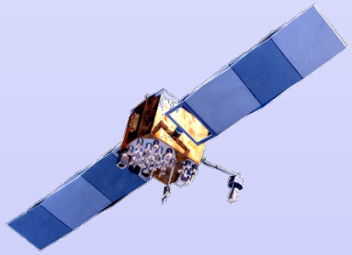

GNSS as Primary Time Source

WSTS 2023 TUTORIAL SESSION

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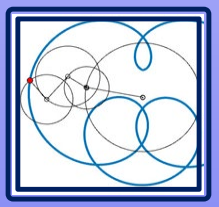
Two Messages About GNSS

1. GNSS are extremely useful
   - Constellations are growing
   - Provide reliable, extremely accurate real-time UTC time and frequency for mostly free
   - Excellent navigation
   - A global > $100B industry

2. GNSS signals are dangerously vulnerable to both accidental and intentional interference



The Family of Global Navigation Satellite Systems

GPS	Galileo	GLONASS	Beidou/Compass
US	EU	Russia	China

Others are Regional Navigation Satellite Systems, (RNSS), typically from satellites in geostationary (GEO) orbits

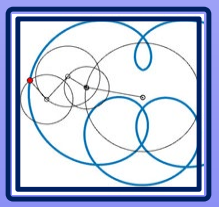
Navigation with Indian Constellation (NavIC)

- IRNSS is the longer acronym, but NavIC is still correct. See

https://en.wikipedia.org/wiki/Indian_Regional_Navigation_Satellite_System

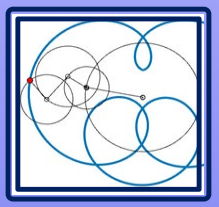
- GAGAN is essentially the Indian version of QZSS, based on GPS. See

https://www.isro.gov.in/spacecraft/satellite-navigation



GNSS: General Properties

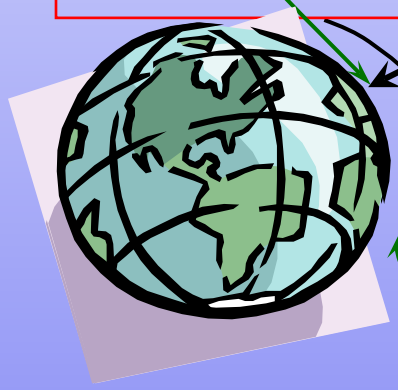
- Position, Navigation, Timing (PNT)
- Four + synchronized timing signals from known locations in space—timestamped at receiver and used to solve for x,y,z, and t or lat,lon, hgt and time
- Two + frequencies measure ionosphere
- Control, Space, User Segments
- Open and Restricted Services
- All signals are weak and clustered in the L-band spectrum
  - Allows interoperability
  - But also makes it is relatively easy to jam GNSS and spoof



Time from GNSS:
Intentional and Unintentional Error Sources

3) Issues at Receiver:

- Coordinates
- Multi-path interference
- Jamming and Spoofing
- Delays in cables
- Delay through receiver
- Receiver software



Troposphere

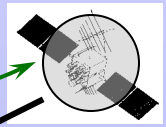
Ionosphere

2) The signal is delayed and inhibited by the iono- and tropo-sphere

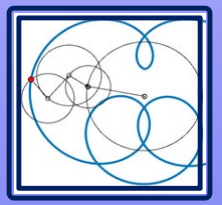
- System Time

Satellite Clock data error

Position data (Ephemeris) error

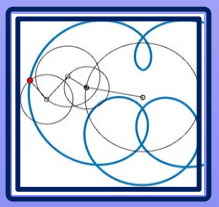


1) GNSS work by transmitting a time signal and satellite position and clock data. These are predictions in uploads.

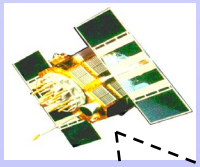


Time From GNSS

- Time signals are the basis of positioning
- Clocks on Satellite Vehicles (SVs) are free-running
  - Data provides the offset in Time and Frequency
  - System time is offset from UTC
- The positions of the satellite and receiver are needed for the delay
- SV Clocks and positions are ***predicted*** and uploaded, for GPS about once per day



GNSS-aided Time and Frequency Systems



GNSS

T/F System

GNSS Rcvr

Compare

Tune

Quartz Crystal Oscillator

Qz Osc.

Output Time & Freq.

