D210 TECHNICAL REPORT V2.0 FINAL

Contents

1 STL Technical Description

Satellite Time and Location (STL) from Satelles provides customers around the globe a Positioning, Navigation, and Timing (PNT) service using low Earth orbit (LEO) satellites. STL is unique in that its signals are powerful, extremely secure, and available worldwide — and they complement the Global Positioning System.

The satellite constellation consists of 66 active satellites in orbit at an altitude of approximately 780 kilometers and an inclination of 86.4°. The orbital period – from pole to same pole – is roughly 100 minutes. The 66 active satellites are equally dispersed in 6 orbital planes, spaced 30° apart, with 11 satellites in each plane.

Due to the proximity of LEO satellites (25 times closer to the Earth than GNSS satellites) and a high-power satellite signal, STL broadcasts are 1,000 times (30 dB) stronger than GPS, allowing them to penetrate deep into GPS-challenged environments where signals are obstructed or degraded, including indoors and underground. The complex, overlapping beam patterns of the satellites combined with signal authentication techniques allow STL to deliver a trusted time and location capability that is highly secure.

2 Performance Parameters

For Timing tests, the two key performance parameters used for evaluating performance are offset from UTC time and timing stability. Both parameters are derived by measuring the Time Interval (TI) from the device under test's (DUT's) Pulse Per Second (PPS) output to a precision calibrated timing reference PPS edge. From the raw TI measurement data all timing performance parameters are calculated including maximum offset from UTC, jitter, and Allan deviation.

For Static positioning tests, the DUT's positioning message outputs are saved to non-volatile storage and compared against a known truth location to facilitate calculation of positioning error. Positioning error will be presented using both graphical and statistical measures.

For Quasi-static positioning tests, the DUT's positioning message outputs are saved to non-volatile storage and compared to location messages from a reference GPS receiver at each UTC second synchronized via message timestamps. Positioning error will be presented using both graphical and statistical measures.

3 Overview of Testing and Equipment

Table 3.1: Overview of Test Results

Key Performance Indicator (x days after GNSS outage)	1 day	14 days	100 days
Horizontal accuracy (95%)	25.699 m	26.559 m	23.845 m
Vertical accuracy (95%)	7.200 m	9.670 m	16.800 m
Availability (%)	100%	100%	100%
Continuity (per hour)	100%	100%	100%
Integrity (per hour)	NA	NA	NA
Time to Alarm (second)	NA	NA	NA
Timing Accuracy to UTC (1 Sigma)	106.8 ns	144.8 ns	135.4 ns
Timing Accuracy to UTC (3 sigma)	498.4 ns	651.7 ns	355.2 ns
Time Synchronization (Allan Deviation)	2.57E-12	2.05E-13	2.28E-13
Timing Stability (Allan Deviation)	2.57E-12	2.05E-13	2.28E-13
First time to provide continuous services upon cold start-up (including system and receiver contributions)	< 15 min	< 15 min	< 15 min

Summary of Test Cases

A series of six tests have been identified that demonstrate how STL can be leveraged to accomplish project objectives. Test IDs T2P and T3D will demonstrate timing performance. Test IDs T6P, T7G, and T7H will provide static and quasi-static positioning performance. Test T4M will demonstrate resiliency features of the system that provide deeper control of signal availability when desired or required.

Table 3.2: List of Test Cases to be Performed

Test ID	Test Name	Duration	Measurements	Metric	Objective
T1E	System Verification	1 day	NA	NA	Confirm equipment was operational.
T2P	Indoor Timing Test	4 tests, 24 hours each	1 PPS	Maximum Timing Interval Error and Allan Deviation vs. stable reference clock	Evaluate timing performance at two different indoor locations
T3D	Hundred-Day Timing Test using Roof Mounted Antenna	100 Days	1 PPS	Maximum Timing Interval Error and Allan Deviation vs. stable reference clock	Medium duration timing performance evaluation using rooftop mounted antenna
T4M	Resilience and Network Monitoring	1 hour	NA	NA	Special case – will demonstrate ability to control signal availability via signal steering and increased signal emissions, and depict constellation health
T6P	Quasi-static Tests	2 Days	Time-tagged PNT	Positioning error measured against truth source	Evaluate quasi-static receiver positioning performance via three outdoor tests cases
T7G	Static Position Test using Roof Mounted Antenna	7 days	Time-tagged PNT	Positioning error measured against truth source	Evaluate static positioning performance using a rooftop mounted antenna

Test ID	Test Name	Duration	Measurements	Metric	Objective
T7H	Static Position Test using Indoor Antenna	4 tests, 24 hours each	Time-tagged PNT	Positioning error measured against truth source	Evaluate static positioning performance using an indoor antenna at two different indoor locations

Test Equipment List

The following table provides a list of the equipment deployed to evaluate STL.

Table 3.3: Static Test Equipment

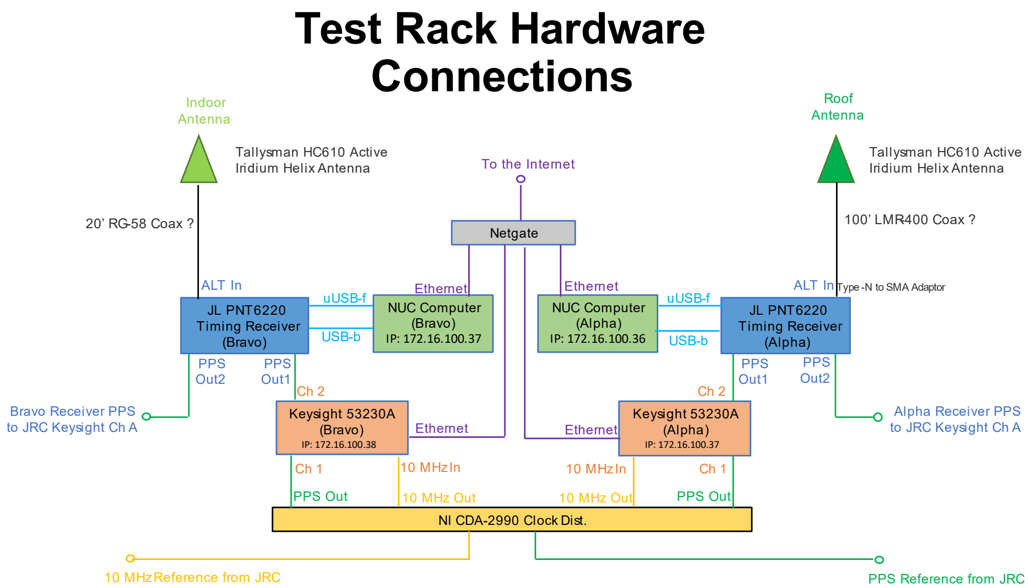
Ref #	Equipment	Furnished by
1	Precision timing reference	JRC
2	Timing measurement system	JRC
3	Clock and PPS reference distribution	JRC
4	STL Timing and location receivers	Satelles
5	Timing measurement system	Satelles
6	Computers and software to log timing and location data	Satelles
7	STL Antennas	Satelles
8	Surveyed location data	JRC

Static Timing and Positioning Test System

Static Timing and Positioning Test System: Configuration

The static timing and positioning system consists of two timing and location receiver setups, each consisting of a Jackson Labs PNT-6220 receiver with the STL option and a NUC computer. The first system (Alpha) is connected to an outdoor antenna and the second system (Bravo) is connected to an indoor antenna. Each PNT-6220 receiver has two USB connections to its NUC computer. The first mini-USB connector (mini-USB-f) on the front of the receiver is used to control and monitor the receiver using a Jackson Labs software tool called GPSCon running on the NUC computer. The second USB connector (USB-b) on the back of the receiver is used to log data from the receiver using a terminal emulator (Tera Term) on the NUC computer. Each receiver has two PPS outputs, one is connected to the Channel 2 of a Keysight 53230A in the system rack with a short 0.5 m cable. All cable delays to and from JRC equipment were removed during calibration.

JRC's precision timing reference provides PPS and 10 MHz clock for all the Keysight 53230A's. A National Instruments CDA-2990 Clock Distribution Device in the system rack is used to distribute PPS and the 10 MHz clock to all the Keysight 53230A's. The 10 MHz reference clock from the distribution is used for the external clock source on all the Keysight 53230A's. The PPS from the distribution provides the reference edge for TI measurements of PPS from the receivers on Keysight 53230A's. For the Keysight 53230A's in the system rack the reference PPS from the distribution is connected to Channel 1 and the PPS from the receivers is connected to Channel 2. The PPS reference edge from JRC is advanced by 500 µs so the TI measurement on the Keysight 53230A's in the system rack is from Channel 1 to Channel 2 and will always be positive.



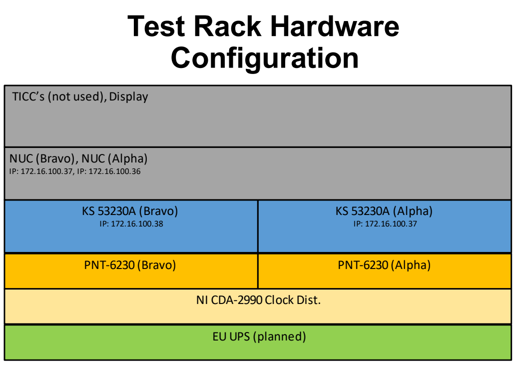


Figure 3.1: Test Rack Hardware Configuration

Table 3.4: Measured Receive Chain Delay Components

Delay Component	Length (m)	Delay (ns)
Outdoor Antenna (Alpha receiver)	50	185.78
Indoor Antenna (Bravo receiver)	10	50
PPS Reference to Distribution	NA	NA
PPS Distribution to Keysight (Alpha/Bravo)	0.5	2.5
PPS Distribution to Keysight (JRC)	NA	NA
Receiver (Alpha/Bravo) PPS out to Keysight (Alpha/Bravo)	0.5	2.5
Receiver (Alpha) PPS out to Keysight (JRC)	NA	NA
Receiver (Bravo) PPS out to Keysight (JRC)	NA	NA

Note: All cable delays from JRC reference and receivers to JRC Keysight were nulled out in calibration.

