Phase Stable RF Transmission System Based On MicroTCA

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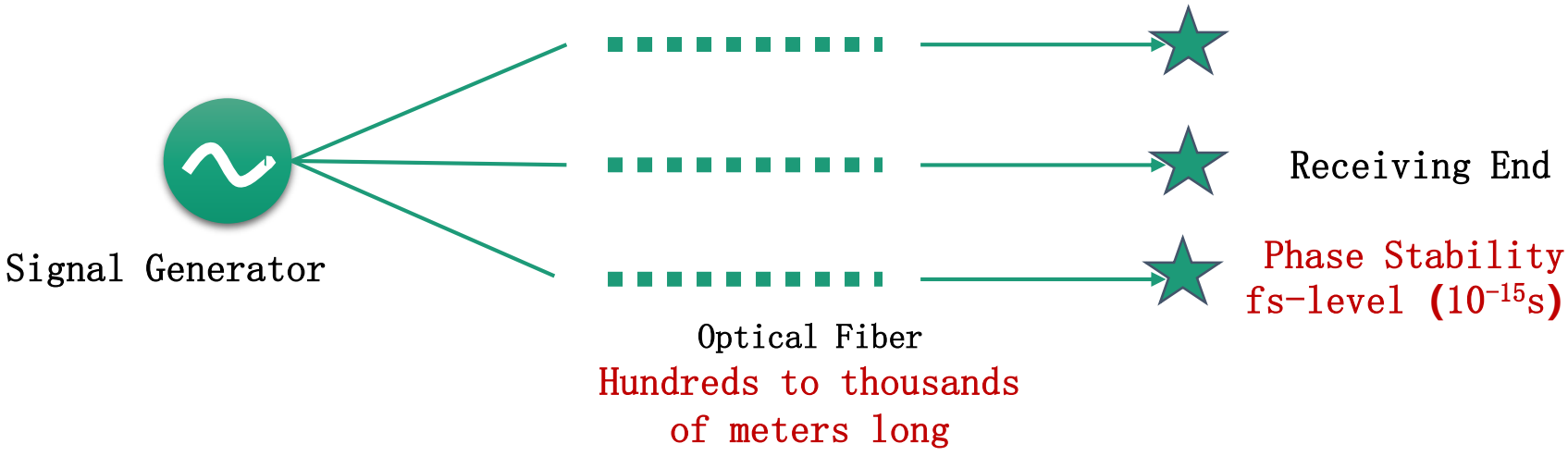
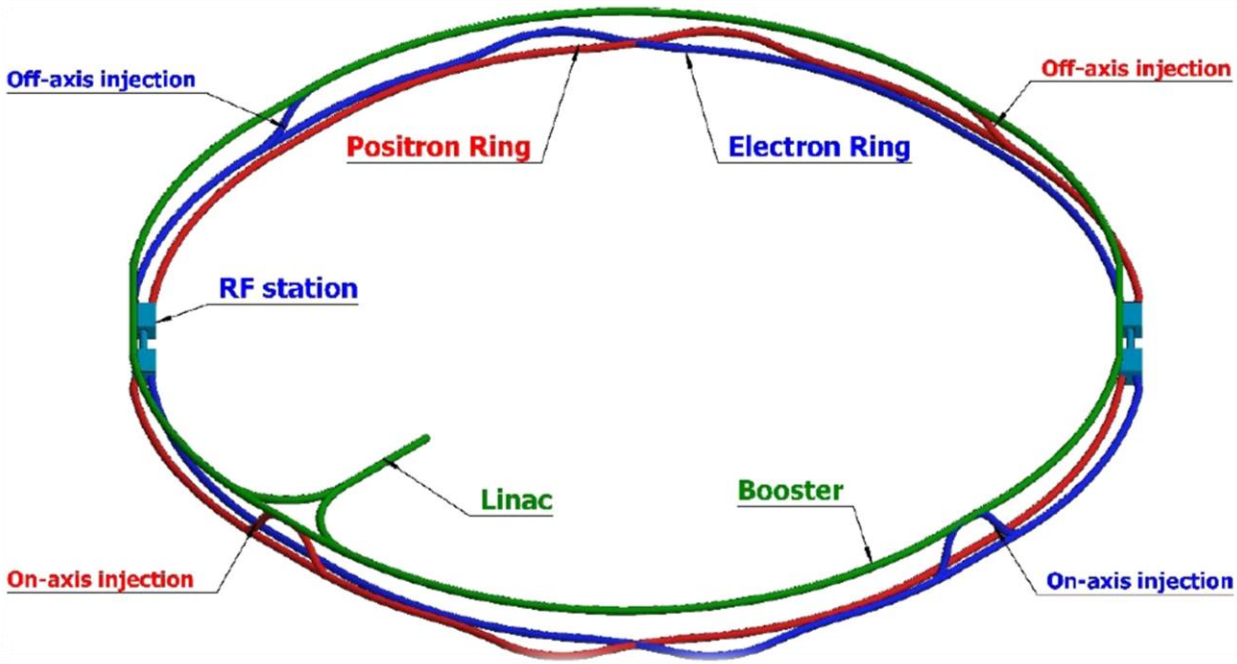
RF Transmission System

- Phase synchronization accuracy will influence the operation stability of the particle colliders and the light sources driven by accelerators.
- The next generation of particle colliders and light sources require the standard RF phase with stability of femtosecond-level.

- RF transmission system is used to assign the standard RF phase to each node of the accelerators. It can transmit the RF signal P2P or P2MP, and control the RF phase noise, the short-term phase stability and long-term phase drift in femtosecond-level.



