



# Coupled inductors on silicon for PwrSoC in the frame of PowerSwipe project

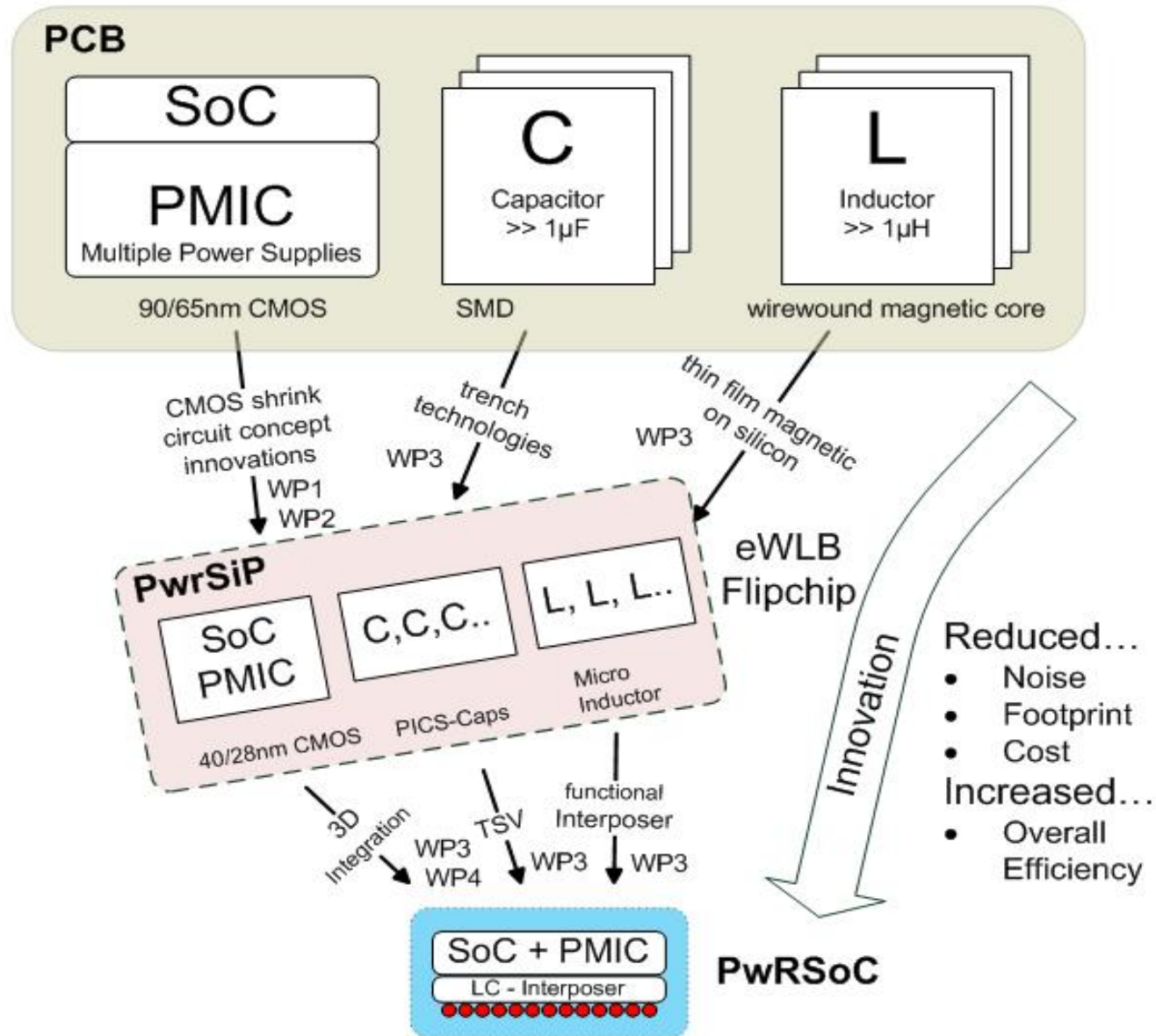


**Santosh Kulkarni\*, Bruno Allard\*\***

\*Microsystems Centre, Tyndall National Institute, University College Cork, Ireland

