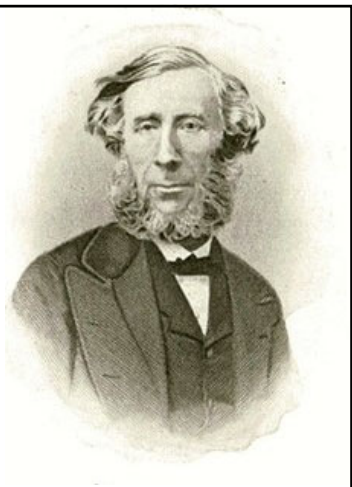
Strategies for Research And Power Electronics in Ireland



John Tyndall,
1820 - 1893

Dr. Cian Ó Mathúna

Microelectronics Applications Integration Group

Tyndall National Institute

Email: omathuna@tyndall.ie

Summary

- Tyndall National Institute, Cork, Ireland
- Ireland – enabling a Knowledge Economy
- Energy Processing for ICT
- Ambient Intelligence

Tyndall - Ireland's First National Institute

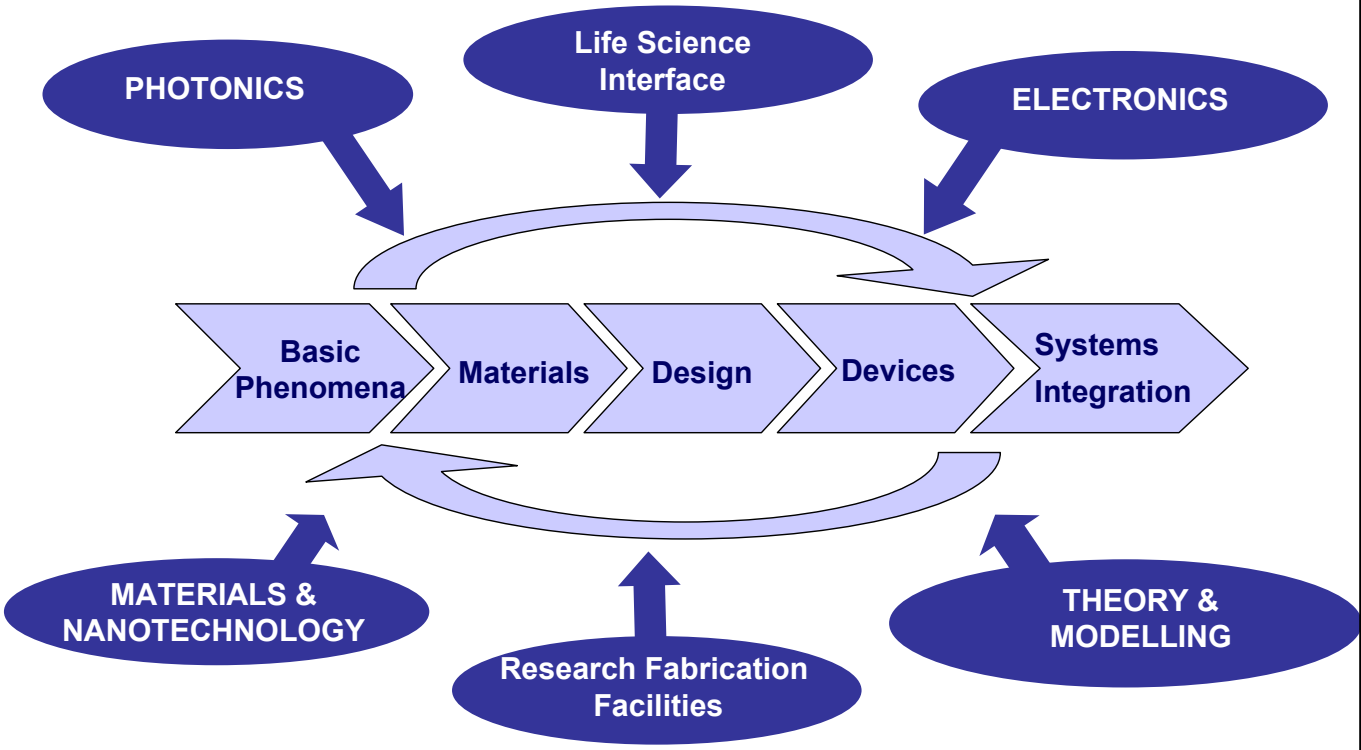
- Ireland's largest ICT Research Institute
- 300 Research Staff and Students
- Incorporates:
  - former NMRC (National Microelectronics Research Centre – since 1982)
  - ICT Research Groups from University College Cork (School of Science, Engineering and Food Engineering - Physics, Chemistry, Microelectronics, Electrical/Electronics Engineering)
  - ICT Research Groups from Cork Institute of Technology
- Annual Budget – 20Million Euro
  - 25% Government/University Grant
  - 25% Irish Science & Engineering Technology Agency Research Programmes
  - 40% EU Research Programmes
  - 10% Direct Industry (80% Irish-based companies)
- Research Mix – Industry Partners – 80%; Basic – 20%

Vision, Mission, Objectives

"Tyndall will excel at creating value from research"

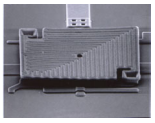
- Excellence in science and engineering technology
- Research of strategic value to Ireland
- Access to research facilities
- Collaborate with industry
- Stimulate innovation
- Engage in national and international partnerships
- Champion outreach in science and engineering

Tyndall National Institute - Research Focus

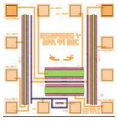


Electronics

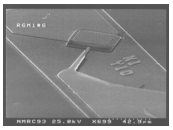
- Electronic devices, circuits & systems
- Packaging & system integration
- Energy processing for ICT
- Life science interface



MIcrobolometer



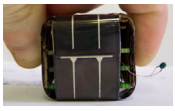
Quadruple RADFET



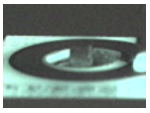
Schottky diode

Microsensor module

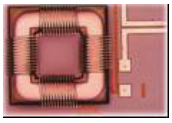
Smart seed



Solar cell

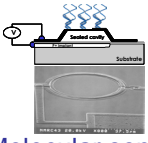


Scavenger

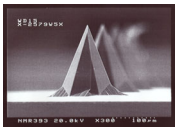


Magnetics on silicon

Microbattery on silicon



Molecular sensor



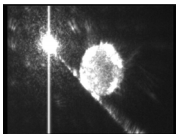
Gene therapy

Point-of-Care Diagnostics

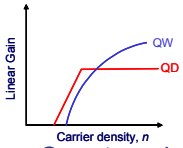
Tyndall National Institute

Photonics

- Basic phenomena
- Devices
- Integration
- Systems

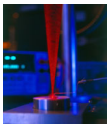


Quantum optics

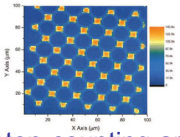


Quantum dots

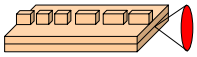
Laser physics



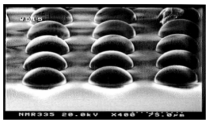
Red VCSL



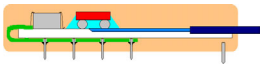
Photon-counting array



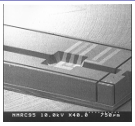
Single-mode Fabry-Perot laser



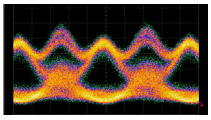
Micro-lens array



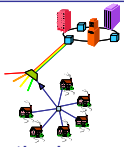
Optical interconnect multichannel module



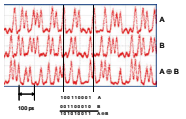
Optical submount



Coherent WDM



Optical access

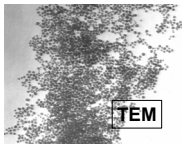


Ultrafast logic

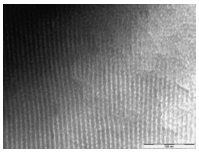
Tyndall National Institute

Materials & Nanotechnology

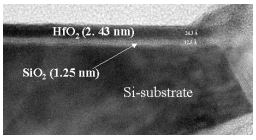
- Advanced growth



Synthesis of nanoparticulates

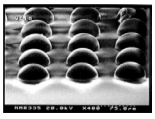


Low-*k* mesoporous thin films

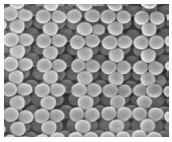


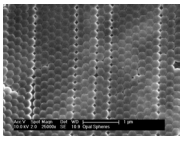
UV-assisted deposition

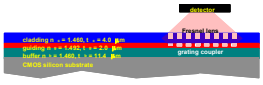
- Photonic materials



Ink-jet printing of polymer components



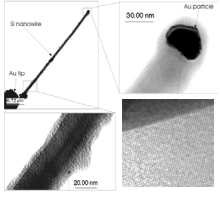




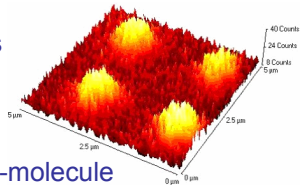
Composite materials processing

Opal photonic thin films

- Molecular & nanoscale devices



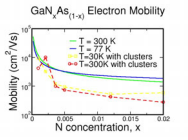
Si/Ge nanowires



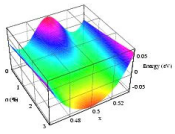
Single-molecule photonic logic gates

Theory & Modelling

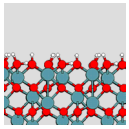
- Materials
- Devices
- Integration
- Frontier tools



