

A Brief Introduction to SHINE and Progress in the Synchronization System

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2023.11.14

Synchronization System

Introduction and current progress

Synchronization Requirements for the SHINE Facility



Main Linac

- 1.4 km(total 3.1km), (75+2)x8 SRF cavities
- Beam energy 8 GeV

RF field stability

- RF phase 0.01 deg
- RF amplitude 0.01%

FEL lines

- 3 FEL lines
- FEL photon energy 0.4-25 keV
- FEL pulse duration 5-200 fs

Synchronization requirements

- Seed laser \leftrightarrow electron bunch < 20 fs
- FEL \leftrightarrow pump-probe laser < 20 fs₃

Reference Signal Requirements

for various subsystems

Laser system

- 36.11MHz (RF)
- 216.67 MHz (RF&Pulses)
- 1300 MHz (RF)

LLRF system

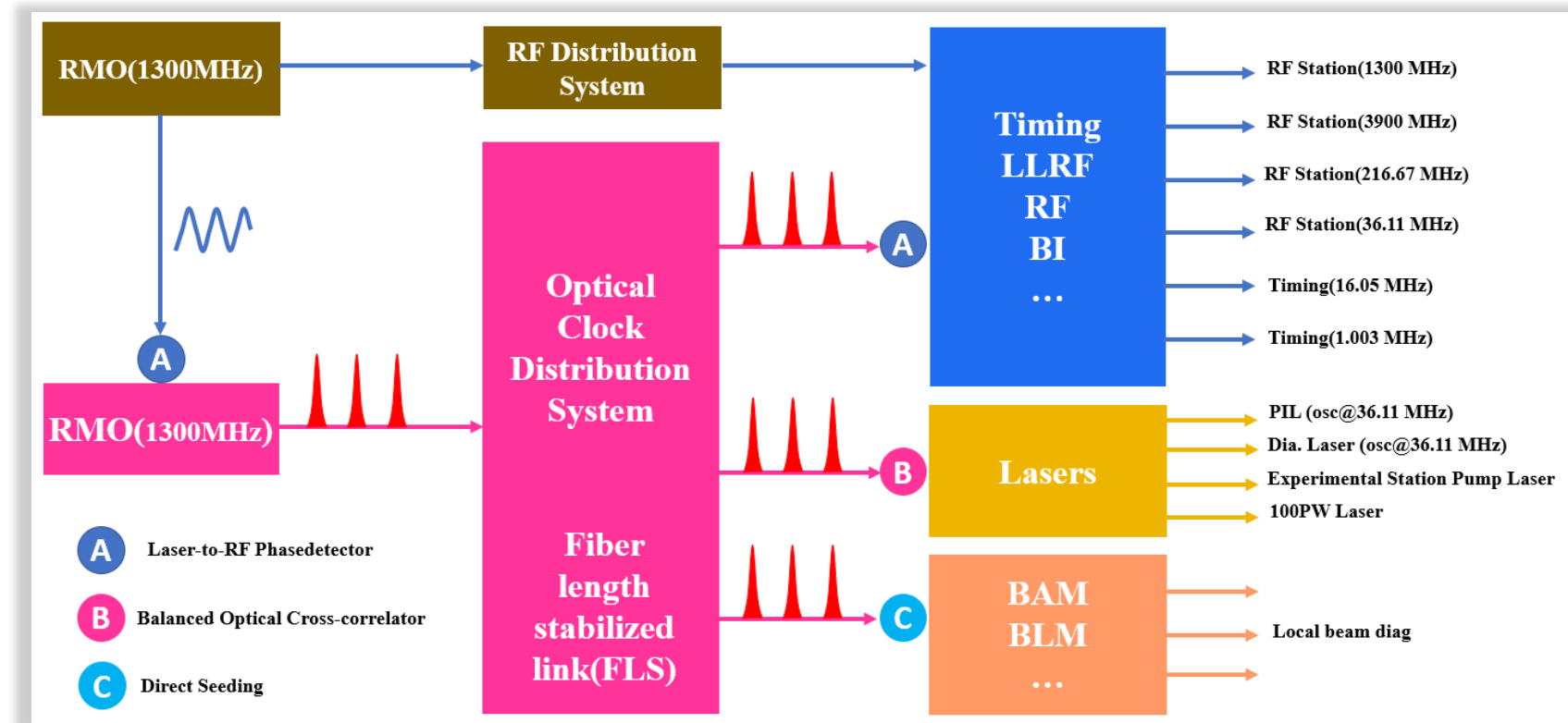
- 216.67 MHz (RF)
- 1300 MHz (RF&Pulses)
- 3900 MHz (RF&Pulses)

