

3D-PEIM 2023

# Practical Challenges with Advanced IVR Solutions for Microprocessors

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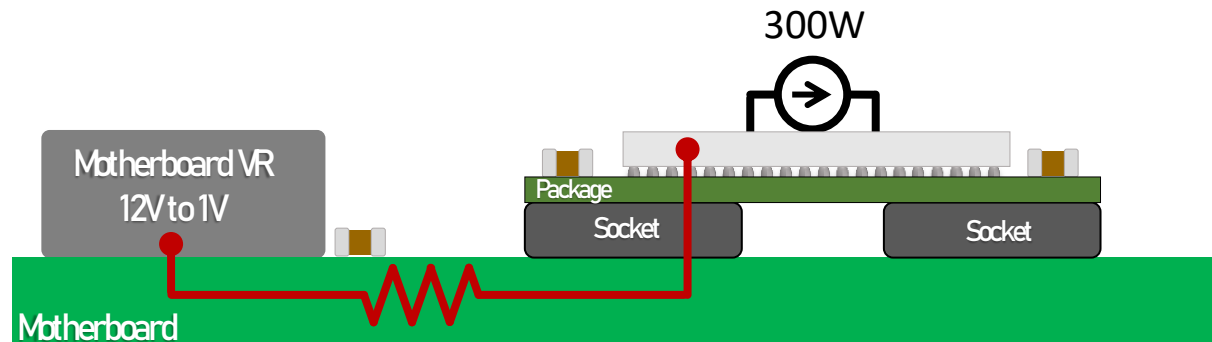
intel<sup>®</sup>

# Agenda

- Why use IVRs in microprocessors
- History
- Where are we today
- Challenges moving forward – the ‘exciting ones’
- Challenges moving forward – the ‘practical ones’
- Summary

# Why Use Integrated VRs – 3 Reasons

## Reason #1



### NO IVR

CPU Power = 300W @1V

CPU Current = 300A

PDN Resistance = 0.7mΩ

Power =  $I^2R$

Loss in PDN R = **63W**

### With IVR

CPU Power = 300W @2V

CPU Current = 150A

PDN Resistance = 0.7mΩ

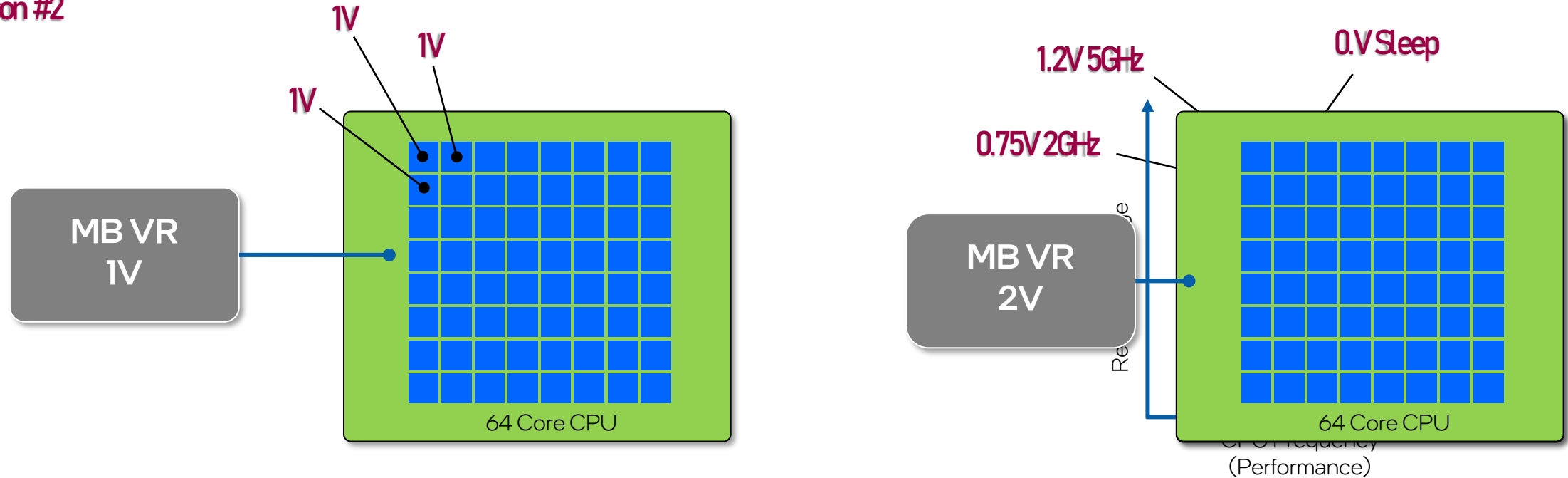
Power =  $I^2R$

Loss in PDN R = **16W**

High power CPUs suffer very large  $I^2R$  losses on input networks

# Why Use Integrated VRs – 3 Reasons

Reason #2



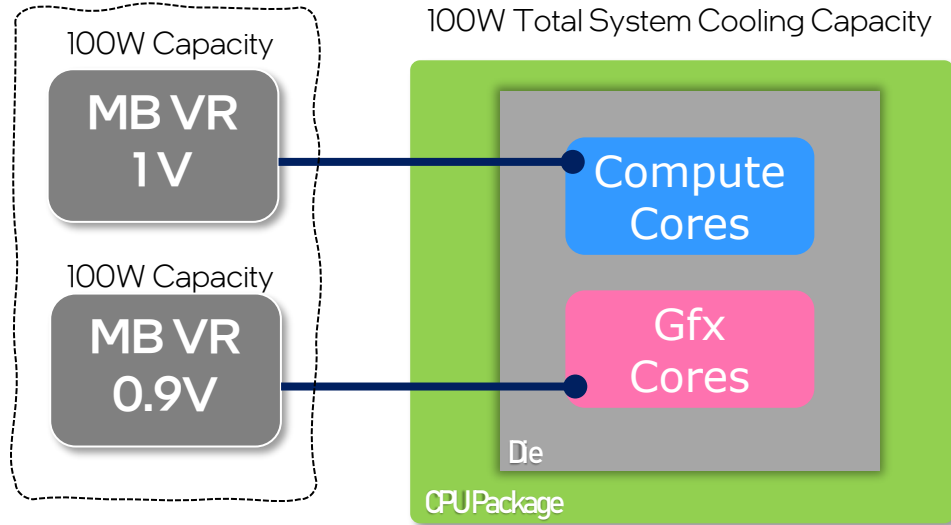
Performance tradeoffs can be optimized when each core has its own supply

