Using LEO PNT to Synchronize Critical Infrastructure

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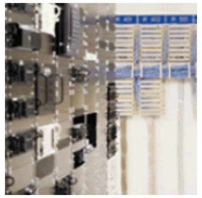
CRITICAL INFRASTRUCTURE

Critical Infrastructure sectors rely on GPS/GNSS for high accuracy timing but often operate significantly without backup


Communications


Emergency Services


Financial Services


Information Technology


Energy


Nuclear Reactors, Materials, and Waste


Commercial Facilities


Defense Industrial Base


Chemical


Dams

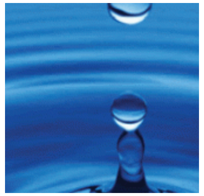

Government Facilities


Transportation Systems


Critical Manufacturing


Food and Agriculture


Healthcare and Public Health


Water and Wastewater Systems

The United States Department of Homeland Security has indicated that all 16 critical infrastructure sectors depend on a reliable source of PNT

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IEEE P1952 - New draft standard under development

The IEEE is developing guidance to rate the resilience of PNT sources

- **Level 0 – No Resilience –** Cannot detect or recover from a Threat or Hazard
- **Level 1 – INTEGRITY –** Can **detect** a Threat, Hazard, or Disruption (THD) event
- **Level 2 – RECOVERY –** Can **reset and recover** from a THD event
- **Level 3 – RESIST –** Can **resist** a THD event with possible degradation
- **Level 4 – WITHSTAND –** Can **withstand** THD events without degradation
- **Level 5 – VERIFY –** Can **verify** the solution accuracy despite THD events

To meet Levels 4 or 5, an alternative PNT source is required

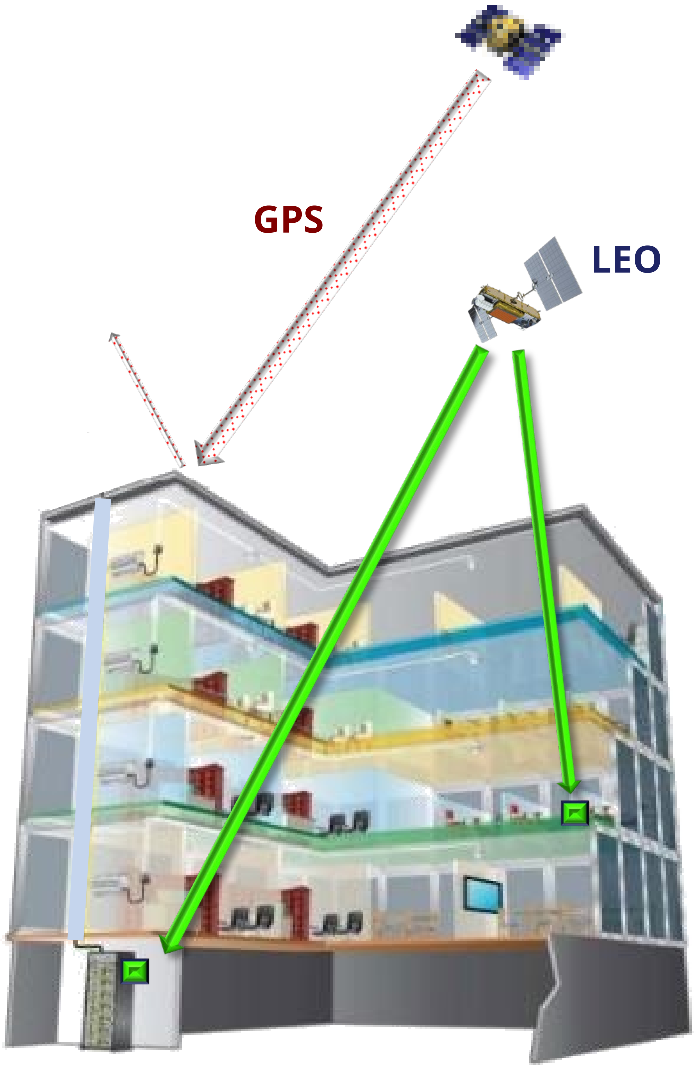
Cesium distributed PTP can sometimes be used, but Cesium clocks are expensive,
timing accuracy degrades quickly in a large distribution network,
and an undisciplined Cesium can maintain timing for only 30-45 days

LEO PNT is an alternative PNT source that is available now and can indefinitely maintain critical infrastructure timing

GNSS Synchronization

GNSS synchronization **is the most accurate method** to meet critical infrastructure timing requirements, however it works poorly or not at all in:

- **Urban canyons (limited sky view)**
- **High multipath environments (signal shredding)**
- **Indoors (excessive attenuation)**
- **Where jamming or spoofing exists**



NOTE: Image depicts indoor reception of STL compared to GPS. Orbital altitudes not to scale.

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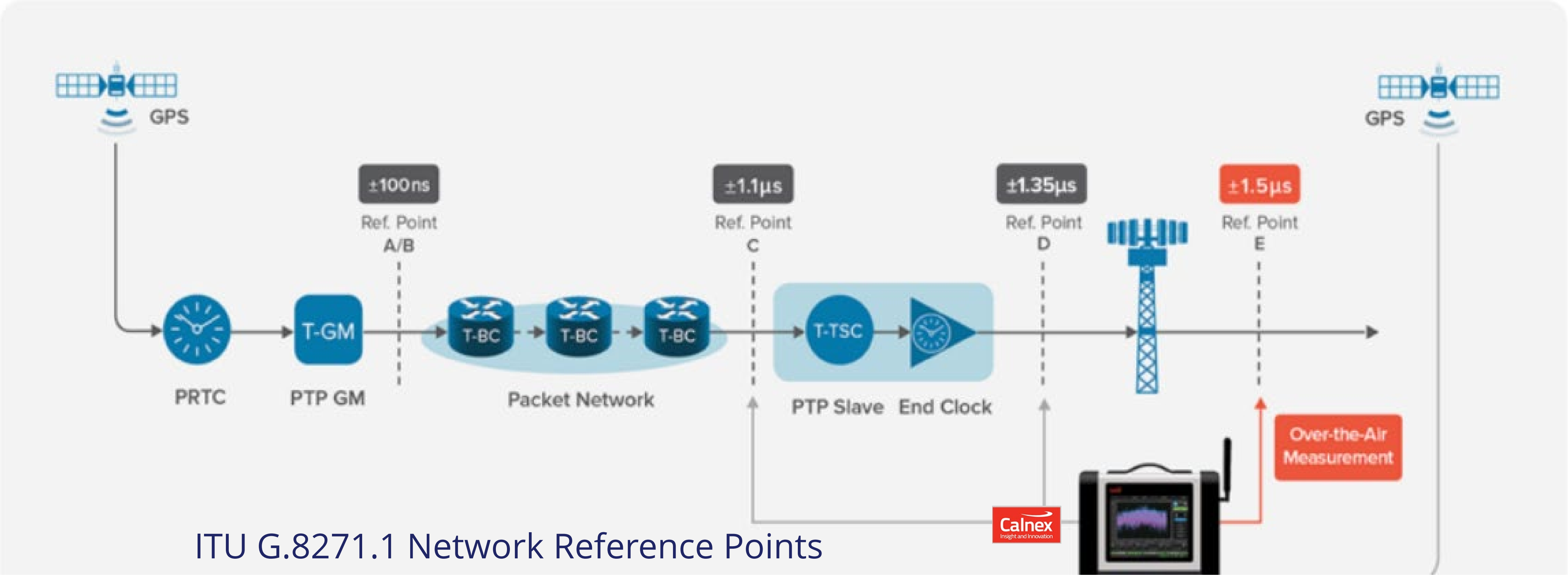
PTP Synchronization