Circular Electron Positron Collider (CEPC/IHEP)

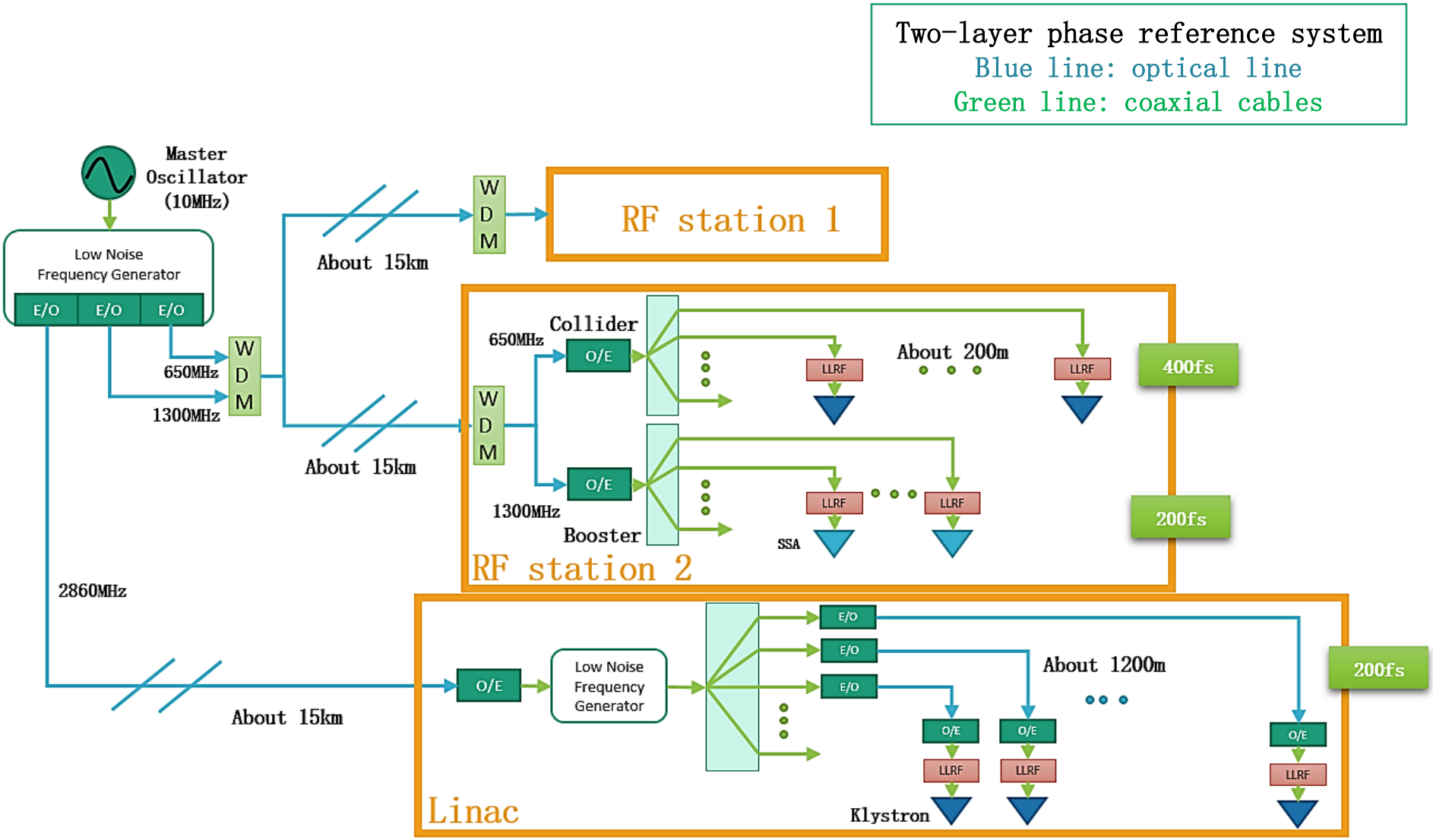


Main parameters	Value
Linac length	1.2km
Injection energy	10GeV
Booster energy	240GeV
Circumference	100km
Center-of-mass energy	240GeV

The requirement of the phase synchronization accuracy for CEPC is 0.2°, corresponding to hundreds of femtoseconds at several main frequencies (500 MHz, 1300 MHz, 2856 MHz).

