

INTEGRATED POWER MANAGEMENT WITH FERROMAGNETIC THIN-FILM POWER INDUCTORS **PwrSoC 2018** Noah Sturcken, PhD - Ferric, Inc. CEO

### **INTEGRATED POWER MANAGEMENT**

On-chip Magnetic Thin-Film Inductors enable integrated power management to Save Power, Space And Cost



## WHERE IS THIS APPLICABLE?

- Integrated Voltage Regulators (IVRs) reduce the size, power and cost of power management for microprocessors and other high performance ICs
  - Datacenter, automotive, mobile, wearable
- Integrated power inductors reduce power management component volume, facilitating the integration of power management functions onchip or in-package with the load IC – reducing size, power and cost



## FERRIC THE COMPANY

Fabless semiconductor technology company, founded in 2011

- Located in New York
- IVR Chip Sales, Design and Process Licensing
- Integrated power conversion and management products, IP and magnetic component technology
- Manufacturing partnership with TSMC
- Team expertise:
  - High speed CMOS power converter design
  - semiconductor device and product manufacturing
  - magnetic thin-films
  - RF device design, characterization and modeling

# FERRIC TECHNOLOGY

### Thin-Film Inductors

- Inductance density
  - > 300nH/mm<sup>2</sup>, > 8,500nH/mm<sup>3</sup>
- Current density > 12A/mm<sup>2</sup>
- DC Resistance <  $50m\Omega$
- Magnetic Coupling k > 0.9
- Ferric Technology fabricated by TSMC





### DC-DC Converters

- High switching frequency > 100MHz
- High bandwidth controller > 10MHz
- Optimization for high efficiency >90%
- Optimization for high density >3A/mm<sup>2</sup>





# FERRIC INDUCTORS

*Ferric* CMOS integrated magnetic thin-films enable high-quality, high-density, low-profile on-chip/in-package inductive components

#### Integrated with Standard CMOS Flow

- Inductor layers available as BEOL process option (similar to MIM)
- Ferric Inductor Cell Library
- Circuit models, DRC, LVS







#### **FERRIC** INDUCTORS L & R VS. FREQUENCY WITH IAVG SWEEP: MEASUREMENT & MODEL

Compact circuit models for Ferric Library devices include magnetic saturation, temperature and large-signal effects



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#### FERRIC INDUCTORS LARGE SIGNAL, HIGH FREQUENCY LOSS CHARACTERIZATION & MODEL



#### **FERRIC** INDUCTORS | Library performance



#### **FERRIC** INDUCTORS | Solenoid inductor example



#### **FERRIC** INDUCTORS | Coupled inductor example



### FERRIC INDUCTORS | Highlights

- Peak Q Factor 30 @ ~225MHz
- Peak Inductance Density ~500nH/mm<sup>2</sup>
- $L/R_{DC} > 1 u H/\Omega$  for L > 100 n H
- $L/R_{DC}$  of 360nH/ $\Omega$  for L ~ 10nH
- Saturation Current exceeding 4.0A for single inductors
- Current Density exceeding 20A/mm<sup>2</sup> for coupled inductors
- Cross wafer (300mm) inductance variability  $\sigma < 3\%$
- Simulation-to-Bench efficiency correlation within 0.5%
- Improvements in process throughput, R<sub>AC</sub> and durability
- Other Devices in evaluation:
  - Transformers, Baluns, antennas, improved inductor designs

## FERRIC Power Converters | Mobile

*Ferric* Power Converters utilize Ferric's CMOS integrated magnetic thin-film power inductors to achieve high density, efficient power conversion with high-bandwidth regulation – enabling **Integrated Power Conversion** for high-performance and space constrained digital ICs in a range of packaging options



Power Supply in Package (PSiP)

 Package Integrated Voltage Regulators (PVR)



 Monolithic Voltage Regulator (MVR)

## **FERRIC** Power Converters | Datacenter

*Ferric* Power Converters relieve demanding power integrity constraints for enterprise processors, while reducing current levels in the up-stream power delivery network. CMOS compatible manufacturing provides flexible packaging options at TSMC to provide best value power solution for a wide range of power requirements



- Package Integrated Voltage Regulators (**PVR**)
- 3D Integrated Voltage Regulator (3DIVR)

 Monolithic Voltage Regulator (MVR)

## **QUESTIONS?**



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