# Why Use Integrated VRs – 3 Reasons

## Reason #3



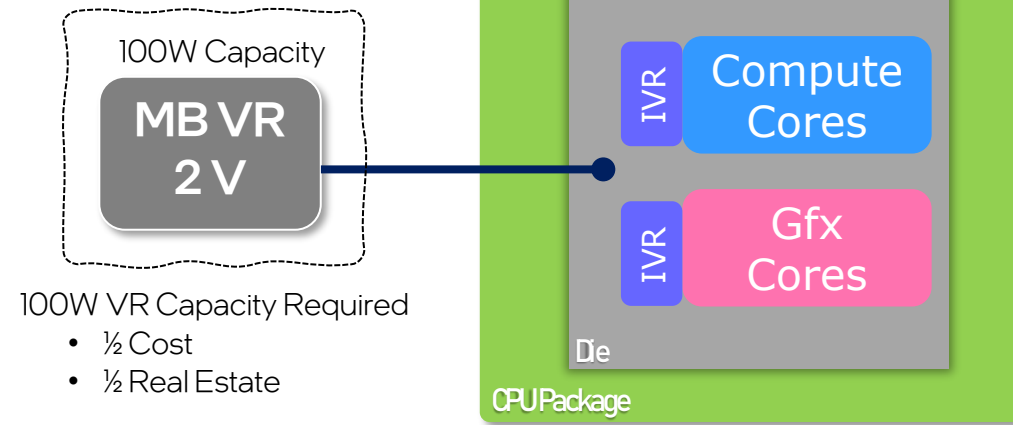
100W Total System Cooling Capacity



**Traditional**



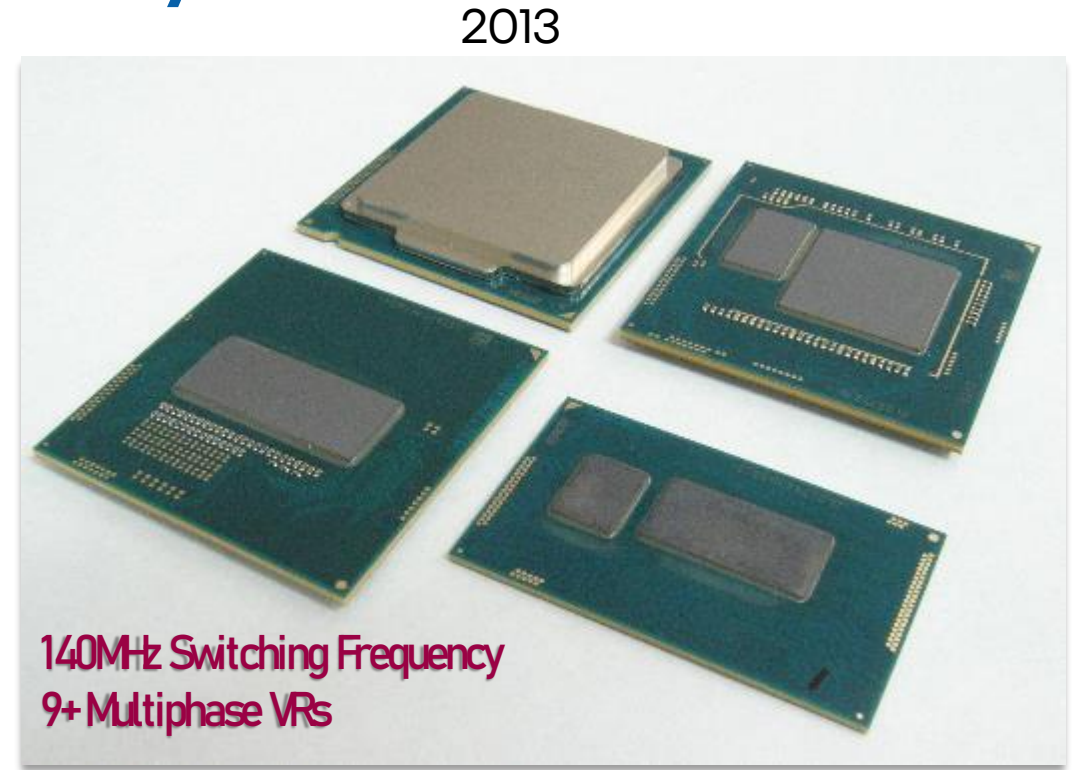
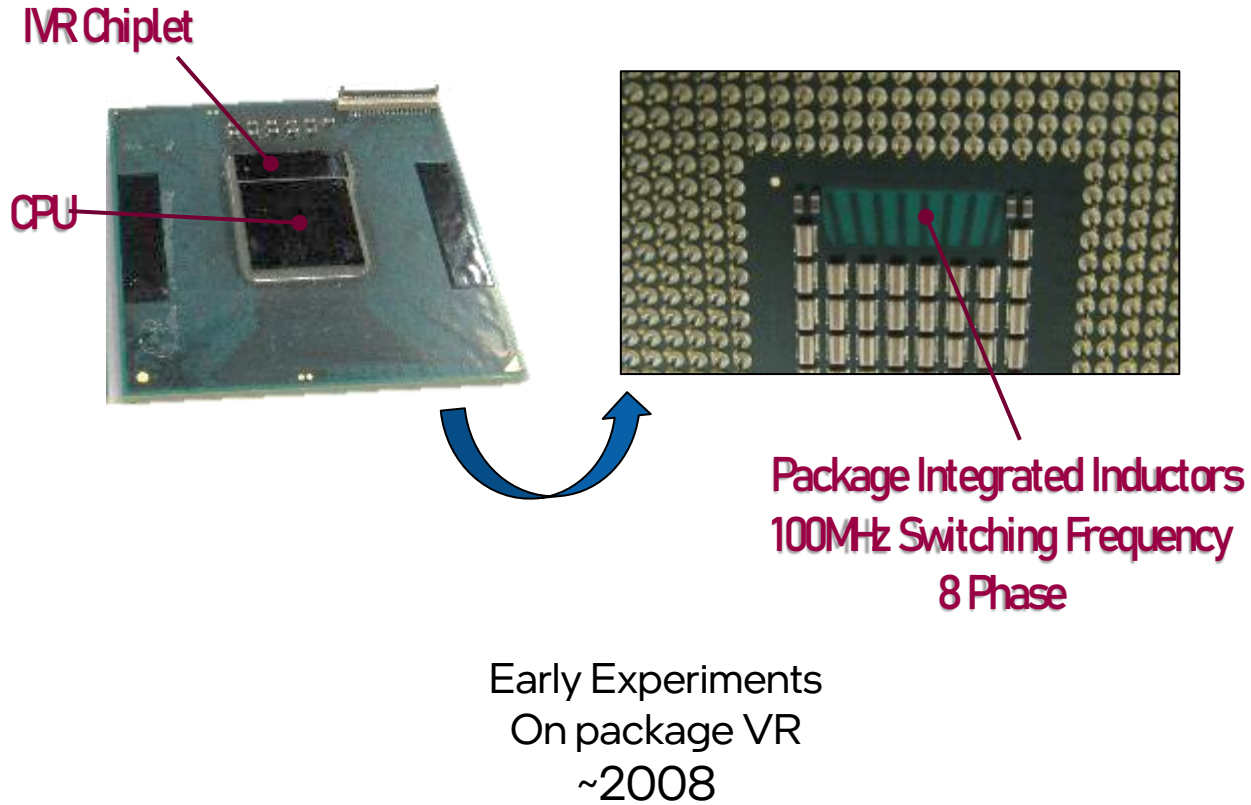
100W Total System Cooling Capacity



