GPS TSPI for Ultra High Dynamics

Use of GPS L1/L2/L5 Signals for TSPI

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Batch of 10 off Q20 HD GPS Modules Being Pick and Place Populated During Manufacture

Contents

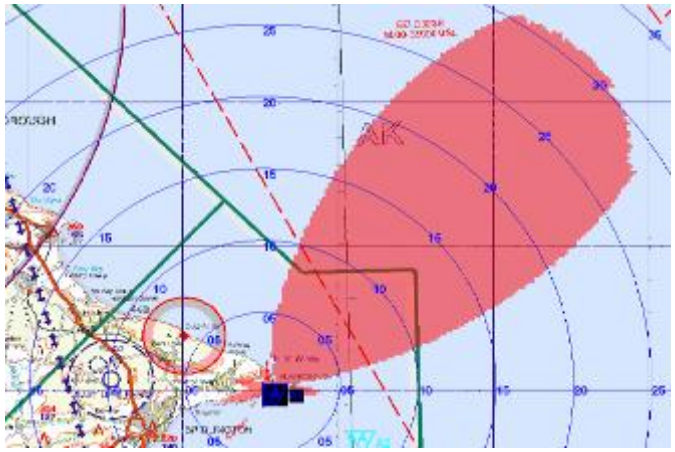
Motivation

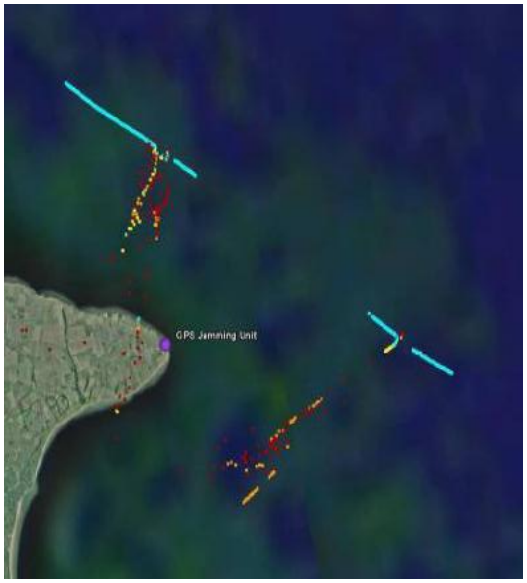
Motivation

Test and Evaluation Applications for Advanced Weapons

- New class of high energy kinetic weapons
  - Distinguishing characteristics
    - High dynamics envelope: acceleration ~500g; velocity ~5km/s; control range safety zone
- New classes of T&E measurement requirements
  - GPS and coupled (MEMS) IMU
    - Accuracy improvement, Support in ‘difficult’ GPS areas (urban warfare)
- High accuracy TSPI results
  - Moderate to low dynamics
    - End game scoring - ~10cms
- Tactical GPS will be subject to intentional denial in areas of military operation
  - Requirement to test for effects on weapons systems
    - L5 signals provide *independent* navigation grid for T&E
  - Jamming causes unpredictable behaviour – see next slide

Observed Effects of Jamming





Images courtesy of Dstl

Coverage of GPS jamming unit; 25m above ground level, maximum power 1.58W ERP

Ship steering course in blue

- Left track (no jamming)
- Right track – GPS L1 locations reported with jammer switched on
  - Red dots are speeds > 100kts

GPS Solution & Signal Evolution

T&E Solutions using 3 Frequency GPS

GPS Broadcasts on 3 Frequencies

- L1 1575.42 MHz (154 x 10.23 MHz) – P(Y) code, C/A code
- L2 1227.60 MHz (120 x 10.23 MHz) – P(Y) code + CM, CL code, broadcast from 10 SV's
- L5 1176.45MHz (115x10.23MHz) – L5I + L5Q, broadcast from 2 SV's
  - L5 (civil) signals on Block IIF SV's

L1, L2, L5 – offer greater range of T&E performance options

- L1: - Rapid time to acquisition & fix; high dynamics envelope ~300g+
  - Long code wavelength (λ_{CA} = 293m); short code of 1ms, range ambiguity (293 km)
- L2: - New civil signals; L2CM, L2CL
  - Longer code wavelength (λ_{L2C} = 586m), potential for dynamics ~500g LOS
  - Codes are 20ms & 1.5 sec, no range ambiguity, greater difficulty in acquisition (esp. CL)
- L5: - Operates in aeronautical safety of life band (ITU protected)
  - Short code wavelength (λ_{code} = 29.3m), 10.23Mcps code rate - same as P(Y)
  - Provides independent low dynamic navigation
    - T&E application used for L1/L2 performance assessment during jamming conditions

