

Timing Measurements in Packet Networks

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- ▶ Measurement Setup
 - Measurement equipment configurations
 - Network configurations
- ▶ Performance Metrics
 - Phase (sequential)
 - Maximum Time Interval Error, MTIE
 - Time Deviation, TDEV
 - Phase statistics
- ▶ Measurements
 - Lab
 - Network

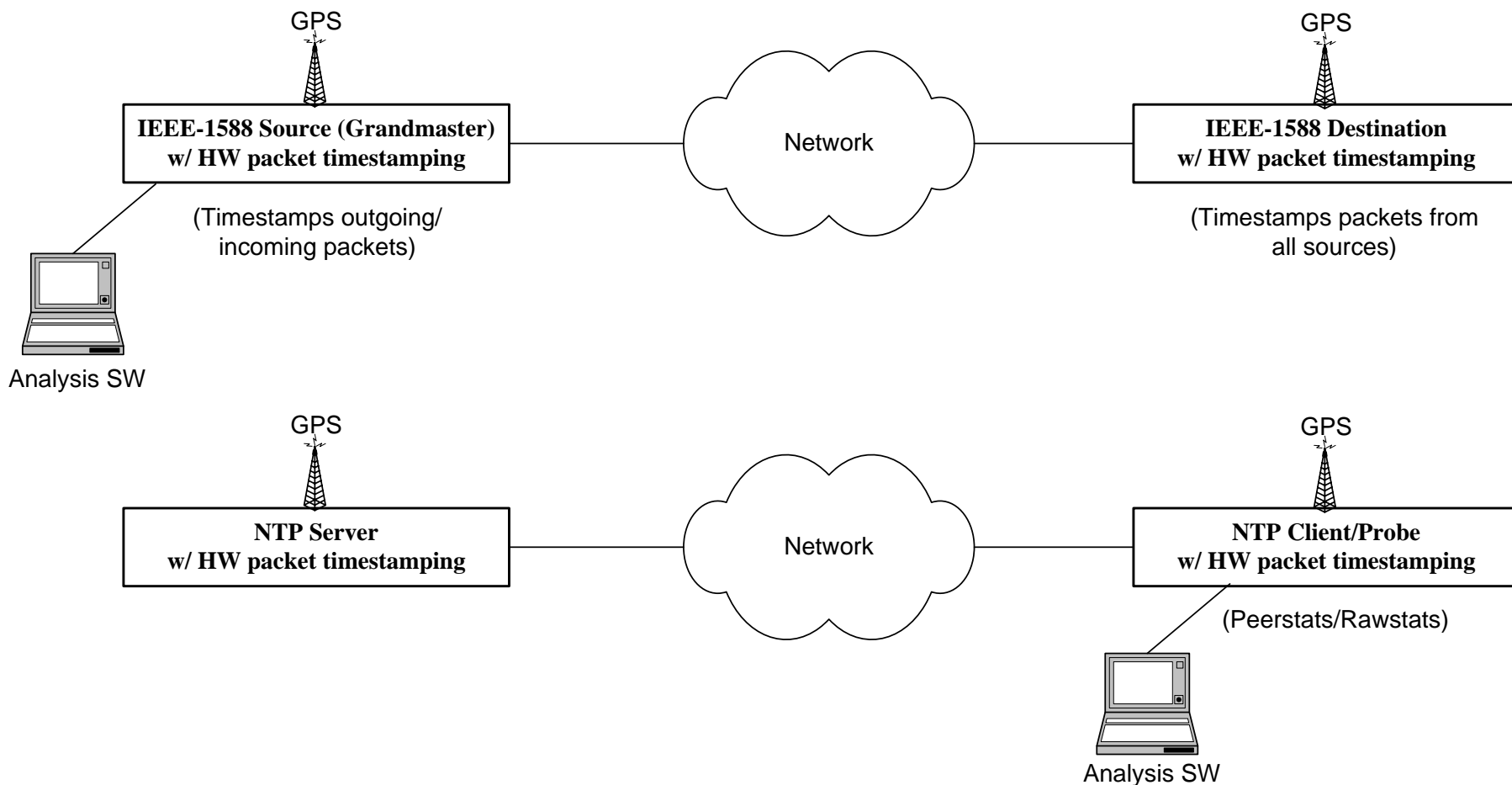
- ▶ Measurement equipment with precision IEEE-1588 or NTP hardware time-stamping
- ▶ GPS time-of-day reference in each unit
 - Required for sub-microsecond end-to-end analysis
 - Log-files of the time-stamp data is post-processed
- ▶ Network configurations
 - Basic: crossover cable, hub, switch
 - Baseline: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

Packet Measurement Example Configurations



Example Measurement Equipment Configurations

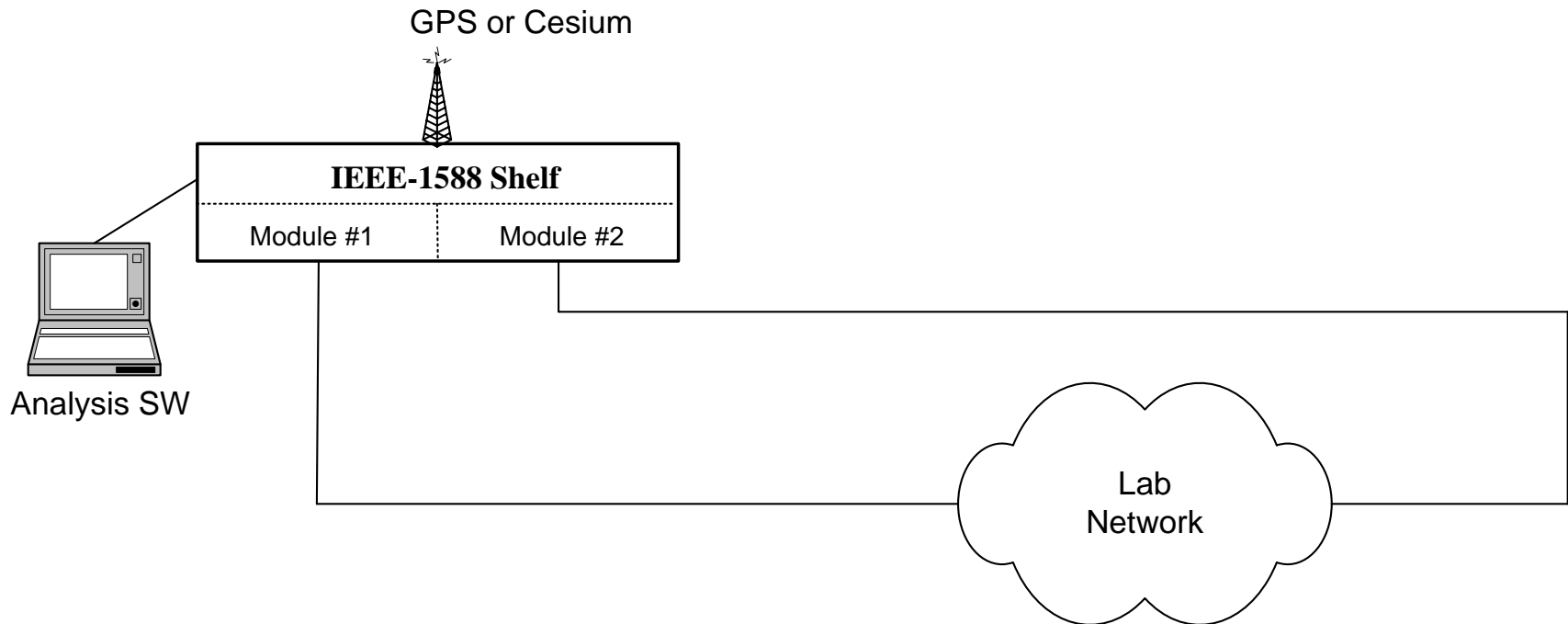
Need (1) PRC TOD reference (2) Precision Packet TimeStamping (3) Analysis SW



Packet Measurement Example Configurations



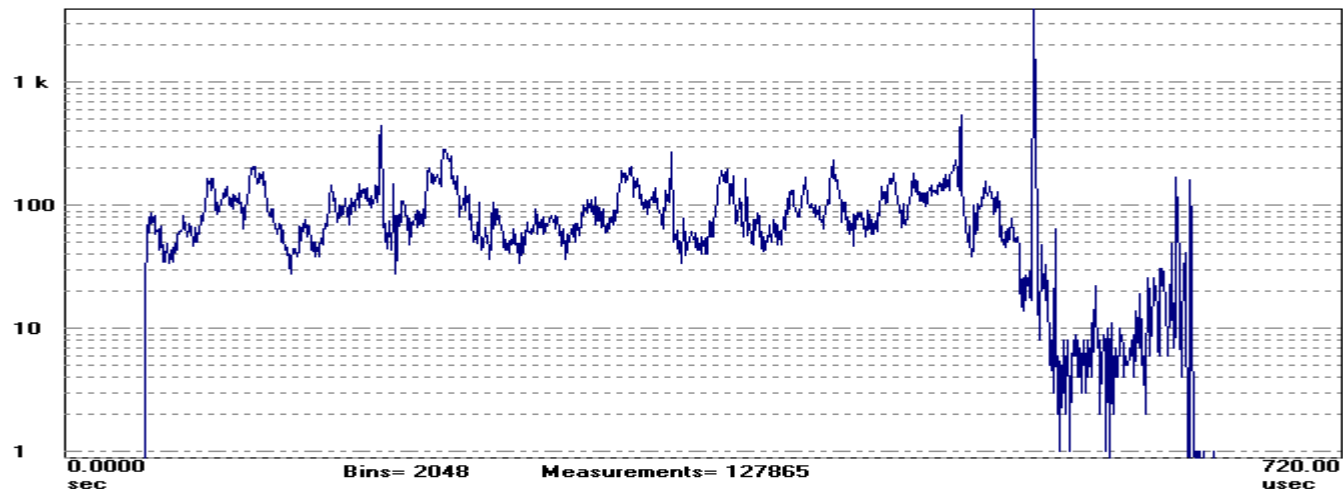
Alternate Measurement Equipment Configuration for Lab



IEEE 1588 vs. NTP Packet Measurement Tools: Example 1

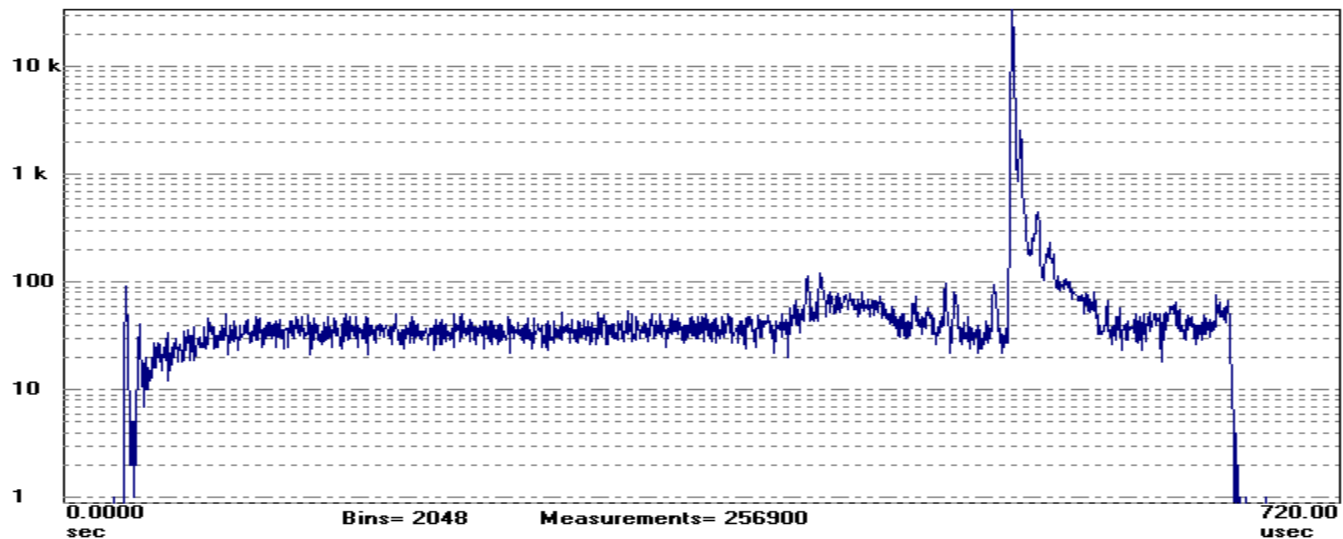


Symmetricom TimeMonitor Analyzer
Phase Deviation Histogram: Fs=500.0 mHz; Fo=10.00 MHz; 2006/06/02 23:17:57
Tahiti Phase; Samples: 127865; UUID: 000055010016; Initial phase offset: 168.872 usec



