How to Get a Good Time

Transferring UTC from a Lab

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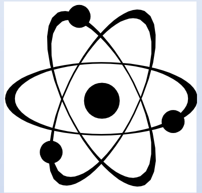
Outline

- Time references
- Time transfer issues
  - One-way time transfer: GPS/GNSS
  - Two-way time transfer: PTP, NTP
  - Holdover
- Conclusions

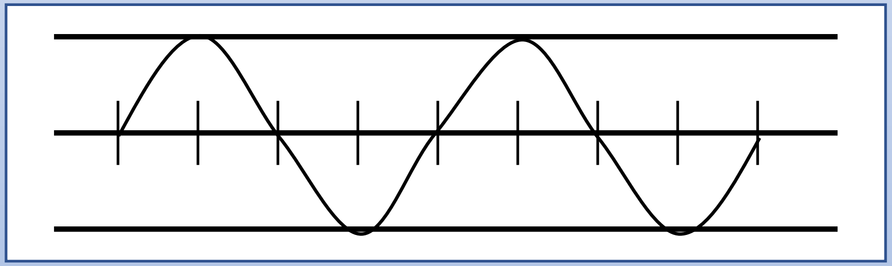
Time and Frequency

- A clock is a frequency device based on physics



Provides “ticks” at precise intervals;
Frequency is reciprocal of period

- Electronic systems count “ticks” for time interval



“Time-Clock” provides the time elapsed since the “start”

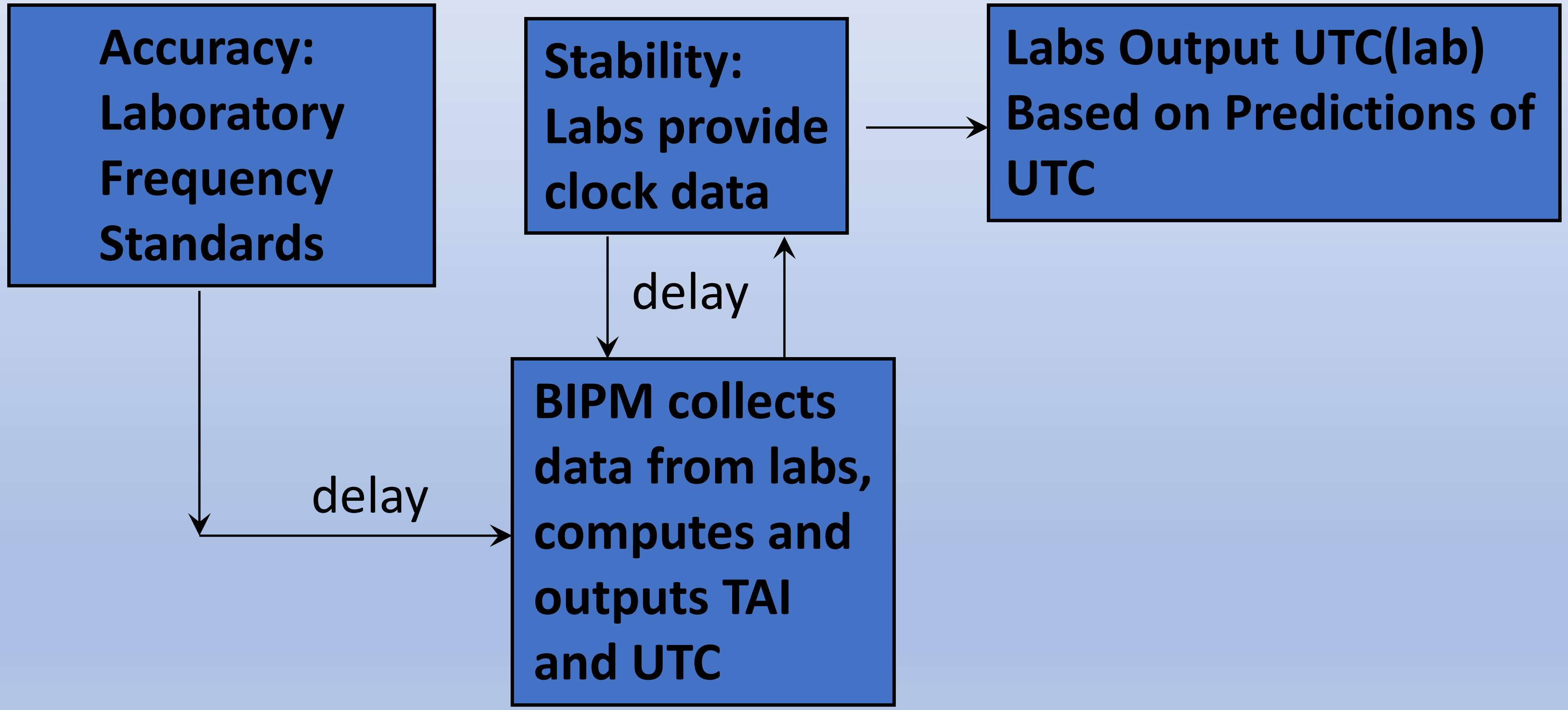
- *Time* is a combination of a *signal* (event) and a *label* (data)

