GNSS Test Vector Distribution Methodology

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CGSIC 2024

Baltimore, MD

Approved for public release, case #24-2543

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Acknowledgements

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Task Order 70RSAT20FR0000062
DHS S&T Next Generation Resilient PNT
The results presented in this report do not necessarily reflect official DHS opinion or policy.

Case Number 24-2543 / 70RSAT20FR-062-19

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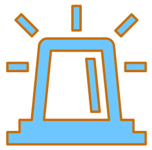
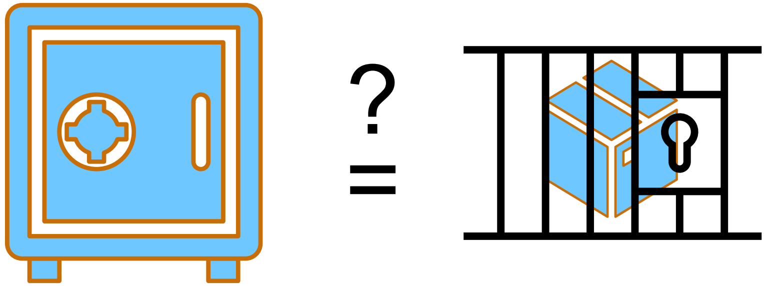
Background

- **Resilient and robust Positioning, Navigation, and Timing is ever more important**
- **Testing PNT systems against threats has historically been challenging**
  - How does system X respond to threats?
  - How do we compare systems X and Y?
  - What happens when a threat is (un)detected?
  - How can I test without being an expert at generating threats?
- **This tool intended to help answer these questions**

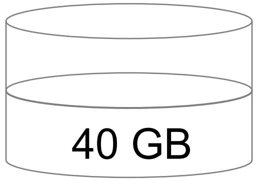




Current Approaches

- **GNSS Simulator plus expert**
- **Custom receiver / simulator**
- **Government run field tests**
- **Pre-generated scenarios (e.g., Texas Spoofing Test Battery)**
- **Avoid testing?**

Test #1 of 75

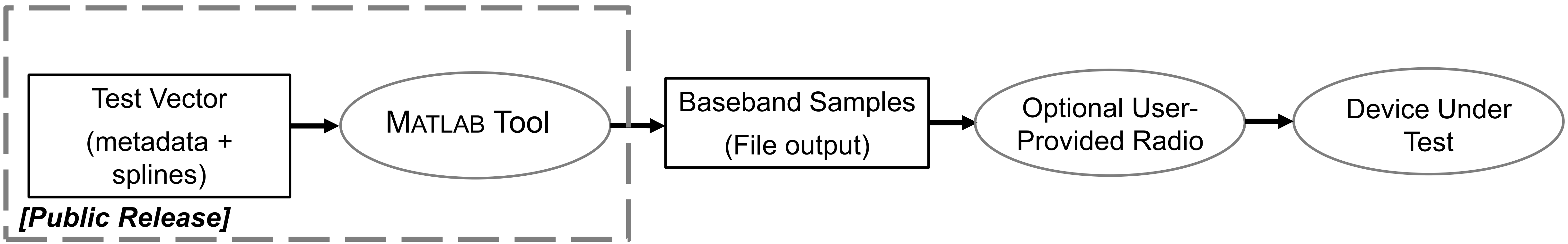


Tool Development Approach

- **Desire a solution that enables threat testing that:**
  - Does not require specialized hardware
  - Does not enable attacks synchronized to the world
  - Is highly flexible
  - Limits infrastructure needed for distribution
  - Can realize realistic and representative threats
  - Doesn’t require user expertise
- **Solution: software tool ingests small (provided) metadata files, generates baseband samples**

P1952, CASC, Field test prep, R&D

Test Vector Distribution Methodology Overview



- **Test vectors are processed by the HSSEDI-provided tool to convert the compact test vector into samples that represent the radiofrequency (RF) signals modeled by the test vector**
- **These samples are then converted to RF by the user-provided tool of choice (e.g., a universal software radio peripheral [USRP])**
- **The resultant RF signals are input to the device under test**

