STEERING UTC(k) TO UTC
19th Meeting of TAI Laboratories
BIPM
September 11, 2012

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1. Introduction
2. Prediction
3. Steering Options
Some Definitions

Synchrony
Alignment of two sources of time

Syntony
Alignment of two sources of frequency
Why do we steer clocks?

Usually, to create either synchrony or syntony

For most communication applications, syntony (same frequency) is all that is required.

For navigation and GPS synchrony (same time) is crucial, yet asyntony usually leads to asynchrony.
Omnipresence of Steering

TAI = EAL + frequency steers to primary frequency standards
(calibrated to meet definition of the second)
(EAL = ave of >200 clocks, including USNO’s)

UTC = TAI + leap seconds
(crude steers, in phase, to Earth’s rotation)

UTC(k) = TA(k) + steers to UTC = realization of UTC by laboratory k
(TA(k) = ave of Lab_k’s clocks)

GPS* = Unsteered GPS clocks + steers to UTC(USNO) [in acceleration]
(Composite Clock= implicit average of steered satellite and monitor station clocks)

Cell Phone’s Time = crystal + steers to UTC(k) or GPS*

Atomic Clock’s time = clock’s crystal + steers to atomic frequencies

(GPS* denotes GPS Time with leap seconds added)
How Timing Labs Steer to UTC

- Some don’t steer at all
- Others wait until UTC-UTC(k) is “too large”
  - Step rate of UTC(k)
  - Step phase of UTC(k)
- Another method:
  - First estimate current and future UTC-UTC(k)
  - Then steer UTC(k) so as to reduce UTC-UTC(k)
    - Adjust Master Clock’s frequency
    - Or adjust microstepper/AOG/synthesizer
    - Or software steer
Effect of Steering

Assumes “perfect” estimate of average rate was made 17 years before
How do you steer to UTC?

1. Predict how your clock’s future performance
   - Performance Standard: UTC-UTC(k) in next Circular T
   - Predict using some real-time timescale that is presumed to be stable

2. Adjust your clock to reduce UTC-UTC(k)
Part II: Estimate UTC-UTC(k)

• Start with published Circular T values of UTC-UTC(k)
• Convert to EAL minus some unsteered real-time timescale
  – When EAL steers become small enough, could stay with UTC
  – Timescale usually internal, could even be one cesium
  – Timescale could also be external real-time UTC realization
    • GPS makes UTC(USNO) easy to use, SIM makes UTC(NIST) easy too
    • UTCr may become an official BIPM product

• Compute EAL-timescale
• Extrapolate to future
• Re-apply known steers to predict UTC-UTC(k)
  – Your laboratory’s steers for UTC(k)-timescale
  – Published steers of EAL to generate UTC, from Circular T
Extrapolating EAL-timescale

• Polynomial Fit
  – Fit Order: linear for Cesiums, quadratic for Masers
  – How far back in time to fit to?
  – First-Order Fit to Random Walk in Phase
    • Use only first and last phase points
    • Last point minus first point yields average frequency
    • Fit to last point for constant phase offset

• Auto-Regressive Integrated Moving Average (ARIMA) and State Space Models
  – Kalman Filters are one form of State Space Models
  – ARIMA and Kalman Estimators can be very similar
Prediction is Only For the Brave

UTC-UTC(k) <simulation based on unsteered USNO data>

Do you
1. Steer negative
2. Steer positive
3. Not Steer?
Homework: What Do You Predict To Happen After 56139?

UTC-UTC(k) < What Really Happened >

Most Reasonable Prediction
Cesium Beam and Masers Usually Vary More Than UTC

UTC vs cesium beam tube and UTC vs maser. Parabolas removed.
Extrapolating EAL-cesiums

Cesium Linear Fits

Days in Fit

RMS (ns)

Cesium Parabolic Fits

Days in Fit

RMS (ns)

Cesium 2-Point Linear Fits

Days in Fit

RMS (ns)
Extrapolating EAL-USNO masers

Viewgraph and Analysis from Panfilo and Arias, EFTF-09
See also: Matsakis et al., ION Annual Meeting, June 2000
Part III: How much to steer?

- You have estimated UTC-UTC(k)
- How best to adjust UTC(k)?
You can’t have everything

• ALL steering involves a trade-off between:
  • frequency offset
  • time offset
  • control effort
    • controlled clock usually more precise in short run
  • Oversteering will mask its precision
• Linear Quadratic Gaussian (LQG) theory can compute the optimal gains for your goals.

Setting the Gain Vector

• Steer = $g_X \ast \text{Phase} + g_Y \ast \text{Freq} + (g_Z \ast \text{Drift})$
Three Ways to Set Gains

• LQG Theory
  – A compromise to minimize weighted sum of phase variance + freq. variance + control power

• Pole Placement
  – Set response times

• Minimal Control Effort (Gentle Steering)
  – Decide numerical value for phase and frequency shift
  – Steer to achieve it with minimum amount of control
Recommended Starting Point

• Estimate difference in UTC-UTC(k), 30 days into the future
  – When next Circular T comes
  – Assuming you did nothing
• Steer so that 30 days into the future you will have removed 50% of the predicted frequency difference and 50% of the phase difference
• Ignore frequency drift for steering
• Make one steer every 6 days
  – Use formula on next slide (N=5) …
Minimizing Control Effort

Change clock’s time by $\Delta x$ and frequency by $\Delta y$
Use $N$ steers $U_n$ spaced $\tau$ seconds apart
Minimum Amount of Control Effort
Useful for steering to Circular T

http://www.pttimeeting.org: Koppang and Matsakis, PTTI-00, pp. 277-284

\[
U = -\frac{6}{N(N+1)} \begin{bmatrix}
\frac{1}{\tau} & \frac{2N-1}{3} \\
\frac{1}{\tau} & \frac{1}{(1-\frac{2}{N-1})} \\
\vdots & \vdots \\
\frac{1}{\tau} & -(N-1) + \frac{2N-1}{3}
\end{bmatrix} \begin{bmatrix}
\Delta x \\
\Delta y
\end{bmatrix}
\]
Warning!

• Be careful what you ask for ...

• With control theory, you might get it.

• Therefore, simulate control performance