High Accuracy Time Transfer over Traditional Networks

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ITU G8272.2 Coherent Network PRTC Standard (excerpt)

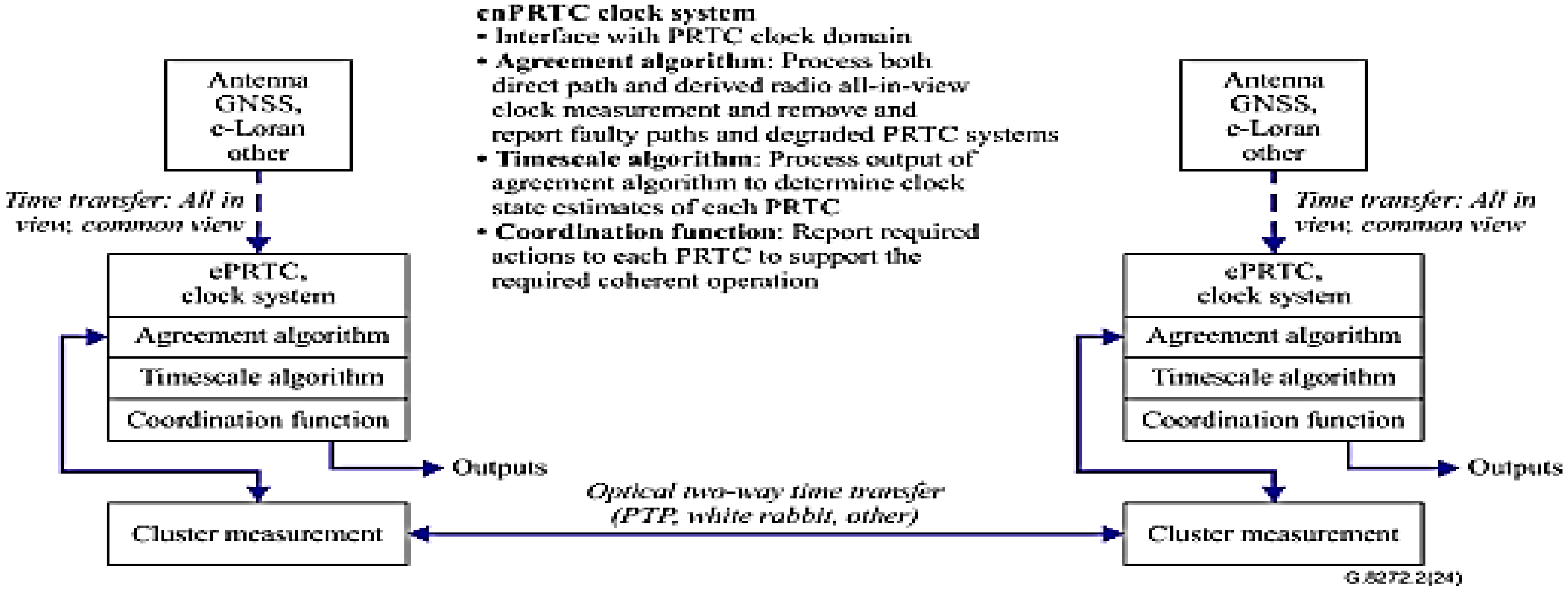


Figure I.2 – Coherent network PRTC functional architecture

Figure I.2 shows that there are three components to the ensembling function: 1) agreement algorithm; 2) timescale algorithm; and 3) coordination function. These are discussed in this clause. As noted in the first paragraph, the timescale algorithm is at the heart of the ensembling function, though important aspects are also contained within the agreement algorithm and coordination function.

NOTE – Performance requirements of high-accuracy time transfer over optical links ("Optical two-way time transfer" in Figure I.2) are covered in [ITU-T G.8271.1].