-- CEPC Conceptual Design Report, Volume I Accelerator

RF Transmission and Distribution System of CEPC



RF Transmission System Overview

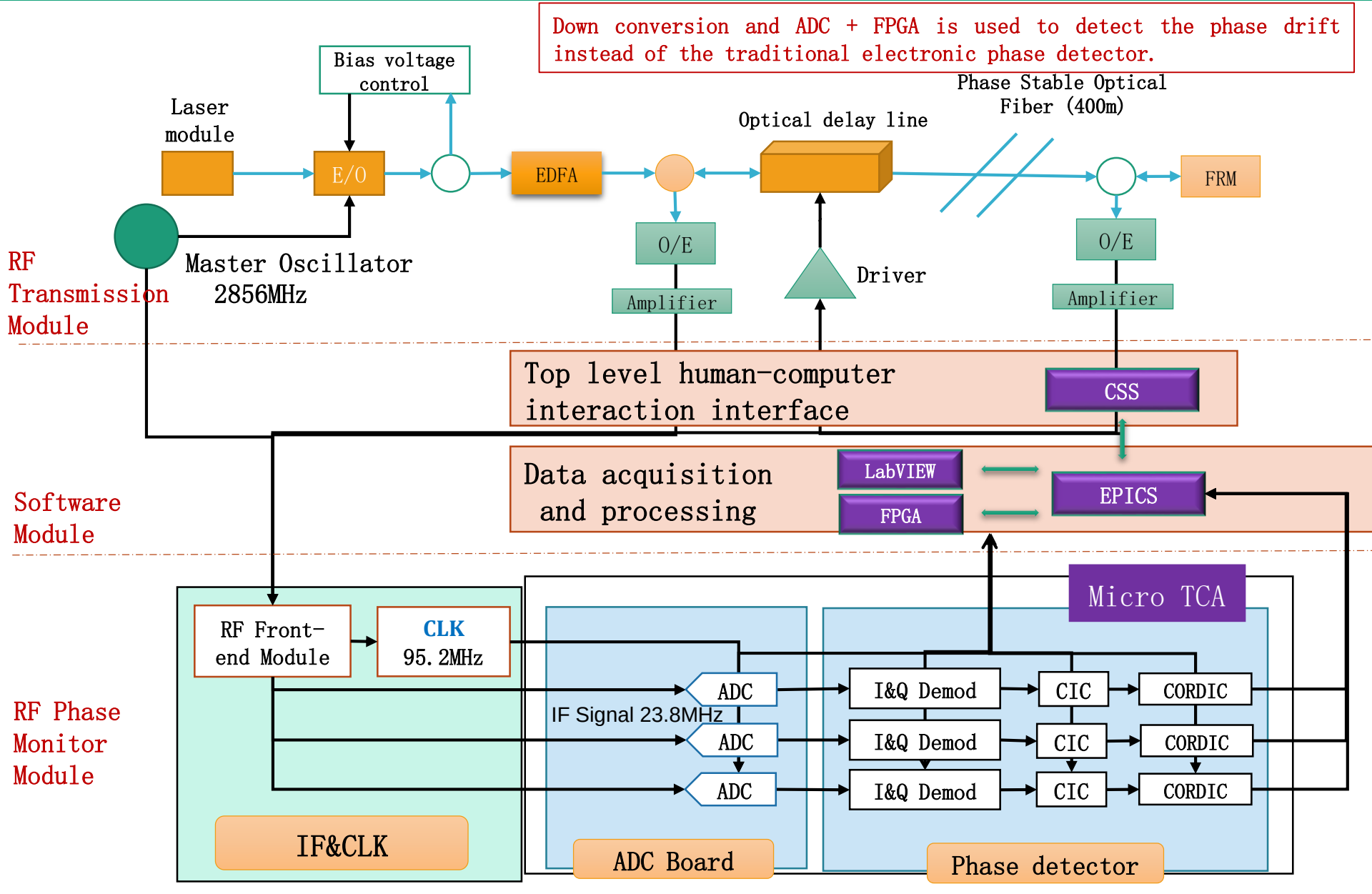
- RIO Narrow Linewidth Laser → 1550nm CW laser
- Agilent Analog Signal Generator → 2856MHz RF signal

- RF signal is modulated onto the CW laser through E/O, and transmitted to the receiving end.
- Phase stable optical fiber. (TCD is 7ps/km/K)
- Faraday Rotator Mirror is placed at the receiving end to reflect the forward CW laser.

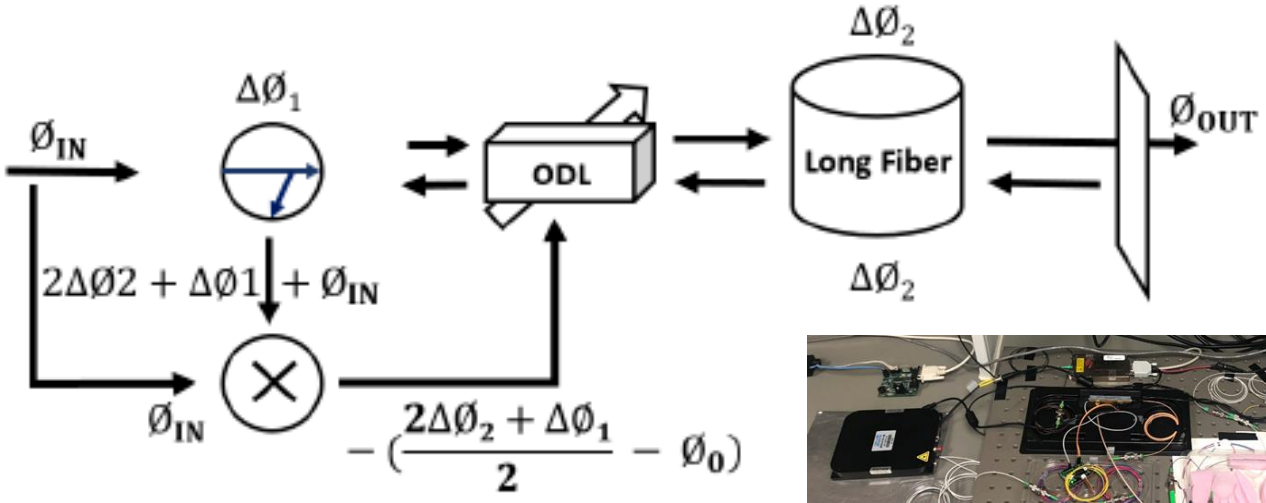
- Feedback loop was designed to eliminate the phase drift:
  - RF phase monitor module composed of RF front-end chassis and MicroTCA chassis is adopted to sample, calculate and compare the local and the reflected RF phase.
  - Optical Delay Line is used to compensate the phase drift by adjusting the fiber length.

Layout of The RF Transmission System

Down conversion and ADC + FPGA is used to detect the phase drift instead of the traditional electronic phase detector.



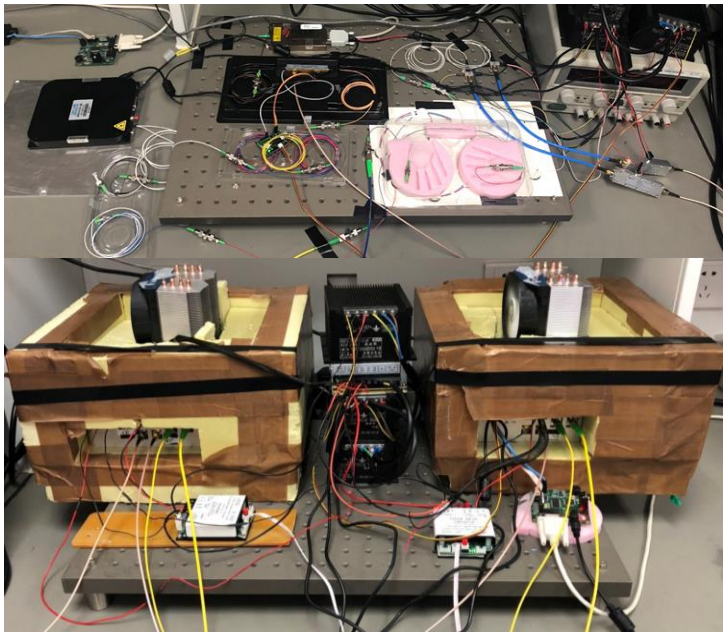
Layout of The Phase Drift Compensation Mechanism



