Ethernet Time Transfer through a U.S. Commercial Optical Telecommunications Network

WSTS 2015

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Outline

- Motivation
- Project plan
- Current results, February 2015
  - Transfer results using two transports
  - Check baseline then add traffic
  - Diagnostic efforts to determine cause of asymmetry
- Concerns and next steps

Motivation

- Need to back up critical infrastructure for time at microsecond (µs) or better
  - NTP over internet no better than ~ 1millisecond (ms)
- Research use of public telecom networks to transfer time
  - Optical fibers excellent for two-way time transfer
  - Public network fibers are unidirectional
- Need a method that is commercially viable
  - PTP is a new standard for time transfer
  - Format cannot improve accuracy - requires access to physical signal

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History of Project

- Centurylink provider agreed in principle to two-year experiment linking NIST Boulder and USNO AMC at Schriever AFB (Source of UTC from GPS)
- DHS issued RFI, December 2011
- One vendor, Symmetricom-Microsemi, gave a detailed plan
- Tri-lateral MOU written: DoC (NIST)-DHS-DoD (USNO)
  - Not yet signed
- Three-way Cooperative Research and Development Agreement (CRADA) NIST with Centurylink and Symmetricom-Microsemi signed in January 2013
- CRADA extended to January 2017

NIST-AMC Timing Experiment Microsemi PTP + CenturyLink Circuit

- Microsemi provides PTP timing signals over Gigabit Ethernet
- CenturyLink provides two different circuits to carry the timing signals
  - STS over SONET with varied bandwidths on an OC-192
  - OTN on an ODU-0, within an ODU-2 transport

Time Transfer Experiment

- Two-way time transfer using neighboring unidirectional fibers
  - No time-awareness anywhere in network
  - No routers in path
  - No real traffic, though traffic noise can be added
- Measurements at NIST and AMC against UTC(NIST) and UTC(USNO)

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PTP Over SONET/OTN

- April 2014 - July 2014: studied SONET
- July 2014 – present: studying OTN
  - Better performance
  - Better for studying asymmetry
- PDV measurements made in two directions
  - GM at USNO AMC and PTP probe at NIST
  - Forward means USNO AMC to NIST
  - Reverse means NIST to USNO AMC

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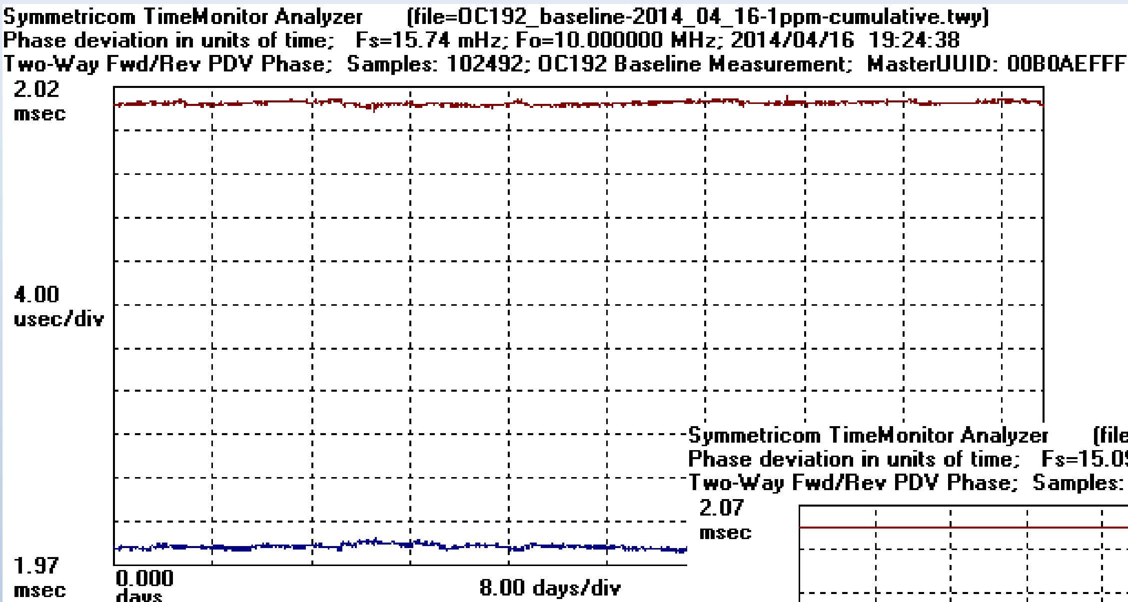
PTP over SONET vs. PTP over OTN

- **Asymmetry**: Both show large asymmetry of 40 μs between forward and reverse directions (cause unknown)
- **Delay**: Both show ~2 ms delay over 150 km of fiber
- **Jitter**:
  - SONET: 200 ns
  - OTN: <4ns
- **Wander**:
  - SONET: Variations on order of 300 ns
    - Deterministic if nodes timed by Cs (50 ns/day slope reset every 6 days)
    - Random wander if nodes timed by GPS
  - OTN: Usually close to 0 ns, occasional excursions 10's of ns