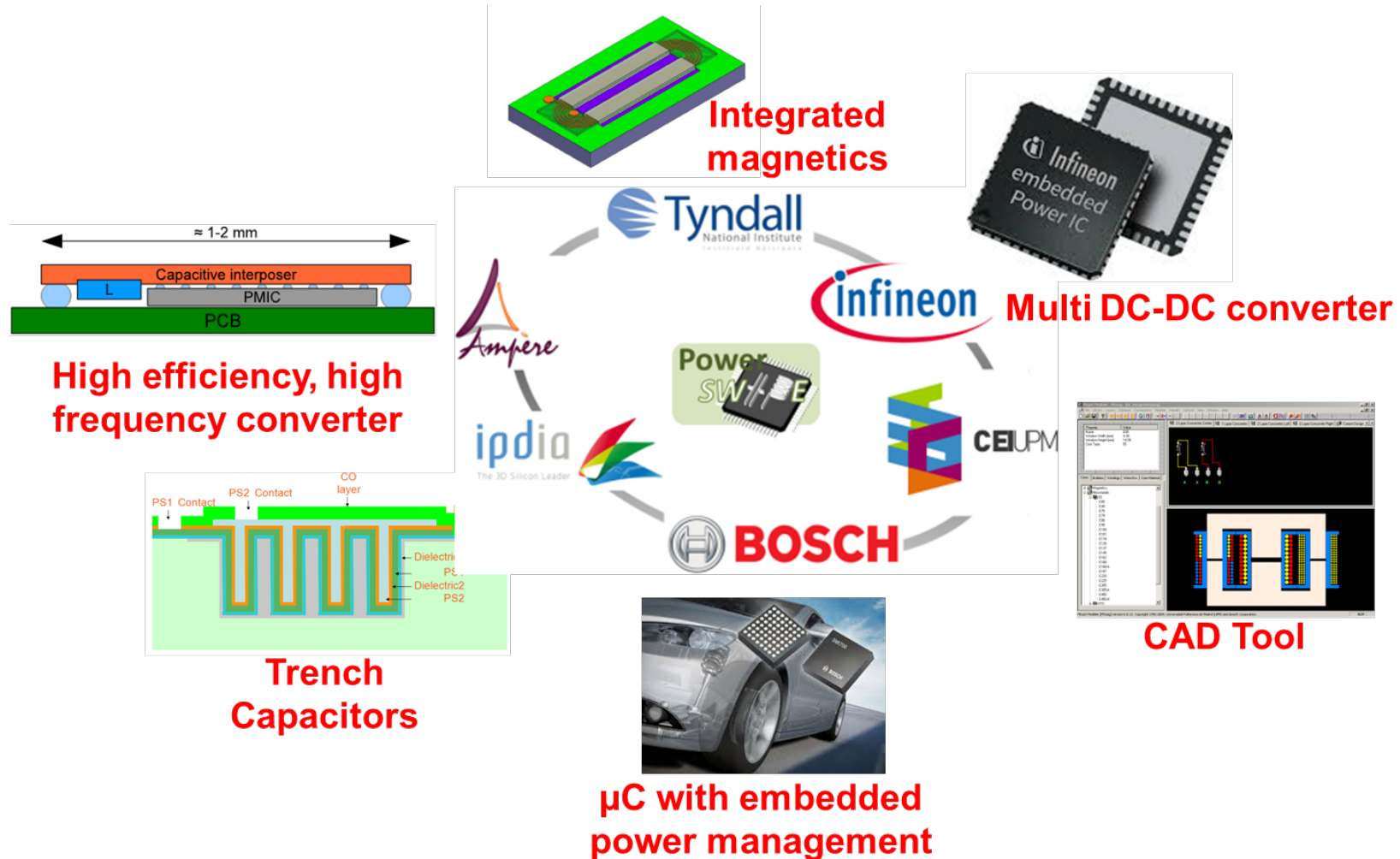
\*\*Ampere lab, INSA Lyon, France

# PowerSwipe Concept



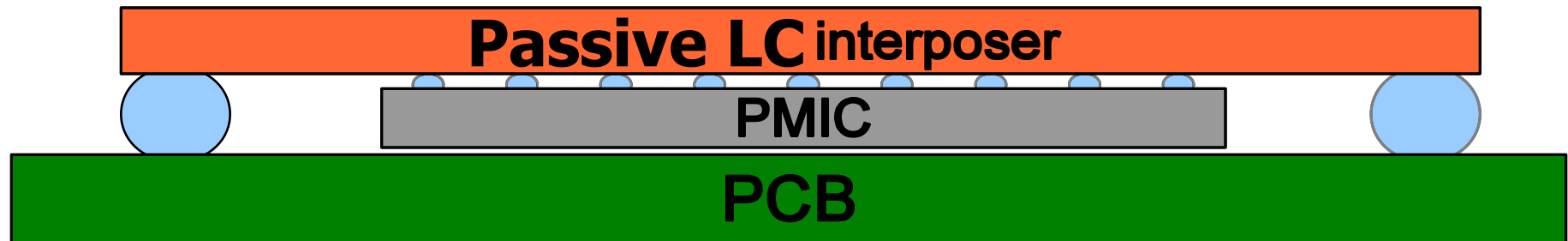
# PowerSwipe Consortium Partners

## First EU Funded programme on PwrSoC/PwrSiP





## Demo 1- Low Frequency dc-dc for Automotive



## Demo 2- High Frequency dc-dc for multi-phase IVR applications

- Powerswipe' integrated coupled inductors
- Design, Fabrication & Small Signal testing of 'Loosely' coupled inductor device
- Large Signal characterization of integrated coupled inductors
  - Large signal Inductance, resistance, BH loop
  - Impact of dc bias on magnetic material under test
- Summary

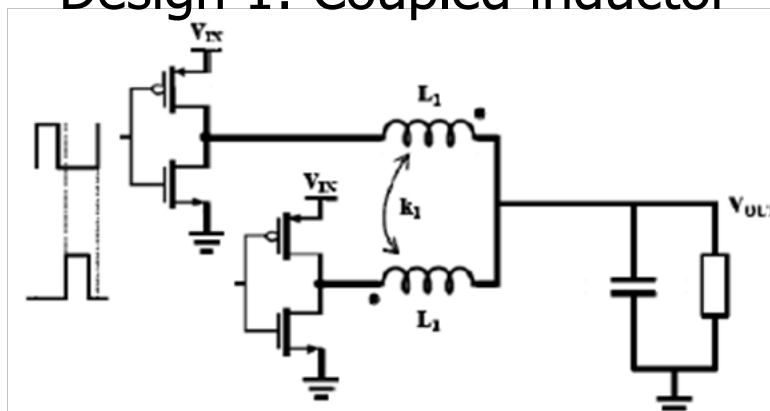
## • Achieve miniaturisation of power passives:

- Increased switching frequency of switched-mode DC-DC converter (10-200 MHz)
- Power passives footprint comparable to DC-DC converter IC (1 to 2 mm<sup>2</sup>)

### HF DC-DC converter-Specs

Inductor design	Freq. (MHz)	L (nH)	Coupling factor	Efficiency (magnetics)	Efficiency (IC)	Total efficiency
Coupled	100	45	~0.4	90%	90,4%	81%

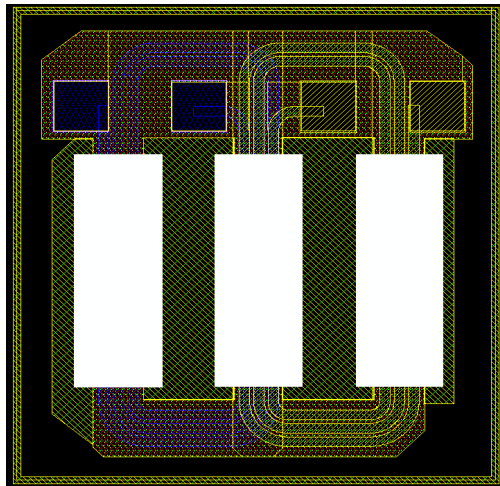
### Design 1: Coupled inductor





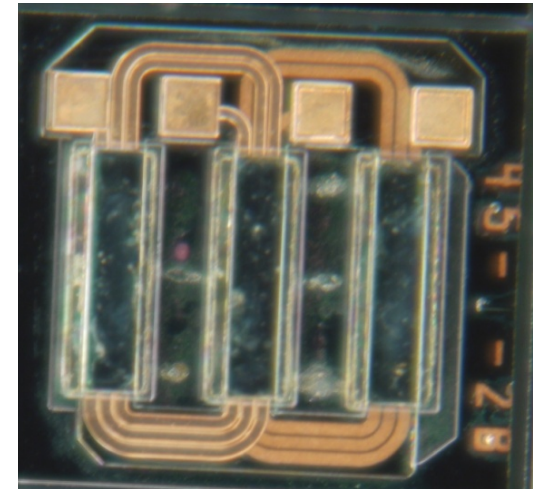
L (nH)	Core Length	Core Thickness	Copper width	Copper Thickness	DCR (Ohm)	Device Footprint
<b>45 Coupled</b>	<b>0.95 mm</b>	<b>2 <math>\mu</math>m</b>	<b>40 <math>\mu</math>m</b>	<b>15 <math>\mu</math>m</b>	<b>0.282</b>	<b>1.25 mm<sup>2</sup></b>

