Reliable Electronics? Precise Current Measurements May Tell You Otherwise…

Hans Manhaeve

Ridgetop Europe

Overview

- Reliable Electronics
- Precise current measurements?
  - Accurate - Accuracy
  - Resolution
  - Repeatability
  - Understanding specifications
- Precise current measurements & reliability
  - Detecting failures
  - Burn-in replacement
- Cases
- Conclusions

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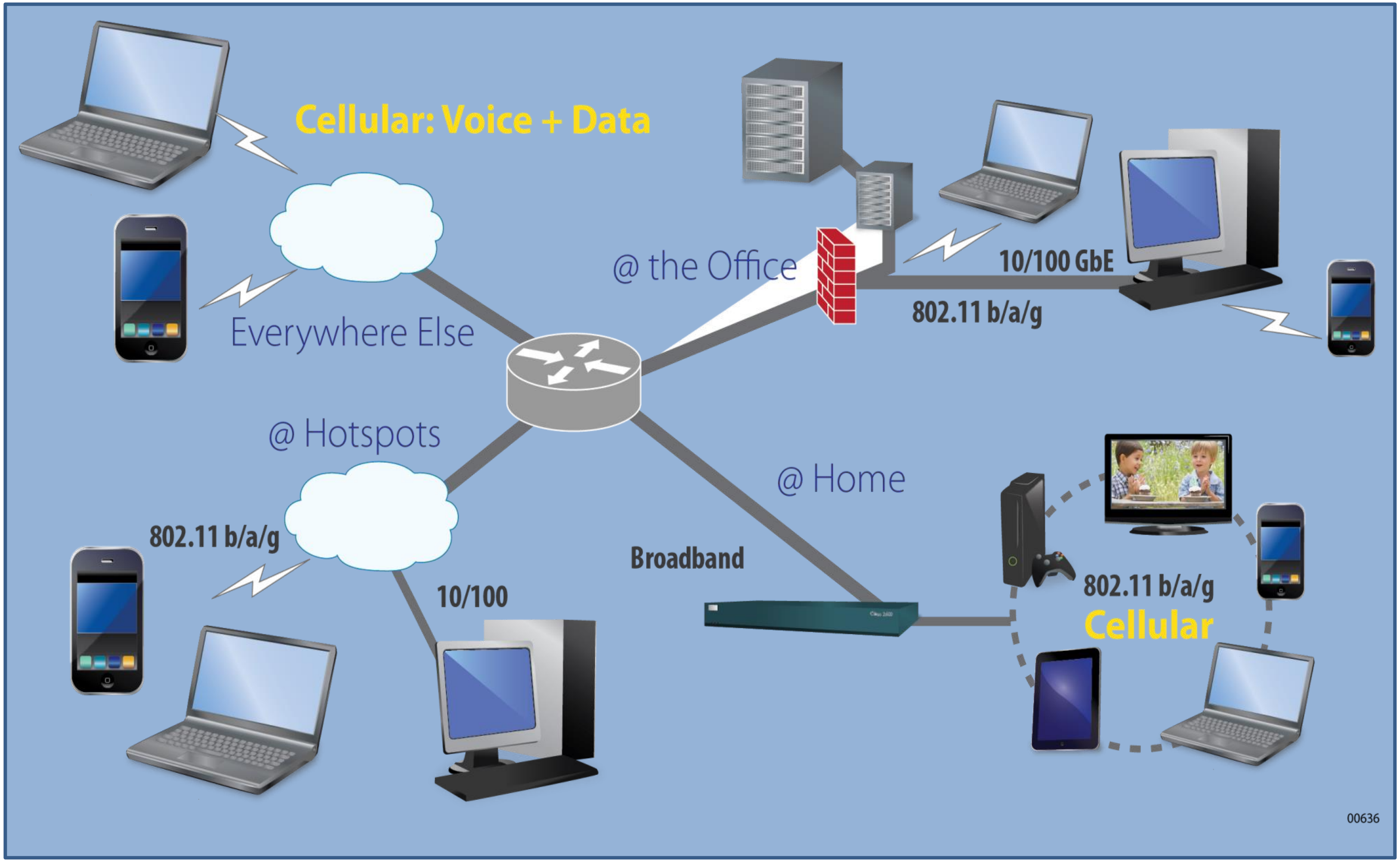
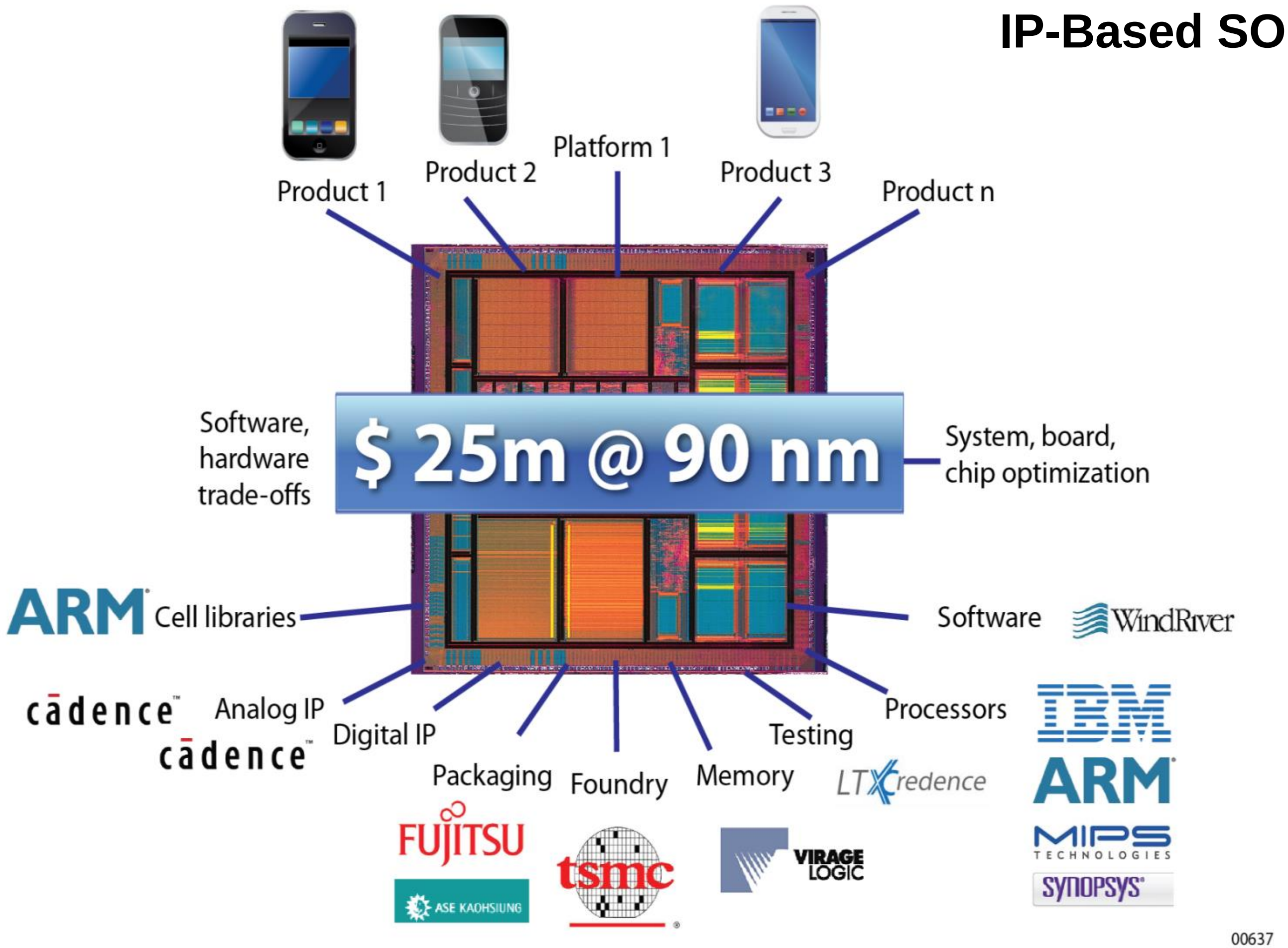
The Need for Test & Reliable Operation



