Practical Aspects Impacting *Time Synchronization Data Quality* in Semiconductor Manufacturing

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NIST
National Institute of Standards and Technology
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Outline

- **Why is time synchronization so important in semiconductor manufacturing?**
- Components in the end-to-end synchronization problem
- Currents efforts in semiconductor manufacturing impacting time synchronization data quality
  - NIST and the University of Michigan
- Key points and future efforts

Time Synchronization and Manufacturing

Manufacturing Automation
- Process Control
- Coordination among tools
- Scheduling/Dispatching

Robotics Coordination for Auto Industry

Fault Diagnosis for Power Industry

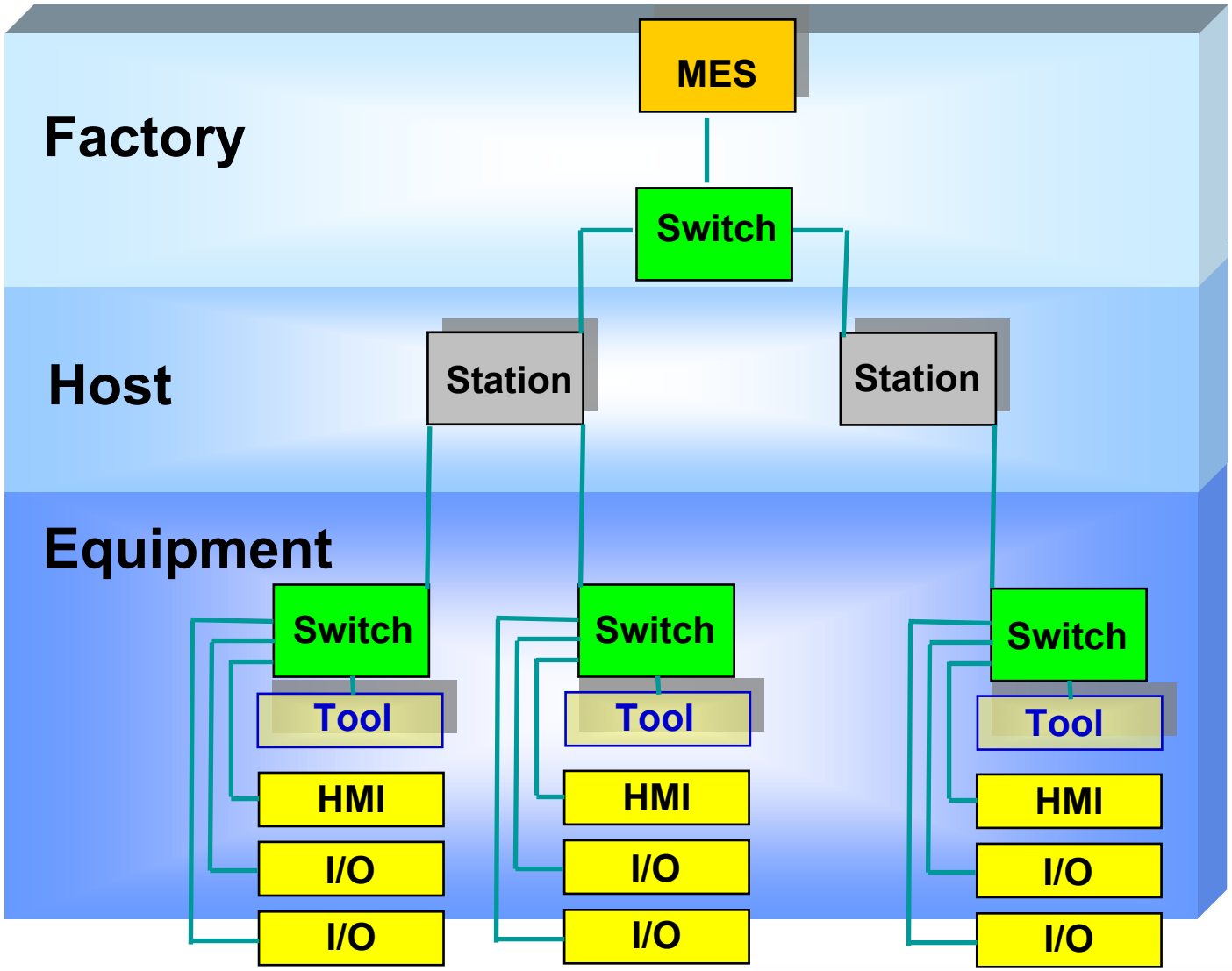
Test and Measurement
- Fault Diagnosis

Network Operations
- Security
- QoS measurement

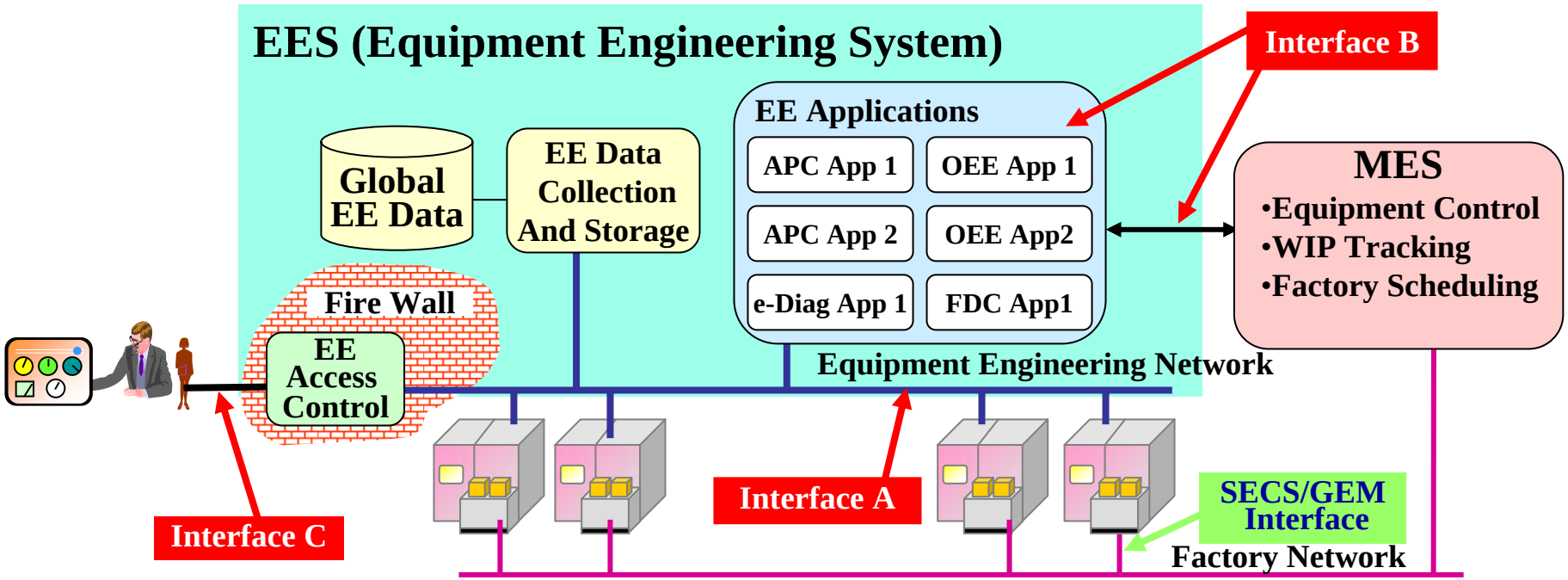
Motivation: The Move to Networks

Ethernet Everywhere!

- Interfaces A, B and C
- EDA, PCS, e-diagnostics
- HSMS
- XML, VPN, OPC
- MES to I/O Level

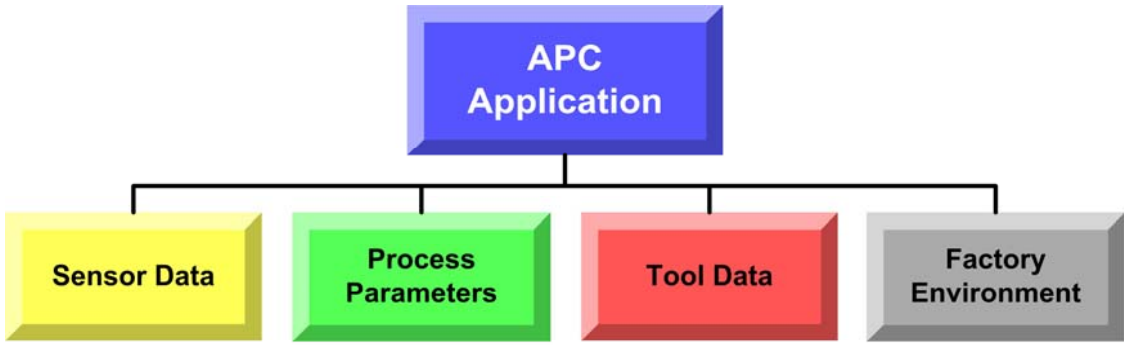


Semiconductor Factory



- *Interface "A" Components*
