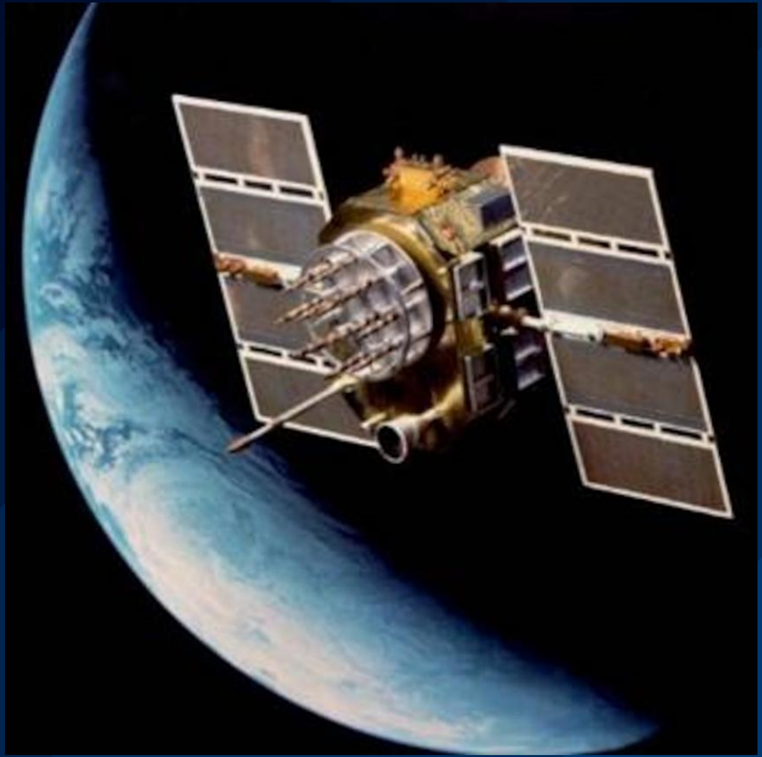
GNSS INTRODUCTION AND SIMULATION



Lily Lee
Mike Wu
RSTW Application Engineer

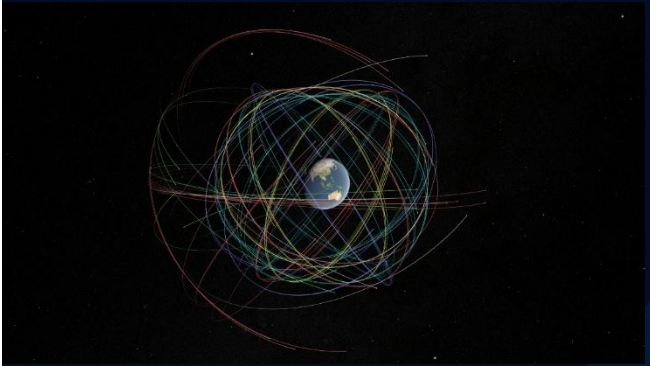
ROHDE&SCHWARZ

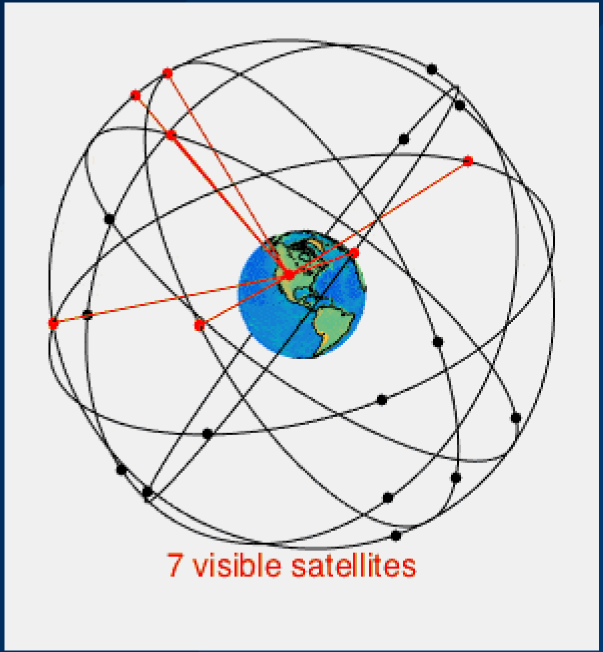
Make ideas real

CONTENTS

WHAT IS GNSS?

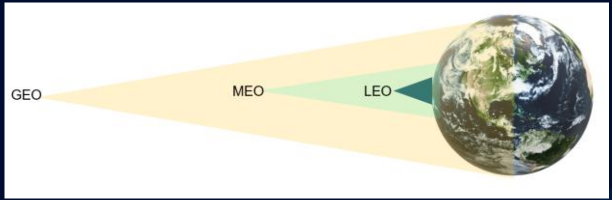
► GNSS (Global Navigation Satellite System) is the standard term for satellite constellations providing autonomous geo-spatial positioning with global coverage.

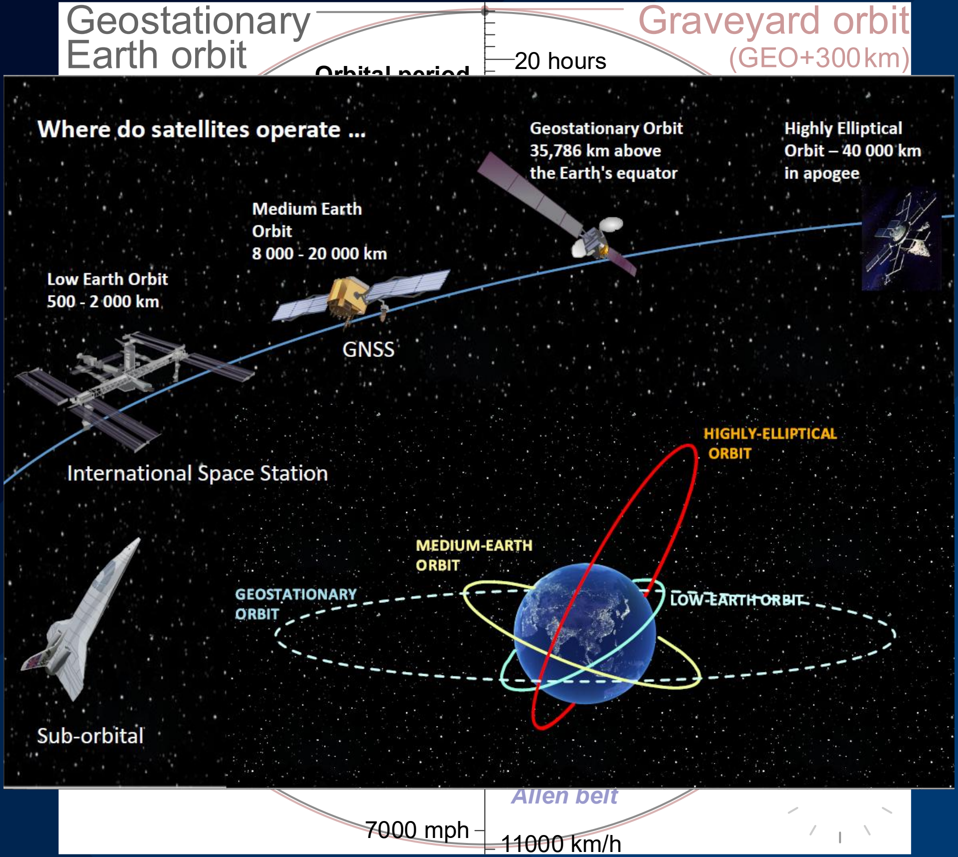




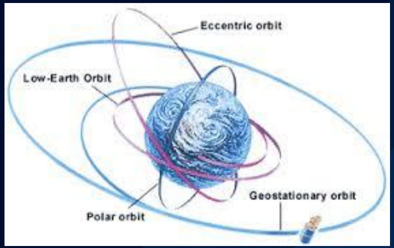
ORBIT INTRODUCE

- GEO Geostationary Earth Orbit
- MEO Medium Earth Orbit
- LEO Low Earth Orbit
- HEO High Earth Orbit





SATELLITE OVERVIEW



Orbit	Distance	Advantages	Disadvantages	Example
LEO	300-2000km	• Global Coverage • Low latency	• Traffic switching between satellites • Large numbers of satellites needed for full coverage	StarLink, Iridium
MEO	20 000-30000 km	• Global Coverage • Predicable Locations	• Traffic switching between satellites	GPS, Galileo, Glonass, SpaceLink
GEO	35786km	• Stationary Ground Equipment • Can cover 1/3 of the Earth with a single satellite	• Limited polar Coverage • Large signal path loss • Large Latency	DirecTV MUOS AEHF Astra, Eutelsat, Intelsat
HEO	35786 above	• Polar Coverage • Lower # of Satellites	• Traffic Switching between satellites • Variation in distance/coverage • Radiation in Van Allen Belt • Variable Latency	SirusXM QZSS

GNSS SYSTEMS

Global Systems

GPS(Global Positioning System)

GLONASS
(Global Navigation Satellite System)

BeiDou
(BeiDou Navigation Satellite System)

Galileo

Regional navigation satellite systems (RNSS)

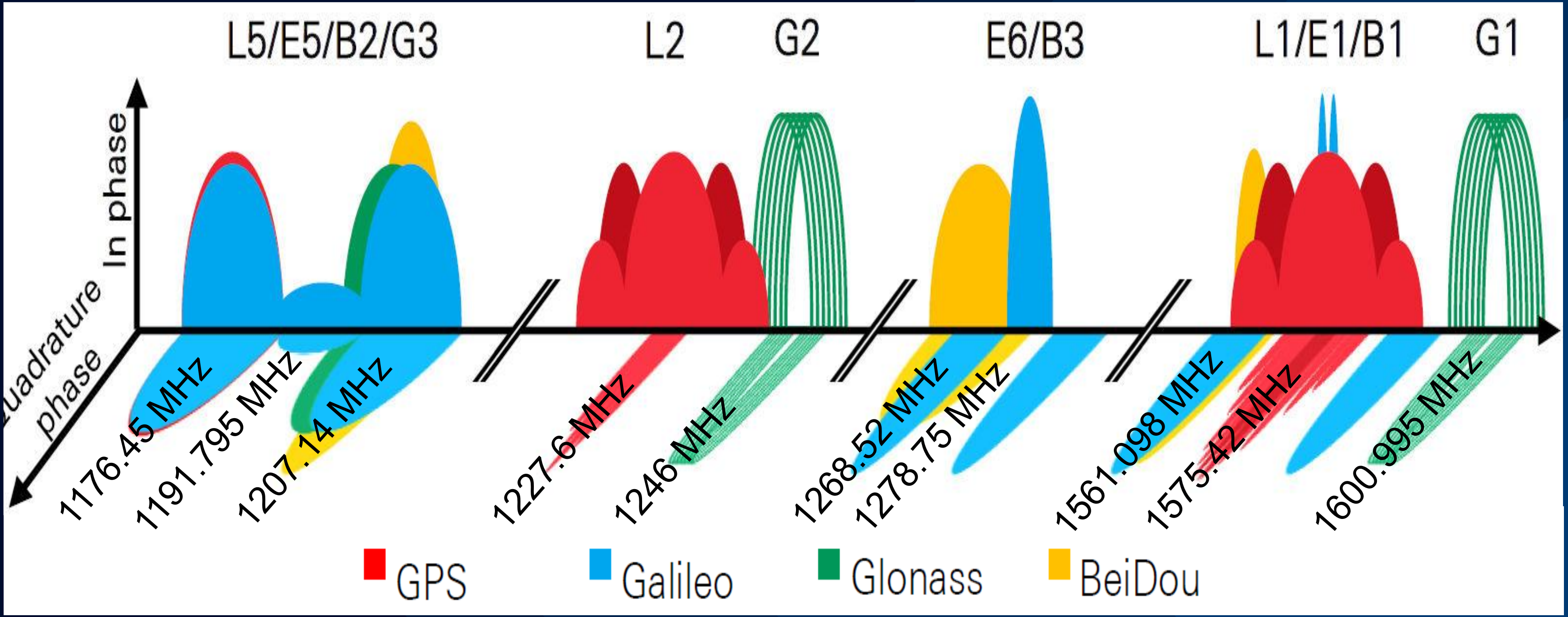
QZSS
(Quasi-Zenith Satellite System)

