Google

Thermal Challenges and Opportunities in Components to System Integration for AI

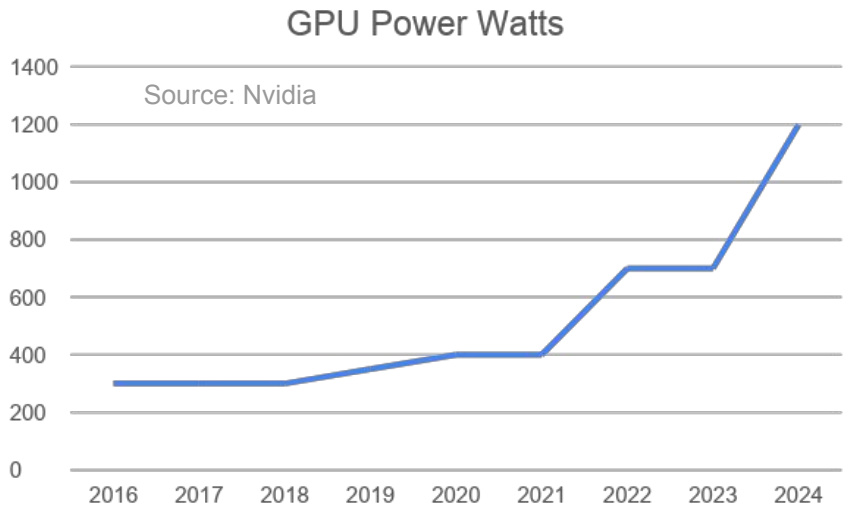
IEEE Heterogenous Integration Workshop at ECTC Conference

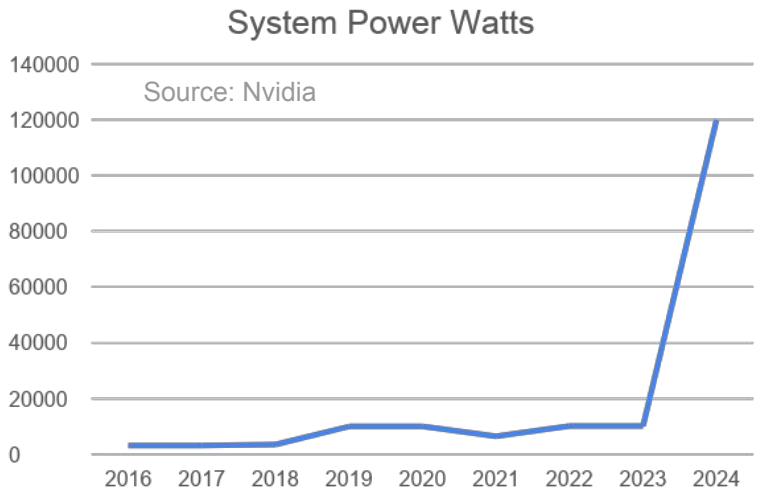
Weihua Tang and Madhusudan Iyengar

Google

ML Training GPU & System Power over Time

Source: Thermal TWG Update at 2025 HIR Annual Workshop





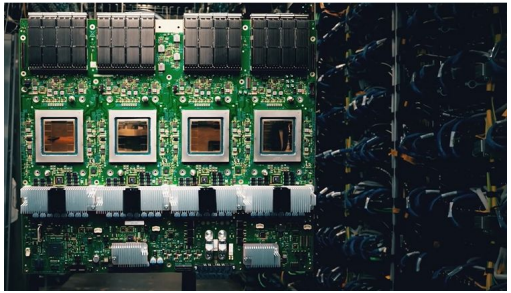
- Increasing Power over time
- Even with improvements of 45,000x throughput/watt in last 8 year

R. Ober and M. Iyengar, "*The Exponential Demands AI Places on the Rack & Datacenter*"
Open Compute Project (OCP) 2024 presentation, Special session on Artificial Intelligence LINK

Cooling demands beyond ASIC

More components require better cooling solution

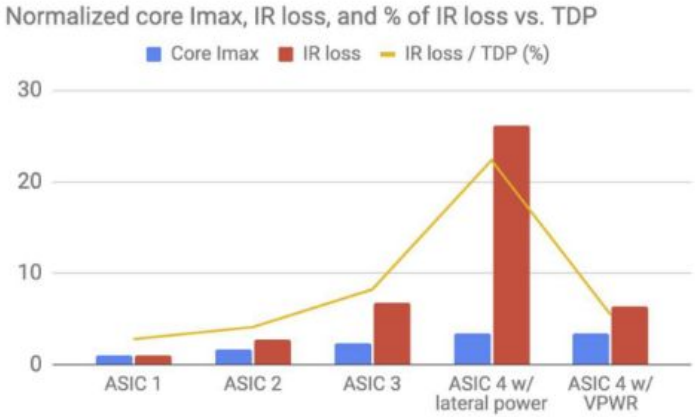
- ASIC: TDP > 1000W
- IR loss from power delivery with current >1000 Amps: Vertical Power Module (VPM), Intermediate Bus Controller (IBC),
- Joule heating from motherboard
- OSFP (Octal Small Form-factor Pluggable) modules



