Powering the industrial Internet of Things with vibrational energy

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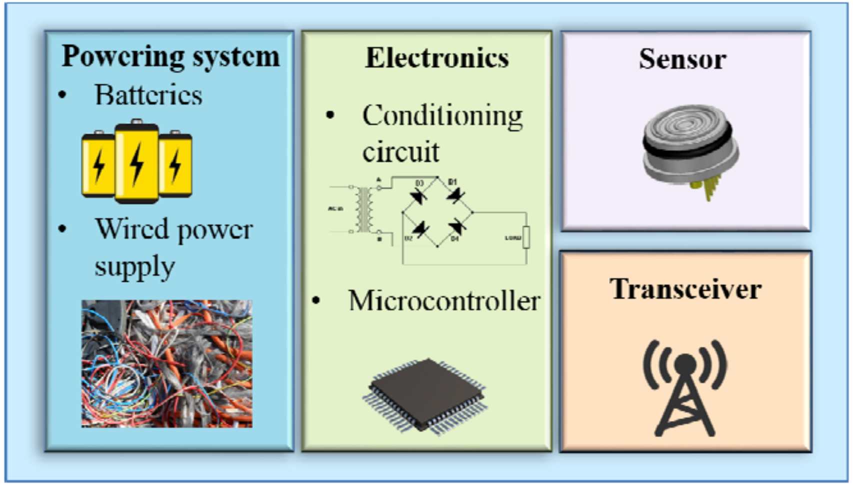
Wireless sensor for IoT

Temperature sensor

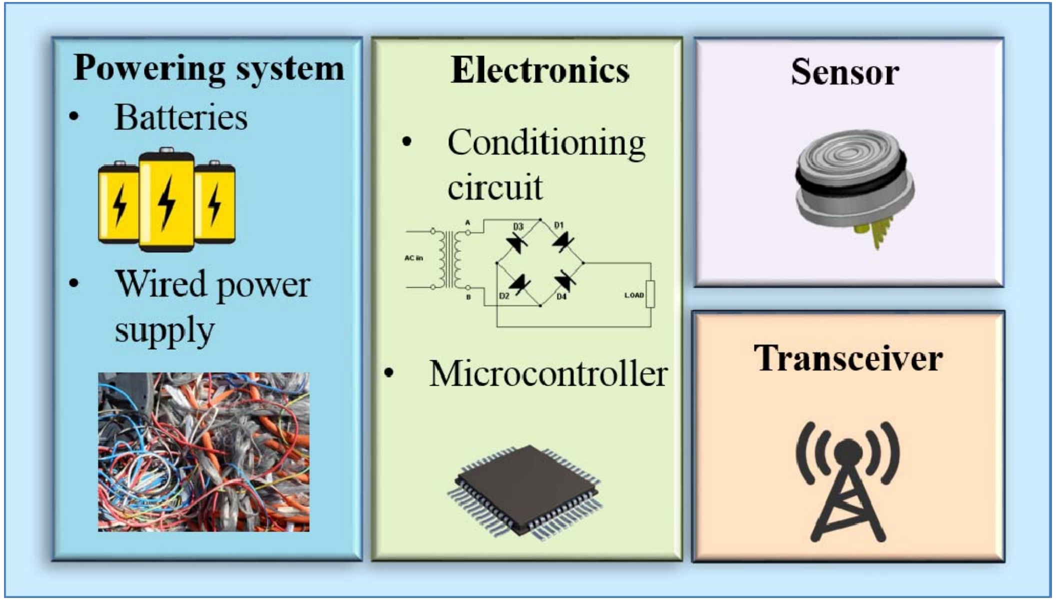


By 2025 there will be 34.2 billion devices connected to the internet (IOT Analytics)

