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GNSS
POSITION
NAVIGATION
TIMING

Multi-GNSS

Advantages, challenges and test solutions

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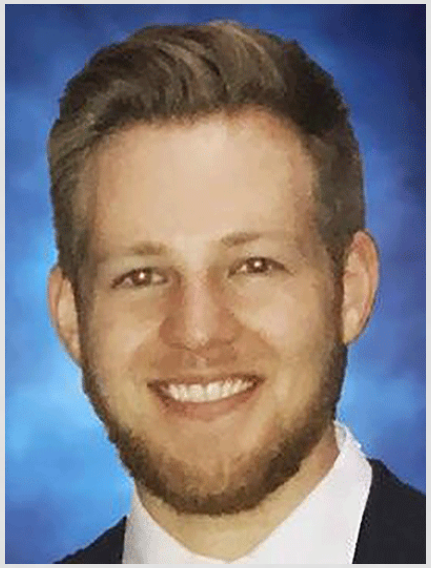

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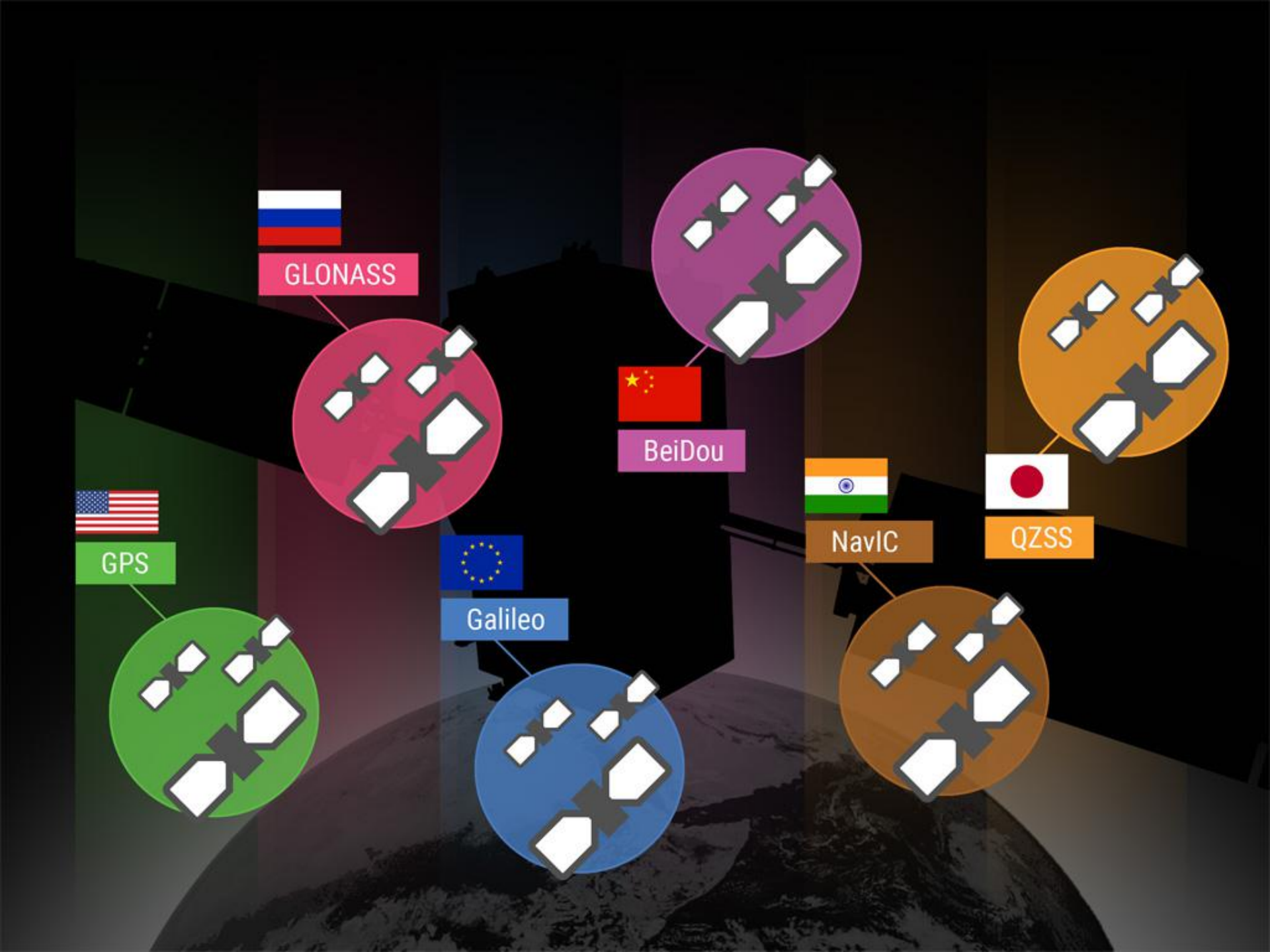
Multi-Constellation

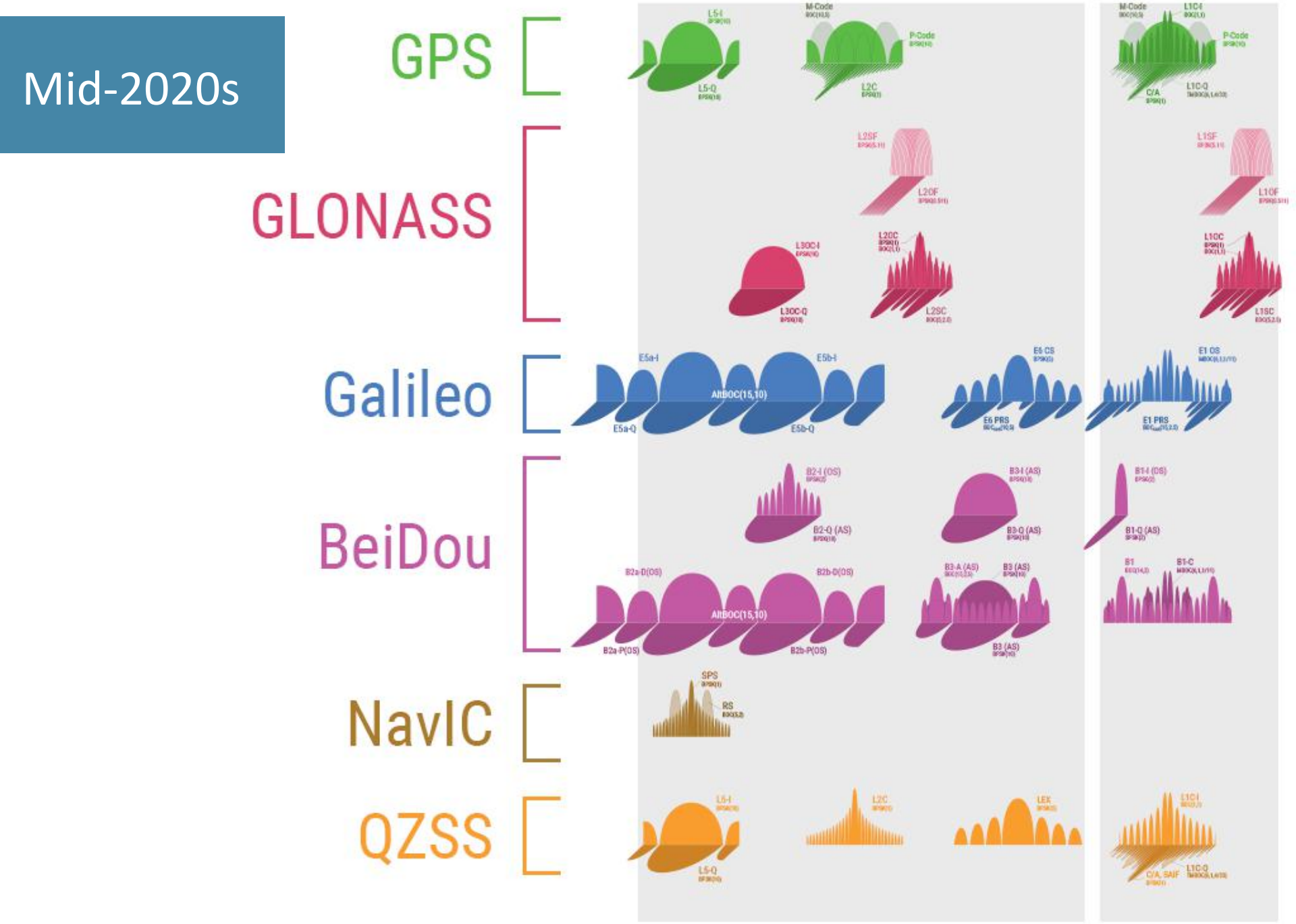
Intro


GLONASS
BeiDou
GPS
Galileo
NavIC
QZSS

GNSS Status

Constellations	Nominal number of satellites and type of orbits	Operational satellites	Number of signals	Number of frequencies
GPS	24	31	8	3
GLONASS	24	24	5	3
BeiDou	27-MEO, 3-IGSO, 5-GEO	3-MEO, 6-IGSO, 6-GEO	6	4
Galileo	30	17	6	4
QZSS	3-IGSO, 1-GEO	3-IGSO, 1-GEO	5	4
IRNSS/NavIC	4-IGSO, 3-GEO	4-IGSO, 3-GEO	2	1

