UTC and GNSS
ITSF 2014 Tutorial
Time to Learn

Budapest, Hungary

Marc A. Weiss, Ph.D.
NIST Contractor
Time & Frequency Division

303-497-3261
mweiss@nist.gov

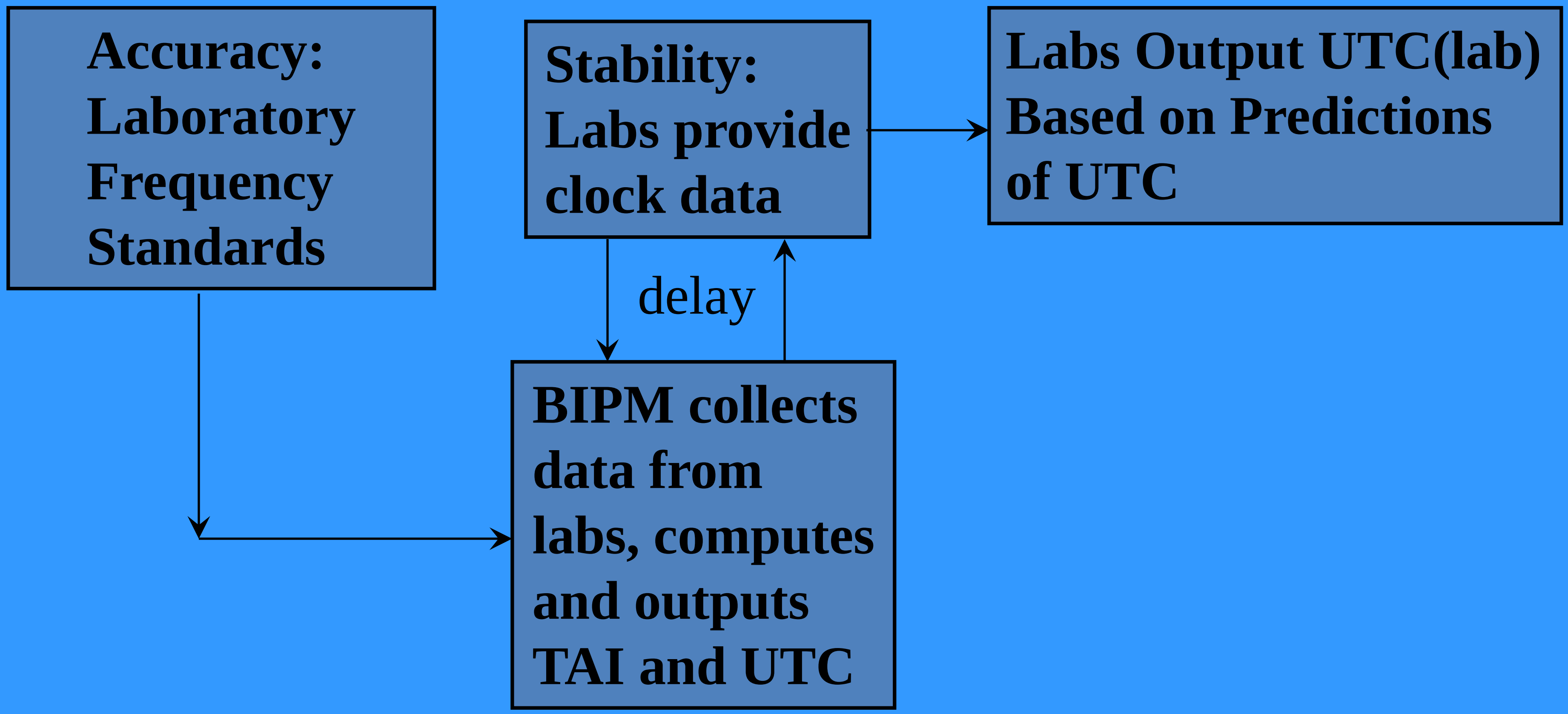
Outline: UTC and GNSS

- The Source Time Standard: UTC
- GNSS delivers UTC
- What can you get from GNSS?
- A little bit of how it works
- Vulnerabilities/options
- Conclusions

Time, Phase, Frequency, and UTC

- **Frequency** comes from a clock, usually one locked to a master
- **Phase** must be transferred between clocks
- **UTC Time** must come from a national lab, generally from GNSS

The Generation of UTC: Time Accuracy
Any Real Time UTC is only a Prediction
A PLL with a one-month delay



UTC and Leap Seconds

- International Atomic Time (TAI) is a continuous time scale
- UTC = TAI - leap seconds
  - Since June 30, 2012, UTC-TAI = -35
- Earth is a noisy clock compared to atomic clocks
  - Leap seconds keep Atomic Time within 0.9 s of UT1, Earth-aligned time
  - Proposal in IGU to stop or alter leap seconds

Arguments to Stop Leap Seconds

- 1. The leap second is implemented by repeating 23:59:59 twice. This effectively stops the clock for one second. A time interval across the leap second is not computed correctly and physical processes (e.g. velocity) do not stop during the leap second.

- 2. The leap second is often implemented incorrectly or not at all because it doesn't happen often enough and the bugs are not found. Problems fixed in one version of a program often re-appear in the next version and are not detected until the next leap second.

- 3. The leap second occurs in the middle of the working day in California (4 pm) and in the morning of the next day in Asia and Australia. This compounds the problems.

Arguments to Keep Leap Seconds:

- 1. It is important for civil time keeping to keep a close connection between the time scale and the position of the sun.
- 2. Many astronomers and others who calculate orbits use the UTC time as a proxy for the angle of the Earth. This assumption is buried in lots of software and finding and fixing all of the places is a big job.
- 3. WWVB and other time services that transmit dUT1 cannot handle a value greater than 0.9 s. This value would become larger than this if leap seconds were not used.

