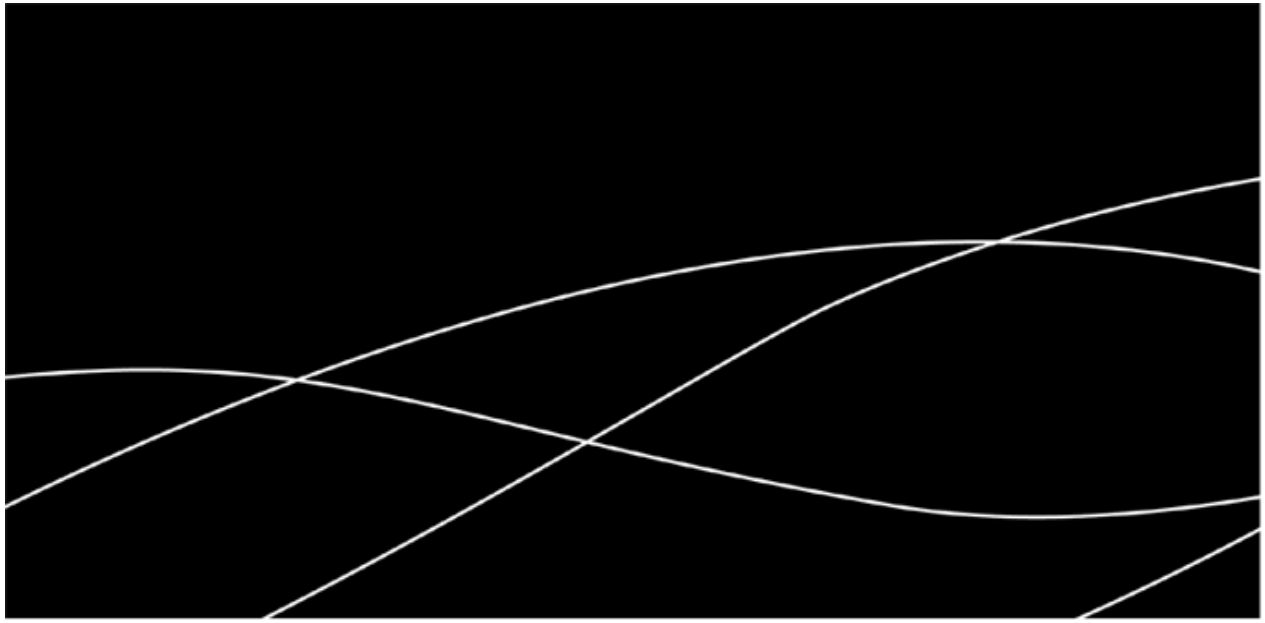

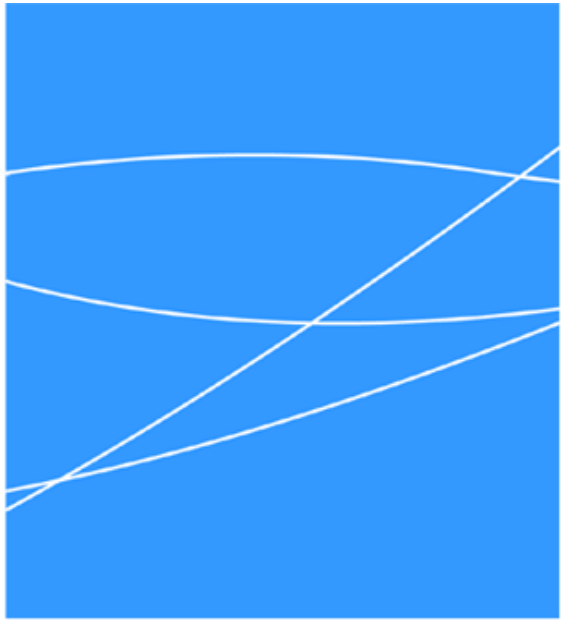

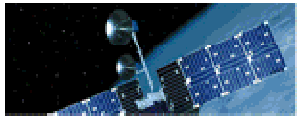

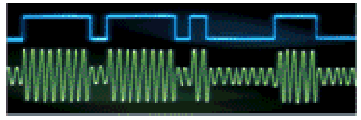

Timing Measurements in Packet Networks

ITSF November 2007

Lee Cosart

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Symmetricom®

Presentation Outline

- Measurement Setup
  - Measurement equipment configurations
  - Network configurations
- Performance Metrics
  - Phase (sequential)
  - MTIE, TDEV, PPSD, minTDEV
  - Phase statistics
- Measurements
  - Lab
  - Network

Measurement Setup

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- Measurement equipment with precision IEEE-1588 or NTP hardware time-stamping
- GPS time-of-day reference in each unit
  - Required for sub-microsecond end-to-end analysis
  - Log-files of the time-stamp data is post-processed
- Network configurations
  - Basic: crossover cable, hub, switch
  - Baseline: switch, router, multi-hop with no traffic
  - Traffic: load based upon G.8261 “data” profile
  - Production Network with Live Traffic
  - Company LAN and Public Internet

“TIE” vs. “PDV”

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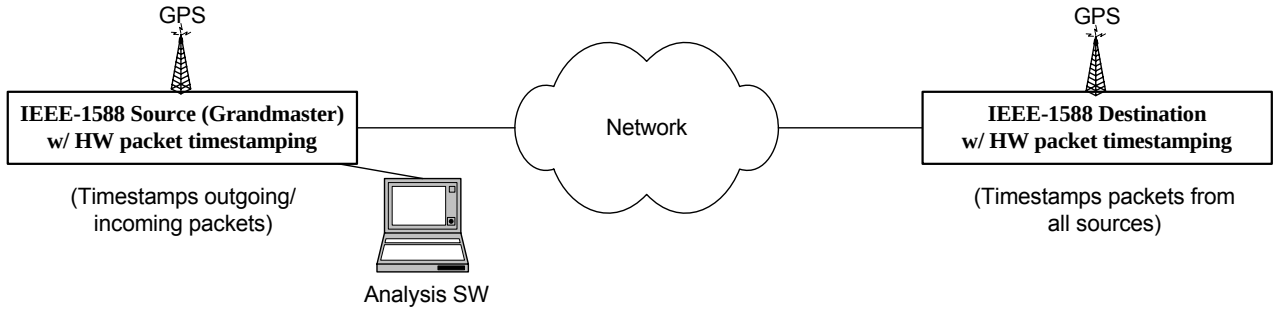
- “TIE” vs “PDV”
  - Traditional TDM synchronization measurements: signal edges are timestamped producing a sequence of samples
  - Packet timing measurements: packet departure/arrival times are sampled and packet delay sequences are formed
- Phase measurements (TIE) can be made using:
  - Frequency/time interval counters
  - Time interval analyzers
  - Dedicated test-sets
  - BITS/SSU clocks with built-in measurement capability
  - GPS receivers with built-in measurement capability
- Packet phase measurements (PDV) can be made using:
  - IEEE 1588 grandmaster/probes
  - NTP servers/probes
  - Specialized network probes

Packet Measurement Example Configurations

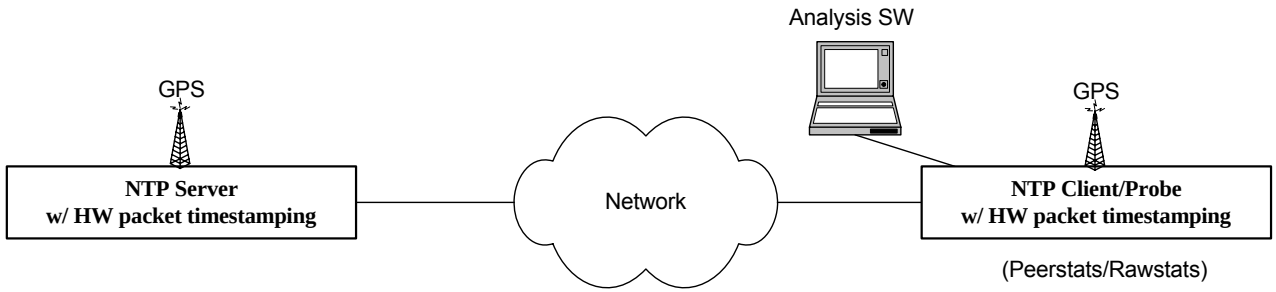
Example Measurement Equipment Configurations

Need (1) PRC TOD reference (2) Precision Packet TimeStamping (3) Analysis SW

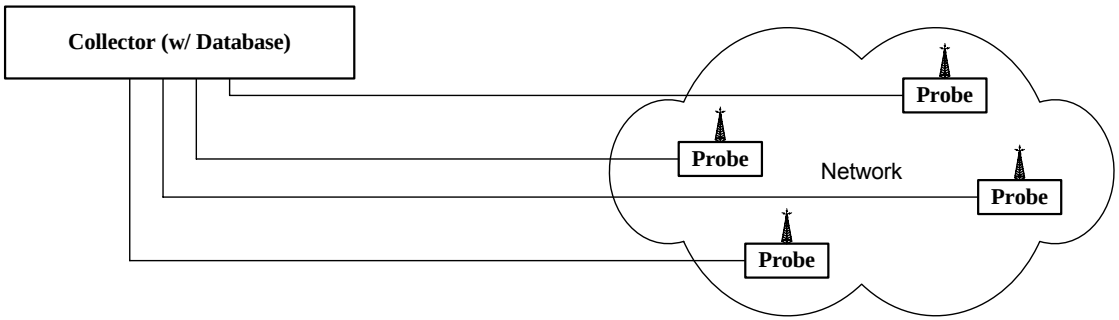
IEEE 1588



NTP



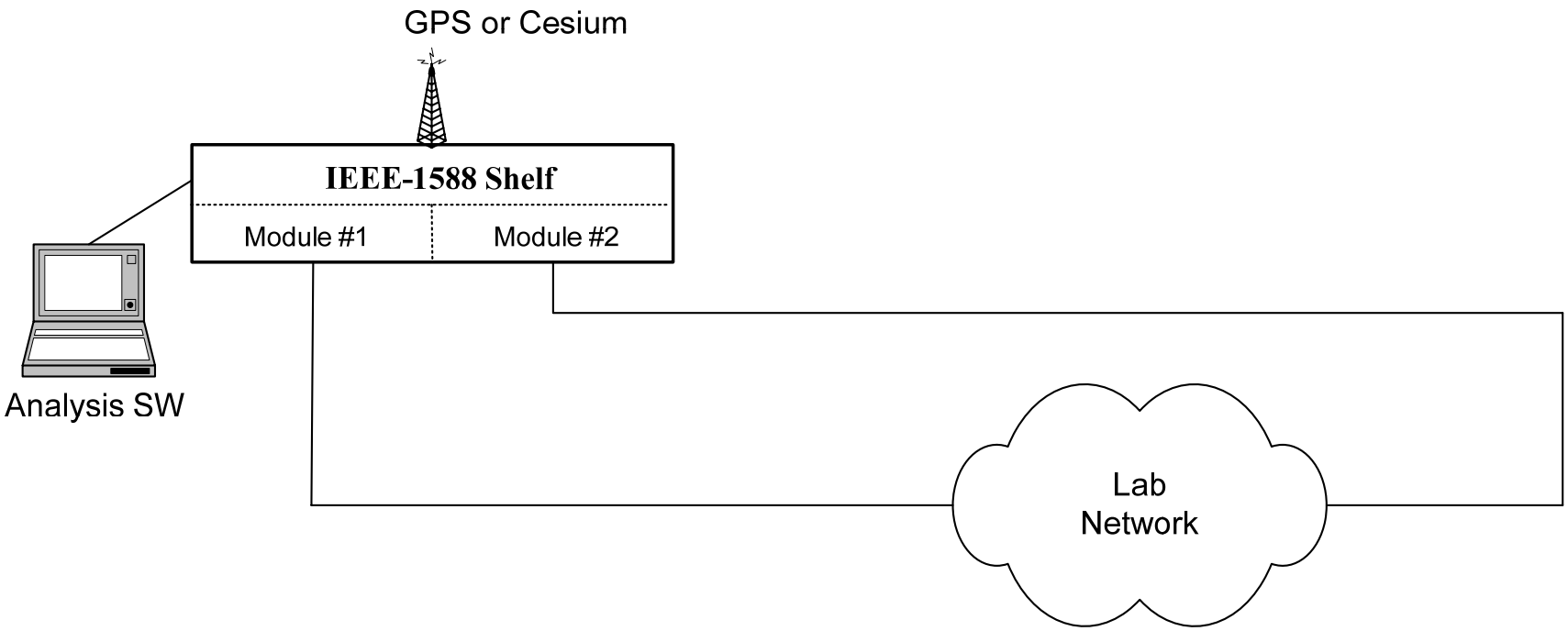
QoE Probes



Packet Measurement Example Configurations

Symmetricom

Alternate Measurement Equipment Configuration for Lab



PTP PDV Files

Source File:

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SEQ: 23238 UUID: 000055010016 UTC: DATE 2006:124:01:48:56 NSEC 0772791251
SEQ: 23906 UUID: 000055010017 UTC: DATE 2006:124:01:48:56 NSEC 0942353061
SEQ: 23239 UUID: 000055010016 UTC: DATE 2006:124:01:48:57 NSEC 0742766301
SEQ: 23907 UUID: 000055010017 UTC: DATE 2006:124:01:48:58 NSEC 0122405371
SEQ: 01196 UUID: 00A069012FB9 UTC: DATE 2006:124:01:48:58 NSEC 0649898076
SEQ: 23908 UUID: 000055010017 UTC: DATE 2006:124:01:48:59 NSEC 0512342921
SEQ: 23240 UUID: 000055010016 UTC: DATE 2006:124:01:49:00 NSEC 0372820611
SEQ: 01197 UUID: 00A069012FB9 UTC: DATE 2006:124:01:49:00 NSEC 0649723496

Destination File:

SEQ: 01195 UUID: 00A069012FB9 UTC: DATE 2006:124:01:48:56 NSEC 0650356493
SEQ: 23238 UUID: 000055010016 UTC: DATE 2006:124:01:48:56 NSEC 0772511963
SEQ: 23906 UUID: 000055010017 UTC: DATE 2006:124:01:48:56 NSEC 0942073173
SEQ: 23239 UUID: 000055010016 UTC: DATE 2006:124:01:48:57 NSEC 0742522643
SEQ: 23907 UUID: 000055010017 UTC: DATE 2006:124:01:48:58 NSEC 0122085883
SEQ: 01196 UUID: 00A069012FB9 UTC: DATE 2006:124:01:48:58 NSEC 0650169943
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SEQ: 23909 UUID: 000055010017 UTC: DATE 2006:124:01:49:01 NSEC 0712120953

NTP Rawstats File

Symmetricom®

```
53670 65597.542   69.25.96.14   192.168.5.26 3339425597.531763871 3339425597.538087700 3339425597.538856700 3339425597.541986235
53670 65598.621   69.25.96.14   192.168.5.26 3339425598.531791267 3339425598.534250000 3339425598.618500000 3339425598.620880216
53670 65599.535 192.168.5.198 192.168.5.26 3339425599.531832760 3339425598.532465024 3339425598.533733347 3339425599.534835067
53670 65599.542   69.25.96.14   192.168.5.26 3339425599.531982140 3339425599.538061600 3339425599.538876600 3339425599.541980469
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53670 65603.538   69.25.96.14   192.168.5.26 3339425603.532238421 3339425603.534553000 3339425603.535296200 3339425603.538452633
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53670 65606.535 192.168.5.130 192.168.5.26 3339425606.532160571 3339425605.532799972 3339425605.533900287 3339425606.534984607
53670 65606.641   69.25.96.11   192.168.5.26 3339425606.532307531 3339425606.540500000 3339425606.638500000 3339425606.640780864
```
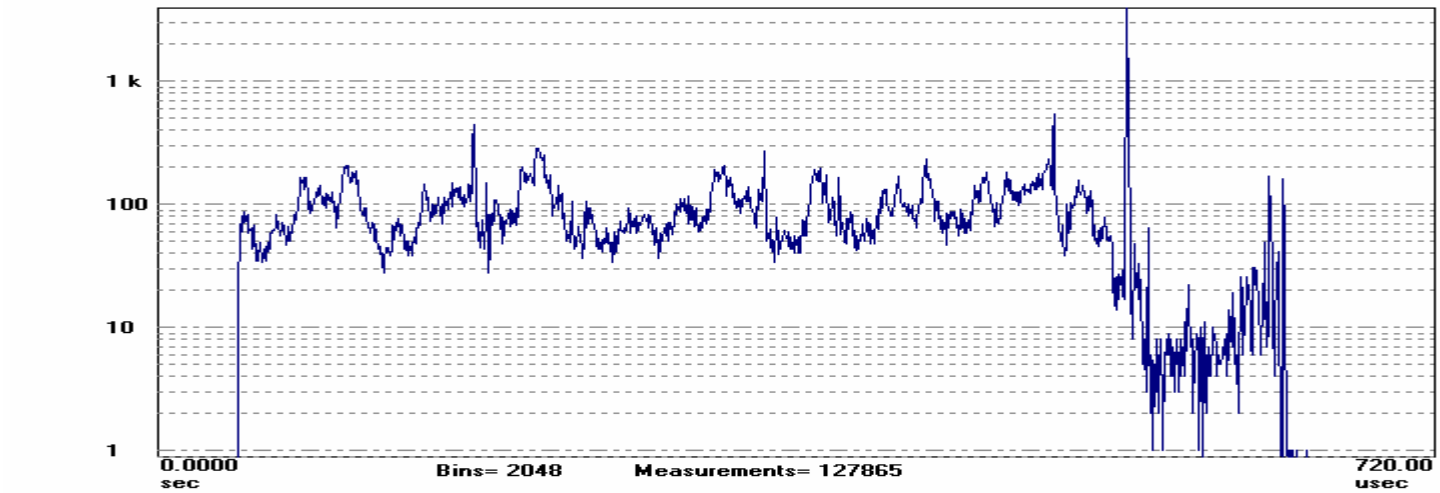