45nH Coupled



Device Schematic

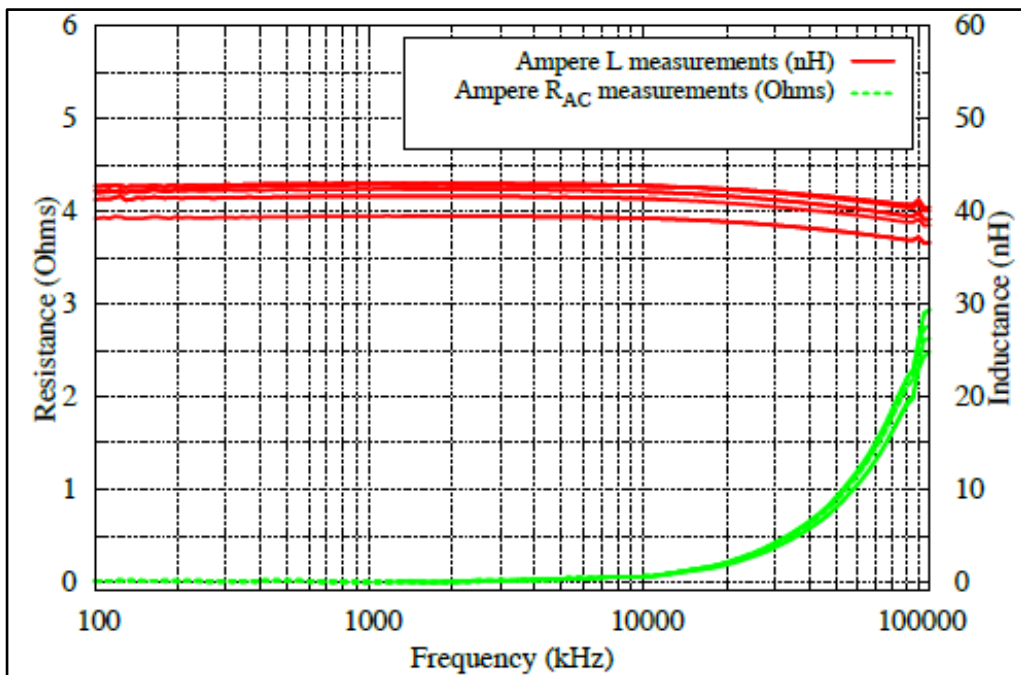
Coupled inductor prototype



Device Cross-section

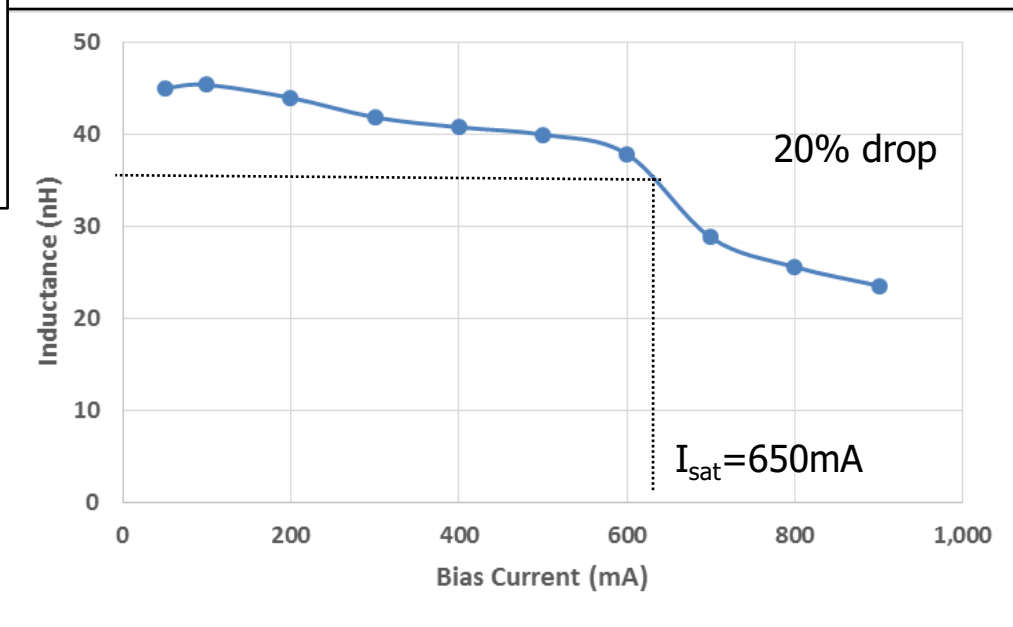


Small signal testing: LCR meter & 4-probe Kelvin setup- INSA Lyon



✓ Good frequency & current response

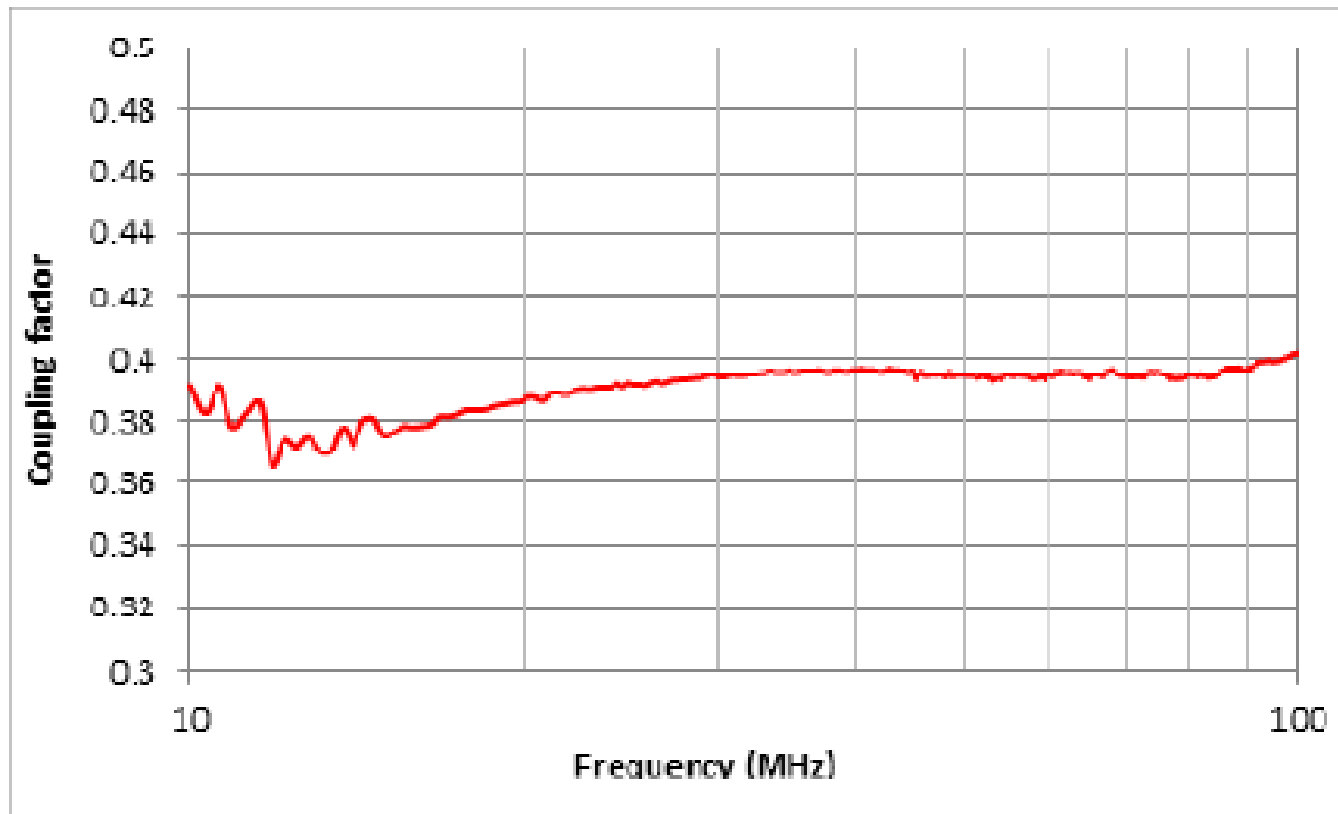
Small signal testing: L vs DC bias-  
Tyndall