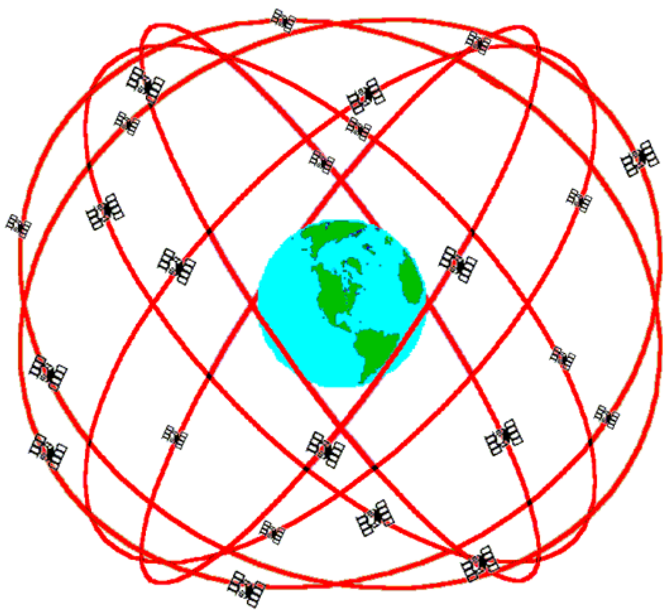
PTP distributed timing using partial timing support (ITU G.8275.2) often cannot meet critical infrastructure timing requirements when there are too many hops, and full timing support (G.8275.1) is very expensive and not always feasible or possible to implement



ITU G.8271.1 Network Reference Points

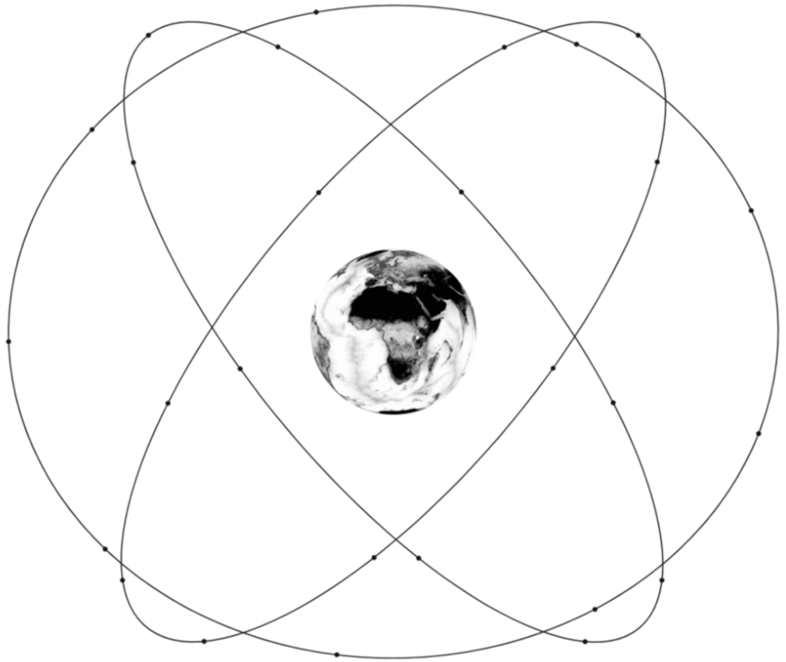
Customers using PTP over leased fiber typically have no idea how many hops are being used and when measured often find errors exceeding 3 us

GNSS (MEO) Constellations vs Iridium (LEO) Constellation



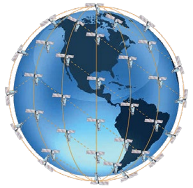
GPS Constellation

24+ Satellites in 6 Orbital Planes
4 Satellites in each Plane
20,180 km Altitude, 55 Degree Inclinations
Orbital speed 14,000 km/hr (9k mph)
Orbital period 12 hours (2x/day)
Different satellite in each plane every 3 hrs



Galileo Constellation

24+ Satellites in 3 Orbital Planes
8 Satellites in each Plane
23,222 km Altitude, 56 Degree Inclinations
Orbital speed 13,200 km/hr (8k mph)
Orbital period 14 hours (~2x/day)
Different satellite in each plane every ~1.5 hrs



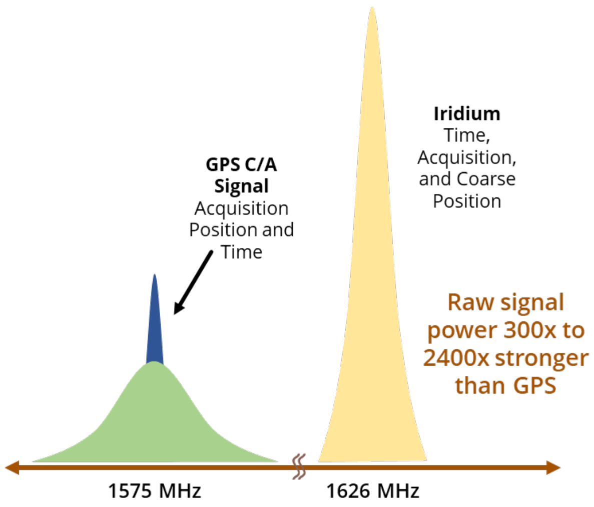
Iridium LEO Constellation

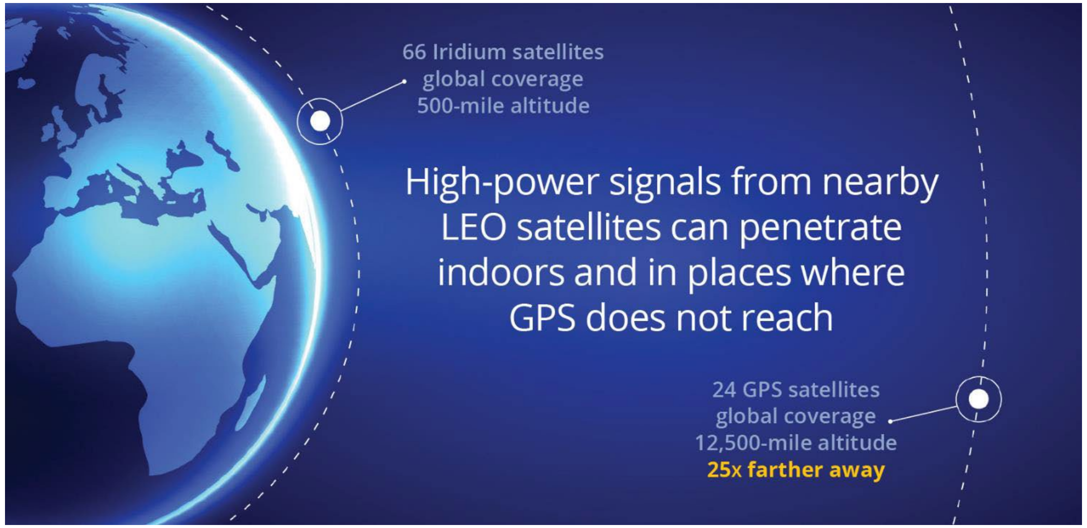
66 Satellites in 6 Orbital Planes
11 Satellites in each orbital plane, spaced 30° apart
781 km Altitude, Polar orbits (86.4 degrees)
Orbital speed 27,000 km/hr (17k mph)
Orbital period 100 minutes (14x/day)
Different satellite in each plane every 9 min

PNT from the Iridium LEO Constellation (Satelles STL Service)

Satelles has exclusive license to use the **Iridium LEO constellation** to transmit a UTC traceable PNT signal called **STL** (Satellite Time and Location)

- **Higher Power –** STL is an **L-band** signal approximately **30 dB stronger** than MEO GNSS allowing it to penetrate through walls and windows to indoor receivers
- **Robust Signal –** STL signal is not a CDMA overlay of multiple systems (like GPS+Galileo+SBAS), so there are no uncorrelated signals from other systems, and the orbital velocity is so fast that multipath signal cancellations are effectively non-existent

