Core of Synchronization: The Adaptive Servo

Precision Timing Intelligence for Modern Networks

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TIMING & SYNCHRONIZATION SUMMIT

SyncMonk
Synchronizing World

The Synchronization Challenge

Distributed systems today depend on nanosecond-accurate time—but face unavoidable disruptions

Key Challenges

Clock Drift

Oscillators slowly diverge due to temperature, aging & noise

Network Instability

Delay variation, Jitter, Congestion alter phase

Loss of Timing Sources

GNSS/SyncE/PTP outages degrades sync instantly

Holdover Degradation

Clocks rapidly accumulate error without reference

Mission-Critical Dependency: Even small timing errors cause major failures

Impact Area

- Telecom & 5G/6G fronthaul
- High-frequency trading
- Power grid phase synchronization
- Data center distributed computing
- Military & aerospace systems

Environmental Impact on Timing Accuracy

Temperature is the single largest contributor to frequency instability

Oscillator Sensitivity

TCXO

±1–2 ppm, ~10 ppb/°C
>7 µs drift/day

OCXO

±50 ppb, ~0.01 ppm/°C
<50 ns drift/day

CSAC

±0.1 ppb
<10 ns drift/day

Key Insight

Even premium oscillators cannot eliminate drift—they merely slow it.

Only an adaptive servo can actively compensate in real-time.

Why Traditional Servos Are not Enough

Traditional control-loop servos were designed for stable, predictable networks

- **Fixed loop bandwidth** → cannot adapt to jitter changes
- **Static gain values** → over/under-correction
- **No predictive capability** → only reacts after error occurs
- **Poor holdover behavior** → rapid drift
- **No anomaly understanding** → cannot detect faulty timing sources

Results

Good performance in labs, inconsistent performance in the real world.

Adaptive (AI-Assisted) Servo

Modern networks demand a servo that is intelligent, not static

1. Adaptive Learning

- Learns oscillator characteristics (SoftXO model)
- Learns temperature-drift correlation
- Learns network delay patterns

2. Predictive Algorithms

- Forecasts clock drift before it manifests
- Predicts packet-delay variation from historical data
- Compensates proactively, not reactively

3. Dynamic Servo Configuration

- Real-time loop bandwidth adjustment
- Dynamic KP/KI gains based on noise level
- Smooth transition between sources

4. Intelligent Source Switching

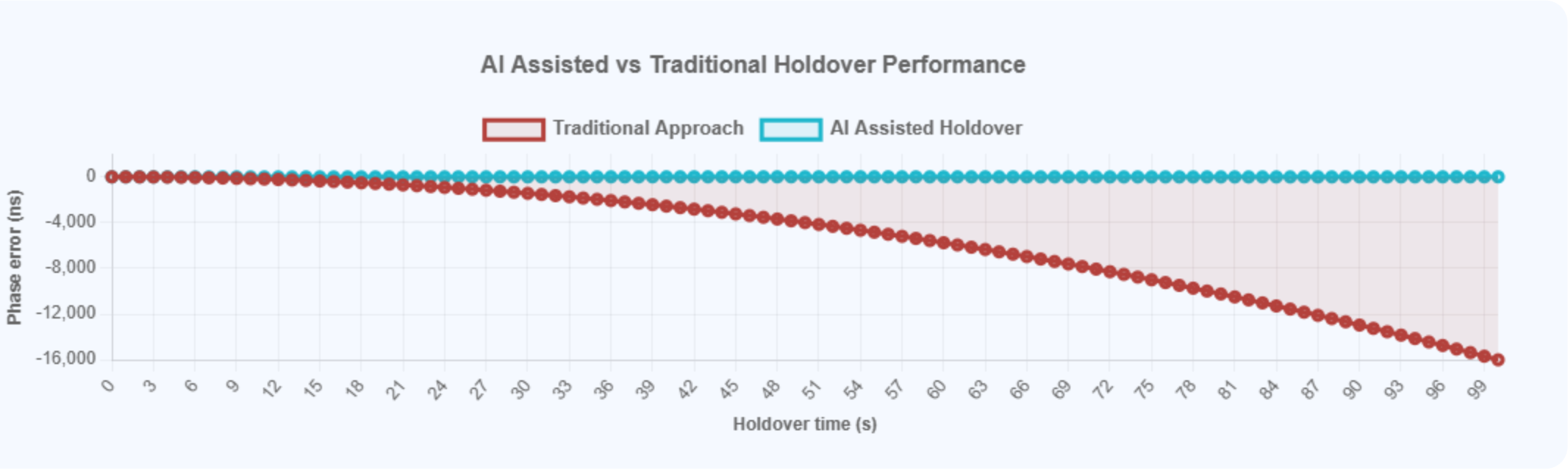
- Detects anomalies in reference timing
- Auto-switches to alternate sources
- Prevents sync degradation before impact

Outcome

Nanosecond-class stability even under harsh network and environmental conditions.