Communicating Time vs. Data

- Time signals are Physical
  - Accuracy and stability are no better than the physical layer
  - Data layers disrupt the T & F signals
  - Interference to the physical signal blocks access to T & F
- Communications systems are layered with devices only connected to the neighboring layers
  - Sync gets worse farther from the physical layer
- Time accuracy requires access to UTC through a national lab – GNSS used

The Generation of UTC: Time Accuracy

Any Real Time UTC is only a Prediction,
A PLL with a one-month delay



Time and Frequency Transfer: How to Deliver a Timing Reference

- Time Transfer Accuracy Requires Calibrating Delays

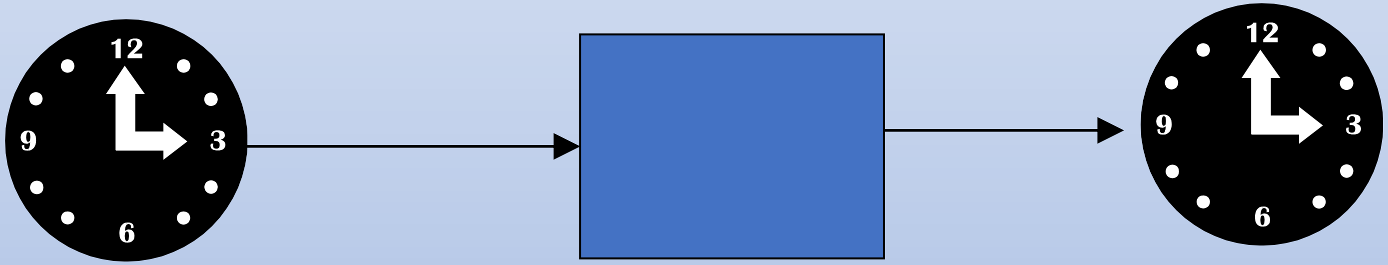
- Imagine writing a letter: "It is now 2 PM– set your watch"
- Seal it in an envelope and drop it in a mail box
- Only useful if you know how long it took to get to you
- Now suppose you timestamped when you sealed the letter and the receiving person timestamped when he got it…