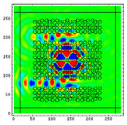
Carrier mobility



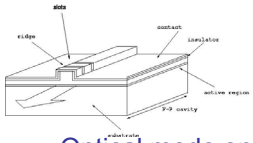
Coherent control



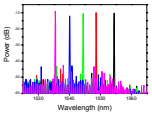
TMA precursor

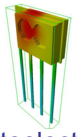


Add-drop filter

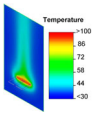


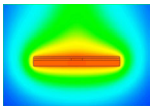
Optical mode engineering



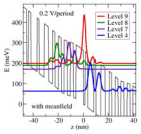


Optoelectronics packaging

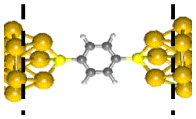


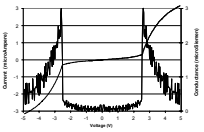


Thermal management



Wannier-Stark states





Molecular electronic transport

Tyndall National Institute

Central Research Facilities

Fabrication

- Silicon, MEMS, III-V
- Polymer, E-Beam, Hot Embossing
- FIB nanofabrication, Nano-imprinting
- Plating – Electro and Electroless

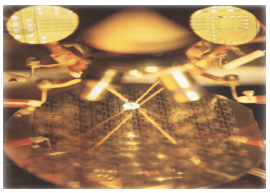
Test & Characterization

- Electronic
- Optical
- Thermo-Mechanical
- Materials
  - FTIR, EDX, Raman, DLTS, VASE, STM, NSOM
- Environmental Reliability/Failure Analysis
- SEM, FIB

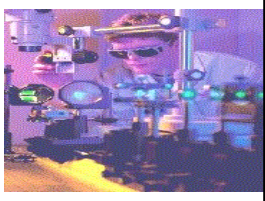
Fully Equipped Research Laboratories

Silicon Fabrication

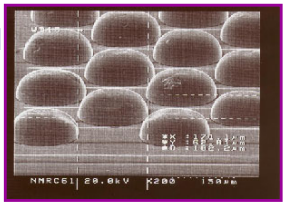
E-Beam



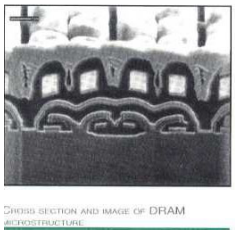
Electronic Test



Optical Test



Plating

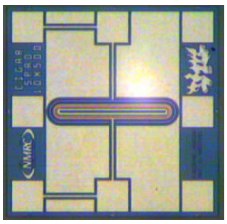


FIB

Tyndall National Institute

Value from Tyndall Research/Technology

Avalanche Photodiode Technology

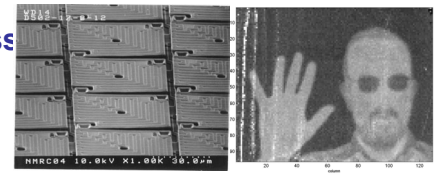


World-leading technology

- Capable of detecting single photons of light
- Developed from 10 years+ Tyndall research

- SensL (www.sensl.com)
- Tyndall spin-off company (2004) to exploit the technology
- Major applications in biomedical field (Fluorescence of Biochemical species)

Infra-Red Detector Technology – MEMS Bolometer



- Novel patented integrated sensing element with CMOS process
- Low cost infra-red imaging (bolometer) technology
- Bolometer process transferred to commercial fab (XFAB, UK)
- Integrated with 0.75um CMOS process

Silicon RADFET (In-house Design/Fab)

- World-leading supplier of RADFETs (ESA, NASA, JAXA, CERN, …)
- Supplied to Sicel Inc - OneDose product on US Market
- FDA-approved dosimeter patch and reader for monitoring of Radiotherapy Treatment

Tyndall National Institute

Product Differentiation
Market Diversification
Adding Value to CMOS

250nm 180nm 130nm 90nm 65nm 45nm 32nm

Moore's law

Silicon Technology Roadmap
1 Billion Transistors on a Chip
Chip Size Reduction
System on Chip

BiCMOS

bipolar

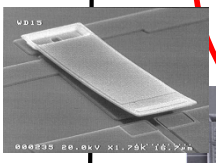
rf CMOS + passives

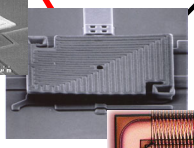
Embedded MEMS

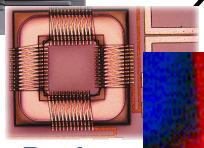
On-chip Power

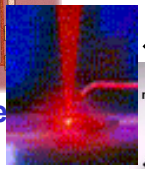
Integrated Photonics

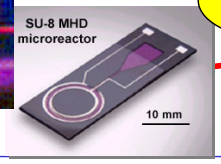
Biochips

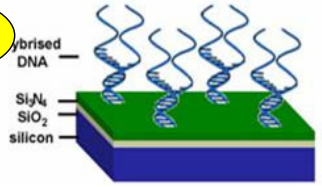












More than Moore

System on Chip / System in Package
Post-Processing of CMOS
Heterogeneous Integration

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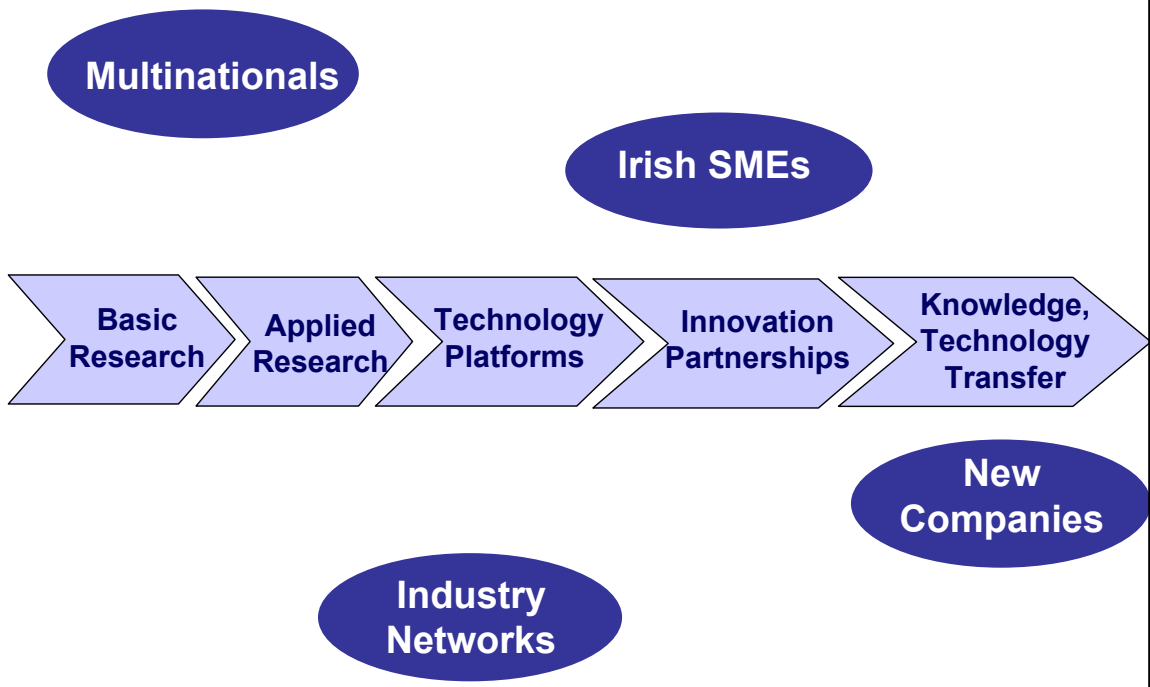
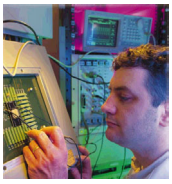
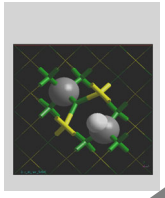
Tyndall National Institute – Industry Partnerships







New Company Support

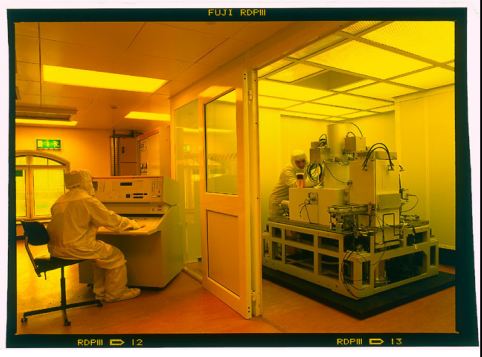
New product development

Technology transfer to industry

Training & skill-sets

Knowledge & Intellectual Property

Strategic Industry Relevant Research



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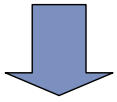
Ireland's Imperative to Compete in the Global Knowledge Economy

- Build top quality R&D teams
- Attract and build strong industry research
- Build on tradition of entrepreneurship
- Create culture of partnership & cooperation
- Maintain the momentum of growth (Celtic Tiger)
- Resource with skilled personnel



Return on Investment:
Economic, social and cultural value-impact for Ireland's knowledge economy.