Mid-2020s

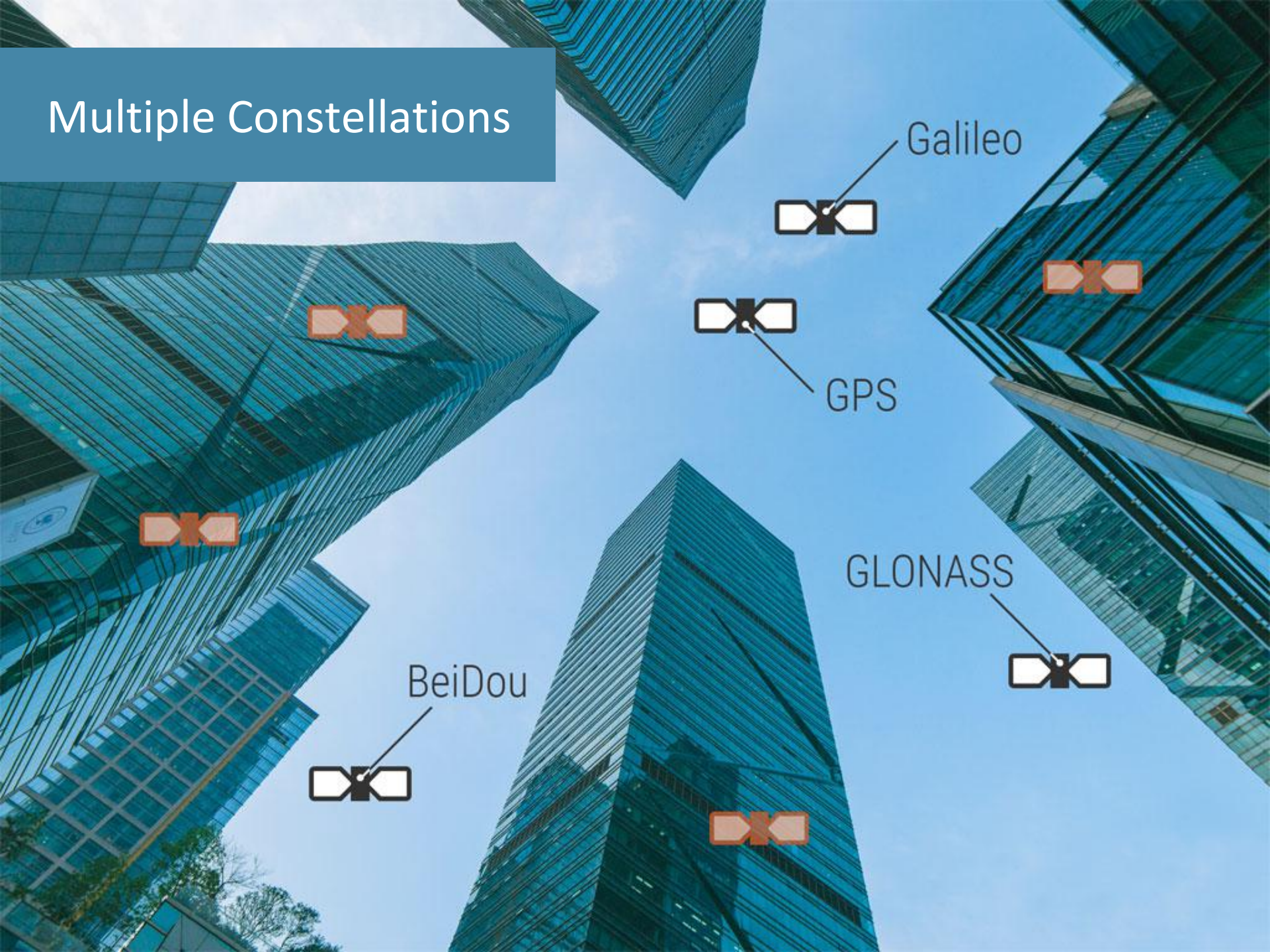

GPS
GLONASS
Galileo
BeiDou
NavIC
QZSS
L5-I
L5-Q
M-Code
P-Code
L2C
L2SF
L2OF
L3OC-I
L3OC-Q
L2OC
L2SC
L1SF
L1OF
L1OC
L1SC
E5a-I
E5a-Q
AltBOC(15,10)
E5b-I
E5b-Q
E6 CS
E6 PRS
E1 OS
E1 PRS
B2-I (OS)
B2-Q (AS)
B3-I (AS)
B3-Q (AS)
B1-I (OS)
B1-Q (AS)
B2a-D(OS)
B2a-P(OS)
AltBOC(15,10)
B2b-D(OS)
B2b-P(OS)
B3-A (AS)
B3 (AS)
B1
B1-C
SPS
RS
L5-I
L5-Q
L2C
LEX
L1C-I
C/A, SAIF
L1C-Q

Multi-constellation: Benefits

- ✓ Availability
- ✓ Continuity
- ✓ Integrity
- ✓ Accuracy
- ✓ Robustness
- ✓ Speed up operation performance
- ✓ Opens new opportunities

Single Constellation

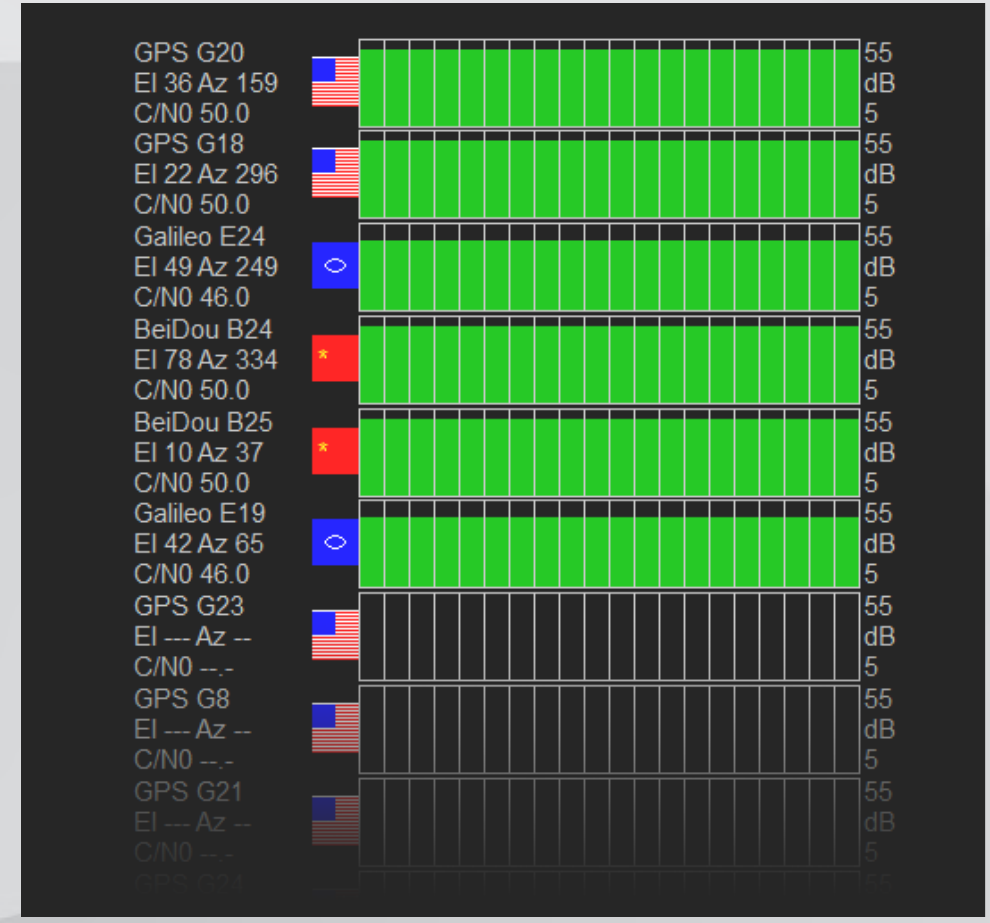
Multiple Constellations

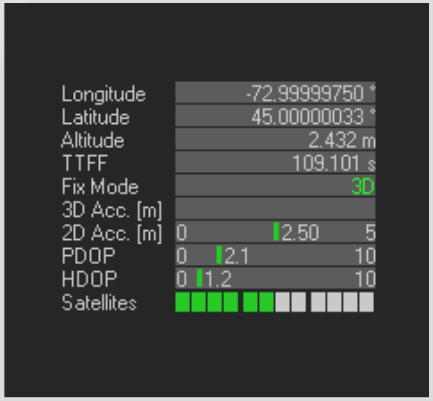


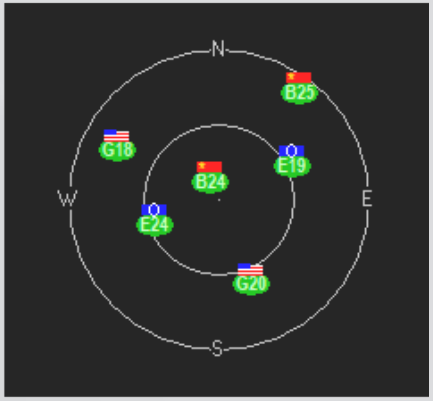
Challenges

- ✓ Intelligent algorithm in observation model
  - Multi-frequency
  - Multi-constellation
- ✓ Inter-system Biases
  - System clock
  - Inter-frequency
  - Ionosphere
  - Antenna phase center
- ✓ GNSS signal processing
  - Interferences and jammers
  - Spoofing
  - Authentication
- ✓ Constellations control
  - Time reference
  - Master constellation