NavIC
(Navigation with Indian Constellation)

GNSS SPECTRUM

Lower L-Band

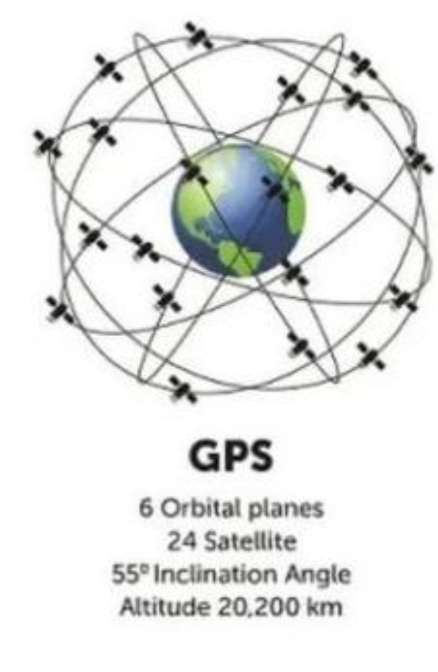
Higher L-Band



GPS (GLOBAL POSITIONING SYSTEM)

- Orbital Height : 20,180 km
- Orbital Period : 11h 58m
- MEO

GPS Signal Plan						
Service Name	C/A	P(Y)	L1C	L2C	M Code	L5I, L5Q
Frequency Band	L1	L1, L2	L1	L2	L1, L2	L5
Center Frequency (MHz)	1575.42	1575.42 1227.6	1575.42	1227.6	1575.42 1227.6	1176.45
Modulation	BPSK	BPSK	TMBOC	BPSK	BOC	QPSK
Code Frequency	1.023	10.23	1.023	0.5115	5.115	10.23

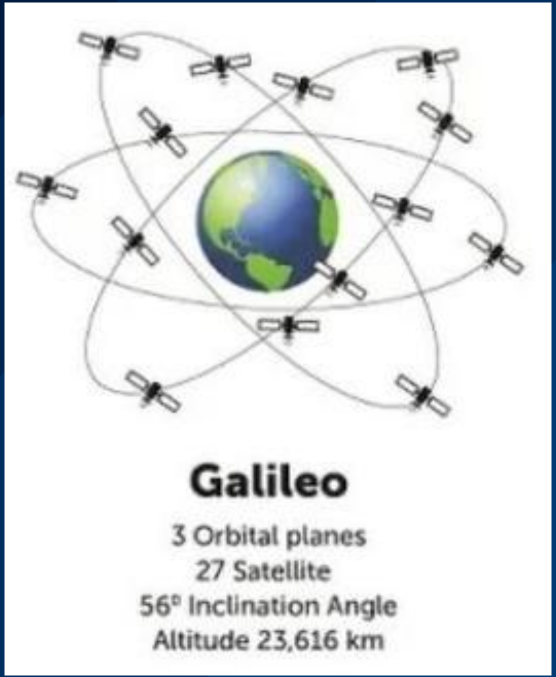


Pictures:https://inertiallabs.com/what-are-the-limitations-of-gnss/

GALILEO

- ▶ Orbital Height : 23,222 KM
- ▶ Orbital Period : 14h 4m 45s
- ▶ MEO

Galileo Signal Plan				
Service Name	E1 OS	E1 PRS E6 PRS	E5a, E5b	E6
Frequency Band	E1	E1, E6	E5	E6
Center Frequency (MHz)	1575.42	1575.42 1278.75	1176.45 1207.14	1278.75
Modulation	CBOC	BOC	AltBOC	BPSK
Code Frequency	1.023	2.5575 5.115	10.23	5.115

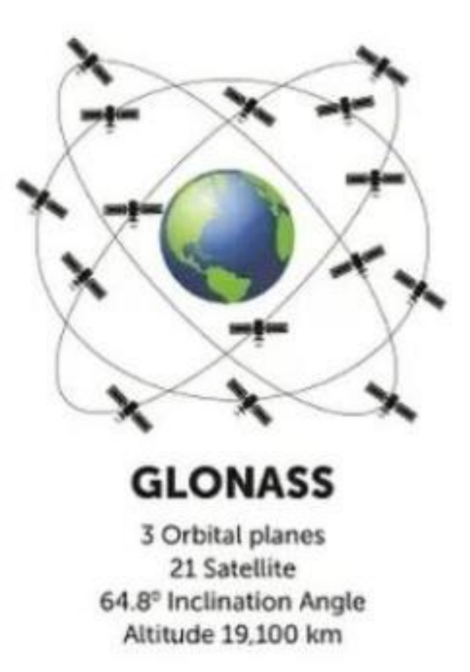


Pictures:https://inertiallabs.com/what-are-the-limitations-of-gnss/

GLONASS

- Orbital Period : 19150 KM
- Orbital Period : 11h 16m
- MEO

GLONASS Signal Plan			
Service Name	C/A	P	G3I, G3Q
Frequency Band	G1, G2	G1, G2	G3
Center Frequency (MHz)	1602 1246	1602 1246	1202.025
Modulation	BPSK	BPSD	QPSK
Code Frequency	0.511	5.11	1.023



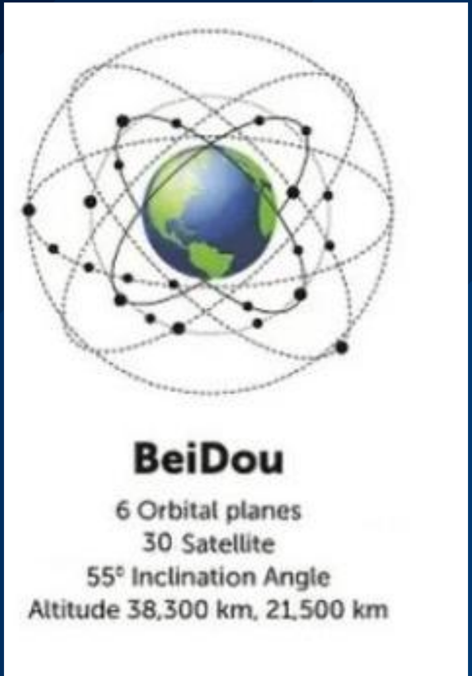
Pictures:https://inertiallabs.com/what-are-the-limitations-of-gnss/

BEIDOU (BEIDOU NAVIGATION SATELLITE SYSTEM,BDS)

- Orbital Height : 21,528 km, 35,786 km
- Orbital Period : 12h 53m
- MEO, GEO, IGSO

BeiDou Signal Plan

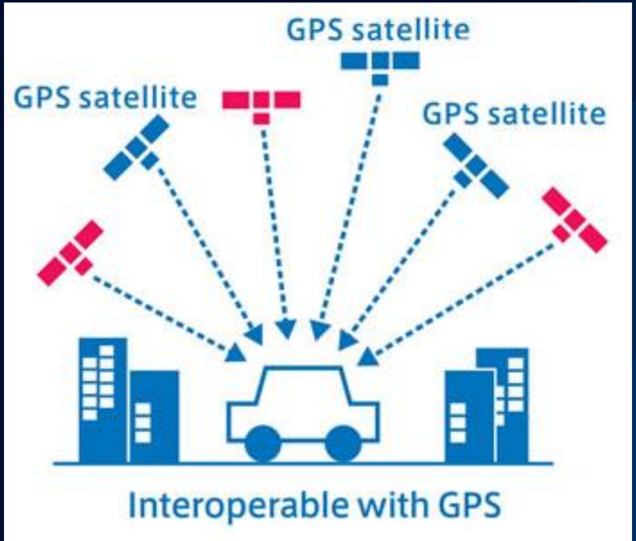
Service Name	B1C	B1I	B2a	B2I	B3I
Frequency Band	L1 (B1)	L1 (B1)	L5 (B2)	L2 (B3)	L2 (B3)
Center Frequency (MHz)	1575.42	1561.098	1176.45	1207.14	1268.52
Modulation	BOC QMBOC	BPSK	BPSK	BPSK	BPSK



Pictures:https://inertiallabs.com/what-are-the-limitations-of-gnss/

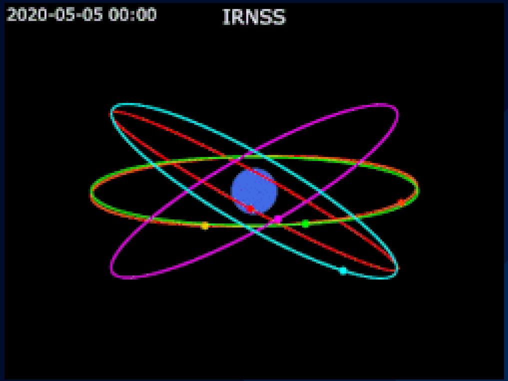
QZSS (QUASI-ZENITH SATELLITE SYSTEM)

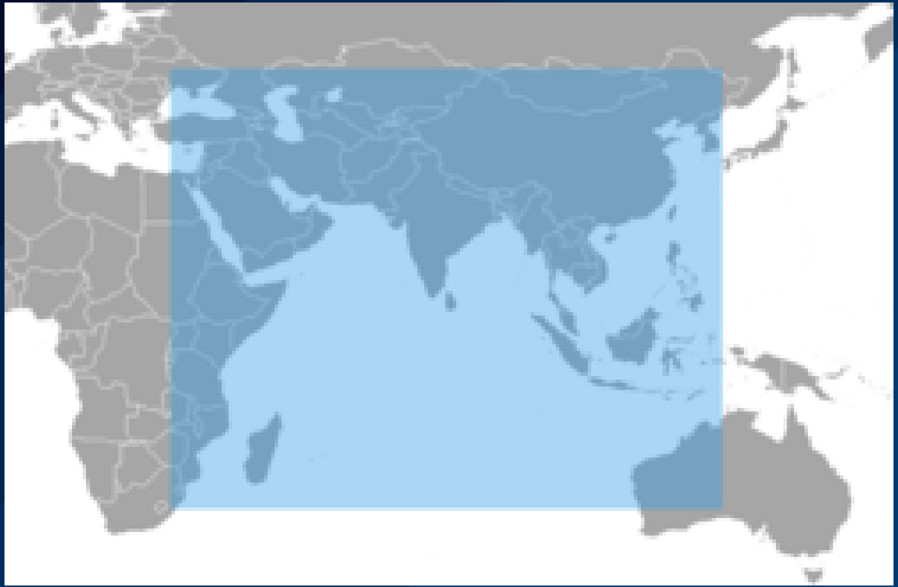
- Also knows as Michibiki (みちびき)
- IGSO



IRNSS (INDIAN REGIONAL NAVIGATION SATELLITE SYSTEM)