IEEE 1588 vs. NTP Packet Measurement Tools: Example 1

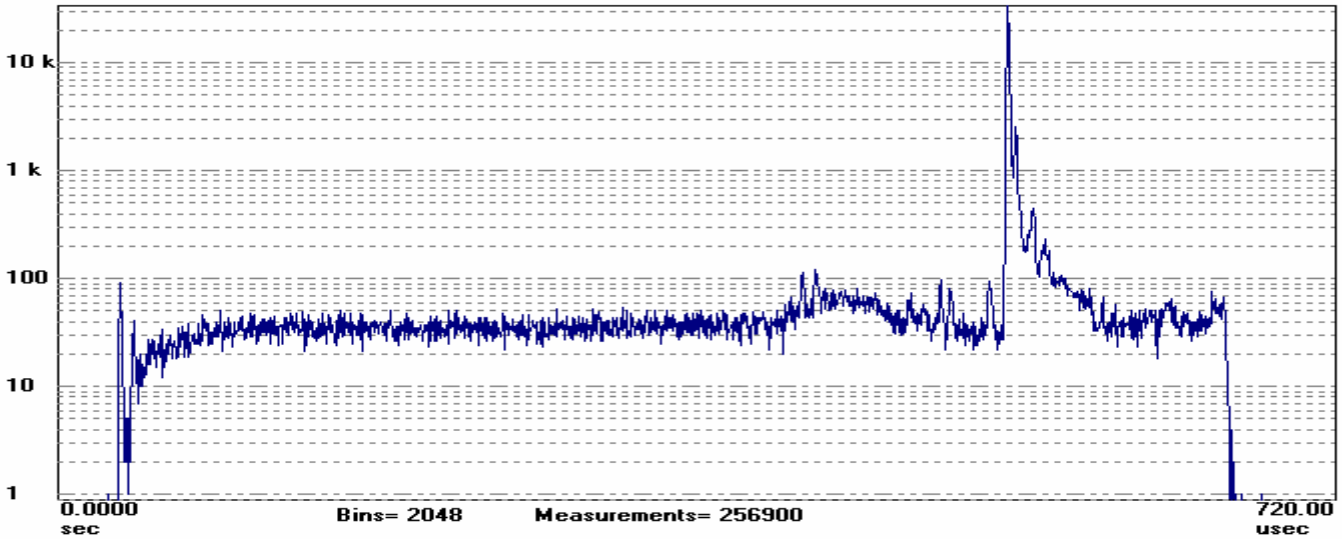
Symmetricom

Symmetricom TimeMonitor Analyzer
Phase Deviation Histogram; Fs=500.0 mHz; Fo=10.00 MHz; 2006/06/02 23:17:57
Tahiti Phase; Samples: 127865; UUID: 000055010016; Initial phase offset: 168.872 usec



IEEE 1588

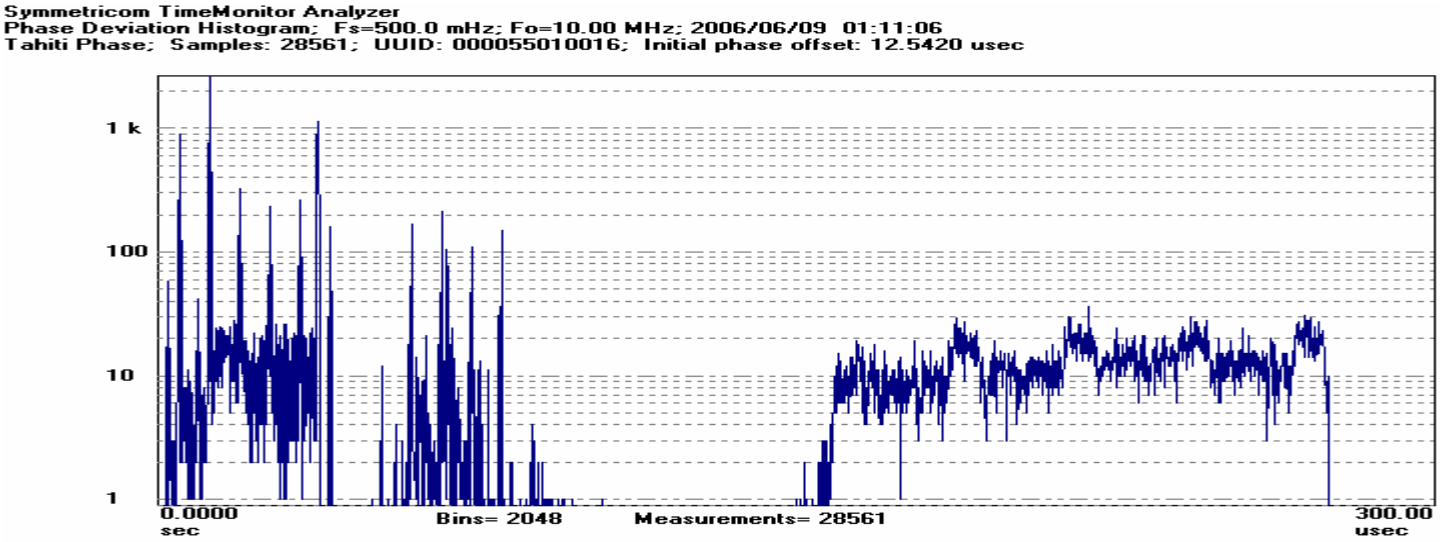
Symmetricom TimeMonitor Analyzer
Phase Deviation Histogram; Fs=999.7 mHz; Fo=10.00 MHz; 2006/06/02 23:18:14
Rawstats Transmit Delay; Samples: 256900; Glitch threshold: 1.00000 ms; Remote IP: 192.168.5.250; Local IP: 192.168.5.3



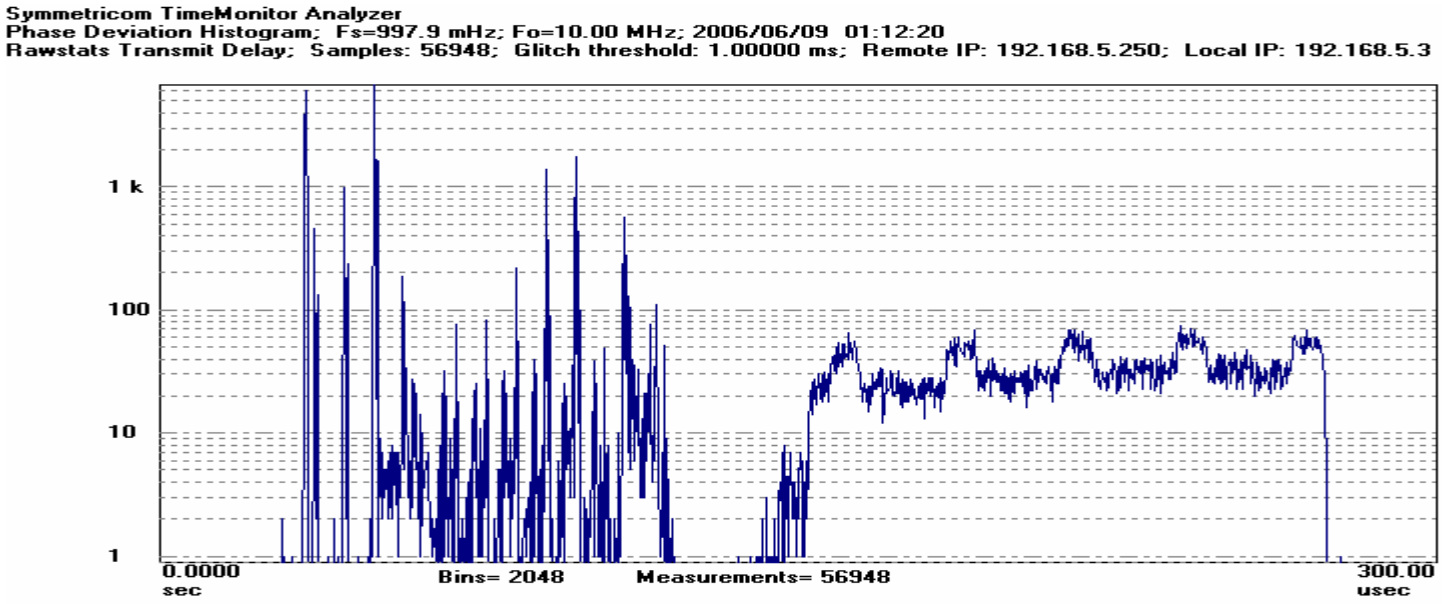
NTP

IEEE 1588 vs. NTP Packet Measurement Tools: Example 2

Symmetricom



IEEE 1588

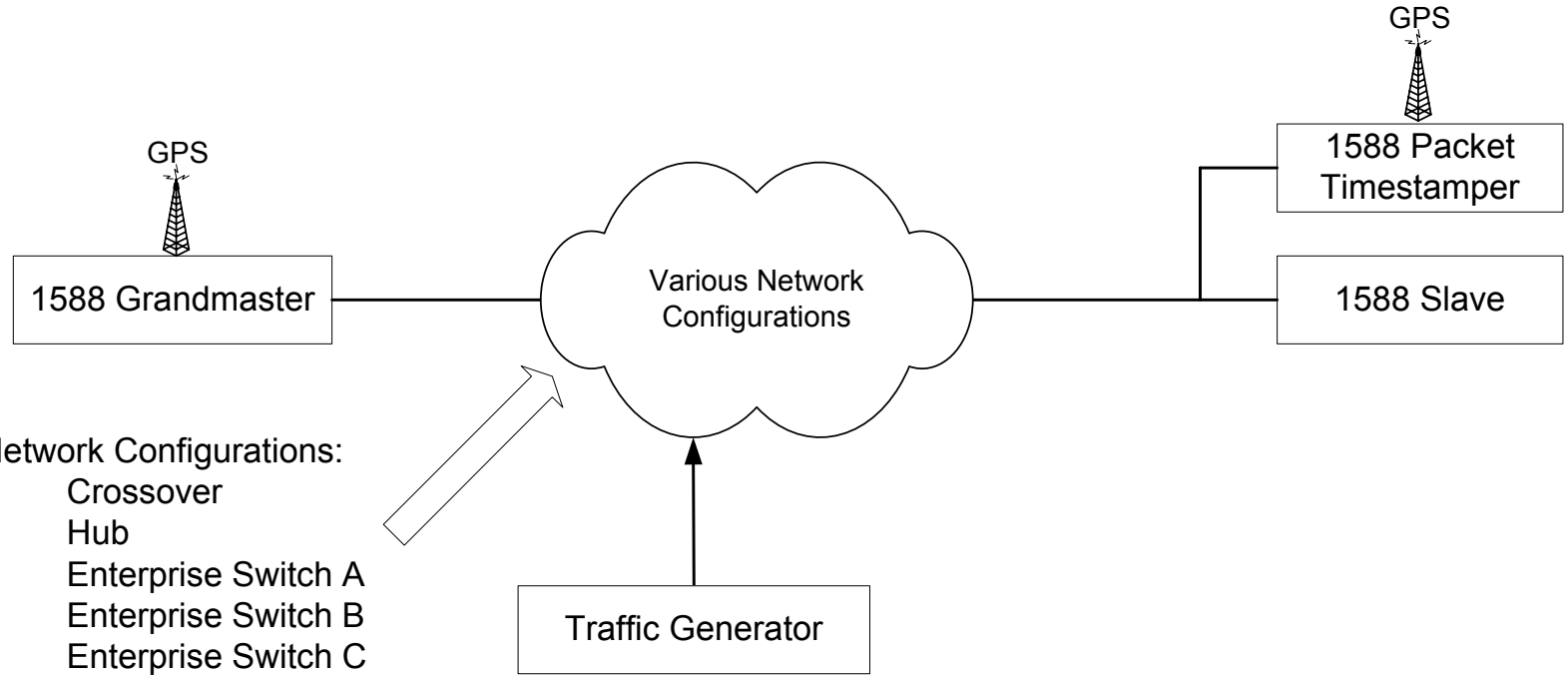


NTP

Lab Network Configurations

Symmetricom

Example Lab Network Configurations



Network Configurations:

- Crossover
- Hub
- Enterprise Switch A
- Enterprise Switch B
- Enterprise Switch C
- Enterprise Switch D
- Multilayer Switch E
- Wirespeed router M
- Router X
- Router Y
- Multi-Hop: SwA/RtX/SwB
- Multi-Hop: SwA/RtM/SwB
- Multi-Hop: SwA/RtX/RtX/SwB
- Multi-Hop: SwA/RtX/RtY/SwB

Interpretation of Measurement Results ("TIE")

Symmetricom

- For traditional synchronization measurements, the measurement analysis used primarily is:
  - Phase (TIE)
  - Frequency (fractional frequency offset)
  - Frequency accuracy
  - MTIE
  - TDEV

  } All are derived from phase

- MTIE and TDEV analysis shows comparison to ANSI, Telcordia/Bellcore, ETSI, & ITU-T requirements

Interpretation of Measurement Results ("PDV")

Symmetricom

- For packet synchronization measurements, some of the measurement analysis used is:
  - Phase (PDV)
  - Histogram/PDF* & Statistics
  - Running Statistics
  - TDEV/minTDEV

} Derived from PDV phase

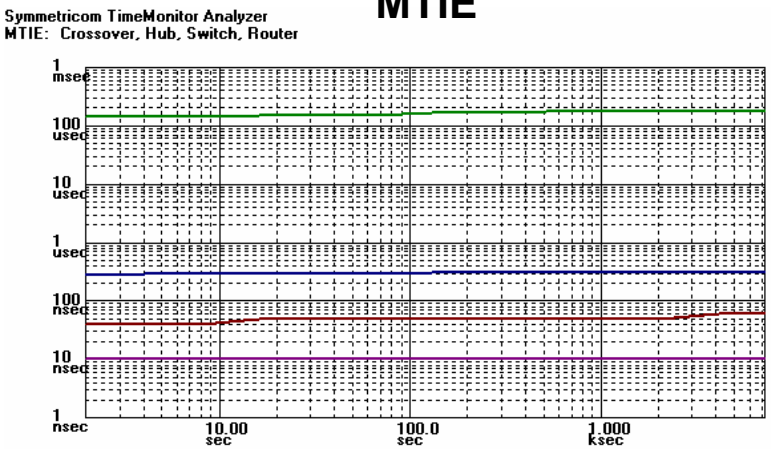
- minTDEV is under study at the ITU-T Q13/SG15 and has references in the latest G.8261 draft

* PDF = probability density function

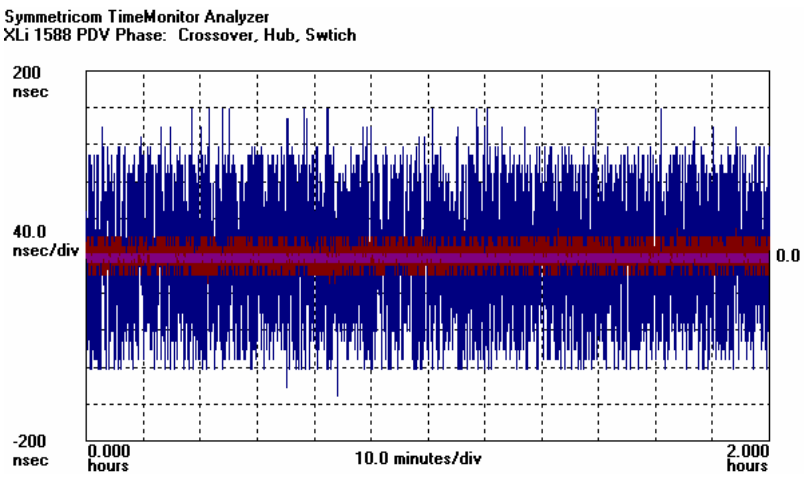
Performance Metrics

- Phase (Packet Delay vs. Time)
  - Basis for all calculations
- MTIE (Maximum Time Interval Error)
  - Typically one dimensional for packet delay data
- TDEV (Time Deviation)
  - Useful indicator of network traffic load

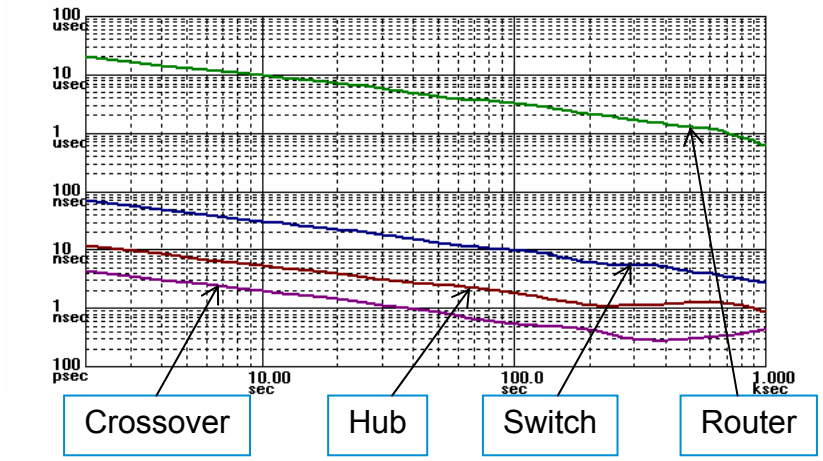
MTIE



Phase



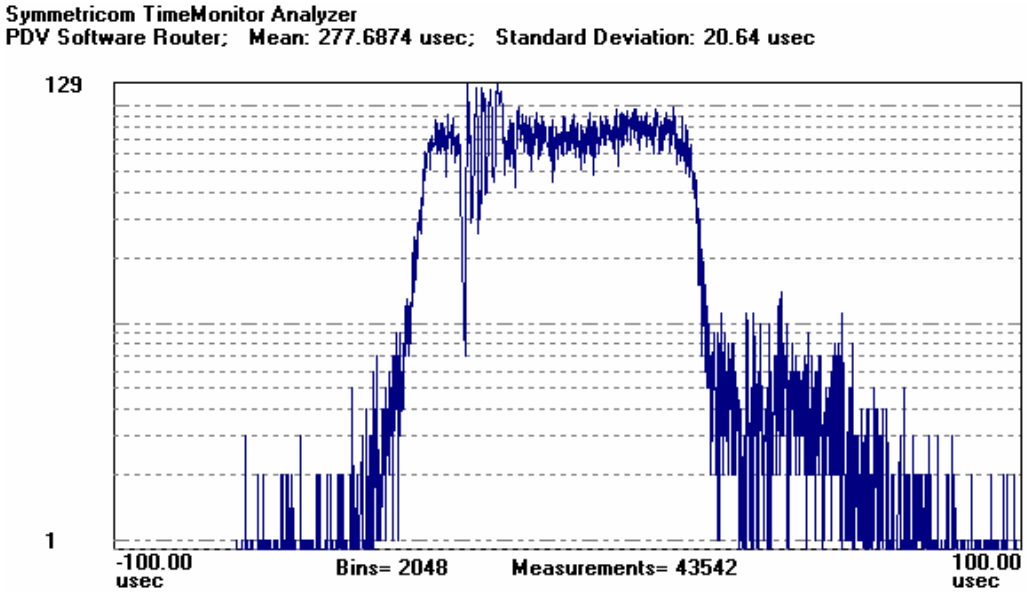
TDEV



Performance Metrics

Packet Delay Distribution and Statistics

- Standard Deviation (PDV)
- Mean (Latency)
- Maximum Peak Deviation (PDV)



Statistics

Crossover cable:
Mean: 287.2818 nsec
Peak to Peak: 10.01 nsec
Standard Deviation: 4.450 nsec