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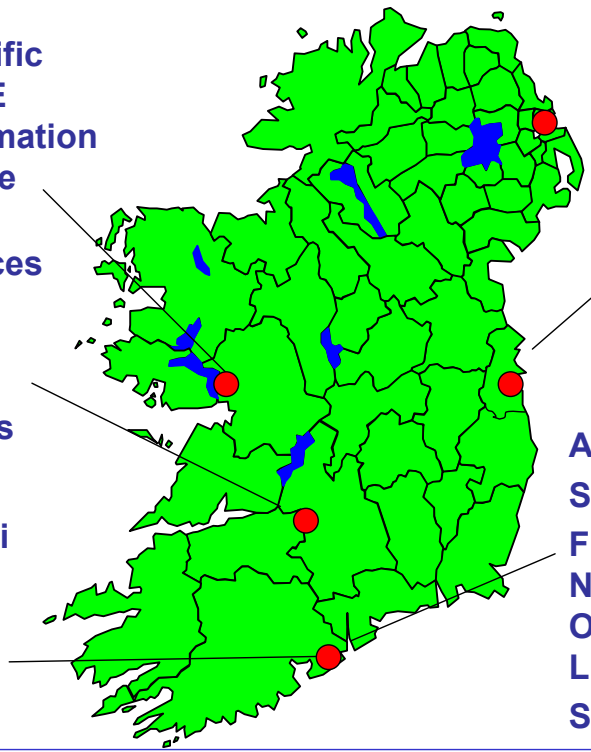
Tyndall Postgraduate Employment in Ireland

Betatherm
Boston Scientific
Medtronic AVE
Western Automation
Marine Institute

Analog Devices
Molex
Kostal
Guidant
EI Electronics

Cypress Semi
Farran
Flextronics
M/A-COM
Moog



Eblana
HP
Intel
IBM
NEC
Loctite
S3
Xilinx

Applied Optotec
Stocker Yale
Firecomms
Nanocomms
Optical Metrology
Luxcel Bioscience
SensL

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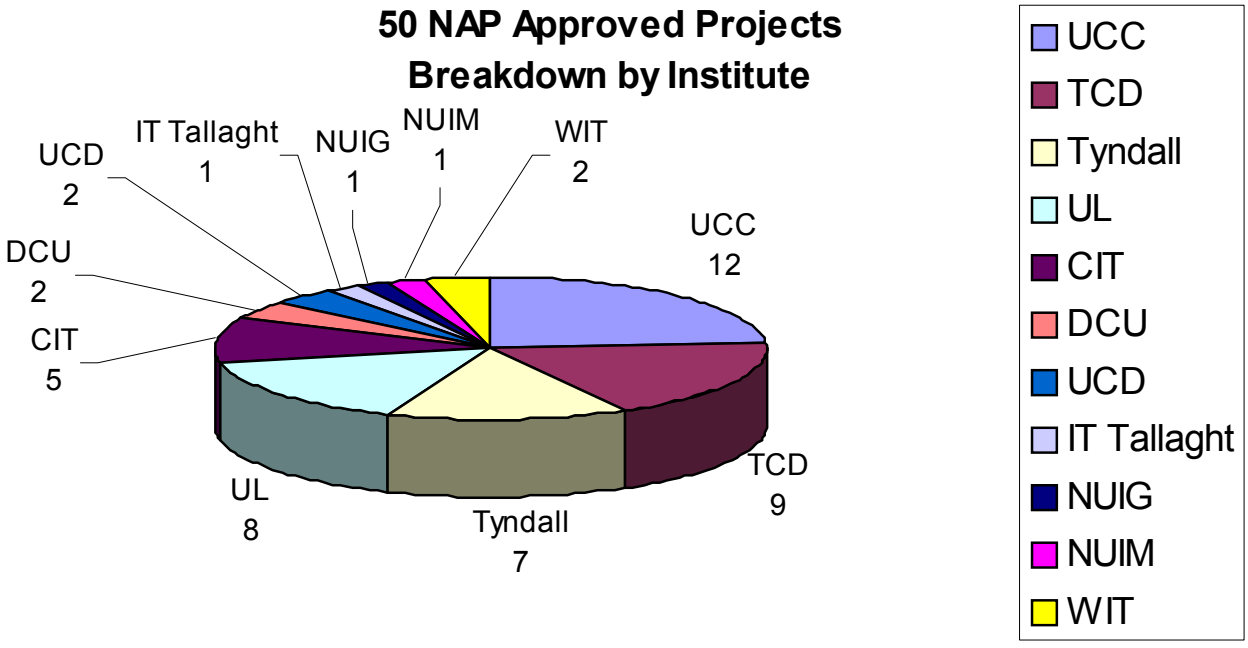
National Institute

National Access Programme

Provides Irish researchers with funded access to Tyndall's facilities & expertise

Annual Budget - Science Foundation Ireland Funding – 2Million Euro



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Enterprise Ireland
Industry Led Research Programmes - ILRP

PEIG - Power Electronics Industry Group

Artesyn, Analog, Commergy, Convertec, Excelys, Intel.

MIDAS - Integrated Circuit Design

Analog, Cadence, Cypress, Duolog, Intel, S3, Xilinx.

WISEN - Wireless Sensor Networks

Analog Devices, Benetel, Connaught Electronics, Cratlon, Duolog, Innovada, Intel.

EI Bio Industry - Micro-analytical & diagnostic systems

Wyeth, Elan, Centrecor, Schering, Trinity Bio, Tridelta

Science Foundation Ireland – SFI

700 Million Euro over 5 Years for Advanced Research in Universities

Focus: ICT and Biotechnology

SFI CSETs

Centres for Science & Engineering Technology

Multi-University Consortia with Industry Partners

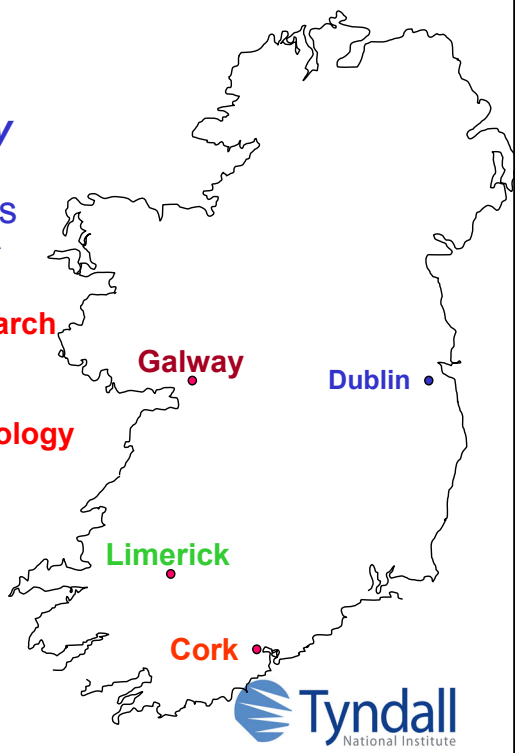
100 Million Euro Investment, 20% from Companies

Partner Companies Locating Research Teams in Centres

CTVR - Centre for Telecommunications Value Chain Research
- Bell Labs Research Ireland

CRANN - Centre for Research in Nano Science and Technology
- Intel Ireland, HP Ireland

BDI - Biomedical Diagnostics Institute
- Analog Devices, Becton Dickinson and Co., Hospira Inc, Inverness Medical Innovations Inc, Amic AB and Enfer Technology



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GeorgiaTech Ireland

Tuesday 14th March 2006
Irish Government announced that:
Georgia Tech Research Institute (GTRI), of Atlanta, Georgia, US,
will establish an applied research institute,
with support from IDA Ireland, to focus on industry R&D needs.

Over the next five years, the Irish operation plans to build up a portfolio of research programmes and collaborations with industry which will be valued in excess of €20 million and at full operation it will employ 50 highly qualified researchers.

Objective: bridge gap between academic and corporate research

Irish Government Strategy on Science, Technology and Innovation 2006-2013

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Energy Processing for Information & Communications Technologies (ICT)

- ICT is Information Processing

  - **ICT needs Energy Processing**

Energy Processing for ICT Research

Total: 64 Researchers - 7 Academics, 17 senior researchers, 10 researchers, 30 postgrads

5 Universities - Total Funding – 5 Million Euro

Power Generation/Transmission

- Inductive Power
- Energy Scavenging

- Vibration Harvesting / Solar Cells

- micro Fuel Cells

Energy Storage

- micro Battery

Conversion / Power Supply

- Embedded Magnetics – PCB, Silicon
- Power Electronics Circuits / ASICs

- Packaging & Functional Integration
- Reliability

Heat Dissipation

- Microchannels / Microjets
- Thermal Interface Materials
- Microfans
- Infra-red

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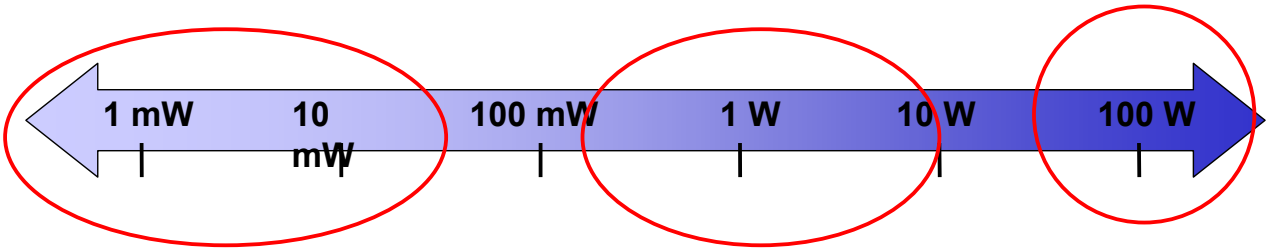
Application Areas



Power for Ambient

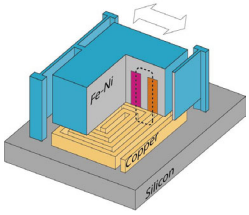
Power for Portable

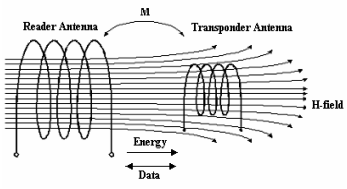
Power for Computing

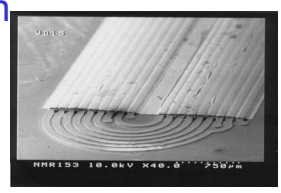
Power Harvesting

Inductive Powering

Integrated magnetics on Silicon







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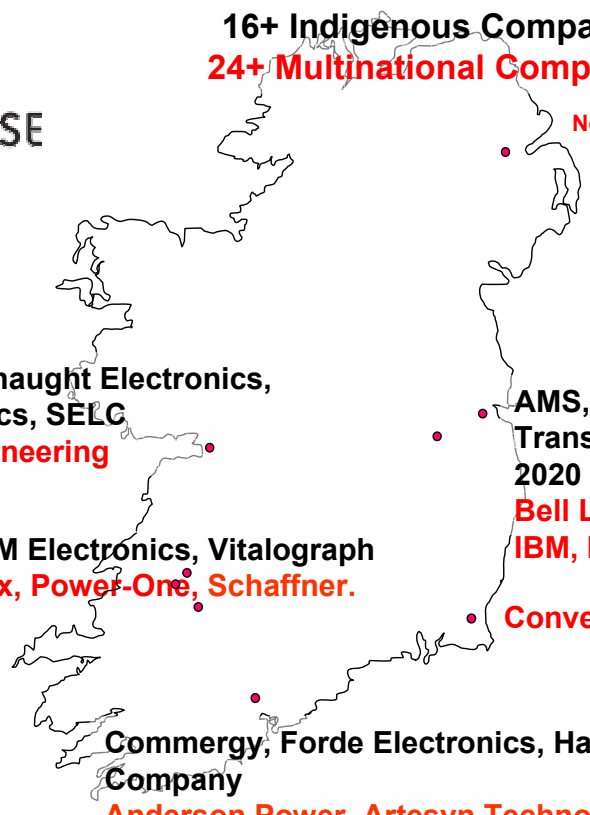
PEIG
POWER ELECTRONICS INDUSTRY GROUP
IRELAND

ENTERPRISE IRELAND

PEIG - Power Electronics Industry Group

16+ Indigenous Companies

24+ Multinational Companies



Nortel Networks

Betatherm, Connaught Electronics, Hitech Electronics, SELC
APC, Pulse Engineering

AMS, Excelsys, Powerplex, Transtest
2020 Progress Innovation Ltd
Bell Labs Research Ireland, IBM, Intel, Lucent, Xilinx

Frontline Medical, MJM Electronics, Vitalograph
Analog Devices, Molex, Power-One, Schaffner.