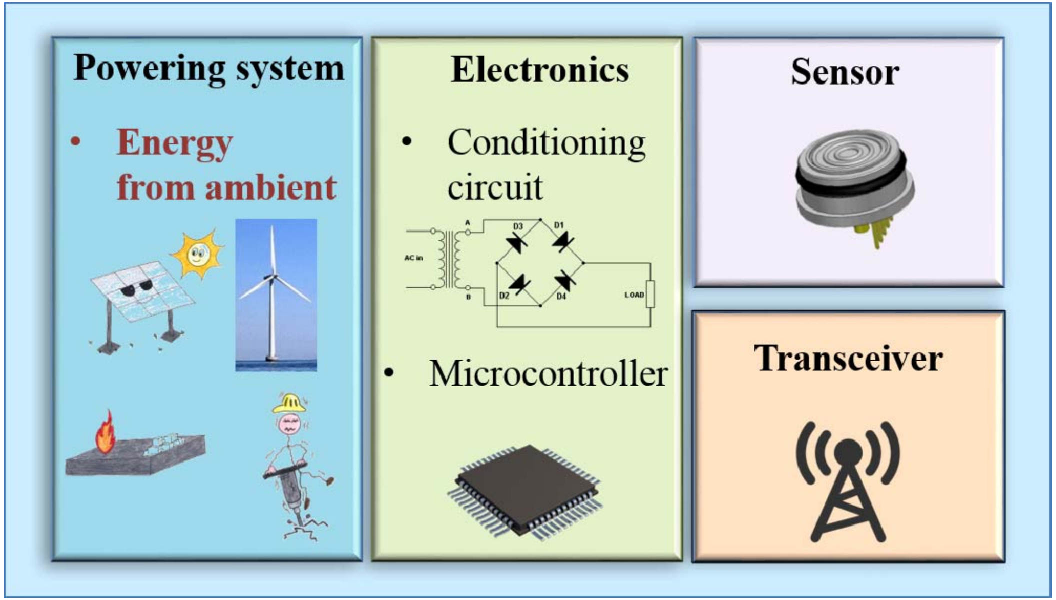
Issues with battery powered IoT devices

- Battery replacement is necessary **before** their expected lifespan.
- In large wireless sensor network, battery replacement is **not feasible**
- In factories where there are >10000 units using 2 batteries each, ~ **30 batteries each day** could be changed
- In 2019 **886 tonnes of portable batteries** were collected by WEE Ireland for recycling, **47%** of the ones placed on the market.
- Raw materials are **mined** → large quantities of metals are released in the environment.
- In most IoT devices, batteries are sealed and the whole device has to be disposed, having a **strong environmental impact**

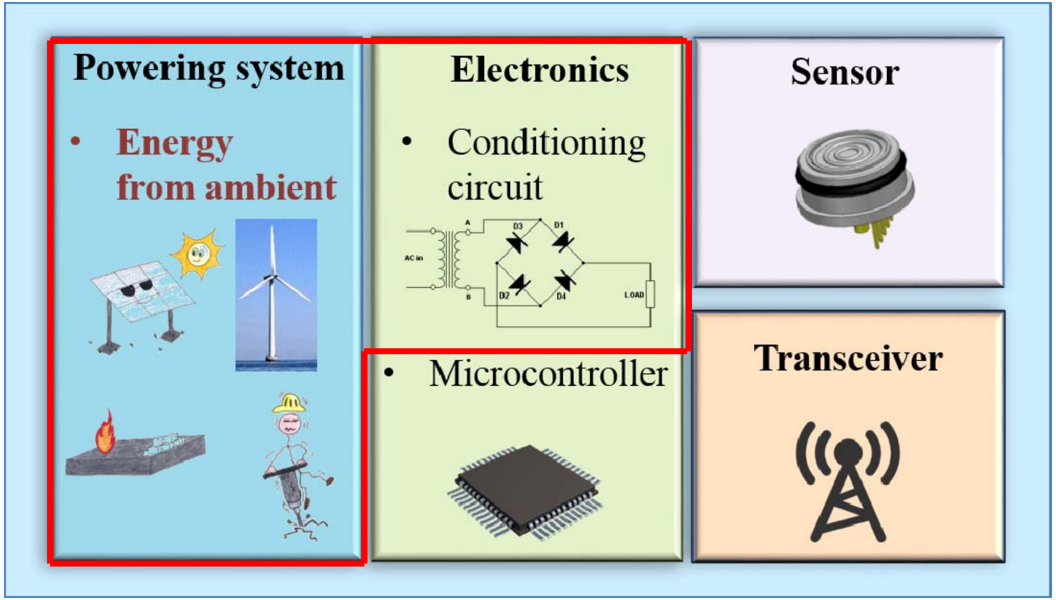
Wireless sensor powered with energy harvesting



Wireless sensor powered with energy harvesting



Wireless sensor powered with energy harvesting

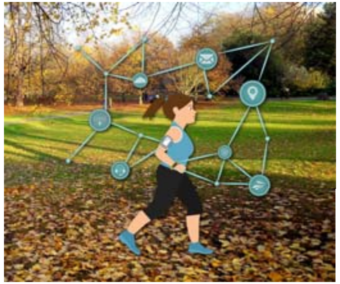


By converting ambient energy into electrical energy it is possible to **sustainably power** IoT devices.

