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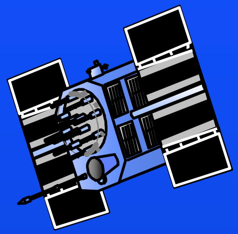

Clocks (Time) and Navigation: from Harrison to GPS

Presented by

Bill Klepczynski
Global Timing Services (GTS)

Time

- It's present everywhere, but occupies no space
- We can measure it, but we can't see it, touch it, get rid of it or put it in a container
- Every one knows what it is and uses it, but no one has been able to define it
- We can spend it, save it, waste it, or kill it. But we can't destroy it or even change it and there is never any more of it or less of it.

Clocks

- Devices by which we measure time
- Frequency (cyclical) is the rate at which a clock runs
- Time (hours, minutes and seconds) is the name which we give to a certain number of cycles

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Units of Time

- Historically units of time have been defined by some kind astronomical phenomenum
- Rotation of the Earth
- 1 day = 24 hours
- 1 day = 360º
- 1 hour = 15º   1 minute = 15' = 15 nautical miles
- 1' = 1 nm
- 1 second = 0.25 nm   5 seconds = 1.25 nm

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Time and Longitude

- Imagine yourself at the bottom of a well. When you see the Sun go by, you know it is local NOON by definition.
- If you have a perfect watch which tells you what the local time is at some location (say London), the time difference between NOON and your perfect watch gives you the longitude difference between the two places.
- Harrison built the perfect watch (well not exactly by today's standards).
- But it did meet the requirements set down by the British Government for winning a 20,000 Pound

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Lunar Distances
An Alternative to a Clock

- **There was another method proposed to finding longitude by astronomers. (30 nm ?)**
- **The method is very complex and the computations necessary to determine longitude were very difficult to do on a ship quickly.**
- **In *1766*, the Nautical Almanac was published by the Royal Greenwich Observatory to aid the navigator in determining his position by Lunar Distances.**
- **This method proved to be "a day late and a dollar short". Harrison had built his fourth generation clock in *1759*.**

The Prize

- The criteria to win the prize was to be able to determine your longitude to within 30 miles after a 6 week journey.

- That would correspond to a clock error of 2 minutes of time.

- Harrison #4 set sail in the HMS Deptford on *18 NOV 1761* and arrived at Jamaica on *21 JAN 1762 (8 weeks later)*. The difference in longitude for Jamaica based on Harrison #4 and a surveyed position was 1¼' of longitude or 5 seconds of time.``

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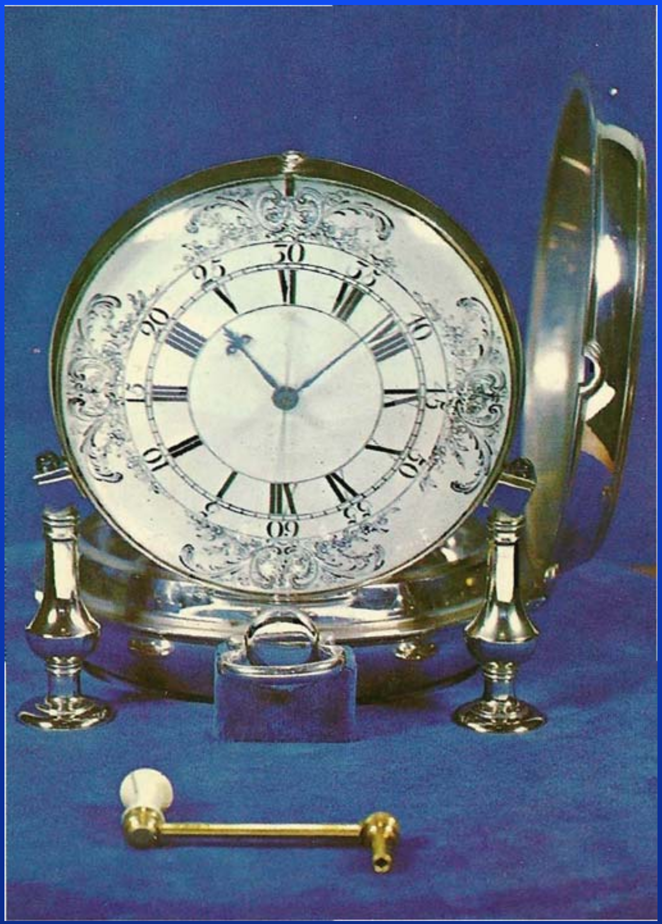
Harrison No. 4