Outline:
UTC and GNSS

- The Source Time Standard: UTC
- GNSS delivers UTC
- What can you get from GNSS?
- A little bit of how it works
- Vulnerabilities/options
- Conclusions

UTC and 3 Segments of GNSS

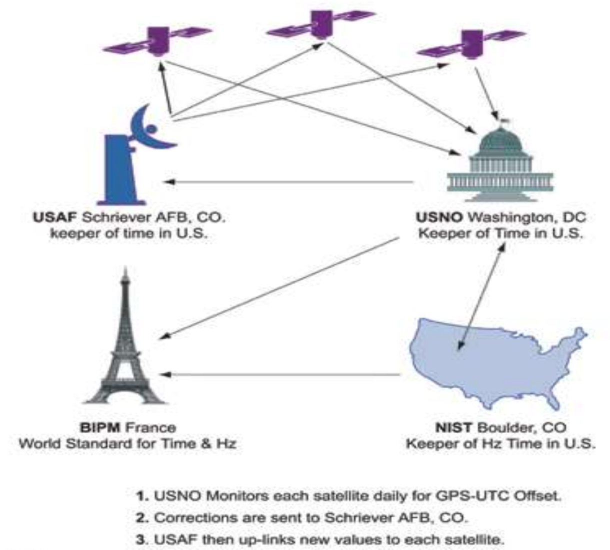
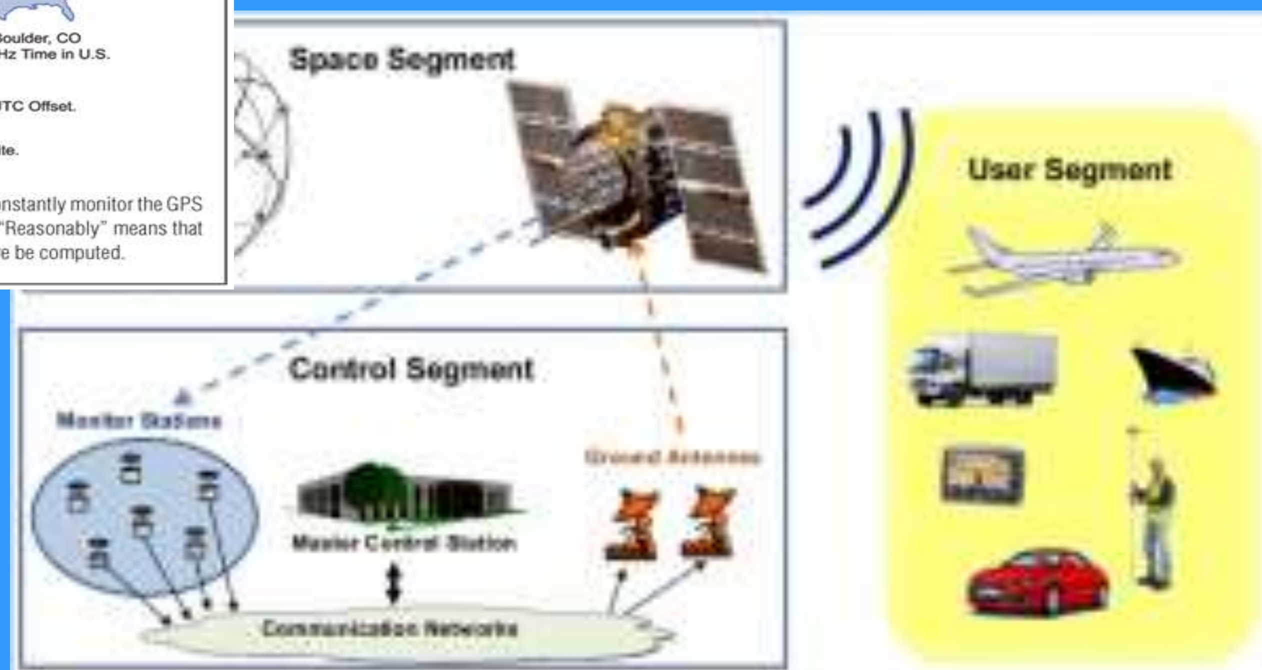


Figure 3

The US Naval Observatory (USNO) and the US Air Force (USAF) constantly monitor the GPS constellation to keep it reasonably in synch with the BIPM's TAI. "Reasonably" means that there is a known error between the time sources. UTC can therefore be computed.