Convertec

Commergy, Forde Electronics, Haswell Consulting, Ship Company
Anderson Power, Artesyn Technologies, Bourns Electronics, EMC, Freescale, Kostal, M/A-COM, Moog, Sensormatic, Transistor Devices

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2005 - Industry Driven Research
Strategic Technology Platforms
3Million Euro over 3 Years

Research Programme

Devices & Components:
- High Efficiency Magnetics on Silicon
- Multi MHz Magnetic Materials

Topologies & Control:
- CMOS ASIC for Digital Power Control
- Driver Technology for 3MHz Switches

Interconnection & Packaging:
- Embedded Multi-chip Converters

Thermal Management:
- Substrate Cooling
- Thermal Interface Materials

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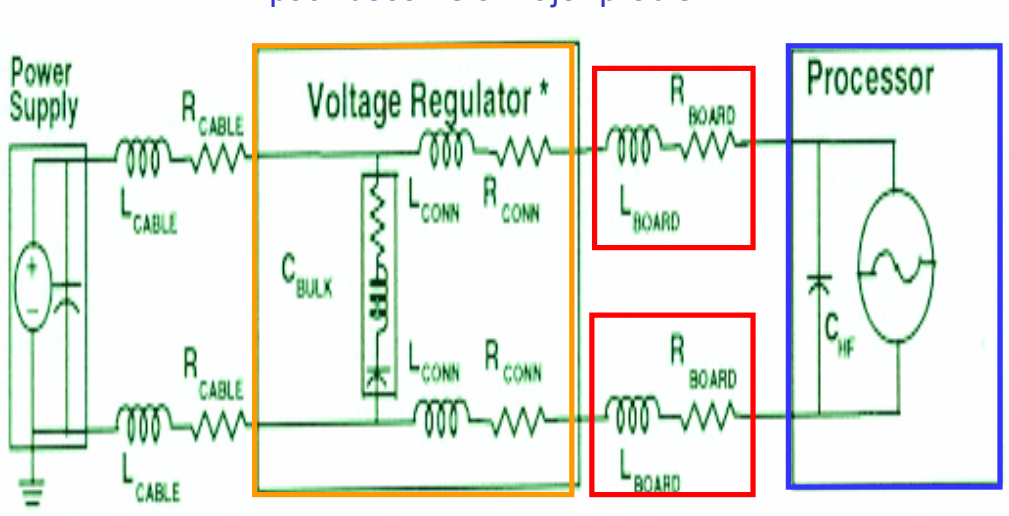
Trends in Processors

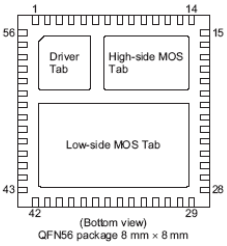
- Voltage decreasing
- Current increasing
- Parasitics in power supply path become a major problem



Potential Solution: Integrate converter on-chip or in-packag

Commercial state of art – Integrated Power Trains

Philips PIP212-12M



Renesas SiP.

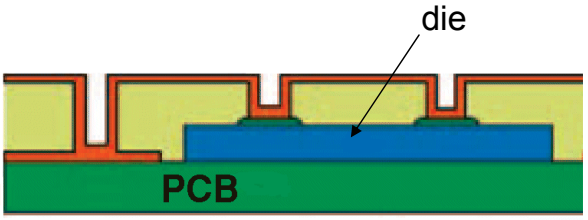
CASE 500
PInPAK

On Semis

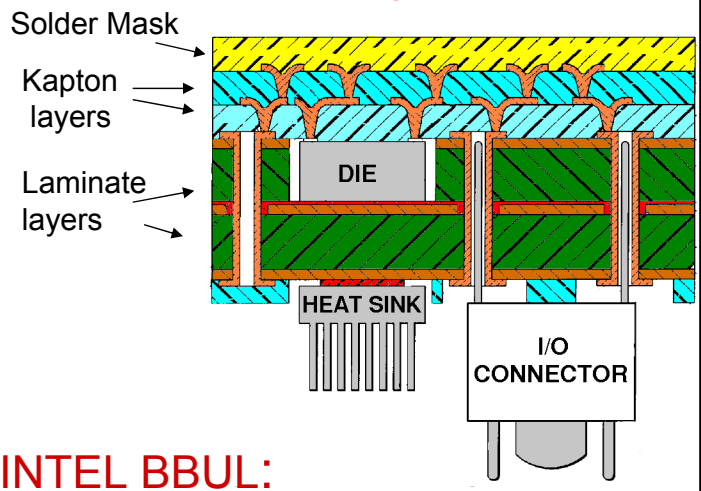
	2006 Competition			
	Philips	***Renesas***	***Vishay***	***ON Semi***
Model	PIP212-12M	R2J20601NP	SiC714CD10	NIS3001A
Vout	0.8V to 6V	1.0V to 5V	0.5V to 6V	0.7V to 5.1V
Vin	3.3V to 16V	Up to 16V	3.3V to 15V	7V to 14V
Iout max	30A	35A	27A	31A
Operating Frequency	Up to 1MHz.	>1MHz possible	Up to 1MHz	Up to 1MHz
Package size (Power Train)	8.1mm x 8.1mm x 0.9mm	8.1mm x 8.1mm x 0.8mm	10mm x10mm x	10.5 mm x 10.5mm x 2.0mm
Underside Pads	3 solderable	3 solderable	3 solderable	21
Rth(j-mb)	5 K/W max		2.6°C/W	8 °C/W
Tj max	150°C	150°C	125°C	125°C
Included	2 Mosfetts,1 Schottky, 1 driver	2 Mosfetts,1 Schottky, 1 driver	2 Mosfetts,1 Schottky, 1 driver	2 Mosfetts,1 Schottky, 1 driver
Required	L, C, Controller	L, C, Controller	L, C, Controller	L, C, Controller
Power Density - power train 27A @1V(W/cm3)	457	514	338	122

Packaging - State of Art

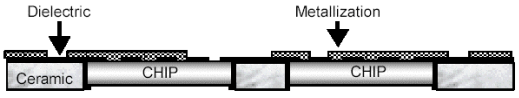
Fraunhofer chip in polymer:



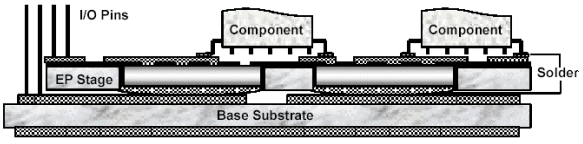
TI multi chip module



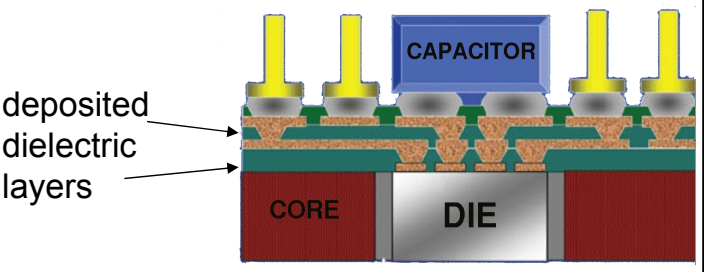
CPES Embedded Power :



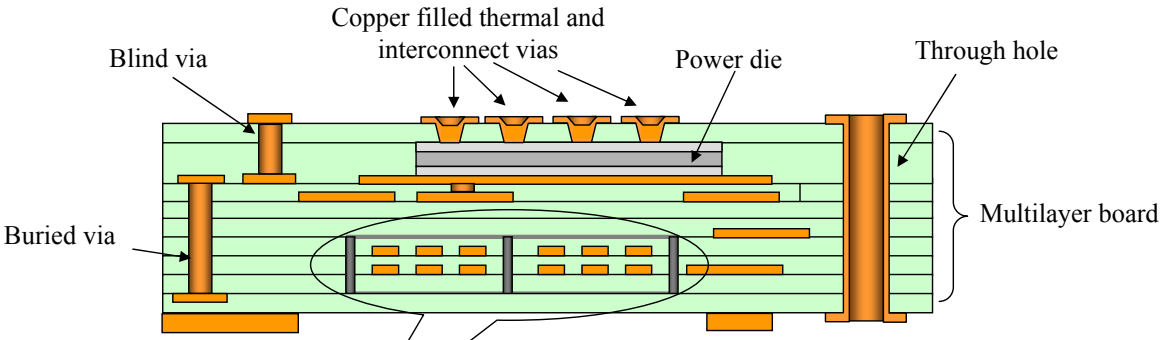
a: Integrated power chips stage



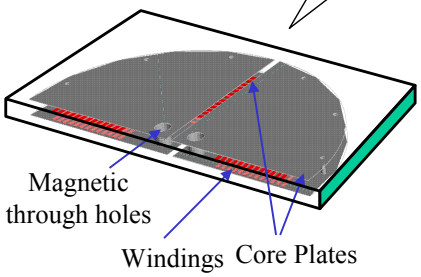
INTEL BBUL:



