Ferric

Integrated Voltage Regulation with Thin-Film Magnetic Core Power Inductors

Magnetics Session

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PWR'14

FERRIC
THE COMPANY

- Founded October, 2011
- Venture Funded Fabless Semiconductor Company
- Delivering complete IVR solution with flexible business model
- Highly Technical Team
- Foundry Partnership

Fe

AGENDA

- **Integrated Voltage Regulator (IVR) Introduction**
- CMOS Integrated Power Inductors
  - Inductor Topology
  - Magnetic Core
  - Inductor Performance
- Integrated Voltage Regulator Applications
  - Package Voltage Regulator
  - Monolithic Voltage Regulator

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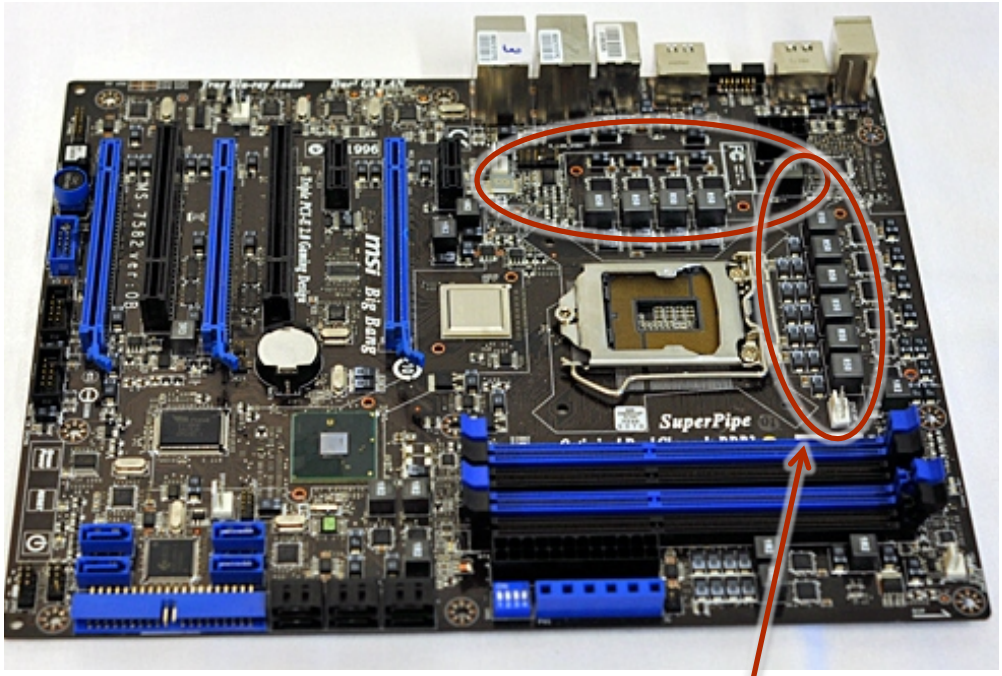
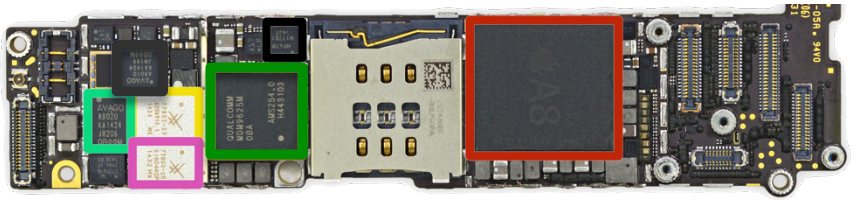
CURRENT TECHNOLOGY | Discrete Voltage Regulators

- Servers, desktops, laptops, tablets, smartphones….
  - All use DC-DC converters to address power requirements of digital ICs
  - Typically buck converters with **discrete inductors**
  - Bulky and poor scalability

