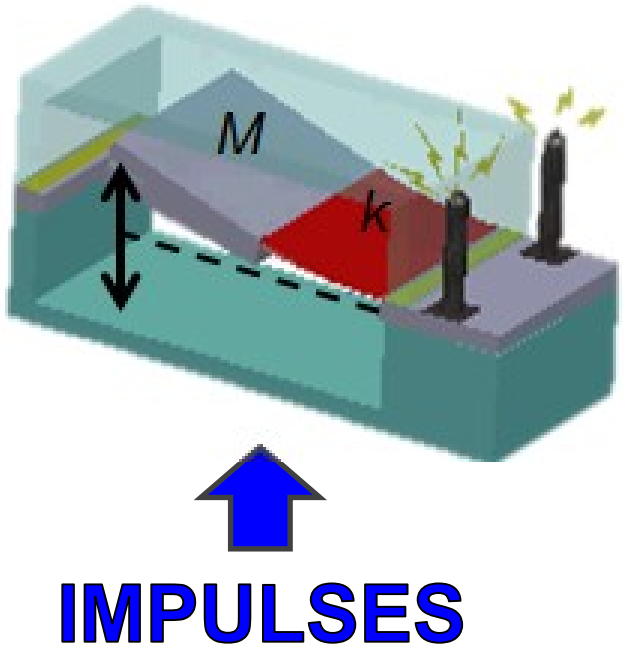
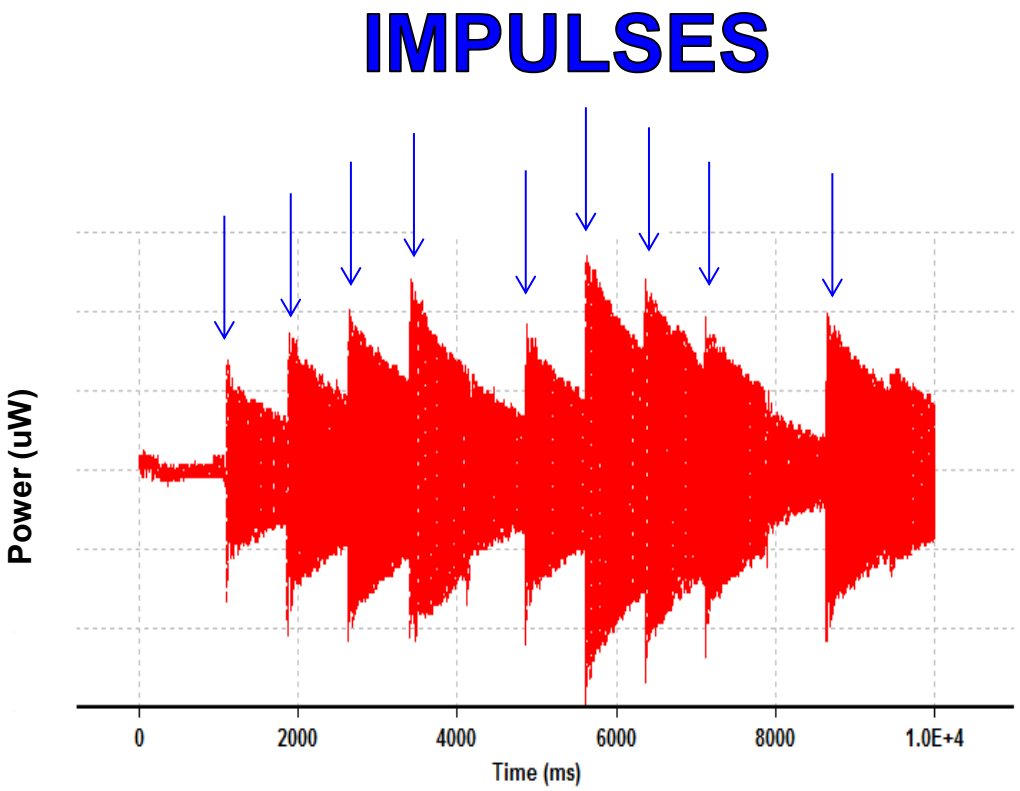
"Impulse mode" Operation
MicroGen's VIBE Product Line





- A high *Q* oscillator will "ring" at its resonant frequency when impulsed.
- Our harvester will ring, generating power/energy each time it is struck.