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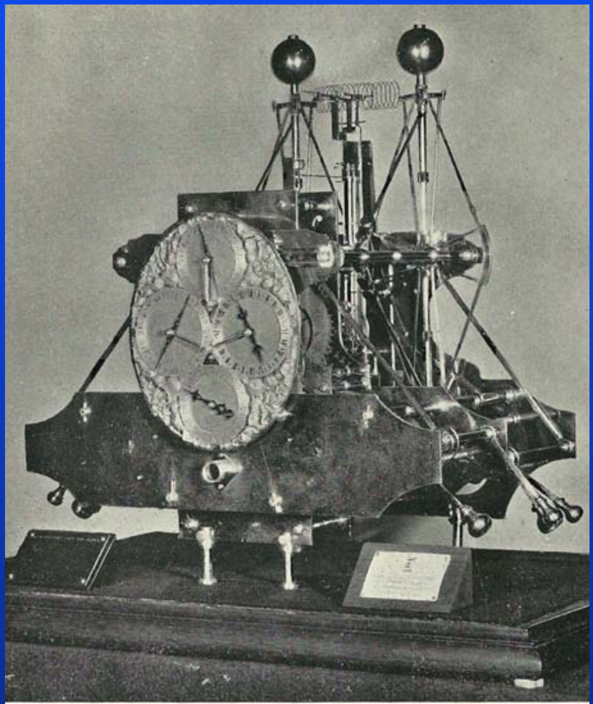
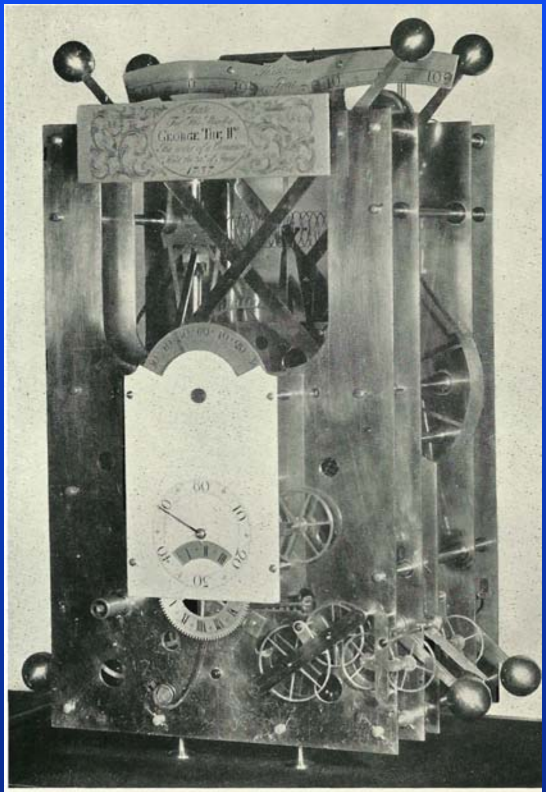
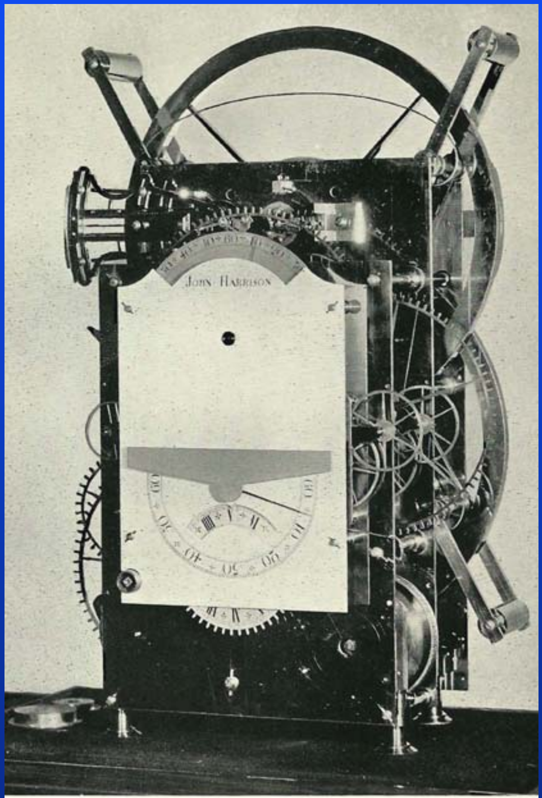
Harrison No. 1,2, and 3