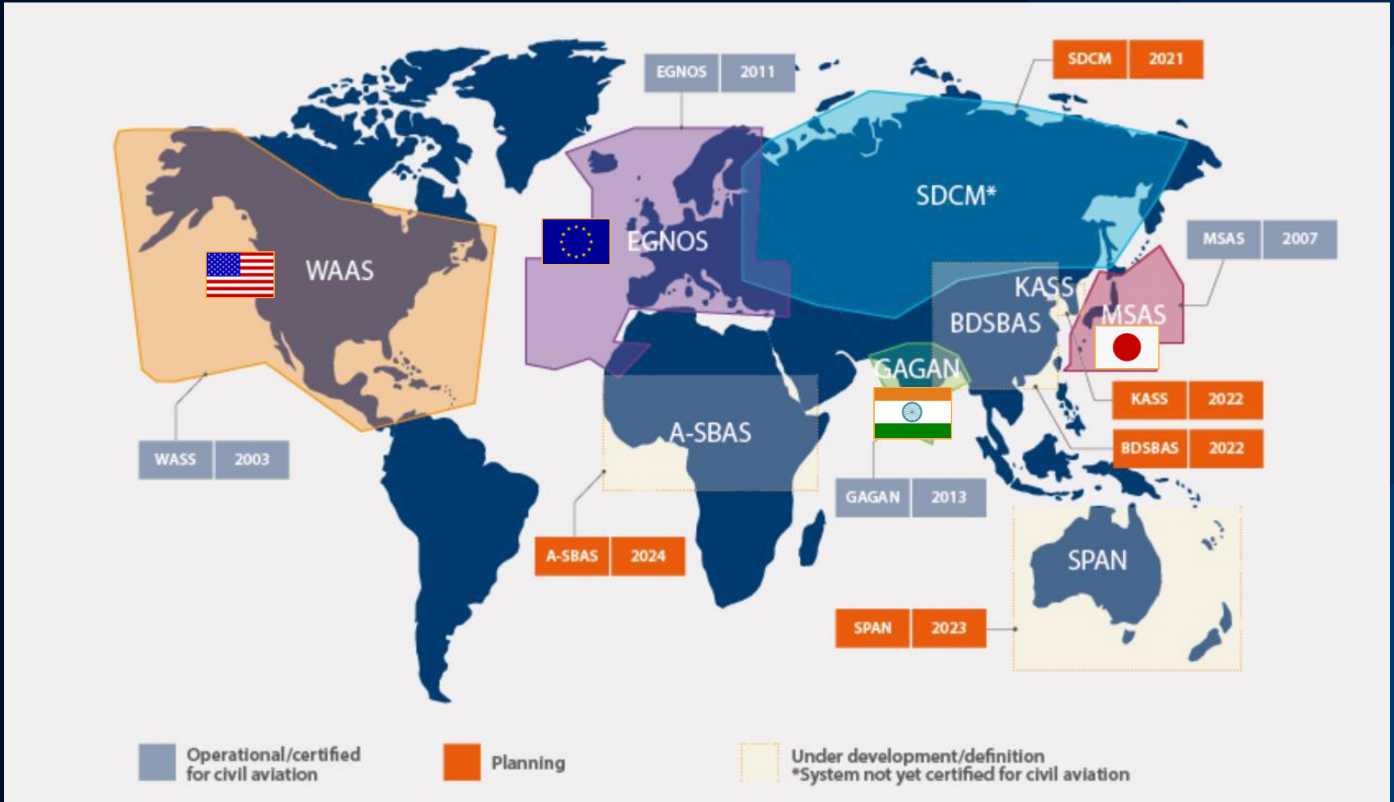
- operational name: NavIC
  (Navigation with Indian constellation)
- GEO + IGSO
- Since 2013





AUGMENTATION SYSTEMS

SBAS (Satellite-based augmentation system)



SBAS (SATELLITE-BASED AUGMENTATION SYSTEM)

Wide Area Augmentation System
(WAAS)

Northern America

European Geostationary Navigation Overlay Service
(EGNOS)

Multi-functional Satellite Augmentation System
(MSAS)

GPS-aided GEO augmented navigation
(GAGAN)

HOW DO WE KNOWN THE POSITION?

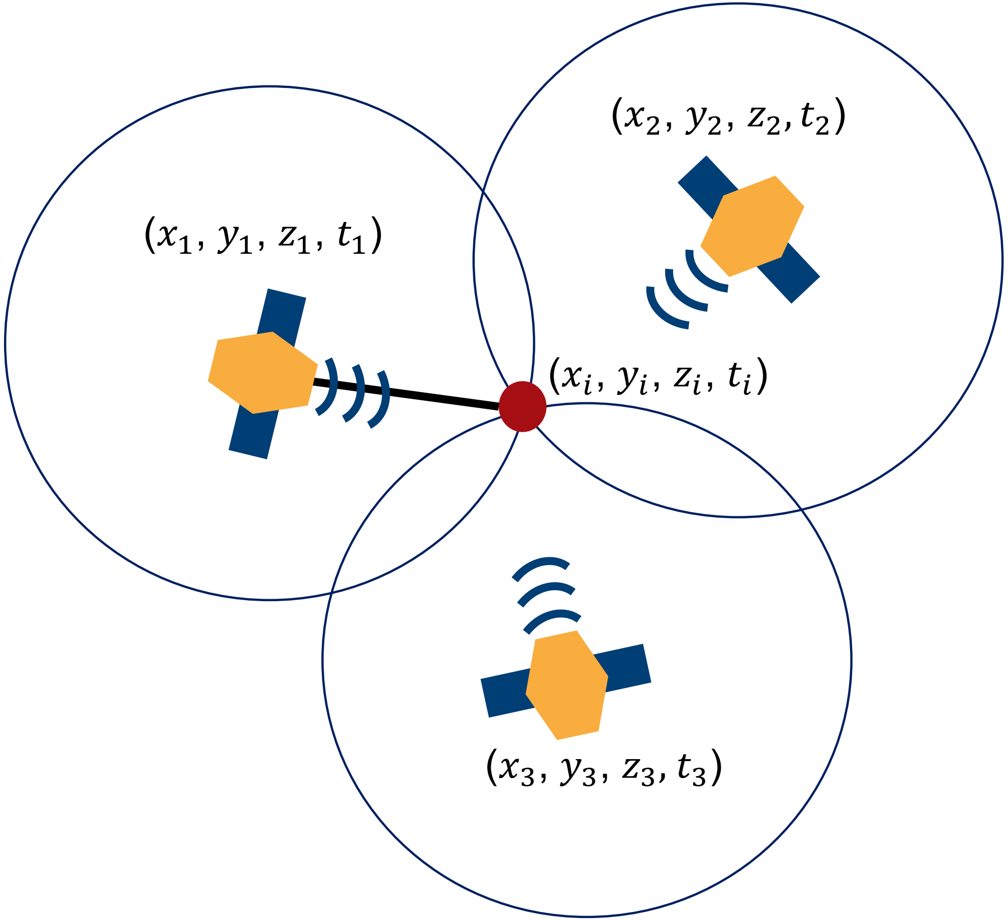
HOW DOES GPS WORK

Distance = Speed × Time

$$S_n = c \times \Delta t = \text{c} \times (t_n - t_i)$$

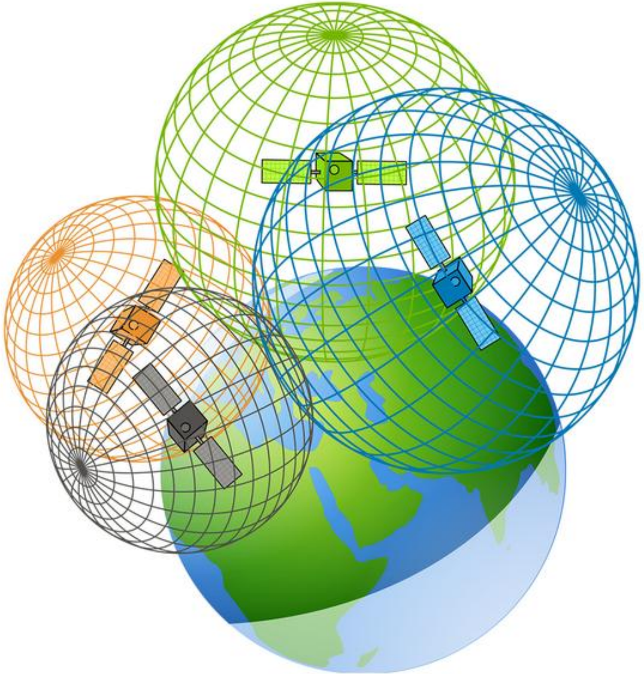
The Multi-Satellite Intersection (Trilateration)

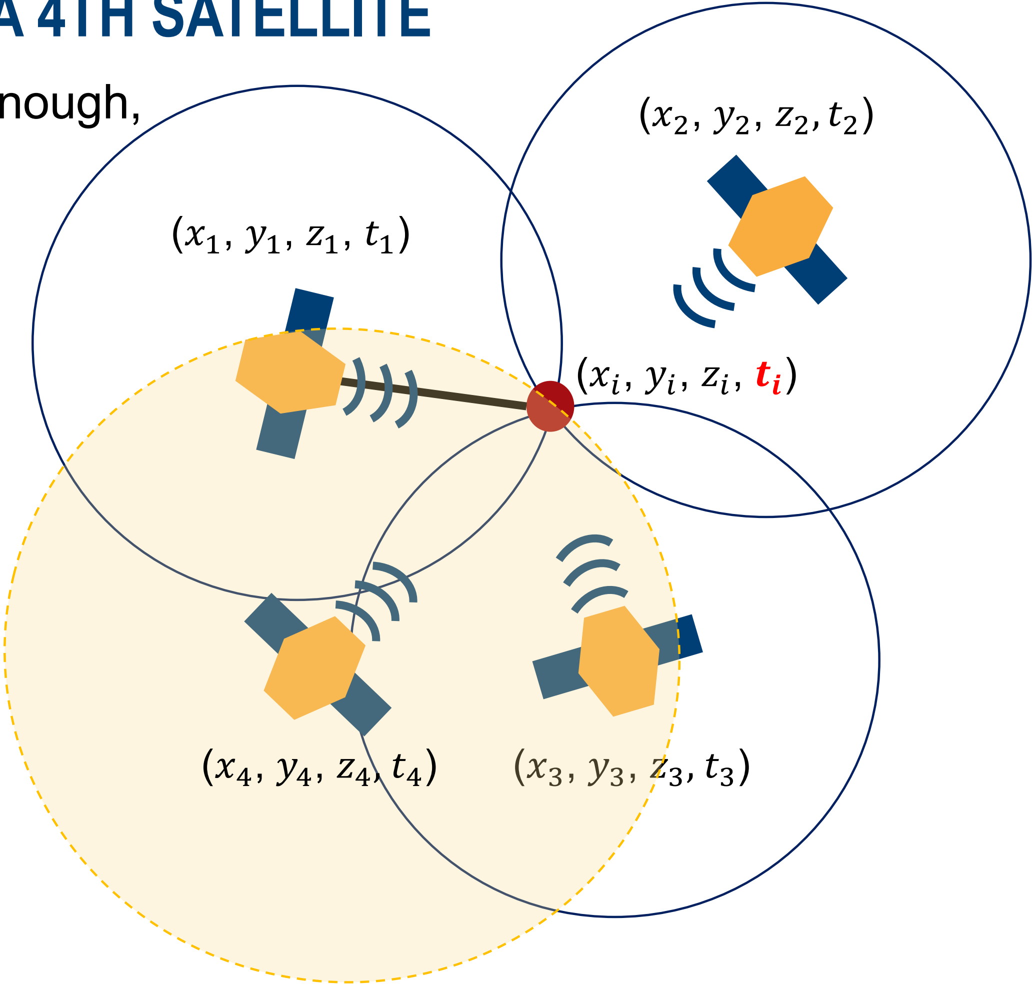
$$S_n = \sqrt{(x_n - x_i)^2 + (y_n - y_i)^2 + (z_n - z_i)^2}$$



WHY YOU ACTUALLY NEED A 4TH SATELLITE

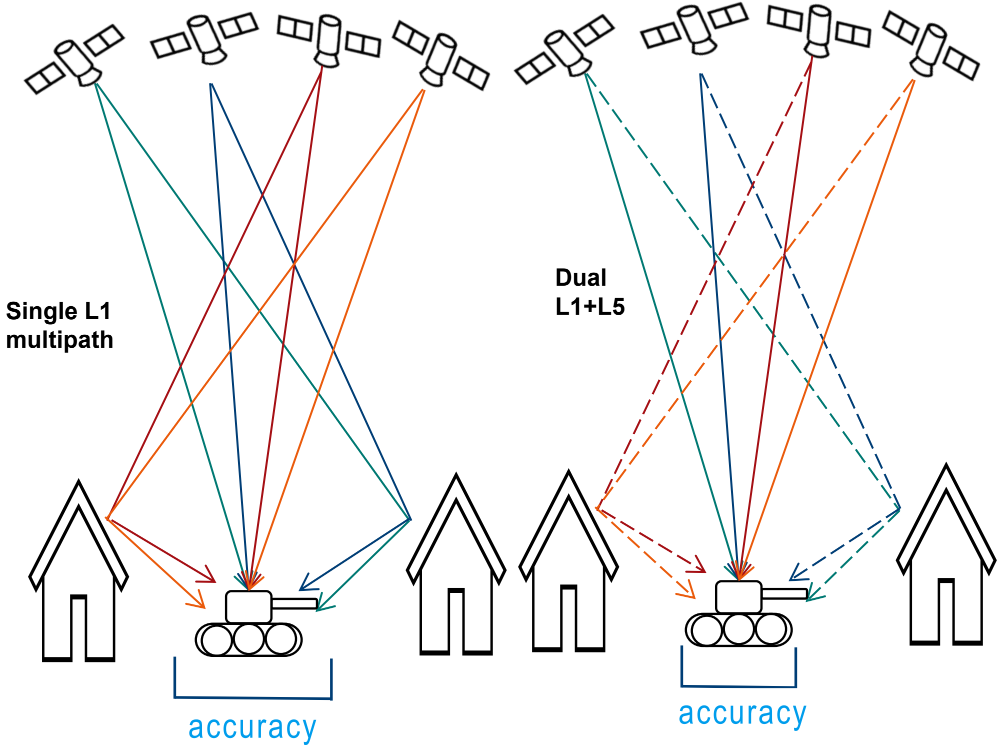
receiver's clock is near accurate enough, there would be exact time error