Any Device, Any Time, Anywhere

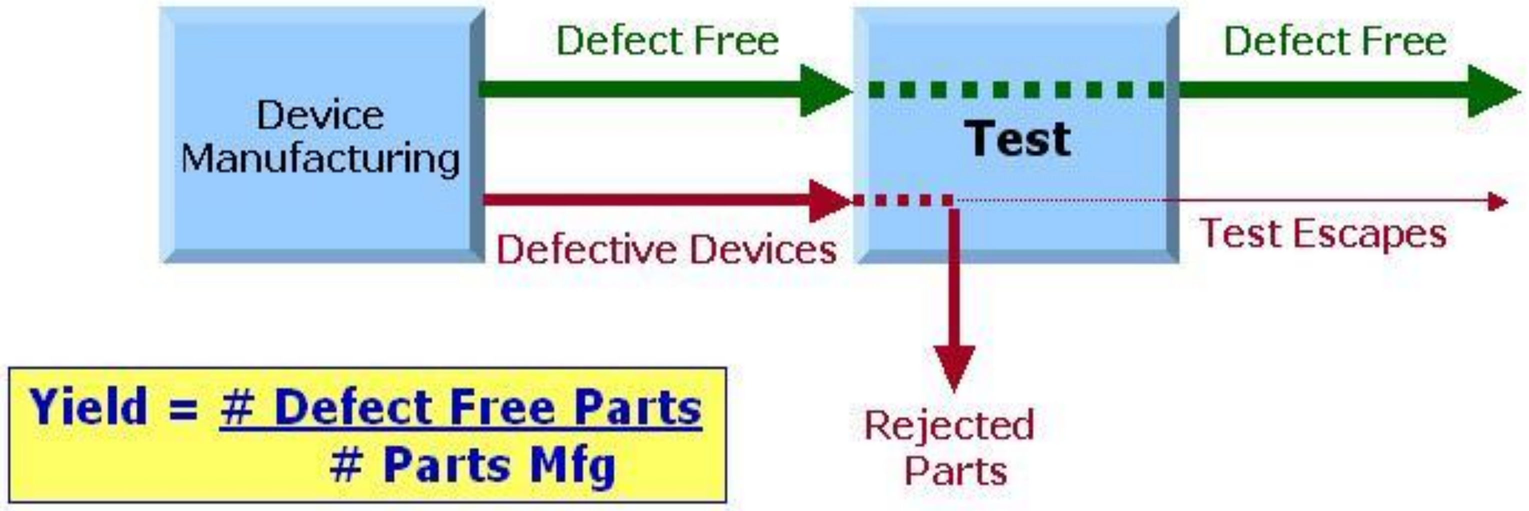
The Need for Test & Reliable Operation

IP-Based SOC Design



The Need for Test

- But we still need to test every single transistor and every single unit



- Test is an important factor of product manufacturing costs (15 → 50 → ….%)

“Find the Defect”

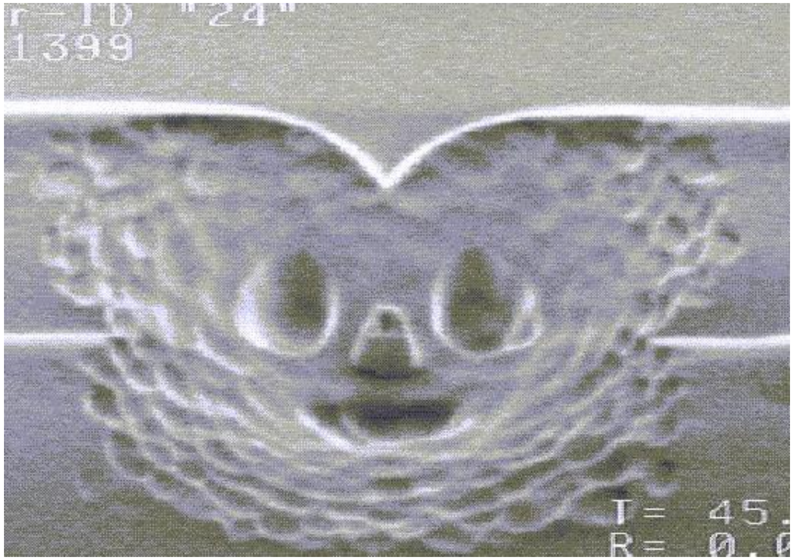
“Find the Defect”

Hyatt Regency - Maui

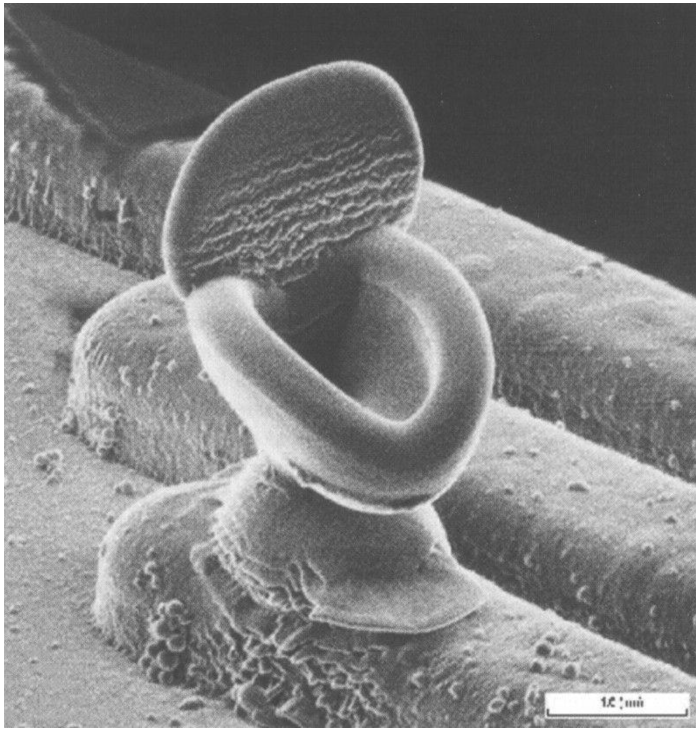
Finding Defects

- Requires to be at the right place and look in the right direction at the right time
  - Apply the proper test conditions
- Have a good set of binoculars
  - Have the right test instrument available
- And know how to use your binoculars and keep them steady
  - Know how to use your instruments
  - Ensure reliable and repeatable test results

The Need for Test



Madge, ITC04



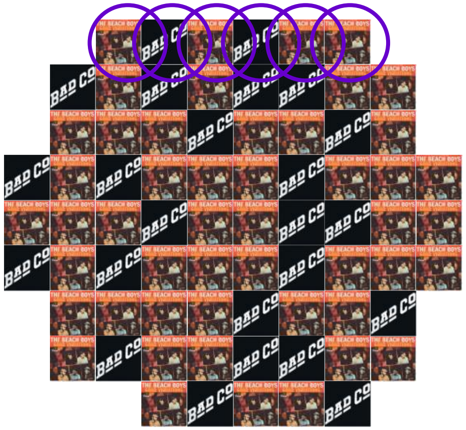
Butler, ITC07

Yield and Reliability

- Yield has a simple definition

$$Yield = \frac{good\ chips}{total\ chips}$$

✓ ✓ ✓ ✓

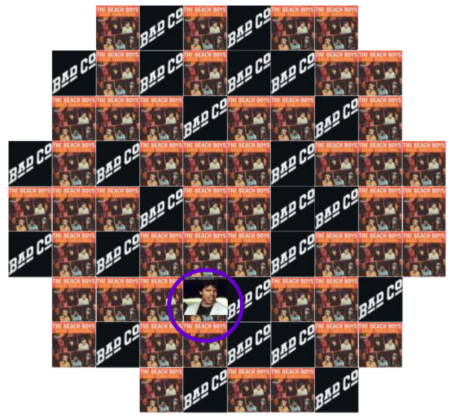


X X

- Challenge is in separating “good” from “bad”

Yield and Reliability - Ambiguity

$$Measured\ \ Yield = \frac{good\ \ parts + test\ escapes - type\ I\ \ failures}{all\ parts}$$



GEORGE THOROGOOD

BAD TO THE BONE

- Competing definitions of "good"
  - **Ideal**: works in customer's application
    - → Can't measure this until it's too late!
  - Is high leakage from a defect or fast transistors?
  - Most chips work at 0.7V, this one doesn't??
  - How complete are these tests?
- Need to agree on "passes the tests we apply"

- Result: Test & yield are part of the same discussion!

Yield and Reliability

- Historically, testing was functional
  - Does the device do what it is supposed to?
  - Function primarily defined logically
  - ***Yield relates to function***
- Next, structural tests were developed
  - Is every circuit structure (e.g., gate) present and working?
  - Coverage metrics are logical (stuck-at fault coverage)
  - ***Yield relates to structure***
- Defect-oriented testing starts with defects
  - What could go wrong with this device?
  - If it went wrong, what would change about the device?
  - Any measurable behavior could be affected, not just function
    → timing, current, voltage, temperature dependence
  - ***Yield relates to absence of defects***

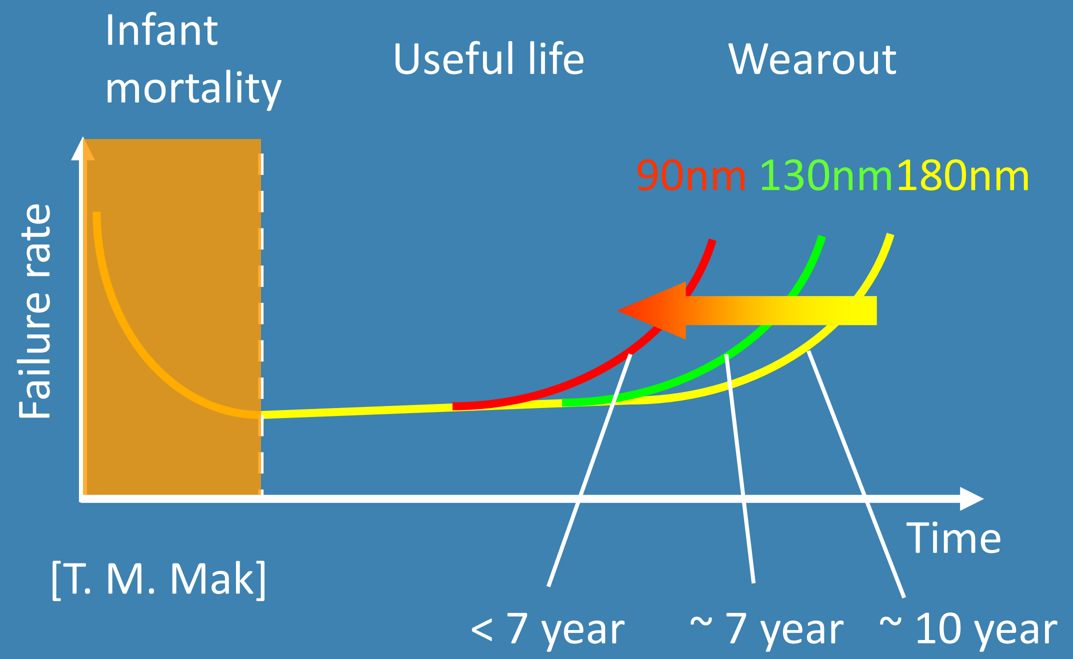
Yield and Reliability

- Semiconductor evolution enables further integration
  - Transistors are nearly for free
- New processes are used for mass production long before they are mature
  - Systematic and random defects
  - Reliability concerns
- Increasing device complexity
  - The “embedded” world
  - Analog – Digital – Memory – Software