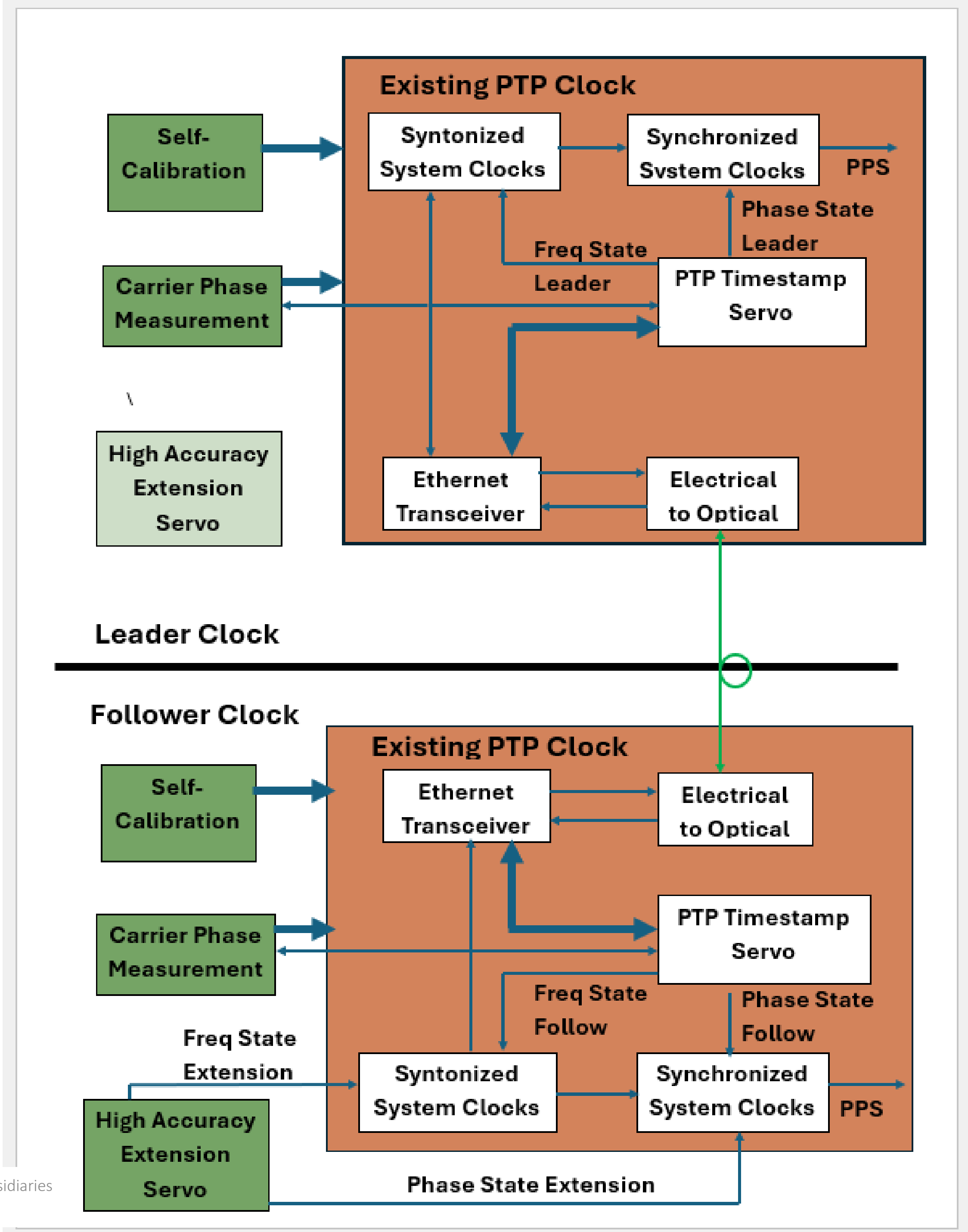
High-Accuracy Time Transfer

Several Levels Available

- **Class D (5 ns time error) boundary clocks (one clock)**
  - Widely deployed in virtual PRTC (vPRTC) horseshoe architectures with multi-domain high performance boundary clocks and ePRTC with east-west directions for redundancy, using Optical Timing Channel (OTC) or Optical Supervisory Channel (OSC)
- **High-Accuracy Time Transfer (HA-TT) (chain of clocks)**
  - Using enhanced hardware platform with world class synthesizer
  - High accuracy extension servo
  - Meets ITU G.8271.1 class A requirements (5 ns time error over 800 km)
  - Hardware ready for class B (1ns over 800km) with software calibration enhancements.

Evolutionary High-Accuracy

- Existing PTP clock red block
- Green blocks show extensions for high accuracy
- Extensions require only a software upgrade
- PTP clock hardware needs to meet sensible requirements