PTP over SONET/OTN

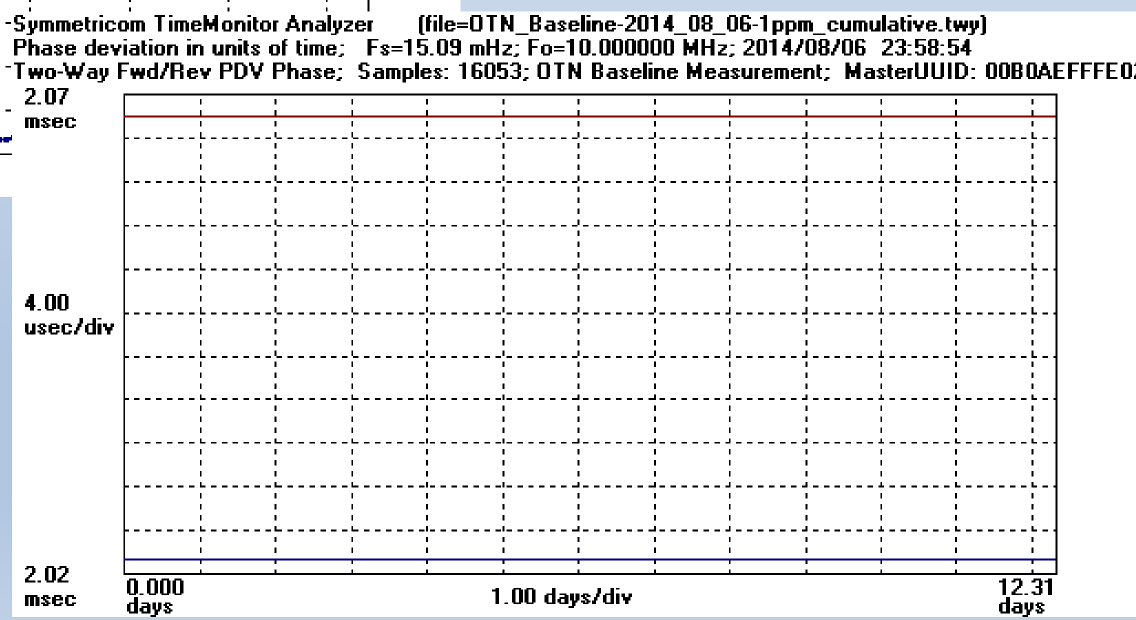
~2 ms total delay, 40 μs asymmetry

OC192 forward (blue) and reverse (red) packet delay



← SONET

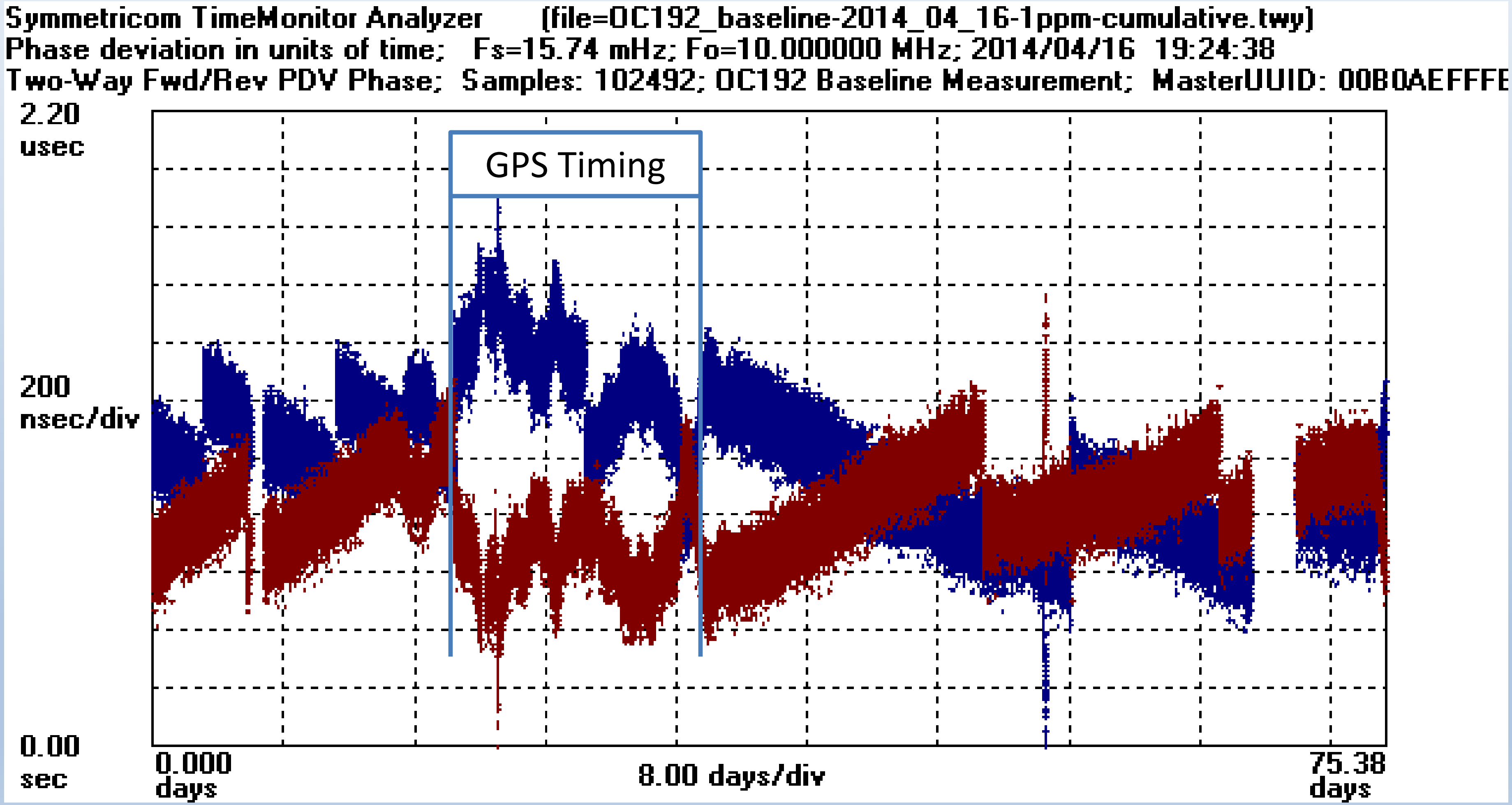
OTN fwd (blue) and rev (red) PDV



OTN →

PTP Over SONET

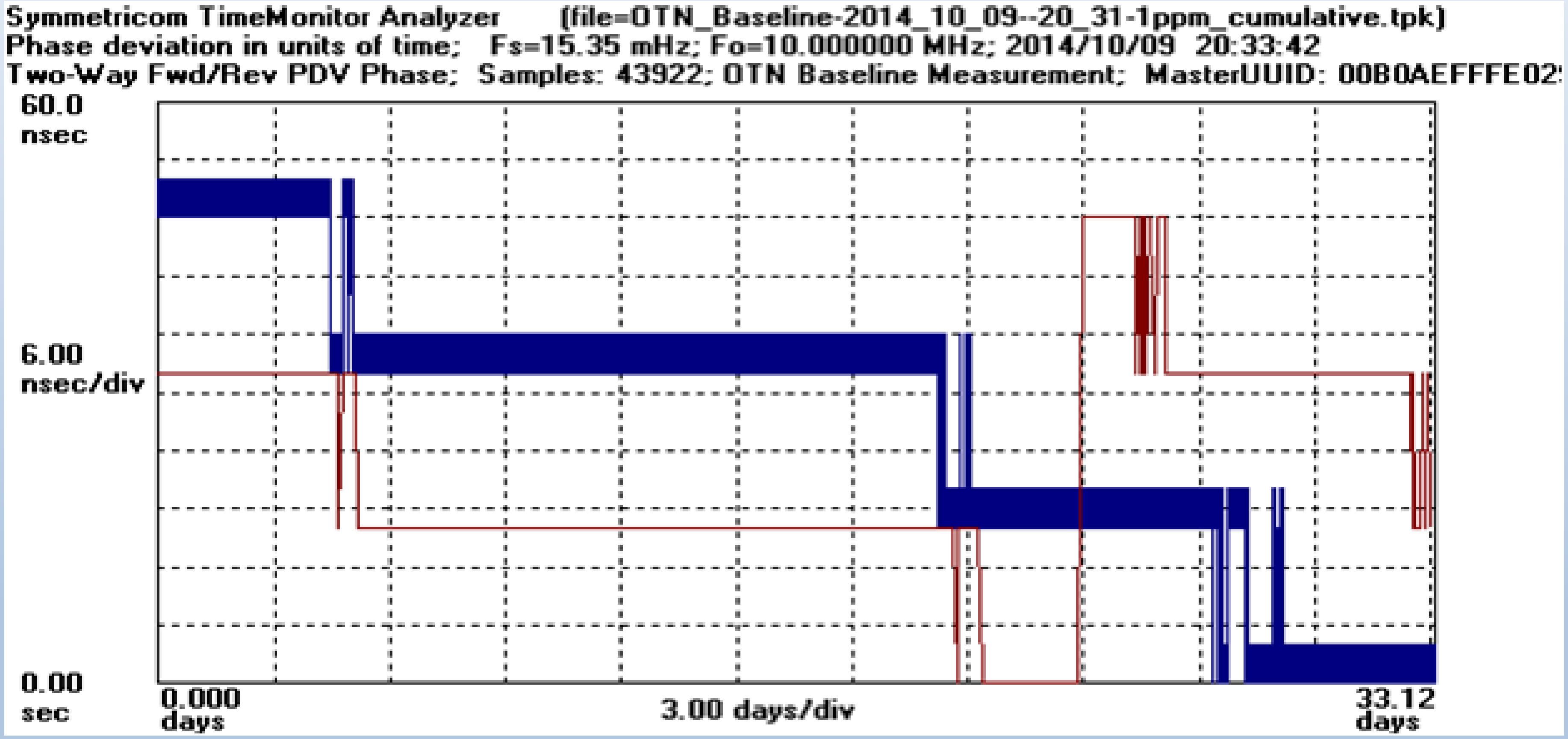
OC192 forward (blue) and reverse (red) packet delay