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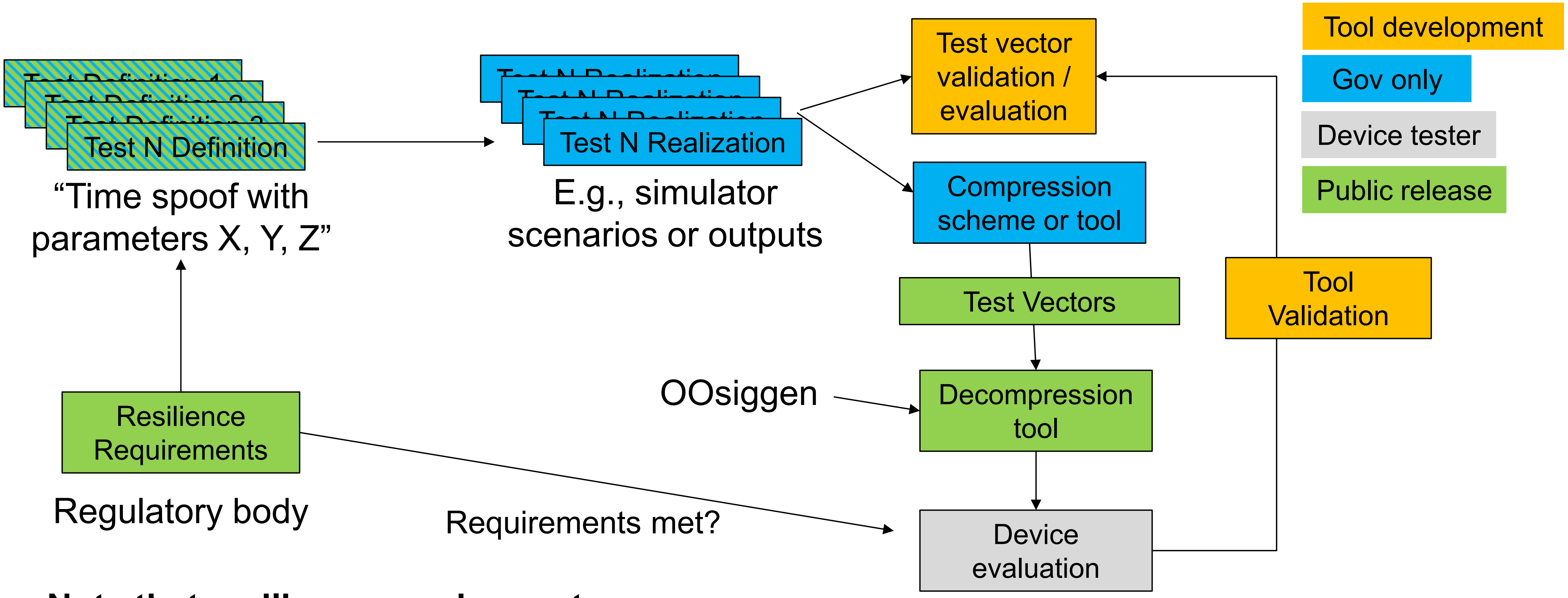
Test Vector Format Overview

A complete test vector as defined for use with these tools comprises various files:

- A JSON file defining the signals that are present in the test vector and various constant parameters for each signal - center frequency, pseudorandom noise code (PRN), etc.
- A set of splines (piecewise polynomials) for each signal defining signal parameters that may change over time:
  - Signal power
  - Pseudorange
  - Doppler Shift
  - Data symbols (supports bi- and quadrature phase shift keying)
  - Noise power