$$\phi_{OUT} = \phi_{IN} + \Delta\phi_1 + \Delta\phi_2$$

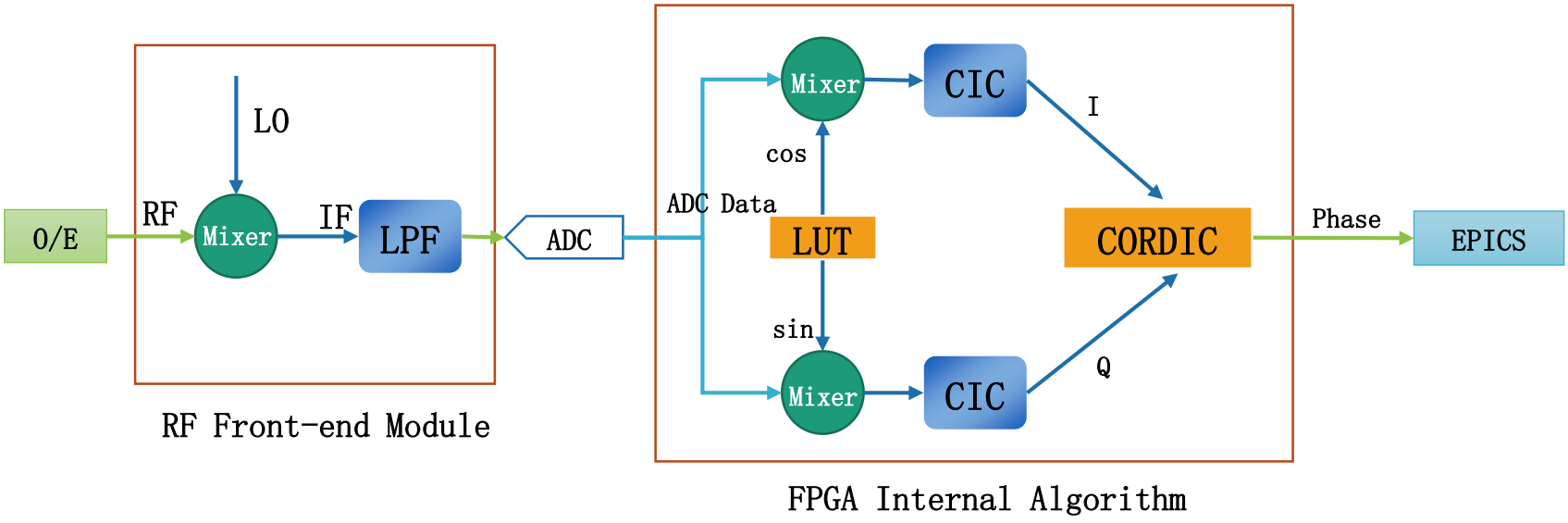
$$\phi_{OUT} = \phi_{IN} + \Delta\phi - \left(\frac{\Delta\phi_1 + 2\,\Delta\,\phi_2}{2} - \phi_0\right)$$

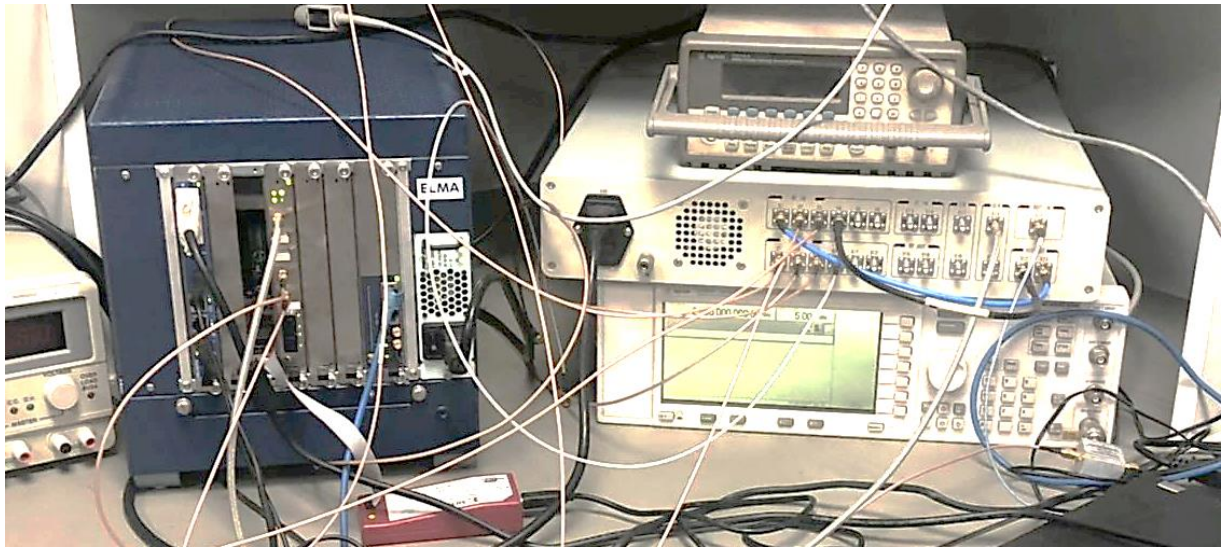
$$= \phi_{IN} + \phi_0 - \frac{\Delta\phi_1}{2}$$



