Tyndall

PwrSiP
Power Supply in Package
Power System in Package

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Tyndall National Institute

University College Cork,

Ireland

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IMPACT FROM EXCELLENCE

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Outline

- Evolution of Power Converters
- Integrated Magnetics
- Killer Applications?
- “Functional Passive” Interposers
- Supply Chains
- Conclusions
- The Magicians!

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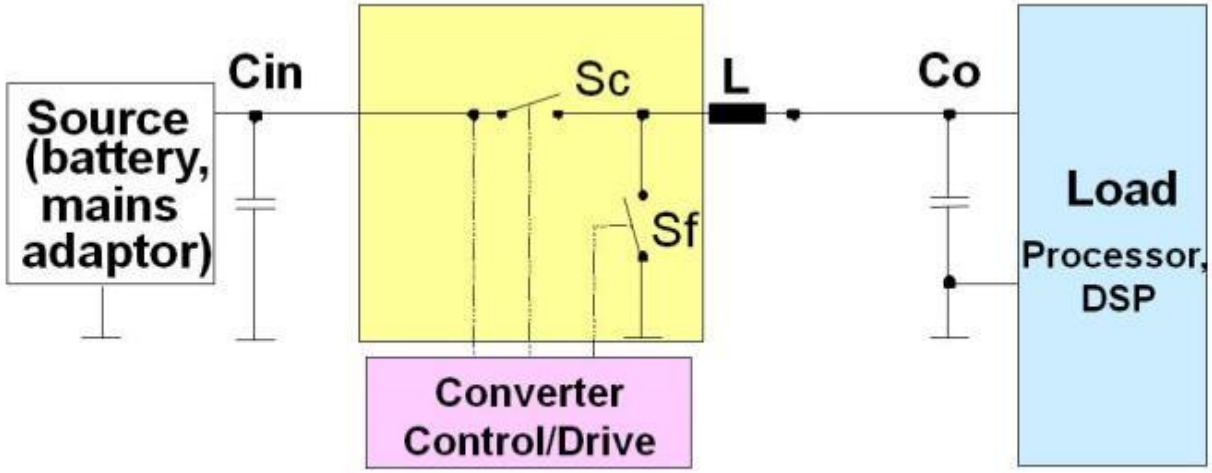
Evolution of Power Management Circuits

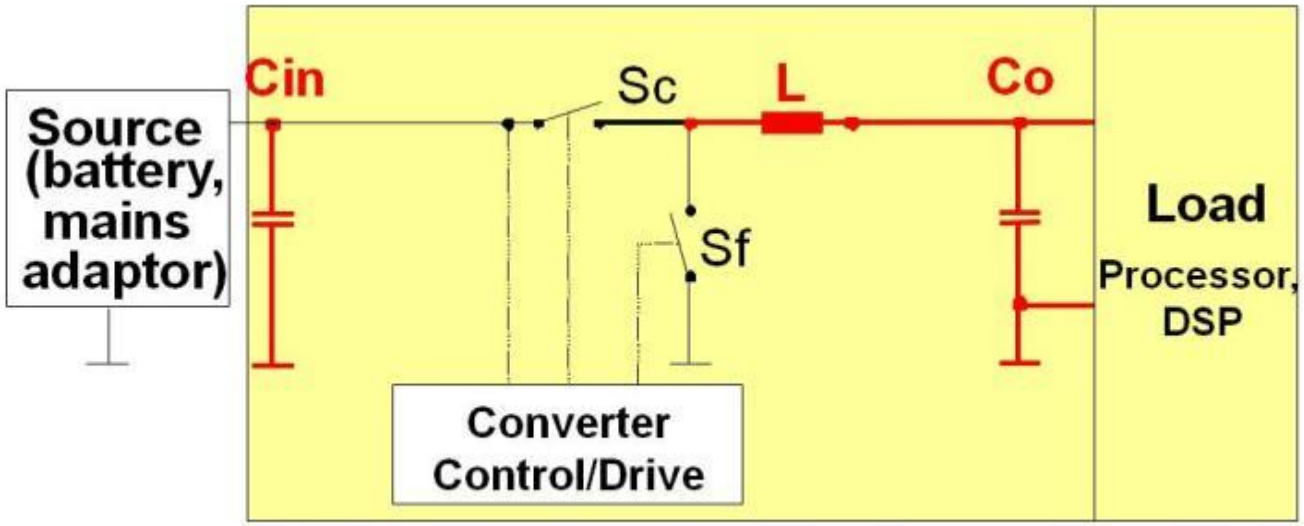


Conventional SMPS

Discrete switches, control, passives & load

PwrSoC

Integrated power with load



Power Management - Supply Chain Evolution

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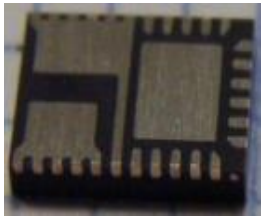
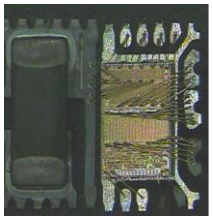
Power Bricks
PSU
Companies

PwrSiP
Power Semiconductor
Semiconductor Companies
PCB Companies

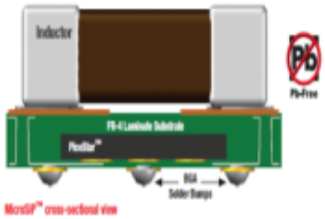
PwrSoC??
System on Chip
Companies

MICREL

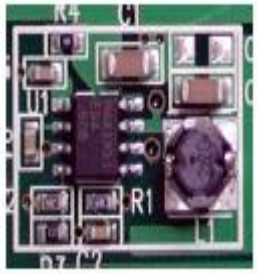


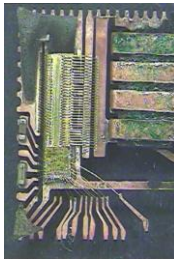


TEXAS INSTRUMENTS



ENPIRION

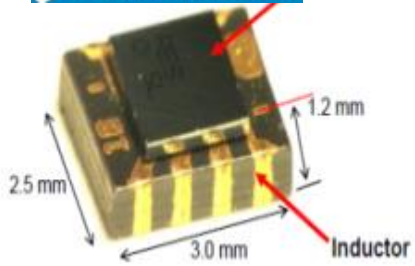




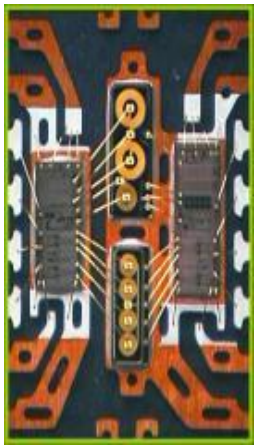
National Semiconductor

1Q 2011

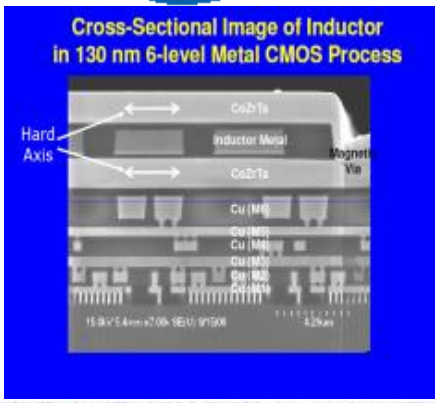
Regulator

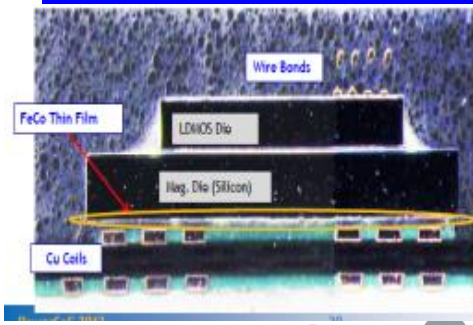


ANALOG DEVICES



intel





ENPIRION

IMPACT FROM EXCELLENCE

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Universal Power Management Specs

- Take Up No Space
- Cost Nothing
- Last Forever
- Zero Power Loss

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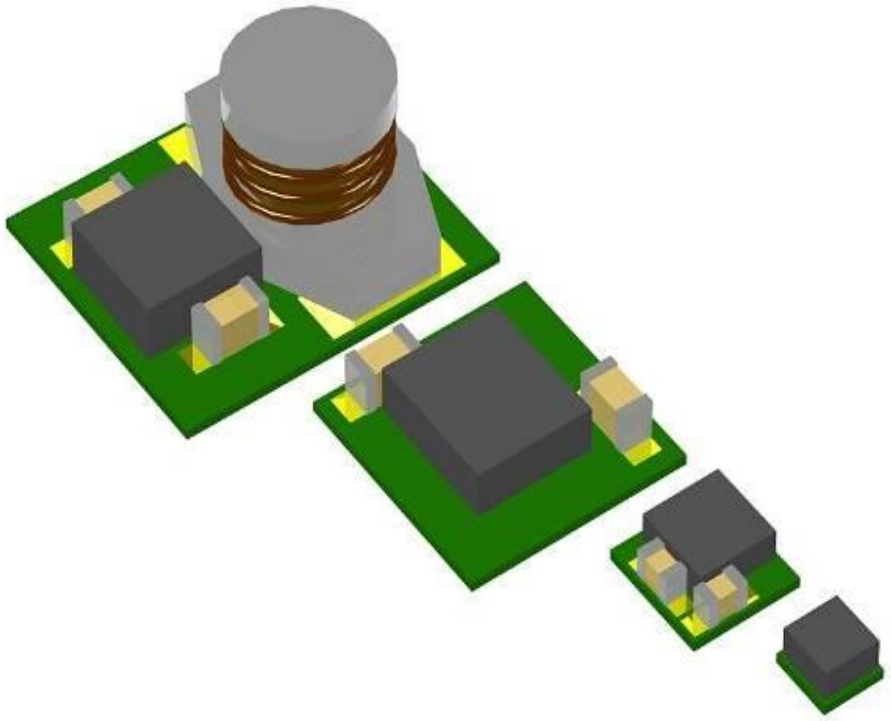
Institiúid Náisiúnta