Test Vector Example Use Case



Note that resilience requirements are not part of this task

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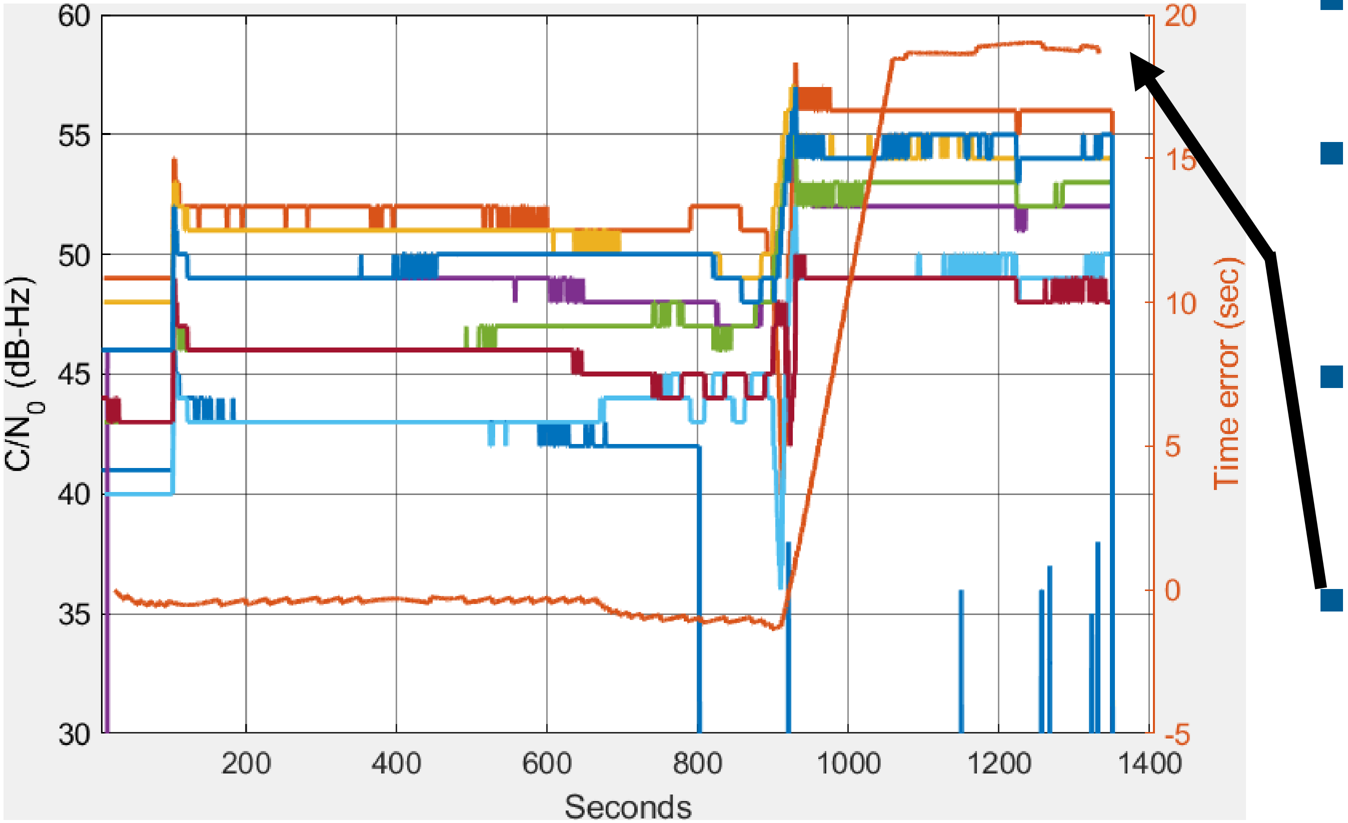
Test Vector Distribution Methodology Capabilities

- **At the time of delivery, the software tool OOsiggen which converts the test vectors into baseband samples supports the following:**
  - GPS C/A, L1C, L5; Glonass L1OF, Galileo E1OS (although only GPS C/A and E1OS are currently supported by the internal test vector creation tool)
  - Broadband noise
  - Any number of signals and constellations
  - Any spoofing scenario that can be created by modifying pseudoranges, carrier phases, signal powers, data bits, or noise power for the support signals
  - Baseband data generated with user-specified sample rate as 16-bit complex interleaved samples

Exemplary Test Vectors

- **Similar to previous sets, for comparison:**
  - TV1: Stationary overpowered time walk
  - TV2: Stationary matched power time walk, freq. lock mode
  - TV3: Stationary matched power position walk, freq. lock mode
  - TV4: Dynamic overpowered position walk
- **Excursions from previous sets**
  - TV5: Stationary overpowered time walk with added noise to maintain C/N0 and Galileo E1OS
  - TV6: Stationary overpowered constant acceleration time walk
  - TV7: Dynamic overpowered position walk with 2 signals unspoofed
- **New tests**
  - TV8: 1 ms time jump with knockoff jamming (demonstrates extended effect duration)
  - TV9: Data compliance check (only one signal set present, subset of satellites with non-compliant data)
- **Scenario details: chose time / location to be generally uninteresting to minimize chance of nefarious use**

Test Vector 1 Design and Impact



- Scenario includes only GPS C/A signals
- Victim is stationary, attacker has very good knowledge of victim antenna location
- Spoof signals have a 10 decibel (dB) power advantage over authentic
- Observed time error very close to intended time error of 2 microseconds (uS) at scenario end

