3D-PEIM 2023

Practical Challenges with Advanced IVR Solutions for Microprocessors

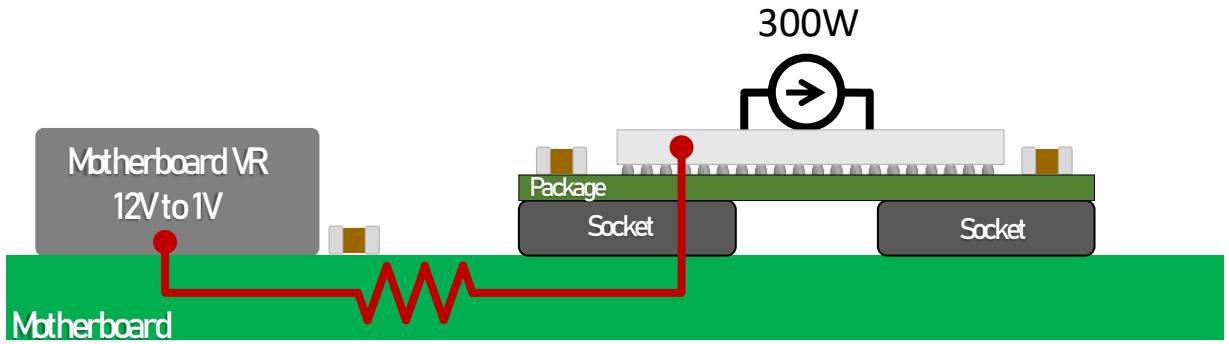
Michael J Hill PhD
Principal Engineer
Assembly and Test Technology Development

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

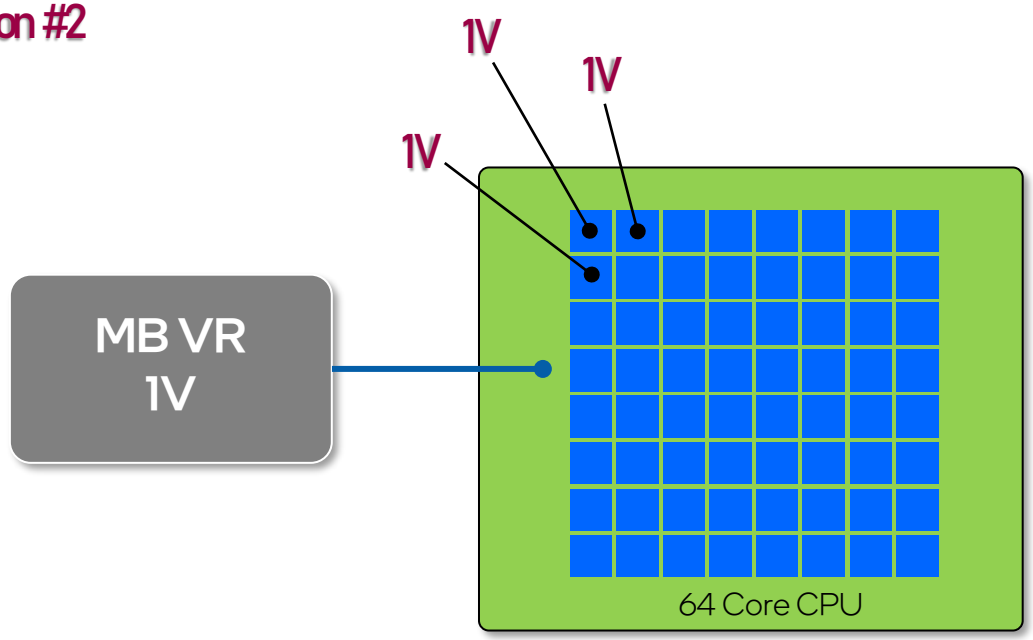
CPU Power = 300W @2V

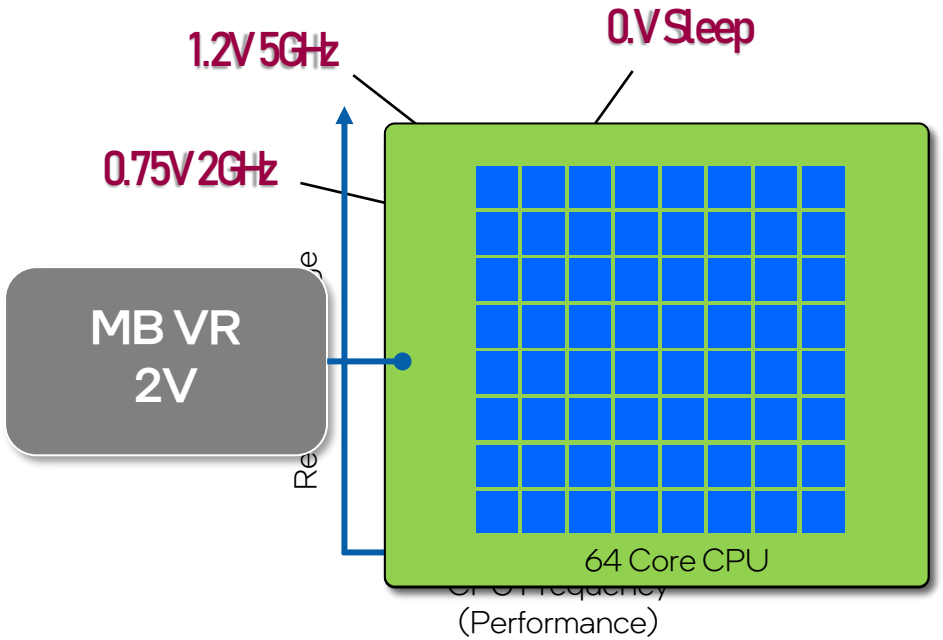
CPU Current = 150A
PDN Resistance = 0.7mΩ
Power = I^2R
Loss in PDN R = 16W

