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A Novel Silicon-Embedded Transformer for System-in-Package Power Isolation*

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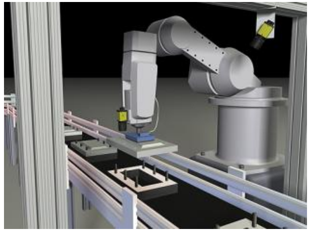
Background

■ Signal & Small Power Isolation Applications

Industrial:
Sensor
Data Bus
Motor Drive



Automobile:
Motor Drive
Battery Manage

Power Generation:
PV Inverter
Wind Turbine

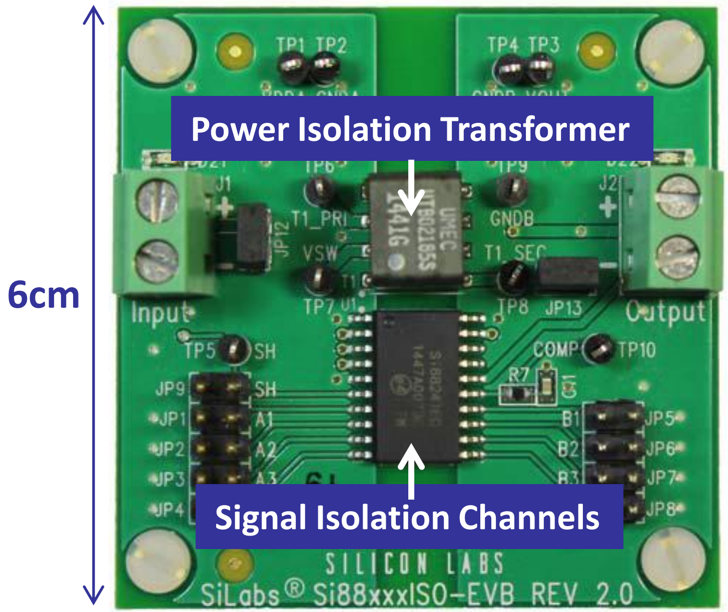
Telecom:
Data Bus
PoE

Medical:
Patient Monitor
Sensor Probe

Others:
Instrumentation
Consumer
Aerospace

Background

- **Small Power Isolation (<2W)**
  - **Allow Simple Power Supply for Signal Isolation Channels**



Ref: Silicon Labs, Si88xxxISO-EVB

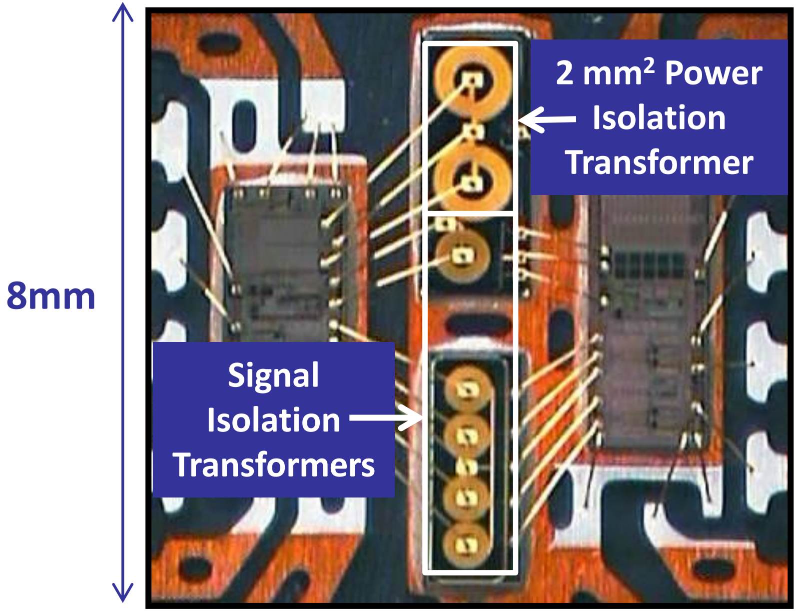
Discrete Transformer Solution

- ✓ 2µH/0.05Ω
- ✓ 200 kHz to 800 kHz
- ✓ Up to 78% dc-dc efficiency
- ✗ Low integration level
- ✗ Large solution size
- ✗ High system cost

Background

Small Power Isolation (<2W)

