NetTimeLogic GMBH

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Capabilities and benefits

Time Card with PCIe PTM support

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What is PCIe PTM?

Precision Time Measurement (PTM)

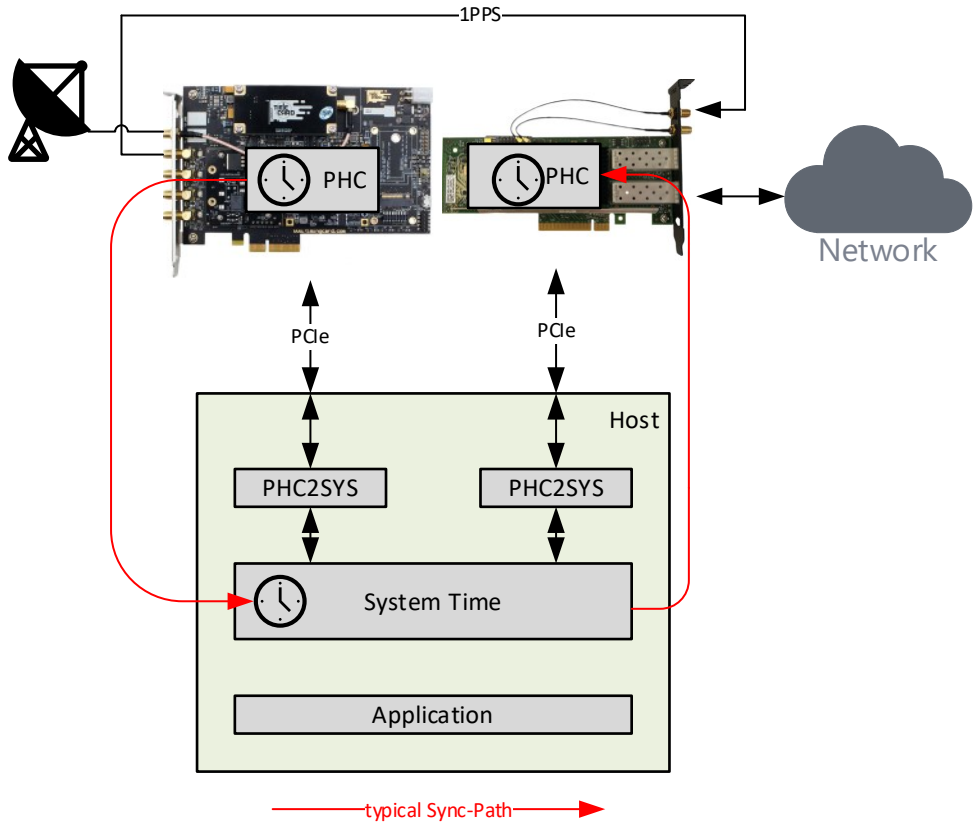
- **Introduced in PCI-SIG® PCI Express 3.0 specification**
  - Released in 2010
- **Aligns PCIe devices to a common clock source for highly accurate timing**
  - Protocol of timing measurement and synchronization messages
- **Nanosecond-Level Accuracy: Ensures precise coordination across devices, minimizing clock drift**

- **More information: a very good and detailed presentation:**
  - Precision Time Within the Computer - In the Last Centimeters (Kevin B. Stanton)

What is PCIe PTM?

How does it work without PTM

- **Time Card without PTM:**
  - Delay between reading the PHC value and updating the System Time is load dependent
  - 1PPS over an external wire to the NIC is used to achieve the required accuracy



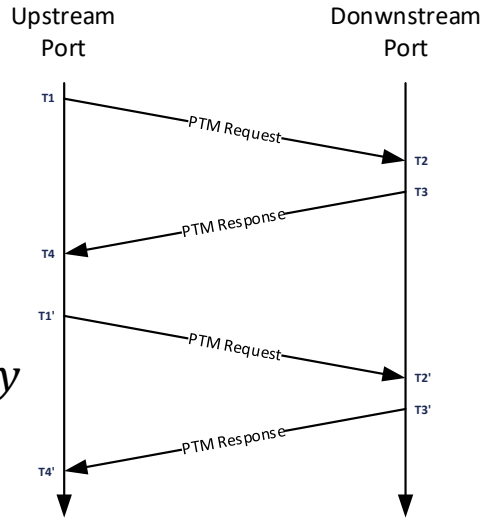
What is PCIe PTM?