- Time Stability = Frequency Accuracy

One-Way Dissemination or Comparison System

Source Clock

User Clock



Source Clock Systematics and Noise

Delay to be compensated, Measurement Noise and Path Perturbations

User Clock Systematics and Noise

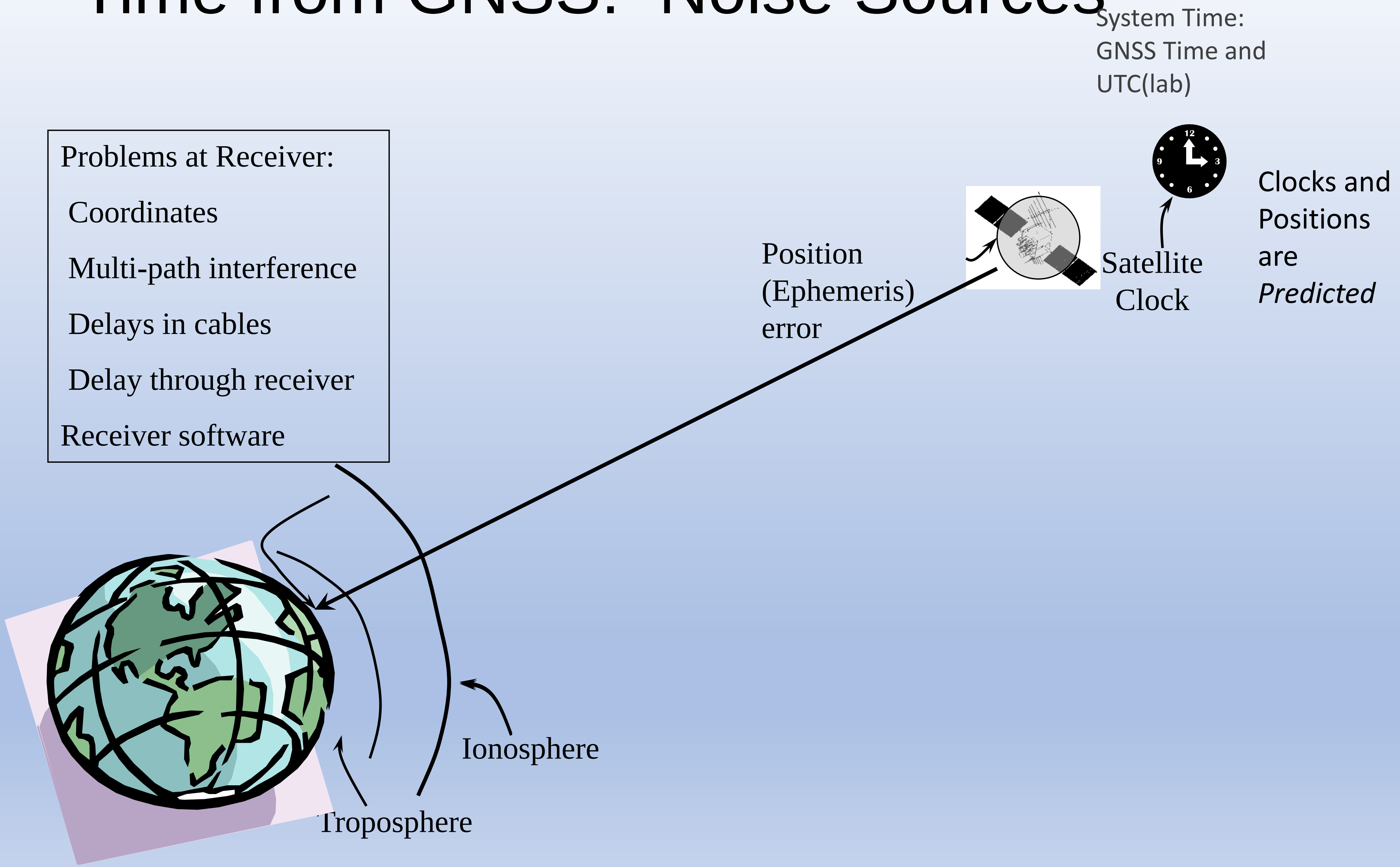
One-Way Time Transfer Systems

- GNSS
- 1 pulse-per-second (PPS)
- IRIG-B

Time From GNSS

- 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

Time from GNSS: Noise Sources



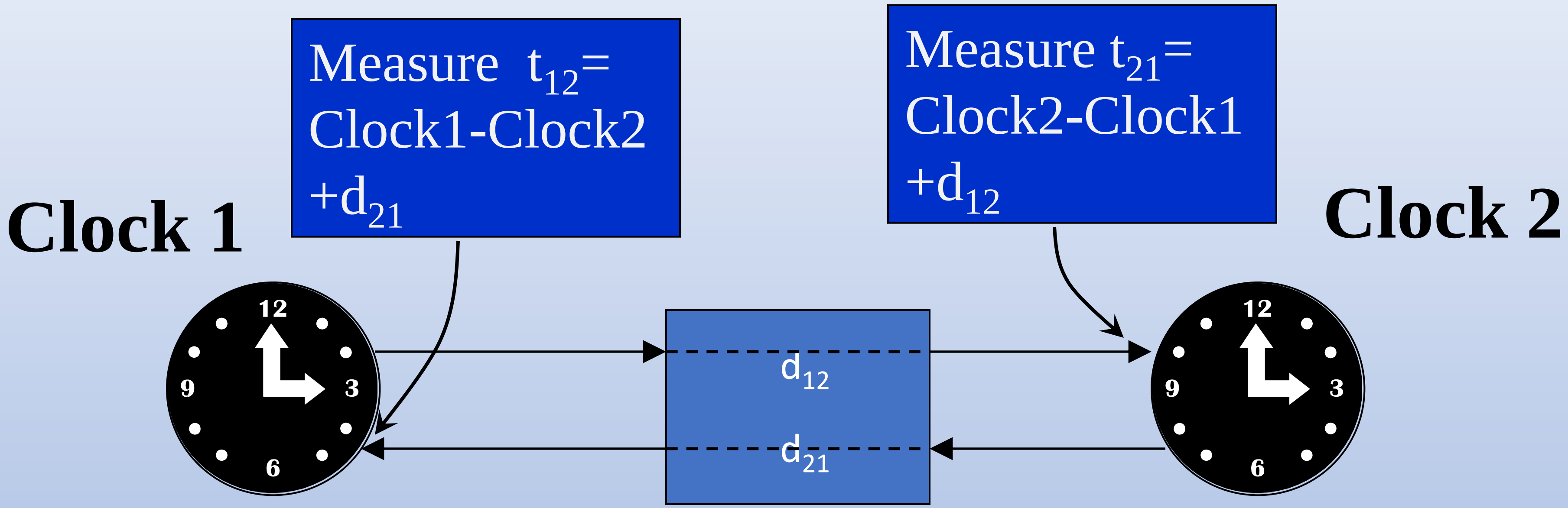
GPS/GNSS Sources of Error

- GPS and other GNSS are widely distributed sources of UTC, but …

- They are dangerously vulnerable to both accidental and intentional interference
- There are failure modes in the systems
- They do not penetrate buildings

Two -Way Comparison System

(e.g. IEEE1588 – PTP, and NTP)



Clock 1 Systematics and Noise

Delay to Cancel, Measurement Noise and Path Perturbations Largely Reciprocal: $d_{21} = d_{12}$

Clock 2 Systematics and Noise

Two-Way Time Transfer Systems

- Only provide UTC(lab) if the source is traceable to that lab
- Via communications satellites
- Via networks
  - NTP
  - PTP
- PTP is not fundamentally better than NTP, just how well it connects to the physical layer
- Cable standard (DTI)

