GPS based time synchronization of PC hardware

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Research goal and background

- Enable accurate network traffic measurements when analysis is based on packet arrival or departure time at different network nodes.
- On fast network 20 us inter-computer clock offset can make measurement results totally misleading.
  - According to time stamps packets seem to be received before even being sent.
- I have a dream:
  - inter-computer clock offset should be less than 2 us

Research timetable

Part 1 **(April 2004 – October 2004, 7 months)**

- Synchronization was done with NTP (Network Time Protocol) utility.
- Time reference: Trimble Acutime GPS receiver
  - NMEA / TSIP ASCII timecode output
  - 1 PPS (Pulse-per-second) output
    - » Pulse rising edge indicates second transition
    - » accuracy to UTC: 50 ns (1 sigma)
- Both signals are interfaced through computer’s serial port.

Research timetable

Part 2 **(since October 2004, 4 months)**

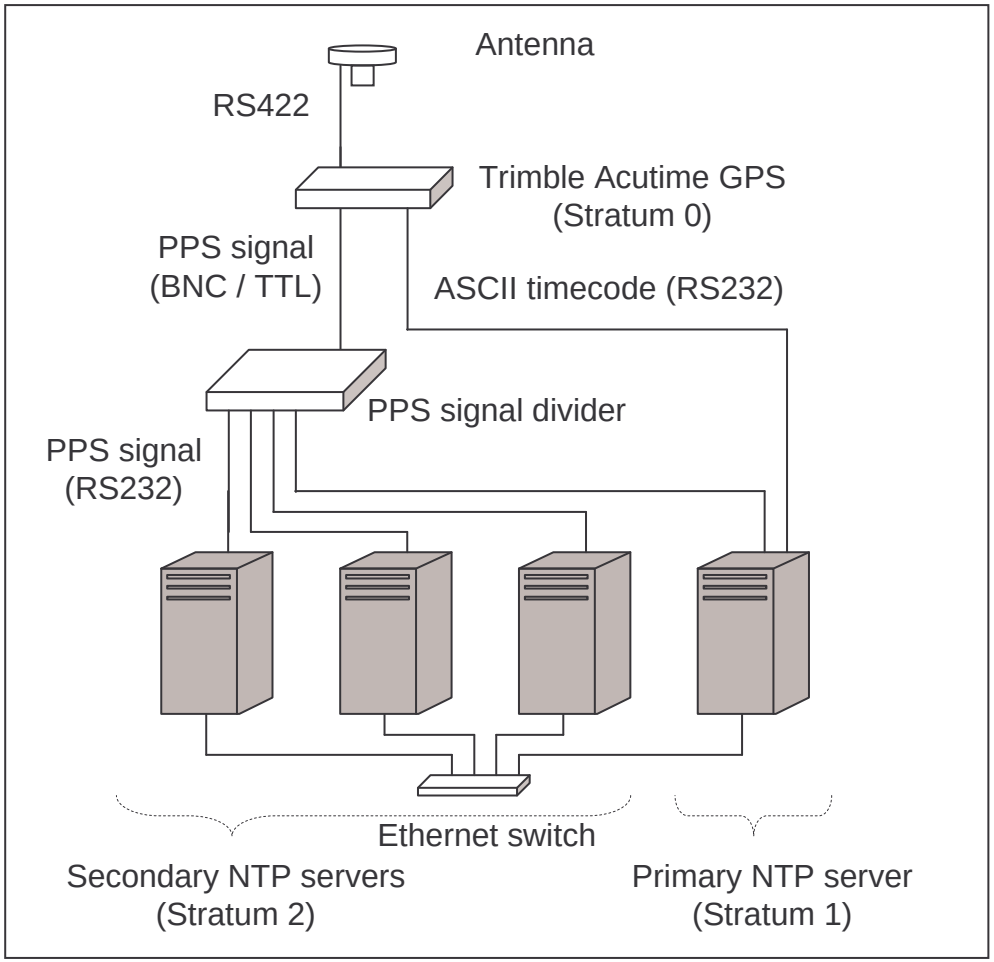
- System clock upkeeping is done using self-made PCI counter card and customized Linux kernel.
- Just make the clock run correctly
  - less need for actual synchronization
- Time reference: Trimble Thunderbolt GPS receiver
  - TSIP ASCII timecode output
  - 10 MHz output
  - 1 PPS output
    - » Pulse rising edge indicates second transition
    - » accuracy to UTC: 20 ns (1 sigma)