Carrier Phase and Time Stamp Measurements

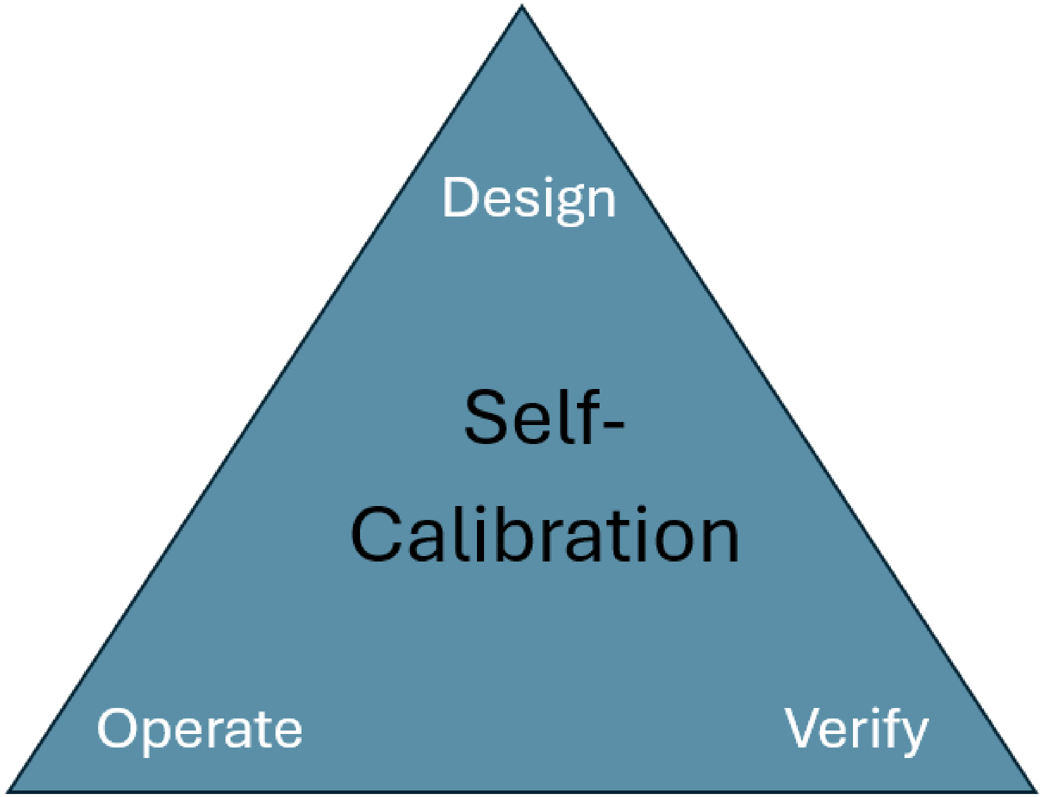
- **Carrier phase measurement**
  - Complements timestamp measurement in much the same way that carrier phase measurement complements code delay measurement in GNSS systems
- **Timestamp measurement**
  - Standard accuracy PTP utilizes event timestamping
  - The timestamp is an isolated event which limits resolution to the single shot performance of the time to digital converter TDC
  - Even so timestamp measurement is now achieving nanosecond performance with well designed TDC and self-calibration

Carrier Phase Measurement - Unparalleled Stability

- **Carrier phase measurement**
  - Observed over a window of time associated with the timestamp events
  - Carrier phase is cyclical which can be leverage to obtain a phase measurement with orders of magnitude less uncertainty than with the timestamp measurements
- **Novel measurement approach**
  - utilizes an interrogation approach controlled by parameters in software to achieve optimal performance over the full range of optical transports and distances