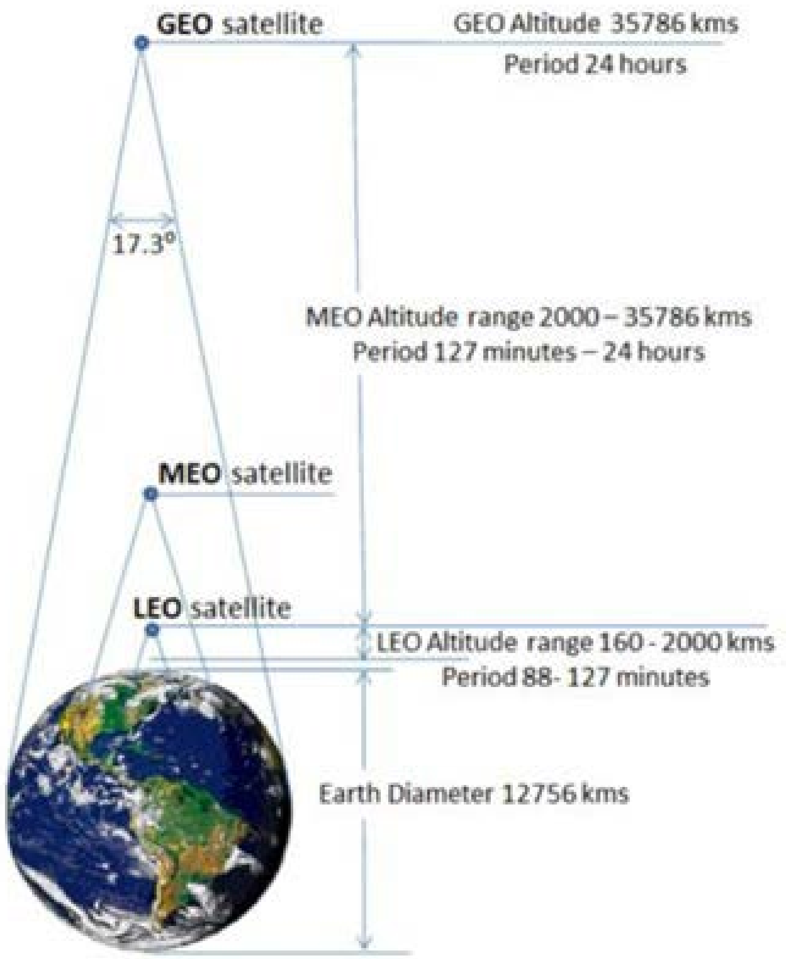




LEO PNT Works Differently Than MEO GNSS

- Unlike GNSS, LEO satellites are much closer to the Earth, so their footprints are much smaller. Each footprint is further divided into 48 regionally targeted and overlapping spot beams.
- The lower altitude and faster velocity of LEO satellites result in an orbital period of only 100 minutes. This allows for many new position calculations **(doppler assisted ranging)** in less than a minute using only a few LEO satellites (GNSS can't do that).
- A Kalman filter is used to integrate these measurements and quickly converge the position and time states to their true values.
- It is typical for a location anywhere on Earth to have 2 to 4 Iridium satellites in view, which is all that is needed to achieve and maintain PRTC-A clock accuracy and an authenticated position.

Satellite Orbits, Periods and Footprints



(Distances are not to scale)

STL LEO PNT is:

Resilient to the loss of GPS

An innovative mesh architecture of 66 cross-linked LEO satellites ensures service worldwide **even in the absence of GNSS**

STL is an alternative PNT source

STL uses modern cryptographic techniques to deliver a spoof-resilient **trusted time and location service**

Authenticated time and location

UTC Accurate

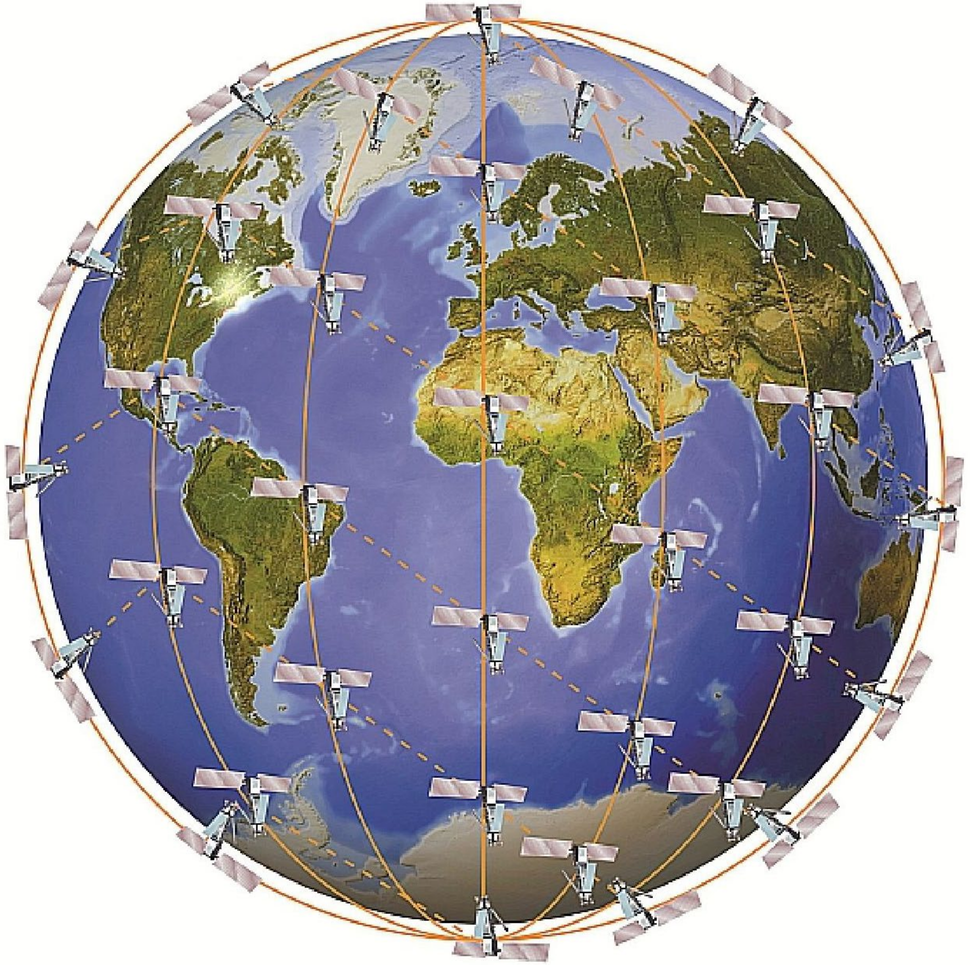
STL timing is traceable and maintained to **UTC(USNO) and UTC(NIST)** via multiple geographically distributed ground tracking stations

STL is a Stratum 0 time source

Timing solutions with **UTC accuracy of less than 100 nanoseconds 1-sigma (oscillator dependent)**

