

Implementation of an Acquisition and Monitoring Module Based on the PTPv2 Protocol on EAST

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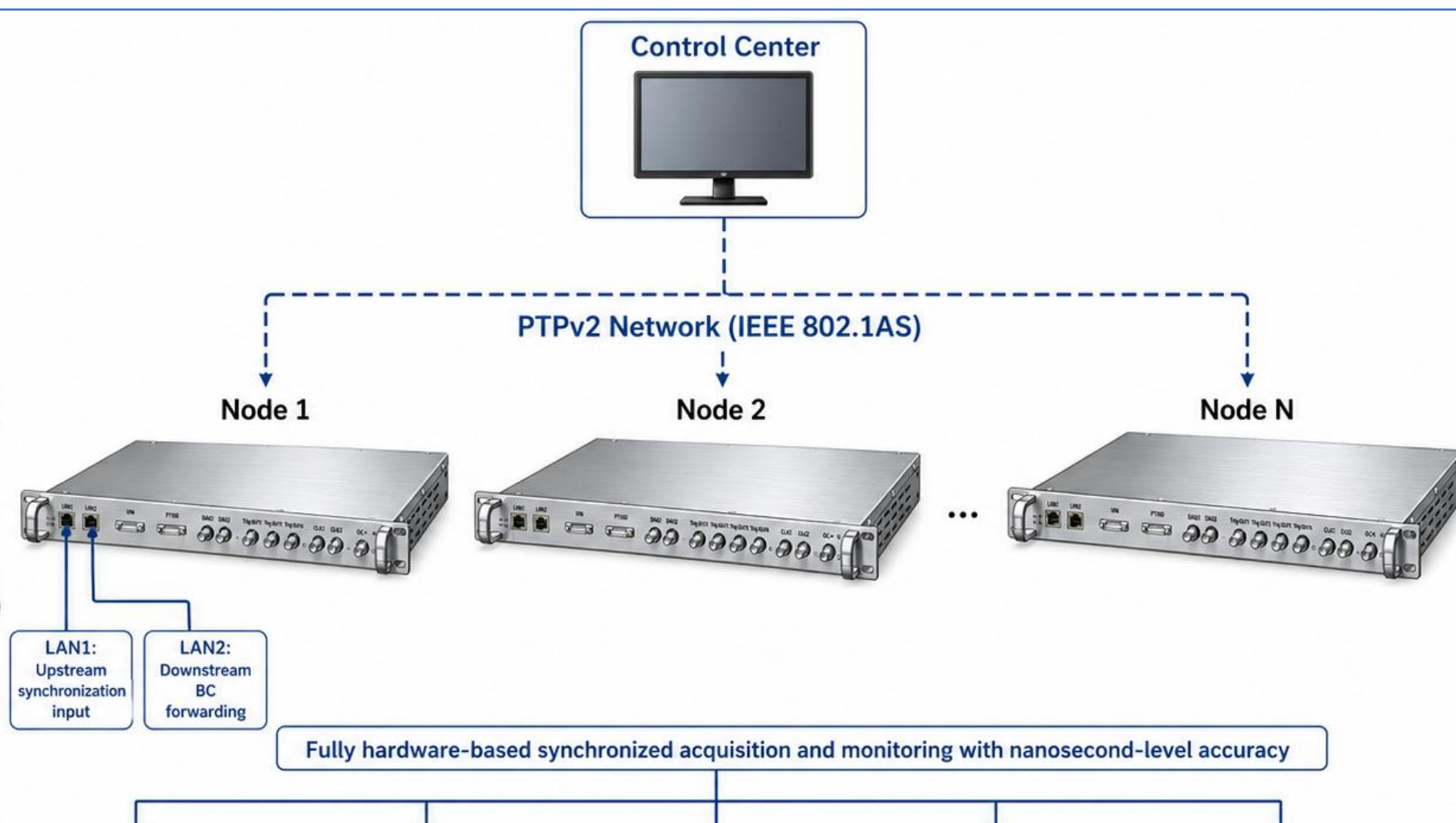
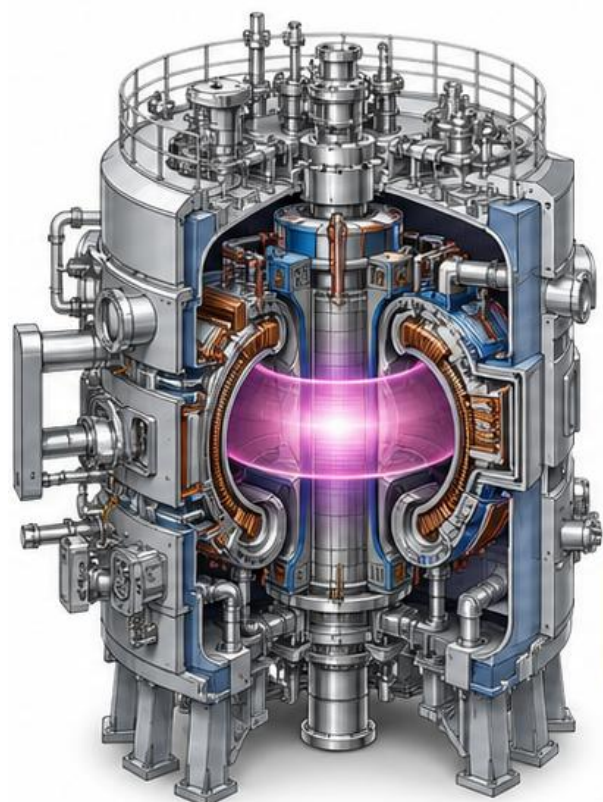
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ABSTRACT: There are a large number of distributed control and monitoring devices in magnetic confinement fusion facilities. It is essential to conduct real-time monitoring of key parameters (such as temperature and voltage) of these devices, which is of great significance for ensuring the safe operation of the facilities and their associated systems. This paper designs a set of monitoring equipment with Field Programmable Gate Array (FPGA) as the core based on the PTPv2 protocol. First, the equipment supports the PTPv2 protocol to ensure consistent timestamps among acquisition and monitoring devices. Second, it is equipped with multi-range voltage conditioning and wide-temperature-range temperature acquisition channels, which, combined with a high-resolution analog-to-digital conversion module, enable dynamic acquisition and data processing of weak signals. Third, the equipment features self-test and remote start-up functions, facilitating remote device management. Test results show that the synchronization accuracy between devices is better than 50 ns; the voltage measurement accuracy is better than 0.04% F.S. in the low range (0–1 V) and better than 0.02% F.S. in the high range (1–10 V); within the temperature range of 20 K to 325 K, the acquisition error does not exceed 0.13 K. All these indicators meet the design requirements.