Available energy

Energy Source	Efficiency	Harvested Power
Solar (outdoors)	10~24%	100mW/cm^2
Solar (indoors)	10~24%	100µW/cm^2
Thermal (Human)	~0.1%	60µW/cm^2
Thermal (Industrial)	~3%	~1-10mW/cm^2
Vibration (Human)	25~50%	~4µW/cm^3
Vibration (Machines)	25~50%	800µW/cm^3
RF (GSM 900MHz)	~50%	0.1µW/cm^2
RF (WiFi)	~50%	0.001µW/cm^2

Possible applications



Wearable devices

Transportation

Available energy

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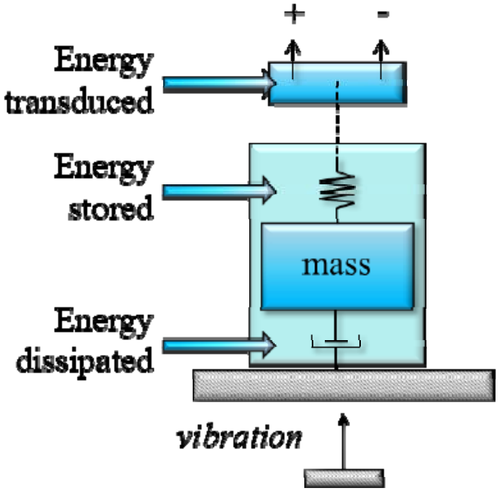
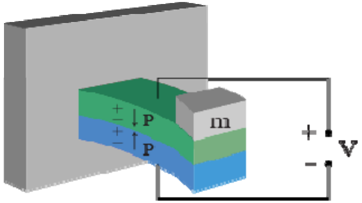
Possible applications