  - *Process Control and Equipment Operational Data*
  - *Host-Independent Data Collection*
  - *Data Collection Plans ➔ E134*
  - *Equipment Self-Description ➔ E125*
  - *Authentication and Authorization ➔ E132*

Motivation in Chip Manufacturing



Precision Time Stamping to Merge Various Data Streams

Advanced Process Control:

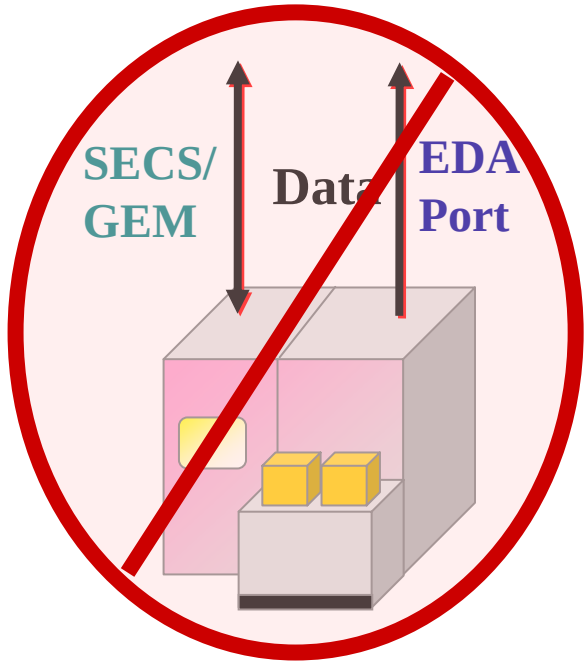
- Fault Detection Classification (FDC)
- e-Diagnostics
- Process optimization
- Virtual metrology

Precision time-stamping and time synchronization:

- Merging data from heterogeneous sources
- Maintain data and event ordering
- Improve multivariate, advanced correlation and analysis
- Expose new cause-effect relationships

Common Time Sync. Pain Points in APC

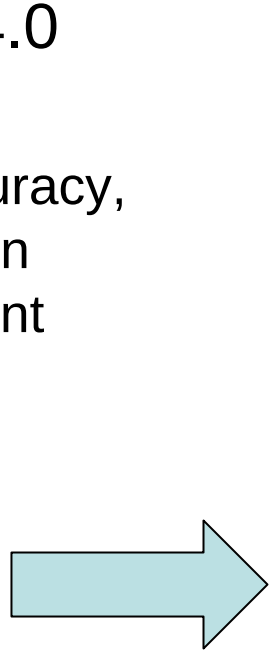
- Events and data are received out-of-order
- Inability to support high data collection rates with good data quality
- Cannot synchronize data across multiple systems (e.g., equipment & metrology systems)
- "False Positives" in fault detection systems bring equipment down unnecessarily
  - Out-of-order data, poor time-stamping
  - Time-stamping at point of sending instead of point of event occurrence