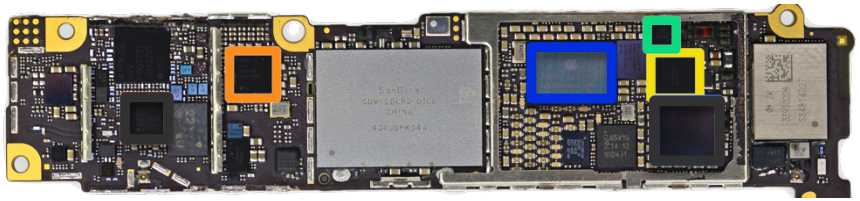


VRM

Front



Back

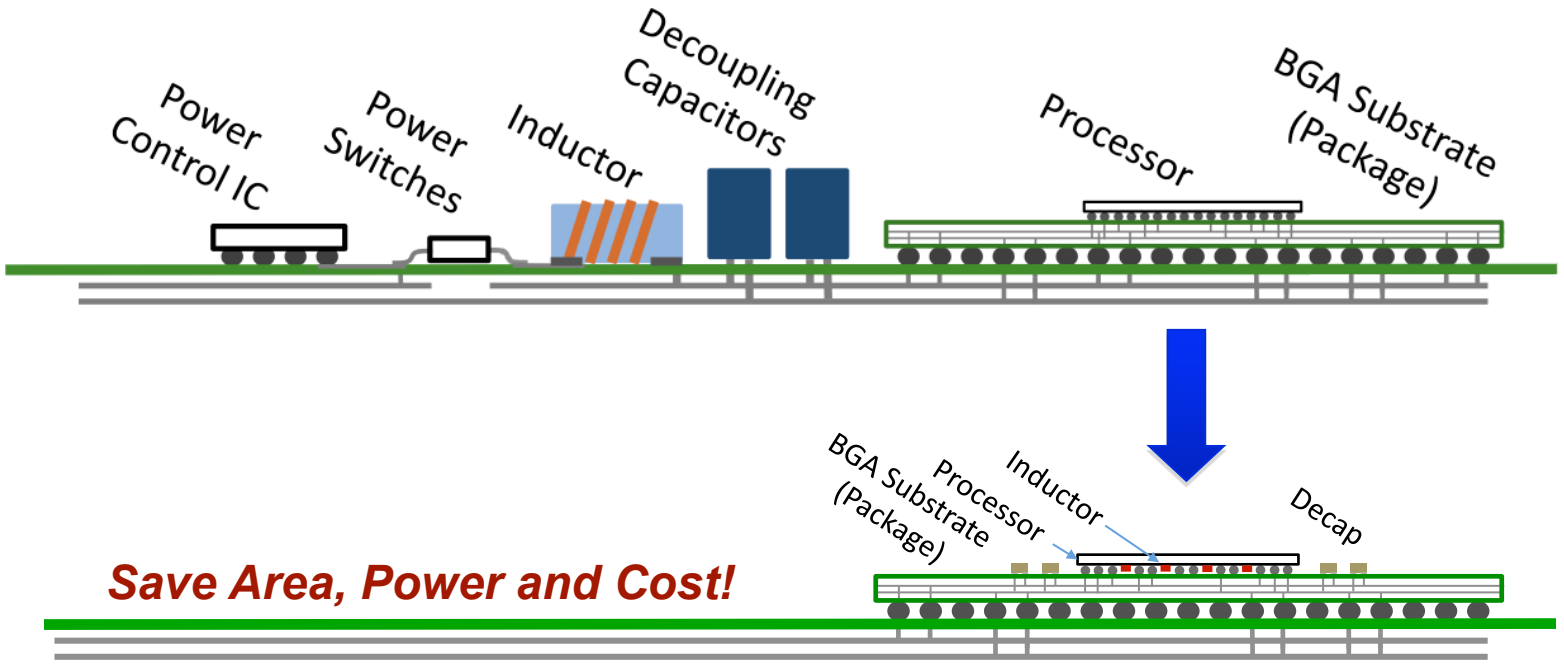


- Apple A8 application processor
- Qualcomm MDM9625M LTE Modem
- Apple/Dialog 338S1251-AZ Power Management IC
- Qualcomm PM8019 Power Management IC

Images from ifixit.com

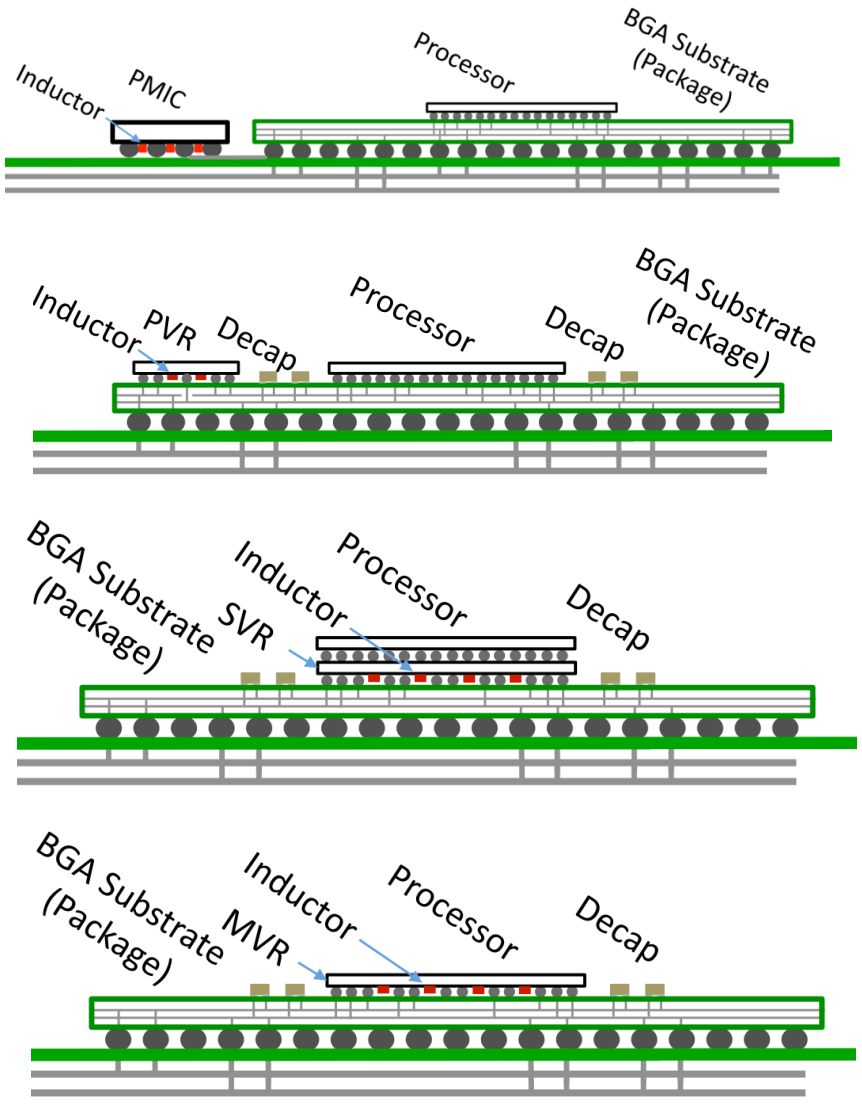
INTEGRATED VOLTAGE REGULATION (IVR)

- Shrink power converters so they can be integrated with the IC
- Reduce I^2R losses associated with high current levels in board + socket + package
- Enable delivery of many independently scalable supplies



Need Integrated Inductors!

