High Accuracy Optical Boundary Clocks

A Leading Provider of Smart, Connected and Secure Embedded Control Solutions

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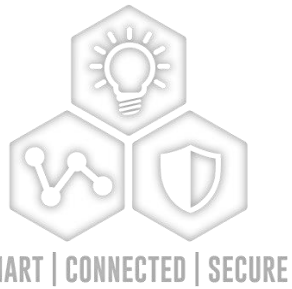
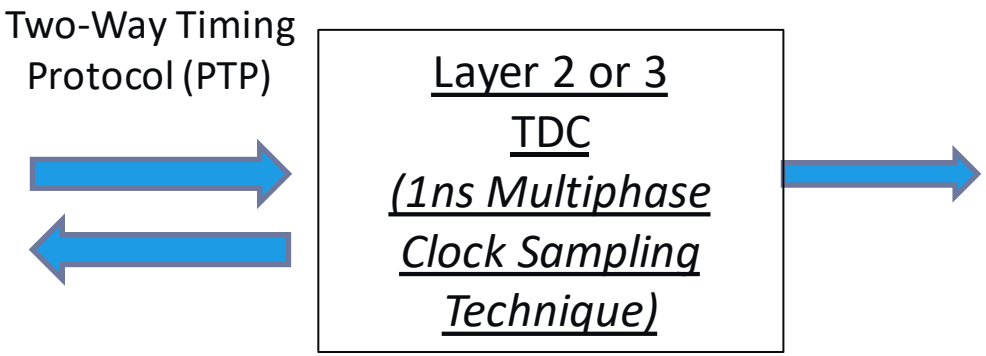


How to Achieve Sub-Nanosecond PTP?

- Precision Timing Protocol (PTP) is built on delay reciprocity
- Optical transport without intervening processing nodes enables sub-nanosecond performance
- To realize optical accuracy the timestamping of the timing packet is moved near the physical layer
- This time stamping process (time to digital conversion) is one critical aspect

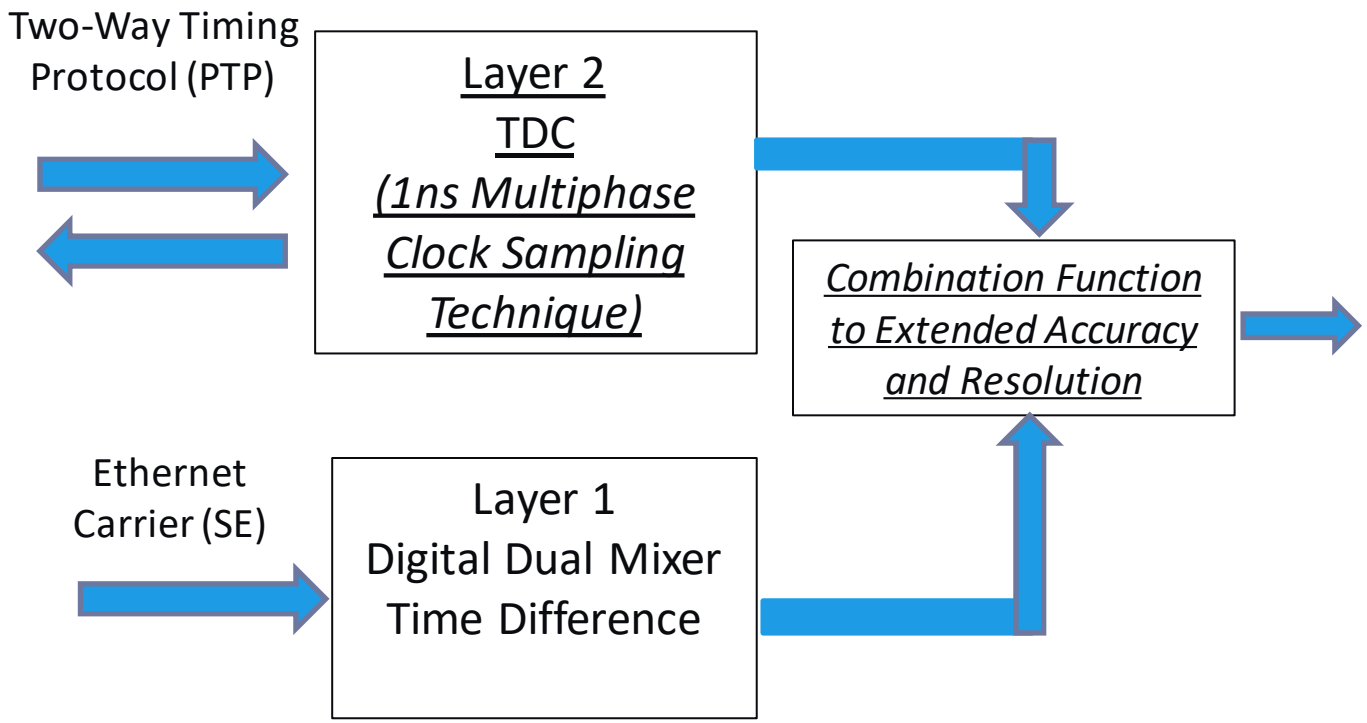
Time Digital Conversion (TDC) in PTP Today