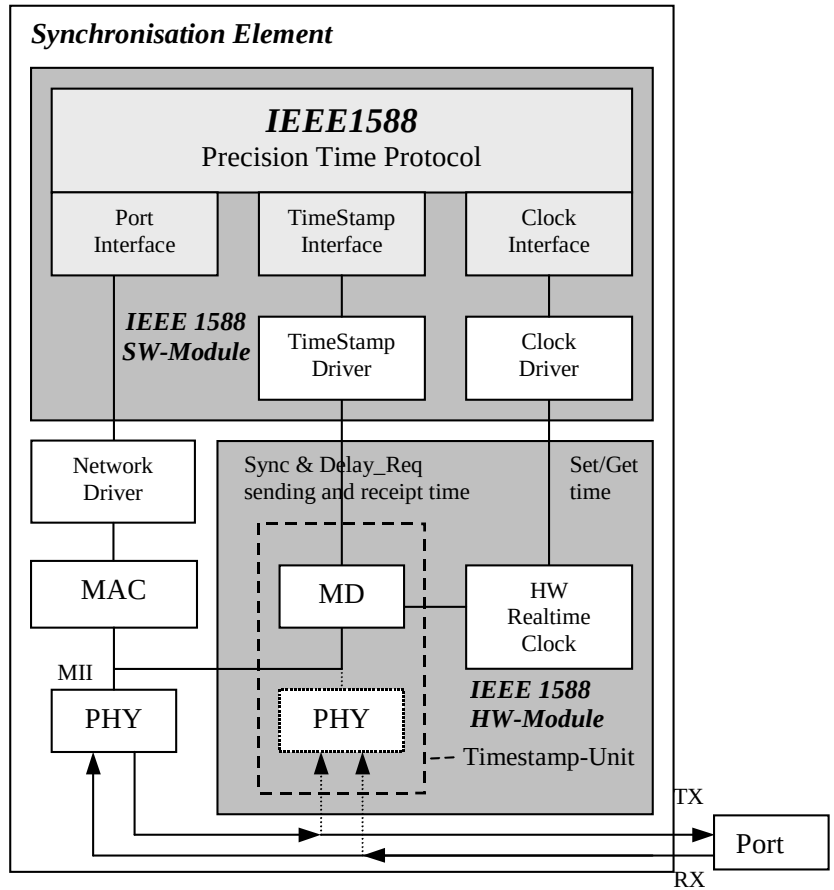


- "Out-of-control" situations for R2R controllers
  - Poor data quality due to delay and ***delay variability***
- Inability to migrate from the equipment level to the factory-wide level with APC systems
- Etc…

Solutions for Time Synchronization

- NTP 4.0 or SNTP 4.0
  - Software only
  - 50 us to 50 ms accuracy, depending largely on software environment
  - More mature
- ANSI/IEEE 1588 – (IEC 61588)
  - Software and hardware
  - Approx 100ns accuracy
  - Infancy in standard and solutions





necessary if no MII- interface available

MD – Message Detector for *Sync* and *Delay_Request* packets

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- **Components in the end-to-end synchronization problem**
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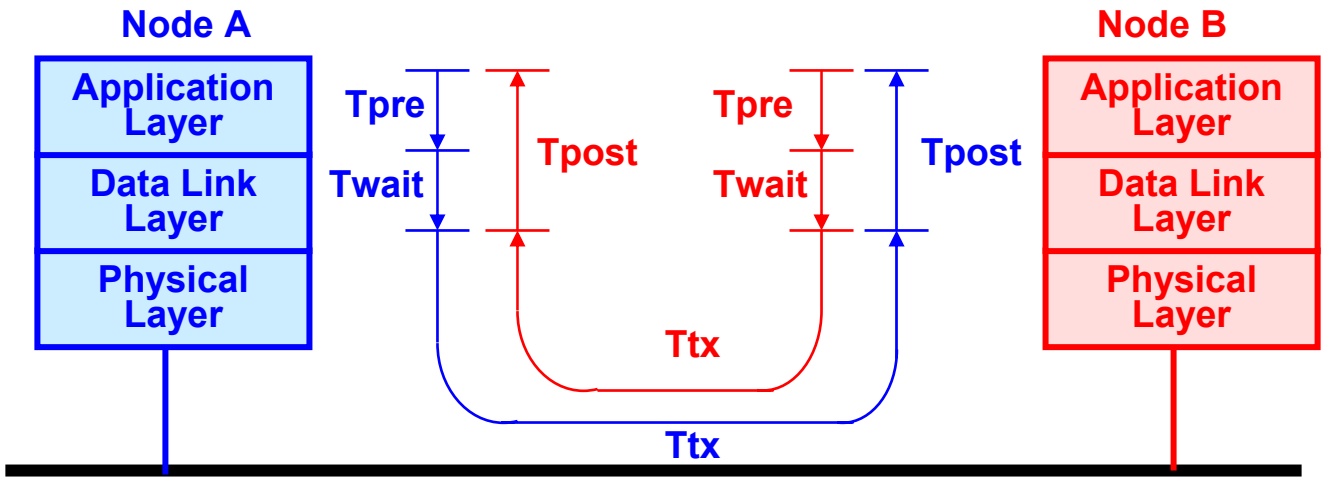
Components of Delay

Where are the sources of delay and variability?