Evolution to Power Supply on Chip (PwrSoC)



Footprint (mm^2)	Volume (mm^3)	Frequency MHz
50	150	1
30	25	5
7.0	3.5	20
2.0	**1.0**	**50-100**

UCC Coláiste na hOllscoile Corcaigh, Éire University College Cork, Ireland

IMPACT FROM EXCELLENCE

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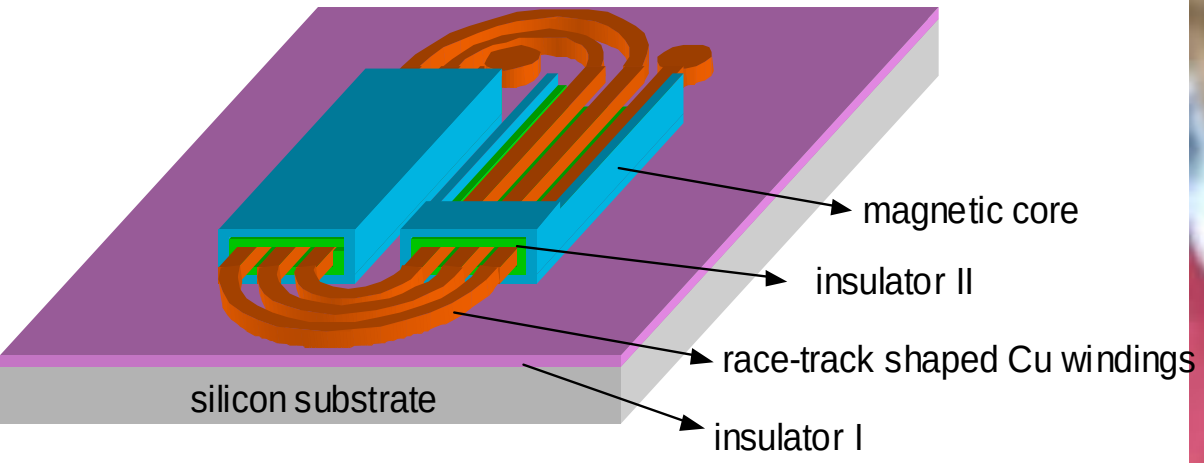
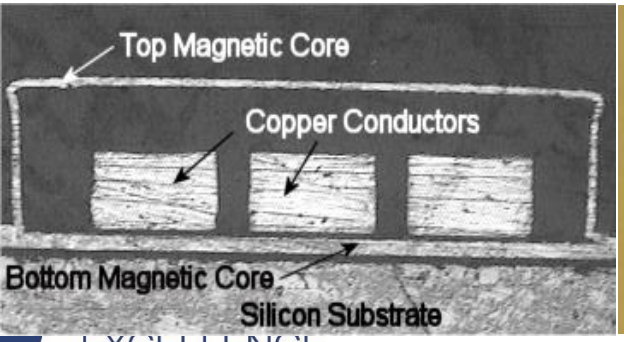
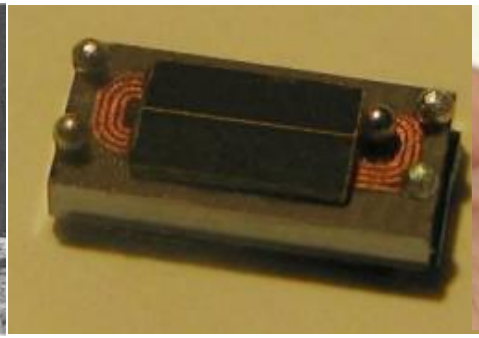
Magnetics on Silicon for Integrated Power

MAGIC

Making Magnetics Disappear into ICs





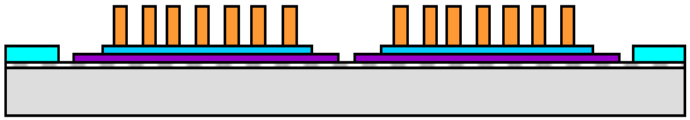


Micro-magnetics Process (Race Track structure)

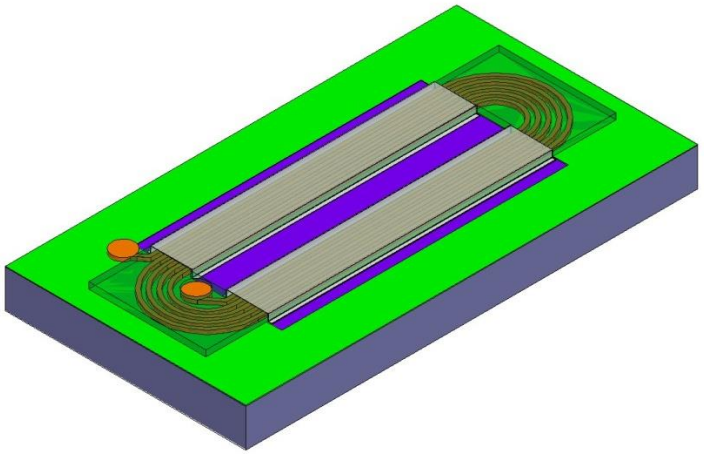
Magnetic cores wrap around windings

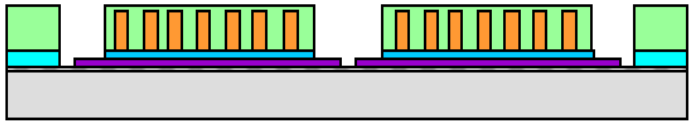
1st Metal Layer

ILD- Insulation layer

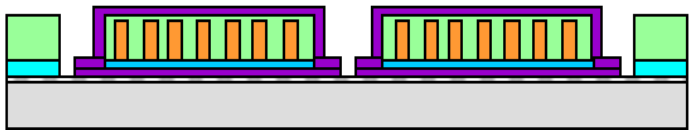


2nd Metal Layer





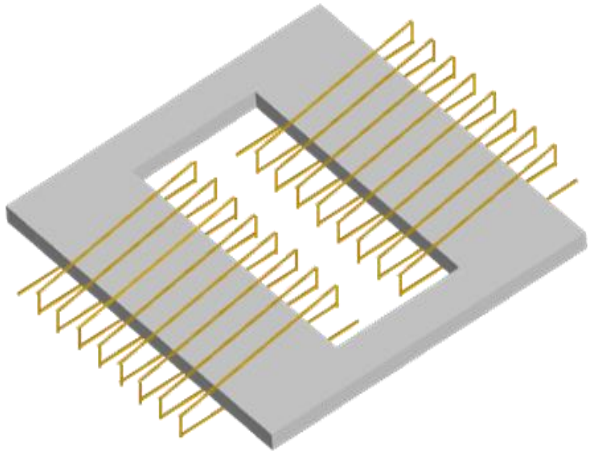
IMD- Insulation Layer



3rd Metal Layer

Micro-magnetics Process (Toroidal structure)