VR INTEGRATION CASES



- Power Management IC

  (**PMIC or PSIP**)

- Package Integrated Voltage Regulators (**PVR**)

- Stack Integrated Voltage Regulator (**SVR**)

- Monolithic Integrated Voltage Regulator (**MVR**)

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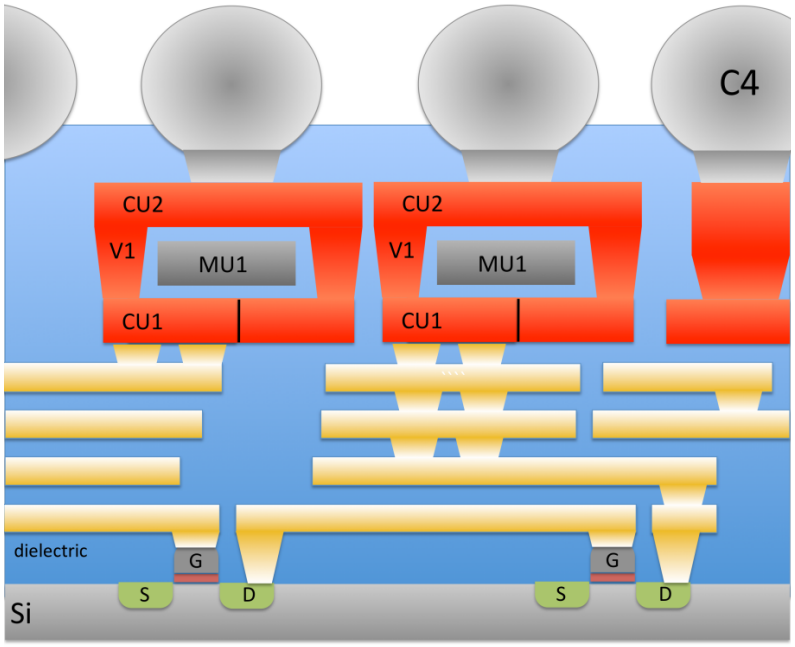
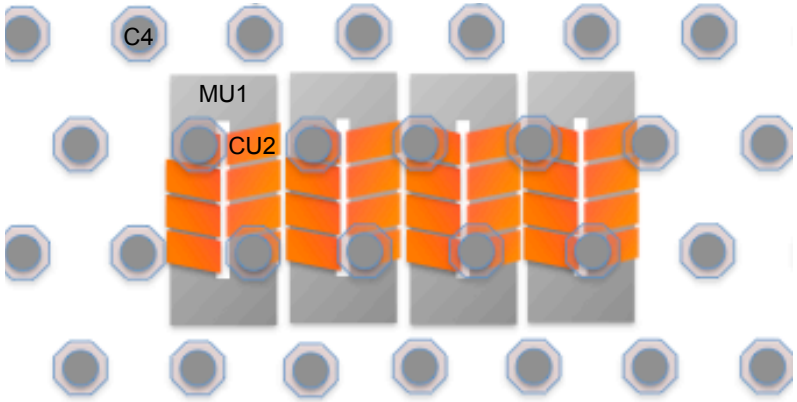
FERRIC Integrated Inductors





- CMOS compatible
- Minimal increase in process steps & complexity
- Exceptional density, utilization and design flexibility
- Best in class current density and quality
- Devices will be accessible through foundry with standard CMOS design flow support (DRC, LVS, xRC, advanced models)

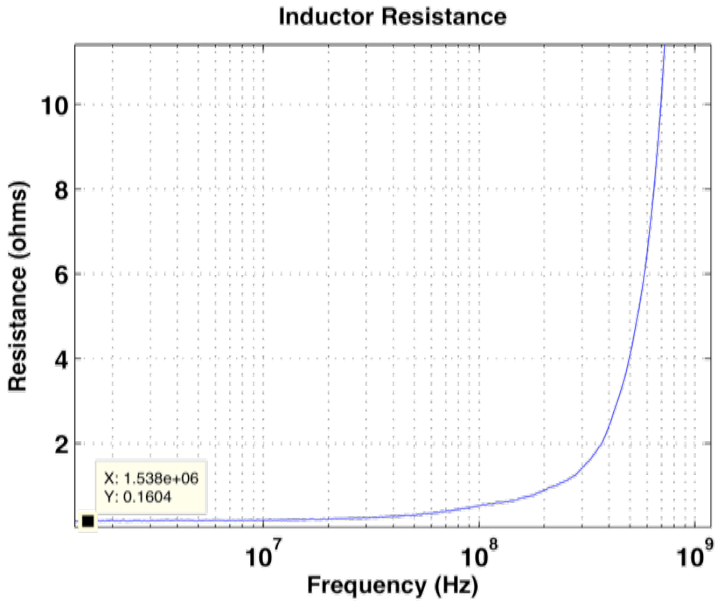
Devices will be available as BEOL process option at TSMC soon!