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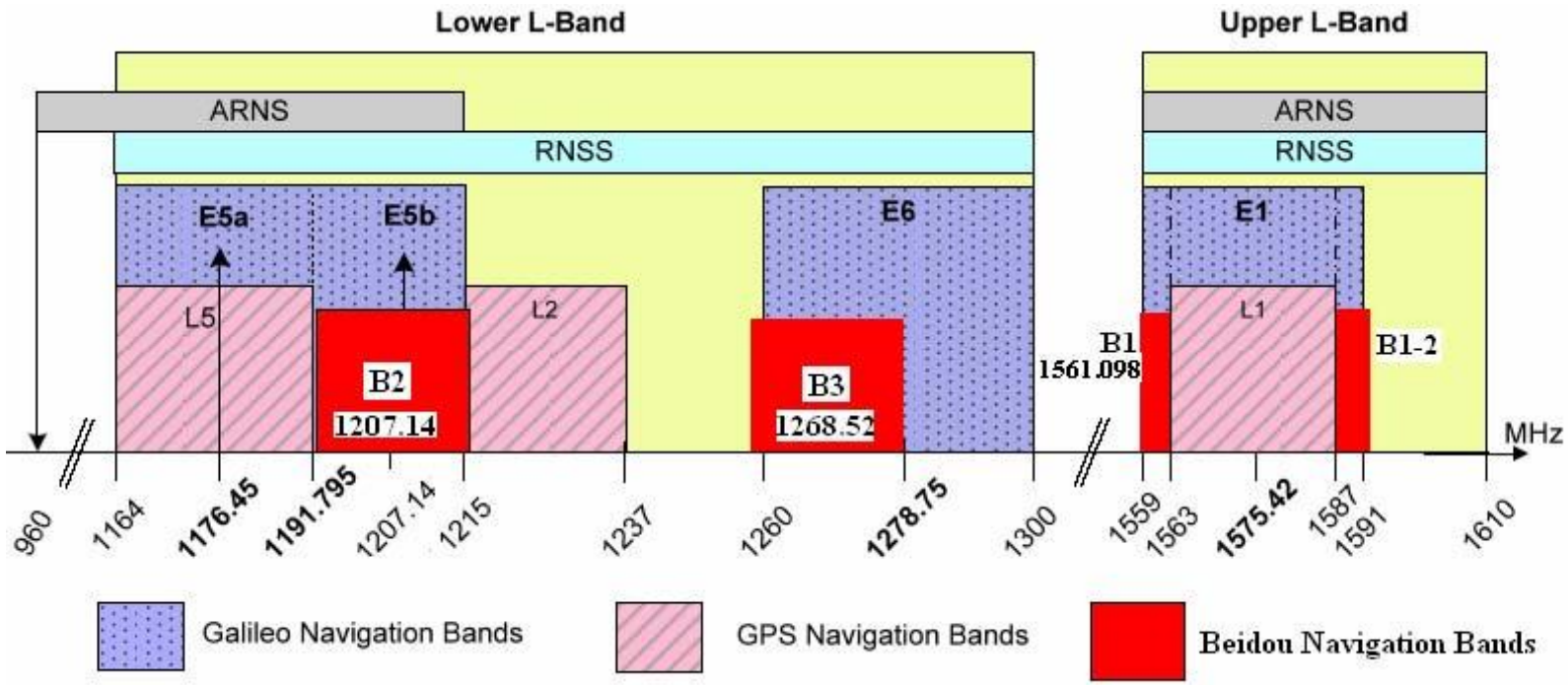
New GPS Signals - ITU Navigation Protected Bands



Navigation Signals in protected bands

- International Telecommunications Union
  - ARNS (aero-nautical band – protected safety of life services)
    - L5 contains DME aircraft transponders

UHD Basic Concepts

Three Frequency GPS Receiver

- Basic civil signal receiver avoiding use of military signals
  - Military code wavelength requires use of IMU to support high dynamics (λ_m=29.3m)
  - Military codes are long (1 week) at 10,230 kchips/sec
    - Limited (10dB) benefit against jamming (compared to C/A code)