Static Timing and Position Test System: Validation Procedure

The Keysight 53230A is used in Time Interval mode to measure the delay from the rising edge of the Pulse Per Second (PPS) output of the timing receiver under test to the rising edge of the PPS from a reference timing source. The Keysight 53230A's and NUC computers are connected to an Ethernet router to control the instruments and make measurements. The TI measurements from the Keysight 53230A are captured at each PPS rising edge using TimeLab software running on the NUC computer. There will be a TimeLab instance running on each NUC computer for the measurements from the Alpha and Bravo receivers. TimeLab can plot Phase Difference, Allan Deviation, and other measurements from the TI data for the duration of the test. The TI data for portions or the entire test can be saved to a file in text format for post analysis with any statistical tools to evaluate the receivers timing performance against the reference.

The PPS edge from the reference is advanced by 500 µs to avoid zero crossings that can cause problems with TI measurements on Keysight 53230A. The variance of the PPS from the timing receiver is less than 1 microsecond so this reference offset ensures that the timing receivers PPS edge is always after the reference PPS edge. The TI measurement is made from rising PPS edge of the timing reference to the rising PPS edge of the timing receiver because only the rising edge of PPS from receiver is guaranteed to be timing accurate. All PPS inputs to the Keysight 53230A are terminated in 50 ohms by the instrument, and the trigger levels are set to 800 mV. Analysis of the TI measurements will remove the 500 µs offset to identify the offset and variance of the timing receivers output relative to the timing reference at 0. The Zero-based phase difference function in TimeLab will remove the offset to show only the variation on the plot.

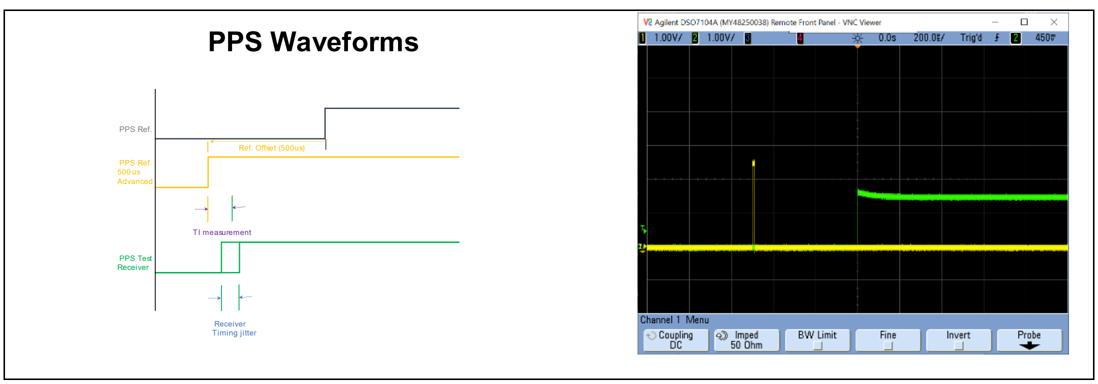


Figure 3.2: PPS Timing Diagram: Yellow trace is the offset from reference PPS, Green trace is the timing receiver's PPS

4 Detailed Test Plan and Results

T1E: SYSTEM VERIFICATION

Test Identification	T1E
Test Name	System Verification
Objective	Setup devices under test and verify they are operating correctly
Output	System is verified operational and deemed ready to go
Time to Execute	—
Metrics	Pass / Fail (i.e., system is Ready / Not Ready)

System verification procedures for timing, static positioning, and quasi-static positioning tests are defined within section 4. A determination will be made by the operator whether or not the system has passed verification and is ready for testing.

T2P: INDOOR TIMING TEST

Test Identification	T2P
Test Name	Indoor Timing Test
Objective	Evaluate indoor timing performance at two different indoor locations
Output	Measurements of receiver 1 PPS outputs
Time to Execute	Total run time is 96 hours (2 test runs, 24 hours per test run, each test run is done twice)
Metrics	Maximum Timing Interval Error and Allan Deviation measured against a stable clock reference

Two indoor test locations were used for the indoor timing performance evaluation. Each test was run for 24 hours with the receiver antenna at each indoor location. The test was repeated at each location for a total of 4 tests over 4 days. The two test locations were: (a) on top of a metal cabinet in the center of the ground floor of building 72C at the European Commission Joint Research Centre (JRC), and (b) a degraded signal environment inside of that same metal cabinet. A third location by the window was considered and dropped because the receiver performance there was not significantly different than seen on the outdoor roof antenna receiver.

Figure 4.1: (a) Top of cabinet. (b) Inside of cabinet

Before the start of each test the receiver was allowed to converge and stabilize for ~ 20 minutes with the antenna at that location. The receiver was not restarted prior to the tests.

The Static Timing and Positioning Test System was utilized to execute each of these test runs. For details on the test system and validation procedures, please refer to section 3. The measurement and analysis of static timing data from the receiver was identical to that of the 100-day static timing test except the duration of each test is 24 hours.

Table 4.1: Indoor Timing Test Results

Indoor Timing Test Run #	MTIE [ns]	Allan Deviation (τ = 24 hours)	Notes
1	-24.653379	3.53E-12	Top of cabinet (1)
2	-185.617994	8.8E-12	Inside of cabinet (1)
3	143.134751	1.76E-12	Top of cabinet (2)
4	-187.654383	7.79E-12	Inside of cabinet (2)

