IEEE-1588 Standard for a Precision Clock Synchronization Protocol for Networked Measurement and Control Systems

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Overview

- Objectives of 1588
- A bit of history
- Where is it being used?
- Comparison with other protocols
- What the 1588 standard defines
- Technical overview
- Prototype results

Objectives of 1588

- Sub-microsecond synchronization of real-time clocks in components of a networked distributed measurement and control system
- Intended for relatively localized systems typical of industrial automation and test and measurement environments.
- Applicable to local areas networks supporting multicast communications (including but not limited to Ethernet)

Objectives of 1588 (continued)

- Simple, administration free installation
- Support heterogeneous systems of clocks with varying precision, resolution and stability
- Minimal resource requirements on networks and host components.

A bit of History

Status of IEEE 1588

- Approved by the IEEE-SA Review Committee on 12 Sept. 2002
- Published on November 8 2002
- Available from the IEEE http://standards.ieee.org

Members of the IEEE-1588 working group

Volker Arlt-Lenze AG

Scott Carter-GE Medical

John Eidson-Agilent

Richard Hambly-CNS Systems

Bruce Hamilton-Agilent

Steve Jennings-Bosch-Rexroth

Robert Johnson-Telemonitor

Bill Kneifel-KUKA

Jurgen Knopke-Lenze

Kang Lee- NIST

Judah Levine-NIST

Anatoly Moldovansky-Rockwell

Ed Powers-Naval Observatory

Jim Read-Hyperfine

Richard Schmidt-Naval Observatory

Steve Smith-ORNL

Joe White-NRL

Stan Woods-Agilent

Where is it being used?
(presentations scheduled for Sept. 24 workshop)

NETWORK DEVICES:

IEEE 1588 and Network Devices: Dirk S. Mohl, Hirschmann Electronics

Boundary Clock implementation: Øyvind Holmeide, Managing Director, OnTime Networks AS.

Extending IEEE 1588 to fault tolerant synchronization with a worst-case precision in the 100 ns range: Nikoaus E. Keroe, Oregano Systems


OnTime

Where is it being used?
(presentations scheduled for Sept. 24 workshop)

TELECOMMUNICATIONS:

Proposal for IEEE1588 use over Metro Ethernet Layer 2 VPNs: Glenn Algie, Senior Advisor, Wireless Technology Labs, Nortel Networks

INDUSTRIAL AUTOMATION:

Impact of Switch Cascading on Time Accuracy: Prof. Thomas Mueller, University Wintherthur, Suisse, Karl Weber, SIEMENS Automation and Drives

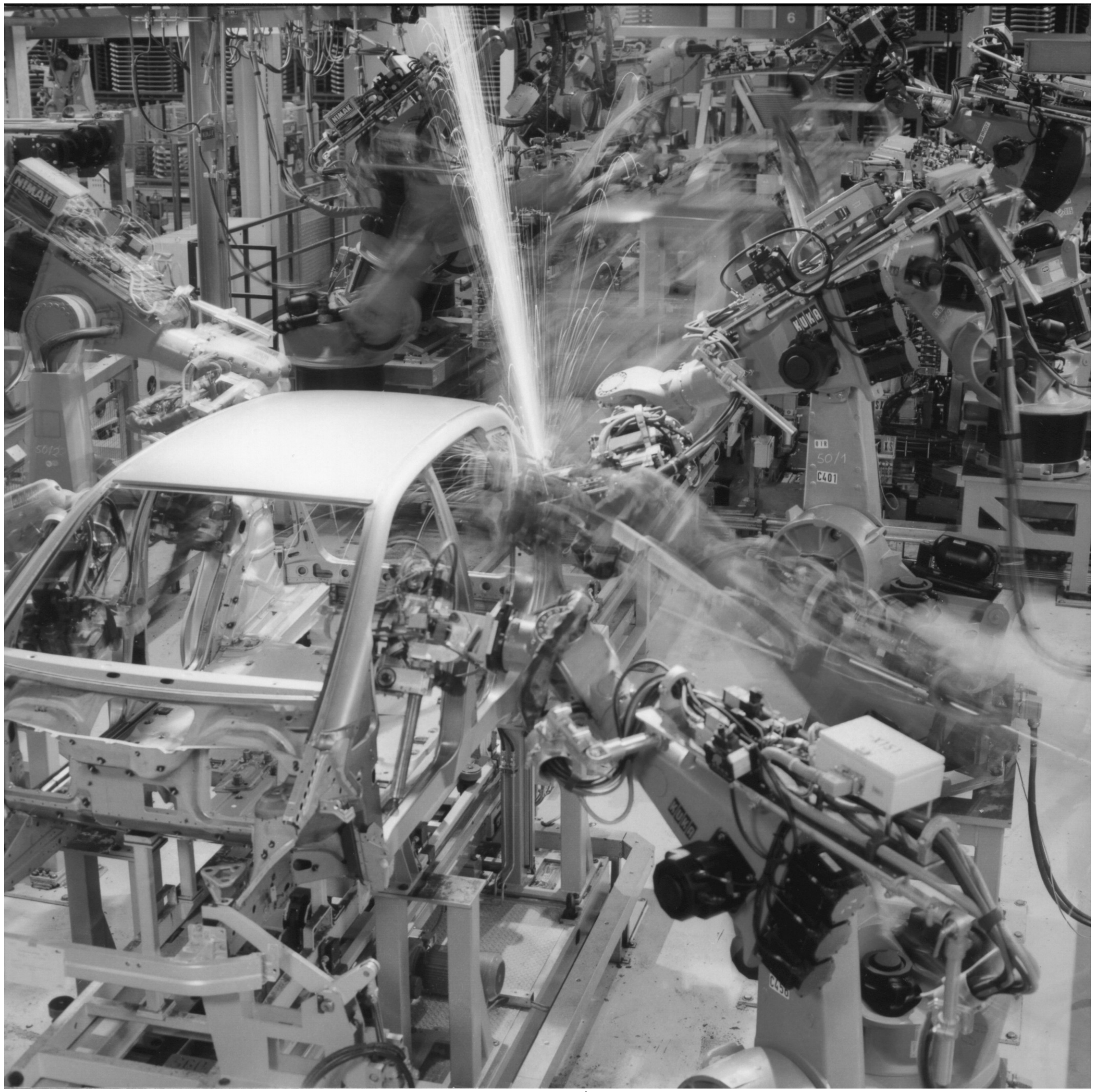
Consequences of Redundant Structures PTP: Ludwig Winkel, SIEMENS Automation and Drives

Application of 1588 for Distributed Motion Control: Kendal R. Harris, Sivaram Balasubramanian and Anatoly Moldovansky, Rockwell Automation