1 Introduction

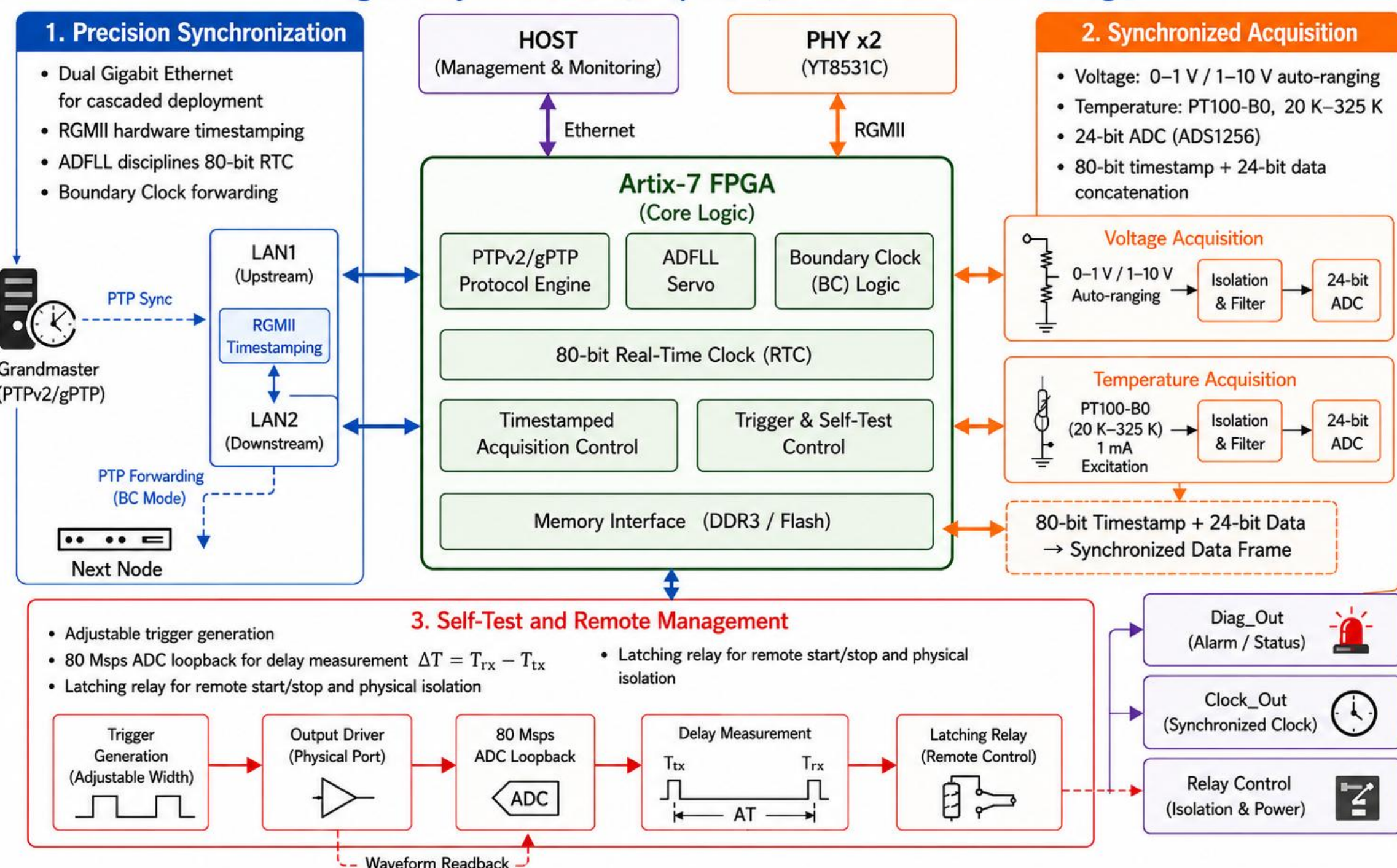
- EAST tokamak operation relies on distributed monitoring systems requiring unified nanosecond-level time base and accurate spatiotemporal data alignment.
- Traditional NTP and independent hardware trigger schemes are difficult to apply in large-scale networks with typical PTPv2 devices based on hardware timestamping + protocol stack.
- This work presents a full-hardware PTPv2 acquisition and monitoring module on a Xilinx Artix-7 FPGA.
- The system incorporates a Boundary Clock (BC) forwarding mechanism to support daisy-chain deployment, providing a reliable and scalable hardware solution for EAST distributed monitoring.