AI-Assisted Holdover Performance

Near-Zero Error Holdover During Network Loss



Key Takeaway

- Traditional approach → continuous downward drift (≈ −16 µs)
- AI-assisted holdover → remains near 0 ns
- 100× improvement in stability
- AI-Assisted holdover achieves OCXO/CSAC-like performance with lower-cost hardware

Oscillator Comparison

Simplified

Oscillator	Stability	Drift (24h)	Cost	Use Case
TCXO	±0.1–2 ppm	>7 µs	$1–20	IoT, consumer devices
OCXO	±50 ppb	<50 ns	$30–300	Telecom, finance
CSAC	±0.1 ppb	<10 ns	$2k–8k	Defense, aerospace

Key Takeaway: AI-assisted servo reduces dependence on expensive oscillators by cancelling drift behavior through prediction and adaptive corrections.

Adaptive Servo Advantages

How Adaptive Servo Achieves Nanosecond Precision

✓ Nanosecond accuracy on TCXO

AI-enhanced drift prediction = low cost + high precision

✓ Enterprise-grade sync for telecom & finance

Adaptive correction maintains <15 ns deviation

✓ CSAC-like holdover without CSAC cost

SoftXO modeling provides long-term stability

✓ Environmental Intelligence

Temperature-driven correction mapping

✓ Hardware-Agnostic

Works across TCXO, OCXO, CSAC — servo intelligence is the differentiator

Why This Matters

Modern networks require timing intelligence, not just timing hardware

Benefits of Adaptive Servo

- ✓ Nanosecond accuracy under real-world impairments
- ✓ Predictive holdover during GNSS/PTP loss
- ✓ High resilience to packet noise & temperature drift
- ✓ Automated anomaly detection & source switching
- ✓ Reduces oscillator cost by 50–90%

Critical Applications

- ✓ 5G/6G networks
- ✓ Power grids
- ✓ Financial networks
- ✓ Defense systems
- ✓ Data centers
- ✓ Aerospace

Intelligence at the Heart of Synchronization

The adaptive servo transforms timing from reactive hardware to proactive intelligence

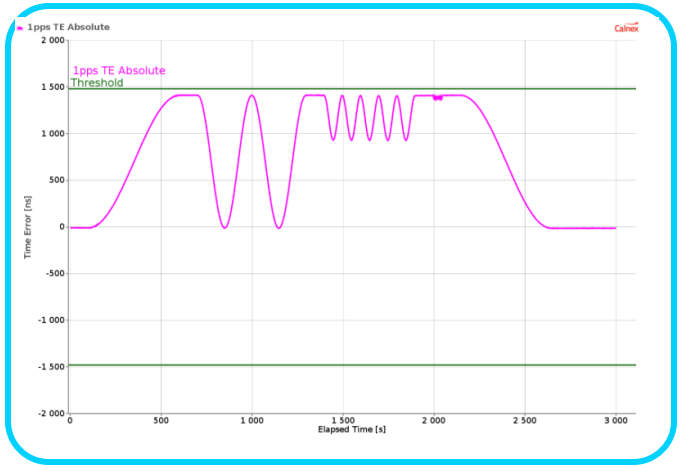
O-RAN WG4 Conformance

(Validated with Calnex)