Part 1

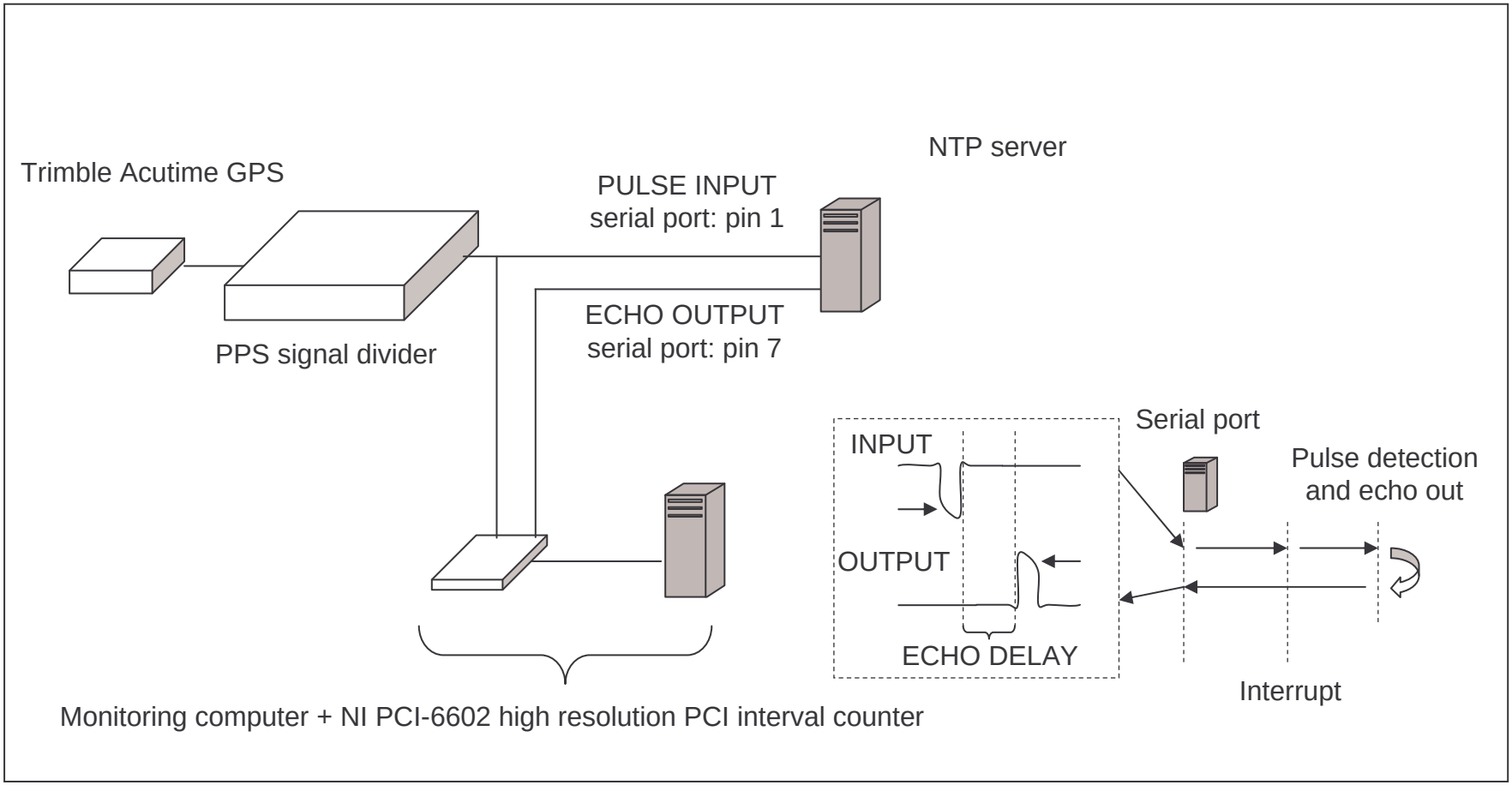
- Motherboard’s clock oscillator can easily have frequency error of 10 ppm. **(= 10 us per second or 864 ms per day)**
- System clock is updated 100 times per second.
  - on each timer interrupt (IRQ 0) 10 ms is added to system clock’s current time.
- NTP software changes the virtual frequency of system clock by changing the time increment on each timer interrupt.
- Stear the clock towards GPS and beat it