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

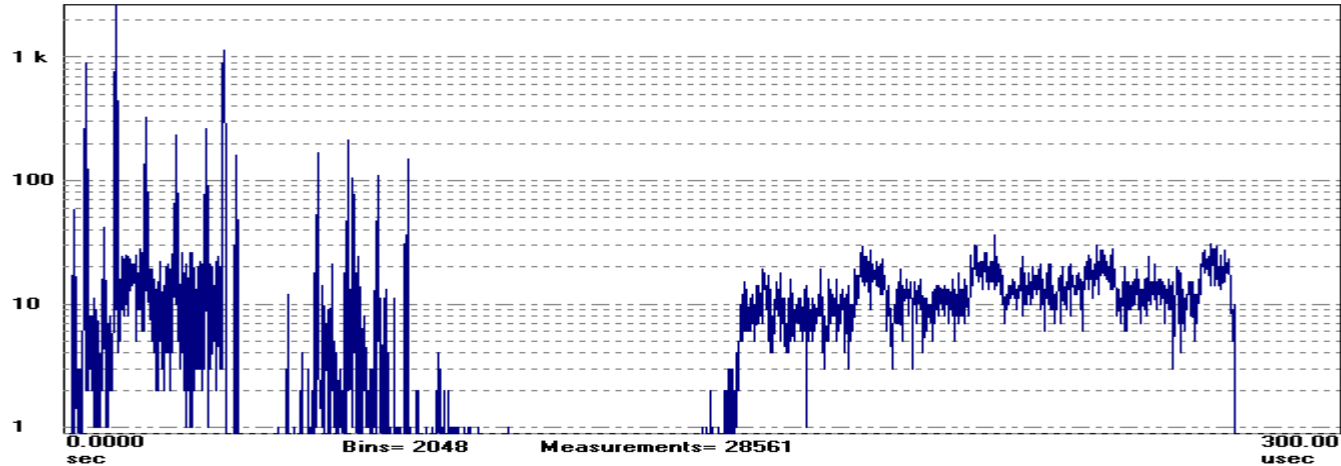


NTP

IEEE 1588 vs. NTP Packet Measurement Tools: Example 2

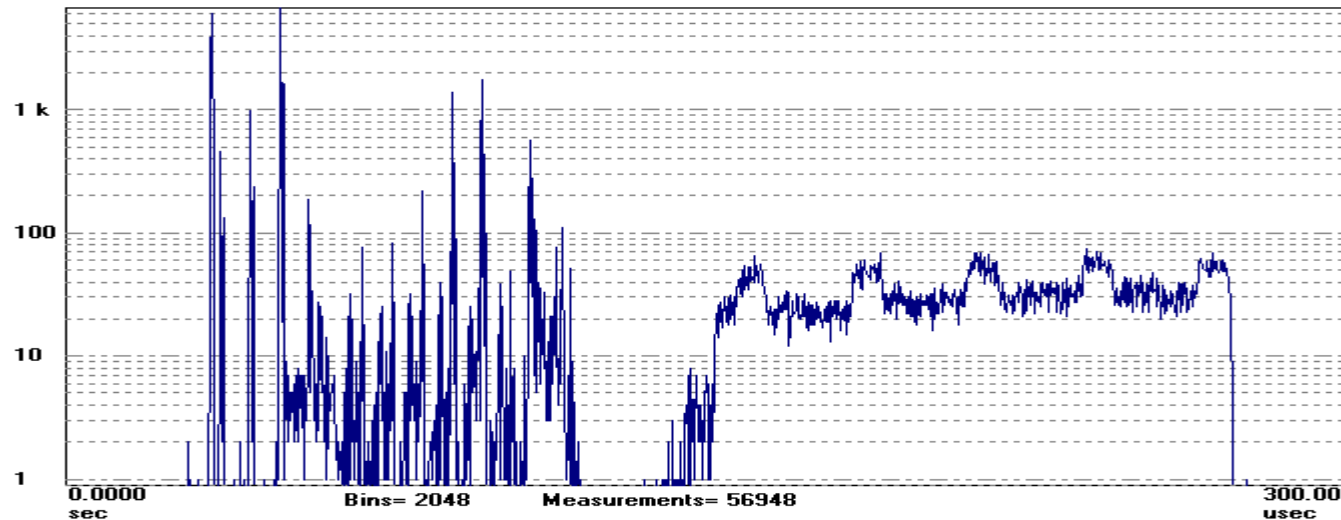


Symmetricom TimeMonitor Analyzer
Phase Deviation Histogram; Fs=500.0 mHz; Fo=10.00 MHz; 2006/06/09 01:11:06
Tahiti Phase; Samples: 28561; UUID: 000055010016; Initial phase offset: 12.5420 usec



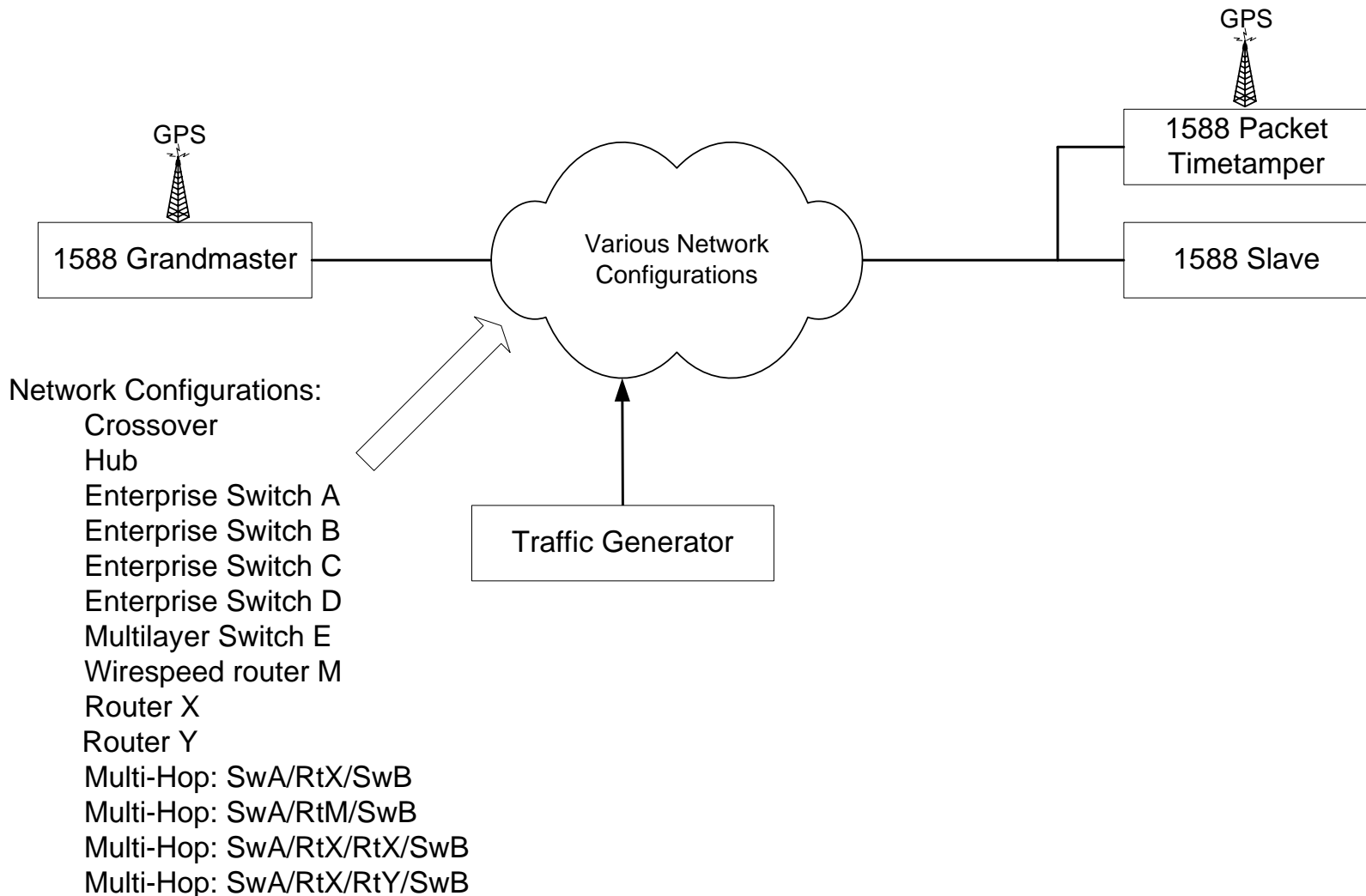
IEEE
1588

Symmetricom TimeMonitor Analyzer
Phase Deviation Histogram; Fs=997.9 mHz; Fo=10.00 MHz; 2006/06/09 01:12:20
Rawstats Transmit Delay; Samples: 56948; Glitch threshold: 1.00000 ms; Remote IP: 192.168.5.250; Local IP: 192.168.5.3



NTP

Example Lab Network Configurations

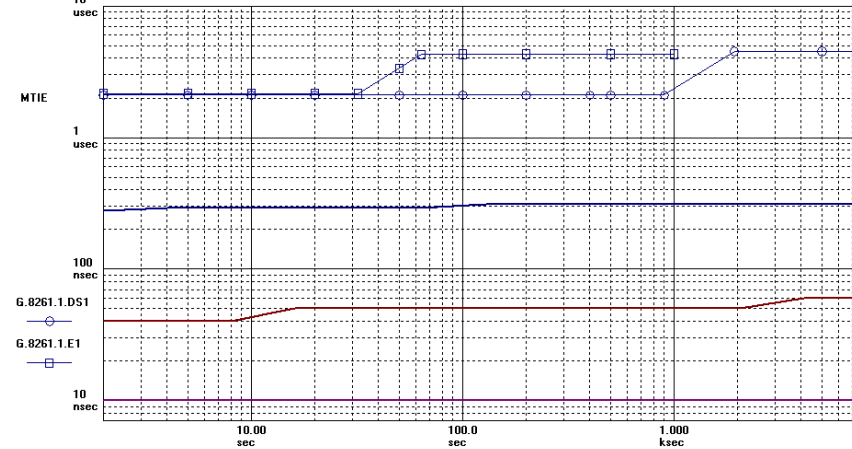


Performance Metrics



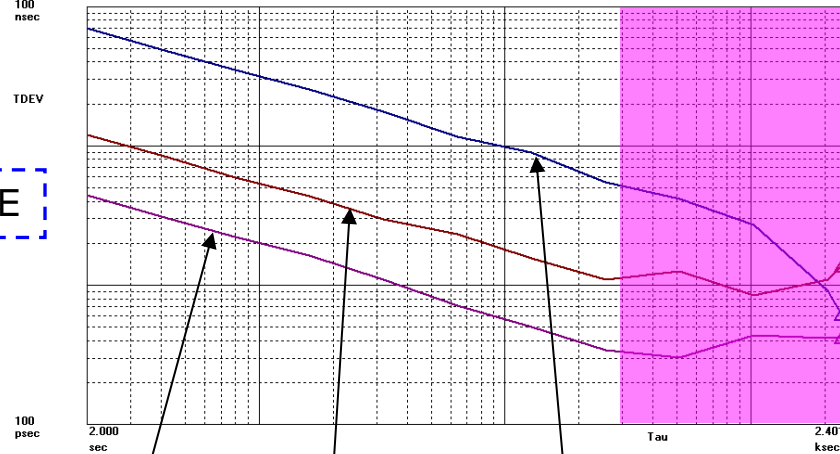
- Phase, TIE (Time Interval Error)
 - Basis for all PM data sets
- Maximum Time Interval Error
 - MTIE, PM definition defined in G.8261 (G.pactiming)
- Time Deviation, TDEV