Indoor Day 1 – Top of Cabinet

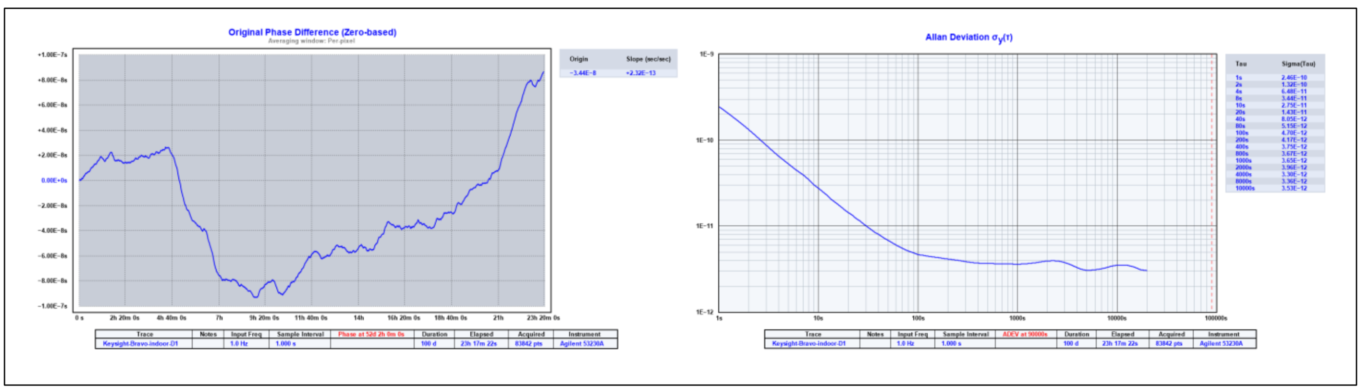


Figure 4.2: Indoor Timing Test Results - Day 1

Indoor Day 2 – Inside of Cabinet

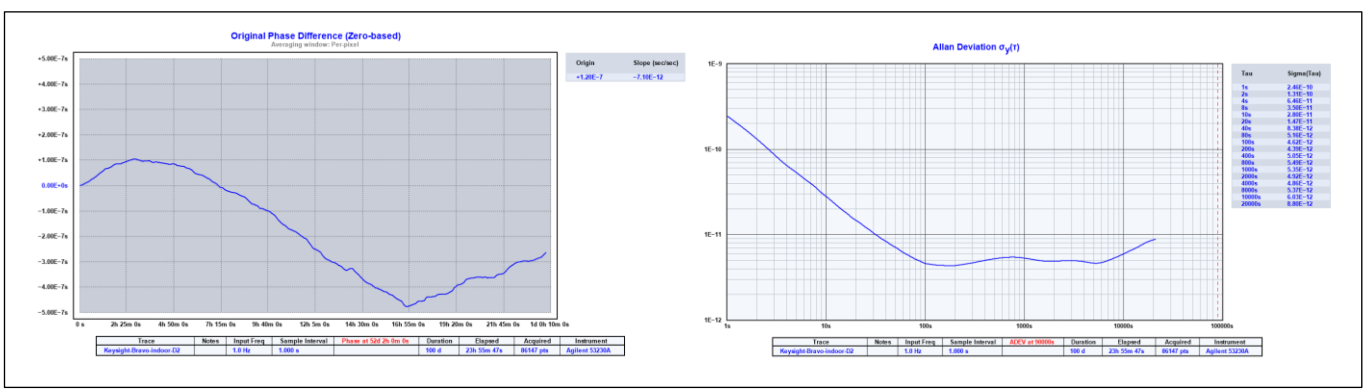


Figure 4.3: Indoor Timing Test Results - Day 2

Indoor Day 3 – Top of Cabinet

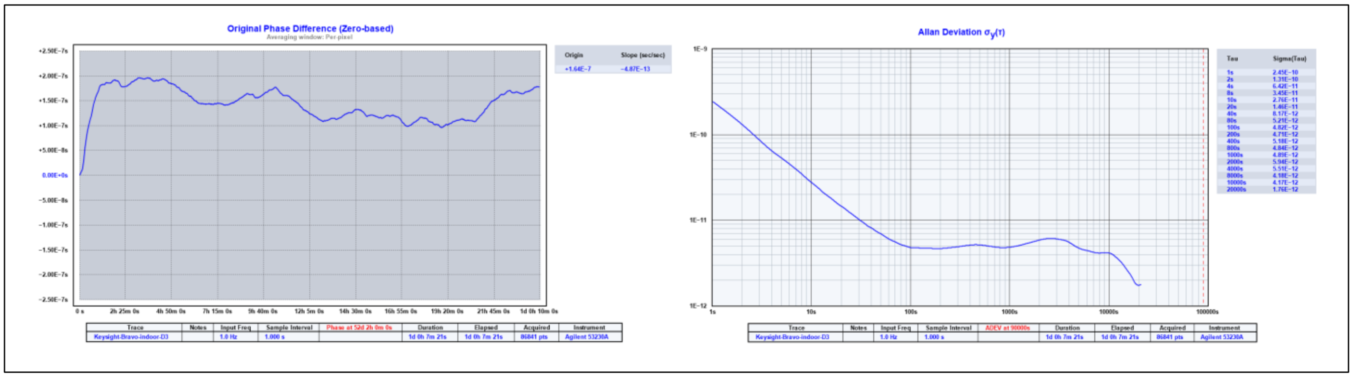


Figure 4.4: Indoor Timing Test Results - Day 3

Indoor Day 4 – Inside of Cabinet

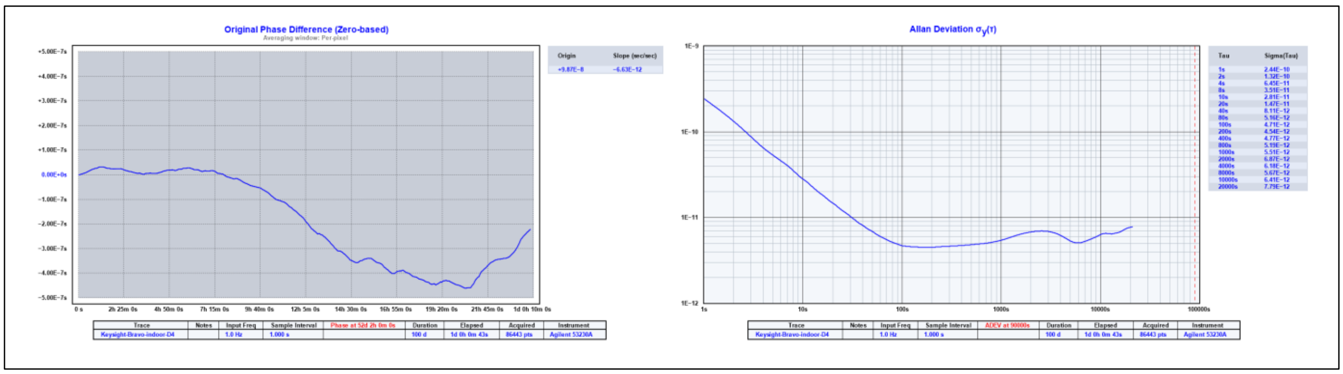


Figure 4.5: Indoor Timing Test Results - Day 4

T3D: Hundred-Day Timing Test using Roof Mounted Antenna

Test Identification	T3D
Test Name	Hundred-Day Timing Test using Roof Mounted Antenna
Objective	Evaluate timing performance of a rooftop mounted antenna over a medium duration
Output	Measurements of receiver 1 PPS outputs
Time to Execute	100 Days
Metrics	Maximum Timing Interval Error and Allan Deviation measured against a stable clock reference

A single, 100-day (medium duration) test run was conducted for static timing performance evaluation.

The Static Timing and Positioning Test System was utilized to execute this test. For details on the test system and validation procedures, please refer to Section 3.

Table 4.2: Rooftop Timing Test Results

Rooftop Timing Test Run #	MTIE [ns]	Allan Deviation (τ = 100 days)	Notes
1	0.4092247	2.28E-13	Antenna Position = [45.8097988°, 8.6298906°, 264 m]

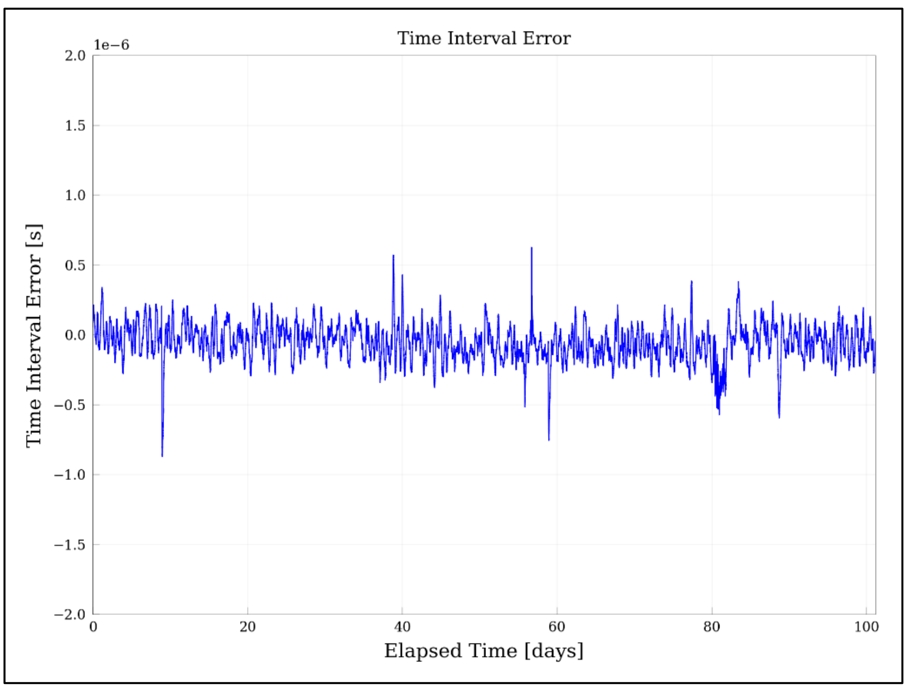


Figure 4.6: Time Interval Error vs. Time

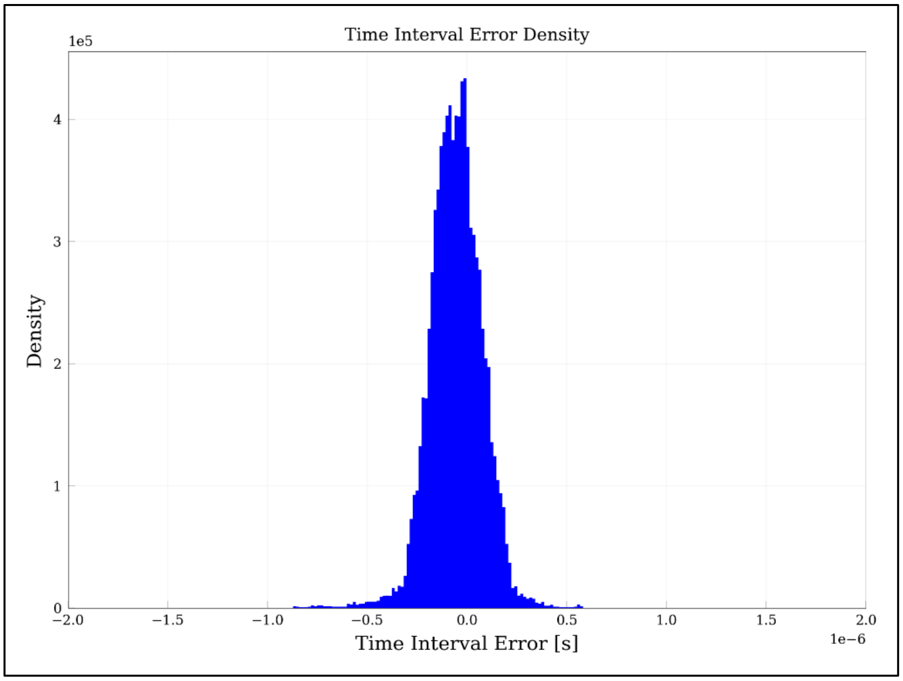


Figure 4.7: Time Interval Error Histogram

Table 4.3: Rooftop Timing Test Results

Samples	Mean [ns]	Std. Dev. [ns]	Min. [ns]	25% [ns]	50% [ns]	75% [ns]	Max. [ns]
8737652	0.4092247	132.2291	-817.2332	-82.3455	0.8625046	84.75899	680.7866

T4M: Resilience and Network Monitoring

Test Identification	T4M
Test Name	Resilience and Network Monitoring
Objective	Special case – will demonstrate ability to control signal availability via signal steering and increased signal emissions, and depict constellation health
Output	NA
Time to Execute	1 hour
Metrics	NA

Broadcast Scheduling

STL service is scheduled through an application called the Regional Controller, allowing control of when and where Iridium spot beams should be activated to send PNT data. New service can be provisioned and active within 10 minutes of order entry.

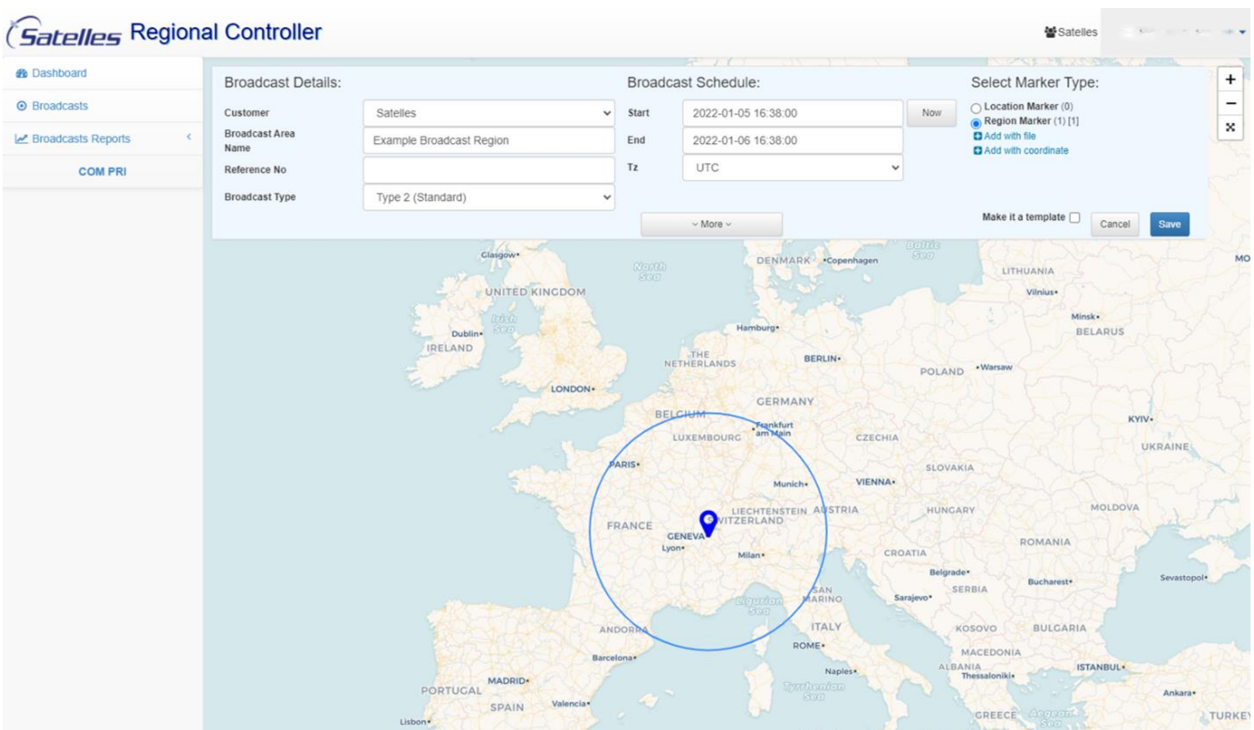


Figure 4.8: Scheduling a broadcast region for a subscription

Operational Monitoring

Satelles monitors STL services through several overlapping tools that provide situational awareness, service performance metrics, and signal quality metrics. Screenshots from just a few of the tool set are shown below.