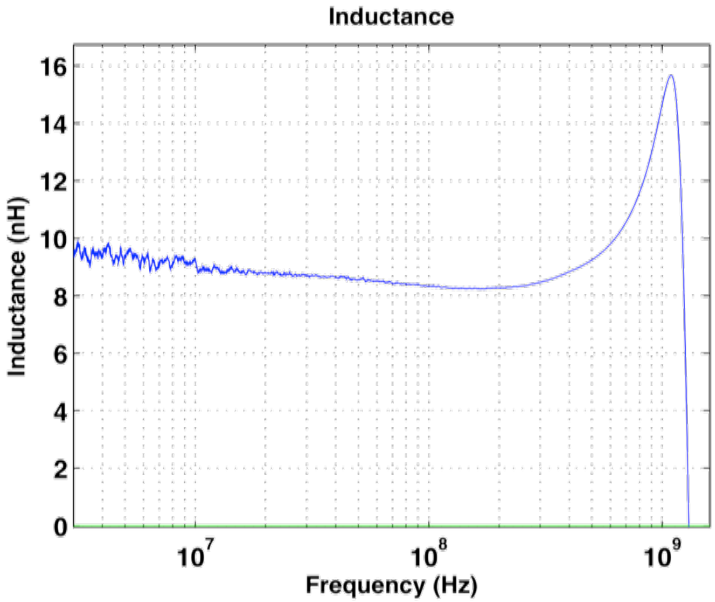
FERRIC INDUCTORS | Initial Results

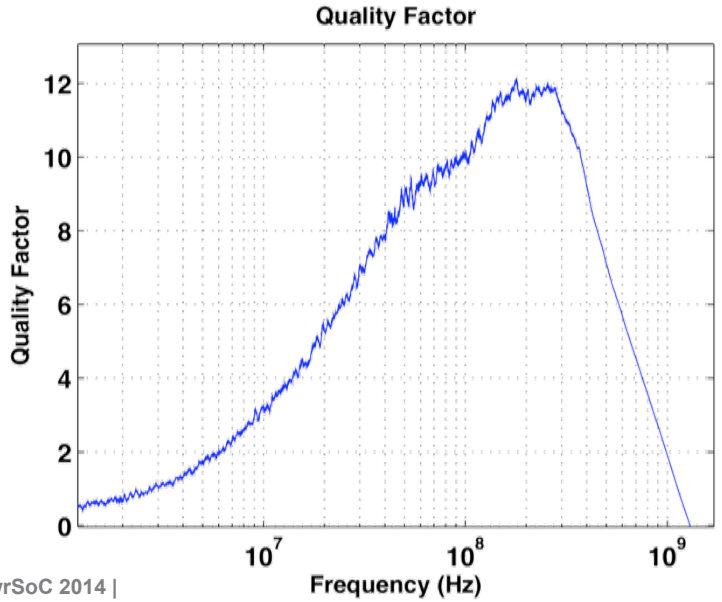
DC Resistance:
189mΩ

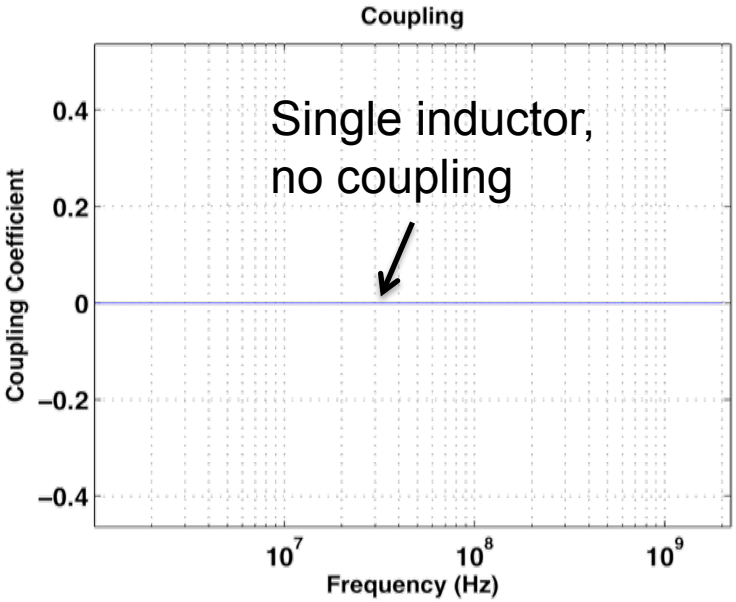
Inductance:
8.7nH

Area:
0.141 mm^2









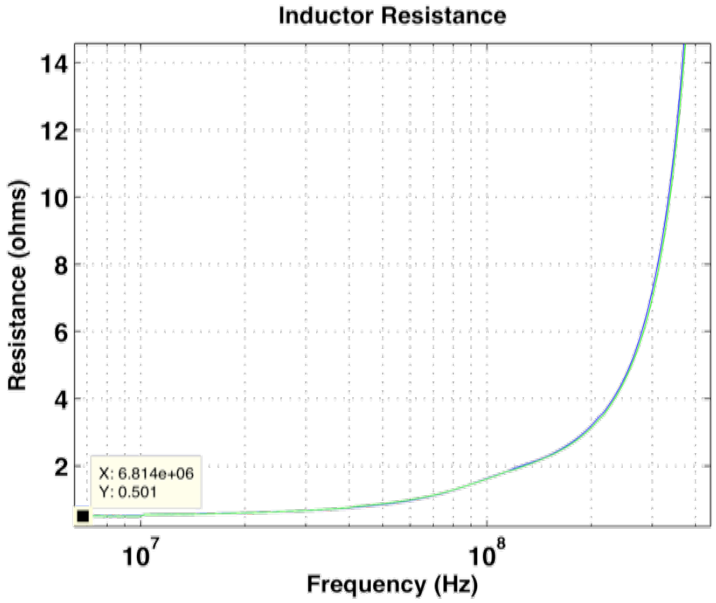
FERRIC INDUCTORS | Initial Results

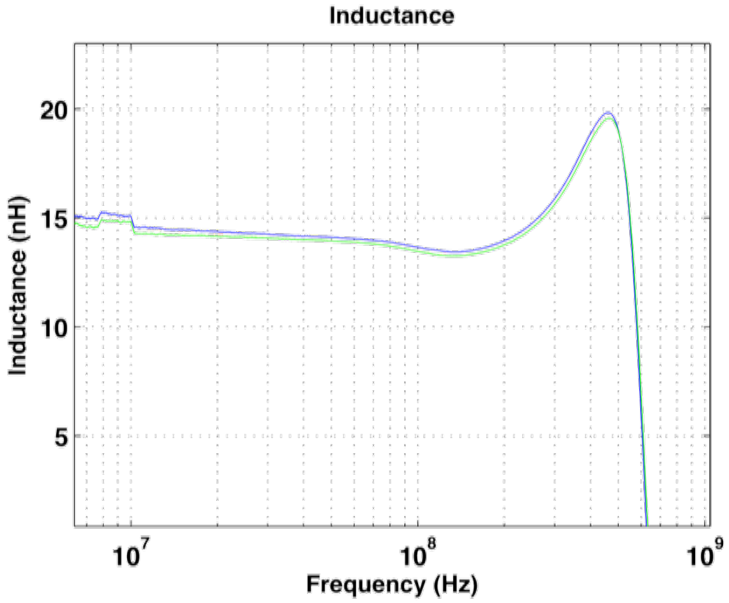
DC Resistance:
412mΩ

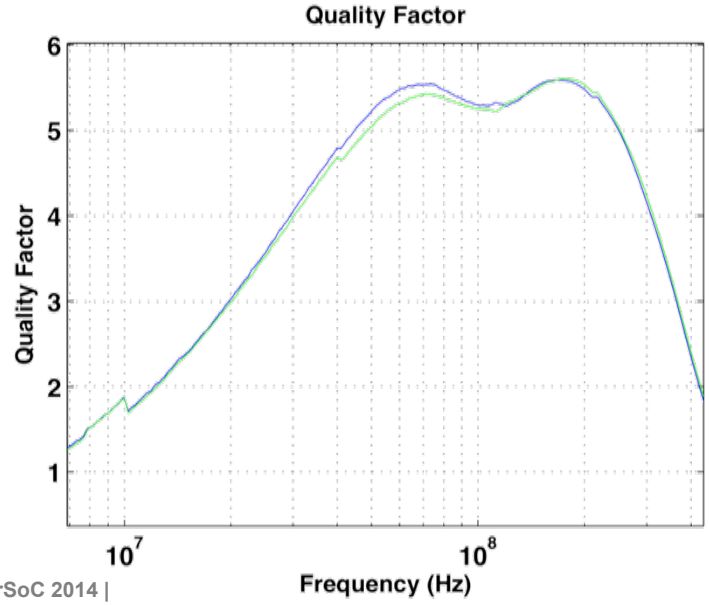
Inductance:
14.4nH