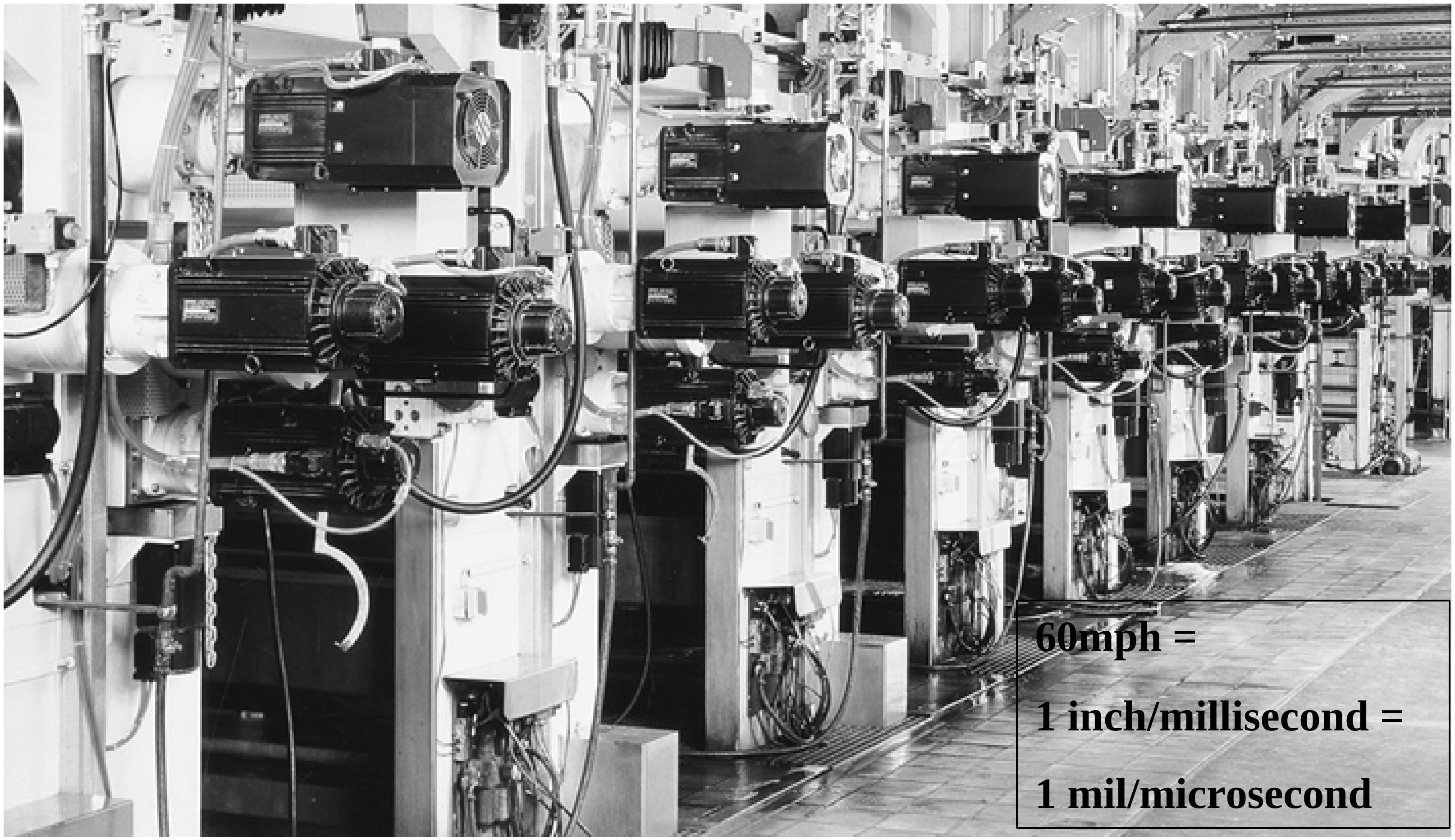
HZx Wrappers

Courtesy of SIG Pack Systems AG

Control of multiple robots



Mulit-stand Printing Press



Where is it being used?
(presentations scheduled for Sept. 24 workshop)

MILITARY FLIGHT TEST:

Time Correlation using network based data acquisition on-board a Military Test Vehicle: Jiwang Dai, Ph.D, Senior Software Engineer, L3 Communications Telemetry East, Thomas DeSelms, Senior Network Systems Engineer, Veridian Engineering, and Edward Grozalis, Senior Engineer, L3 Communications Telemetry East

POWER SYSTEMS:

Implementation of IEEE Std.-1588 in a Networked I/O Node: Mark Shepard, GE Drives & Controls, Inc., Salem, VA

Comparison with other protocols

1588: Target is groups of relatively stable components, locally networked (a few subnets), cooperating on a set of well defined tasks.

NTP: (Network Time Protocol, RFC 1305). Target is autonomous systems widely dispersed on the Internet.

GPS: (Satellite based Global Positioning System of the US Department of Defense): Target is autonomous, widely dispersed systems.

TTP(www.ttpforum.org), SERCOS (IEC 61491): Target is tightly integrated, usually bus or specialized TDMA network based closed systems

	1588	NTP	GPS	TTP	SERCOS
Spatial extent	**A few subnets**	**Wide area**	**Wide area**	**Local bus**	**Local bus**
Communi-cations	**Network**	**Internet**	**Satellite**	**Bus or star**	**Bus**
Target accuracy	**Sub-microsecond**	**Few milliseconds**	**Sub-microsecond**	**Sub-microsecond**	**Sub-microsecond**
Style	**Master/slave**	**Peer ensemble**	**Client/server**	**Distributed**	**Master/Slave**
Resources	**Small network message and computation footprint**	**Moderate network and computation footprint**	**Moderate computation footprint**	**Moderate**	**Moderate**

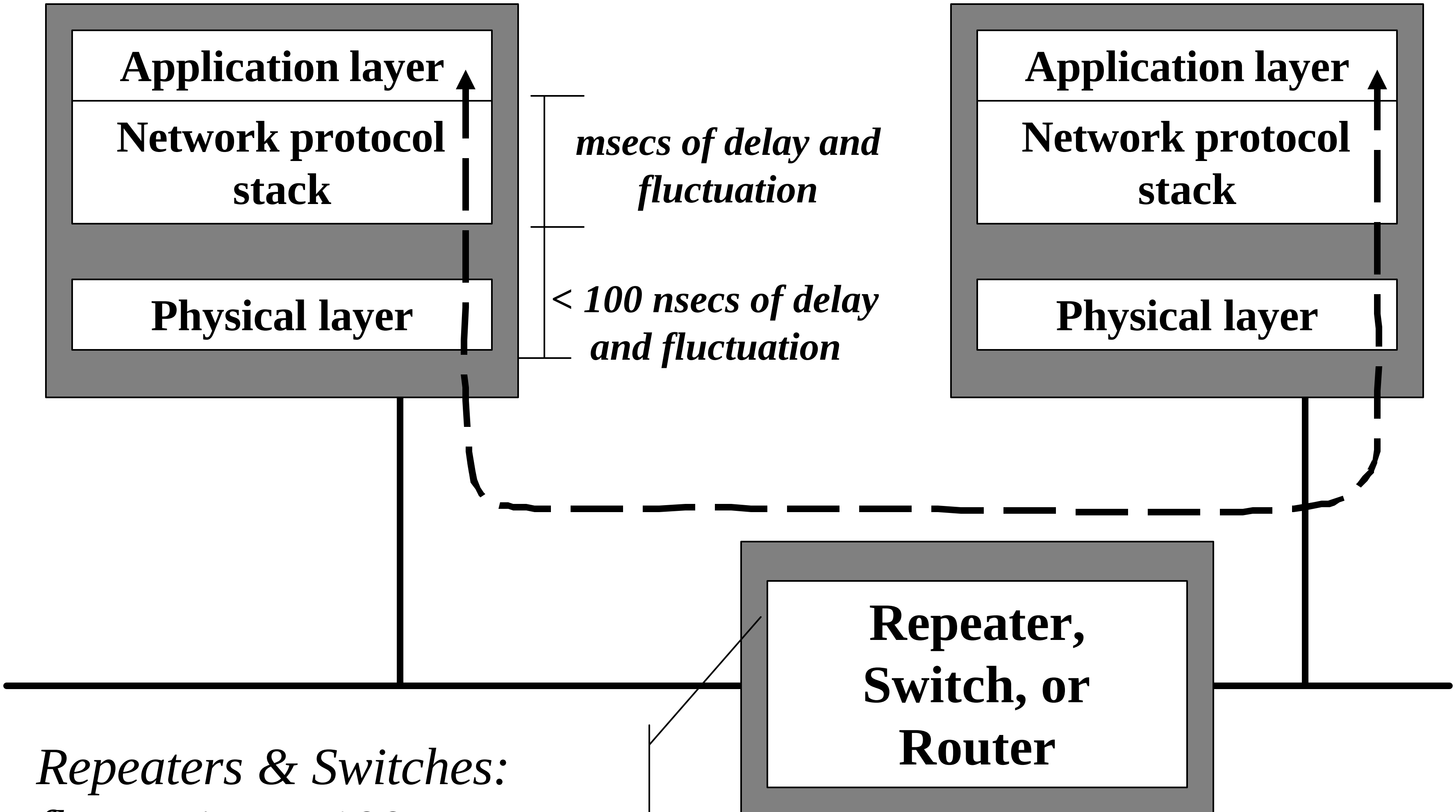
	1588	NTP	GPS	TTP	SERCOS
Latency correction	Yes	Yes	Yes	Configured	No
Protocol specifies security	No	Yes	No	No	No
Administration	Self organizing	Configured	N/A	Configured	Configured
Hardware?	For highest accuracy	No	RF receiver and processo r	Yes	Yes
Update interval	~2 seconds	Varies, nominally seconds	~1 second	Every TDMA cycle, ~ms	Every TDMA cycle, ~ms

1588 Defines:

- Descriptors characterizing a clock
- The states of a clock and the allowed state transitions
- 1588 network messages, fields, and semantics
- Datasets maintained by each clock
- Actions and timing for all 1588 network and internal events

- **Critical physical specifications**
- **A suite of messages for monitoring the system**
- **Specifications for an Ethernet based implementation**
- **Conformance requirements**
- **Implementation suggestions**

