Applications of GPS Provided Time and Frequency

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Navigation and Timing

- Since the early days of Celestial Navigation there has been a strong link between Navigation and Timing
- Celestial Navigation requires three things,
  - Precise knowledge of the location of Stars, Planets, Moon, Sun (Nautical Almanacs)
  - Measurements of the location of these Celestial objects relative to the position of your ship (Sextant)
  - Precise Time (Clock or Chronometer) each minute of clock error would equal several miles of position error

Navigation accuracy measured in Miles was considered very good

Navigation Systems today still require precise timing

- GPS operates on a principle of broadcasting a precise timing signal from know locations in space (the GPS satellites)
- GPS requires three things:
  - Knowledge of position of the GPS satellites (orbit)
  - User GPS receiver to make ranging measurements, and to compute a navigation solution
  - Clock synchronization between satellites, every 3 nanoseconds of timing error ~ 1 meter of position error

GPS navigation accuracy is typically few meters

US Position Navigation and Timing (PNT) Service

- The US government is committed to providing a Position Navigation and Timing (PNT) service from GPS
- The US government recognizes the Global importance of GPS provided timing;
  - The GPS Standard Position Service Performance (SPS) specification defines the level of performance expected from GPS

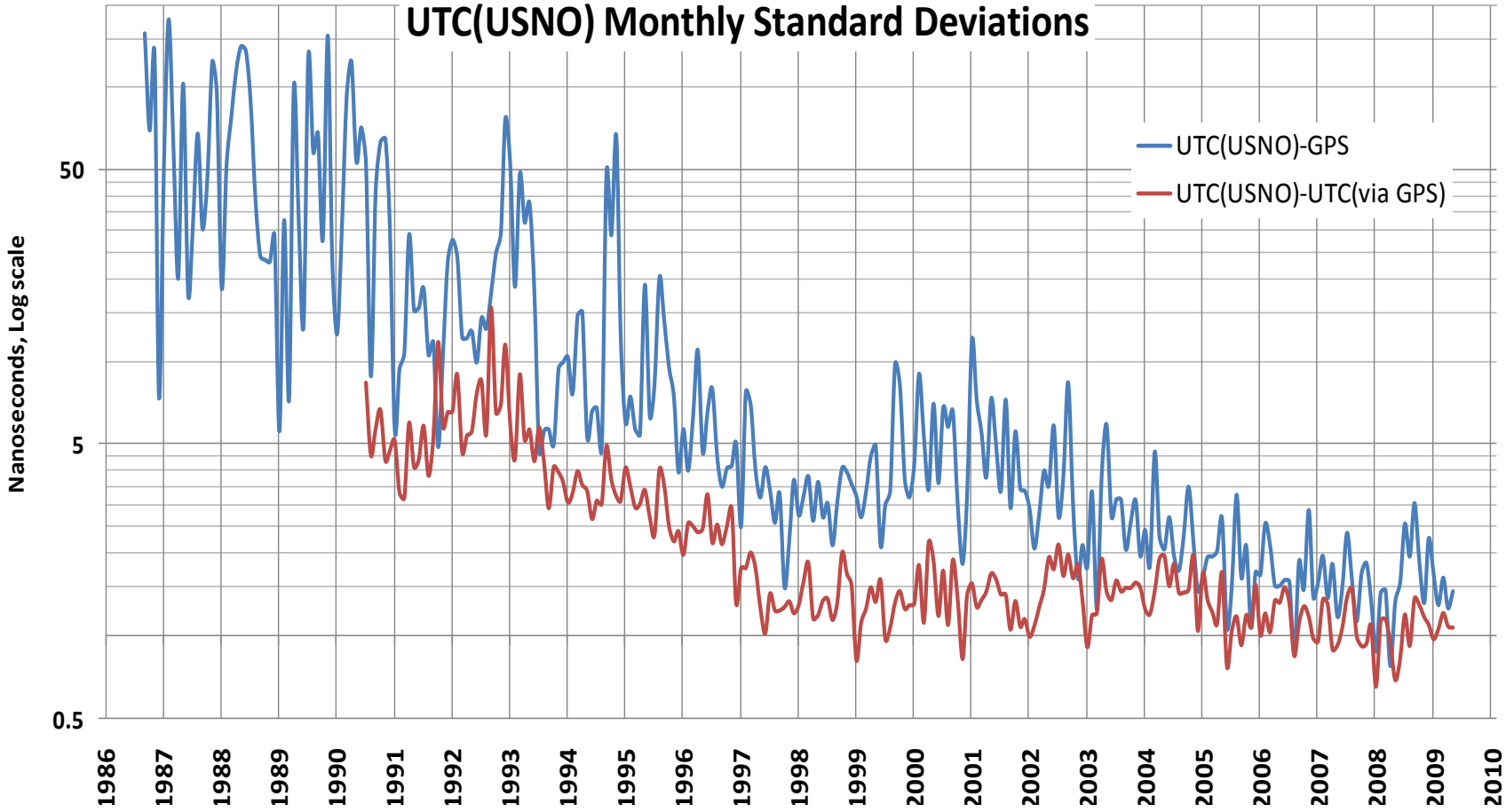
- **A.4.8 UTC(USNO) Offset Accuracy** The SPS SIS NAV message contains offset data for relating GPS time to UTC(USNO). During normal operations, the accuracy of this offset data during the transmission interval is such that the UTC offset error (UTCOE) in relating GPS time (as maintained by the Control Segment) to UTC (as maintained by the U.S. Naval Observatory) is within 40 nanoseconds 95% (20 nanoseconds 1-sigma). See IS-GPS-200 for additional details regarding the UTC(USNO) offset data.