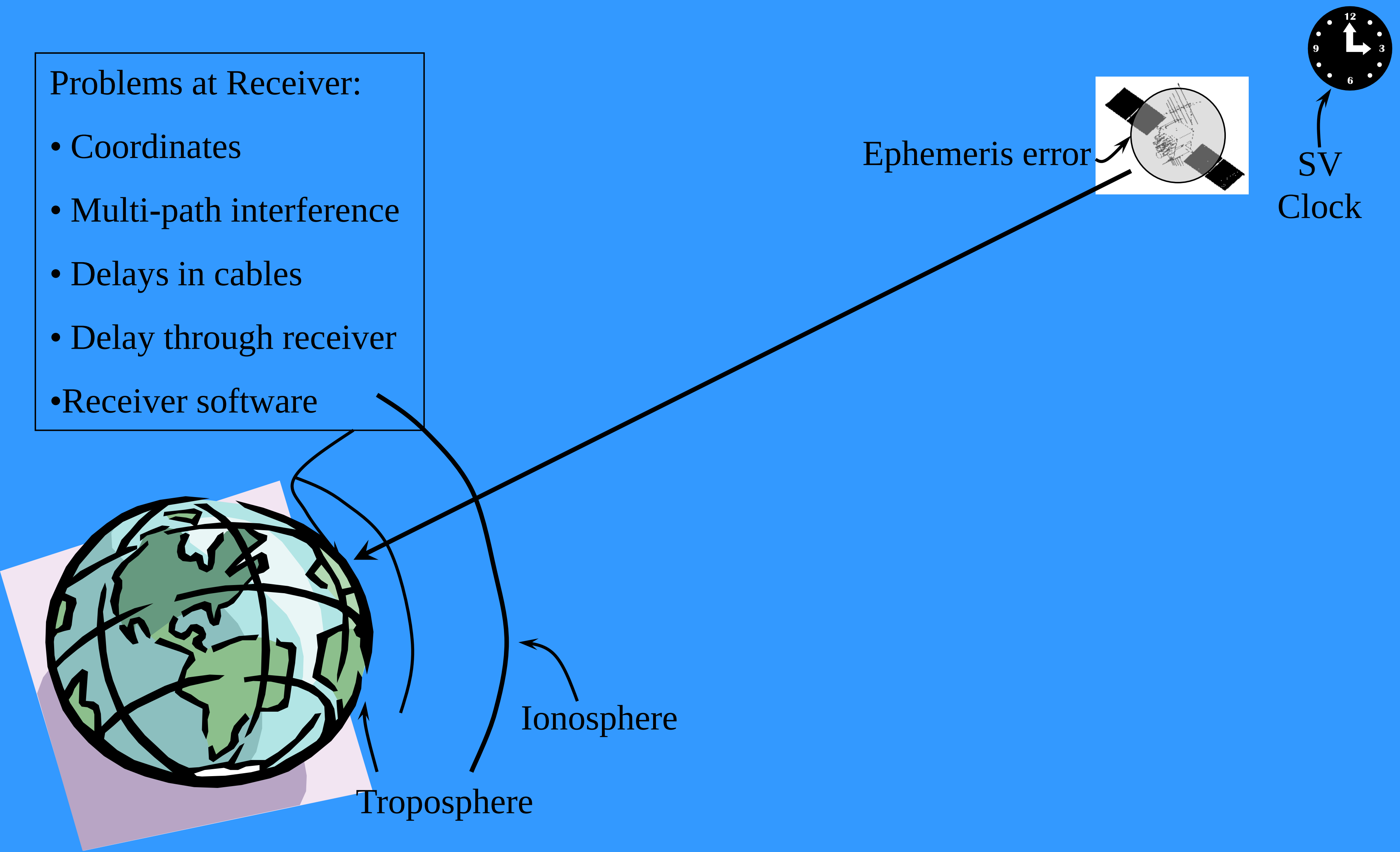
Outline:
UTC and GNSS

- The Source Time Standard: UTC
- GNSS delivers UTC
- What can you get from GNSS?
- A little bit of how it works
- Vulnerabilities/options
- Conclusions

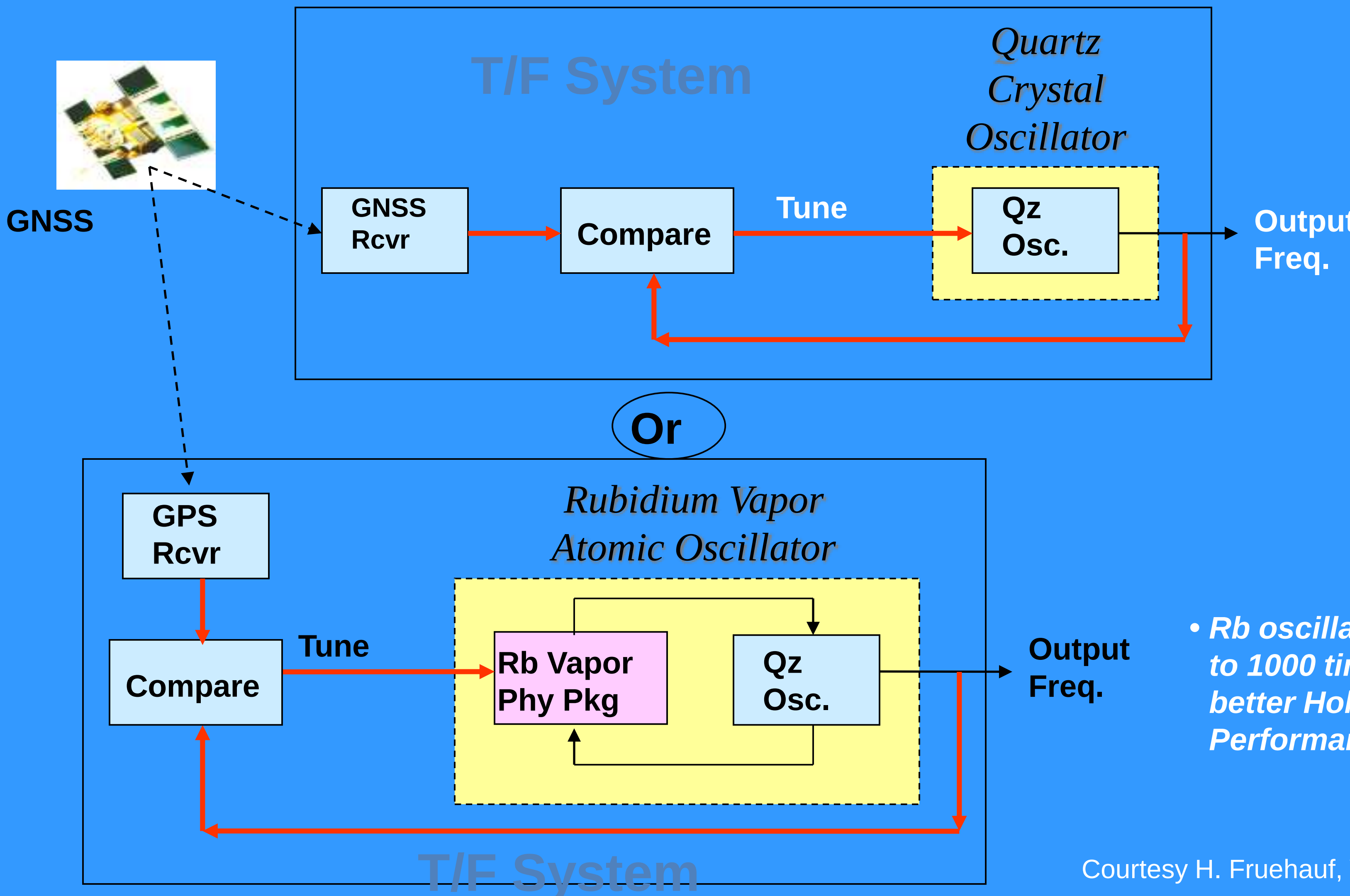
Time from GPS: Noise/Error Sources

Problems at Receiver:

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



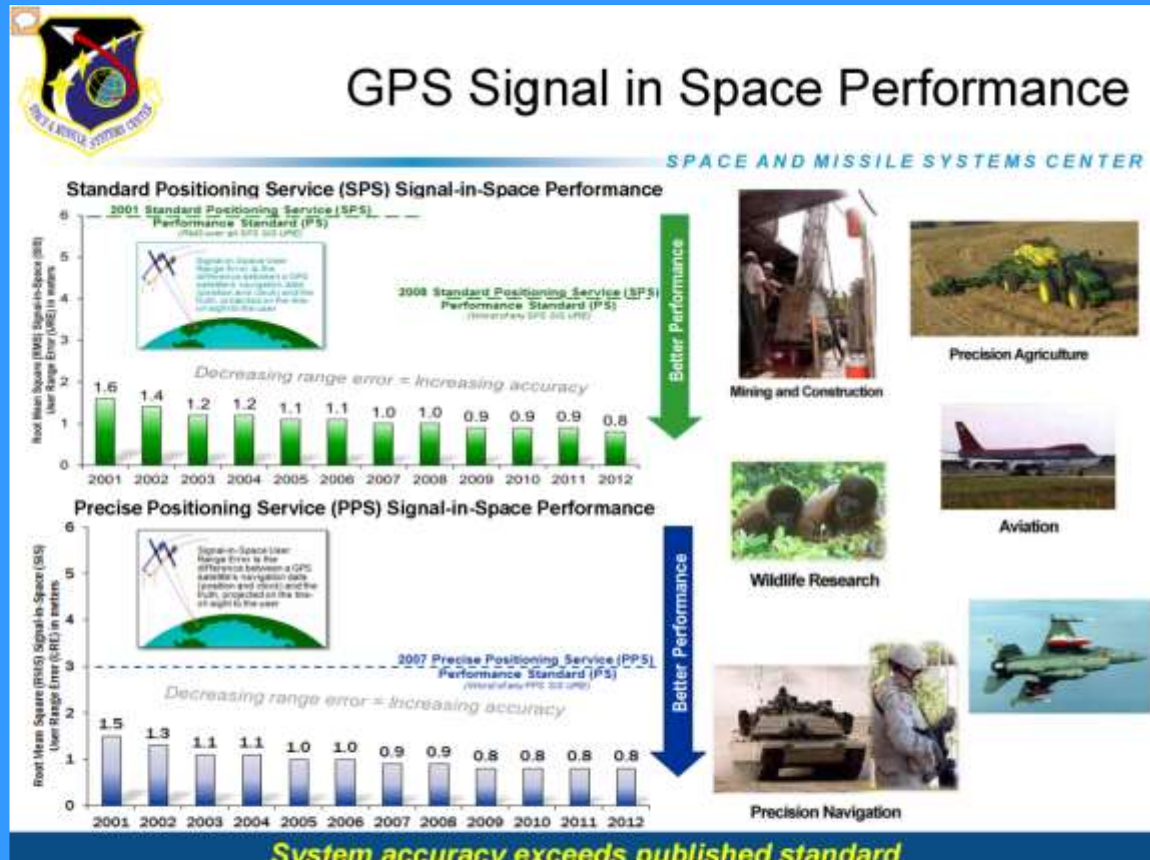
GNSS-aided Time and Frequency Systems



- ***Rb oscillator 100 to 1000 times better Holdover Performance***

Courtesy H. Fruehauf, ViaLogy LLC

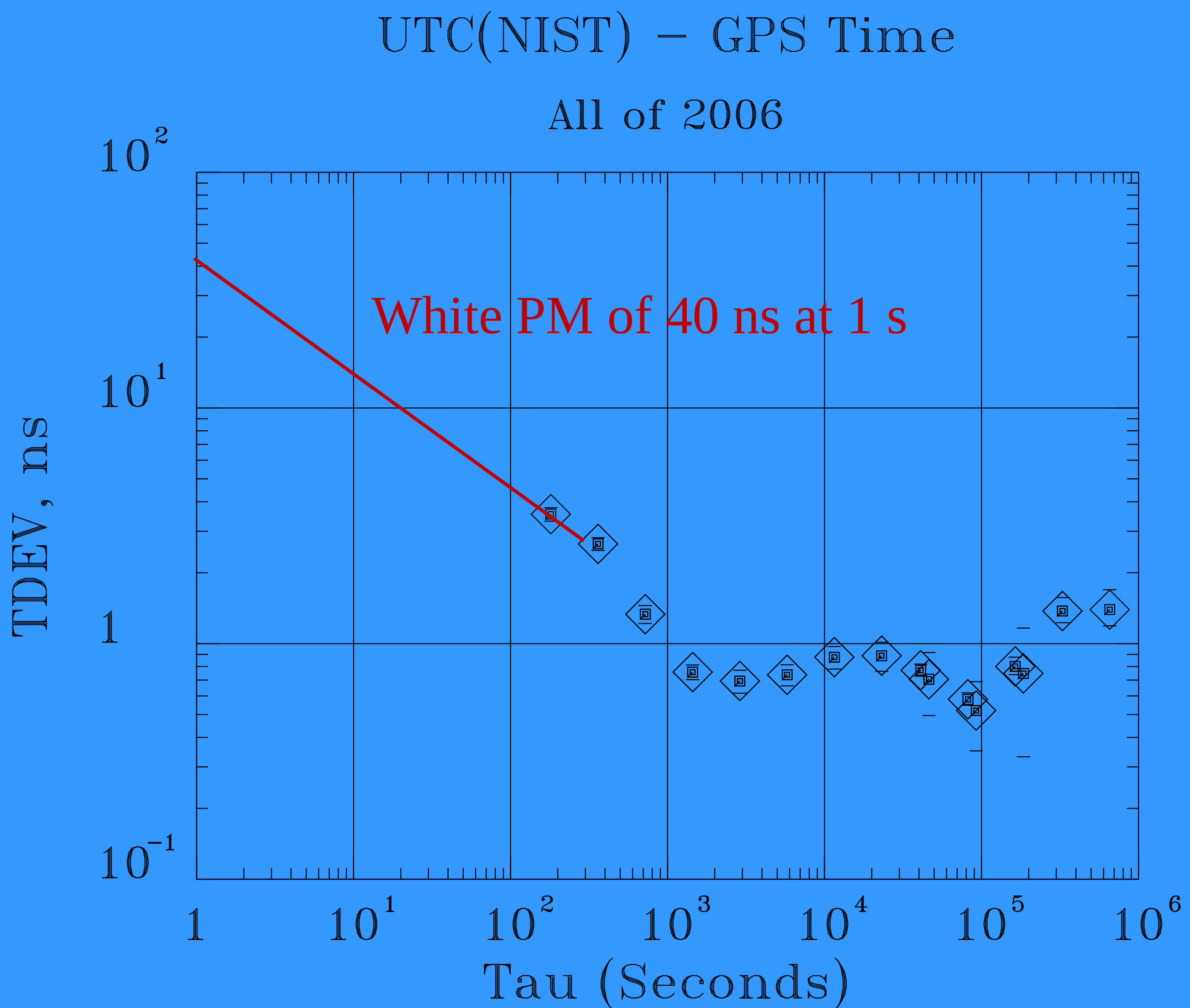
GPS Signal in Space Performance



0.8 m in range = 2.7 ns!