PTP Over OTN

33 days of data; Max deviation 50 ns one-way

OTN forward (blue) and reverse (red) packet delay



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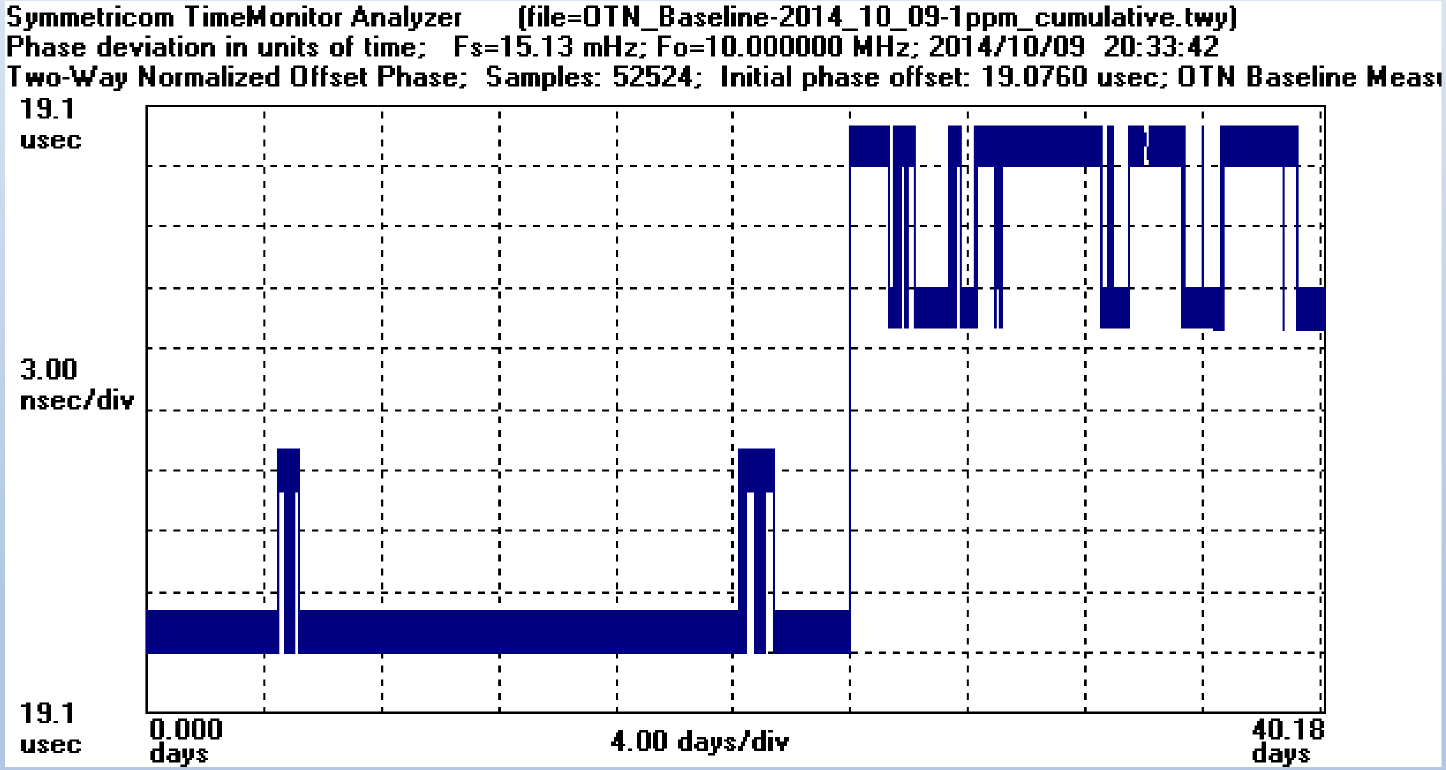
PTP Over OTN Time Transfer