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

Why Use Integrated VRs – 3 Reasons

Reason #2

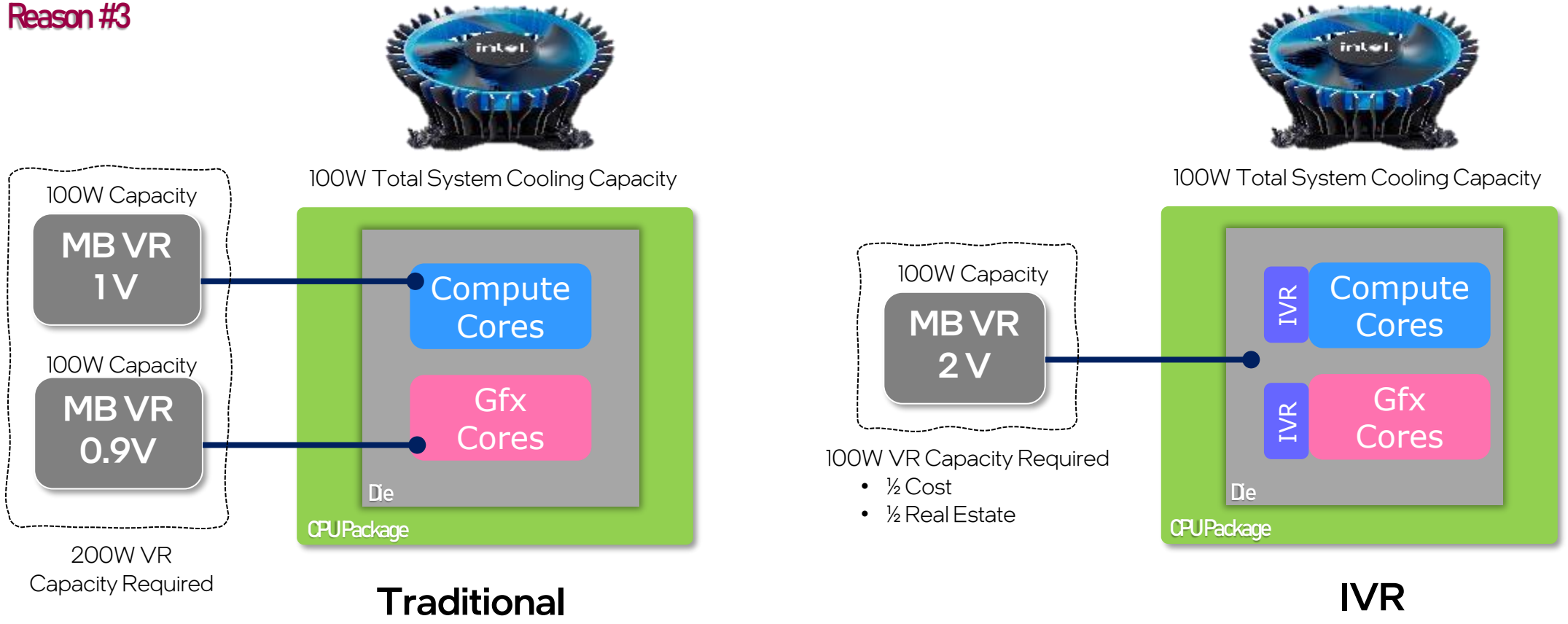




Performance tradeoffs can be optimized when each core has its own supply

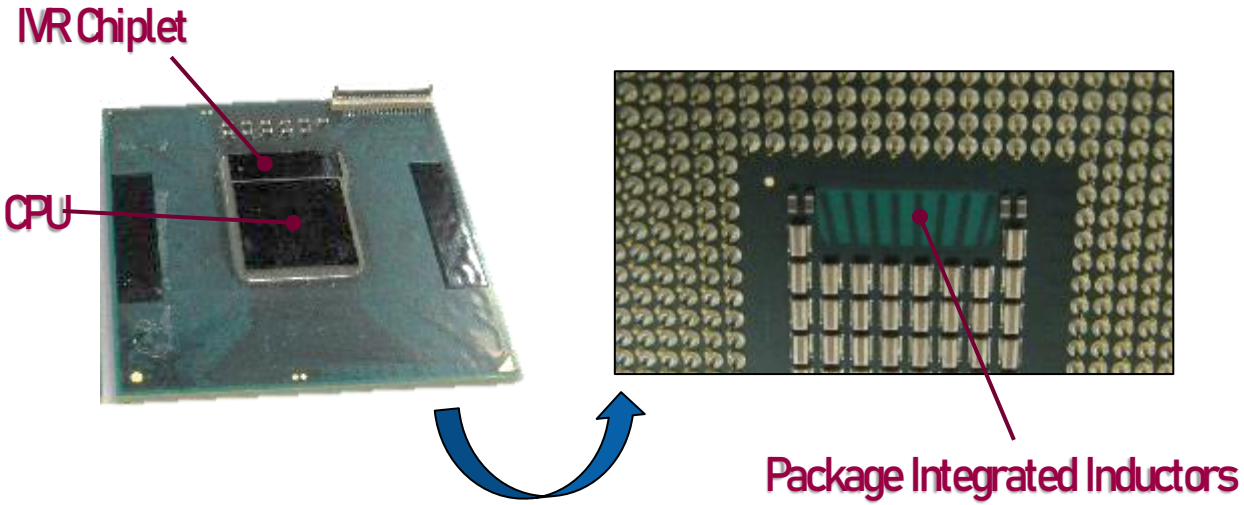
Why Use Integrated VRs – 3 Reasons

Reason #3



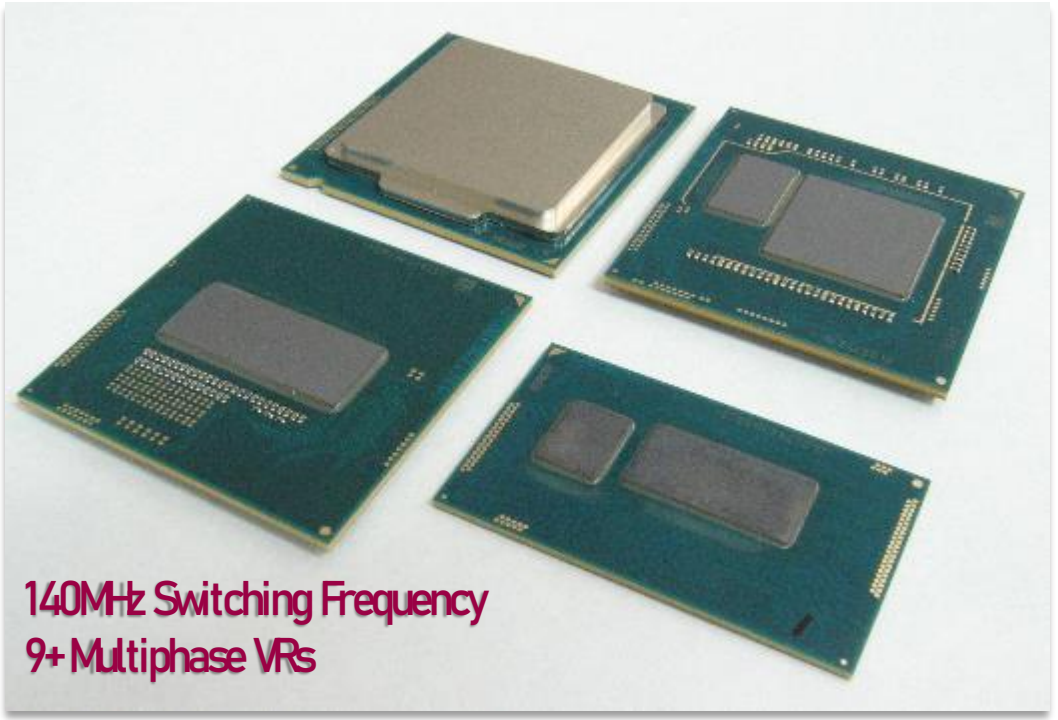
Motherboard VR capacity is wasted when MBVRs are used to provide granularity