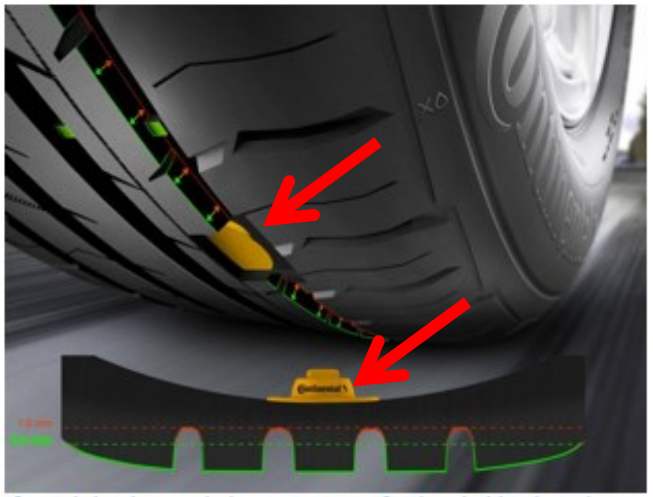
We call this design:

"VIBE" = Vibration Impulsed Broadband Excitation

IoT Example: Tire Management System (TMS) Sensor mounted in tread of tire

TMS unit in tire tread

Actual TMS unit with power source inside



If tread depth goes below a tire-specific threshold value, the on-board electrical system signals that a tire change is due.

Continental Develops Tread Depth E-Sensor ***As reported on May 8th 2014, Tire Review (Online)***

Design Parameters: High G, High Frequency, Minimal Tuning

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Harvesting from Impulses

video

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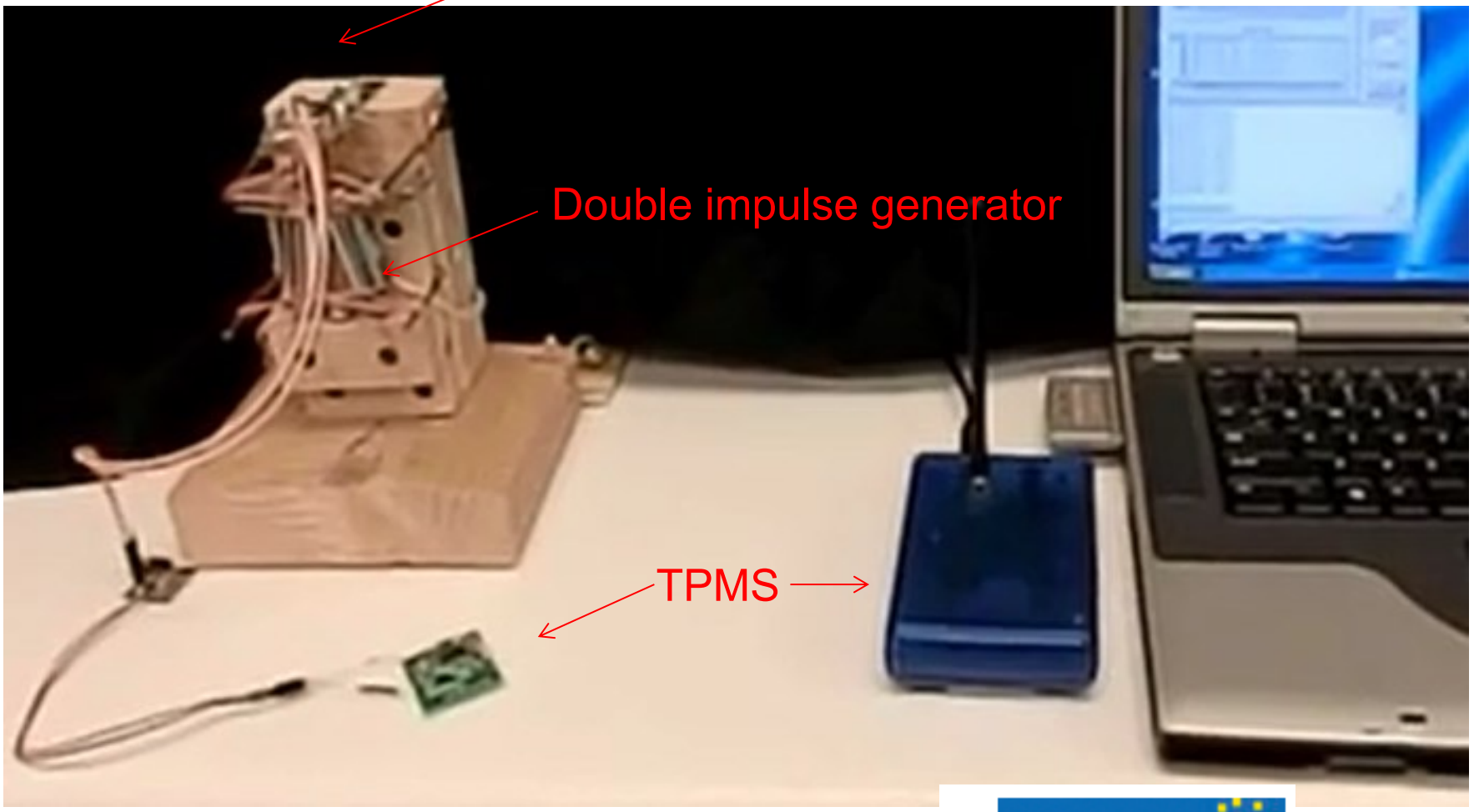
Powering a TPMS unit from a double impulse



Melexis
Microelectronic Integrated Systems

video

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Summary

- MicroGen's piezoelectric energy harvesting Power Cells have the potential to expand the power available for integrated wireless sensors.
  - Frequencies of 100 – 1500 Hz
  - Powers of 50 – 200 μW

