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Virtual Archive

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World's 4th largest fabless IC design company ³ 2020 revenue = 10.9 billion (USD) ~1.5 billion chips shipped annually 17,000+ employees across 35 cities globally

* Source: TrendForce research report - Global Top 10 IC Design Companies in 2020, March 2021

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Complex systems enabled by semiconductor advances









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Testing challenges from converging technology trends

SoC built in advanced process nodes

- Higher transistor count and density
- Local power density increase ⇒ thermal hot spots
- Voltage and thermal stress \Rightarrow short-term aging effects
- Lower operating voltage \Rightarrow reduced noise margin
- Larger variations \Rightarrow sign-off complexity

SiP built with advanced packaging

- Heterogeneous integration of different die types
- Mechanical and thermal considerations
- Known-good and matched dies
- Defects in interconnects and bonds
- Repair/replace to reduce scrap cost

System and application complexity

- More ultra-low voltage operation
- Application scenario-dependent SW-HW interactions
- Stress scenarios trigger abnormal electrical and thermal deviations
- Long error detection latency (billions of clock cycles)



Difficult system failures

- Marginal, transitory
- Low DPPM (rare)
- Structural test escapes
- Require long SLT
- Reliability after T_{zero}
- Hard to diagnose root cause
- No-trouble-found (NTF)

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Small errors in complex systems have outsized impacts

H. D. Dixit et al. (FB), "Silent Data Corruptions at Scale," arXiv:2102.11245v1 [cs.AR] 22 Feb 2021.



P. H. Hochschild et al. (Google), "Cores that don't count," HotOS, June, 2021.

Rising silent errors in Google data centers

- Due to "mercurial" cores
- Triggered by minor software changes
- Large blast radius loss of filesystem
- Decades of engineering time to root-cause

A. Ryan (Siemens), Silicon Lifecycle Management Workshop, October, 2021.

Cost of latency is very material

- Amazon every 100ms latency causes a 1% decrease in sales
- Bing a two-second slowdown was found to reduce revenue per user by 4.3%
- Shopzilla reducing latency from seven seconds to two seconds increased revenue by 7%

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Limitations of component structural test

- Today's products are holistic systems of HW & SW components
- New notions of quality

In the simple past	Present and future
Does this thing work?	Quality of user experience (QoUE)✓ No lag in gaming action✓ Comfortably warm in my hands✓ Battery charge lasts a long time

- Structural test for HW components lack system view to assess QoUE
 - But "quality" of HW component does impact system QoUE
- Integration of well-tested components still fail in the system
 - Leads to no-trouble-found (NTF) phenomenon
- SLT covers the "system view" gap missed by component structural test



Is your OCC scan test working at the expected supply voltage?

6000

4000

2000

CPU-1 CPU-2 CPU-3 CPU-4

V5F1

power supply response

30 at-speed clocks

2000

1000

- Post-silicon technique for fine-grained profiling of internal voltage sensitivities
- 4 identical cores and OCC ٠ patterns in CPU block
- Same external supply voltage ٠ but measure very different internal core voltages

Internal power grid resonance due to large shift-to-capture di/dt change in combination with scan clock phase shifting

scan clock-

CPU-1



CPU-2

CPU-3

CPU-4



U0000

50000

CPU-2

CPU-3

V4F1

PU-1

4 Core MMC Box Plots at 4 VF Corners (F1 = 2.6 GHz)

CPU-1 CPU-2 CPU-3 CPU-4

V6F1

Internal supply variation \Rightarrow overkill in cores with droop escapes in cores with overshoot

CPU-3

V5E1

CPU-1

P. Pant and J. Zelman, "Understanding Power Supply Droop During At-Speed Scan Testing," VTS 2009

3.5%

CPU V4F1

CPU-2 CPU-3

V7F1

It's all about marginalities

- HW components passing structural test are not all perfectly healthy
- Marginal components escape structural test screen
- Fine-grain post-silicon profiling of functional Vmin outliers

On top of systematic voltage sensitivity profile, Vmin outliers show <u>random local regions</u> of abnormally high voltage sensitivity



D. Appello, H. H. Chen, M. Sauer, I. Polian, P. Bernardi, and M. Sonza Reorda, "System-Level Test: State of the Art and Challenges," IEEE 27th IOLTS, 2021.

Deep component data analytics is the link to system QoUE
 Systematic design weakness + Marginal performance outliers

Structural

Test Pass

Component health (\rightarrow system QoUE)

Structural Test Fail

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SLT practice today is ad hoc – methodology lacking

- Test patterns derived from functional verification
- Functional coverage oriented
- No concept of and metric for fault coverage
- Long test times tens of minutes to hours
- Equipment is relatively inexpensive
- Volume throughput is the issue
- SLT failure rate of 500 DPPM ⇒ 99.95% of incoming chips can skip SLT!
- How to create efficient and effective SLT patterns?
- How to optimize WS \rightarrow FT \rightarrow SLT flow?
- How can SLT failure diagnosis help yield learning?







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First ever SLM Workshop was held at ITC 2021



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Variability is a fact of life – adapt to it

- DVFS in 7nm mobile SoC 2.8 GHz CPU core
- {process, voltage, temperature, aging} sensors
- Control µP firmware sets new target operating point based on sensor readings per millisecond

B.-J. Huang, et al, "An Octa-Core 2.8/2GHz Dual-Gear Sensor-Assisted High-Speed and Power-Efficient CPU in 7nm FinFET 5G Smartphone SoC," Paper 25.1, ISSCC 2021.

Error-tolerant system design

Engineering Cybernetics, 1954 ... a reliable system could be composed of unreliable components, and the idea that the overall performance of components would be improved through the optimization of the whole system, ...

Source: "The rise of systems engineering in China," American Assoc. for the Advancement of Science, 23 September 2016.







<u>Qien Xuesen (Tsien Hsue-Shen, 钱学森)</u> Father of Systems Engineering in China Foundation of China's aerospace program



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Towards the future ... control your own destiny

https://semiengineering.com/test-engineers-in-very-short-supply/

SEMICONDUCTOR ENGINEERING DEEP INSIGHTS FOR THE TECH INDUSTRY Test Engineers In Very Short Supply

Why these jobs are so difficult to fill.

DECEMBER 8TH, 2020 - BY: SUSAN RAMBO

Requires multidisciplinary knowledge

- ✓ Testing and diagnosis methods
- ✓ Design flow from system to devices
- ✓ Data analytics, use of ML/AI as tools
- ✓ Reliability, Safety, Security

Test engineers → IC "medical" doctors
DFX to make healthy IC & systems
Run tests to probe health condition
Diagnose IC illness to find correct fix

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Keynote – Harry Chen

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