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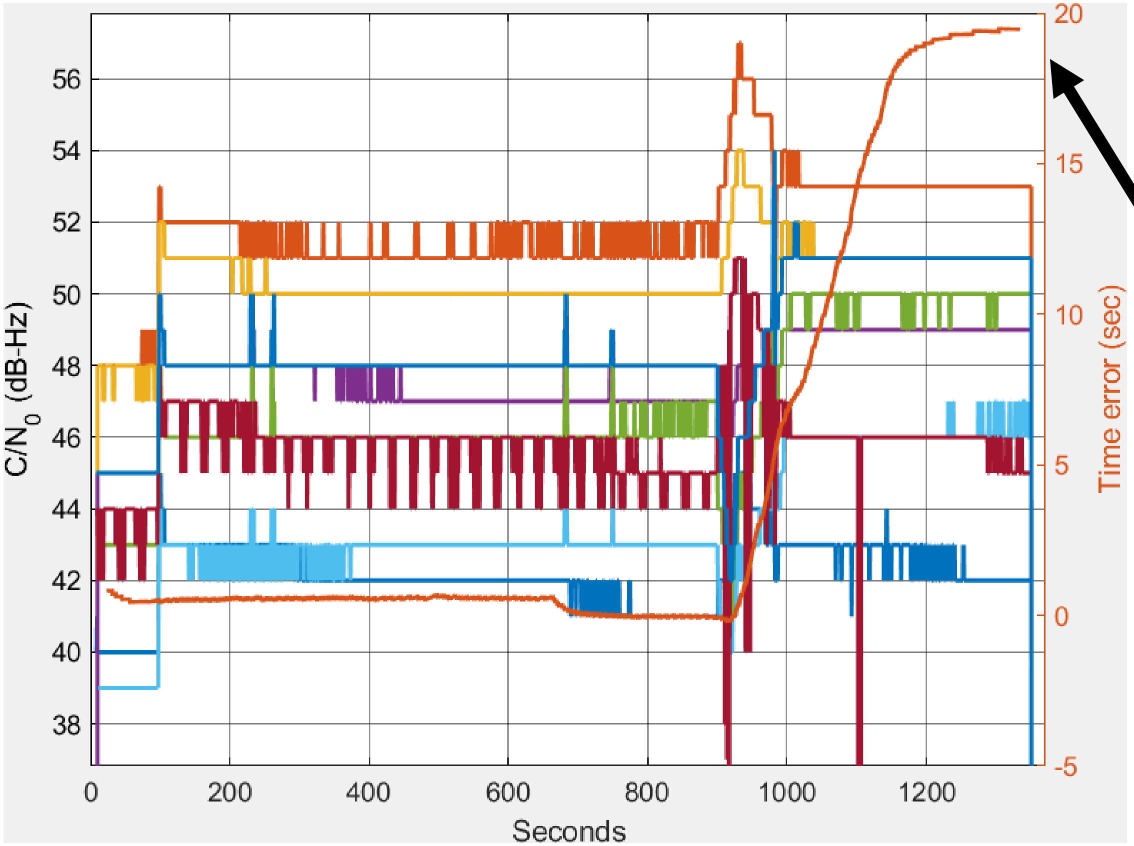
Test Vector 2 Design and Impact



- **This scenario is identical to TV1 except that**
  - Spoofer power advantage is 2 dB
  - Spoofer uses so-called “frequency lock mode” to mitigate beating between true and spoofed signals with small power advantage
- **Observed time error very close to intended time error of 2 uS at end of scenario**