EAST Tokamak



FPGA-Based PTPv2 Acquisition and Monitoring Module

Integrated Synchronization, Acquisition, Self-Test and Remote Management



2 System Design and FPGA Implementation

Built around an Artix-7 FPGA integrating PTPv2 synchronization, multi-modal acquisition, trigger self-test, and remote management.

1 Precision Synchronization

- Dual Gigabit Ethernet ports support cascaded deployment.
 - LAN1 receives PTPv2/PTP messages
 - LAN2 performs Boundary Clock forwarding
- Hardware timestamps in the BMCA interface ensure nanosecond-level synchronization.

2 Synchronized Acquisition

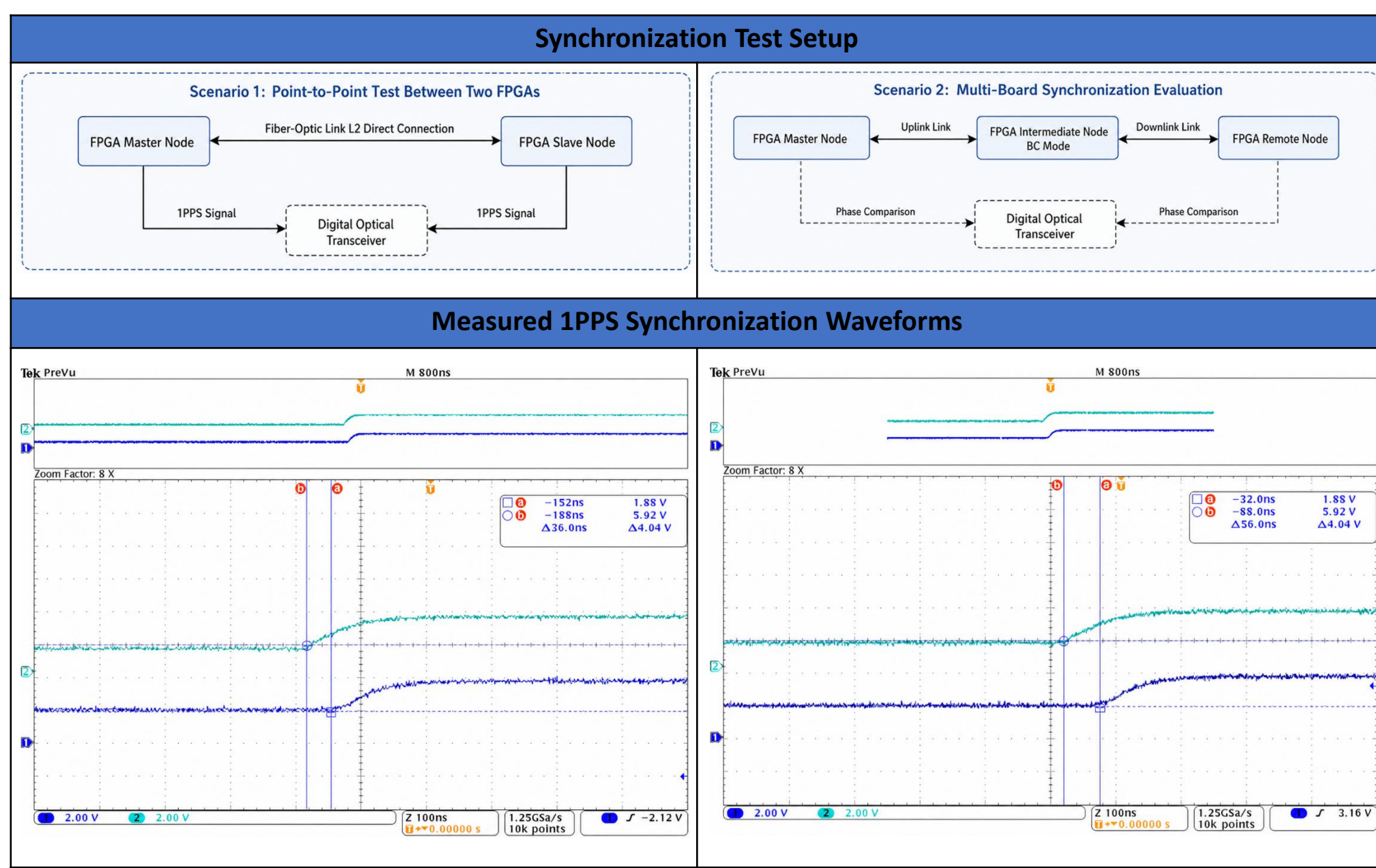
- Voltage channel supports automatic 0–1 V / 1–10 V range switching with 1 mA excitation for PT100.
- 18-bit $\Delta\Sigma$ ADC data enable spatiotemporal alignment.

3 Self-Test and Management

- Multiple trigger pulses for loop delay measurement.
- Remote start/stop control and physical isolation for reliable field operation.

3 System Test and Results

Test platform: FPGA monitoring module, Tektronix oscilloscope, precision resistance box, and MMB multimeter.



- **Direct-link synchronization:** 1PPS phase difference ≈ 36 ns, with peak deviation below 50 ns.
- **Cascaded synchronization:** End-to-end timing error ≈ 56 ns, remaining within 100 ns.
- **Boundary Clock forwarding:** Local time reconstruction suppresses error accumulation in multi-board cascades.