Intel IVR History



Early Experiments
On package VR
~2008

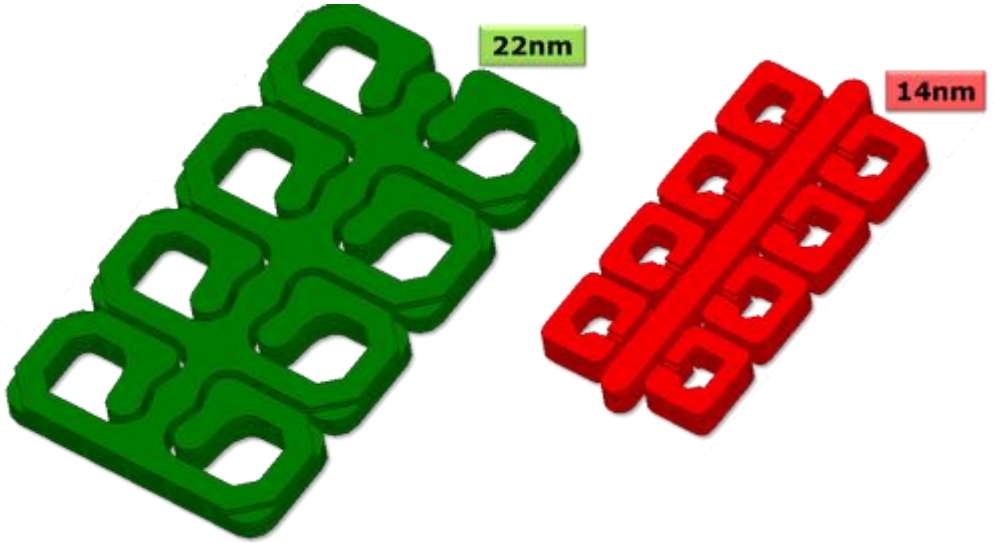
2013

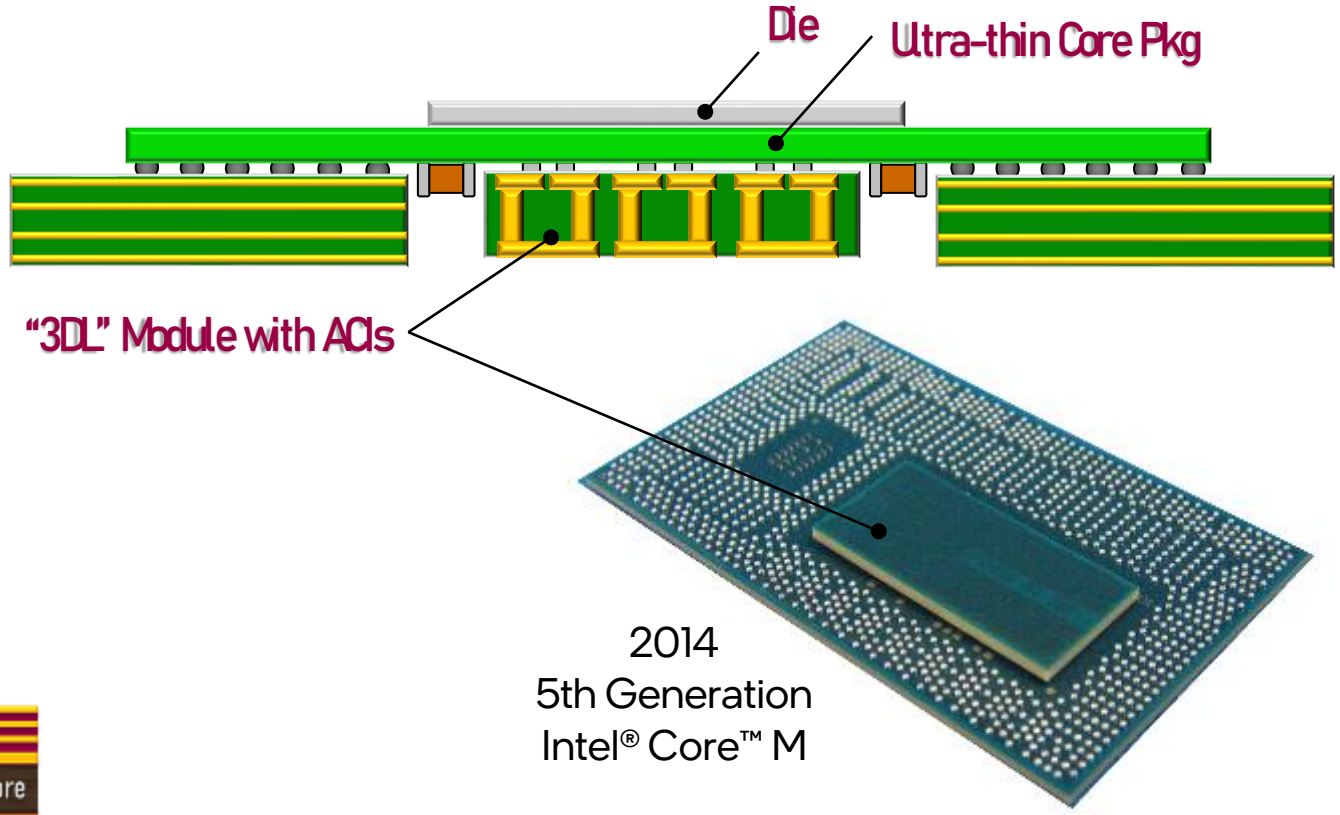


First Ultra High Volume IVRs
4th Generation Intel® Core™ Processor Family
Fully Integrated Voltage Regulator (FIVR)