Presented by Col. Bill Cooley, Director GPS, 09 Sep 2014, CGSIC

GPS Stability



Time from GNSS
"Best" Receiver Error Budget

- UTC as the reference source – if multiple constellations are allowed
  - Different labs produce different real-time UTC_i .... 30 ns
  - UTC from GPS minus UTC(USNO) .... 10 ns

- System calibration by manufacturer
  - Total change .... 5 ns/4 years

- User calibration issues
  - All of these are < 1 ns if done well
    - Antenna coordinates
    - User time reference delay
    - Possible change of antenna cable
    - Disciplining oscillator
  - Multipath .... 5 ns

Time from GNSS
Conservative Error Budget

- If sync to GPS only, 20-50 ns consistency is possible
  - Requires good local oscillator such as Rb.
- Sync to different UTC and GNSS, 100 ns possible
- Lots of possible large errors that can lead to micro- or even milli-seconds of error (even centuries!)

Outline:
Time and Frequency from GNSS

- What does it mean?
- What can you get?
- A little bit of how it works
- Vulnerabilities/options
- Conclusions

The Family of Global Navigation Systems: Design, Active Number of Satellites

as of August 2014

GPS
US
(24+, Now 31)

Galileo
EU
(27, Now 3 IOV)

GLONASS
Russia
(24, Now 24)

Beidou/Compass
China
(35, Now 14=
5GEO+5IGSO+4MEO)

GNSS Systems: General Properties

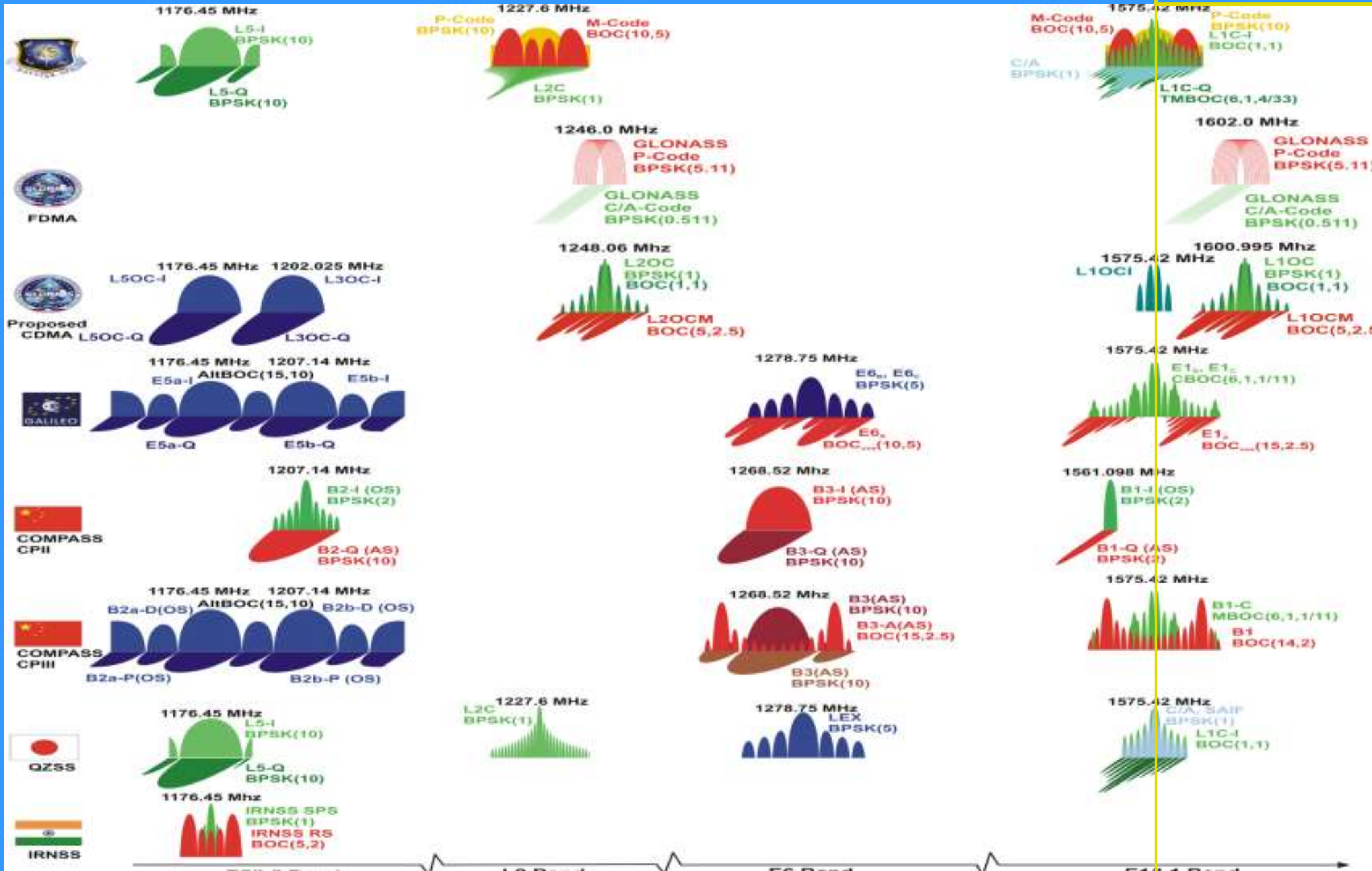
- Position, Navigation, Timing (PNT)
- Four + synchronized timing signals from known locations in space required for navigation
- Two + frequencies measure ionosphere
- Control, Space, User Segments
- Open and Restricted Services

GNSS Systems: General Properties

- All signals are weak
  - E.g. GPS is ~-160dBm
  - All are deliberately well below the noise until the process gain
- Signals are clustered in the spectrum
- Hence it is relatively easy to jam GNSS and becoming easy to spoof