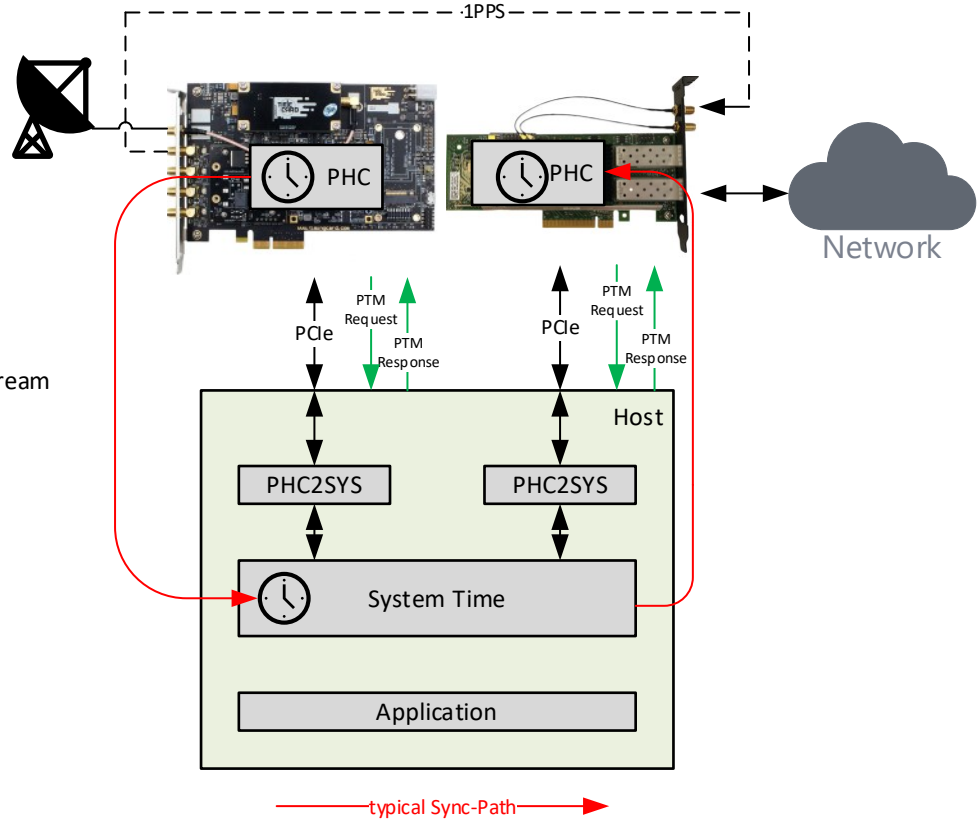
How does it work with PTM

- **Time Card with PTM:**
  - Time Card sends PTM Requests
  - Host responds with PTM Responses
  - LinkDelay can be calculated
  - Time can be calculated

$$LinkDelay = \frac{\big((t4 - t1) - (t3 - t2)\big)}{2}$$

$$PTM\ Master\ Time\ @\ t1' = t2' - LinkDelay$$





How to get PCIe PTM on the Time Card?

Starting point

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- AMD **AXI Memory Mapped to PCI Express (PCIe) Gen2 bridge**
  - → no PTM support
- Initial LitePCIe version (open-source)
  - → no PTM support
- LitePCIe with PTM support
  - → finally PTM support on an AMD FPGA ☺

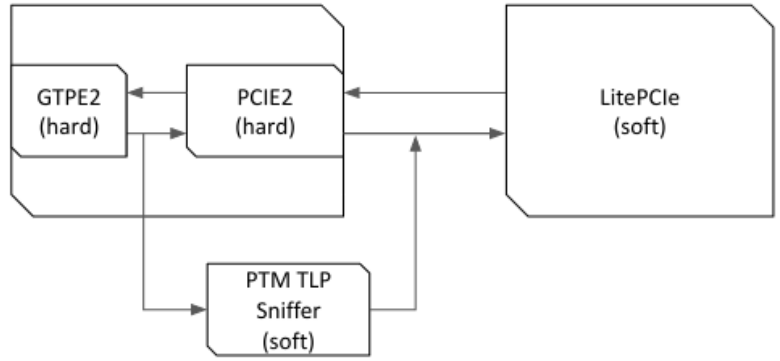
https://github.com/enjoy-digital/litepcie_ptm_test