REALLY REALLY HARD

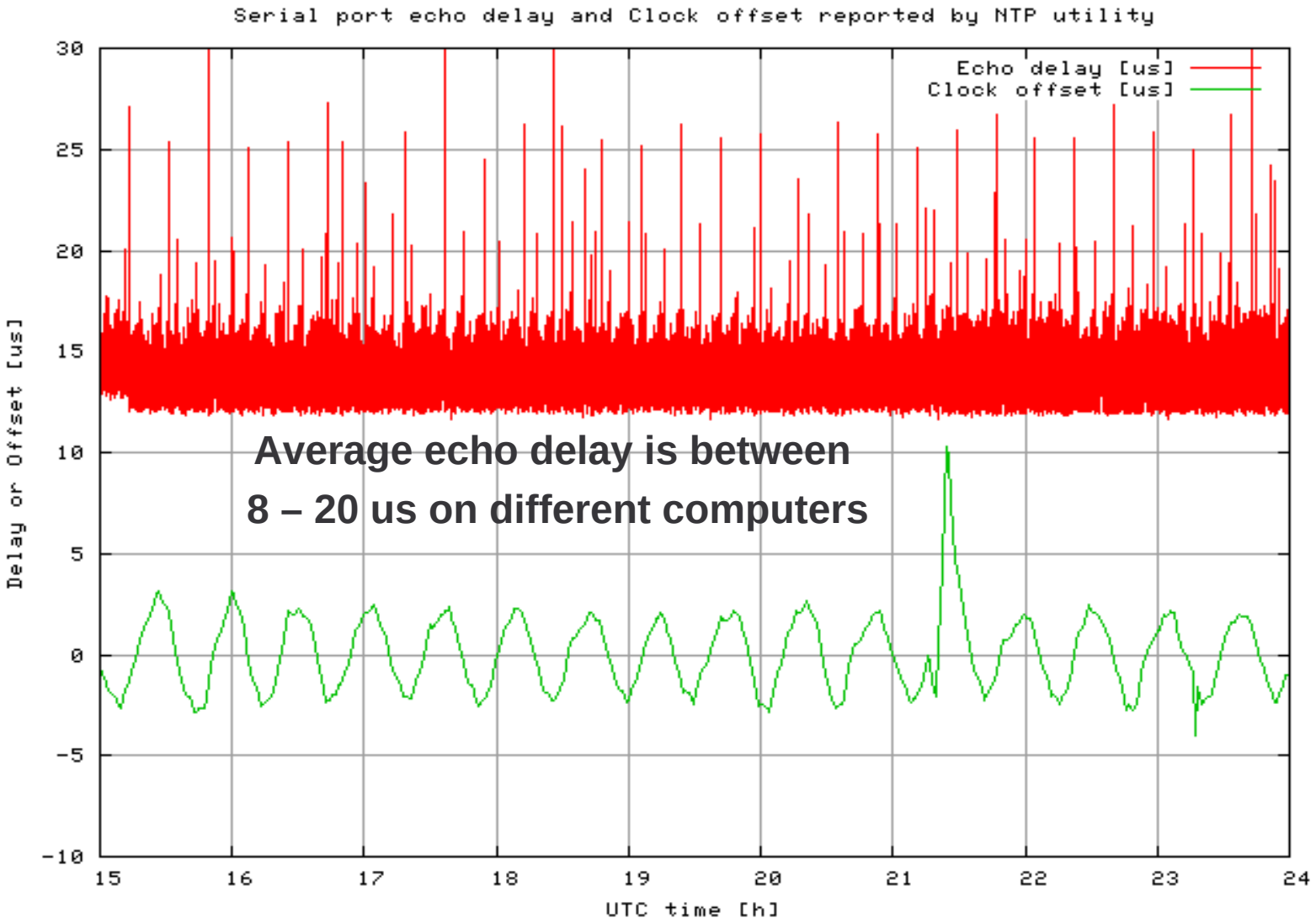
Synchronization system



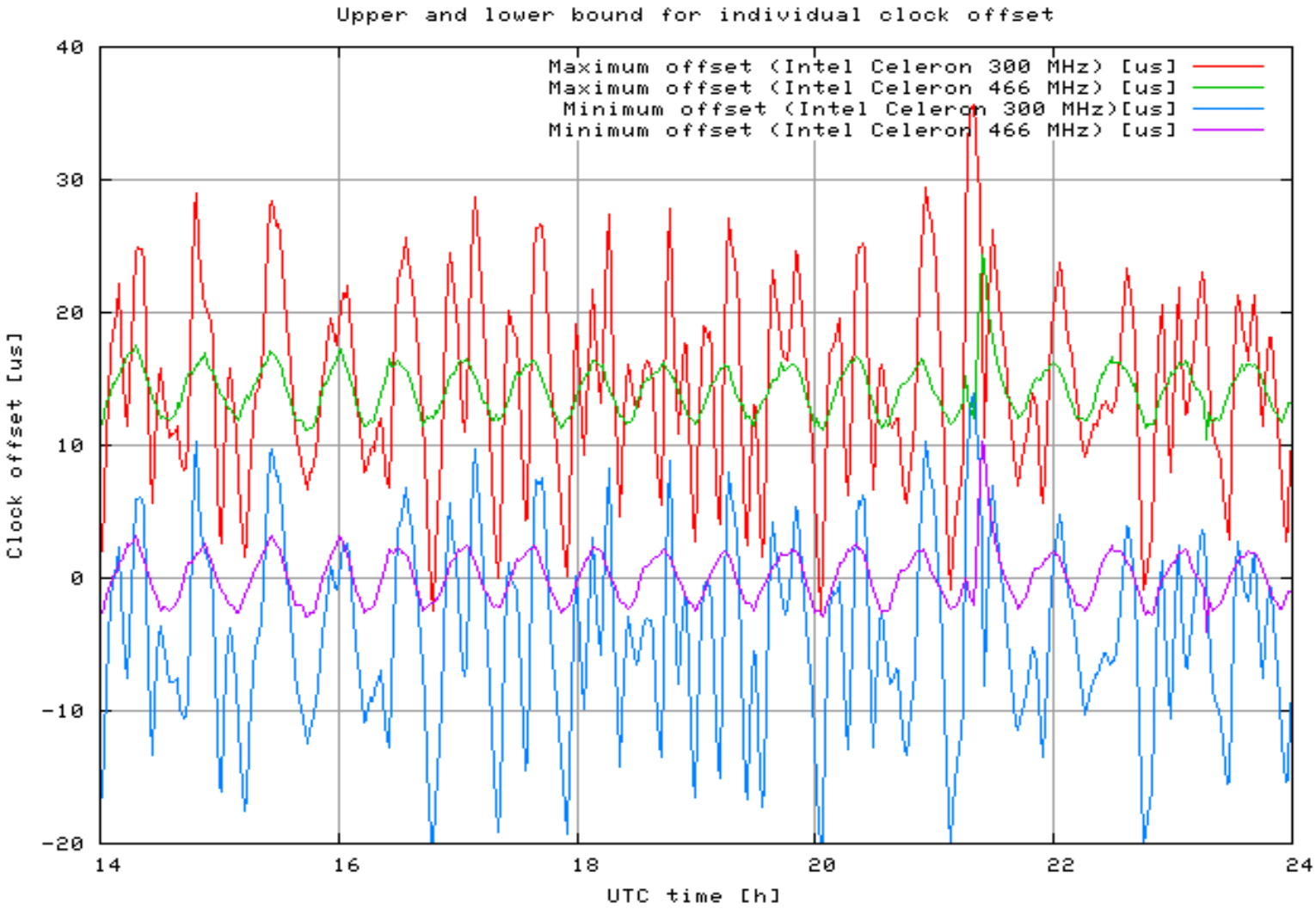
