Tyndall

Power Sources Manufacturers Association
The Multinational Power Electronics Association

Challenges and Considerations for 3D Packaging of Self-Powered IoT Devices

APEC PSMA Packaging Industry Session

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28th March 2017

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IMPACT FROM EXCELLENCE

ENTERPRISE IRELAND

sfi Science Foundation Ireland

Tyndall National Institute
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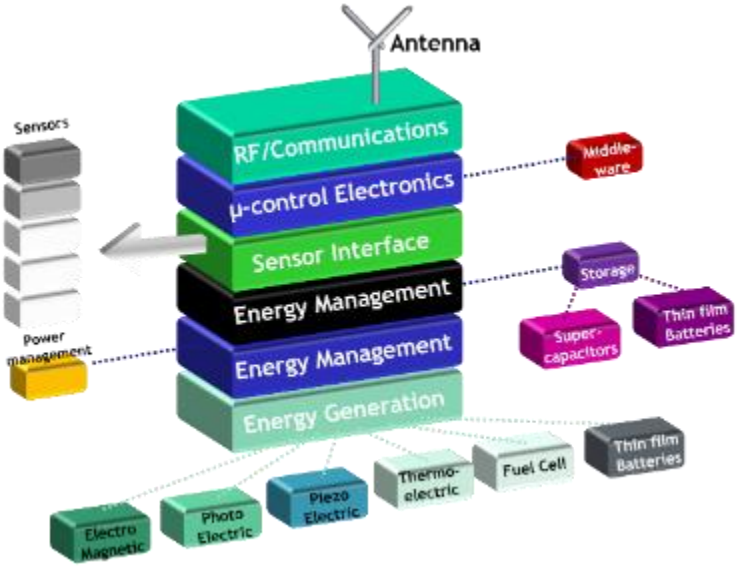
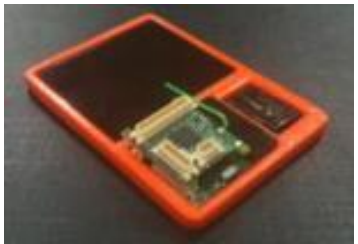
- How to Address Problems
- Summary & Conclusions

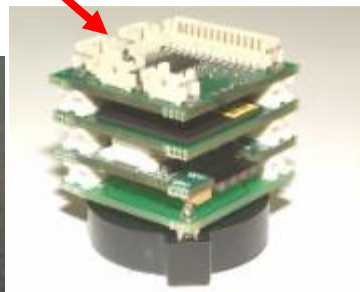
Introduction – IoT devices - WSN Nodes

- **Wireless Sensor Network (WSN) nodes are ultra low power IoT devices that wirelessly capture data.**
- This is critical for applications including
  - Monitoring assets/devices/people/infrastructure
  - Sports, healthcare, environment, transportation
  - Energy & resource efficiency optimisation
- Market size – 1 trillion sensors by 2025



- **Many commercial parts available:- TelosB, Libelium, EnOcean….**
- **Tyndall has developed a modular platform, used for >50 applications**
- **Energy harvesting uses ambient energies as a power source**
  - eliminates need for replacing batteries in sensors
  - (or at least extends battery life)





Introduction - IoT WSN Needs & Applications

Take Up No Space

Cost Nothing

DEPLOY & FORGET

Last Forever

Zero Power

Signal Sources

Sensor

Detector

Processing Storage & Comms

Actuation

Data transmission

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Context and Motivation

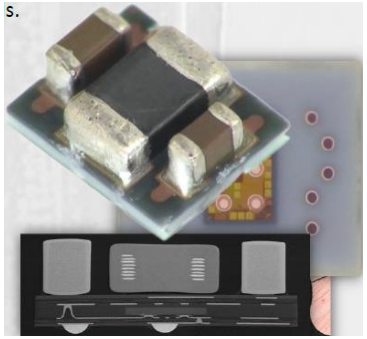
- **Note the presentation title 'challenges and considerations', not 'solutions'**
- **Purpose is to create awareness and stimulate collaborative engagements**
- **IoT devices brings significant potential benefits for power electronics community**
  - ✓ Components usage and technology drive
  - ✓ Enhanced monitoring of devices and systems
- **My work is primarily electronics but need leading edge mechanical, packaging and system integration partners to successfully develop energy harvesting SYSTEMS to power smart sensors**
  - ✓ Requires advanced technology from PSiP, PwrSoC* & other domains
  - ✓ Based on real life applications (sensor needs, working environments)

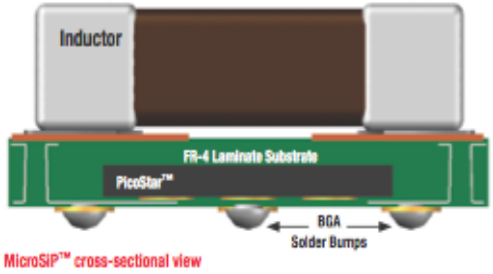
***PSiP - Power Supply in Package** **PwrSoC - Power Supply on Chip**

PSiP & PwrSoC Integration (1)

