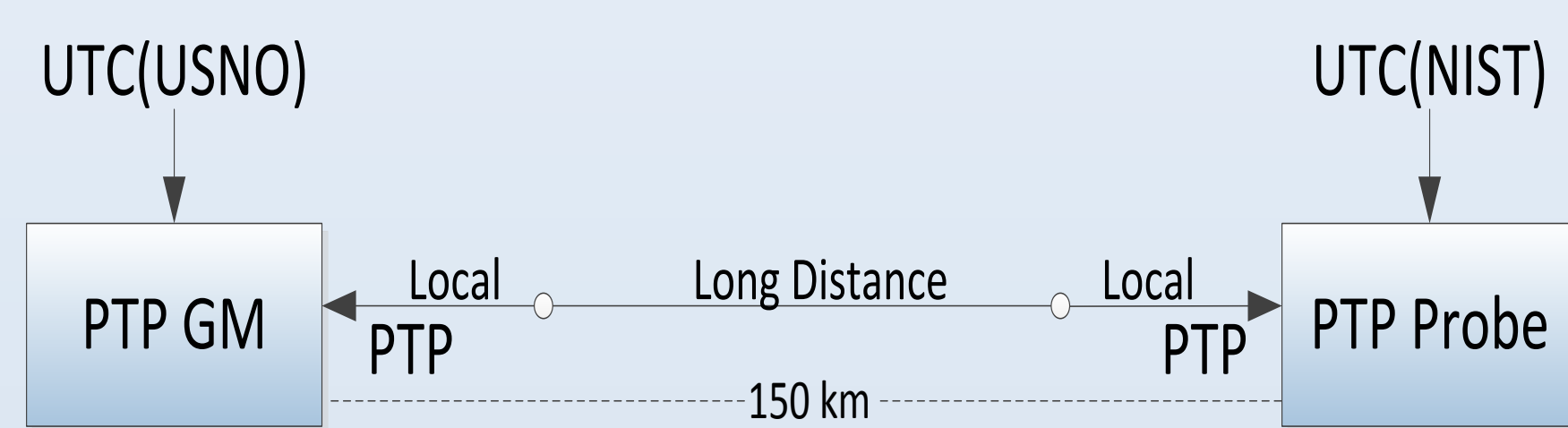


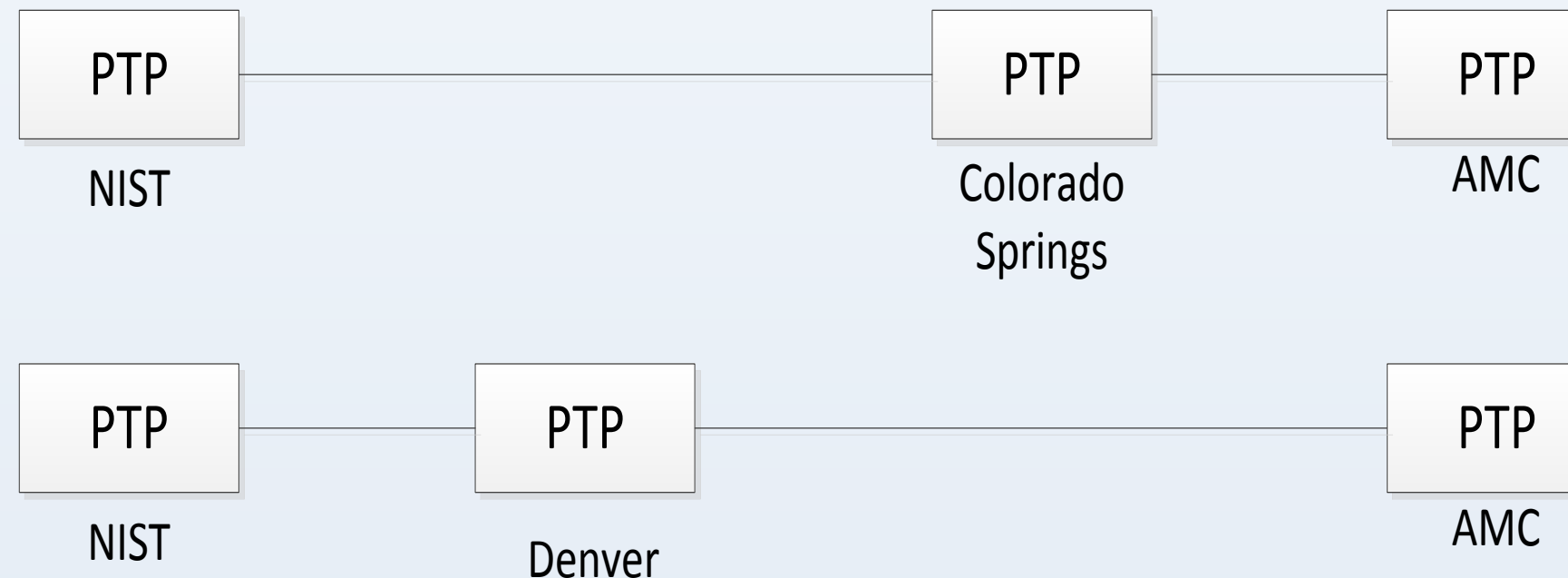
Preparing to Extend Commercial Telecom PTP Across the United States