GPS Timing

- **UTC Time**
  - The UTC broadcast from GPS is referenced to the U. S. Naval Observatory real-time realization of UTC called UTC(USNO) .
  - UTC(USNO) is obtained from GPS by subtracting an integral number of seconds (leap seconds) and applying the fine UTC correction information contained in the broadcast navigation data.
- **Global Positioning System (GPS) System Time**
  - Internal navigation time scale computed from the ensemble of clocks that make up the GPS system and is steered closely to UTC(USNO) modulo one second.

USNO has supported the United States position navigation and timing systems for almost 200 years

GPS Timing Service During the Past 25 Years



Early Usage of GPS Timing Service

- During the initial development phase of GPS (1970's and 1980's) the commercial timing industry used the Block I GPS satellite constellation to support commercial applications.

- By the late 1980's hundred's of GPS timing receiver were in use at commercial telecommunication sites around the world.

- By the time GPS reached its full operational status in April 1995 the timing services provided by GPS were being used as a foundation for the telecommunication industry worldwide.

- Today there are estimated to one million+ timing GPS receivers supporting industry world wide.

GPS Timing Service Today Supports a Wide Variety of Applications

- Telecommunication
- Power Grid
- Time Stamping of Banking and other Financial Transactions, Legal, Clerical, Shipping, etc…
- Scientific Timing Applications

Telecommunication

- Telecommunication Industry makes wide use of GPS provided timing supporting a variety of applications
  - Switched Telephone Networks (1E-11 Frequency) as a primary reference clock
  - Cellular Telephone System (microsecond timing) used to synchronize cell sites allowing seamless switching
  - Network Time Protocol (millisecond) supporting application level usage of accurate time
  - IP based applications like streaming audio, video
  - Precise Timing Protocol (sub-microsecond across a facility)