Or

GNSS Rcvr

Compare

Tune

Rubidium Vapor Atomic Oscillator

Rb Vapor Phy Pkg

•Qz Osc.

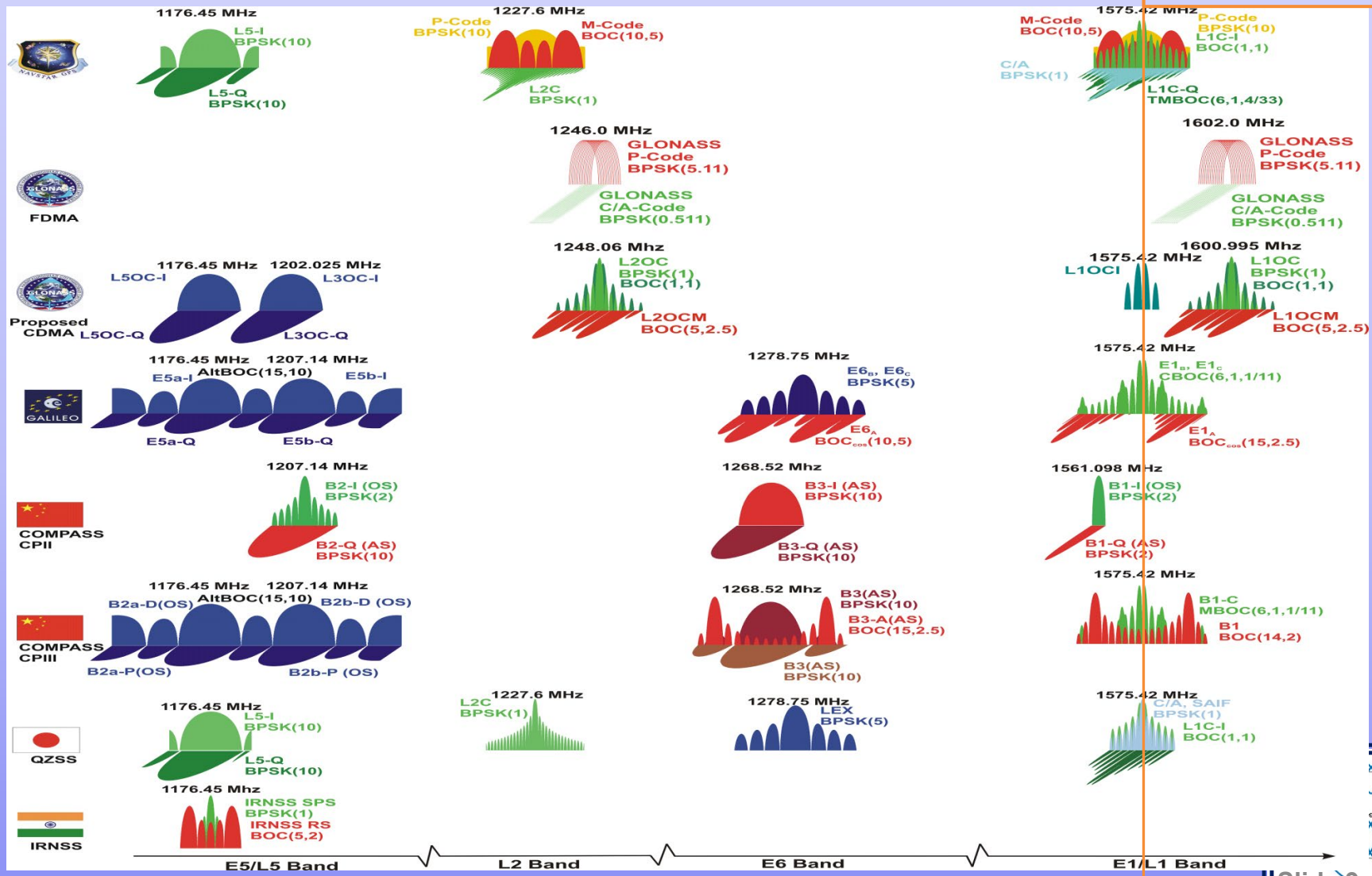
Output Time & Freq.