Live Tracking

Intended largely as a situation awareness tool, the live map shows the location of each Iridium satellite and displays the spot beams that are actively broadcasting STL services. Alert summaries (if any) are also available, as well as the ability to 'rewind' or 'fast forward' the orbit tracks, allowing investigation of past anomalies or visibility into any upcoming service interruptions.

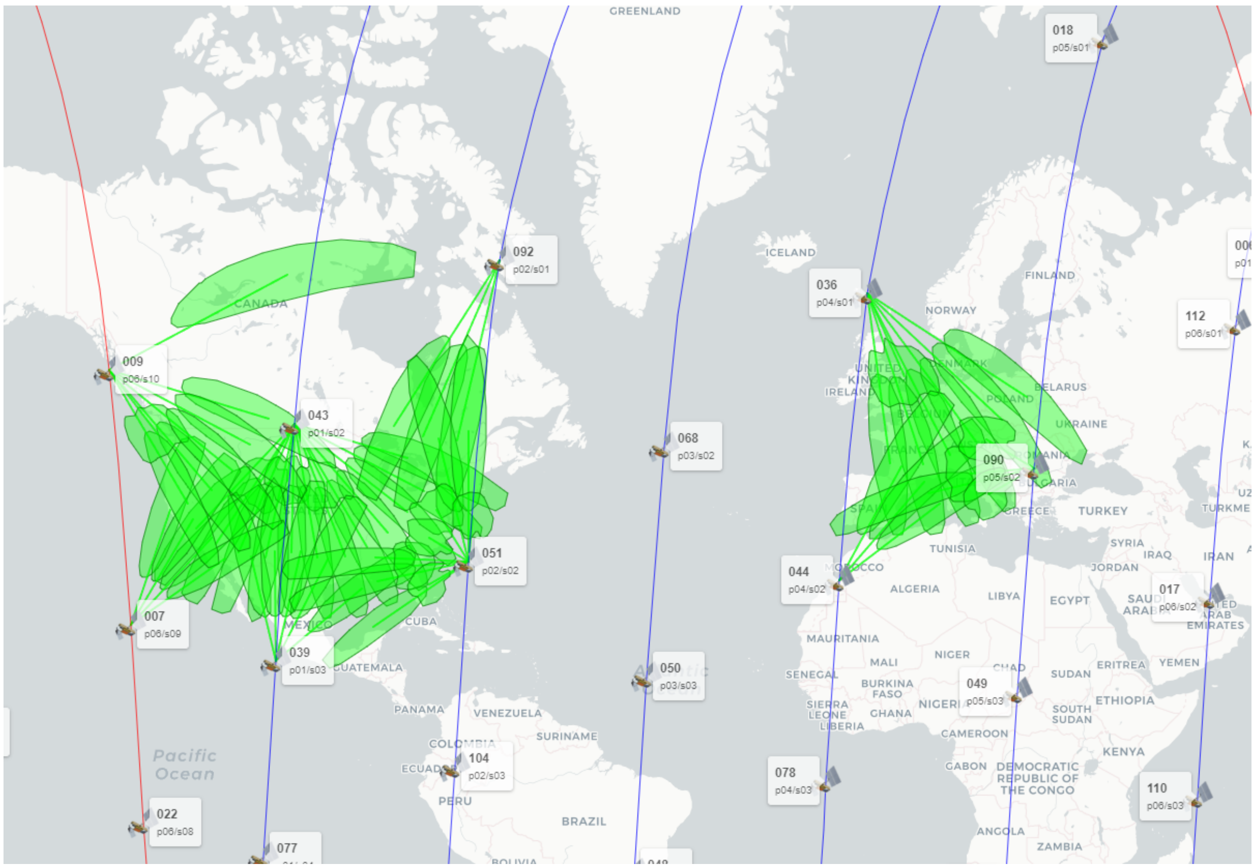


Figure 4.9: Live tracking of satellites and spot beams

Service Status

Applications that generate STL service are heavily instrumented to provide metrics to central monitors. Real-time constellation and ground system status is provided in to Satelles operations staff. “Normal” thresholds for all metrics are defined, and the system automatically generates alerts when thresholds are exceeded for longer than predefined intervals.

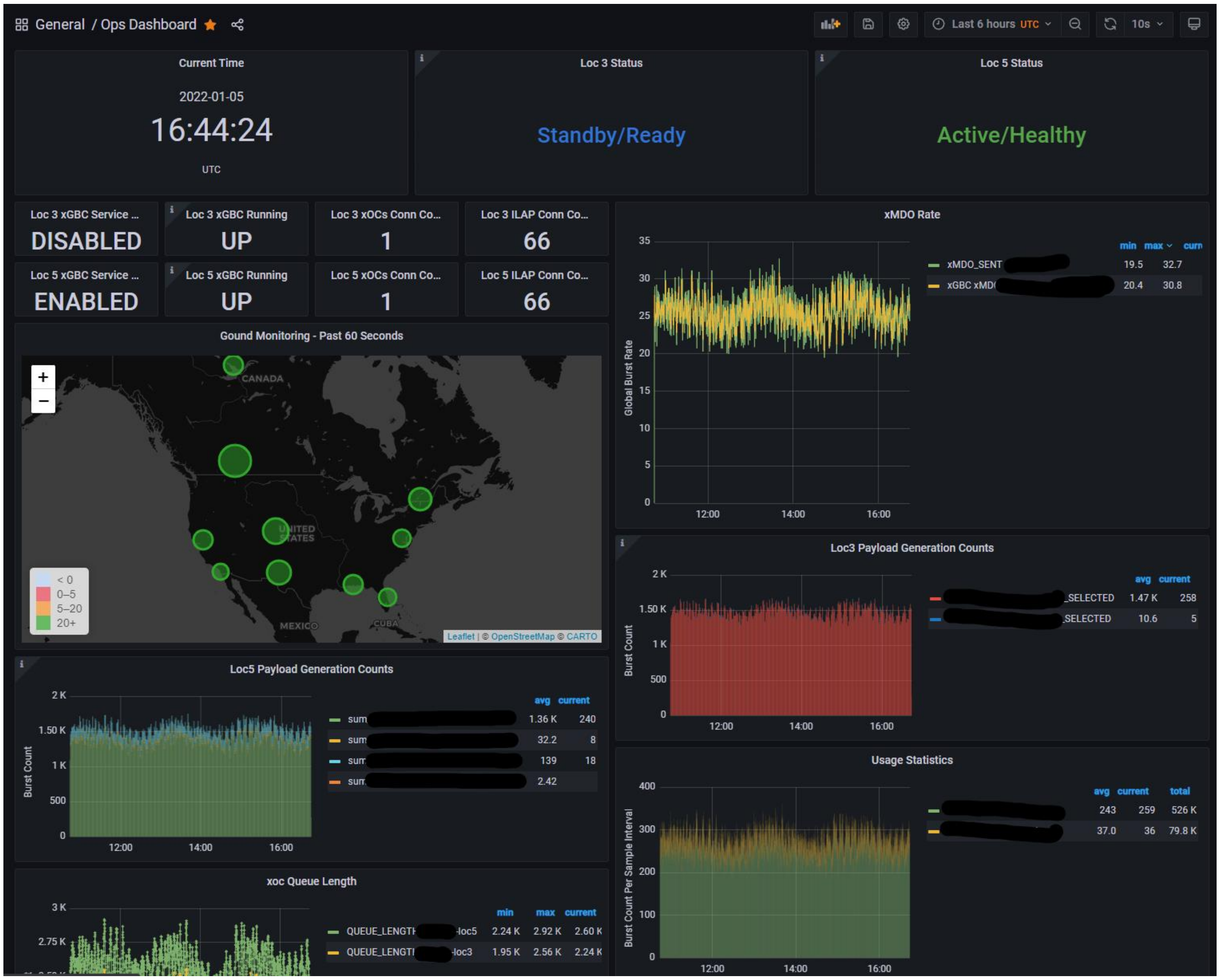


Figure 4.10: Partial view of operations monitoring dashboard – overall status summary

Satellite Status

In addition to monitoring overall system status, Satelles also monitors performance and quality of the PTN signals on each of the 66 Iridium satellites. Again, alerts are generated for any abnormal behavior. Satelles has the direct ability to disable STL service on a misbehaving satellite if necessary.