- TDC observes the local time of the arrival or launch of a key point in the PTP timing packet (Start Of Frame -SOF)
- Serial to parallel conversion results in a 10-bit ambiguity between the local receive 125MHz clock and the SOF.
- Sub 8ns resolution required that this ambiguity be resolved
- With this correction we can consider the TDC timestamp as representing the timestamp of the SOF
- One technique to improve TDC resolution is to operate effectively multiple 125 MHz phases. (8 phases of clock to achieve a 1ns resolution



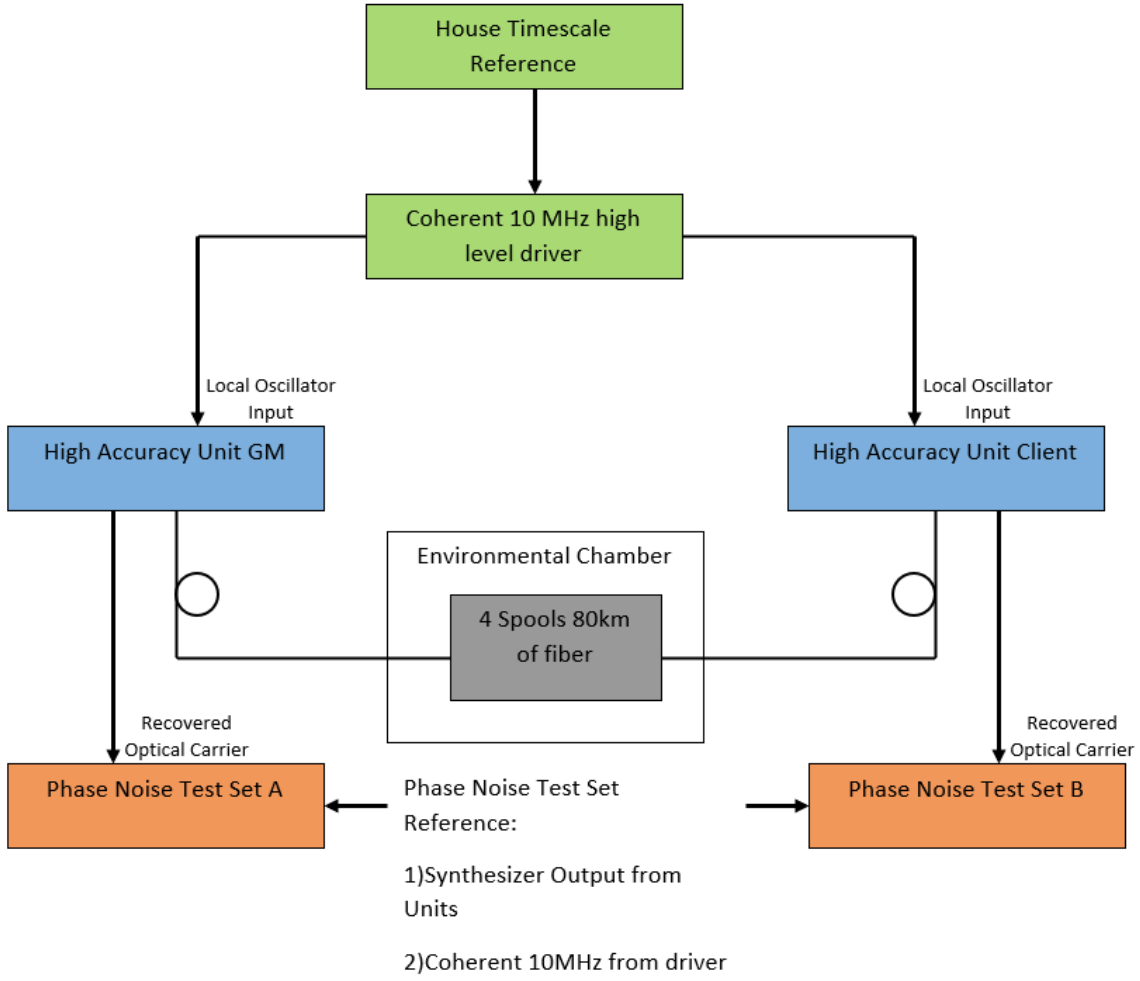
Time Digital Conversion Hybrid Approach H-TDC