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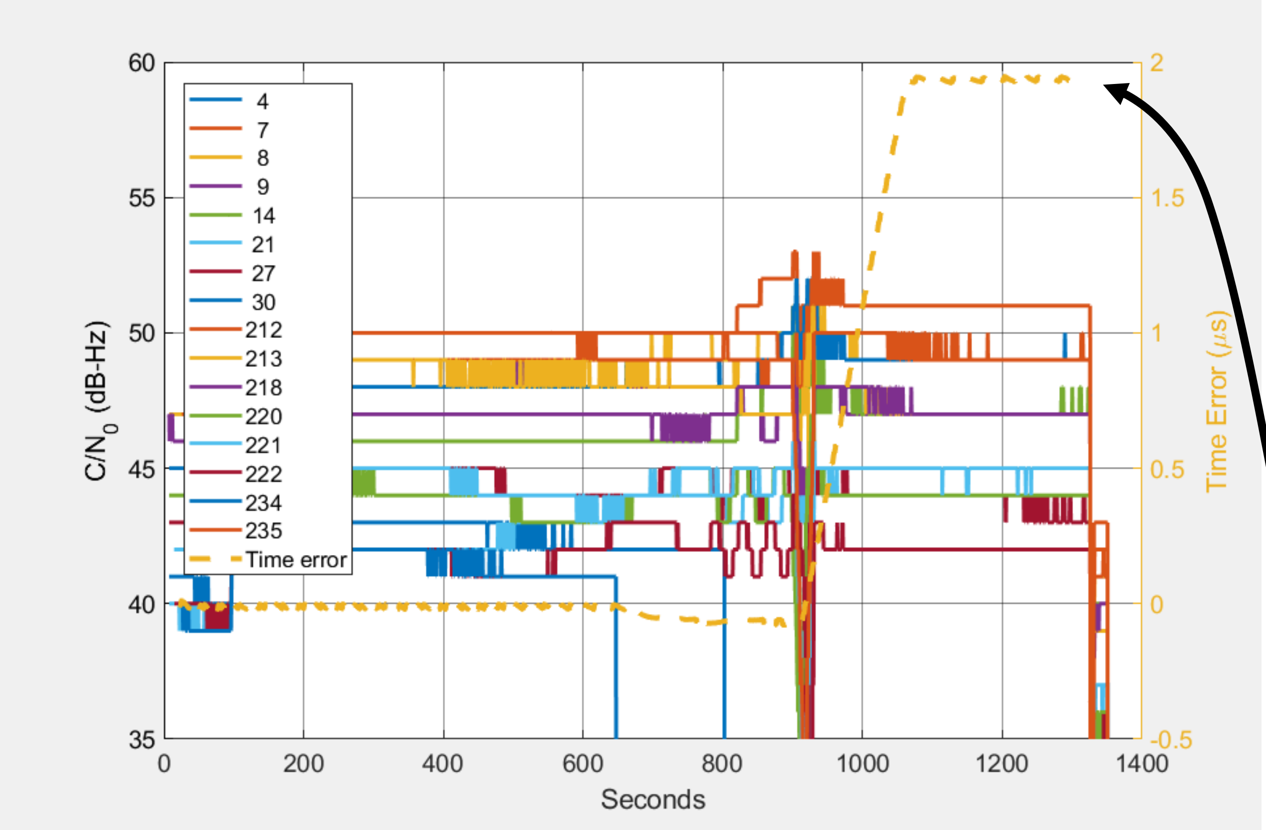
Test Vector 5 Design and Impact