Lock achieved with 6 satellites from 3 different constellations

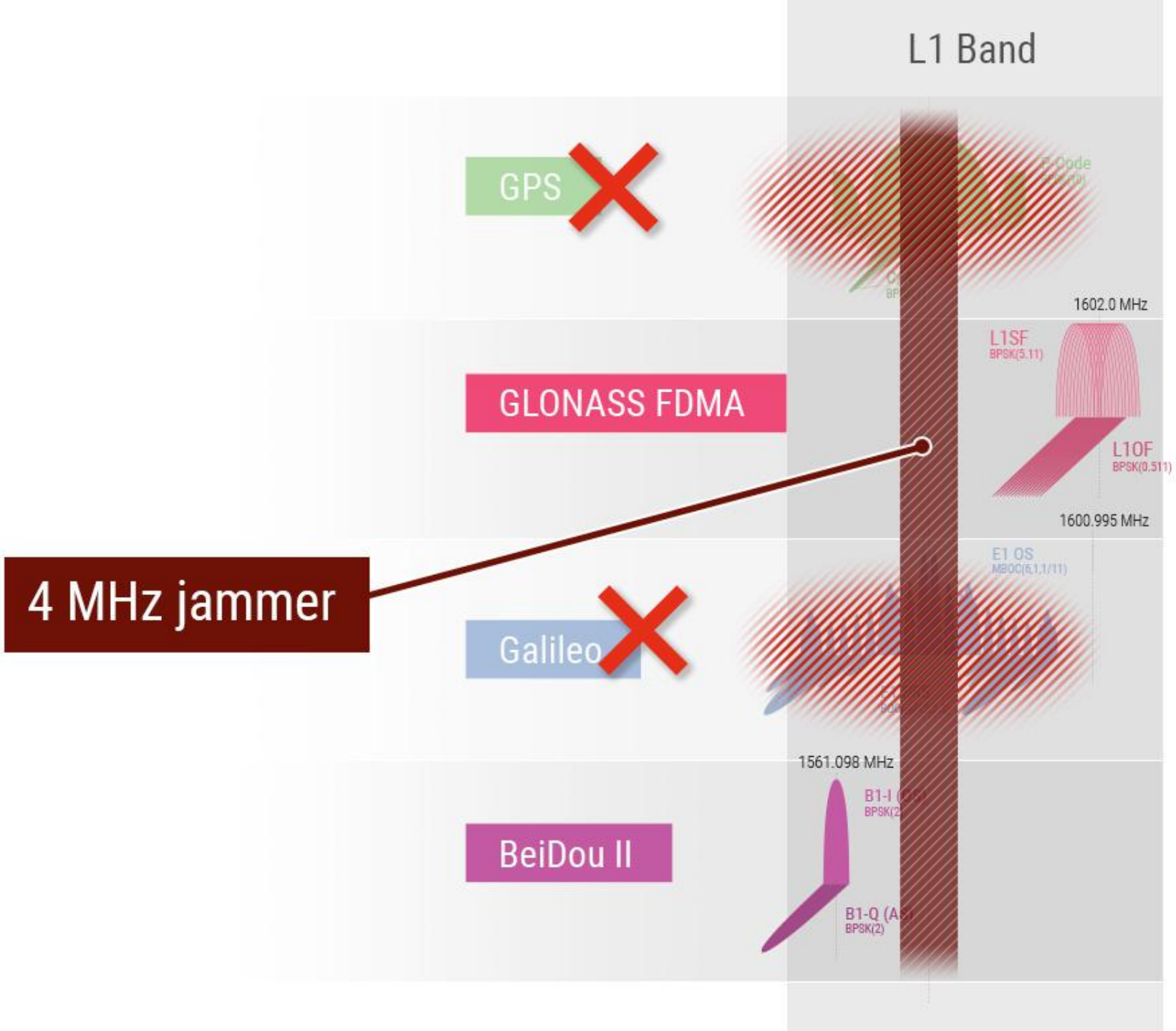


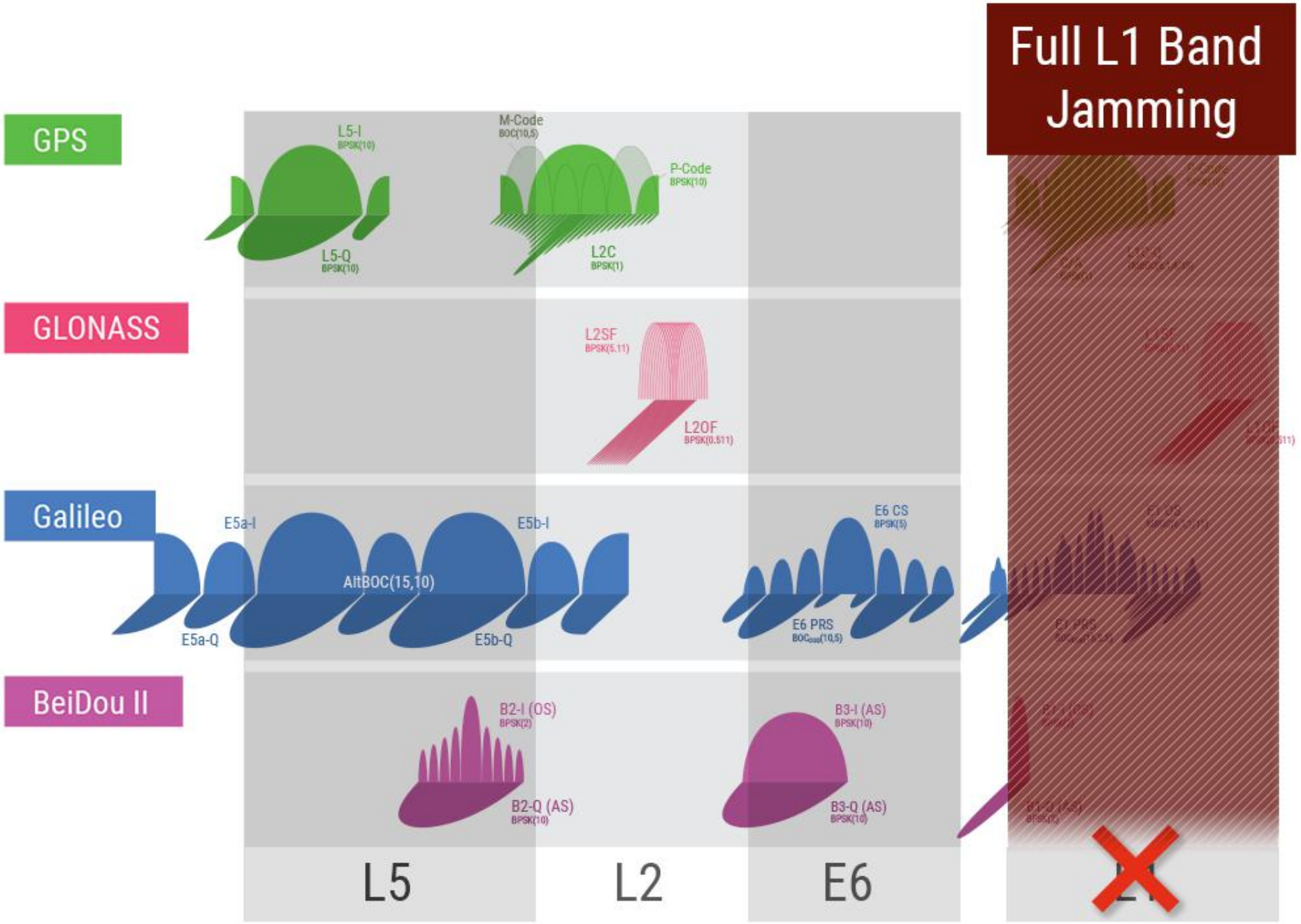




Multi-Constellation and Jamming

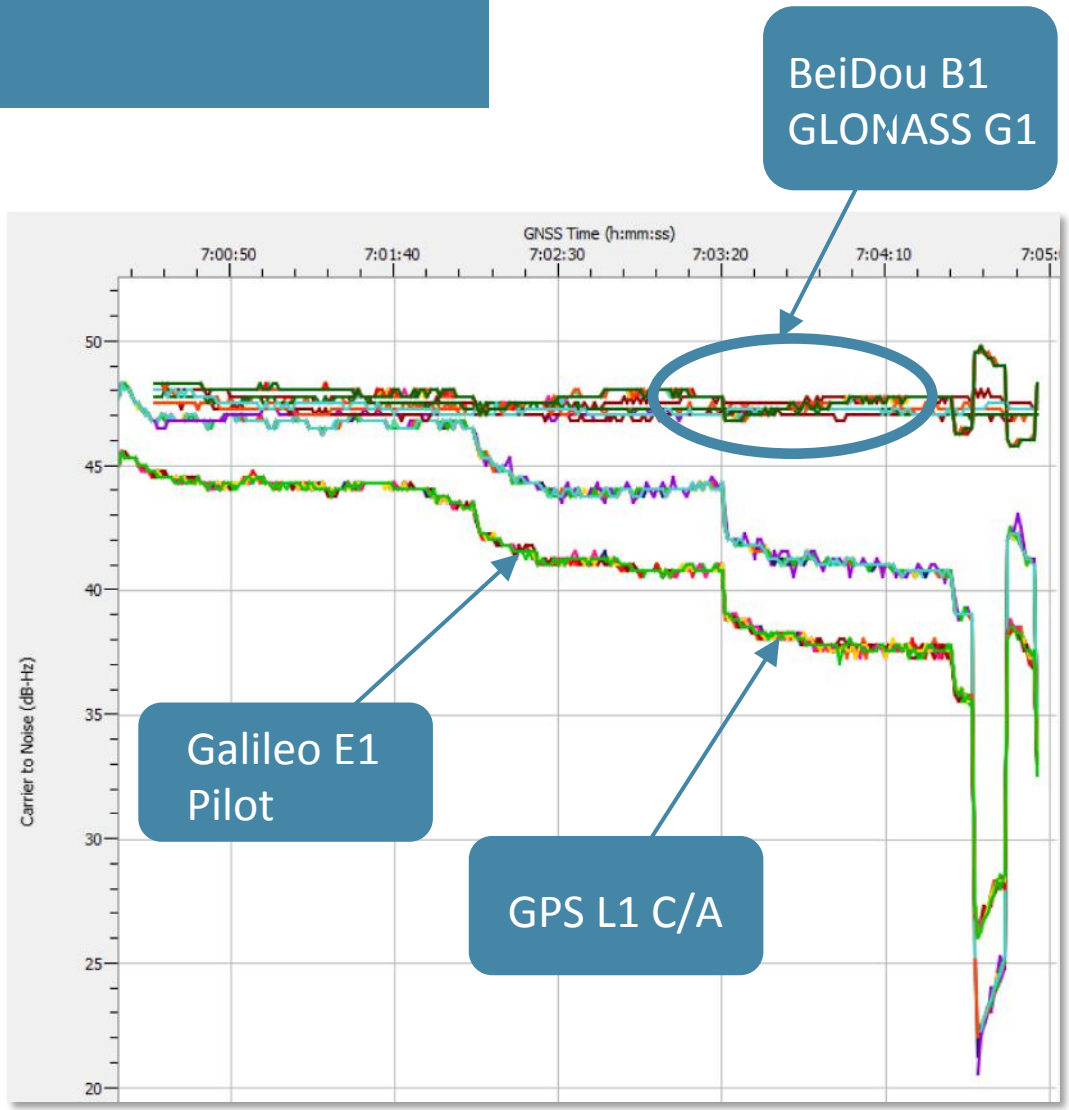
Examples with GNSS receiver


L1 Band
GPS
GLONASS FDMA
Galileo
BeiDou II
4 MHz jammer
1602.0 MHz
L1SF
BPSK(5.11)
L1OF
BPSK(0.511)
1600.995 MHz
E1 OS
MBOC(6,1,1/11)
1561.098 MHz
B1-Q (A
BPSK(2)


Full L1 Band Jamming
GPS
L5-I
BPSK(10)
L5-Q
BPSK(10)
M-Code
BOC(10,5)
P-Code
BPSK(10)
L2C
BPSK(1)
GLONASS
L2SF
BPSK(5.11)
L2OF
BPSK(0.511)
Galileo
E5a-I
E5a-Q
AltBOC(15,10)
E5b-I
E5b-Q
E6 CS
BPSK(5)
E6 PRS
BOC$_{cos}$(10,5)
BeiDou II
B2-I (OS)
BPSK(2)
B2-Q (AS)
BPSK(10)
B3-I (AS)
BPSK(10)
B3-Q (AS)
BPSK(10)
L5
L2
E6
L1

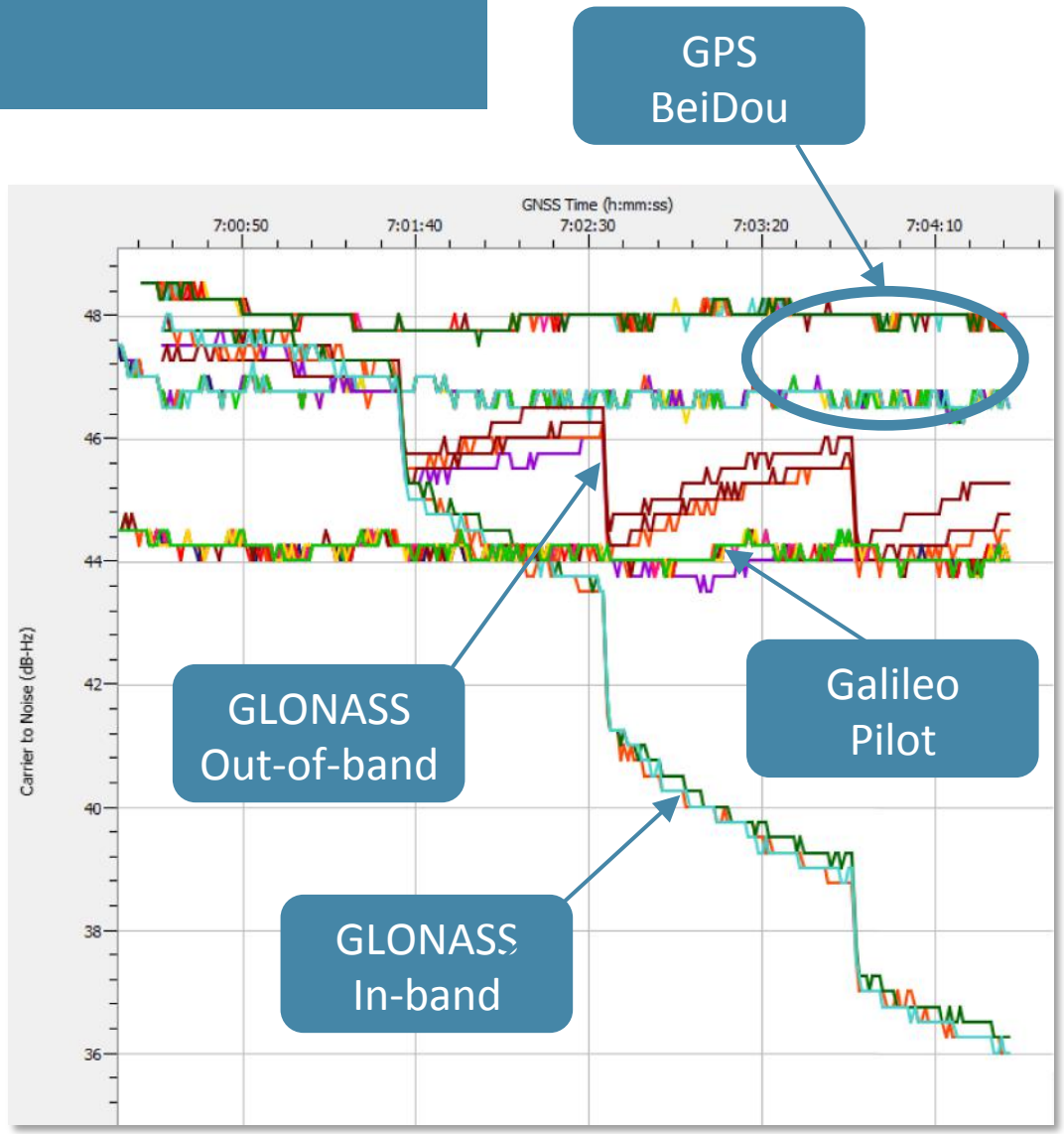
GNSS Receiver Response to Jamming on **GPS and Galileo**