STL receivers can meet ITU-G.8272 PRTC-A timing performance

Worldwide Coverage



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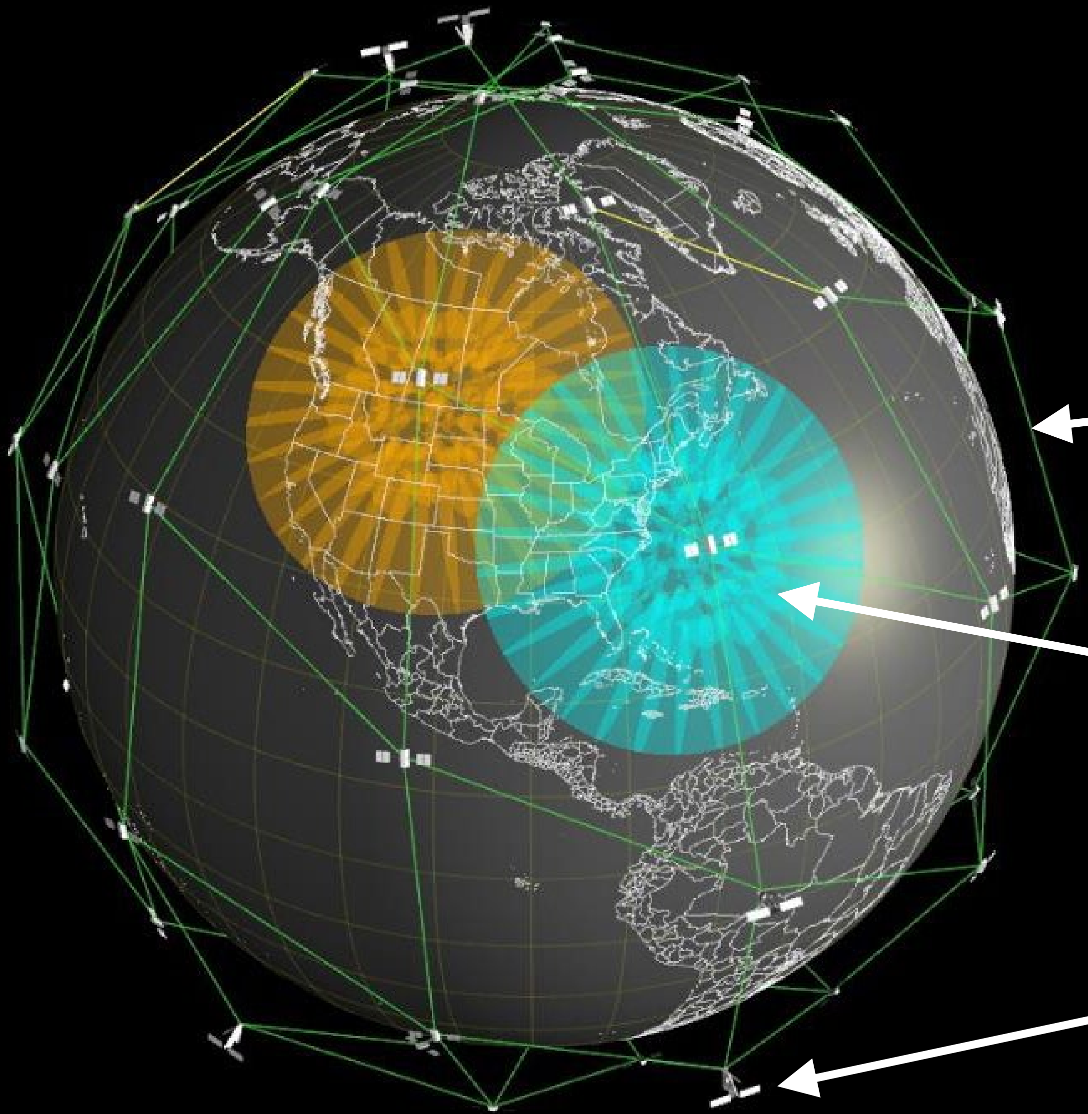
Secure Signal — Impervious to Hacking

STL is secure because the signal is **unpredictable in advance** — yet it is **easy to validate when received** and able to ***prove*** **a user's location**



Cross-links provide continuous orbit and time information on the entire constellation even when most are not in view of ground systems.

Overlapping **spot beams** provide location-specific keys that change every second to support location-based authentication (48 spot beams per satellite × 66 satellites = 3,168 spot beams globally).

Not only do the location keys change every second, but also the **satellites change positions** frequently to activate different spot beams (horizon-to-horizon transit time is just under nine minutes).

LEO vs MEO: Important Distinctions

	STL (LEO)	GPS (MEO)
Footprint	Regionally controlled Spot Beams (difficult to disrupt)	Full facing Surface with no coverage control
Power	-89 to –98 dBm at Earth's surface	-127 to -130 dBm at Earth's surface
Spectrum	L-Band (penetrates indoor)	L-Band (too weak for indoor)
Security (civil)	authenticated	none
Constellation	66+ 2nd Gen Iridium NEXT (launched in 2019)	24+ GPS Block II/III (14 are >13yrs old)
Coverage	Worldwide	Worldwide
Availability	Worldwide	Worldwide
Traceability	UTC (USNO) + UTC (NIST)	UTC (USNO)

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Key Facts about the Iridium LEO technology

Commercial Satellites	At 689 kg, the Iridium LEO satellites are full-sized space vehicles (3.1 m x 2.4 m x 1.5 m)
Spectrum Protection	Iridium uses frequencies that are available, licensed and protected worldwide
Spectrum Characteristics	L-band signal are resilient to storm clouds or rain fade, and able to reach indoor locations
Fuel for Sustained Orbit and Maneuverability	Iridium satellites have large hydrazine fuel cells to power onboard boosters that maintain trajectory and can withstand the orbit drag caused by solar storms. This also allows them to be easily repositioned or replaced by in-orbit spares

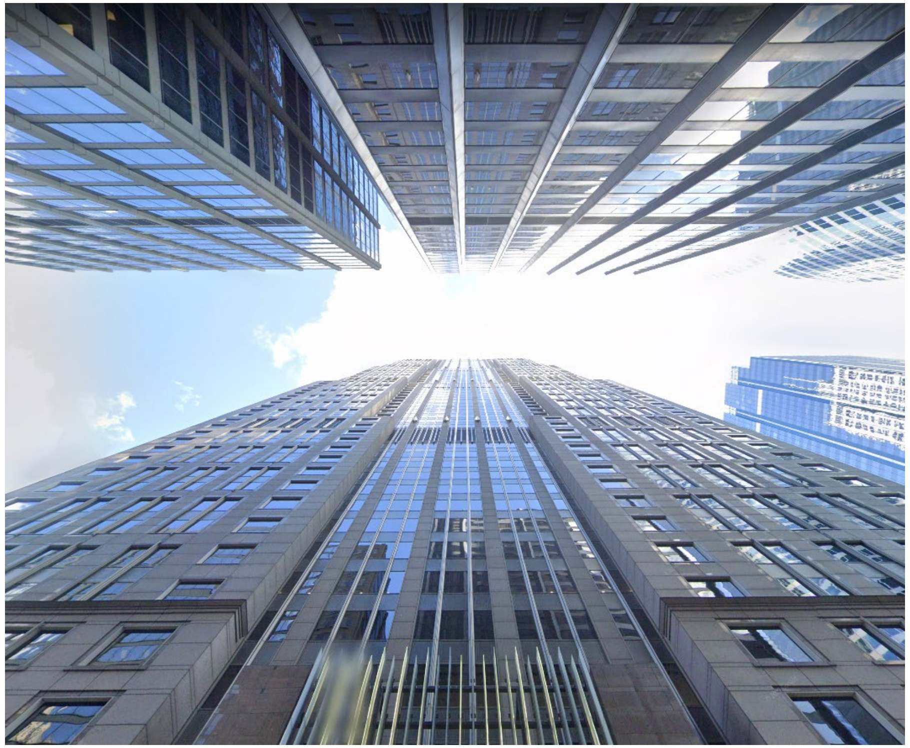
Summary of Timing Synchronization Methods

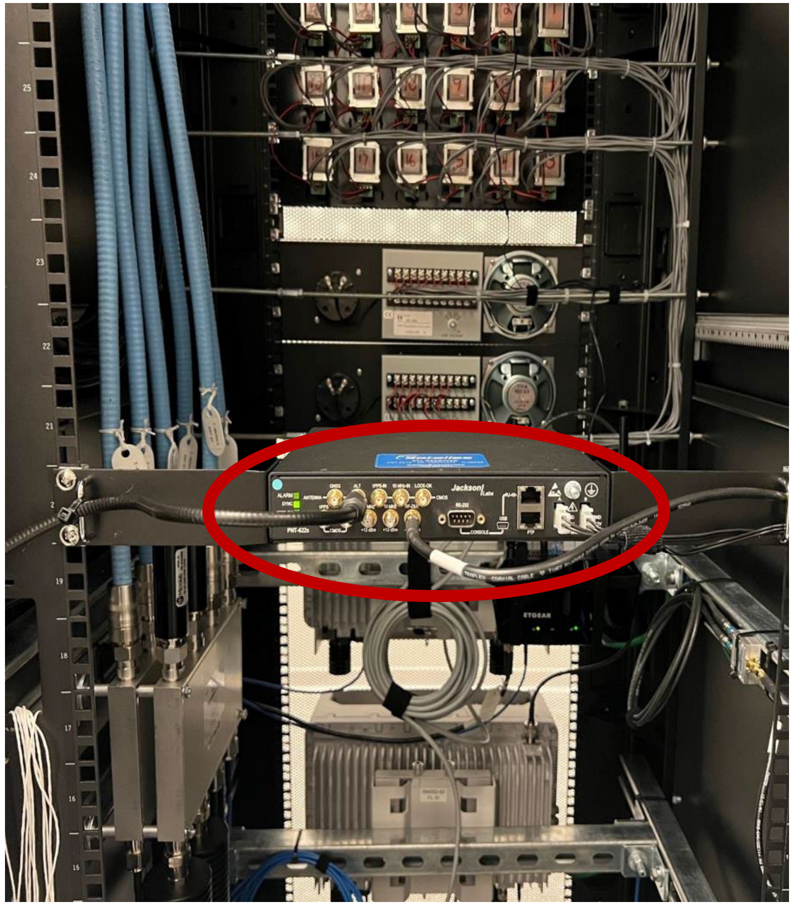
Source	Delivery	Accuracy (typ. 1-sigma)	Indoor Availability?	Urban Canyon Availability?	Solution Cost
GNSS	MEO Satellites	10-20 ns	**No**	**Poor**	Very low
PTP	Remote PNT via Fiber optic distribution network	50-**1500** ns	Yes	Yes	**Very high**
STL	LEO Satellites	10-50 ns	Yes	Yes	Med-Low