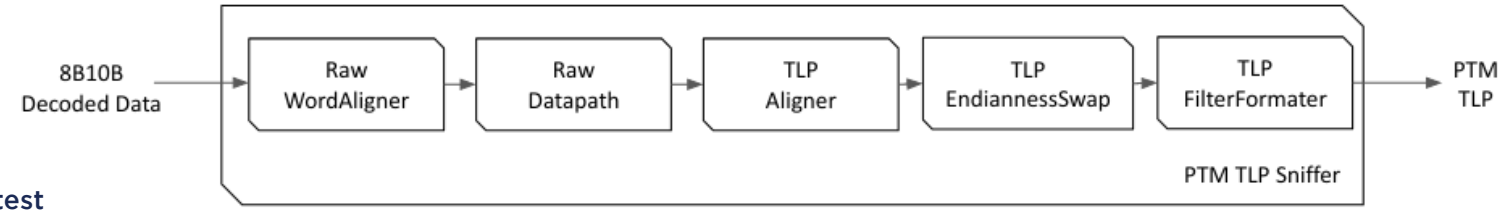
Thanks a lot to the great work of Florent from EnjoyDigital

How to get PCIe PTM on the Time Card?

AMD PHY workaround

- LitePCIe wraps existing PHYs from FPGA vendors
- The Artix PHYs did not redirect the PTM TLP messages
- PCIePTMSniffer has been implemented:



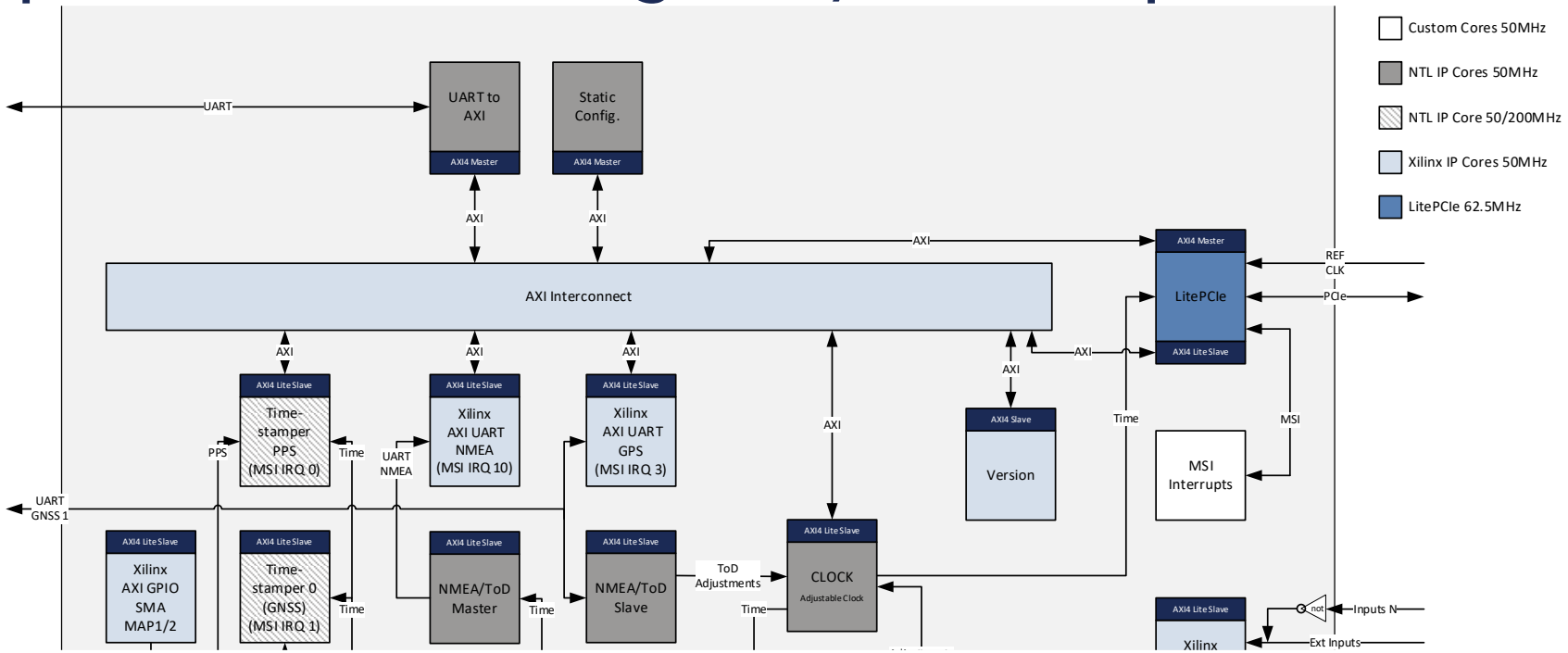


Picture Source: https://github.com/enjoy-digital/litepcie_ptm_test

How to get PCIe PTM on the Time Card?