https://blog.google/products/google-cloud/ironwood-tpu-age-of-inference/



https://www.youtube.com/watch?v=FsxthdQ_sL4

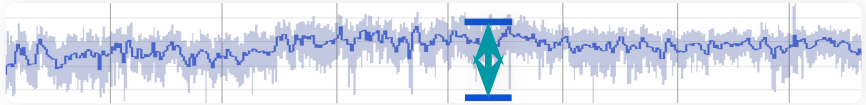


H. Gan *et al.*, "Vertical Power Delivery for 1000 Amps Machine Learning ASICs," *2024 IEEE Applied Power Electronics Conference and Exposition (APEC)*, Long Beach, CA, USA, 2024, pp. 906-909,

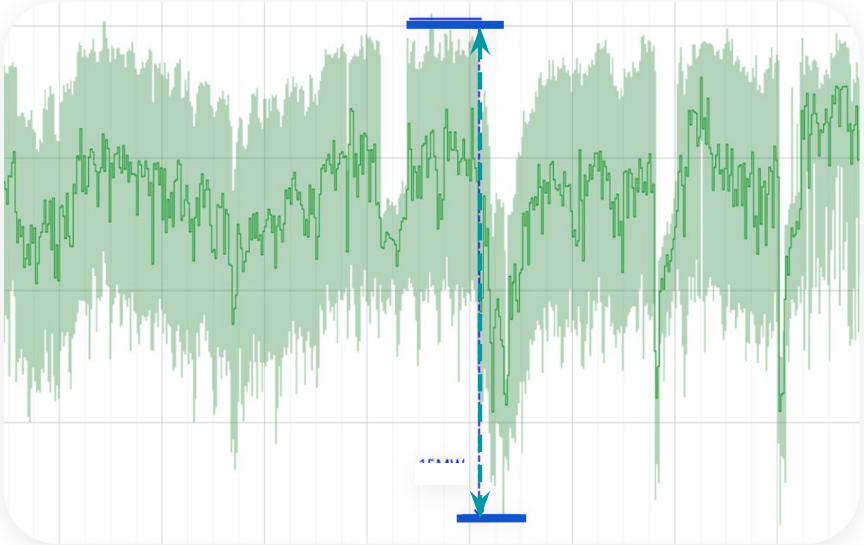
Power & Temp Fluctuations in ML Workload

- ML Workload tends to drive large and frequent power and temperature swing
- Challenges on
  - temperature control
  - component reliability: SJR, TIM