Windings wrap around magnetic core



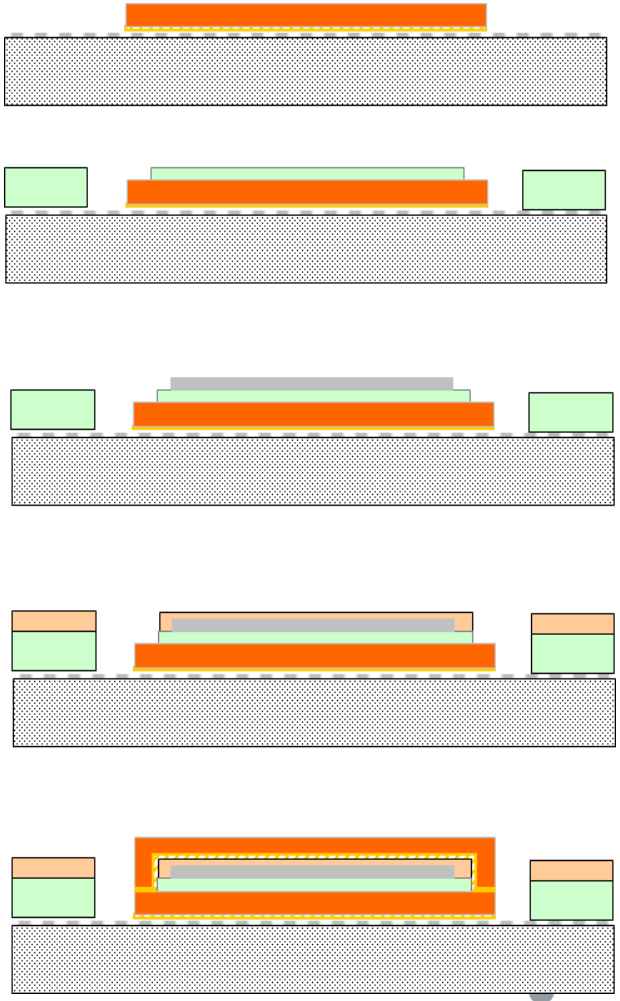
1st Metal Layer

ILD- Insulation layer

2nd Metal Layer

IMD- Insulation Layer

3rd Metal Layer



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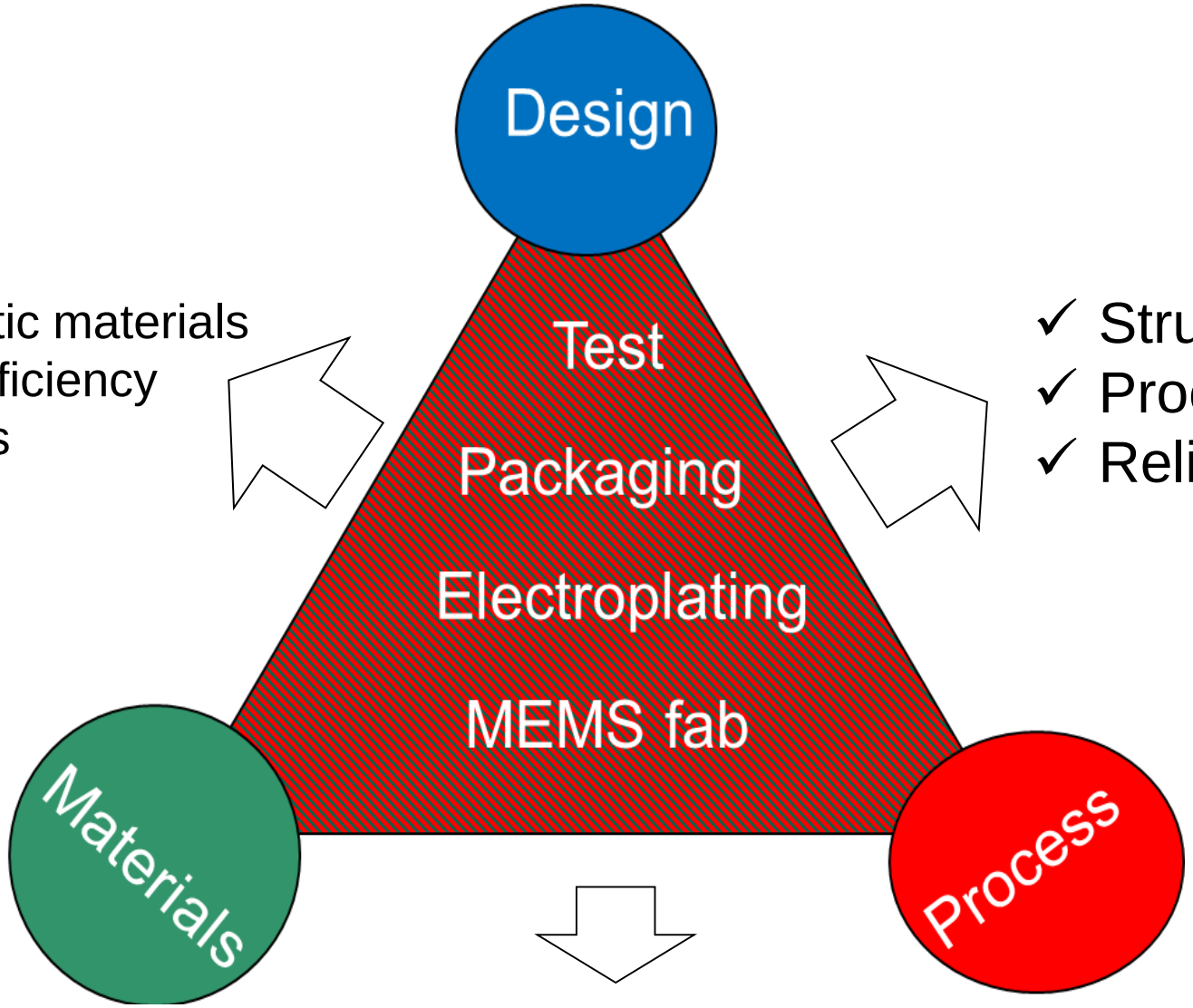
Micro-inductor structures - Summary

Conventional Micro-inductors	Advantages	Disadvantages
Solenoid & Toroid	• High saturation currents • Ease of magnetic core deposition and lamination • Uniaxial anisotropy applicable in solenoid cores	• Complex fabrication process for windings • Uniaxial anisotropy for closed core structures difficult to realise for toroidal cores
Planar/ Spiral	• Ease of winding deposition • High inductance densities • Suitable for low-medium current applications	• Higher DC resistance • Low saturation current • Needs two layer magnetic core for higher inductance • Uniaxial anisotropy for closed core structures difficult to realise
Racetrack	• Ease of winding deposition • High inductance densities • Suitable for low-medium current applications • Uniaxial anisotropy applicable in racetrack cores • Higher operational frequency	• Higher DC resistance • Low saturation current (<1 A) • Needs two magnetic layer core • Core laminations is more difficult to realise
Stripline	• High inductance densities • High current handling • Low DC resistance • Easy of winding deposition • Uniaxial anisotropy applicable in stripline cores • High operational frequency	• Needs two magnetic layer core • Core laminations is more difficult to realise • Difficult to achieve high inductance within reasonable aspect ratio structure

Tyndall Magnetics Research / Technology Roadmap



- ✓ Magnetic materials
- ✓ High efficiency designs

- ✓ Structures
- ✓ Processes
- ✓ Reliability

- ✓ Low loss Magnetics; laminations; high AR windings

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On-Chip Coreless Transformer for Isolated Power (and Signal Transfer/Communications)

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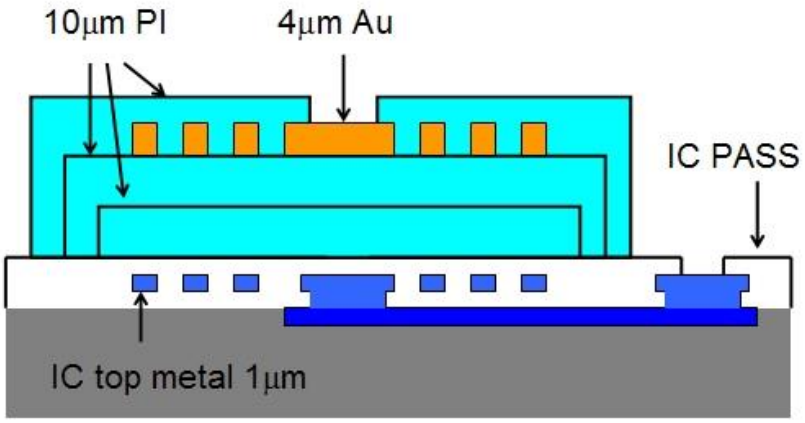
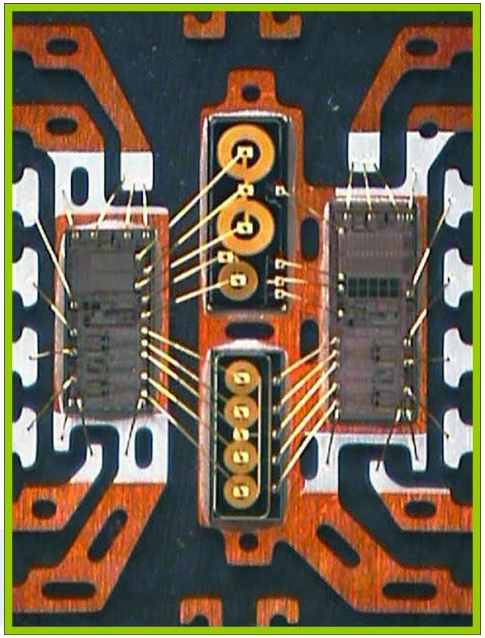


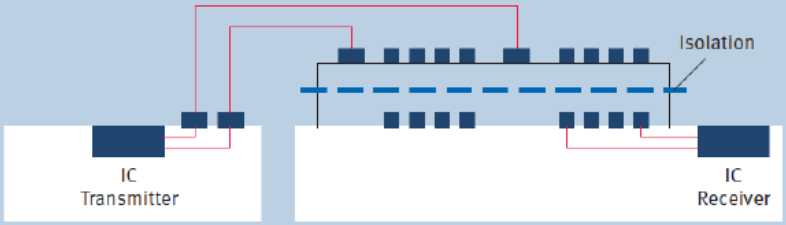


iCoupler

ANALOG DEVICES

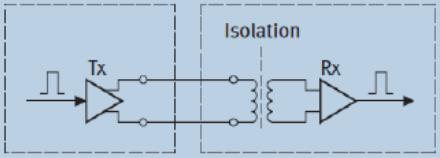
ISOFACE™ PowerSiP

Coreless Transformer Principle



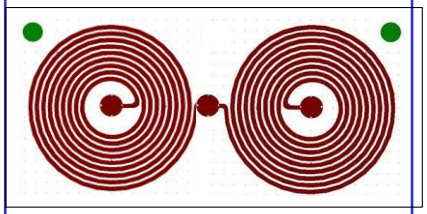
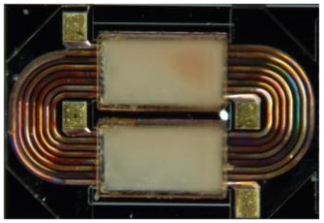
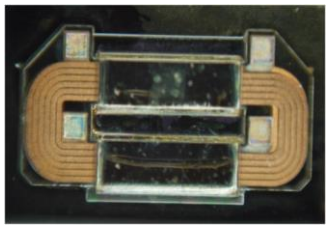
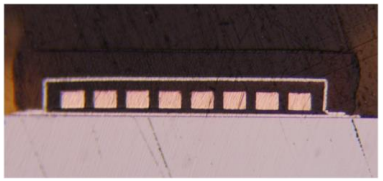
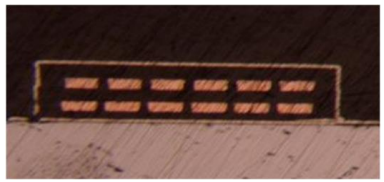
A lot of advantages compared to optocoupler

- No degradation over time
- Gain reliability
- High temperature range ... 150°C
- Very fast transmission (10 ... 100MHz)
- Low power consumption



infineon

Measured Microtransformer Performance
Air-Core Vs Magnetics Core

	Air Core	Tyndall Gen1	Tyndall Gen2
			
Technology	Air Core		
Device Size	2mm^2	24mm^2	3mm^2
Frequency	180MHz	10MHz	20MHz
Inductance	8nH	440nH	240nH
L Density	17nH/mm^2	18nH/mm^2	80nH/mm^2
Coupling	0.85	0.93	0.97
DC R	0.46 Ohms	0.5 Ohms	0.96 Ohms
Efficiency	70%	63%	78%