Processing for fast Time To First Fix (TTFF)

- Direct data download from satellite too slow (30+sec)
  - Typical requirement < 3sec
- Hybrid receiver mode
  - Uses ground Reference Station includes GPS receiver resource
    - Navigation Messages from visible satellites
    - Establishes position estimate and GPS time solution
    - *Optionally* measure and correct for satellite clock and ephemeris errors (differential mode)
- Solution computed in ground station
  - Options for measurement combinations

UHD Receiver Architecture & Performance Simulation

Main Developments in UHD

Three Frequency GPS Reception

Sustained or Improved TTFF

- Efficient use of hardware architecture to provide >1M acquisition channels
  - Simultaneous frequency and code search algorithm

Multi-channel Tracking for all-in-view Satellites

- Every frequency/signal simultaneously tracked
- Hardware uses high speed multiplex technique
  - Benefits from speed of current FPGA/ASIC switching circuits
    - Reduces circuit area but not power consumption

Tracking Loop Design for Maximum Acceleration Dynamics

- Trades sensitivity for dynamics to limit of GPS capability

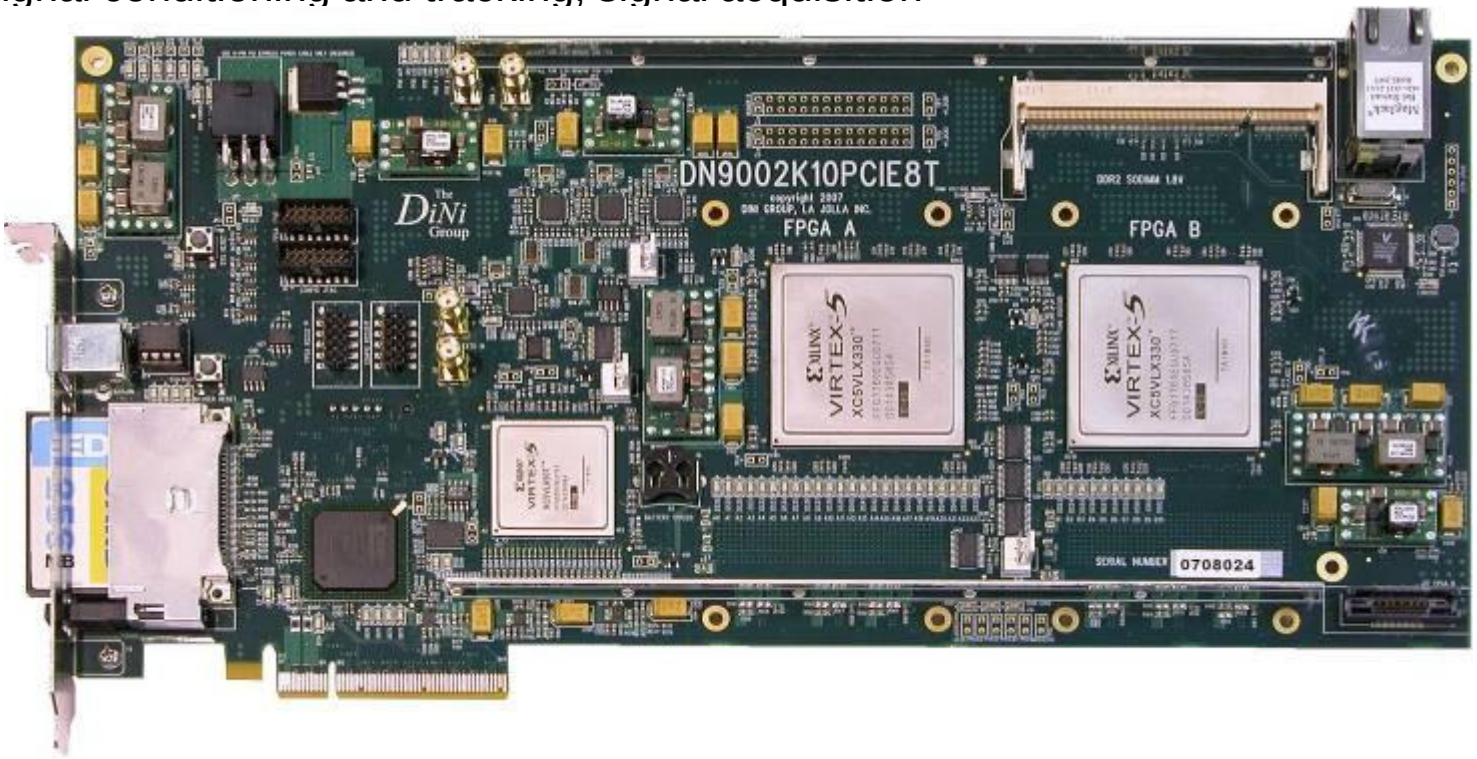
Hybrid Receiver Technique to Sustain sub-30 sec TTFF