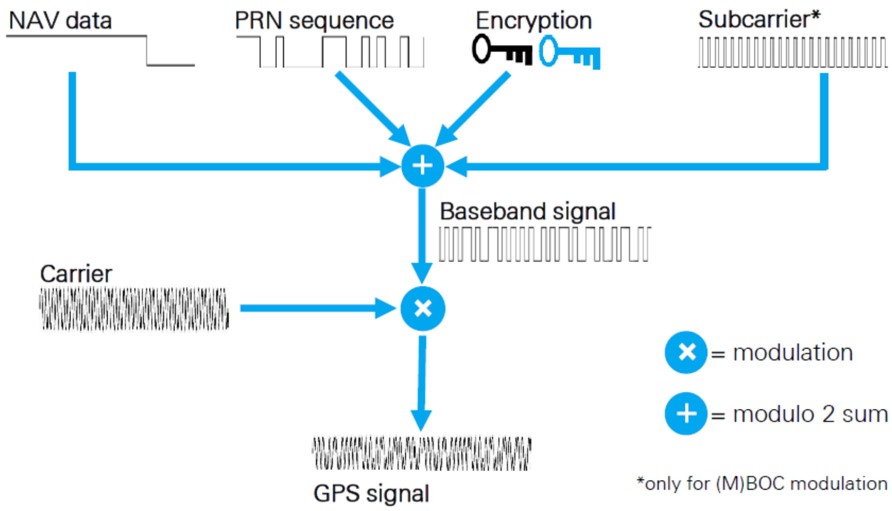


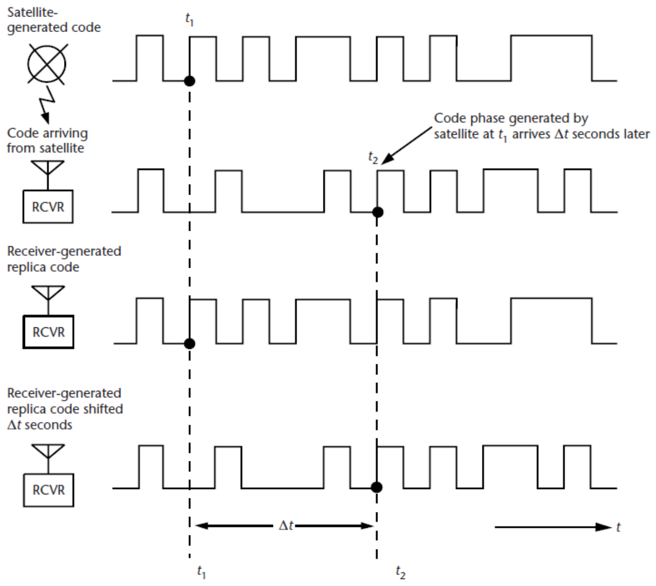
WHY NEED MULTI-BAND GNSS?

- Eliminating Ionospheric Delay
- Mitigating "Multipath Effects" in Urban Canyons
- Achieving Centimeter-Level Accuracy and Faster "Lock-On“
- Signal Redundancy and Anti-Jamming/Anti-Spoofing



PRN (PSEUDORANDOM NOISE)