History of Project

- Desire to back up critical infrastructure
- Three-way CRADA with NIST, Microsemi, and CenturyLink, started January 2013, now extended to January 2019
- Thus far have linked NIST, Boulder with the USNO Alternate Master Clock – UTC(NIST) with UTC(USNO)
- Two circuits studied
 - STS over SONET, OC-192
 - OTN on ODU-0 within ODU-2
- PTP Two-way time transfer using neighboring unidirectional fibers



- Asymmetry Investigation
- Placed Microsemi PTP Equipment in CenturyLink Offices



	AMC to NIST delay	NIST to AMC delay	Asymmetry
Direct circuit	2025 μ s	2066 μ s	40.5 μ s
Circuit broken in Colorado Springs	2270 μ s	2300 μ s	30.2 μ s
Circuit broken in Denver	2232 μ s	2278 μ s	46.5 μ s

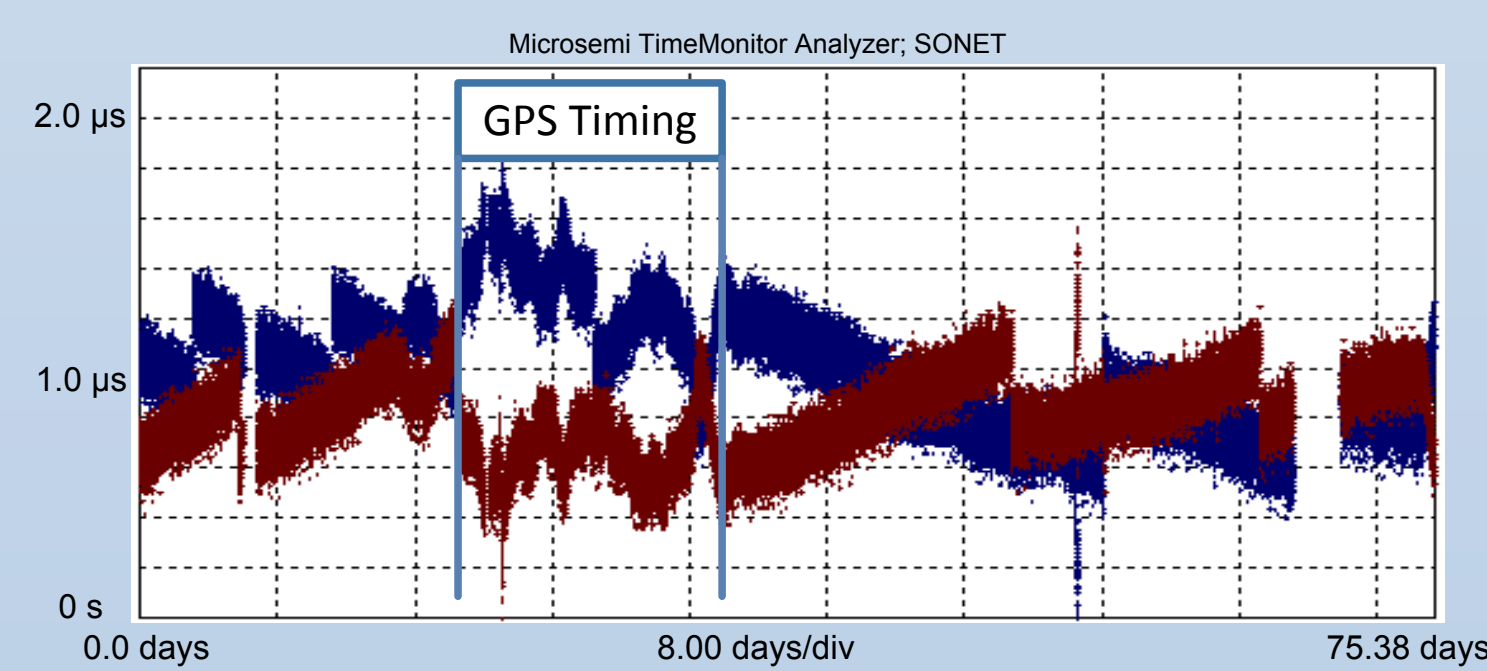
- PTP Probe gathers all timestamps
- One-way measurements are made in both directions