Prior to 2008, fast switching regulators were 500KHz

Intel IVR Advancements



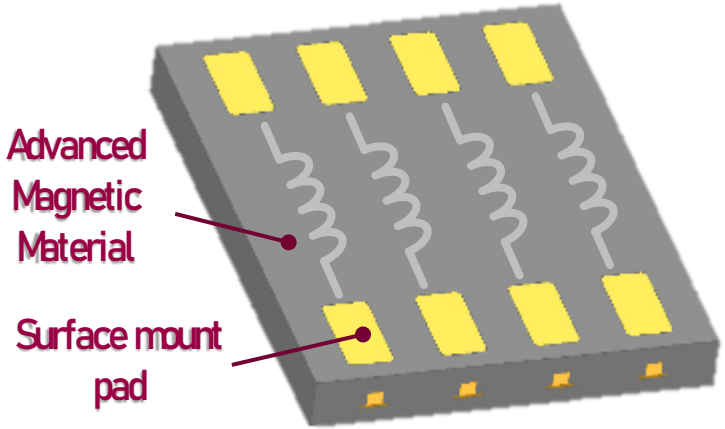


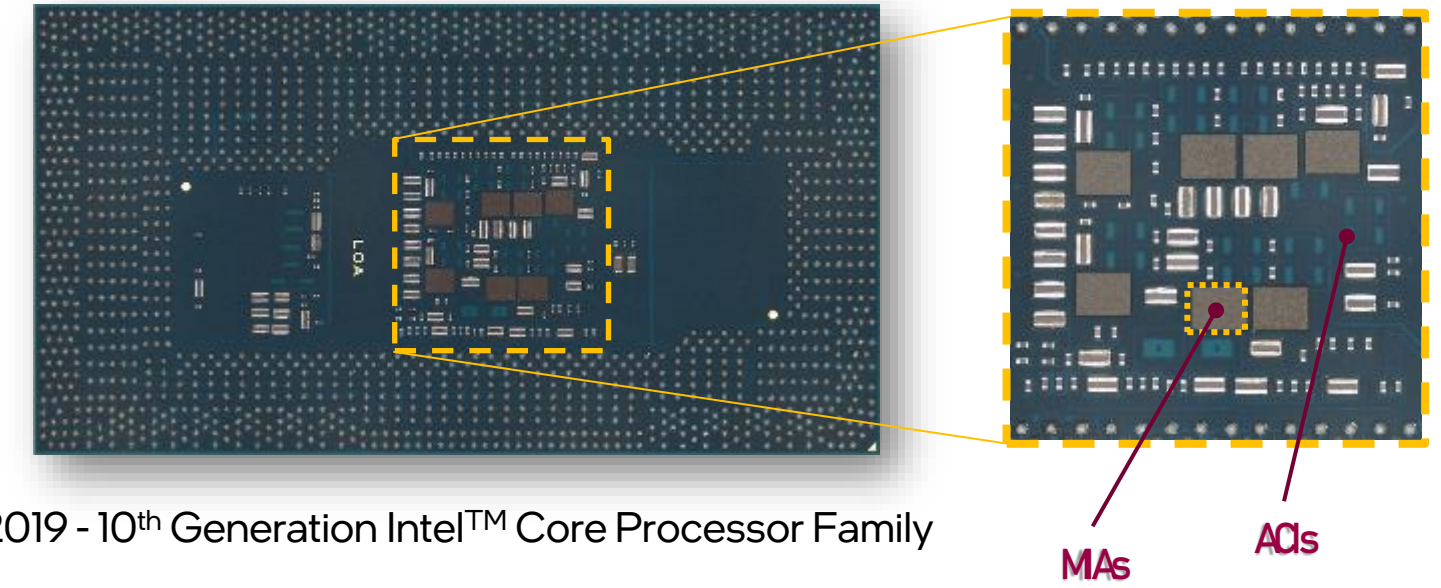
2014
5th Generation
Intel® Core™ M

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

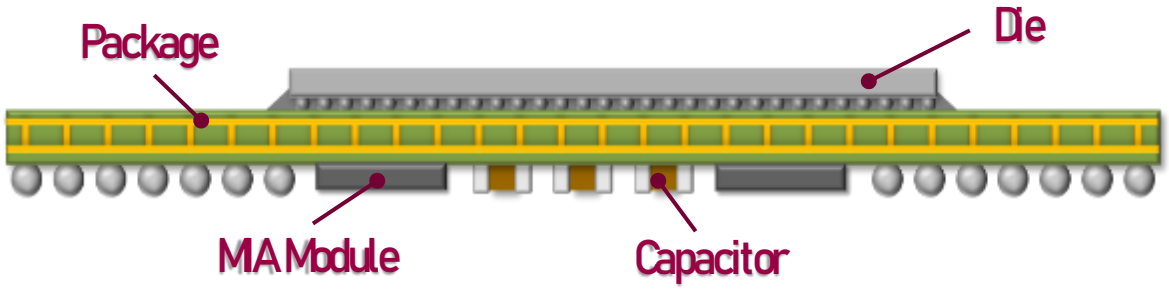
Magnetics Modules

Magnetic Inductor Array Module





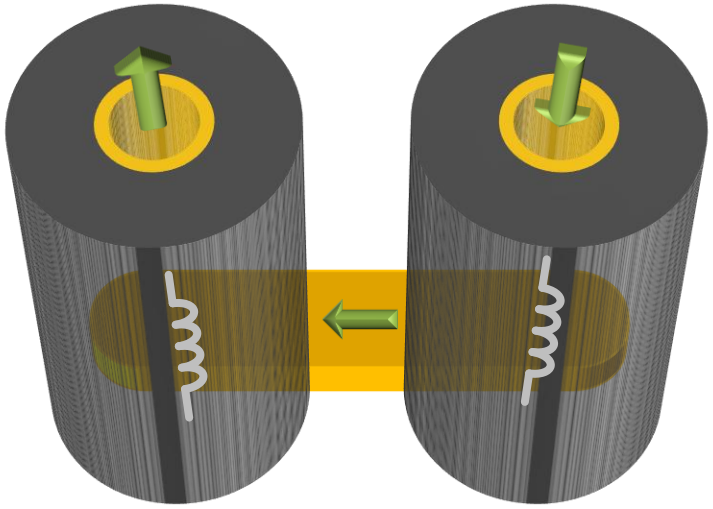
2019 - 10th Generation Intel™ Core Processor Family