Symmetricom TimeMonitor Analyzer (file=switch2h.tsh)
 MTIE: Fo=10.00 MHz; Fs=500.0 mHz; 2006/01/31; 19:10:06
 1: Tahiti Phase; Samples: 3601; UUID: 00A0690BC1A4; Initial phase offset: 16.7500 usec; 2006/01/31; 19:10:06
 2: Tahiti Phase; Samples: 3601; UUID: 00A0690BC1A4; Initial phase offset: 660.000 nsec; 2005/12/24; 15:34:08
 3: Tahiti Phase; Samples: 3601; UUID: 00A0690BC1A4; Initial phase offset: 290.000 nsec; 2006/01/31; 16:10:21



MTIE

Symmetricom TimeMonitor Analyzer (file=crossover2h.tsh)
 TDEV: No. Avg=1; Fo=10.00 MHz; Fs=500.0 mHz; 01/31/06; 19:10:06
 1: Tahiti Phase; Samples: 3601; UUID: 00A0690BC1A4; Initial phase offset: 16.7500 usec; 01/31/06; 19:10:06
 2: Tahiti Phase; Samples: 3601; UUID: 00A0690BC1A4; Initial phase offset: 660.000 nsec; 12/24/05; 15:34:08
 3: Tahiti Phase; Samples: 3601; UUID: 00A0690BC1A4; Initial phase offset: 290.000 nsec; 01/31/06; 16:10:21



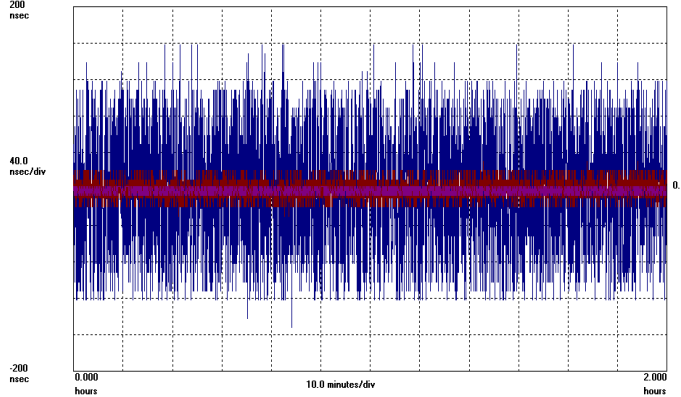
TDEV

Crossover

Hub

Switch

Symmetricom TimeMonitor Analyzer (file=crossover2h.tsh)
 Phase deviation in units of time: Fs=500.0 mHz; Fo=10.000000 MHz; 01/31/06; 19:10:06
 1: Tahiti Phase; Samples: 3601; UUID: 00A0690BC1A4; Initial phase offset: 16.7500 usec; 01/31/06; 19:10:06
 2: Tahiti Phase; Samples: 3601; UUID: 00A0690BC1A4; Initial phase offset: 660.000 nsec; 12/24/05; 15:34:08
 3: Tahiti Phase; Samples: 3601; UUID: 00A0690BC1A4; Initial phase offset: 290.000 nsec; 01/31/06; 16:10:21



PHASE

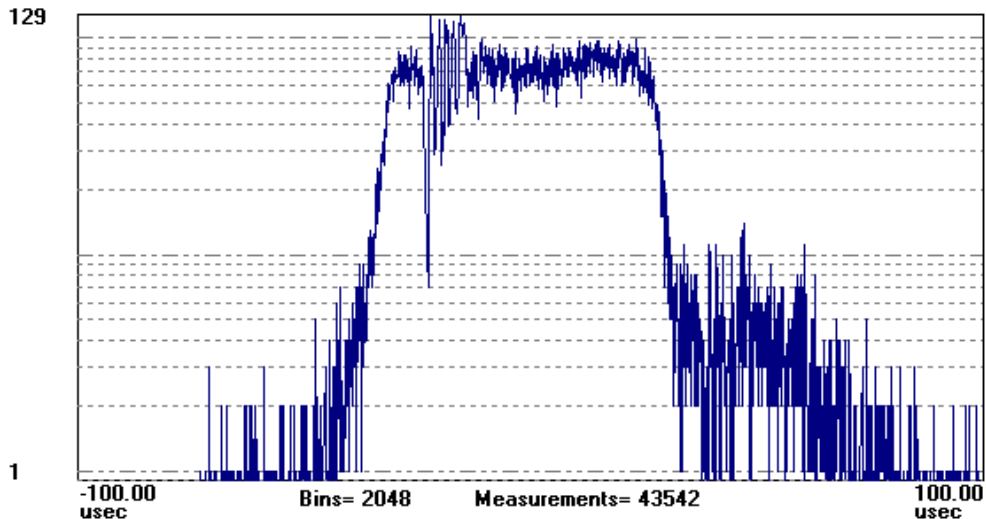
Performance Metrics



Statistics

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

Symmetricom TimeMonitor Analyzer
PDV Software Router; Mean: 277.6874 usec; Standard Deviation: 20.64 usec



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 μ sec

Peak to Peak: 310.0 nsec

Standard Deviation: 70.10 nsec

Router:

Mean: 277.6874 μ sec

Peak to Peak: 212.5 μ sec

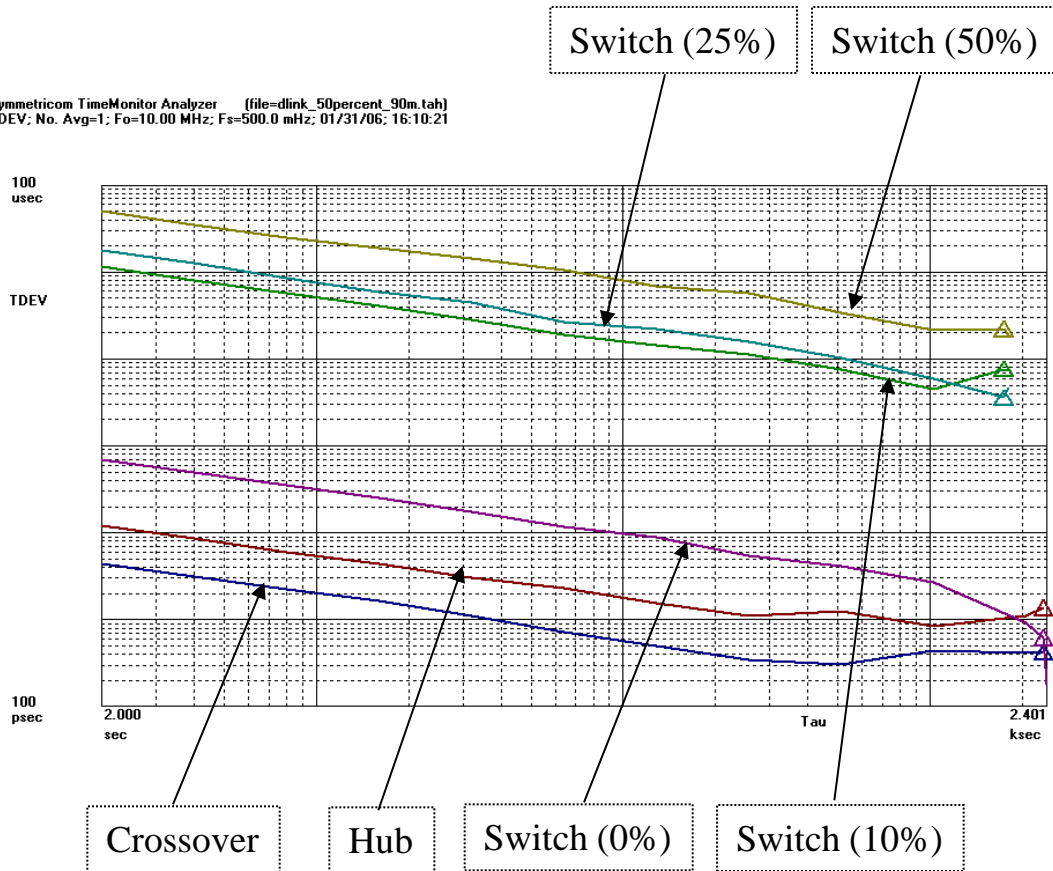
Standard Deviation: 20.64 μ sec

Performance As a Function of Load



Statistics

Symmetricom TimeMonitor Analyzer (file=dlink_50percent_90m.tah)
TDEV; No. Avg=1; Fo=10.00 MHz; Fs=500.0 mHz; 01/31/06; 16:10:21