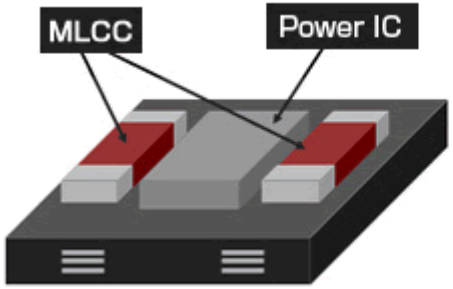
- **Miniaturized IoT devices need miniaturized POWER SOURCE**
- **Leading technology examples (ref next slides)**
  - **PSiP**:– embedding of power supplies (magnetics, switches, capacitors, etc.) in multi-chip modules/substrates
  - **PwrSoC**:- embedding onto Silicon
- **Devices are already in development/some commercially available**
  - TSMC already has standard processes for embedding magnetics
  - Companies such as IPDIA embedding storage devices, CMOS compatible
- **Applications such as mobile phones and wearables driving such needs where size and form factor is critical**
- **Nanotechnologies, multi-modal modelling & additive manufacturing are all enablers**
- **Pushing for PSiP & PwrSoC to be extended to potentially include WSN & self-powered constituents**

PSiP & PwrSoC integration - examples (2)*



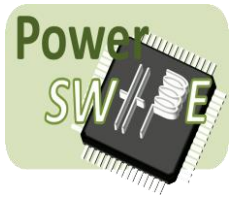


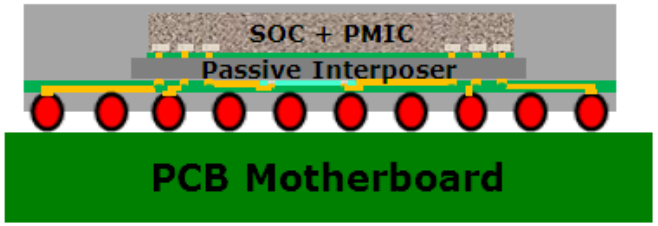
TDK-EPC SESUB



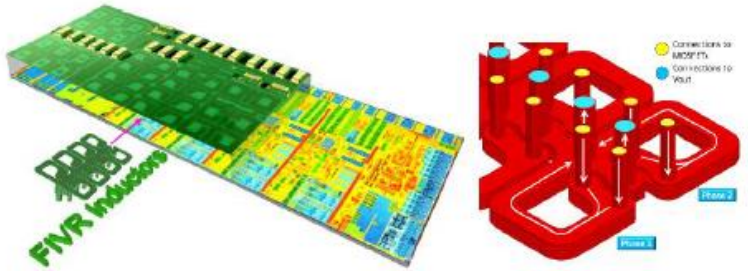
Ferrite substrate with embedded inductor

Murata LXDC DC/DC Series





Infineon eWLB - embedded Wafer-Level Ball Grid Array
Functional Interposer with
LC, RDL (re-dist. Layer), TSV (thru Si via)
EU PowerSwipe Project [1]



On chip switches and capacitors – packaging based air-core inductors

Intel Fully Integrated Voltage Regulation (FIVR)

PSiP

PwrSoC

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* Ref PSMA stage 1 and 2 3D packaging reports for further details

Relevance to Tyndall - Energy Harvesting & Storage

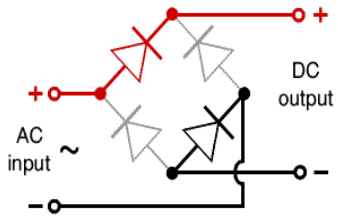
Control

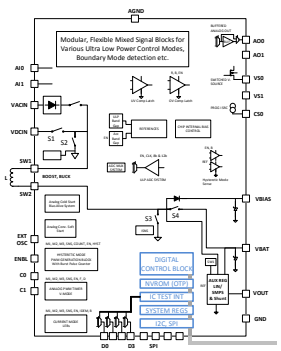
Power Management ICs & Circuits

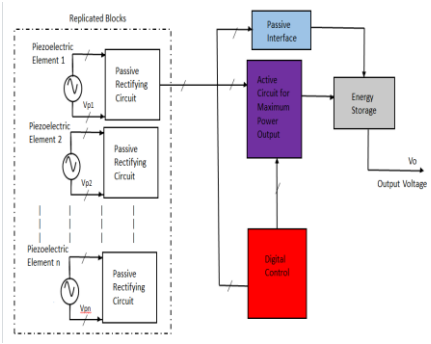
Multi-source

Self-start

High efficiency







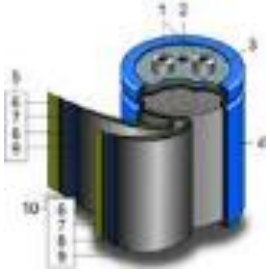
Storage

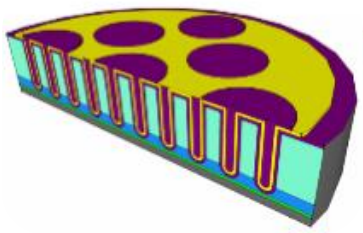
Supercaps on Silicon

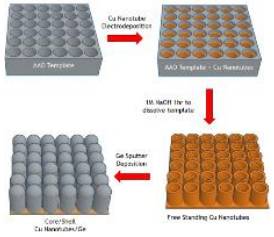
Flexible batteries

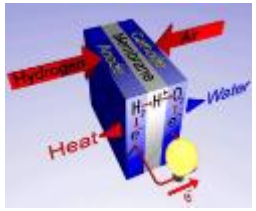
Micro-batteries

Nanotube high density









Generation

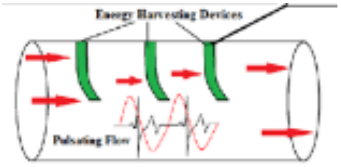
Generators on silicon

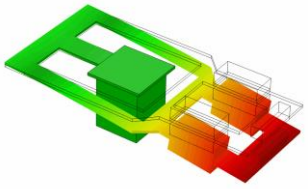
Wide bandwidth vibration

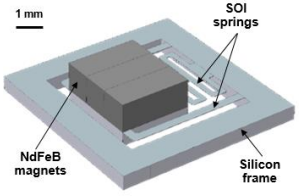
(Electromagnetic & piezo)