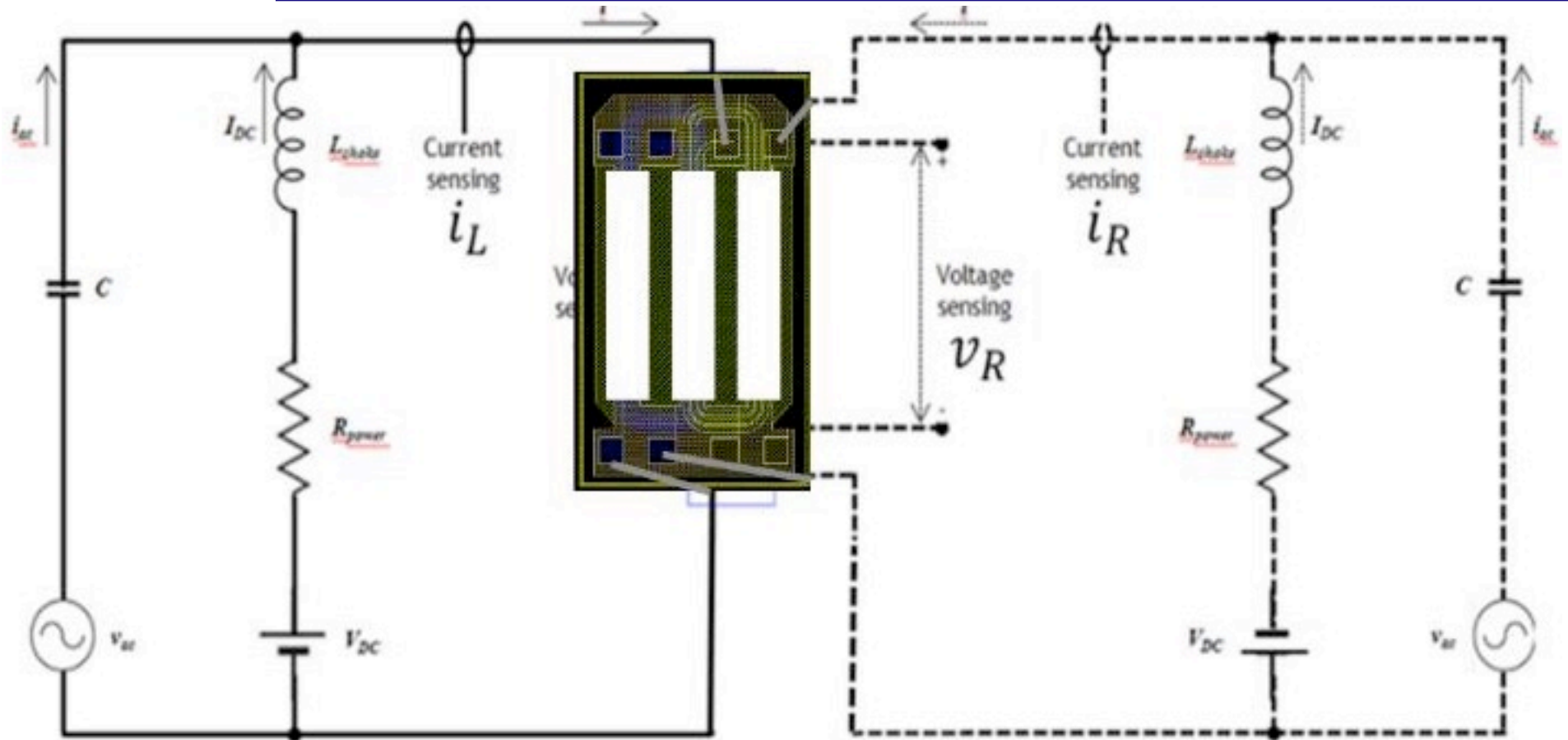




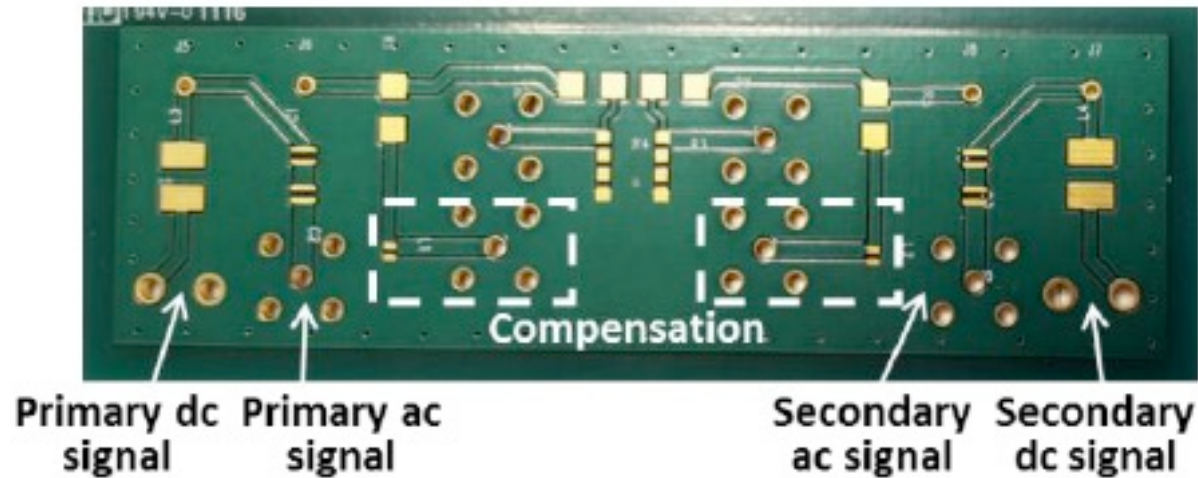
- Two port VNA test for coupling

$$k_{\text{measured}} = 0.38; k_{\text{design}} = 0.4$$





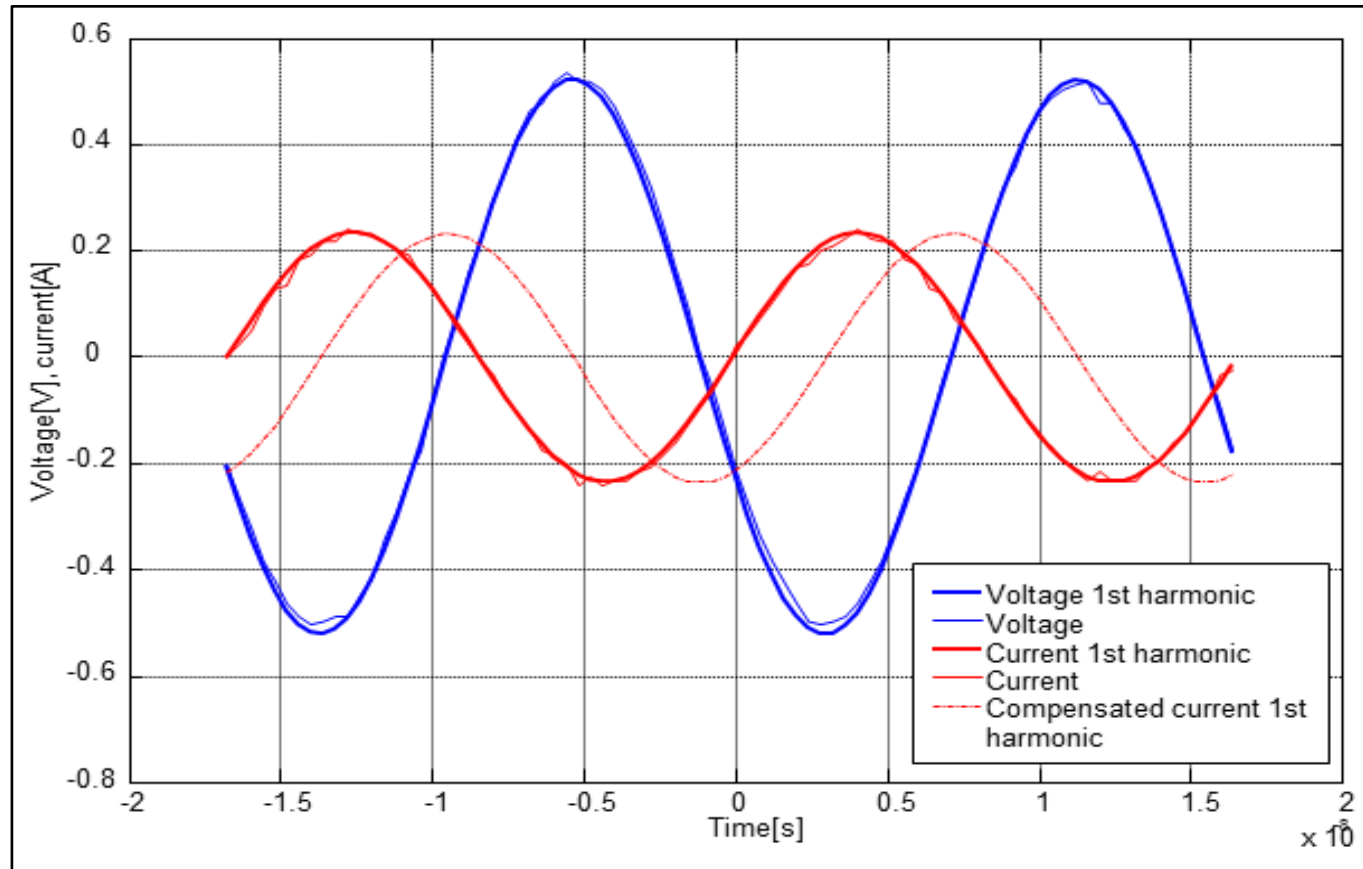
- Signal generator- Agilent E8257D
- Power amplifier- Applied Research 25A250A
- Current probe- Pearson current 2877
- Voltage probe- Tap 1500



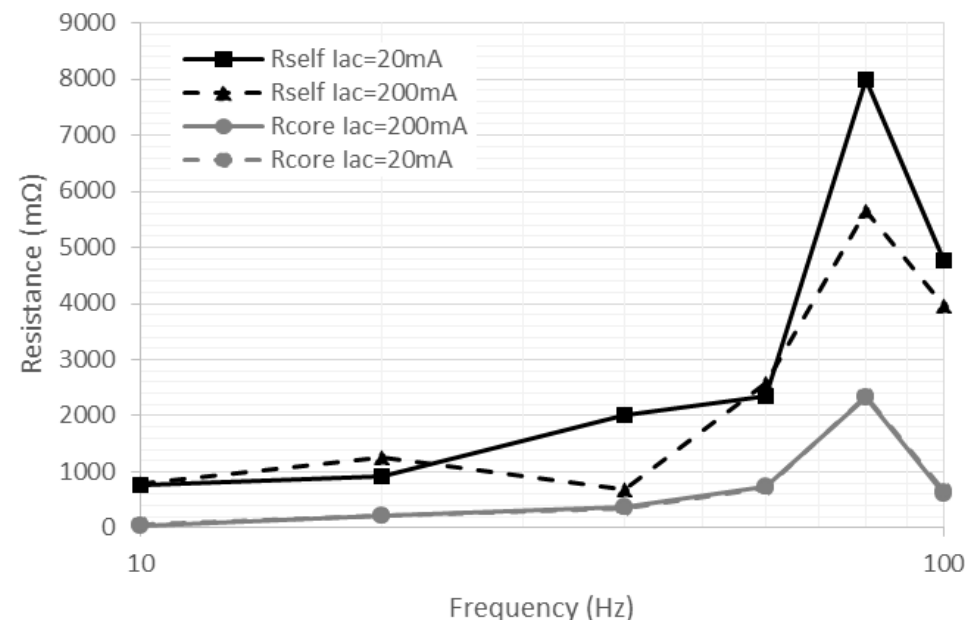