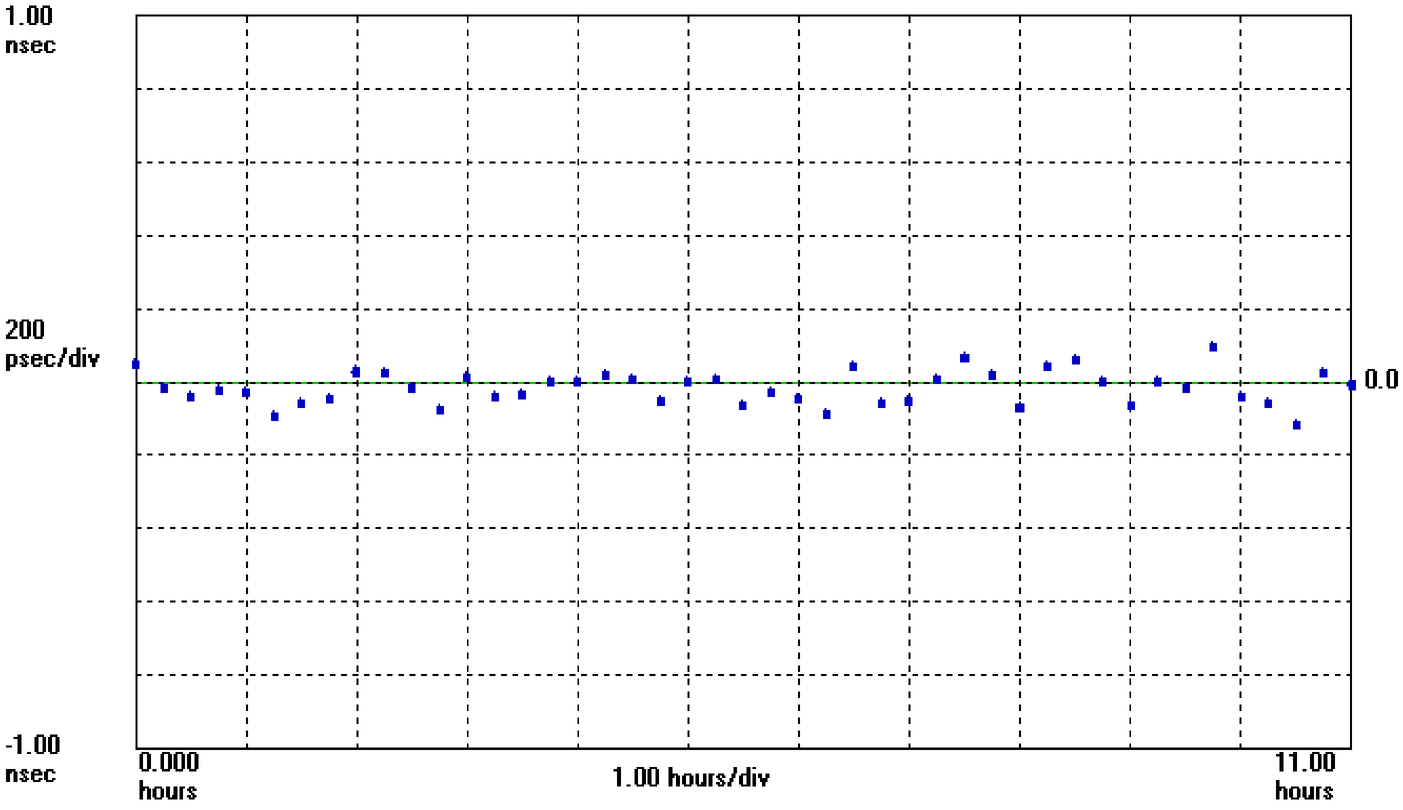
Self-Calibration Principles

- **Measurements are only as good as delay calibration**
- **Design: delays constrained by intentionally good design**
- **Operate: certain delays (e.g. transceiver) are prone to modal behaviors mitigated with proper operation**
- **Verify: delay paths are verified with internal (FPGA) techniques**



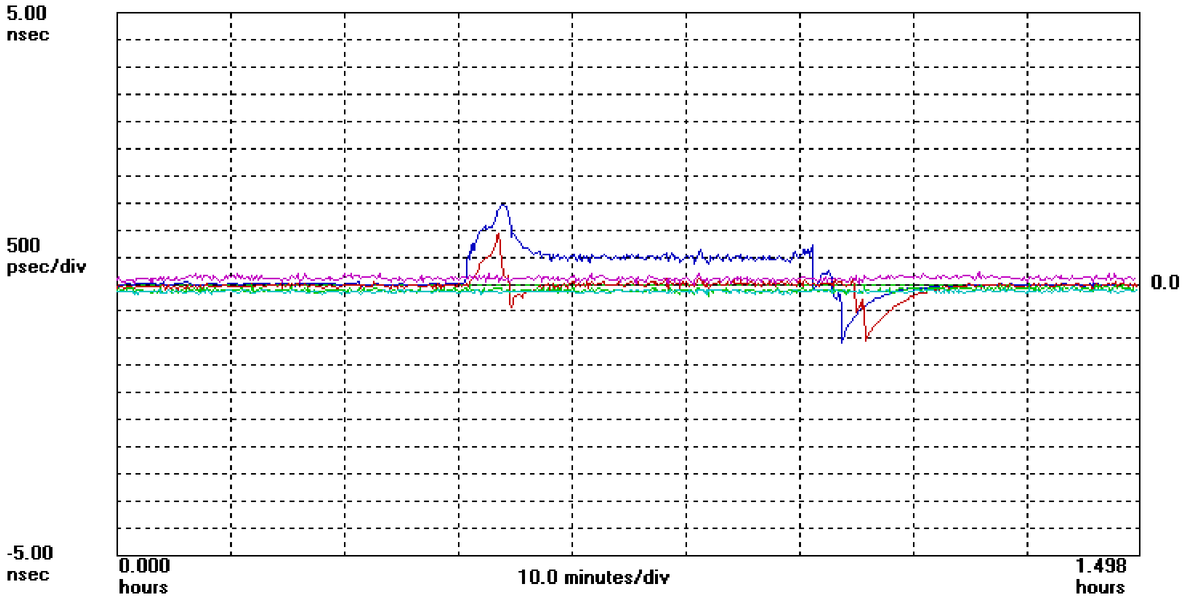
Self-Calibration Repeatability Overnight Fiber Cuts

- **Two units upgraded with high accuracy software**
- **100 km fiber (on bench)**
- **Fiber cuts every 15 minutes**
- **Calibration repeatability better than 50 ps (one sigma)**