Rb oscillator 100 to 1000 times better Holdover Performance

Courtesy H. Fruehauf, ViaLogy LLC

T/F System

Spectra of GNSS's



GNSS Vulnerability

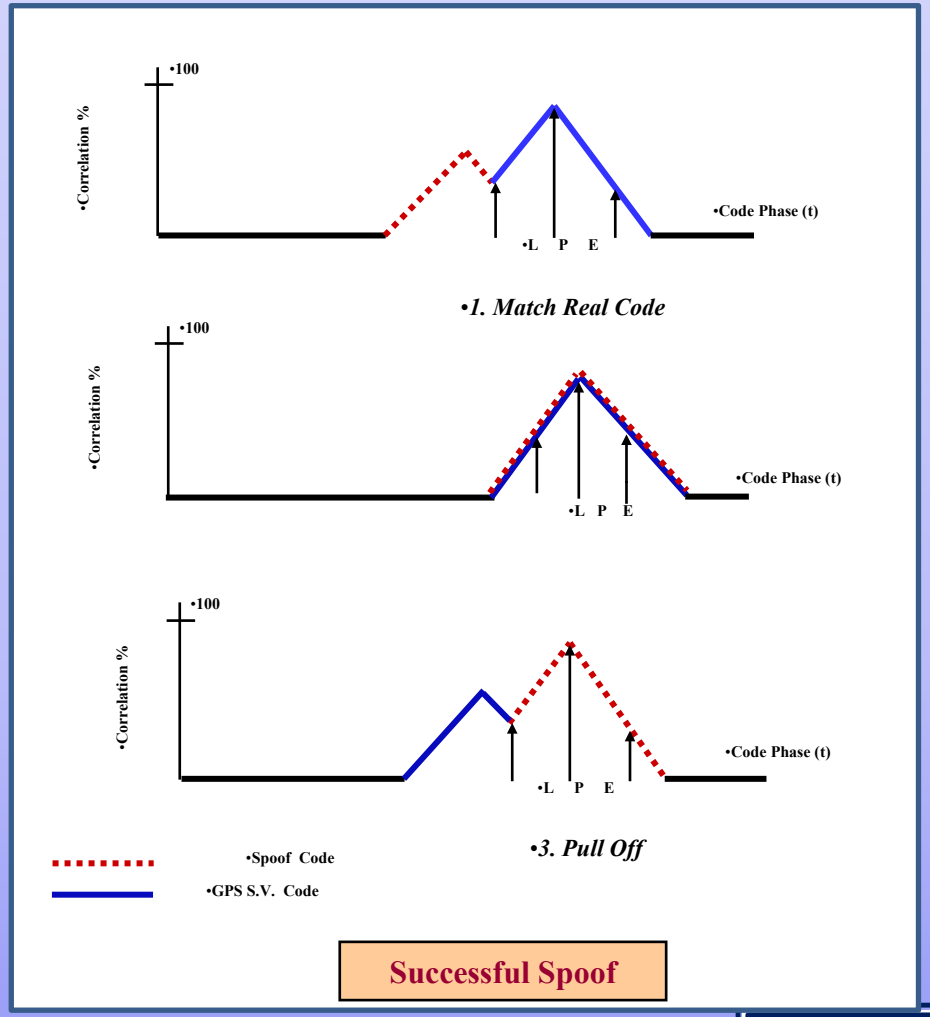
- GNSS best feature and worst problem: it is extremely reliable
  - Leads users to not use backup systems
- Jamming Power Required at GNSS Antenna
  - On order of a Picowatt (10^{-12} watt)
- Many Jammer Models Exist
  - Watt to MWatt Output – Worldwide Militaries
  - Lower Power (<100 watts); Available online, though perhaps illegal

"Personal Privacy" Device

Military Jammer

Spoofing/Meaconing

- Spoof – Counterfeit GNSS Signal
  - C/A Code Short and Well Known
  - Widely Available Signal Generators
  - Many possible techniques
- Meaconing – Delay & Rebroadcast
- Possible Effects
  - Force receiver to give wrong position or time or both
  - No warning from receiver without special anti-spoof design
- No “Off-the-Shelf” Mitigation



Civil GNSS Spoofing Threat Continuum*

Simplistic ***Intermediate*** ***Sophisticated***

Commercial signal simulator

Portable software radio

Coordinated attack by multiple phase-locked spoofers

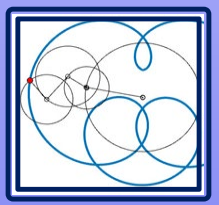
*** Courtesy of Coherent Navigation, Inc**