➢ Allow Simple Power Supply for Signal Isolation Channels



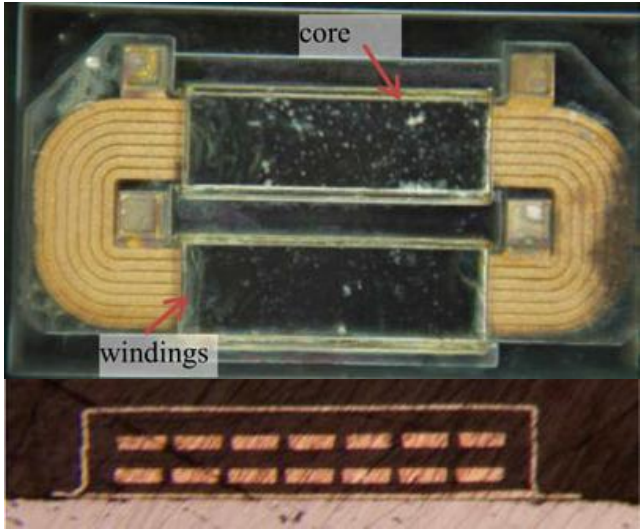
Ref: Analog Devices, B. Chen, PwrSoC, 2008

On-Chip Transformer Solution

- ✓ System-in-package integration
- ✓ Small solution size
- ✓ Low system cost
- ✖ 16nH/1.6Ω
- ✖ 170 MHz
- ✖ Up to 34% dc-dc efficiency

Background

- **Needed: High Performance On-Chip Transformers**
  - **High Efficiency @ Low Frequency → Large L/R**



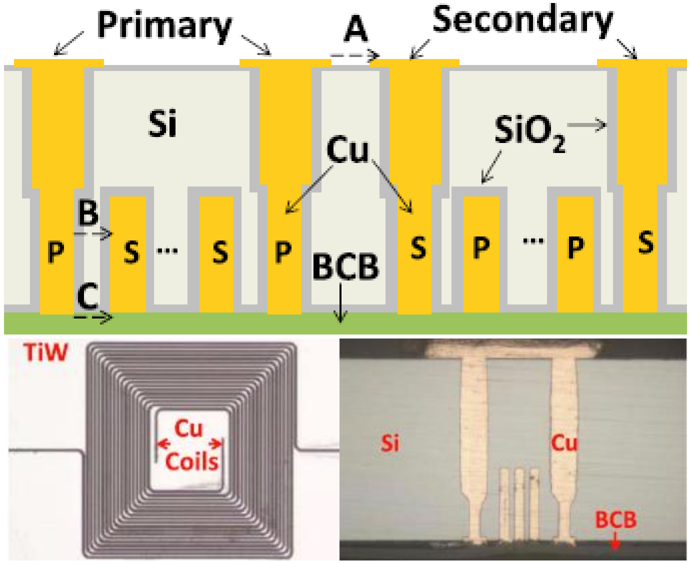
Ref: Tyndall, N. Wang et al., IEEE TPEL, 2015

DLM Microtransformer

- ✓ 4.5 µm core & 15 µm metal
- ✓ 270 nH/1.22 Ω
- ✓ 78% efficiency @ 20 MHz
- ✓ 6kV Isolation
- ✖ core related issues
- ✖ 7 masks
- ✖ 3 mm^2

Background

- **Needed: High Performance On-Chip Transformers**
  - ➢**High Efficiency @ Low Frequency → Large L/R**