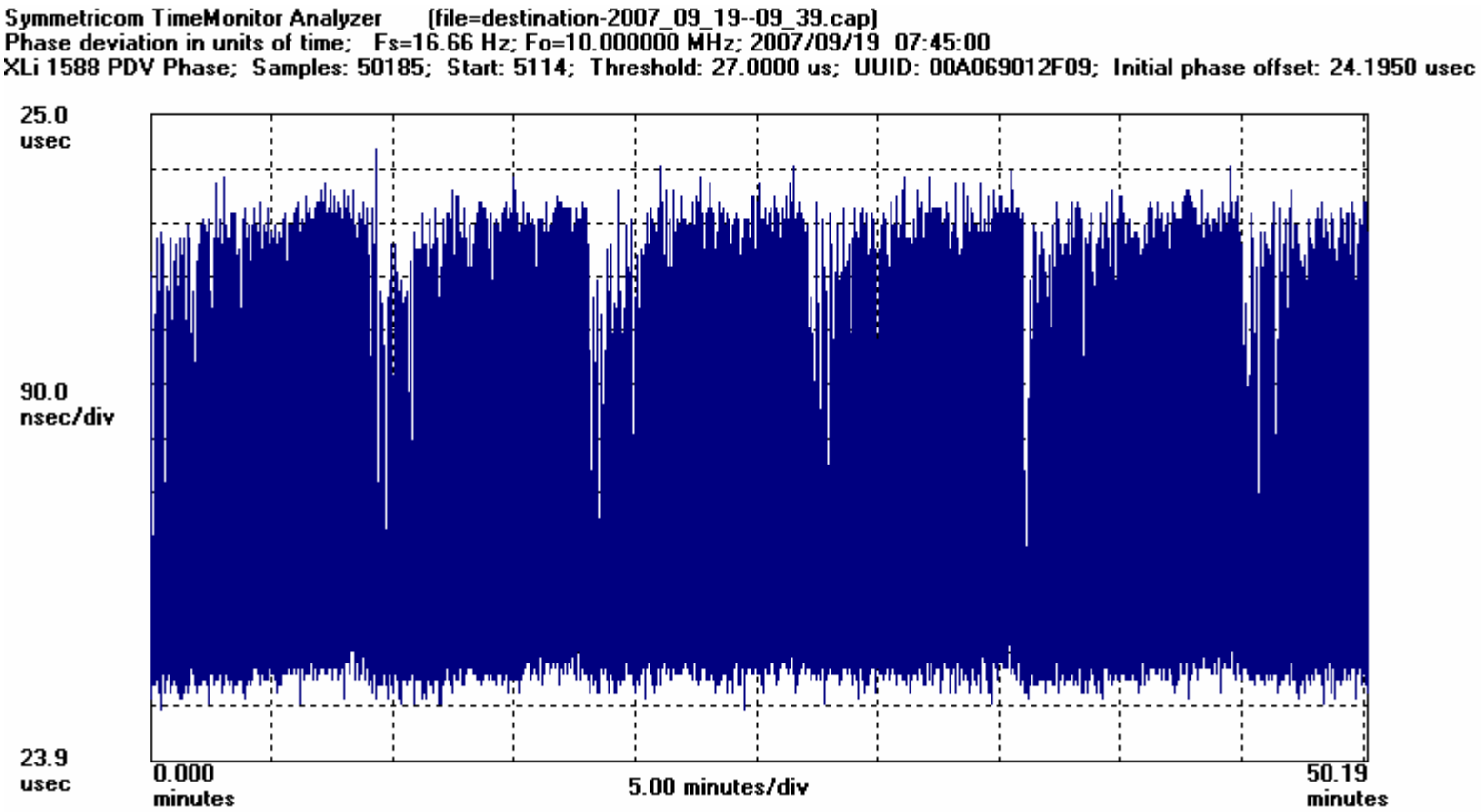
Hub:
Mean: 659.7955 nsec
Peak to Peak: 60.01 nsec
Standard Deviation: 12.13 nsec

Switch:
Mean: 16.75112 µsec
Peak to Peak: 310.0 nsec
Standard Deviation: 70.10 nsec

Router:
Mean: 277.6874 µsec
Peak to Peak: 212.5 µsec
Standard Deviation: 20.64 µsec

Raw PDV vs. Running Statistics

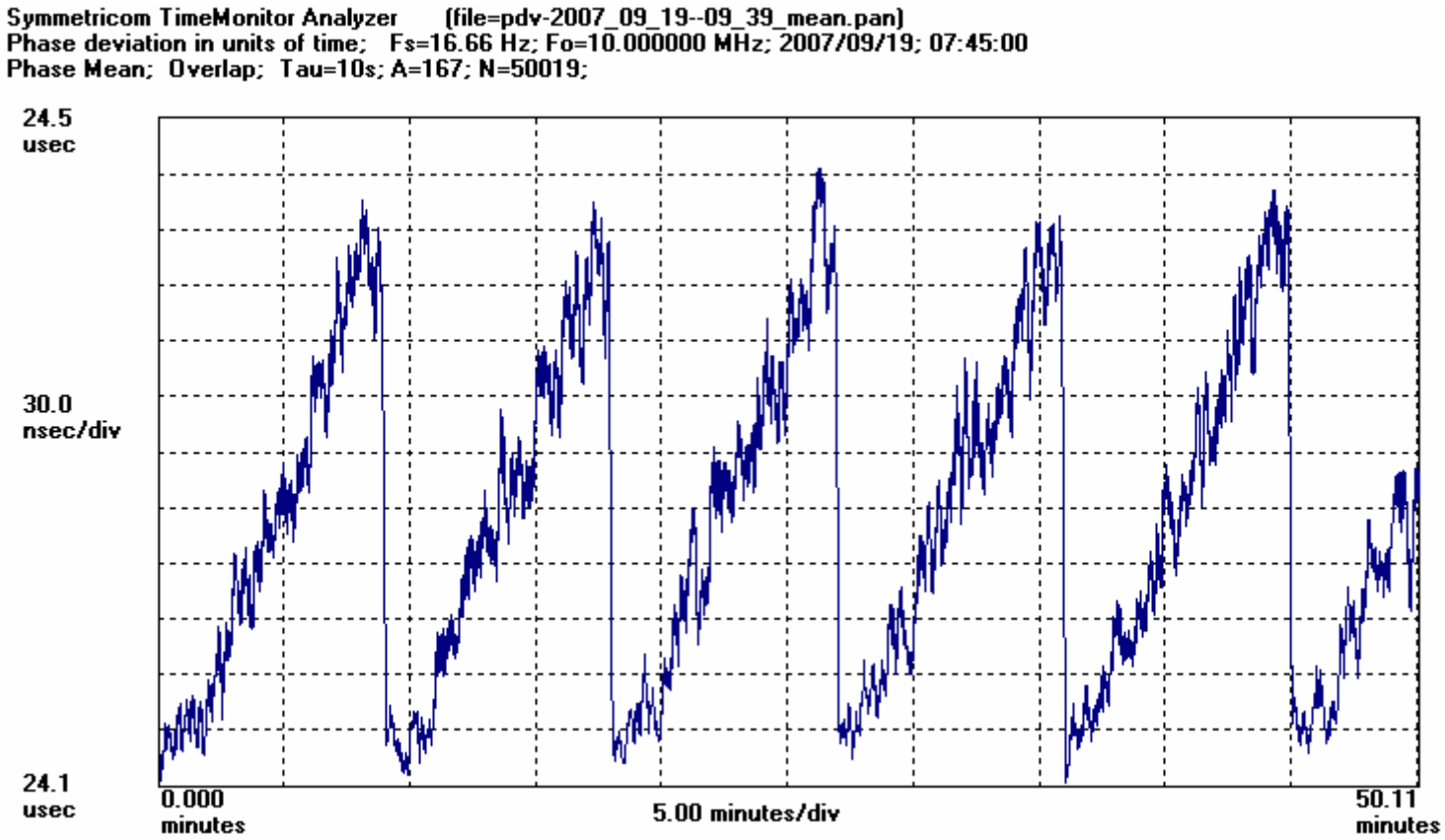
Raw packet delay appears relatively static over time



Raw PDV vs. Running Statistics

Symmetricom

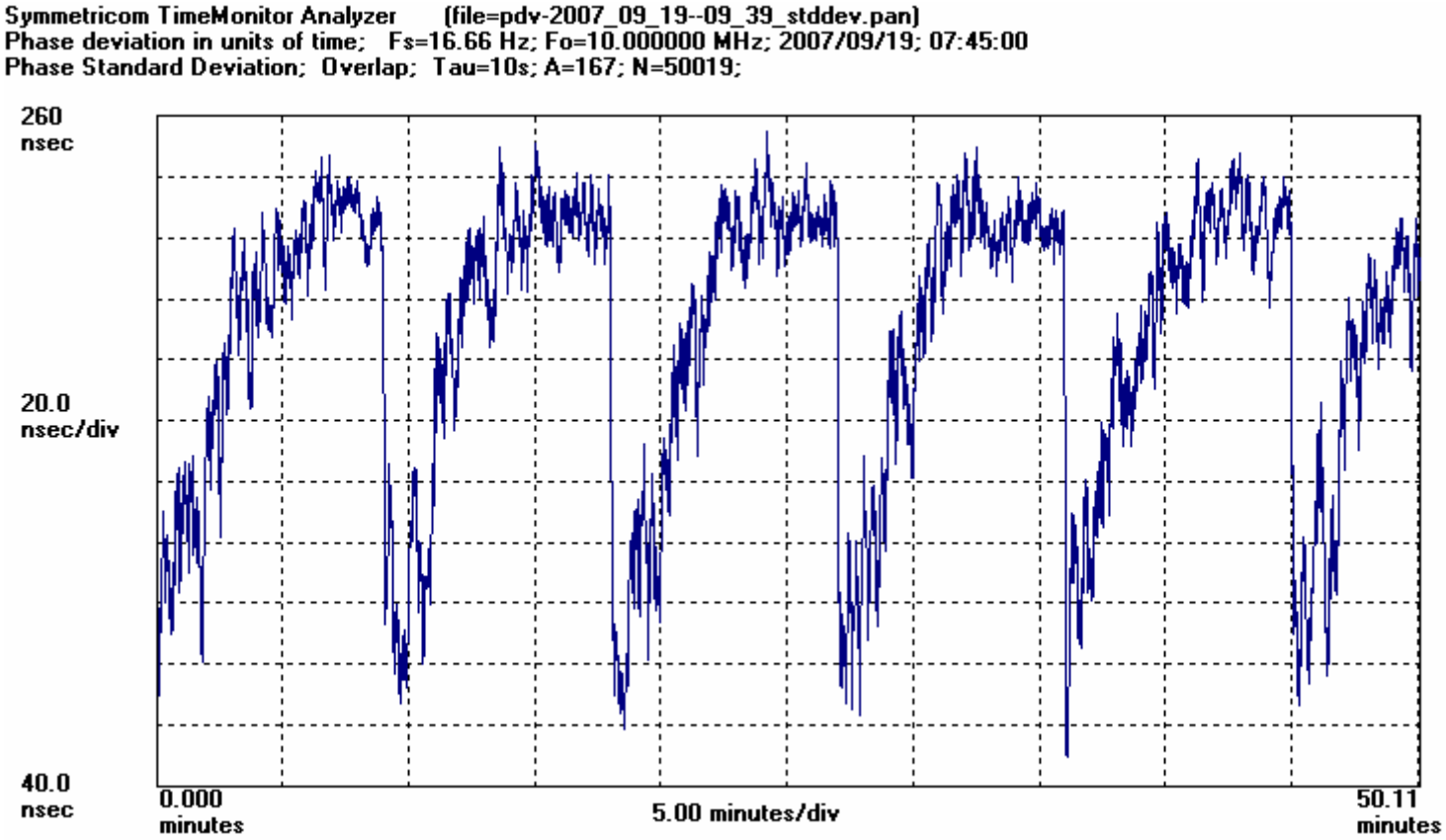
Mean vs. time shows cyclical ramping more clearly



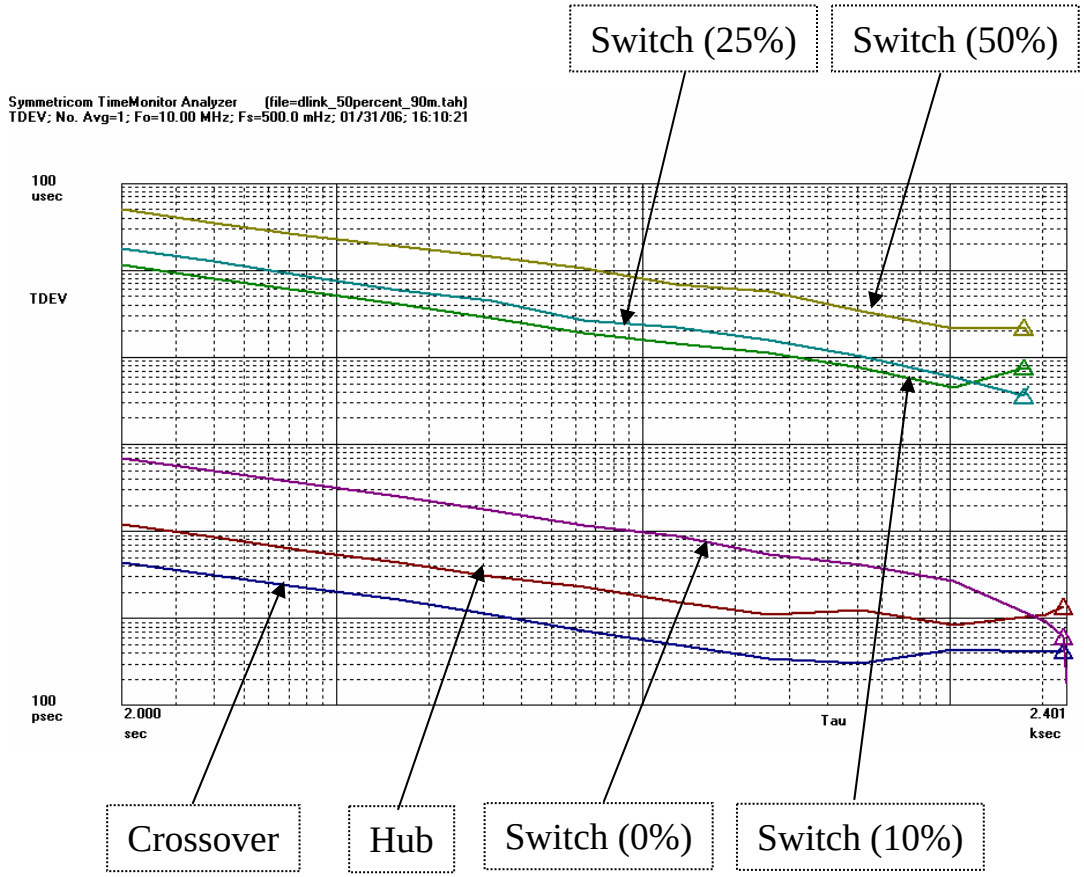
Raw PDV vs. Running Statistics

Symmetricom

Standard deviation vs. time shows a quick ramp up to a flat peak



Performance As a Function of Load



Statistics

No traffic:
Mean: 16.75112 µsec
Peak to Peak: 310.0 nsec
Standard Deviation: 70.10 nsec

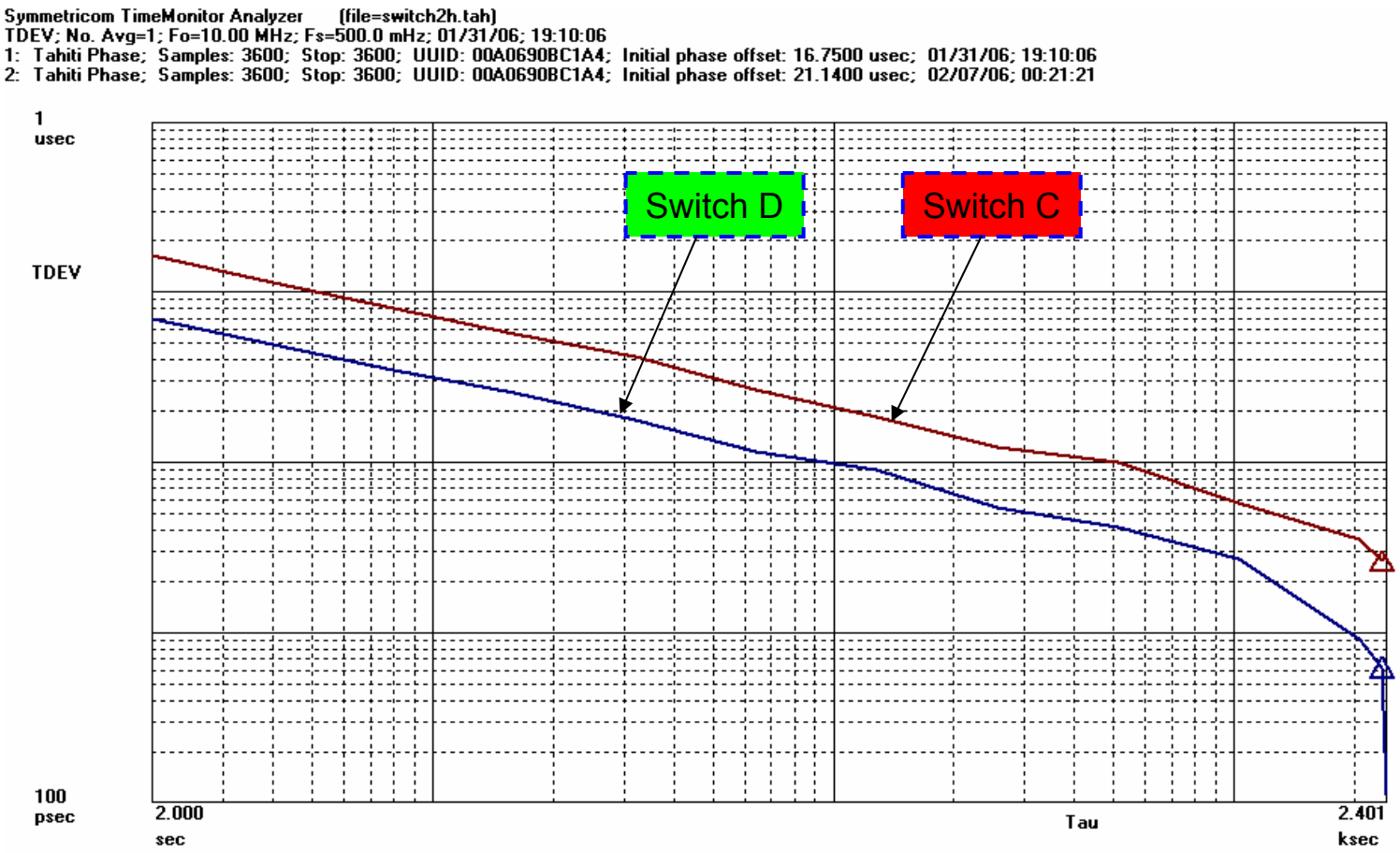
10% BW Utilization:
Mean: 17.93500 µsec
Peak to Peak: 121.4 µsec
Standard Deviation: 11.53 µsec

