

# RPL Time Service

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2009-11-09 V0.03

# What RPL Time Service Provides

- Absolute Time in “Seconds, not samples”  
Pure, continuous, binary time, Independent of any clock domain, available consistently in every clock domain
- Application-Specific Range and Precision  
 $m$ -Integer bits of Seconds :  $n$ -Fractional bits of Seconds
- Precision Synchronization Discipline  
Time Servo Loops drive measured phase-errors to zero
- A simple, standard way of accessing time  
OCP-IP Worker Interface Profile : Worker Time Interface

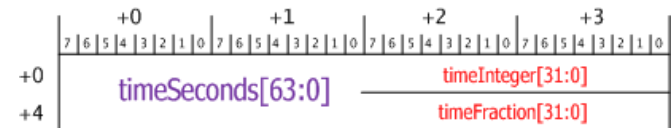
# Seconds, not samples

- Time, purposefully divorced from signal sample rates
- At any point in space, “now” is absolute
  - Relativity of simultaneity
  - Practical need to know “now” in any clock domain

# Representation of Time

- Fixed-Point binary  $m$ -bits integer,  $n$ -bits fraction
- Application specifies range and precision
- Infrastructure provides required resources

- Example: timeSeconds[32.32]



Bit[63] of the 64b timeSeconds field is equal to  $2^{31}$  seconds ( ~68 years)

Bit[32] of the 64b timeSeconds field is equal to  $2^0$  seconds (one second)

Bit[31] of the 64b timeSeconds field is equal to  $2^{-1}$  seconds (one half second)

Bit[00] of the 64b timeSeconds field is equal to  $2^{-32}$  seconds (~232 picoseconds)

# WIP:: Worker Time Interface (WTI)

- Allows any worker to easily observe “now”
- Worker chooses which clock domain they wish to observe time in
- Worker chooses how much range and precision (SecondsWidth.FractionWidth)
- Infrastructure provides Time “now”
- Also, provides associated quality of time
  - Unknown, Tracking, Locked

# Quality Of Time

- “Unknown” – The time is unknown
  - At reset, and until the time is explicitly set
- “Tracking” – The time is known, loop settling
  - The time servo loop is attempting frequency-lock
  - Accuracy of time is only as good as using the uncompensated local worker clock since last set
  - When locked criteria achieved, transition to Locked
- “Locked” – The time is known, loop locked
  - The time servo loop has stabilized
  - Accuracy as good as it will get
  - Loss of sync, or explicit time set outside window, transition to Tracking

# Spec Sheet - Tracking

- Worst-Case, single-sample, error while Tracking is bound by the sum of Time Quantization Error and Worker Clock Drift

$$\text{Time Quantization Error} \leq \frac{2}{F_{wrkclk}}$$

$$\text{Wrkclk Drift} \leq \left( \frac{F_{wrkclk}}{F_{sync}} \right) \left( \frac{PPM_{wrkclk}}{F_{wrkclk} \times 1E6} \right)$$

$$\text{Wrkclk Drift} \leq \left( \frac{PPM_{wrkclk}}{F_{sync} \times 1E6} \right)$$

# Spec Sheet - Locked

- Worst-Case, single-sample, error while Locked is bound by the sum of Time Quantization Error and Worker Clock Short Term (per *Fsync* interval) Drift

$$\text{Time Quantization Error} \leq \frac{2}{F_{wrkclk}}$$

$$\text{Wrkclk ST Drift} \leq \left( \frac{PPM_{wrkclkST}}{F_{sync} \times 1E6} \right)$$



# Spec Sheet: Example 1

- Consider  $F_{wrkclk}=250$  MHz;  $F_{sync}=1$  Hz;  $PPM_{wrkclk}=200$ ;  $PPM_{wrkclkST}=1$ ;

Time Quantization Error:  $\leq 8\text{ns}$       Time Quantization Error  $\leq \frac{2}{F_{wrkclk}}$

Wrkclk Drift:  $\leq 200\text{ }\mu\text{S}$        $\text{Wrkclk Drift} \leq \left( \frac{PPM_{wrkclk}}{F_{sync} \times 1E6} \right)$

Wrckclk ST Drift  $\leq 1\text{ }\mu\text{S}$        $\text{Wrckclk ST Drift} \leq \left( \frac{PPM_{wrkclkST}}{F_{sync} \times 1E6} \right)$

- Tracking: Time accurate to  $\pm 200\text{ }\mu\text{S}$

200 $\mu\text{S}$  swamps 8ns by  $\sim 25,000:1$  ratio

- Locked: Time accurate to  $\pm 1.008\text{ }\mu\text{S}$

1 $\mu\text{S}$  bests 8 nS by  $\sim 125:1$  ratio

# Precision Synchronization

- RPL Time Service may be implemented with one or more Time Servo Loops (TSL)
- Each TSL contains a phase-accumulator state variable that integrates a particular clock over time

$$\varphi(t) = \int \omega(t)$$

- With sufficient precision, the phase-accumulator may function as a time-accumulator, converting angular-frequency to time

# TSL Phase Detector (1/2)

- Each TSL contains a phase-detector that measures the difference between a TSL's current state and an input time signal. That signal can be implicit or explicit about time:
  - A periodic event, with *implicit* phase  
e.g. 1PPS GPS Sync Pulse, 10 MHz Freq, TCXO
  - A (possibly) aperiodic event with *explicit* phase  
e.g. Time message from grandmaster, master, or another TSL
- At least one explicit time message is required to bring a TSL to a known phase-time
  - Until then, only its 1<sup>st</sup> derivative, frequency, is known

# TSL Phase Detector (2/2)

- The TSL phase-detector measures “Big Phase”
  - Linear over all time (Compared with PLL  $2\pi$ )
  - Allows infinite capture window (w/explicit phase)
  - All digital down to  $\frac{1}{F_{wrkclk}}$  (2ns for 500 MHz TSL)
  - Sufficient to asymptotically approach F-lock
- Time-to-Digital phase augmentation
  - Adds 5~6 bits of monotonic, sub-sample phase
  - Achieves ~80 pS resolution per sub-sample LSB
  - Analog measurement on FPGA substrate

# TSL P/PI Digital Servo

- The Proportional (P) component of the servo provides a non-linear response when the absolute value of the error exceeds a set threshold
- The Proportional-Integral (PI) component of the servo is 1-pole, adjustable- $\alpha$  IIR loop-filter
- The resultant feedback provides a signed bias to the fractional  $2\pi/\omega$  phase-increment

# TSL Summary

- Exposes time in the worker clock domain
- Improves the accuracy of time provided by an uncompensated local worker clock by several orders-of-magnitude

*“Short-term stability provided over the long term”*
- When needed for added accuracy, sub-sample phase detector provides meaningful linear compensation data