- Network and nodes

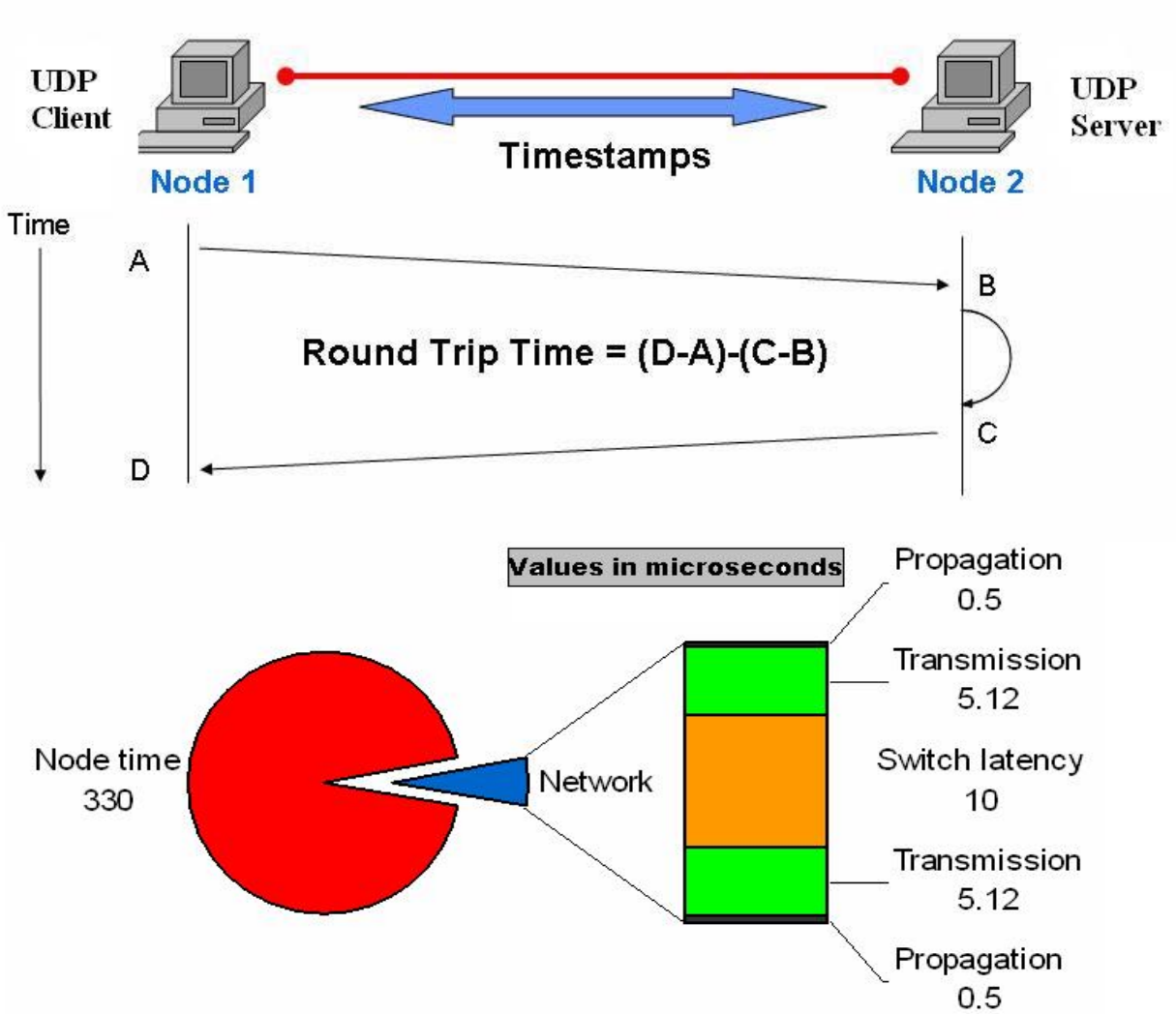


- **Total end-to-end delay is the sum of**
  - Pre-processing time: microprocessor
  - Waiting time: network protocol - MAC
  - Transmission time: data rate & length
  - Post-processing time: microprocessor

Device Delays

Network Delays

Experimental Analysis

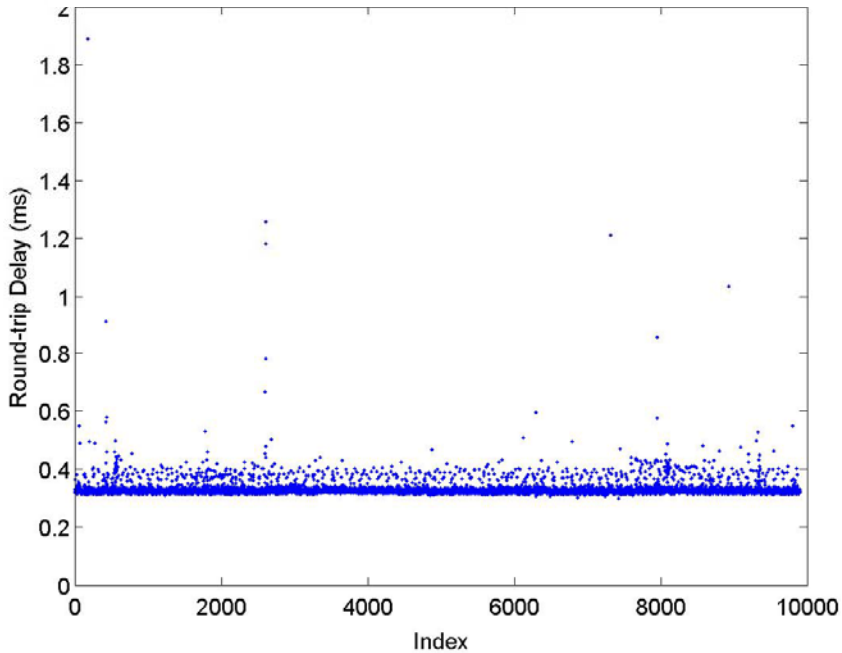


The Delay is in the *Node Software*

(Tpre, Twait and Tpost)