- Type: Chirp
- Fc = 1575.42 MHz
- B = 4 MHz
- J/S = 0 … 40 dB
- GPS L1 C/A, GLO G1, Gal E1, BDS B1
- Position Fix: Yes



GNSS Receiver Response to Jamming on **GLONASS**

- Type: Chirp
- Fc = 1602 MHz
- B = 4 MHz
- J/S = 0 … 40 dB
- GPS L1 C/A, GLO G1, Gal E1, BDS B1
- Position Fix: Yes



GNSS Receiver

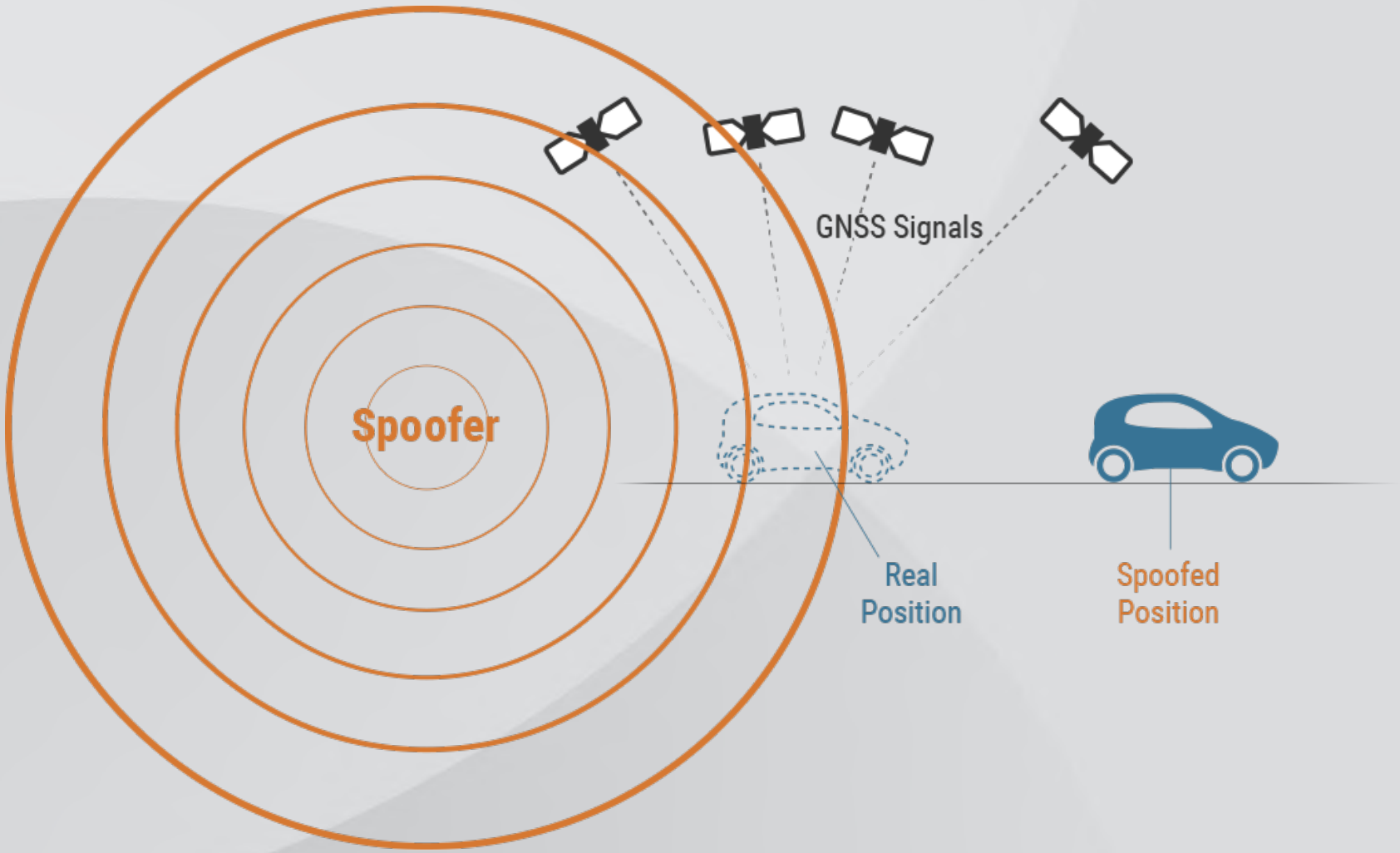
vs

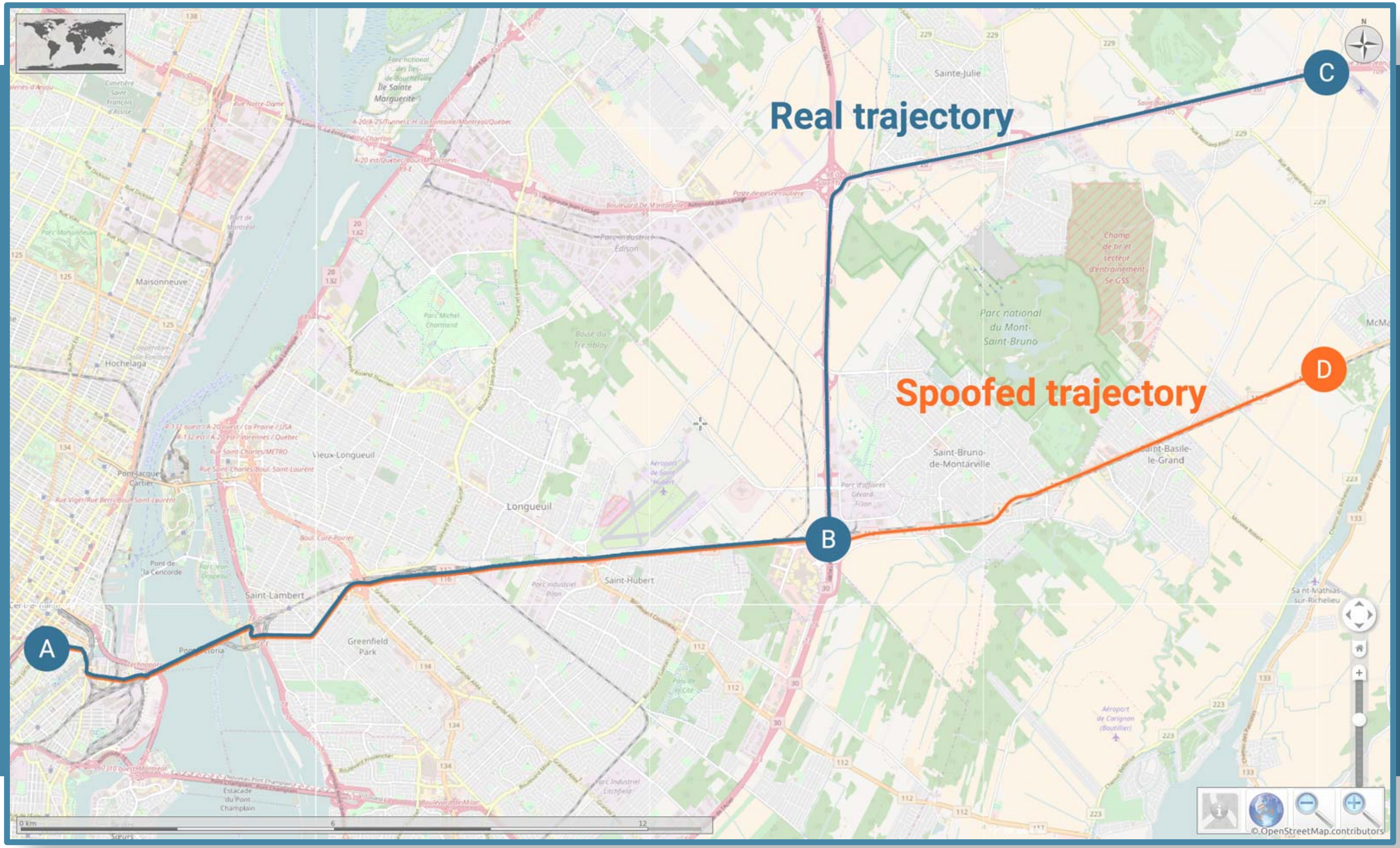
Constellation Input

	Receiver A				Receiver B				Receiver C			
Tracking	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Position Fix	✓	✗	✓	✗	✓	✗	✗	✓	✓	✓	✓	✓
GPS	●				●				●			
GLONASS		●				●				●		
Galileo			●				●				●	
BeiDou				●				●				●