25% BW Utilization:
Mean: 19.62525 µsec
Peak to Peak: 122.6 µsec
Standard Deviation: 17.61 µsec

50% BW Utilization:
Mean: 47.99551 µsec
Peak to Peak: 122.8 µsec
Standard Deviation: 50.90 µsec

Not All Devices are *Equal*

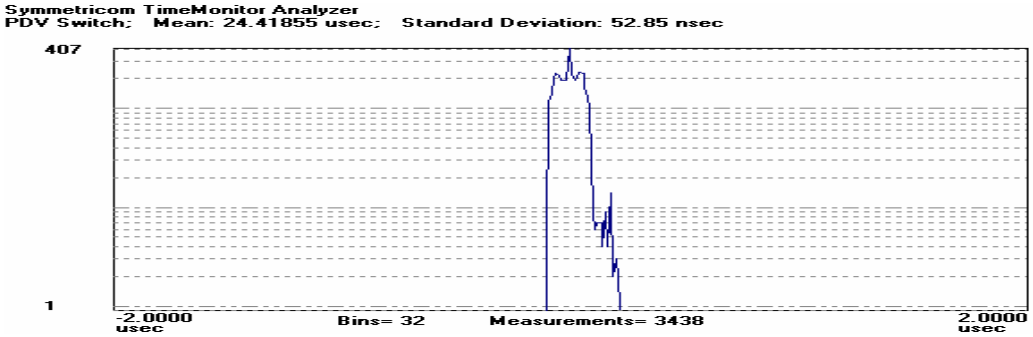
Symmetricom

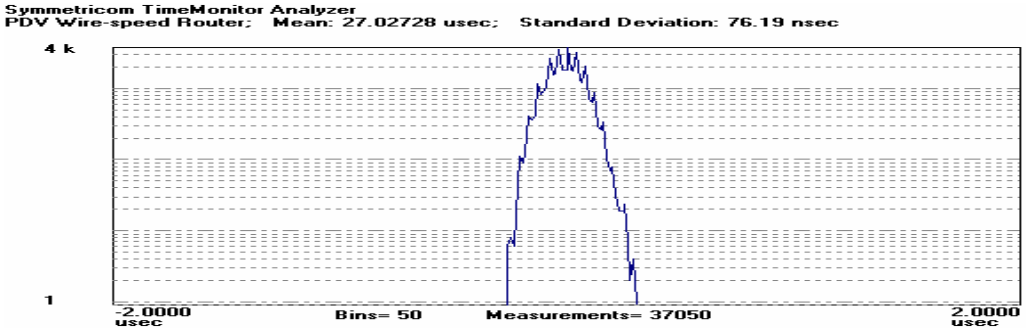


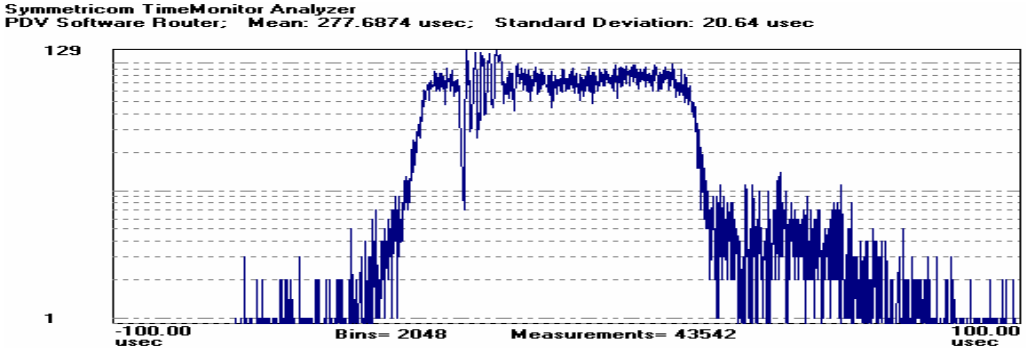
Not All Devices are *Equal*

Symmetricom

Switch vs. Multilayer switch vs. Router







Statistics

Switch:

Mean: 24.41855 µsec

Peak to Peak: 334.8 nsec

Standard Deviation: 52.85 nsec

Multilayer Switch:

Mean: 27.02728 µsec

Peak to Peak: 576.0 nsec

Standard Deviation: 76.19 nsec

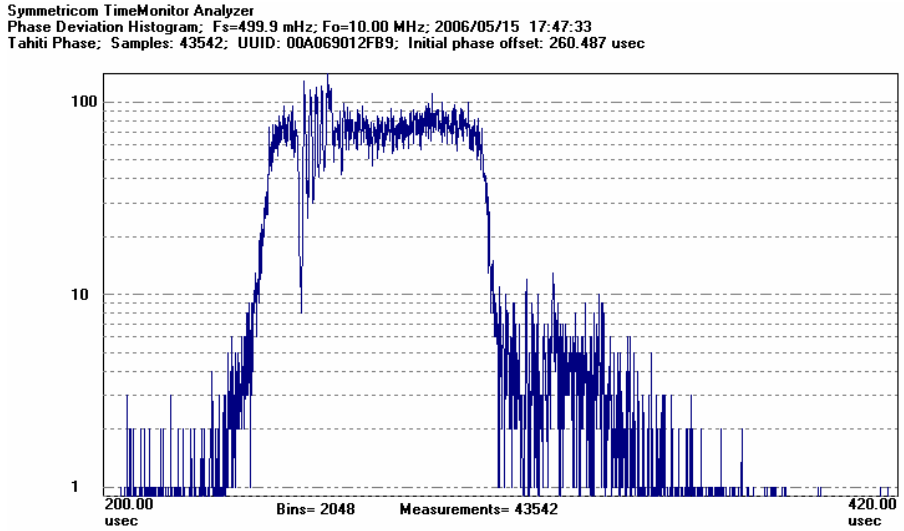
Router:

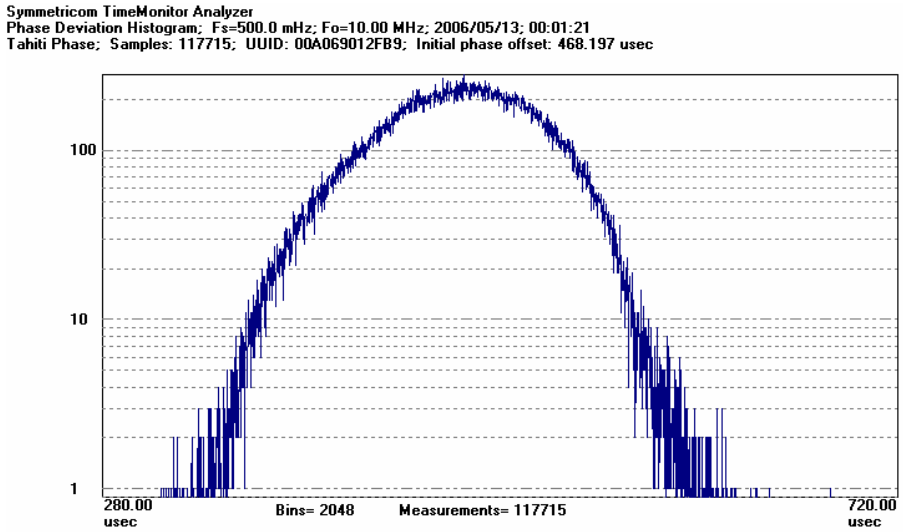
Mean: 277.6874 µsec

Peak to Peak: 212.5 µsec

Standard Deviation: 20.64 µsec

One vs. Two Routers





Statistics

One router:

Mean: 277.6874 µsec

Peak to Peak: 212.5 µsec

Standard Deviation: 20.64 µsec

Two routers:

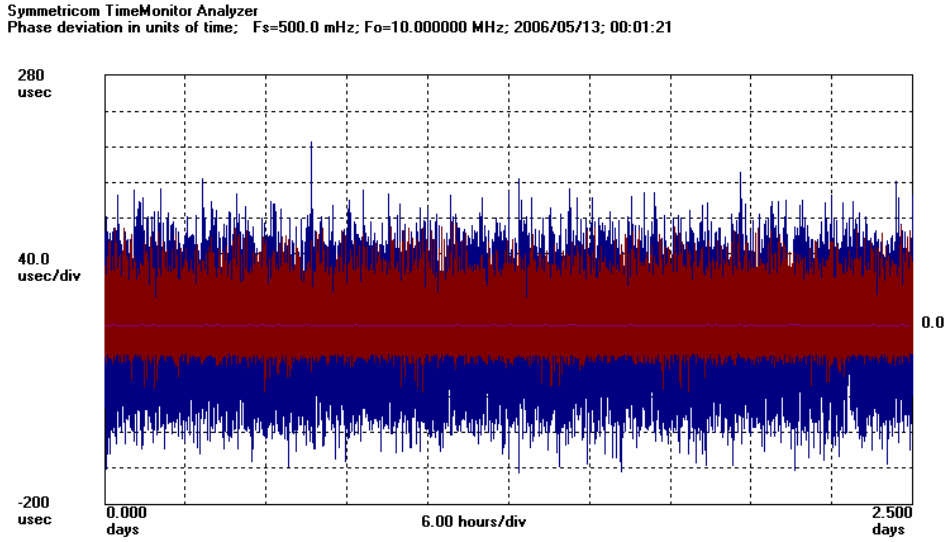
Mean: 477.6874 µsec

Peak to Peak: 369.7 µsec

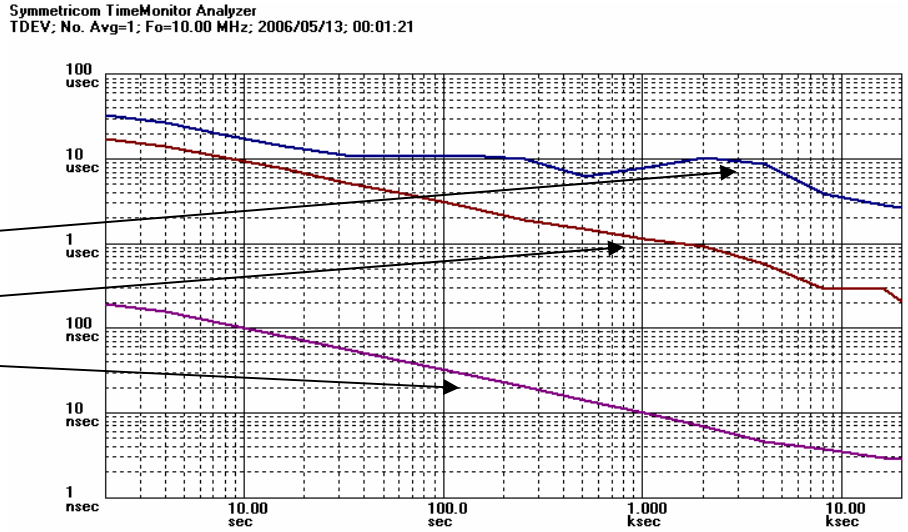
Standard Deviation: 43.18 µsec

One vs. Two Routers

PHASE



TDEV

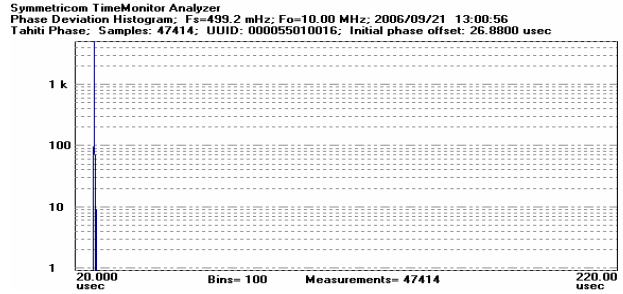


Two Routers: No Load

One Router: No Load

Switch: No Load

Multilayer Switch with Traffic



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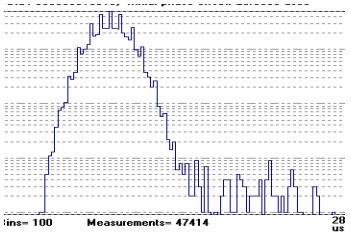

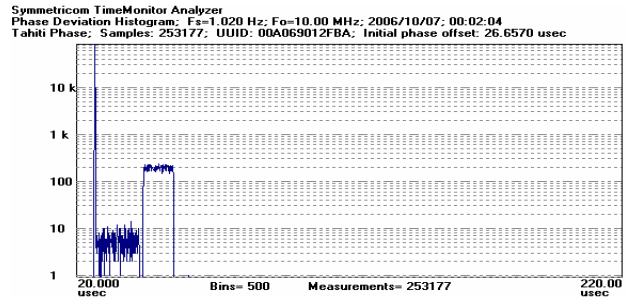

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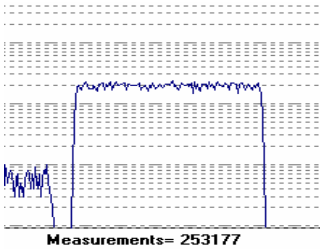
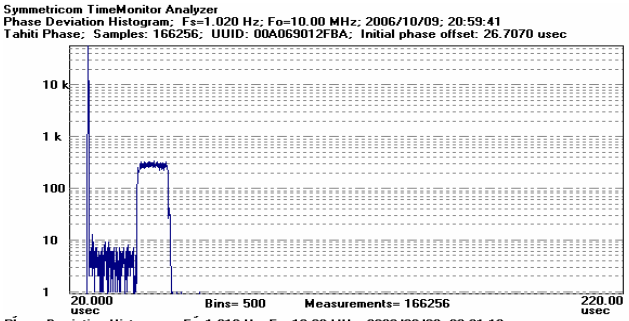
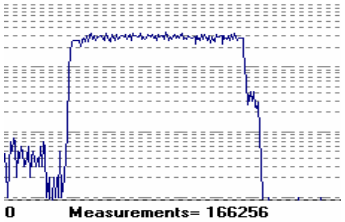
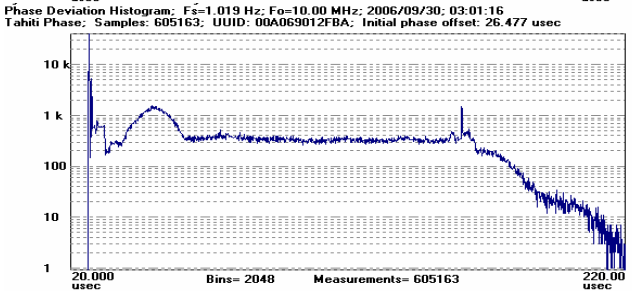




20%



Zooms



50%

No traffic:
Mean: 26.9586 µsec
Peak to Peak: 620.4 nsec
Standard Deviation: 73.20 nsec

5% BW Utilization:
Mean: 26.9462 µsec
Peak to Peak: 1.209 µsec
Standard Deviation: 79.12 nsec

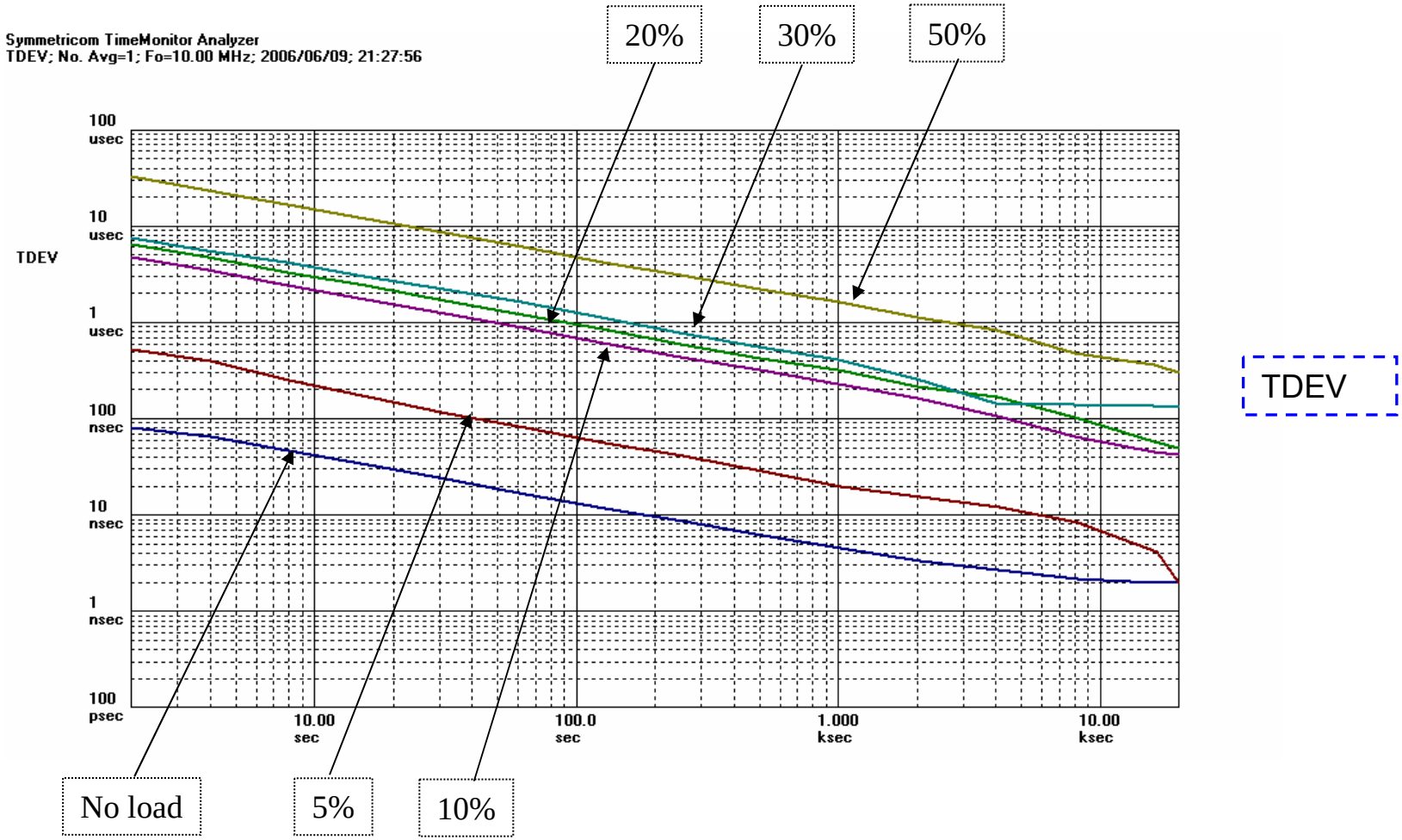
10% BW Utilization:
Mean: 28.9450 µsec
Peak to Peak: 34.77 µsec
Standard Deviation: 7.008 µsec