Application level delays

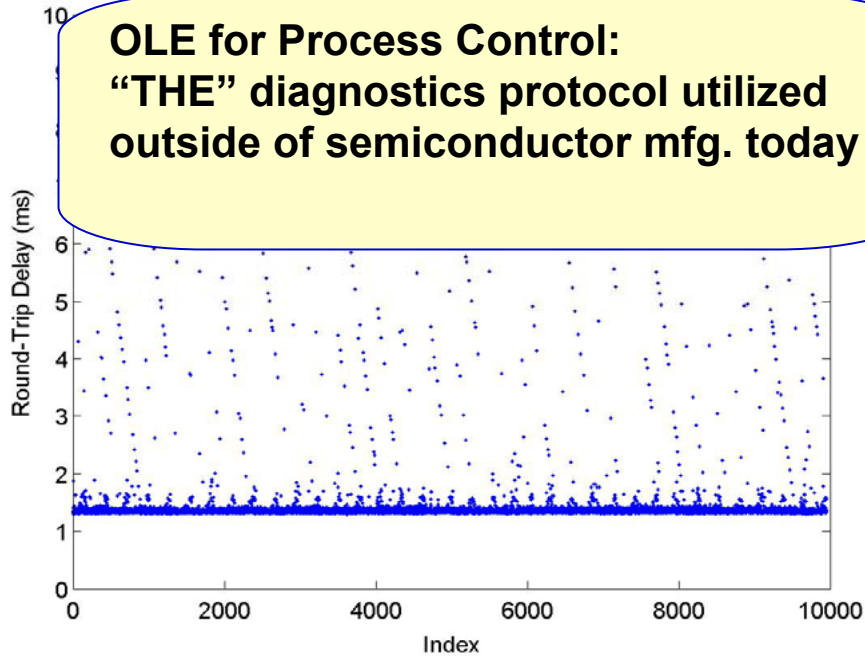
- UDP round-trip delays (100Mbps switched network)



- Mean = 0.33ms, max = 1.89ms
- Stdev = 0.03ms

- OPC round-trip delays (100Mbps switched network)

OLE for Process Control:
"THE" diagnostics protocol utilized outside of semiconductor mfg. today

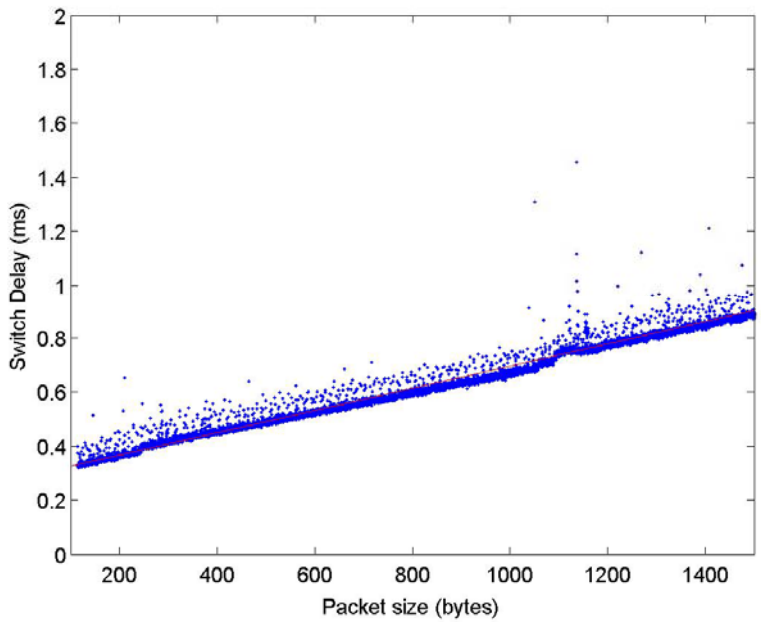


- Mean = 1.5ms, max = 16.8ms
- Stdev = 0.81ms

The Delay and delay Variability is in the *Node Software*

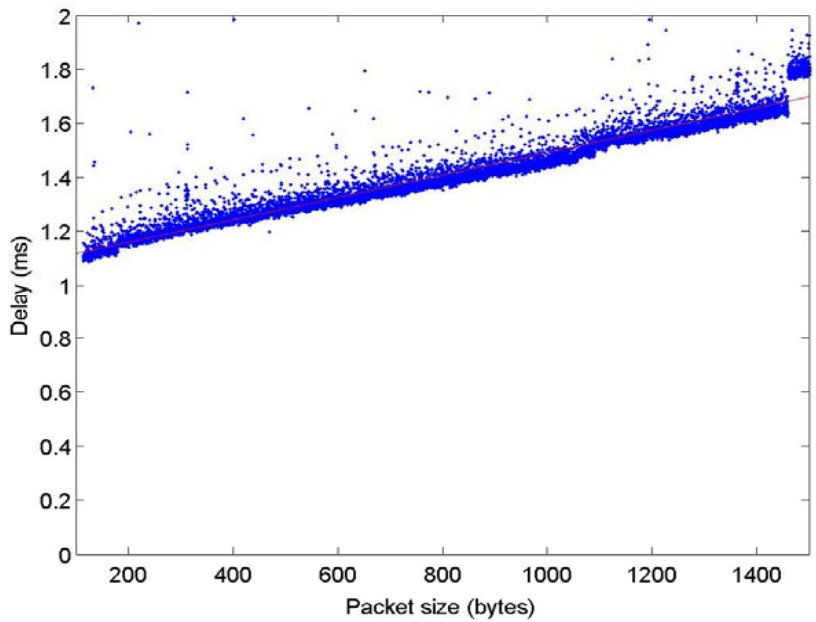
Varying packet size

- **UDP round-trip delays (100Mbps switched network)**



- **Slope = 0.411μs/bit**
  - **Theory: 0.32 μs/bit**
- **Intercept: 0.285ms**

- **VPN round-trip delays (100Mbps switched network)**



- **Slope = 0.848μs/bit**
- **Intercept: 1.07ms**
- **Using DES (data encrypt. std)**