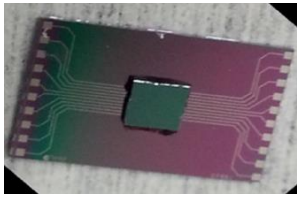
High density MEMS

IC integrated highest efficiency TEG materials (thermoelectric)



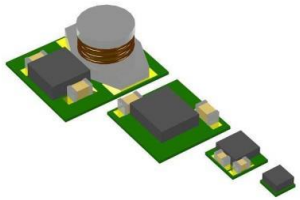


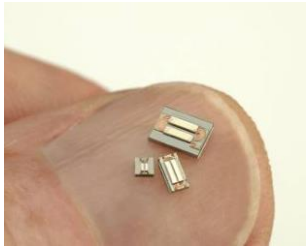


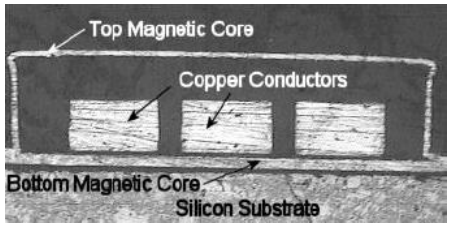


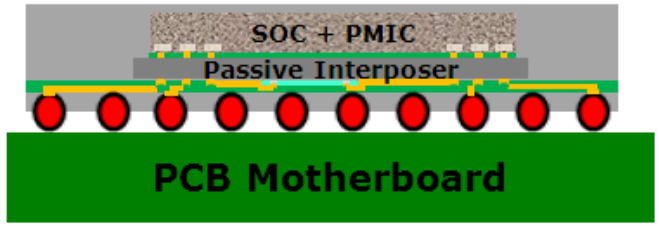
Relevance to Tyndall - PSiP, WSN, System Integration

Embedded Magnetics



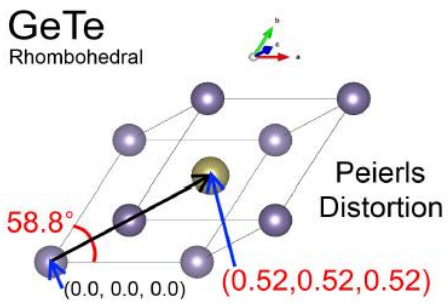




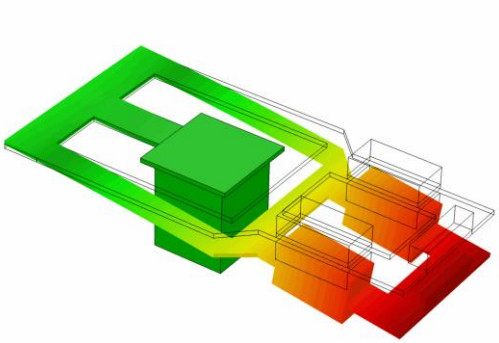


Making magnetics disappear in packages (PSiP) & onto ICs (PwrSoC)

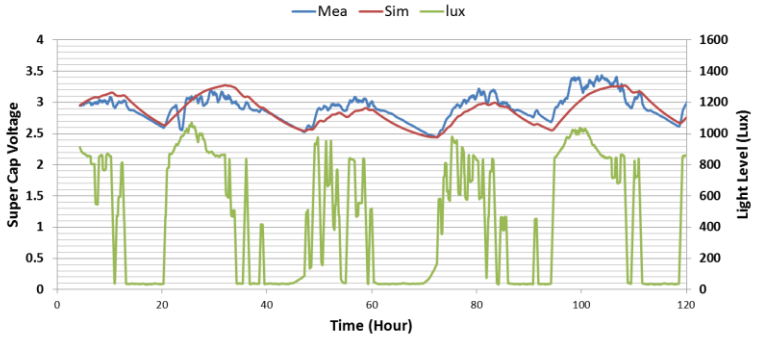
Simulation



Atomic/material (TEG)



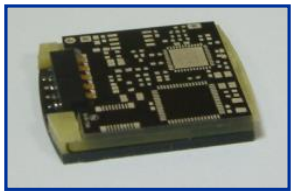
Physical/mechanical (VEH)



Design/Deployment tool
Circuits (discrete & CMOS)