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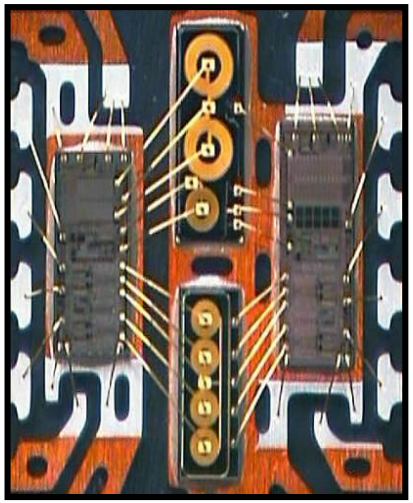
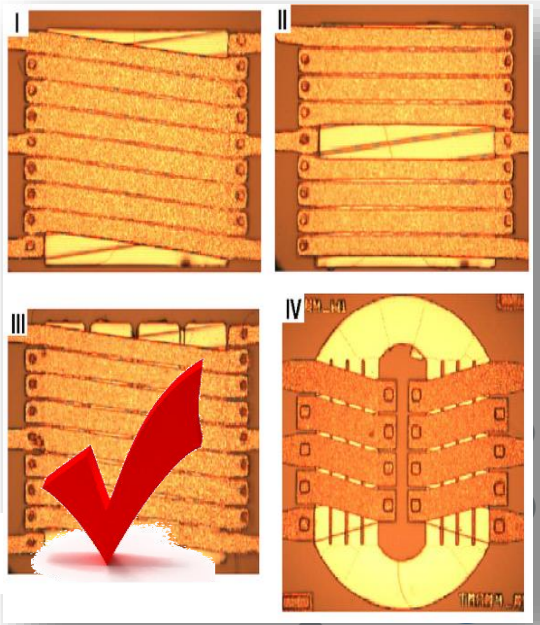
Wafer-level Magnetics for isolated power transfer

- Today's air-core transformers will be replaced with magnetic-core transformers.



- Multiple and Conflicting Design Contraints:
  - coupling, power loss, open circuit inductance, isolation, physical size.

- Magnetic Core *iso*Power Solenoid:
  - FeCoB multilayer.
  - Better Efficiency & Power.
  - Low Noise Emissions (EMI).



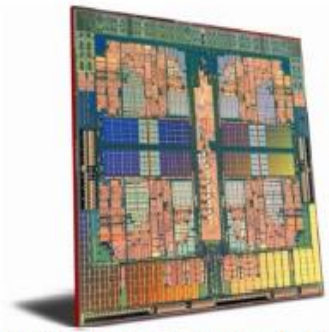
ANALOG DEVICES

Xing Xing, Baoxing Chen, Analog Devices.

IMPACT FROM EXCELLENCE

Granular Power Management for Complex SoCs

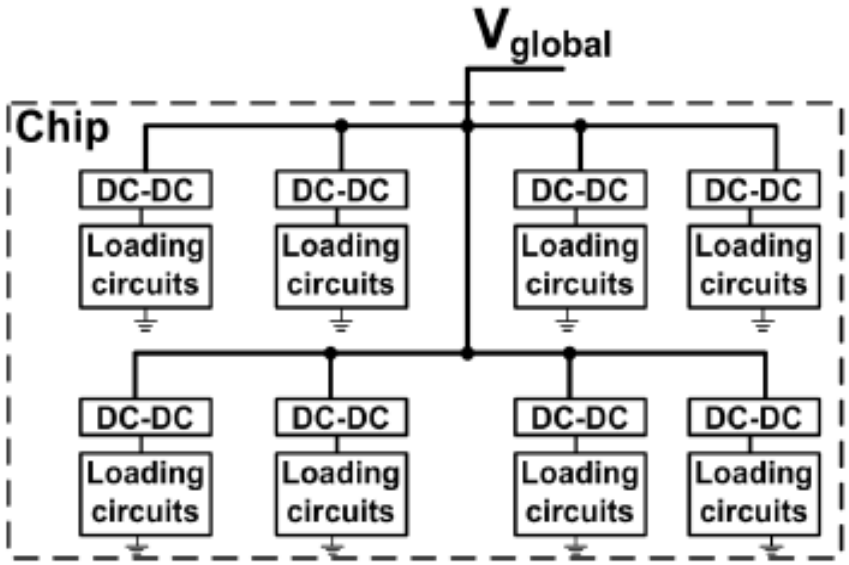
Ex. 1: Multi-Core On-Die VR Motivation – Power Reduction



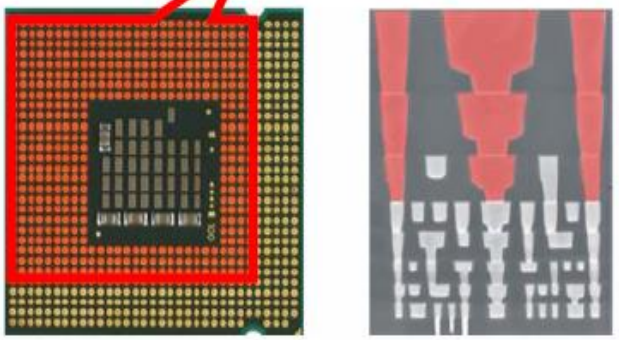
AMD Phenom Quad Core Processor

- Clear need for separate supplies to enable per-core power management.

How to efficiently support multiple voltage rails on the die?



70% of pins just for power



100W - 1V - 100A - 1mΩ
(Power ~ 1W/mm²)

Source: PwrSoC 2010

Endura Technologies and MediaTek Inc. Announce Commercial Partnership

DUBLIN, Ireland and HSINCHU, Taiwan, **May 4, 2016** /PRNewswire/ -- Endura Technologies (International) Ltd. announced a commercial partnership with MediaTek

Endura Technologies (International) Ltd, headquarters in Dublin, Ireland

- fabless semiconductor company providing leading edge power management solutions for the microelectronics industry

- two main focus areas are **embedded power management** for very demanding system-on-chip (SoC) CPU type applications, as well as stand-alone power management integrated circuits (PMICs)

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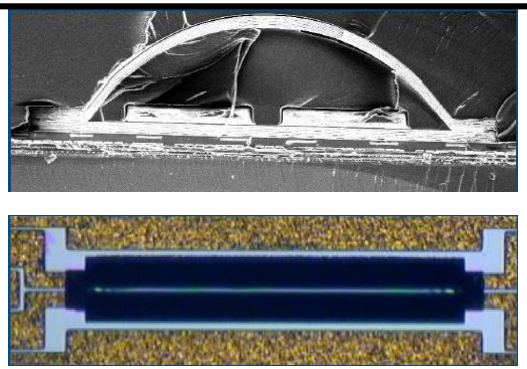
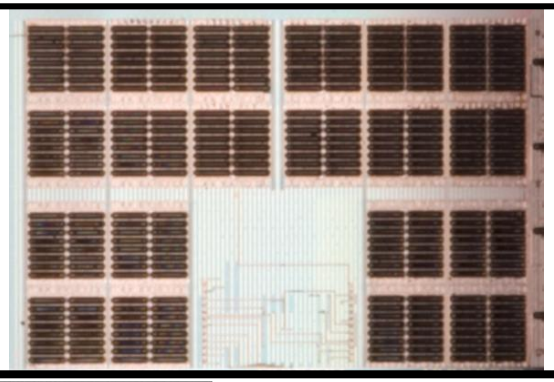
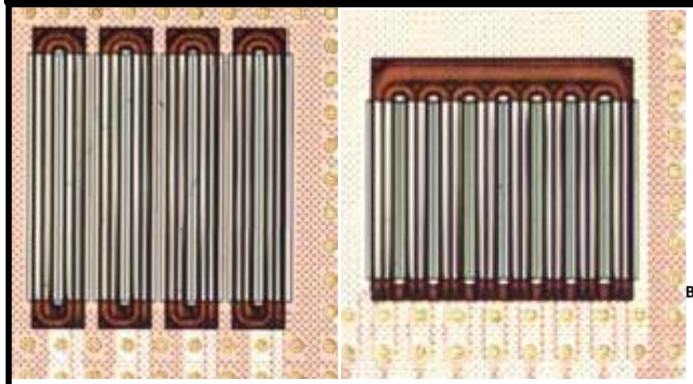
High Frequency IVR with Integrated Magnetics

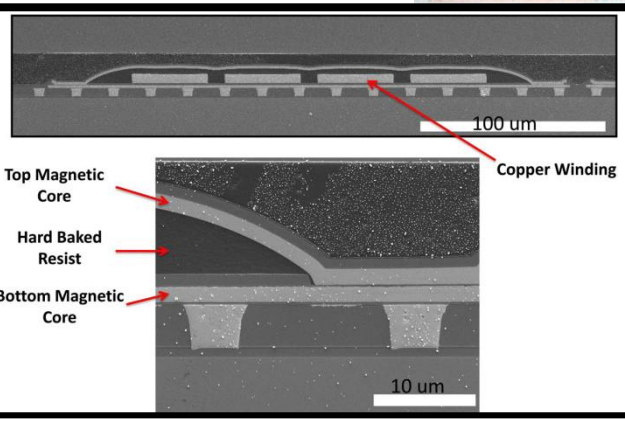
	Frequency (MHz)	Inductance (nH)	Peak Converter efficiency (%)	topology	Inductor area (mm^2)	Current density (A/mm^2)	Inductance density (nH/mm^2)
Intel	30-140	21	76%	16 phases	2.8	8.93	~170
IBM	30-300	12.5	71%	8 phases	1.96	3.21	50

Monolithically integrated multi-phase Buck from Intel(2010)









2.5D stacked multi-phase Buck from IBM (2013)

Device 2 - Integrated coupled inductor

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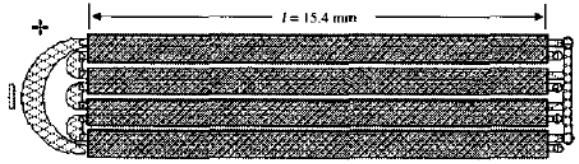
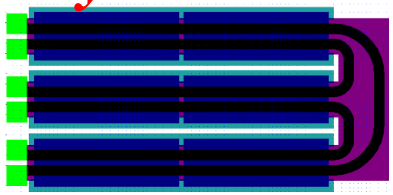
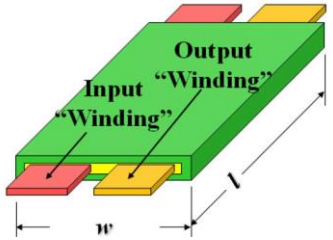
Dartmouth/Tyndall'04