**IVR**

**Motherboard VR capacity is wasted when MBVRs are used to provide granularity**

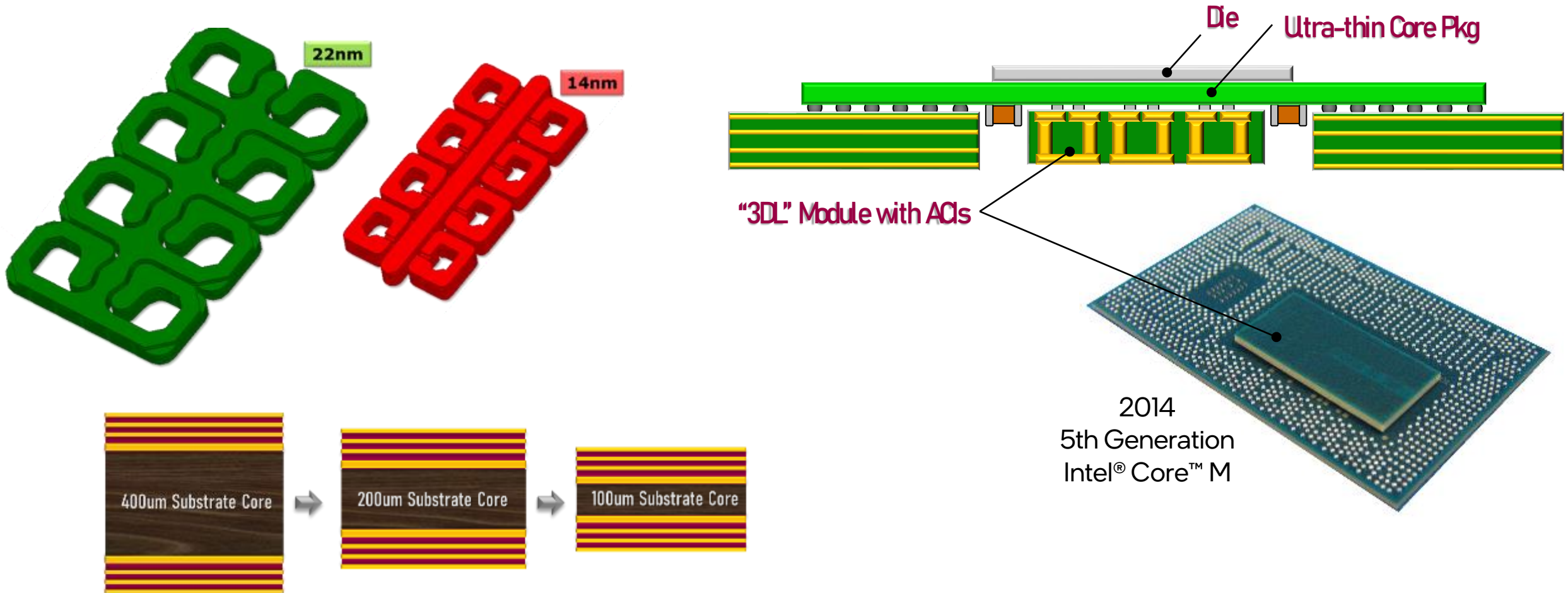
# Intel IVR History



First Ultra High Volume IVRs  
4<sup>th</sup> Generation Intel® Core™ Processor Family  
Fully Integrated Voltage Regulator (FIVR)

Prior to 2008, fast switching regulators were 500KHz

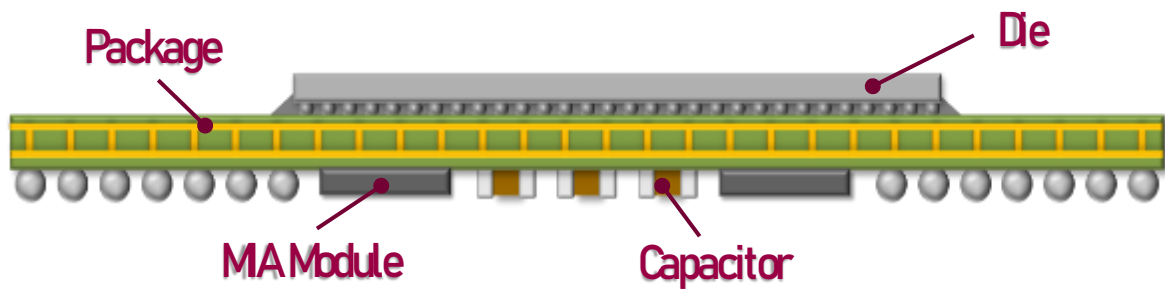
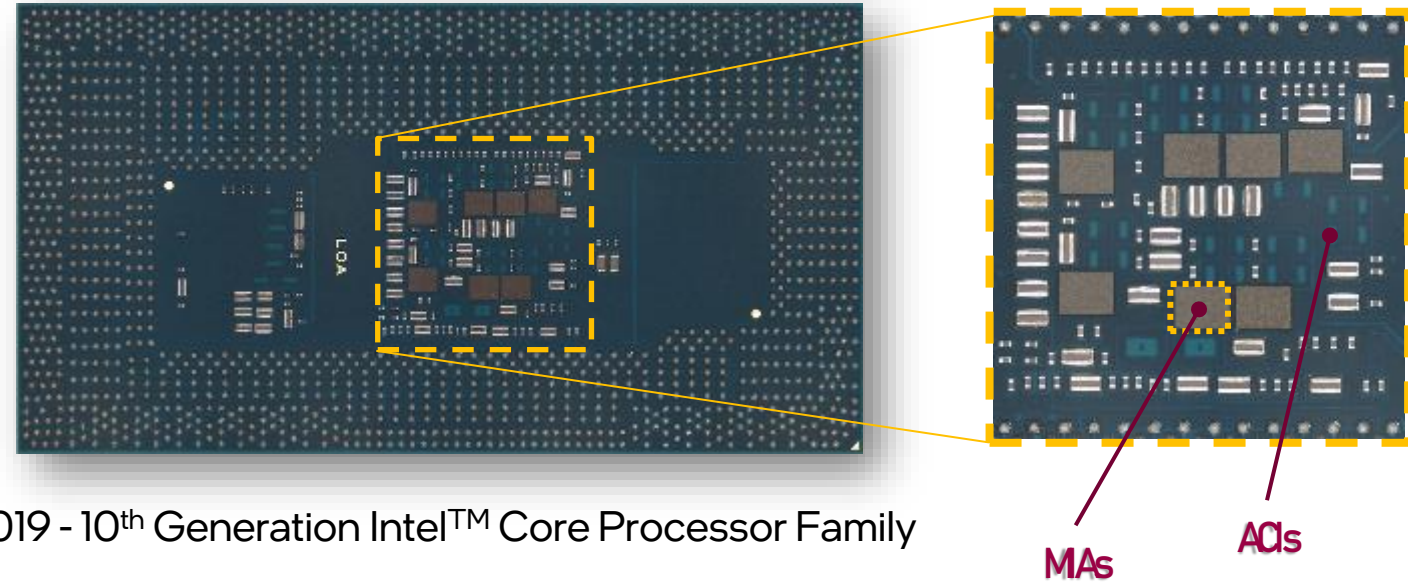
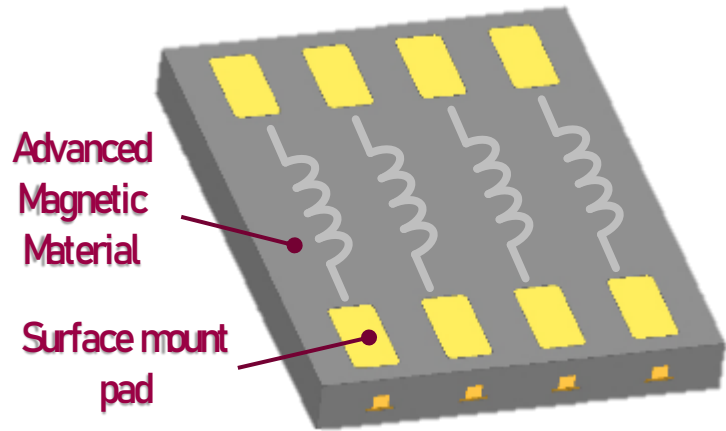
# Intel IVR Advancements