  - Accuracy improvements through DGPS possible

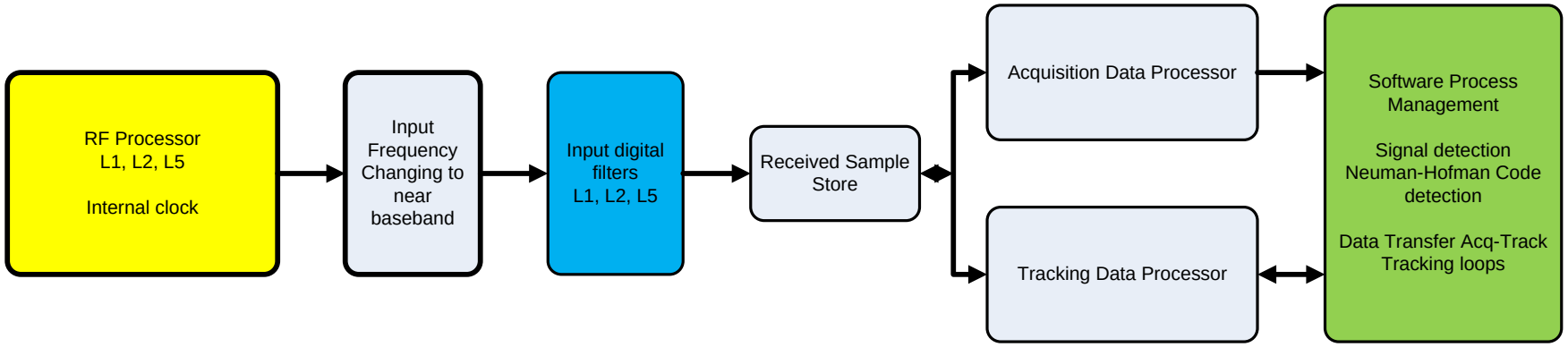
Physical Breadboard

COTS Platform

- 2 FPGA with sufficient capacity
- 2 x Virtex 5 LX220 -2 (Xilinx)
  - Signal conditioning and tracking; signal acquisition



UHD System Architecture



System Architecture

- Separate channels for acquisition and tracking
  - Acquisition requires 100,000's channels to support short TTFA
  - Tracking requires few physical channels dedicated to visible SV's (~60 for 5 signals /SV)
    - L1(1); L2(1); L5 (5)
- Signal conditioning
  - Digital transversal filters to set bandwidth (allowing lower sample rates)
  - Received signal samples are stored
    - Acquisition based on analysis of stored data sample (eg 1ms for C/A code; 20ms for L2CM)
      - Acquired signals referenced to common timebase