- Market demands for cheaper and better electronics
- Market demands for RELIABLE electronics

Yield and Reliability

- Lifetime reliability becomes a serious concern



[T. M. Mak]

Failure mechanisms

EM / SM

NBTI / PBTI

QBD / TDDB

HCI

Reliability-related factors

Temperature

Voltage / Current

Frequency

Radiation

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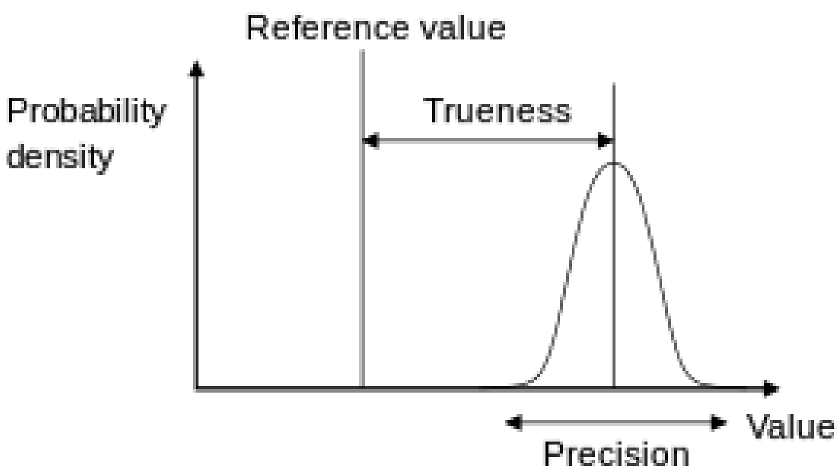
Qualifying Measurement Results

- Quality and reliability decisions require data
- Gathering data == Making measurements
- Measurements are qualified in terms of
  - Accuracy
  - **Resolution**
  - Precision - **Repeatability**

Accurate - Accuracy

- Accurate
  - Correct, exact, error-free, on target, …
- Accuracy
  - Measurement ←→ actual (true) value
  - ISO 5725-1:
    → Accuracy consists of
    - Trueness (proximity of measurement results to the true value)
    - Precision (repeatability or reproducibility of the measurement)



Source: Wikipedia

Resolution

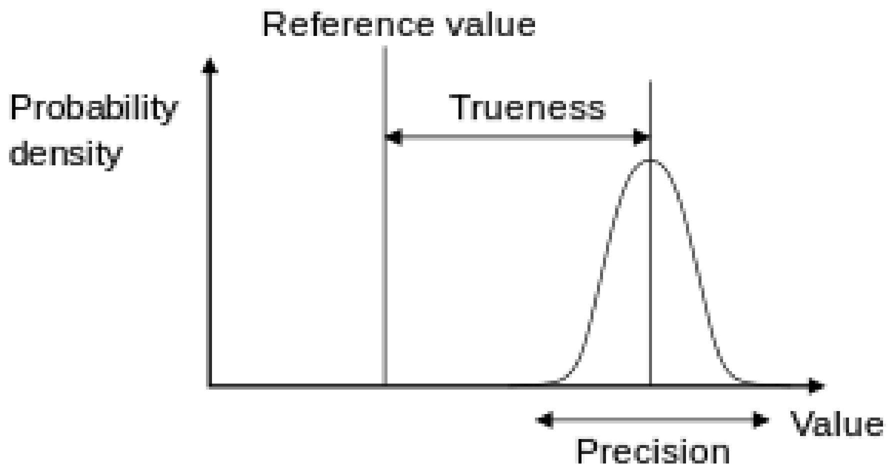
- Resolution
  - smallest change in the underlying physical quantity that produces a response in the measurement
  - Linked to noise levels or # of bits

- Effective resolution
  - # of bits ←→ ENOB
  - S/N ratio of signal path
  - Sampling frequency
  - Sampling technique used

Repeatability

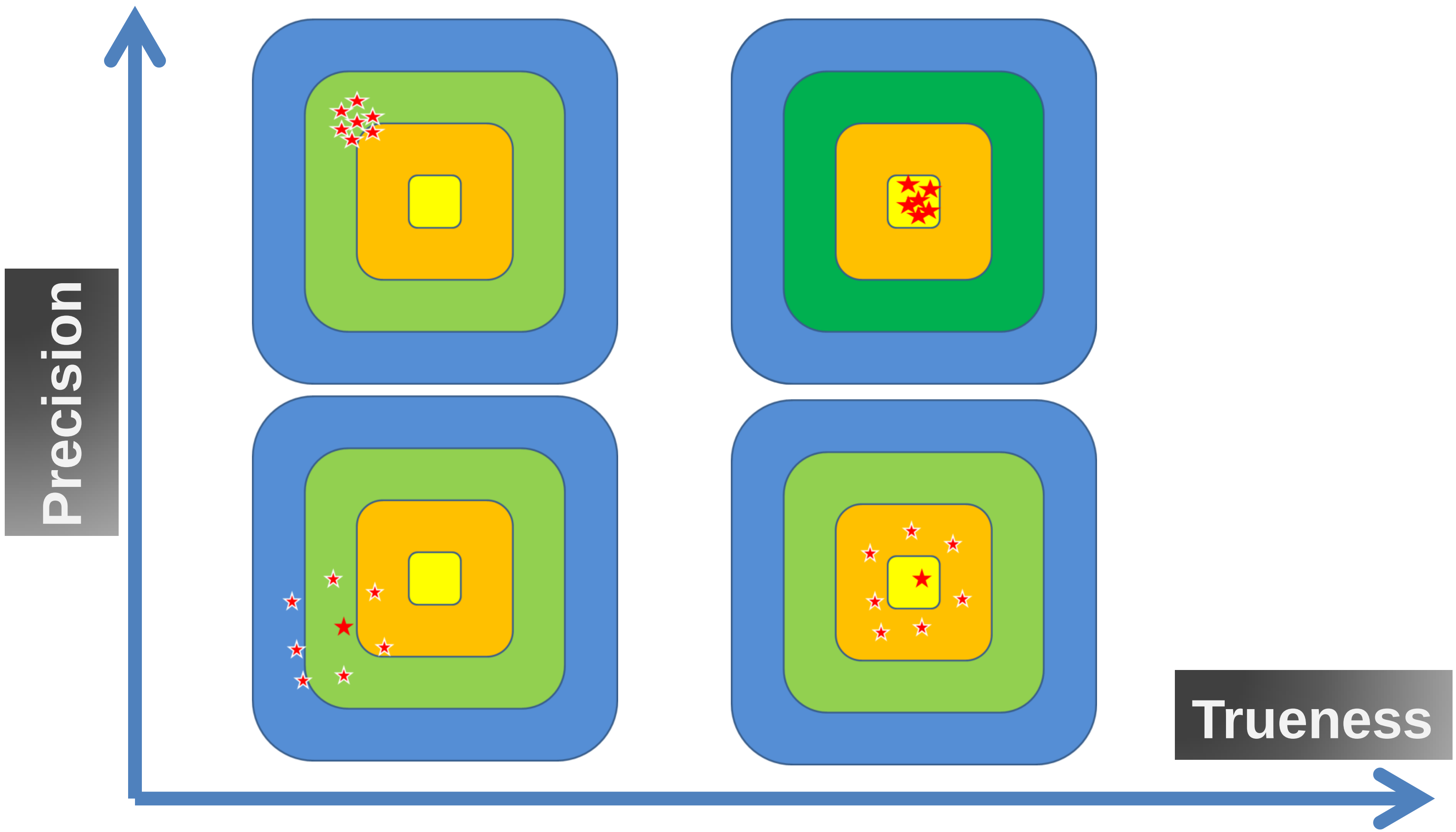
- Precision / Repeatability
  - variation in measurements taken by a single person or instrument on the same item and under the same conditions
  - Deviation of measured values
- Reproducibility
  - degree to which repeated measurements under unchanged conditions show the same results
- Also function of signal stability / settling