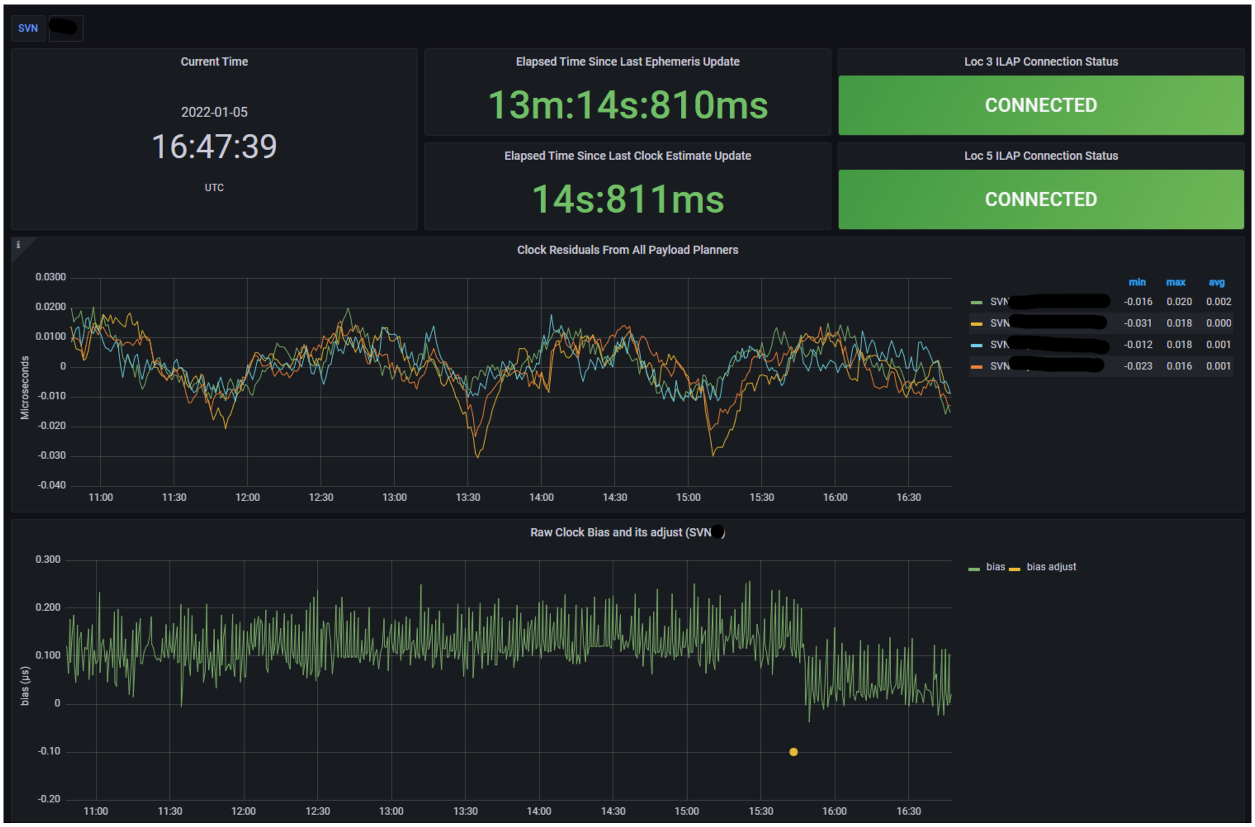


Figure 4.11: Individual SV Performance

Overall System Redundancies

Multiple levels of redundancy exist throughout the system, including automatic failover at the server level, multiple network paths for data used by the system, and failover between Iridium ground stations in the event of an extended outage at the primary uplink site.

The ground infrastructure for STL service consists of identical sets of computing, storage, and networking hardware co-located inside of two geographically diverse Iridium ground stations. One of the ground stations is considered ‘active’ for the service; the other is ‘standby’. A failover from one site to the other can be accomplished in less than 10 minutes. Failovers are exercised 3-4 times per year in the absence of actual failures.

At the individual site level, every physical compute, storage, and network component for STL services is physically redundant; there are no single points of failure. Recovery from hardware failure is generally instantaneous, with the only indication of a failure appearing as operational alerts within the monitoring environment.

STL application services are run as virtual machines on the hardware clusters described above. Using virtualization allows for strong isolation of services and for load balancing across the hardware cluster. Recovery of a failed VM requires approximately 100ms (for critical services) to a maximum of 2 minutes (for non-critical services).

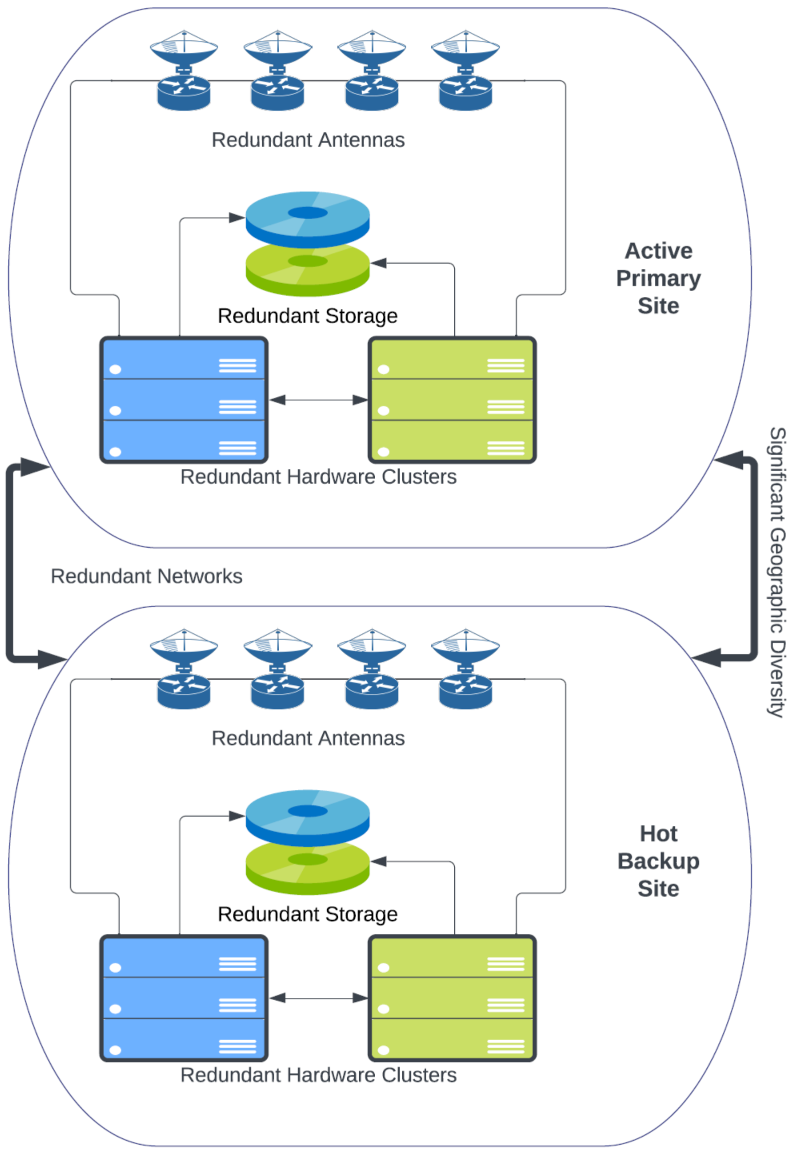


Figure 4.12: Summary of Overall System Redundancies

Additional Information

The details of time coordination within the Satelles ground and space network are proprietary and sensitive. What we can say is that the network includes over a dozen satellite monitoring and ground network sites with high-end atomic clocks for long-duration operation across the network. These allow the network to be resilient to localized and widespread GNSS denial or disruption events. For local area or widespread (e.g., nationwide) GNSS denial or disruption, the system would continue to operate indefinitely (infinite operation). The United States National Institute of Standards and Technology (NIST) also confirmed that STL is independent of GNSS.[1] Testing conducted by NIST compared a GPS-disciplined clock (getting its signal from an outdoor antenna) and an STL receiver (with an indoor antenna) to UTC (NIST) for 50 days. The study showed that based on one day of averaging, the GPS instability was less than two nanoseconds (< 2 ns), and the STL instability was only slightly higher at under three nanoseconds (< 3 ns).

[1] U.S. National Institute of Standards and Technology, NIST Technical Note 2187 – *A Resilient Architecture for the Realization and Distribution of Coordinated Universal Time to Critical Infrastructure Systems in the United States*, (November 2021), pp. 158-161, https://nvlpubs.nist.gov/nistpubs/TechnicalNotes/NIST.TN.2187.pdf

T7G: Static Position Test using Roof Mounted Antenna

Test Identification	T7G
Test Name	Static Position Test using Roof Mounted Antenna
Objective	Evaluate static receiver positioning performance over a week-long period
Output	Measurements of time-tagged positioning data
Time to Execute	Up to 7 days
Metrics	Positioning error referenced to truth source

A static positioning test using a receiver antenna mounted on a rooftop was conducted for a duration of 7 days.

The Static Timing and Positioning Test System was utilized to execute each of these test cases. For details on the test system and validation procedures, please refer to section 3. For purposes of positioning, the “Bravo” receiver from this test setup was used for position performance evaluation.