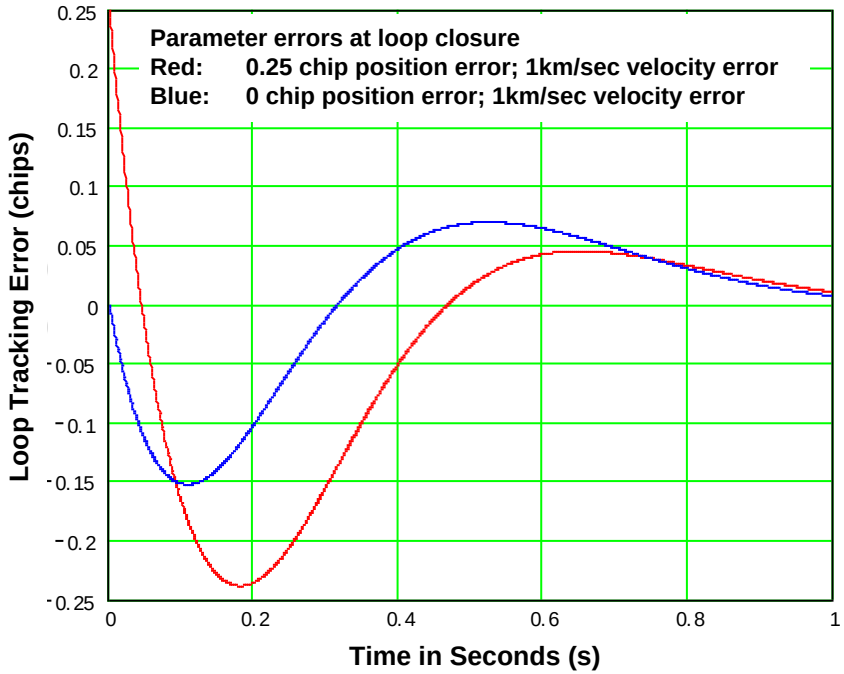
Dynamic Envelope for Host Vehicle

Stresses the Receiver Measurement Circuits

- Satellite tracking lost if stress too large

- Tracking circuits experience 2 types of stress:
  - Noise - mainly controlled by bandwidth and C/N_0 levels
  - Sources of dynamic stresses:
    - host body - satellite motion resolved along line of sight (LOS) to satellite
- Dynamic stresses arise due to:
  - During signal acquisition
    - transients – imperfect match of estimated code delay and Doppler to actual
  - Un-modeled motion (after acquisition)
    - Tracking architecture holds vehicular motion states (such as position, velocity, etc)
      - Stable states do not contribute to stress
    - Host vehicle states are useful if stable for reasonable intervals
    - Highly dependent on expected host vehicle trajectory
  - Mainly controlled using 3rd order tracking loops
    - Model position, velocity, acceleration states

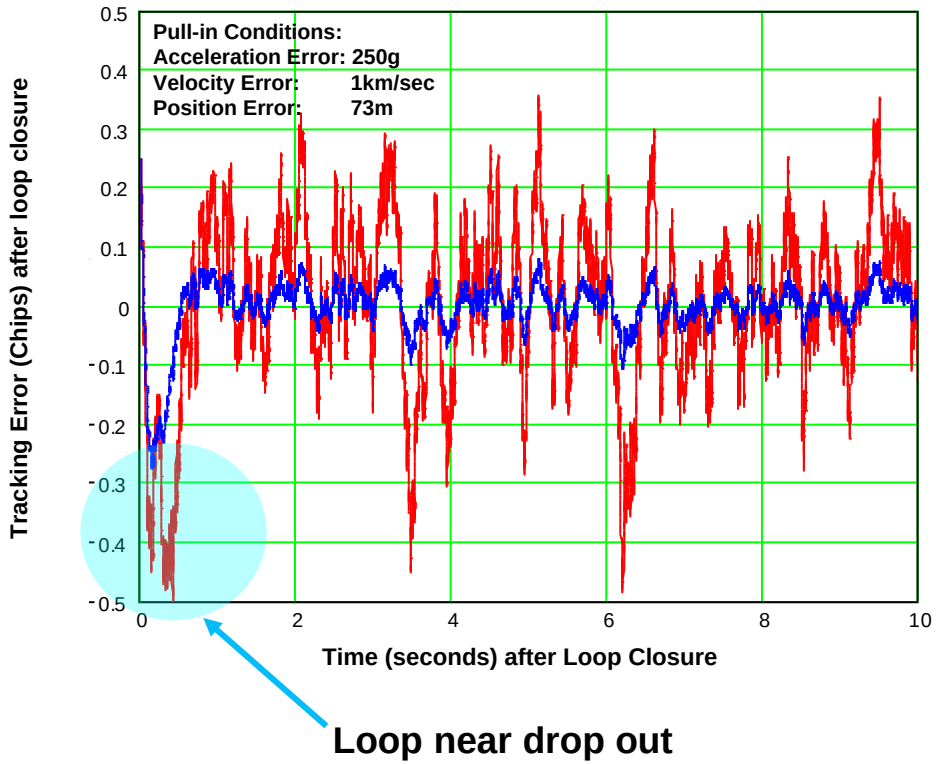
Simulated results for Loop Pull-in Responses