Timing Latency & Fluctuation



Repeaters & Switches:
fluctuations ~100ns to usec
Routers:fluctuations ~ms

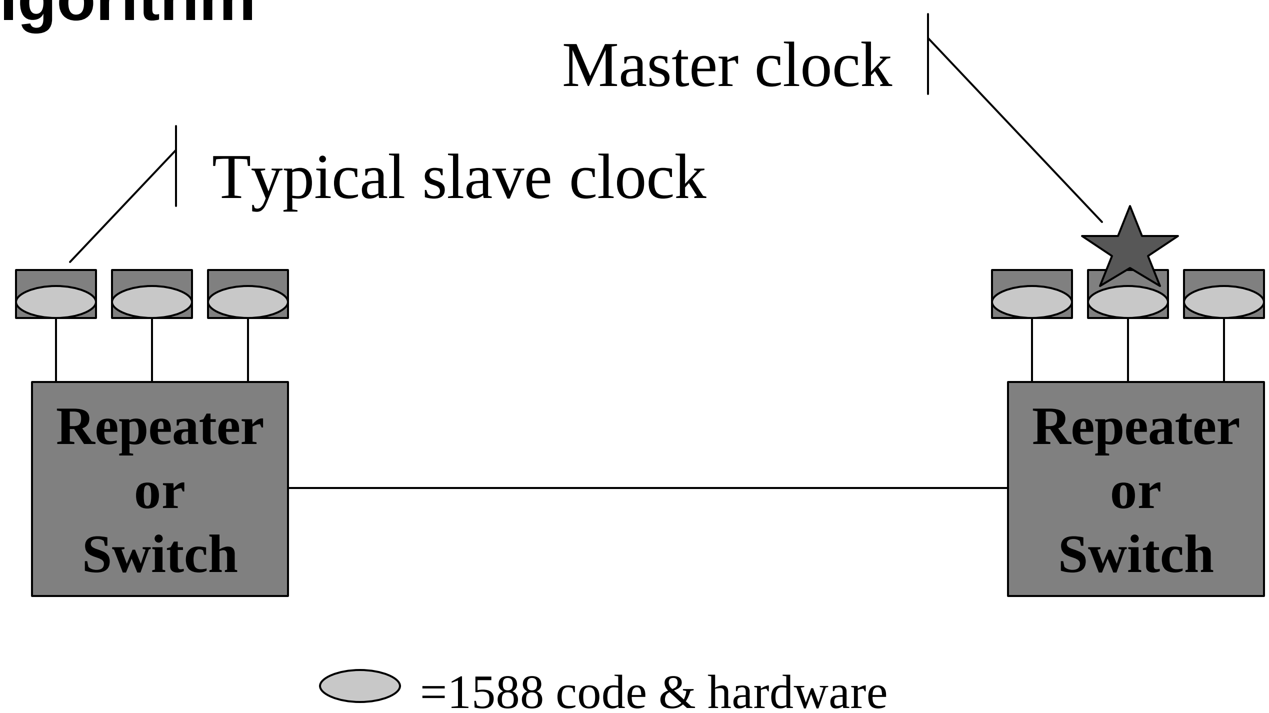
Reducing Timing Latency & Fluctuation

- **Within a node:**
  - **Make timing measurements as close to the physical layer as possible to eliminate protocol stack and operating system fluctuations.**
  - **Use statistical techniques to further reduce residual fluctuations from PHY layer, network and repeaters and switches.**
- **Routers:**
  - **Use transfer devices (1588 boundary clocks) to reduce router latency and fluctuations**

Selecting a Master Clock-Single Subnet

Self-configuring based on clock characteristics

- **Information contained in ‘Sync’ messages**
- **All clocks run an identical ‘Best Master Clock’ algorithm**



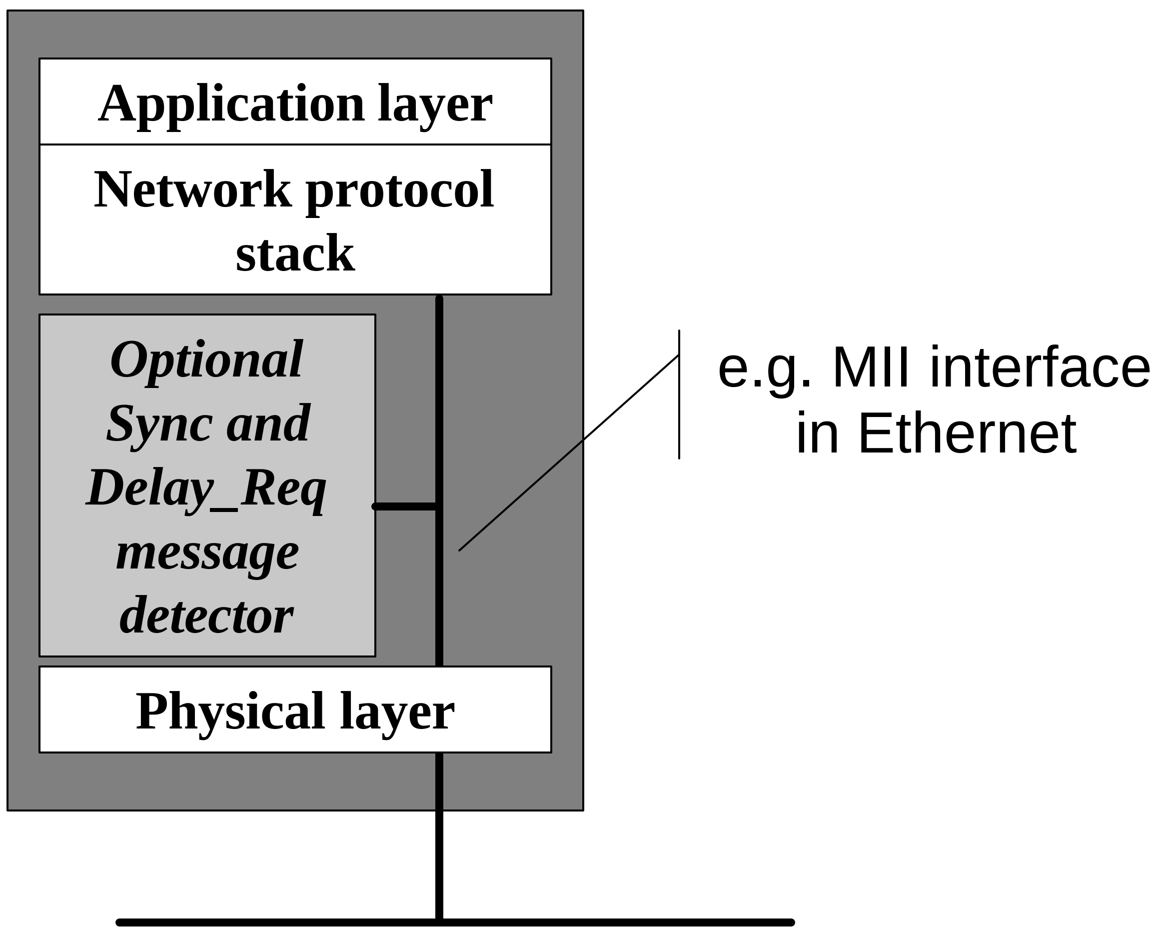
1588 Characterization of Clocks

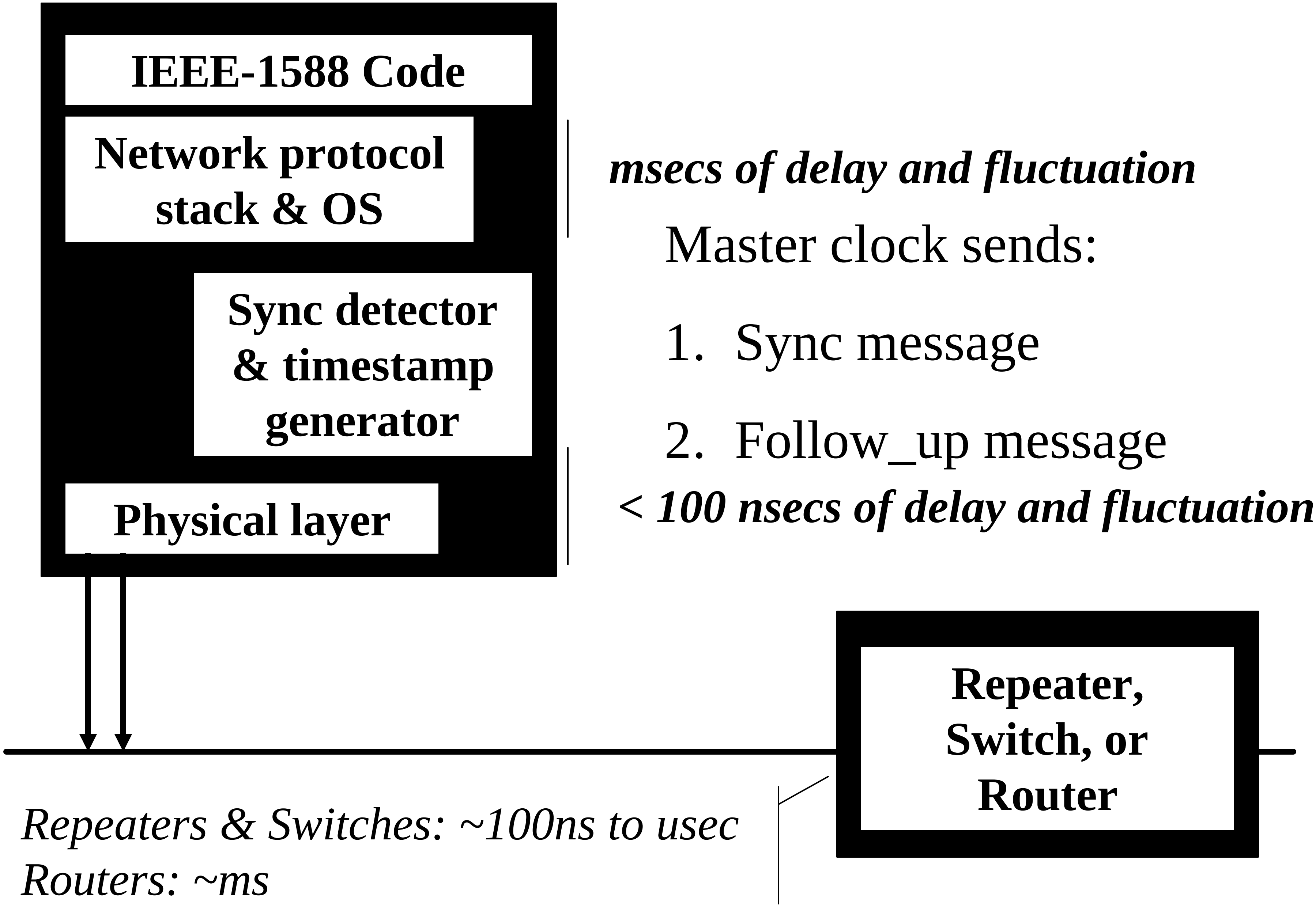
- **Based on primary source of time, e.g. GPS, local oscillator…**
- **Accuracy**
- **Variance**
- **Preferred set membership**
- **Type: Boundary clock (spans subnets) or ordinary clock**
- **UUID**