WSN

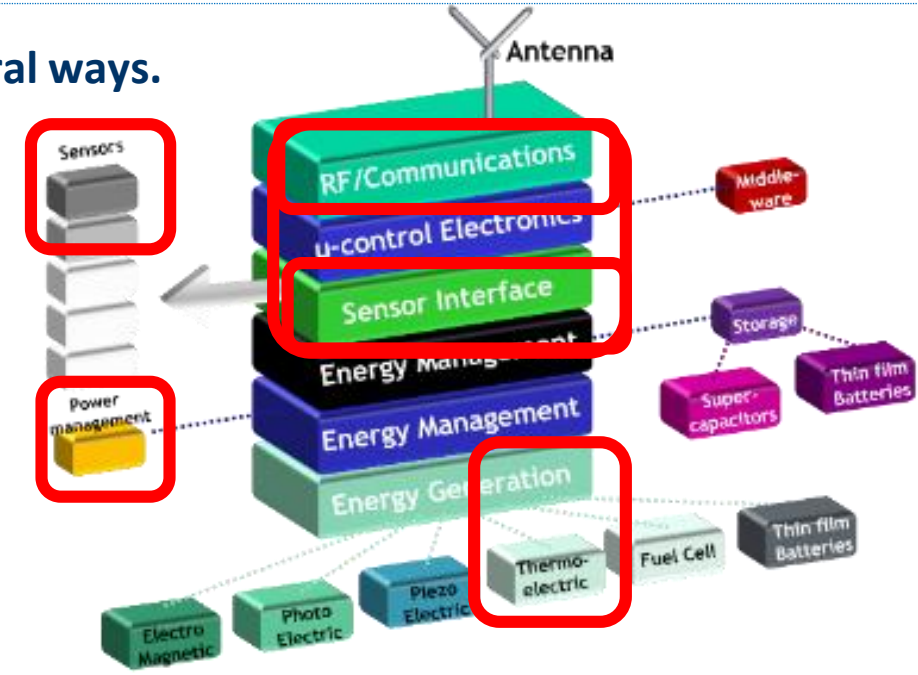
System application optimised parts & devices e.g.
Harmonise methodologies & specifications
Compatibility:- Mfg. Process, Electrical, Packaging



Partitioning (1)

- **IoT Solutions in the market partition in several ways.**

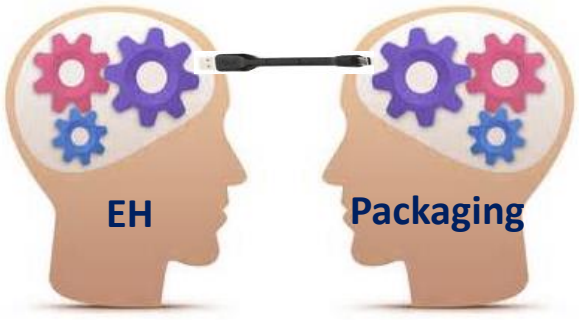
  e.g. chips that integrate
  - uController + sensor I/F + RF
  - uController sensor I/F+ RF + (some) PM
  - Sensors + I/F + RF (e.g. some PIR & temp sensors)
  - Multiple sensor types (e.g. Temp + Hum + CO2)
  - A few offer embedded EH&S but limited …
    - (performance, variety, protocols)

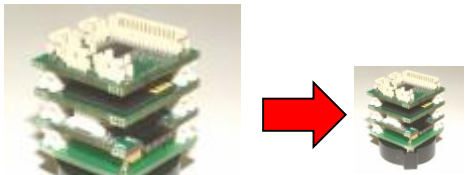


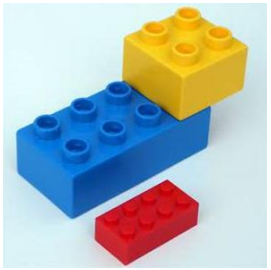
- **Also need to take into account**
  - Design of antenna
  - Design of enclosure
  - Power source/generator/transducer (impedance, voltage, no. of cycles…..)
- **For most solutions users need to mix and match -> solution will be non-optimal, due to lack of expertise**
- **May also need to develop/use additional circuits for start up, power management, interface, battery back-up, etc.**

Partitioning (2)

- **Most commercial solutions with Energy Harvesting are basic, non-optimised & generic**
- **Emerging technology EH parts are mainly in proof of concept stage @ lower TRL and lack latest packaging technology integration**
- **We need**
  - State of the art miniaturization and packaging technologies at device and system level
  - Modular solutions that can be easily scaled for diversity of needs (size, power, ambient energies, form factor…)
  - Easy application re-configuration with little expertise
  - Increased collaboration with packaging designers to embed latest technologies
  - Consideration by designers of materials, circuits, devices of packaging constraints and opportunities for real life applications

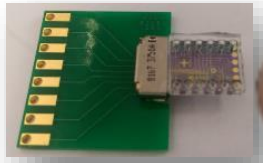




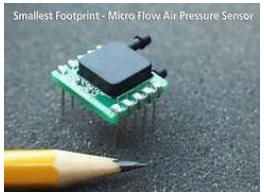


Problems with Sensors

- Need both ‘protection’ & ‘exposure’
- Issue is well known to IoT world at present, e.g. WSN with mixed success
- Embed onto semiconductor (-style) packaging has helped
- But it is going to become more difficult
- If we embed further into the IoT device how do we ‘expose’ the sensor