- Multiple recent demonstrations include:
  - Powering of wireless temperature sensor network in a building exhaust fan system
  - Powering off electrical frequencies (multiples of 60 Hz)
  - Powering a TPMS unit under double impulse conditions

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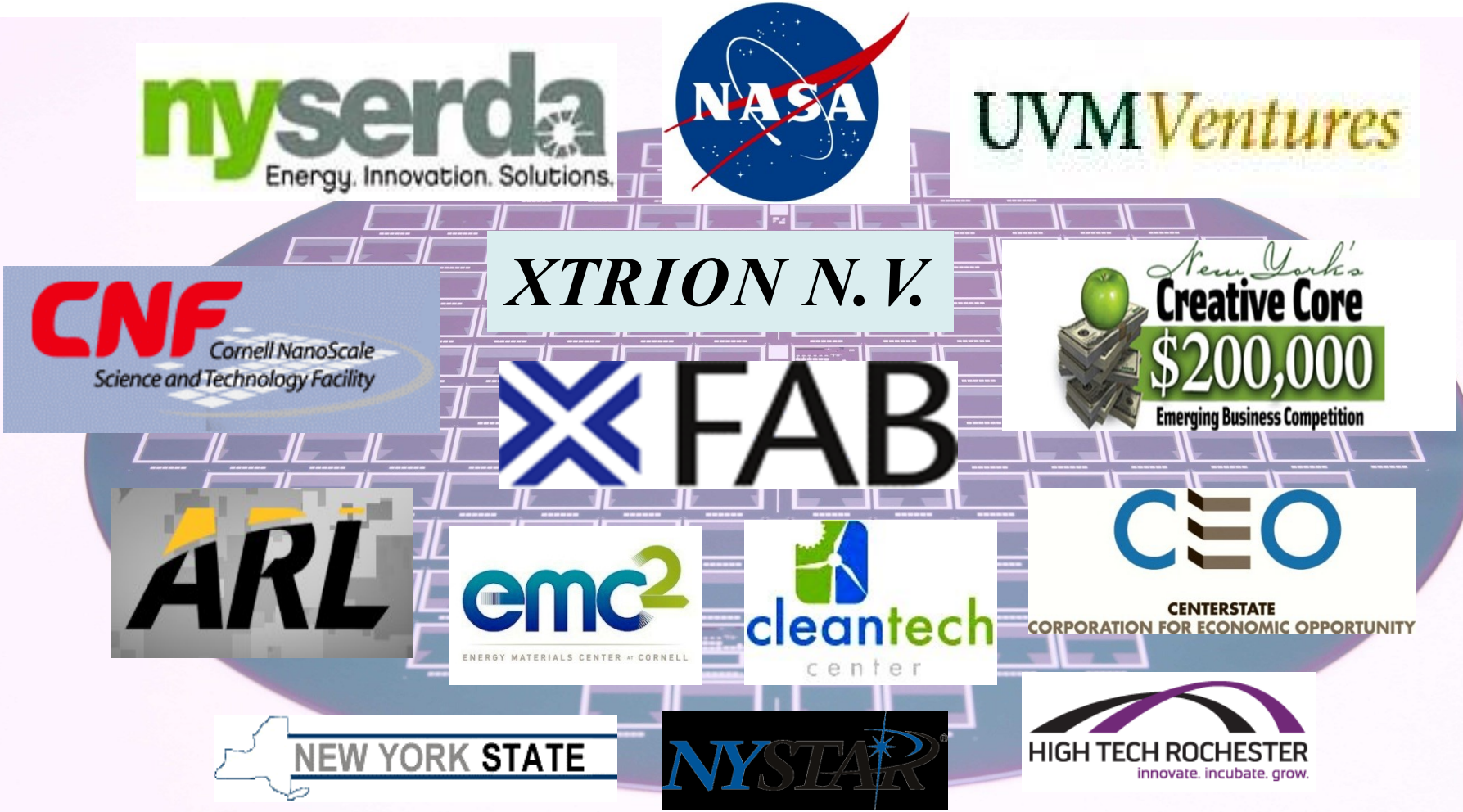
Thank You!



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Various YouTube video demos

Vibration Powered Motion Sensing Demo using Analog Devices' ADXL362Z accelerometer
YouTube November 15, 2013
Click here to view demo

UAV 'drone' vibration power!!
YouTube October 28, 2013
Click here to view demo

Impulse VIBE™ demo
Operation mode for Smart Tire/TPMS
YouTube October 28, 2013
Click here to view demo

BOLT™ energy harvester enables Linear Technology SmartMesh™ IP network
YouTube May 10, 2013
Click here to view demo

Distributed power/ vibration transmission and energy harvesting
YouTube April 18, 2013
Click here to view demo

Batteries NOT Included
Industrial and building applications
YouTube – March 29, 2013 (~6,000 views)
Click here to view demo