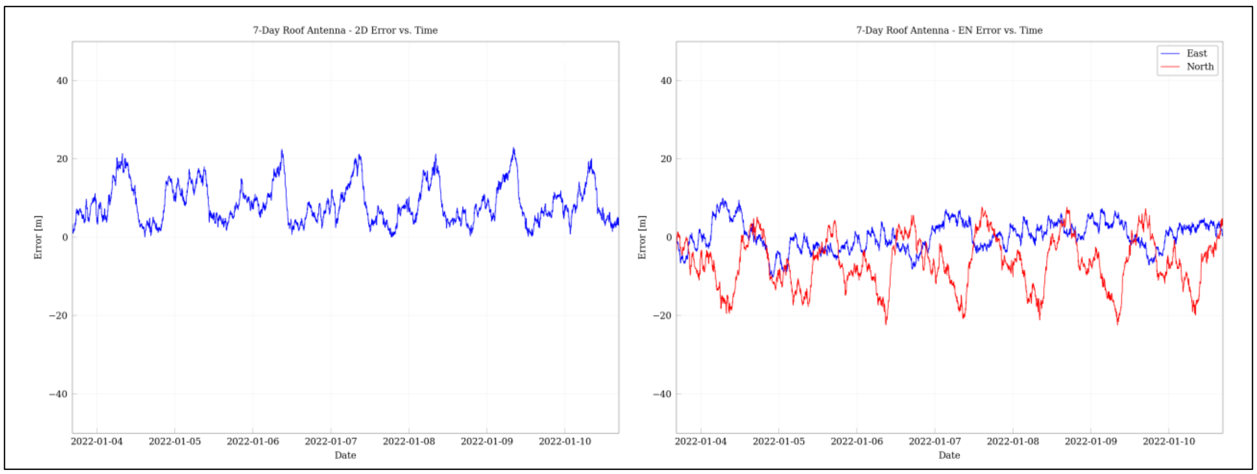


Figure 4.13: Rooftop Positioning Test Results

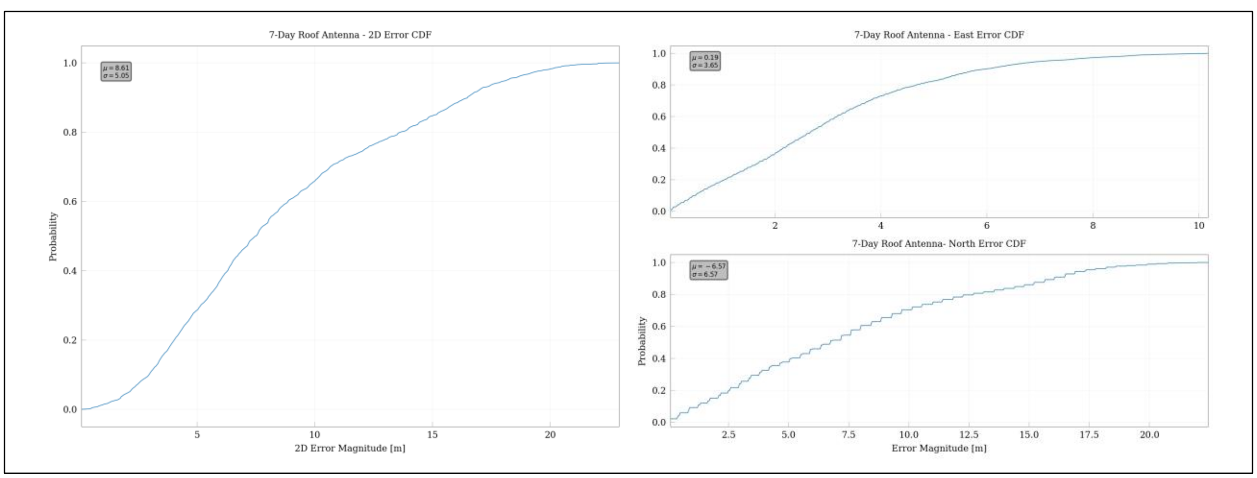


Figure 4.14: Rooftop Positioning Test Results

T7H: Static Position Test using Indoor Antenna

Test Identification	T7H
Test Name	Static Position Test using Indoor Antenna
Objective	Evaluate static indoor receiver positioning
Output	Measurements of time-tagged positioning data
Time to Execute	4 Tests, 24 hours each
Metrics	Positioning error referenced to truth source

A total of four 24-hour static positioning tests, using a receiver antenna mounted at two indoor locations, were conducted.

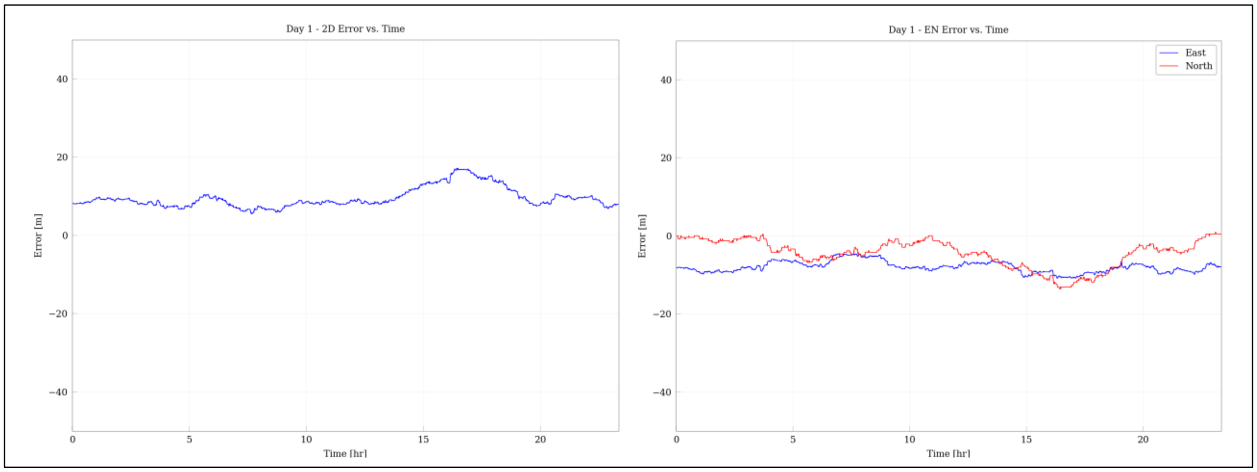
The Static Timing and Positioning Test System was utilized to execute each of these test cases. For details on the test system and validation procedures, please refer to section 3. For purposes of positioning, the “Alpha” receiver from this test setup was used for position performance evaluation.

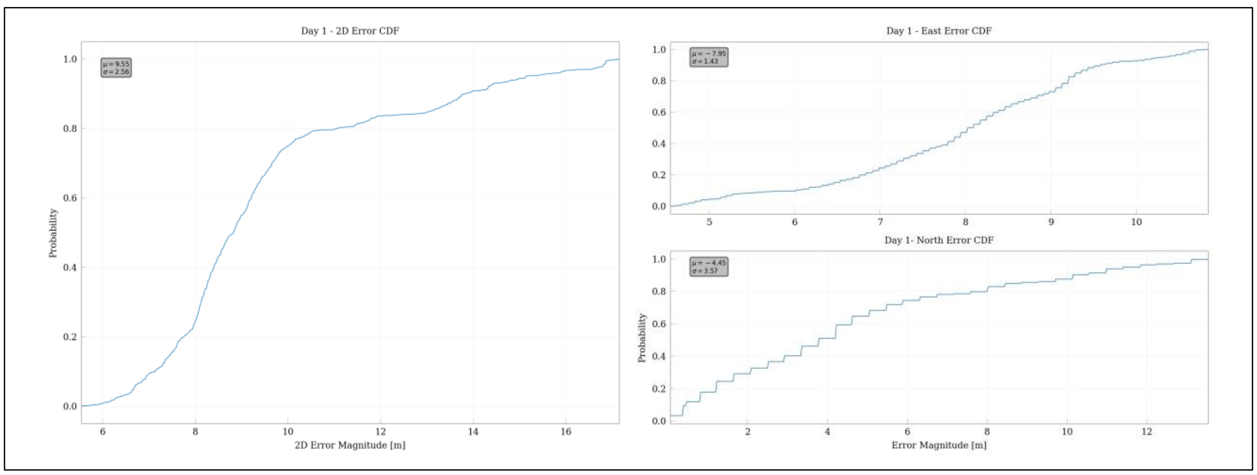
Table 4.4: Indoor Positioning Test Results

Indoor Test Day	Antenna Location	Average 2D Error (m)
1	Top of cabinet	9.5512
2	Inside cabinet	6.2377
3	Top of cabinet	6.2016
4	Inside cabinet	1.8949