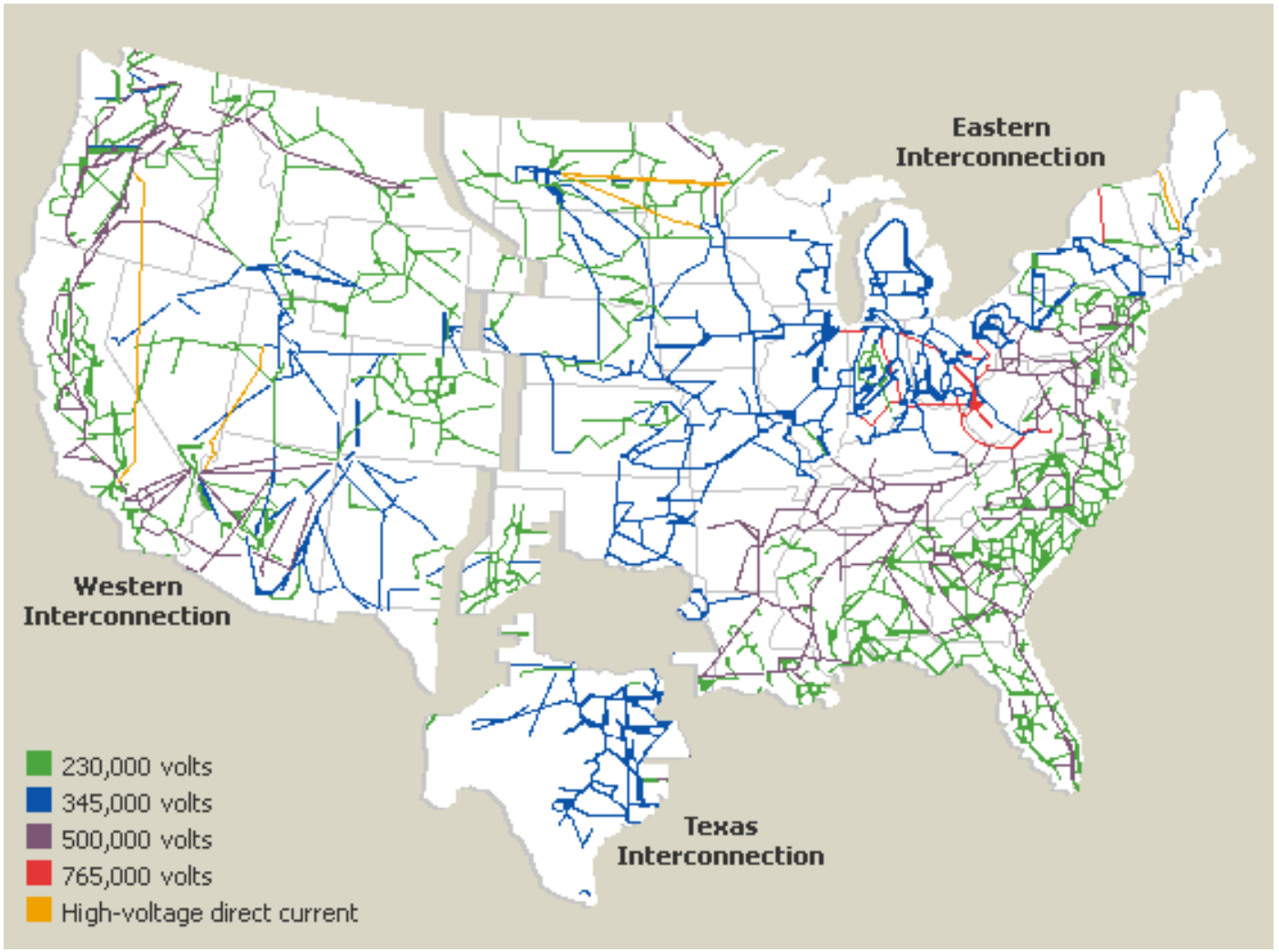
Cellular Telephones and GPS Timing

- Many different types of second generation cellular telephone network exist today, most with some degree of dependence on precise time.
  - CDMA requires precise time (microseconds) and uses GPS timing to coordinate time between base stations.
  - GSM has less stringent timing requirements, but third generation requirements are trending toward reliance of GPS timing.
- There are an estimated 500,000 cellular base stations in operations globally, most with embedded GPS timing equipment.