Pulse prosessing delay measurement setup



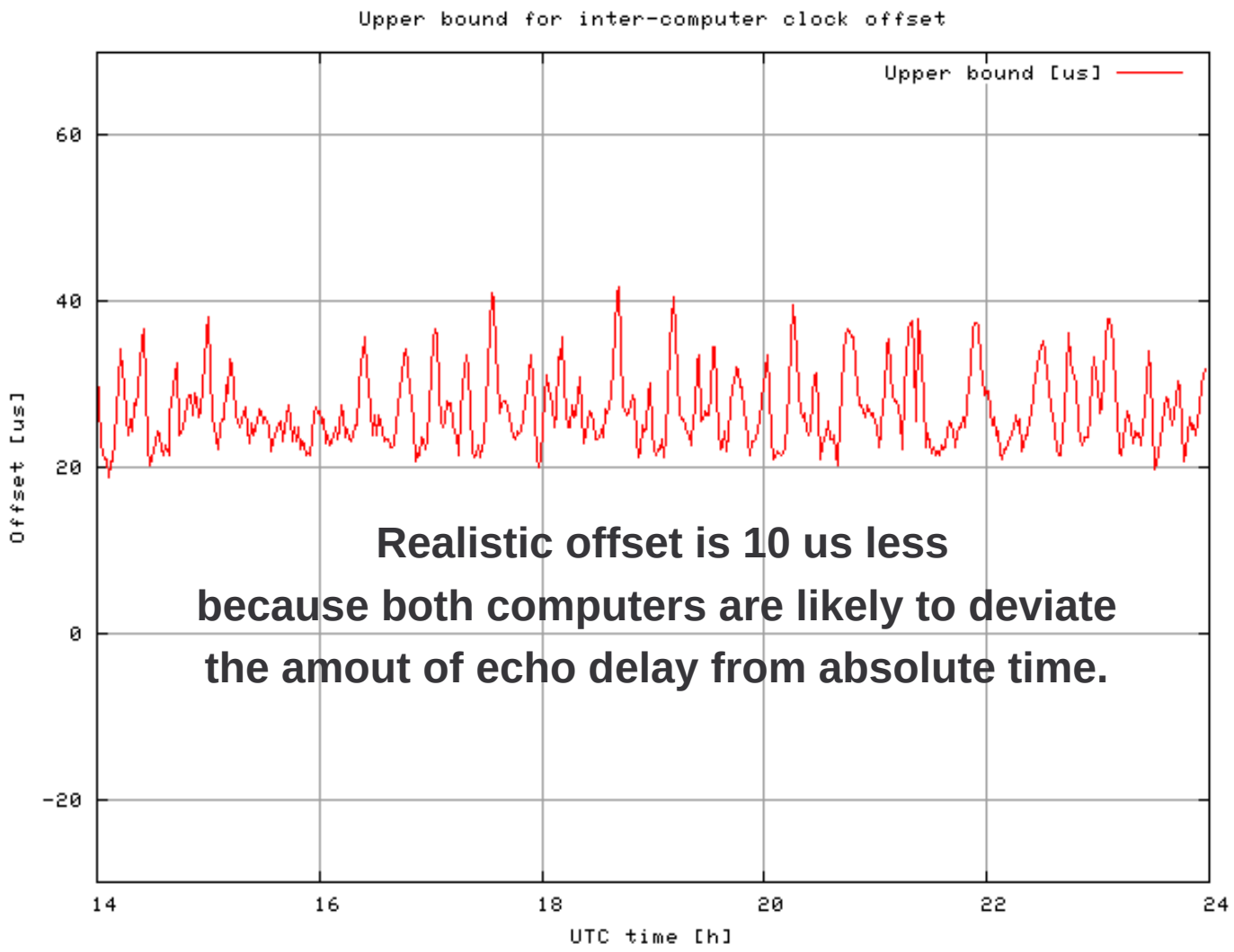
Measured serial port echo delay and clock offset reported by NTP utility