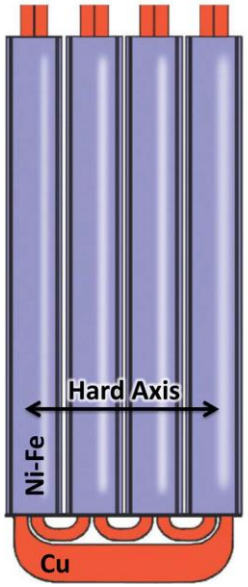
Tyndall'14



INTEL'11

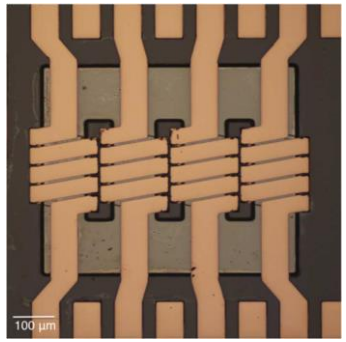


Columbia/IBM /Duke'12



	L self (nH)	DCR (mΩ)	Foot print (mm^2)	Freq (MHz)	Convert Effic (%)
Dartmouth/ Tyndall'04	14	40	80	5	50
INTEL'11	25	14	2.8	>60	76
Columbia/ IBM/Ferric'12	7.4	480	10.9	100	71
Columbia/ IBM/Duke'13	12.5	270	2.5	>40	
Tyndall'14	45	27	3	5	
Tyndall/ Powerswipe' 15	35	155	2	100-200	81 Expect!
NUIG/Tyndall'15	23	71	5	20	55

Columbia/IBM /Fe rric'13



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- "Functional Passive" Interposers
- Supply Chains
- Conclusions
- The Magicians!

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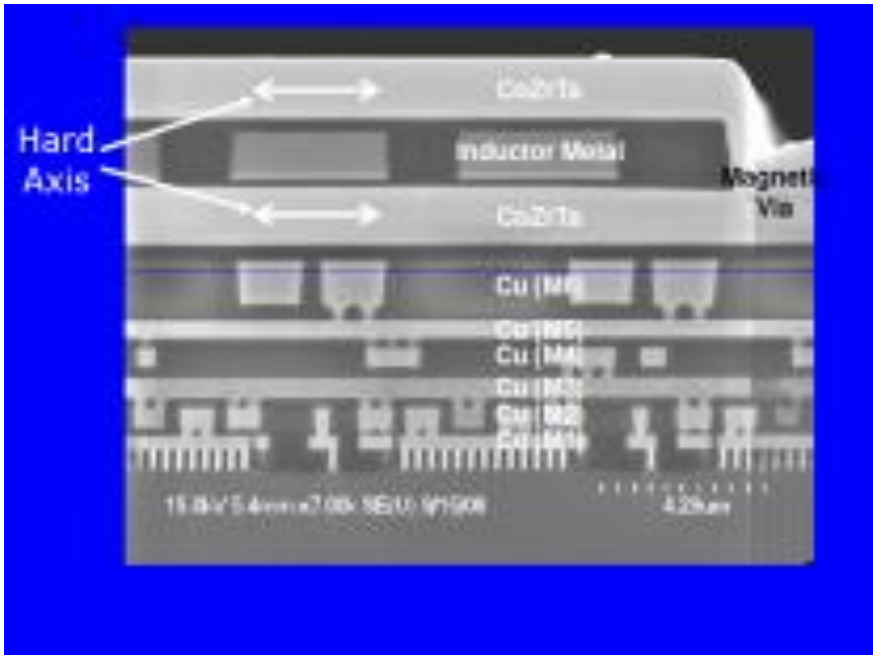
Evolution of Power Converters

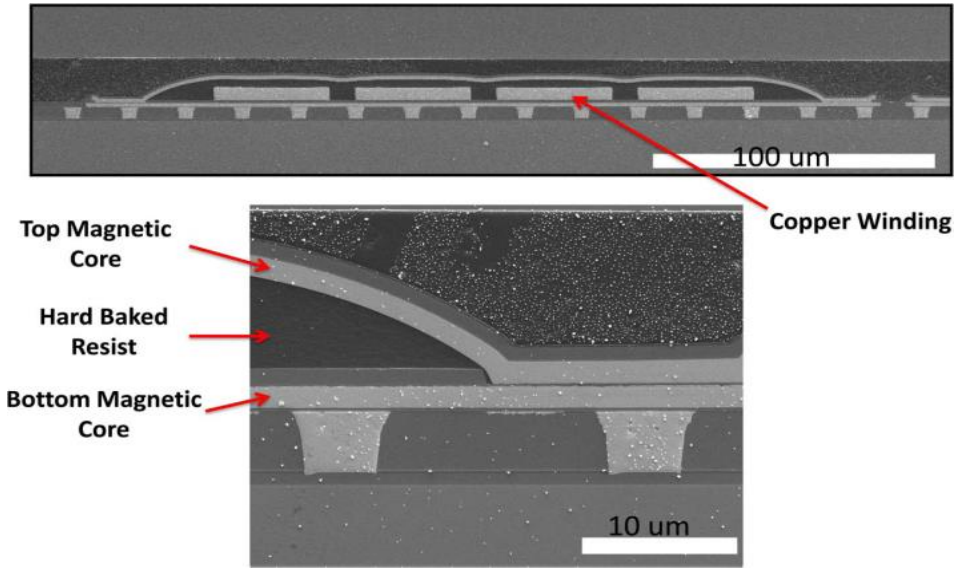
PwrSoC

Inductor fabricated on Si die, load may also be integrated

intel

2.5D stacked multi-phase
Buck from IBM (2013)





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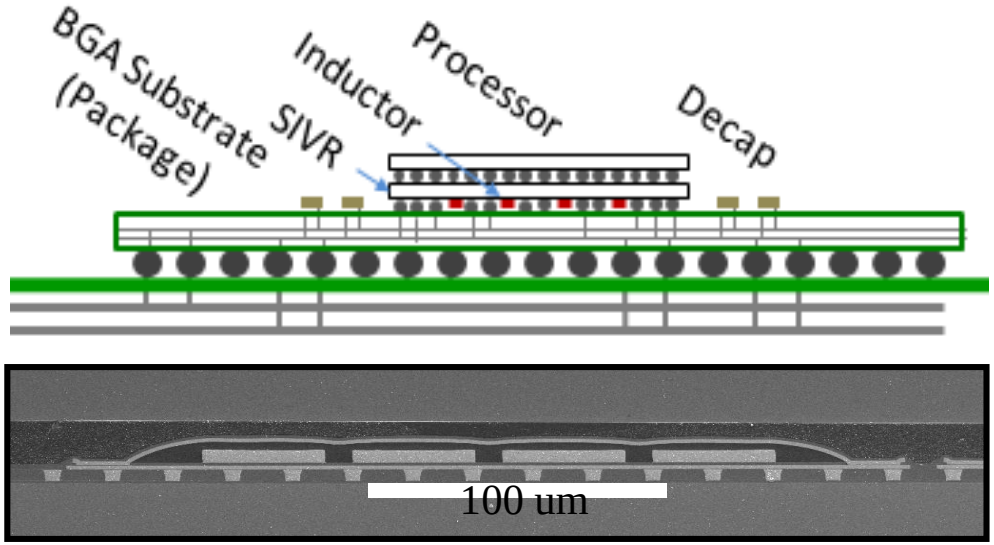
2.5D/3D Chip Stacking
Power Passive Interposers

- **Increased power density from custom fabricated power inductors:**
  - Inductors fabricated on low-cost interposer and integrated with IC via chip-stacking.
  - Decap and power switches can be included on interposer design.
  - Allows “one-way” current flow improving efficiency.
  - Better transient performance due to lower impedance of input supply.
  - Step on the way to monolithic integration?