Ref: Our Work, R. Wu et al., IEEE TED, 2015

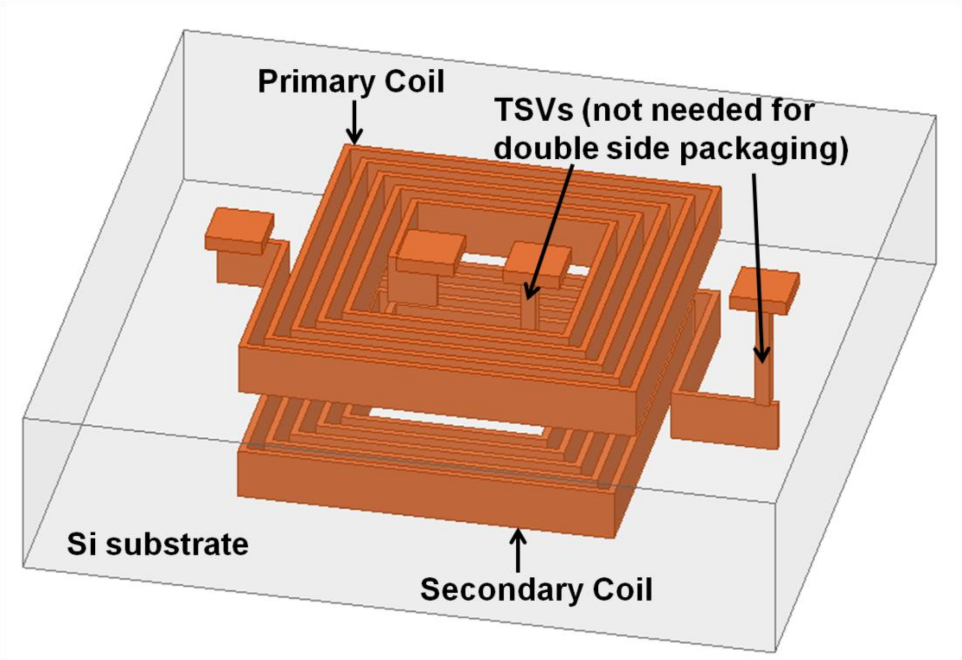
Interleaved Embedded Transformer

- ✓ 100 µm metal
- ✓ 88 nH/0.45 Ω
- ✓ 80% efficiency @ 20 MHz
- ✓ 3 masks
- ✓ 2 mm^2
- ✖ 380 V isolation

breakdown path C at chip surface

Double-Side Embedded Transformer

■ Device Structure



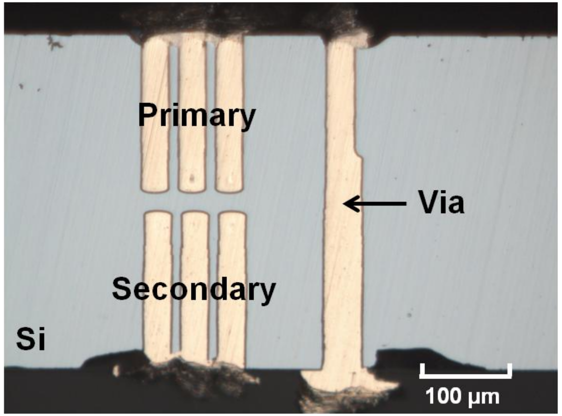
Ref: R. Wu et al., IEEE TED, in press

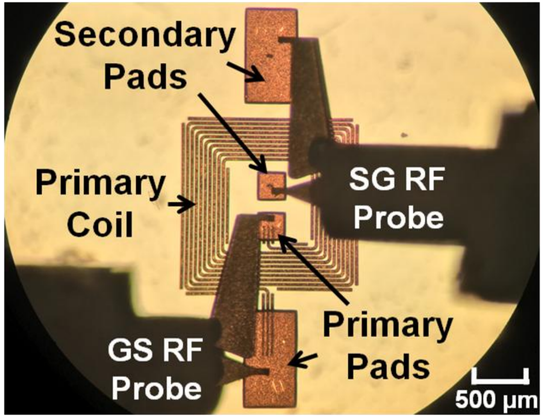
- ✓ large thicknesses for both coils
- ✓ whole area usage for both coils
- ✓ breakdown through substrate: Cu-oxide-Si-oxide-Cu for isolation
- ✓ balanced stresses at two sides
- ✖ weaker coupling

Double-Side Embedded Transformer

■ Transformer Design & Fabrication

Coil Diameter (μm)	Si Thickness (μm)	Cu Thickness (μm)	Track Width (μm)	Track Spacing (μm)	Number of Turns	Oxide Thickness (μm)
1400	350	150	22	15	9	2