Mining

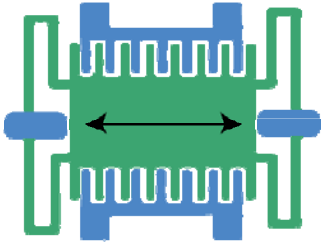
Industry 4.0

Vibrational energy harvesting

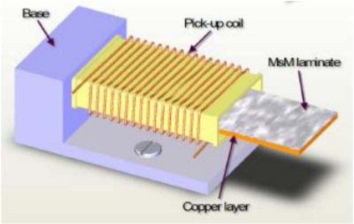




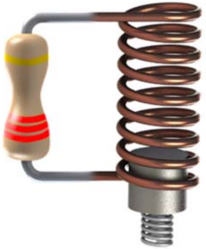
Piezoelectric



Electrostatic



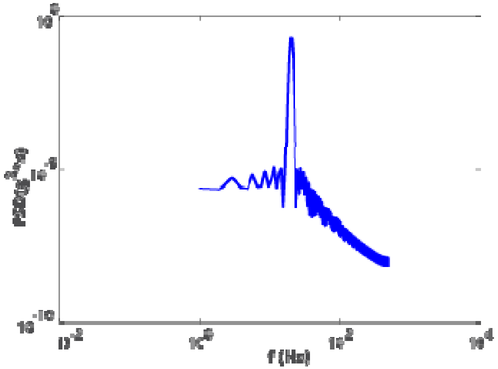
Magnetostrictive



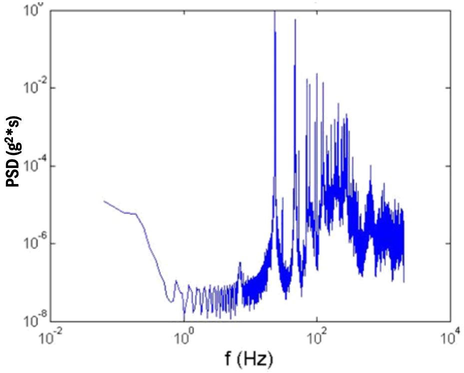
Electromagnetic

Challenges of vibrational energy harvesting

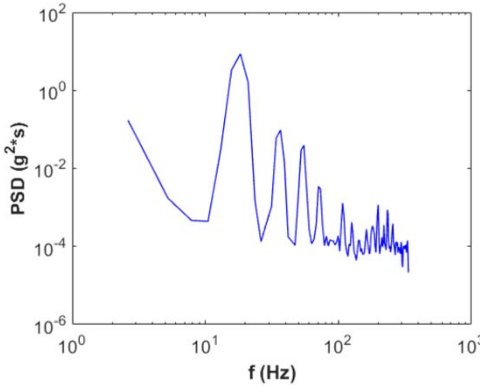
Ideal harmonic excitation



Acceleration of an air compressor

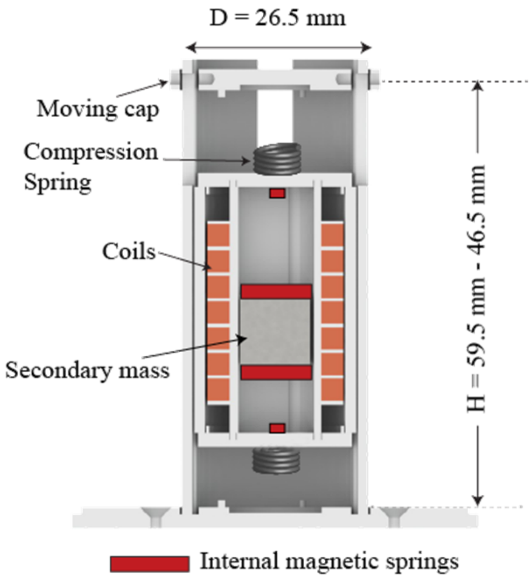


Acceleration of a screening machine

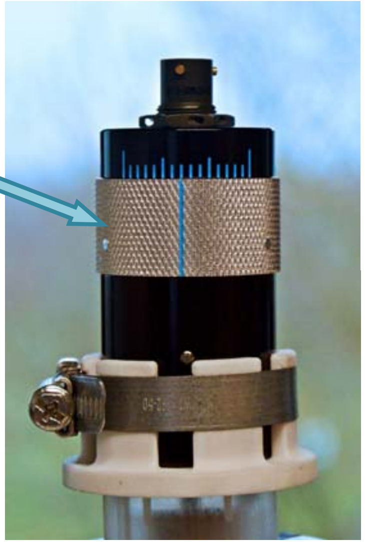


- Acceleration amplitude and frequency content depends on the vibration source → **easy tuning feature**
- Multiple peaks at frequencies below 100 Hz → **multimodal harvester**
- Commercially available harvesters can harvest energy <u>only from one frequency</u>

Stokes Power: VEH-1



Tuning feature



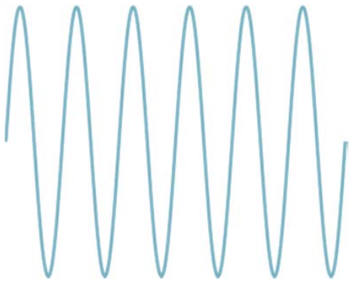
- Larger primary mass that holds coils
- Smaller inner secondary mass made of a magnet
- Tuning feature