Spoofing example, GPS World, April 2020:
‘circle spoofing’ in Tehran

This heat map shows GPS spoofing at a government complex in Tehran,which houses the Ministry of Defense, Communication Regulatory Authority, Telecommunications Infrastructure Company, and Ministry of Telecommunications and Technology. (Screenshot: courtesy of Dana Goward)

“Some of GPS devices received fake signal and show the fake valid location. Yesterday I test a device, it can get signal and give real position. After 10 minutes the device show moving around a big circle in Tehran by 35 km/h speed. I can’t fix this problem by restarting the device. “The GPS module time is correct but the location is not. I attach Excel file of data and map of the track. I can’t get any response from Communications Regulatory Authority (CRA) of The I.R. of Iran. Do you know about this?”

https://www.gpsworld.com/gps-circle-spoofing-discovered-in-iran/

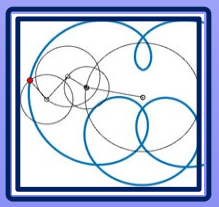


EXTRA SLIDES:
CURRENT STATUS OF GNSS CONSTELLATIONS AS OF WSTS 2023

Conclusions

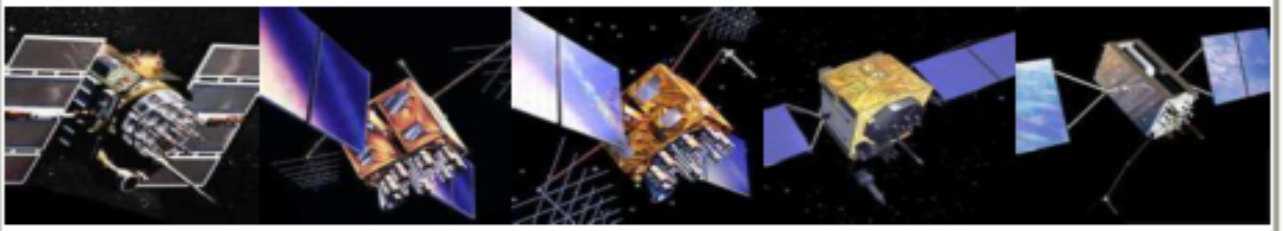
Global Navigation Satellite Systems are very accurate both for time and frequency, many signals free for use, and are extremely reliable

- Perhaps both their greatest advantage and disadvantage!
- Signals are subject to interference



"Advanced"), Block IIR ("Replenishment"), Block IIR-M ("Modernized"), Block IIF ("Follow-on"), GPS III, and GPS IIIF ("Follow-on").

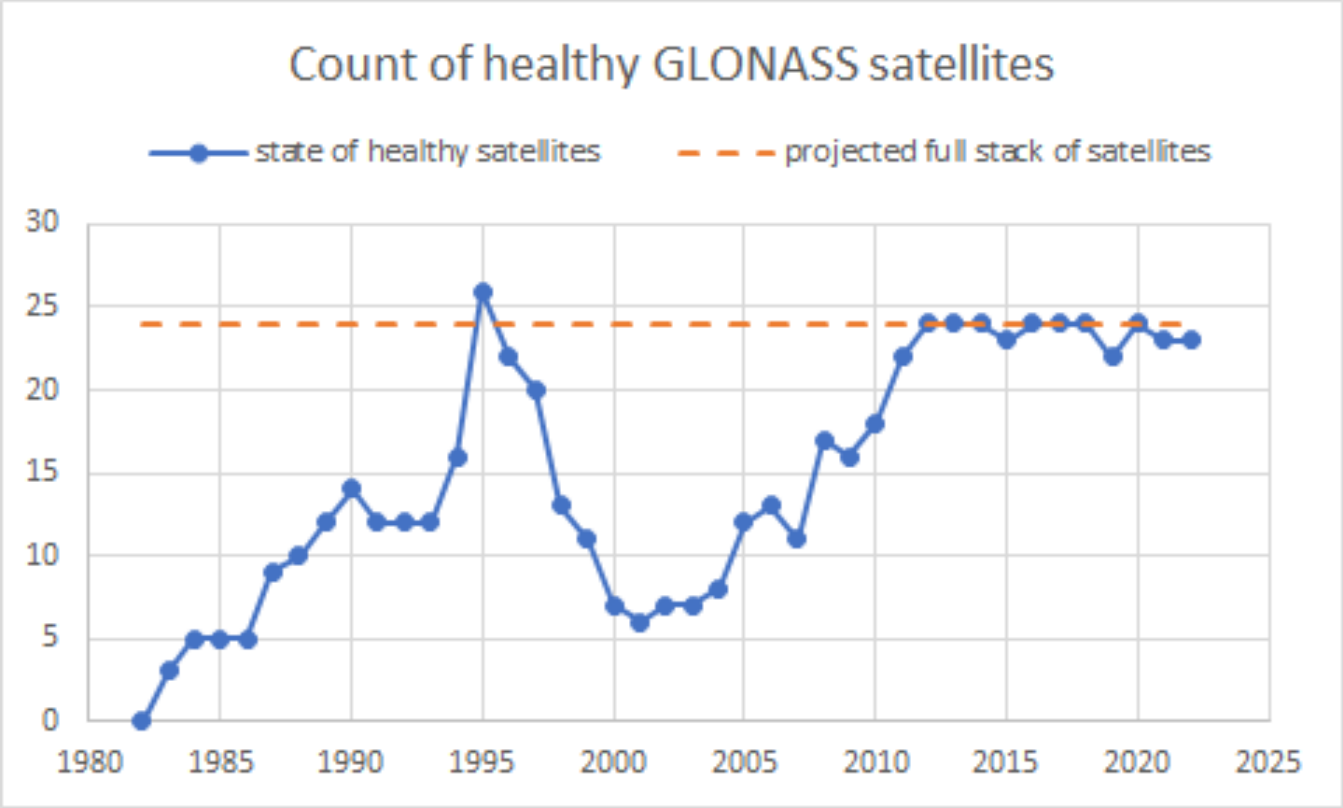
LEGACY SATELLITES | MODERNIZED SATELLITES