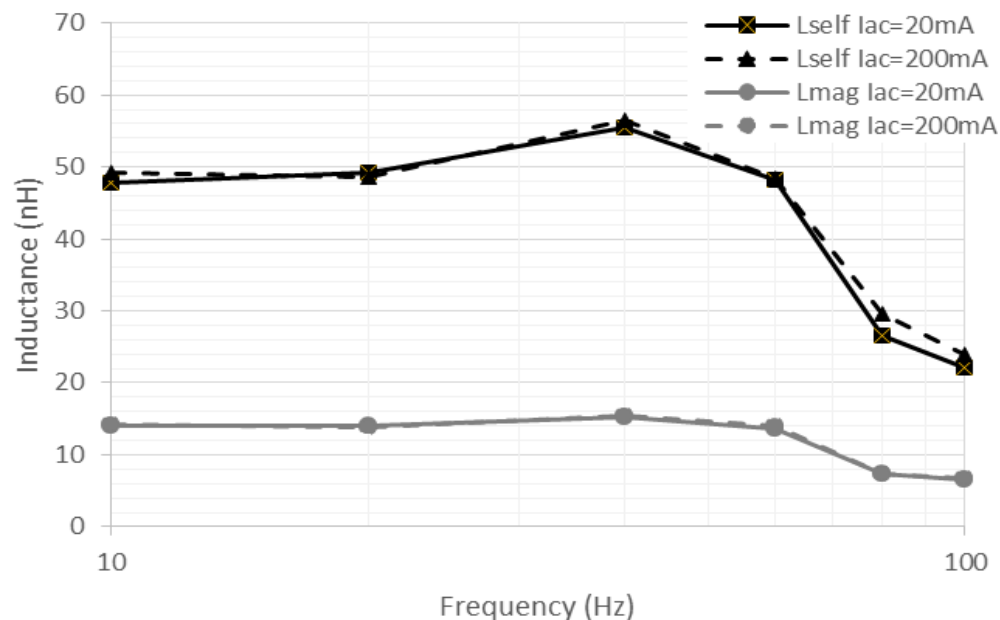
## Key issues with large signal testing set-up

- Noise
  - Use 4 wire measurement for the DUT
- Error in amplitude & phase measurement
  - Attenuation & time delay from current & voltage probes
  - Accurate compensation system to correct this skew
- Compensation is done through a measurement on a capacitor of known impedance