40 days of data; Max deviation 26 ns two-way

Baseline: No traffic

OTN forward (blue) and reverse (red) packet delay

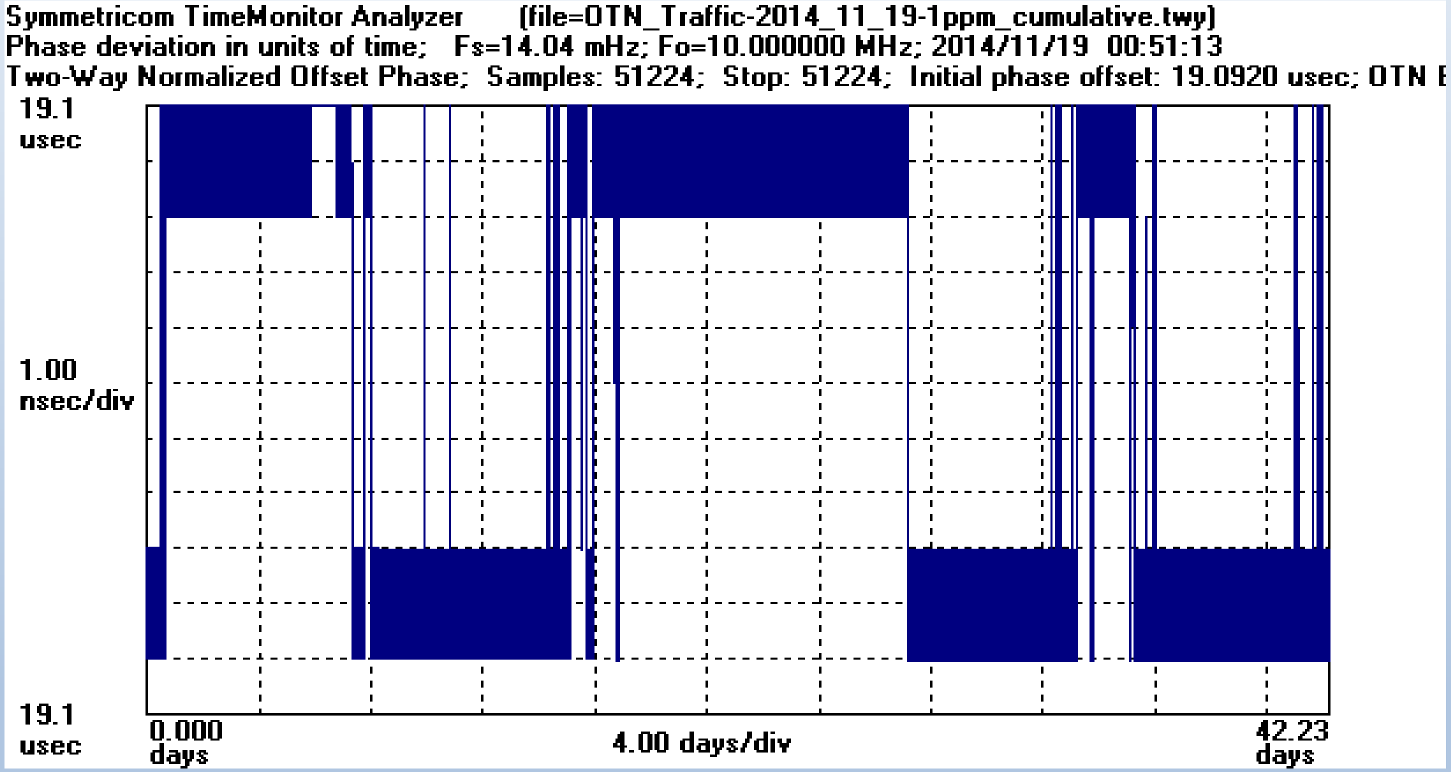


PTP Over OTN Time Transfer

42 days of data; Max deviation 10 ns two-way

With traffic

OTN forward (blue) and reverse (red) packet delay



- ***Performance not affected by the addition of traffic***

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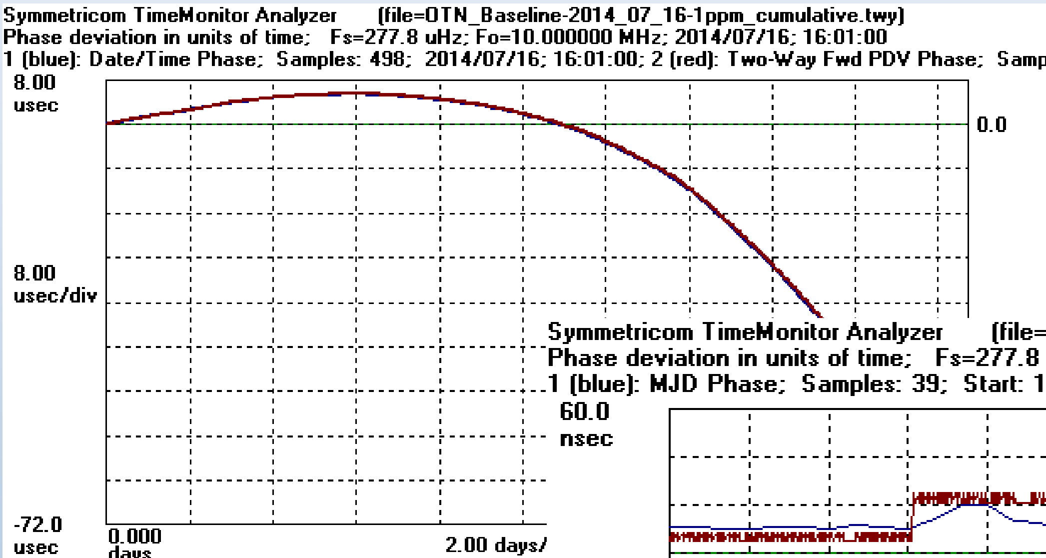
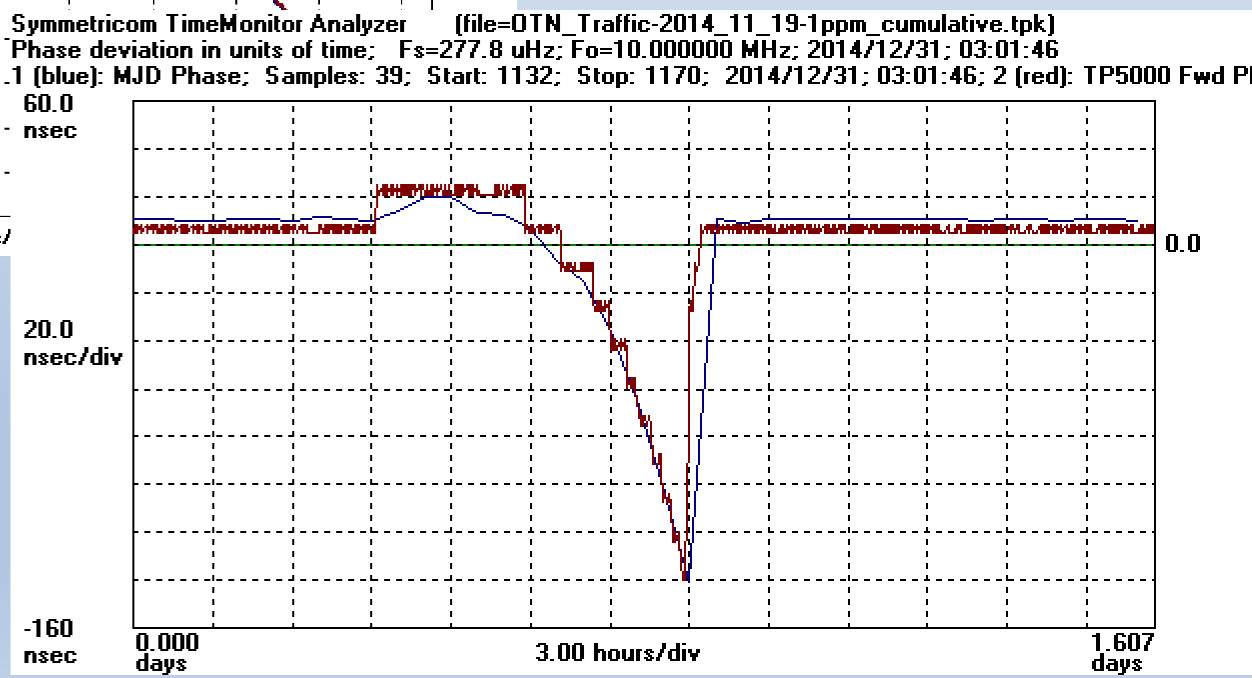
Sanity Check

Local (blue) measurements of unlocked master clock vs. remote (red) measurements of master clock using PTP (July 2014, Dec 2014)



July 2014



December 2014

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Asymmetry Investigation

- Easiest method to begin to diagnose cause of asymmetry
- Changing card determines whether the asymmetry is in the card

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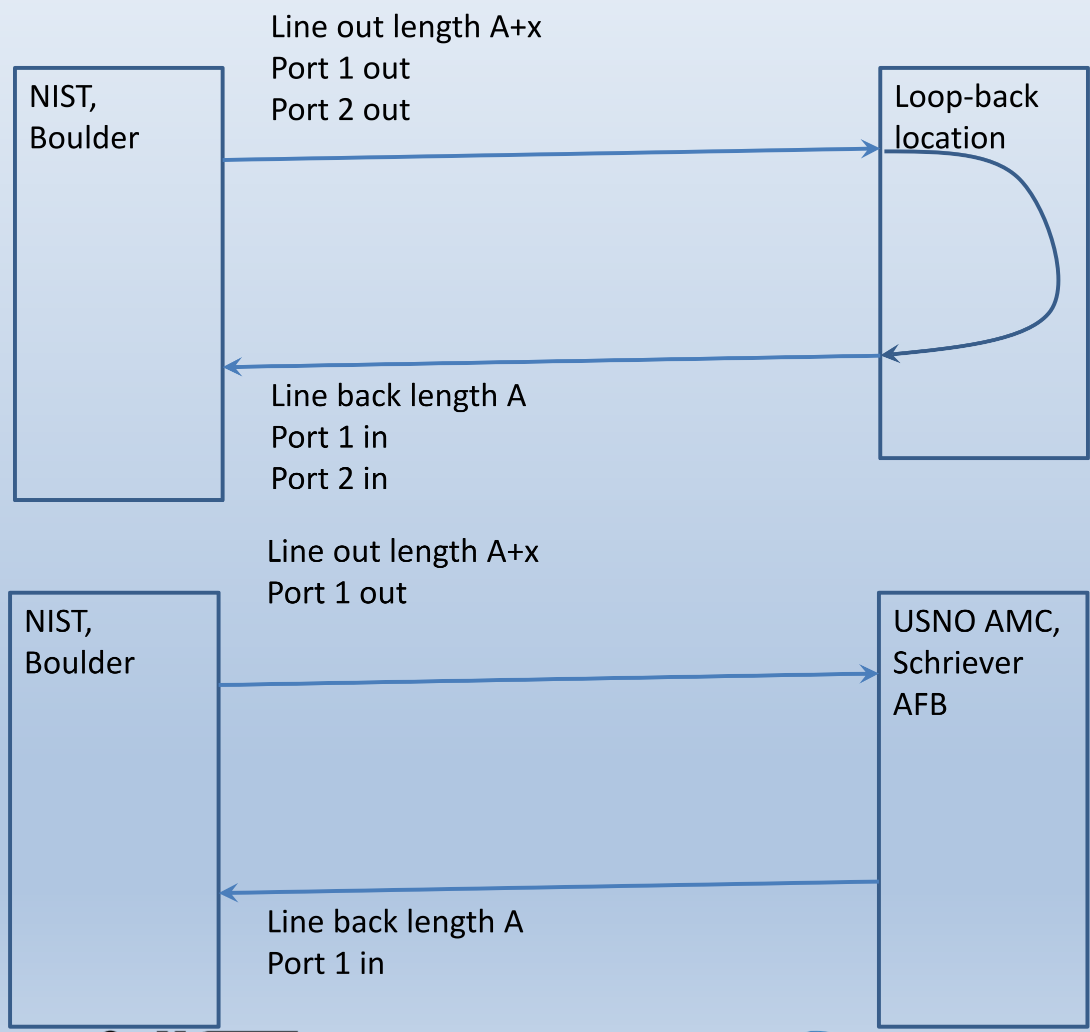
Sectionalize Circuit with Loopback