20% BW Utilization:
Mean: 31.2810 µsec
Peak to Peak: 40.41 µsec
Standard Deviation: 9.426 µsec

30% BW Utilization:
Mean: 33.6201 µsec
Peak to Peak: 41.70 µsec
Standard Deviation: 10.88 µsec

50% BW Utilization (2 Traffic Sources):
Mean: 80.8216 µsec
Peak to Peak: 206.6 µsec
Standard Deviation: 47.06 µsec

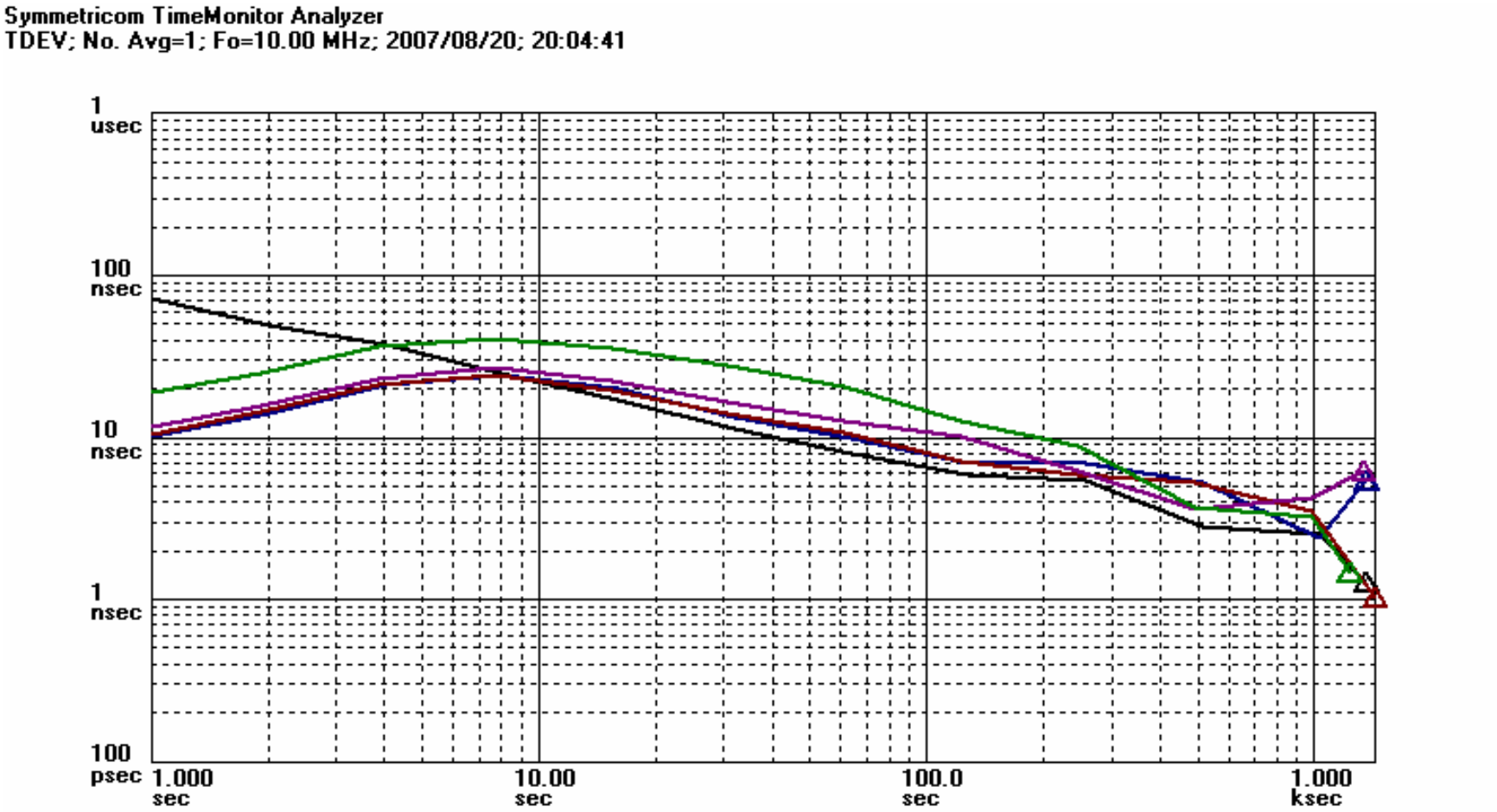
Multilayer Switch with Traffic



TDEV with Selection Algorithm: minTDEV

Symmetricom

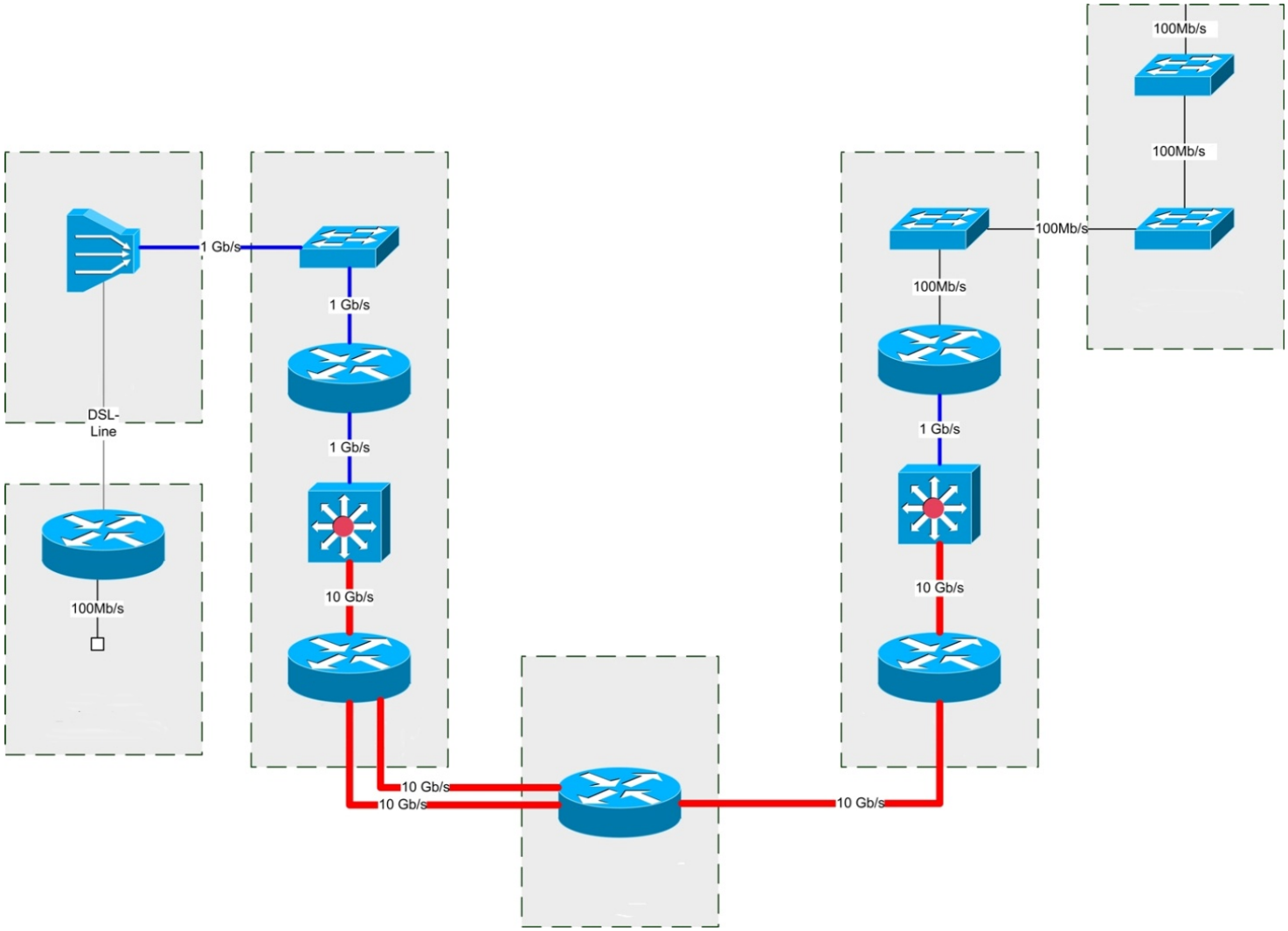
Lower levels of noise with the application of a MINIMUM selection algorithm
TDEV at various traffic levels on a switch (0% to 80%) converge



Production Network with DSL Access

Symmetricom

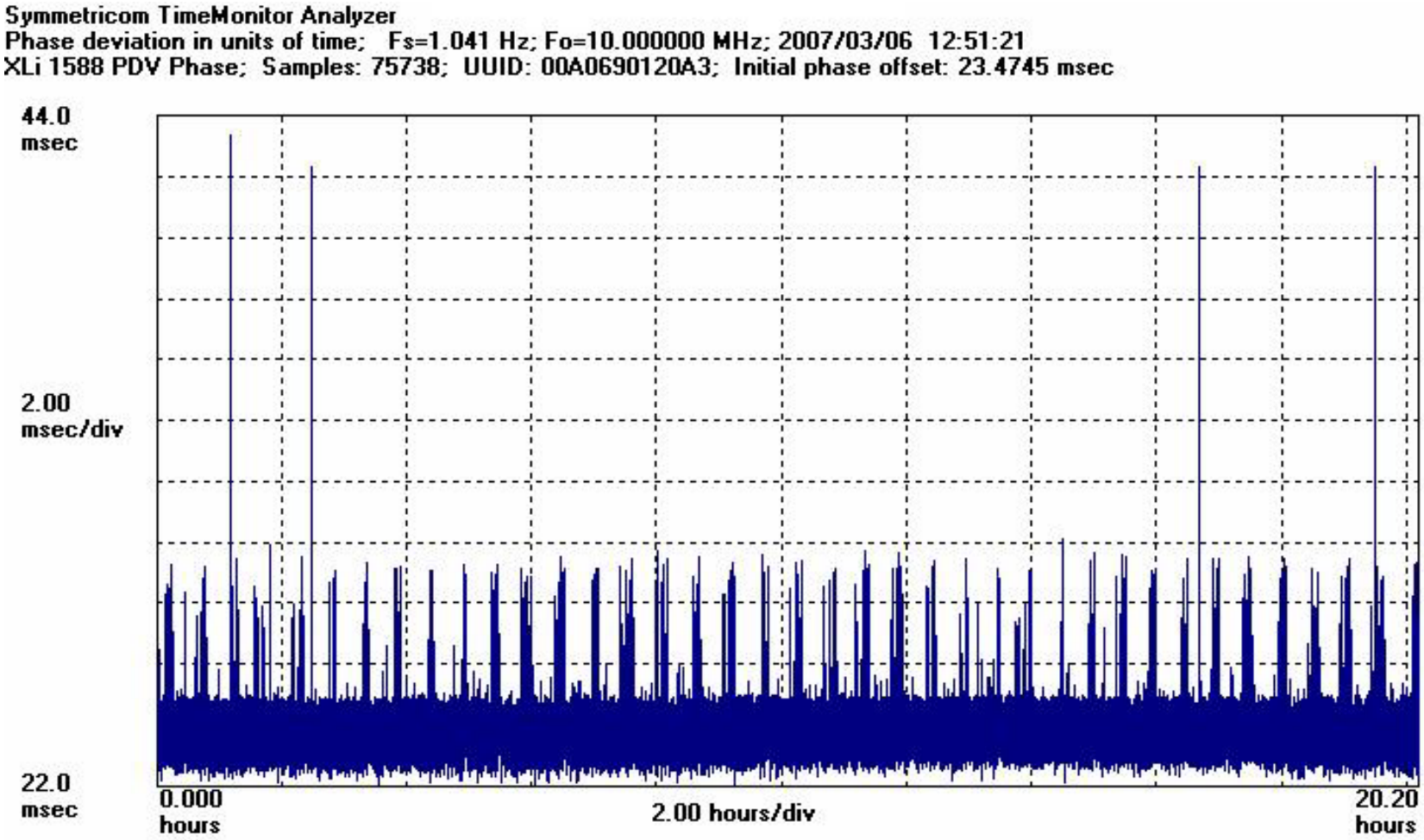
Network spanning 500 km between two European cities



Production Network with DSL Access

Symmetricom

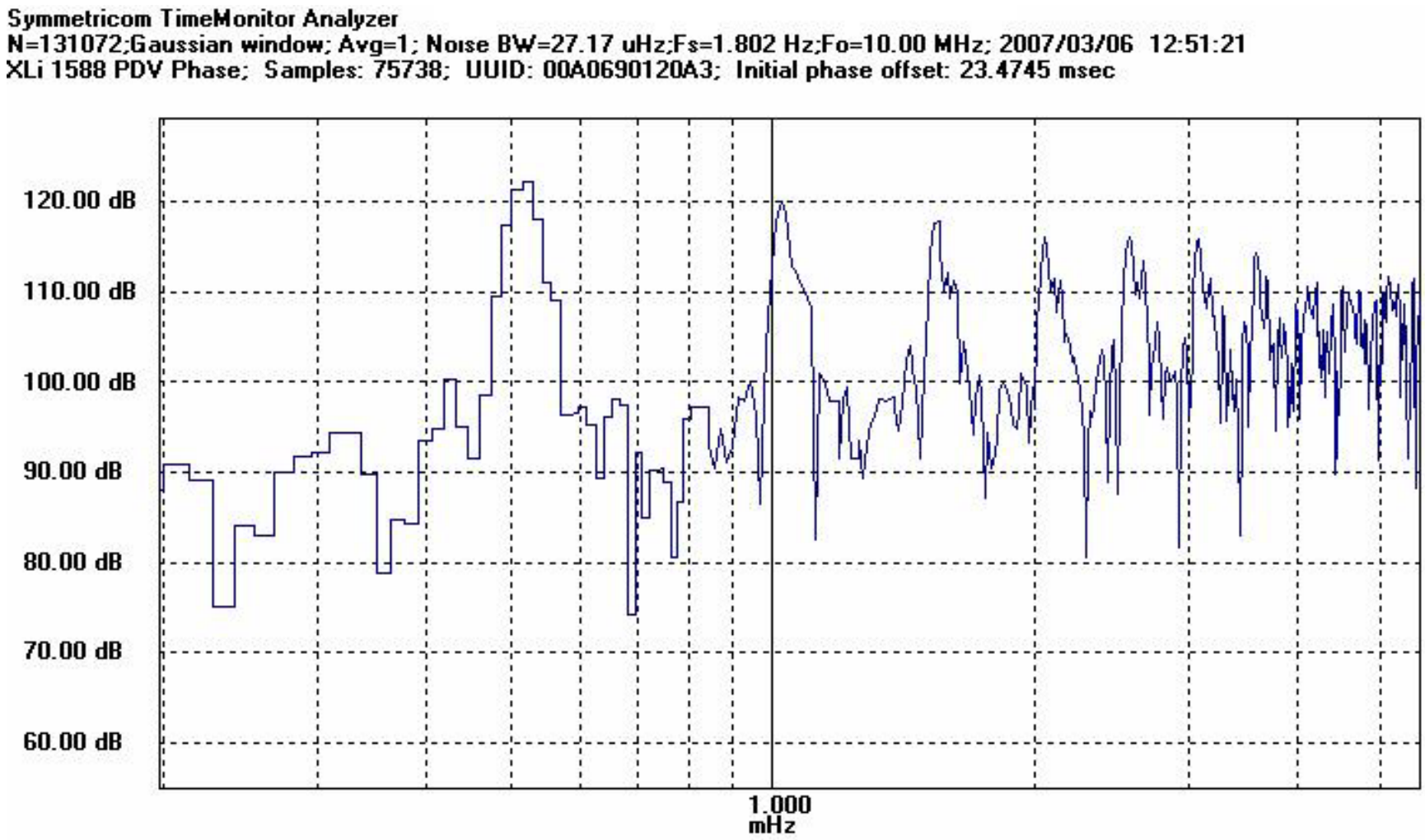
Packet delay changes over time periodically due to periodic change in network loading (30 minute cycles)