HARRISON'S No. 1 TIMEKEEPER
Navigation Room, National Maritime Museum



HARRISON'S No. 2 TIMEKEEPER
Navigation Room, National Maritime Museum



HARRISONS' No. 3 TIMEKEEPER
Navigation Room, National Maritime Museum

Evolution of Clock Making

- 1656 – Pendulum Clocks
- 1675 – Spiral Spring Controlled Watch
- 1840 – Electric Clocks using direct current
- 1918 – Electric Clocks using alternating current
- 1921 – Shortt Synchronous Pendulum Clock
- 1921 – Quartz Clock
- 1955 – Atomic Clocks

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GPS Atomic Clocks

- Atomic Clocks are based on properties of atoms – NOT radioactive
- GPS uses 2 kinds of Atomic Clocks
  - Rubidium Gas Cells (very good short term stability, smaller and do not weigh much)
  - Cesium Beam Frequency Standards (best long term stability, but weigh more and are bigger)
- The satellite control center is now updating orbits and clocks about twice a day. GPS will probably use only Rubidium clocks in the future

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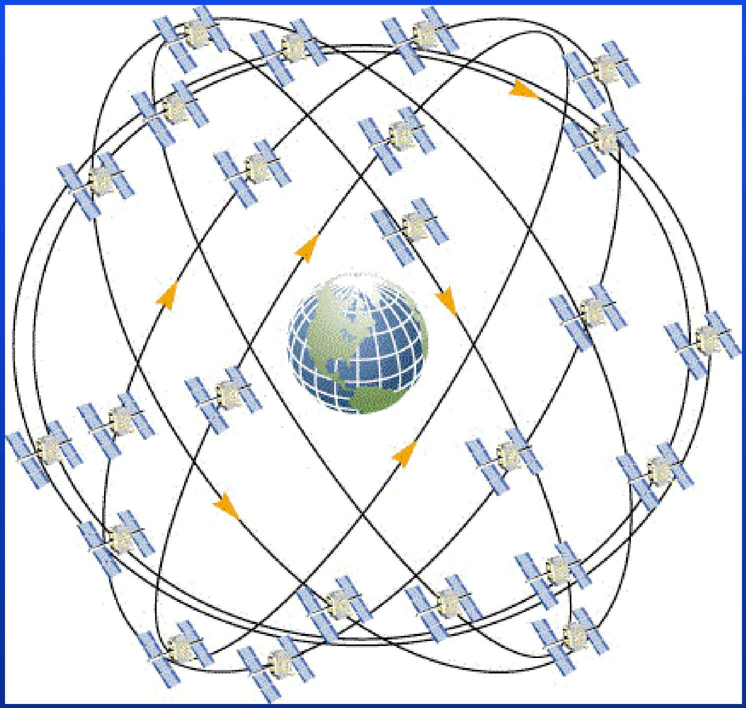
GPS Constellation

- Six planes
- Twenty four primary slots
- Seven additional satellites (currently)
- 55 º inclination
- 20,182 km altitude
- 12 hour orbits



How GPS works

- Satellites in orbit transmit signals which contain navigation information
- User on Earth receives the signals and the computer within the receiver computes his/her position
- Very simplistic answer

What makes GPS work?