- Cause of 40 μs asymmetry difference still unknown, but likely not the card (SONET vs OTN)
- "Loopback" test to sectionalize the circuit
  - Two fibers out and back each pair going to a different port on the same PTP device
  - From Boulder lab, loopback locations: Local Boulder, Denver, Colorado Springs, Security (last office before Schriever AFB)

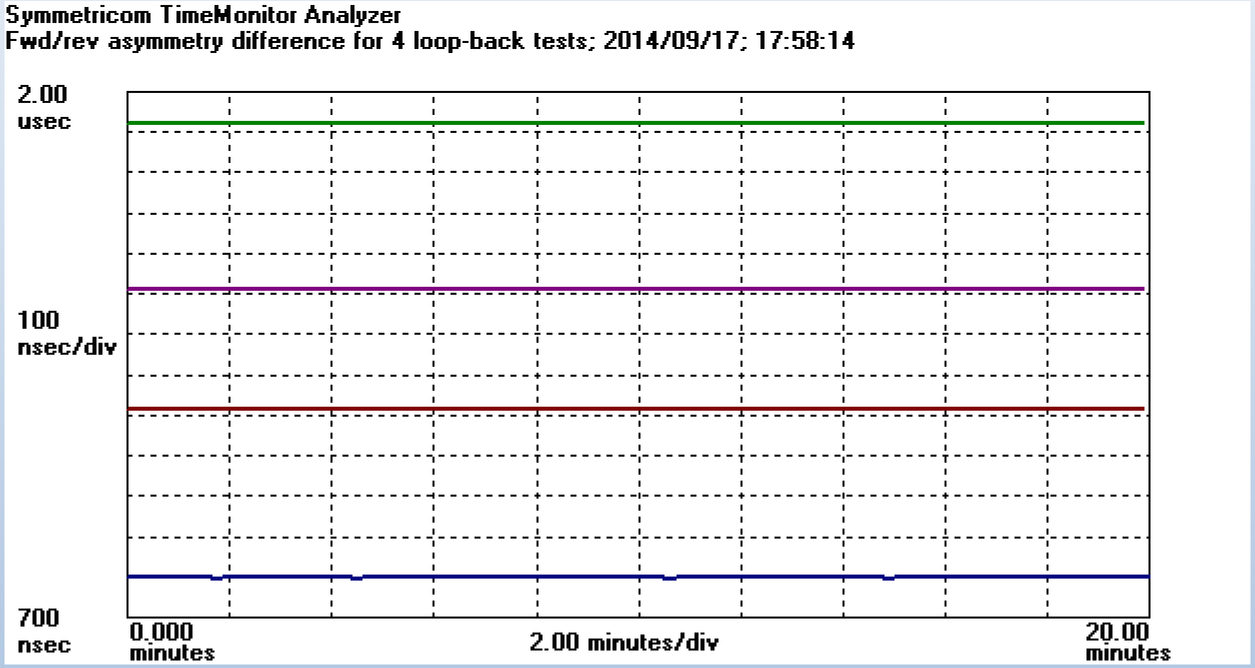
Loopback Test

The loopback test cannot measure the asymmetry of a single two-way time transfer



PTP Over OTN Loopback to Local Office

- Known random offset up to 3 µs when set up circuit at local office
  - We found 0.8, 1.2, 1.5 and 1.9 µs by closing and setting up circuit in local office



- Total delay ~ 220 µs, though circuit is loop back through about 2 miles of fiber
  - Fiber length accounts for 1-2 µs
  - Clearly most of delay is in equipment
- Max deviation ~ 4 ns

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Next Step to Place Microsemi PTP Equipment in Centurylink Offices

- Place two PTP+GPS devices, TP5000, same model as what is at NIST and USNO AMC now
- Place a TP5000 at the Denver and Colorado Springs Office
- Allow for direct two-way time transfer in three sections
  - Between NIST, Boulder and Denver
  - Between Denver and Colorado Springs
  - Between Colorado Springs and USNO AMC, Schriever AFB

Goal for This "Next Step" Experiment

- Isolate cause of 40 microsecond asymmetry
  - Perhaps find a protocol to eliminate or reduce this
- Show time transfer capabilities
  - Currently, with calibration of constant offset, using OTN transport we can maintain accuracies within 10 nanoseconds
  - Without calibration there is a 6 microsecond known random error
  - A 40 microsecond error would imply a 20 microsecond time transfer offset if uncalibrated

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Next Steps

- Results of experiment are to be published
- ATIS sync standards committee (COAST-SYNC) has a project for GPS backup
  - This experiment to show capabilities across one commercial carrier
  - Consider extending this experiment to other geographic areas or using other carriers

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Thank You for Your Attention