Electrochemical



Airflow

Pressure

Temp + humidity

PIR

Multiple gas

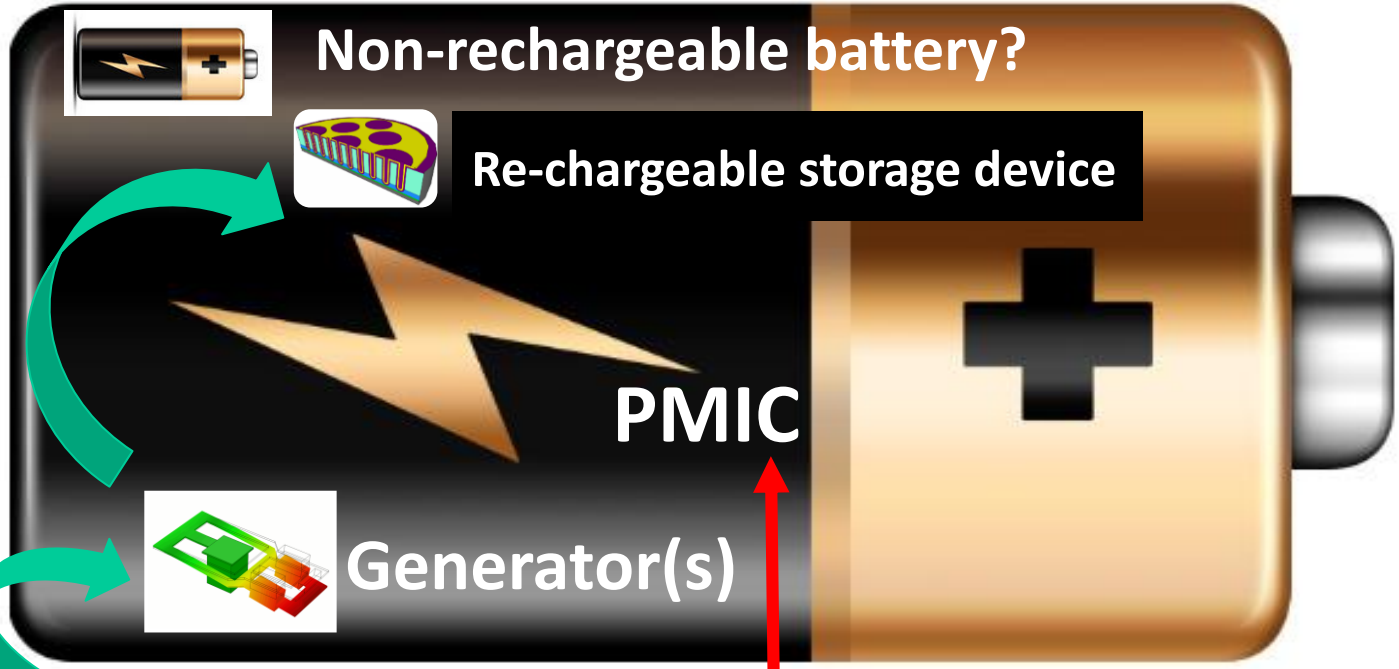
Problems with Energy Harvesting powered solutions (1)

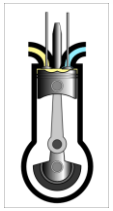
- **Battery needs replacement with a much more complex device bringing new electronic, mechanical & interconnect challenges (ref next slide)**
- **Ambient energy sources need to be 'exposed' to energy source & yet 'embedded' near the load**
- **Ambient energy sources may sit in harsh environments**
  - e.g. major temperature extremes, outdoor fouling, ingress, etc.
- **Variation in placement strategies and accuracy of the packaged solution, how to ensure alignment with ambient energy (heat pulse, light, good thermal interface)**
- **Diminishing volumetric space available to squeeze in all of this for some apps (e.g. wearable, healthcare)**

IOT device (WSN + PMIC +….)

Problems with Energy Harvesting powered solutions (2)

- Complex array of stuff to be integrated to replace function of battery





Ambient energies

WSN Load

Sensors + Interface
Microcontroller
RF

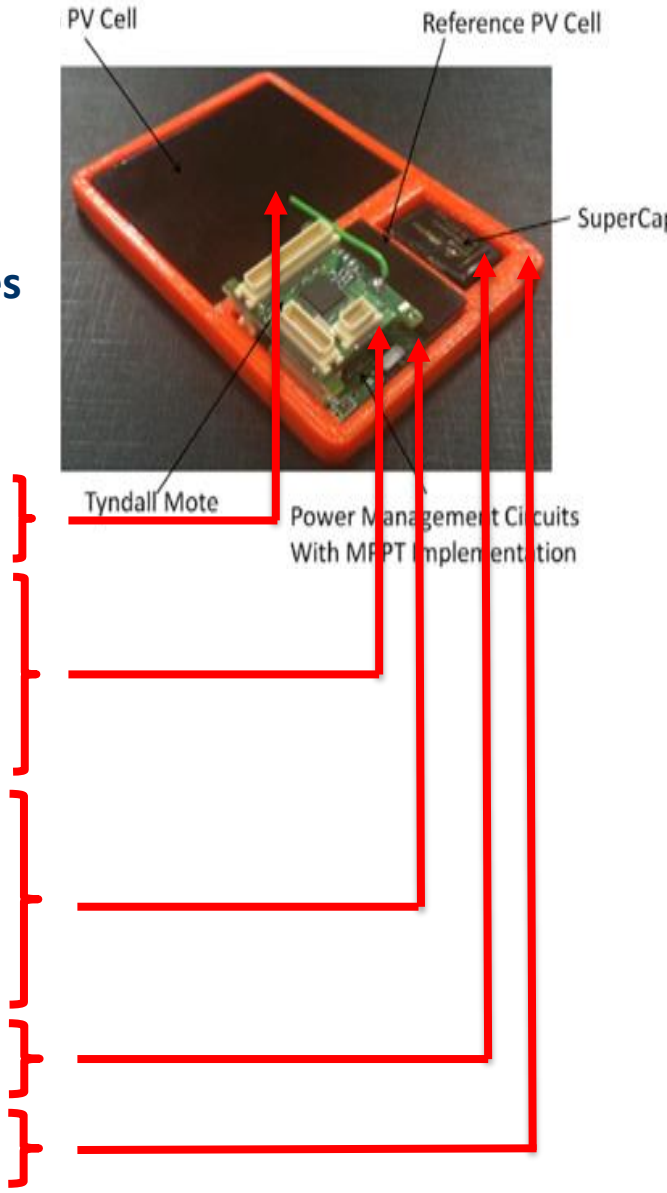
Intelligent switching between ambient energies + battery + storage devices
Cold start
Voltage conversion
Impedance matching
Charge management
Peaks, transients
Status monitoring