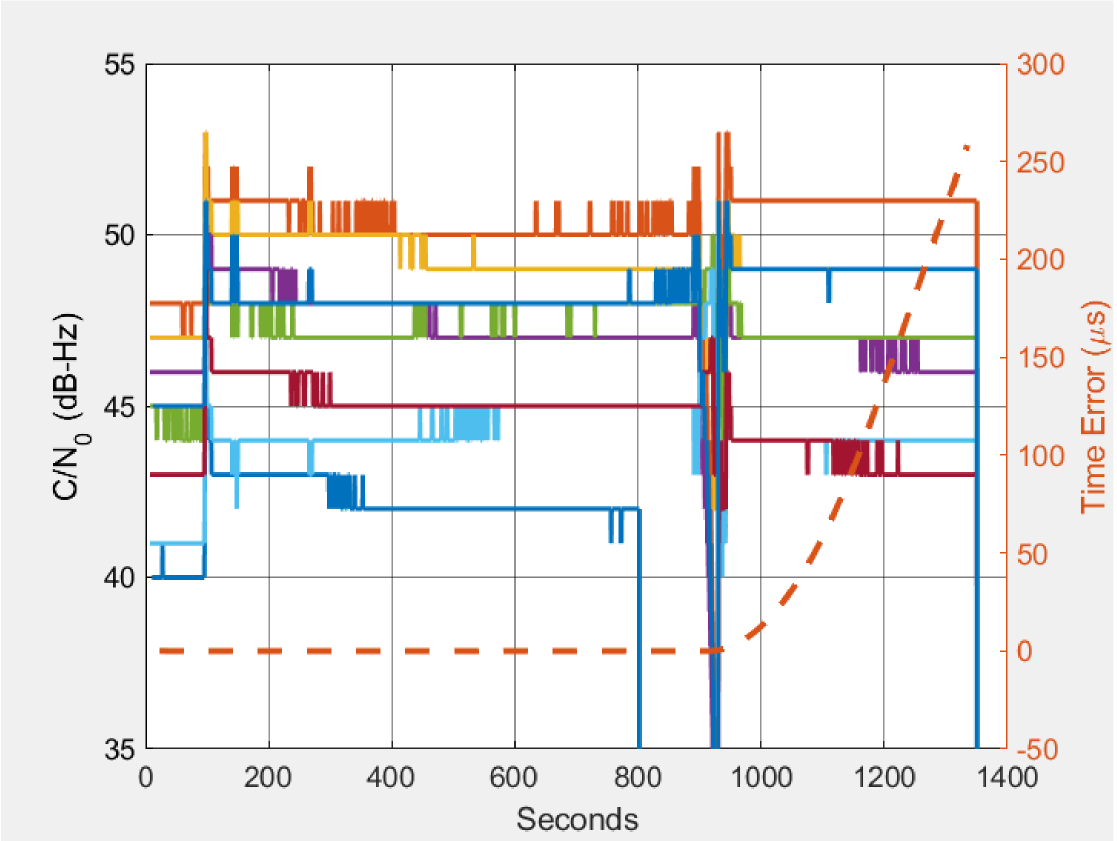


- **Stationary target**
- **Noise is added as spoof power is increased to hold victim C/N0 constant.**
- **Also include Galileo E1OS signals spoofed in the same manner.**
- **Note that Galileo PRNs are (PRN + 210) in plot legend**
- **Induced time error matches intended spoof**

Test Vector 6 Design and Impact

- **Stationary target**
- **GPS C/A only**
- **Time spoof has constant acceleration of 1 m/s^2 from 930-1200 seconds, then constant velocity after that**
- **1.3 dB spoof power advantage with commensurate added noise**
- **Receiver time error very closely matches intended spoof, reaching 250 µs at scenario end**

C/N0 and Time Error from Device Under Test



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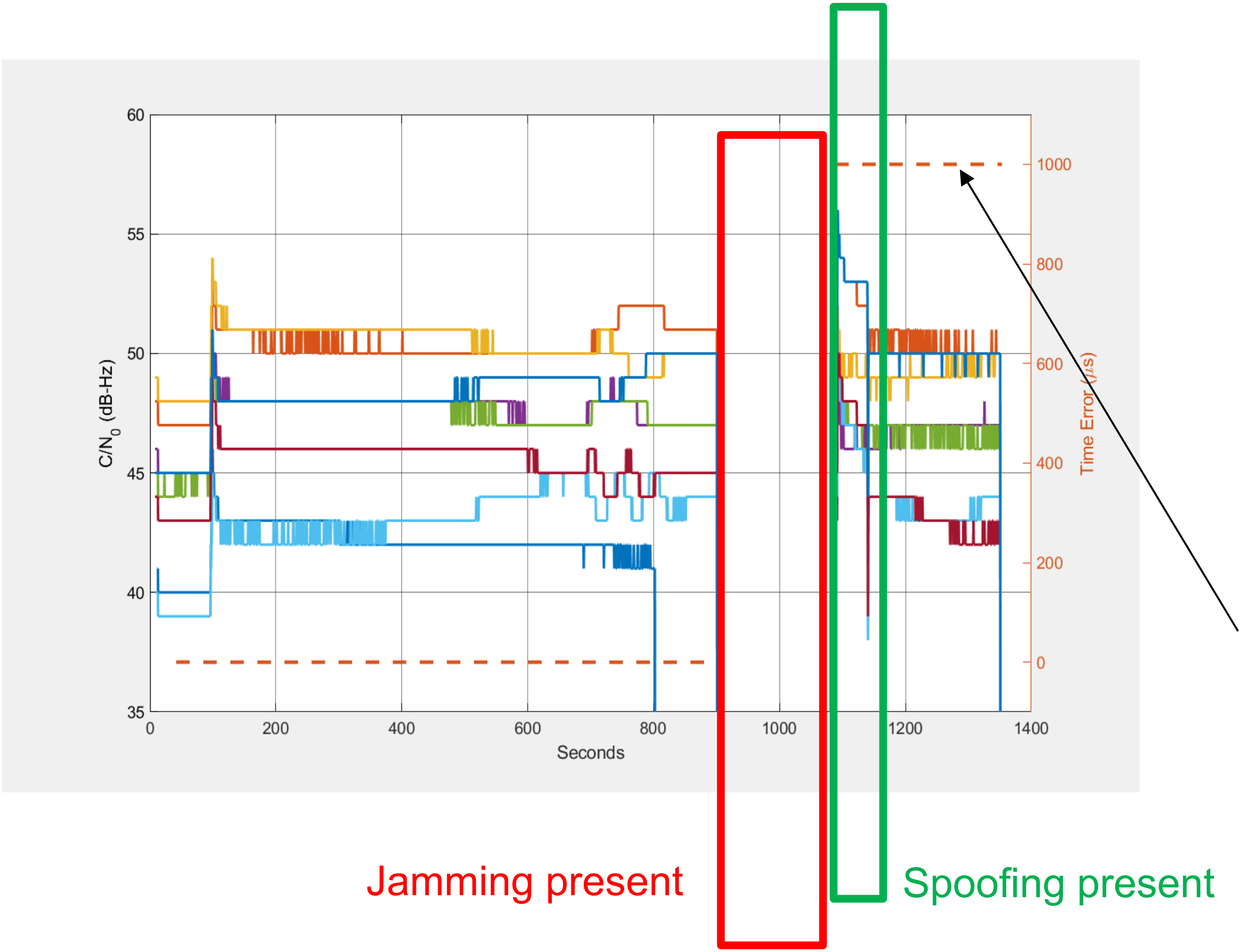
Test Vector 8 Design and Impact