BLOCK IIA	BLOCK IIR	BLOCK IIR-M	BLOCK IIF	GPS III/IIIF
0 operational	7 operational	7 operational	12 operational	5 operational
▪ Coarse Acquisition (C/A) code on L1 frequency for civil users ▪ Precise P(Y) code on L1 & L2 frequencies for military users ▪ 7.5-year design lifespan ▪ Launched in 1990-1997 ▪ Last one decommissioned in 2019	▪ C/A code on L1 ▪ P(Y) code on L1 & L2 ▪ On-board clock monitoring ▪ 7.5-year design lifespan ▪ Launched in 1997-2004	▪ All legacy signals ▪ 2nd civil signal on L2 (L2C) *LEARN MORE* ➡ ▪ New military M code signals for enhanced jam resistance ▪ Flexible power levels for military signals ▪ 7.5-year design lifespan ▪ Launched in 2005-2009	▪ All Block IIR-M signals ▪ 3rd civil signal on L5 frequency (L5) *LEARN MORE* ➡ ▪ Advanced atomic clocks ▪ Improved accuracy, signal strength, and quality ▪ 12-year design lifespan ▪ Launched in 2010-2016	▪ All Block IIF signals ▪ 4th civil signal on L1 (L1C) *LEARN MORE* ➡ ▪ Enhanced signal reliability, accuracy, and integrity ▪ No Selective Availability *LEARN MORE* ➡ ▪ 15-year design lifespan ▪ IIIF: laser reflectors; search & rescue payload ▪ First launch in 2018

As of June 26, 2022, there were a total of **31 operational satellites** in the GPS constellation, not including the decommissioned, on-orbit spares.

GLONASS article from Wikipedia:
https://en.wikipedia.org/wiki/List_of_GLONASS_satellites#:~:text=As%20of%20December%202022%2C%20144,and%2023%20are%20currently%20operational
As of December 2022, … 23 are currently operational.



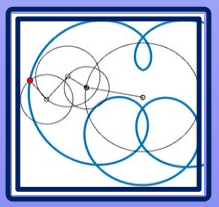
Galileo Status

From GPS World: Galileo High Accuracy Service (HAS) operational as of 20 January 2023 with 20 cm accuracy

https://www.gpsworld.com/galileo-has-now-operational-with-20-cm-accuracy/

Current status available at:

https://www.gsc-europa.eu/system-service-status/constellation-information



China's BeiDou Navigation Satellite System in the New Era

- China Daily | Updated: 2022-11-05 10:52
- Editor's note: The State Council Information Office of the People's Republic of China published a white paper titled "China's BeiDou Navigation Satellite System in the New Era“
- Full text at: https://www.chinadaily.com.cn/a/202211/05/WS6365cfe7a3105ca1f2274368.html