Multi-Constellation and Spoofing

Examples with GNSS receiver

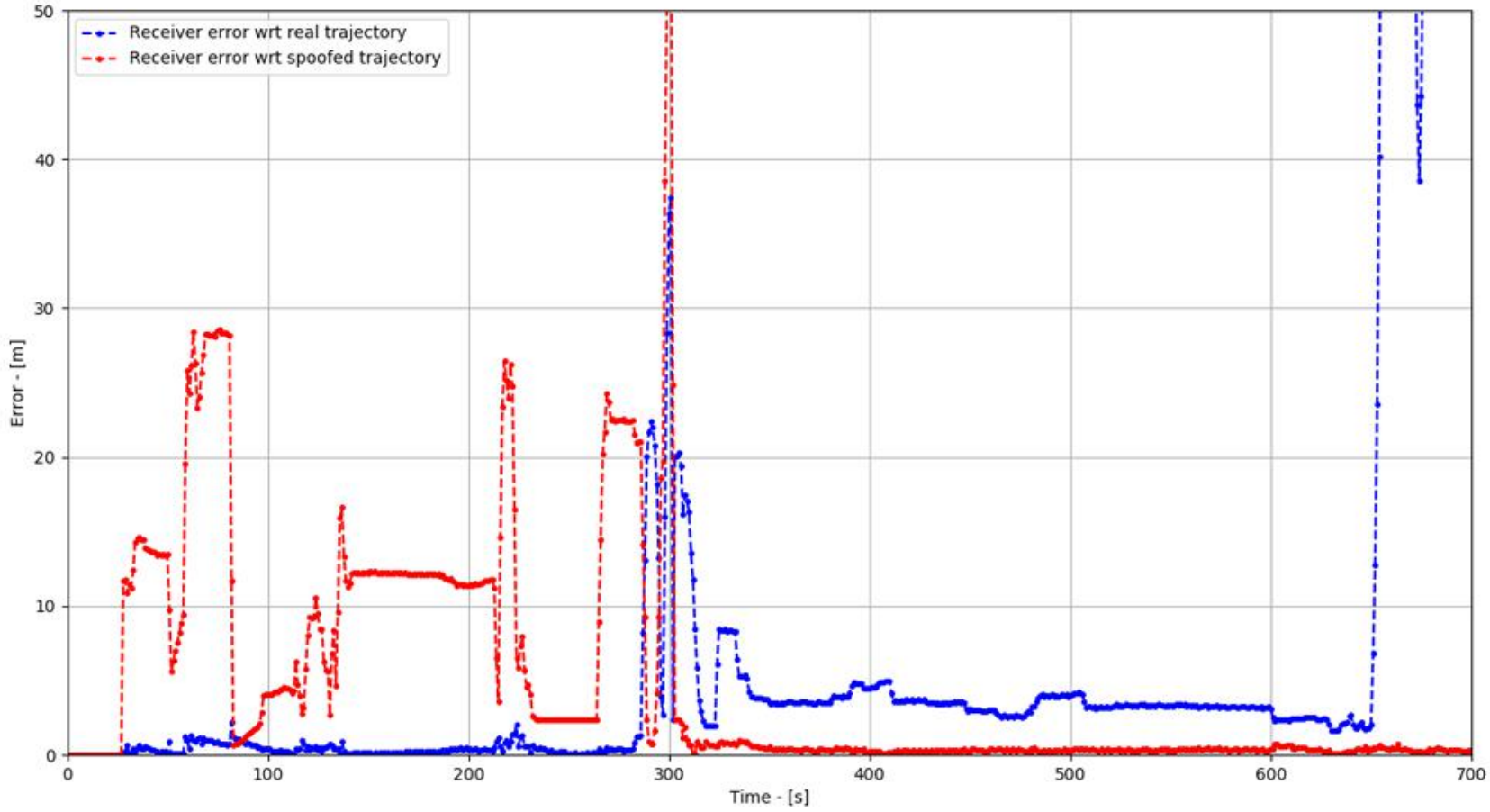

GNSS Signals
Spoofer
Real
Position
Spoofed
Position



Real trajectory
Spoofed trajectory
A
B
C
D

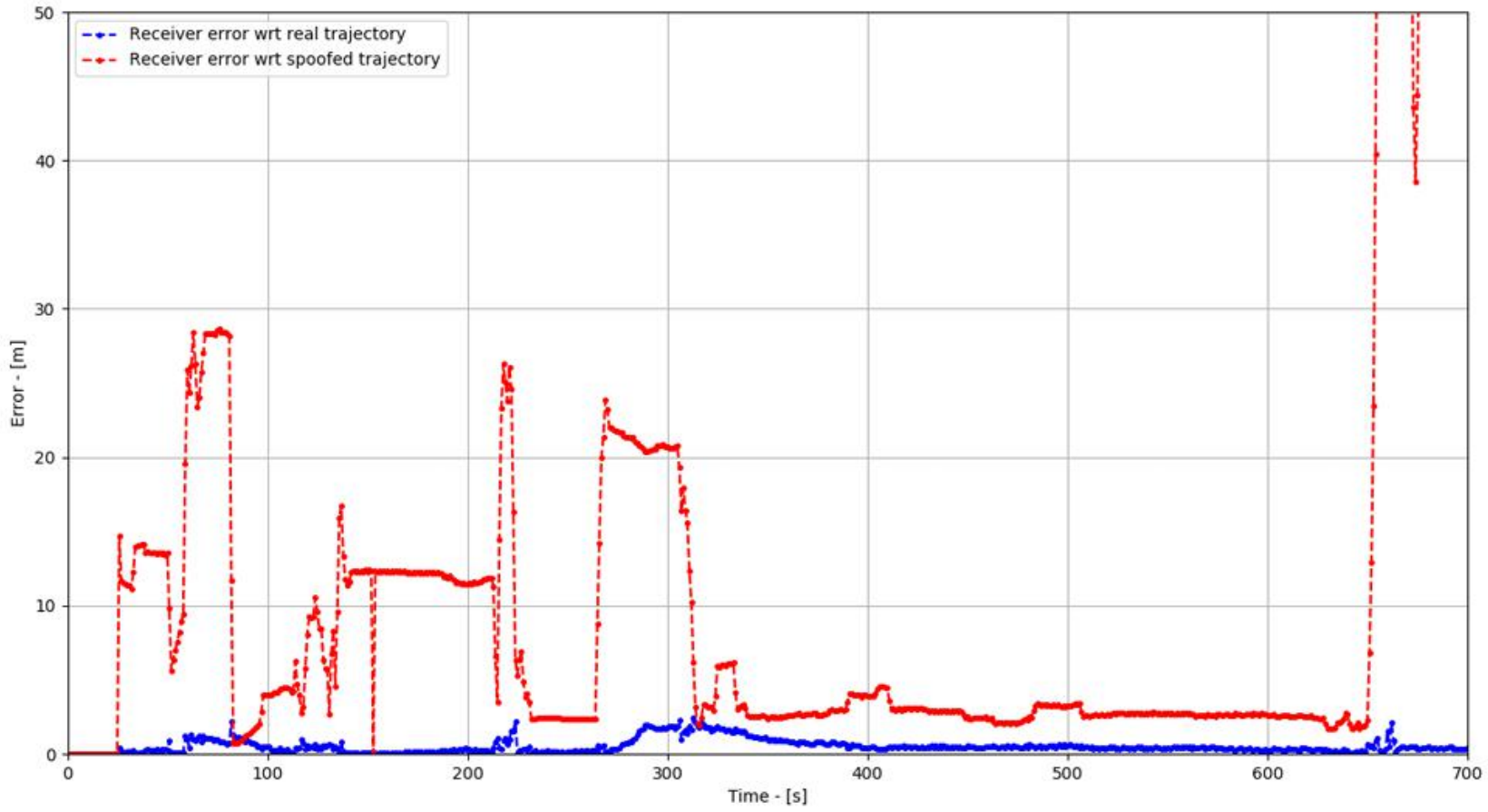
2D Positioning Error

Real Constellation GPS | Spoofer GPS



2D Positioning Error

Real Constellation GPS and Galileo | Spoofer GPS

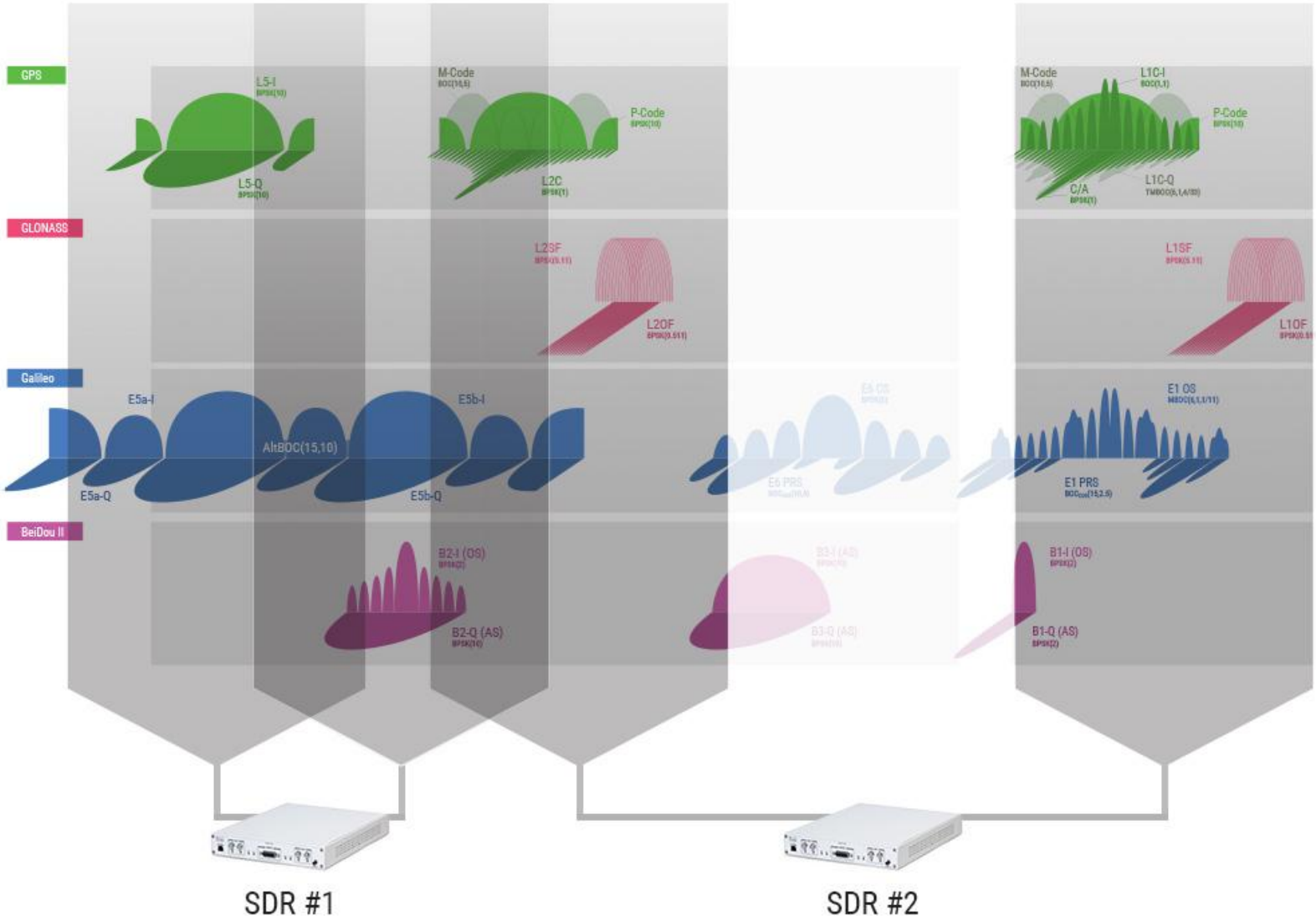


Test Solutions for GNSS

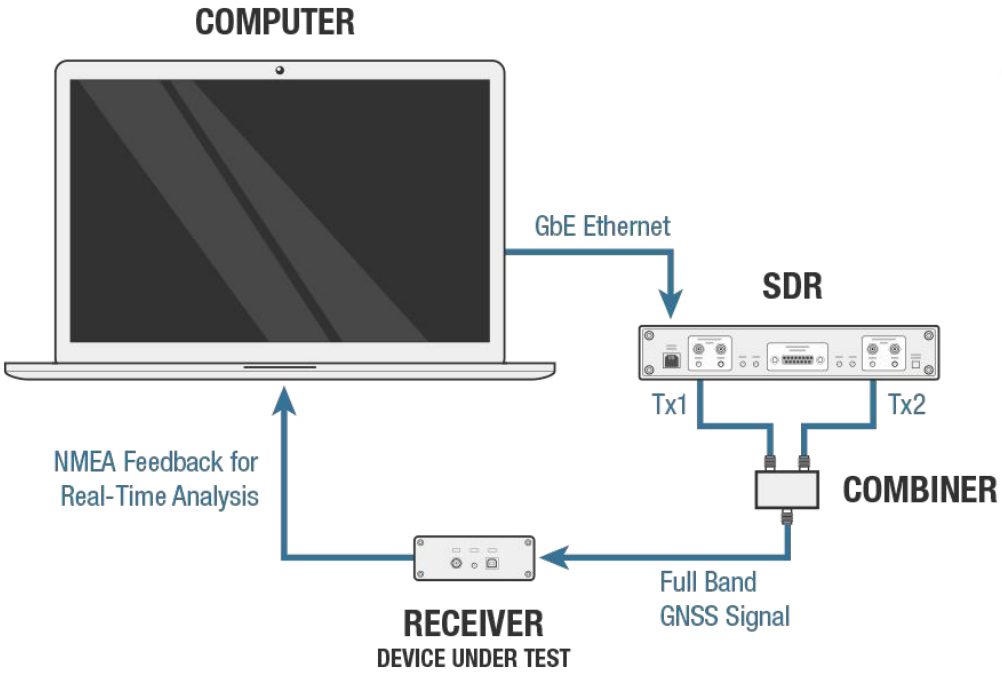
GNSS Simulators

1 SDR Setup Example for Multi-Constellation Testing

Dual SDR Setup

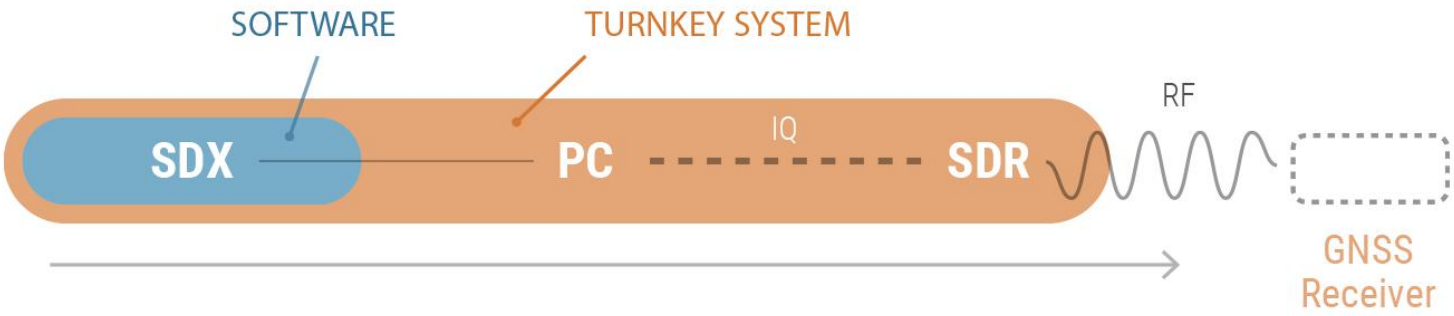


Basic Setup



- Computer
  - 10 Gb Ethernet Link
  - NVIDIA GPU
- SDR
  - 10 MHz Ref. Clock
  - UBX-160 RF boards
- RF Cables
- Attenuators
- DC Block
- Combiner

How It Works