LEO PNT EXAMPLE: Urban High-Rise Building

STL LEO receiver used to synchronize Nokia 5G Micro BTS RANs on 40th floor of office building

LEO antenna mounted in office area ceiling





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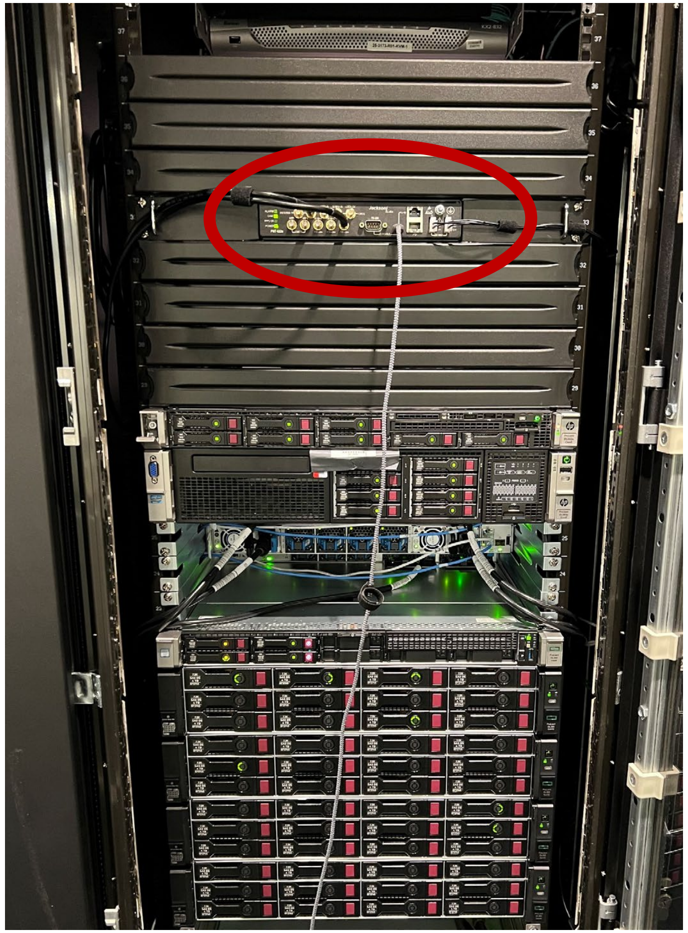
LEO PNT EXAMPLE: Data Center

STL LEO receiver used to synchronize data center servers



LEO Antenna mounted inside server room at the top of the server rack

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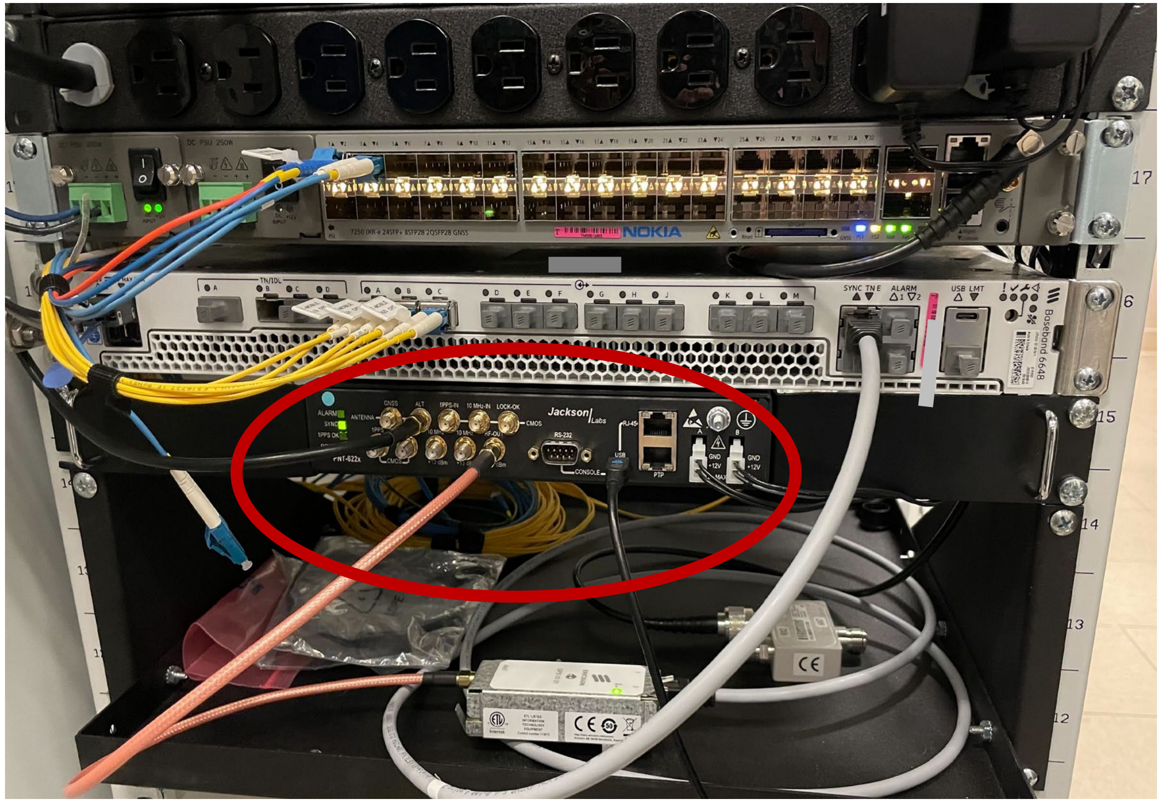
LEO PNT EXAMPLE: Hospital Installation

STL LEO receiver used to synchronize Ericsson 5G Micro BTS RANs in hospital data center



LEO PNT Validated by NIST

NIST has concluded that (STL) LEO PNT is a reliable source of UTC timing and available today.