- Scenario location and other parameters identical to TV1
- Jamming present from 900-1080 seconds
- Spoofing w/ 1 ms time advance present from 1080-1140 seconds
- Returns to truth-only after that
- Receiver time remains 1 ms off even after removal of spoofing signals

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Summary

- **A software tool for generating GNSS receiver test vectors has been developed**
  - The test vectors used by this system are compact and easy to distribute
  - This tool greatly lowers barriers to GNSS receiver testing
- **A set of exemplary GNSS spoofing test vectors has been created, and results from one example test receiver processing these test vectors are shown**
  - Additional test vectors are easy to create and distribute
- **The software tool and exemplary test vectors are approved for public released**
  - Hosting location is yet TBD, but stay tuned!

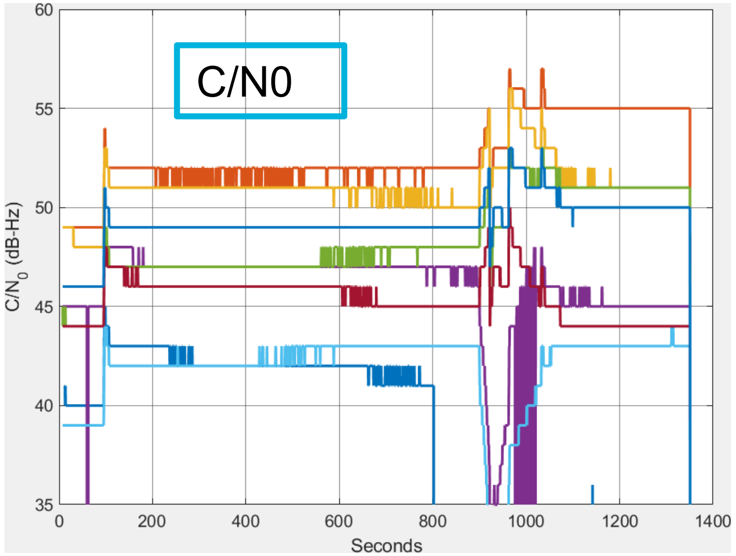
Backup – Additional Exemplary Results

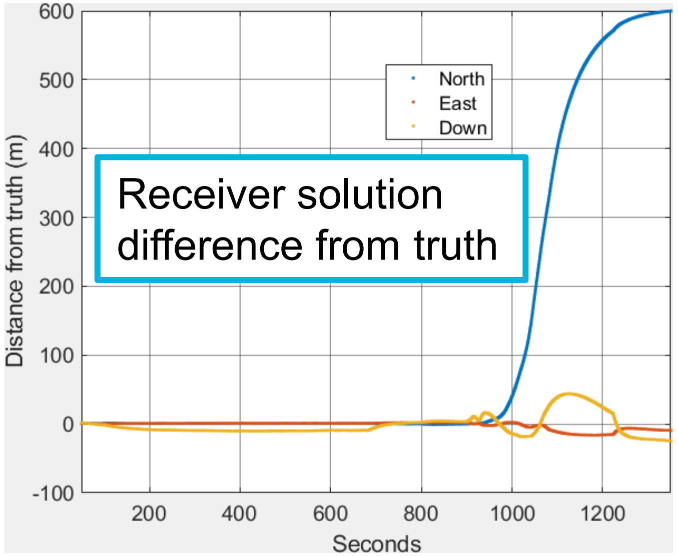
Common Test Vector Details

- Victim Receiver location fixed at 39.833333 North 98.58333333 West, 0 meters height above ellipsoid (static scenarios)
- Start time 2023-Jan-03 21:20:00
- 10-degree elevation mask applied
- Ephemeris reference time is ~2200
- Data bits all set to true (or true-like) at actual scenario time

Test Vector 3 Design and Impact

- **Receiver is stationary at same location as TV1**
- **Spoofer power advantage is 3 dB, frequency lock mode**
- **Intended position spoof moves victim 600m due north over 150 seconds starting at 930 seconds**
- **Spoofed position eventually arrives at intended position; receiver filtering / tracking loop design results in delayed response**