1588 Timing Related Messages

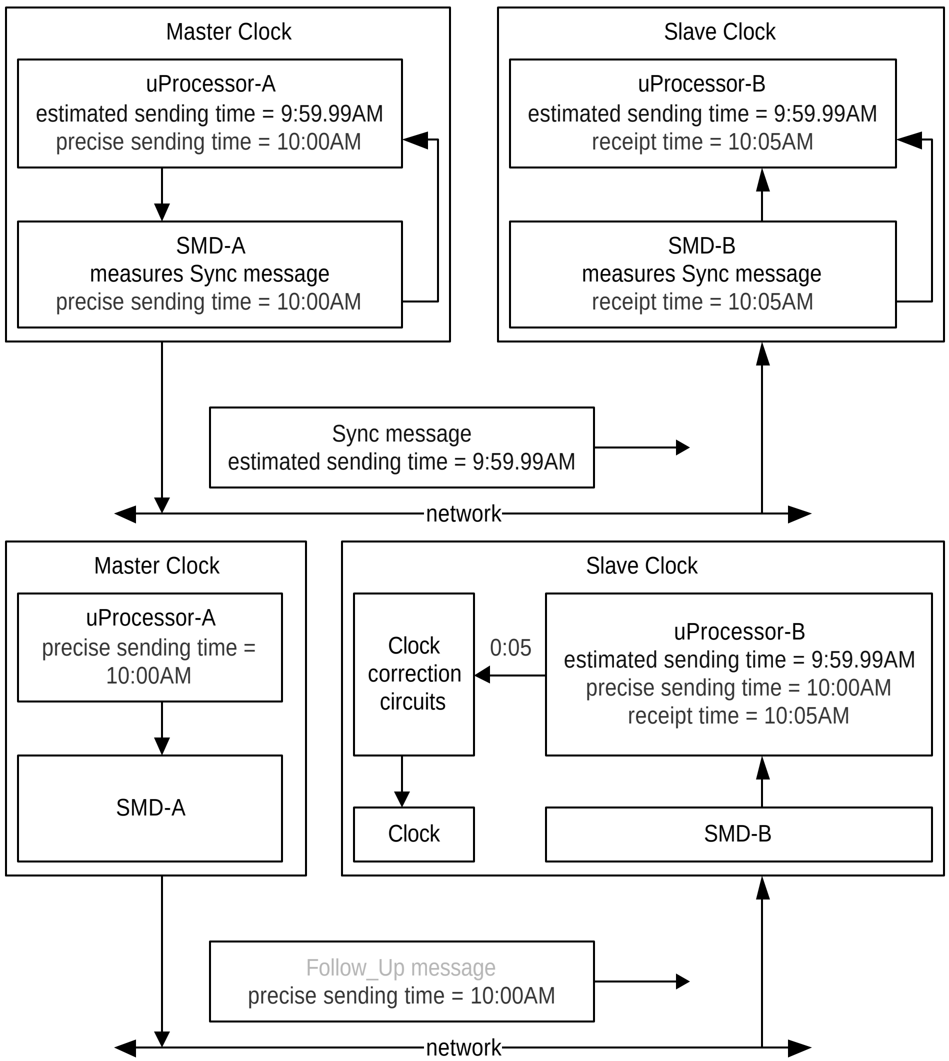
- Multicast only within a subnet
- Four types of timing messages: Sync, Follow_Up, Delay_Req, Delay_Resp
- Issuing and response to these messages dependent on the ‘state’ of each clock

Detection of Sync messages




IEEE-1588 Code
Network protocol stack & OS
Sync detector & timestamp generator
Physical layer
msecs of delay and fluctuation
Master clock sends:
1. Sync message
2. Follow_up message
< 100 nsecs of delay and fluctuation
Repeater, Switch, or Router
Repeaters & Switches: ~100ns to usec
Routers: ~ms

1588 Synchronization



Step 1:

- Sync message sent from master to slaves
- All Sync message detectors (SMD) note the time on the local clock this message appears at the SMD

- ## Step 2:

- Follow-Up message containing precise sending time sent from master to slaves
- All slaves compute offset and correct their clock

Synchronization computation

offset = receipt time – precise sending time – one way delay (for a Sync message)

one way delay = {master to slave delay + slave to master delay}/2 (assumes symmetric delay)

master to slave delay = receipt time – precise sending time (for a Sync message)

slave to master delay = Delay_Req receipt time -precise sending time (of a Delay_Req message)

Sync messages:

- Issued by clocks in the ‘Master’ state
- Contain clock characterization information
- Contain a estimate of the sending time
- When received by a slave clock the receipt time is noted
- Can be distinguished from other legal messages on the network
- For best accuracy these messages can be easily identified and detected at or near the physical layer and the precise sending (or receipt) time recorded

Follow_Up messages:

- Issued by clocks in the ‘Master’ state
- Always associated with the preceding Sync message
- Contain the ‘precise sending time’ as measured as close as possible to the physical layer of the network
- When received by a slave clock the ‘precise sending time’ is is used in computations rather than the estimated sending time contained in the Sync message