NMEA 0183

- NMEA also known as National Marine Electronics Association

- Receiver output files or simulate past time and path

```
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$GPGSV,3,2,11,02,39,223,16,13,28,070,17,26,23,252,,04,14,186,15*77
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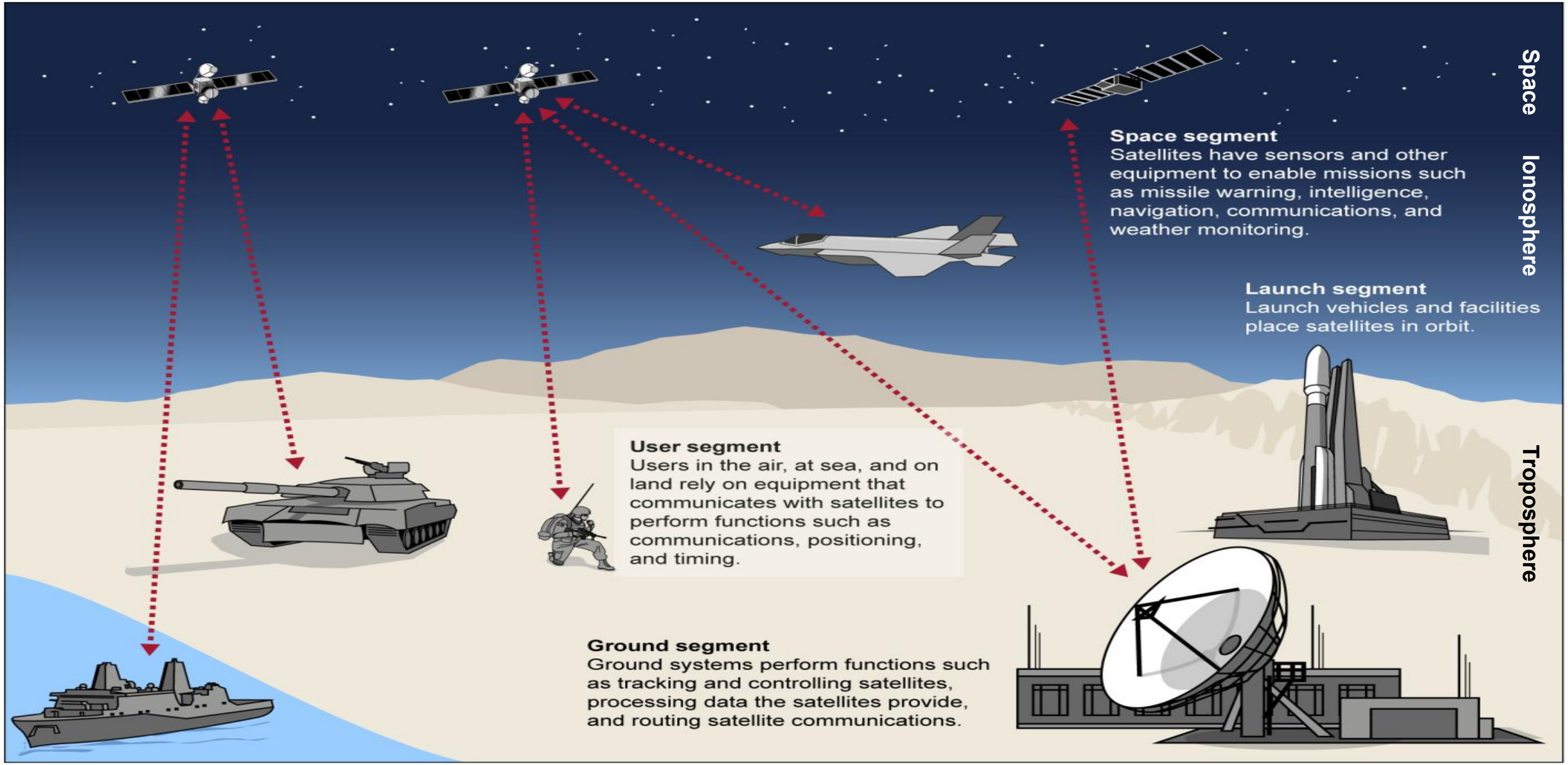
GNSS on Modern Warfare



Source: GAO analysis of Department of Defense (DOD) documentation. | GAO-20-80

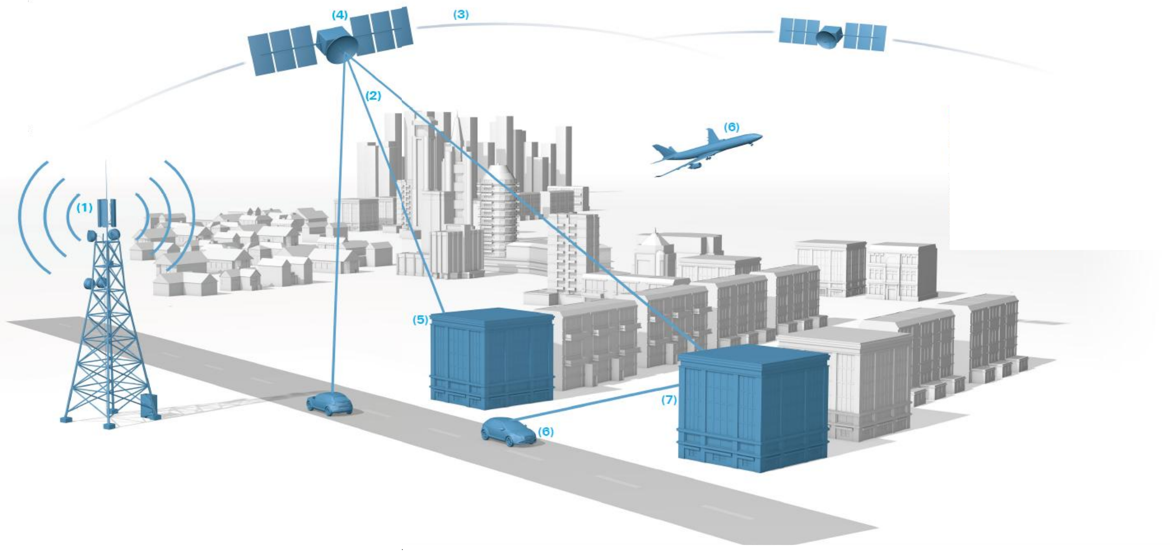
GNSS ON MODERN WARFARE

- Precision Strike & Lethality
- Situational Awareness & Force Tracking
- Critical Tactical Timing
- The NAVWAR Paradigm Shift

Source:https://www.twz.com/land/u-s-striking-iranian-navy-ships-with-ballistic-missiles

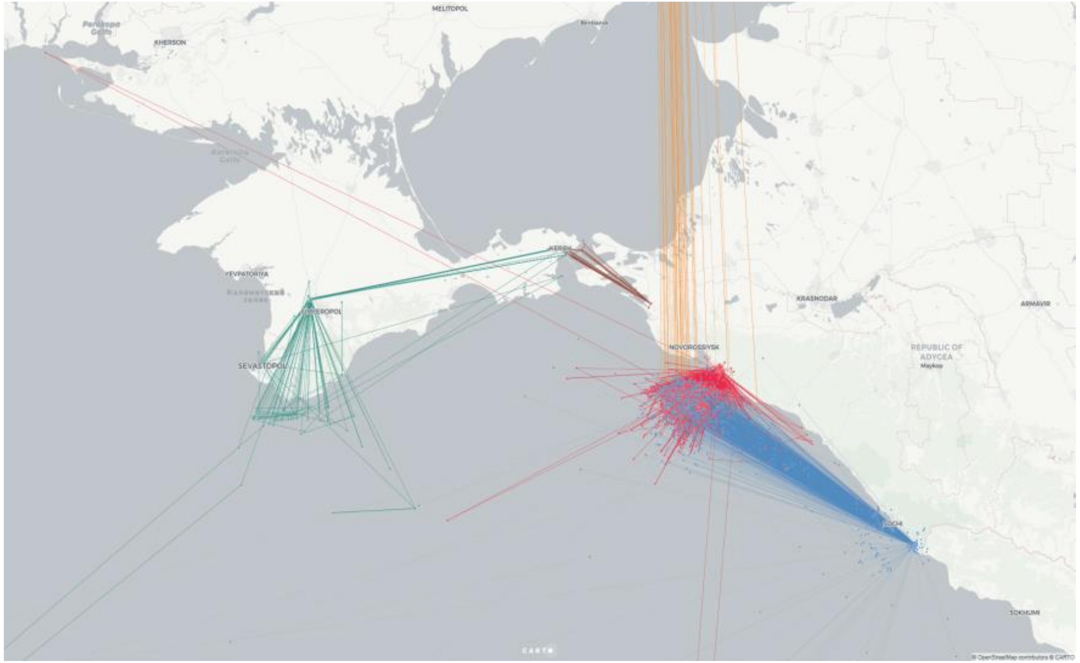
THE NAVWAR THREAT

- Signal Masking
- Multipath
- Ionospheric Scintillation
- Tropospheric Effects
- Space Debris or Meteorites
- Unintentional Jamming



GNSS SPOOFING ATTACK

- **Brute-Force GNSS Jamming**
- **GPS Spoofing**
- **Russian GNSS Spoofing**



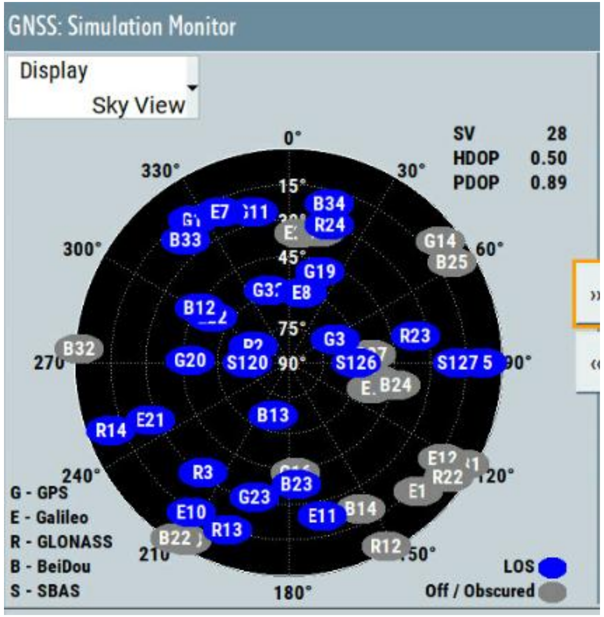
Russian Black Sea Spoofing Activity

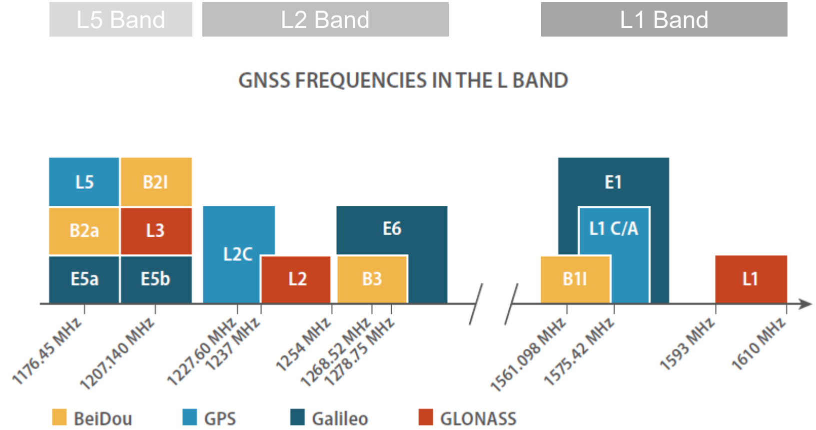
HOW DO WE AVOID?
COULD WE SIMULATE THE GNSS SIGNAL?

MULTI-CONSTELLATION, MULTI-FREQUENCY

More than one frequency band (e.g. L1 + L2)

More than one GNSS (e.g. GPS + Galileo)





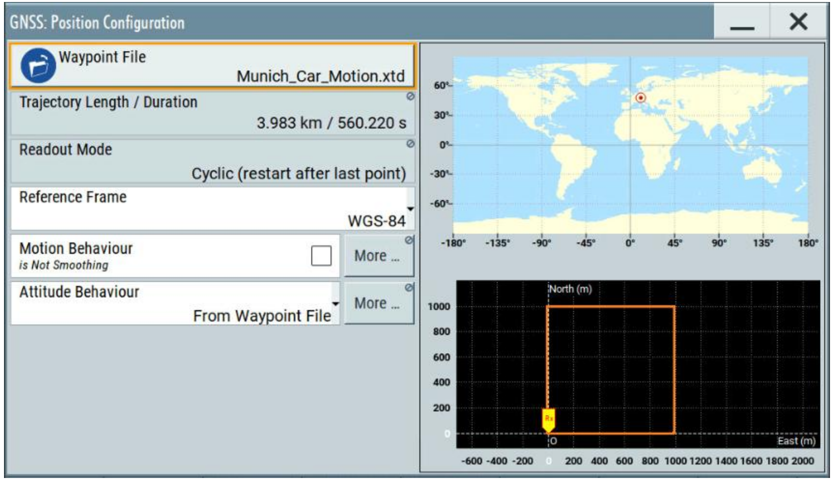
R&S SMW200A

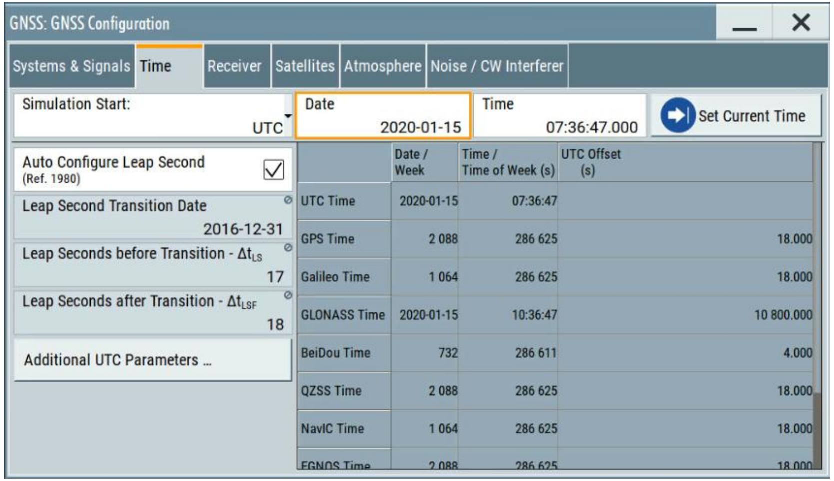
CONSTELLATIONS VS BANDS

	Constellation	L1 (E1)	L2 (E6)	L5 (E5)
GNSS	GPS	C/A, P, L1C, P(Y)-Noise, M-Noise	C/A, P, L2C, P(Y)-Noise, M-Noise	L5