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*

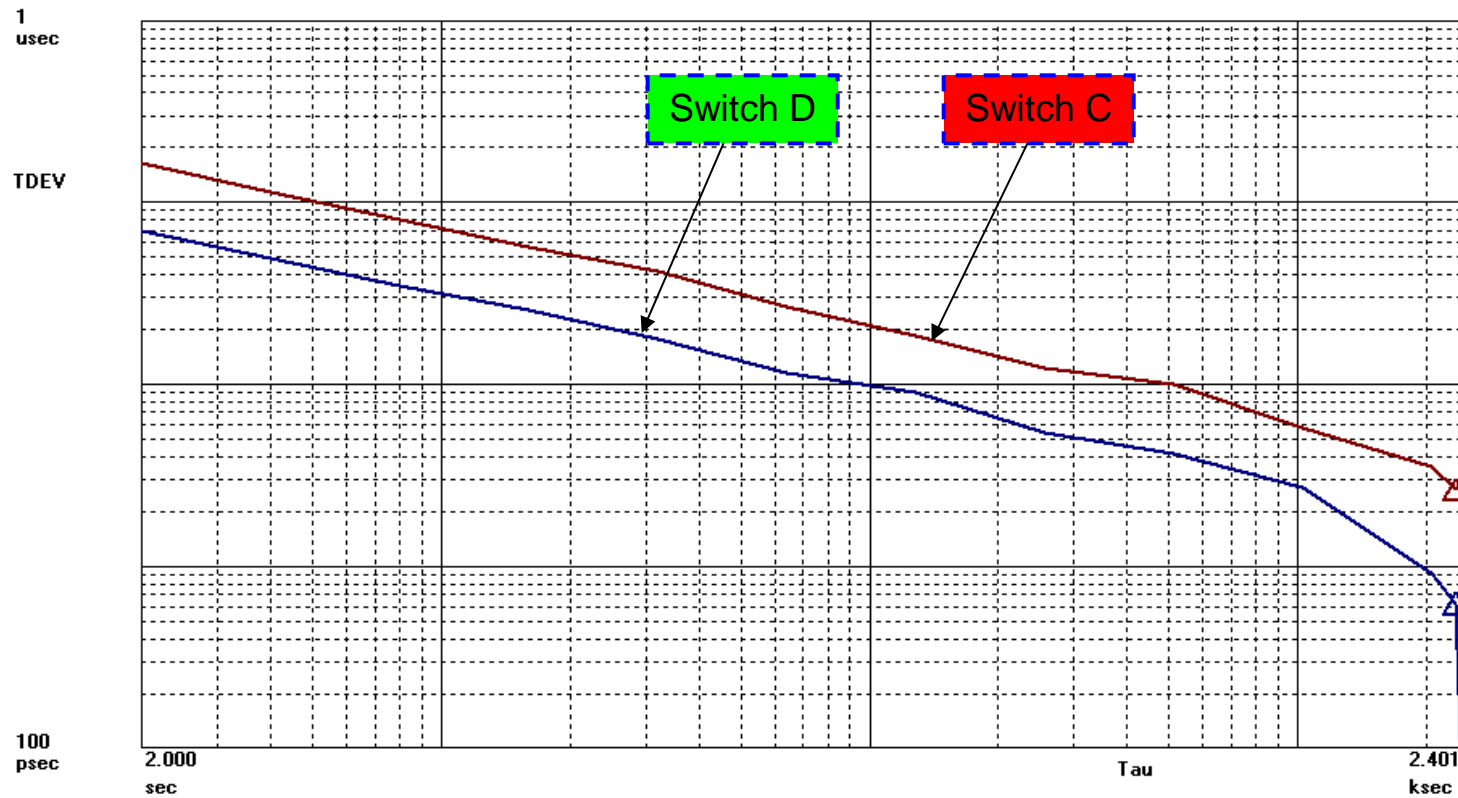


Symmetricom TimeMonitor Analyzer (file=switch2h.tah)

TDEV: No. Avg=1; Fo=10.00 MHz; Fs=500.0 mHz; 01/31/06; 19:10:06

1: Tahiti Phase; Samples: 3600; Stop: 3600; UUID: 00A0690BC1A4; Initial phase offset: 16.7500 usec; 01/31/06; 19:10:06

2: Tahiti Phase; Samples: 3600; Stop: 3600; UUID: 00A0690BC1A4; Initial phase offset: 21.1400 usec; 02/07/06; 00:21:21

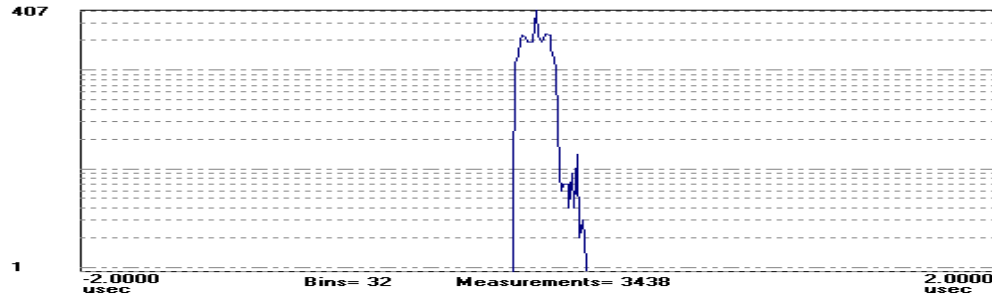


Not All Devices are *Equal*



Switch vs. Multilayer switch vs. Router

Symmetricom TimeMonitor Analyzer
PDV Switch; Mean: 24.41855 usec; Standard Deviation: 52.85 nsec



Statistics

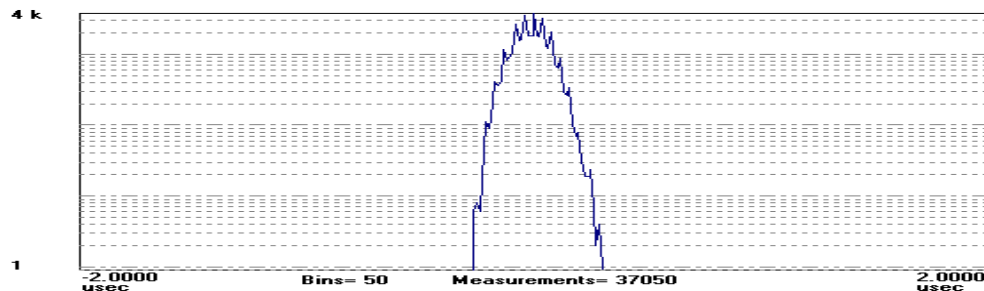
Switch:

Mean: 24.41855 μ sec

Peak to Peak: 334.8 nsec

Standard Deviation: 52.85 nsec

Symmetricom TimeMonitor Analyzer
PDV Wire-speed Router; Mean: 27.02728 usec; Standard Deviation: 76.19 nsec



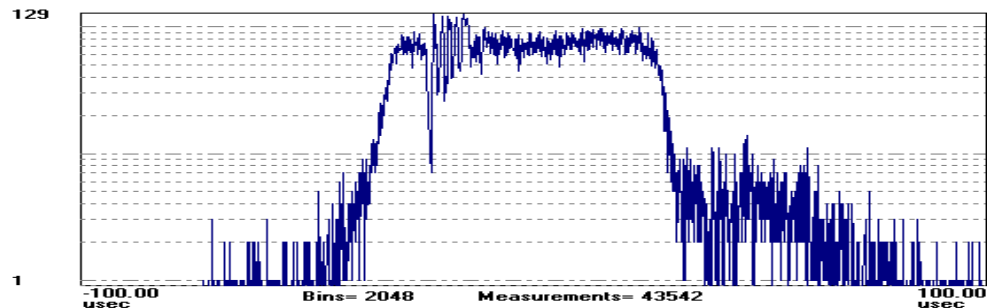
Multilayer Switch:

Mean: 27.02728 μ sec

Peak to Peak: 576.0 nsec

Standard Deviation: 76.19 nsec

Symmetricom TimeMonitor Analyzer
PDV Software Router; Mean: 277.6874 usec; Standard Deviation: 20.64 usec



Router:

Mean: 277.6874 μ sec

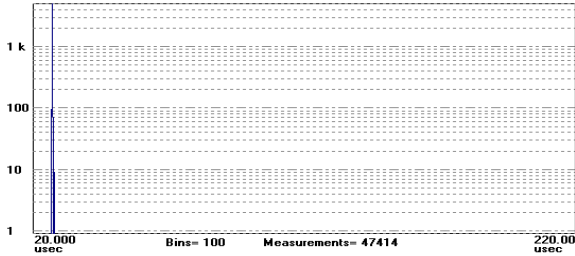
Peak to Peak: 212.5 μ sec

Standard Deviation: 20.64 μ sec

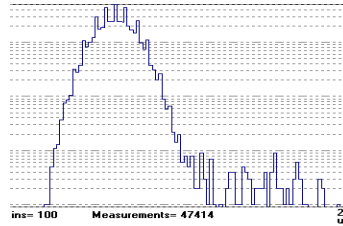
Multilayer Switch with Traffic



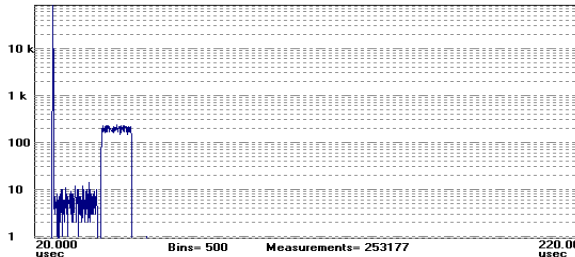
Symmetricom TimeMonitor Analyzer
Phase Deviation Histogram: Fs=499.2 mHz; Fo=10.00 MHz; 2006/09/21 13:00:56
Tahiti Phase; Samples: 47414; UUID: 000055010016; Initial phase offset: 26.8800 usec



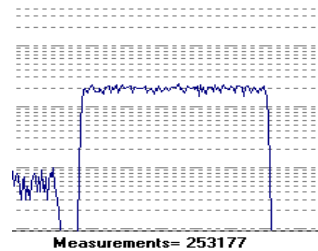
5%



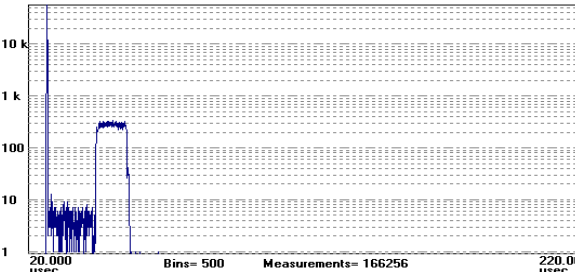
Symmetricom TimeMonitor Analyzer
Phase Deviation Histogram: Fs=1.020 Hz; Fo=10.00 MHz; 2006/10/07 00:02:04
Tahiti Phase; Samples: 253177; UUID: 00A069012FBA; Initial phase offset: 26.6570 usec



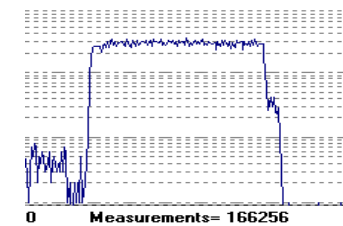
10%



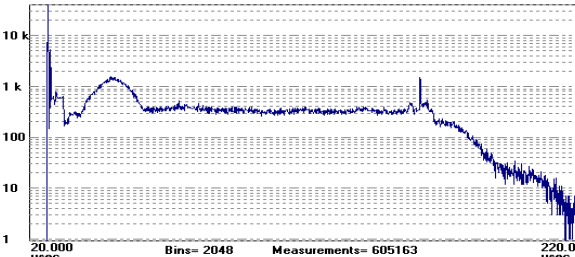
Symmetricom TimeMonitor Analyzer
Phase Deviation Histogram: Fs=1.020 Hz; Fo=10.00 MHz; 2006/10/09 20:59:41
Tahiti Phase; Samples: 166256; UUID: 00A069012FBA; Initial phase offset: 26.7070 usec



20%



Phase Deviation Histogram: Fs=1.019 Hz; Fo=10.00 MHz; 2006/09/30 03:01:16
Tahiti Phase; Samples: 605163; UUID: 00A069012FBA; Initial phase offset: 26.477 usec



50%

Zooms

No traffic:

Mean: 26.9586 μ sec

Peak to Peak: 620.4 nsec

Standard Deviation: 73.20 nsec

5% BW Utilization:

Mean: 26.9462 μ sec

Peak to Peak: 1.209 μ sec

Standard Deviation: 79.12 nsec

10% BW Utilization:

Mean: 28.9450 μ sec

Peak to Peak: 34.77 μ sec

Standard Deviation: 7.008 μ sec

20% BW Utilization:

Mean: 31.2810 μ sec

Peak to Peak: 40.41 μ sec

Standard Deviation: 9.426 μ sec

30% BW Utilization:

Mean: 33.6201 μ sec

Peak to Peak: 41.70 μ sec

Standard Deviation: 10.88 μ sec

50% BW Utilization (2 Traffic Sources):