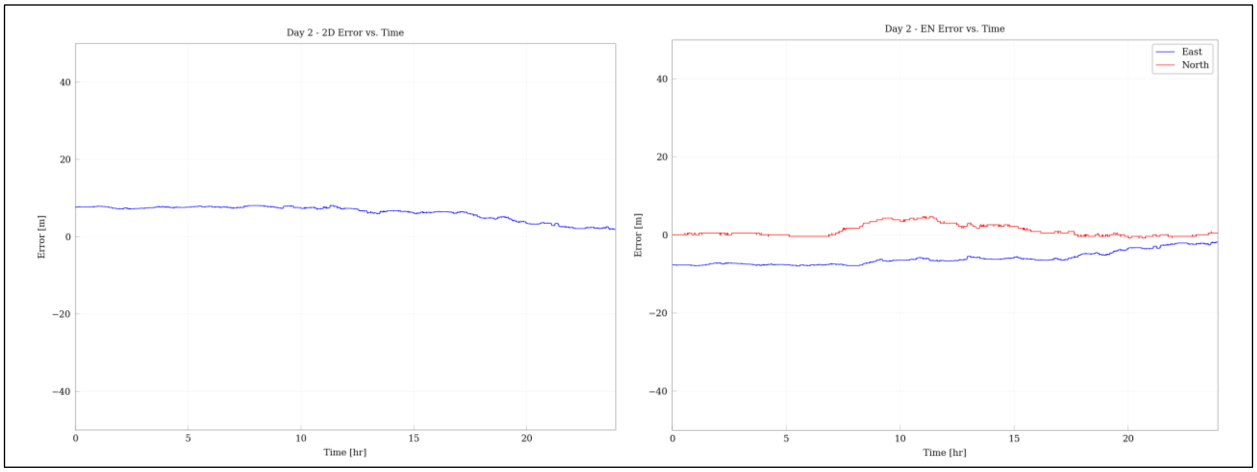
Appendix A: T7H Plots

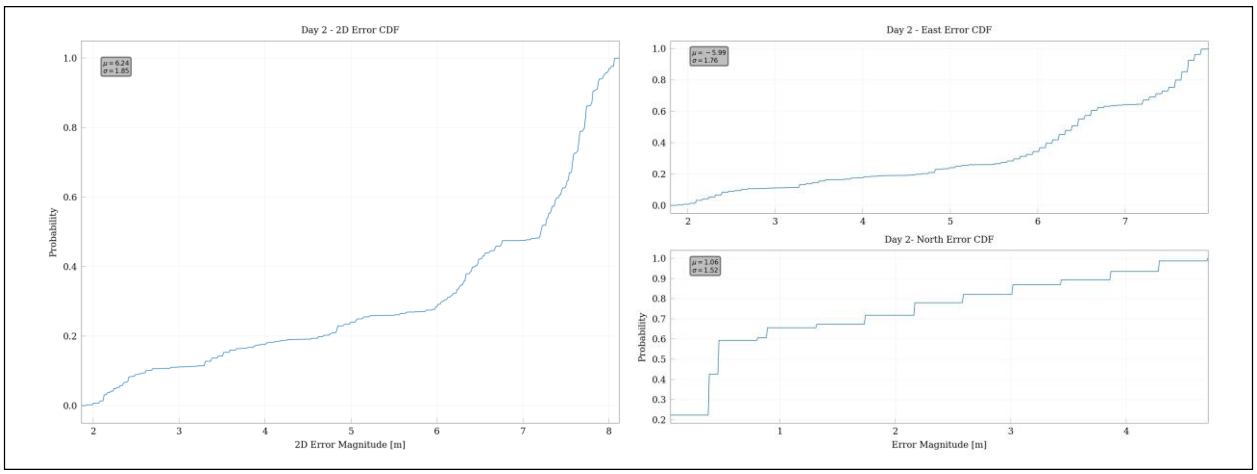
Indoor Day 1 – Top of Cabinet



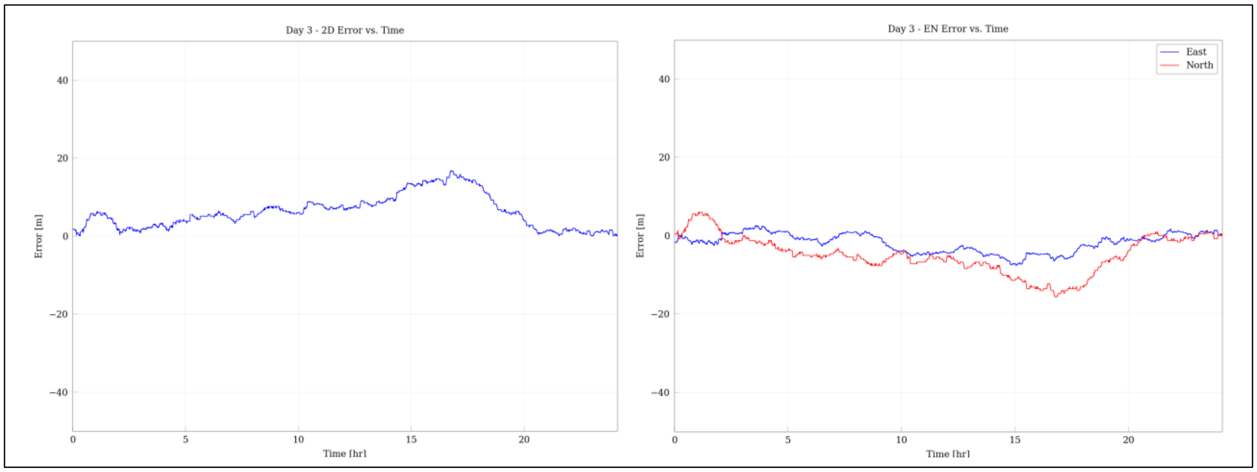


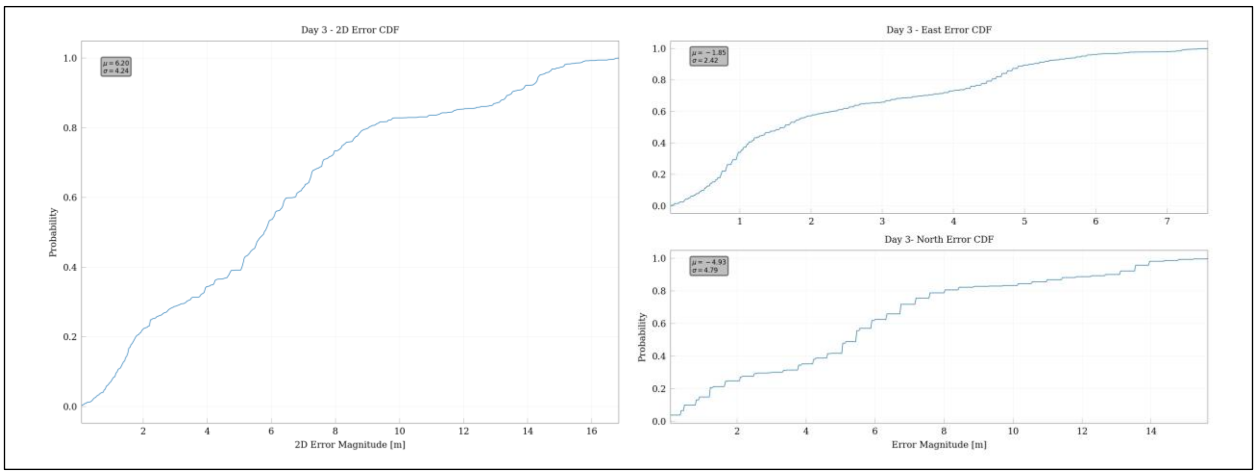
<u>**Indoor Day 2 – Inside of Cabinet**</u>



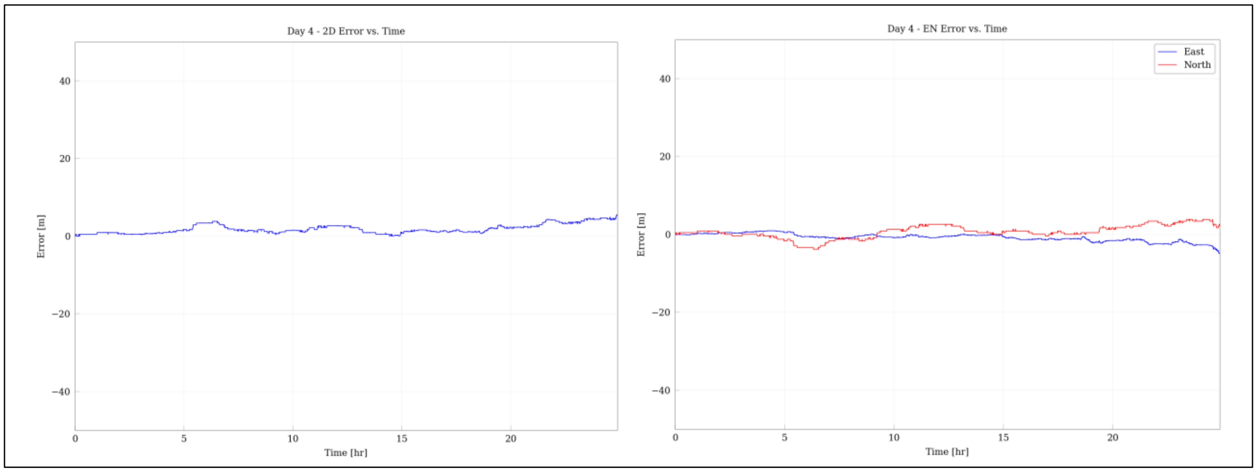


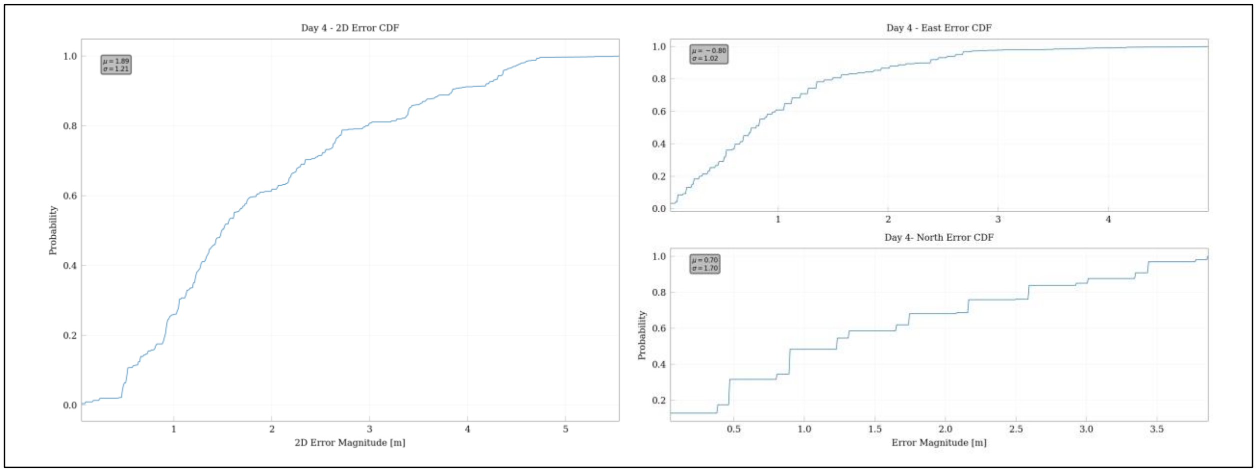
Indoor Day 3 – Top of Cabinet





Indoor Day 4 – Inside of Cabinet





Looking at the error plots from Test T7G and T7H, a pattern can be observed in the rooftop antenna and top-of-cabinet antenna results. The T7G error plots produce a sawtooth pattern and while it is less pronounced in the Test T7H top-of-cabinet results, it is still present. This sawtooth shape does not appear in the Test T7H inside-cabinet error plots which is due to the lower signal power received in the degraded environment. Measurements with higher carrier-to-noise densities tend to be trusted more than low power measurements. When operating in static unknown-position mode, as these receivers were, the power of received signals have a larger impact on the position solution. This fact coupled with the significantly reduced signal power inside of the cabinet, results in less jitter in the position output from the receiver. Though the errors in the inside-cabinet solutions are lower relative to the rooftop and top-of-cabinet solutions, this should be considered an exception to the norm. While less jitter in the solution might be expected, one should not count on improved position errors when operating indoors as opposed to outdoors.