	Asymmetry	Delay	Jitter	Wander
PTP over SONET	40 μ s	2 ms	200 ns	300 ns
PTP over OTN	40 μ s	2 ms	< 4 ns	10's of ns

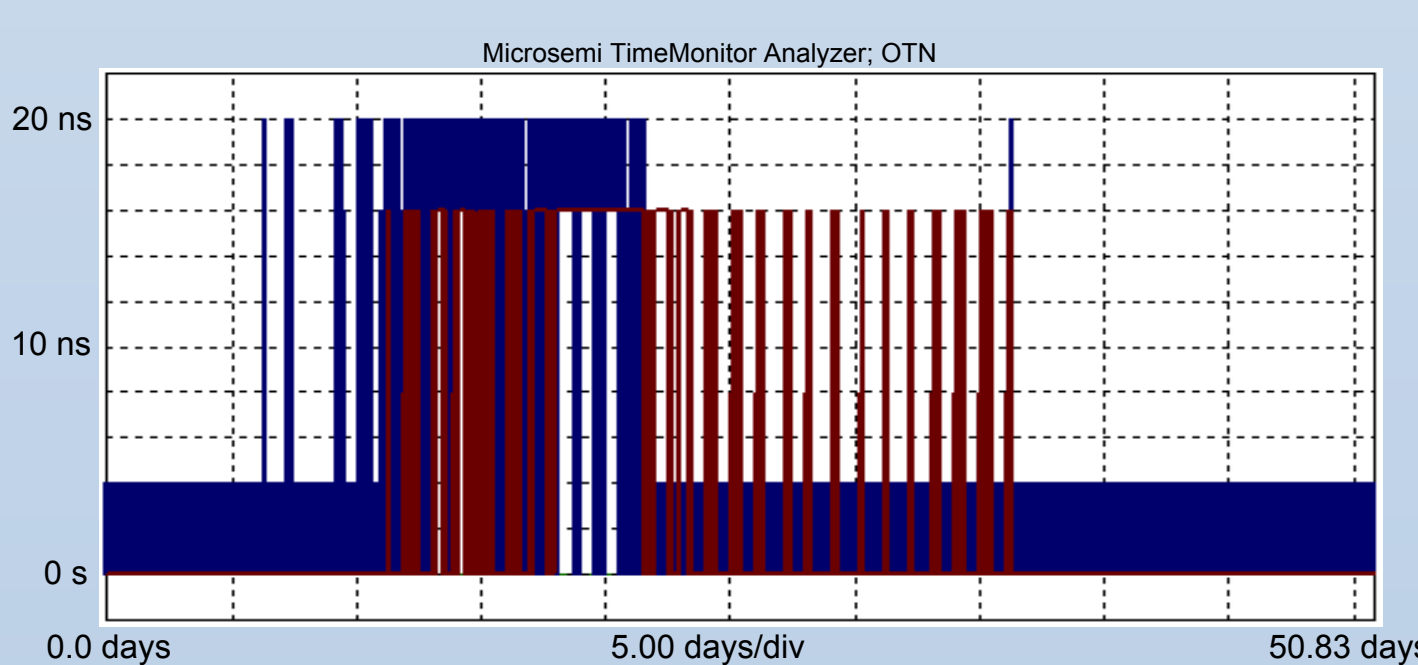
- Two important points
 - When circuits are rebuilt, latency and asymmetry change (see table above)
 - **Asymmetry is static and can be calibrated out as long as the circuit stays up: <100ns of time holdover indefinitely**
- Solving Asymmetry – APTS: G.8275.2
“Precision time protocol telecom profile for time/phase synchronization with partial timing support from the network”
- **Stability under 100 ns becomes accuracy, once the bias is calibrated, such as with GPS**