In November 2021, NIST published Technical Note 2189, *An Evaluation of Dependencies of Critical Infrastructure Timing Systems on the Global Positioning System (GPS)*

In this report NIST has…

- concluded that LEO PNT is a reliable source of timing that is highly consistent with Coordinated Universal Time (UTC)
- categorized (STL) LEO PNT as an indirect distribution source for UTC(NIST)
- attested that LEO PNT is a commercial alternative that exists today
- verified that the timing accuracy specification for STL LEO PNT is ±500 ns (0.5 µs) which meets critical infrastructure requirements, and they acknowledged that published measurements indicate an accuracy of better than 200 ns
- confirmed STL LEO PNT's long-term stability of better than 25 nanoseconds with short-term time deviation of 50 nanoseconds

☞ **Satelles has an STL ground monitoring station directly connected to NIST's main clock ensemble — the source of UTC(NIST)**

UPDATE

*A paper co-authored by Satelles and NIST entitled **"Measuring the Timing Accuracy of Satellite Time and Location (STL) Receivers"** was presented at the **ION ITM/PTTI** conference in January 2023. The underlying research demonstrated that a calibrated STL receiver can achieve an average time offset better than 18 ns with respect to UTC(NIST) with a peak-to-peak variation of 325 ns for a typical OCXO receiver and better than 80 ns with a rubidium-based receiver.*

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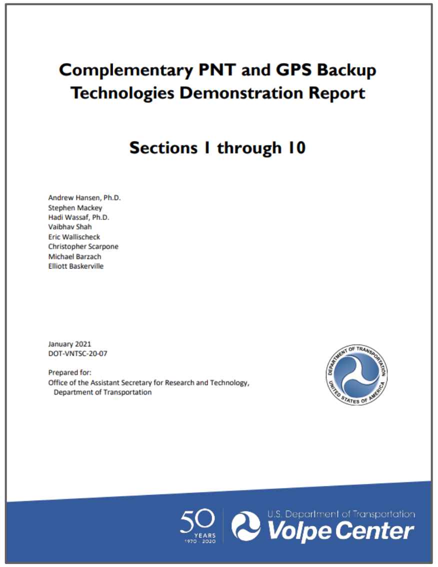
LEO PNT Evaluated by DOT


Complementary PNT and GPS Backup Technologies Demonstration Report

Sections 1 through 10

Andrew Hansen, Ph.D.
Stephen Mackey
Hadi Wassaf, Ph.D.
Vaibhav Shah
Eric Wallischeck
Christopher Scarpone
Michael Barzach
Elliott Baskerville

January 2021
DOT-VNTSC-20-07

Prepared for:
Office of the Assistant Secretary for Research and Technology, Department of Transportation

50 YEARS 1970 - 2020 | U.S. Department of Transportation Volpe Center

In January 2021, the DOT published a report summarizing the performance, availability, and readiness of 11 alternative PNT technologies.

Report Summary of (STL) LEO PNT Technology:

- **Technical Readiness Level:** 9 (Ready now)
- **Spectrum Protection:** Protected Spectrum
- **Service Deployment Effort:** Low (no new infrastructure needed)
- **Service Coverage:** 66 LEO satellites provide worldwide PNT service
- **Service Synchronization:** UTC
- **PNT Signal Robustness:** Strong (available indoors and is authenticated)
- **Service Resilience:** Fail-Over (STL promptly reports loss of service)
- **PNT Distribution Mode:** Orbital RF (Iridium Constellation)
- **Service Interoperability:** High (STL is significantly compatible with GPS)
- **PNT Information Security:** High (uses signal authentication for maximum security)
- **Time to Service Implementation:** Short (STL service is available now)
- **PNT System/Service Longevity:** Medium (projected satellite life of 15 to 30 years)

Of the 11 providers evaluated, STL from Satelles is the ONLY alternative PNT technology that is nationally and globally scalable and is available today.

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STL LEO PNT Evaluation by European Commission (DEFIS)

PREVIEW

A technical demonstration was conducted Dec 2021 as part of an evaluation of STL and other technologies by the European Commission's Directorate-General for Defence Industry and Space (DEFIS) in a study conducted by the EC's Joint Research Centre (JRC) in Ispra, Italy.

	STL Performance Summary		
Key Performance Indicator	**1 day**	**14 days**	**100 days**
Timing Accuracy to UTC (1 Sigma)	106.8 ns	144.8 ns	135.4 ns
Timing Stability (Allan Deviation)	2.57E-12	2.05E-13	2.28E-13
Availability (%)	100%	100%	100%
Continuity (per hour)	100%	100%	100%
Horizontal accuracy (95%)	25.699 m	26.559 m	23.845 m
Vertical accuracy (95%)	7.200 m	9.670 m	16.800 m
First time to provide continuous services upon cold start-up (including system and receiver contributions)	< 15 min	< 15 min	< 15 min

Rigorous testing conducted by EC evaluators confirmed the STL LEO PNT service performed well in all categories verifying that it can provide the accuracy and reliability needed for critical infrastructure operations

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STL LEO PNT UTC Accuracy and Traceability

- STL is a NIST-verified Stratum 0 UTC source of timing that can be used to create a Stratum 1 timing clock compliant with the ITU-T G.8272 PRTC-A performance standard
- Timing stabilities of 10-50 nanoseconds (1-sigma) are available depending on oscillator type
- STL timing is traceable and maintained to UTC(USNO) and UTC(NIST) via multiple geographically distributed tracking stations

	OUTDOOR ANTENNA		INDOOR ANTENNA	
Oscillator Type	**Stability (ns 1-sigma)**	**Max Error (ns)**	**Stability (ns 1-sigma)**	**Max Error (ns)**
TCXO (Stratum 3)	42	218	53	241
OCXO	41	176	43	152
DOCXO	31	96	35	82
Rubidium (MAC)	18	56	33	81
Rubidium (lamp)	10	27		

Examples of STL timing performance by oscillator type

Note: Testing performed at room/lab temperature

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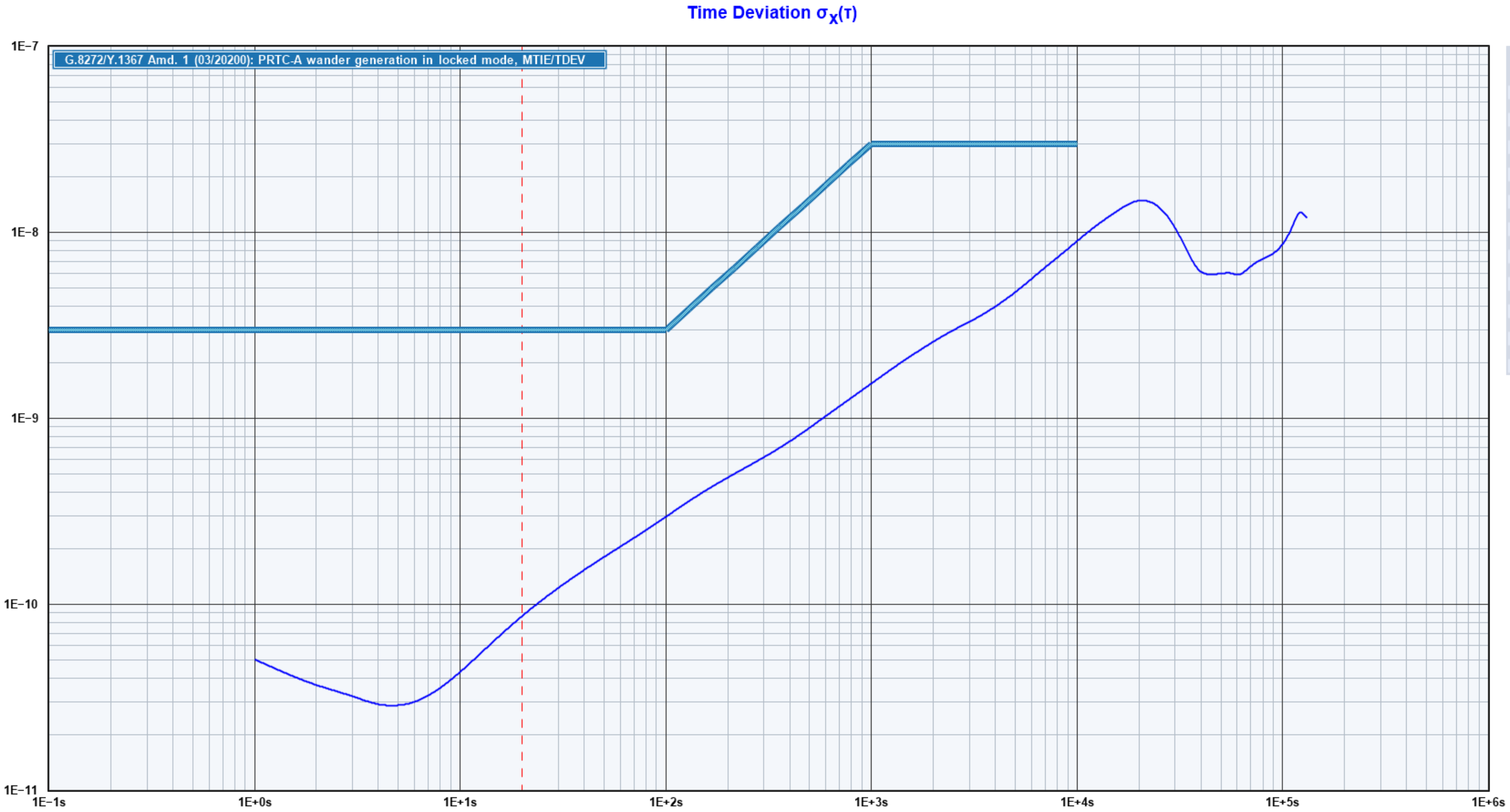
STL LEO PNT - TDEV with PRTC-A mask
(Rb-MAC oscillator, outdoor antenna), stability 18 ns, 1-sigma