	Galileo	E1 OS, E1 PRS-Noise	E6, E6PRS-Noise	E5a, E5b
	GLONASS	C/A, CDMA L1	C/A, CMDA L2	CDMA L3
	BeiDou	B1I, B1C	B3I	B2I, B2a
RNSS	QZSS	C/A, L1C	L2C	L5
	NavIC			SPS
SBAS	EGNOS	C/A		L5
	WAAS	C/A		L5
	MSAS	C/A		
	GAGAN	C/A		

POSITION AND TIME SIMULATION

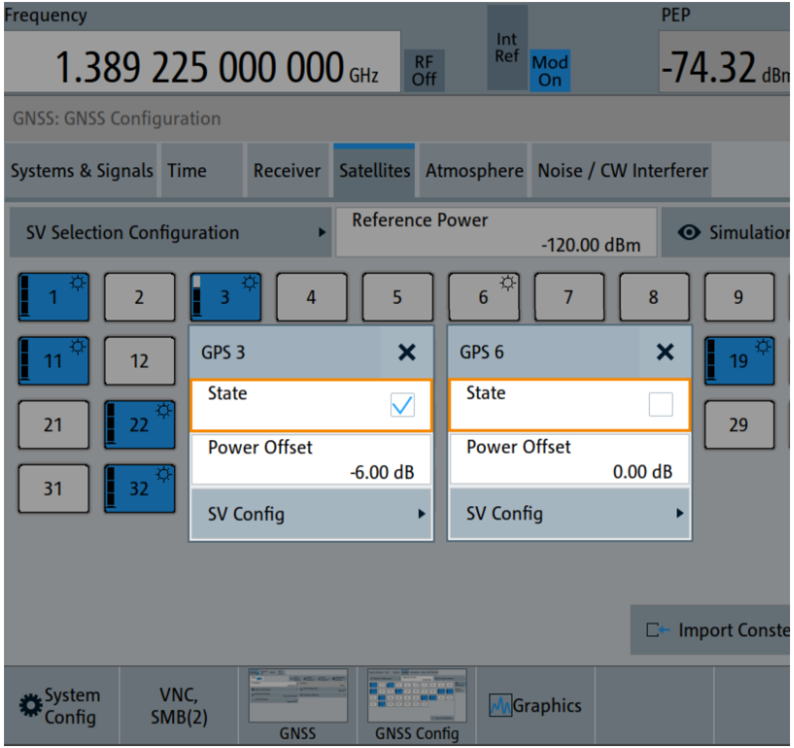
- Position
  - Static
  - Moving
  - Remote Control (HIL)
- Time
  - UTC, GPS,
  - Leap second

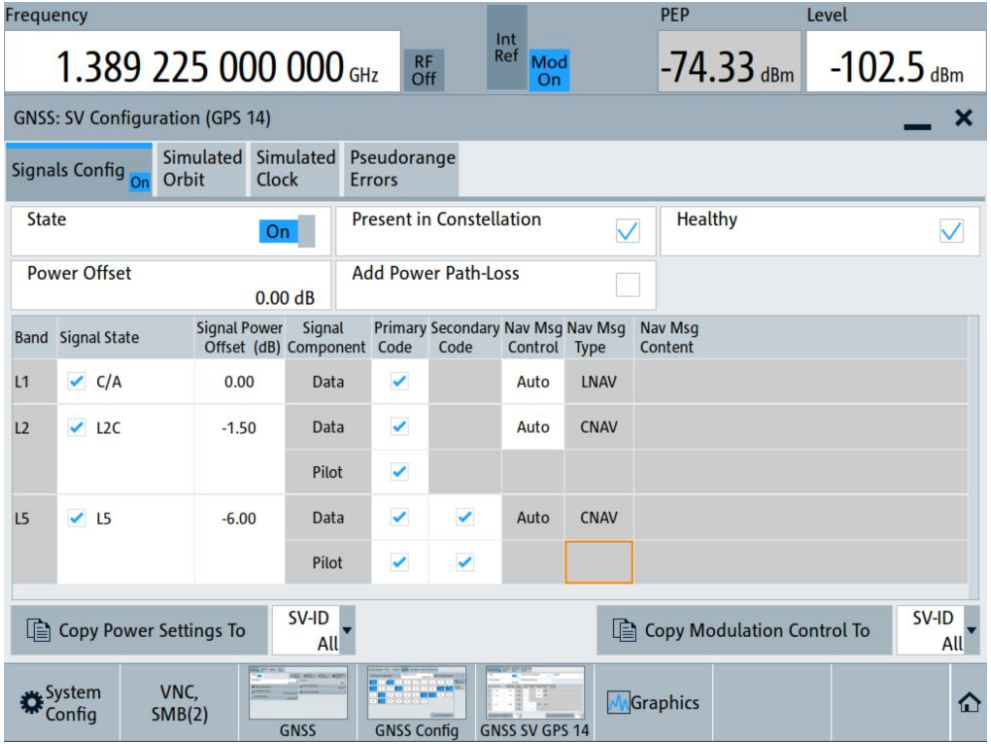




	Date / Week	Time / Time of Week (s)	UTC Offset (s)
UTC Time	2020-01-15	07:36:47	
GPS Time	2 088	286 625	18.000
Galileo Time	1 064	286 625	18.000
GLONASS Time	2020-01-15	10:36:47	10 800.000
BeiDou Time	732	286 611	4.000
QZSS Time	2 088	286 625	18.000
NavIC Time	1 064	286 625	18.000
EGNOS Time	2 088	286 625	18.000

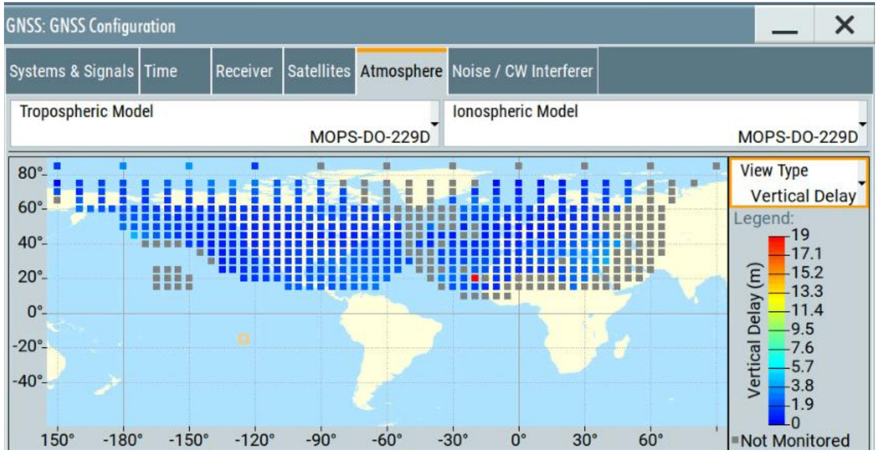
SV CONFIGURATION

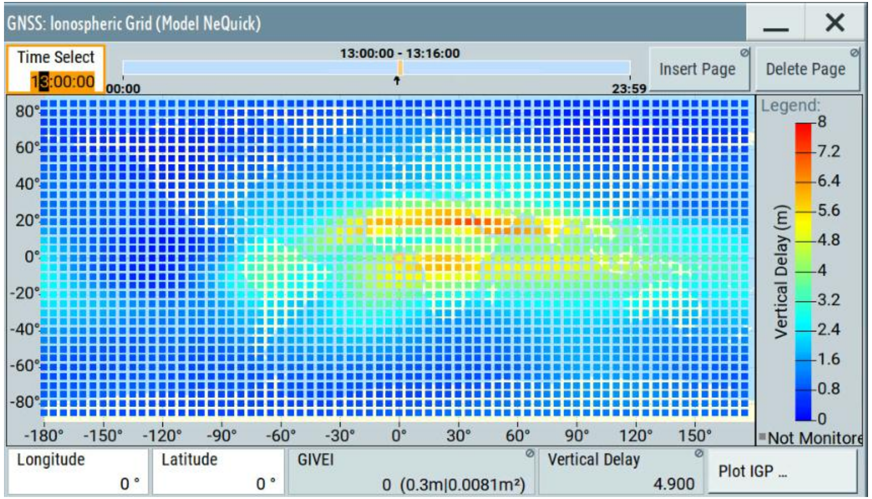




REAL-WORLD SIMULATION (ATMOSPHERE)

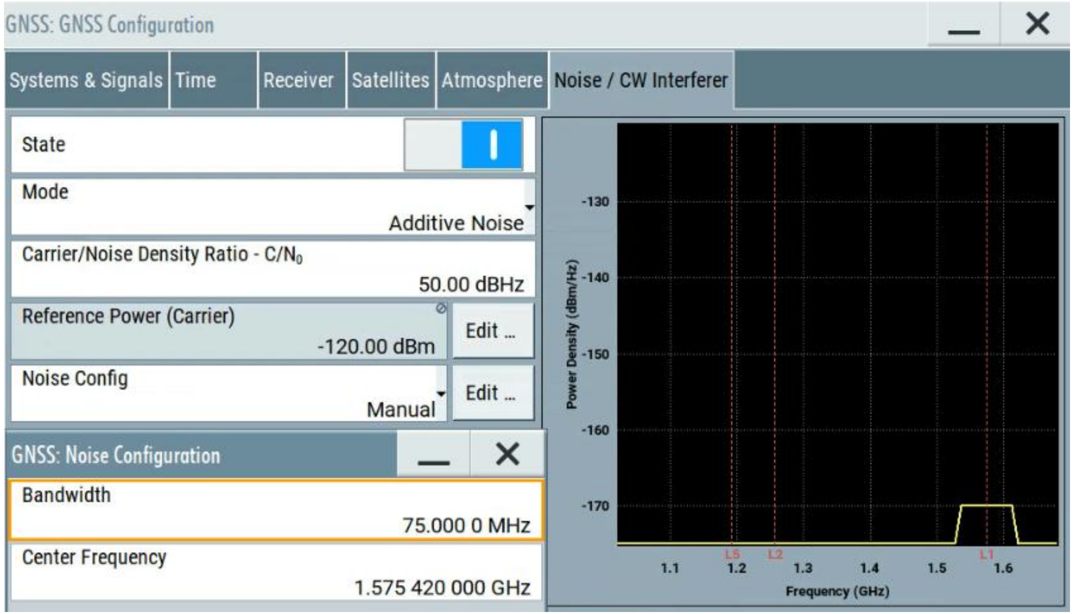
- ► Tropospheric Model
  - – STANGAG
  - – MOPS-DO-229D
- ► Ionospheric Model
  - – Klobuchar
  - – NeQuick
  - – MOPS-DO-229D



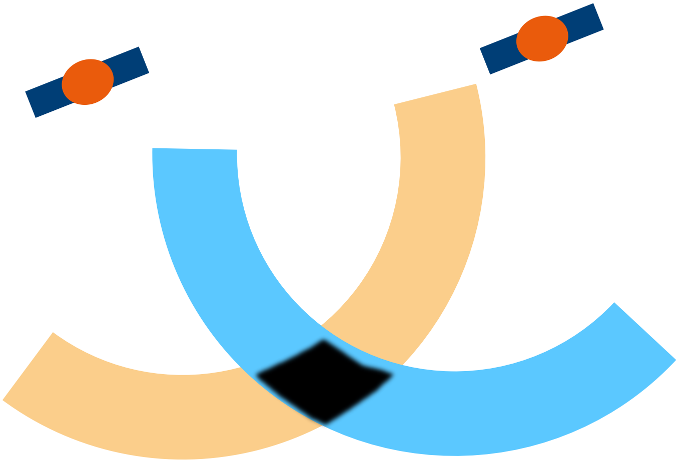


REAL-WORLD SIMULATION (NOISE/ INTERFERE)

- Noise, Interferer
  - Additive Noise
  - CW Interferer



DILUTION OF PRECISION (DOP)



HDOP	Horizontal DOP
VDOP	Vertical DOP
PDOP	Position DOP
TDOP	Time DOP
GDOP	Geometric DOP

TESTING

- TTFF (time to first fix)
- Positioning / Velocity Accuracy
- Receiver Sensitivity
- C/No (Carrier to noise density)

TTFF TIME TO FIRST FIX

Cold Start