Moore's law drove core shrink, and with it, inductor shrink

# Magnetics Modules

## Magnetic Inductor Array Module

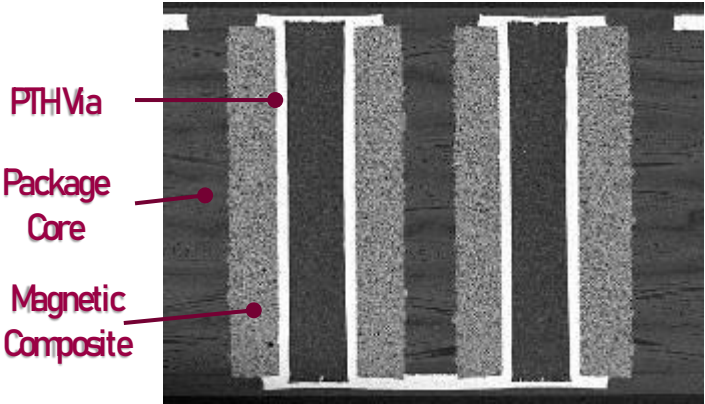
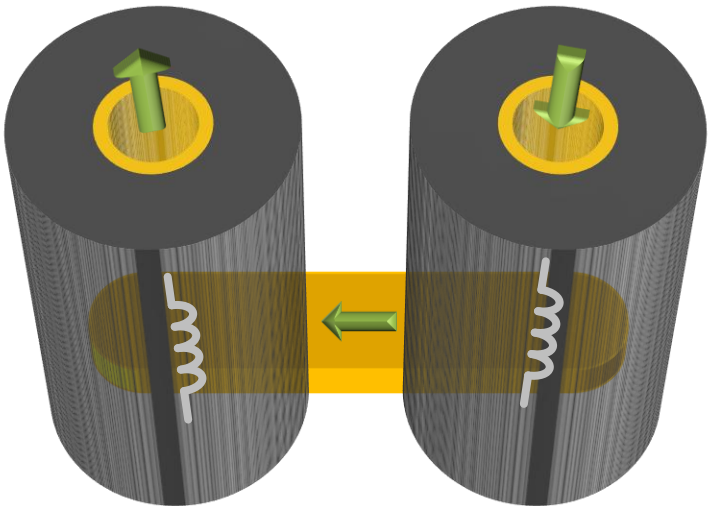


Magnetics needed for continued inductor density increases



# Coaxial Magnetic Integrated Inductor

Coax MIL



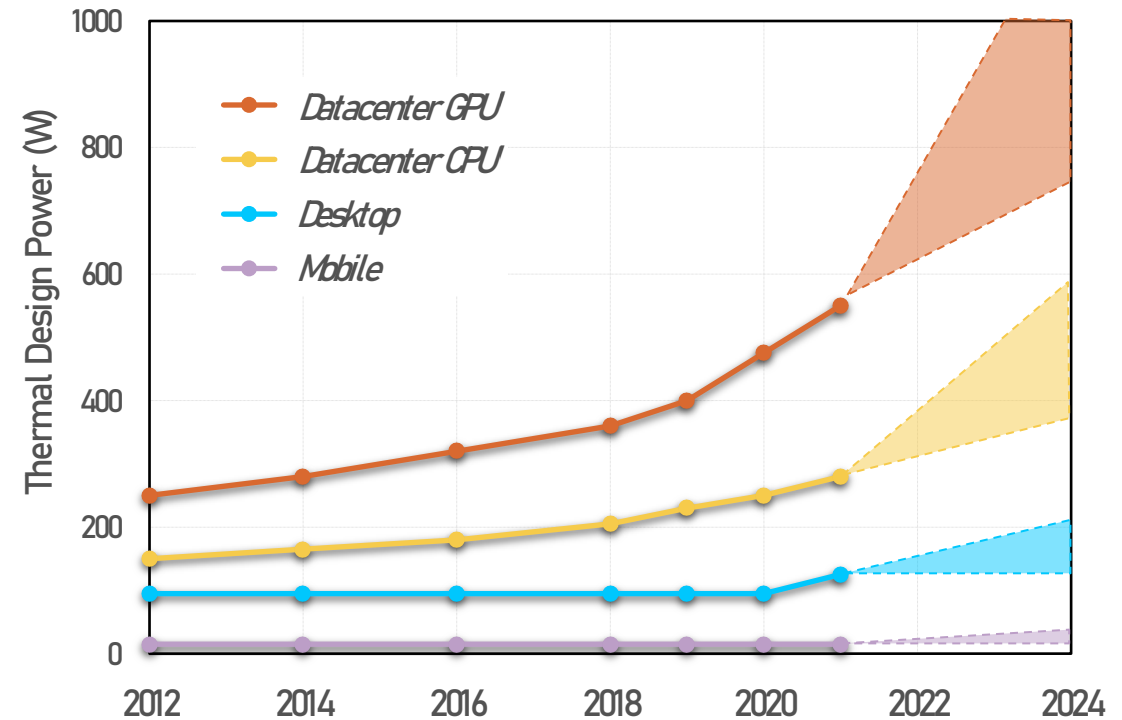
2023 - 4<sup>th</sup> Generation Intel® Xeon® Scalable Processors