P Cubed - "Chip in laminate" for Power



"Embedded die" – Ship Co. Ltd June 2002



PCB integrated magnetics

Possible process flow

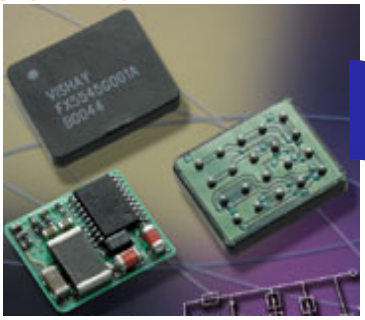
1. Fabricate integrated magnetic
2. Place die on PCB core
3. Apply prepreg layers
4. Laminate
5. Drill and plate thermal and interconnect vias

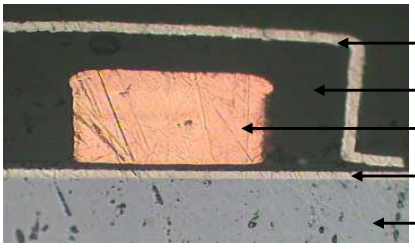
Future Power Supply on Chip

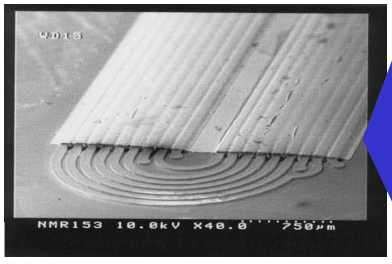
Functional Integration of Power & Control ASICs
with Passives on Silicon (Magnetics and Capacitors)

Disruptive Transition from Multicomponent, PCB/Hybrid Assemblies to Monolithic Power Supply on Chip (PSOC)

- **Power ASIC**
- **Integrated Magnetics on Silicon**
- **Embedded Capacitors**
- **Advanced Packaging**







Cian Ó Mathuna et al, "Magnetics on Silicon - An Enabling Technology for Power Supply on Chip",
***IEEE Transaction on Power Electronics** - Special Issue on Integrated Power Electronics, Vol. 20, No. 3, **May 2005**, pp. 585-592.*

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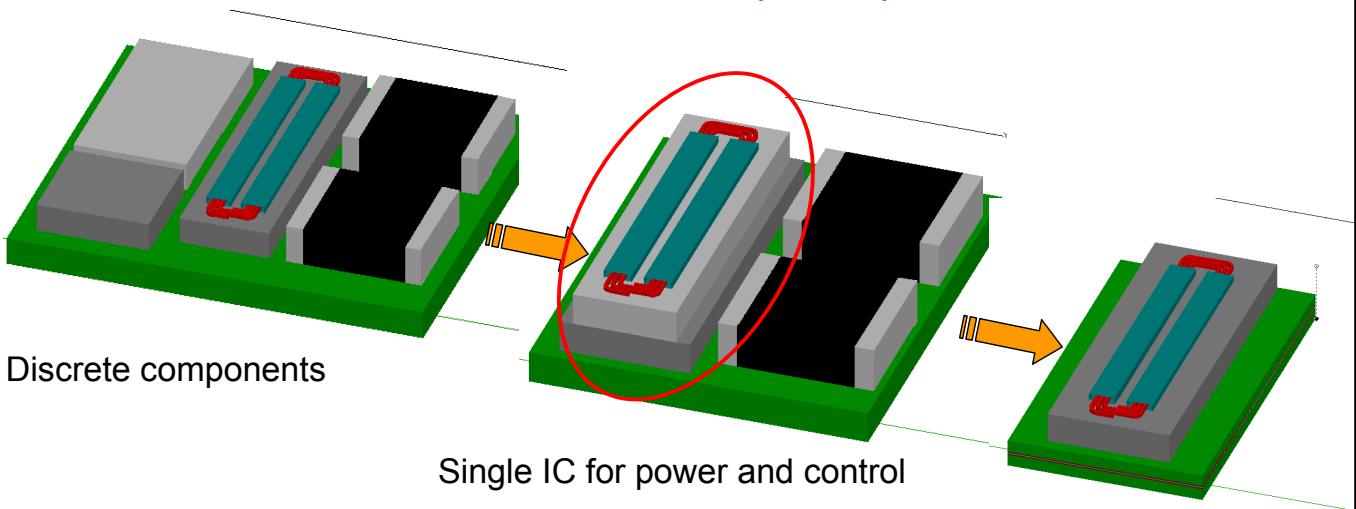
Concept of Power Supply on Chip

Low Power (2 –3 W) DC/DC converter



Discrete components

Single IC for power and control

Inductor chip mounted on-top of the IC

Capacitors are external

Inductor fabricated directly on top of IC

Capacitors external

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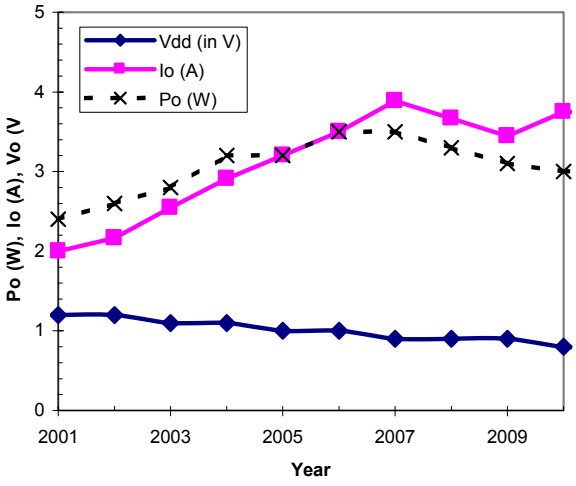
ITRS Roadmap for Hand-held Equipment



Estimated Reduction in Passive Components in Switch Mode Power Supply

Year: Frequency, Inductance (L), Capacitance (C)

2004	**2MHz**	**700nanoHenry**	**3.4microFarads**
2008:	**2MHz;**	**600nH;** ↓ **x1.2**	**4.0 µ F** ↑ **x1.2**
2008:	**5MHz;**	**240nH;** ↓ **x3**	**1.6 µ F** ↓ **x2.1**
2008:	**10MHz;**	**120nH;** ↓ **x5.8**	**0.8µF** ↓ **x4.3**

- Power supply miniaturization and integration can only be achieved by increasing power supply switching frequency into multi MHz region
- Integrate Magnetic Components on Silicon to achieve miniaturisation

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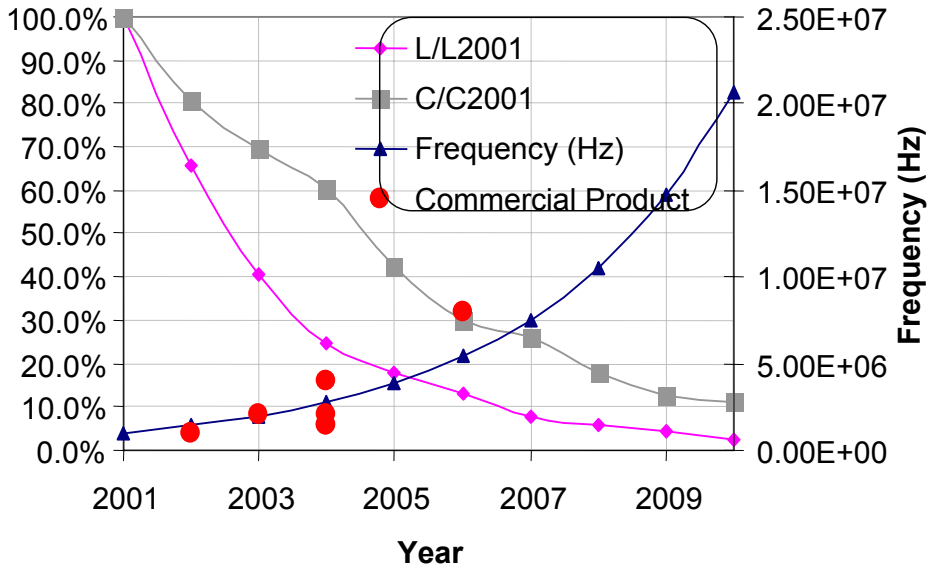
Reduction in Passive Components