- Sub-nanosecond high accuracy extension achieved with synchronous Ethernet
- Analogous to the mature carrier phase enhancements used in GNSS
- Combination function performs cycle ambiguity resolution to generate a single extended resolution timestamp
- One time calibration is performed before field operation to ensure accurate timestamping and supports existing standard protocols (8275.1)
- Since the output is an ultra-accurate timestamp, existing analysis such as floor population can detect anomalies



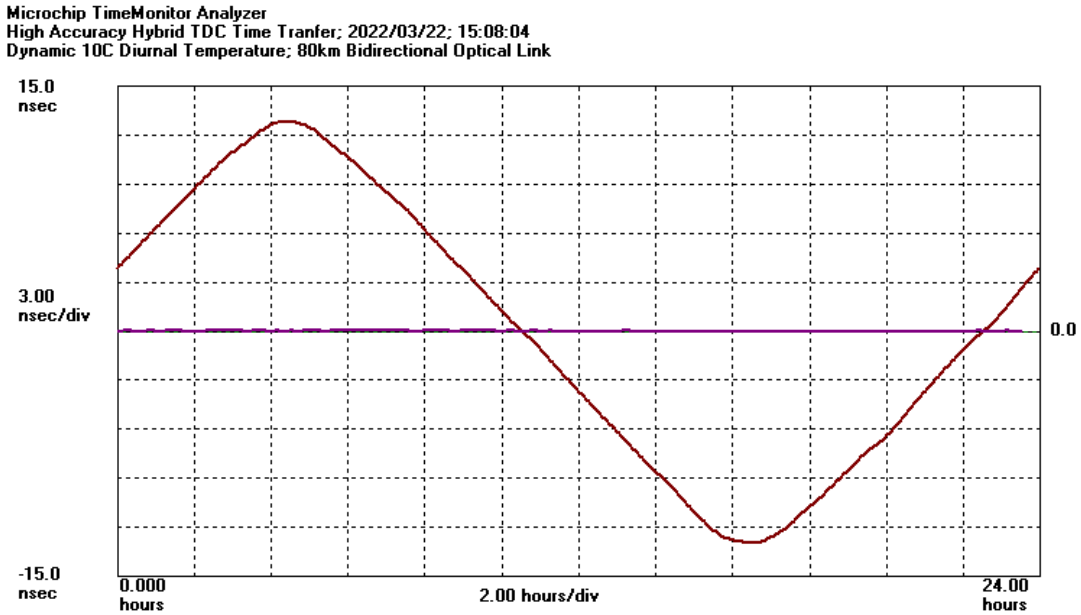
Optical Link Temperature Sensitivity Test Setup