Along those same lines, it can be observed that position errors improve as the antenna was moved from the rooftop, to on top of the cabinet, to inside of the cabinet. The main takeaway from these results should be that all three test conditions produced results that are at the limits of STL's accuracy, and difference between them is in the noise. Outside of antenna location, there are several factors which play a part in receiver accuracy such as time of testing and satellite geometry. Therefore, no conclusions should be drawn based on the relative accuracy results between the three tests, as they are all effectively getting the same accuracy results within the confidence level of the technology. If data collection had continued on indoor test days 2 and 4 for an extended amount of time, one should expect to observe a dampened sawtooth pattern rather than the apparent convergence to zero error.

Appendix B: Test Data Description

Timing Data Format

TimeLab is used to capture the timing data from Keysight 53230A for the TI measurements from the PPS output of the receiver to the timing reference for the duration of the test. TimeLab continuously captures data from the Keysight 53230A and displays the measurement results graphically. The test data will be saved to a file at the end of the test and incremental saves can be done at any time during the test. All TimeLab files are saved on the hard drive of the NUC computer (Alpha or Bravo) associated with that test, Alpha for the T3D test. The data files from TimeLab are text files that can be read back into TimeLab for post analysis with various measurement options (Phase difference, Allan Deviation, Time Deviation, Frequency Difference) or the raw data can be analyzed separately with other statistical tools. The saved data files from TimeLab have the following format: Several header lines that contain information about the test setup followed by the measurement data. The last line of the header before the data starts has the number of lines of data that will follow in the file. Below is an example of a TimeLab data file.

Example of TimeLab Output File

```
;
;Measurement log file C:\Users\Europa\Keysight-Alpha-tuesday-24hrs.tim
;Written by TimeLab 1.51 of Jun  5 2020 by John Miles, KE5FX (john@miles.io);
STR 0x00000000 "Driver" HP 53220A/53230A ...
STR 0x79000000 "Channel" Ch 0
STR 0xC8000000 "Time/Date" 10/5/2021 6:11:06 AM
DBL 0xCD400000 "MJD" 59492.54942015046
STR 0x05000001 "Trace" Keysight-Alpha-tuesday
STR 0x0A000001 "Notes"
DBL 0x32200041 "Sample Interval" 1.0
S32 0x00000000 "Data Type" 0
DBL 0x2D000000 "Scale Factor" 1.0
DBL 0x14000081 "Input Freq" 1.0
S32 0x5A000000 "Bin Density" 29
S32 0x5F000000 "Bin Threshold" 4
S32 0x50000000 "Trace History" 1
STR 0xF0000000 "Address" 172.16.100.37
BLN 0x00000000 "Prologix Compatibility Mode" False
BLN 0x00000000 "Query Instrument ID" True
BLN 0x00000000 "Automatic Configuration" False
STR 0xE6000001 "Instrument" Agilent 53230A
STR 0xE6000000 "Rev" MY61210281,03.02-1924.2831-3.15-4.16-127-159-35

DBL 0x3C001001 "Duration" 100
S32 0x00000000 "Duration Type" 4
S32 0x00000000 "Stop Condition" 0
STR 0x00000000 "Interface" .
S32 0x00000000 "Driver version" 112

TIC 98535
   5.7062902399376999E-007
   5.7069250055627004E-007
   5.7028722711877001E-007
   5.6994543024377003E-007
   5.6964269586877003E-007
   5.6938878961876995E-007
   5.6951574274377004E-007
   5.7001867243127002E-007
   5.7013097711876999E-007
   5.6996984430626999E-007
   5.7003332086877004E-007
```

Positioning Data Formats

Tera Term is used to capture and store PNT log messages from the Jackson Labs PNT-6220 receiver setups employed within the Static Timing and Positioning Test System. All log files are saved on the hard drive of the NUC computer (Alpha or Bravo) associated with that test. The log files are post process to extract only the location messages using Unix grep or other suitable tool to identify them by their message type, “PJLTPOS” in this case. The following is an example of an extracted location message line: $PJLTPOS,7,1317685132,0,45.80972290,008.63023853,253.43,4403258,668307,4550712,0.2217,0.0810,0.1729,0.0000,0.0000,0.0000,0.0,-1.0,1,1*65

The fields are delimited by commas and the latitude, longitude and altitude data are contained in columns 5, 6, and 7 respectively. The latitude and longitude are in decimal degrees and altitude is in meters. The position messages from the receiver are sent once per second and the GPS time of the message is in column 3. The details for the data in all the columns of position message follow:

The PJLTPOS string has the following data format: $PJLTPOS,v,ssssssssss,f,ll.llllll,yyy.yyyyyy,aaa.aaaaaa,xxxxxxxxx,yyyyyyyyy,zzzzzzzzz,uu.uuuuuu,uu.uuuuuu,uu.uuuuuu,uu.uuuuuu,uu.uuuuuu,uu.uuuuuu,b.b,s.s,p*[checksum]

Where

v is the message version,

ssssssssss is the current time with "format of time" below,

f is the format of time with 0 = GPS time and 1 = Unix time,

ll.llllll is the latitude in decimal degree,

yyy.yyyyyy is the longitude in decimal degree,

aaa.aaaaaa is the antenna altitude above/below GPS height in meters when receiving STL signals, and MSL height when operating from the GNSS receiver,

xxxxxxxxx is the position in ECEF-X axis, in meter,

yyyyyyyyy is the position in ECEF-Y axis, in meter,

zzzzzzzzz is the position in ECEF-Z axis, in meter,

uu.uuuuuu are the uncertainty represented as local level covariance for EE, NN, UU, EN, EU, and NU, respectively,

b.b is the age of position in seconds since last received signal,

s.s is the age of position in seconds since last sensor update,

p is the position figure of merit (PFOM) of current solution.

Data from the STL-2600 receiver, utilized in the Quasi-static Positioning Test System, is identical to that used in the Static Timing and Positioning Test System. Data from the EVK4 receiver is logged slightly differently than the “PJLTPOS” message shown above. The following is an example data line from the EVK4 log file:

1322271527.0,37.34645656,-121.97362697,-2.485,15.4,6.3,19.2

The fields are delimited by commas and the latitude, longitude, and altitude data are contained in columns 2, 3, and 4 respectively. Latitude and longitude are presented in decimal degrees and altitude is presented in meters. This message from the receiver is sent once per second and the GPS time of the message is in column 1. A more detailed description of the message follows:

The EVK4 log message has the following format: ssssssssss.s,ll.lllllll,yyy.yyyyyyyy,a.aaa,uu.u,uu.u,uu.u

Where,

ssssssssss.s is the current GPS time

ll.lllllll is the latitude in decimal degrees

yyy.yyyyyyyy is the longitude in decimal degrees

a.aaa is the altitude in meters

uu.uuu are the uncertainty represented as local level covariance for EE, NN, and UU respectively

Truth data will be recorded in two formats. The simple GPS receiver truth positions, utilized in the quick-look analysis, will be logged using standard NMEA messages. The high-accuracy truth positions will be logged using Novatel's Inertial Explorer as shown in the table below.

Novatel Output from Inertial Explorer

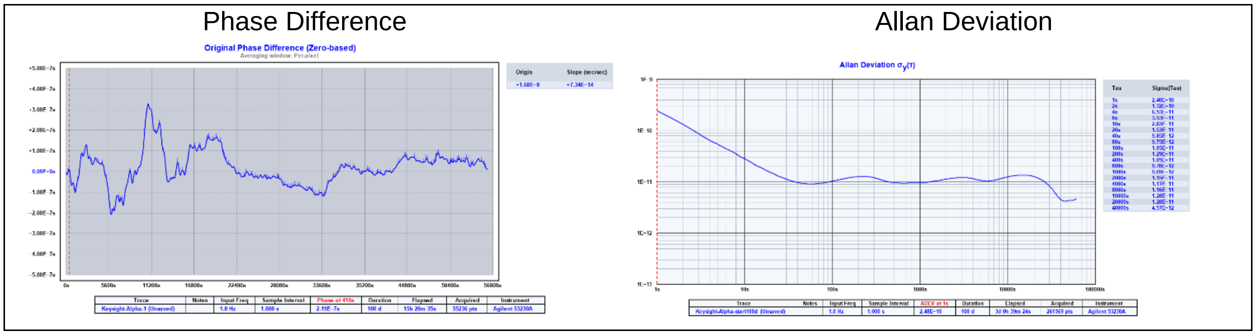
```
Project:     urban1
Program:     Inertial Explorer Version 8.90.2428
Profile:     Test_melania
Source:      GNSS/INS Epochs(Smoothed TC Combined)
SolFile:      C:\Users\damysop\Documents\Test_Lukasz_altpnt\211126_dryRunT6\urban1\urban1.cts
ProcessInfo: urban1 by Unknown on 11/26/2021 at 18:23:38

Datum:       WGS84
Master 1:    Name base_emsl, Status ENABLED
             Antenna height 0.000 m, to L1PC [Generic(NONE)]
             Lat, Lon, El Hgt 45 48 37.31961, 8 37 47.82033, 278.873 m [WGS84, N/A]
Remote:      Antenna height 0.000 m, to L1PC [Generic(NONE)]
IMU to GNSS Antenna Lever Arms:
             x=0.174, y=0.000, z=0.000 m (x-right, y-fwd, z-up)
Body to IMU Rotations:
             xRot=0.000, yRot=-0.236, zRot=1.888 degrees

  GPSTime       Latitude      Longitude        H-Ell    VNorth     VEast       VUp
    (sec)          (rad)          (rad)          (m)     (m/s)     (m/s)     (m/s)
480421.00   0.7995337362   0.1505502273      260.511    -0.002    -0.000     0.004
480422.00   0.7995337362   0.1505502273      260.511     0.000     0.001     0.005
480423.00   0.7995337362   0.1505502273      260.511    -0.000    -0.001     0.005
…
```

Appendix C: Data Analysis and Results

The following two sub-sections describe the data analysis and results which will be generated for the various timing and positioning test cases.

Analysis of Static Timing and Positioning Data

After a timing test has completed, the TimeLab data will be processed to generate plots depicting the necessary evaluation metrics. The following are examples of a TimeLab measurement plots.



After a static positioning test has completed, the log files will be analyzed to produce error plots. The latitude, longitude, and altitude values from the location messages of each receiver are compared to those from the Truth receiver at each GPS second and used to calculate the horizontal and vertical error for the entire route of the test.