The Test Perspective



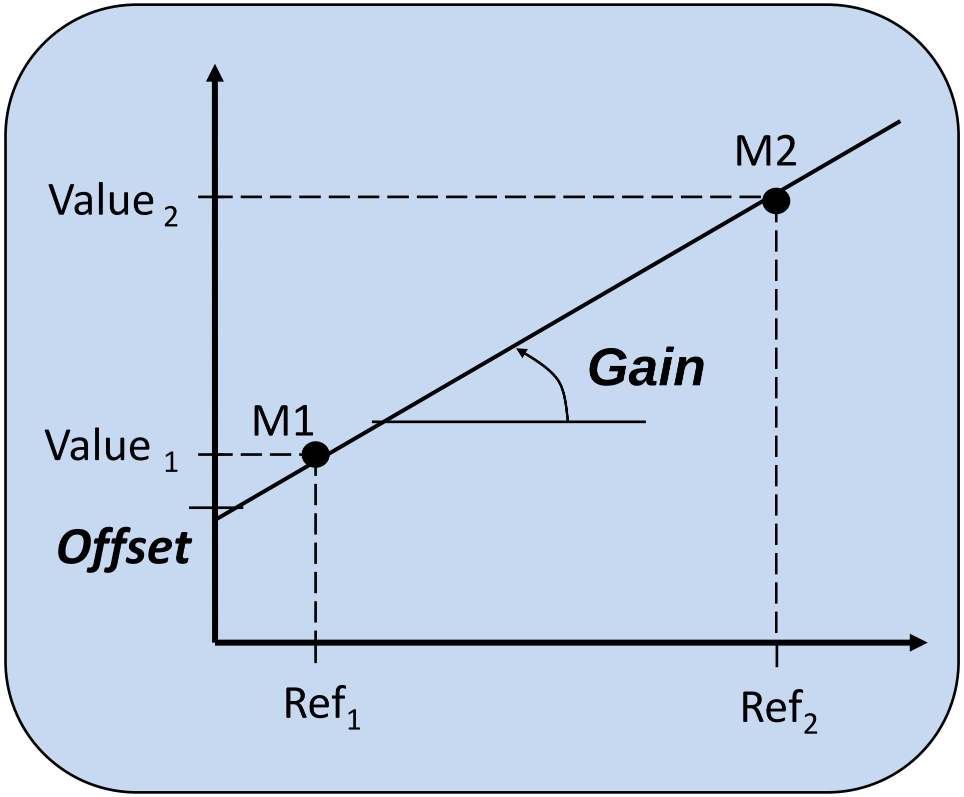
- Trueness
  - Relates to systematic errors
  - Subject to calibration
  - Not so critical – what matters is that “all are treated equal”
- Precision
  - Relates to random errors
  - Reflects instrument quality and performance
  - Is key to decision making

Trueness versus precision



Calibration Considerations

- Offset & gain
  - Offset
    - → Precision is key
  - Gain
    - → Set-point reproducibility and precision are key



Understanding Specifications

- Example: Teradyne Catalyst
  - matrix source specifications

Range	Resolution	Accuracy	Average Error
200mA	25 uA	+/-(0.1% + 100 uA)	+/- 225 uA
100mA	12.5 uA	+/-(0.1% + 50 uA)	+/- 112.5 uA
50mA	6.25 uA	+/-(0.1% + 25 uA)	+/- 56.25 uA
20mA	2.5 uA	+/-(0.1% + 10 uA)	+/- 22.5 uA
10mA	1.25 uA	+/-(0.1% + 5 uA)	+/- 11.25 uA
5mA	625 nA	+/-(0.1% + 2.5 uA)	+/- 5.625 uA
2mA	250 nA	+/-(0.1% + 1 uA)	+/- 2.25 uA
1mA	125 nA	+/-(0.1% + 600 nA + 1 nA/V)	+/- 1.225 uA
500uA	62.5 nA	+/-(0.1% + 350 nA + 1 nA/V)	+/- 663 nA
200uA	25 nA	+/-(0.1% + 200 nA + 1 nA/V)	+/- 325 nA
100uA	12.5 nA	+/-(0.1% + 150 nA + 1 nA/V)	+/- 213 nA
50uA	6.25 nA	+/-(0.1% + 125 nA + 1 nA/V)	+/- 156 nA
20uA	2.5 nA	+/-(0.1% + 110 nA + 1 nA/V)	+/- 123 nA
10uA	1.25 nA	+/-(0.1% + 105 nA + 1 nA/V)	+/- 116 nA
5uA	625 pA	+/-(0.1% + 103 nA + 1 nA/V)	+/- 113 nA

Understanding Specifications

- Example: Teradyne Catalyst matrix source
  - 2mA range, 14 bit
  - Nominal resolution: 250nA
  - Accuracy: ± (0.1% measure + 1uA)

  - Measurement error:
    min: ±1.25µA -- max: ±3.25µA

  - True Value: 1.5mA
    → Measured value: 1.49725 – 1.50275mA (0.37%)
  - True Value: 100µA
    → Measured value: 98.65 – 101.35µA (2.7%)

Understanding Specifications

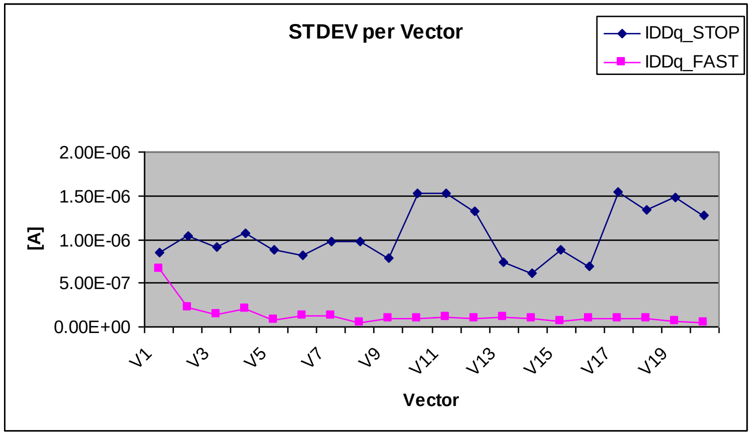
- Q-Star QD-1011 specs:

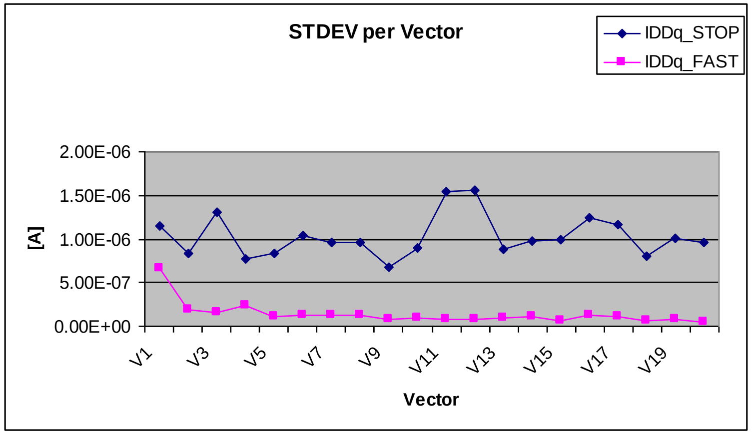
$\Delta I_{DDQ\ RMS} = f(C_L, \#Samples)$ [nA] [5]				
Measurement Range [1]	**C_L**			**# Samples** [2]
	0.0 – 0.5 µF[3]	**0.5 – 2.0 µF**[3]	**1.0 – 10.0 µF**[4]	
0 – 100 µA	*20*	*50*	*330*	**1**
	15	*25*	*230*	**4**
	10	*15*	*110*	**16**
0 – 1 mA	*50*	$\boxed{90}$	*500*	**1**
	30	*60*	*300*	**4**
	15	*20*	*150*	**16**
0 – 10 mA	*360*	*400*	*550*	**1**
	200	*220*	*290*	**4**
	125	*130*	*180*	**16**
0 – 30 mA	*2200*	*2200*	*2200*	**1**
	700	*700*	*700*	**4**
	220	*220*	*220*	**16**