- **Timestamped acquisition:** Each 24-bit ADC sample is concatenated with an 80-bit PTP absolute timestamp.
- **Acquisition accuracy:** Voltage accuracy reaches $<0.04\%$ F.S. and temperature error remains <0.13 K.

Acquisition Performance Summary Table		
Test Item	Condition	Result
Timestamped acquisition	10 kHz sampling	100000 ns interval
Low-range voltage	0–1 V	Max error: 0.40 mV, $<0.04\%$ F.S.
High-range voltage	1–10 V	Max error: 1.88 mV, $<0.02\%$ F.S.
Temperature sensing	20–325 K	Error <0.13 K
Data frame	ADC + PTP time	24-bit data + 80-bit timestamp

4 Conclusion

- ✓ This paper designs and implements an FPGA-integrated monitoring module based on the PTPv2 protocol to address the synchronization and acquisition needs of distributed nodes in the EAST device.
- ✓ The system suppresses non-deterministic software jitter, achieving synchronization accuracy better than 50 ns.
- ✓ It integrates multi-range voltage and wide-temperature channels, featuring wide-range dynamic signals and precise measurement.
- ✓ Tests indicate the performance meets expectations, providing a highly reliable hardware solution for distributed monitoring in traditional systems.
- ✓ Future work will explore integrating Time-Sensitive Networking (TSN) technology for deterministic transmission and high-concurrency environments to further enhance online computing algorithms and improve the fusion device's safety interlock system.

5 References

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