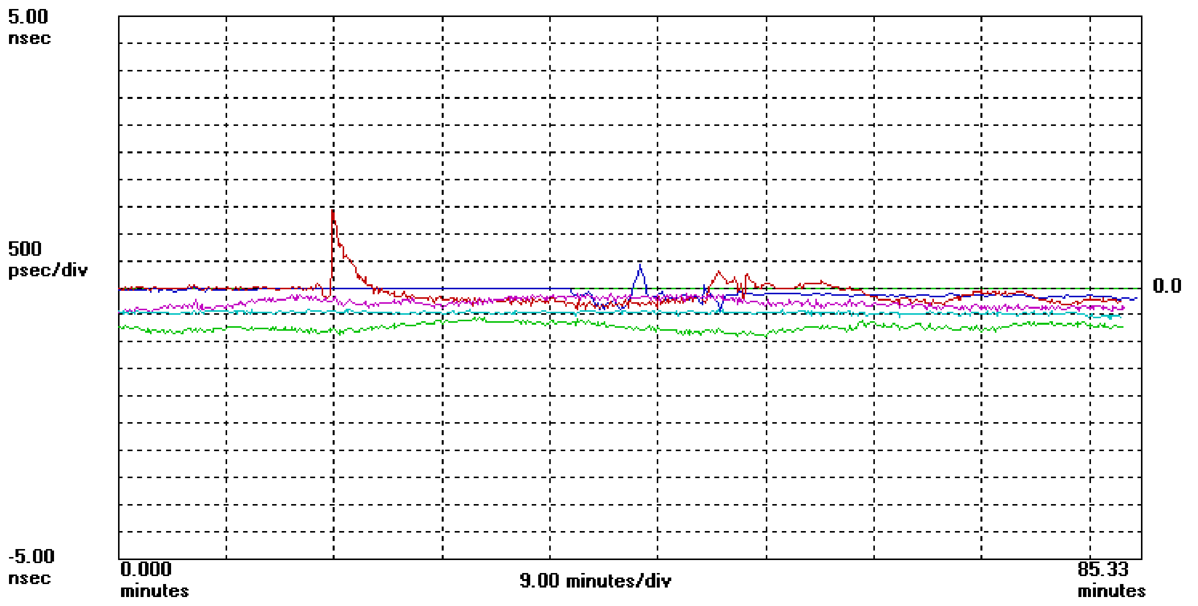
Fiber Cut in 400 km Six Node Ring

- BC1, BC2 on clockwise path to start
- BC3-5 on counterclockwise
- Fiber cut between master and BC1 at 30-minute mark
- Fiber restored at 60-minute mark
- Transients well within ITU Class A 5 ns limit
- Residual dispersion offset related to simple model dispersion compensation



Node Outage in 400 km Six Node Ring

- **BC1, BC2 on clockwise path to start**
- **BC3-5 on counterclockwise**
- **BC1 suffers a dual power failure at 15-minute mark**
- **Power restored at 30-minute mark**
- **No manual intervention node powers up, self-calibrates and returns to service**



High-Accuracy Time Transfer over Distance

1 km

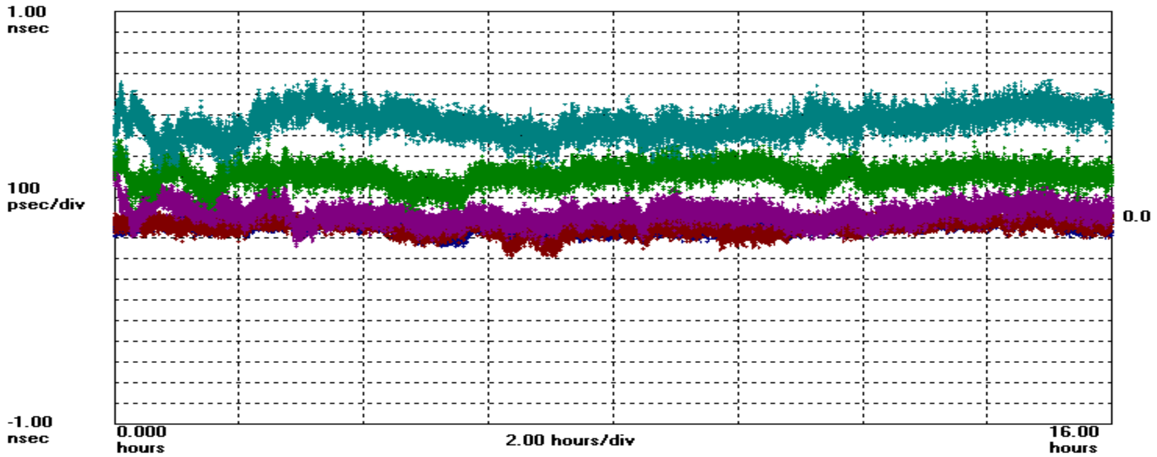
- 6 nodes spanning less than 1 km (bottom)