Non-AI Workloads



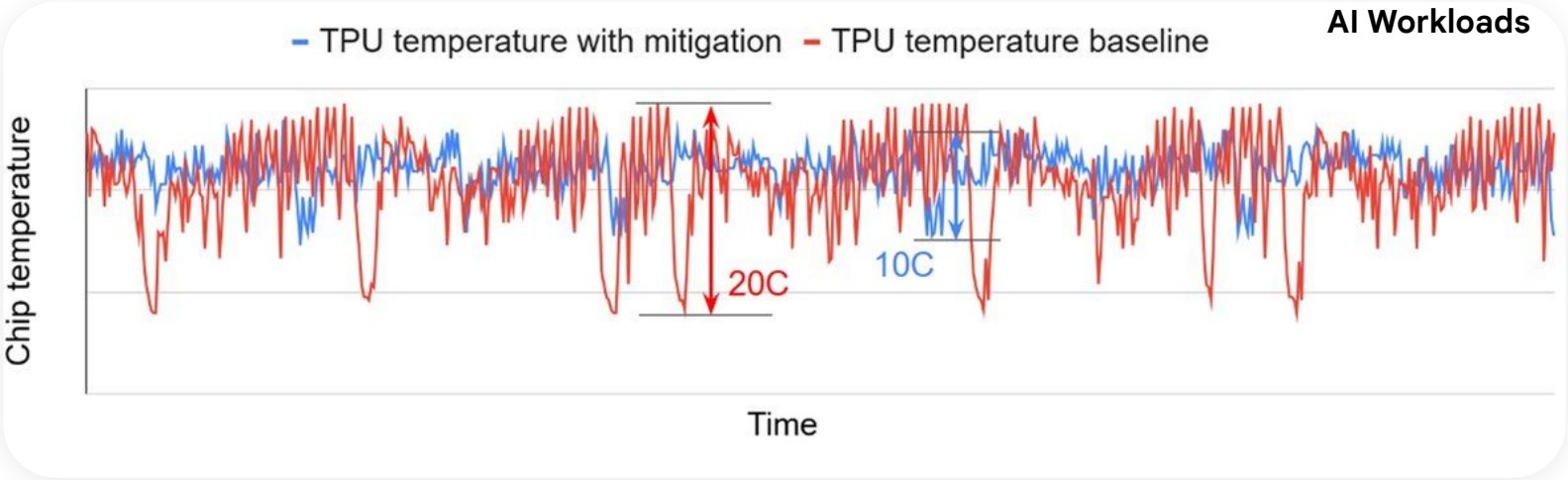
AI Workloads



Google blog, 2025, https://cloud.google.com/blog/topics/systems/mitigating-power-and-thermal-fluctuations-in-ml-infrastructure
OCL EMEA 2025 Google keynote: https://www.youtube.com/watch?v=cLJCOuWLWtk

Power & Temp Fluctuations in ML Workload (cont)

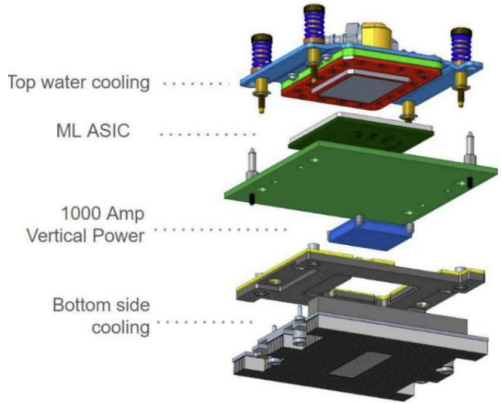
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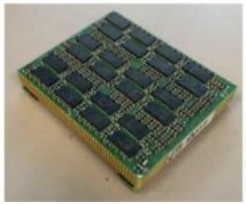


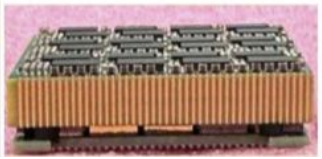
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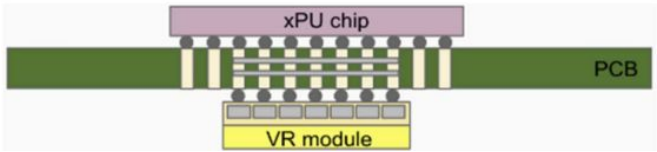
Challenges in System Integration

- Design: Heat sinks and cold plates. Micron channel liquid cooling for PCB will be very challenging
- Manufacturing Process Yield:
  - Dual-side BGA for assembly of ASIC and VPM (non-traditional package to system)
  - Thermal Impedance of TIM





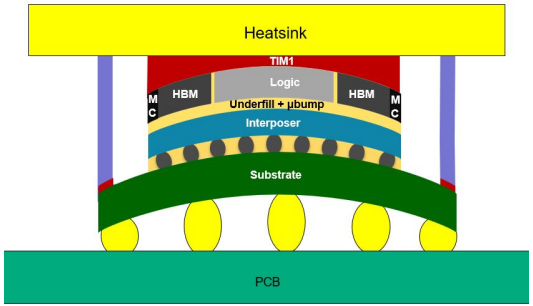


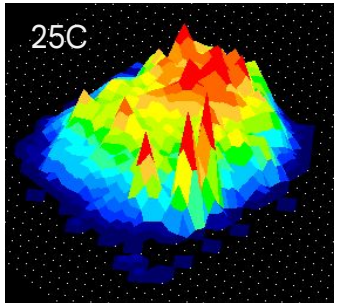


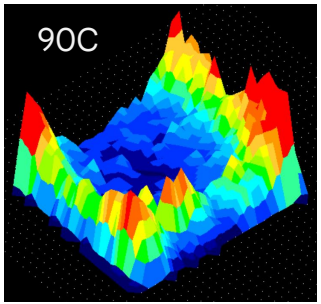
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Challenges in System Integration (cont)

- Reliability: solder joint reliability and TIM aging from power/temperature cycling







Example TIM Pressure at room and high temperature

Opportunities

- Pre and post SMT warpage modeling and mitigation in large packages
- multi-laminate PCB: reduce Joule heating and improve heat spread in PCB with higher Cu density
- 3D chip thermal management (ASIC & HBM)
- Cooling for power delivery devices and conductors
- Co-packaged optics thermals
- Novel materials & mfg for chip level heat spreading
- Advanced Thermal Interface Materials - metal, CNT, nano-structures
- On chip microfluidics advancement - design, materials, mfg, and more