- Many packaging challenges
- Then need to integrate with WSN load

Opportunities Example (1) – indoor solar energy harvester

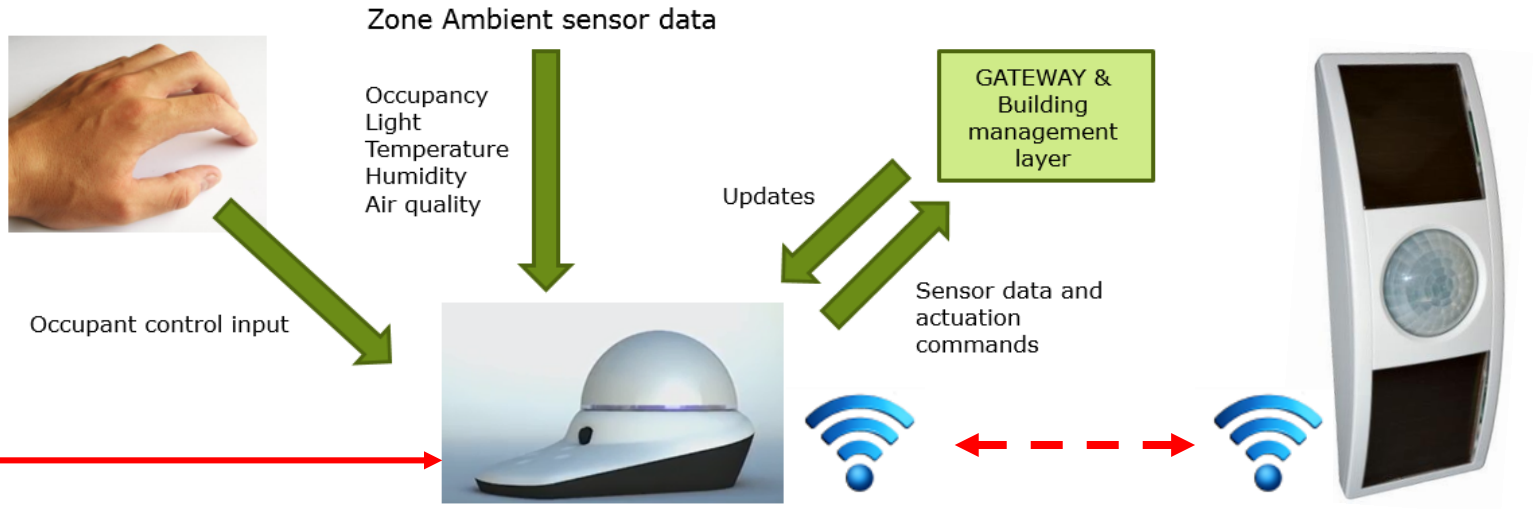
- **Proof of concept available – credit card (3D printed)**
  - Temperature, light, humidity sensing
- **PwrSoc & PSiP technologies can help realise opportunities**
- **Remember sensor + EH problems outlined in previous slides**
  - (embed Vs exposure, harsh environments, aesthetics, etc.)

Opportunities
Add other Energy Harvesting (EH) sources
Add other sensors e.g. CO2, occupancy
Integrate the IoT device (e.g. WSN node)
Move from discrete to PMIC to improve efficiency & enable multi-source EH with Battery back up
Miniaturize magnetics around PMIC
Embed storage (harvesting cycles + battery backup)
Improve aesthetics and robustness of packaged IoT device



Opportunities Example (2) - BEM integration

- **BEM (building energy management) application of indoor solar EH**
- **Level of embedding/miniaturisation depends on size & form factor of IoT device**



Desk mounted sensor – helps improve comfort and optimise energy use [2]

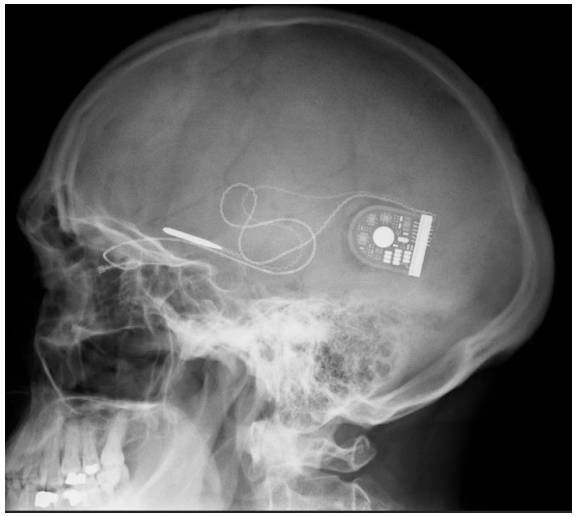
- **Opportunity:- Embed more sensors, Battery back-up & PV**
- **Need to put PIR sensor in a different location (e.g. high on a wall) with embedded transceiver?**
- **PV may need to be flexible to fit (e.g. DSSC – Dye Sensitised Solar Cells)**