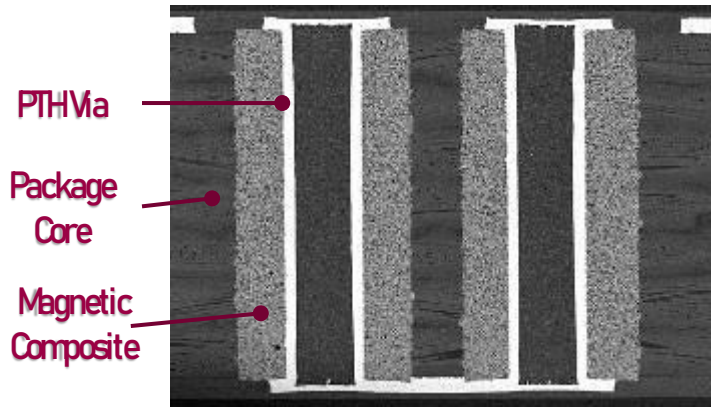


Magnetics needed for continued inductor density increases

Coaxial Magnetic Integrated Inductor

Coax MIL



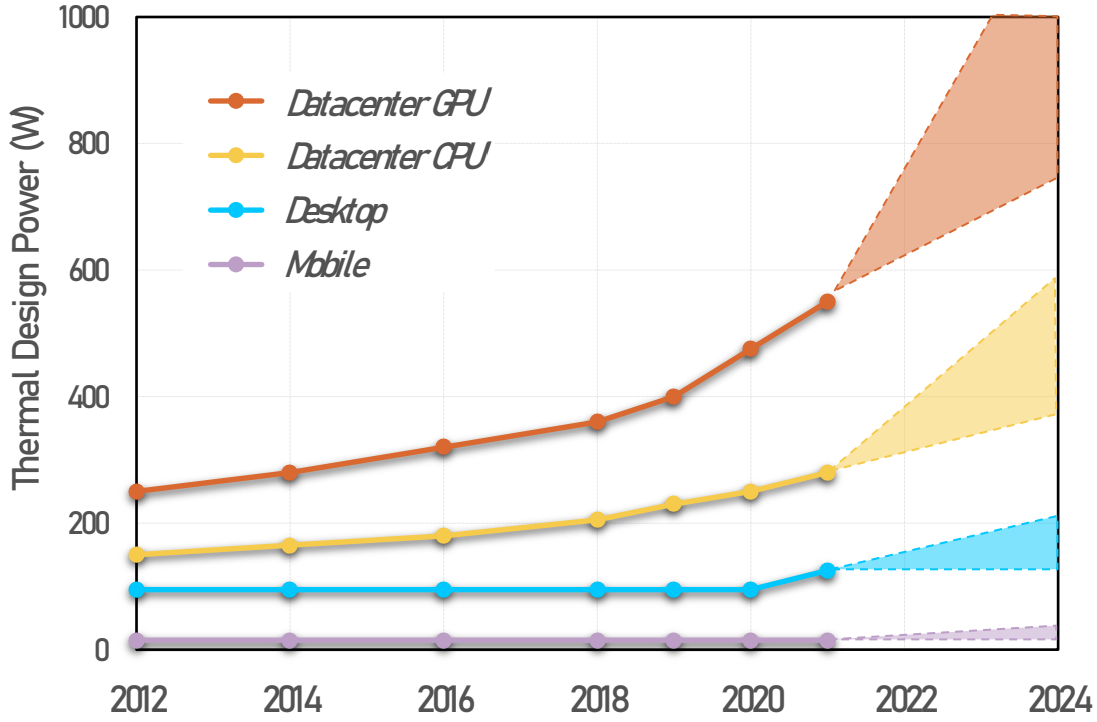


2023 - 4th Generation Intel® Xeon® Scalable Processors

The importance of advanced magnetics will continue to grow

Moving Forward – Common IVR Focus Topics

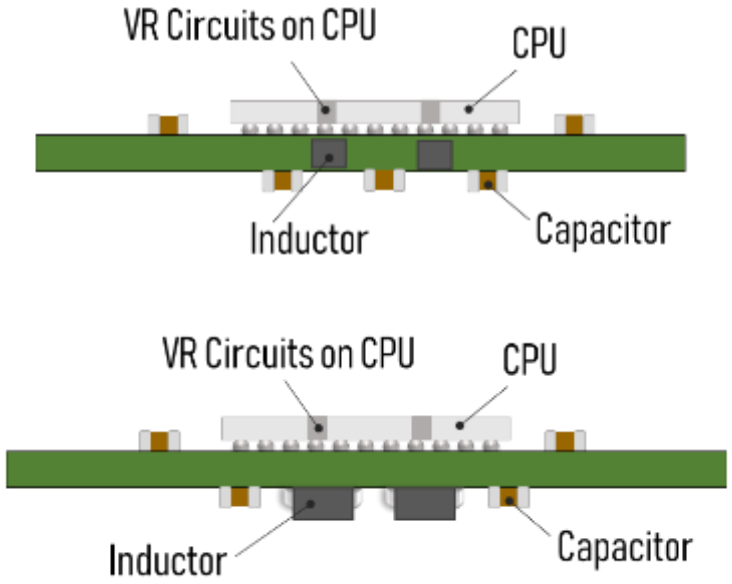
- Efficiency
  - Heat must be removed pkg & building
  - Loss not used for compute
  - 100's of Millions of VRs x 1% is a lot of power
- High Input Voltage
  - System efficiency driver
- Fast response time at the load
  - MIM Density + VR Design
- Magnetic Materials
  - New, exotic materials
- New Topologies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



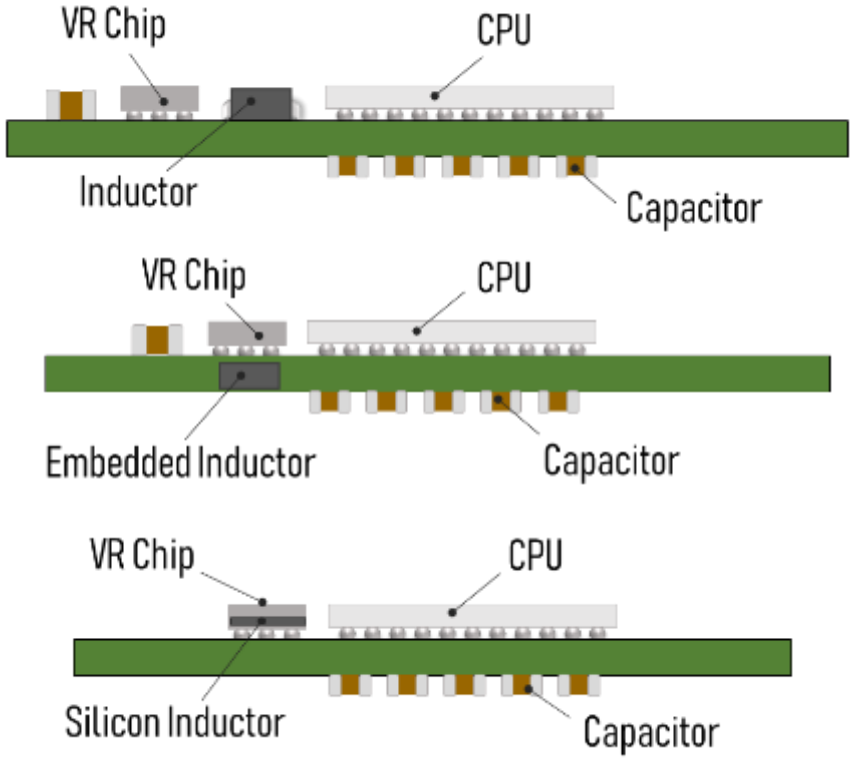
These topics are all very important but not the subject of today's presentation

Practical Issues

Placement – where does an IVR go?