Ref: Ken Shepard – Columbia University

IMPACT FROM EXCELLENCE

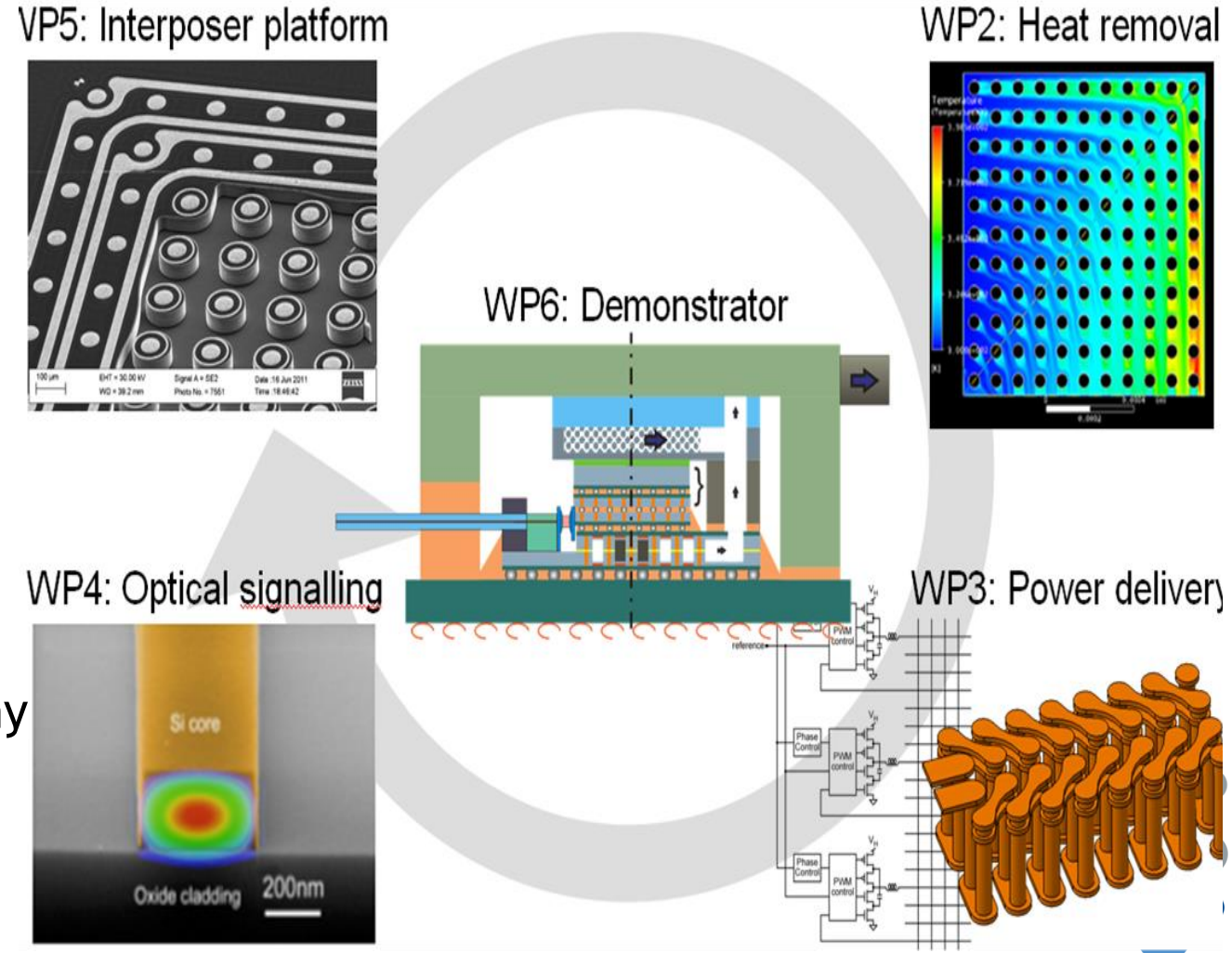
IBM

CarrICool: Interposer supporting optical signaling, liquid cooling, and power conversion for 3D chip stacks

- EU FP7 Project: 619488 - Begin: Jan. 2014 - End: Dec. 2016

CarrICool

- **IBM Research Zurich**, Switzerland
- **ETH Zurich**, Switzerland
- **Tyndall National Institute**, Ireland
- **Fraunhofer**, Germany
- **TU Chemnitz**; Germany
- **AMIC**, Germany
- **IPIDIA**, France;
- **Optocap**, Scotland;

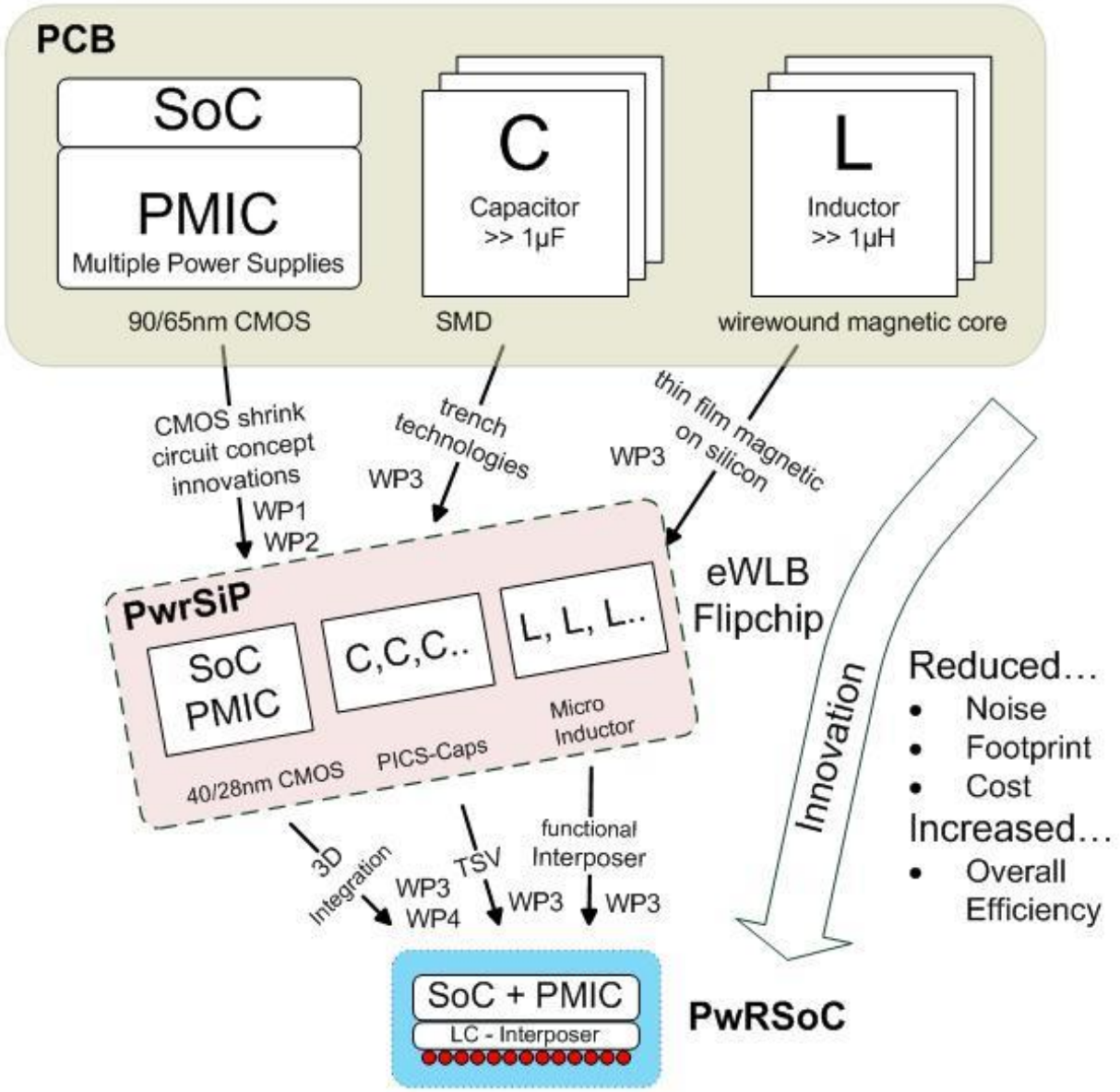


POWER SoC With Integrated PassivEs

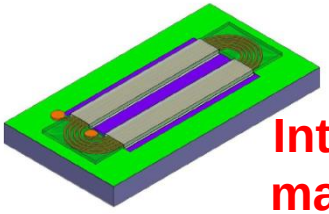
First EU-funded Project in Power Supply on Chip

PowerSwipe

EU FP7-ICT-2011-8 – Project no.: 318529

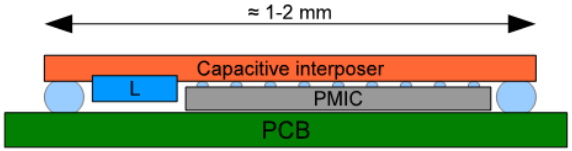


Consortium Partners

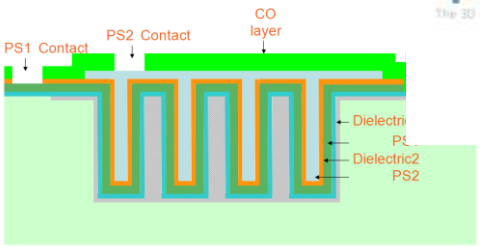


Integrated magnetics

Multi DC-DC converter

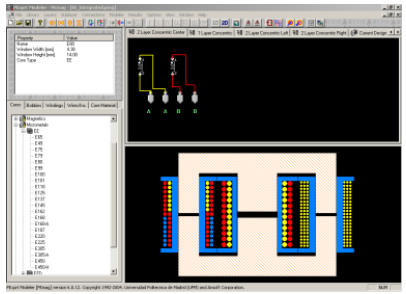


High efficiency, high frequency converter



Trench Capacitors

µC with embedded power management



CAD Tool

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Outline

- Evolution of Power Converters
- Integrated Magnetics
- Killer Applications?
- “Functional Passive” Interposers
- Supply Chains
- Conclusions
- The Magicians!

EE Times Connecting the Global Electronics Community

Intel Haswell packs integrated voltage regulator

Rick Merritt

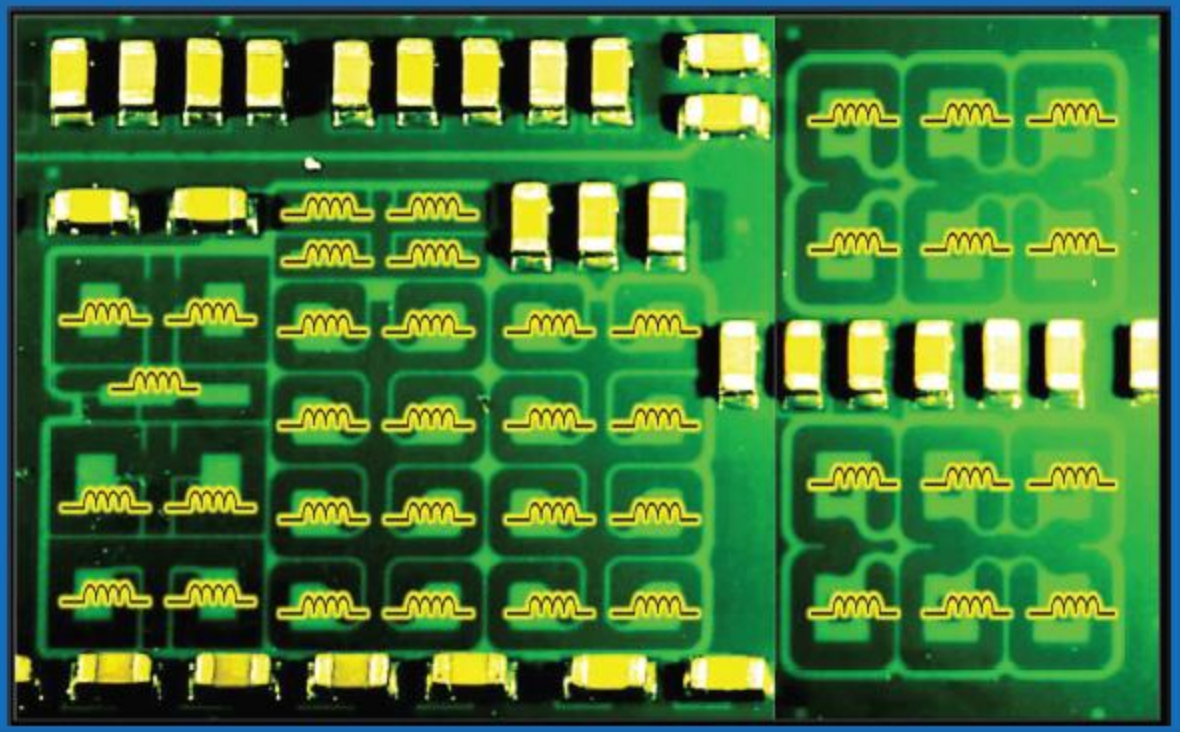
5/23/2013 06:53 PM ED

• .... seven external voltage regulators made by third parties, lower the bill of materials and motherboard footprint.