1

Normal Operation LLS-C1

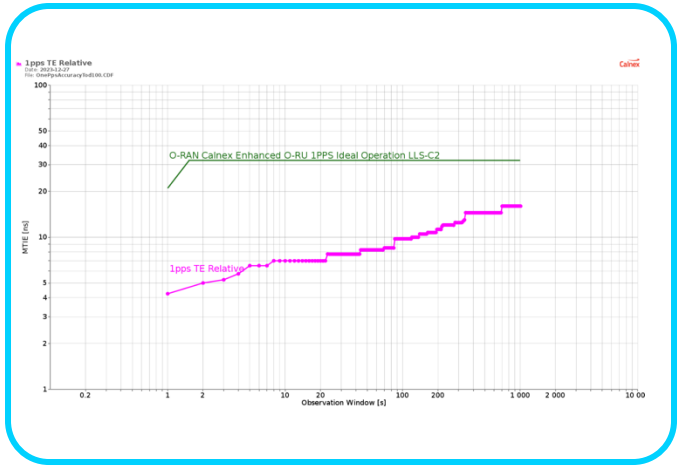
Regular O-RU 1PPS



2

Ideal Operation LLS-C1

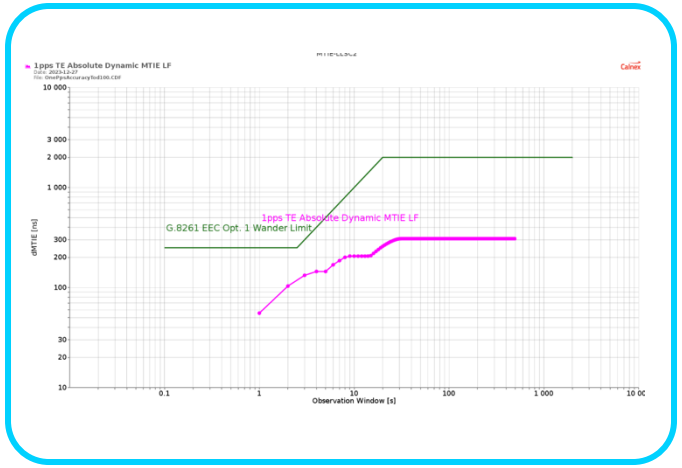
Enhanced O-RU 1PPS



3

SyncE Wander Tolerance

Regular O-RU 1PPS



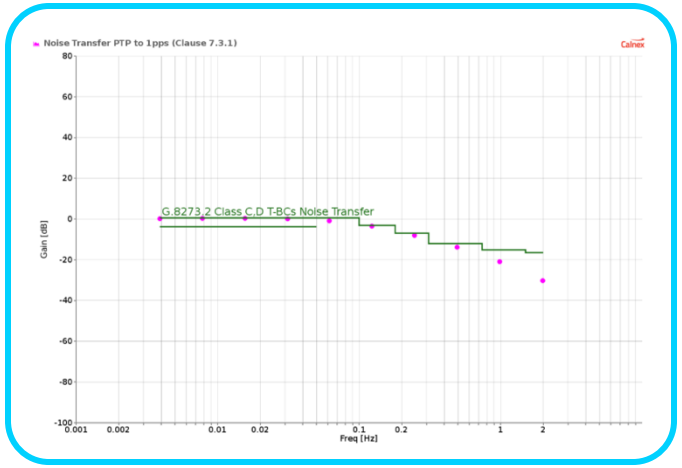
Result: Full O-RAN compliance achieved with adaptive servo algorithms validated through rigorous Calnex testing.

G.8273.2 Conformance

(Validated with Calnex)