Initial Delay and Velocity Parameters

- Measured during search and acquisition
  - Propagated forward in time to loop closure
  - Delay and velocity errors stimulate transients
    - Example:
      - In linear detector region
      - Non-oscillatory response (direct pull-in)
    - Largest error ~ 0.25 chip (~75m) mainly due to position error
    - Velocity error produces ~0.15 chip response
  - Majority of error is dissipated after 1 sec
- Loop will pull in from larger errors
  - Loop gain approaches zero at ±0.5 chip
    - Pull-in will not occur for larger errors
- Noise degrades pull-in limits

Noise Response at Pull-in



Realization of Loop Response

- Results from simulation
- Combined response of:
  - Noise input
  - 250g acceleration step
  - ¼ chip position error
  - 1km/s LOS velocity error
- Balance between:
  - Noise and dynamic stimuli
- See approach to critical error (½ sec)
  - C/N_0 ~ 23dB (red); 36dB (blue)
    - Identical noise realization in simulation
    - Generated from random number source

Performance Tests and Results

UHD GPS Testing

Verification and Validation Testing Carried Out

- Test cases defined based on User and System requirements
- Performed at QinetiQ and GWEF (Eglin AFB) facilities

Tests with Simulated RF Signals

- Provides repeatability, control, dynamics and truth data - common test scenarios
- QinetiQ: Spirent GSS8800
- GWEF: Spirent GSS7700
- Tested under dynamics
  - acquisition and tracking performance
  - position and velocity accuracy, carrier phase

Tests with Off-air Signals

- L1 (31 satellites), L2C (10 satellites)
  - Combined L1/L2 antenna
- L5 insufficient satellites (2 only so far)

UHD GPS Headline Achievements

Acquisition and Tracking

- L1 signals, off-Air and simulated
- L2CM/L2CL signals, off-Air and simulated
- L5 signals, simulated – insufficient coverage for off-air testing

All satellites acquired in under 3 seconds in any frequency band

Independent Position solutions generated from L1, L2C, L5 signals

- Uses existing ground segment equipment

Carrier Phase Tracking

- Carrier phase tracking of simulated L1, L2C, L5 signals at >50g Acceleration
  - (Manual) data demodulation and time decoding from L1 carrier tracked off-air signals

Performance detailed on next slides

UHD GPS Provisional Performance Results

Parameter	Specification			
	Existing JAMI Performance	Current Target	Ultimate Goal	Achieved at End of Program
Max Acceleration at Satellite Acquisition	**50*g***	**600*g***	**1,000*g***	**L1: 800*g*** **L2: 1000*g*** **L5: 100*g***
Tracking through Acceleration	**50*g***	**600*g***	**1000*g***	**L1: 1000*g*** **L2: 2000*g*** **L5: 100*g***
Maximum (Body) Velocity at Satellite Acquisition	**500m/s**	**3000m/s**	**5000m/s**	**L1: 9000m/s** **L2: 11000m/s** **L5: 3000m/s**
Maximum (Body) Velocity Tracking	**500m/s**	**3000m/s**	**5000m/s**	**Approx 16000m/s**
Position Accuracy	**<10m**	**<10m**	**<0.3m (with processing)**	**L1: <5.8m** **L2: <6.4m** **L5: <25m**
Velocity Accuracy	**1m/s**	**<1m/s**	**<0.3/s**	**L1: <7.9m/s** **L2: <9.5m/s** **L5: <14.3m/s**

Note: Some performance issues with L5 accuracy to be resolved

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UHD GPS Provisional Performance Results (cont…)

Parameter	Specification			
	Existing JAMI Performance	Current Target	Ultimate Goal	Achieved at End of Program
Time To First Fix	**3.5s**	**<3s**	**<3s**	**L1: 1.35s**
Time to detect last SV (SV32) **Maximum time to acquire all in view**	**7s**			**L1: 0.113s** **L2: 1.634s** **L5: 1.064**
Receiver Type	**L1**	**L1/L2**	**L1/L2/L5**	**L1/L2/L5**
Receiver Channels	**12 channels**	**>24 channels**	**>36 channels**	**72 pseudo-channels**
Nominal Simultaneous search windows	**25,000**	**>100,000**	**>10^6**	**>$5*10^6$ per second**

Acknowledgements

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