Spectra of GNSS's

Primary
Commercial
Signal



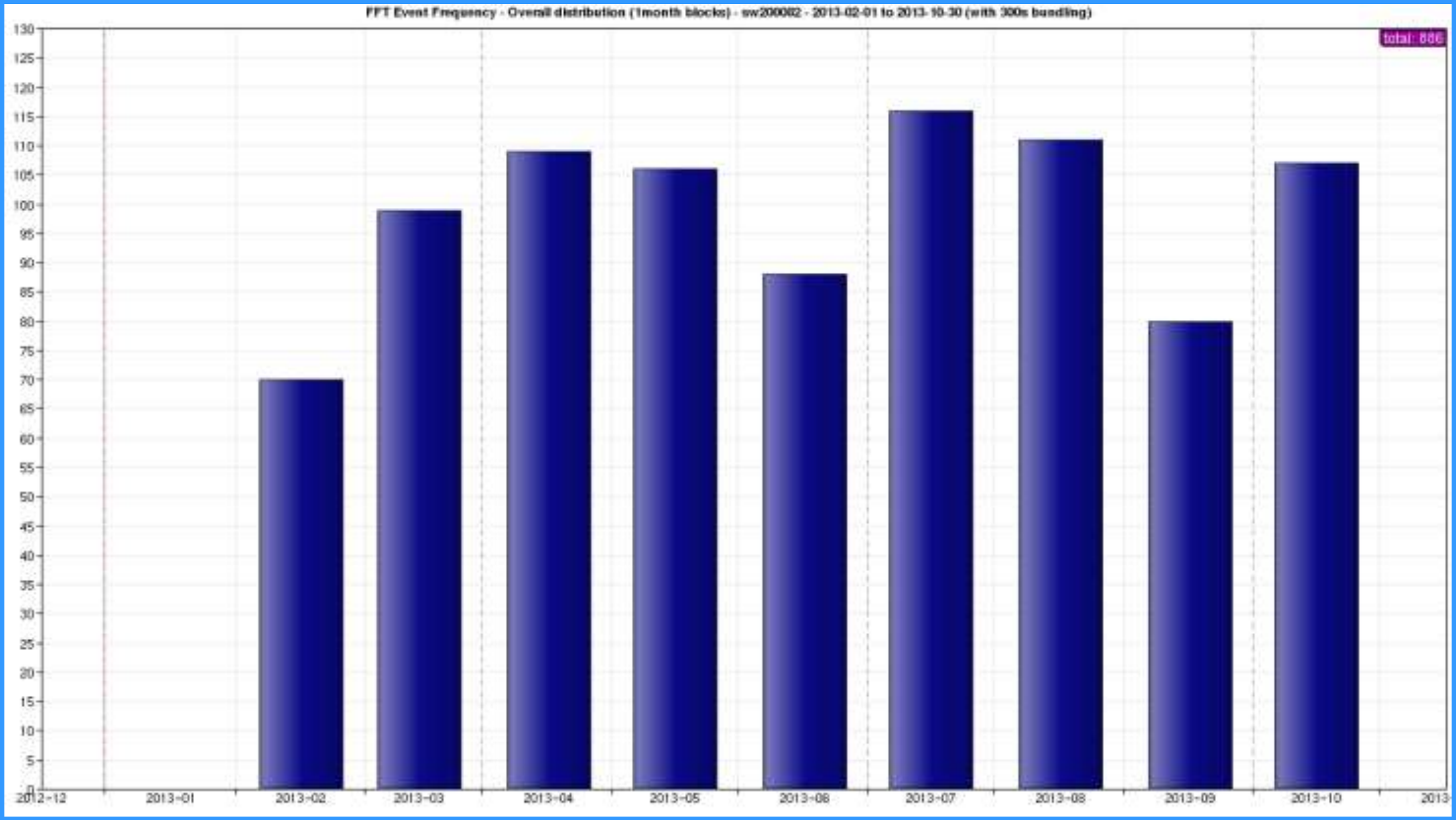
Outline:
Time and Frequency from GNSS

- What does it mean?
- What can you get?
- A little bit of how it works
- Vulnerabilities/options
- Conclusions

GNSS Vulnerability

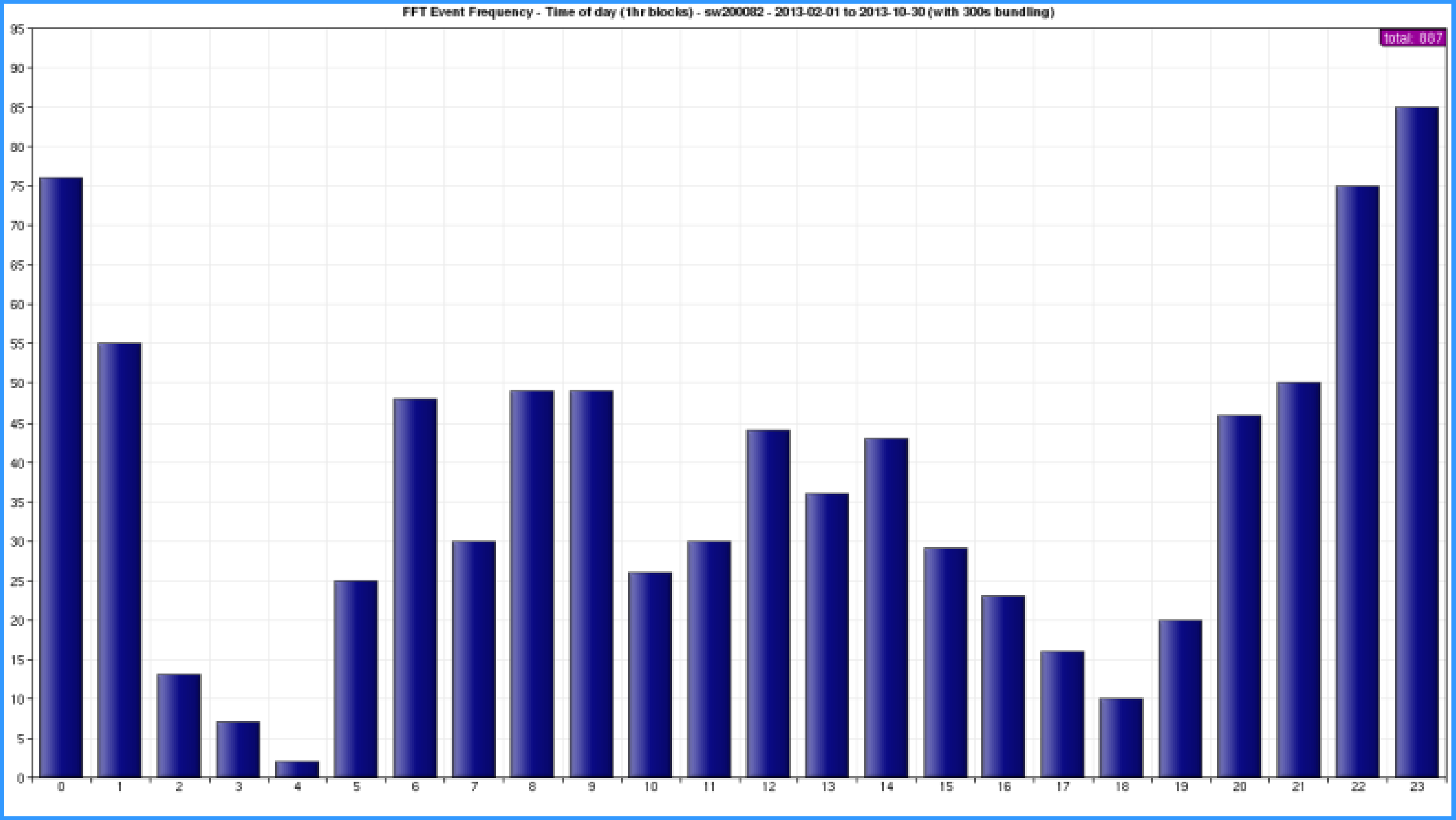
- GNSS best feature and worst problem: it is extremely reliable
- Jamming Power Required at GPS Antenna
  – On order of a Picowatt (10^{-12} watt)
- Many Jammer Models Exist
  – Watt to MWatt Output – Worldwide Militaries
  – Lower Power (<100 watts); "Hams" Can Make

