Advancing Factory-Wide Data Quality for APC Applications

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Outline

• Data Quality Overview
  – Background
  – Industry Experiences
  – IC Maker Consensus
  – Guiding Principles

• Time Synchronization and time-stamping
  – Guidelines
    • Timing Matrix
  – Standards Ballots
    • Key Features

• Data Quality Key Messages

• References
Data Quality Background

• As the industry moves toward automated decision-making, the data each tool generates is critical to improving productivity

• Today, the quality of equipment data is poor; it must be dramatically improved if applications are to effectively apply collected data

• APC needs high quality data for accurate decision-making
Industry Data Quality Needs

APC Challenges:
- Unsynchronized sensor/tool data available
- Bandwidths/polling rates vary greatly
- Difficult to synchronize data streams

APC Application Needs:
- Current FDC requirements (10 ms to 1 ms time-stamp precision)
- Support data sampling rates up to 10,000 Hz (< 1 ms precision)
- Equipment/metrology data should synchronize to wafer or lots
- Improve multivariate, advanced correlation and analysis
- Virtual Metrology support
- Expose new cause-effect relationships
Sensor vs. SECS Data Comparison

Data time lag

SECS data not capturing the sensor overshoot data
Interface A Data Freshness

Running DCP at 100ms shows the values change every 400ms to 750ms.

Another problem encountered with a parameter is its resolution. Is a change of 0.2% of full scale acceptable when you may need 0.01% resolution?
IC Maker Consensus Experiences

• Issues Experienced
  – Equipment interface has software defects
  – Documentation does not match software
  – Reports send wrong format of data
  – Equipment performance affected by data collection
    • Resulting in lost data
  – Short data collection period with a high rate can take tool down
    • Resulting in product loss
  – Missing data, including context data
  – Reporting not current data
  – Data report and event latency
  – Inaccurate error reporting
  – Unclear level of data collection limits, without affecting process
    • Not clear what the equipment is capable off
  – Context data missing, e.g., linking data with a wafer
  – Non-existent time synchronization
    • Data reports cannot be used to correlate events, alarms, or process issues
  – Inconsistent point of timestamping and non-existent time synchronization

Time Synchronization + Time Stamping -> Data Quality
Equipment Data Quality Principles

• Data must be provided with sufficient **accuracy, resolution, and sampling frequency** to allow high fidelity extraction of relevant data features for process/equipment characterization, fault detection, failure diagnosis, and process control.

• Event data and **context information must be complete, consistent, and correct** as well as reflect the **actual time and conditions** pertaining to the occurrence of the indicated event.

• **Timely transfer of data** is necessary to achieve fault interdiction.

• A **time synchronization** solution is the initial focus.
Time Synchronization Working Group

Mission
Require accurate equipment and factory clock synchronization for future implementations, while maintaining compatibility with legacy systems

Goals
• Factory time source
• Factory clock synchronization precision
• Embedded clocks within equipment need to be synchronized with factory clock
• Factory applications timing requirements
• Common time-stamp format/basis
• Consistent point of time-stamping
• Synchronization traceability/quality for verification
• Facilitate data merging and analysis

SEMI Time Synchronization Working Group
• IC makers and equipment/software suppliers
• To participate, contact: Harvey.Wohlwend@ismi.sematech.org
Time Synchronization Approach

1. Leverage definitions from standard sources, e.g., NIST, ISO, IEEE

2. Publish Time Synchronization Guidelines
   • Characterized processes for timing accuracy and precision requirements
   • ismi.sematech.org/docubase/abstracts/4781aeng.htm

3. Specifications in new standard
   • Submitting to SEMI for balloting

4. Update existing standards to support time synchronization/time-stamping
   • E5, E30, E40, E54, E116, E127, E133, E134
   • Backward compatibility is an absolute requirement
Guideline Objective

To complement the proposed new time synchronization standard and provide guidance in establishing a factory time synchronization architecture for realizing effective data collection and time-stamping

Goals:
- Facilitate the establishment of effective factory time synchronization architecture
- Ensure synchronization quality
- Provide recommendations and methods for meeting the new SEMI Time Synchronization standard requirements
- Guidance on data time-stamping for ensuring data quality
- Guidance on current and upcoming time synchronization accuracy requirements
Time Synchronization and Time-Stamping Guidelines Overview

Time Synchronization Architecture
- UTC time scale
- Reference time source and traceability
- NTP strata and modes
- Fault tolerance

Time Synchronization Quality
- Clock quality
- Synchronization frequency
- Security
- Monitoring

Accuracy and Precision Requirements
- Current and upcoming requirements based on working group discussions
- General agreement is about 1 ms accuracy for e-Manufacturing applications

Effective Time-Stamping
- Timestamp format and time base
- Point of time-stamping
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<td>Time Stamping Resolution</td>
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Time Synchronization Requirements

Equipment clocks must:

- Synchronize to factory time servers via NTP
- Communicate UTC date/time information based on ISO 8601
- Converge to single time base, e.g., NTP
- Provide synchronization quality parameters as defined in SEMI ballot 4291
- Provide synchronization error messages as defined in SEMI ballot 4291
- Provide configurable NTP synchronization parameters

Factory Time Synchronization Recommendations:

- Fault-tolerant synchronization architecture
- Improve clock quality to minimize synchronization resources
- Ensure sufficient synchronization frequency
- Adhere to factory network security measures
- Minimize jitter in network and applications during synchronization
- Ensure sufficient clock resolution for the most stringent requirements
- Monitor synchronization quality
Time-Stamping Requirements

Data time-stamping must:

• Adhere to the format defined in the SEMI 4291 ballot
• Reflect only the resolution of the clock

Data time-stamping recommendations:

• Reflect the time when the data was measured
• Mitigate latencies between data generation and time-stamping
  – Record types of latencies (network, application, etc.)
  – Calculate total latency
  – Provide an estimated timestamp based on calculations
Time Synchronization Architecture

Achieving 1 ms time synchronization accuracy requires carefully architected time synchronization system

- Clients should be able to exchange the local time to the server whenever processing and network bandwidth are available
- Minimizing network jitter (variability in network delay) improves synchronization quality
- A stable, high resolution clock improves time stamping quality while relieving the time synchronization frequency and network bandwidth
- Adhere to security precautions to avoid accidental or malicious interference with system clock synchronization
Time Stamping Data

Time stamps coupled with a piece of data shall reflect the time the data was measured, generated as closely as possible to provide a sufficient level of data quality.

- Include accuracy information on the time stamp including estimated clock deviation from UTC and estimated time stamping latency from when the event occurred to when it was actually time-stamped.
**Application Timing Requirements**

**On-tool Examples**

<table>
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<tr>
<th>Application</th>
<th>Description/Needs</th>
<th>Absolute Accuracy</th>
<th>Relative Accuracy</th>
<th>Minimum Data Sampling Interval</th>
<th>Precision Required</th>
</tr>
</thead>
<tbody>
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<td>Intra-tool Sensor Integration</td>
<td>Connect sensors to embedded tool control system for use in real-time control and/or communication to external applications.</td>
<td>5 sec</td>
<td>5 ms</td>
<td>5 ms</td>
<td>1 ms</td>
</tr>
<tr>
<td>End-Point Detection</td>
<td>Analyze key equipment/process parameters to detect the end of a recipe step.</td>
<td>5 sec</td>
<td>10 ms</td>
<td>10 ms</td>
<td>1 ms</td>
</tr>
<tr>
<td>In-Situ FDC</td>
<td>Need to correlate sensor data, tool data, and other process data to a specific wafer/lot for multivariate analysis.</td>
<td>5 sec</td>
<td>5 ms</td>
<td>5 ms</td>
<td>1 ms</td>
</tr>
<tr>
<td>Integrated Metrology (IM)</td>
<td>Standard calls for synchronized clocks to accurately time stamp metrology data.</td>
<td>5 sec</td>
<td>100 ms</td>
<td>100 ms</td>
<td>1 ms</td>
</tr>
</tbody>
</table>
Time Synchronization Ballot (4291)

Specifications in new standard

- Equipment and factory applications shall support synchronization using NTP
- Time-stamp reporting format (ISO 8601)
  - Format to be used by other standards
- Defines a clock object
  - To readily obtain time information from equipment
    - Method to query date/time
    - Accuracy/precision of internal clock
    - Time synchronization status
Define immediate needs and specific tasks for updating and developing SEMI standards to facilitate rapid deployment of factory and equipment clock synchronization.

Goals

- Establish factory clock synchronization
- Facilitate data merging
  - Common time-stamp format
  - Consistent point of time-stamping
  - Time-stamp traceability/quality
- Leverage new SEMI Time Synchronization ballot
- Maintain compatibility with legacy systems
SEMI Standards: Planned Updates

- SEMI ISO 8601 time-stamp format among all standards
- Reference time synchronization standard clock object
- Ensure consistent time-stamping
- Specify time accuracy and reference standard clock object
- Sensor clock synchronization and time-stamping
- Reference time-stamp format

Equipment

- E5 SECSII
- E134 EDA
- E30 GEM
- E54 SAN
- Sensors

FICS

- Control Client
- Data Client

E40 PM

E133 PCS

E116 EPT
Time Synchronization Summary

• Data from sensors and tools cannot be readily merged today to meet factory application needs
  – Unreliable time-stamps prevent advanced analysis capabilities
  – Clocks within the tools should readily synchronize
    • All tool and tool components’ clocks should support synchronization

• Synchronization solutions exist
  – The factory provides accurate timing
    • Time servers and time sources inside the factory should propagate timing information to all equipment and equipment modules using mainstream synchronization protocols

• Standards/guidelines being developed to
  – Improve synchronization communication of equipment clocks
    • Provide consistent time-stamping
  – Verify clock synchronization/time-stamping quality

• Time synchronization is an initial step to addressing the overall data quality issue
Data Quality Key Messages

• Data producers are the equipment suppliers; they are the only ones that can improve data quality.
• Data consumers are IC makers, who are at the mercy of the producers; the quality of the decisions made is wholly dependent on the quality of the data.

Garbage in, garbage out

• Semiconductor equipment generates data critical to improving equipment and factory productivity.
• Data must be provided with sufficient accuracy, resolution, and sampling frequency for process/equipment characterization, fault detection, failure diagnosis, and process development/control.

How does your organization measure data quality?
What are the costs associated with the lack of data quality?
Time Synchronization References

ISMI Reports
- Factory and Equipment Clock Synchronization and Time Stamping Guidelines
  ismi.sematech.org/docubase/abstracts/4781aeng.htm
  ismi.sematech.org/docubase/abstracts/4736aeng.htm
- Semiconductor Factory and Equipment Clock Synchronization for e-Manufacturing
  ismi.sematech.org/docubase/abstracts/4557aeng.htm

ISO 8601:2004
- Internet standard for date/time format: www.w3.org/TR/NOTE-datetime.html

NTP
- www.ntp.org

IEEE 1588
- iee1588.nist.gov