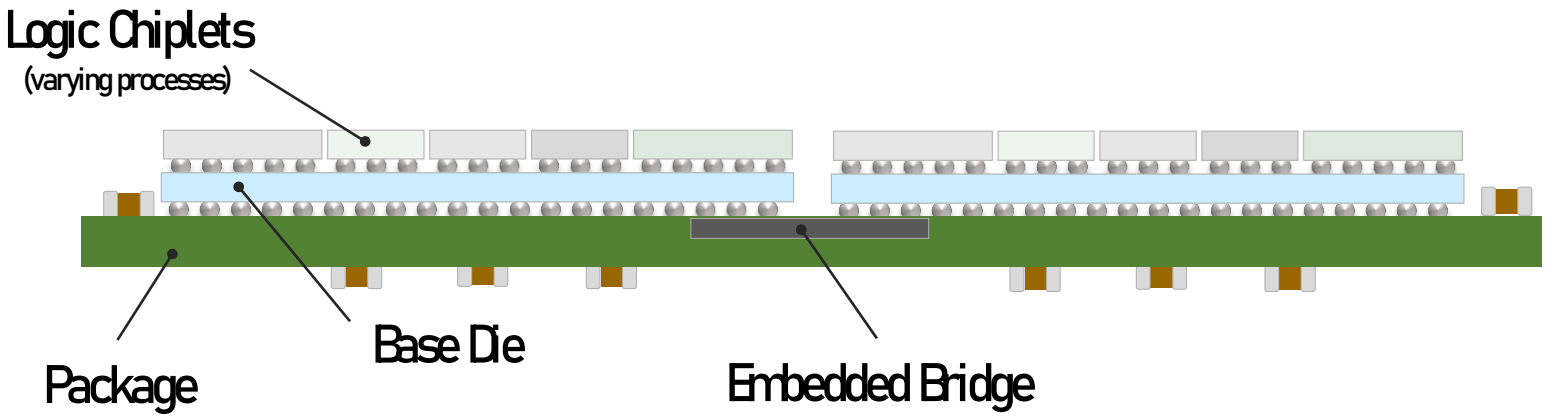
Traditional Designs

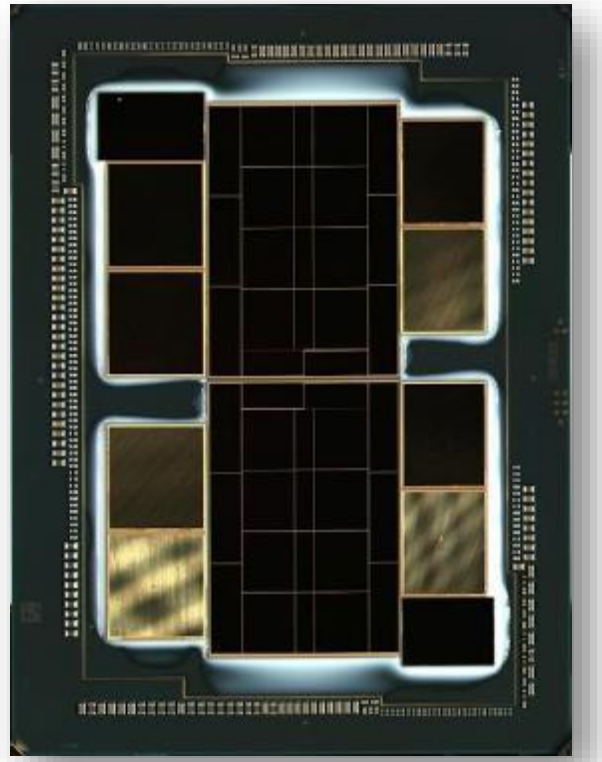


Chiplet Options

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

IVR Placement 3D Integration





Intel® Data Center GPU Max

>100 Billion Transistors

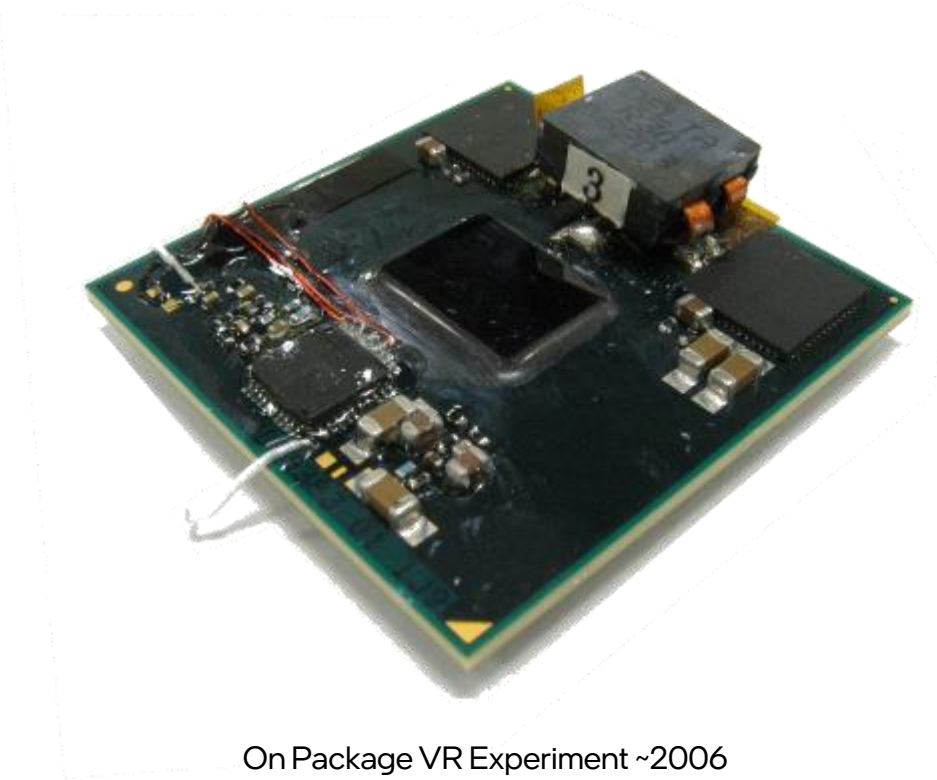
3D Packaging

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

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



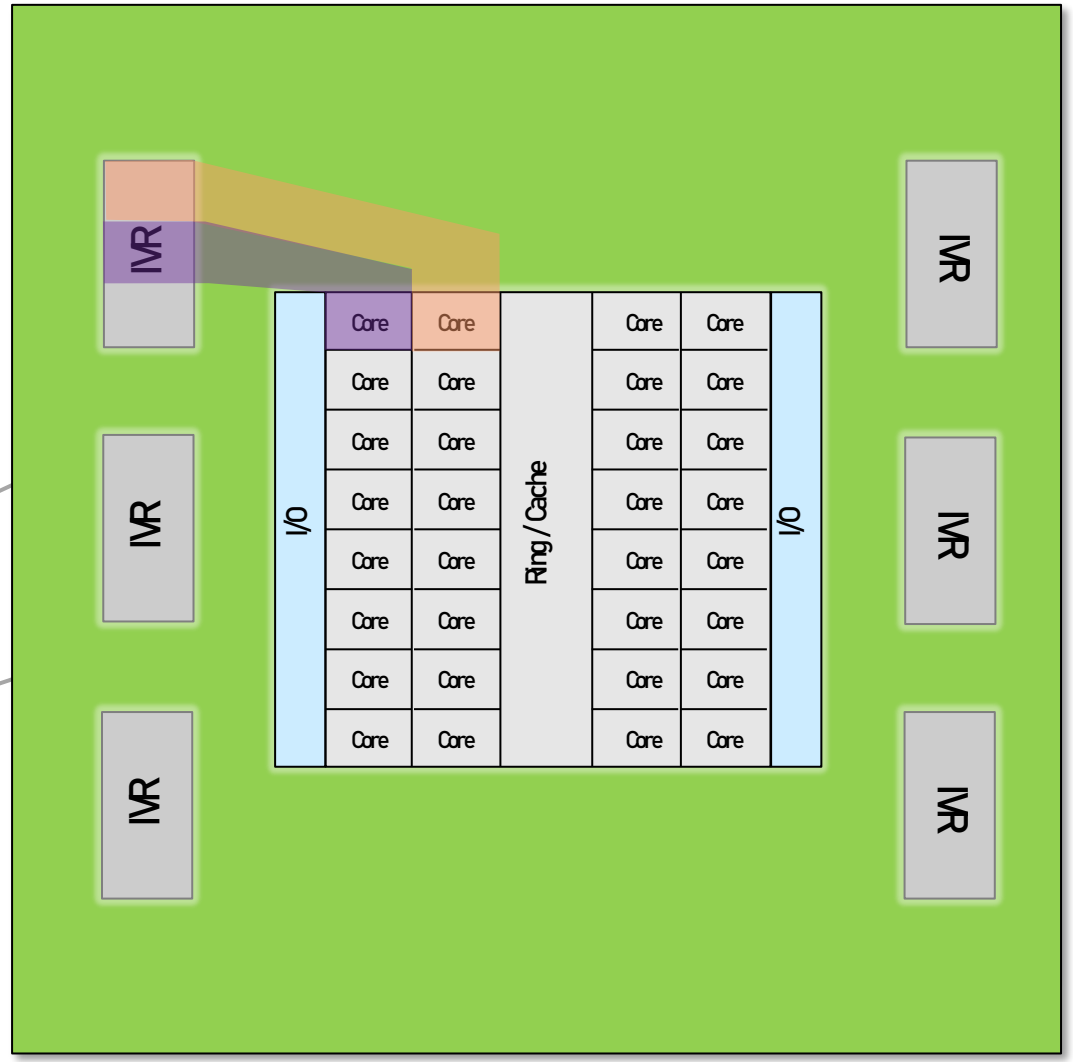