Network Delay Test Results

	UDP	VPN (UDP)	OPC (TCP)		DeviceNet
Delay Average (ms)	0.33	1.21	1.48		0.3-1.2
Delay Variation (3σ) (ms)	0.09	0.49	2.43		0.005-0.2
Min. Network Delay Contribution (ms)	0.035	0.035	0.035		0.188
% of Delay Due to Network	11%	3%	2%		63%

The Message:

- We need time synchronization and time-stamping to mitigate delay and delay variability disturbances of end-to-end network communication
- We need standards for time synchronization and *when* to timestamp information in the end-to-end communication path
- Using synchronization and time-stamping, we can decouple application node time from communication network time

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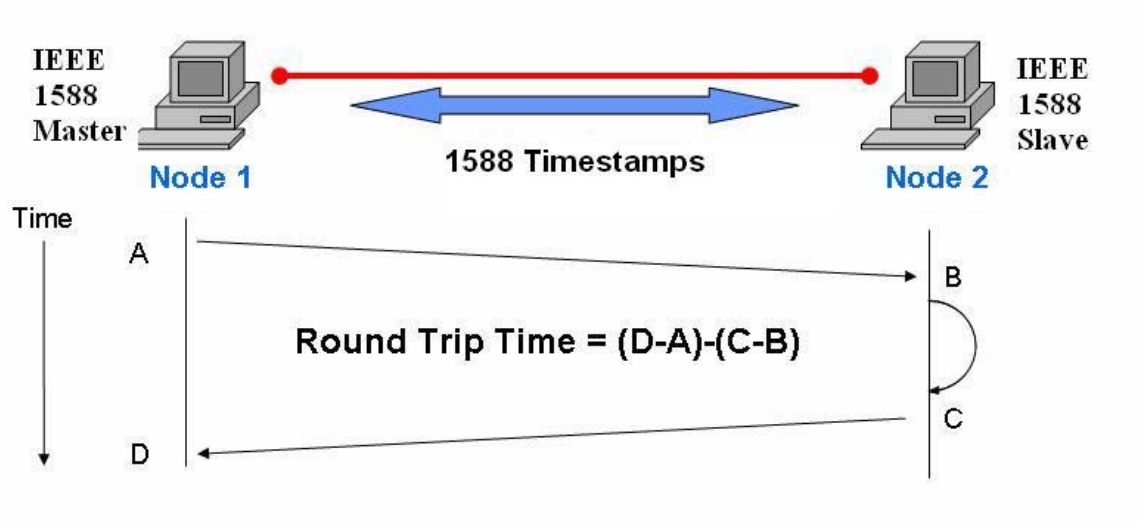
NIST / University of Michigan Project

- **IEEE 1588 testbed in operation**
  - 1588 hardware I/O cards
  - LabVIEW as the application software
  - XML traffic generators
  - Routines for encapsulation, e.g., VPN, OPC, UDP, as necessary

- **Performance testing of IEEE 1588 for semiconductor manufacturing applications**
  - Data collection
  - Event reporting
  - Remote monitoring

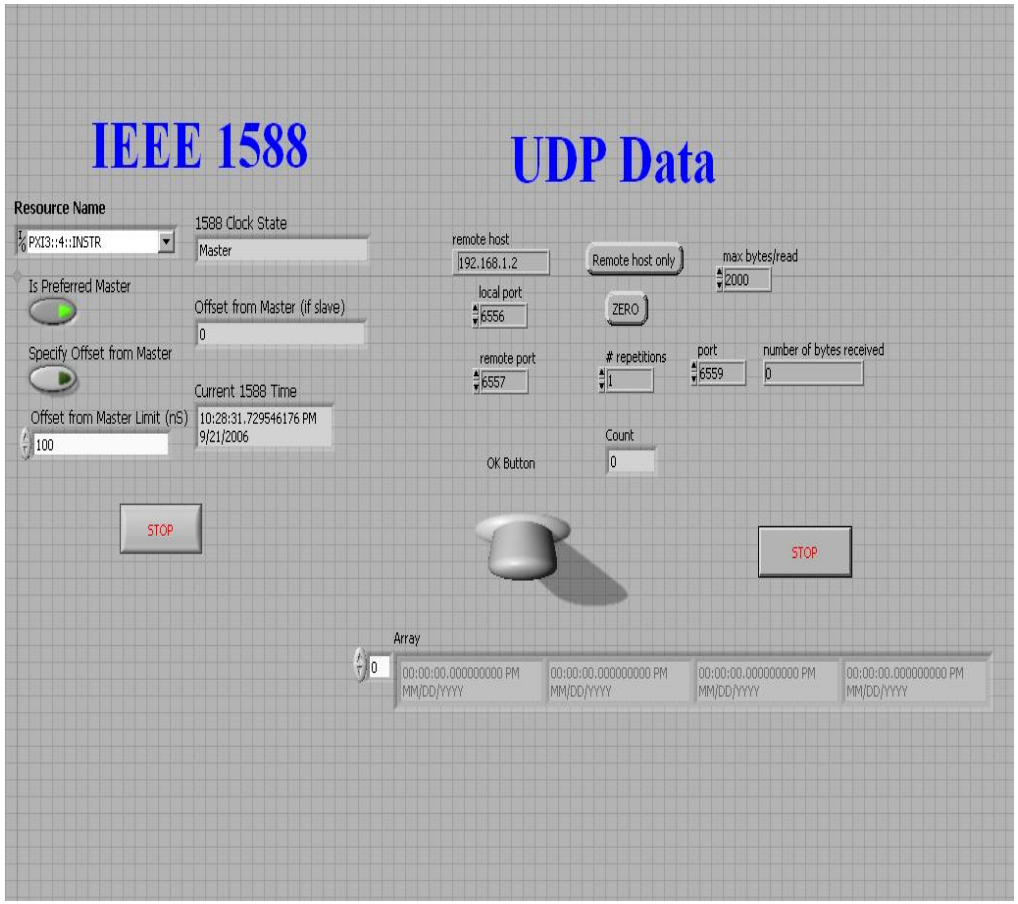
NIST / University of Michigan Project

- **Tests with 1588**



- Tests designed to see effect of 1588 time-stamping and synchronization
- Nodes synchronized through IEEE 1588 protocol
- Time-stamping through 1588 clock
- 1588 timestamps exchanged