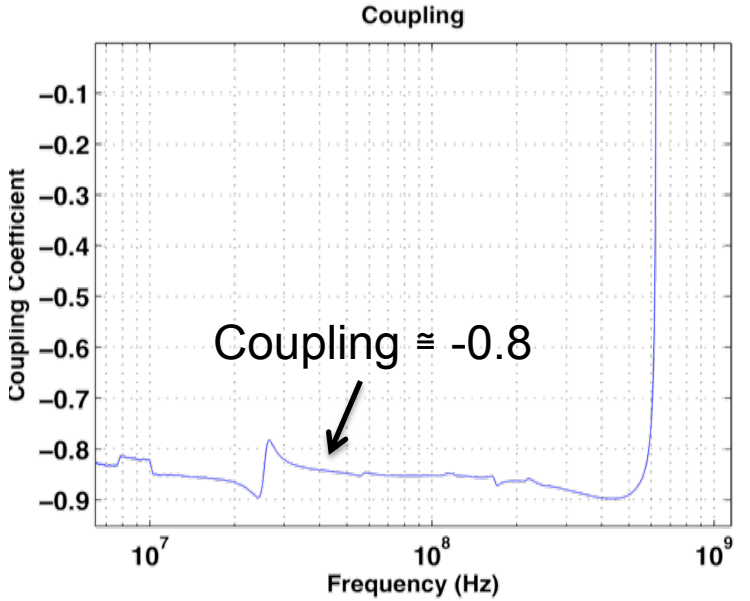
Area (2 ind's):
0.229 mm^2

Coupling:
-0.84









FERRIC INDUCTORS | *Relative Performance*

Ferric + TSMC 2013

- Inductance density of 85nH/mm^2
- Peak Quality Factor of 12 @ 200MHz
- Best performance of all inductors in 100MHz to 1GHz range or “torodial” type
- Coupled inductors achieve current density exceeding 2A/mm^2 before onset of magnetic saturation
- “Fed-Ex process”