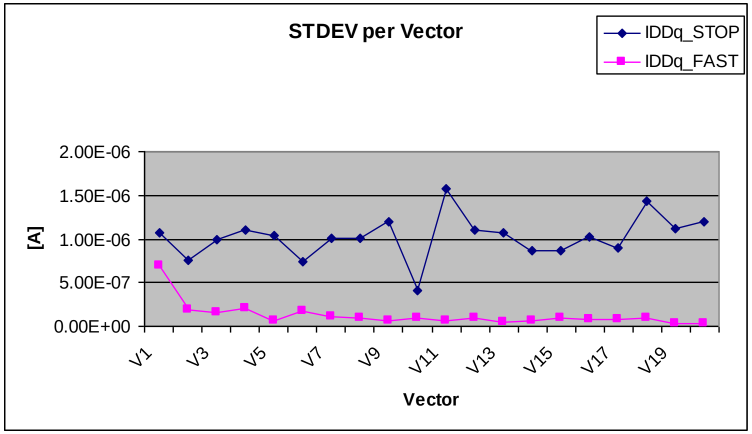
Understanding Specifications

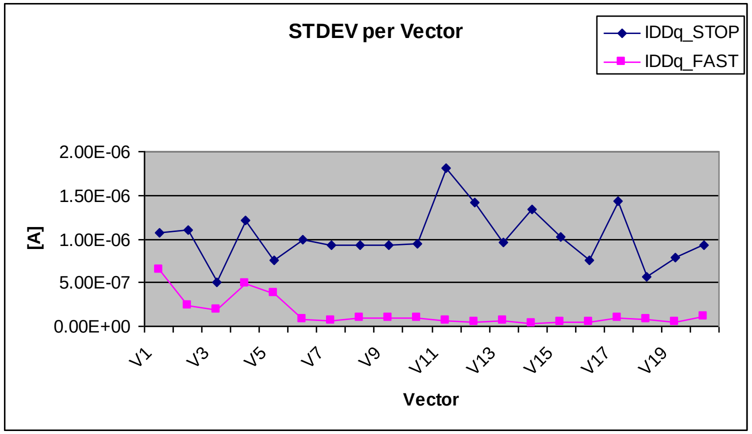
ATE

Q*



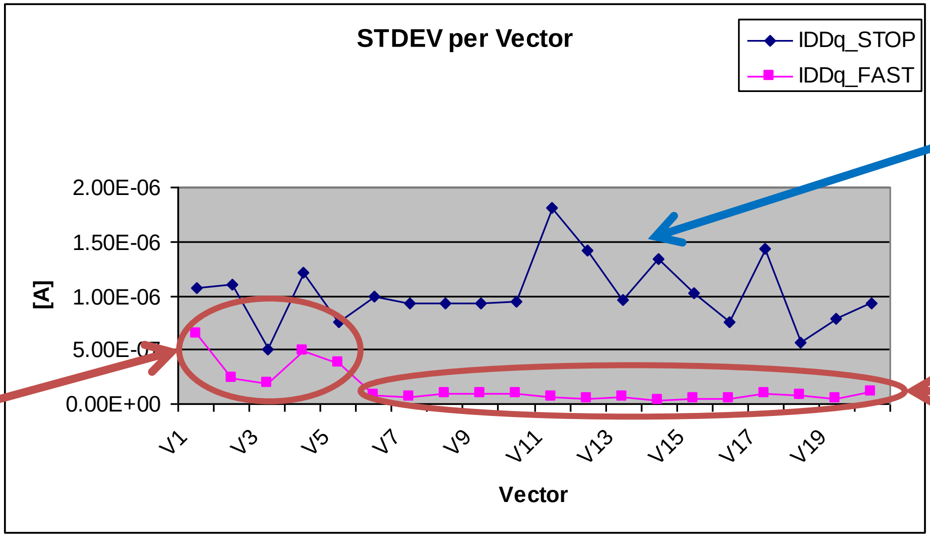






IDDQ Measurement repeatability, 20 strobes, 10 iterations per strobe

Impact of Settling



Q*: no settling

ATE: >10ms settling

Q*: 10-50μs settling

- ATE measurements: ~100ms/measurement
- Q* measurements: 150-200μs/measurement

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Current & Reliability

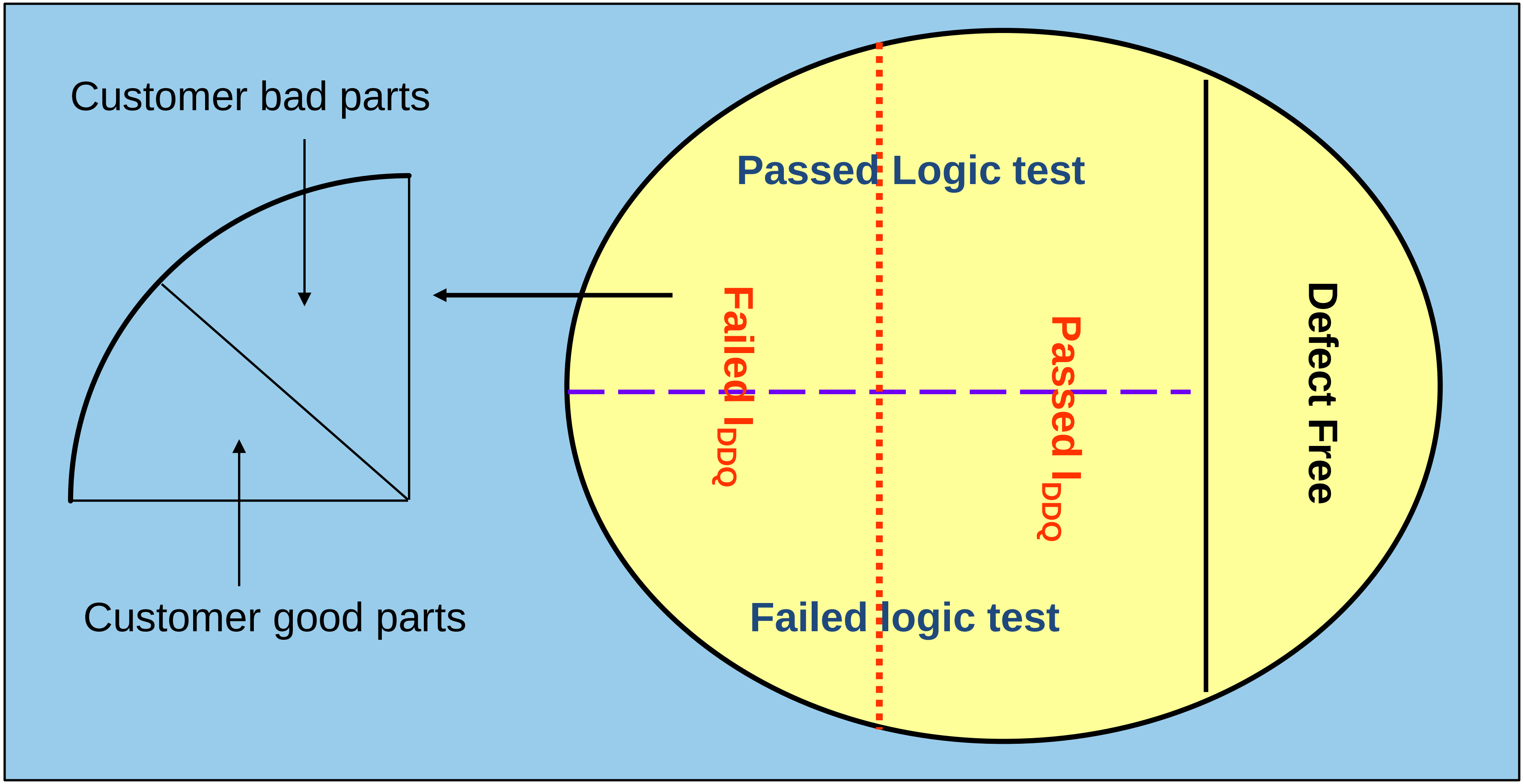
- Deviations in current behavior
  - indication for reliability risks of devices and systems.
  - Often overlooked as focus is typically on functional behavior

- Research results published by IBM and Sematech clearly shows that “IDDQ-only” failures are posing reliability risks.

- High correlation between burn-in failures and IDDQ test failures.

- *Appropriate* current measurements can easily reveal problem parts/systems
  - Information is “hidden” in both static as well as dynamic current behavior

Test Qualification



Test Coverage

- What coverage do we need?
  - 4 out of 10 *IDDQ only* failures pose problems
  - Desired : 100 (10) (1) ppm reliability level
    - → Acceptable defect level : 250 (25) (2.5) ppm
    - → Case 1 : “IDDQ yield loss” : 5% (50000ppm)
      - Required IDDQ coverage : 99.5% (99.95%) (99.995%)
    - → Case 2 : “IDDQ yield loss” : 0.1% (1000ppm)
      - Required IDDQ coverage : 75% (97.5%) (99.75%)

The Value of Eliminating Burn-In

- INTEL : 1.25 M$ savings
  - product : i960JX CPU
  - elimination of Burn-in

- SEMATECH Consortium
  - monthly production of 1 M IC's
  - savings ranging from 267 k$ to 1.95 M$ (monthly !)

    → Burn-in replaced by I_{DDQ} + voltage stress

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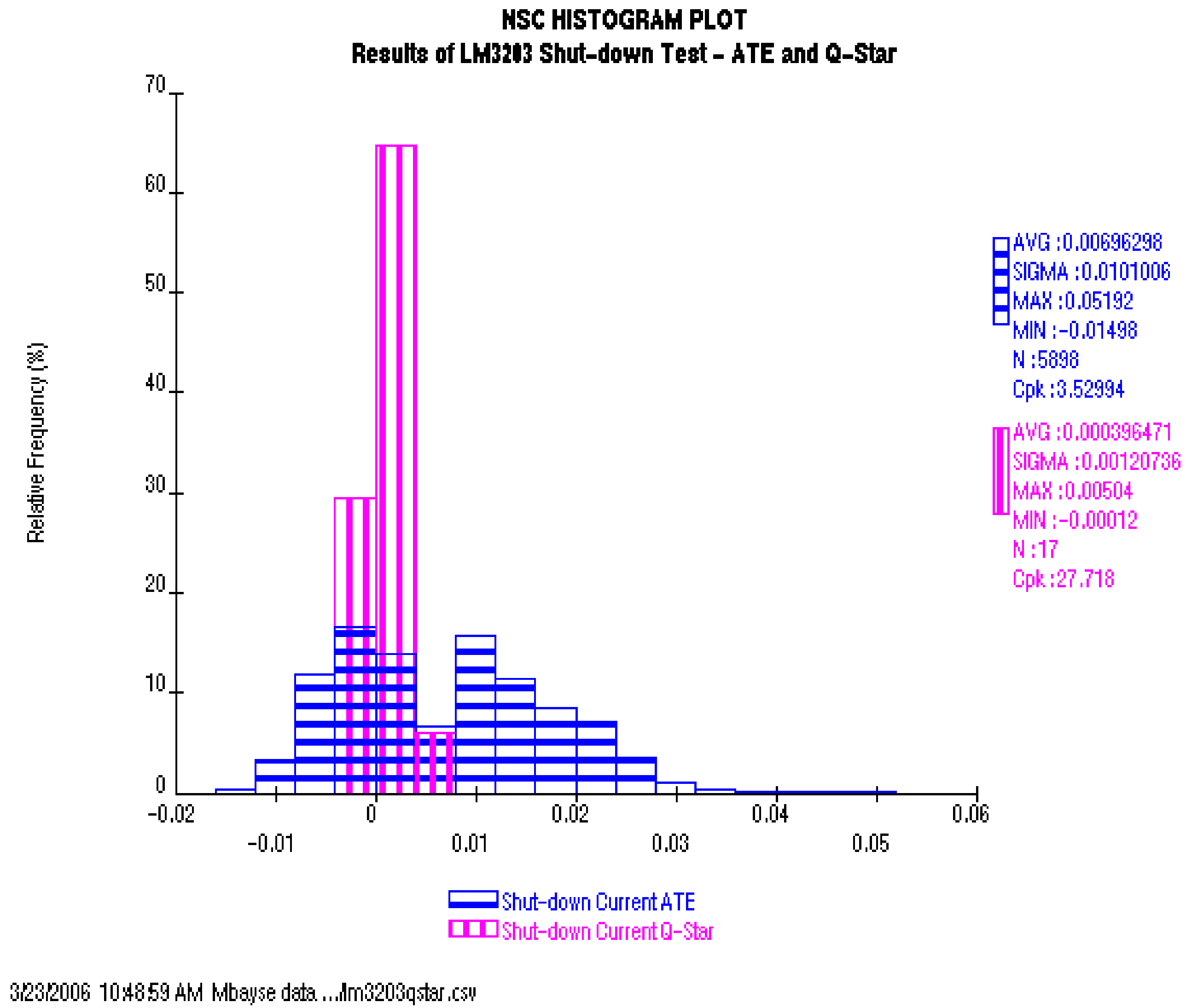
Case 1