Integration into the Time Card FPGA design

- LitePCIe has a PTM Time Interface (Clk, Reset and Time in ns)
- LitePCIe gets the time from the PHC of the Time Card
- LitePCIe provides different registers/timestamps to handle PTM in the driver



How to get PCIe PTM on the Time Card?

Integration into the Time Card Driver design

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- **getcrossstamp calls syncdevicetime**
  - Trigger a PTM Request from the Time Card
  - Wait until the PTM State is not busy and the internal PTM Status becomes valid
  - Read t1', get t2' and the propagation delay (t3-t2) from the PTM Response
  - Calculation of the PTM Master Time (@ t1'): t2'- LinkDelay
  - Returned as Cross-Timestamp

PTM Requirements

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- **PTM devices require hardware time stamping**
  - Time stamping of TLPs on transmission and reception
- **PTM-enabled Root Complex (PCIe host controller)**
- **Firmware and drivers that support PTM**
- **Application that uses it**

→ PCIe 3.0 or later is not really a requirement for the endpoint devices

PTM Capabilities

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- **Precise correlation of clocks within a platform**
  - Synchronize the host from a device
  - Synchronize a device from the host
- **Minimize the drift between devices**
- **Dynamic Time Adjustments**
  - e.g., with linuxptp phc2sys
- **Accurate latency measurement of the communication channel**

PTM Benefits

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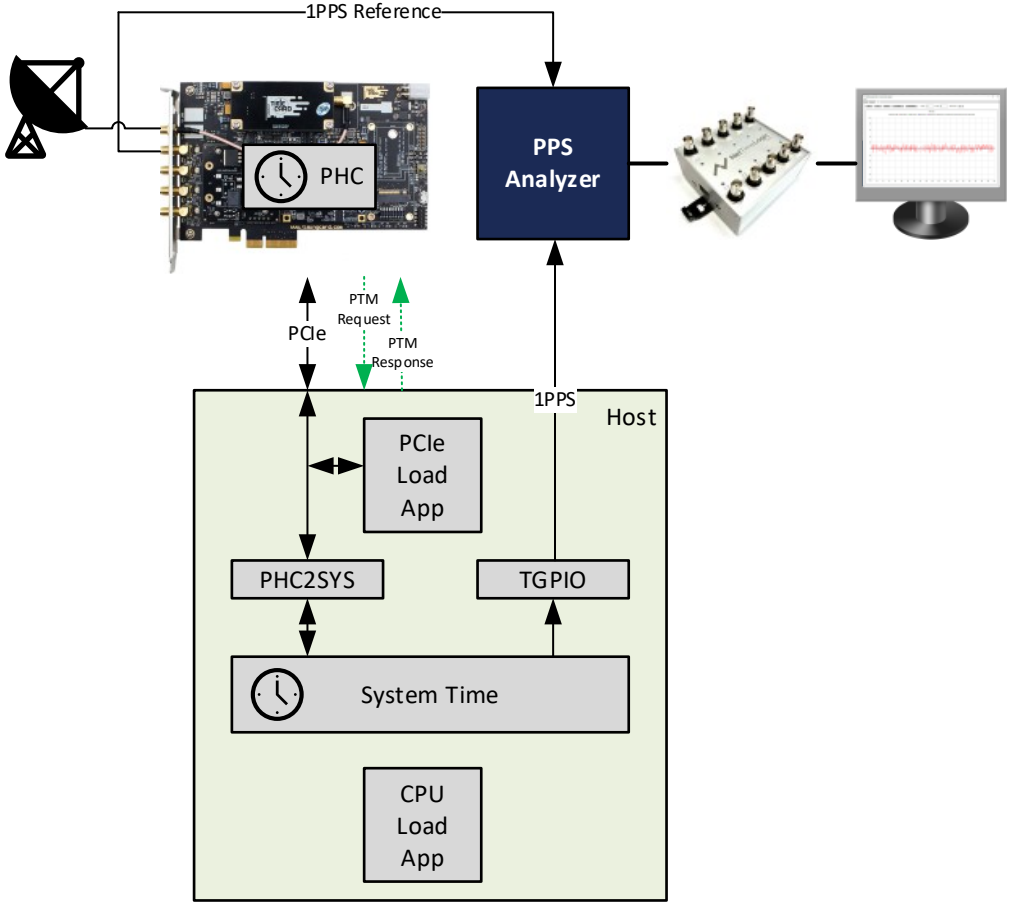
- Reduced Timing Jitter in a system
- Improved Accuracy in a system
- Improved Determinism in a system
- Precise Cross-Device Synchronization
  - PTM allows easy combination with PTP