AMC to NIST (blue), NIST to AMC (red)

SONET - OC192

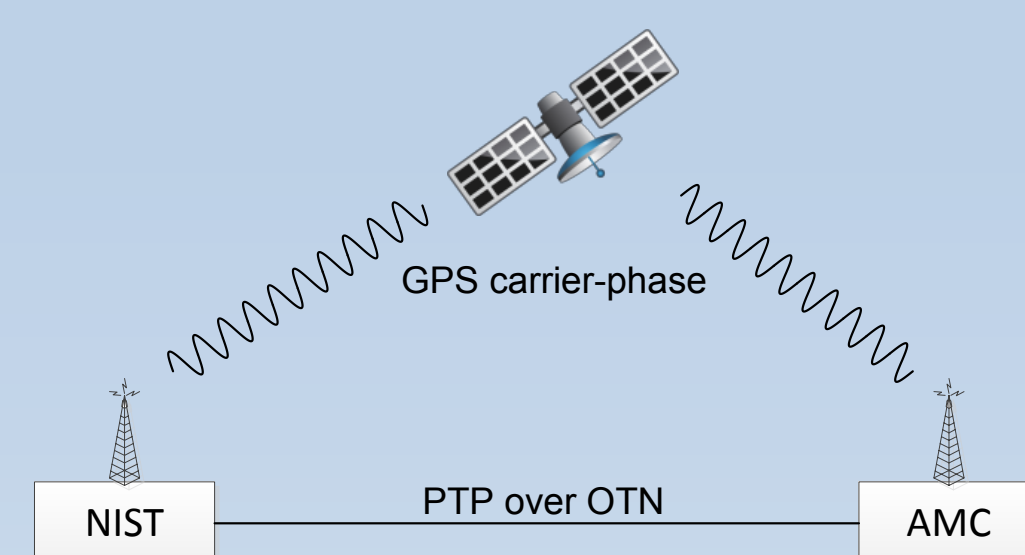


OTN

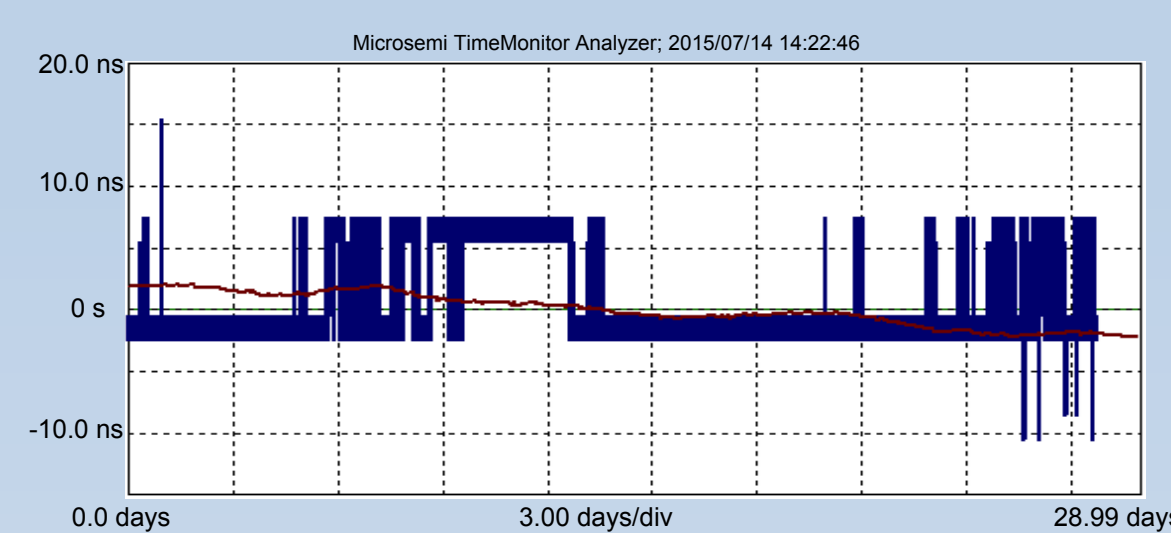


PTP fiber vs. GPS Carrier Phase