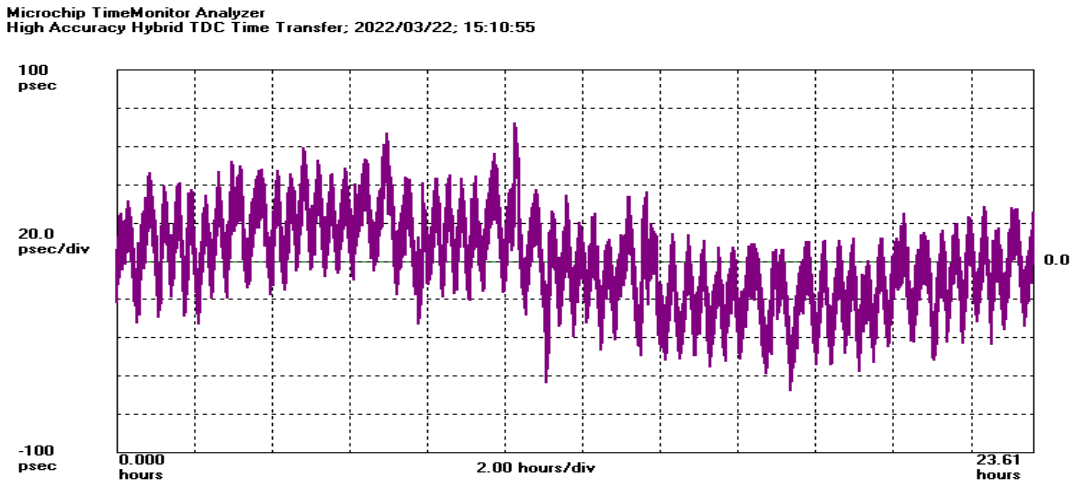
- Common coherent LO to both units under test
- Optical Interconnect fiber spools in chamber
- Hybrid TDC (H-TDC) data observed on both units
- External precise phase noise test sets observed 125 MHz carriers as well



80 km Optical Link Temperature Sensitivity

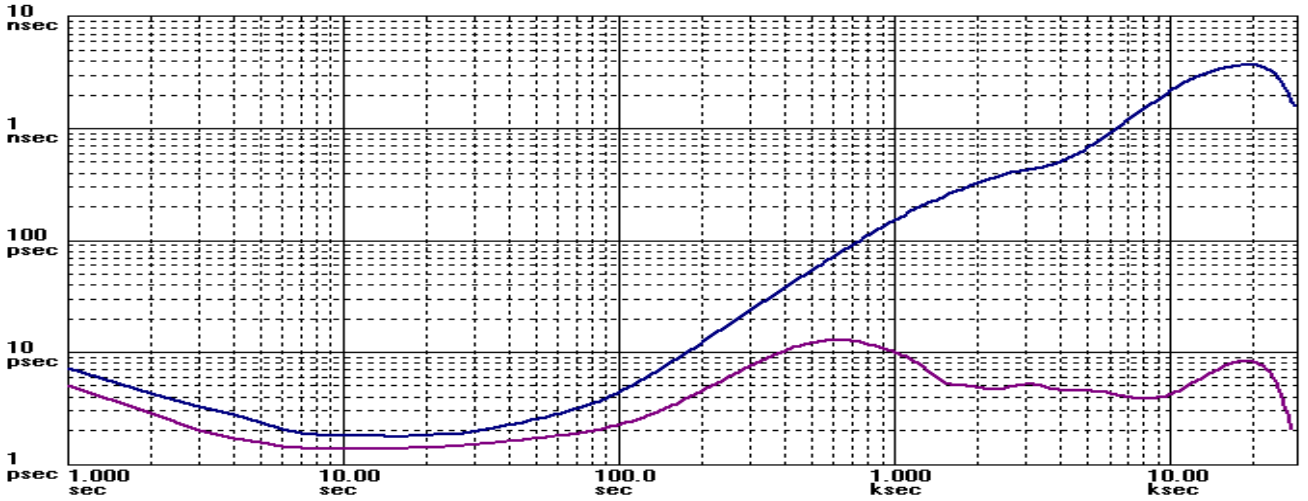
- 80 km optical link subject to 24-hour 10C cycle
- First graph show 25ns delay variation in both directions
- One directional Sync E is exposed to temperature wander
- H-TDC supports excellent cancellation as seen in second graph (20 ps per div)