Production Network with DSL Access

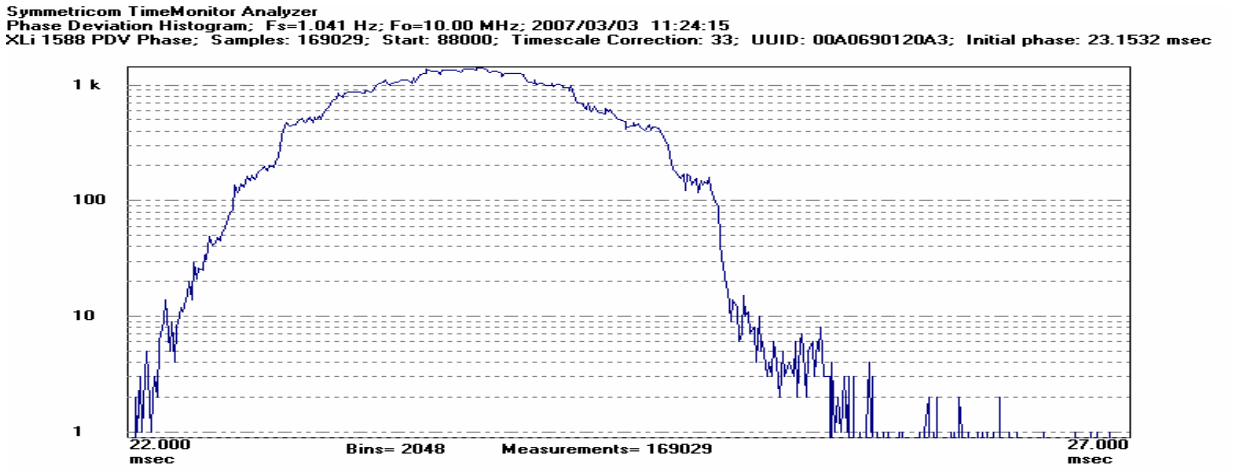
Symmetricom

Phase power spectral density (PPSD) analysis clearly shows periodicity

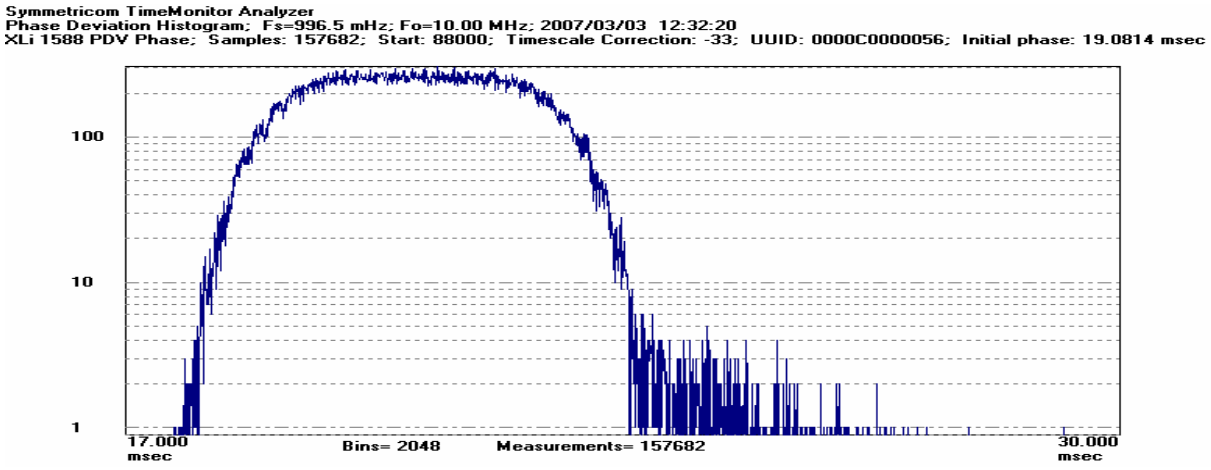


Production Network with DSL Access

Asymmetrical packet delay with DSL



Upstream Packet Delay
Minimum: 22.04297 msec
Peak to Peak: 4.866 msec

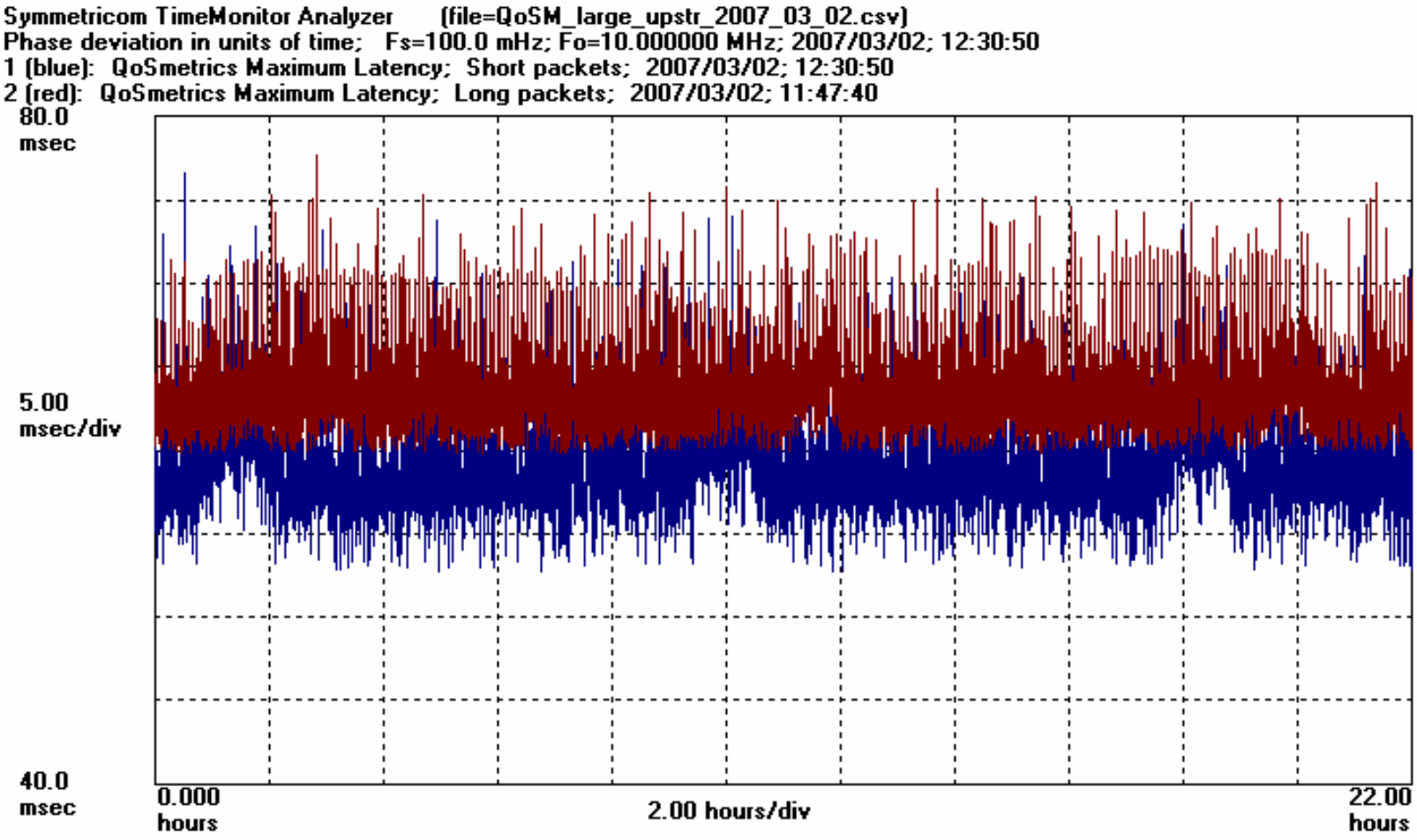


Downstream Packet Delay
Minimum: 17.64111 msec
Peak to Peak: 11.64 msec

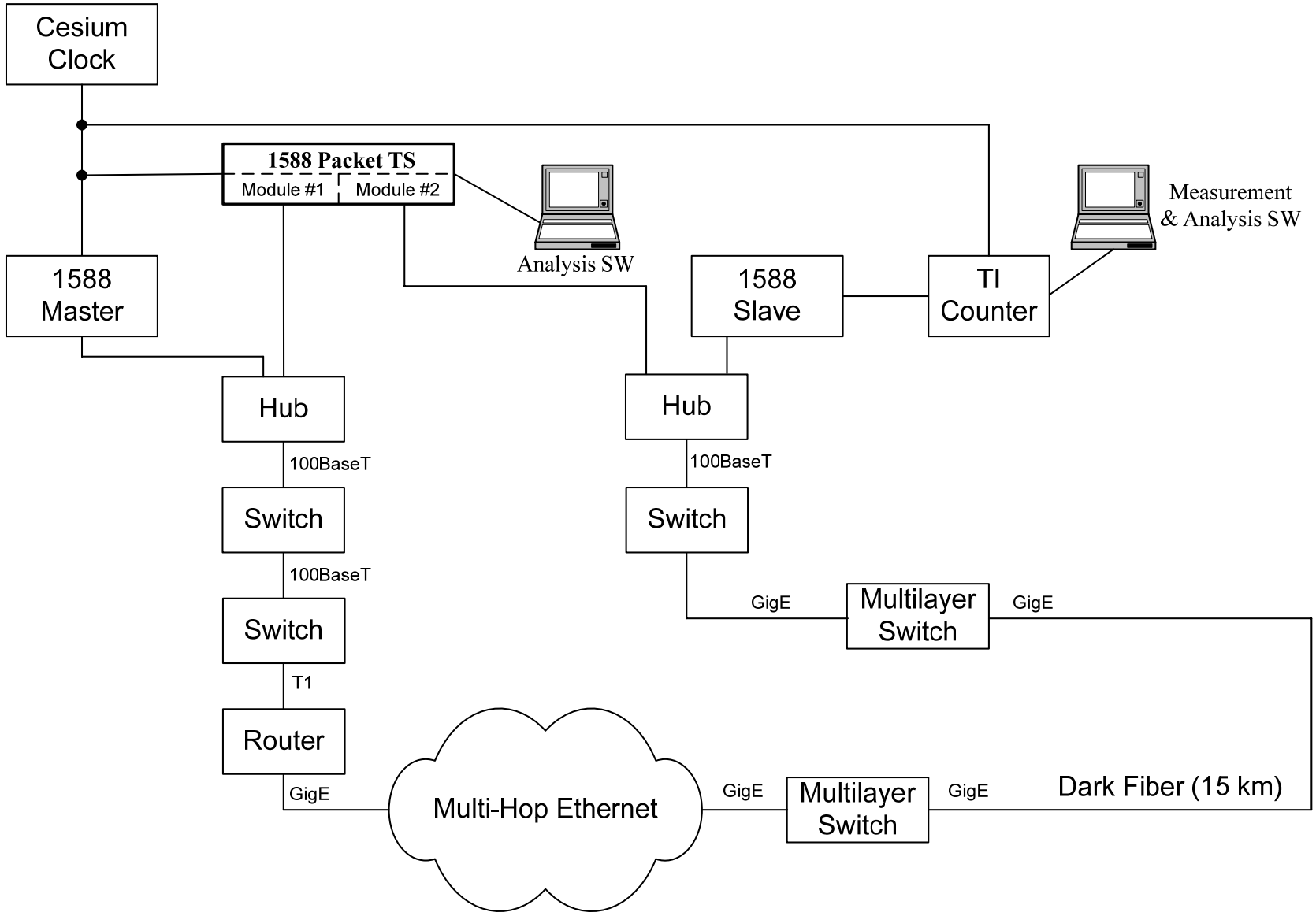
Production Network with DSL Access

Symmetricom

Short packets vs. long packets



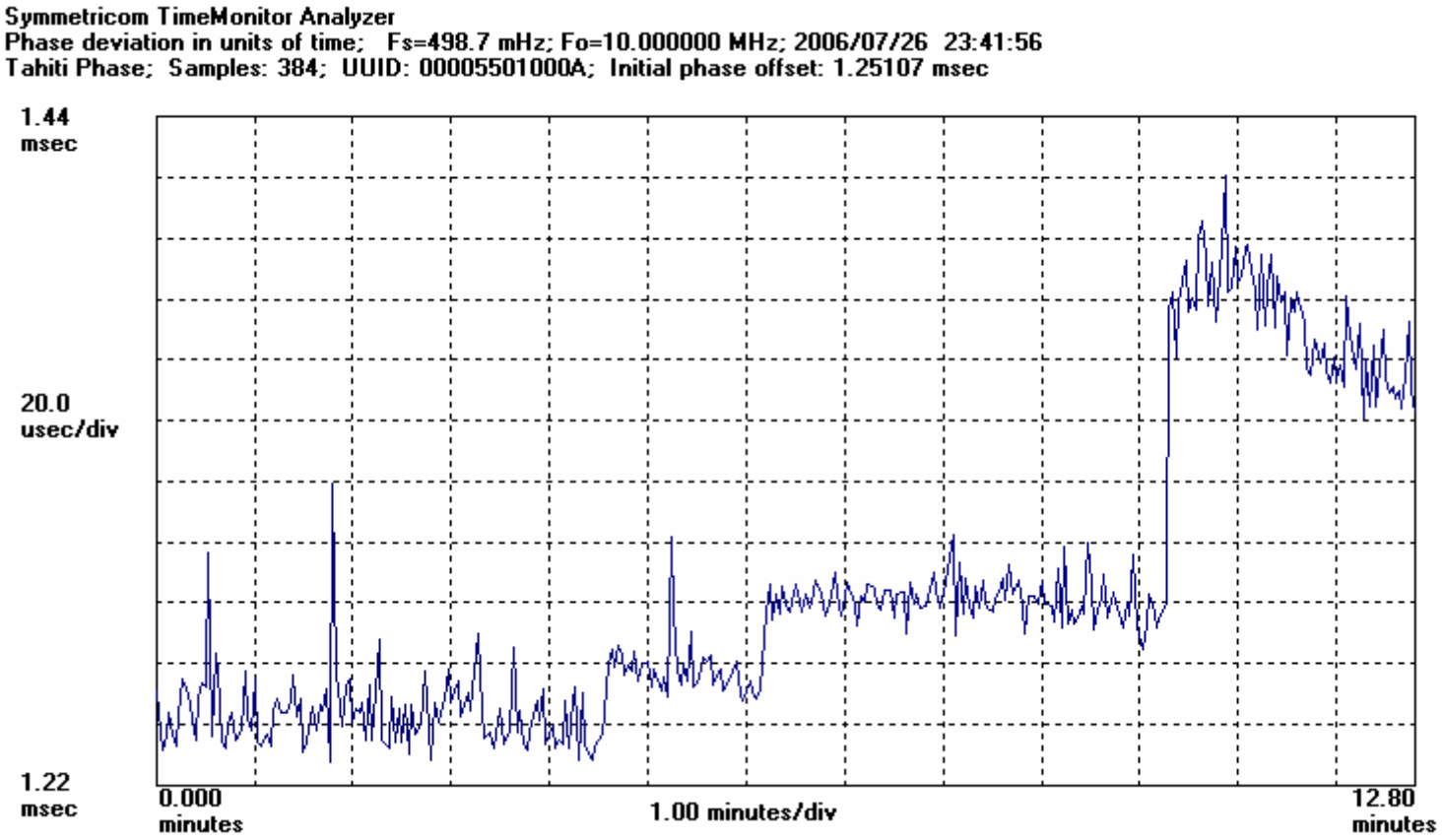
Metro Ethernet Production Network



Metro Ethernet Production Network

Symmetricom

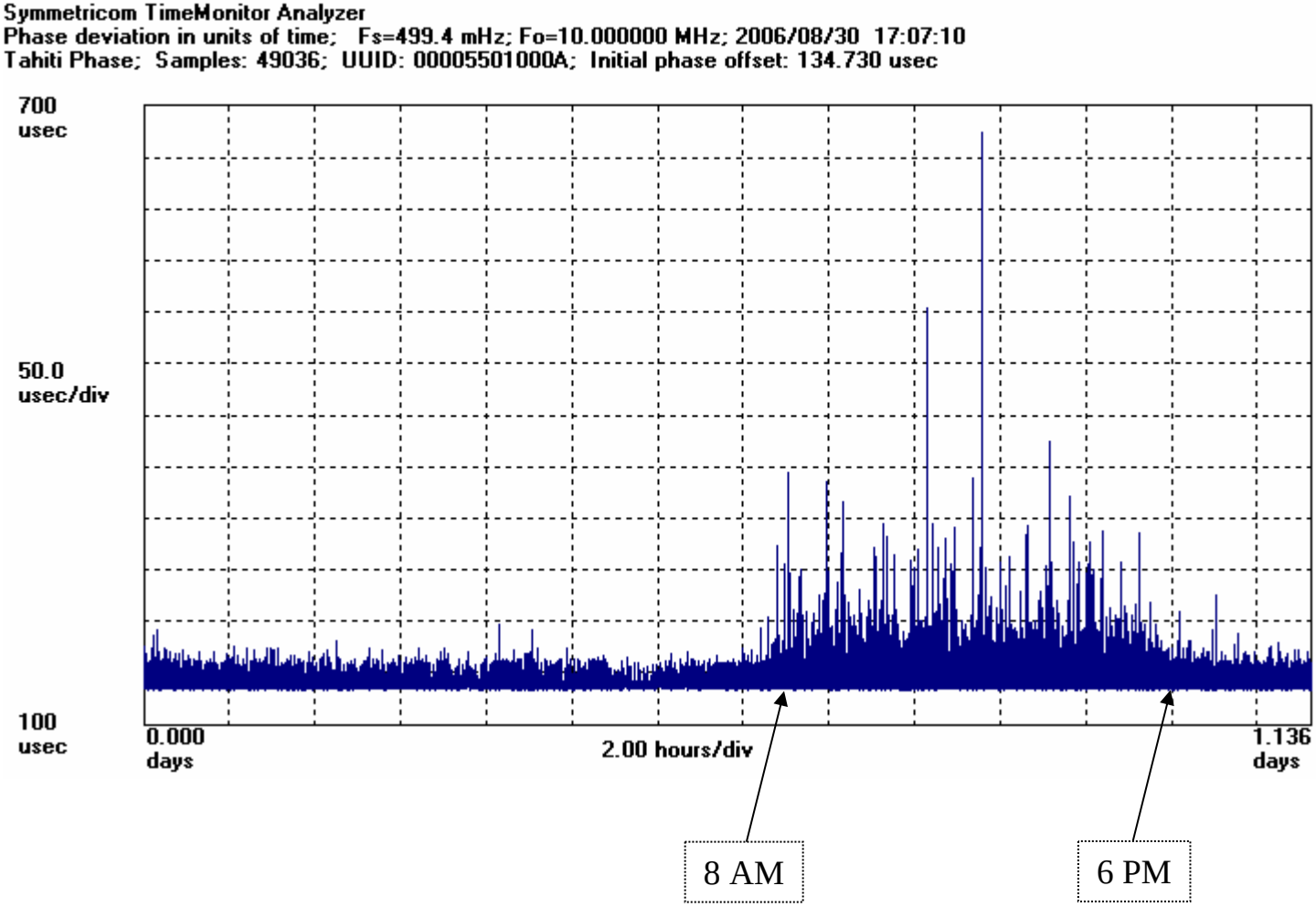
Packet delay changes over time during network reconfiguration