On Package VR Experiment ~2006

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

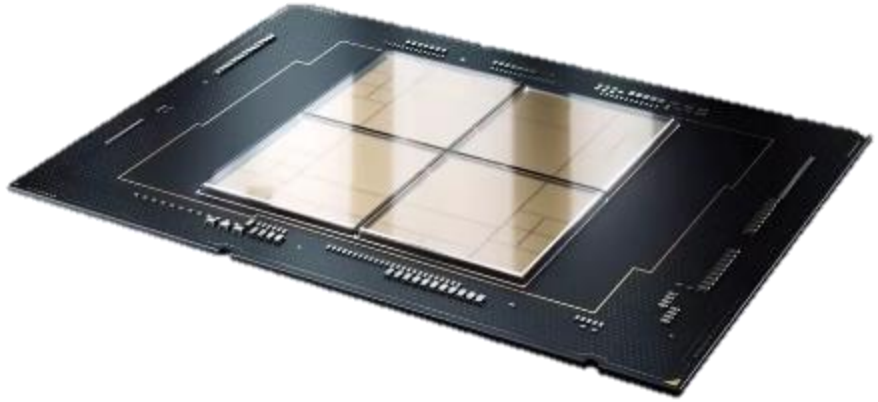


Power plane and control signal routing severely limits IVR placement options

Can You Build 10's of Millions?

Each unit will have many IVRs

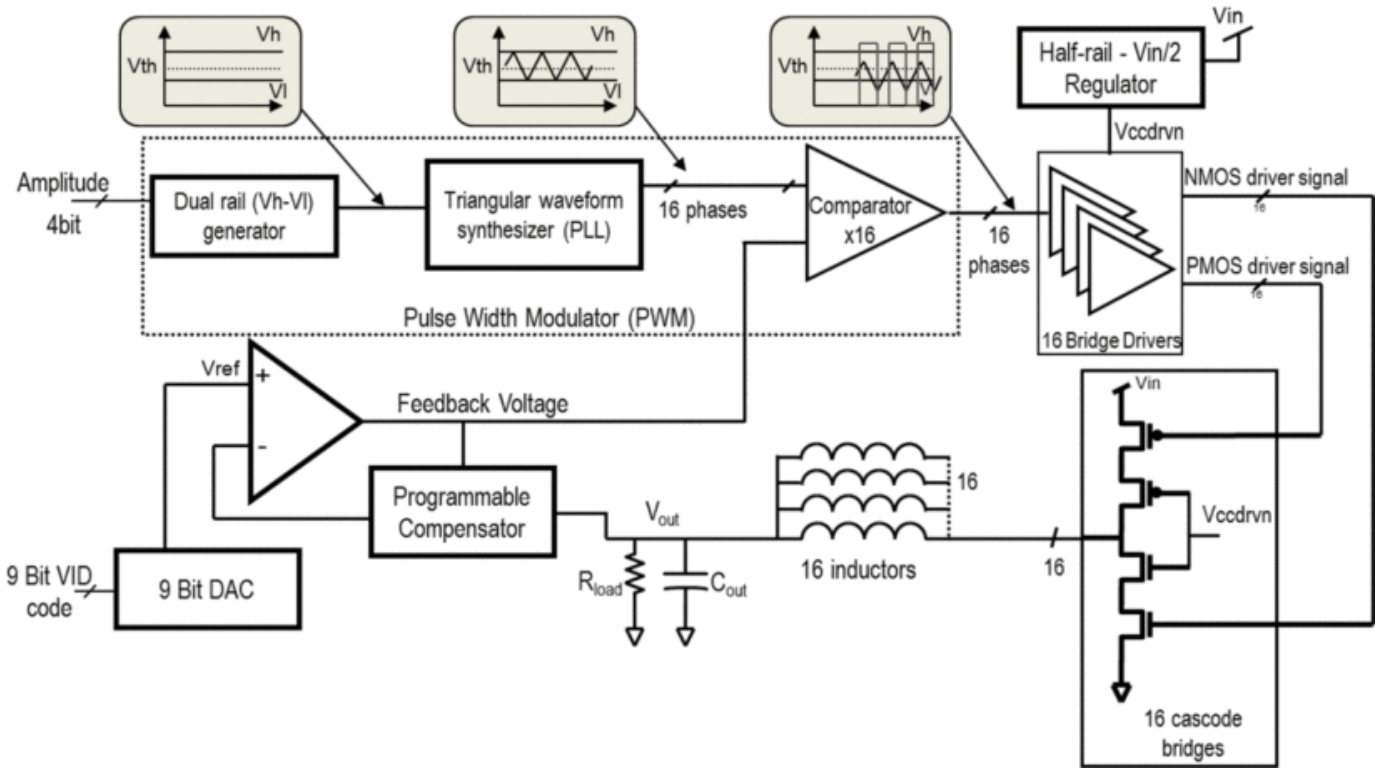
- My have 600+ Inductors per package
- Can Single IVR fail kill part?
- Manufacturing tolerances
- How do you know if all inductors are good?