Ferric + TSMC 2014

- New devices being fabricated now…

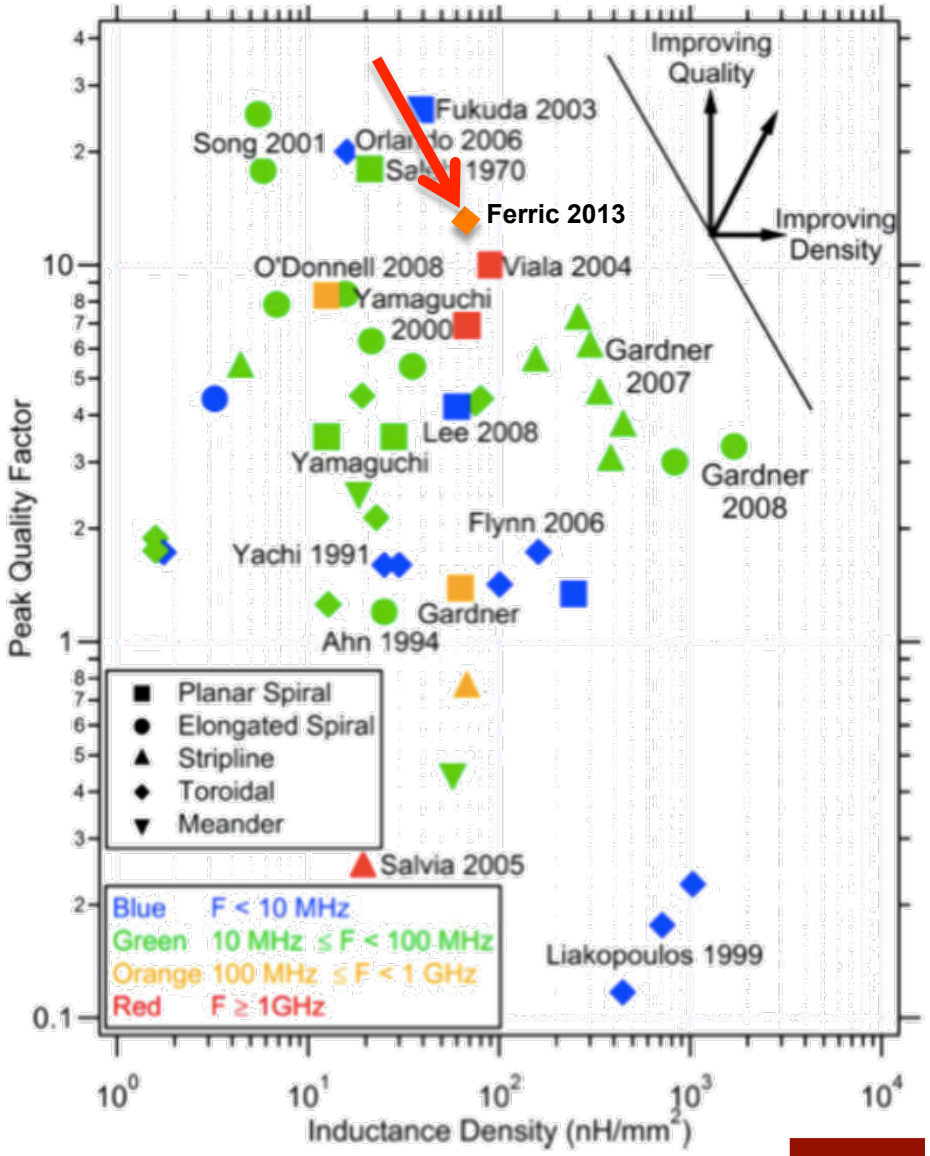


Figure from Gardner et al. IEEE TRAN. MAG., Vol. 45, No. 10, October 2009

DESIGN WITH INTEGRATED INDUCTORS

Necessary elements for IVR design with CMOS integrated inductors…

- Inductor IP and PDK Support (available from Foundry)
  - Inductor library covering design space (L, R, K, Area)
  - Compact circuit models (SPICE & Spectre)
  - PDK Support (DRC, LVS, extraction)
- Circuit IP (developed internal or available from Ferric or other IP providers)
  - Powertrain, Controller, Interface…
- Design Know-How
  - Inductor selection (optimal efficiency, density…)
  - Converter topology (multi-phase buck, coupled inductor…)
  - Other Design trade-offs …

Ferric is developing inductor libraries, models and complementary circuit IP

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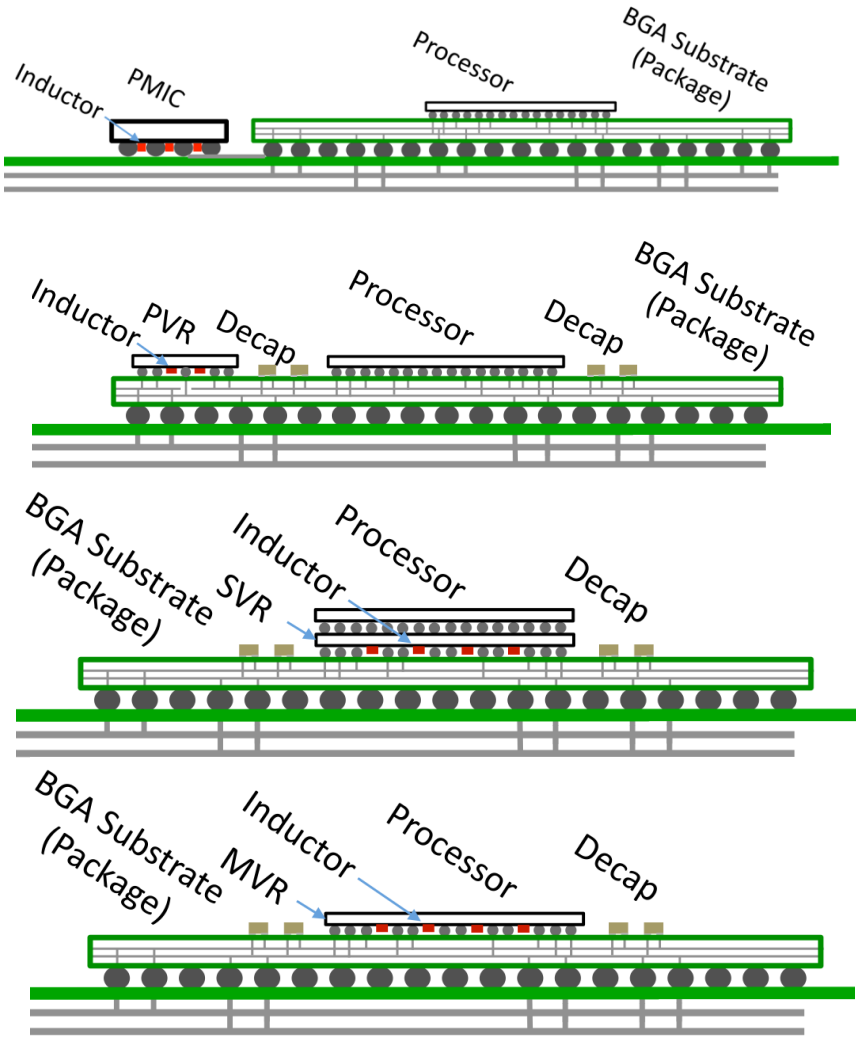
INTEGRATED INDUCTOR APPLICATIONS