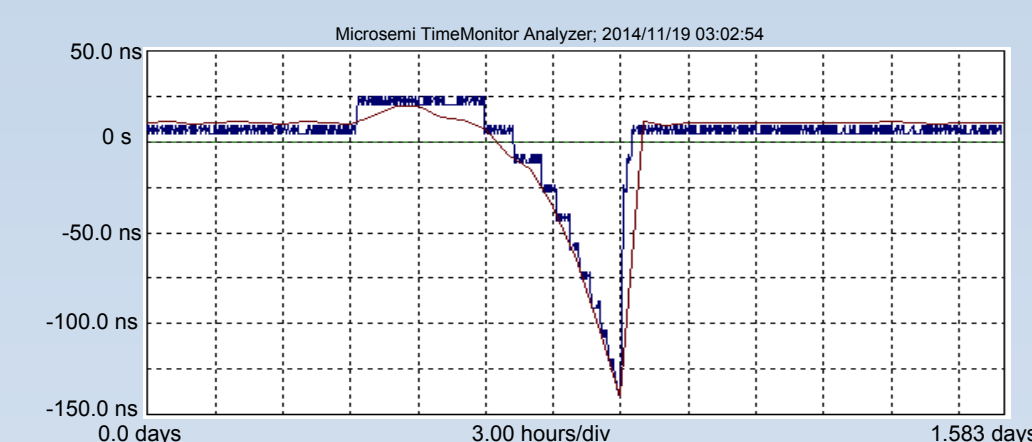
PTP (blue) and GPS carrier-phase (red)



Normal



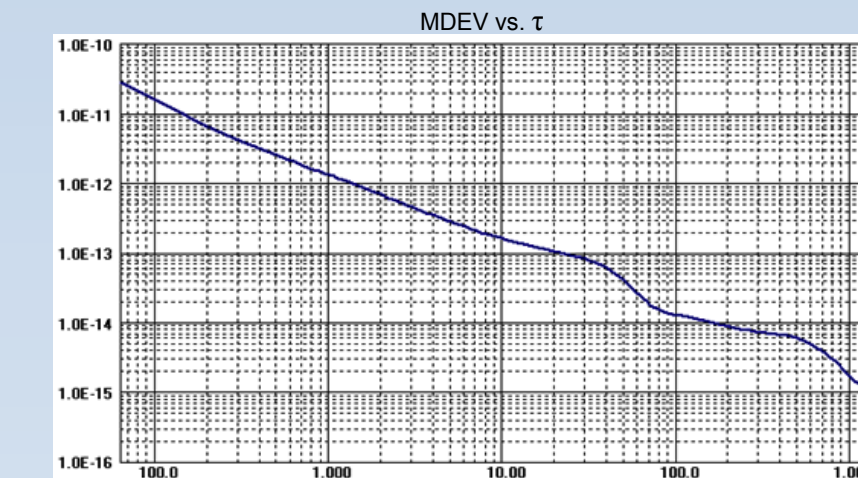
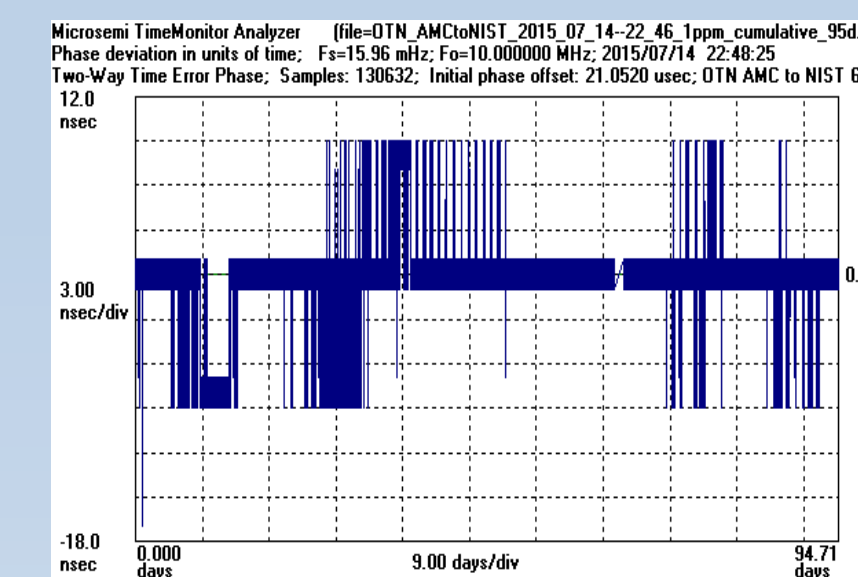
Failure