- Computers
- Modern Electronics
- Atomic Clocks
- Lot of Dedicated People

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Characteristics of GPS Transmissions

- Satellites all transmit on the same frequency
- Each satellite transmits a unique code
  - User receiver generates similar codes
- Satellites transmit their positions in space
- Clocks in the satellites are synchronized

Other Global Navigation Satellite Systems (GNSS)

- **GLONASS**
  - **Developed by USSR (already in use) [Cesium Clocks]**
  - **Competitive to GPS but signal transmission different**
  - **23 Operational GLO-M (24 needed for worldwide coverage)**
  - **L1, L2 and L3 capabiluty in some, definitely in GLO-K**

- **Galileo**
  - **Being developed by the EU [2 Rubidium + 2 Cesiums]**
  - **4 satellites currently flying (IOV Phase) – 30 FOC**
  - **Early analysis indicates that they are at the same level as GPS**

- **Beidou (Compass)**
  - **Being developed by China [Rubidium ???]**
  - **Could possibly cause interference to Galileo**
  - **35 satellites planned (4 GEO, 27 MEO [7] and 3 IGEO)**

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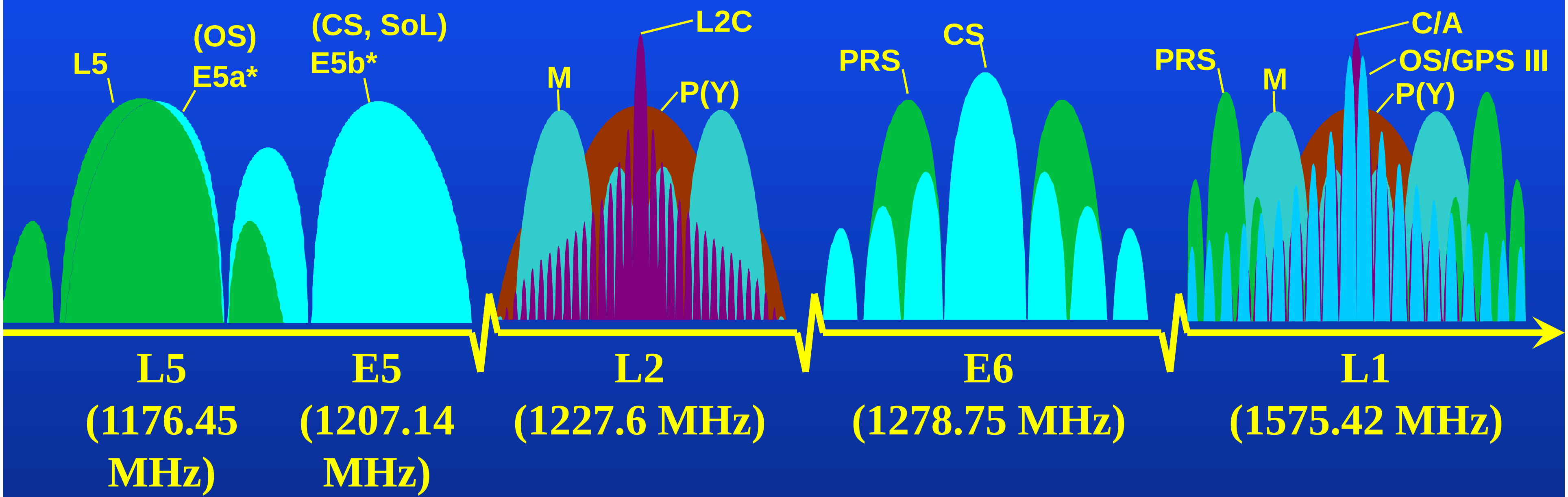
GPS and Galileo Signal Spectra



*BOC(15,10) modulation option shown for E5a/E5b.