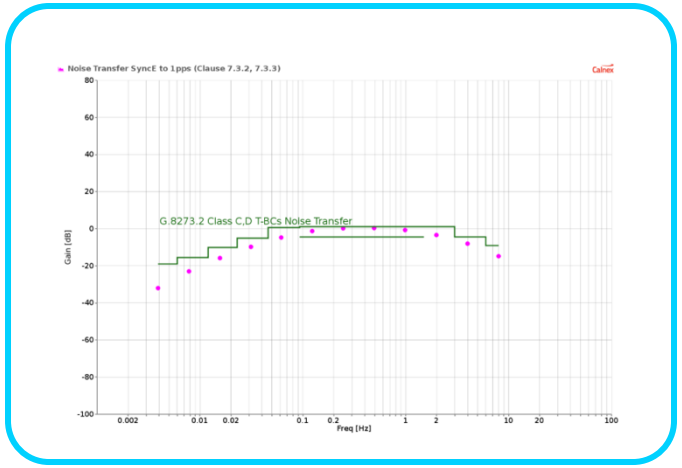
1

Noise Transfer
PTP to 1PPS



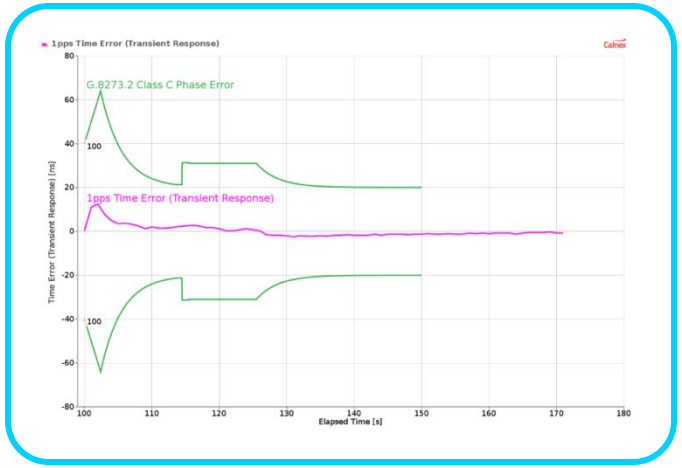
2

Noise Transfer
SyncE to 1PPS



3

Transient Response
1PPS Time Error



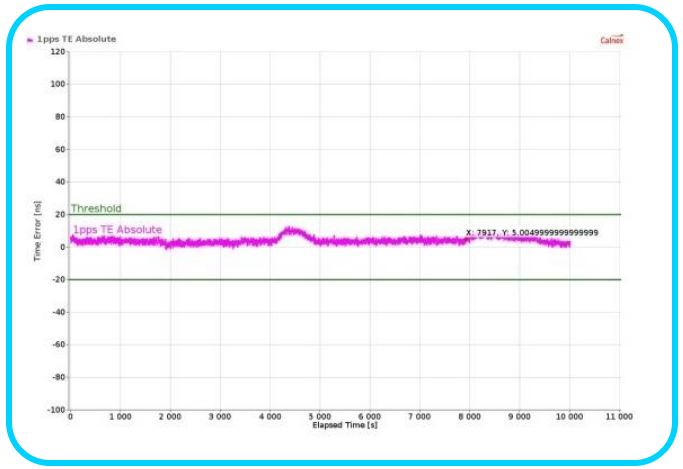
Result: G.8273.2 Full timing compliance achieved with adaptive servo algorithms validated through rigorous Calnex testing.

G.8275.2 Conformance

(Validated with Calnex)

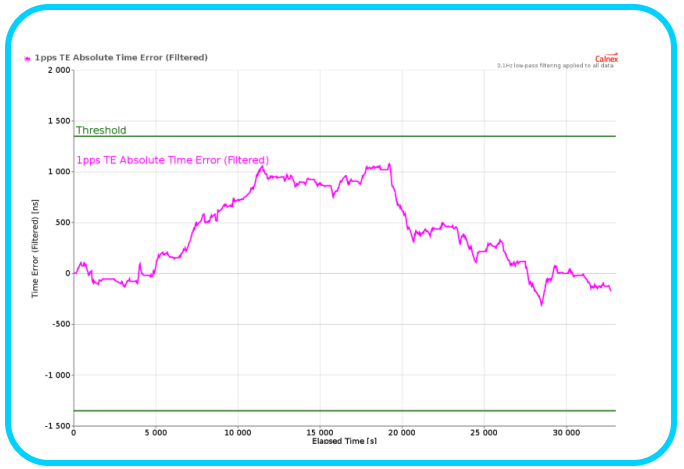
1. Noise Generation (No SyncE)

Mean TE: **3.96 ns**
Std Dev: **1.952 ns**
Max: **12.755 ns**



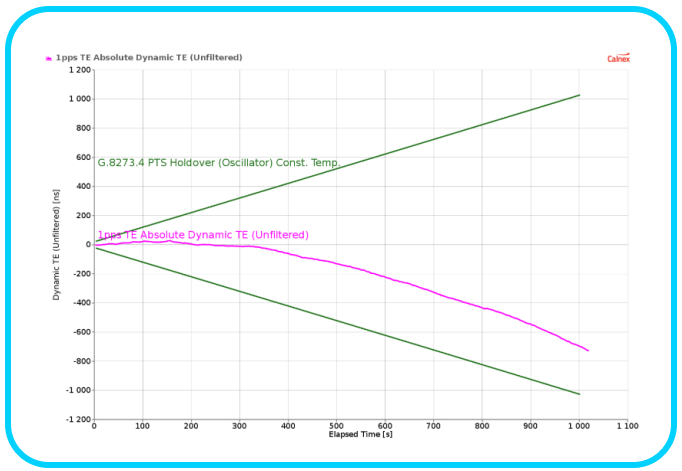
2. Noise Tolerance (SyncE + TCXO)

Peak deviation: **<1500 ns**
Mean TE: **stable**



3. Holdover & Transient Response

Holdover: **1000+ seconds**
Drift: **±800 ns**



Result: Full G.8275.2 compliance achieved with adaptive servo algorithms validated through rigorous Calnex testing.

Summary

Adaptive Servo = Intelligence at the Heart of Synchronization

What Adaptive Servo Does

- ✓ Predicts drift
- ✓ Learns patterns
- ✓ Adapts in real-time
- ✓ Maintains precision
- ✓ Powers mission-critical timing

SyncMonk's Contribution

- ✓ Real network test data
- ✓ Calnex compliance validation
- ✓ Multi-oscillator performance
- ✓ Industry-ready architectures
- ✓ Enterprise-grade timing intelligence

Delivering Enterprise-Grade Timing Intelligence

SyncMonk Technologies enables nanosecond precision timing through adaptive AI-powered servo technology, validated and ready for deployment in mission-critical infrastructure.

Let's Partner

Transform Your Synchronization Infrastructure

- AI-Assisted Technology
- Enterprise Support & SLAs
- Custom Integration Services

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