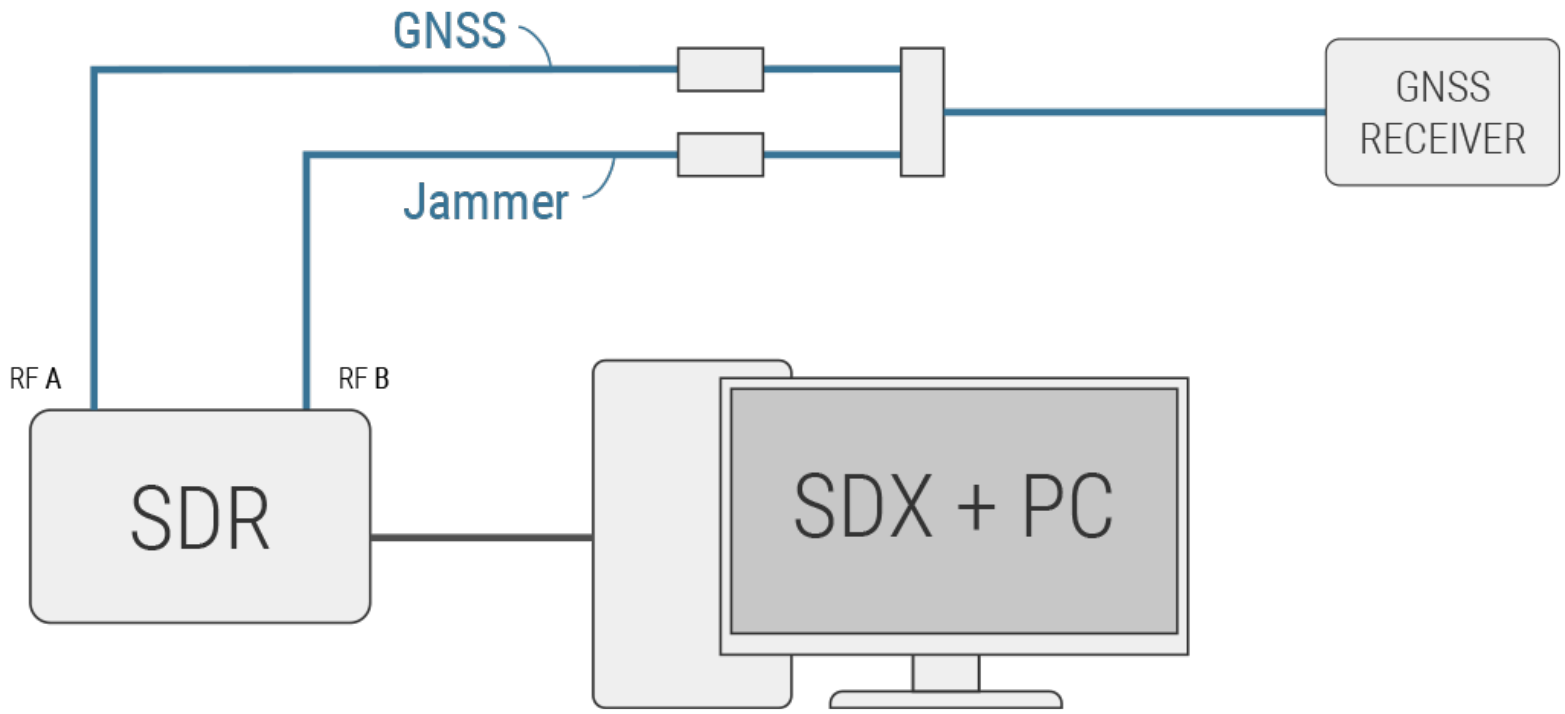


SDX uses the PC's GPU to generate – in real time – high-rate baseband signals that are converted to RF by the SDR.

Channels per GPU Model

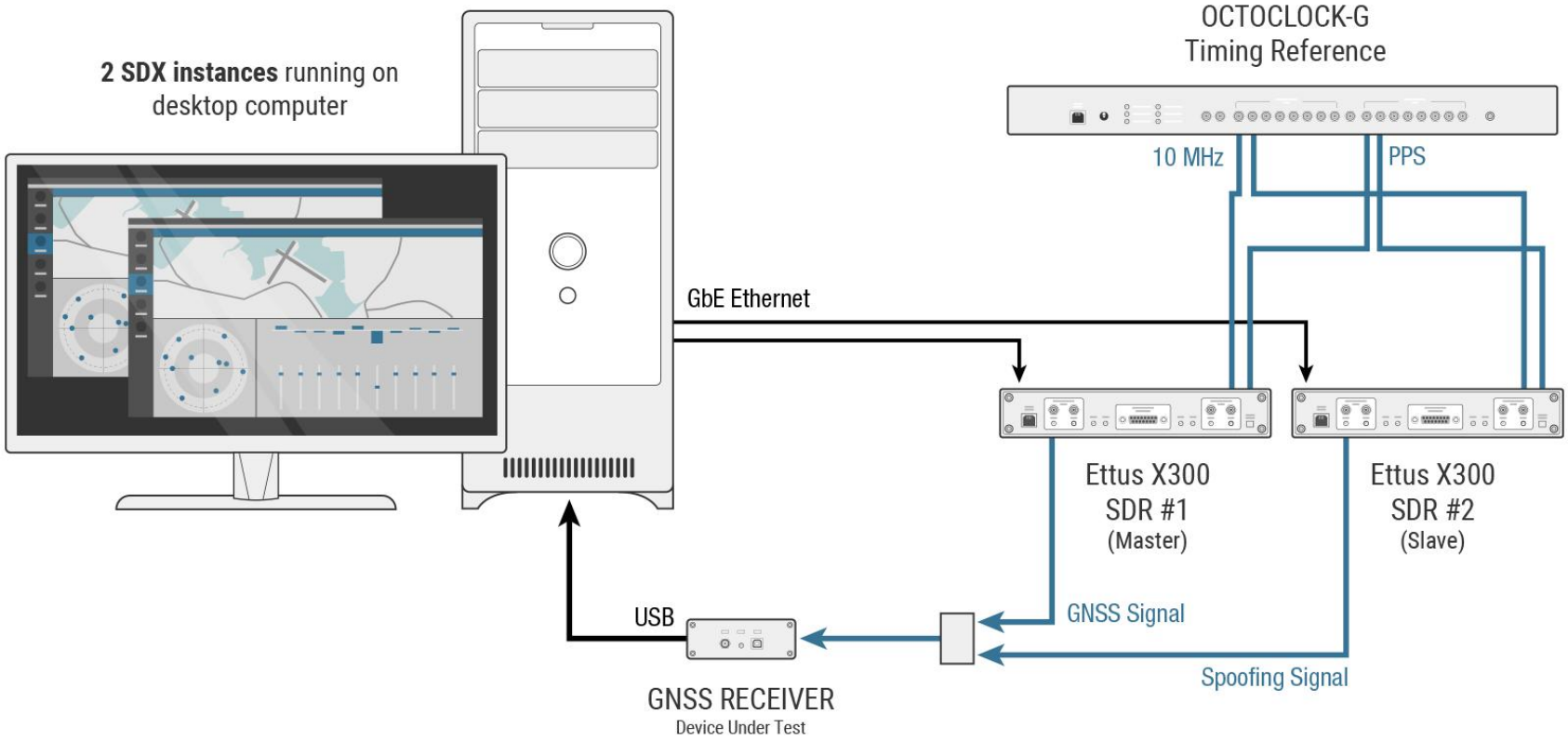
		GTX 1050Ti	GTX 1080	GTX 1080Ti
Bandwidth	10 MHz	**140**	**180**	**240**
	50 MHz	**50**	**90**	**110**

Jammer + Multi-Constellation



- ✓ GNSS and Jammers on the same radio
- ✓ Up to 120 dB of J/S ratio
- ✓ Multi-constellations

Spoofer + Multi-Constellation



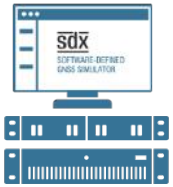
SDX Configuration Examples

The flexible nature of SDX in relation to hardware allows a variety of configurations depending on the simulation needs of the client. Upgrades are easy, use COTS and “enable to grow” a configuration for additional capabilities.