Reduction in Passive component size with frequency and time



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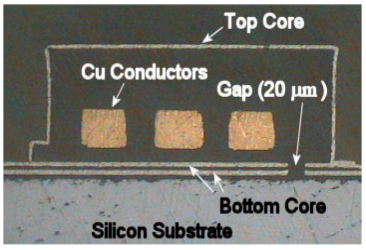
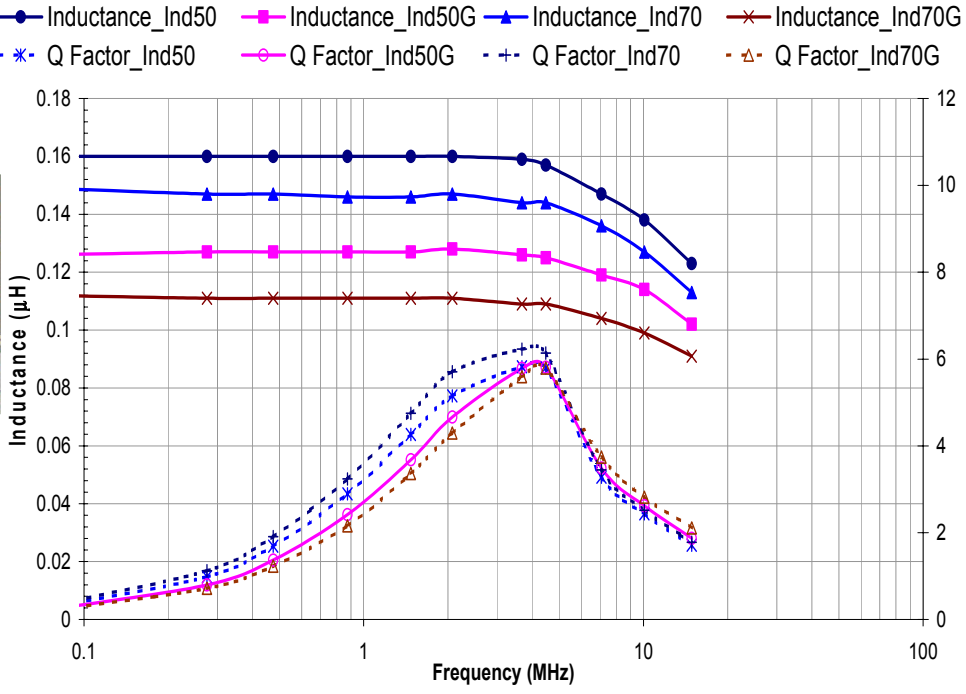
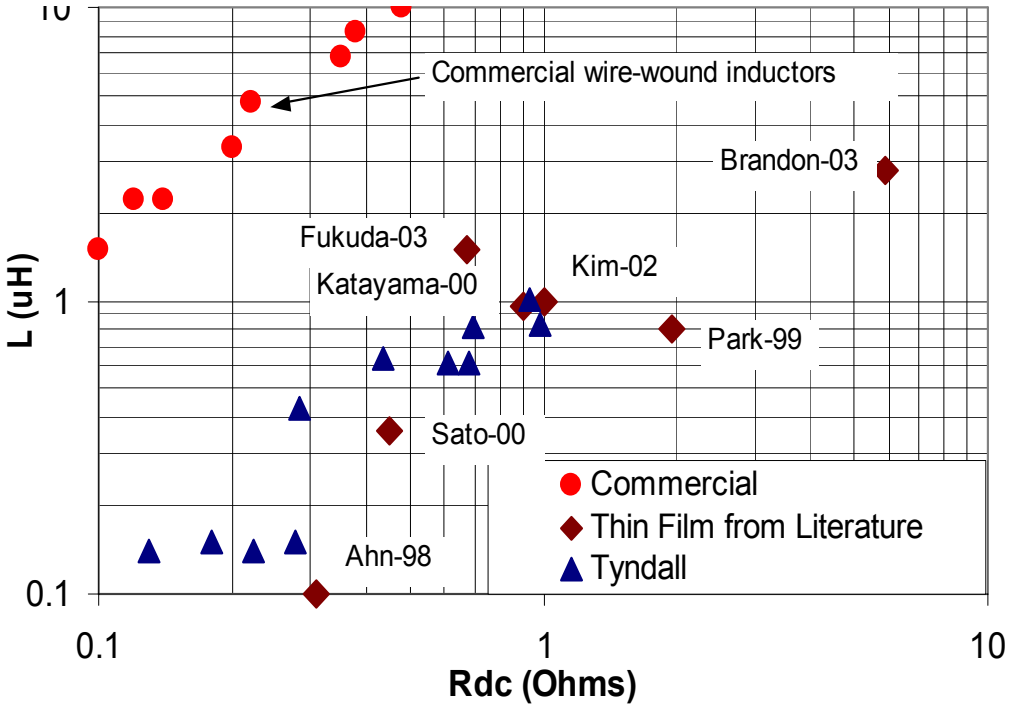
Inductance and Q-factor vs. frequency



Cross-section of prototype gapped inductor



Comparison to State of Art: Inductance & DC resistance



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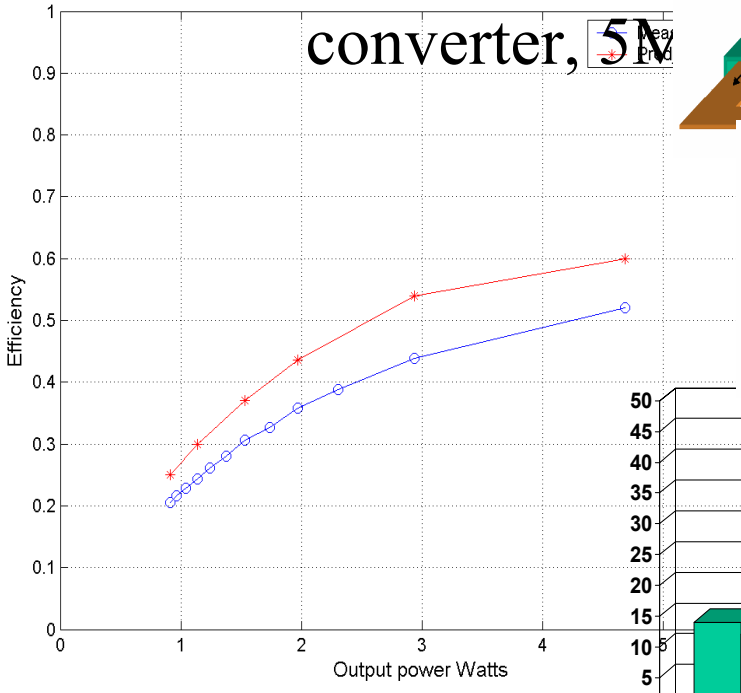
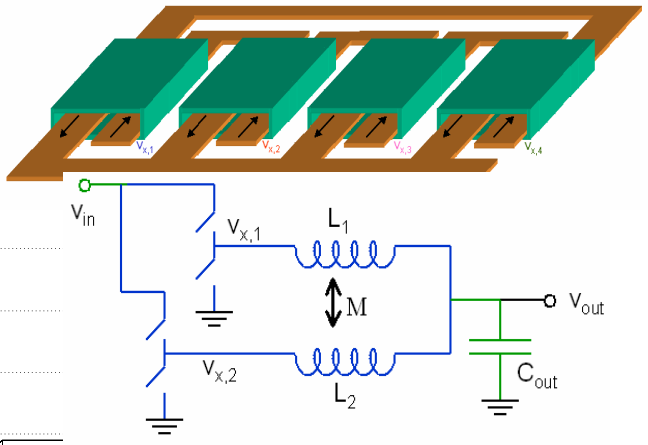
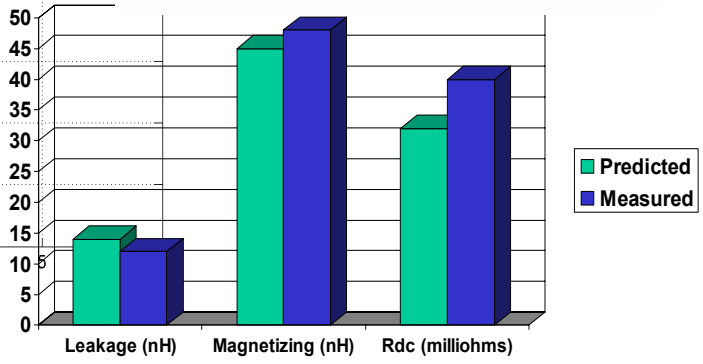
First reported micro-fabricated coupled inductor for fast converter, 5V







Collaboration with Prof. C. Sullivan, Dartmouth College, NH, USA.

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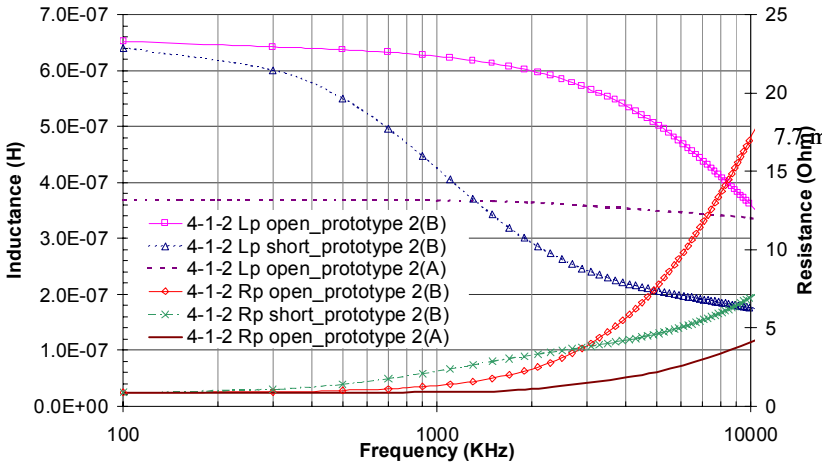
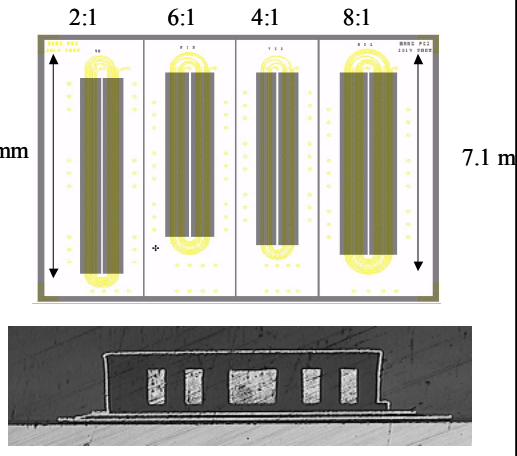
Transformer Results

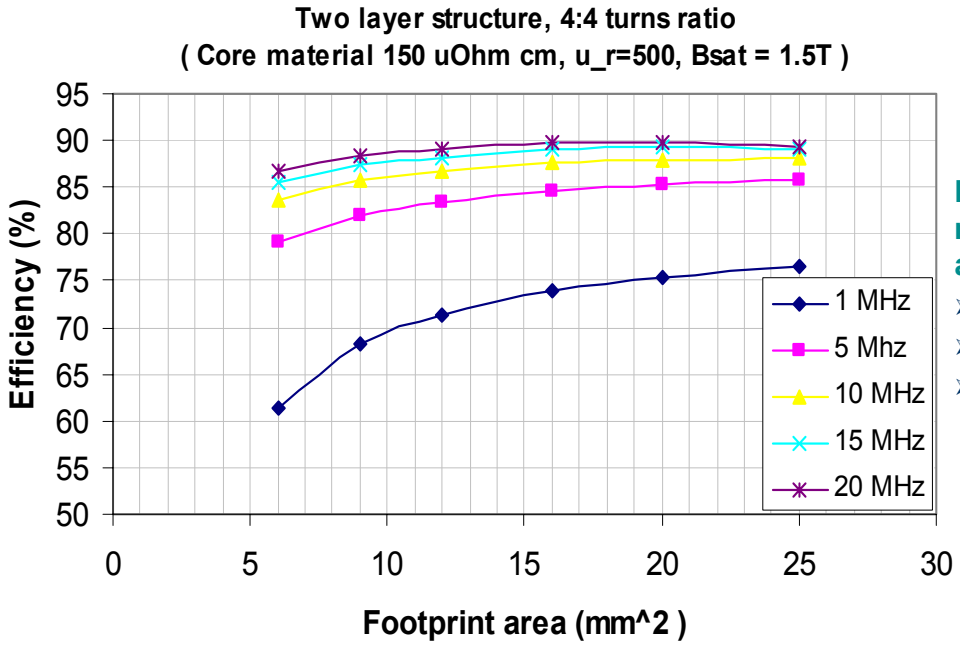




N_{pri}	Nsec	W_{pri}	W_{sec}	S_{p-p}	S_{p-s}	W_{device}	L_{device}
4	1	30 µm	80 µm	35 µm	45 µm	1.43 mm	6.76 mm

Future Directions - Technology

How can Transformer Efficiency be further increased?