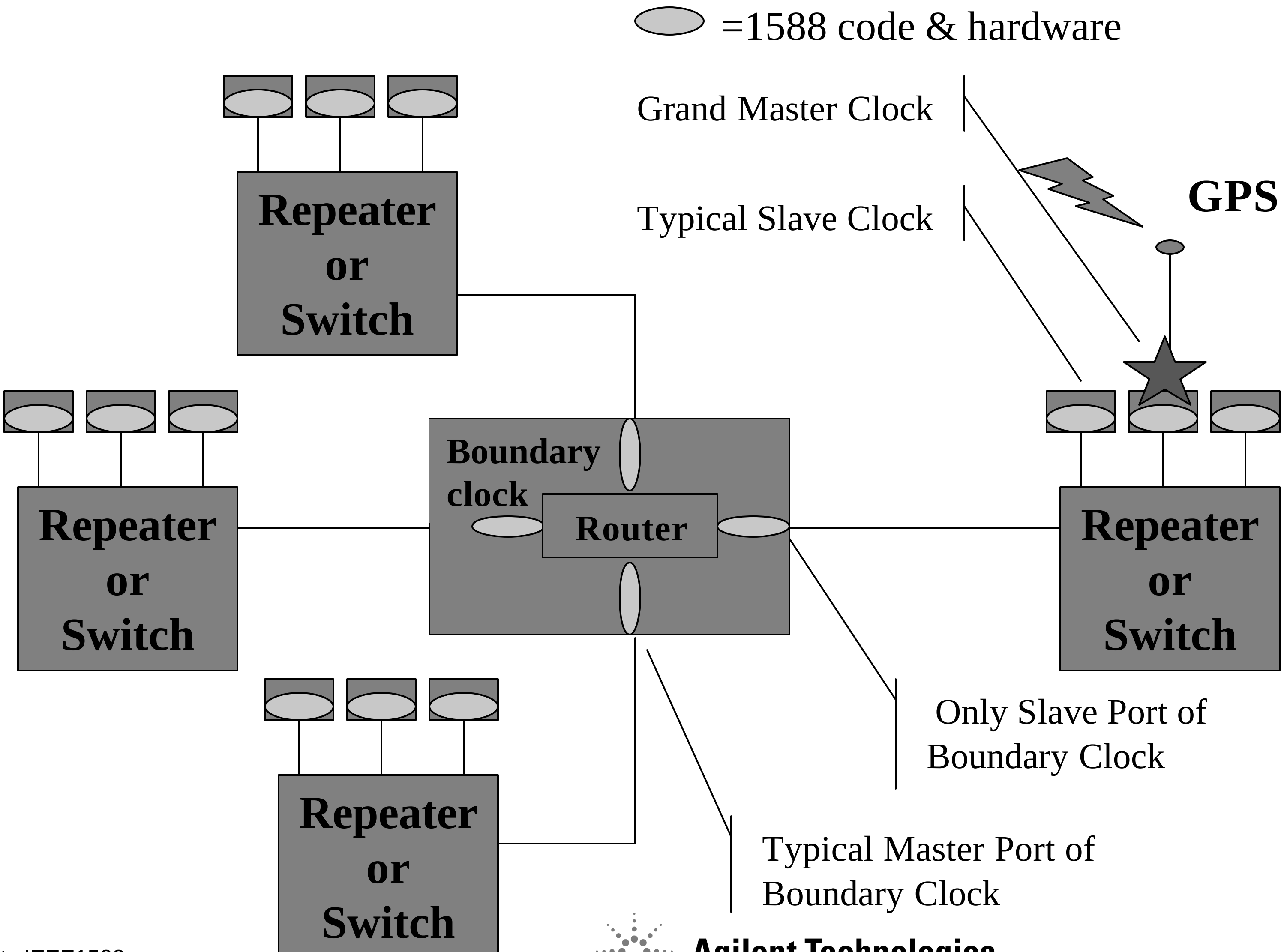
Delay_Req messages:

- Issued by clocks in the ‘Slave’ state
- When received by the master clock the receipt time is noted
- The slave measures and records the sending time
- Can be distinguished from other legal messages on the network
- For best accuracy these messages can be easily identified and detected at or near the physical layer and the precise sending (or receipt) time recorded

Delay_Resp messages:

- Issued by clocks in the ‘Master’ state
- Always associated with a preceding Delay_Req message from as specific slave clock
- Contain the receipt time of the associated Delay_Req message
- When received by a slave clock the receipt time is noted and used in conjunction with the sending time of the associated Delay_Req message as part of the latency calculation

1588 Multiple Subnet Topology



Multiple Subnet Synchronization &Master Clock Selection

- **Boundary clocks do NOT pass Sync, Follow_Up, Delay_Req, or Delay_Resp messages**
- **Within a subnet a port of a boundary clock acts just like an ordinary clock with respect to synchronization and best master clock algorithm**
- **The boundary clock internally selects the port that sees the 'best clock' as the single slave port. This port is a slave in the selected subnet. All other ports of the boundary clock internally synchronize to this slave port.**

- **Boundary clocks define a parent-child hierarchy of master-slave clocks.**
- **The best clock in the system is the Grand Master clock.**
- **If there are cyclic paths in the network topology the best master clock algorithm reduces the logical topology to an acyclic graph.**

1588 Management Messages

- Management messages are multicast ONLY within a subnet.
- Boundary clocks, not routers, transfer management messages between subnets.
- Management messages allow appropriate query and update of selected database information maintained by each clock.

1588 Time Scales

- The time base in a 1588 system is the time base of the Grand Master Clock. All other clocks synchronize (perhaps via boundary clocks) to the grand master.
- The Grand Master Clock time base is implementation dependent.
- If the Grand Master Clock maintains a UTC time base, the 1588 protocol distributes the appropriate leap second information to the slaves.

Basic Uses of Explicit Time in Measurement and Control

Time stamping (relative or absolute)

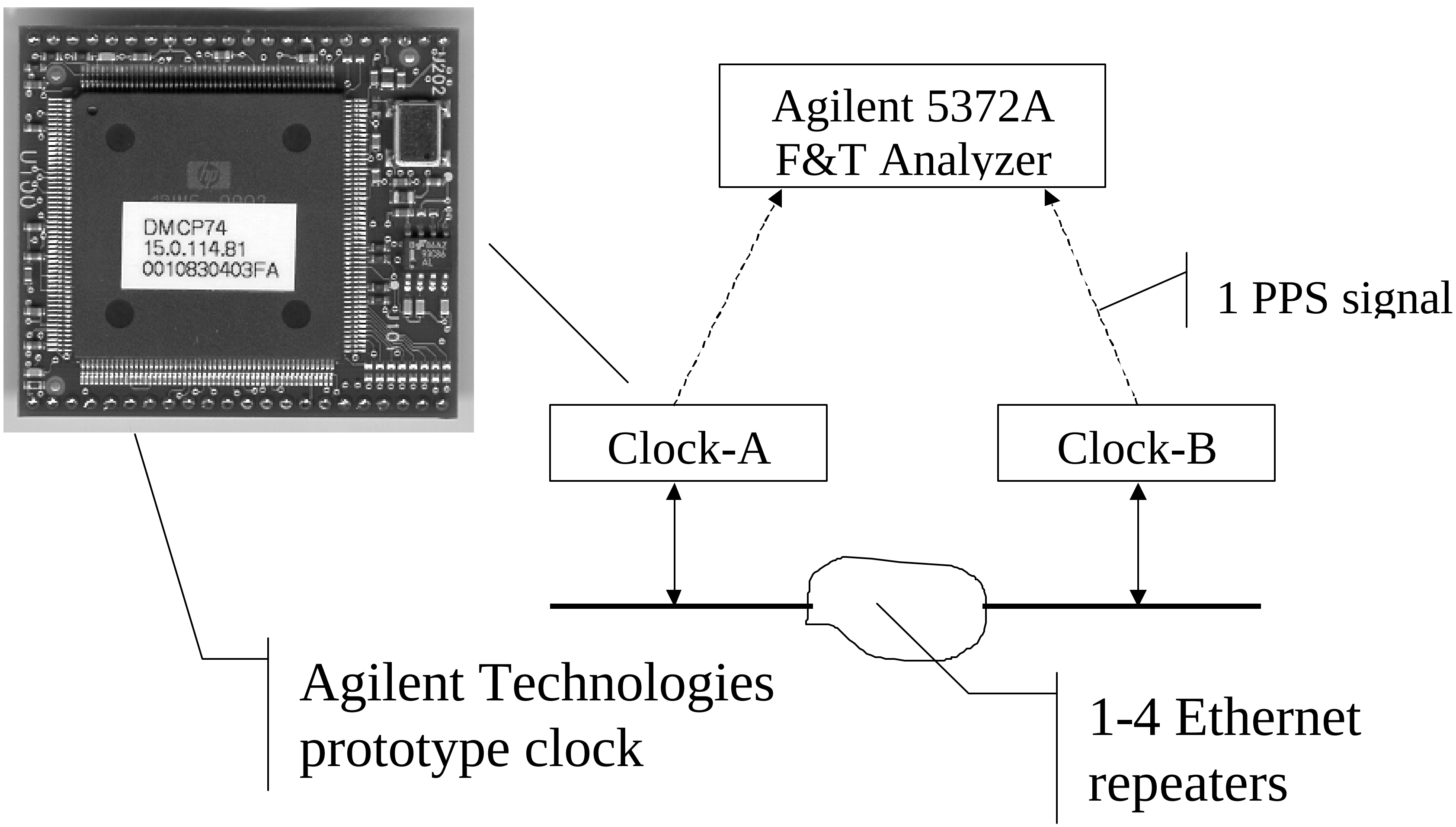
- Time stamping system events for debugging
- Time stamping data to allow correlation with other data or events

Coordination of measurement: (sampling and triggering)