The importance of advanced magnetics will continue to grow

# Moving Forward – Common IVR Focus Topics

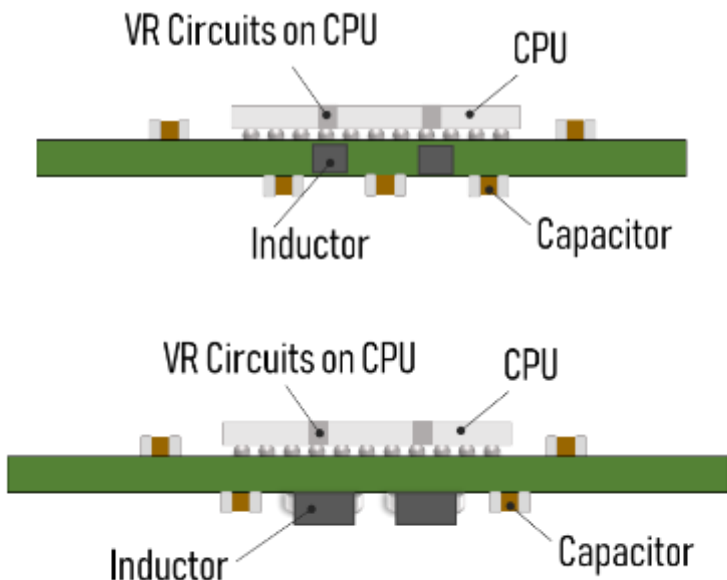
- Efficiency
  - Heat must be removed pkg & building
  - Loss not used for compute
  - 100's of Millions of VRs x 1% is a lot of power
- High Input Voltage
  - System efficiency driver
- Fast response time at the load
  - MIM Density + VR Design
- Magnetic Materials
  - New, exotic materials
- New Topologies
  - VR and components



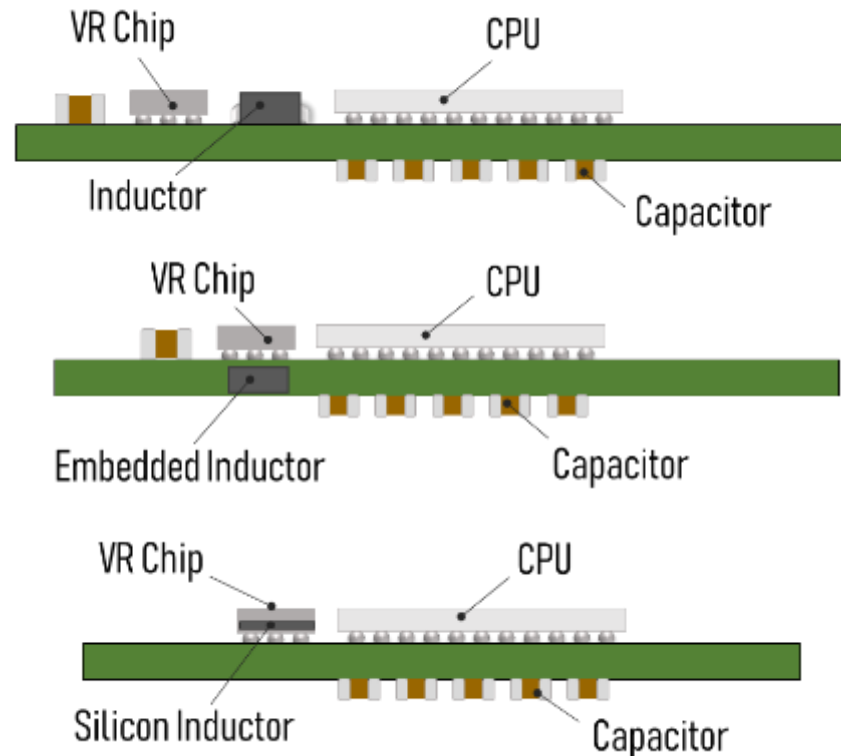
**These topics are all very important but not the subject of today's presentation**

# Practical Issues

Placement – where does an IVR go?