Modelled efficiency of micro transformer assuming :

- **1:1 Transformer,**
- **5 V input,**
- **100 mA ouput current,**

Magnetics on Silicon
Future Challenges

- **Increased Efficieny**
  - Presently efficiency is 70% – 80 %, need > 95%
  - Requires better magnetic materials
    - High Resistivity Magnetic Materials
    - Laminated magnetic cores
- **Integration and Packaging**
  - Real benefit is in integration with other devices
  - Integration with Capacitors, active devices
  - Reduction of process complexity

Energy Considerations

Data Centers

50 MW projected heat 'load' for a 10,000m^2 facility

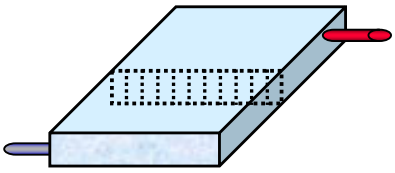
Additional 20MW for air conditioning

$100 / MWh cost → $18M pa for cooling alone!

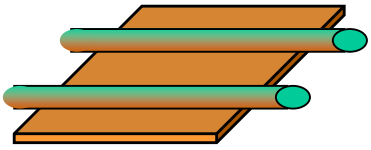
From: Shah et al (2004)

Thermal Management → Energy Management

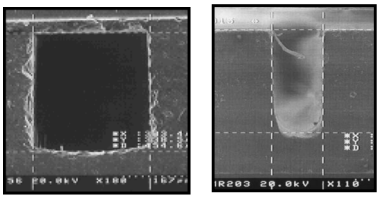
Liquid Cooling Demonstrator
heat flux removal of order 100W/cm^2 (≈500W/in^2)



Cold plate with heat transfer matrix



Surface-Mount Heat Collector



Silicon and Plastic µChannels

Increasing Pressure Drop

A. Card-level cold plate

B. Substrate-level cooler

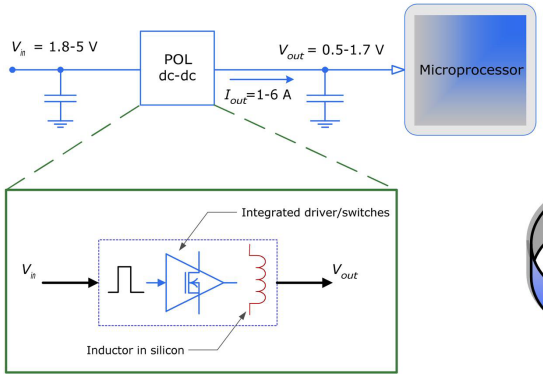
C. Package-level micro-channels

Primary heat removal techniques

swiftD Power Supply System

Principal Investigator: Dr. Dara O'Sullivan

Small Form Factor, Low component-count, Monolithic Point-of-Load dc-dc Converter



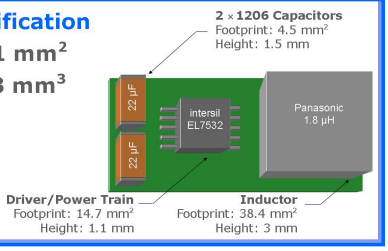
Target Data Sheet

Parameter	Value
V_{in}	1.8-5 V
V_o	0.5-1.7 V
I_o	1-6 A
F_s	20-150 MHz
Target Converter Footprint	< 25 mm^2
Target Component Height	< 1.5 mm
Load Regulation	0.50%
Over Temperature Threshold	125 °C

Current Specification

Footprint: **62.1 mm^2**

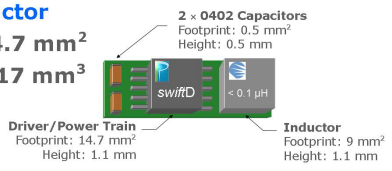
Volume: **186.3 mm^3**



Shrink Inductor

Footprint: **24.7 mm^2**

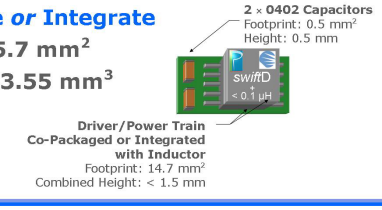
Volume: **27.17 mm^3**



Co-Package *or* Integrate

Footprint: **15.7 mm^2**

Volume: < **23.55 mm^3**



Targeted research areas include RF-based power supply architectures and inductor-in-silicon technology incorporating high-bandwidth control with very-high-frequency pulse generation and efficiency maximization over the load range.

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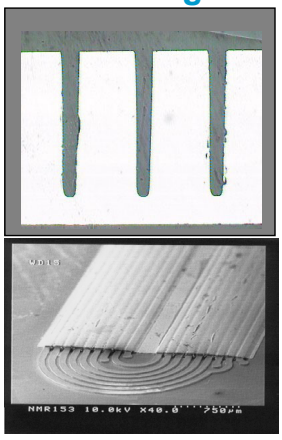
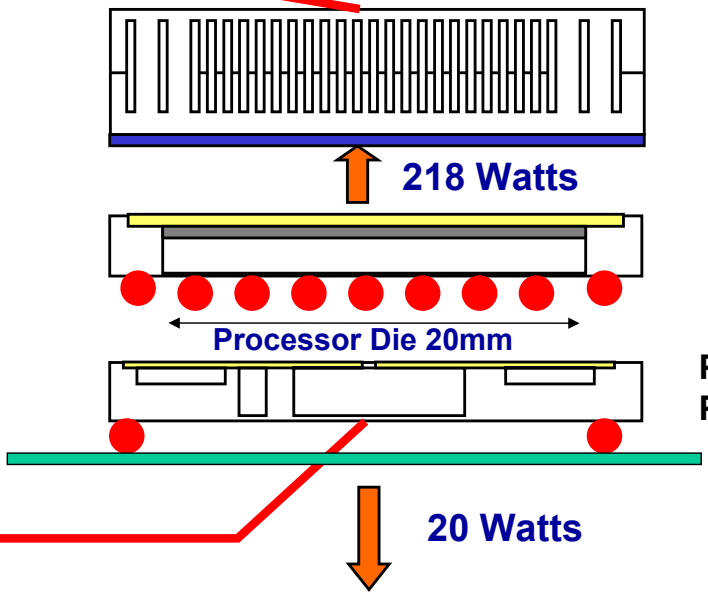
Integrated Power Delivery and Heat Dissipation for High Performance Microprocessor

Silicon Microchannel Cooling



Micro-Magnetics on Silicon



Cooling

2010 Processor 363 Amps

Point of Load Power Supply

Power Supplies - 2010
Enabled by Silicon and Microtechnologies

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Ambient Intelligence

"Ubiquitous Computing is the opposite of virtual reality. Where virtual reality puts people inside a computer-generated world, ubiquitous computing forces the computer to live out here in the world with people." - Mark Weiser, Xerox Parc.

Features of Ubiquitous Computing Systems:

- Unobtrusive, invisible and seamless - Embedded into everyday objects.
- Context awareness – security, health, entertainment, comfort.
- Intelligence, autonomous, emergent behaviour.
- Proactive interfaces
- Intuitive interaction - Easy learning curves.
- Networked – distributed, ad-hoc.
- Wireless Communications (and Power)

Tyndall Ambient Research

Vision

Technology Platforms for the Miniaturisation and Functional Integration of Hardware and Software for Future Intelligent Sensor Systems in Personal-Health & Well-Being and Sustainable Development

Drivers

- Sensors Everywhere, Always On
- Miniaturisation, Functional Integration, Robustness,
- CMOS Compatible
- Wireless, Networked

From Computer Centric to Person Centric

In the Body

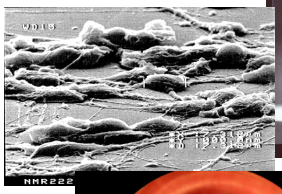
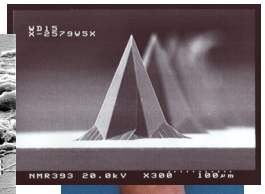
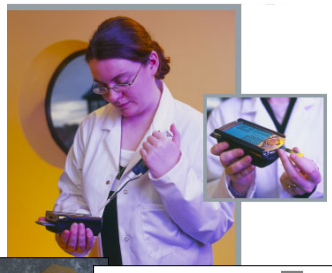
Retinal Implants
Electrogenetherapy
Smart Pill
Neural Stimulation
Telemetry