Output Power

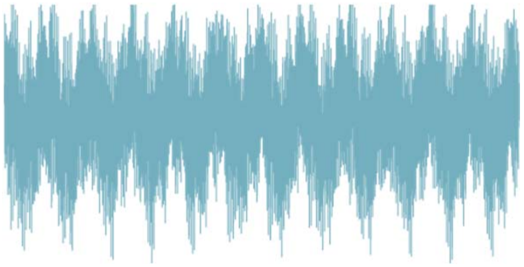
Depends on vibration source

- Frequency content
- Amplitude

Harmonic excitation

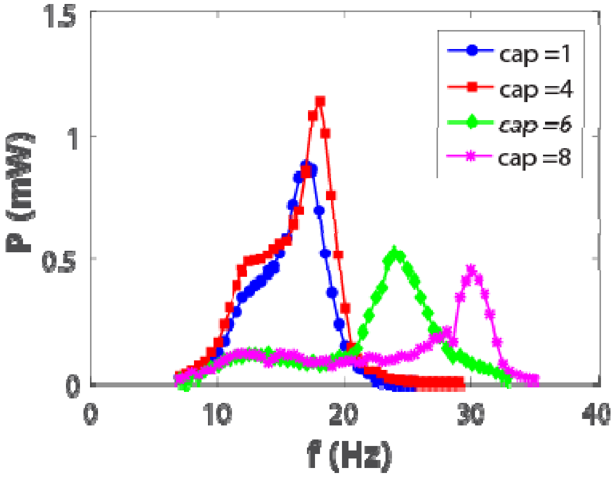


Real excitation

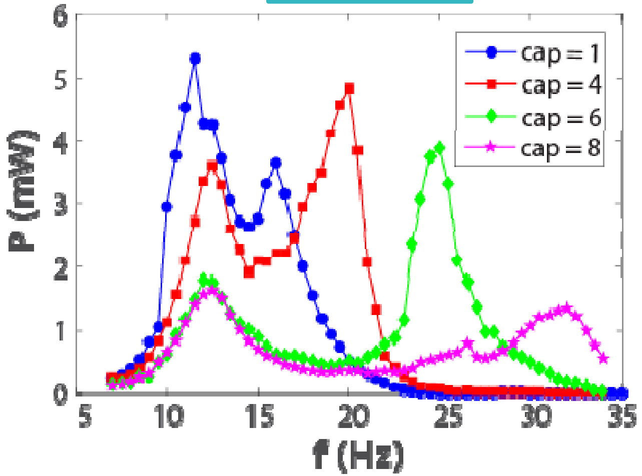


Ideal harmonic excitation – resistive load

a_{rms} = 0.2g



a_{rms} = 0.4g

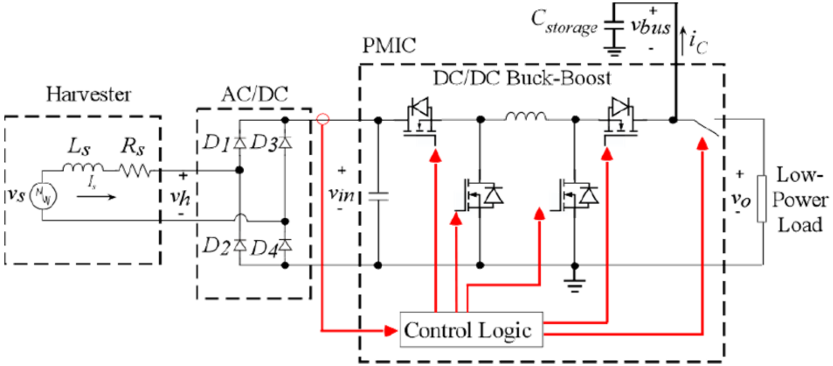


Two peaks are visible

Second peak shifts to the right when adjuster is twisted → **TUNABILITY**

Output power depends on the acceleration level

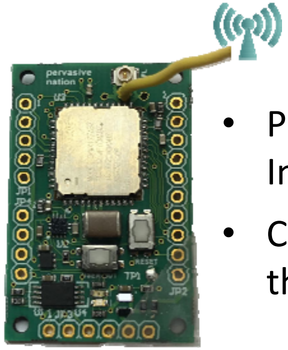
Power Management circuit



- Power management circuit has been developed
- AC/DC conversion and MPPT has been implemented
- Harvested energy is stored in a supercapacitor
- 3.3V standard output

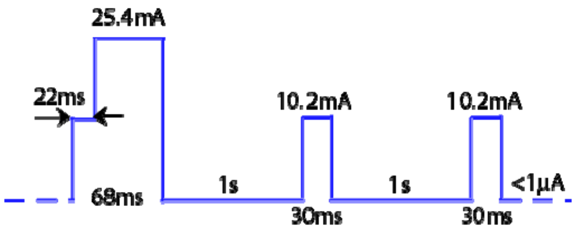
Suitable for a range of IoT communication protocols

Powering wireless sensor nodes



- Pervasive Nation's (CONNECT) Integrated Device
- Connects to LoRaWAN network through gateway (868MHz)

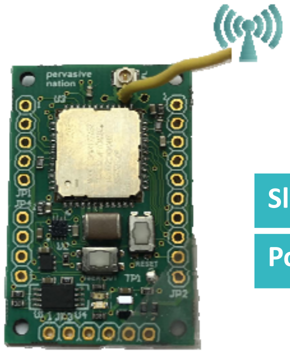
Pervasive Nation



- Texas Instruments's CC2650 SensorTag
- Connects to Bluetooth Low Energy (BLE) network (to smartphone)

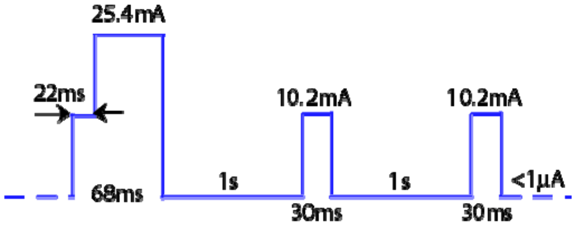
Texas Instruments

Powering wireless sensor nodes



Pervasive Nation

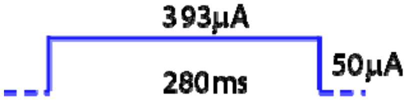
Sleep time	10 s	40 s	2 min	5 min	15 min
Power (µW)	714.5	205.9	71.0	28.7	9.6