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

Complex Control Scheme Challenges

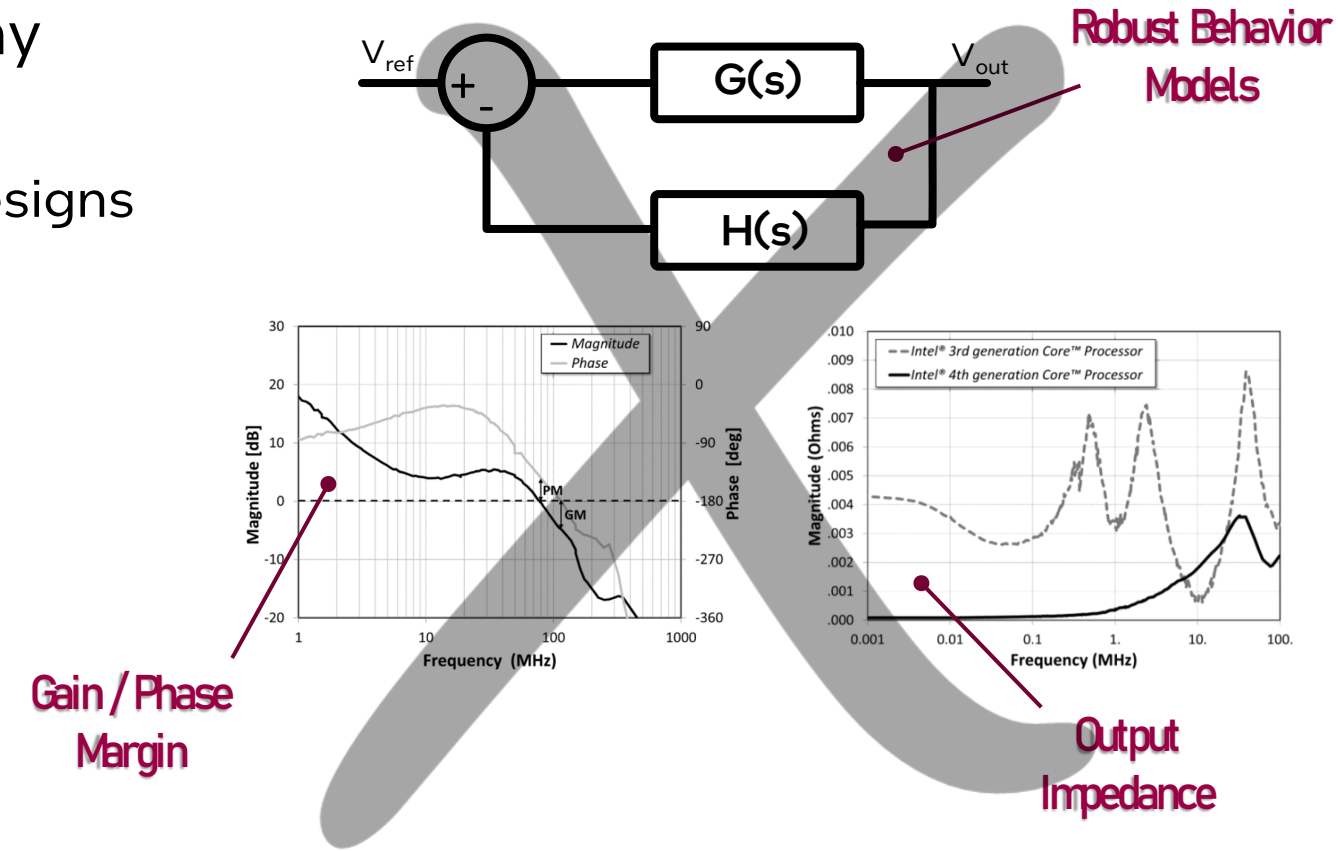
- Trimming Common
  - Examples
    - Amplifiers / Comparators
    - Bias voltages
    - Compensator settings
    - Sensors
    - Waveform generators
  - Test Time
  - Test Complexity
  - Power on / debug



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

Fundamentals - Non-Linear Control

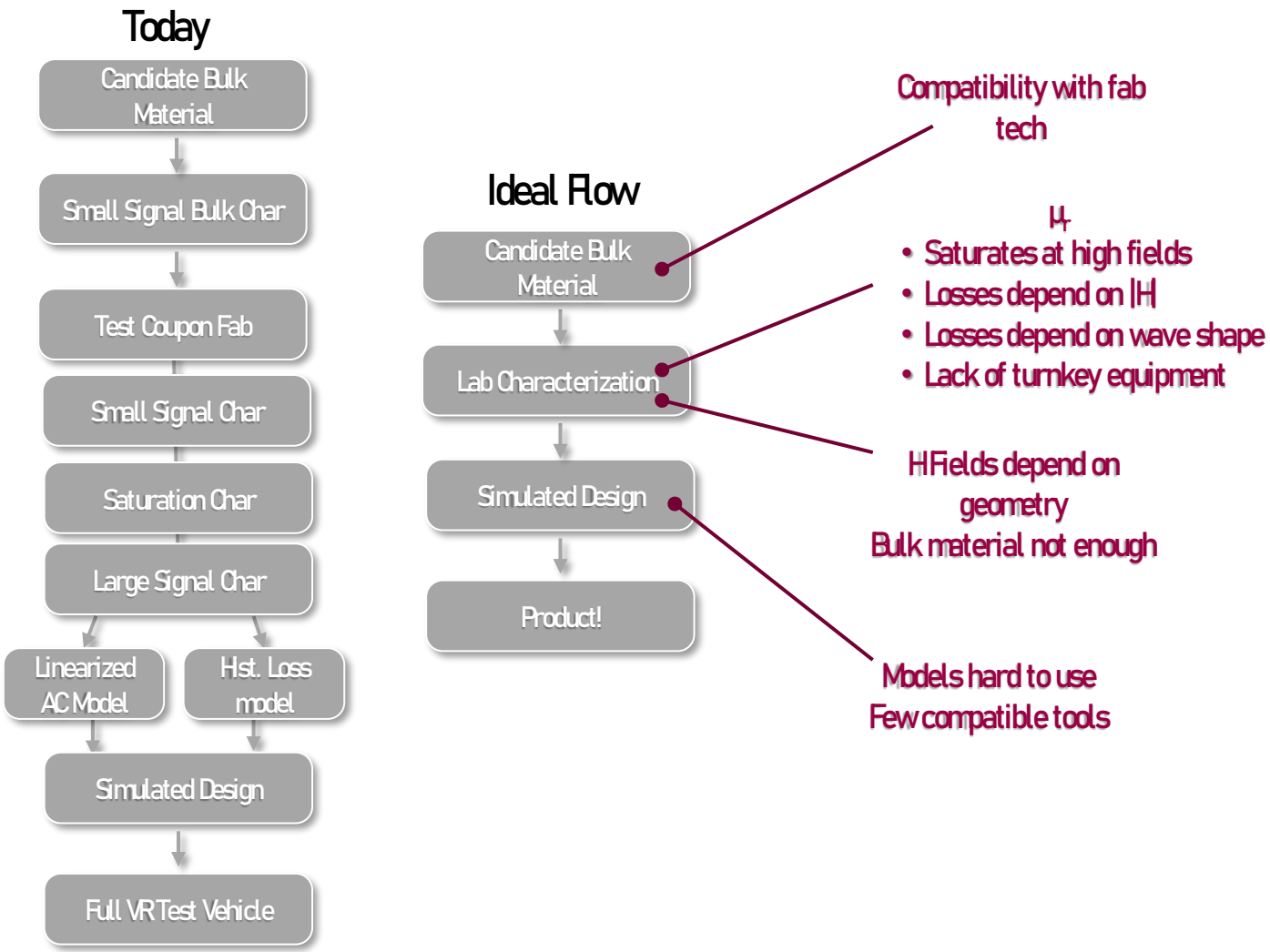
- Many NL Control schemes in play
  - Old and new NL buck features
  - Highly complex switch capacitor designs
- Lack Fundamental
  - Stability metrics
  - Performance metrics
  - Theoretical frameworks



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

Fundamentals - Non-Linear Magnetics

- Density pushes high μ_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