- Case 1:
  - Qualification of a LM3203 voltage regulator
  - Data Source: National Semiconductor
  - Test Subject: Shutdown current
  - Test Focus: Instrument precision

Case 1


NSC HISTOGRAM PLOT
Results of LM3203 Shut-down Test - ATE and Q-Star
Relative Frequency (%)
70
60
50
40
30
20
10
0
-0.02
-0.01
0
0.01
0.02
0.03
0.04
0.05
0.06
AVG :0.00696298
SIGMA :0.0101006
MAX :0.05192
MIN :-0.01498
N :5898
Cpk :3.52994
AVG :0.000396471
SIGMA :0.00120736
MAX :0.00504
MIN :-0.00012
N :17
Cpk :27.718
Shut-down Current ATE
Shut-down Current Q-Star
3/23/2006 10:48:59 AM Mbayse data ...\lm3203qstar.csv

Case 1

- Considerations
  - Q-Star QD-1011 based measurements show a tighter distribution and a higher measurement repeatability.
    - → Measurement repeatability of 1-2nA for a 100µA module was obtained (0.002% of range)
  - The improved measurement quality enabled easy detection of outlier devices that escape the ATE current based tests that are marginal to comprehensive time expensive specification tests and lead to field failures.
  - Additional experiments confirmed the correctness of the QD-1011 results

Case 1

- Conclusions
  - An IDDx based test strategy using Q-Star add-on current measurement instrumentation has proven to provide improved measurement quality combined with test cost reduction.
  - Reduction of **Field failure rates and Field returns**
  - Further benefits include test time reduction, measurable improvement in test quality and test confidence.
  - The approach provides a common test solution that can be applied across device technologies and product mixes and has been successfully adopted as a working flow in the production test environment.

Case 2

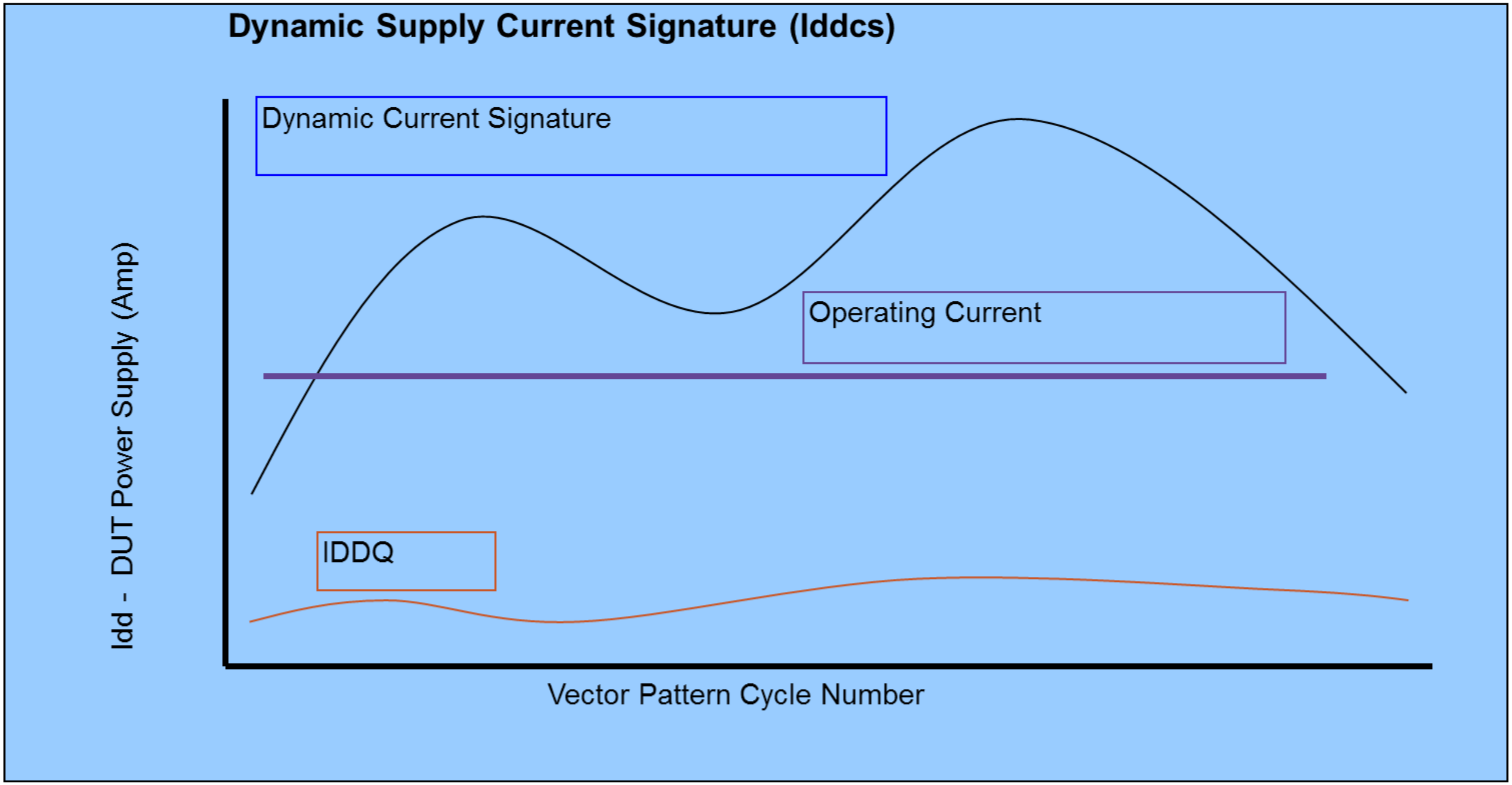
- Case 2
  - Reliability issue with high performance network device
  - Data Source: LSI Logic
  - Test Subject: Power Profiling
  - Test Focus: Instrument precision

Case 2

- Field return issue
  - Limitation of test platform measurement capabilities was masking devices with potential reliability risk
  - Detailed FA on field returns revealed
    - → Sensitivity to Memory-BIST failures @ Low Vdd
    - → VDD droop on internal supply test pin under particular conditions
- IC Design/Application Engineers wanted better Power Management
  - Device power profile and marketing requirements
  - Feedback to design tools for software tool calibration on power consumption
- Solution: Deployment of QT-1411