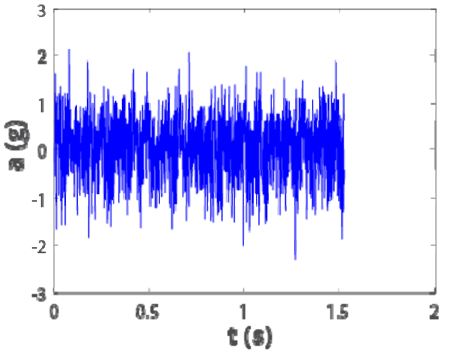
Texas Instruments

Sleep time	1 s	2.5 s	2 min	5 min	15 min
Power (µW)	419	205.9	148*	147*	146*

*estimated



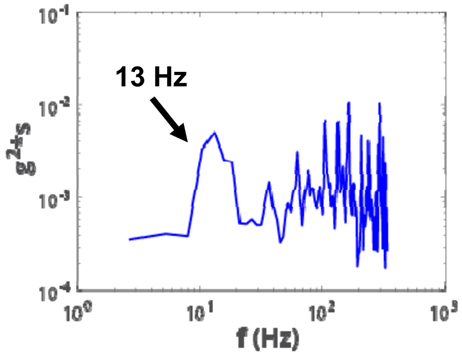
Air-Compressor excitation

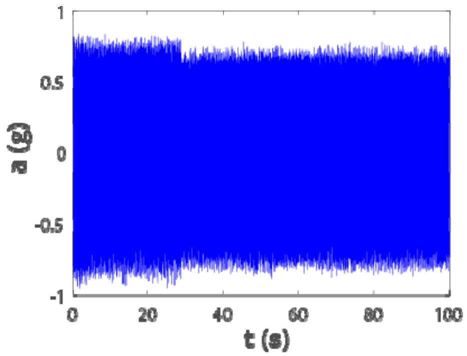


Compressor 1

a_{rms} = 0.73g

f_{main} = 13 Hz

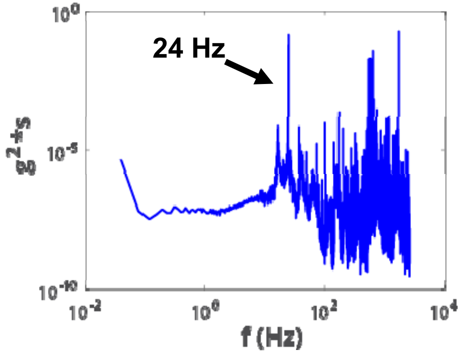




Compressor 2

a_{rms} = 0.33g

f_{main} = 24 Hz

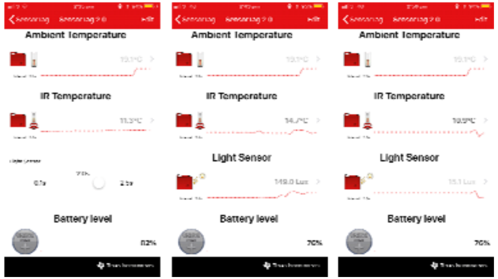


Compressor 1 excitation – PM circuit and sensor board

RX Time	RSSI	Seq, SF	Decoded Payload
13:25:16 31-10-2018	-69	5, SF7	Fixed: 1, Battery: 100 Mag X: 443, Mag Y: 195, Mag Z: -41
13:24:46 31-10-2018	-67	4, SF7	Fixed: 1, Battery: 100 Mag X: 450, Mag Y: 196, Mag Z: -45
13:24:16 31-10-2018	-72	3, SF7	Fixed: 1, Battery: 100 Mag X: 440, Mag Y: 193, Mag Z: -47
13:23:46 31-10-2018	-76	2, SF7	Fixed: 1, Battery: 100 Mag X: 451, Mag Y: 196, Mag Z: -53
13:23:16 31-10-2018	-69	1, SF7	Fixed: 1, Battery: 100 Mag X: 437, Mag Y: 187, Mag Z: -49
13:17:40 31-10-2018	-47	0, SF7	Fixed: 1, Battery: 100, Mag X: 434, Mag Y: 36, Mag Z: -131
13:17:07 31-10-2018	-60	17, SF7	Fixed: 1, Battery: 92, Mag X: 464, Mag Y: 157, Mag Z: 7
13:16:46 31-10-2018	-60	16, SF7	Fixed: 1, Battery: 94, Mag X: 468, Mag Y: 159, Mag Z: 12
13:16:27 31-10-2018	-60	15, SF7	Fixed: 1, Battery: 95, Mag X: 468, Mag Y: 160, Mag Z: 7
13:16:07 31-10-2018	-60	14, SF7	Fixed: 1, Battery: 96, Mag X: 470, Mag Y: 153, Mag Z: 11
13:15:46 31-10-2018	-63	13, SF7	Fixed: 1, Battery: 98, Mag X: 464, Mag Y: 150, Mag Z: 10
13:15:27 31-10-2018	-58	12, SF7	Fixed: 1, Battery: 99, Mag X: 468, Mag Y: 157, Mag Z: 7
13:15:07 31-10-2018	-65	11, SF7	Fixed: 1, Battery: 100 Mag X: 470, Mag Y: 153, Mag Z: 6