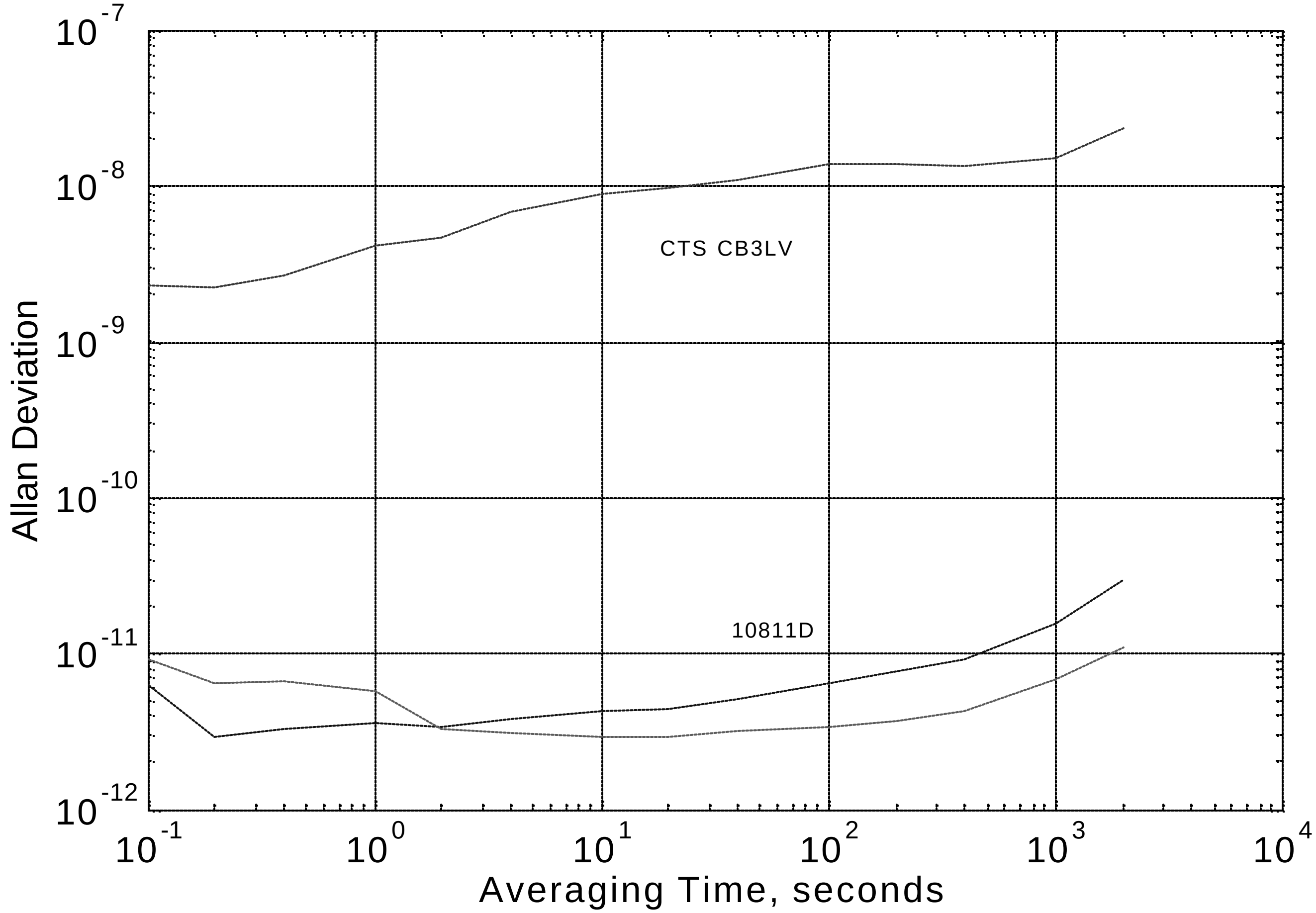
Coordination of action (time based behaviors)

- Timed execution scripts
- Temporal mutual exclusion: (time slots)

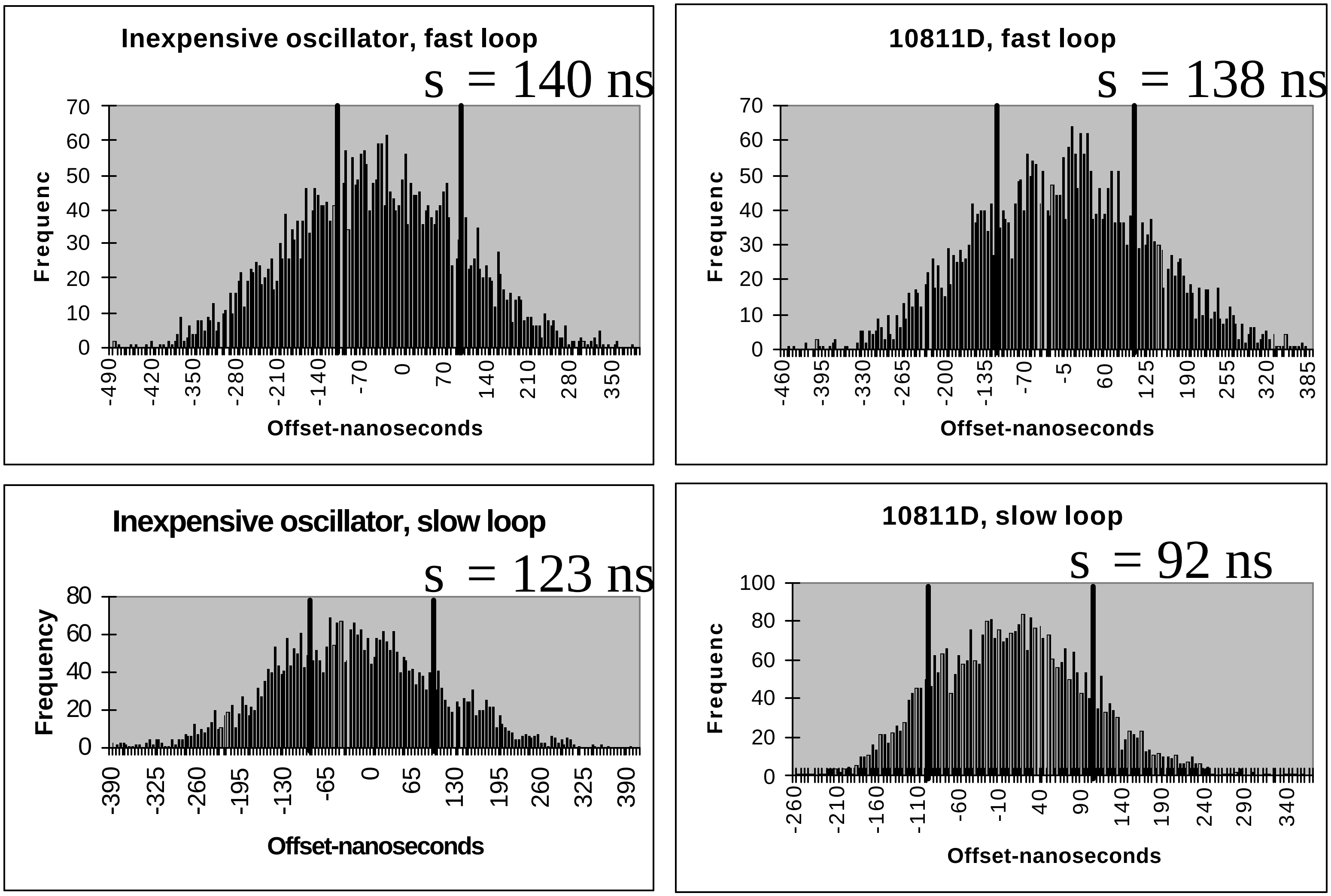
Measurement setup to test prototypes of an earlier version of 1588



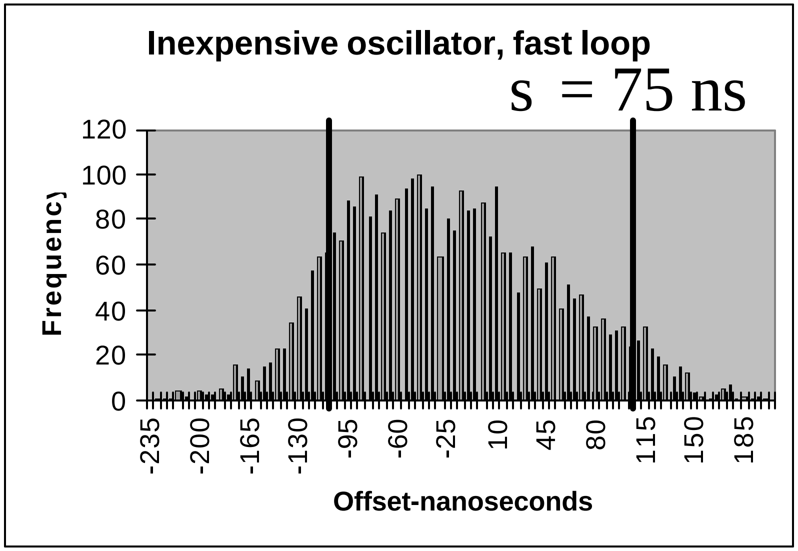
Allan frequency deviations for test oscillators