► No valid ephemeris, almanac or position data.

<32s

Warm start

► Valid almanac and time data.

<24s

Re-Acquistion

1~5s

POSITIONING / VELOCITY ACCURACY

Horizontal / Vertical Accuracy

- HDOP
- VDOP

- Horizontal accuracy : 1~2.5m
- Vertical Accuracy : 2~5m

Dynamic Velocity Accuracy

- Velocity Error (RMS)
- Heading / Course Accuracy
- Max Dynamics
- Latency (RT)

SENSITIVITY

1. Base Power

~27W Output

+44.3 dBm

2. Satellite EIRP

+13 dBi Antenna Gain

+57.3 dBm

3. Space Path Loss

23,000 km Divergence

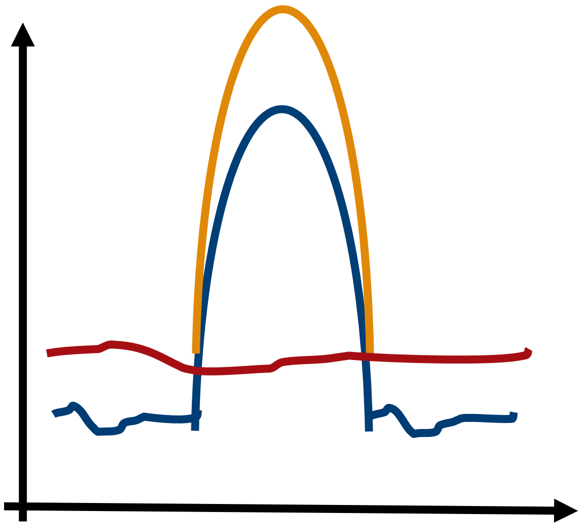
-184.4 dB

4. Earth Surface

With Atmospheric Loss

<-130.1 dBm

CARRIER TO NOISE DENSITY



C/N_0 Range	Quality Level	Receiver Impact
40 - 50 dB-Hz	**EXCELLENT**	Optimal sky conditions. High-precision carrier phase tracking.
30 - 39 dB-Hz	**ACCEPTABLE**	Typical urban edge/tree canopy. Higher position jitter.
20 - 29 dB-Hz	**MARGINAL**	Demodulation of Nav Data becomes difficult. High risk of loss-of-lock.
< 15 dB-Hz	**LOSS OF LOCK**	Signal is buried in noise. No positioning possible.

CRPA

CONTROLLED RECEPTION PATTERN ANTENNA

GNSS ATTACK

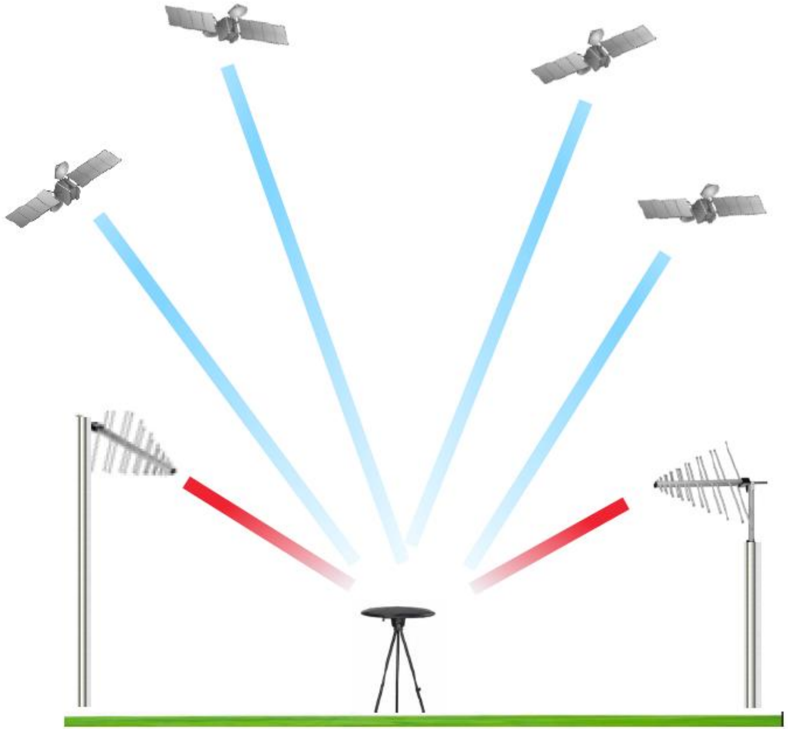
- **Jamming**

  Inject interference signal

- **Spoofing**

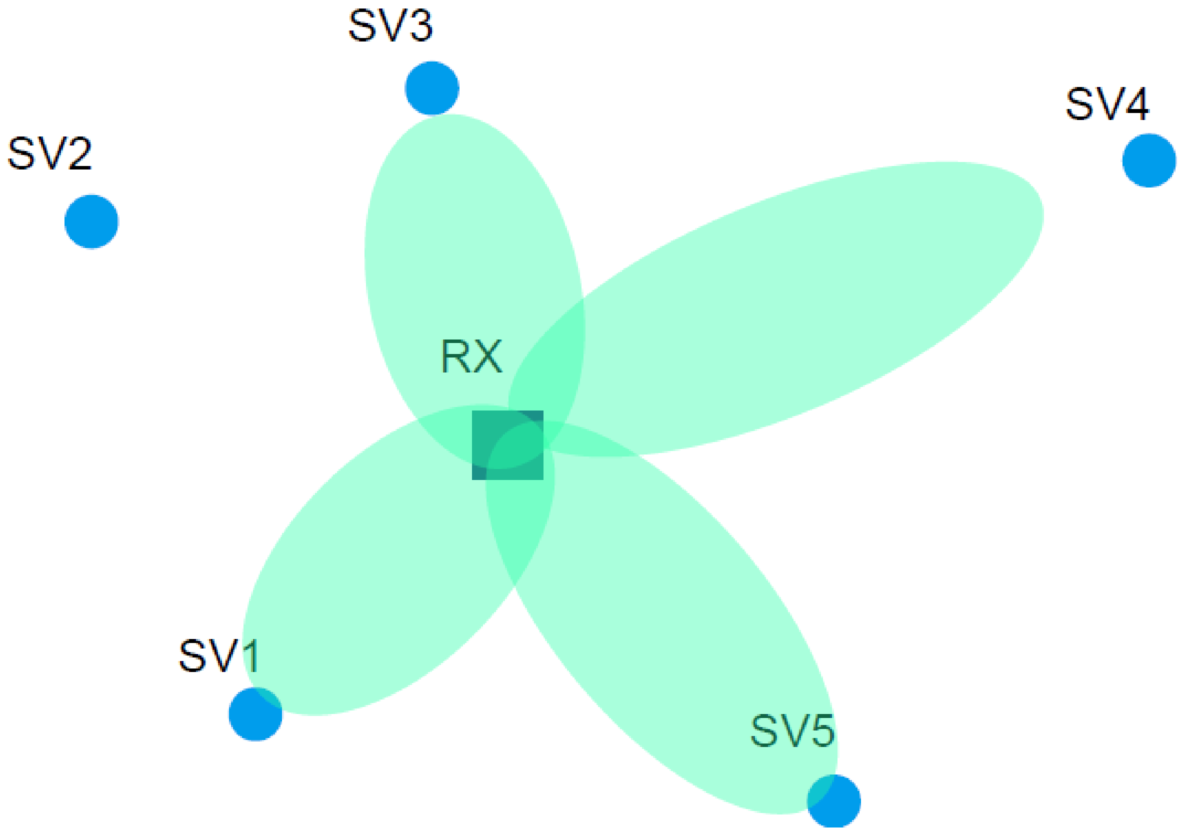
  Inject fake GNSS signal

Electronic Attack!



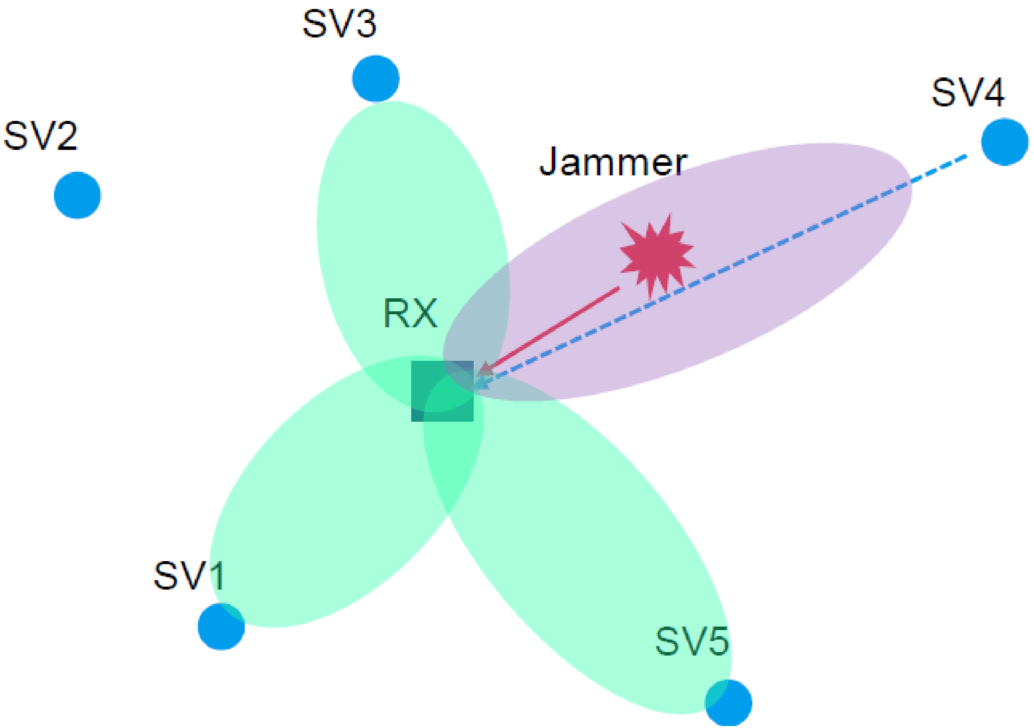
NORMAL SCENARIO

- Receive all real satellite signal.



GNSS ATTACK

- Jamming or spoofing signal from enemy.

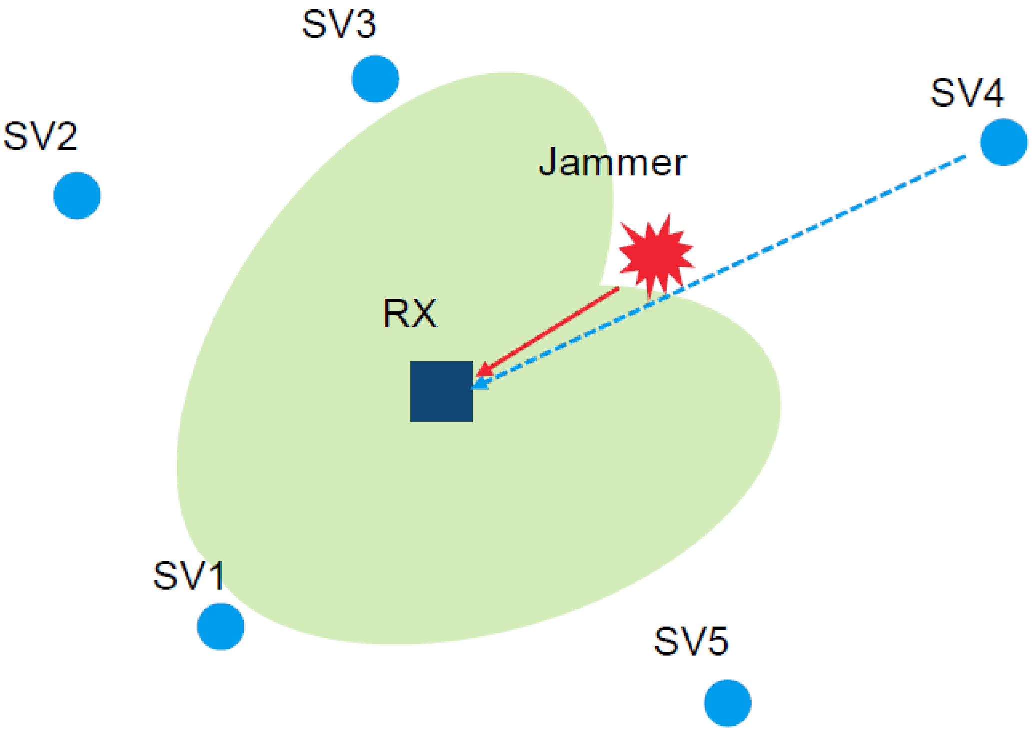


GNSS PROTECTION

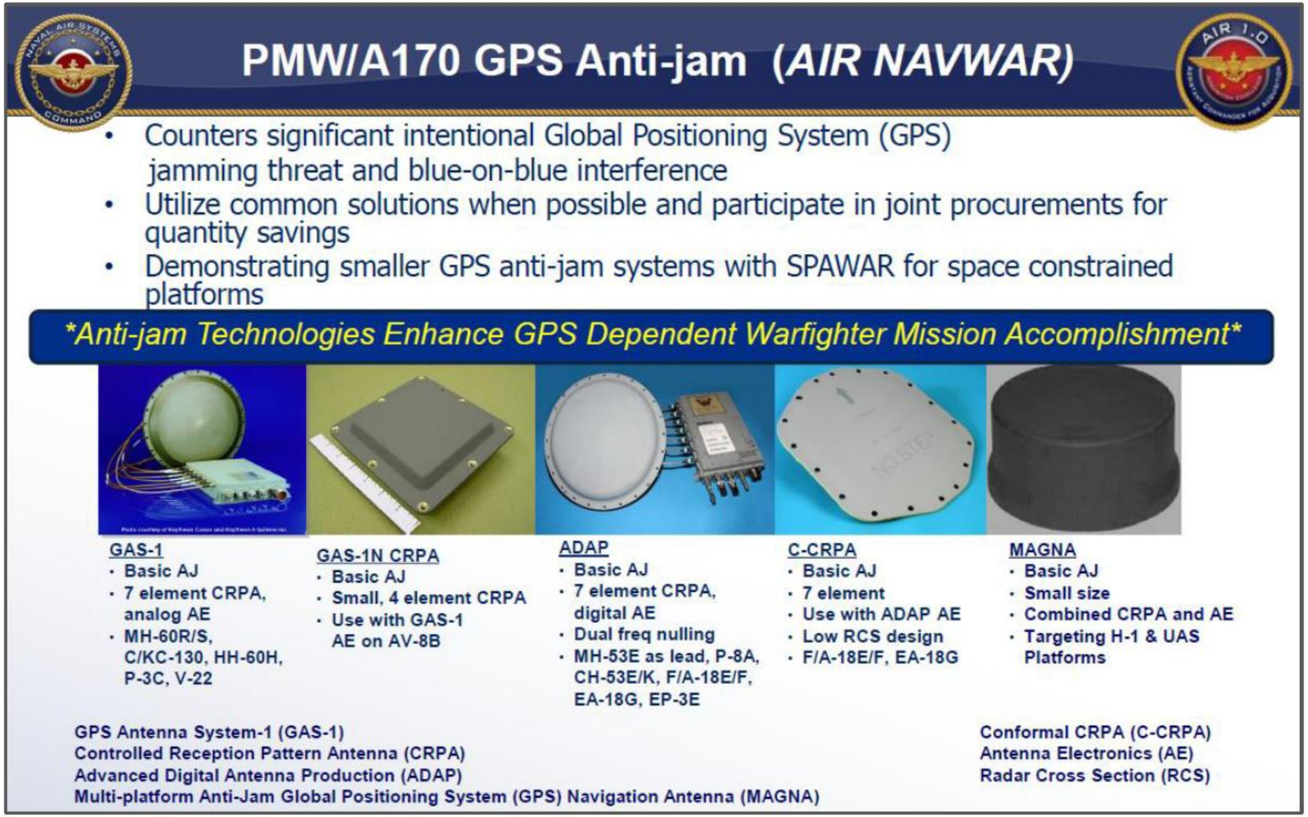