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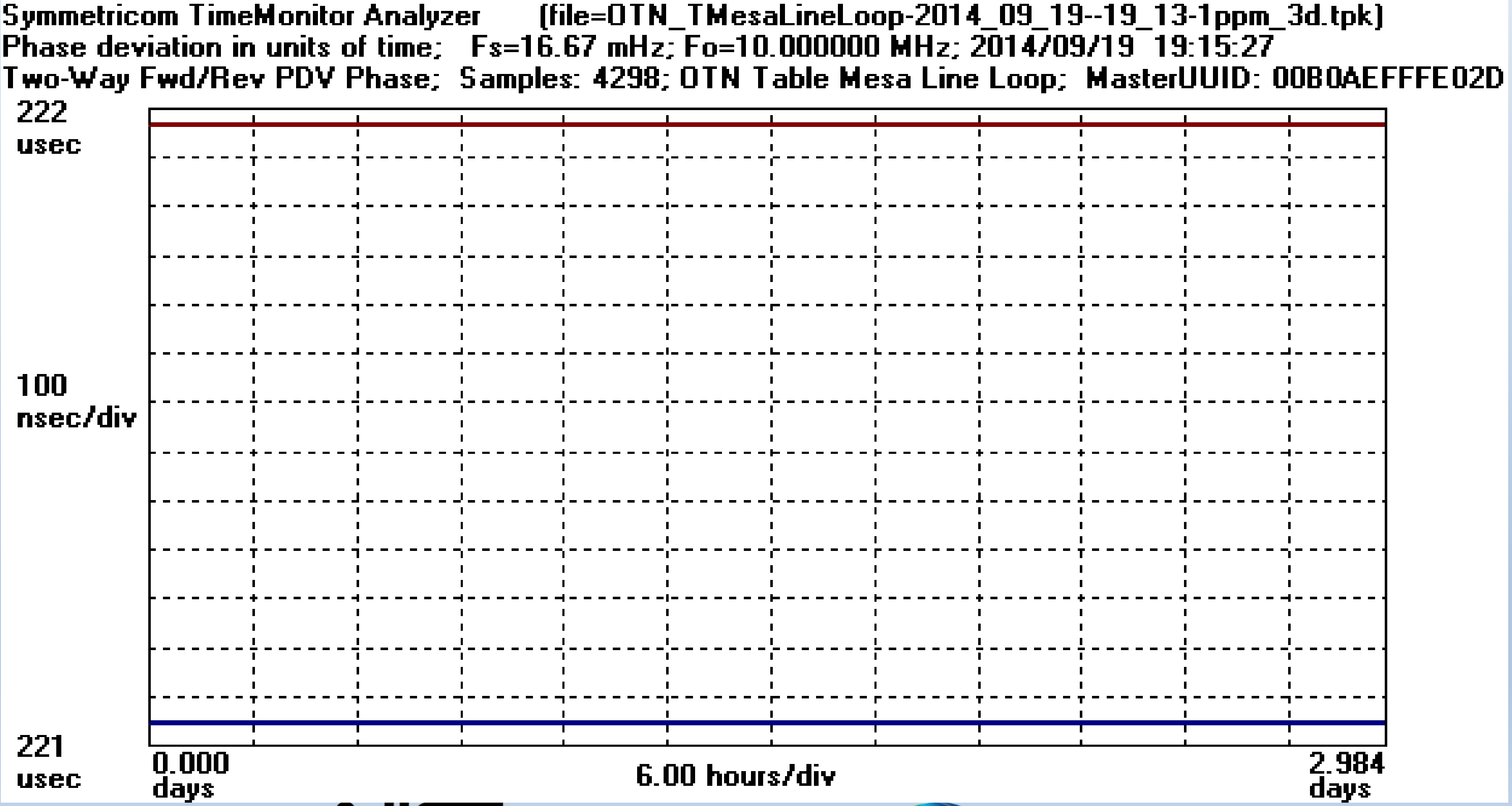
Extra Slides

PTP Over OTN Loopback to Local Office

Random Offset up to 3 µs

Here we have 1.2 µs



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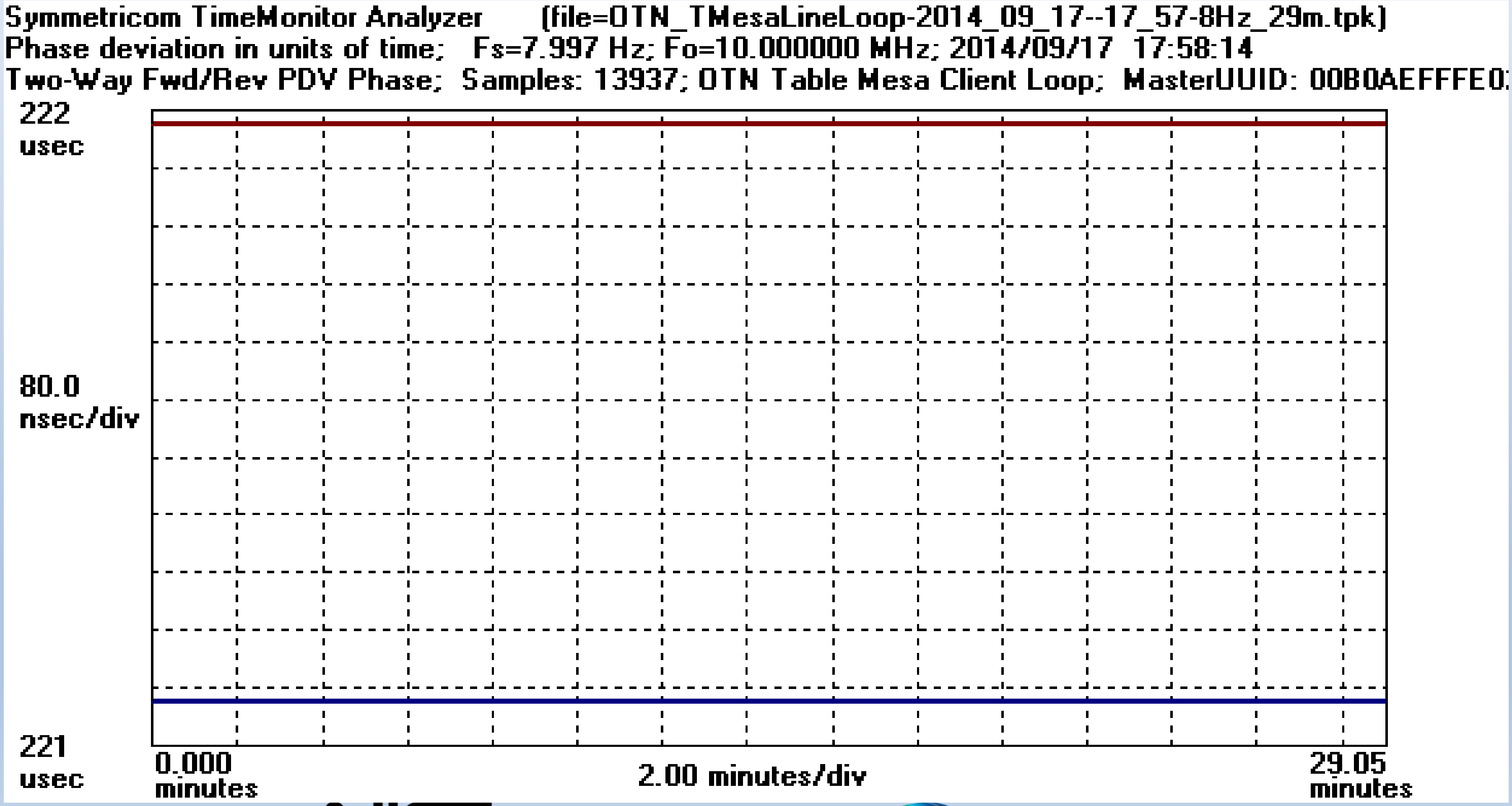
PTP Over OTN Loopback to Local Office