Metro Ethernet Production Network

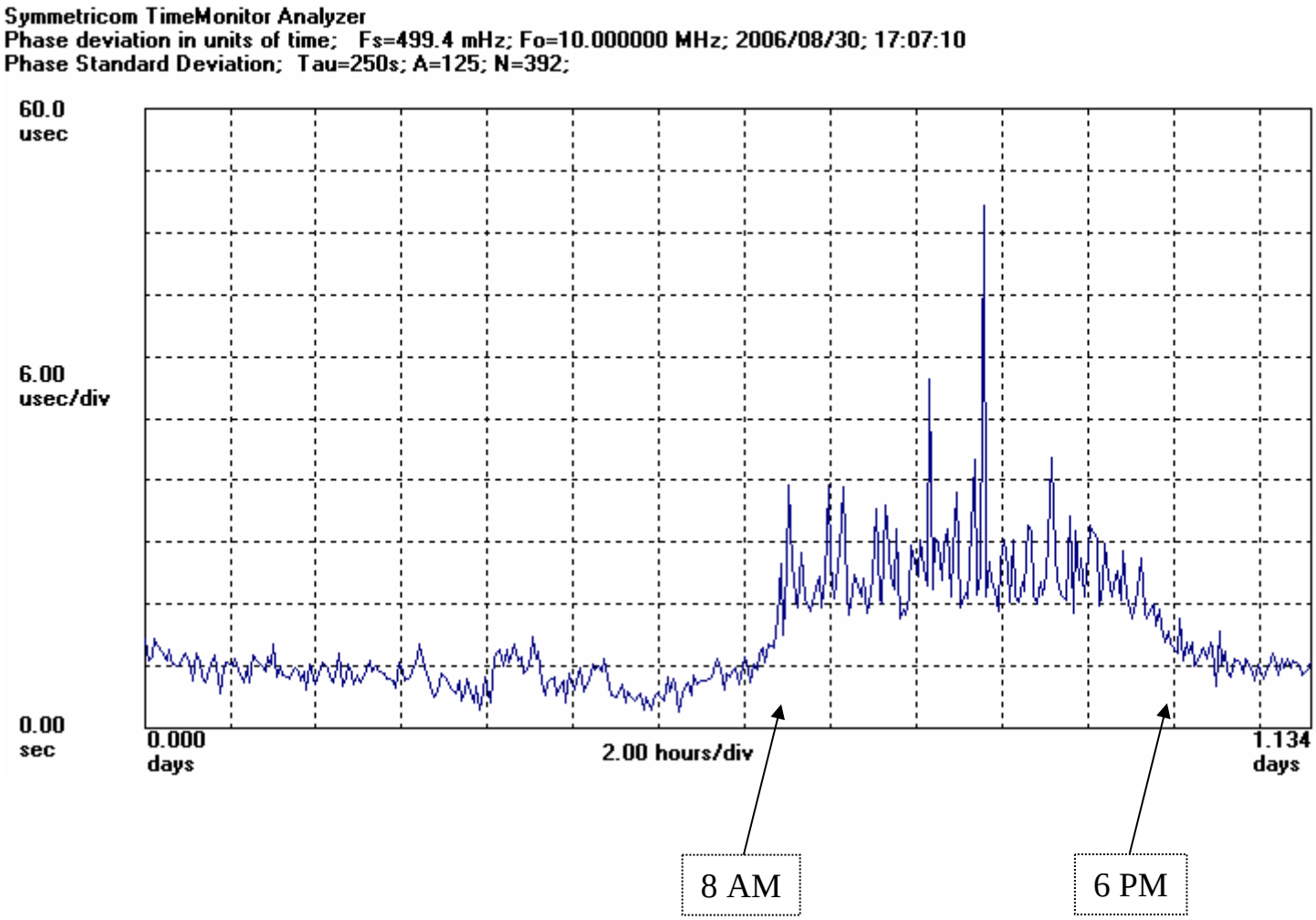
Symmetricom

In another measurement, minimum packet delay remains constant but packet delay variation (PDV) changes over time (diurnal)



Metro Ethernet Production Network

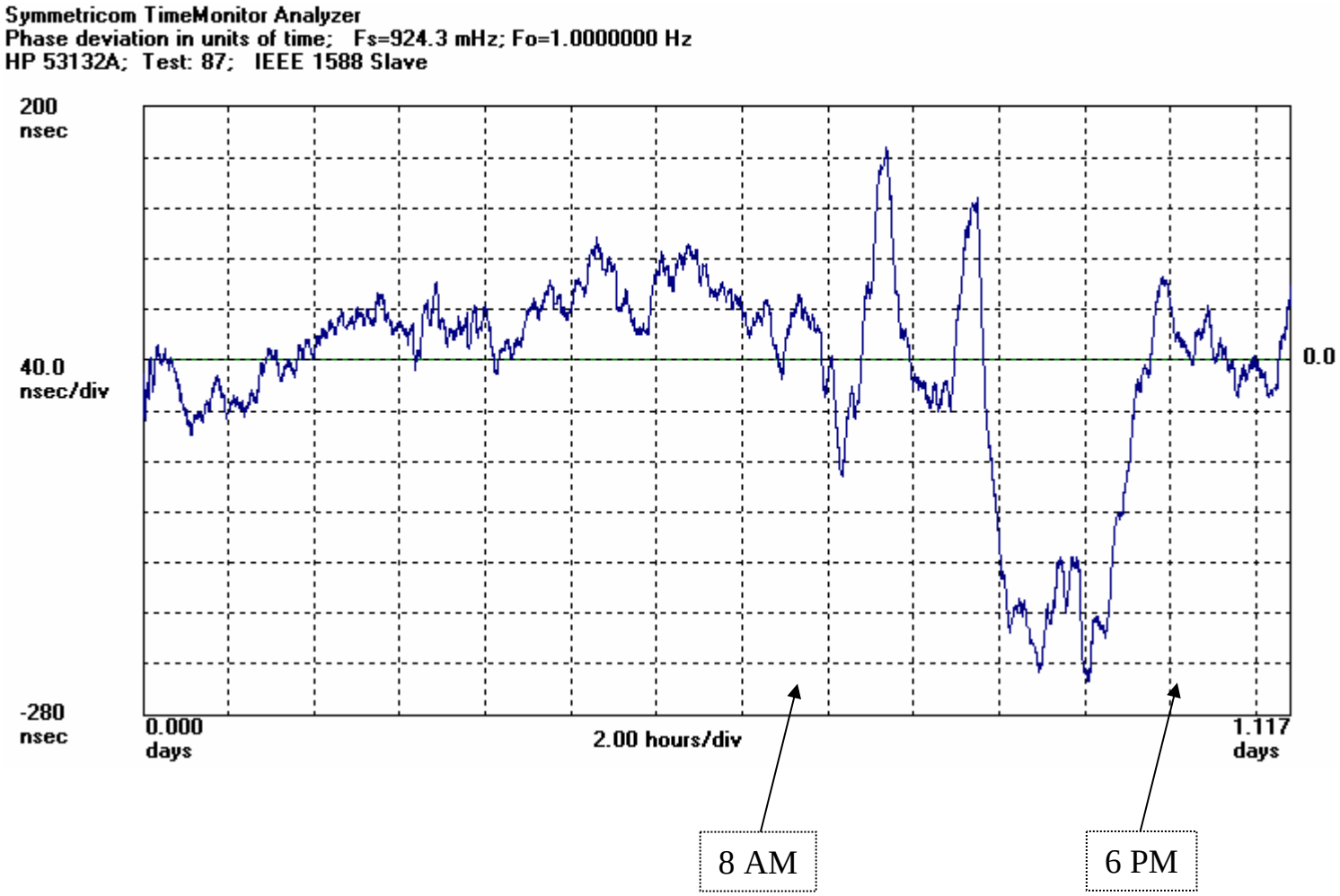
Tracking packet standard deviation over time shows gradual decrease through the night and then large increase during business hours



Metro Ethernet Production Network

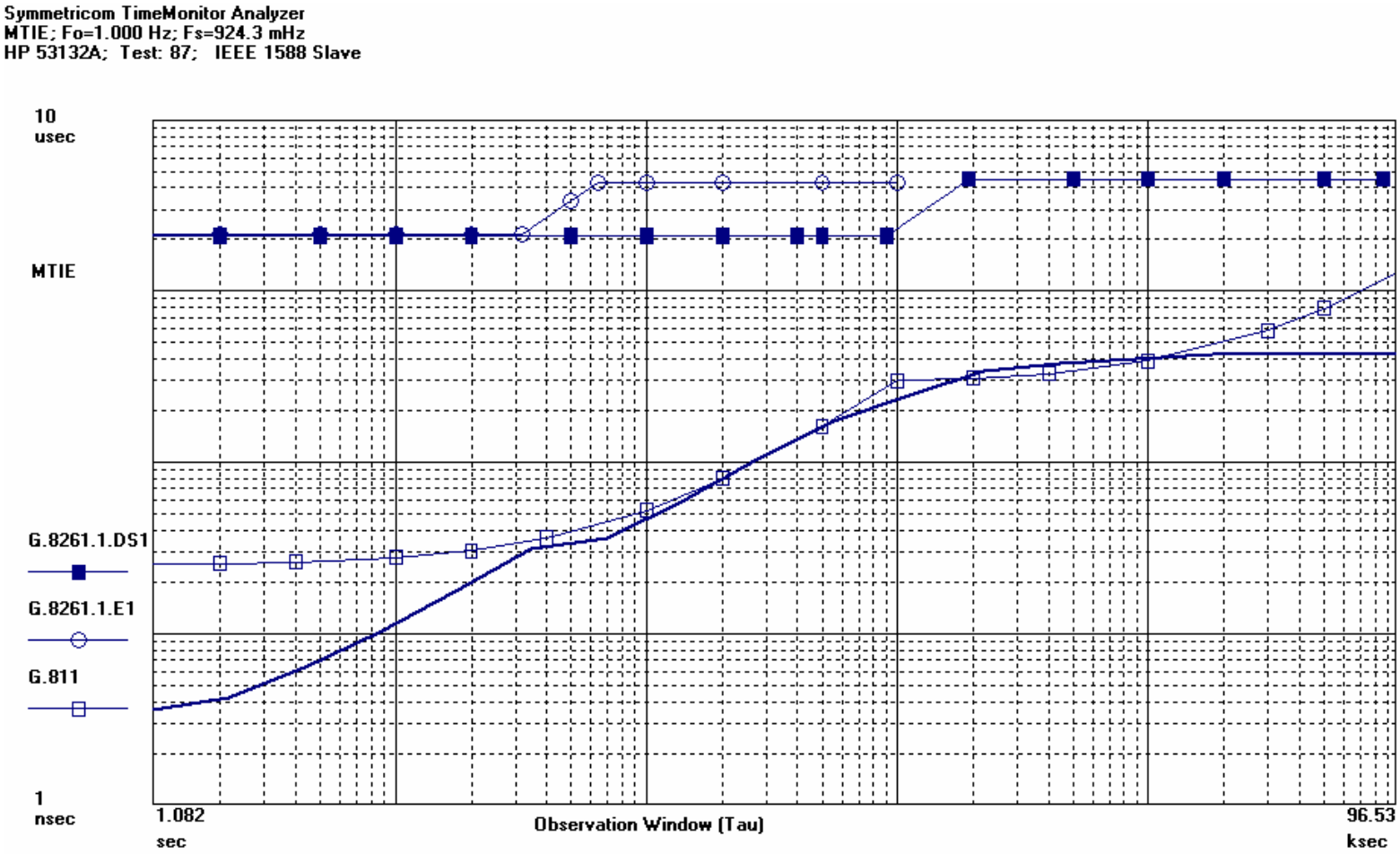
Symmetricom

IEEE 1588 slave performance can be correlated with PDV variations



Metro Ethernet Production Network

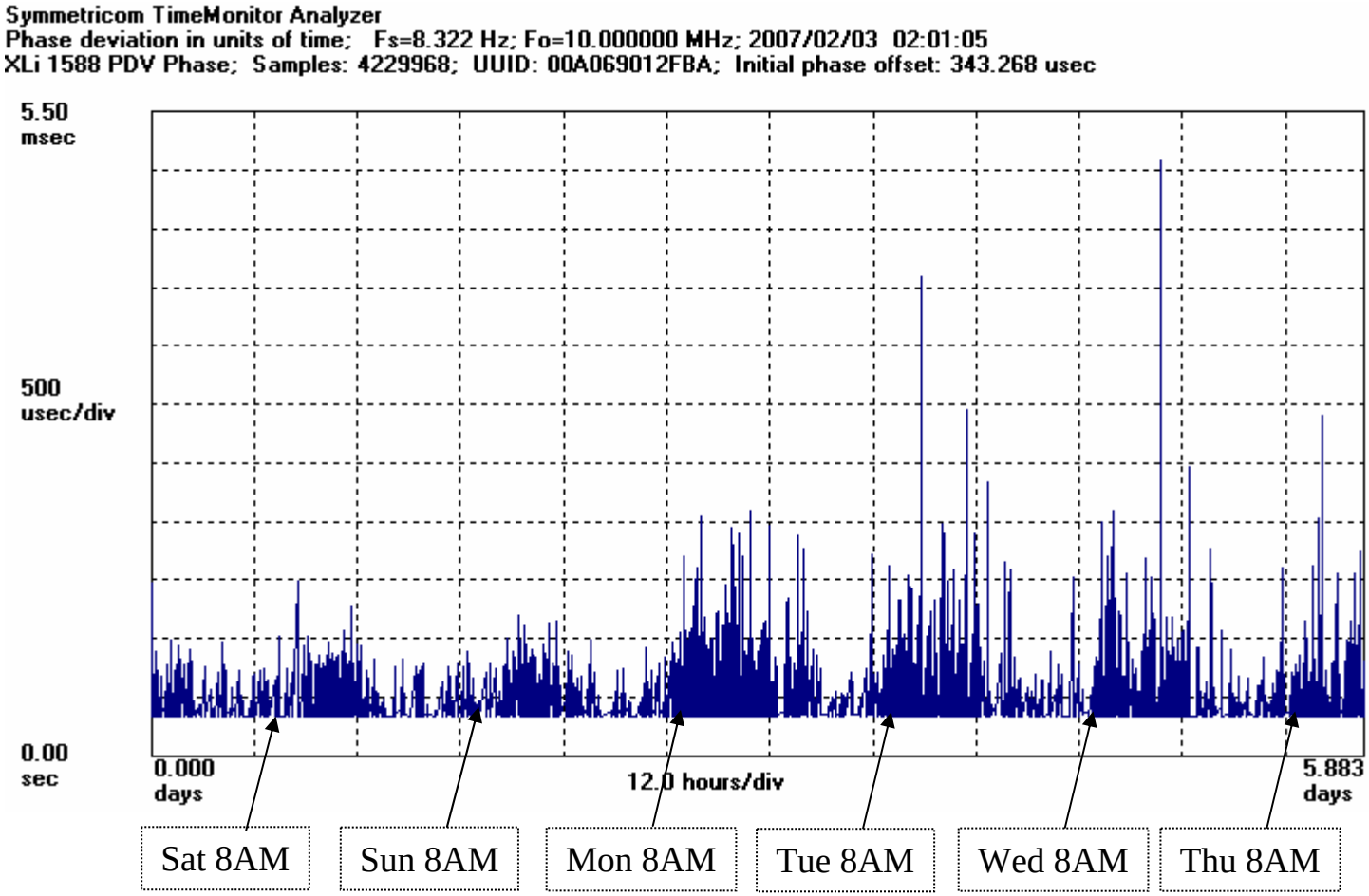
For the entire 24 hour period the IEEE 1588 slave meets G.8261 requirements and nearly meets G.811 requirements



Company LAN San Jose

Symmetricom

Packet delay: 335 usec to 5.08 msec

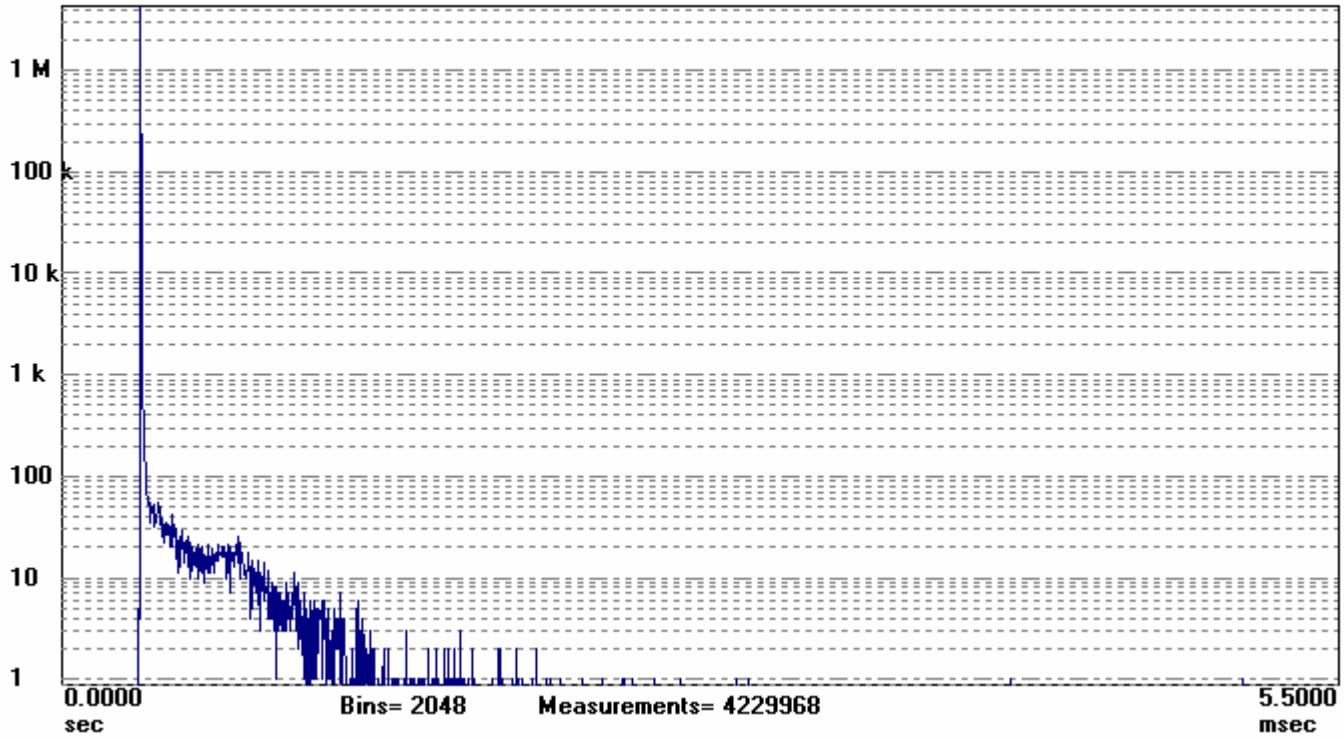


Company LAN San Jose

Symmetricom

Mean: 342.8 µsec
Peak to Peak: 4.75 msec
Standard Deviation: 14.03 µsec

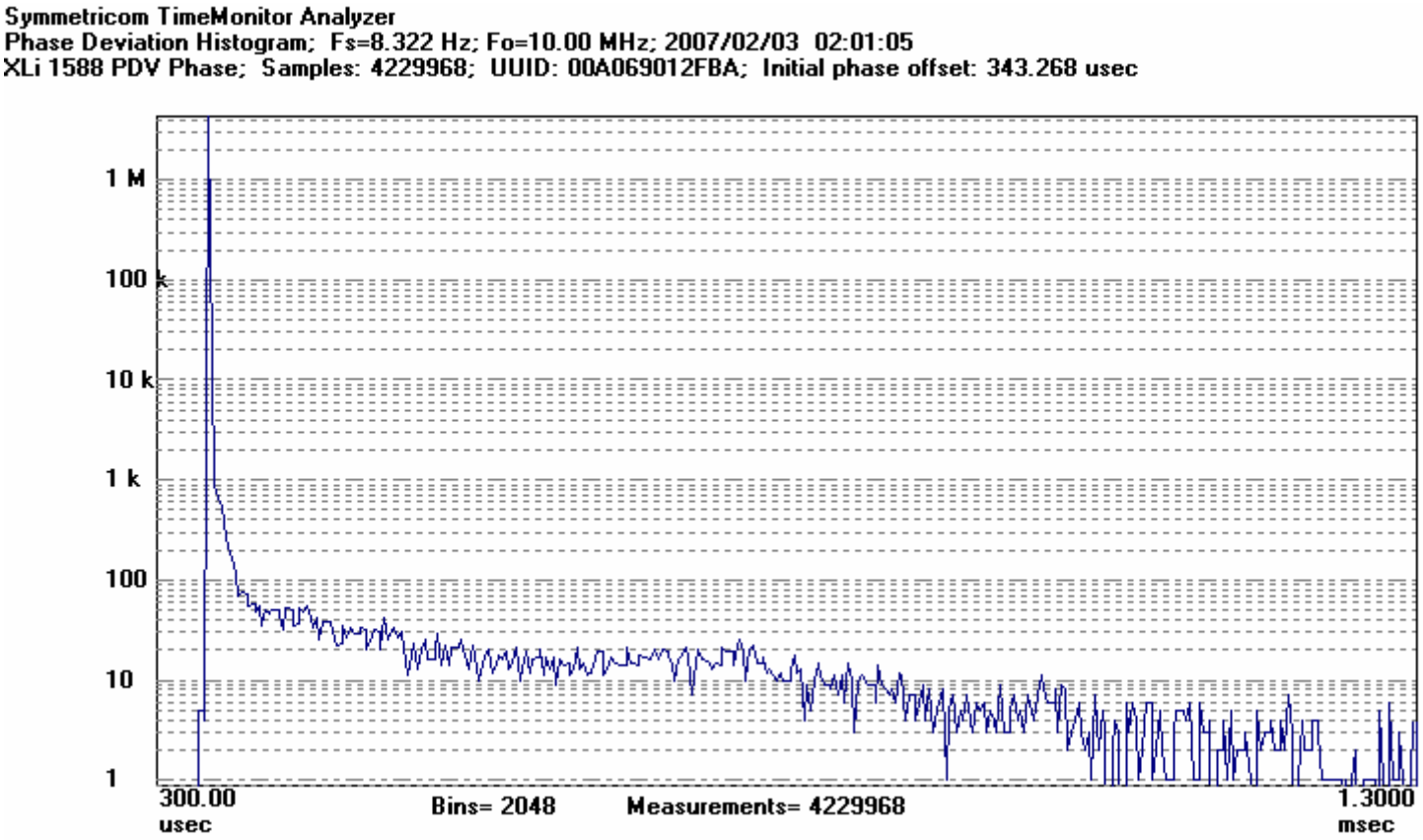
Symmetricom TimeMonitor Analyzer
Phase Deviation Histogram; Fs=8.322 Hz; Fo=10.00 MHz; 2007/02/03 02:01:05
XLi 1588 PDV Phase; Samples: 4229968; UUID: 00A069012FBA; Initial phase offset: 343.268 usec