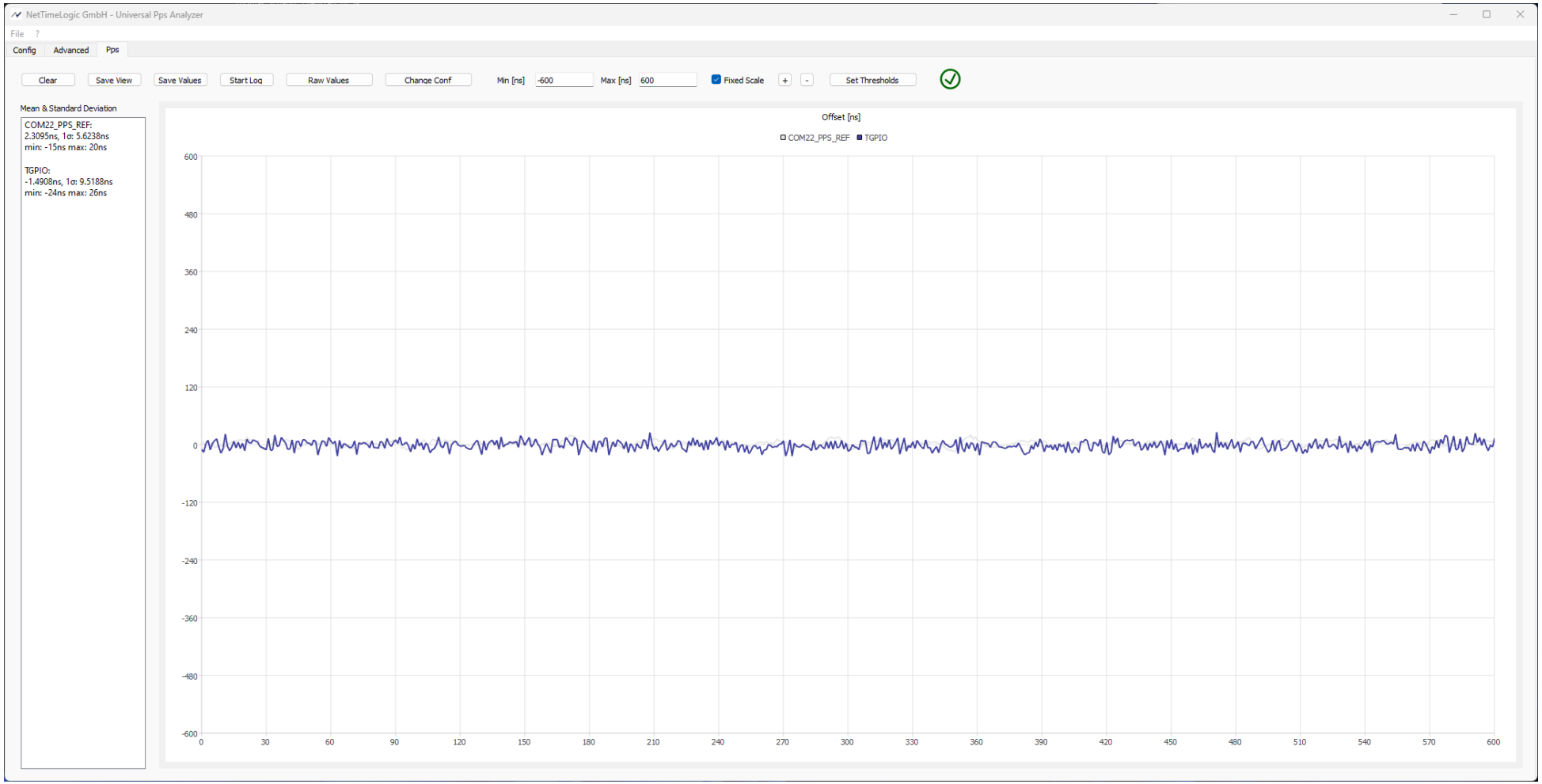
Measurements
Test Setup



- Measured 1PPS Ref Jitter: +/- 20ns
- Measurement Duration: 10 minutes
- PCIe Load App that reads a lot of registers on the Time Card
- CPU Load App that creates up to 100% CPU load
- linuxptp v4.3 was used
- App generates a 1PPS from the system time of the host and provides it to a TGPIO pin

