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

$ 25m @ 90 nm

Software, hardware trade-offs

System, board, chip optimization

ARM Cell libraries

Software

WindRiver

Analog IP

Digital IP

Processors

IBM ARM

Fujitsu

TSMC

Synopsys

LTXcademie

Virage Logic

MIPS Technologies

$ 25m @ 90 nm

00637
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 → ….%)
Badwater, Death Valley
-85.5m (-282ft)
“Find the Defect”
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
  \[ \text{Yield} = \frac{\text{good chips}}{\text{total chips}} \]

- Challenge is in separating “good” from “bad”
Yield and Reliability - Ambiguity

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

- 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
  - \textit{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)
  - \textit{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
  - \textit{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**

  ![Diagram](image)

  - **Infant mortality**
  - **Useful life**
  - **Wearout**

  - **Failure mechanisms**
    - EM / SM
    - NBTI / PBTI
    - QBD / TDDB
    - HCI

  - **Reliability-related factors**
    - Temperature
    - Voltage / Current
    - Frequency
    - Radiation

[T. M. Mak]
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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)

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 $\leftrightarrow$ 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**

<table>
<thead>
<tr>
<th>Range</th>
<th>Resolution</th>
<th>Accuracy</th>
<th>Average Error</th>
</tr>
</thead>
<tbody>
<tr>
<td>200mA</td>
<td>25 uA</td>
<td>+/-(0.1% + 100 uA)</td>
<td>+/- 225 uA</td>
</tr>
<tr>
<td>100mA</td>
<td>12.5 uA</td>
<td>+/-(0.1% + 50 uA)</td>
<td>+/- 112.5 uA</td>
</tr>
<tr>
<td>50mA</td>
<td>6.25 uA</td>
<td>+/-(0.1% + 25 uA)</td>
<td>+/- 56.25 uA</td>
</tr>
<tr>
<td>20mA</td>
<td>2.5 uA</td>
<td>+/-(0.1% + 10 uA)</td>
<td>+/- 22.5 uA</td>
</tr>
<tr>
<td>10mA</td>
<td>1.25 uA</td>
<td>+/-(0.1% + 5 uA)</td>
<td>+/- 11.25 uA</td>
</tr>
<tr>
<td>5mA</td>
<td>625 nA</td>
<td>+/-(0.1% + 2.5 uA)</td>
<td>+/- 5.625 uA</td>
</tr>
<tr>
<td><strong>2mA</strong></td>
<td><strong>250 nA</strong></td>
<td><strong>+/-(0.1% + 1 uA)</strong></td>
<td><strong>+/ 2.25 uA</strong></td>
</tr>
<tr>
<td>1mA</td>
<td>125 nA</td>
<td>+/-(0.1% + 600 nA + 1 nA/V)</td>
<td>+/- 1.225 uA</td>
</tr>
<tr>
<td>500uA</td>
<td>62.5 nA</td>
<td>+/-(0.1% + 350 nA + 1 nA/V)</td>
<td>+/- 663 nA</td>
</tr>
<tr>
<td>200uA</td>
<td>25 nA</td>
<td>+/-(0.1% + 200 nA + 1 nA/V)</td>
<td>+/- 325 nA</td>
</tr>
<tr>
<td>100uA</td>
<td>12.5 nA</td>
<td>+/-(0.1% + 150 nA + 1 nA/V)</td>
<td>+/- 213 nA</td>
</tr>
<tr>
<td>50uA</td>
<td>6.25 nA</td>
<td>+/-(0.1% + 125 nA + 1 nA/V)</td>
<td>+/- 156 nA</td>
</tr>
<tr>
<td>20uA</td>
<td>2.5 nA</td>
<td>+/-(0.1% + 110 nA + 1 nA/V)</td>
<td>+/- 123 nA</td>
</tr>
<tr>
<td>10uA</td>
<td>1.25 nA</td>
<td>+/-(0.1% + 105 nA + 1 nA/V)</td>
<td>+/- 116 nA</td>
</tr>
<tr>
<td>5uA</td>
<td>625 pA</td>
<td>+/-(0.1% + 103 nA + 1 nA/V)</td>
<td>+/- 113 nA</td>
</tr>
</tbody>
</table>
Example: Teradyne Catalyst matrix source

- 2mA range, 14 bit
- Nominal resolution: 250nA
- Accuracy: ± (0.1% measure + 1µA)

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%)
### Q-Star QD-1011 specs:

<table>
<thead>
<tr>
<th>Measurement Range (1)</th>
<th>( C_L )</th>
<th>( 0.0 - 0.5 \mu F ) (3)</th>
<th>( 0.5 - 2.0 \mu F ) (3)</th>
<th>( 1.0 - 10.0 \mu F ) (4)</th>
<th># Samples (2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 – 100 ( \mu A )</td>
<td>20</td>
<td>50</td>
<td>330</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>25</td>
<td>230</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>10</td>
<td>15</td>
<td>110</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>0 – 1 ( mA )</td>
<td>50</td>
<td>90</td>
<td>500</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>60</td>
<td>300</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>20</td>
<td>150</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>0 – 10 ( mA )</td>
<td>360</td>
<td>400</td>
<td>550</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>200</td>
<td>220</td>
<td>290</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>125</td>
<td>130</td>
<td>180</td>
<td>16</td>
<td></td>
</tr>
<tr>
<td>0 – 30 ( mA )</td>
<td>2200</td>
<td>2200</td>
<td>2200</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td></td>
<td>700</td>
<td>700</td>
<td>700</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td></td>
<td>220</td>
<td>220</td>
<td>220</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>

\( \Delta I_{DDQ \ RMS} = f(C_L, \#Samples) \ [nA] \) (5)
Understanding Specifications

**ATE Q***

**IDDQ Measurement repeatability, 20 strobes, 10 iterations per strobe**
Impact of 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

- Customer bad parts
- Customer good parts
- Passed Logic test
- Failed logic test
- Passed IDAQ
- Failed IDAQ
- Defect Free

Customer bad parts
Customer good parts
Passed Logic test
Failed logic test
Passed IDAQ
Failed IDAQ
Defect Free
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:
- 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 (%)

Shut-down Current ATE
Shut-down Current Q-Star

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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
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

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

![Graph showing Dynamic Supply Current Signature (Iddcs)](image)

- Dynamic Current Signature
- Operating Current
- IDDQ

Idd - DUT Power Supply (Amp)

Vector Pattern Cycle Number
Case 2

- Initial problem observation: VDD droop

Area of functional failure
Case 2

Iddcs Dynamic Current - MemBIST
Period = 6.67ns/200ns (30vec/meas)

Entire Vector pattern
**Case 2**

**Iddcs Dynamic Current - MemBIST**

*Period = 6.67ns/200ns (30vec/meas)*

![Graph showing Iddcs Dynamic Current - MemBIST - 1000 Cycles](image)

*Period = 6.67ns/20ns (3vec/meas)*

![Graph showing Iddcs Dynamic Current - MemBIST - 1000 Cycles](image)
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 IDDQ 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.
- 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!

Ridgetop Group, Inc.

3580 West Ina Road
Tucson, AZ 85741