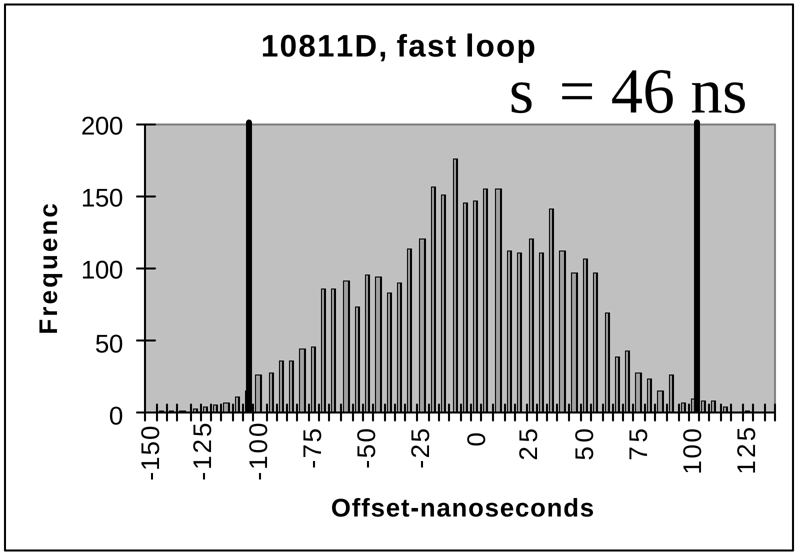


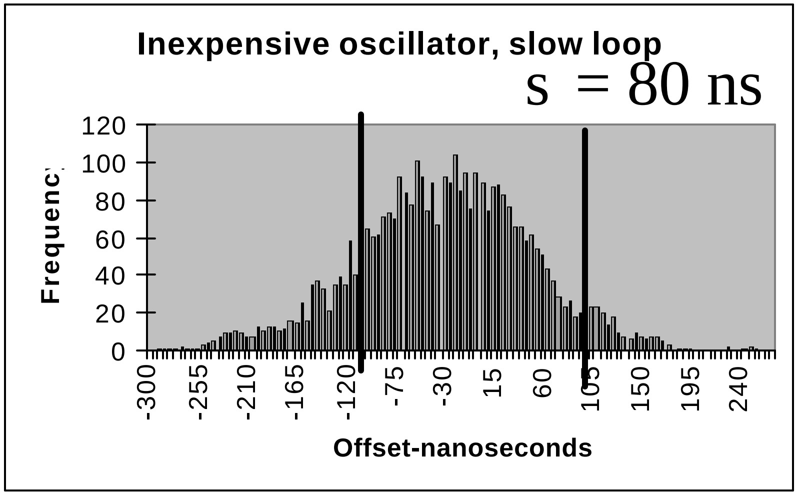
Switch Connection

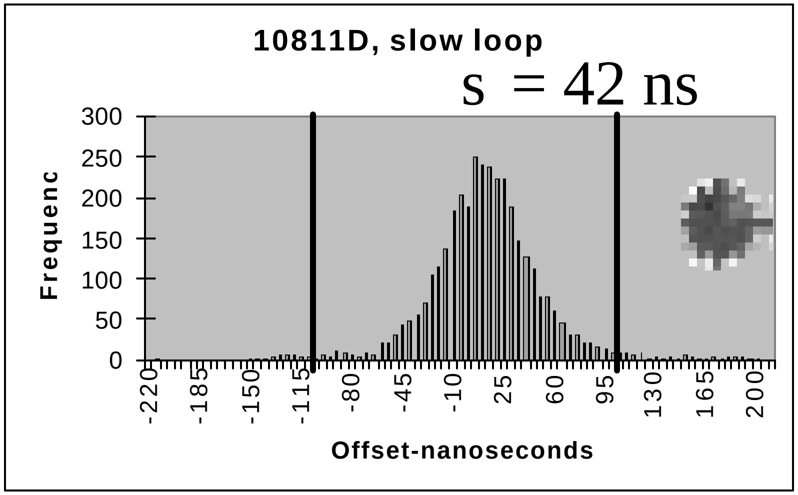


Repeater Connection

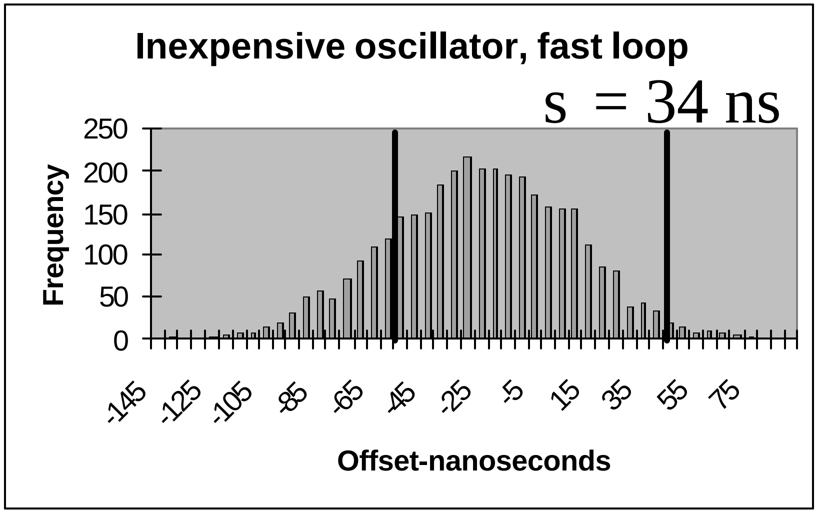


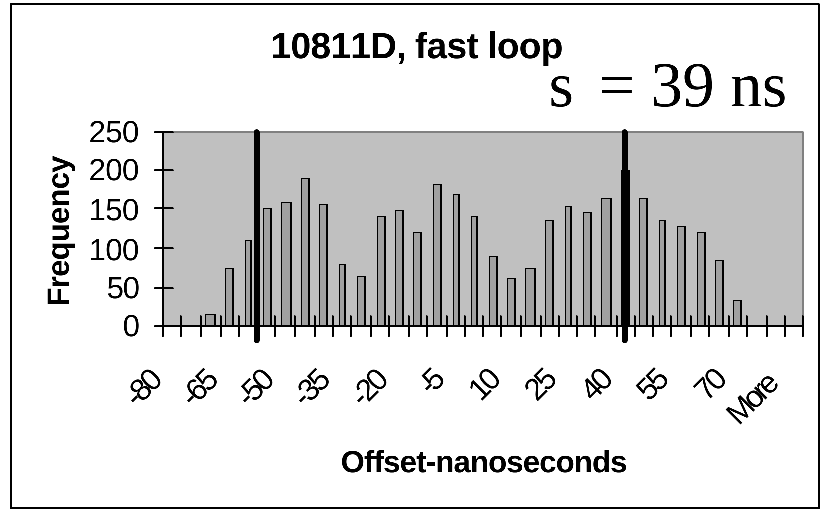


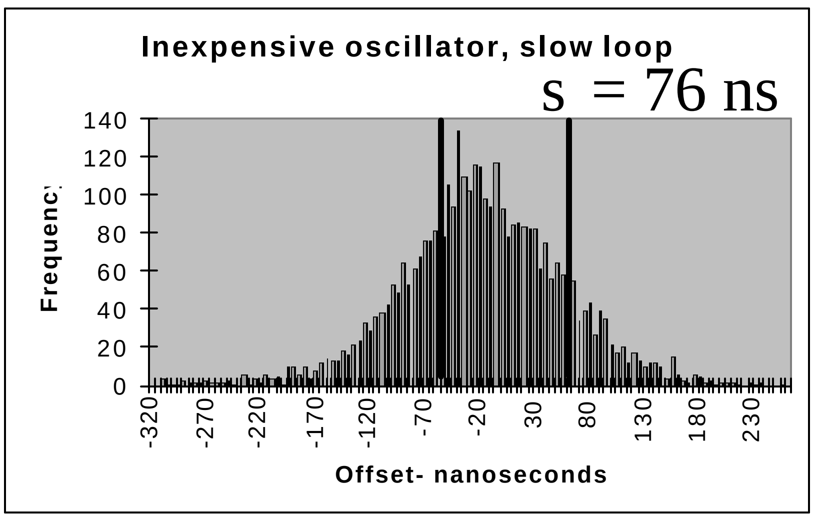


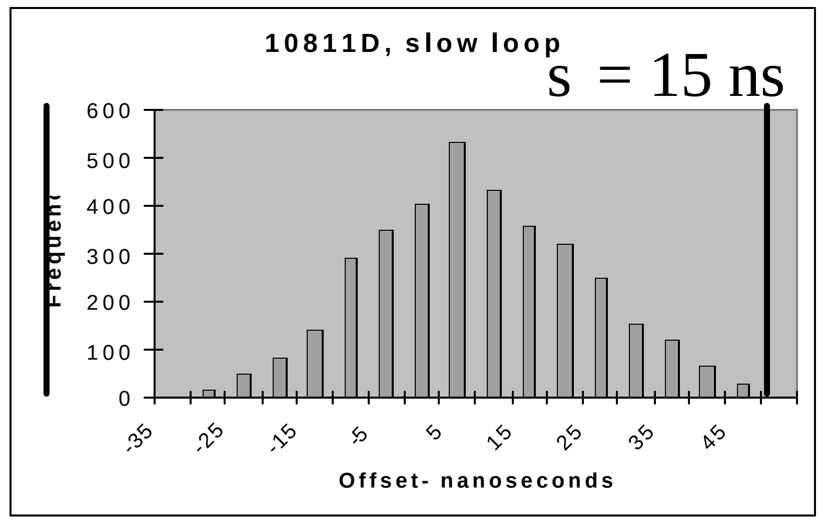


Direct Connection