Mean: 80.8216 μ sec

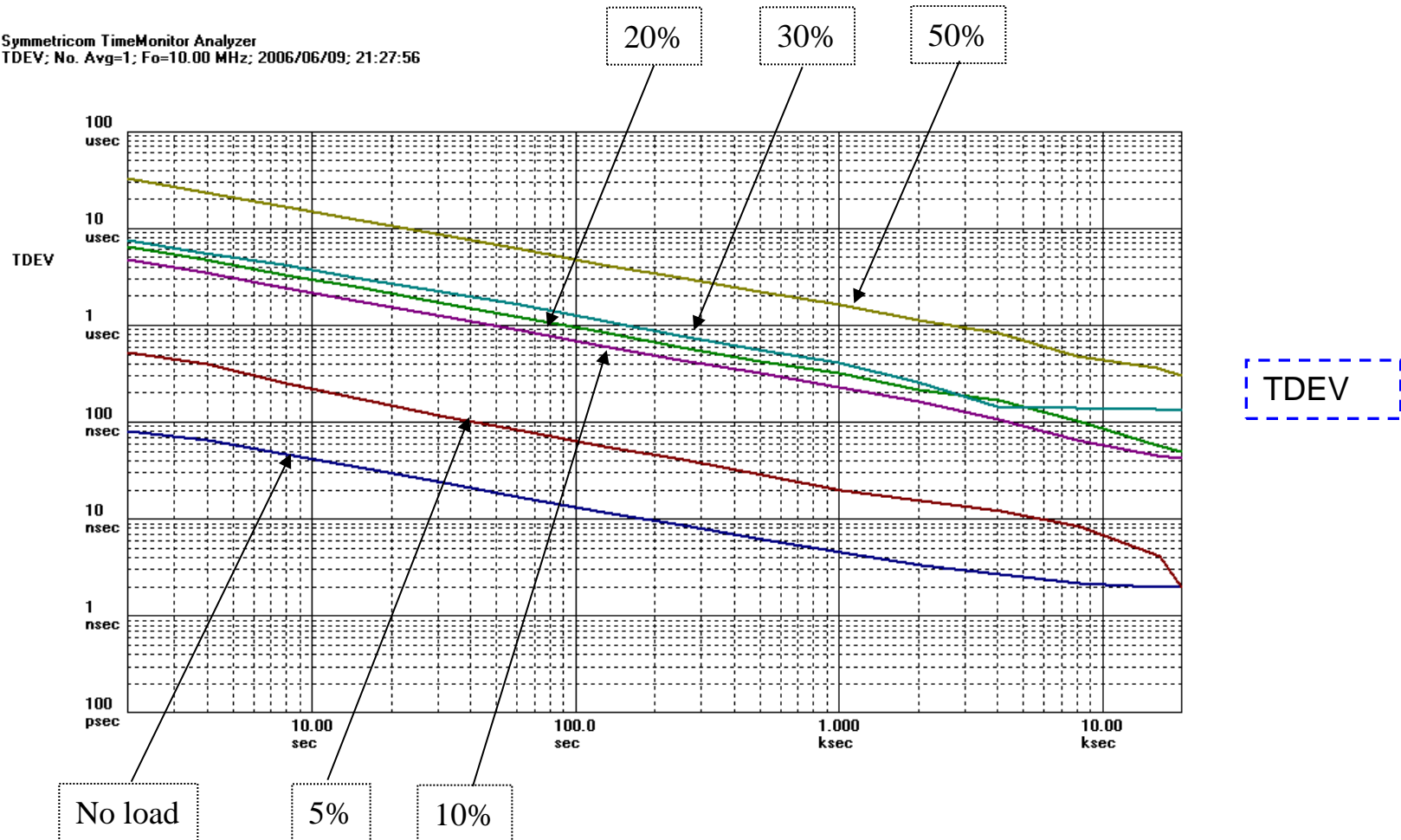
Peak to Peak: 206.6 μ sec

Standard Deviation: 47.06 μ sec

Multilayer Switch with Traffic



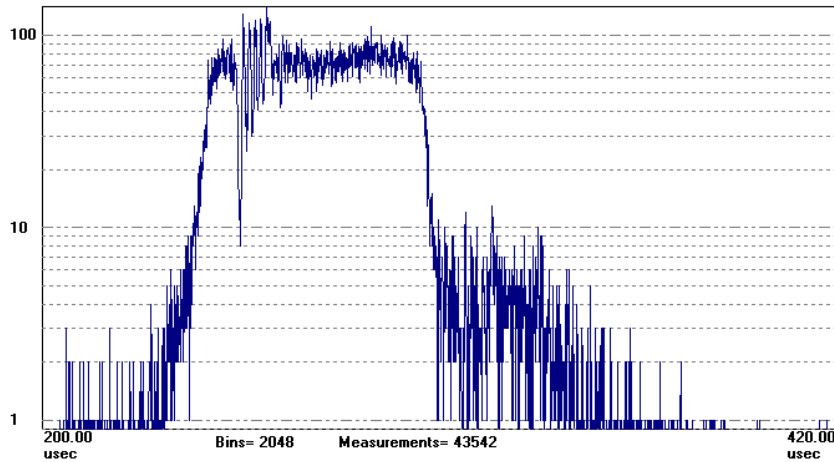
Symmetricom TimeMonitor Analyzer
TDEV; No. Avg=1; Fo=10.00 MHz; 2006/06/09; 21:27:56



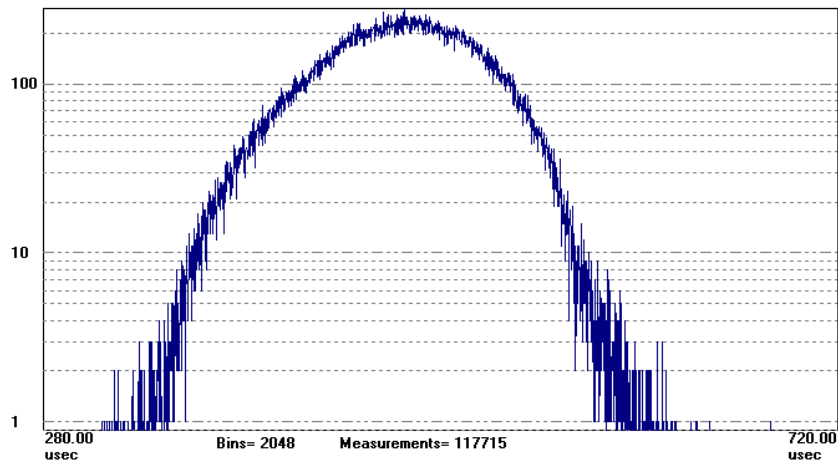
One vs. Two Routers



Symmetricom TimeMonitor Analyzer
Phase Deviation Histogram: Fs=499.9 mHz; Fo=10.00 MHz; 2006/05/15 17:47:33
Tahiti Phase; Samples: 43542; UUID: 00A069012FB9; Initial phase offset: 260.487 usec



Symmetricom TimeMonitor Analyzer
Phase Deviation Histogram: Fs=500.0 mHz; Fo=10.00 MHz; 2006/05/13; 00:01:21
Tahiti Phase; Samples: 117715; UUID: 00A069012FB9; Initial phase offset: 468.197 usec



Statistics

One router:

Mean: 277.6874 μ sec

Peak to Peak: 212.5 μ sec

Standard Deviation: 20.64 μ sec

Two routers:

Mean: 477.6874 μ sec

Peak to Peak: 369.7 μ sec

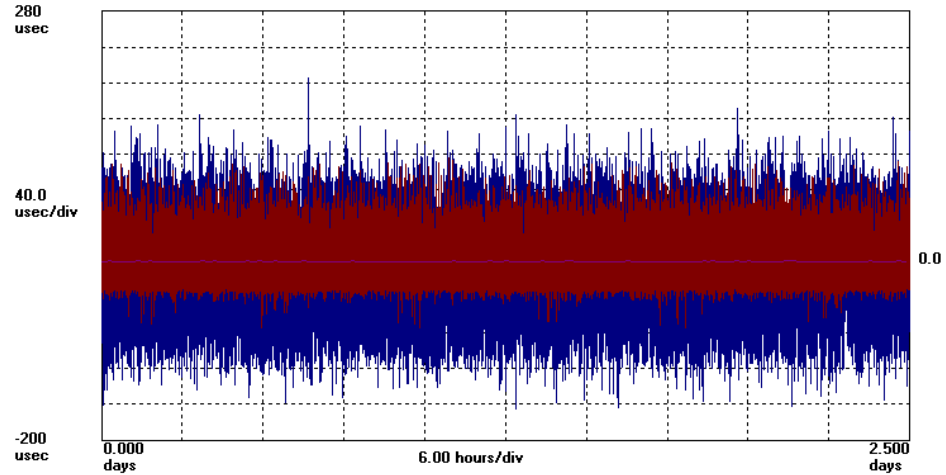
Standard Deviation: 43.18 μ sec

One vs. Two Routers



Symmetricom TimeMonitor Analyzer
Phase deviation in units of time; Fs=500.0 MHz; Fo=10.000000 MHz; 2006/05/13; 00:01:21

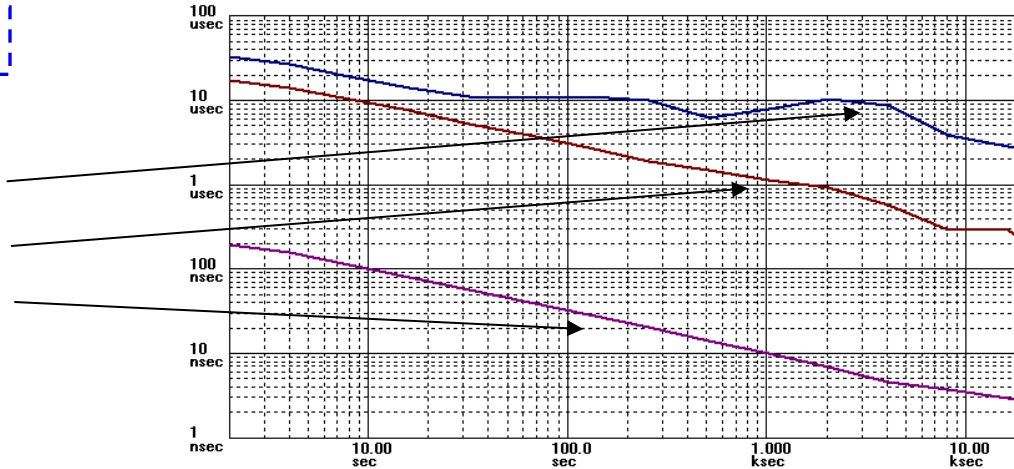
PHASE



TDEV

Symmetricom TimeMonitor Analyzer
TDEV; No. Avg=1; Fo=10.00 MHz; 2006/05/13; 00:01:21