Long-term PTP Fiber Measurement

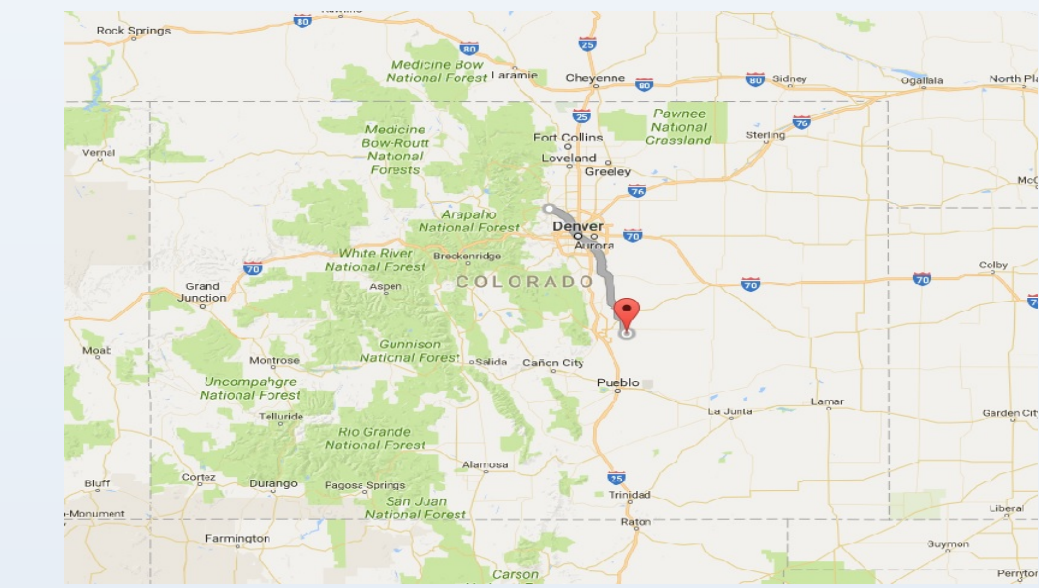
Two-way time error calculation on 95-day measurement shows 26 ns peak-to-peak over the entire run, **supporting the potential for providing 100 ns indefinitely**

The Modified Allan Deviation (MDEV) on 95-day PTP fiber measurement, **shows the capability of frequency transfer approaching 1 part in 10¹⁵ at 10 days**