Beam diagnostic system

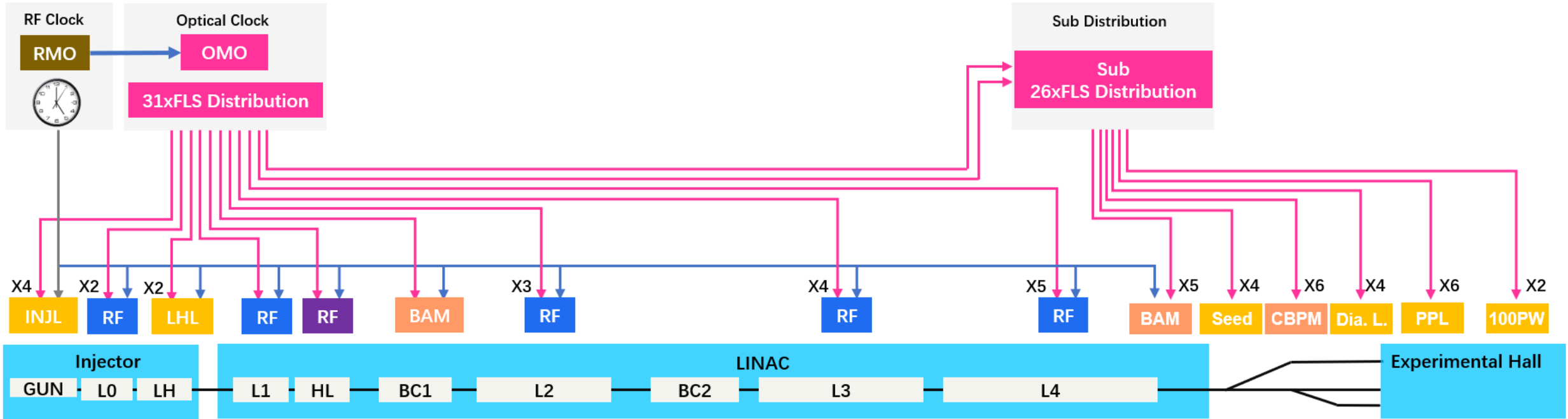
- 216.67 MHz (RF&Pulses)
- 1300 MHz (RF&Pulses)

Timing system

- 16.05 MHz (RF)
- 1Hz (TTL)



Reference Distribution



Reference Sources

- RMO(1+1)
- OMO(1+1)

Distribution System

- RF Reference Distribution
- Fiber Link Distribution

Clients

- Stage 0(Injector)
- Stage 1(L1,HL)
- Stage 2(BC1,L2)
- Stage 3(BC2,L3)
- Stage 4(L4)
- EOBAM(2)
- OMO(2)
- Seed(4)
- CBPM(6)
- PPL(6)
- 100PW(2)
- PIL(2+2)
- **2# SYN lab(2)**
- Heat laser(1+1)
- RF stations(16+3)

Reference

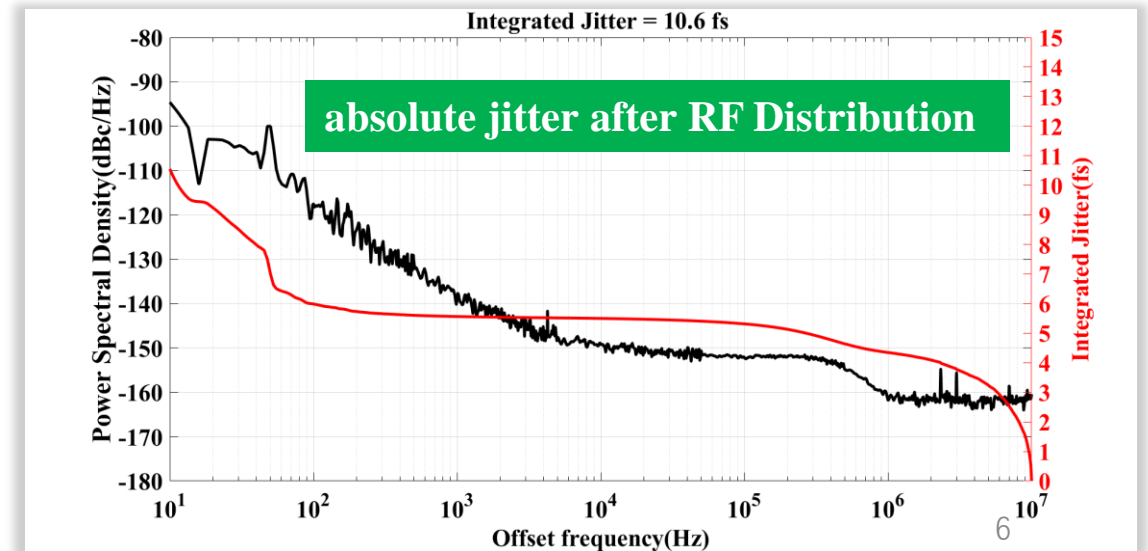
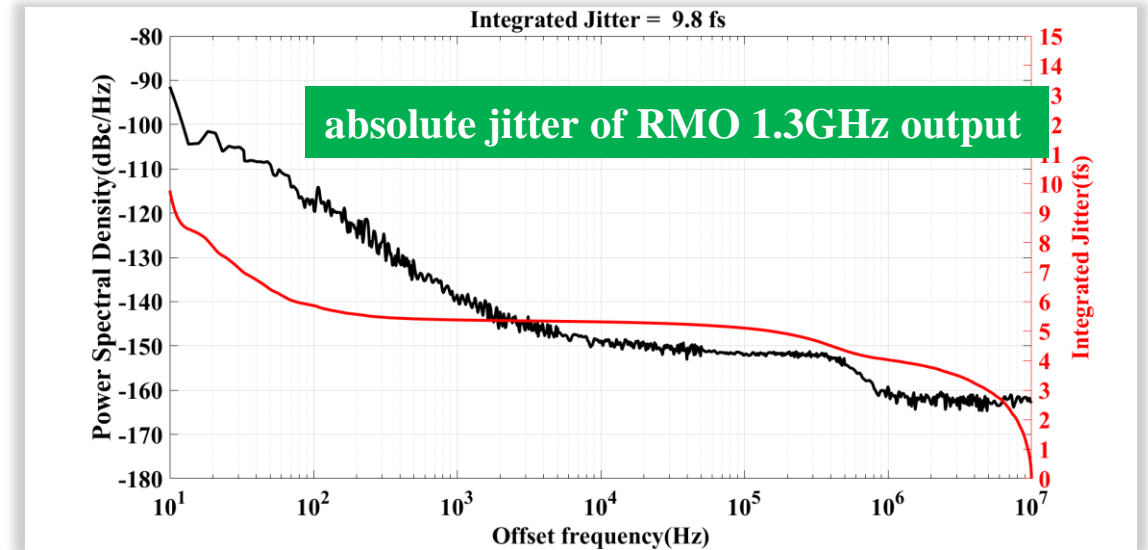
RF Master Oscillator(RMO)