Two Routers: No Load
One Router: No Load
Switch: No Load



Raw PDV vs. Running Statistics

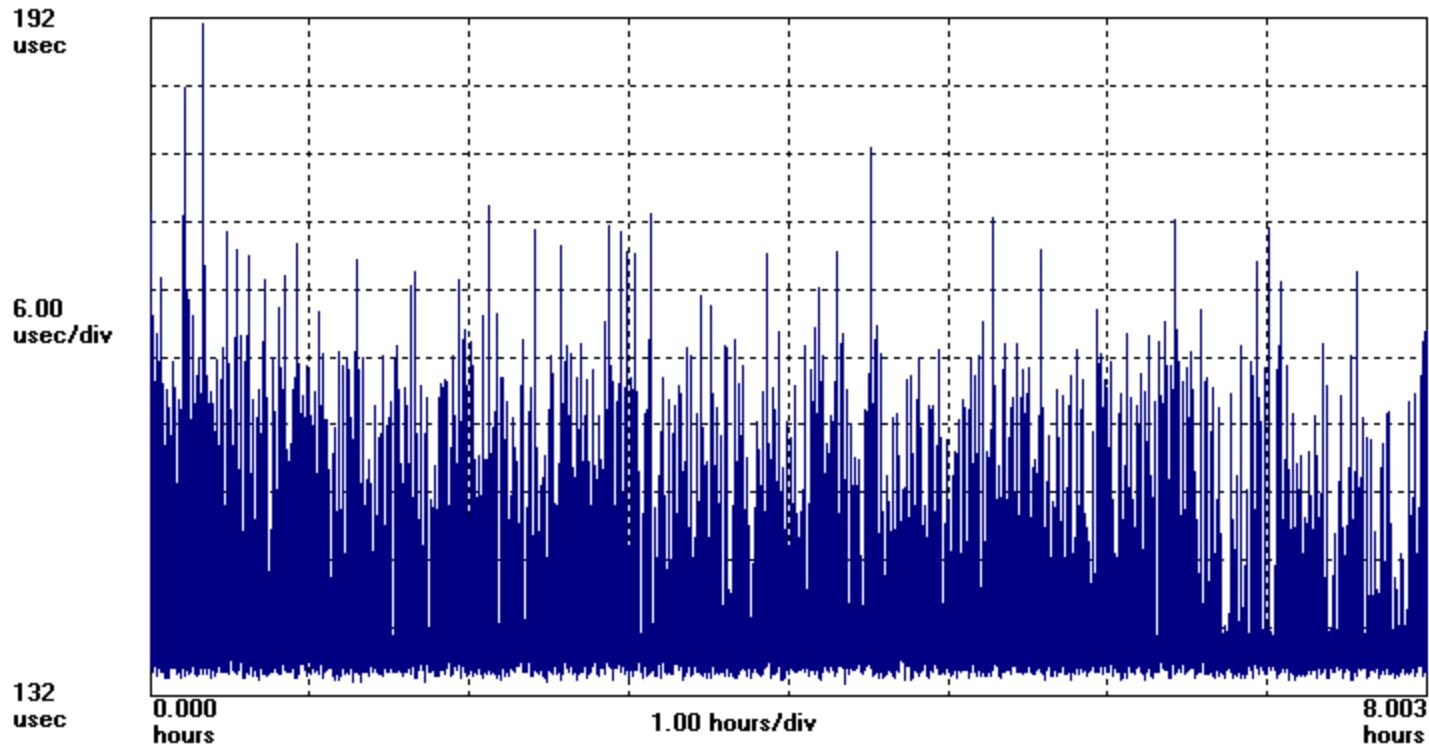


Raw packet delay appears relatively static over time

Symmetricom TimeMonitor Analyzer

Phase deviation in units of time; $F_s=500.0$ MHz; $F_o=10.000000$ MHz; 2006/08/30 21:07:10

Tahiti Phase; Samples: 14405; Stop: 14405; UUID: 00005501000A; Initial phase offset: 134.730 usec



Raw PDV vs. Running Statistics

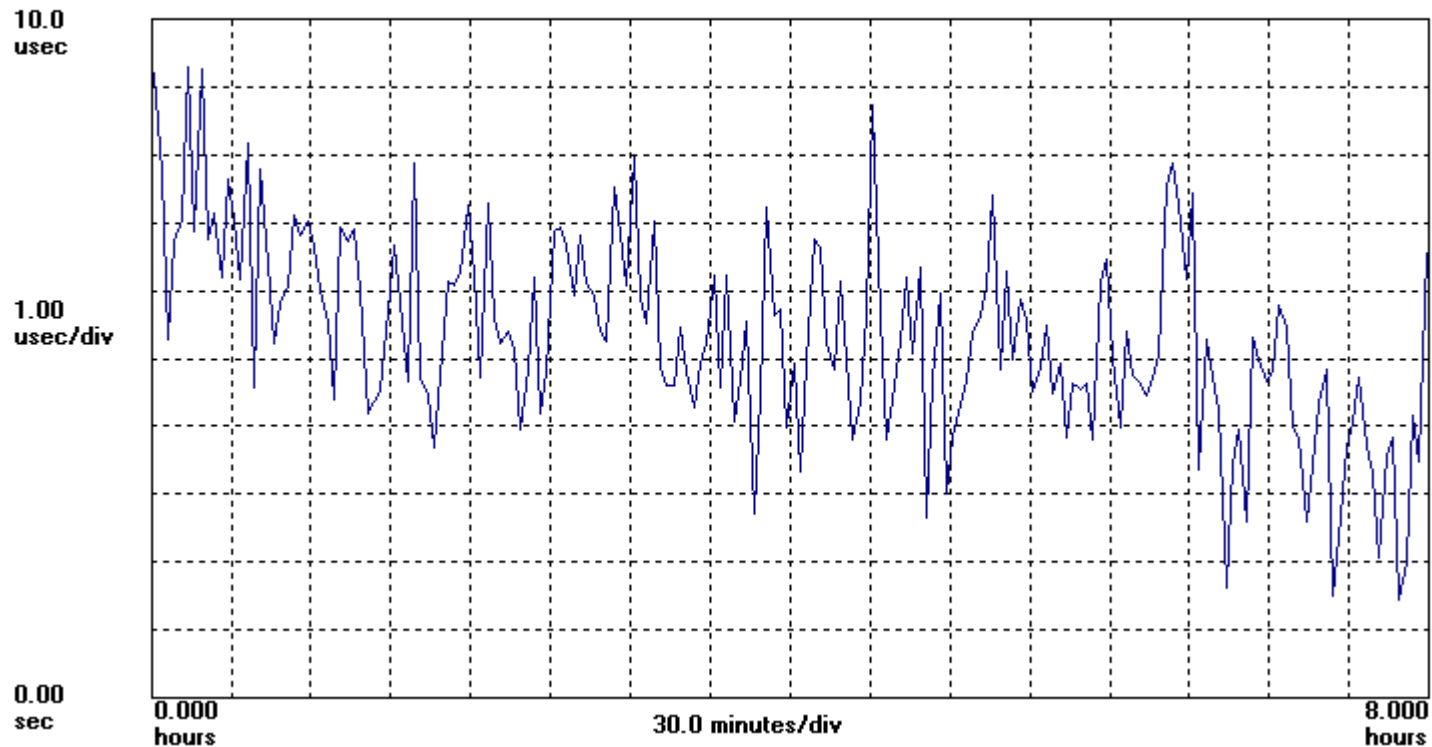


Standard Deviation vs. time shows decreasing noise more clearly

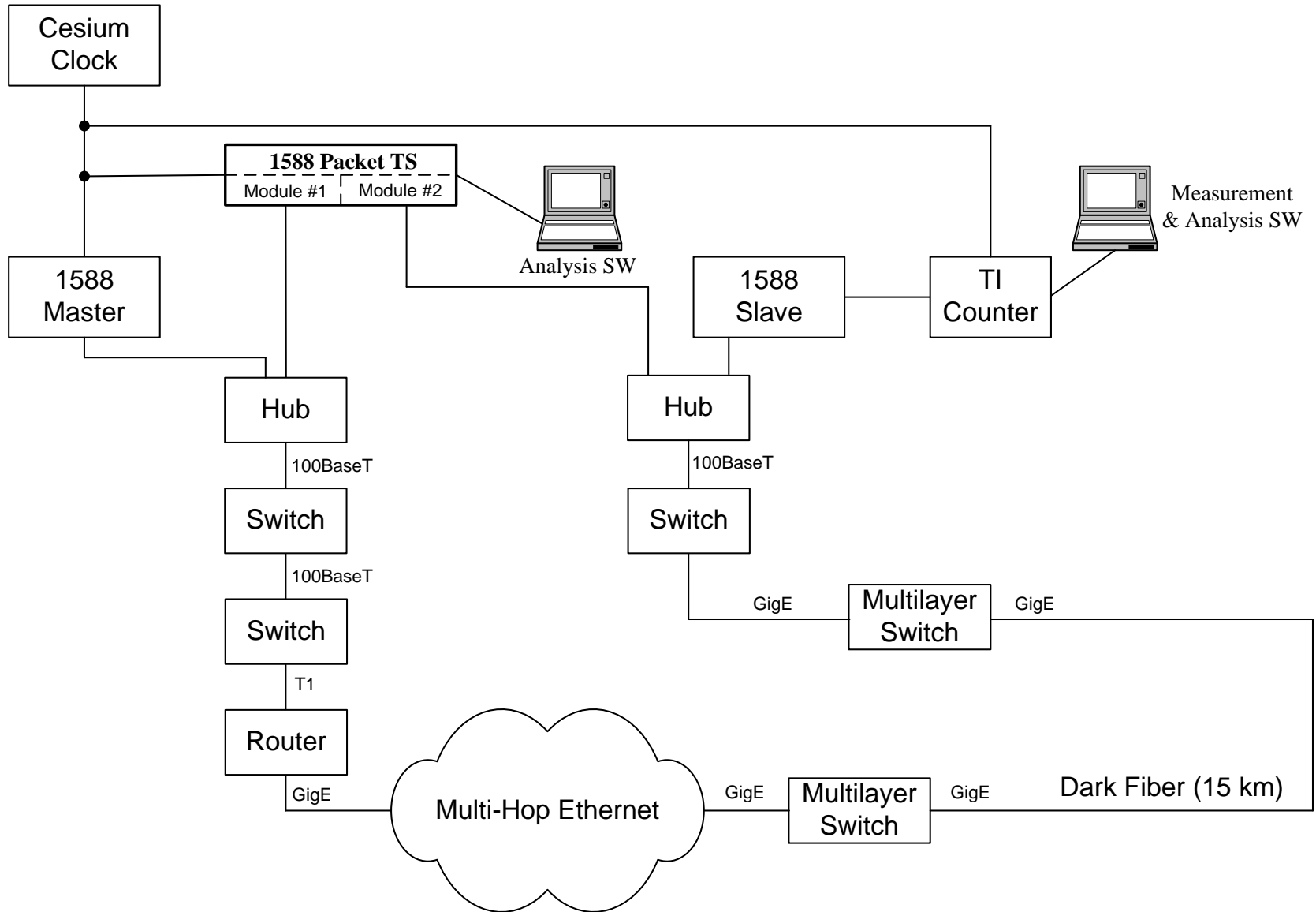
Symmetricom TimeMonitor Analyzer

Phase deviation in units of time; $F_s=500.0$ MHz; $F_0=10.000000$ MHz; 2006/08/30; 21:07:10

Phase Standard Deviation; $\tau=150$ s; $A=75$; $N=192$;