Opportunities Example (3) – wearable/implantable

- **Lots of start-ups, concepts, etc. but not many mainstream products yet**
  - Mainly because they do not produce enough average power
  - Solutions rely on a single type of ambient energy
  - Most commercial parts just use a battery and need frequent re-charge or have short use life (which is ok for some applications but not most)
- **Wearable multisource PV/TEG/VEH* concept is attractive but….**
  - Huge variation in ambient energies (levels and intermittency) and interfaces needed
  - How to expose align, exposure & aesthetically embed and interconnect
  - Major challenges to interconnect and package
  - If embedded there will be limitation , e.g. some battery chemistries not allowed, e.g. magnetic materials based generation (vibrational) materials not allowed for VEH (MRI compatibility)

***TEG = thermoelectric, VEH = vibrational**

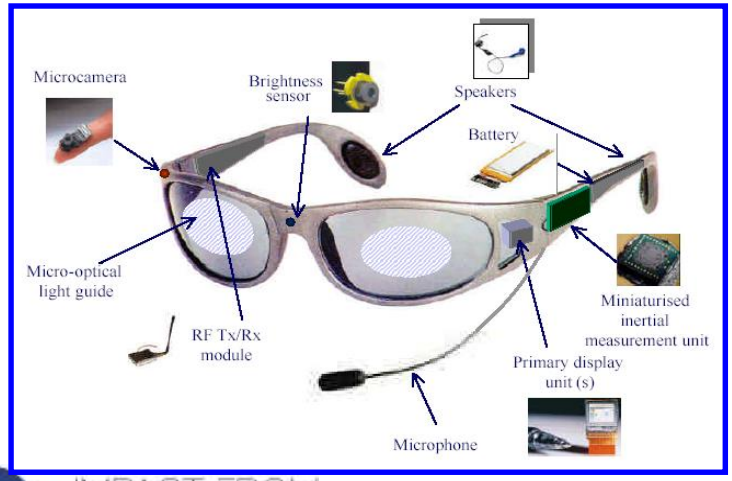
Some wearable concepts



Eye/brain implants (need to get smaller!) [3]

Emerging smaller technology from Stanford [3]

Smart patch

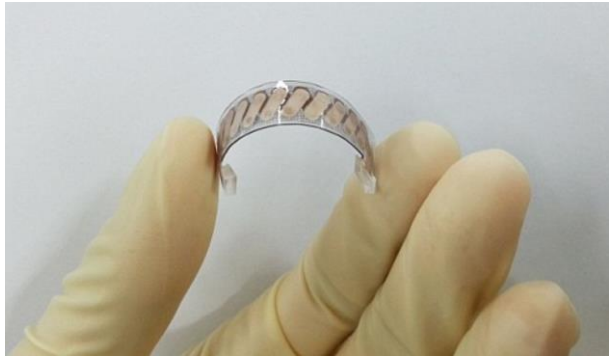


Smart glasses

Tyndall WSN for sports performance

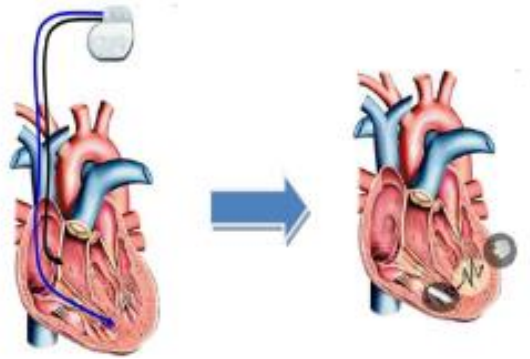
GRASP gait monitoring [4] (sports, rehabilitation)

Some attempts to self power

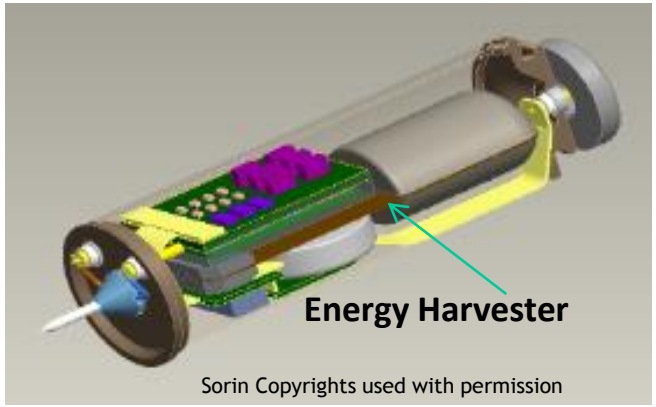


- PV wireless headphones: Exod UK start-up 2015 [5]

Wearable TEG: KAIST, 40mW @ wristband size



Tyndall transducer



- Implantable energy harvesting device to power pacemaker
  - EU MANPOWER project [6]
- Miniaturization, reliability & biocompatibility critical for many applications

How to Address Problems (Suggestions)

- **Concurrent system level optimisation engineering**
  - Developers of transducers, storage, IoT devise, WSN all work together and design parts optimised for SYSTEM needs
  - Leverage from & guide state of the art packaging from materials to devise and systems
  - Bring in industrial designers early – aesthetics, manufacturability, testability
  - Allow for variations in deployment (ambient energies, placement sensitivities)
- **Use System Integration tools**
  - Utilise multi-domain modelling – e.g. PowerSWIPE (thermal, electrical, mech, EMI)
  - Utilise additive manufacturing – early prototype, collaborative reviews of concepts
- **Consider user experience early (where appropriate)**
  - Unobtrusive, biocompatible
  - Wear and tear, etc.
  - Ease of repair, maintenance