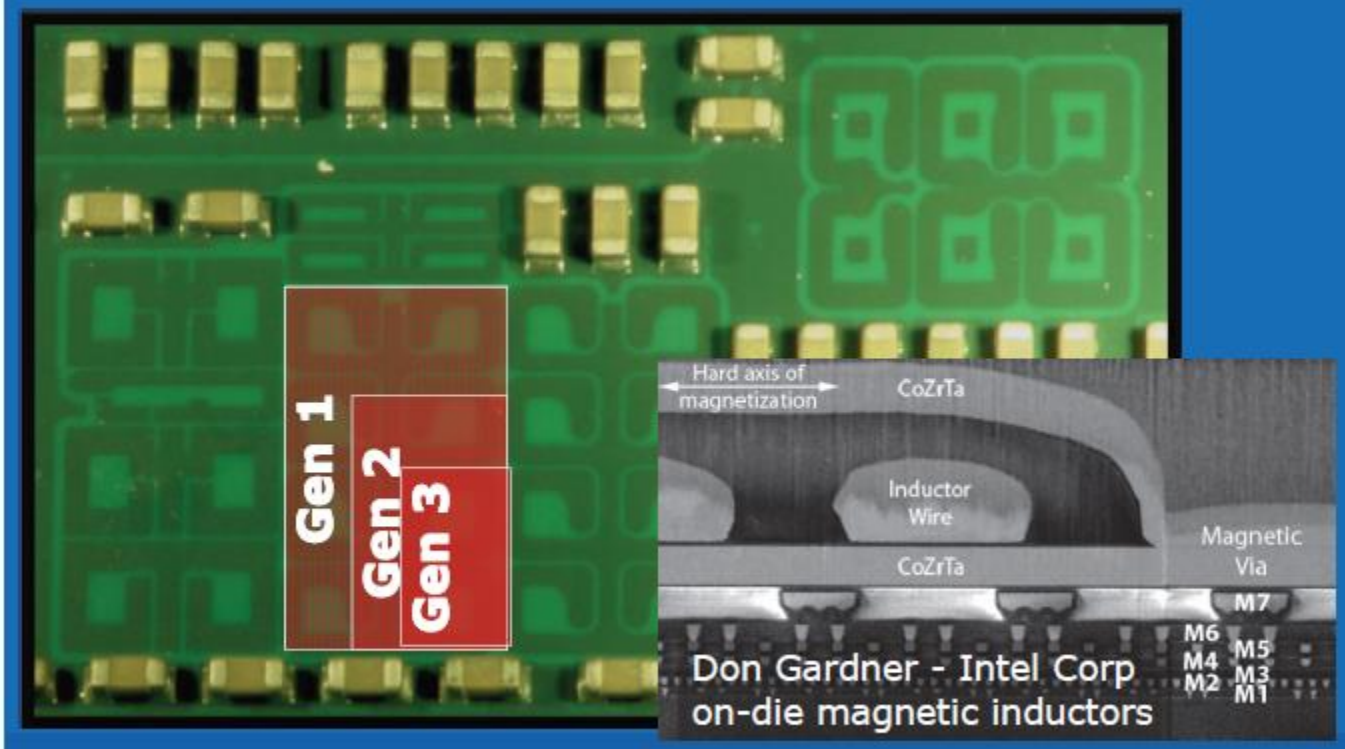
• .... deliver about 50 percent better battery life than the prior Ivy Bridge on active workloads while doubling graphics performance.

• Power Chip Vendors: ON Semiconductor, Intersil and Texas Instruments .... Linear Technology, Infineon, Maxim, Volterra and International Rectifier.

FIVR Photo - Package Underside



Future Scaling Issue & Solution



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Power Supply on Chip(PwrSoC) International Workshops

ANALOG DEVICES
AMD
ASE GROUP
DELL
dialog SEMICONDUCTOR
Ferric
FAIRCHILD SEMICONDUCTOR
Google
HUAWEI
IBM
Infineon
ipdia
IOR
intel
maxim integrated
muRata Innovator in Electronics
NXP founded by Philips
QUALCOMM
TEXAS INSTRUMENTS
tsmc
WE WÜRTH ELEKTRONIK
pels IEEE POWER ELECTRONICS SOCIETY Powering a Sustainable Future
psma Power Sources Manufacturers Association
EXCELLENCE

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PWR SC '14

Integrated Power Conversion and Power Management

next generation technology for emerging business opportunities

new technologies new applications new markets

189 Attendees
50:50 Industry/Academia
Boston, MA, USA – October 2014

Altera (2), Anagenesis (2), Analog Devices (6), Apple (2), Dell (2), Dialog (3), Fairchild (2), Ferric Semiconductor (2), Huawei (7), IBM (6), Infineon (2), Intel (5), IPDIA (2), Maxim (9), Mornsun Guangzhou S&T Co., (2), Murata (4), NXP (3), Qualcomm (4), Raytheon (2), Silana Semiconductor (2), TI (4), Treehouse Design (2), TSMC (2), Wurth Electronik (4)

Carnegie Mellon (2), Dartmouth College (5), Harvard (6), Insa Lyon (3), MIT (10), NCSR Demokritos (2), Northeastern (2), Tyndall (3), UC Berkeley (2), U. Illinois UC (2), U. of Toronto (6), UP Madrid (2)

Highlights

- **Switched Capacitor Vs Inductor Converters**
- **Granular power for multi-volatge rail, multi-core, microprocessors, servers, HPC**
- **High density on-chip, capacitors**
- **Foundry Opportunities – PSiP (including PCB embedded silicon) to PwrSoC**

Personal Highlights
Magnetics on Silicon

- **Ferric Semiconductor:**
  - Fabless Semiconductor Company
  - Delivering complete IVR solution
  - Package Voltage Regulator / Monolithic Voltage Regulator
  - CMOS compatible integrated power inductors
  - Integrated power inductor devices will be accessible through High Volume Manufacturing Foundry with standard CMOS design flow support (DRC, LVS, xRC, advanced models).
  - Devices will be available as BEOL process option at TSMC s

3D Chip Stacking
Power Passive Interposers

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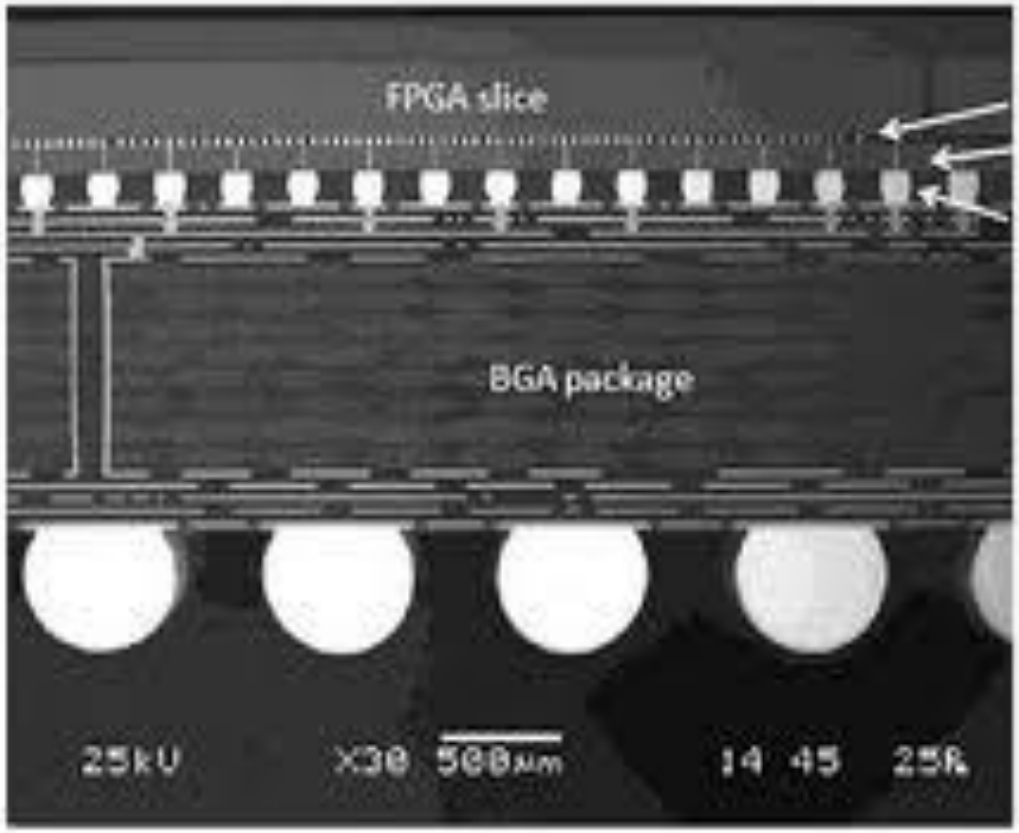
EE Times Connecting the Global Electronics Community