Jamming Events Each Month, Feb – Oct 2013: London Financial District



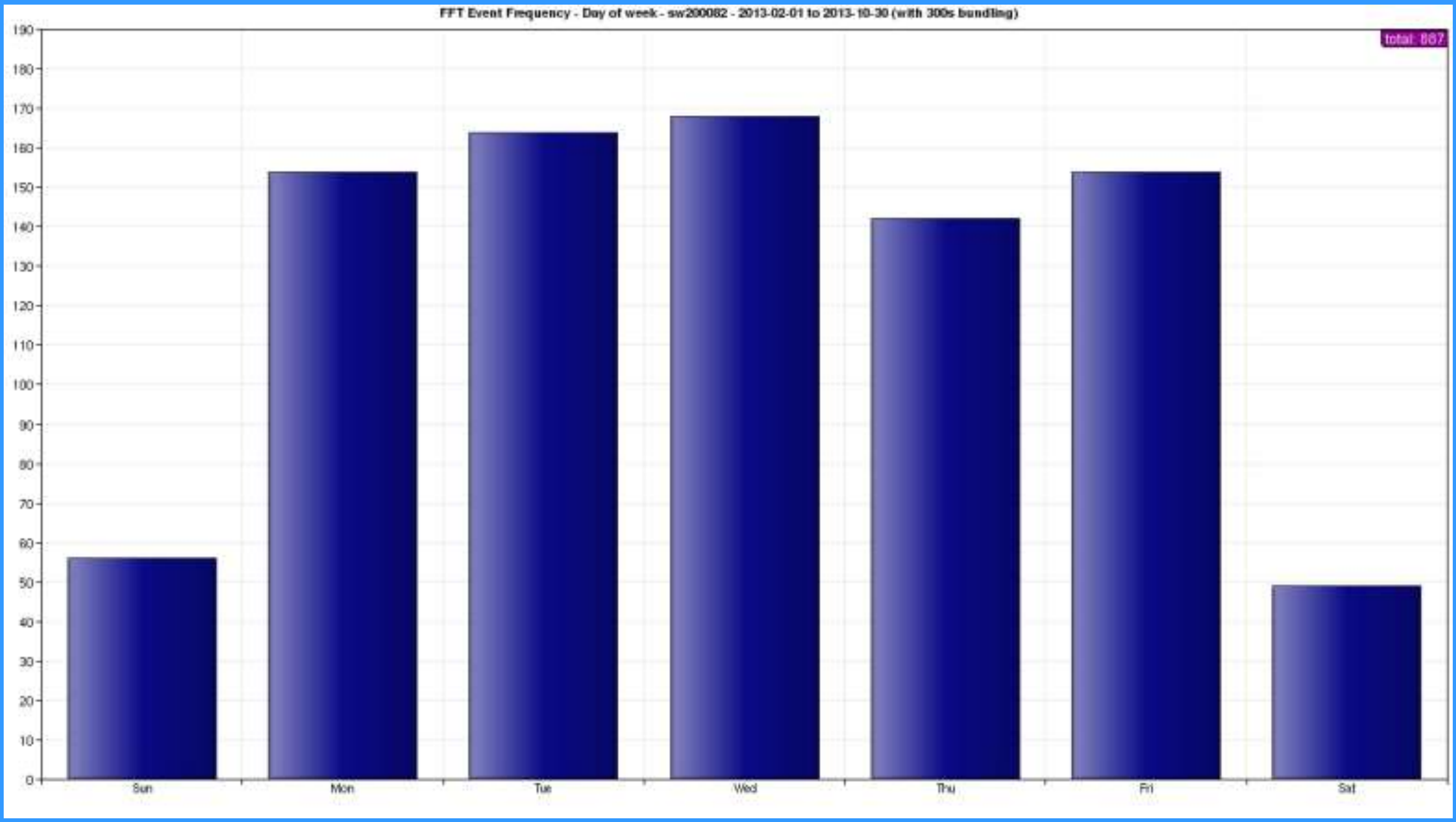
Data and image courtesy of Charles Curry, Chronos Technology Ltd and the SENTINEL Research Project