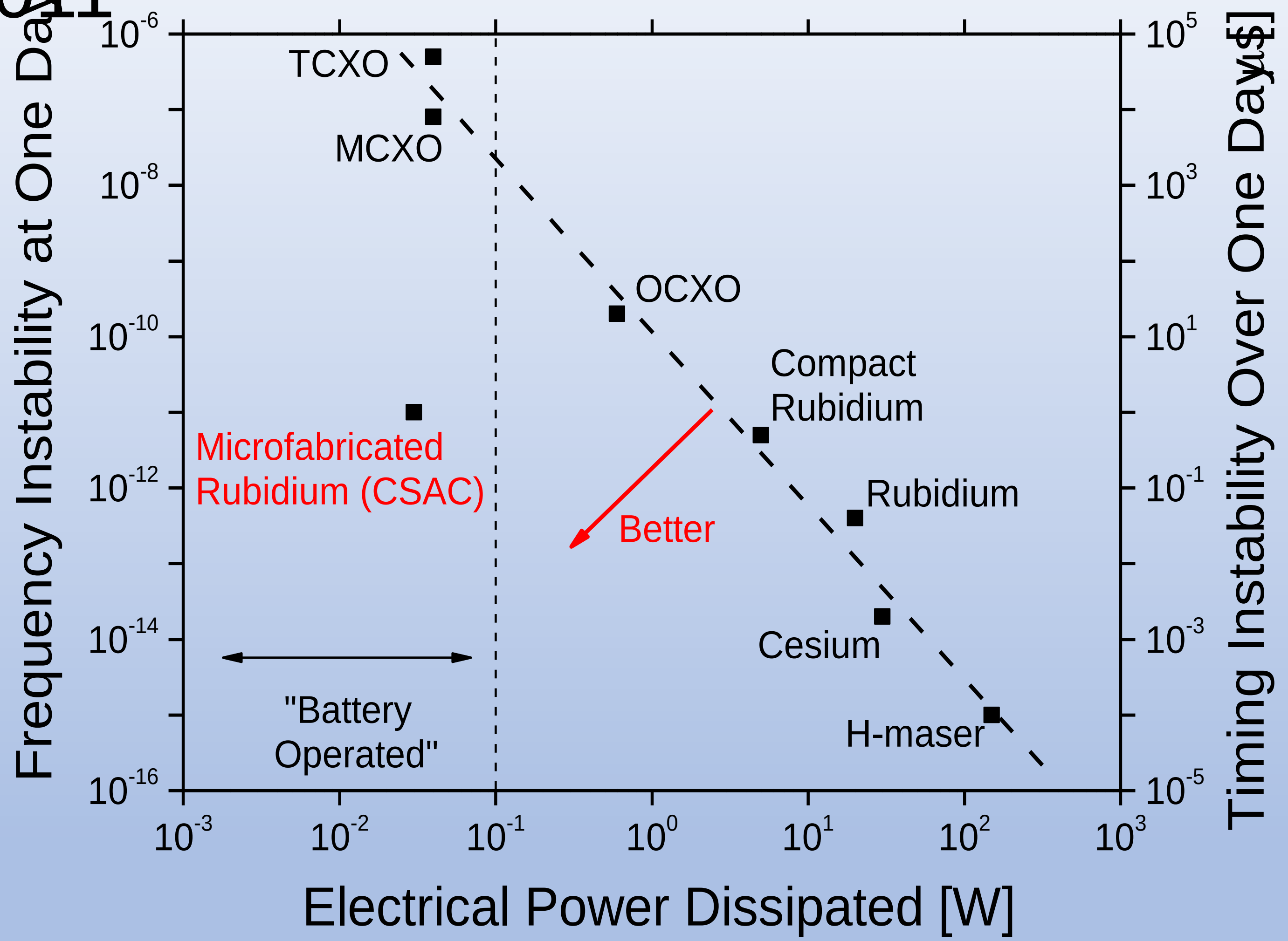
Network Time Transfer Error Sources

- The Source (Grandmaster) may lose traceability
  - If this is GPS, it has all the vulnerabilities of GPS!
- Store and Forward buffers have random and large delays
- Delays in two directions are generally not equal
- Time stamps can have errors, especially software time stamps
- Time through networks
  - LANs can be well-controlled
  - Public internet is unpredictable – the best is maybe 1 ms

Holdover

- Local clock needed to hold time in the case of failure
- Also local clock can help detect and eliminate errors or noise
- You get what you pay for generally

(A Very Rough) Oscillator Comparison, from 2011



Adapted from figure by J. Kitching, NIST and M. Garvey, R. Lutwak, Symmetricom

Tech	Cost
Cheap Quartz, TCXO	≈ $1s
Hi-quality Quartz, OCXO	≈ $100s
Rb Oscillator	≈ $1000s
Cesium Beam	≈ $10Ks
Hydrogen Maser	≈ $100Ks

Conclusions

- UTC must be transferred from lab, accounting for delay
- GPS/GNSS are one-way systems, have pros and cons
- NTP and PTP are two-way systems with their own pros and cons
- Highly reliable time-transfer requires redundant and differently types of systems