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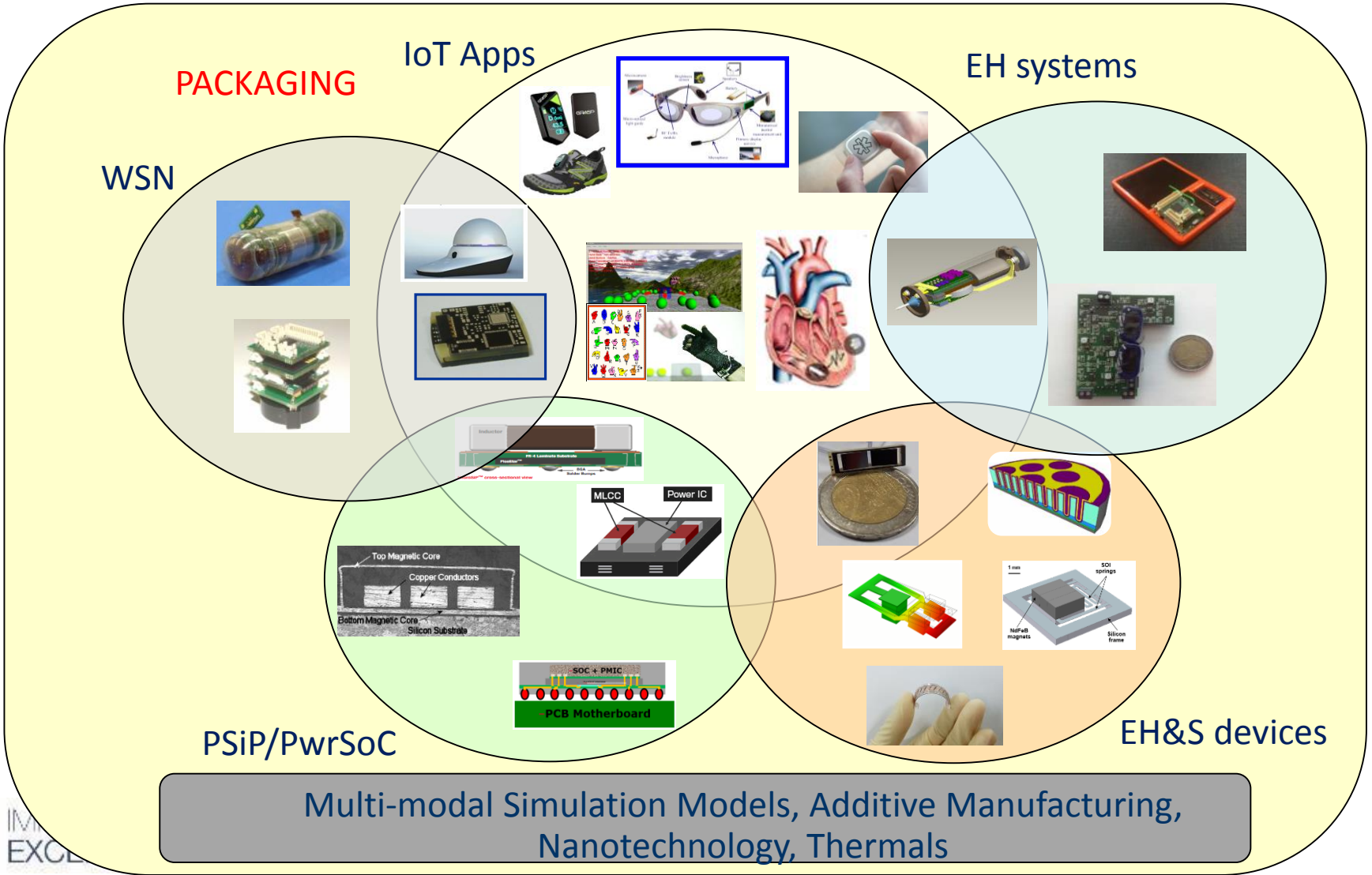
Summary & Conclusions

- **IoT market (1 trillion sensors by 2025) brings many opportunities to PSU industry**
  - Components
  - Enhanced monitoring of devices and systems
- **Challenges in embedding sensors in IoT devices intensifies as we miniaturise**
- **Further challenges when we attempt to integrate energy harvesting solutions**
- **PSiP & PwrSoC are key initiatives that must be more strongly linked to Energy Harvesting & WSN/IoT**
- **Closer collaboration needed within and between communities – bring ecosystem together**
- **Think about system level optimisations - carefully consider application needs**
- **Multi-domain modelling and additive manufacturing are very helpful tools**

Summary & Conclusions (VISUAL)

- **3D packaging technology collaboration is critical**



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Thank you!

Go raibh maith agaibh!

Come and see demo of tools and hardware at

Energy Harvesting Industry Session

Thurs 30th March

IS16 room 4

8.30-11.30am

References

[1] http://www.powerswipe.eu/aboutus/

[2] http://www.moeebius.eu/about-the-project (project hardware in development)

[3] https://www.extremetech.com/extreme/182686-here-come-the-rice-grain-sized-brain-implants-stanford-discovers-way-of-beaming-power-to-microimplants-deep-inside-your-body

[4] http://graspwt.com/

[5] http://pubs.rsc.org/en/content/articlelanding/2014/ee/c4ee00242c#!divAbstract

[6] http://www.themanpowerproject.eu/uploads/%28Public%29604360_MANpower_D1_1_Specifications_Report_Final_Version.pdf