Production Network with Live Traffic



Production Network with Live Traffic

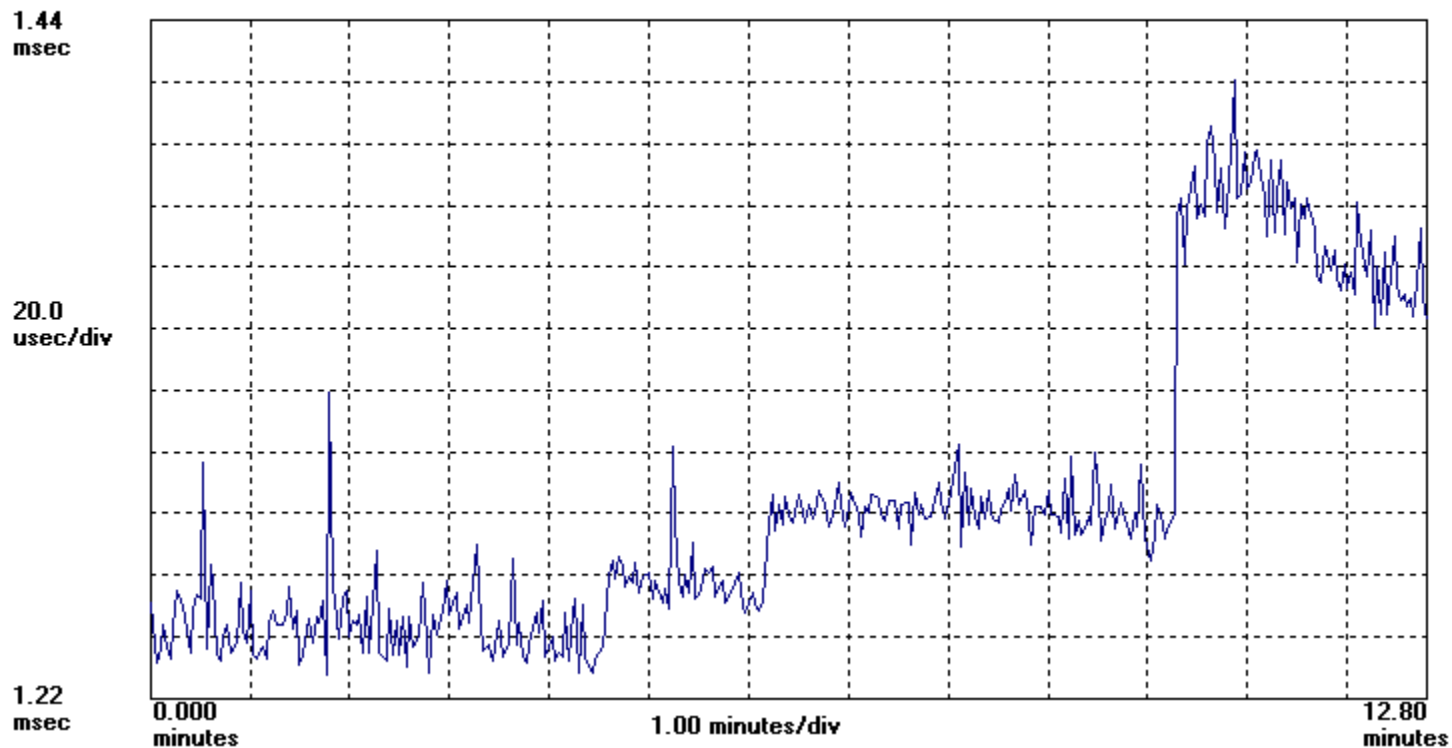


Packet delay changes over time with live traffic in a production network

Symmetricom TimeMonitor Analyzer

Phase deviation in units of time; $F_s=498.7$ mHz; $F_o=10.000000$ MHz; 2006/07/26 23:41:56

Tahiti Phase; Samples: 384; UUID: 00005501000A; Initial phase offset: 1.25107 msec



Production Network with Live Traffic

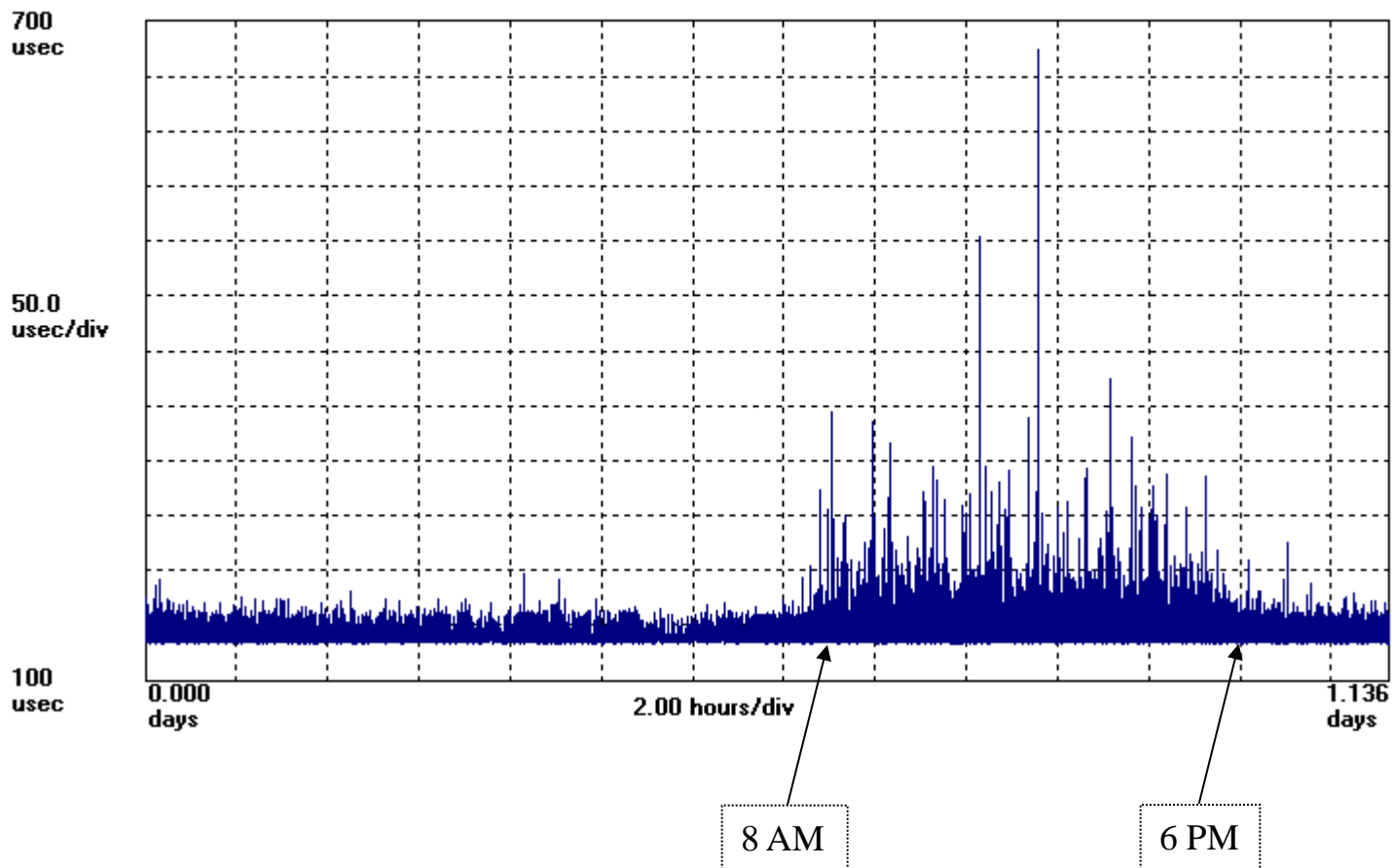


In another measurement, minimum packet delay remains constant but packet delay variation (PDV) changes over time (diurnal)

Symmetricom TimeMonitor Analyzer

Phase deviation in units of time; $F_s=499.4$ MHz; $F_o=10.000000$ MHz; 2006/08/30 17:07:10

Tahiti Phase; Samples: 49036; UUID: 00005501000A; Initial phase offset: 134.730 usec

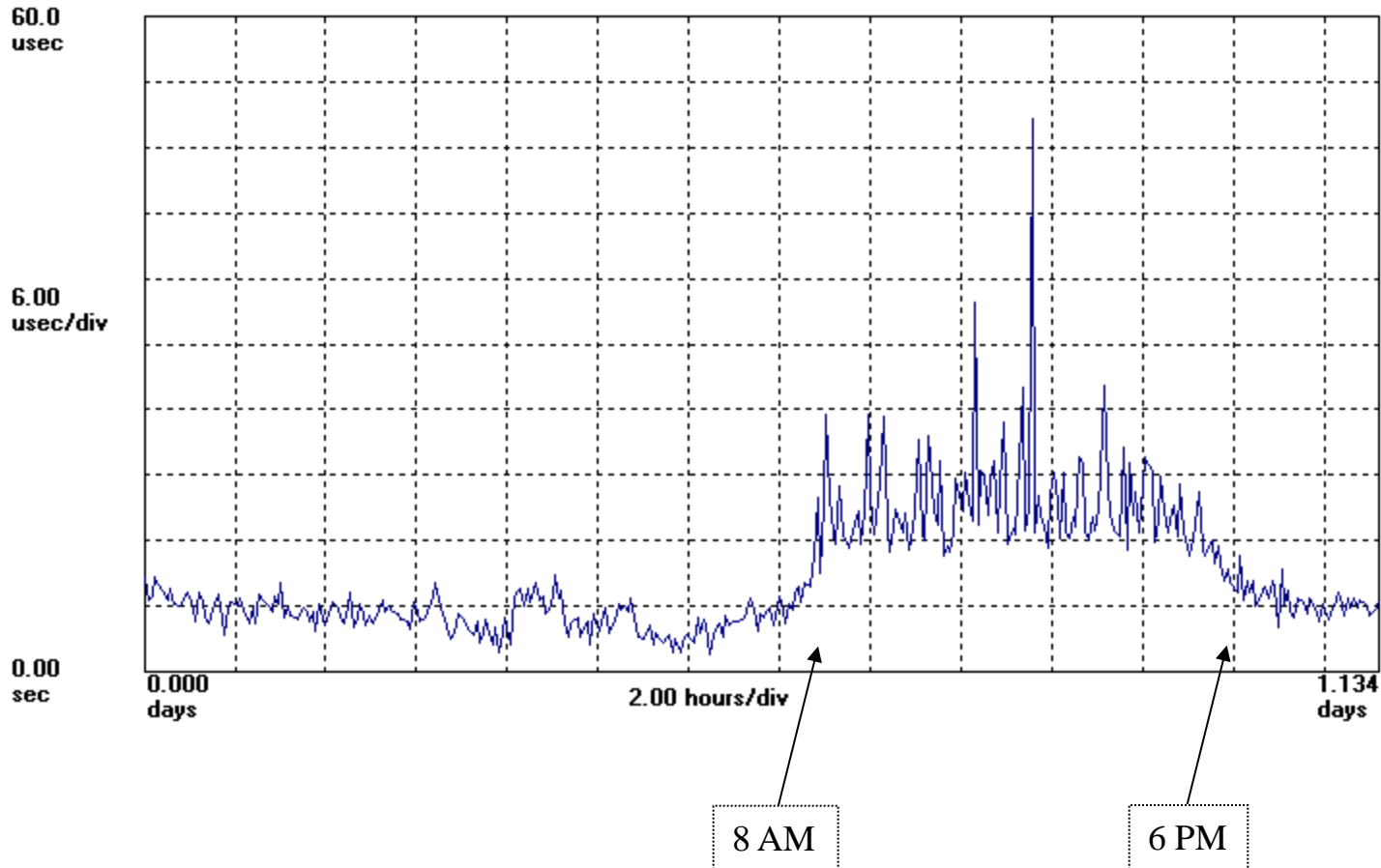


Production Network with Live Traffic



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

Symmetricom TimeMonitor Analyzer
Phase deviation in units of time; $F_s=499.4$ MHz; $F_o=10.000000$ MHz; 2006/08/30; 17:07:10
Phase Standard Deviation; $\tau=250$ s; $A=125$; $N=392$;