400km

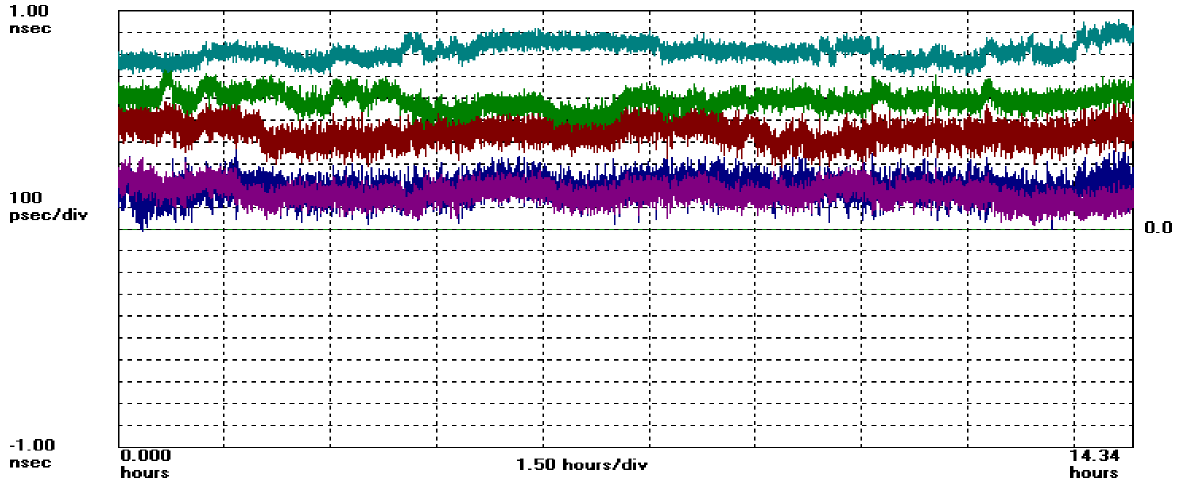
- 6 nodes spanning 400 km (right-top)

800km

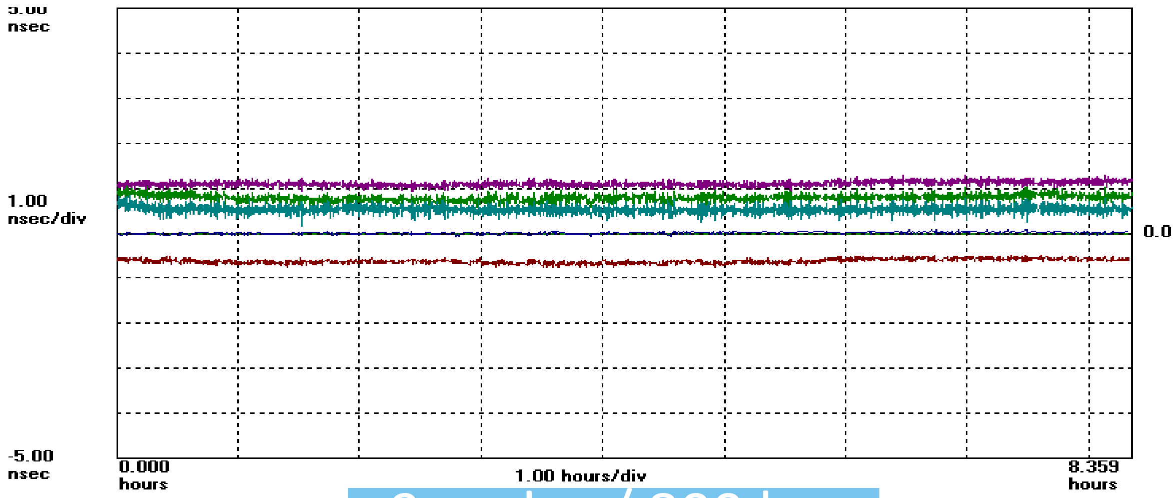
- 9 nodes spanning 800 km (right-bottom)