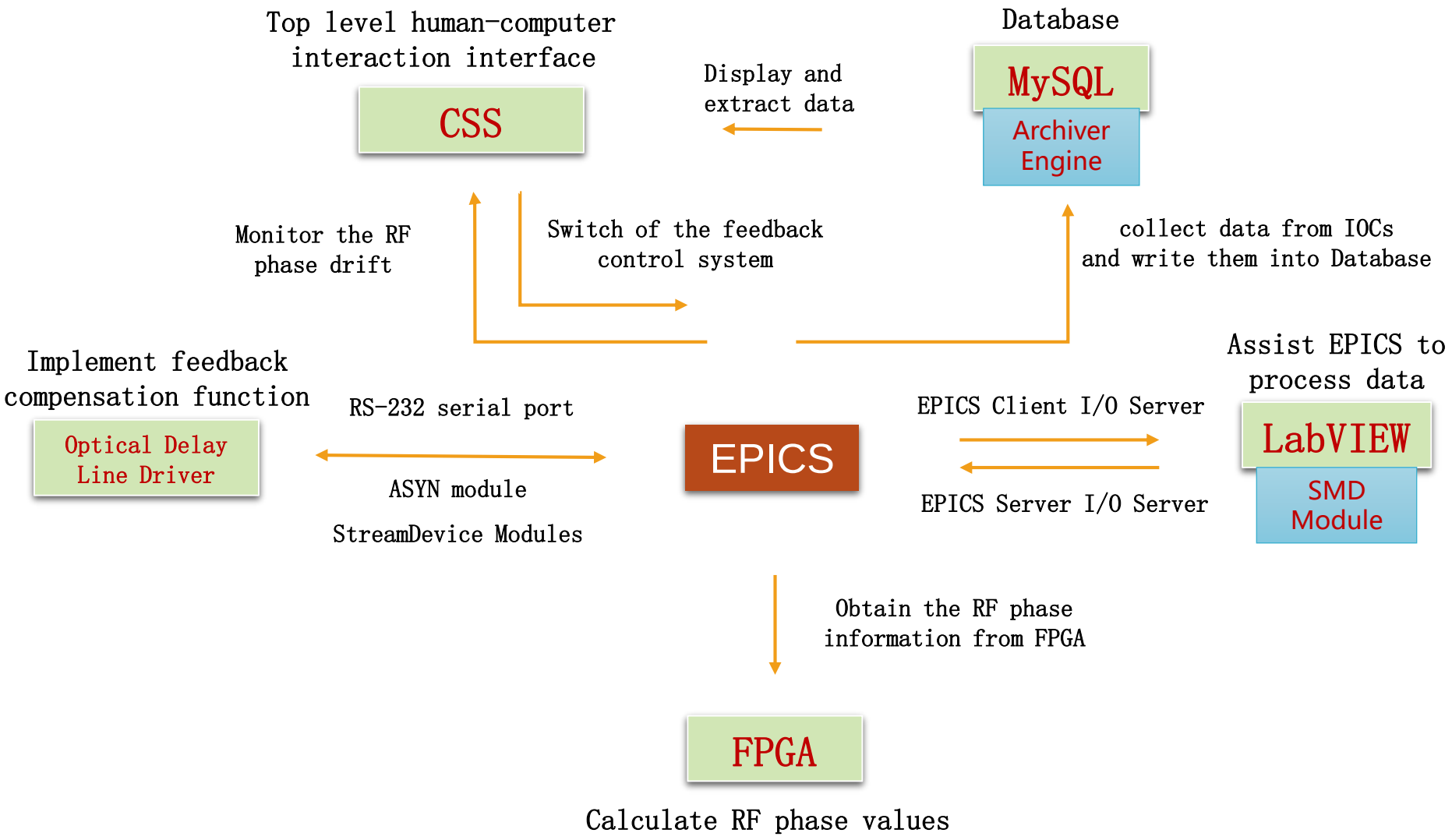
$\Delta\emptyset_1$ can be reduced by controlling the temperature of the sending end. So, the phase difference between the sending end and the receiving end can be kept at a relatively uniform value $\emptyset_0$.