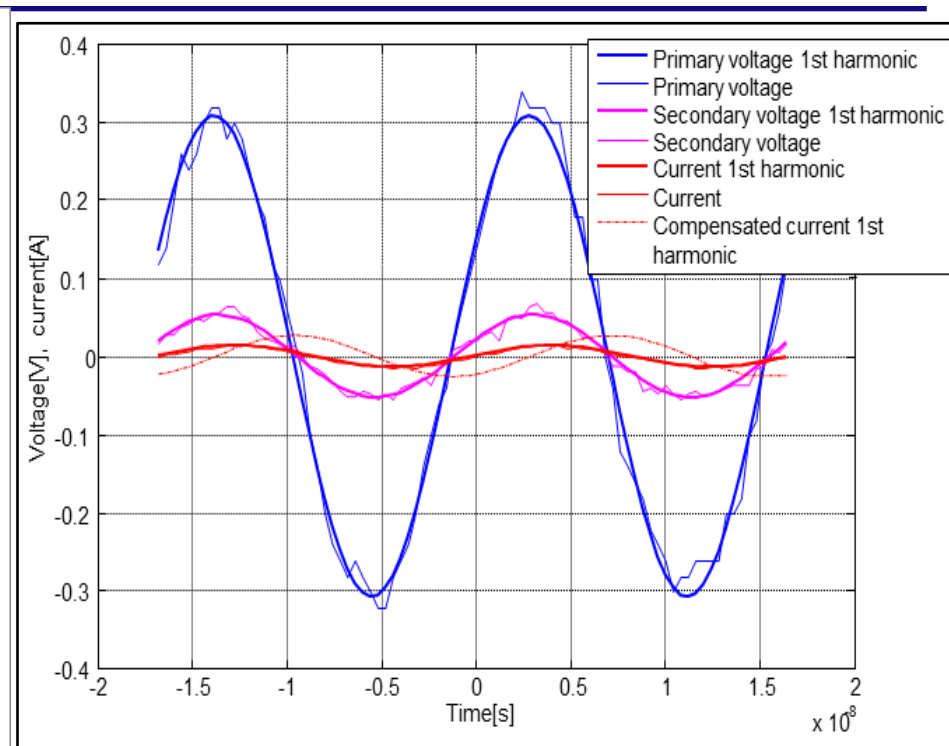
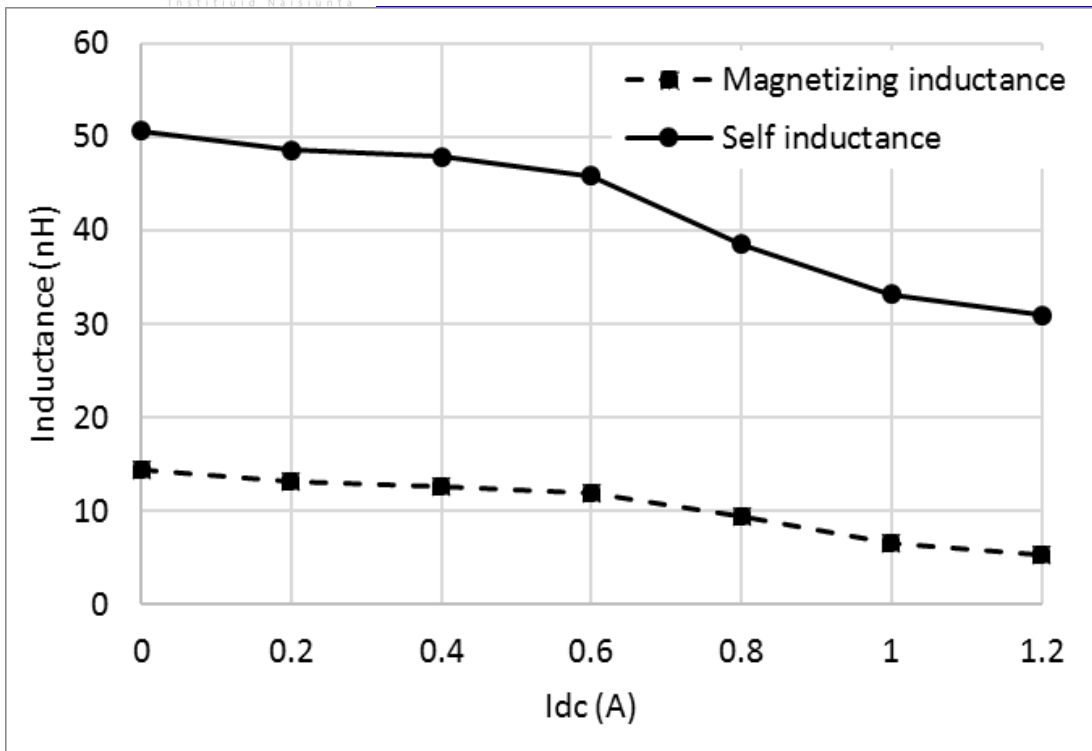
# Voltage & Current waveforms for Capacitor-Compensation