LoRaWAN Board

Transmission every 30 seconds



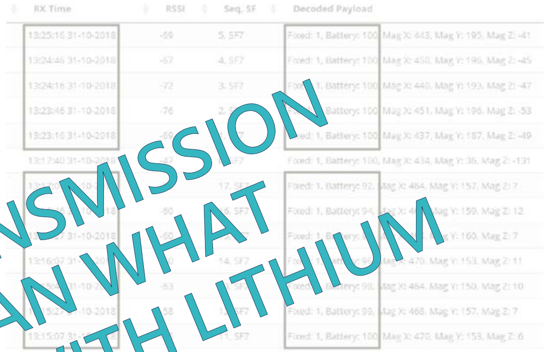
Bluetooth board

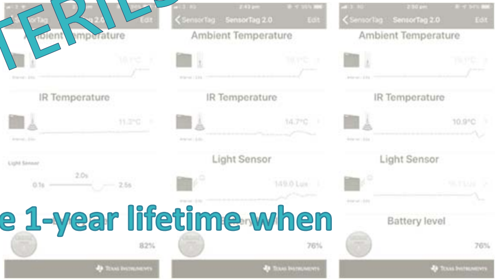
Transmission every 2 seconds

Available power stored in the super capacitor:

P = 0.29 mW

Compressor 1 excitation – PM circuit and sensor board





FASTER TRANSMISSION TIME THAN WHAT ACHIEVABLE WITH LITHIUM BATTERIES*

Available power stored in the super capacitor:

P = 0.29 mW

* A 2400mAh battery can achieve 1-year lifetime when transmitting every 300 seconds

LoRaWAN Board

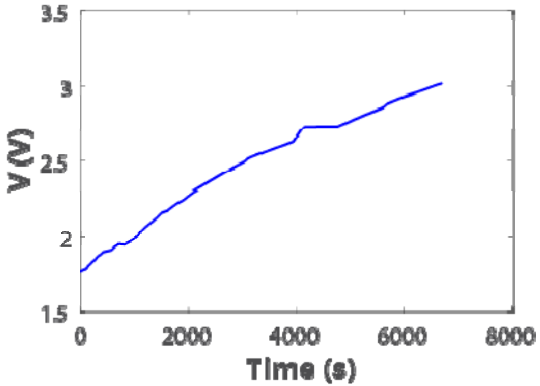
Transmission every 30 seconds

Bluetooth board

Transmission every 2 seconds

Compressor 2 excitation – PM circuit

- A "beta site" trial was carried out.
- The harvester was mounted on the motor of an Ingersol Rand RS37n industrial compressor.
- An average power of **9.4 μW** of conditioned power was harvested – sufficient to enable the operation of a **LoRaWAN sensor every 15 minutes**

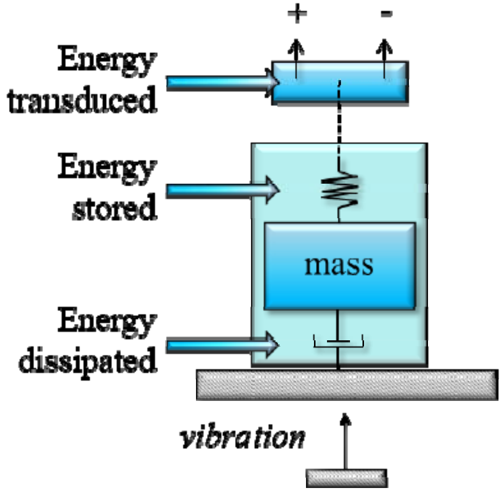


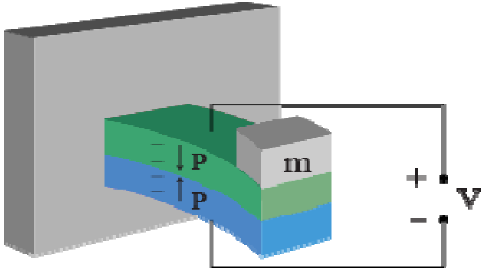
Conclusions

- Vibrational energy harvesting can be used as alternative to batteries
- Due to the nature of ambient vibrations a nonlinear 2-Dof EM VEH was been developed
- **Output power depends on the vibration source**
- The harvester was able to energise a LoraWAN board every **30 seconds** under the vibrations of compressor 1
- The energy stored on the supercapacitor under the vibrations of compressor 2 would be enough to energise the LoRaWAN board every **15 minutes**.