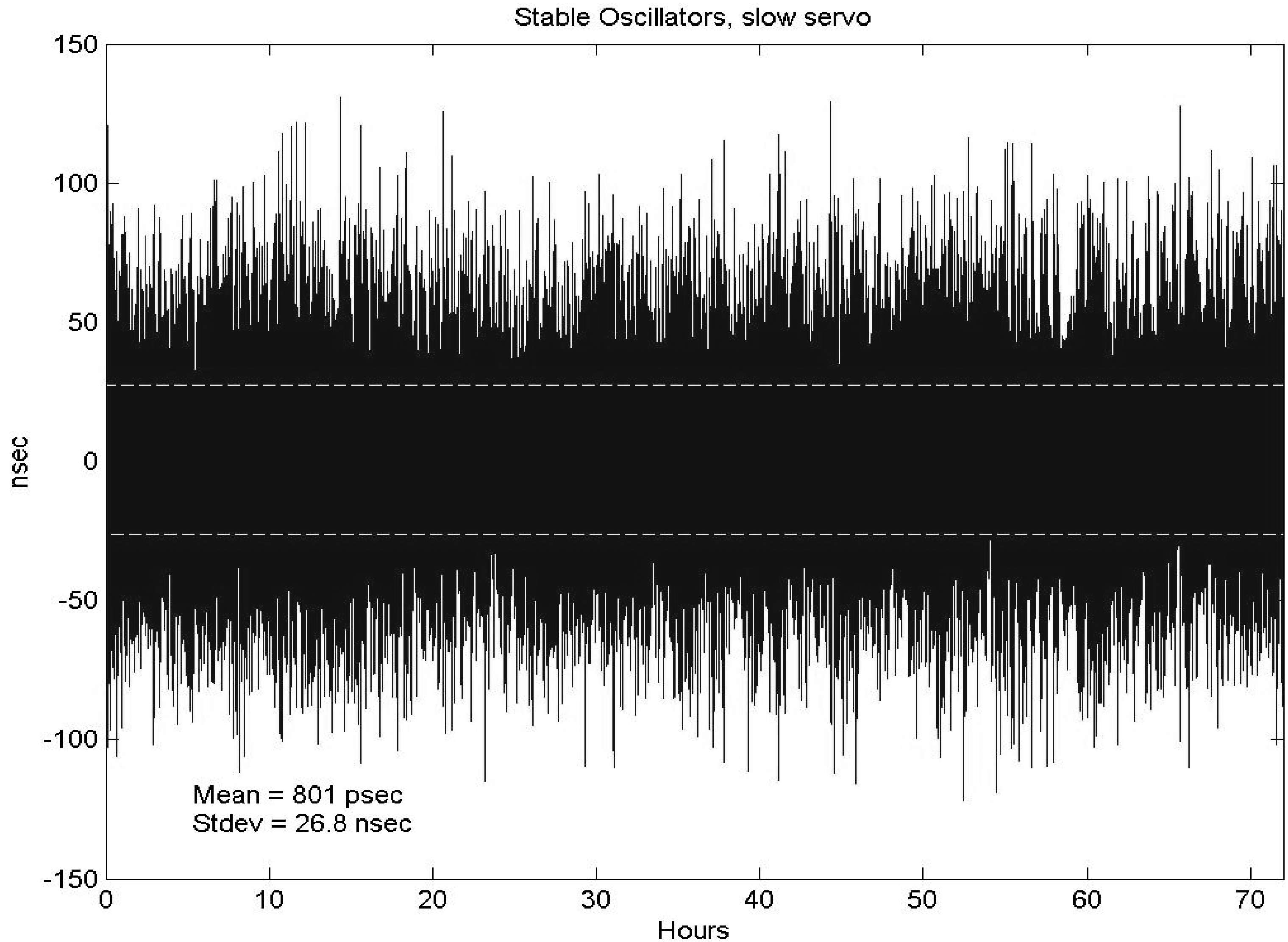








Seconds tick deviations: connection via a repeater



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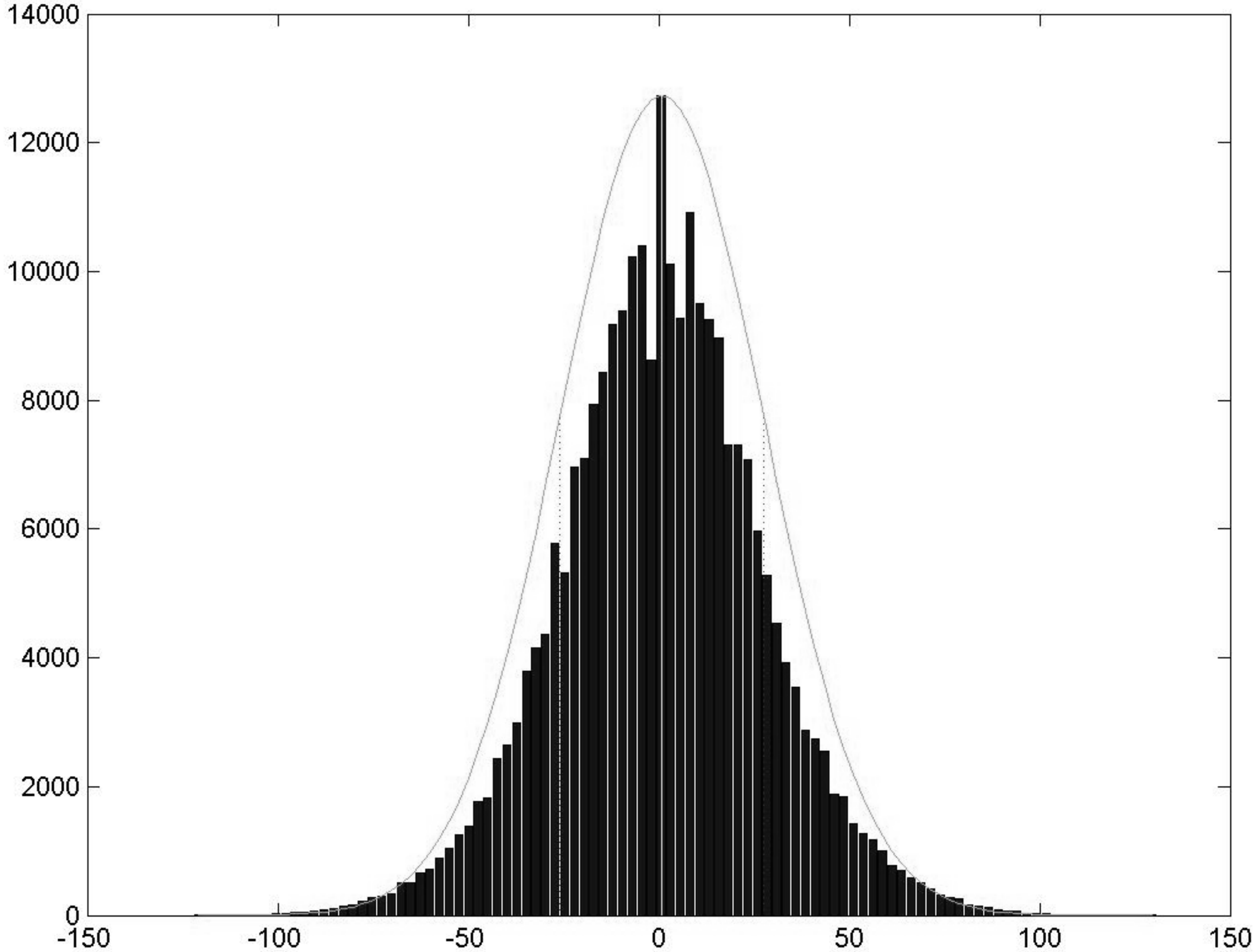

nanoseconds

For further information:

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September 24, 2003 IEEE1588 Workshop

http://ieee1588.nist.gov