- Time lag @ 40MHz- 0.671 ns
- Current attenuation- 0.895



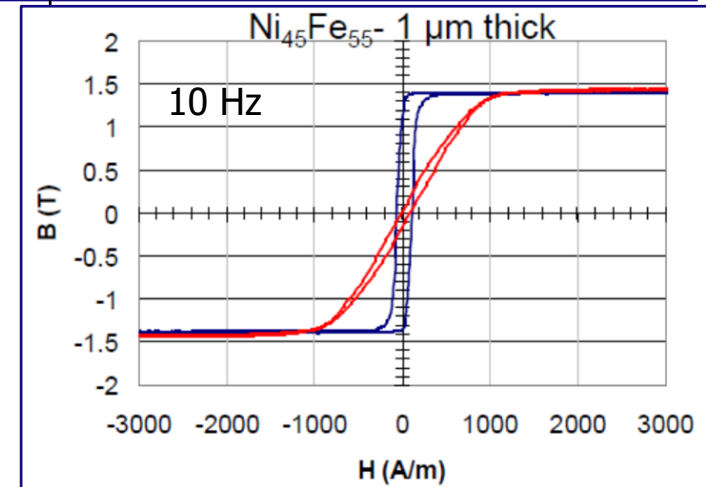
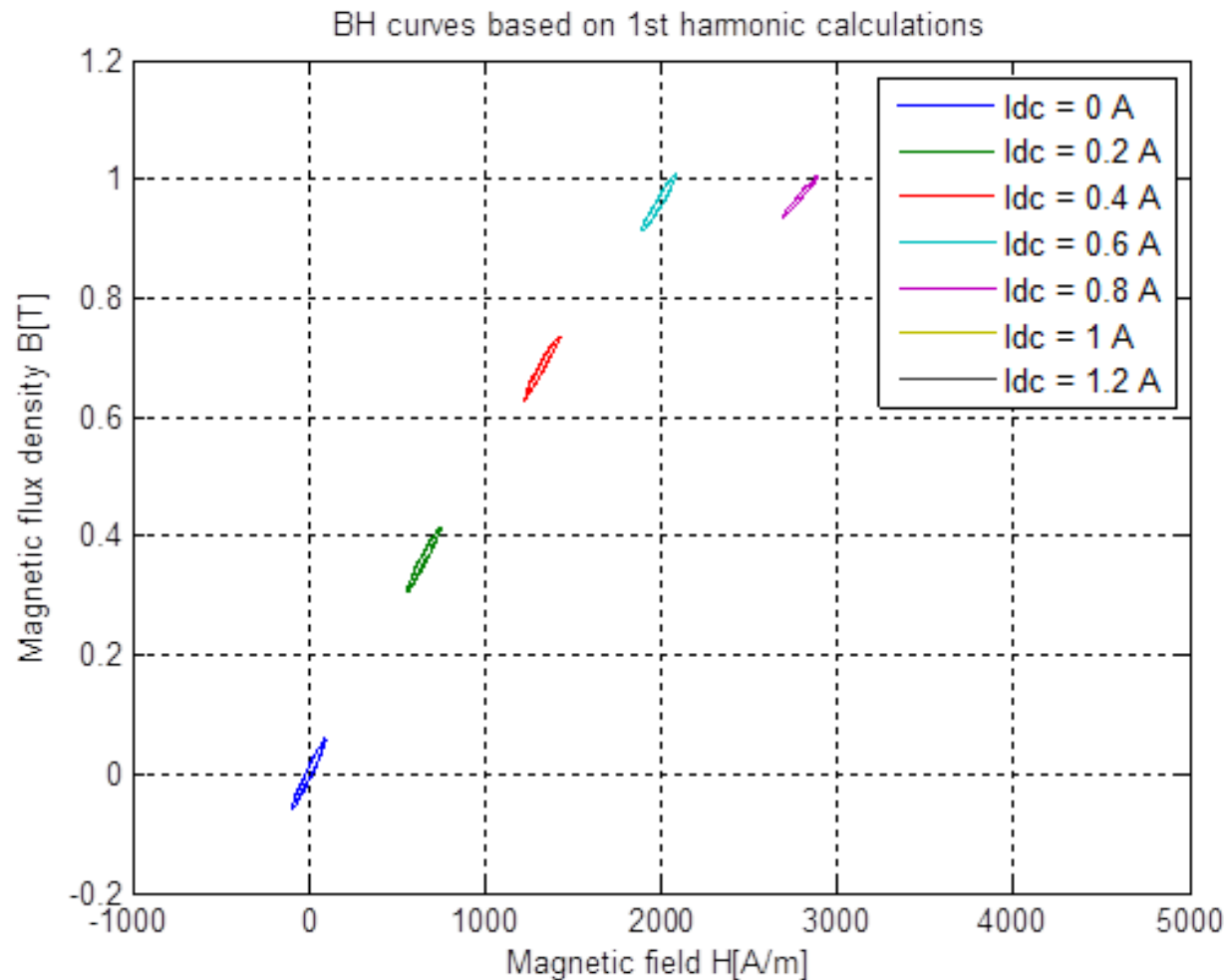
- Inductance (Self/Mutual) stays constant upto 60MHz
- Resistance measurement shows a dramatic increase after 60MHz
- This behaviour not consistent with small signal test data
- Possible explanation- Voltage probes damaged



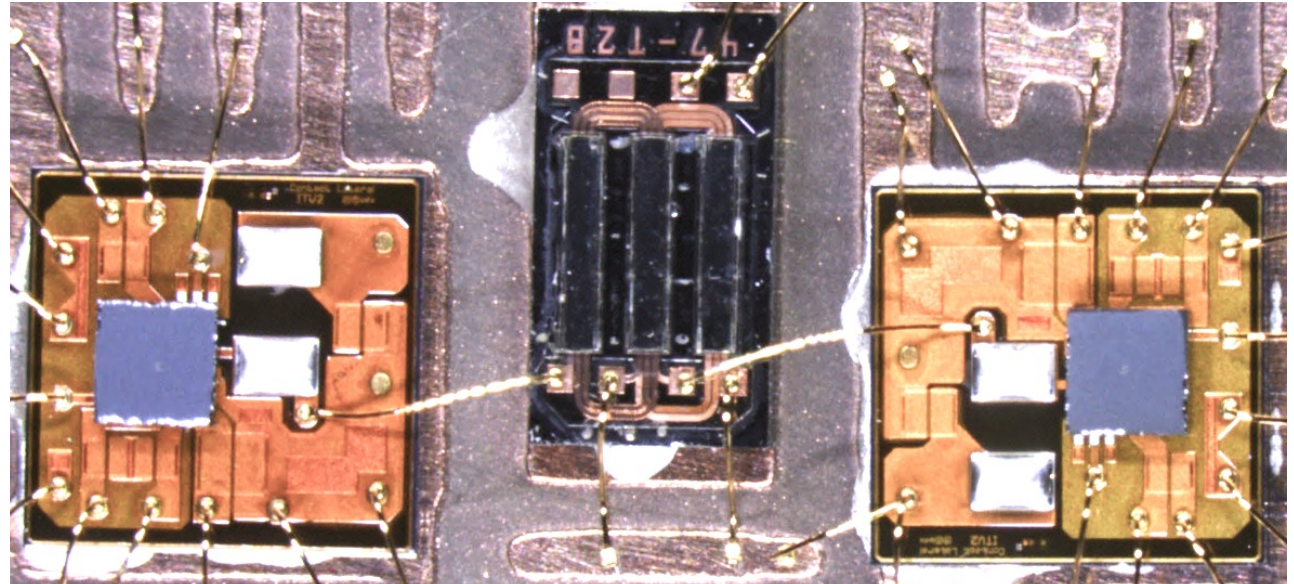
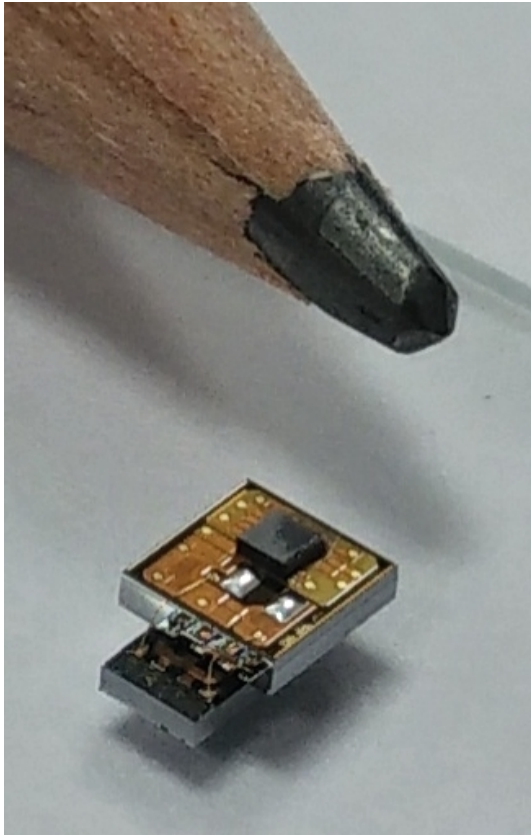
- Voltage & Current waveforms including compensated current loops
- $I_{ac}$ - 20mA; Frequency- 60MHz
- DC saturation current- 700 mA (consistent with small signal measurement)