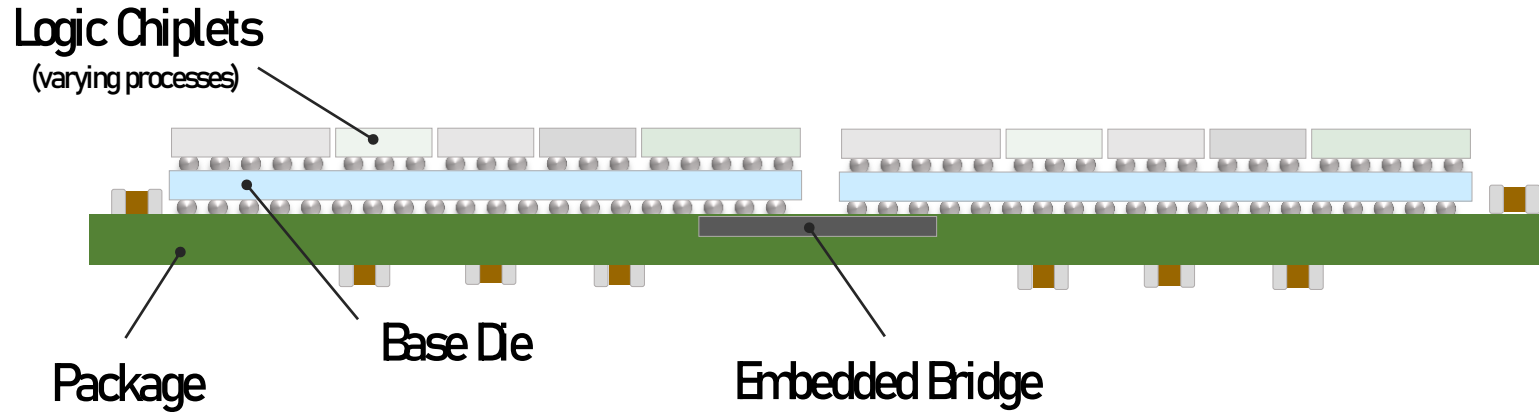
Traditional Designs



Chiplet Options

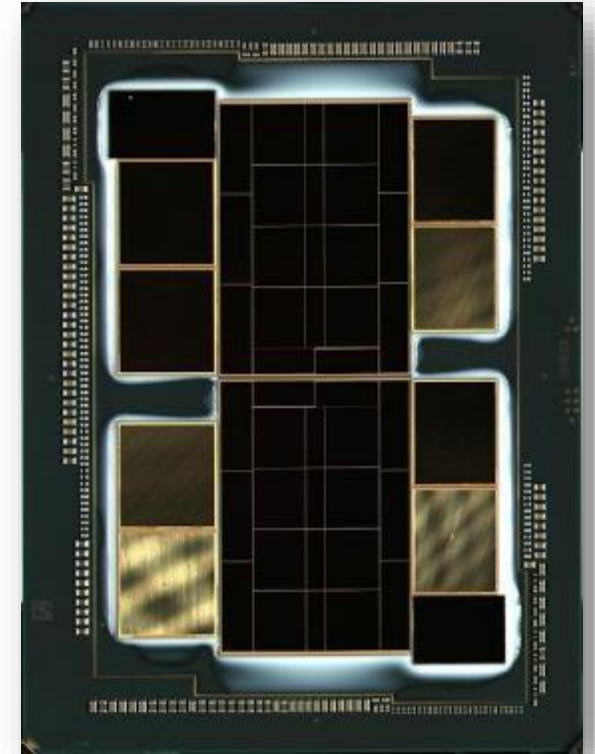
Choice of placement of the IVR creates many boundary conditions on the IVR circuit design

# IVR Placement 3D Integration



## 3D Packaging

- All same options, plus many more
- Where do my IVRs go?
- Inductors, capacitors?



Intel® Data Center GPU Max

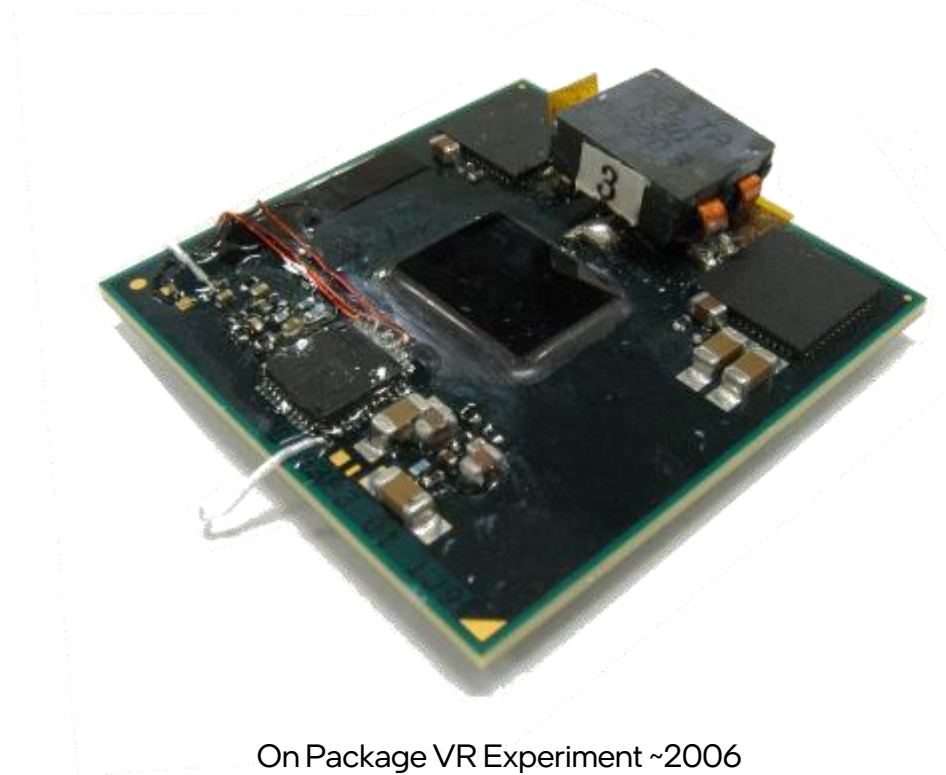
>100 Billion Transistors

Matching placement to IVR design critical for viability

# Practical Issues Often Neglected

- Examples

- Routing Challenges
- Design complexity
- Modeling complexity
- Cross team execution
- Production Test
- Assembly
- Yield Impact
- EMI / RFI
- Trimming
- Burn in