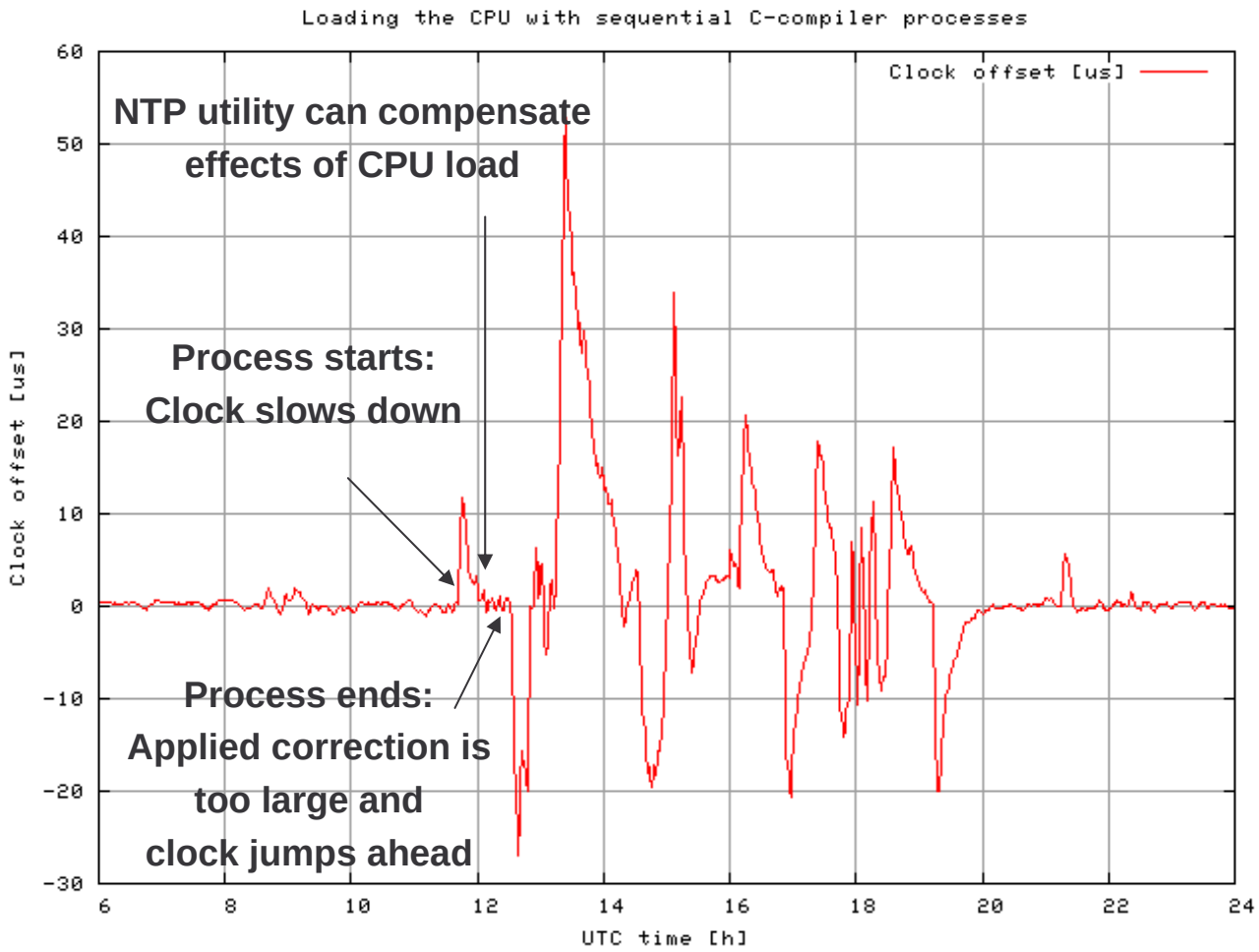
Upper and lower bound for individual clock offset