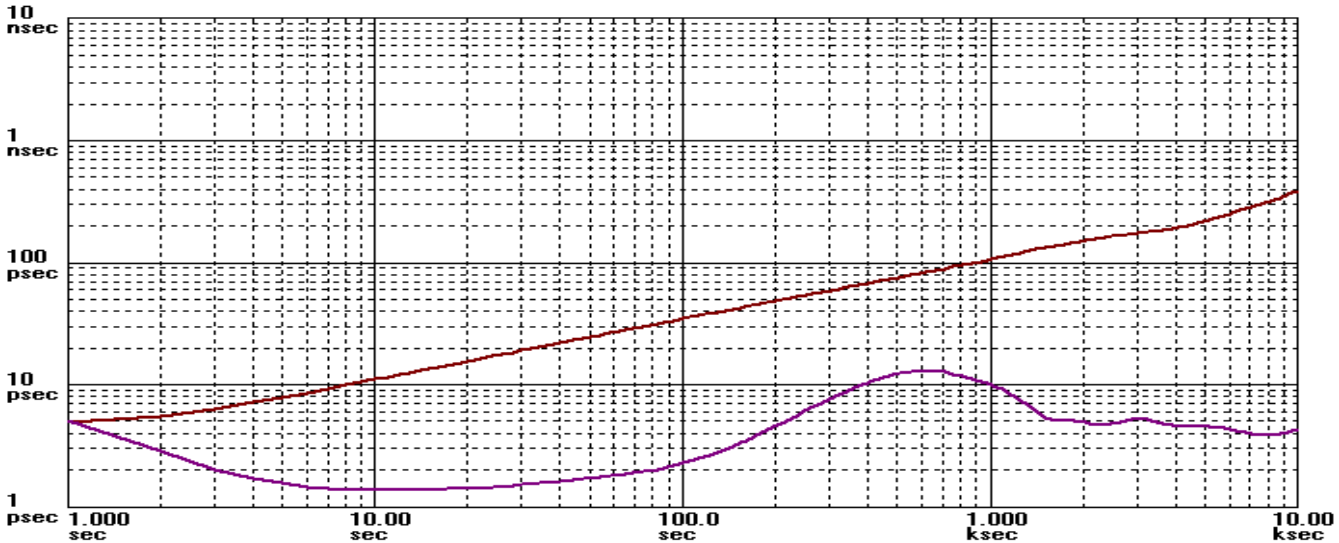




80 km Optical Link Temperature Sensitivity

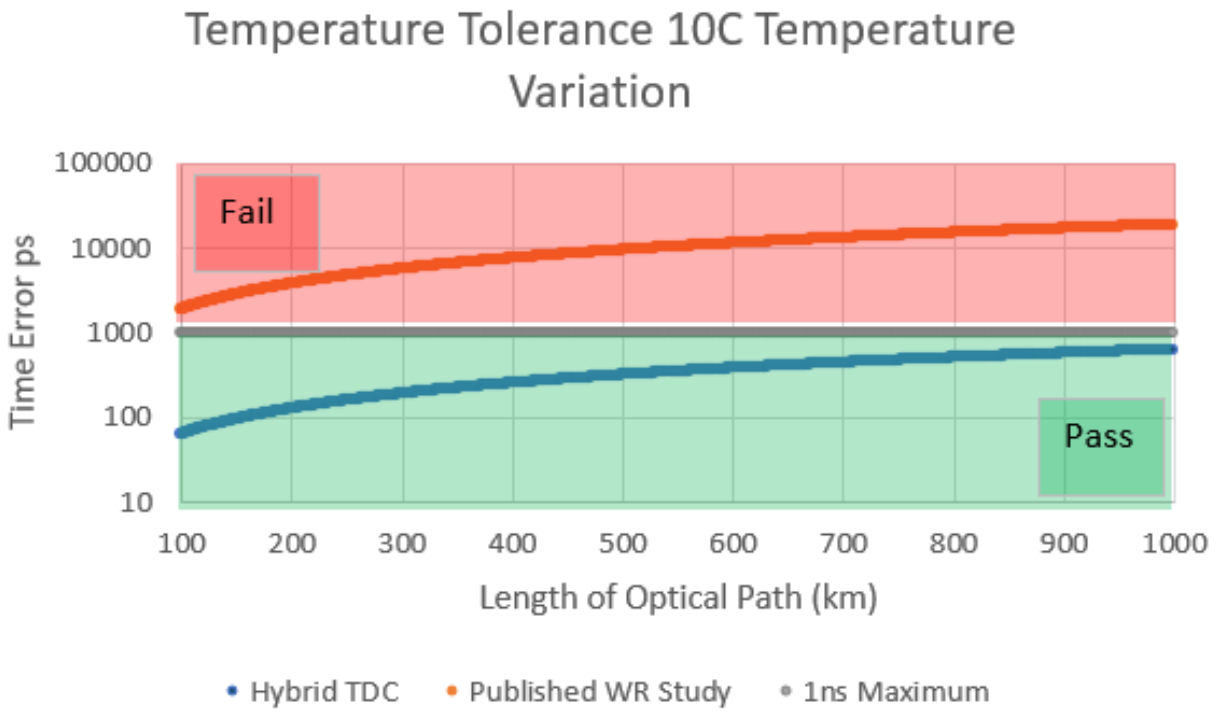
- First graph compares one-way to two-way time transfer TDEV
- Over 500x reduction in fiber temperature sensitivity (62fs/km-C)
- Second graph shows suitability to measure remote Cesium
- Time transfer floor better than Cesium even under temperature stress