Power Grid

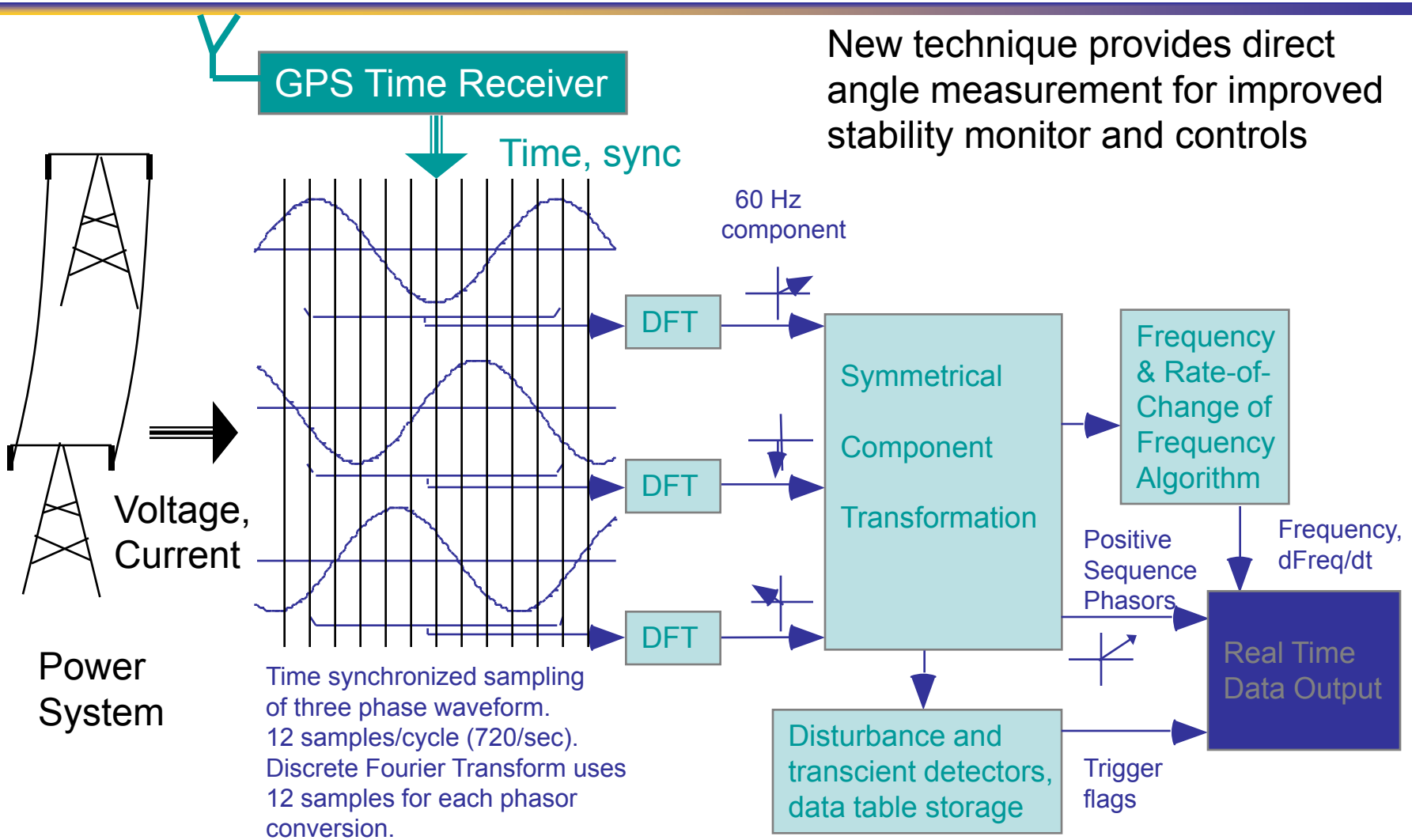
- The world power grid requires synchronization of the alternating current (50/60 Hz) which historically has been accomplished by adjusting the phase at local power generating plants to match the overall power grids phase.
- Small phase inaccuracy will reduce efficiencies and larger errors may result in damage to equipment and power outages.
- GPS based Phasor synchronization equipment is starting to be installed globally resulting in:
  - Higher efficiency in power transmission
  - Fewer black outs
  - Better fault isolation
- Power line fault isolation is often accomplished using GPS timing to measure the distance to a break in a power line, which greatly reduces the time to find the break and to restore service