RF Phase Monitor Module Based On MicroTCA





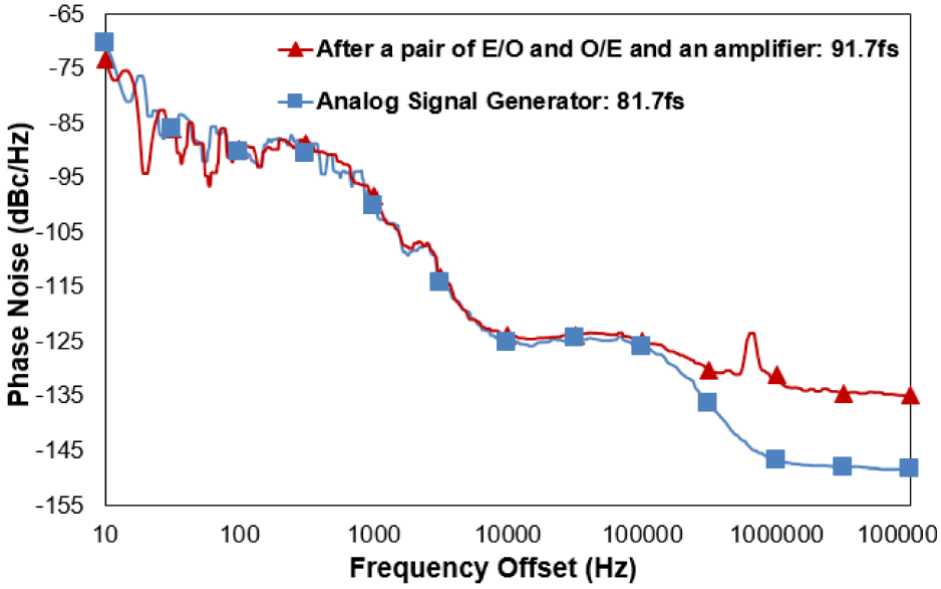
Software Module

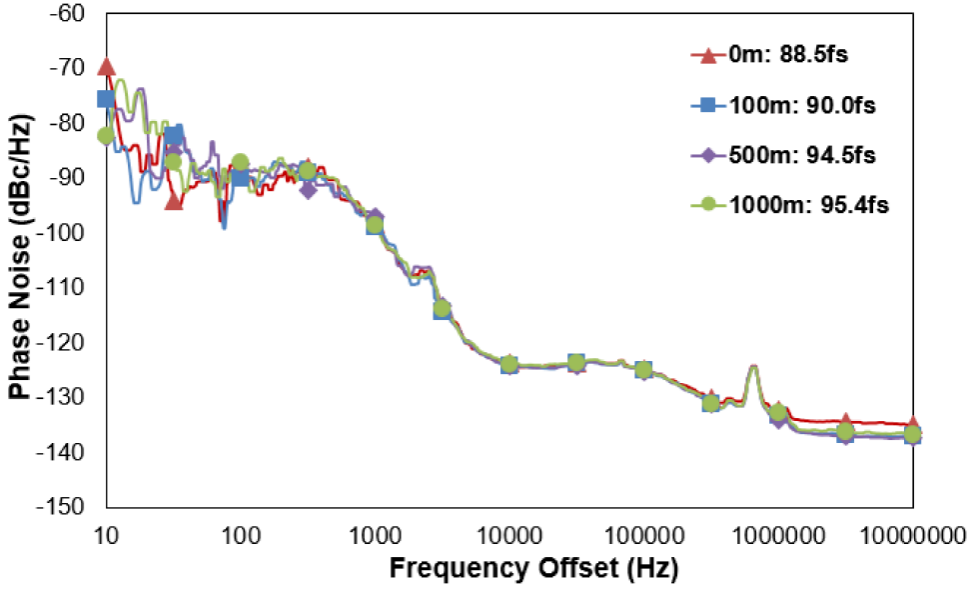


SSB Phase Noise

Center frequency: 2856MHz / Side band: 10Hz - 10MHz

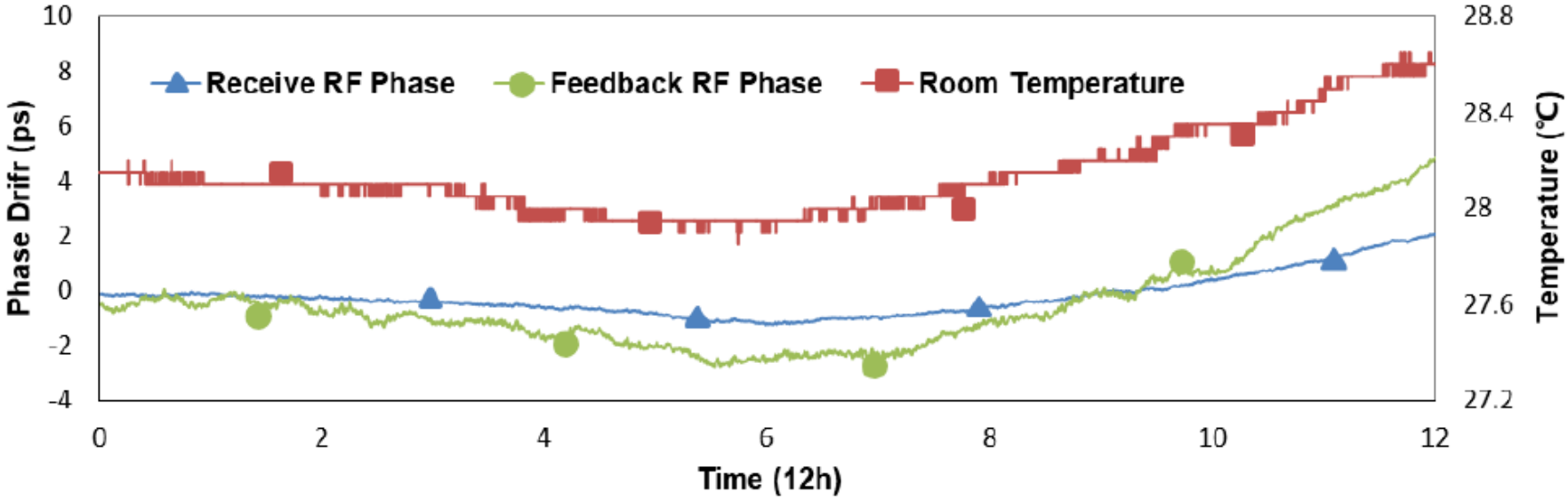
- Analog Signal Generator noise is 81.7fs.
- A pair of E/O and O/E and an amplifier only add 10fs phase noise.
- Phase noise of the received RF signal is within 100fs.(optical fiber < 1km)