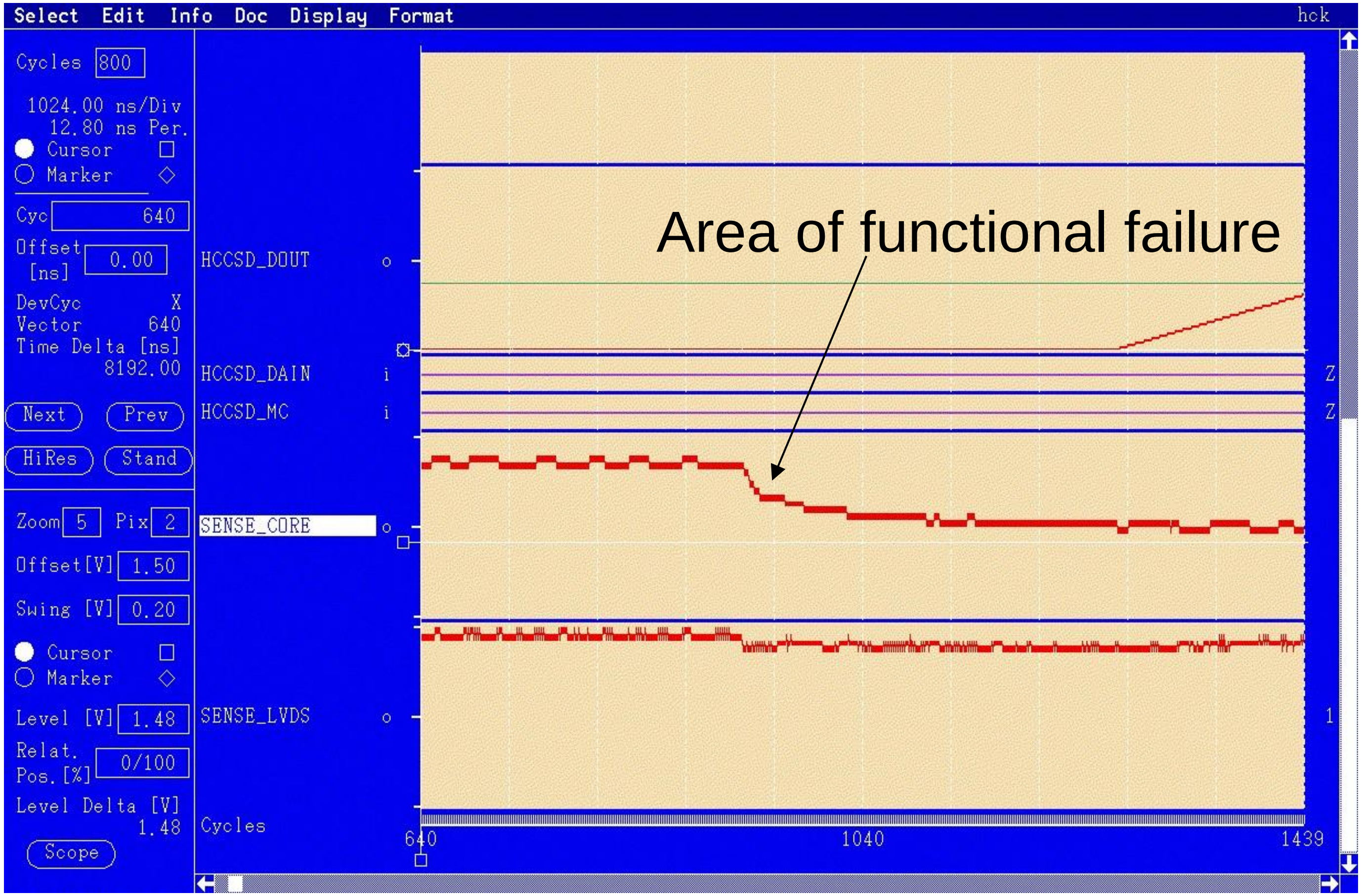
Case 2

- Current behavior

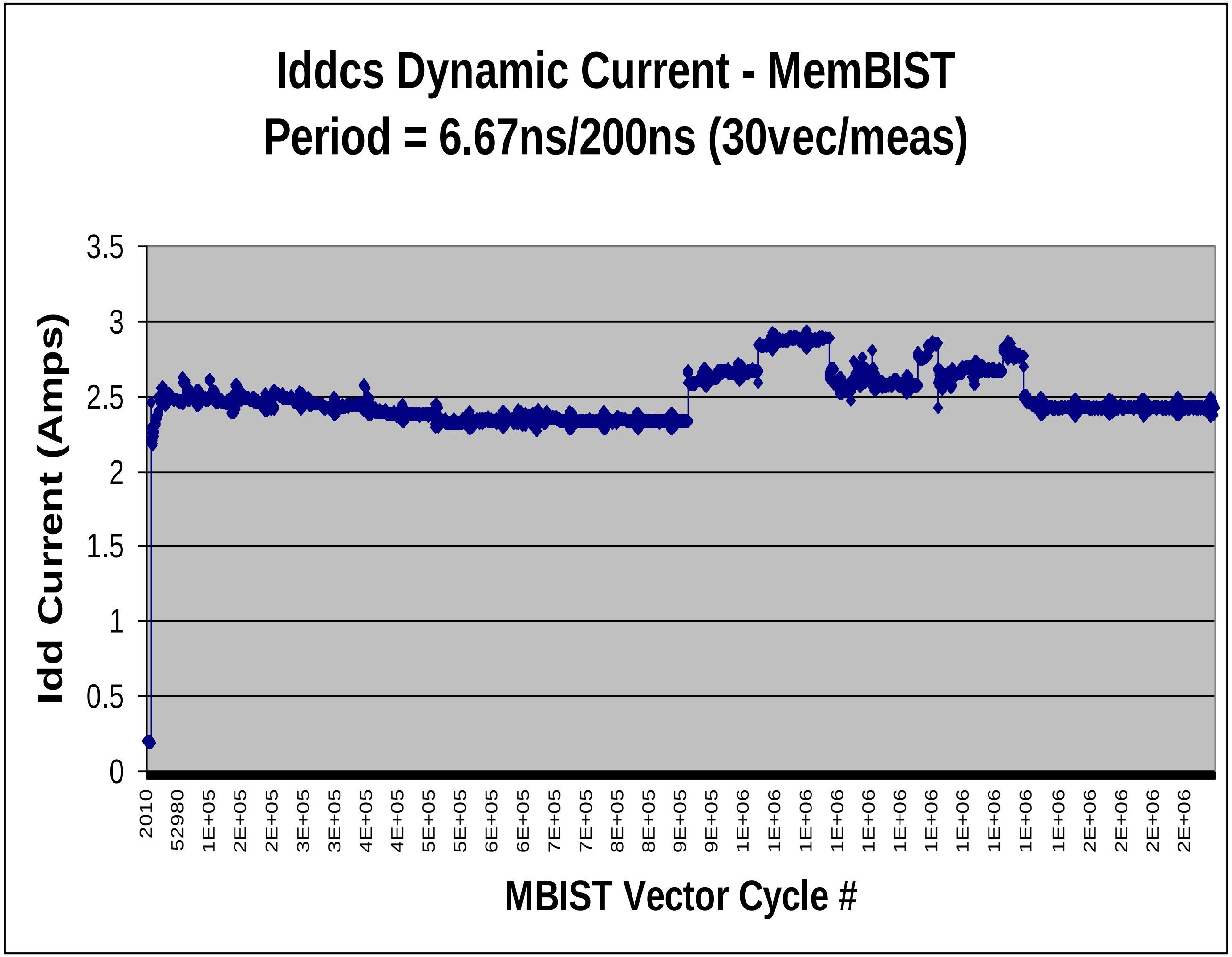


Case 2

- Initial problem observation: VDD droop



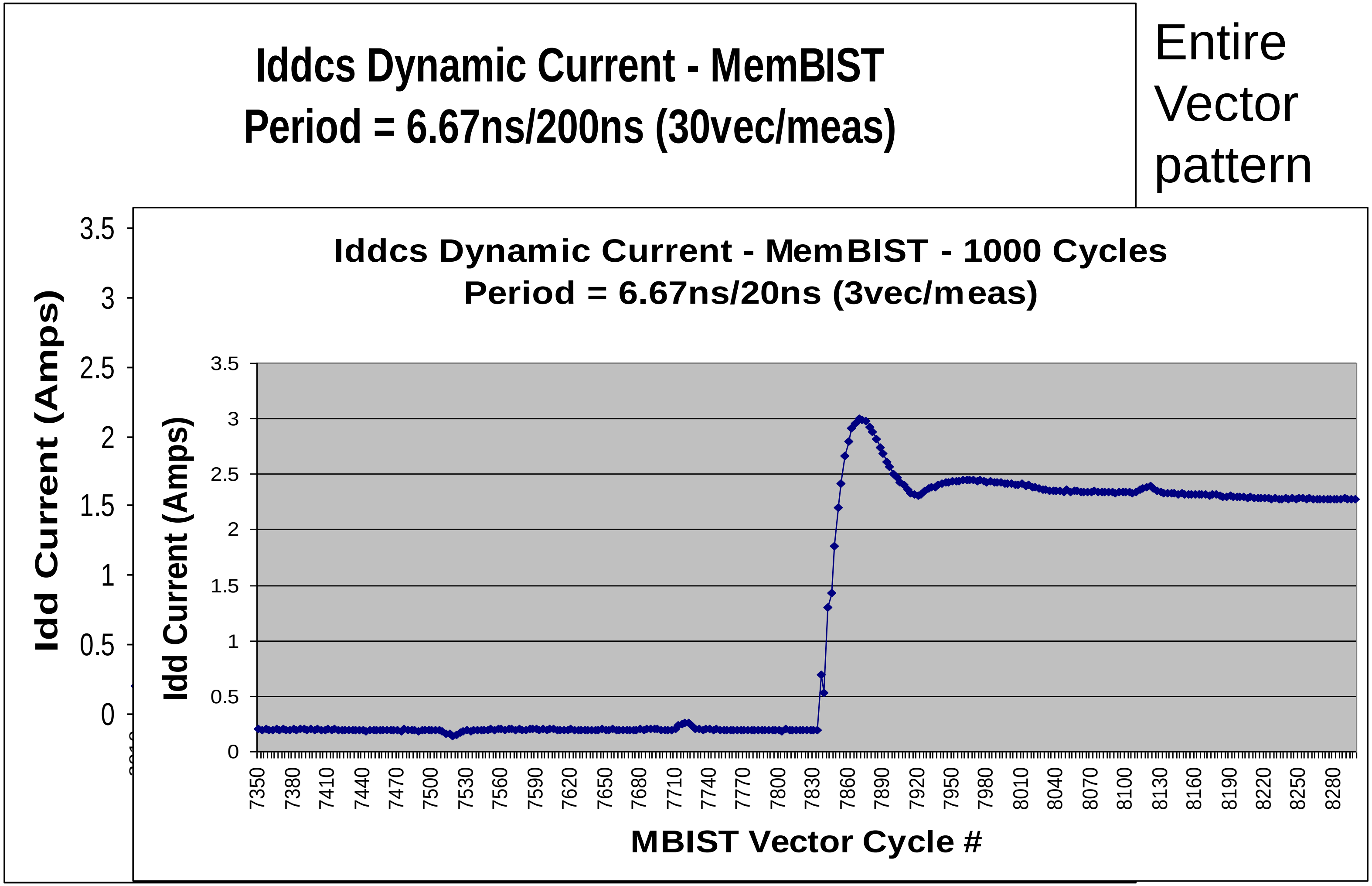
Case 2



Entire Vector pattern

Case 2

Entire Vector pattern



Case 2

- Benefits of good power profiling:
  - **Design engineering**
    - → design verifies marketing requirements
    - → early and easy design tools adjustments for faster time to market
  - **Test engineering**
    - → identification of current and voltage droop issues
    - → lower cost of test with faster test program debugging and execution
  - **Product Engineering**
    - → better tool to monitor the silicon process and faster identifications of variances and processing speeds
  - **Failure analysis**
    - → identification of IC fault locations with the comparison of the known good device current signature