NIST / University of Michigan Project



- LabVIEW is used as the application layer for programming
- Time synchronization interval for PTP set at two seconds
- Interface through LabVIEW for accessing 1588 clock
- UDP data time-stamped with 1588 clock and exchanged
- UDP Round Trip time calculated from data exchange

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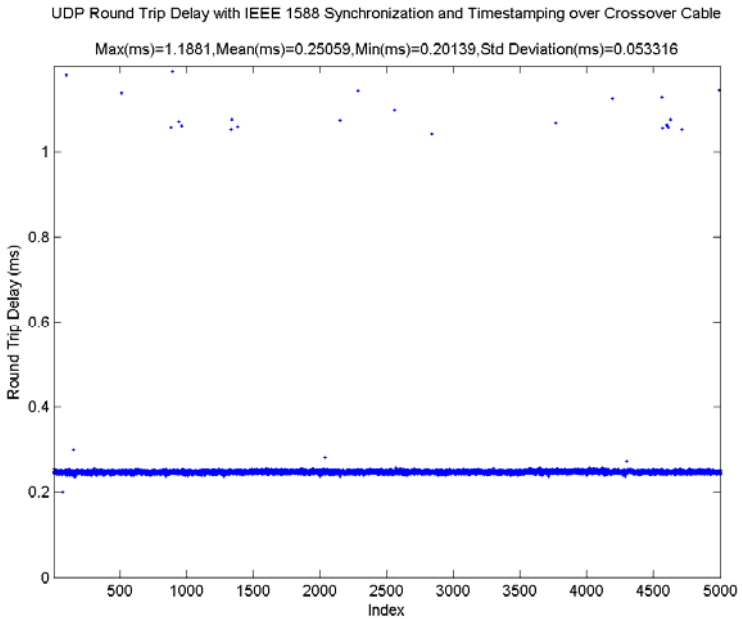
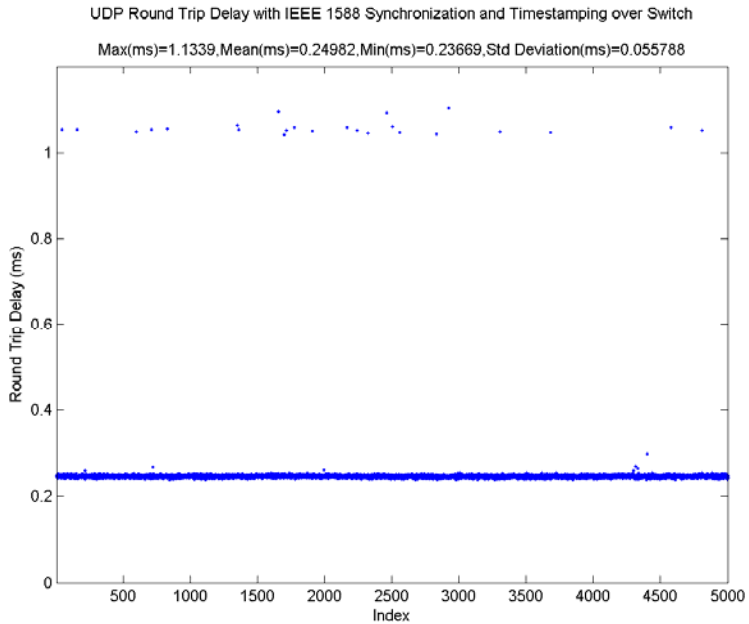
UDP Round Trip delays for 100 Mbps network (250ms delay between packets)



Crossover Cable



Switch

Values for 5000 packets with a delay of 250ms between packets

	Max (ms)	Mean (ms)	Min (ms)	Std Dev (ms)
Crossover	1.188	0.251	0.201	0.053
Switch	1.134	0.250	0.237	0.056