Random Offset up to 3 µs

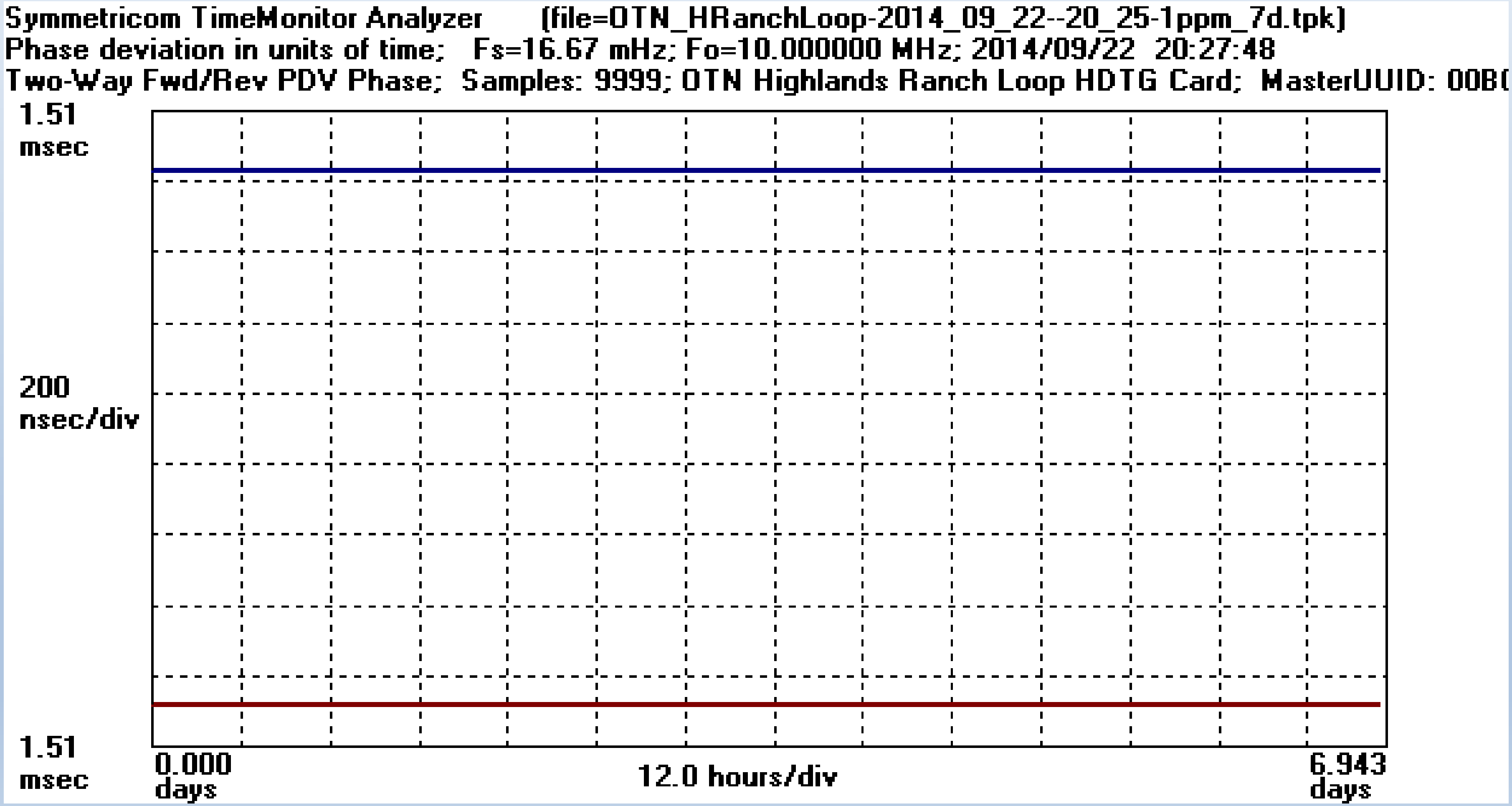
Here we have 0.8 µs



PTP Over OTN Loopback to Denver Office

Known Random Offset up to 3 µs

Here we have 1.5 µs



PTP Over OTN Loopback to Offices Beyond Boulder: Denver, CO Springs, Security

- Asymmetry of 1.5 μs probably due to local office
- Total delay ~ 1.5 ms round-trip
  - Note that total one-way delay NIST to Schriever AFB was about 2 ms
- Max deviation ~ 4 ns over 4 days
- The loopback test cannot measure the asymmetry of a single two-way time transfer

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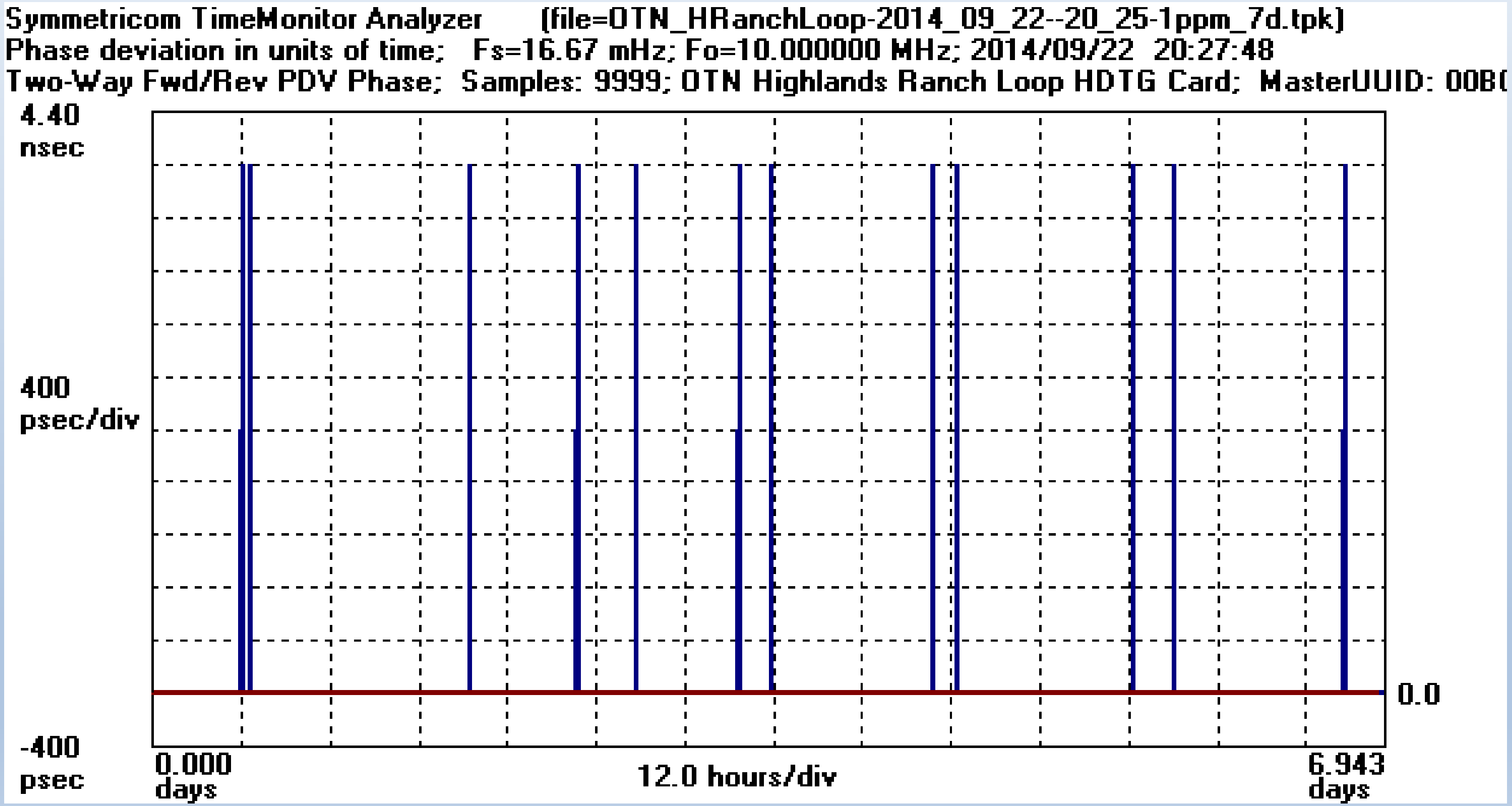
PTP Over OTN Loopback to Denver Office Max Deviation = 4 ns over 7 d