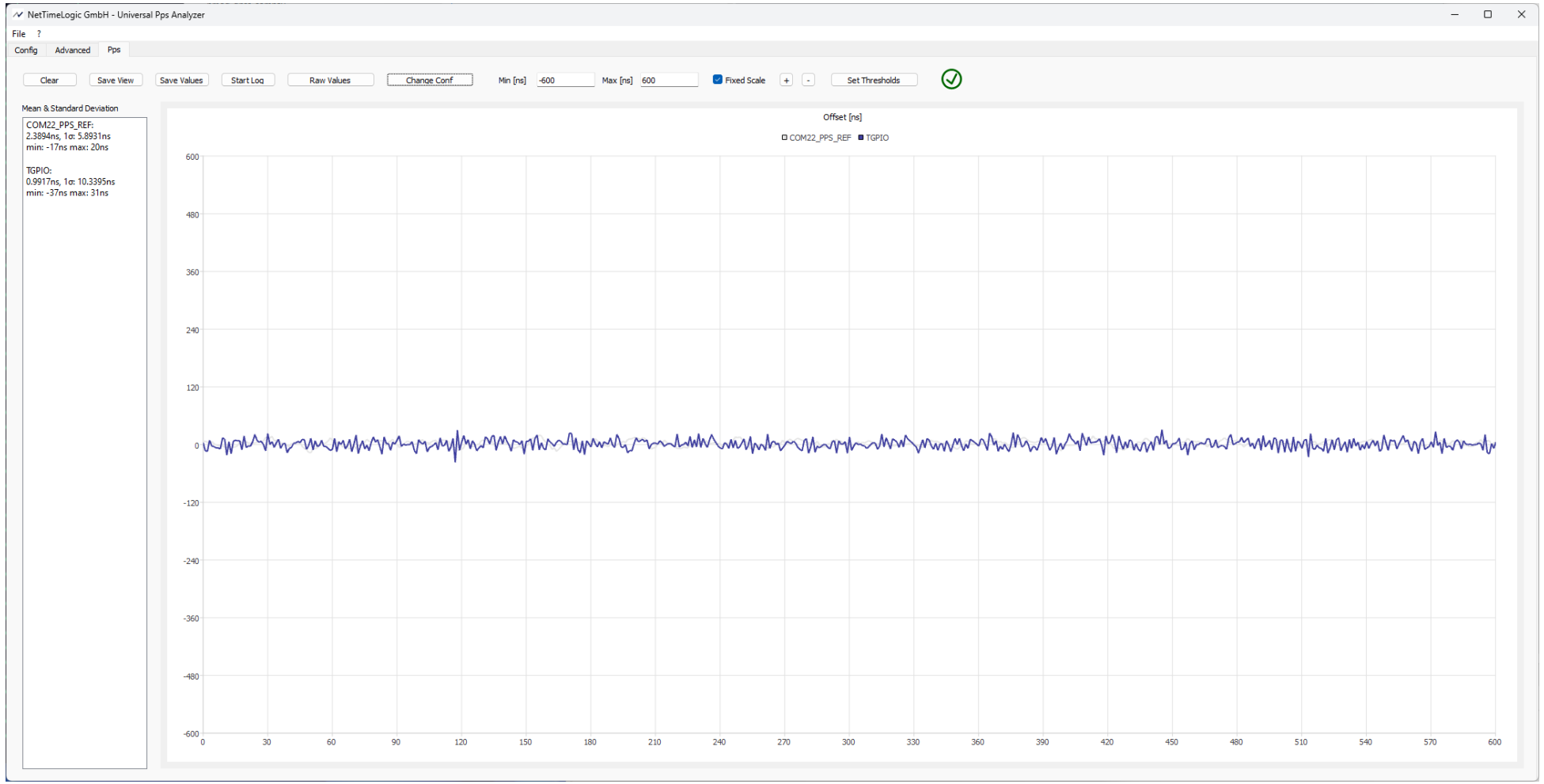
Measurements

Without PTM - No load on PCIe and CPU



Measurements

With PTM - No load on PCIe and CPU



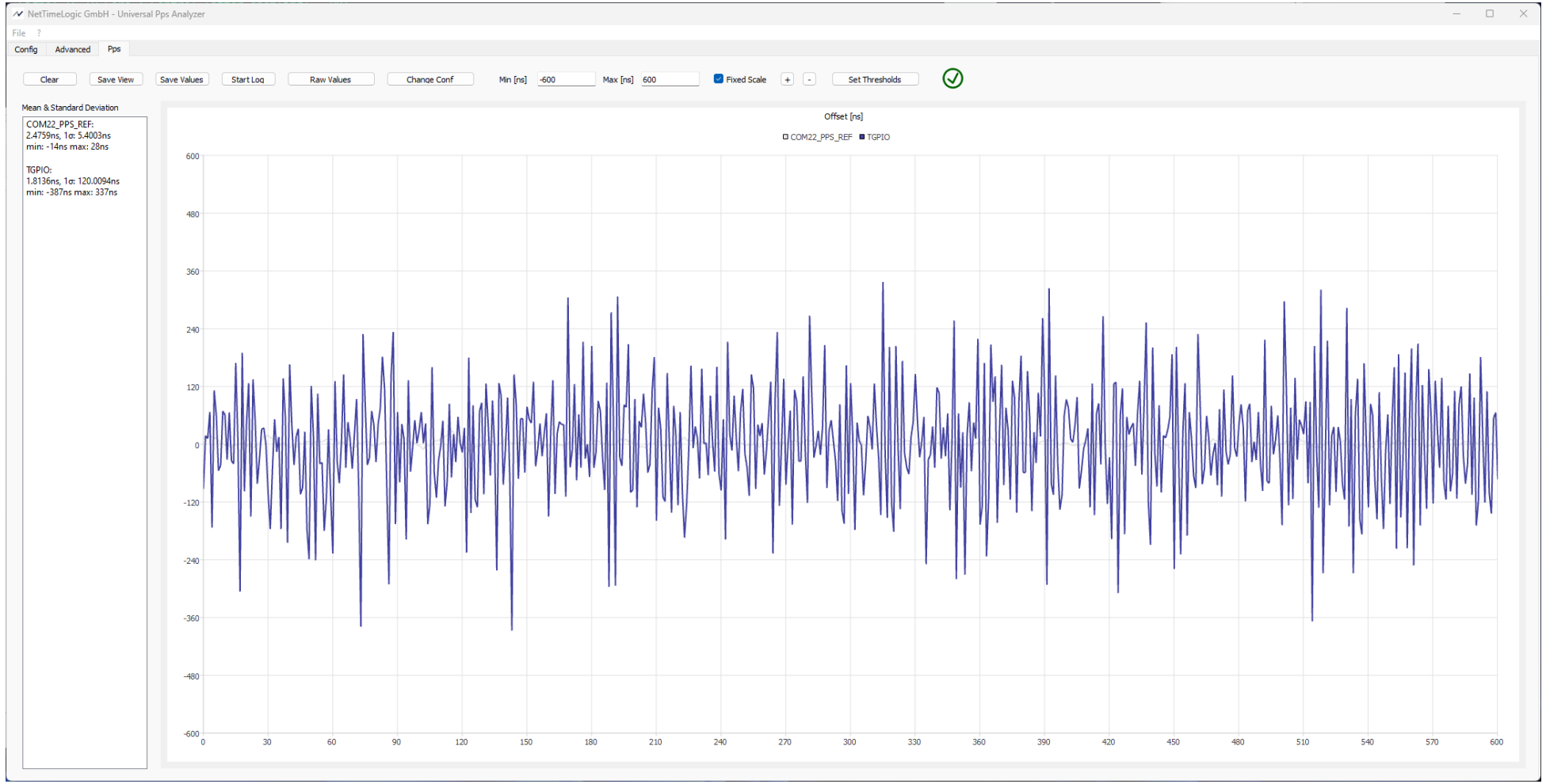
Measurements

No load on PCIe and CPU

- No measurable difference between the version with PTM and without PTM support
- TGPIO Jitter: ~ +/- 30ns
- PCIe without PTM support can achieve similar synchronization accuracy when almost no load is applied