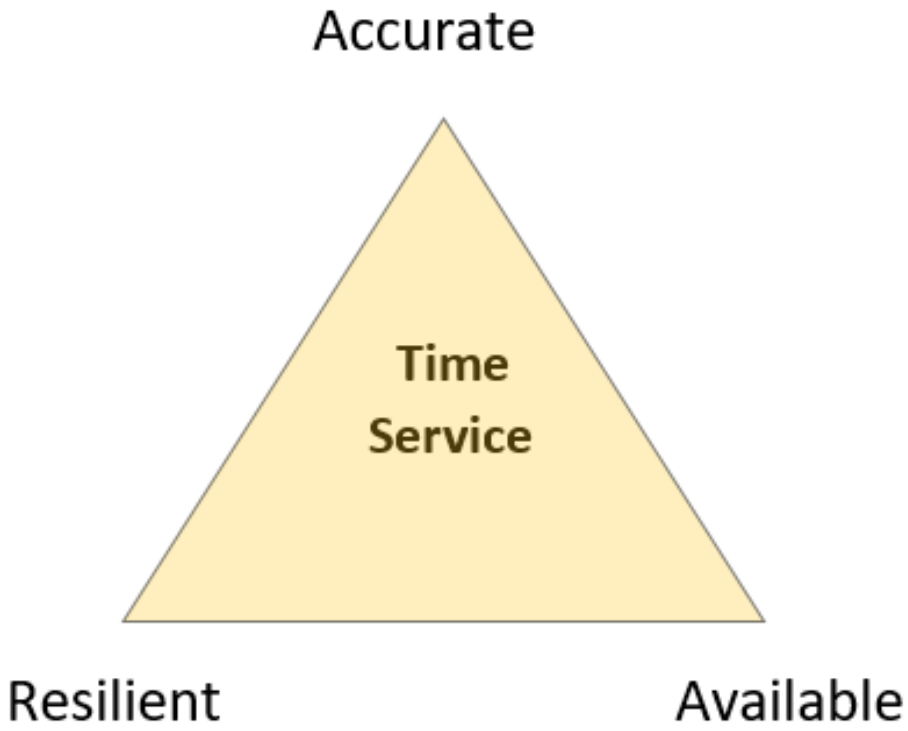
80 km Optical Link Temperature Sensitivity

- **ITU high accuracy 1ns**
- **Long distance (800km)**
- **Consider temperature**
  - Temperature variations 10C
  - Daily and seasonal
  - Buried and aerial fiber
- **Resilient time transfer in actual environment challenging**
  - H-TDC 10x better than recent published WR study



Time Transfer More Than Accuracy

- High a**ccuracy** is not the whole story
- For most applications there is a need to deliver time services in real time
- A complete system must address resiliency and availability
- **Resiliency** ensures the system can tolerate real world issues such as intentional or unintentional degradation of optical link or device
- **Availability** ensures that the system has adequate redundancies and back-up to maintain high accuracy under failure and maintenance



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High Accuracy Optical Time Transfer Summary

- **Hybrid TDC achieves picosecond-level optical time transfer performance with required temperature resiliency**
- **Optical Boundary Clocks with hybrid TDC synergistic with standards**
  - Sub-nanosecond does not require new protocol standards
  - H-TDC is fully complaint with new high accuracy protocols
- **Optical Boundary Clocks need to address not just high accuracy but also resiliency and availability**

Thank you

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