6 nodes / 400 km



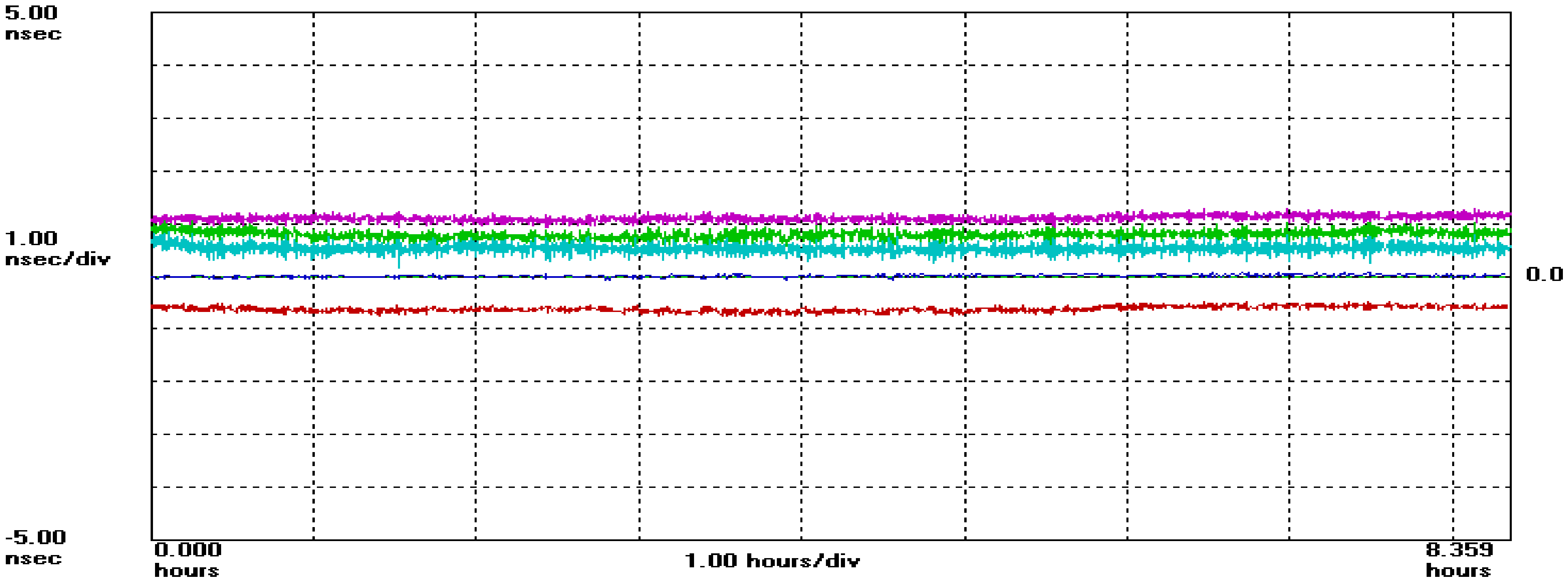
6 nodes / 1 km



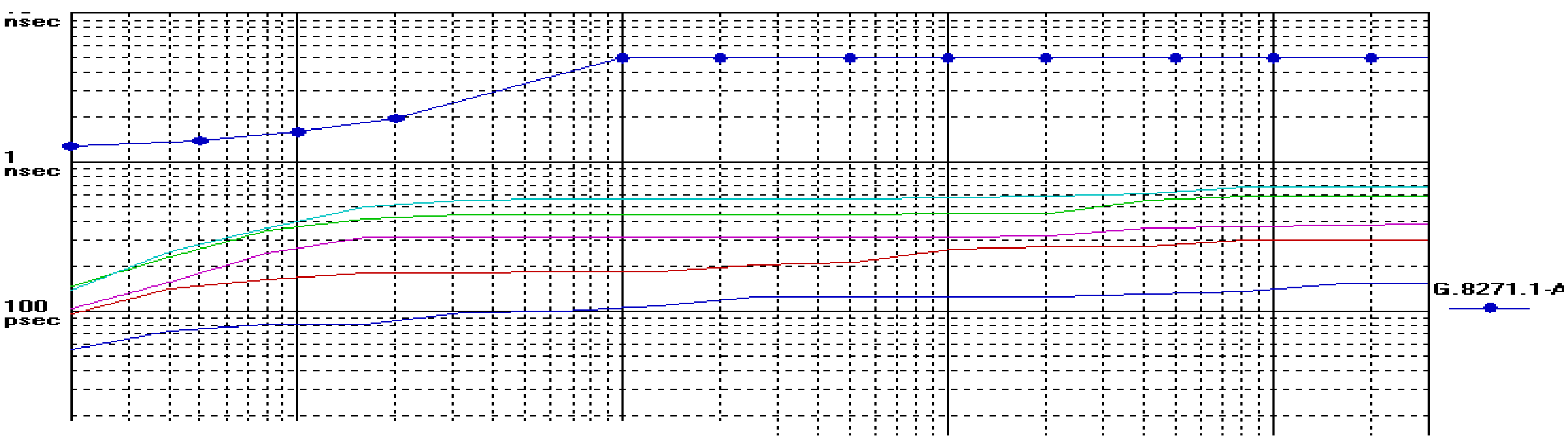
9 nodes / 800 km

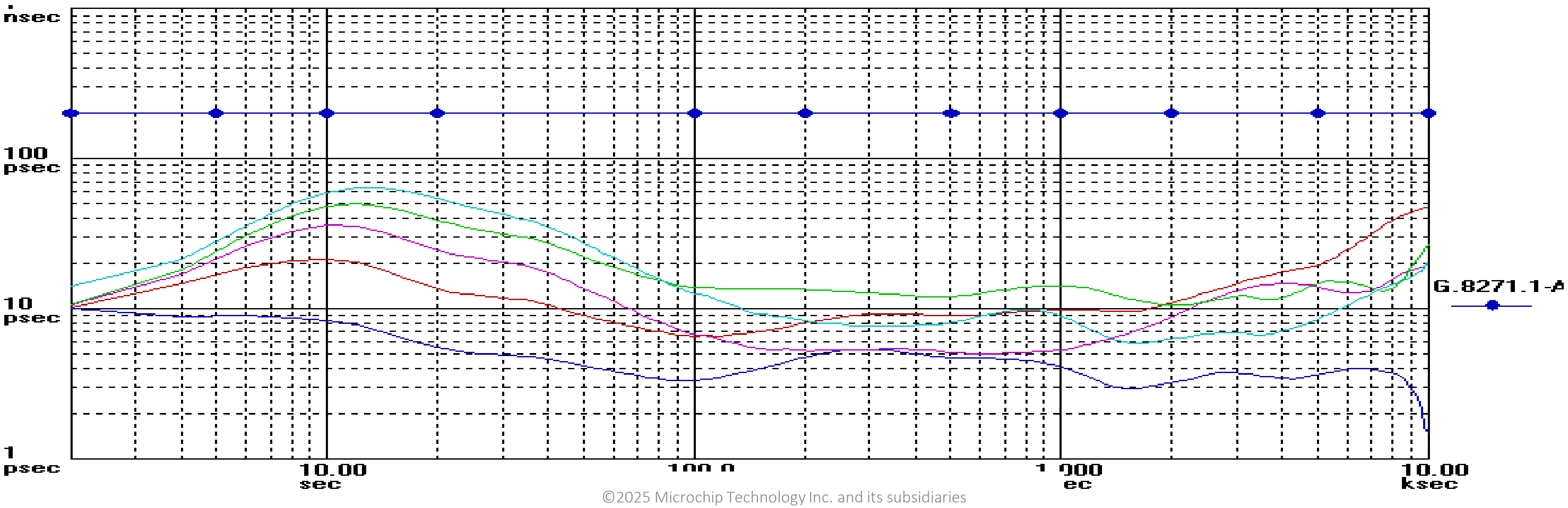
High Accuracy 800 km ITU G.8271.1 Compliance