Tau	Sigma(Tau)
1E+0s	5.09E−11
2E+0s	3.70E−11
4E+0s	2.92E−11
8E+0s	3.60E−11
1E+1s	4.39E−11
2E+1s	8.75E−11
4E+1s	1.55E−10
8E+1s	2.53E−10
1E+2s	2.99E−10
2E+2s	4.86E−10
4E+2s	7.60E−10
8E+2s	1.31E−9
1E+3s	1.56E−9
2E+3s	2.61E−9
4E+3s	4.04E−9
8E+3s	7.40E−9
1E+4s	9.08E−9
2E+4s	1.49E−8
4E+4s	6.16E−9
8E+4s	7.28E−9
1E+5s	8.81E−9

Trace	Notes	Input Freq	Sample Interval	TDEV at 2E+1s	Duration	Elapsed	Acquired	Instrument
PNT-6235 Rb2	STL mode	1.0 Hz	1.000 s	8.75E−11	100 d	4d 19h 37m 20s	416240 pts	Agilent 53230A

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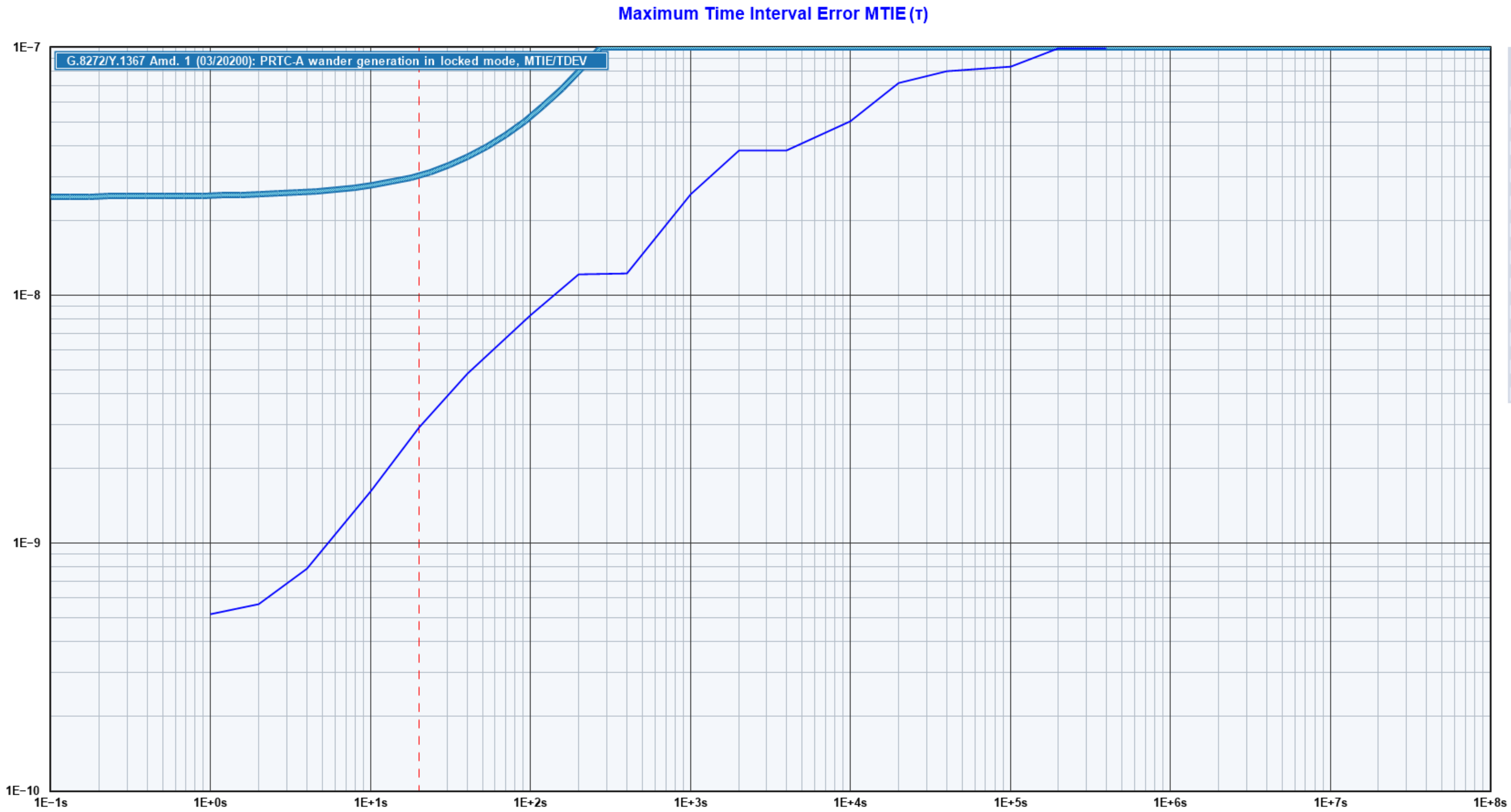
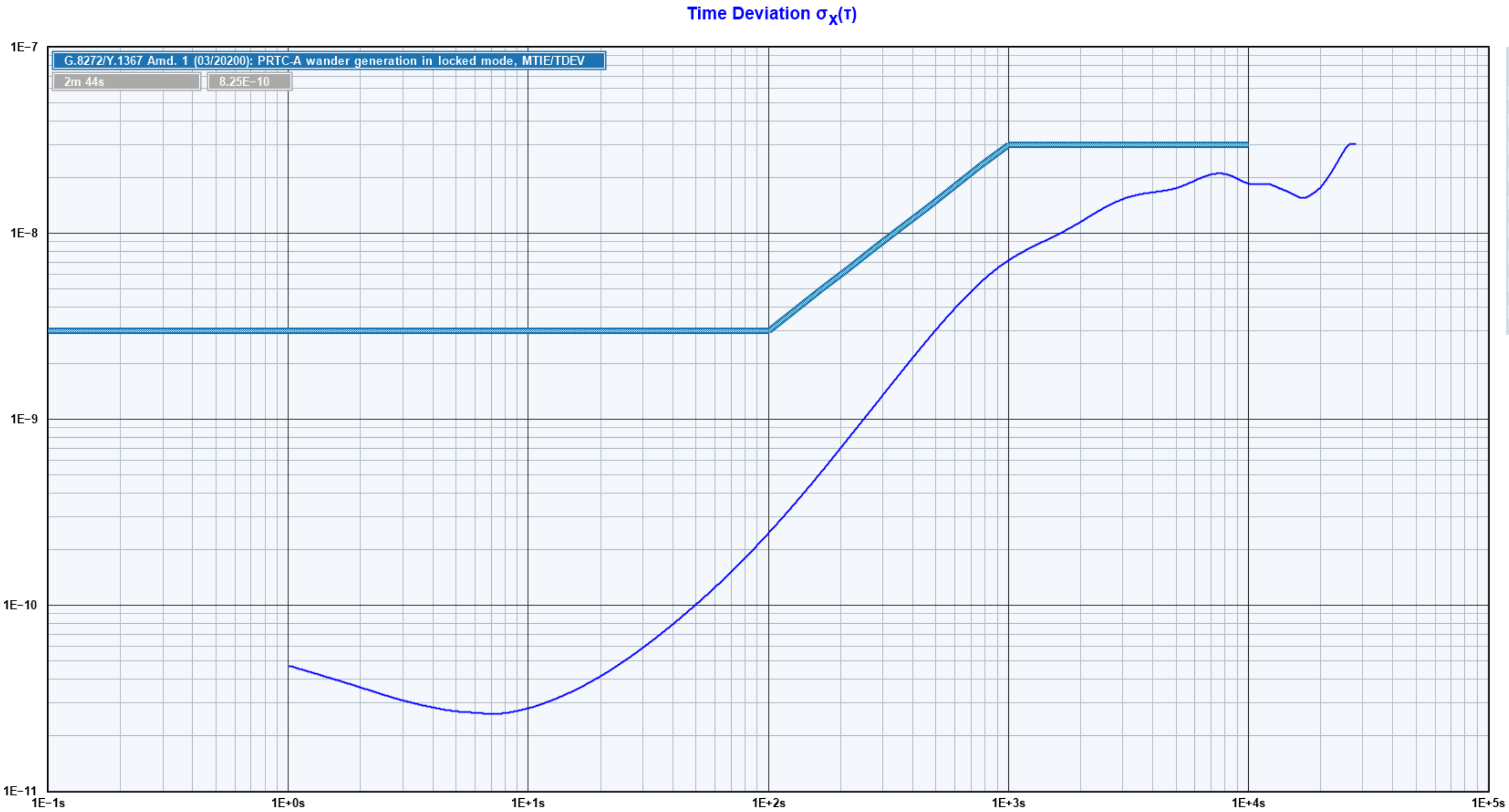
STL LEO PNT - MTIE with PRTC-A mask (Rb-MAC oscillator, outdoor antenna)