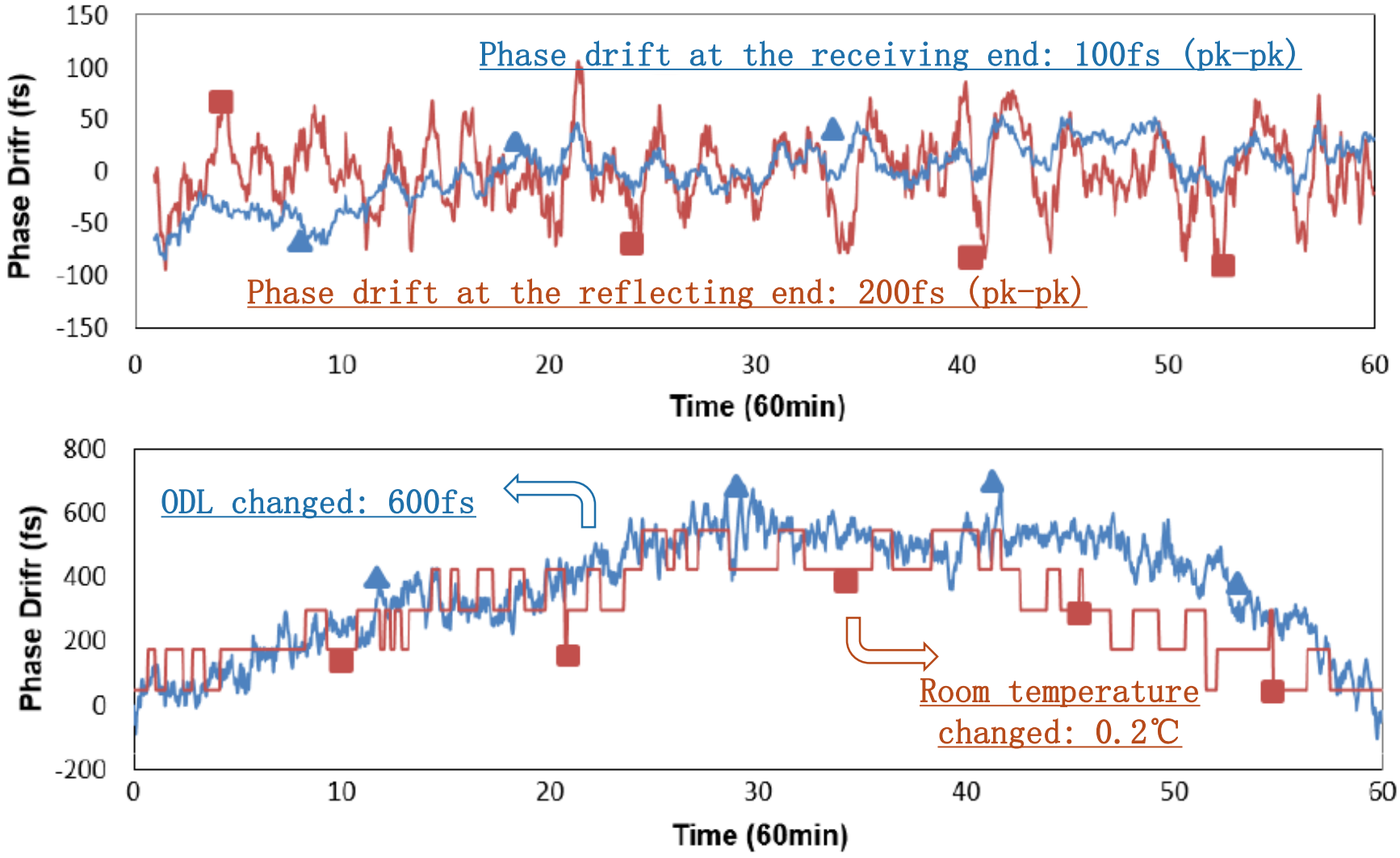
Open-Loop for 12 Hours

Phase stable optical fiber: 400m

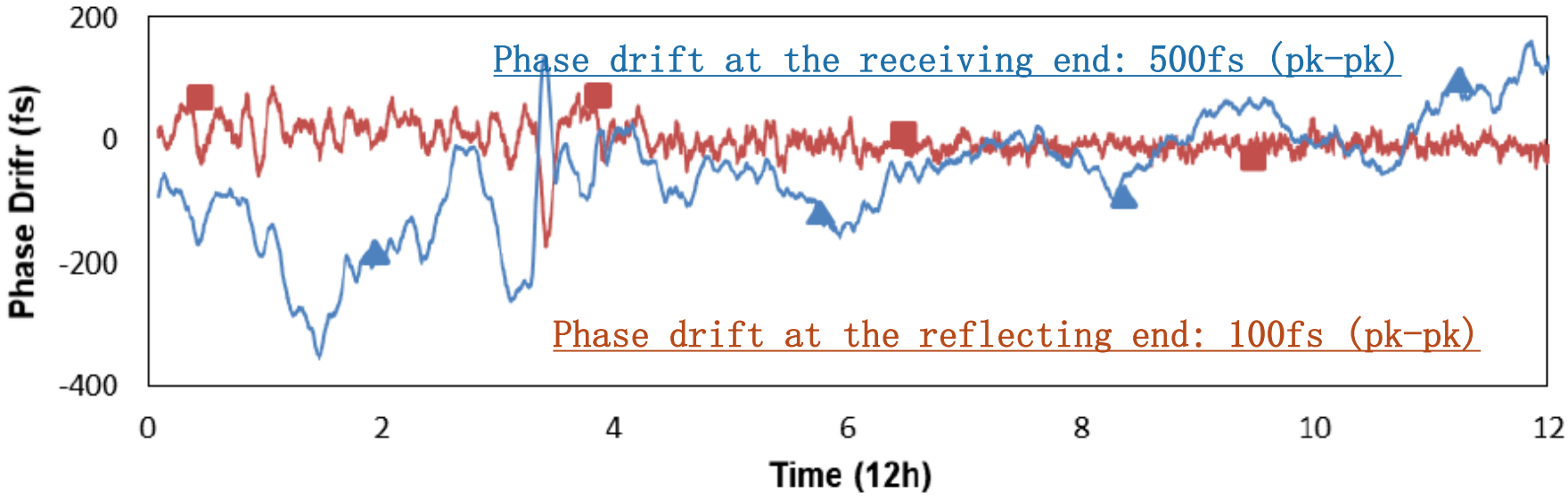


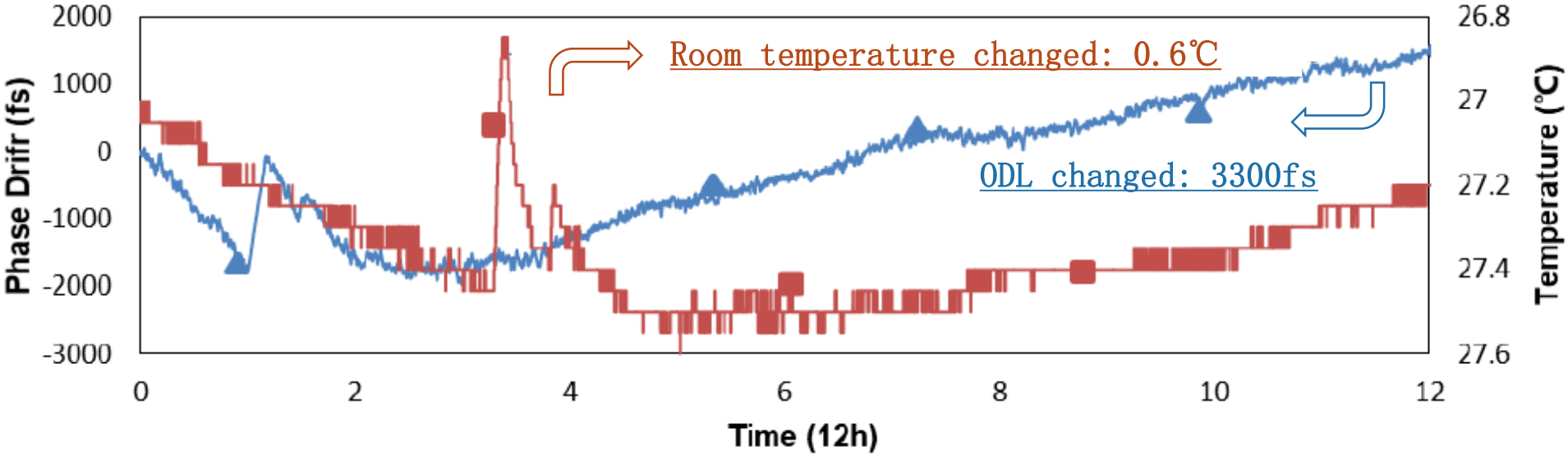
- Room temperature change: 0.63 ℃.
- Phase drift of the received RF signal was 3.5ps (pk-pk).
- Phase drift of the reflected RF signal was 7.2ps (pk-pk).
- These three curves changed in the same trend, and the RF phase drift at the reflecting end is almost twice as large as that at the receiving end.

Close-Loop for 60 Minutes

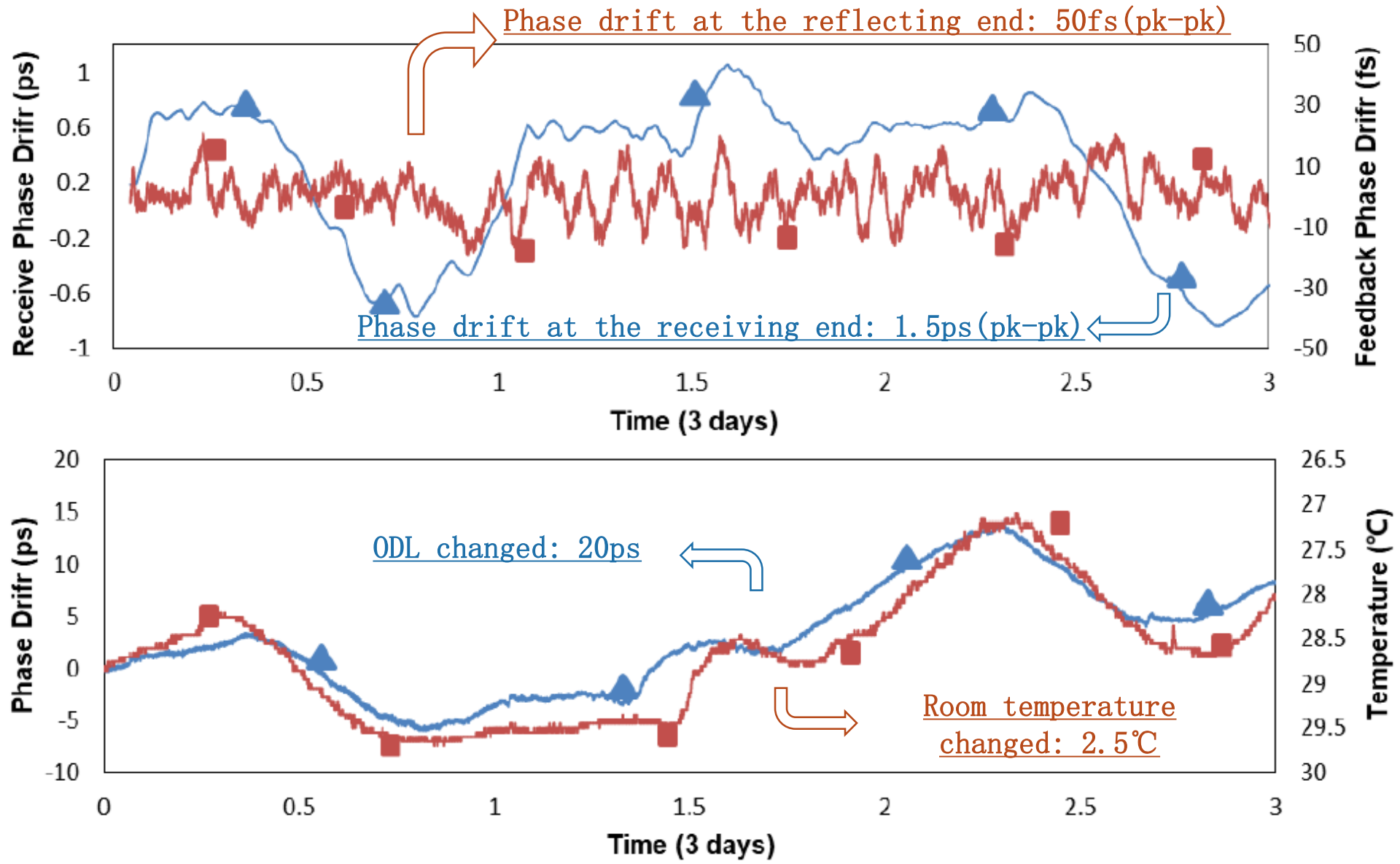


Close-Loop for 12 Hours





Close-Loop for 3 Days



Summary

- RF transmission system with fs-level phase stabilization is required by the next generation of particle colliders like CEPC.
- An RF transmission system based on MicroTCA has been designed and manufactured.
- System performance: phase drift at the reflecting end can be controlled into 50fs (pk-pk), and 92.5% phase drift at the receiving end can be compensated. (3 days / 2856MHz / 400m).

Outlook

- Put the Phase Monitor Module into a temperature control box to reduce the phase drift introduced by it.
- Use heterodyne interferometry to detect the phase drift, and compensate the phase drift by Piezo.

THANK YOU