**The un-glamorous aspects of IVR integration can render a new topology unusable**

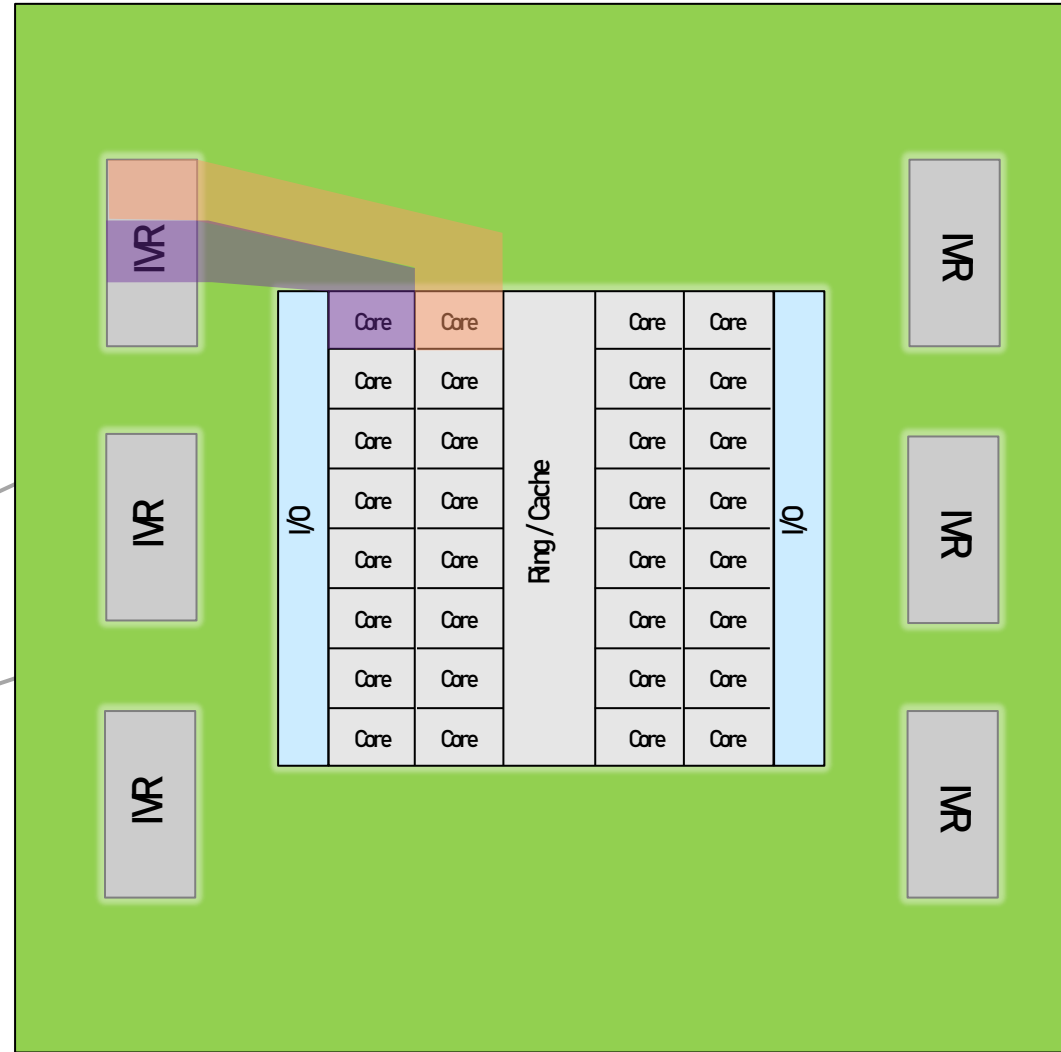
# Package Routing is a Huge Challenge

Examples –

- IVR to Core power
- Response time degrades with distance
- IVR Control signals
- IVR to IVR communication

Large Die Region

Dense, High-Speed Routing



Power plane and control signal routing severely limits IVR placement options

# Can You Build 10's of Millions?

Each unit will have many IVRs

- My have 600+ Inductors per package
- Can Single IVR fail kill part?
- Manufacturing tolerances
- How do you know if all inductors are good?

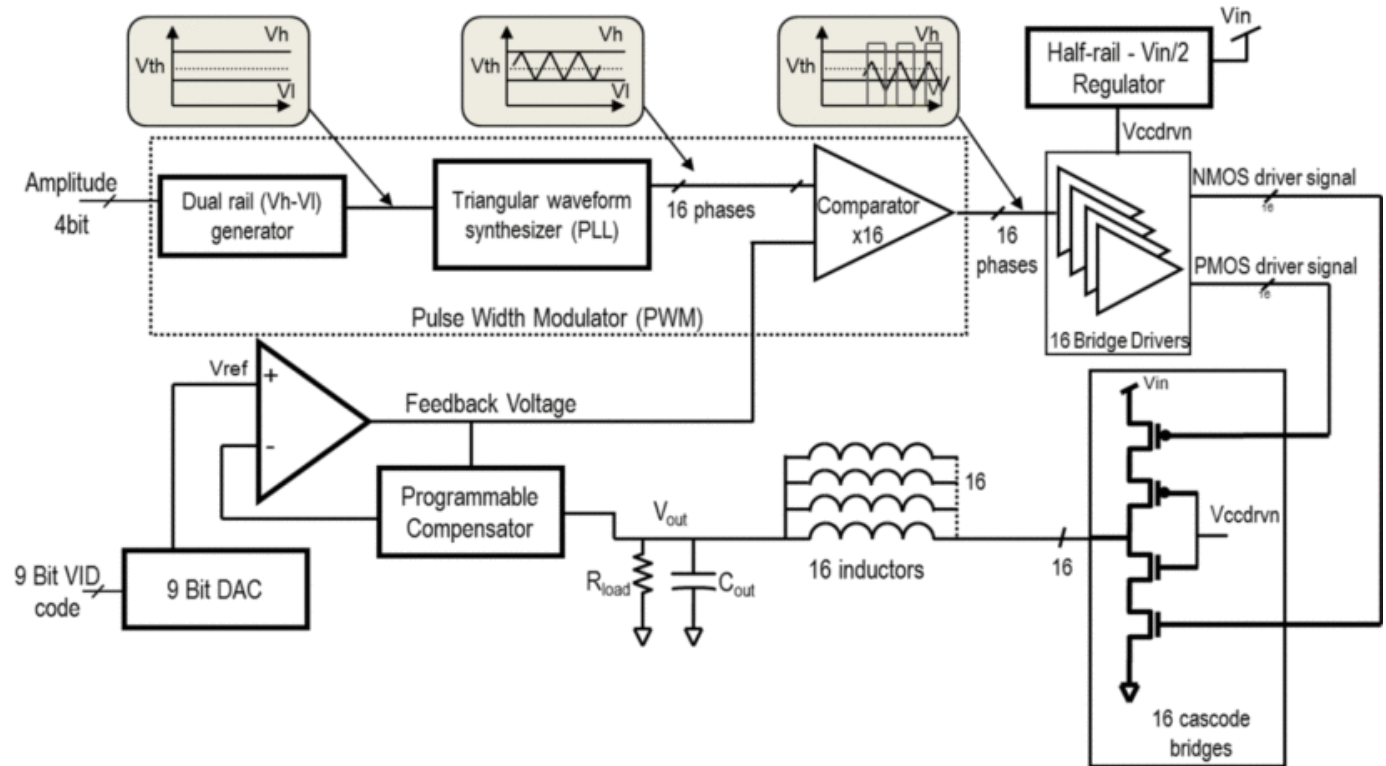


**Designs friendly to recoverability, testability and HVM component variation enable scalability**

# Complex Control Scheme Challenges

## Trimming Common

- Examples
  - Amplifiers / Comparators
  - Bias voltages
  - Compensator settings
  - Sensors
  - Waveform generators
- Test Time
- Test Complexity
- Power on / debug