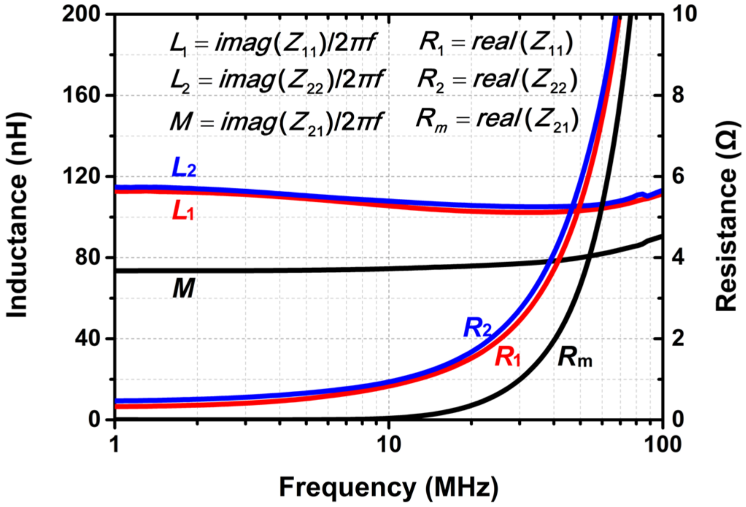


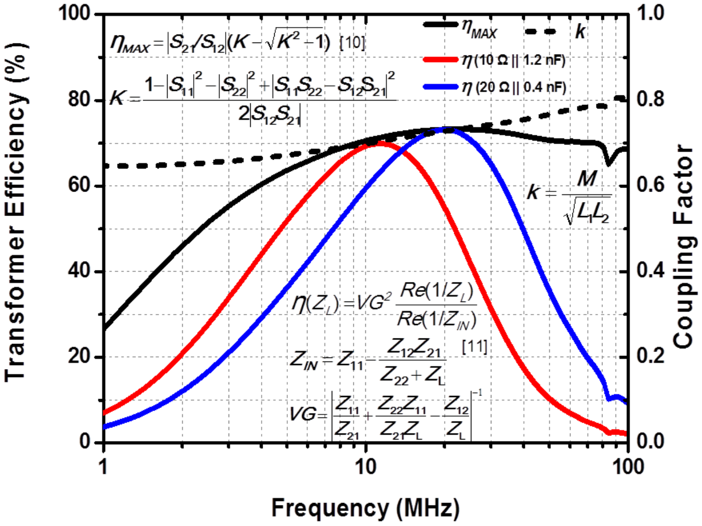


Ref: R. Wu et al., IEEE TED, in press

Double-Side Embedded Transformer

■ Measurement Results





- ➢1050 V isolation for 2×2 µm thermal oxide isolation
- ➢insulating substrate for further improving isolation capability

Ref: R. Wu et al., IEEE TED, in press

Performance Comparison

	Coilcraft [1]	CityU [2]	ADI [3]	Tyndall [4]	Our Work [5]	This Work [6]
Technology	discrete	PCB	Si	Si	Si	Si
Magnetic Core	Yes	No	No	Yes	No	No
No. of Masks	N/A	N/A	5	7	3	4
Area (mm^2)	23	21	2	3	2	2
Inductance (nH)	4700	242	16	270	88	113
Resistance (Ω)	0.32	0.66	1.6	1.22	0.45	0.31
L/R (μH/Ω)	14.7	0.37	0.01	0.22	0.20	0.36
Coupling	0.97	0.58	N/A	0.9	0.98	0.65
Efficiency	N/A	76%	70%	78%	80%	70%
Frequency (MHz)	1	8	170	20	20	10
Isolation (kV)	1.5	15	7	6	0.38	1.05

[1] Coilcraft: "Miniature transformers LPD5030V," Revised 2015.
[2] CityU: S.C. Tang et al., IEEE Transactions on Power Electronics, pp. 311-315, 2001.
[3] ADI: B. Chen, PwrSoC, 2008; ADuM6000 Datasheet ,Revised 2013.
[4] Tyndall: N. Wang et al., IEEE Transactions on Power Electronics, pp. 5746-5754, 2015.
[5] Our Work: R. Wu et al., IEEE Transactions on Electron Devices, pp. 220-223, 2015.
[6] This Work: R. Wu et al., "A Novel Double-Side Silicon-Embedded Transformer for 10-MHz, 1-kV-Isolation, Compact Power Transfer Applications," IEEE Transactions on Electron Devices, in press

Conclusions

- On-chip transformers with high efficiencies at low frequency are needed for compact, low cost, system-in-package isolated power supply (<2W).
- The double-side embedded transformer features large thicknesses and whole area utilization for both coils. It achieved a best reported L/R of 0.36 μH/Ω with an area of 2 mm^2. Consequently it can work at a low frequency of 10 MHz with a reasonable efficiency of 70%.
- The only breakdown path is through the substrate. An isolation capability of 1050 V was achieved with two 2-μm-thick thermal oxide isolation layers, and can be further improved by using an insulating substrate.