Prepared by Chris Hegarty, MITRE

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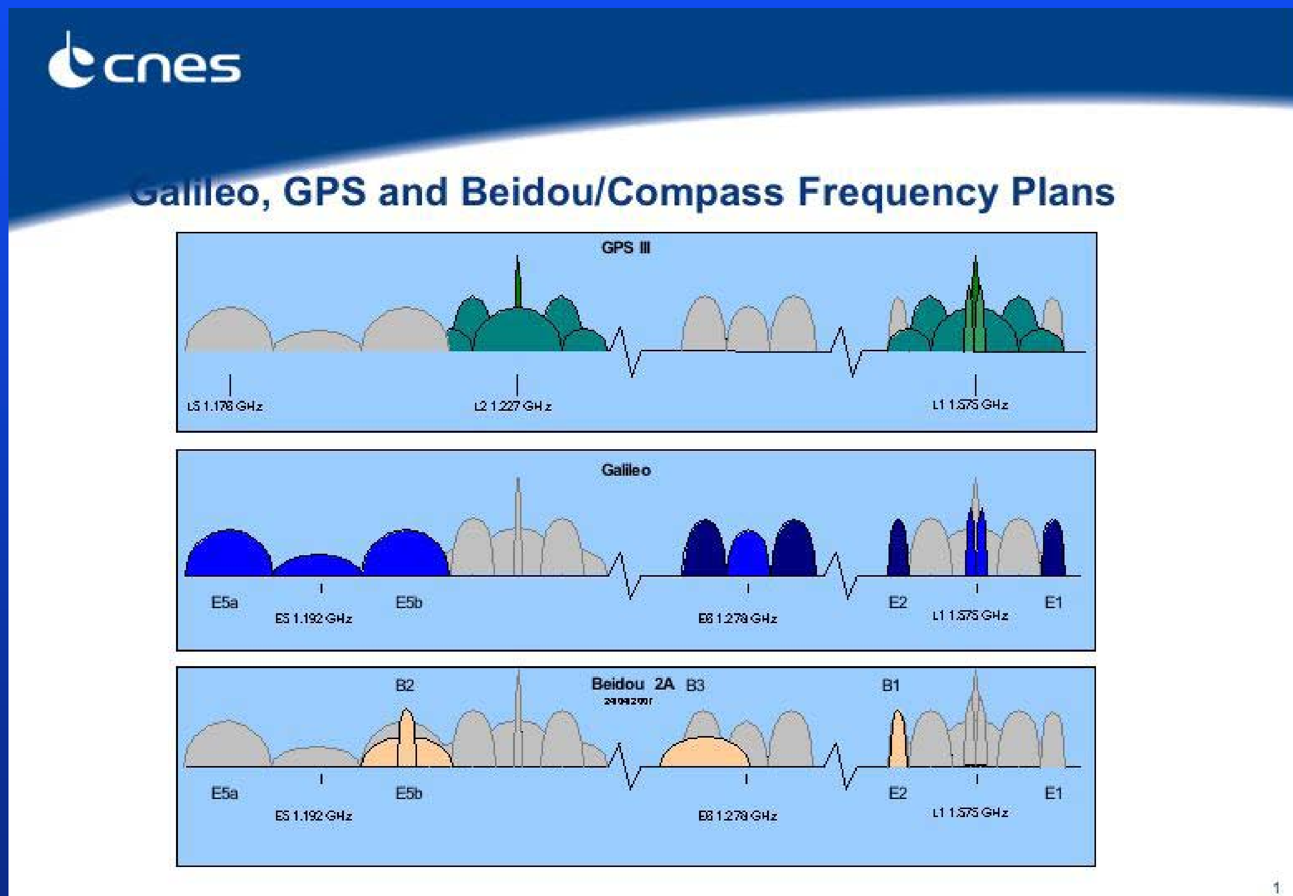
Concern over Interference



Regional Navigation Satellite Systems (RNSS)

- **WAAS (Wide Area Augmentation System)**
  - **Developed by FAA for commercial and civil aviation**
  - **Improve reliability and performance of GPS for civilian**
- **EGNOS (European Geostationary Nav Overlay System)**
  - **Developed by EU**
  - **Improve satellite coverage over Europe**
- **QZSS (Quasi-Zenith Satellite System)**
  - **Developed by Japan**
  - **Improve satellite coverage over Japan (Tokyo)**
- **IRNSS (Indian Regional Nav System)**
  - **Developed by India**
  - **Another regional satellite system**

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Characteristics of Frequency Stability