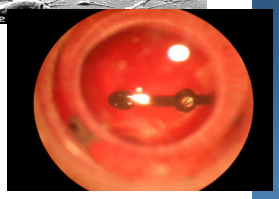
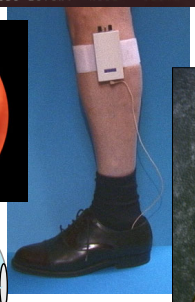
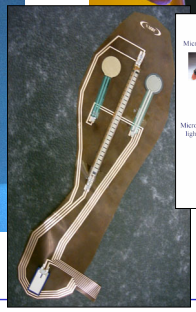
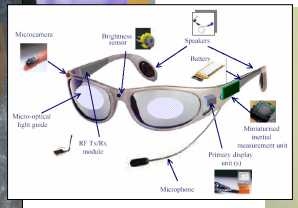
On the Body/Wearable

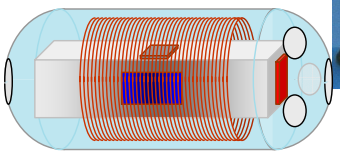
Motion Sensing
Human-Computer Interface
Bio-Signalling
Transdermal Drug Delivery
Point-of-Care Diagnostics

Around the Body

Building Management
Environment Management
Sustainable Agriculture

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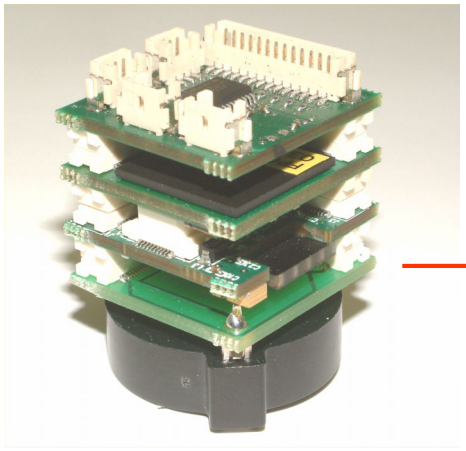
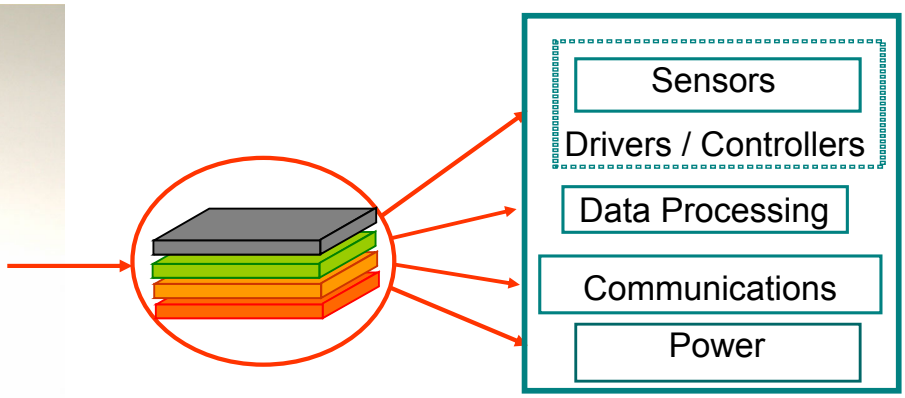
Tyndall Research in Ambient Intelligence

Hardware and Software Technology Platforms for Autonomous Systems

- Miniaturised Autonomous Wireless Microsensor Modules
- Distributed, Ad-hoc Wireless Sensor Networks
- Micropower Delivery Systems

- Hardward Features: Modular, Flexible, Reconfigurable, Scaleable, Robust





Tyndall 25mm Mote - Under Evaluation by more than 20 European Research Teams

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Applications – Sustainable Development

EU Water Framework Directive

2015 - All water to achieve good quality status

- Inland (surface and ground)
- Transitional & coastal (1 mile)
- Territorial waters (12 miles)

Automatic Water Quality Measurement

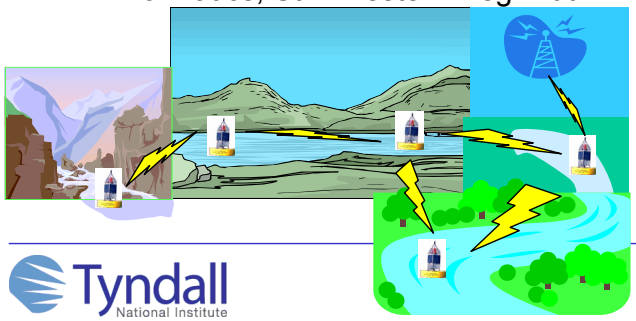
- Temperature, pH, Dissolved Oxygen
- Conductivity, Nutrients

Spec. for Intelligent Sensor Platform:

- Scalable, Intelligent Sensor Network
- Low Power, Adaptive, Interactive,
- Low Maintenance, Real-time Information

Smart Coast – Marine Institute/EPA

- NCSR, DCU; Tyndall; MAC; Marine Informatics, Sth. Western Reg. Auth.



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Automated Crop Management

- Concept of "Communicating Plant"

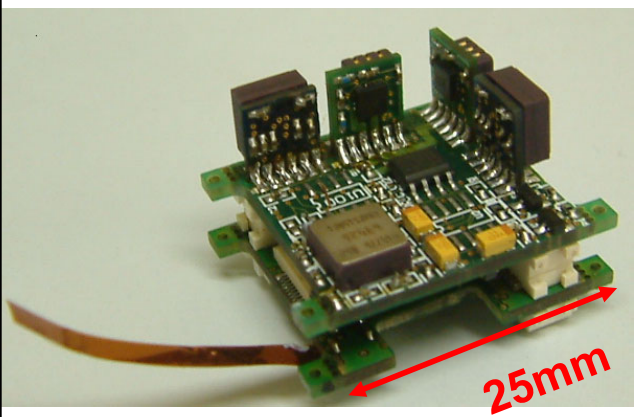
- EU crop output worth ca. €180billion
  - Resource management
  - reduce pollution,
  - agriculture/horticulture productivity
  - improve food quality

- Wireless sensor/actuator network & communications platform to control automated self-regulation of inputs
  - volatiles (gas emission = stress)
  - electromagnetic (temperature, chlorophyll fluorescence, leaf colour, photosynthetic activity).

- EU collaboration with UCC ZEPS

Tyndall Wireless Inertial Measurement Unit

Motion Sensing: 6 degrees of Freedom, 3-axis Accelerometers, 3-axis Gyroscopes
Magnetometers for Location Data
Application Scenarios being Investigated:
- Homecare for the Elderly, Interactive Dance



Antenna
On Flex

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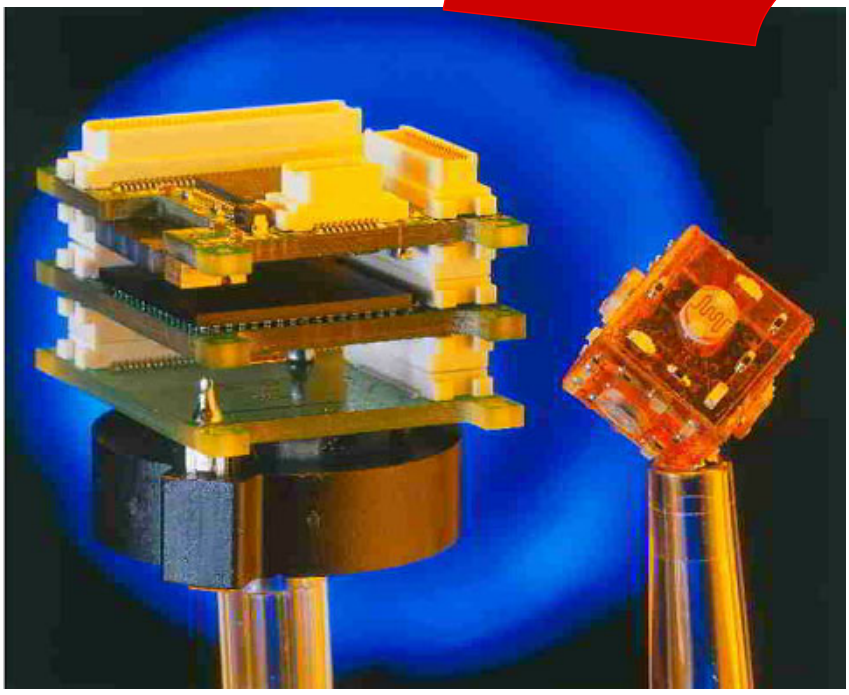
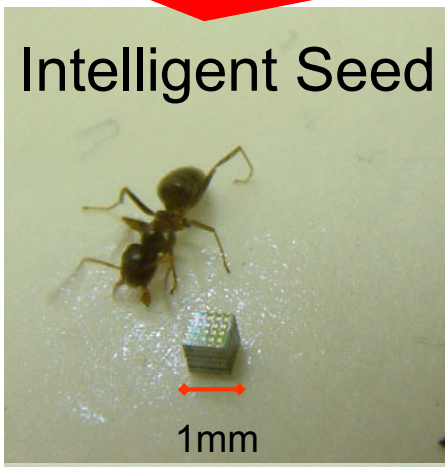
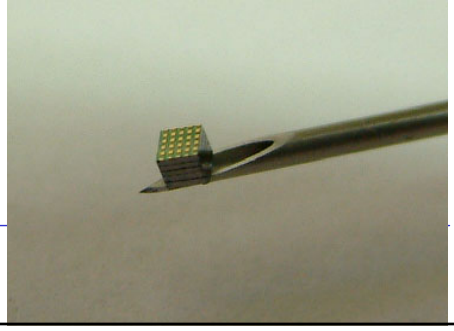
Tyndall Roadmap - 25mm to 10mm to 1mm







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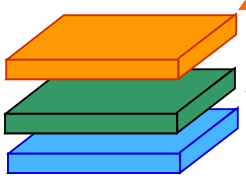
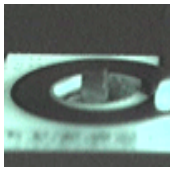
Energy Processing for Ambient

Generation/Transmission – Conversion - Storage



Energy Source



- Vibration Harvesting
- Solar Cells
- Piezoelectric insole
- Electromagnetics
- Inductive Power

Energy Storage

- Microbatteries
- Capacitors

Power Conversion

- Power Supply on Chip
- Magnetics on Silicon

Thank you for your Attention