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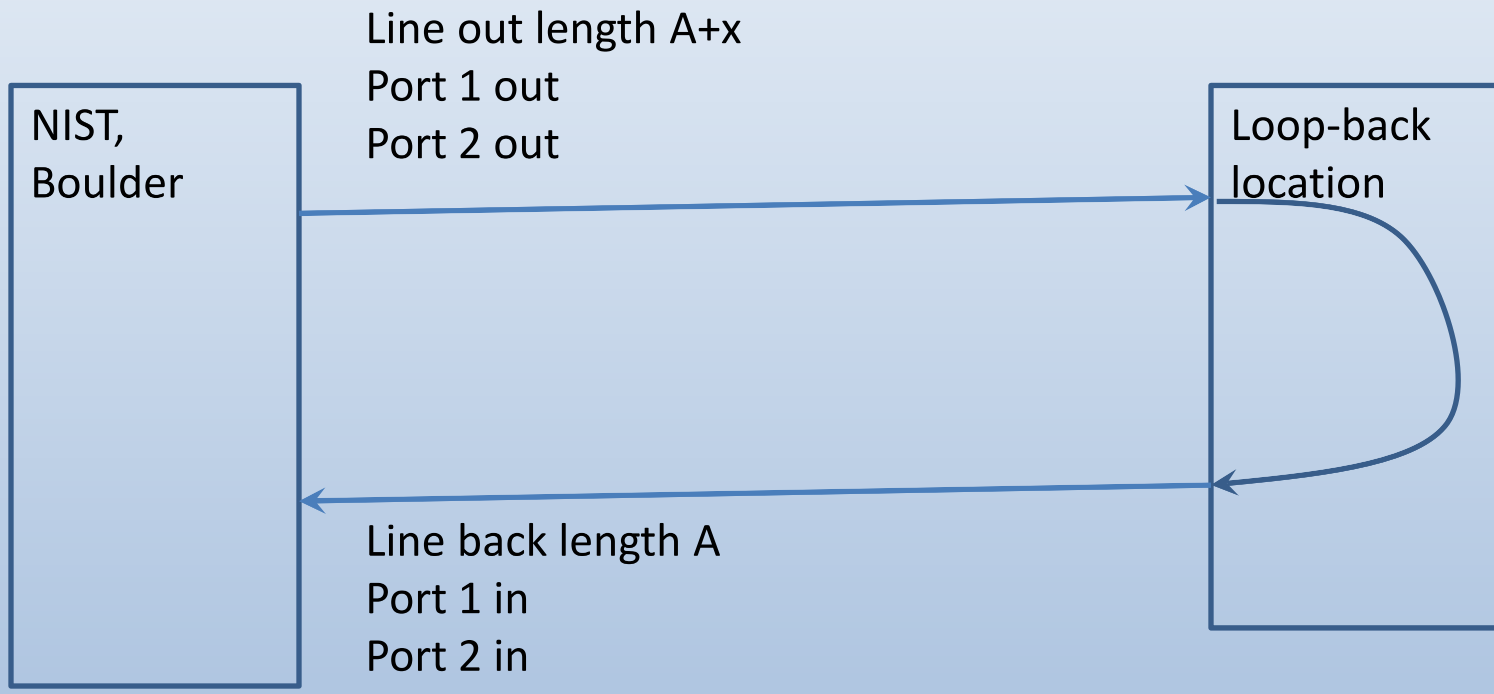
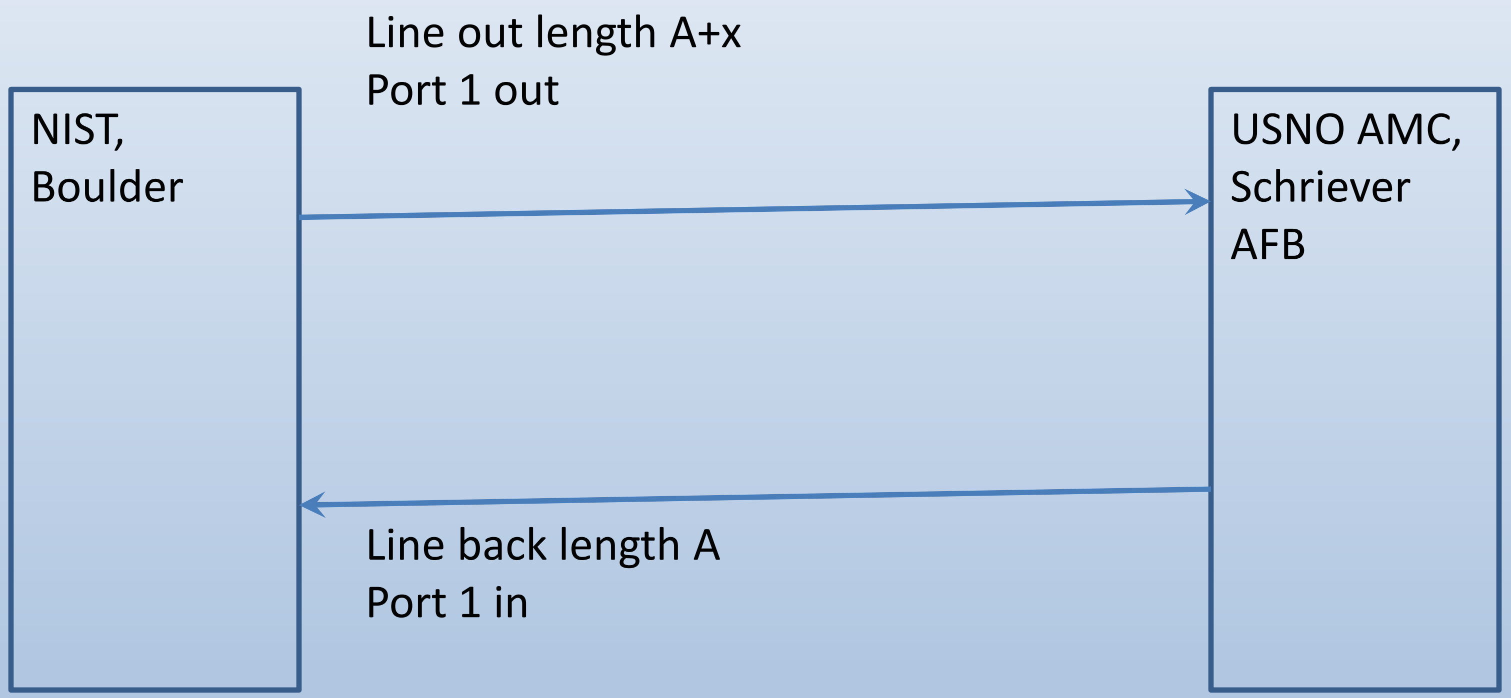
Loop-Back Test



For loop-back we are emulating time transfer between two locations by using two ports on the same device in NIST. Both the loop from Port 1 and from Port 2 measure a delay of 2A+x, hence the difference between length A and length A+x is not seen.

One-Way Measurement
NIST, Boulder to USNO AMC, Schriever AFB



Because NIST and USNO both have UTC synchronized within 10 ns, we measure the one-way delays in each direction. We see the difference x between the path of length A+x and the path of length A. We have seen a differential x of 40 µs.

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Remaining Issues for PTP over Fiber

- Sending PTP signals over long distances directly from a UTC source requires further testing
  - Native Gbit Ethernet networks with routers
    - With and without on-path support
    - Asymmetry issues
  - Other potential transports

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Expectations

- Time transfer accuracy will depend on the length of transport and number and type of network elements, as well as any impediments in signal transport
- Better than 100 ns *stability* probable over short links, and short times
- Accuracy depends on reducing or calibrating asymmetry – hope for sub microsecond