Jamming Events Each Hour, Feb – Oct 2013: London Financial District



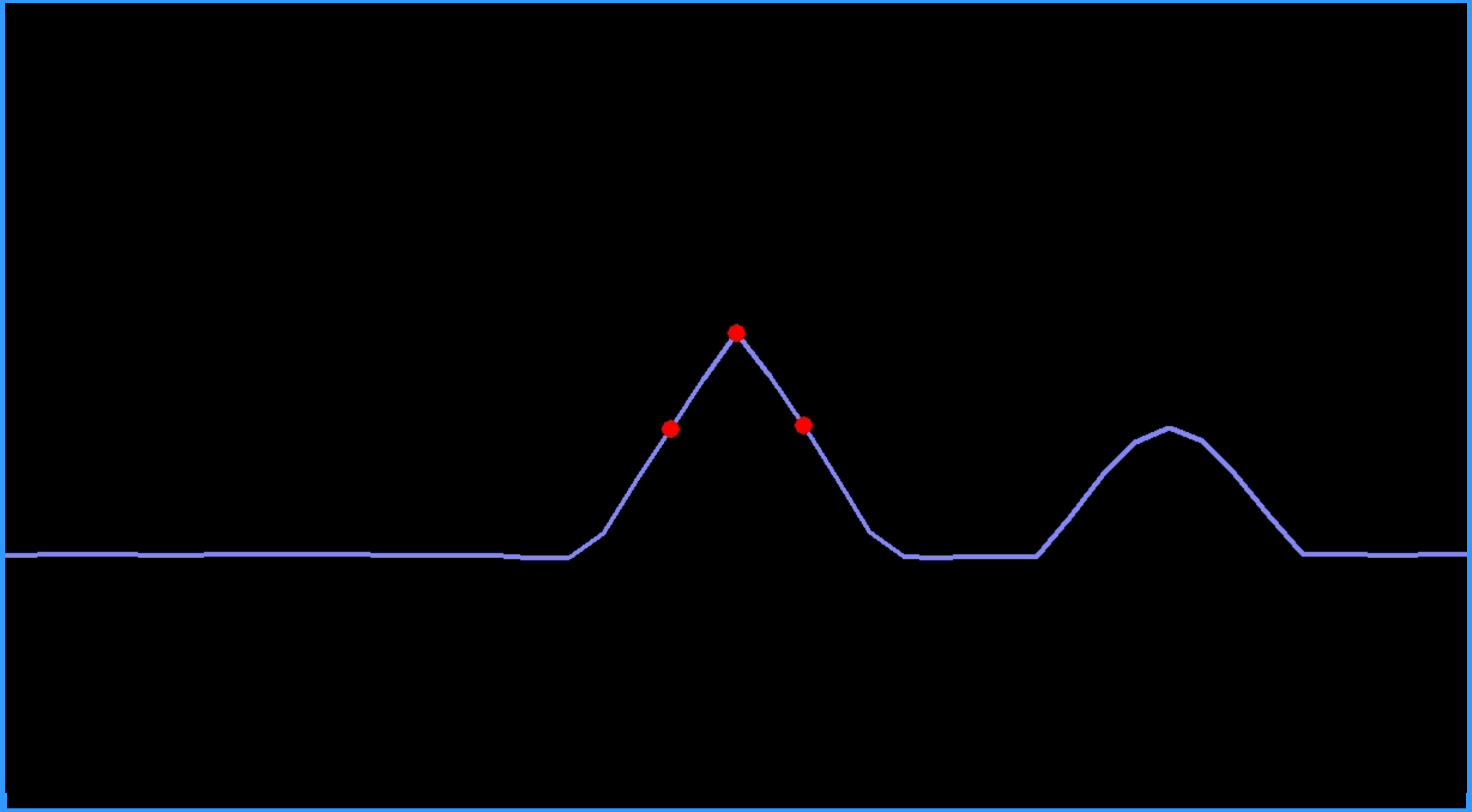
Data and image courtesy of Charles Curry, Chronos Technology Ltd and the SENTINEL Research Project

Jamming Events Day of Week, Feb – Oct 2013: London Financial District



Data and image courtesy of Charles Curry, Chronos Technology Ltd and the SENTINEL Research Project

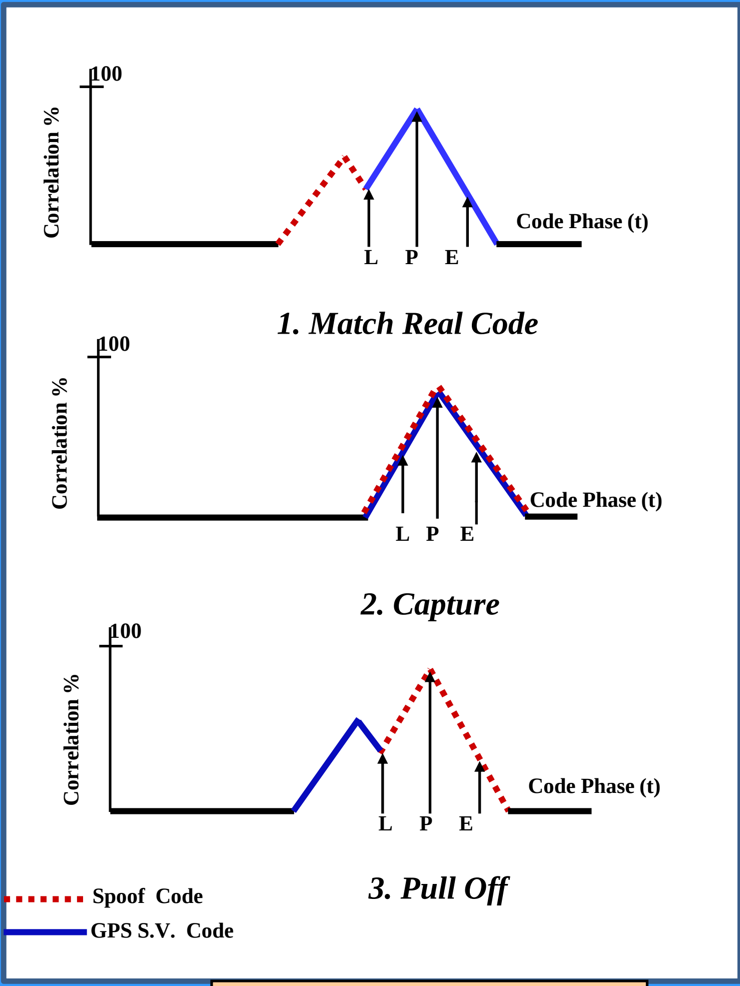
GNSS Spoofer



Slide courtesy of Kyle D. Wesson, The University of Texas at Austin

Disruption Mechanisms - Spoofing/Meaconing

- Spoof – Counterfeit GNSS Signal
  - C/A Code Short and Well Known
  - Widely Available Signal Generators
- Meaconing – Delay & Rebroadcast
- Possible Effects
  - Long Range Jamming
  - Injection of Misleading PVT Information
- No "Off-the-Shelf" Mitigation



Successful Spoof

Civil GPS Spoofing Threat Continuum*

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

Commercial signal simulator | Portable software radio | Coordinated attack by multiple phase-locked spoofers

* Courtesy of Coherent Navigation, Inc

Conclusions

- GNSS provide all three types of sync: Time and Frequency and Phase

- GNSS accuracy meets PRTC and PRC specs

- GNSS are growing internationally

- GNSS are Vulnerable,

  best feature and worst problem:

  extremely reliable

Resources

http://www.gps.gov/cgsic/meetings/2014/

http://www.navcen.uscg.gov/

http://tf.nist.gov/time/gps.htm

http://www.usno.navy.mil/USNO/time/gps

http://gpsworld.com/the-almanac/

http://www.insidegnss.com/current

And that's all

- Thank you for your interest