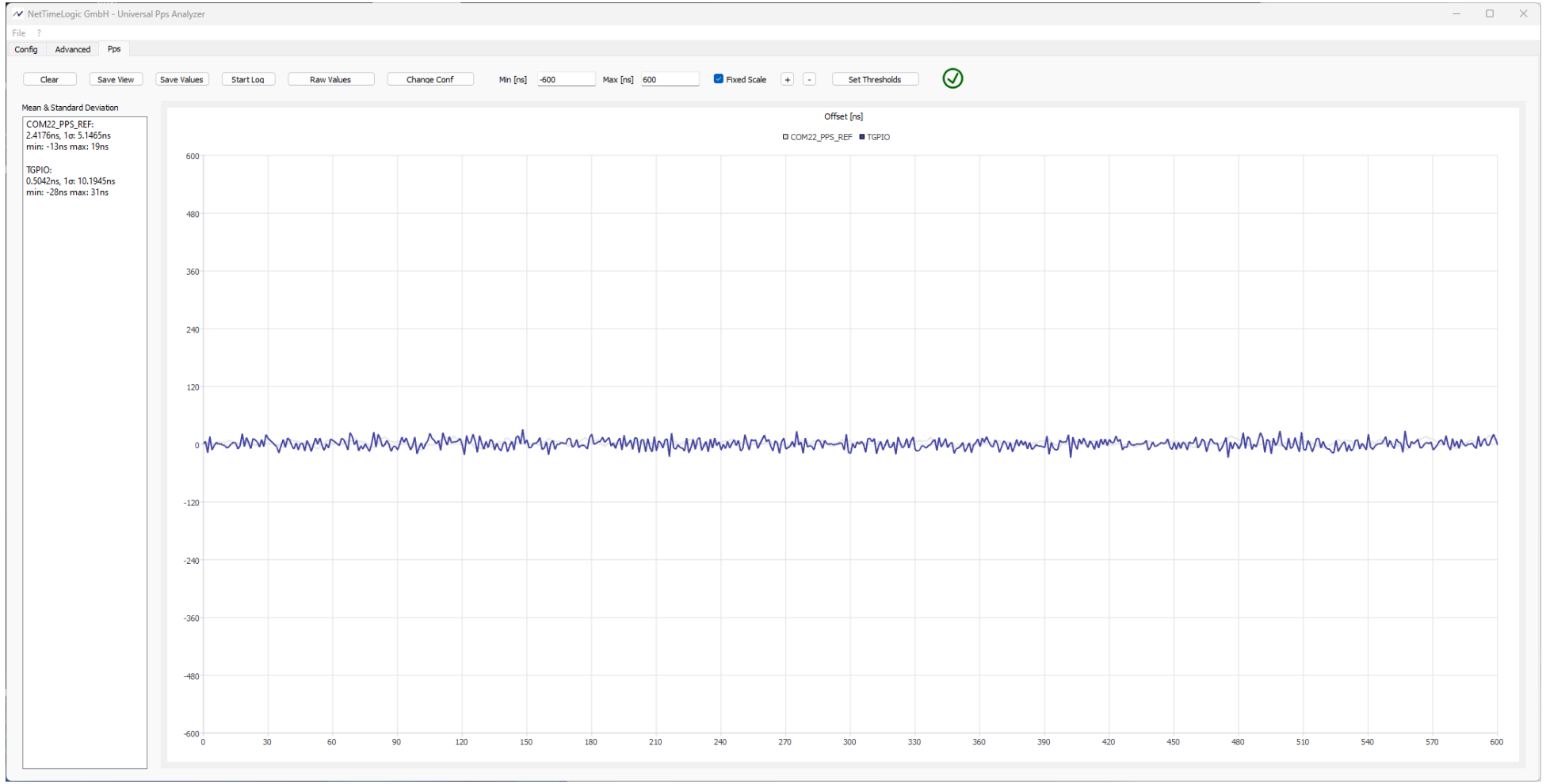
Measurements

Without PTM - Load on PCIe and CPU



Measurements

With PTM - Load on PCIe and CPU



Measurements
Load on PCIe and CPU

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- **Without PTM support:**
  - TGPIO Jitter: > +/- 330ns
- **With PTM support:**
  - TGPIO Jitter: ~ +/- 30ns
  - Immunity against both kind of load
- **CPU load only does not really affect the synchronization accuracy with and without PTM**

Conclusion

- The measurement confirms the expectations
- The difference between PTM and no PTM support is not huge when there is no load
- With PTM we get immunity to load on the PCIe-Bus and on CPU load
- PTM support ensures that accuracy remains unaffected

Future Work and Vision

- **Make Time Card FPGA Design available for all versions**
- **Deploy the Time Card with PTM**
  - Show the benefits of PTM
- **Mainline the PTM capable driver**
- **Promote the PCIe PTM capable LitePCIe solution for AMD FPGAs**
  - It is currently the only known solution for AMD FPGAs

Questions?

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Thank you!

See Network Timing, Network Redundancy and our modular Hardware Platform AIONYX live at our booth!!!

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