Even the entry-level configuration **can simulate 100 satellites with multiple constellations.**

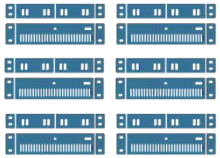
Desktop computer with single radio

Rack-mount computer with single radio



Rack-mount computer with dual radio

Double Rack-mount with dual radio



Large array of synchronized simulators

RF OUTPUTS	**1 or 2**	**1 or 2**	**2-4**	**2-4**	**4+**
CAPABILITIES	★★★	★★★	★★★★	★★★★	★★★★+

100+ satellites – multi-constellation – multi-frequency
Advanced interferences

Synchronized Multi-Simulator

Large Signal Array (GNSS & non-GNSS)

Conclusions

Take advantage from multi-constellations

Multi-constellation: GNSS

- For full advantage from multi-constellation, need better algorithms to process GNSS
- With no doubt, multi-constellation is more robust to jamming and especially to spoofing
- For multi-constellation testing, need to simulate all constellation in the same time and in perfect synch
- Software-defined solution is very flexible, allows for easy expansion and for interference simulation using the same radios
- Software-defined solution is cost effective

Multi-GNSS: Advantages, Challenges and Test Solutions

Tyler Hohman

TALEN-X
COMMUNICATE - NAVIGATE - EXCEL

Multi-GNSS Testing

- New receivers are more powerful than ever
  - Concurrent multi-constellation tracking
  - Integrated jamming suppression
  - Spoofing detection
- Thousands of combinations of test
  - Jam C/A only, C/A + G1, E1 + C/A, etc.
  - How does my receiver perform?
  - When am I protected/vulnerable?
- Multiple environments to test in
- New capabilities require new methods to test
  - Automated testing
  - Easy scenario creation
  - Scalable flexibility
- Engineers could spend years testing

New Multi-GNSS Receivers

+ More complexity, more to test…

Multi-frequency

- L1, L2, L5
- A lot of HW required to generate

Multiple codes

- 8 for GPS alone!
- Expense to add licenses/HW

Jamming suppression / detection built in

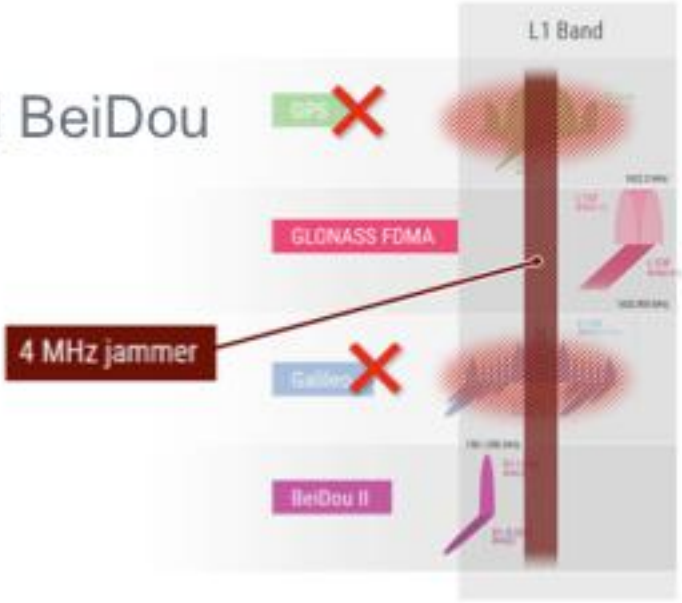
- Require advanced jammers

Spoofing resiliency

- Double your hardware…

What to Test - Example

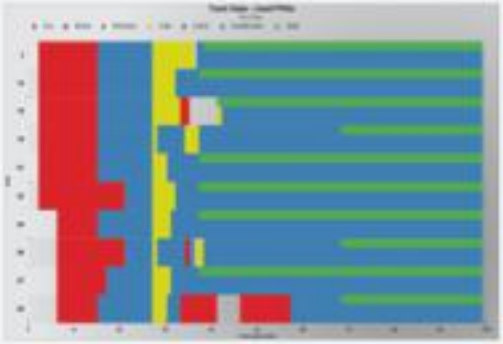
- Your GNSS receiver
  - Tracks L1 GPS, GLO, Galileo, and BeiDou
- Your environment
  - L1: 4 MHz jammer
  - GPS and Galileo jammed
  - GLO and BeiDou available
    - 1 spoofed
- Your performance
  - What happens to your NAV solution?
  - What is the tracking performance?
  - How can you compare results to truth? What is truth?

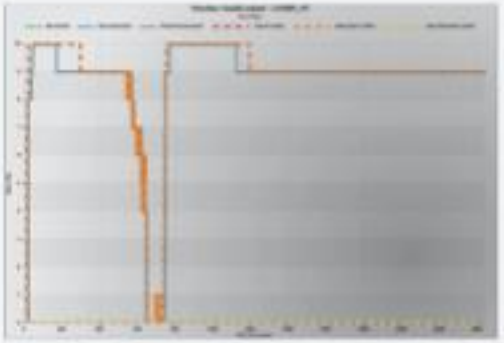


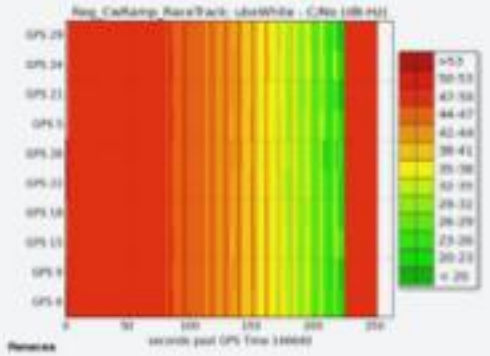
Graphic: Skydel

Applications

- Receiver performance
  - Acq, reacq
  - Tracking
- Interference resistance
  - How much jamming?
  - What constellations are relied on?
- Vulnerability studies
  - How does spoofing affect the Rx
  - What types are effective?
- Acceptance/Verification







Testing in Multiple Environments

Laboratory

Anechoic Chamber

Over-the-air Field Test

Photos: U.S. Department of Defense. The appearance of U.S. Department of Defense (DoD) visual information does not imply or constitute DoD endorsement.

Laboratory

- Controlled environment
- High precision equipment
- Scalable and flexible configuration
- Easy to log and analyze data
- Repeatability
- Convenience
- Cost
- Challenges
  - Cannot test the full system

Photo: U.S. Department of Defense. The appearance of U.S. Department of Defense (DoD) visual information does not imply or constitute DoD endorsement.

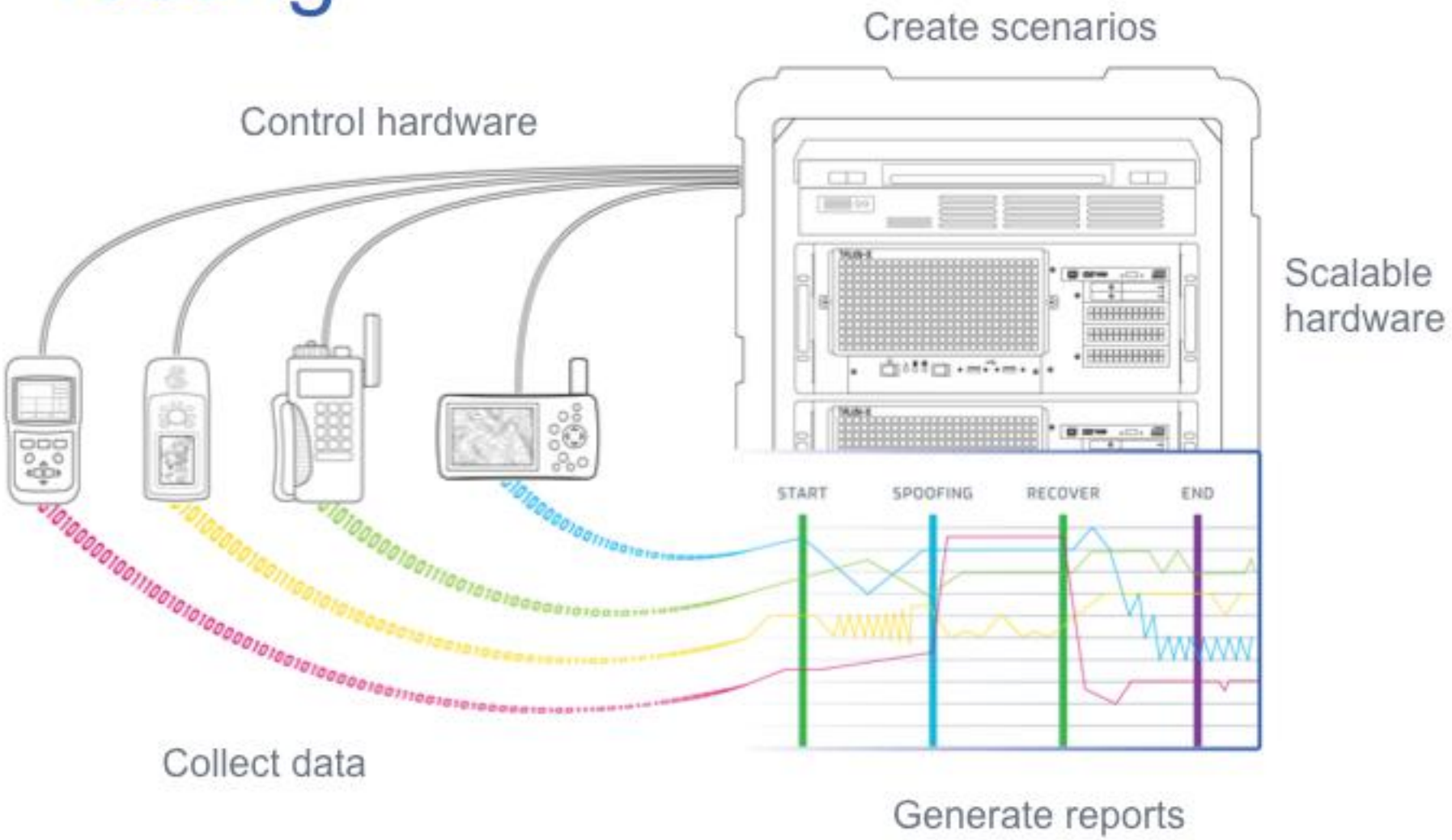
Anechoic Chamber

- System level testing
  - AJAS
  - Equipment integrated into platform
  - Vehicle systems/sensors
- More real-world threats
  - Multiple angles of arrival
- Challenges
  - Cost of adding jamming and Multi-GNSS
  - Limited dynamics
  - Calibration