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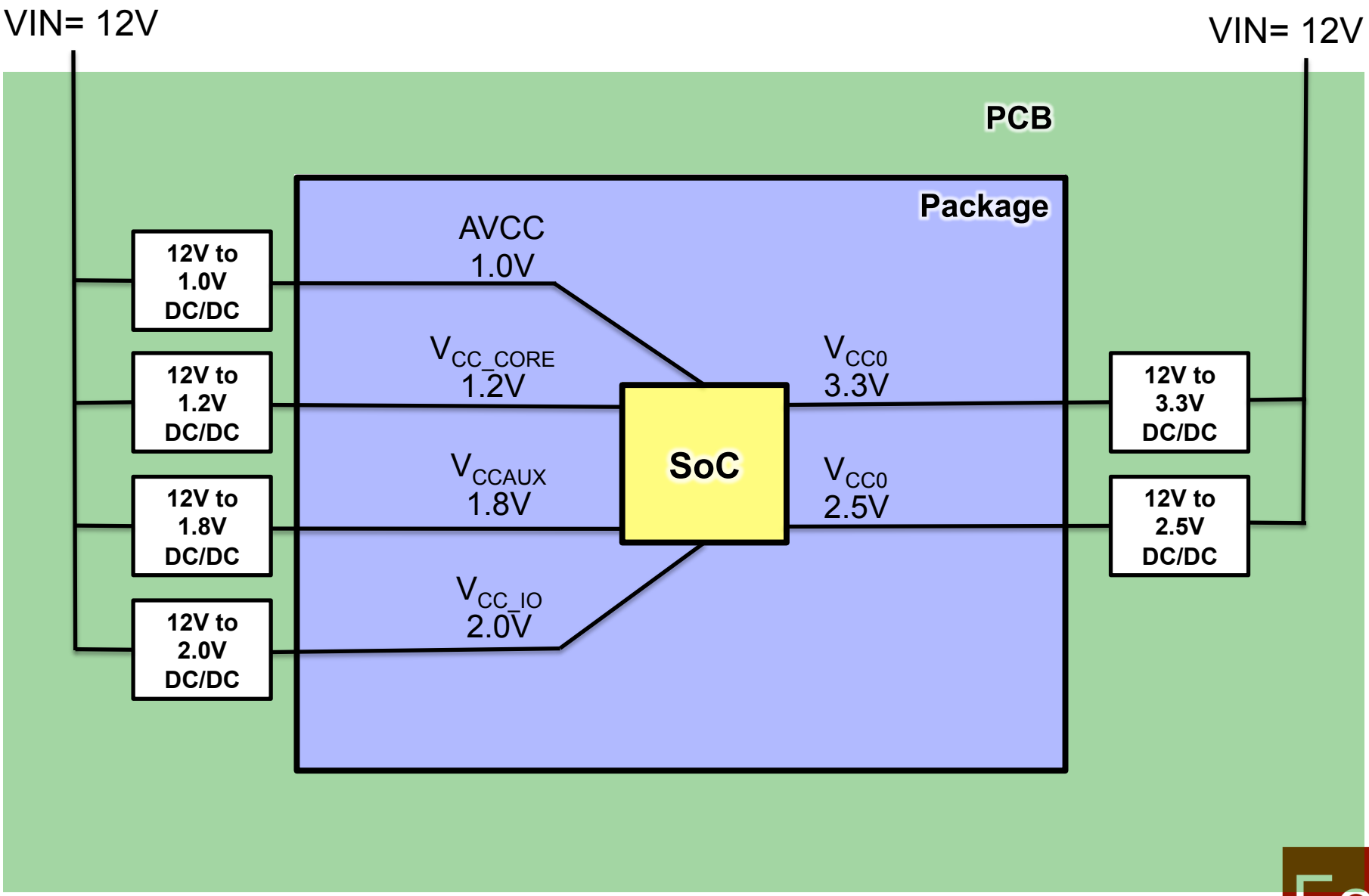
CURRENT TYPICAL IMPLEMENTATION



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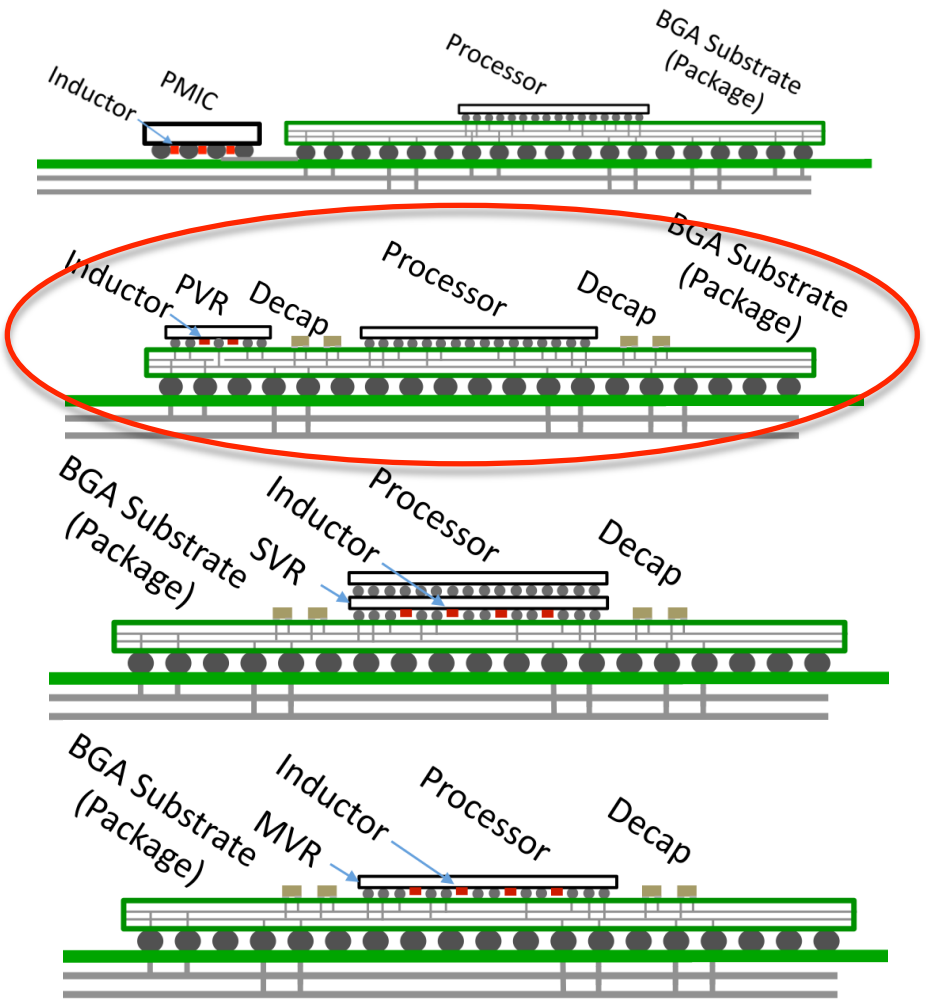