Upper bound for inter-computer clock offset



Loading the CPU with sequential C compiler processes



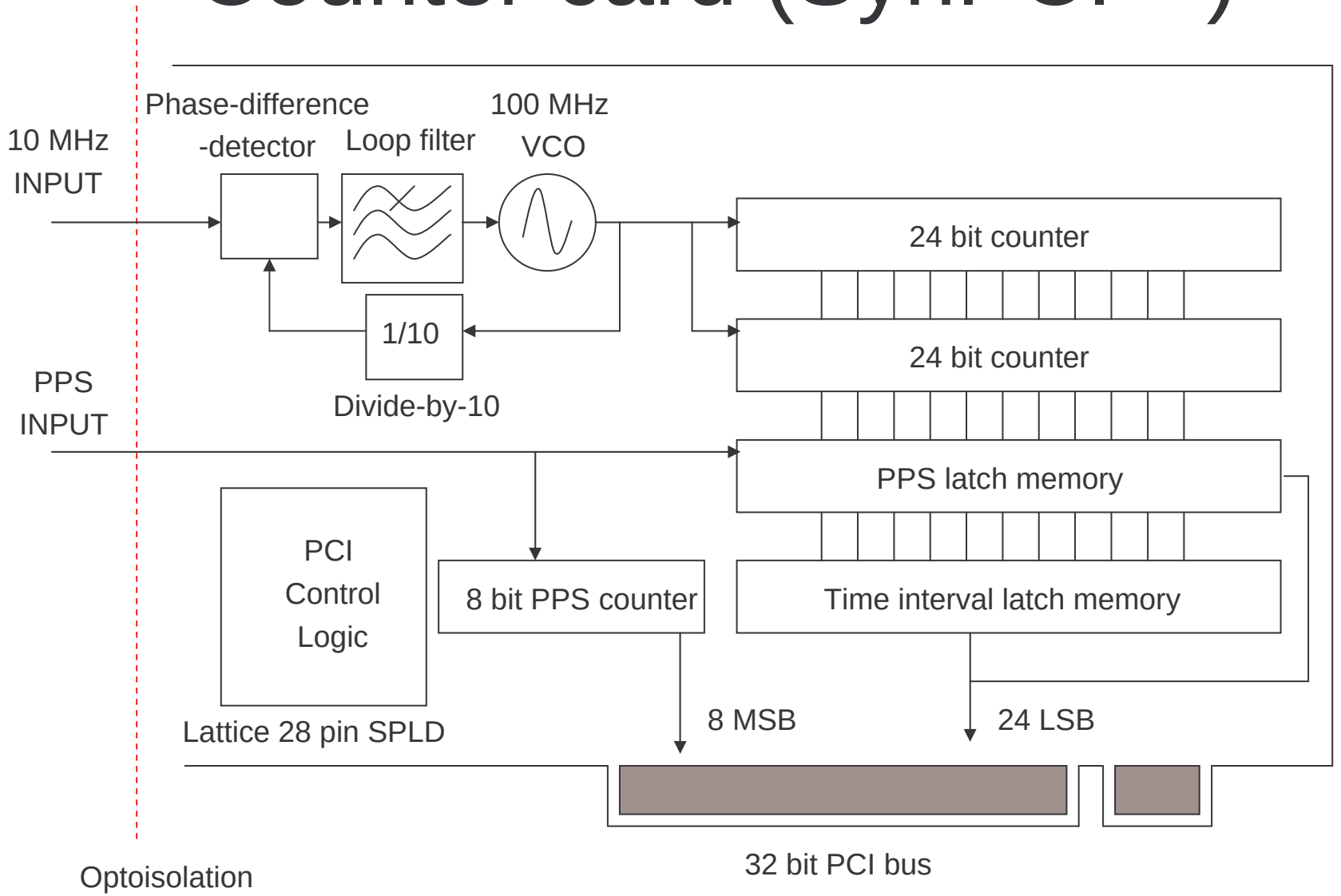
Conclusions

- Inter-computer clock offset < 46 us (99%)
- Major error contributors:
  - Prosessing delay on serial port (avg 10 – 20 us)
  - Temperature fluctuations can cause periodical clock offset as high as ± 20 us.
  - CPU load variations can cause over 50 us instantious clock offset.
- NICE, BUT NOT ENOUGH!!!
  - What time is it, sir?
    - » well it’s 12:15:36.455567 ± 20 us
- Let’s go even further and push the GPS system to it’s limits.