Tau	Sigma(Tau)
1E+0s	5.18E−10
2E+0s	5.66E−10
4E+0s	7.91E−10
8E+0s	1.36E−9
1E+1s	1.62E−9
2E+1s	2.92E−9
4E+1s	4.82E−9
8E+1s	7.26E−9
1E+2s	8.29E−9
2E+2s	1.21E−8
4E+2s	1.23E−8
8E+2s	2.14E−8
1E+3s	2.56E−8
2E+3s	3.86E−8
4E+3s	3.86E−8
8E+3s	4.72E−8
1E+4s	5.04E−8
2E+4s	7.17E−8
4E+4s	8.01E−8
8E+4s	8.29E−8
1E+5s	8.38E−8
2E+5s	9.94E−8
4E+5s	9.94E−8

Trace	Notes	Input Freq	Sample Interval	MTIE at 2E+1s	Duration	Elapsed	Acquired	Instrument
PNT-6235 Rb2	STL mode	1.0 Hz	1.000 s	2.92E−9	100 d	4d 19h 37m 20s	416240 pts	Agilent 53230A

STL LEO PNT - TDEV with PRTC-A mask
(Rb oscillator, indoor antenna), stability 34 ns, 1-sigma

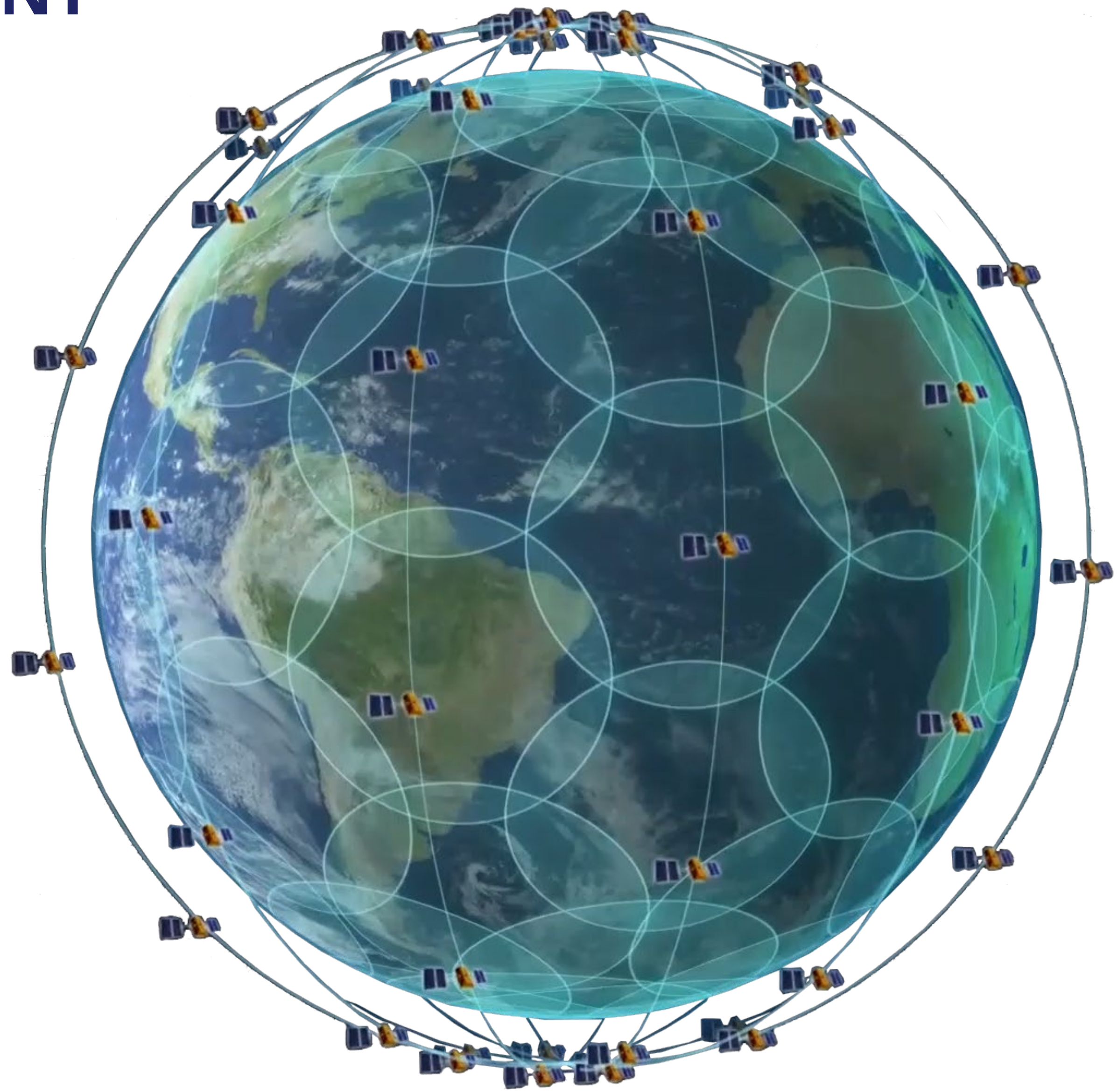


Tau	Sigma(Tau)
1E+0s	4.76E−11
2E+0s	3.63E−11
4E+0s	2.84E−11
8E+0s	2.65E−11
1E+1s	2.82E−11
2E+1s	4.21E−11
4E+1s	8.02E−11
8E+1s	1.83E−10
1E+2s	2.48E−10
2E+2s	7.12E−10
4E+2s	2.19E−9
8E+2s	5.81E−9
1E+3s	7.23E−9
2E+3s	1.17E−8
4E+3s	1.67E−8
8E+3s	2.09E−8
1E+4s	1.86E−8
2E+4s	1.80E−8

Trace	Notes	Input Freq	Sample Interval	TDEV at 4E+5s	Duration	Elapsed	Acquired	Instrument
PNT-6235 Rb-MAC	STL indoor 34 ns1-sigma	1.0 Hz	1.000 s		1d 0h 0m 23s	1d 0h 0m 23s	86423 pts	Agilent 53230A

Summary of Benefits of STL LEO PNT

- ✓ Resilient Backup for GNSS
- ✓ Authenticated Time and Position
- ✓ Spoof-proof features
- ✓ Available worldwide now



Questions?

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