Over-the-air Test Events

- Full integrated systems
  - AJAS
  - IMU/INS
  - Other aiding sensor inputs
- Dynamic scenarios
  - Vehicle trajectories
  - Threat trajectories
  - Various environments (land, sea, air, etc.)
  - Real multi-path
- Challenges
  - Frequency clearances
  - Often government hosted and by invitation only
  - Jam multiple frequencies
  - Spoofing multiple frequencies

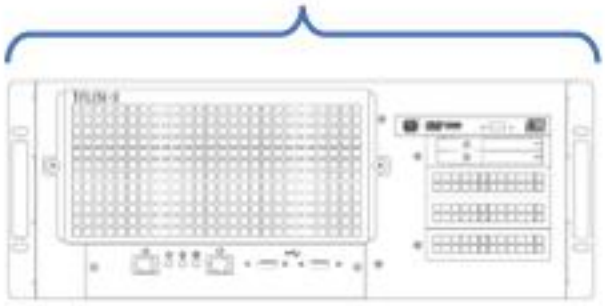
Automated Approach to Testing



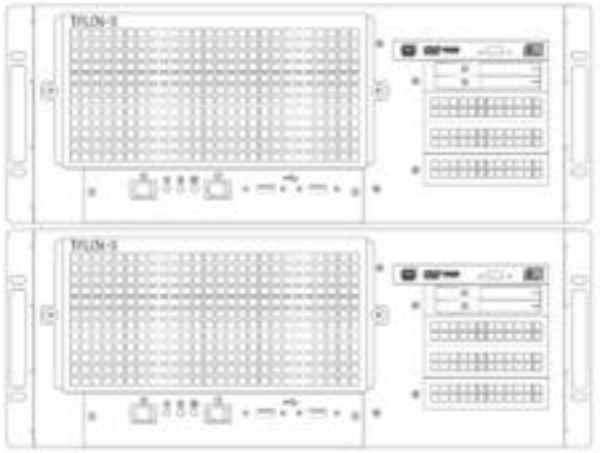
SDR Approach from Lab to Field

- COTS SDRs keep cost low
- Flexible and scalable
  - IQ generation supports all constellations
  - Base is hardware capable of all GNSS signals
- Same system used in the lab can scale to work in a chamber and in the field
- Leverage prior engineering hours
  - Scenario development
  - Time to learn GUI, etc.

4 RF OUTPUTS



8 RF OUTPUTS
(SYNCED SYSTEMS)



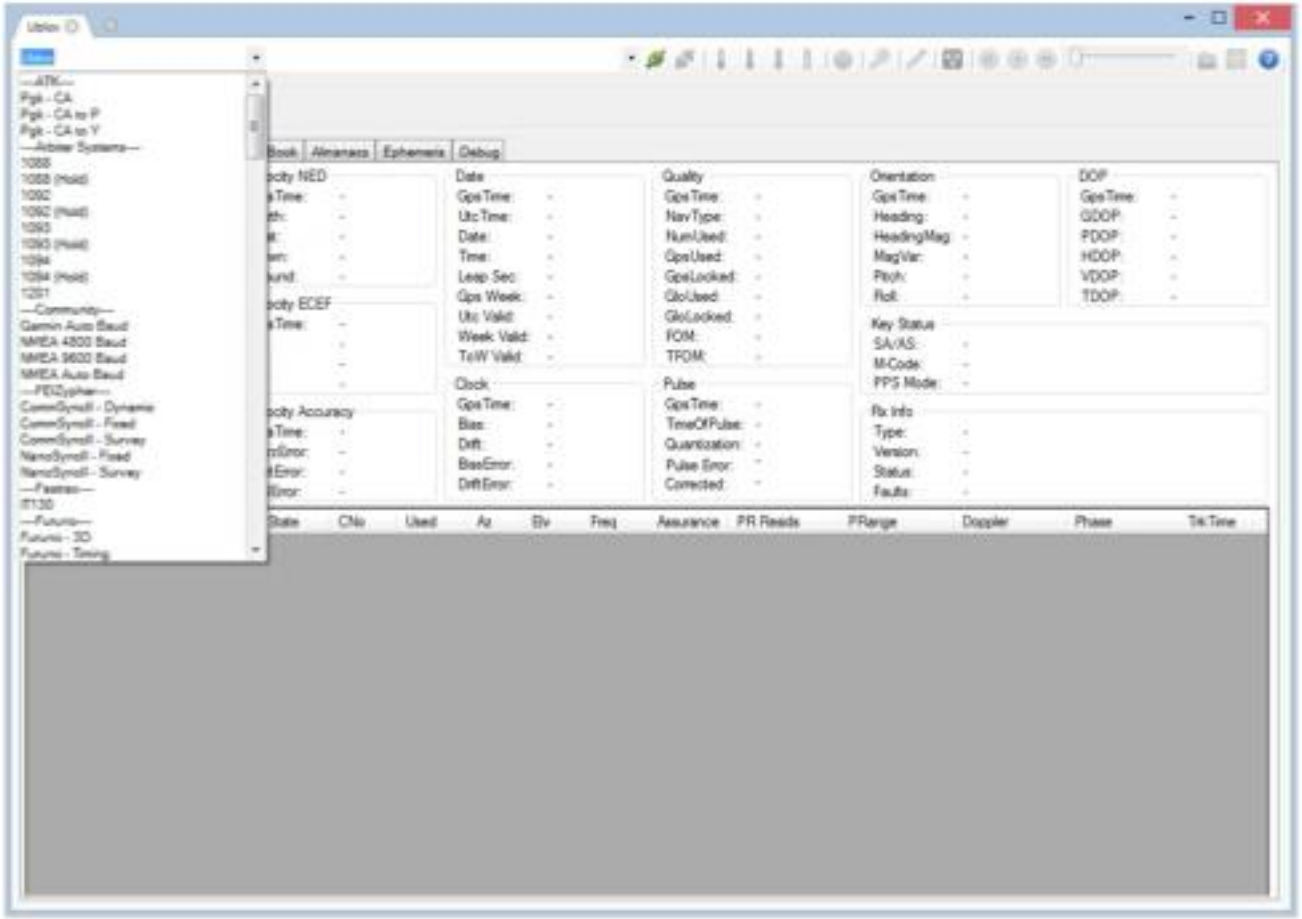
Scenario Creation – Make it Easy

- One application that generates the whole environment
  - GNSS simulation
  - Jamming
  - Spoofing
  - Time synchronization
  - Trajectories
- Control your simulator and jammers
  - Adjust power levels and set noise floor

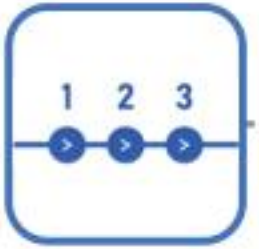
Collect Data – Common Format

- Every GNSS receiver is different
  - Data
  - Capabilities
- Output the data into a common format
  - Human readable
  - Easy to plot
- Accurately time stamp (0s-XXXs)
- Control multiple Units-Under-Test
  - Remove user interface besides connecting to system

Collect Data – Common Format



Spend Time Analyzing Data and Making Decisions

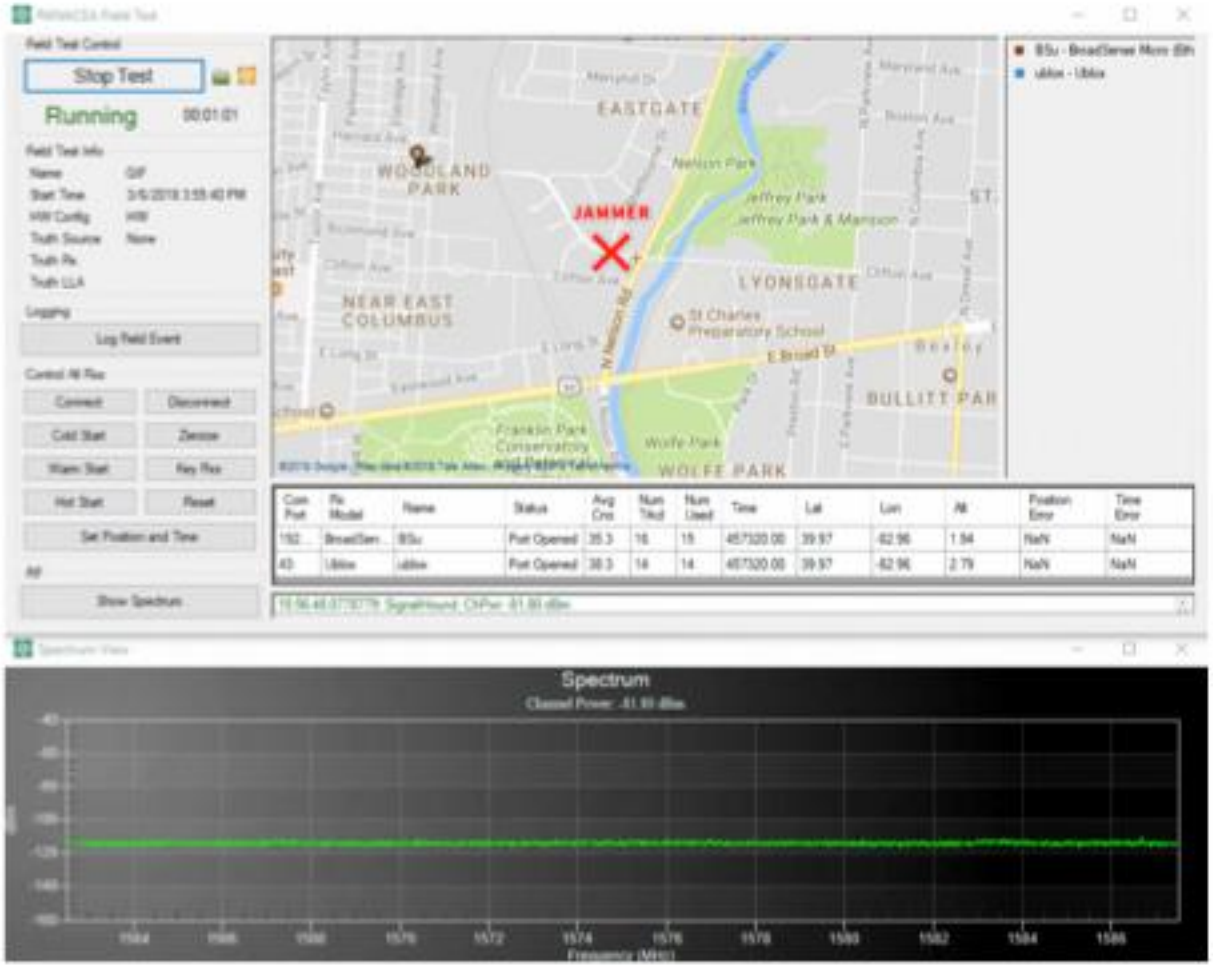


Automate the process to work for you

Come in each morning to auto generated plots and reports, not Excel files

Make decisions

Automation



- Creating test scenarios takes time
- Use the same test scenarios in all test environments

Conclusion

- ✓ There are many ways to test Multi-GNSS receivers
  - Lab
  - Chamber
  - Open environment
- ✓ New capabilities require new methods to test
  - Automated testing
  - Easy scenario creation
  - Scalable flexibility
- ✓ Some issues can arise with Multi-GNSS
  - Cost
  - How to test
  - Performance expectations

QUESTIONS?

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