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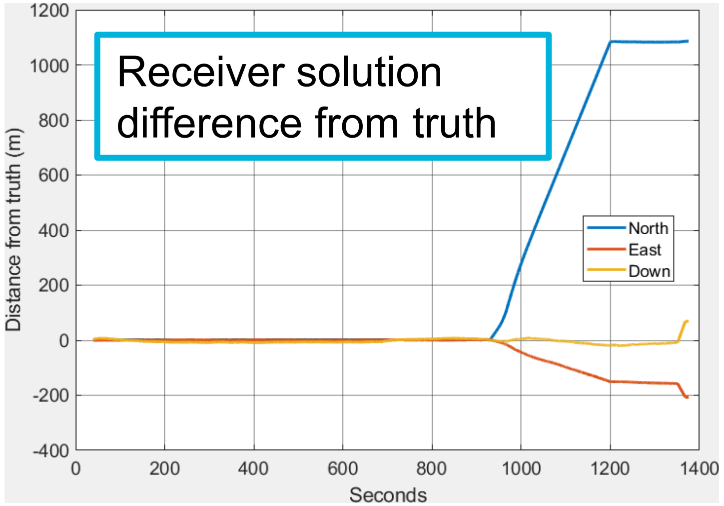
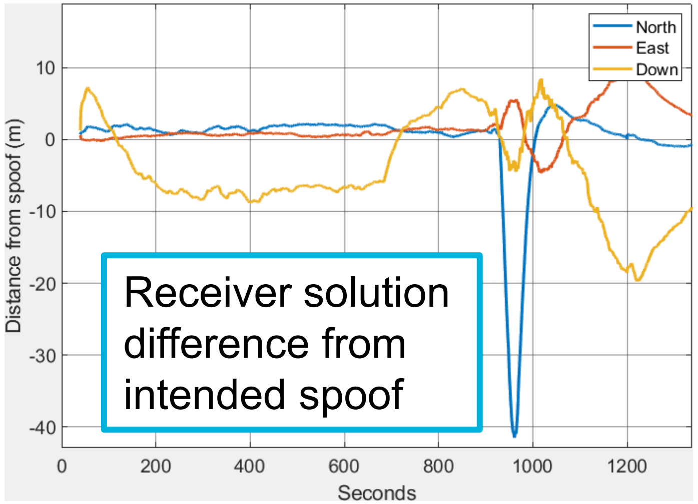
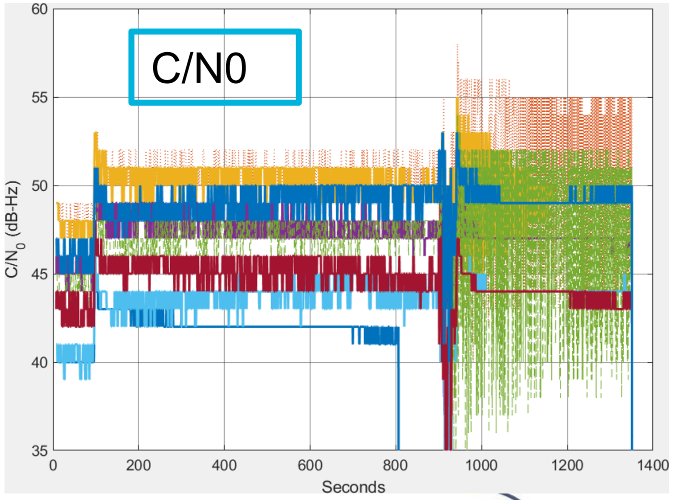
Test Vector 4 Design and Impact

- **Receiver location starts at 39.833333 N 98.58333333 W, 0m HAE**
  - Receiver moves due East at 13 m/s
- **Spoof signals appear at 15:00 and ramp up to +2.3 dB over 30 seconds; noise added to maintain C/N0 at un-spoofed level**
- **Position spoof begins at 15:30, intended spoof would result in receiver turning 17.9 degrees to the north and maintaining 13 m/s speed**
- **Observed C/N0 for 2 signals oscillate significantly due to satellite geometry**
- **Receiver trajectory fairly closely matches intended spoof trajectory**







Test Vector 7 Design and Impact

- **Scenario exactly as TV4: moving victim with position spoof**
  - Except that PRNs 9 and 14 are un-spoofed
  - Intended to emulate an imperfect spoofing scenario or fault in spoofing system
  - Scenario primary utility is in testing spoofing detection algorithms under inconsistent spoofing, thus position response of unprotected receiver (as shown in TV4 plots) is not relevant
- **Note C/N0 for PRNs 9 and 14 decrease due to increased noise and AGC action**