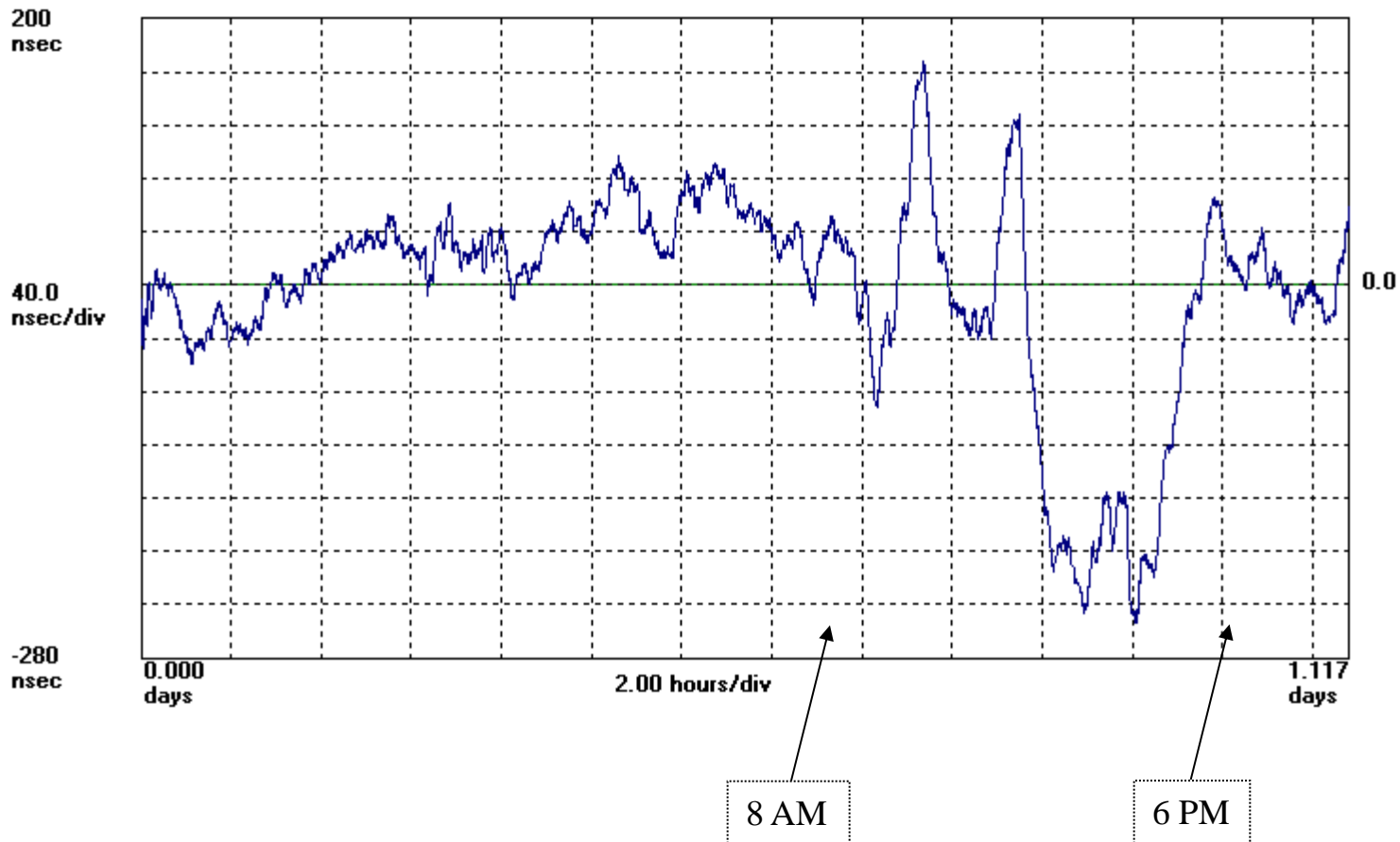


Production Network with Live Traffic



IEEE 1588 slave performance can be correlated with PDV variations

Symmetricom TimeMonitor Analyzer
Phase deviation in units of time; $F_s=924.3$ mHz; $F_o=1.0000000$ Hz
HP 53132A; Test: 87; IEEE 1588 Slave

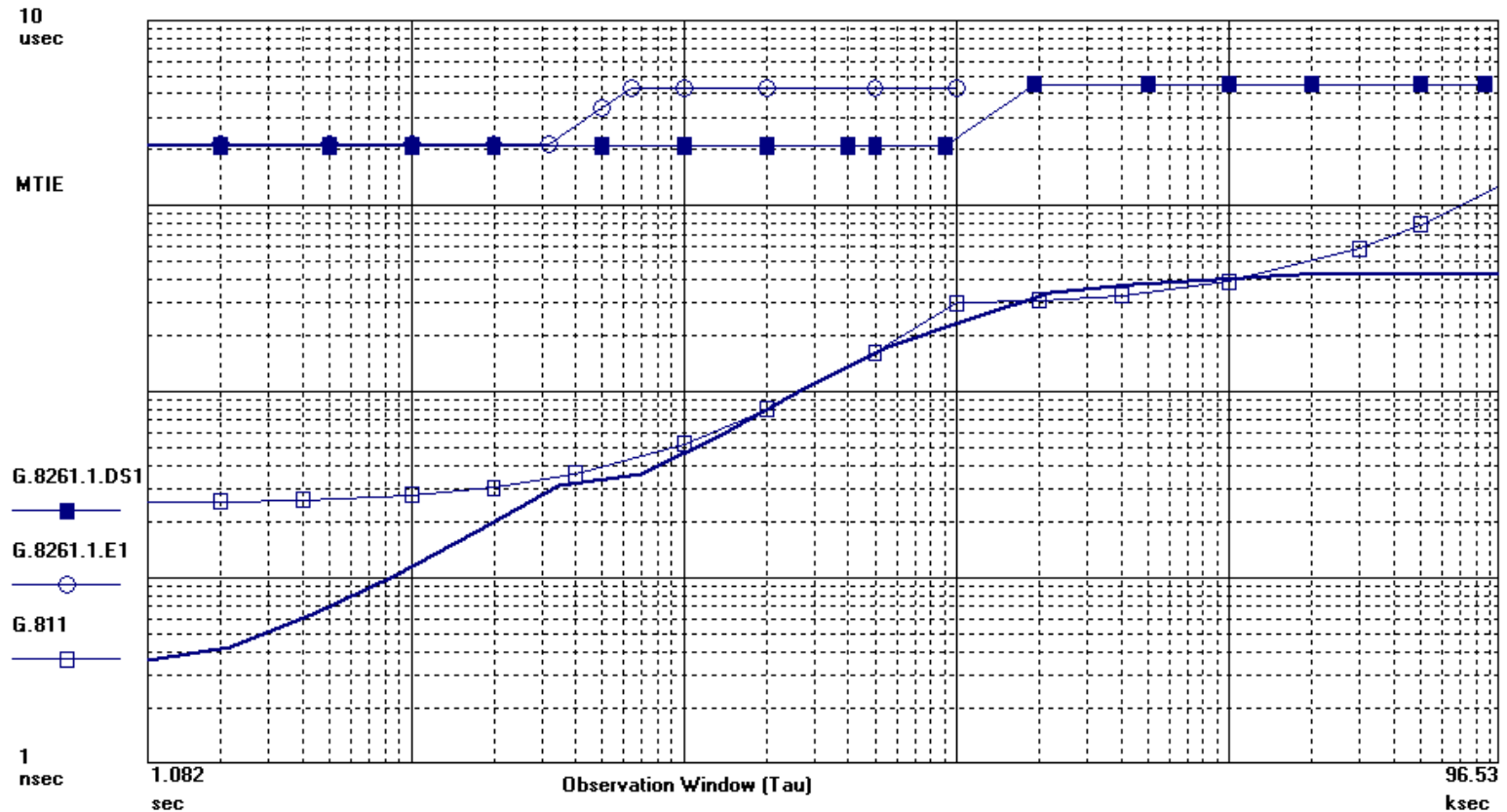


Production Network with Live Traffic

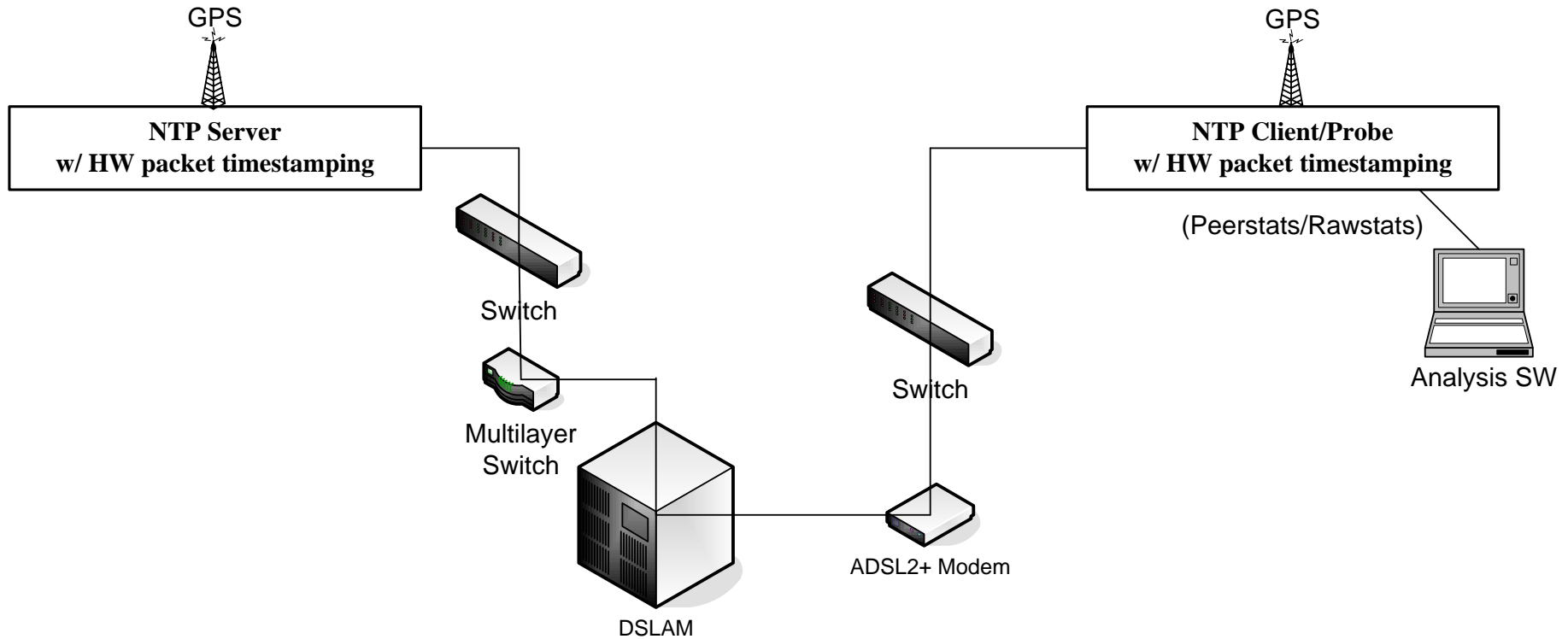


For the entire 24 hour period the IEEE 1588 slave meets G.8261 requirements and nearly meets G.811 requirements

Symmetricom TimeMonitor Analyzer
MTIE; $F_0=1.000$ Hz; $F_s=924.3$ mHz
HP 53132A; Test: 87; IEEE 1588 Slave



DSLAM/ADSL2+ Modem



DSLAM/ADSL2+ Modem



Large packet delay: 3 msec

Mean: 2.93986 msec
Peak to Peak: 2.682 msec
Standard Deviation: 219.1 μ sec

Symmetricom TimeMonitor Analyzer

Phase Deviation Histogram; Fs=999.3 mHz; Fo=10.00 MHz; 2006/06/26 00:20:37

Rawstats Transmit Delay; Samples: 88788; Remote IP: 40.10.0.70; Local IP: 30.10.0.70