- Do NOT receive the Jammer's signal

- But how?

Electronic Protection!



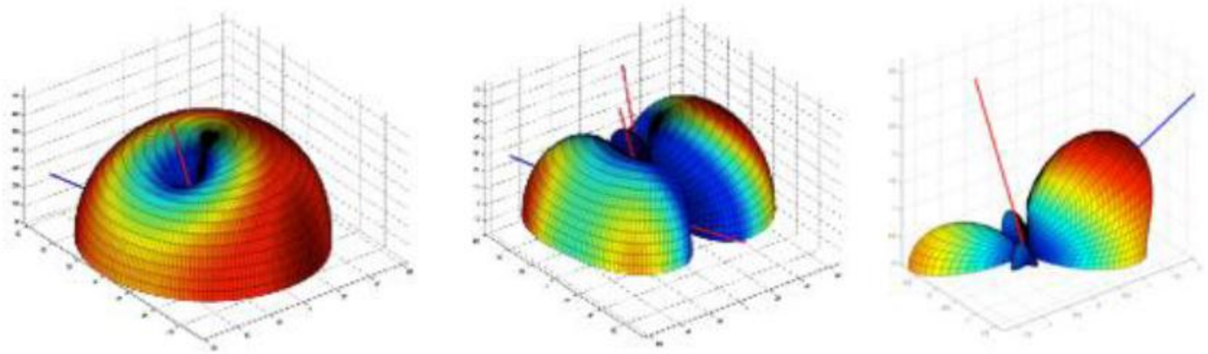
APPLICATION PRODUCT



3D ANTENNA PATTERN

Using Beamforming to avoid the jammer's signal

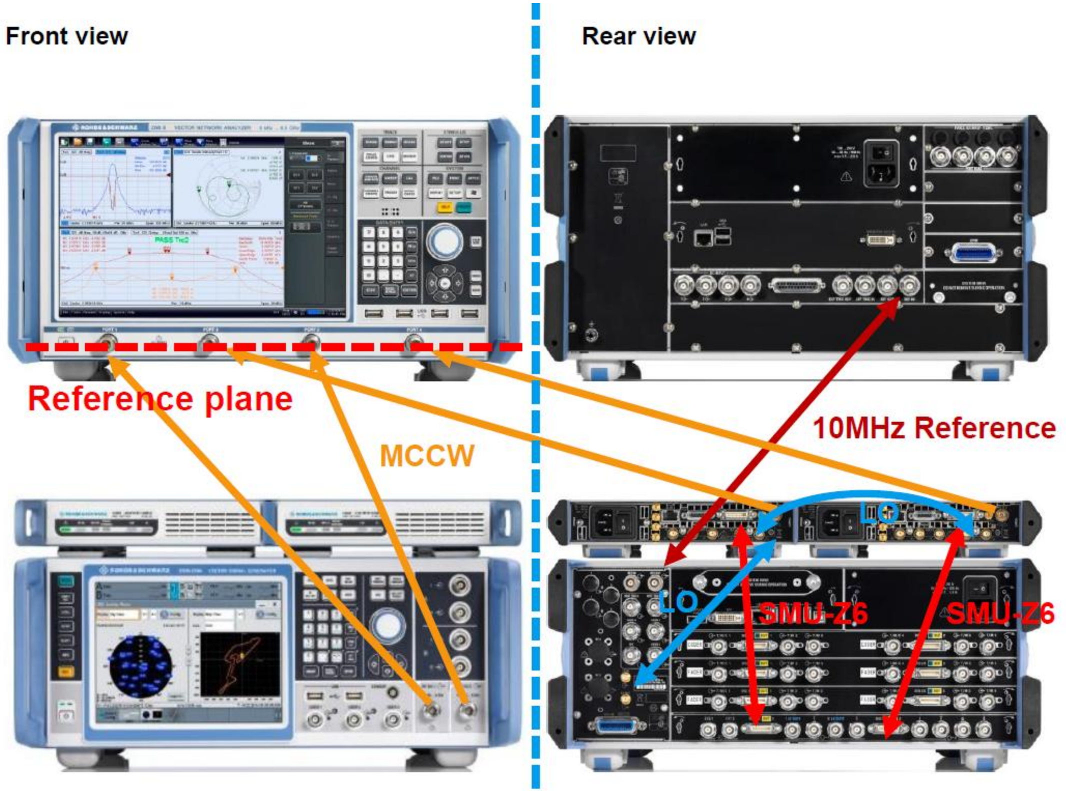
Single jammer nulled out *Multiple (3) jammers nulled out* *Beamforming towards a particular satellite*



REAL WORLD SIGNAL AND ELECTRONIC ATTACK SIGNAL

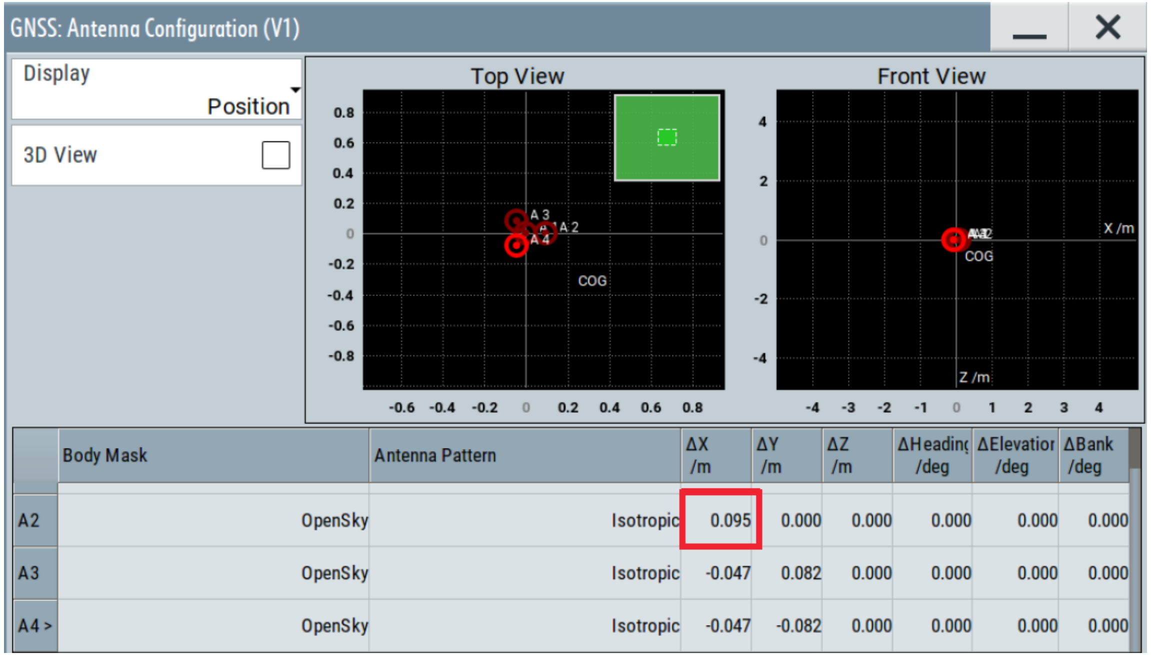
AOA CALIBRATION

► Using Vector Analyzer to align all signal delay.



ANTENNA SETUP ON SIMULATOR

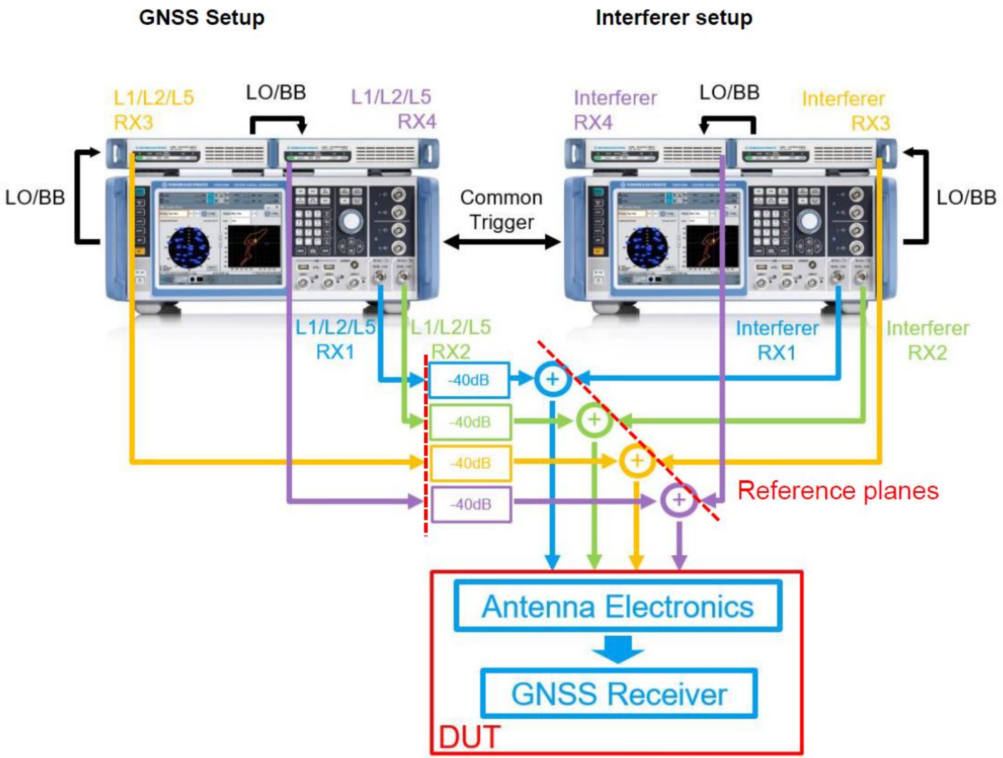
- The antennas are configured with a distance of half a wavelength, which is a typical value for multi-antenna applications.
- For L1 this is equal to 9.5cm.



TEST SETUP

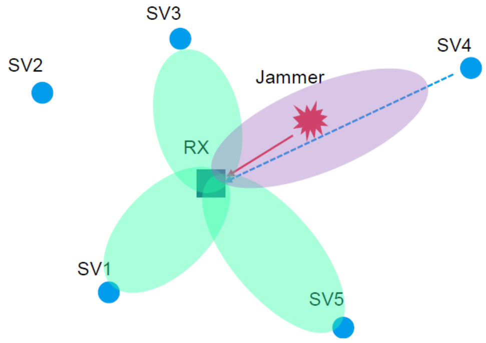
- Using GNSS Simulator to provide the real world's scenario
- Using another Jammer Simulator to provide "Electronic Attack" signal.

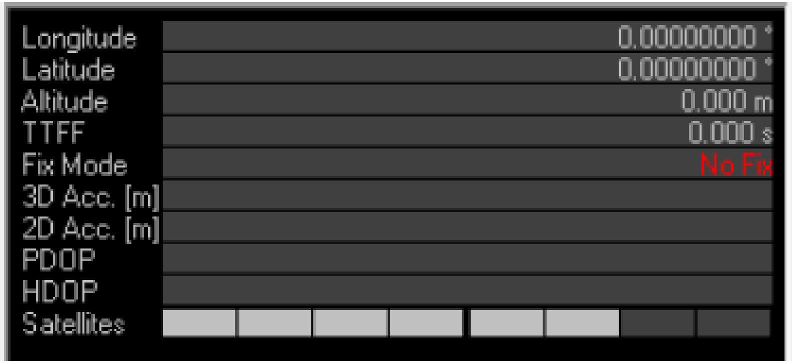
- Combine these into your CRPA receiver.

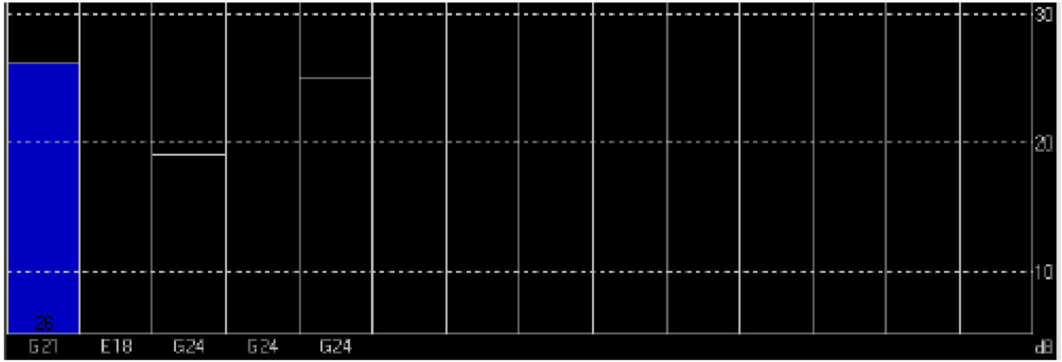


TEST RESULT

► **No any satellite received**

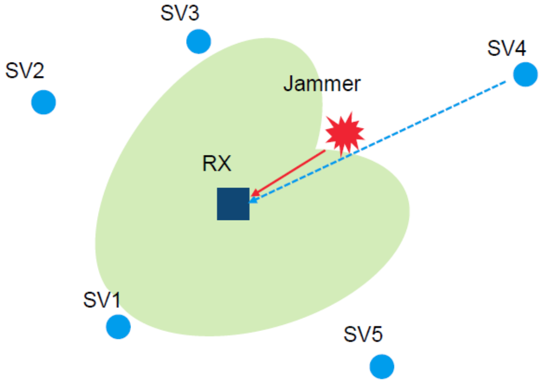






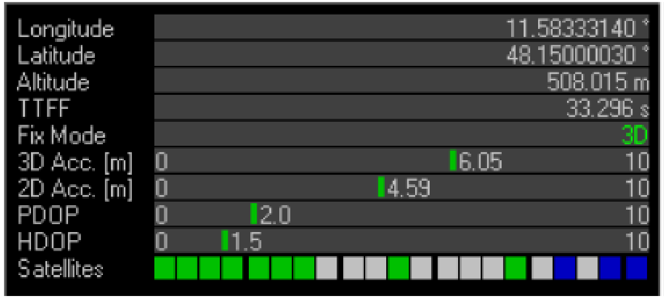
TEST RESULT

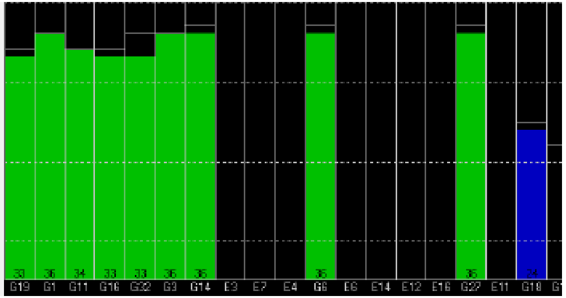
Simple power minimization algorithm



Complex conjugate weights	RX1 / SMW RF A	RX 2 / SMW RF B	RX 3 / SGT 1	RX 4 / SGT 2
Amplitude (dB)	0	-8.11	-7.72	-7.67
Phase	0°	49.1°	-66.98°	-166.2°

*calculation of these complex weights is described in the attachment.






THANK YOU FOR YOUR ATTENTION