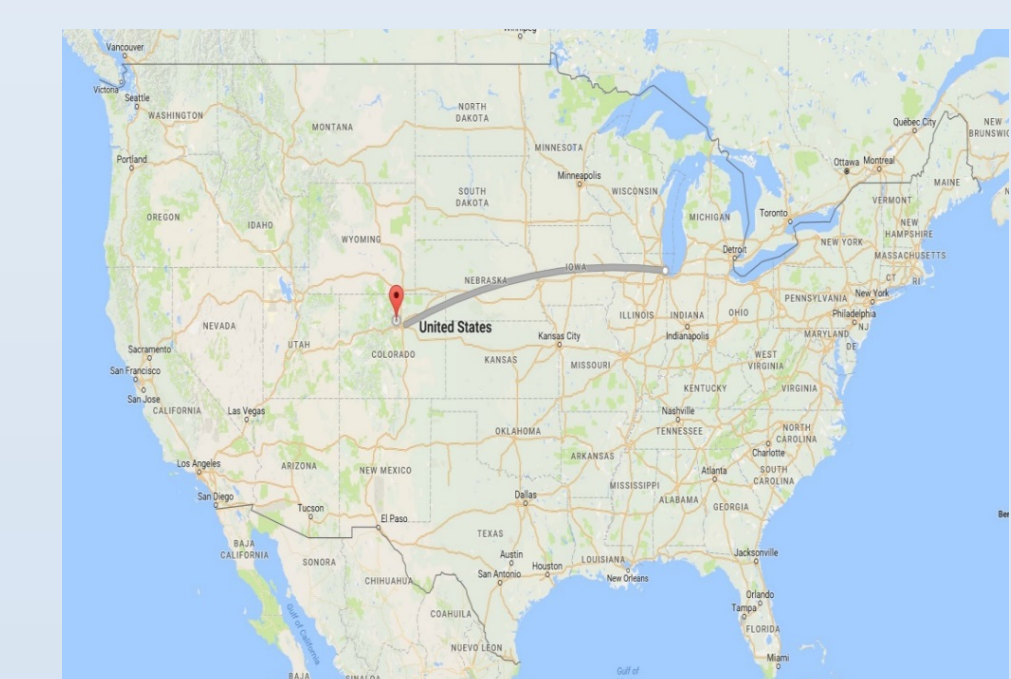


Next Phase: Long-range Circuit

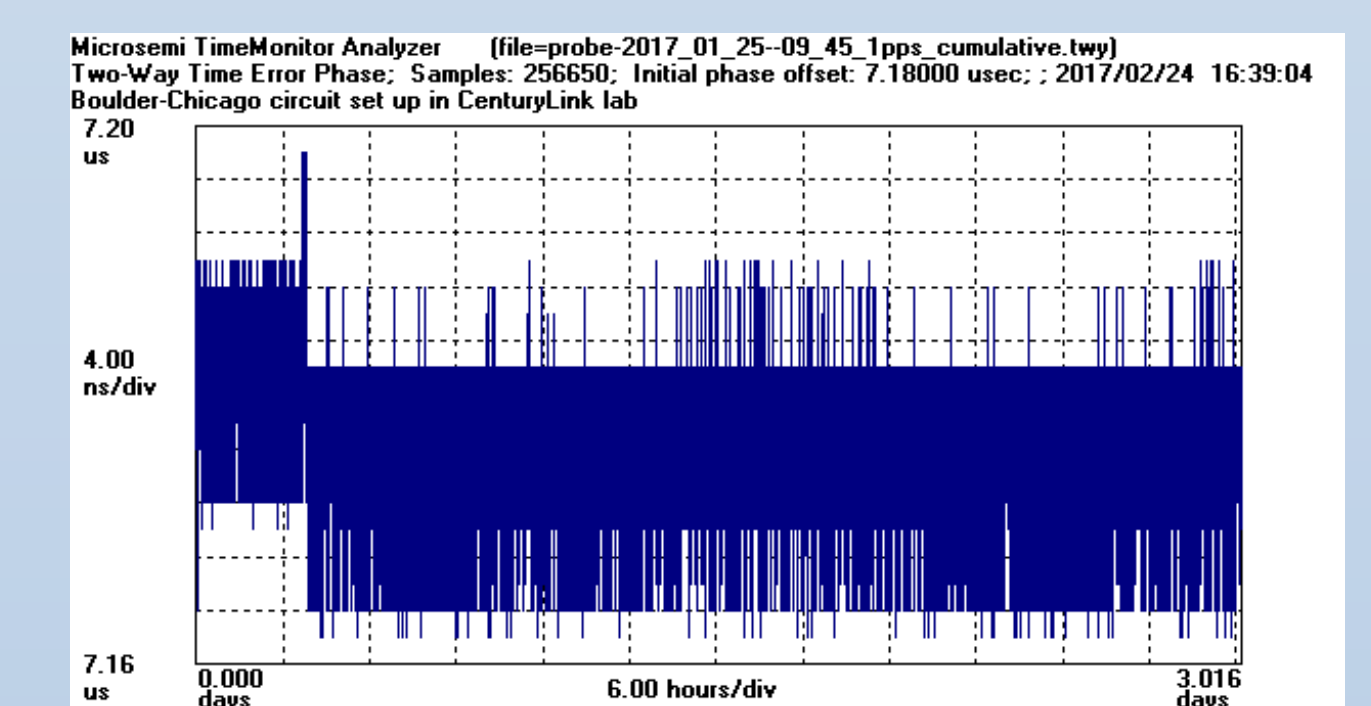
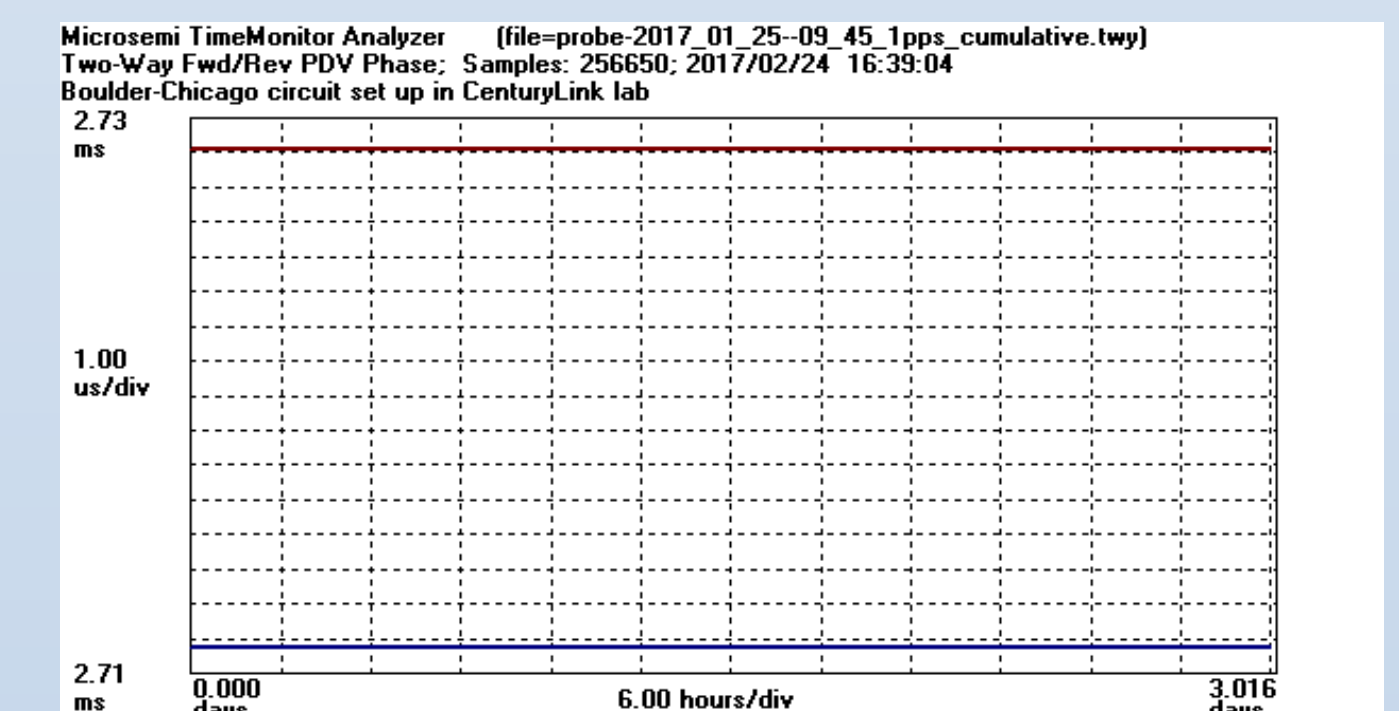
Current: Boulder (NIST) to Schriever AFB (USNO) **150 km**



Next phase: Boulder (NIST) to Chicago **1700 km**



Long-haul Equipment Measurements: Boulder-Chicago circuit in CenturyLink lab:



- 14 μ s asymmetry
- 2.7 ms delay
- 36 ns stability

Conclusions

- The OTN transfer shows the potential for a time service < 100 ns, once calibrated, e.g. APTS
- Lab tests suggest that this will work across the country
- Actual testing remains to be done