THANK YOU
&
QUESTIONS

Vibrational energy harvesting

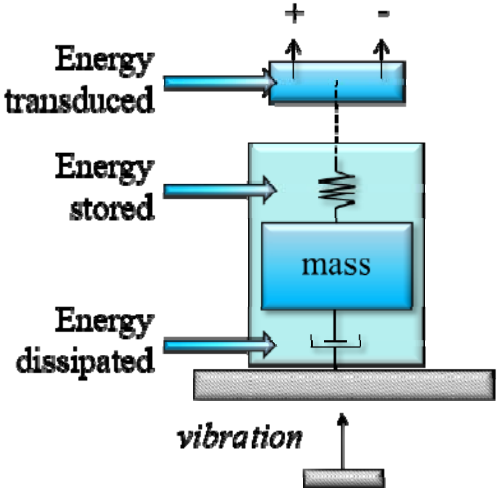


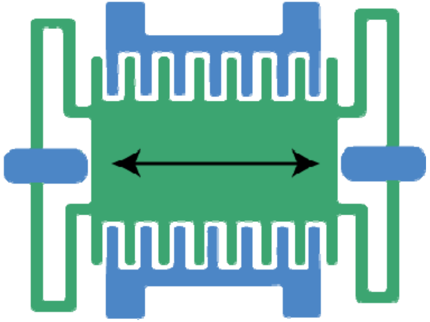


Piezoelectric

Advantages	Disadvantages
• No external voltage source; • High output voltage; • Compatible for small scale applications.	• Depolarisation; • Piezoelectric ceramics are brittle; • High output resistance and hence low output power

Vibrational energy harvesting

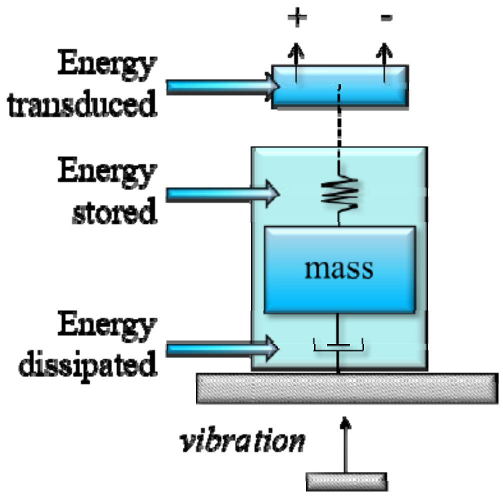


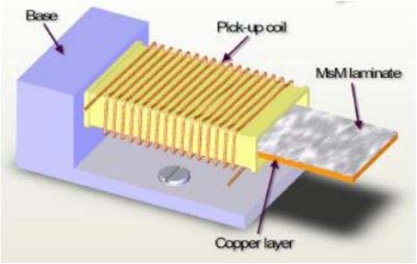


Electrostatic

Advantages	Disadvantages
• No need for smart material; • Compatible with MEMS.	• External voltage source can be required; • Mechanical stoppers for the plates; • High resonant frequency.

Vibrational energy harvesting

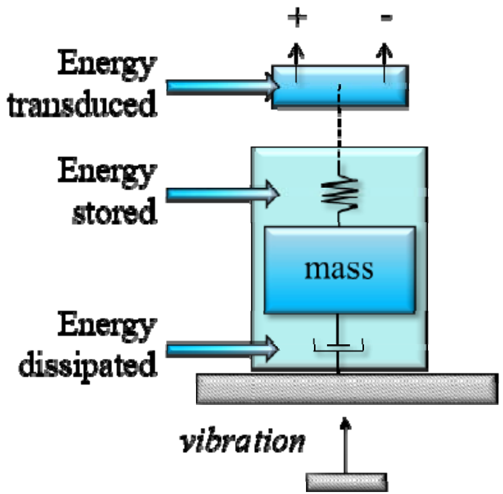


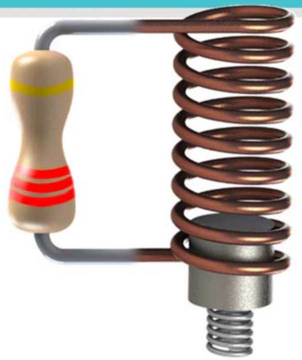


Magnetostrictive

Advantages	Disadvantages
• High coupling coefficient; • High flexibility	• Needs another conversion stage; • May need bias magnets and pre-stress; • Difficult to integrate with MEMS

Vibrational energy harvesting





Electromagnetic

Advantages	Disadvantages
• No need for smart material; • No external voltage source; • High currents; • Highest theoretical energy density.	• Bulky size; • Difficult to integrate with MEMS.