Part 2

- Motherboard’s timer interrupts determine only the time instant when system clock is updated.
  - Actual time increment between two successive timer interrupts is determined using counter card.
- Several error factors should be minimized:
  - PLL vs Temperature fluctuations
  - Dynamic time increment vs CPU load variations
- One might be attempted to modify motherboard directly but more general solution is desirable.

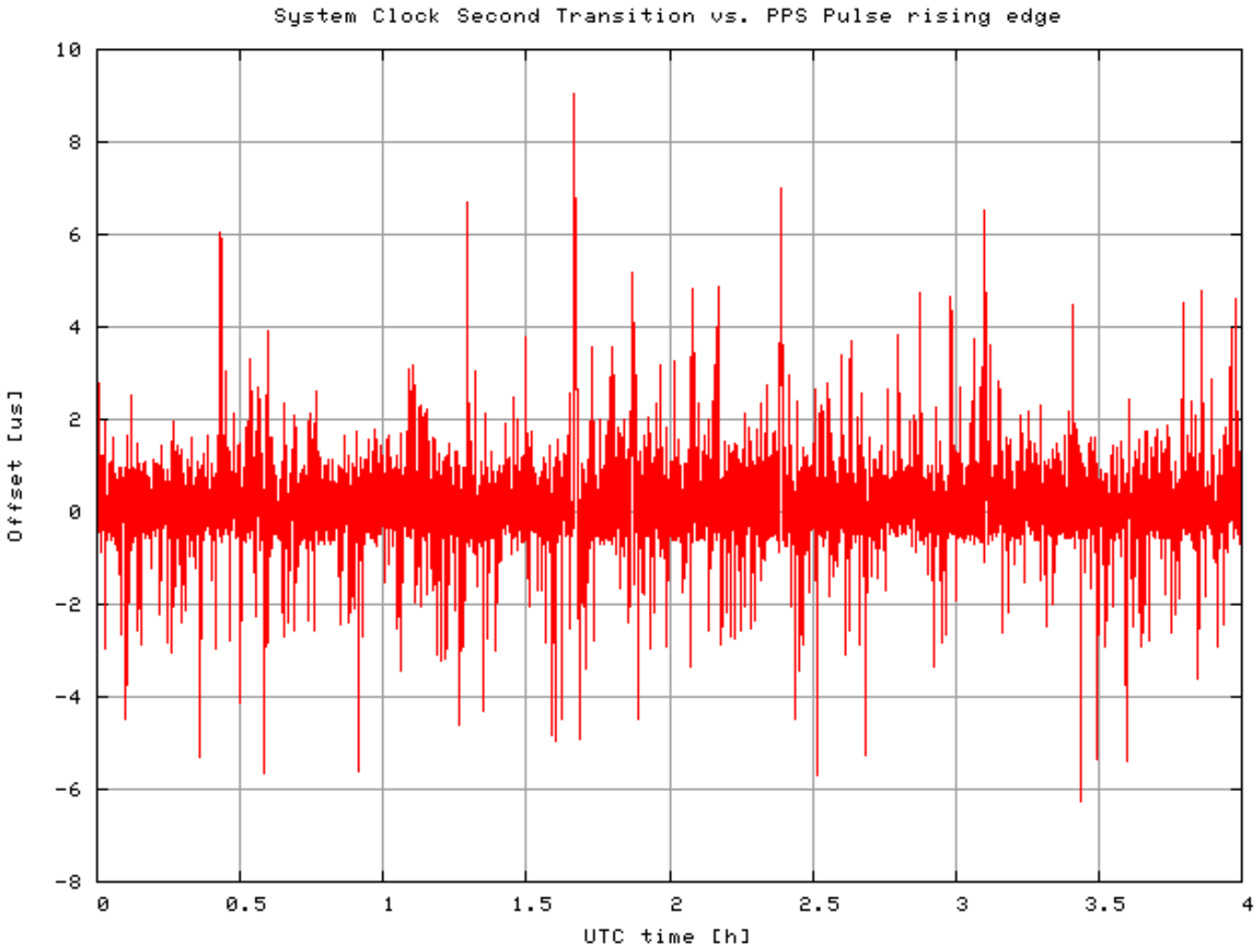
Counter card (SynPCI™)



Counter card (SynPCI™)