Product News

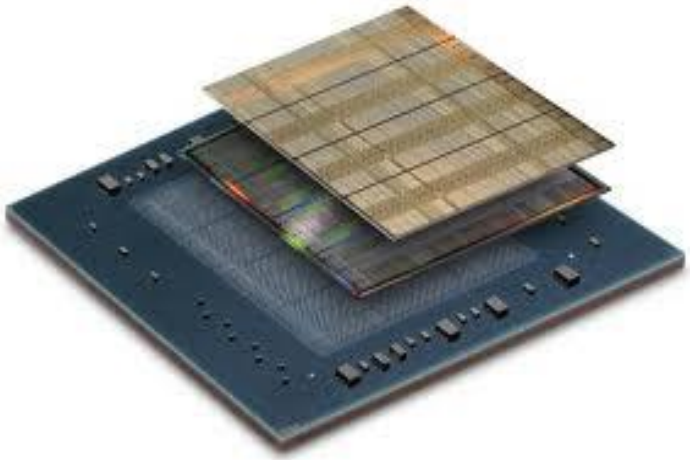
Xilinx ships the world's first heterogeneous 3D FPGA

Clive Maxfield 5/30/2012 03:43 PM EDT

XILINX®

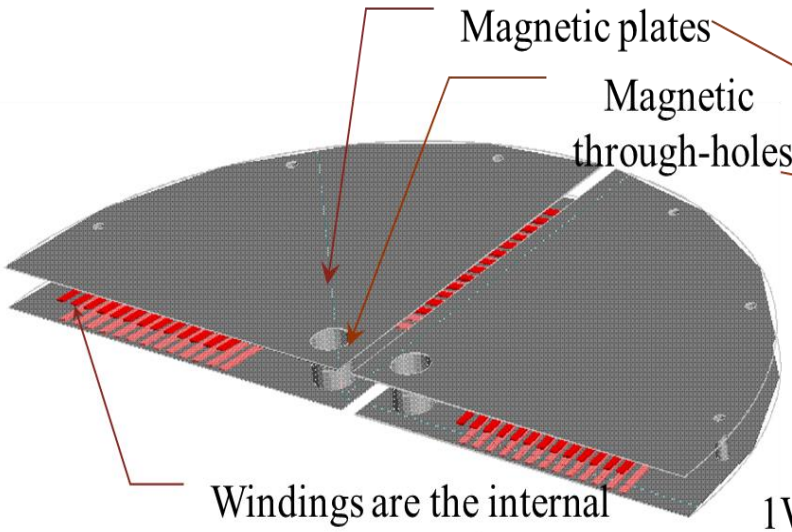


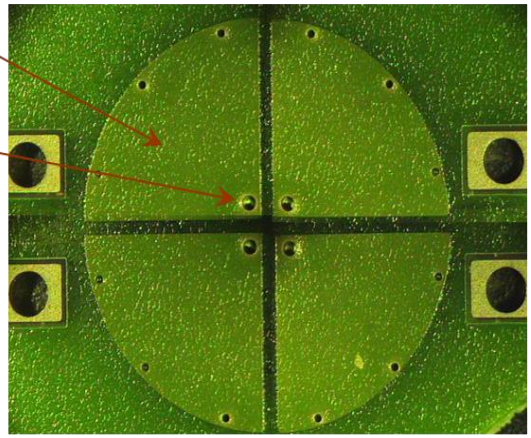
Micro bumps
Si Interposer with TSV
C4 bumps



Tyndall PCB Integrated Magnetics

Pot-core transformer structure
[US Patent No. 6.150,915]





1W Transformer embedded in 6 layer PCB, [M.Duffy et al. PESC'00]

- Magnetic layers and windings embedded in the printed circuit board
- Magnetic through-holes provide closed magnetic path
- Patterning of magnetic plates reduces eddy-current effects

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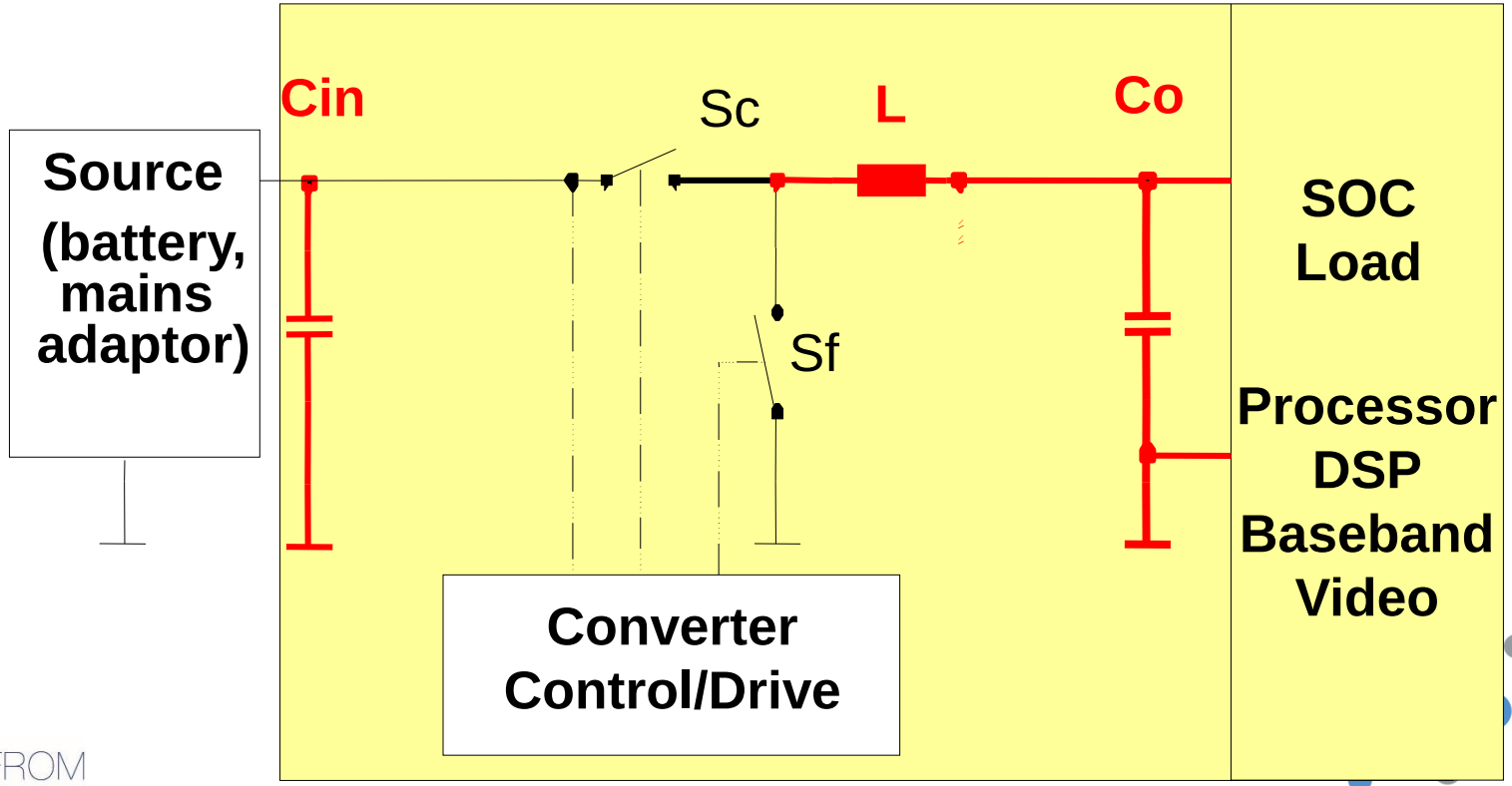
PwrSiP - Multidisciplinary Challenge

Applications | **System Integration** | **Manufacturing Supply Chain**

Magnetics | **Capacitors** | **Topologies & Control** | **Power Switches**



Integrated Magnetics for PwrSiP
Roadblocks to Commercialisation

- **System-level Solution**

- **Technology Progression:**
  - High frequency operation
  - EMI
  - Wafer-level Test
  - Reliability

- **Manufacturing Supply Chain:**
  - Magnetics on Silicon – BEOL / Foundry / OSAT
  - 2.5D / 3D Integration
  - Passive Interposers with integrated inductors and capacitors

- **Integrated CAD**

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PWR SOC 16

International Workshop on Power Supply On Chip
October 3-6, 2016 (provisional)
Madrid, Spain

CEI UPM
Centro de Electrónica Industrial

Integrated Power Conversion and Power Management

POLITÉCNICA
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The 5th edition of the International Workshop on Power Supply On Chip will be held at the Universidad Politécnica de Madrid, Spain, provisionally scheduled for October 3-6, 2016. This conference is organized by the Centro de Electrónica Industrial (CEI-UPM).

PwrSoC 2016 is the leading international technical workshop dedicated to advancing important power conversion technologies. The workshop focuses on the integration of both modular and granular commercially successful electronic power converters for multiple applications, by accessing a broad range of leading-edge technologies. Complete on-die integration and integration within package are of prime interest. System performance requirements presented by present day and emerging applications demand ever-greater current density, voltage regulation and optimized control, form factor reduction, efficiency, and cost reduction.

A major challenge on the path to integration and form factor reduction of dc-dc converters is the difficulty of integrating energy handling power passive components with conventional silicon processes. Advanced technologies for the design and manufacture of these passives are focal topics for the workshop. Strategies at circuit and system levels are of fundamental importance.

Sessions

- Plenary Sessions
- Systems & Applications
- Topologies and Control
- Power Semiconductor Technology
- Magnetics
- Capacitors for Power Electronics
- System Integration, Packaging and Manufacturing
- Granular Power
- Open Forum Discussion

Conference Site

The site of the conference is the Escuela Técnica Superior de Ingenieros

Ireland's EU Structural Funds Programmes 2007 - 2013
Co-funded by the Irish Government and the European Union

UCC

The Magicians

- PSMA
- EU PowerSwipe Team
- EU Carricool Team
- Tyndall Team
  - – Integrated Magnetics
  - - MEMS Fabrication
  - - Electrodeposition
  - - Test and Characterisation
  - - Packaging and Integration
  - - Business Development
  - - Technology Transfer / Legal