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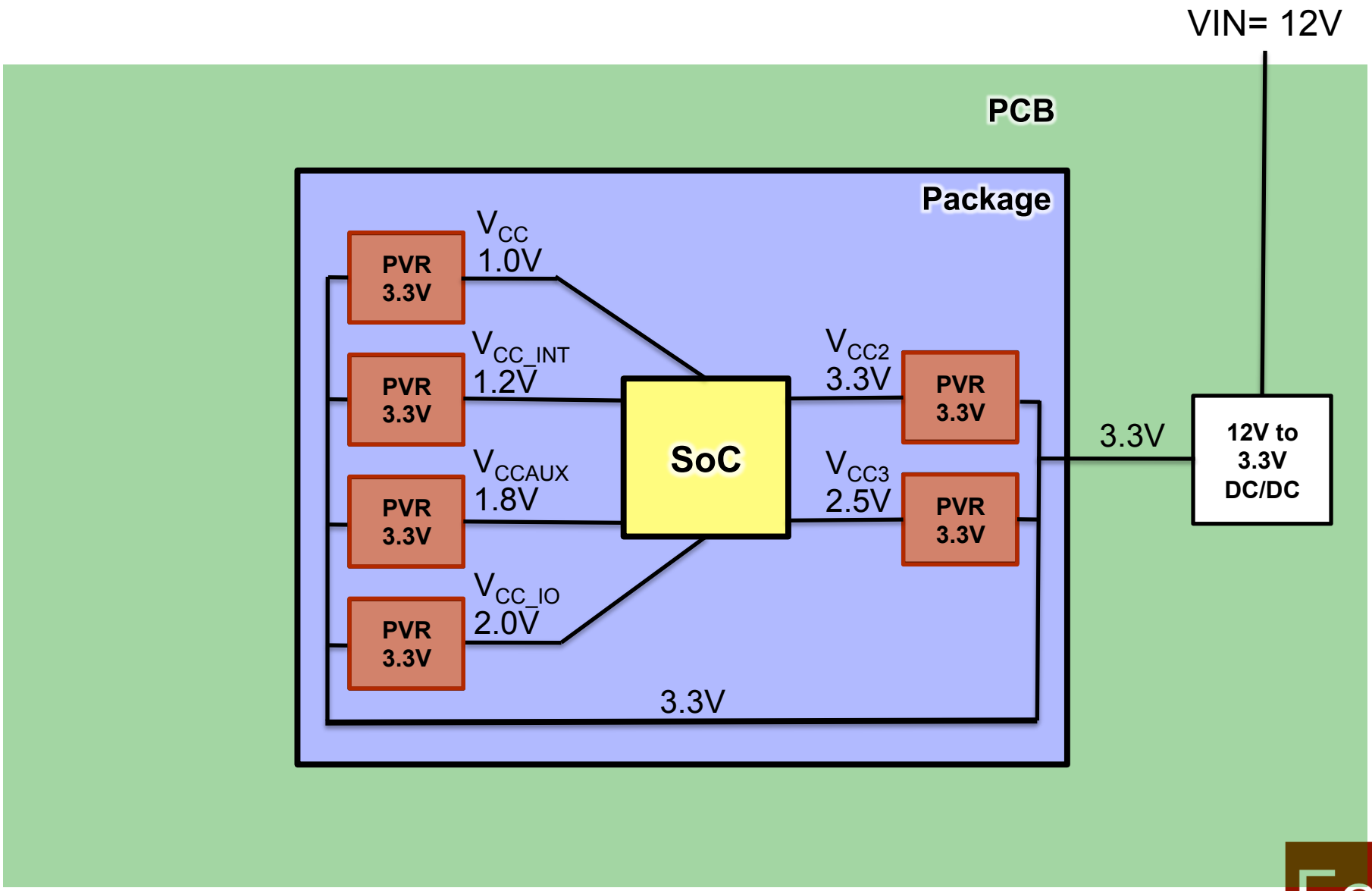

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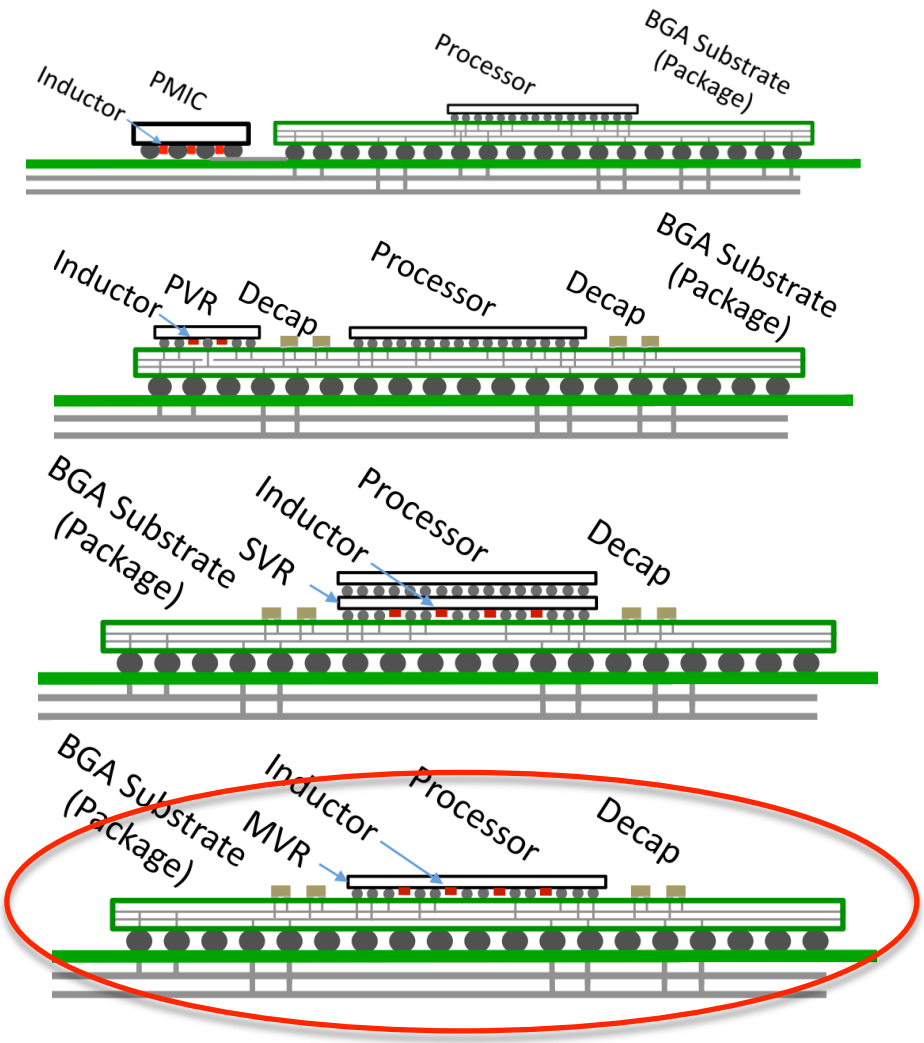

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