- Count resolution: 10 ns
- Maximum count: 167 ms
- Mapped on I/O address space (0x0000 – 0xFFFF)
  - Address is configured with on-board jumpers
- For example: configured address 0x300
  - I/O read from 0x300 ->
    - » poll active counter value
  - I/O read from 0x304 ->
    - » read counter value + 8 bit PPS counter value and change active counter
  - I/O read from 0x308 ->
    - » read PPS latch value

System clock second transition vs PPS pulse rising edge



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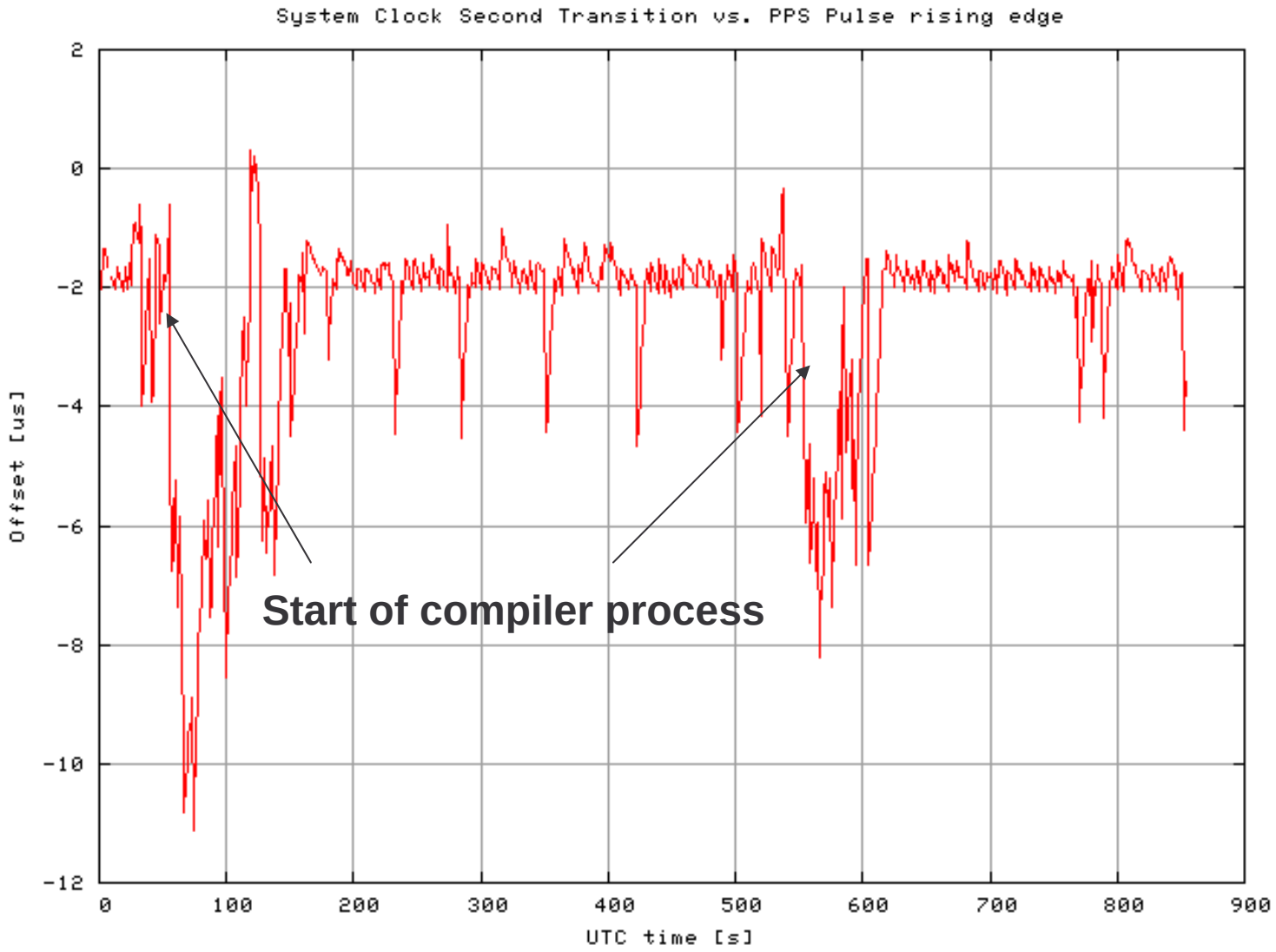

Conclusion

- NICE AND ALMOST ENOUGH!!!
- Minor clock adjustments are still needed
- Time increments should be filtered to enhance system clock stability.
- Reading the system clock accurately is yet another problem.
  - If time reading procedure is delayed, the time it returns can be several microseconds wrong.
- Possible Applications
  - Test networks, time critical network services and general timing.

Any Questions?

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Research must go on!

Please keep us in mind when giving away your money!