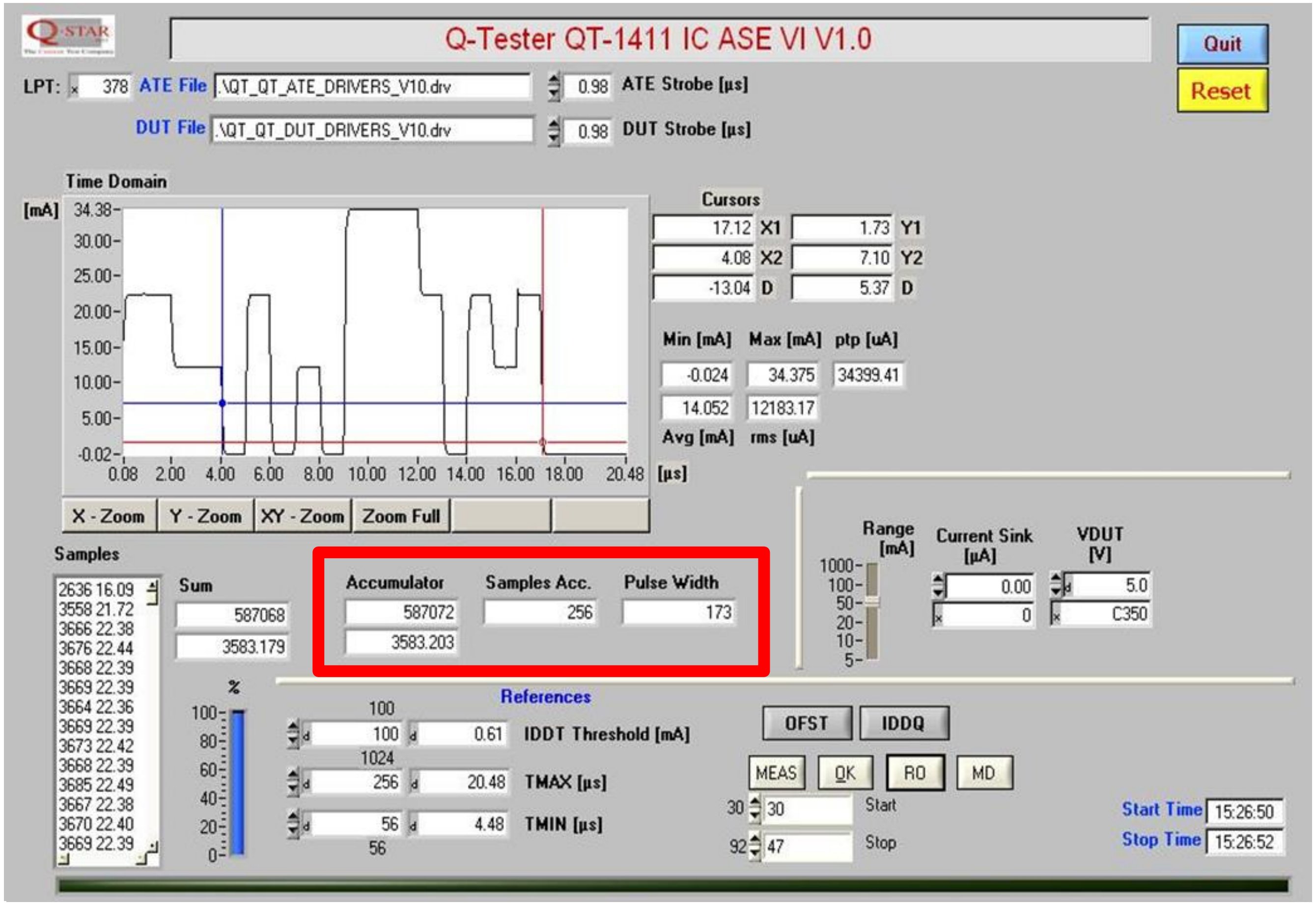
Case 2

- Conclusions
  - Q-Star's QT-1411 met LSI's dynamic signature requirements by providing
    - → fast and accurate results
    - → flexible sampling rate
    - → fast and easy implementation on the V93000
  - The dynamic current signature resulted in
    - → faster time to market
    - → Improved test quality
    - → **Increased device & system reliability**
    - → Cost of Test savings

Other examples

- Freescale:
  - *“Making use of Q-Star Test’s QD-1020 product allows us to reduce test costs whilst meeting our stringent quality demands when implementing our advanced IDDQ screening methodologies that include running hundred’s of IDDQ strobe points, as well as offering us improved IDDQ data quality”*
- Dialog Semiconductor:
  - *“Combining precise current measurements and appropriate data processing ensures product reliability and eliminates the need for burn-in as reliability screen”*
- TSMC and IBM:
  - *“Precise current profiling of fuse burning current ensures reliability of reconfigured memories and avoids “walking wounded” entering the field”*
- Sharp:
  - *“ Enabled by a Q-Star I_{DDQ} monitor, a die-to-die & test set-up independent DSM strategy based on Current Ratios was developed & successfully implemented in a production environment, yielding significant improvement of product quality and reliability”.*
- Reliability qualification of remote controllers

- Battery lifetime – reliability assessment



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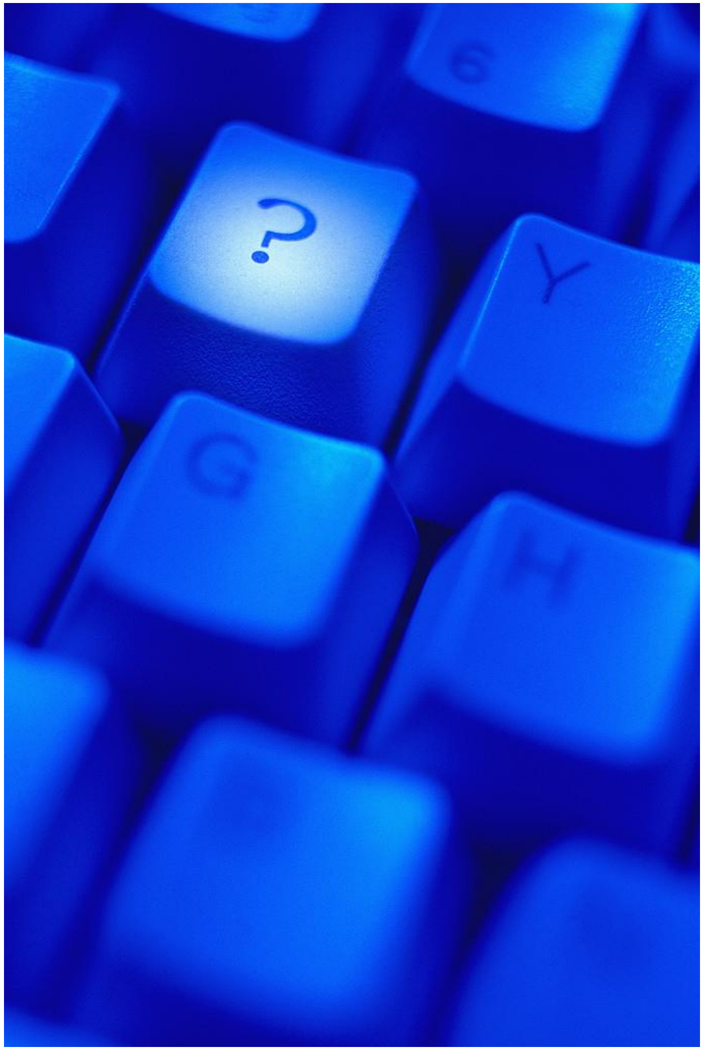
Conclusions

- “Current” hides/reveals reliability related info.
- Precise measurements of both Static and Dynamic current behavior unlock the secrets and support easily identification of reliability risks at device – board – system level.
- Requires use/deployment of appropriate instrumentation, eventually combined with suitable data analysis strategies.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- Slides and recording of the webinar will be available shortly via an e-mail from Ridgetop
- E-mail follow-up questions & comments to hans.manhaeve@ridgetop.eu
- Please fill out our brief feedback survey at https://www.surveymonkey.com/r/R5GYLND

Thanks for your time and interest!

Thank you!

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