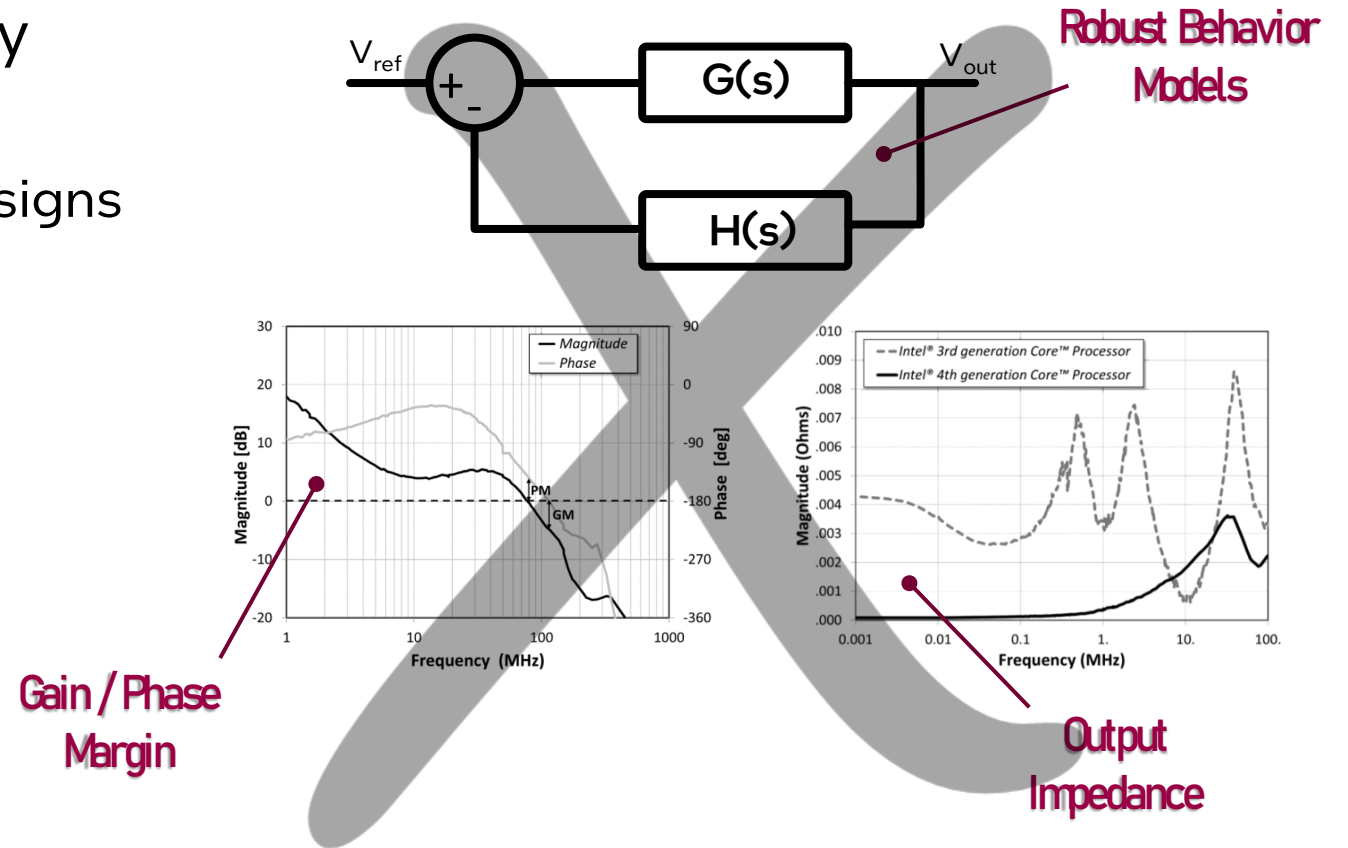


Designs not needing many trims or fuses are required for high IVR count products



# Fundamentals - Non-Linear Control

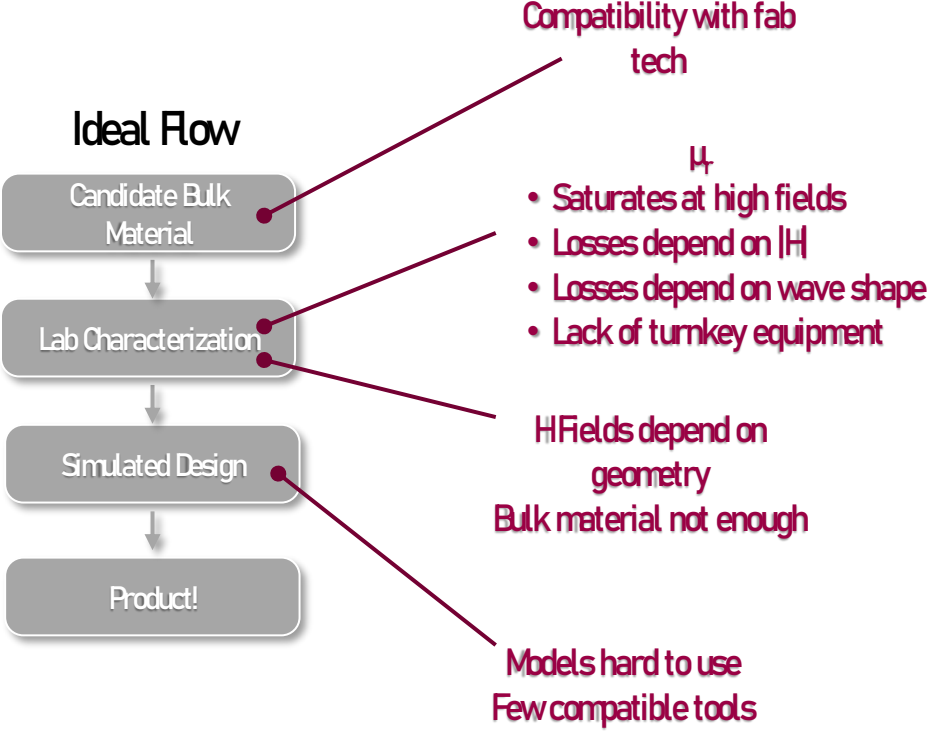
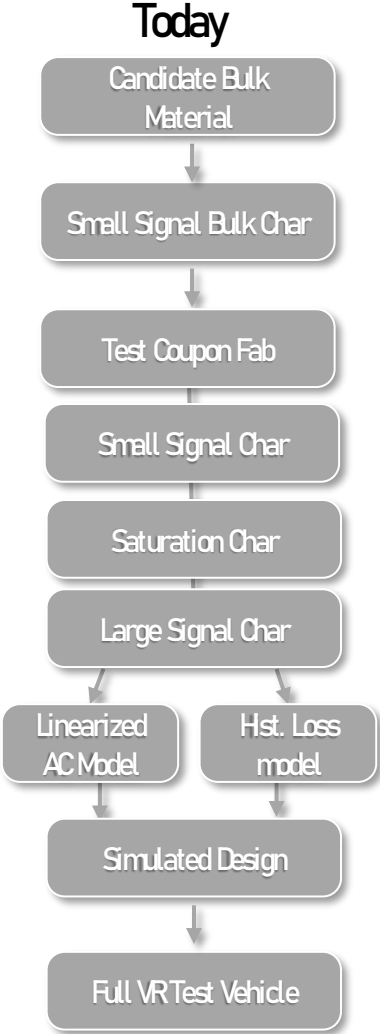
- Many NL Control schemes in play
  - Old and new NL buck features
  - Highly complex switch capacitor designs
- Lack Fundamental
  - Stability metrics
  - Performance metrics
  - Theoretical frameworks



Most Non-Linear designs lack solid fundamental theoretical frameworks to guarantee performance

# Fundamentals - Non-Linear Magnetics

- Density pushes high  $\mu_r$ 
  - Saturation effects
  - Large signal loss effects
- Traditional 'trial and error' inductor methods not feasible
- Creation and use of models require deep expertise



Magnetics models need advancements to improve usability and precision

# Summary

- IVRs Are here to stay
- Many advances being made
- Be careful – practical challenges make many new IVR ideas unusable
- Fundamental work still needed in many areas



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