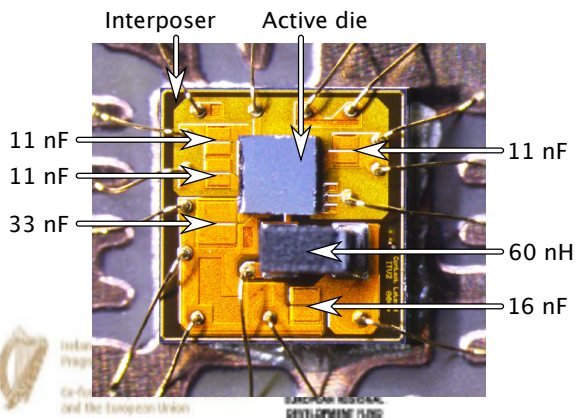
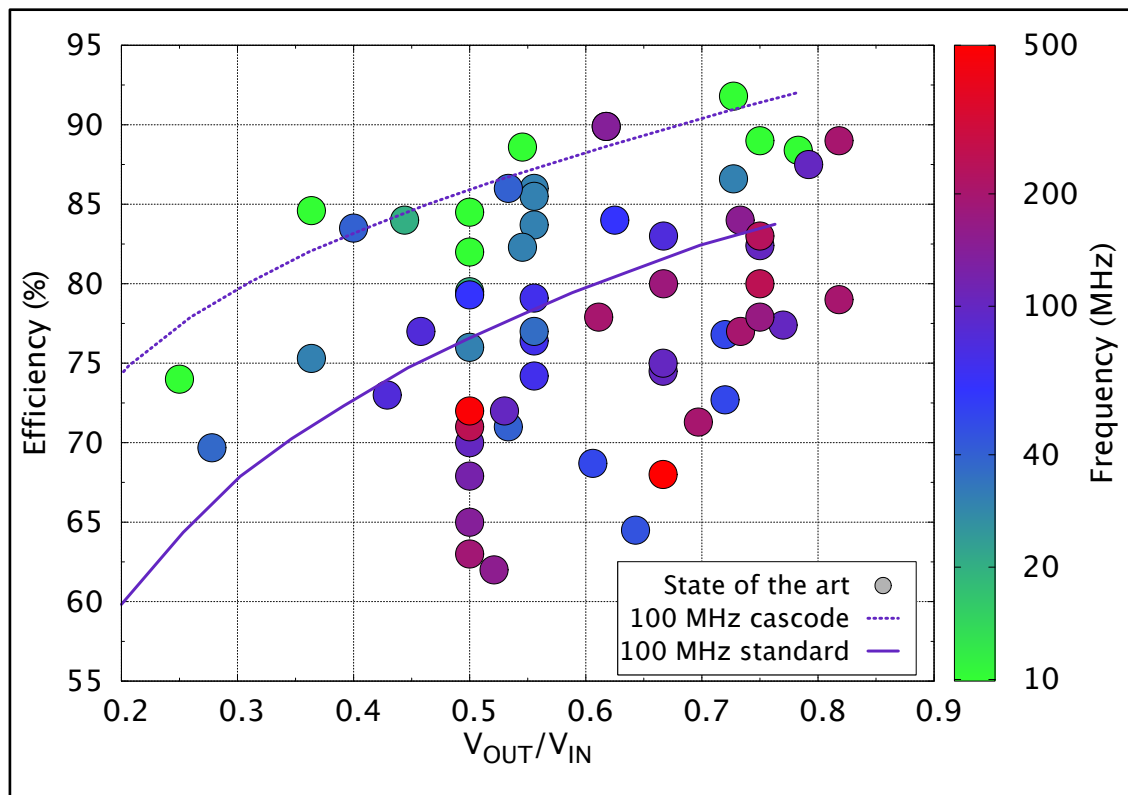
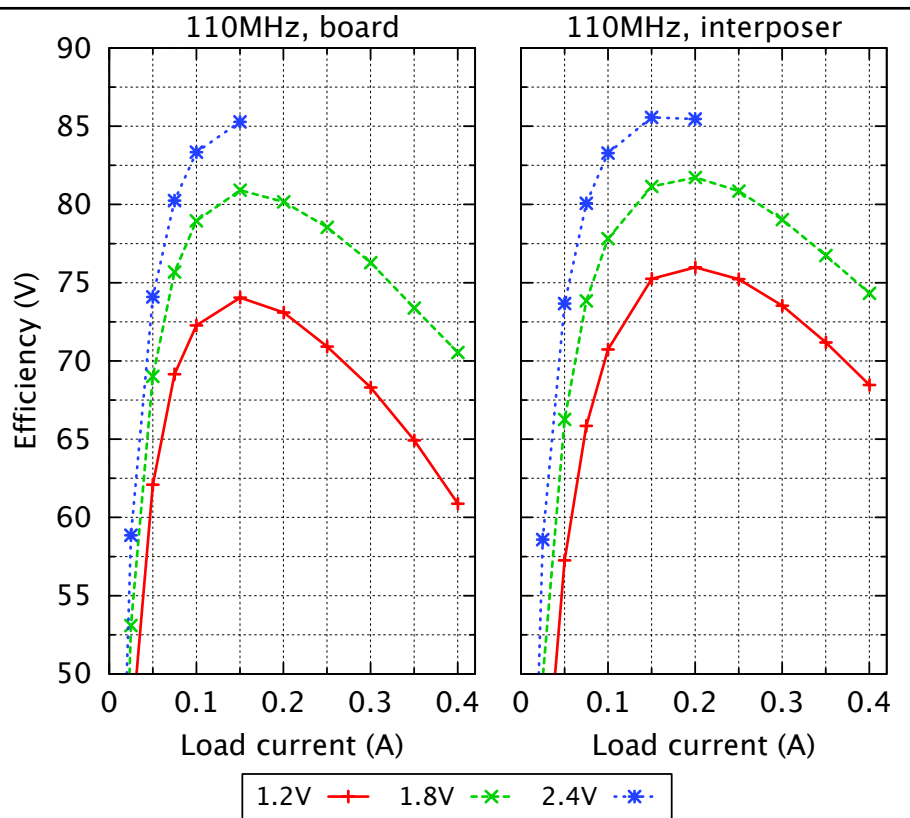
# Large signal testing to plot BH loops @ different bias currents



- B value estimated using Faraday's law
- H value estimated using Ampere's law



- Initial test on single phase discrete inductor with Interposer completed
- Circuit testing of coupled inductor with VR ongoing at INSA, Lyon- Result will be presented at future conferences



## Efficiency

- Globally better on interposer
- Slightly increased on-board for low load current

- First EU funded project on PwrSoC/PwrSiP
  - Target applications- Automotive & IVR
- Developed multiphase coupled inductors for IVR
  - Racetrack coupled inductors designed using CAD tool
  - Fabricated using Tyndall's Double Metal Layer process
  - Small signal measurement in good agreement with design data
- Developed large signal characterization system for measuring coupled inductor performance
- Circuit level testing of VR's ongoing

**Tyndall National Institute-** Prof. Cian O'Mathuna, Dr. Paul McCloskey, Dr. Ningning Wang, Dr. Zoran Pavolvic, Ricky Anthony, Nicolas Cordero, Margaret Hegarty, Joe O'Brien, Declan Casey, James Rohan, Anne-Marie Kelleher, Graeme Maxwell

**Lab Ampere, INSA, Lyon-** Florian Neveu, Dr. Christian Martin

**Universidad Carlos III de Madrid-** Dr. Cristina Fernandez Herrero

**Funding- European Union for funding the work through FP7 (Project: PowerSwipe) under Grant 318529.**