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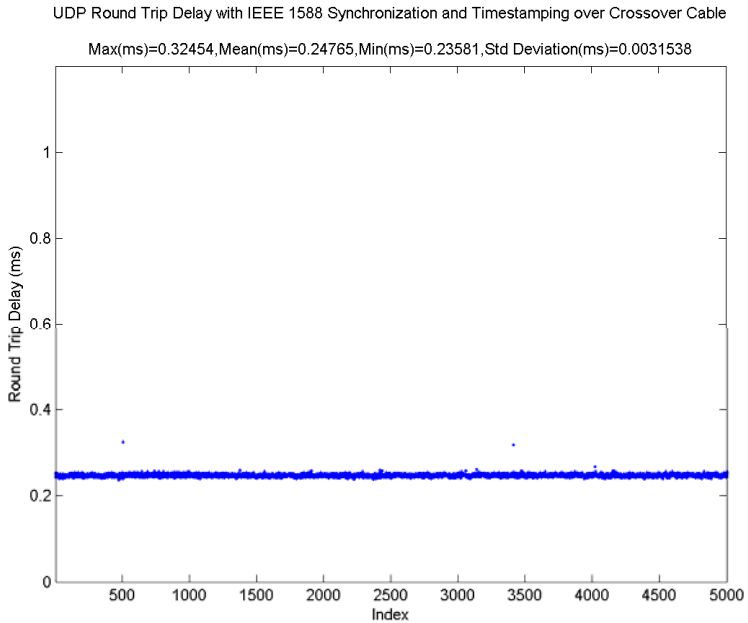
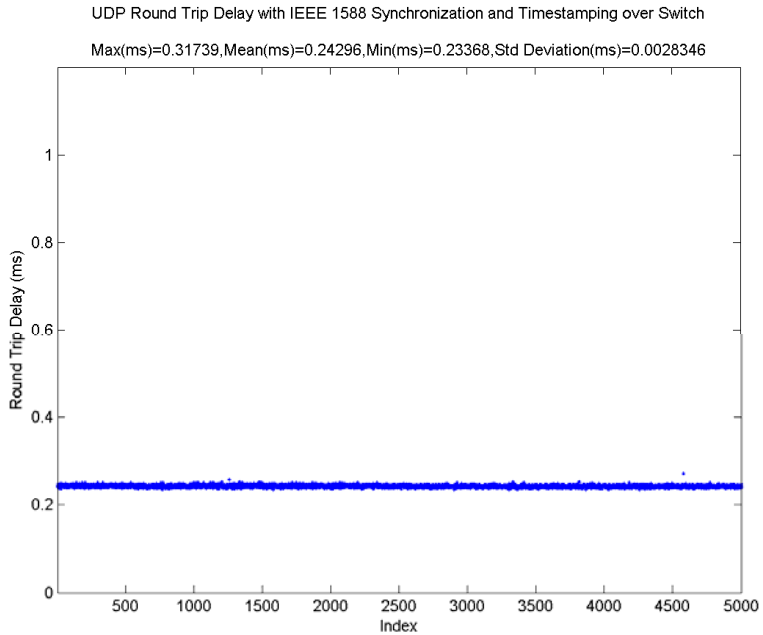
UDP Round Trip delays for 100 Mbps network (1s delay between packets)



Crossover Cable



Switch

Values for 5000 packets with a delay of 1s between packets

`	Max (ms)	Mean (ms)	Min (ms)	Std Dev (ms)
Crossover	0.325	0.248	0.236	0.003
Switch	0.317	0.243	0.234	0.003

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- **Summary of initial results**
  - With 1588 time-stamping, increasing the delay between packets led to lower values of jitter for the UDP round trip delay
  - LabVIEW used on Windows (OS used) may introduce variability
  - UDP data exchanged is time-stamped through the application (LabVIEW) GUI, no hardware time-stamping of data
- **Future tests**
  - Use Linux OS and 1588 time-stamping

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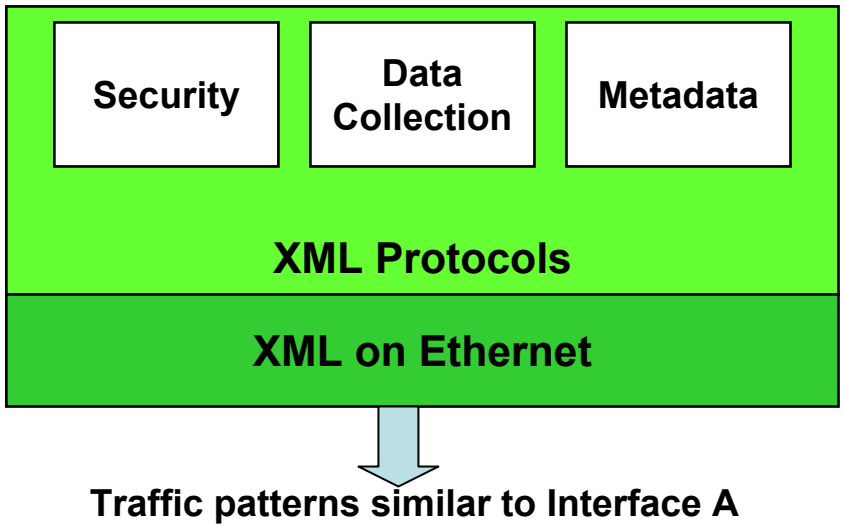
- **Next Steps**
  - Benchmark common protocol scenarios (XML, VPN, etc.)



  - Interface “A” traffic volume analysis and performance benchmarking
  - Simple equipment EDA traffic simulators
  - APC scenario analysis

- **Outcome**
  - Exploration of Time Synchronization for Semiconductor Manufacturing
  - Identification of weak links in equipment, software systems, standards, etc.
  - Input into SEMI standards effort

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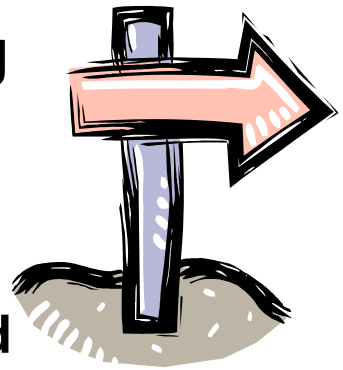
Key Points

- Many efforts in implementing EDA and PCS implementation will fail if data quality is not addressed
- Lack of time synchronization and accurate time-stamping is a common source of poor data quality
- The weak link is often the tool software performance, so *where you timestamp* is very important
- NIST, The University of Michigan and SEMI are working together to address this issue, with the end result being standards and prototypes that will impact PCS, EDA and e-diagnostics

Future Efforts



- Identify and quantify the weak links in timing and time synchronization for APC
- Education
  - When and how to apply time synchronization, and at what level
- Simulation of semiconductor factory environment
- Provide cost / benefit analysis
  - What level of time synchronization is needed at various places throughout the fab; e.g., is hardware time synchronization required?
- SEMI standards for time synchronization and time-stamping

Thank You !! ☺

- **For further information**
  - **James Moyne: moyne@umich.edu**
  - **UM-ERC-RMS: http://erc.engin.umich.edu**
  - J. T. Parrott, J. R. Moyne, D. M. Tilbury, "Experimental Determination of Network Quality of Service in Ethernet: UDP, OPC, and VPN," *Proceedings of the American Control Conference,* Minneapolis, MN, June 2006.

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  - **Jonathan Parrott and Dawn Tilbury**

- **Questions?**

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