US Power Grid



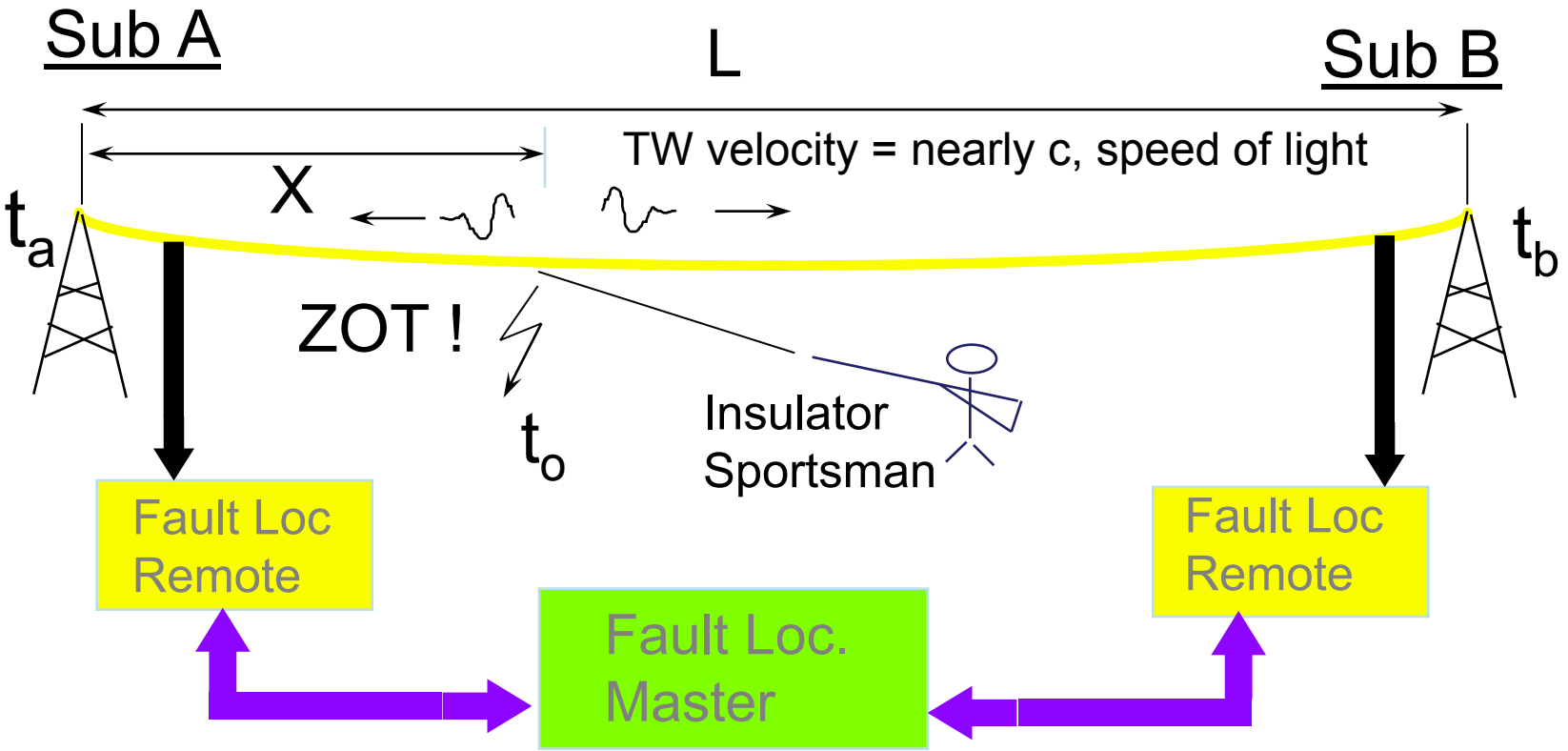
Phasor Measurement

New technique provides direct angle measurement for improved stability monitor and controls



Traveling Wave Fault Locator

FL remotes provide microsecond accuracy TW timetags at substations using GPS timing. Timetags are compared in the master to determine fault location.



$$X = \frac{L - c\,(t_b - t_a)}{2}$$

Summary of Timing Requirements for Power Grid

System Function	Measurement	Optimum Accuracy	Time Sources
TW Fault Locator	300 m (line span)	1 μs	GPS
Relaying (line protection)	1000 m	3 μs	GPS
Phasor Measurement	+/- 0.1 degree	4.6 μs (60 Hz)	GPS
Networked Controls	+/- 0.1 degree	4.6 μs	GPS
Stability Controls (RAS,etc)	+/- 1 degree	46 μs	GPS
Event recording (DFR, etc)	Record compare	1 ms	GPS
Generation Control (AGC)	Freq, time error	10 ms	GPS, Net
Scheduling, reservation	Time of day	0.5 sec	GPS, Net

Banking and other Financial Transactions

- With billions of financial transactions per day and the emergence of fully automated computer trading, precisely timing of trades are critical.

- An inaccurate time stamps could result in unfair advantage being gained and loss of revenue.

- Today time stamp traceability requirements are at the single second level, and within a few years millisecond timing will be required to support high speed computer trading.

Scientific Timing Applications

- Many areas of science require time stamping of when event occur ranging from when an earthquake starts to measurements of signals from distant quasars.
- Example: GPS provides the most widely used means of comparing precise atomic frequency standards operated by timing laboratories.
- Example; Very Long Baseline Interferometry (VLBI) requires stable clocks with GPS providing the synchronization of these global observations.
- Example; Particle physics experiments may need to time stamp when a neutrino arrives at multiple detection facilities scattered around the world. Again GPS provides the coordinating reference.

Conclusion

- The US Government understands the criticality of GPS provided timing to the world.
- The GPS timing services have been in use by industry for more than 25 years providing an exceptional quality of service.
- GPS timing services provides the global standard for access to precise time supporting:
  - Critical infrastructure
    - Telecommunication,
    - Power Grid,
    - Banking, Financial transactions (Time Stamps),
    - and scientific applications.

Future

- GPS is adding a second and third civil signal (L2C and L5), and will add a modernized L1 signal with the GPS III satellites (L1C)
- These new signals will contain a modernized navigation message with improved resolution of the timing data (1 ns -> 30 ps).
- These new signals could be beneficial to the timing community providing, frequency diversity and redundancy which should help mitigate local interference.

Other GNSS systems

- As GLONASS becomes operational in the coming weeks and with the addition of other Global and Regional GNSS systems in the near future a more diverse set of timing signals will be available.
  - More frequency diversity, additional signals can help mitigate local interference.
  - A diversity of systems could provide for additional integrity