- **9 node linear chain with 100 km fiber between nodes (800 km ITU reference connection)**
- **Accuracy well within 5 ns over 800km required**



High Accuracy 800 km ITU G.8271 MTIE and TDEV

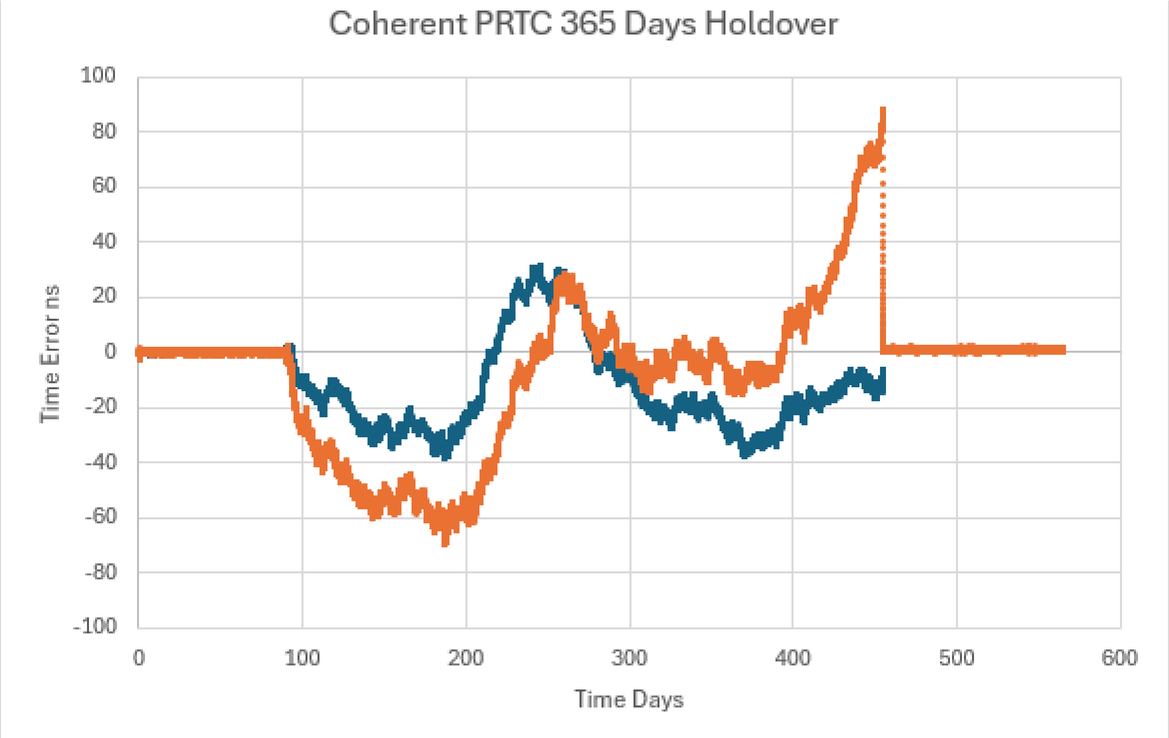




MICROCHIP

Coherent PRTC Performance Compliance

- **Time traceability through HA-TT path back to UTC-K site.**
- **Local (gold) utilized local co-located cesium**
- **Collaborative ensemble (blue) optimally combines local cesium with remote cesium of neighboring sites.**
- **Loss of time traceability last for 1 year**



Conclusions

- **HA-TT does not require a revolution but an orderly evolution leveraging traditional PTP networks and optical network**

- **Resilient high accuracy operation under real world events such as fiber cuts and node outages is essential**

- **ITU G8271.1 performance is demonstrated over local, metro and national distances**
- **Coherent PRTC operation is demonstrating showing resiliency of distributed timescale in extended loss of external traceability**