Company LAN San Jose

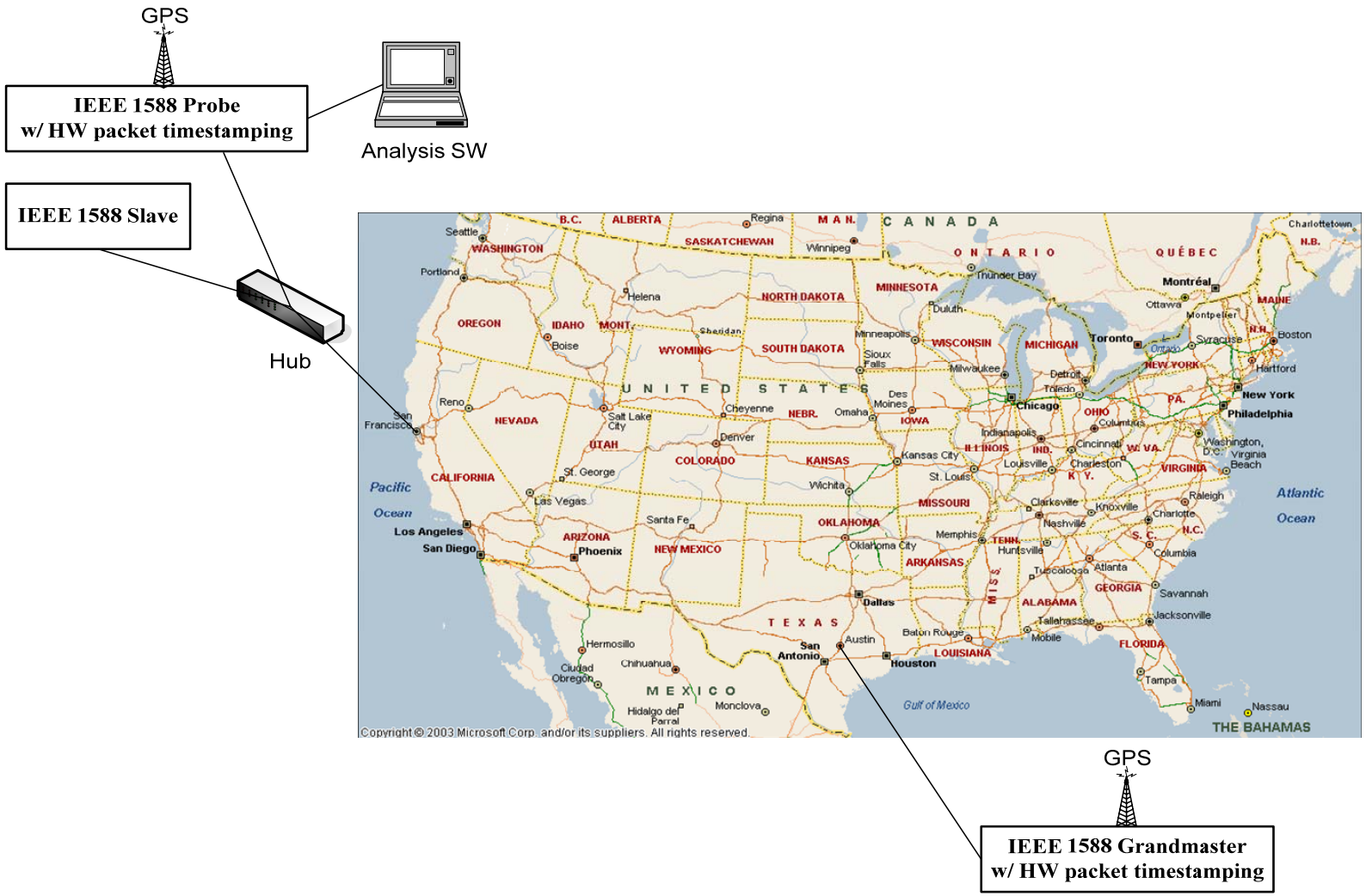
Zoom into 300-1300 µsec

Mean: 342.8 µsec
Peak to Peak: 4.75 msec
Standard Deviation: 14.03 µsec



Public Internet San Jose-Austin

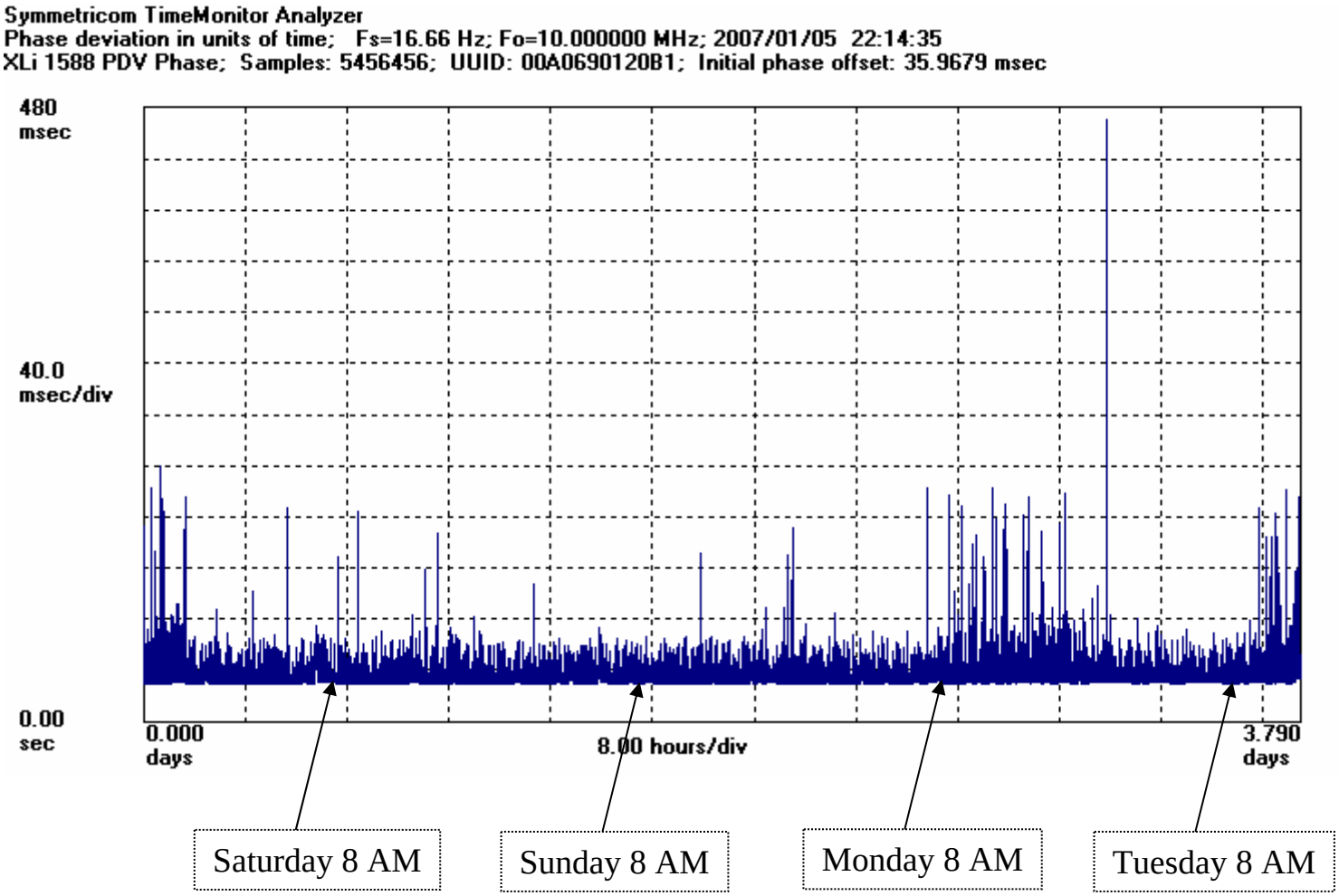
Symmetricom



Public Internet San Jose-Austin

Symmetricom

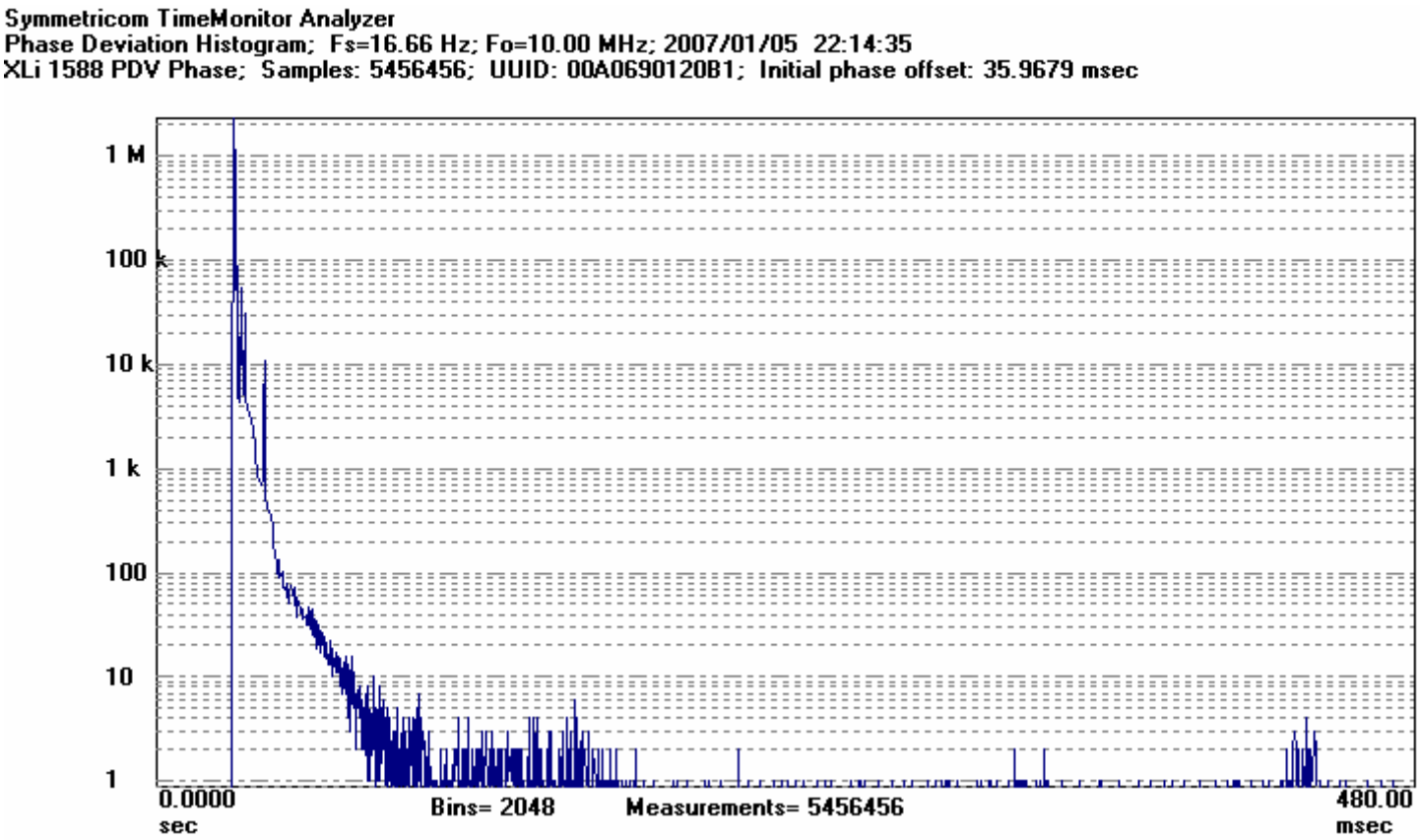
Packet delay: 29 to 471 msec



Public Internet San Jose-Austin

Symmetricom

Mean: 30.28 msec
Peak to Peak: 442.7 msec
Standard Deviation: 2.54 msec

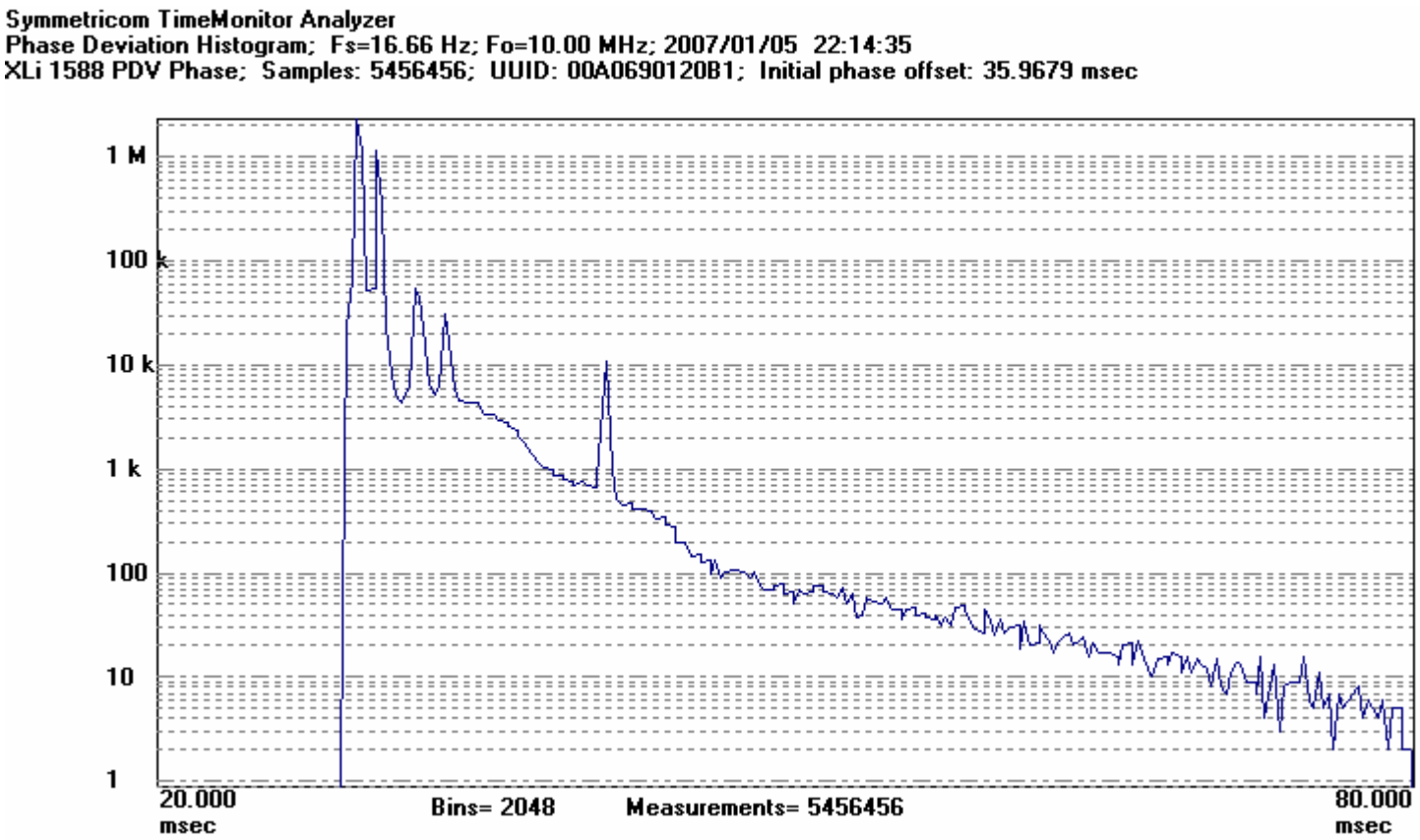


Public Internet San Jose-Austin

Symmetricom

Zoom into 20-80 msec

Mean: 30.28 msec
Peak to Peak: 442.7 msec
Standard Deviation: 2.54 msec



Conclusions

Symmetricom

- Timing measurements in packet networks
  - Precision hardware timestamping together with UTC traceable TOD provides a precision tool for studying even the fastest networks and network equipment
  - Unicast capability is critical for the study of production networks and certain network devices such as DSLAM's (upstream multicast messages not provisionable for security reasons - depends on vendor)
  - Use of fast sync rates provides a means of characterizing rapid temporal packet network and device behavior (transients and systematics), facilitates selection algorithms both for analysis and servo design, and allows for quick collection of statistics