RMO (R&S SMA100B)

- Absolute jitter@1300MHz: **9.8 fs** [10Hz,10MHz]

RF-SD

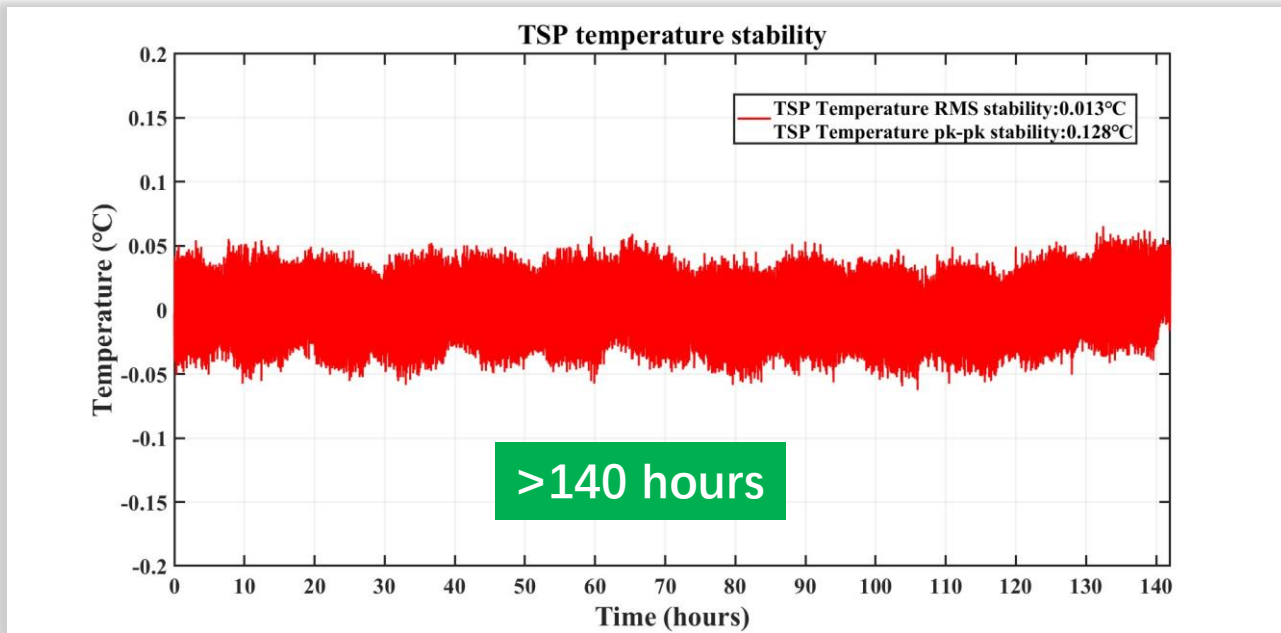
- Absolute jitter@1300MHz: **10.6 fs** [10Hz,10MHz]



Temperature-Stabilized Platform (TSP)

Environmental insulation and temperature-stabilized platform (TSP)

- RMS stability **0.013 °C (140h)**

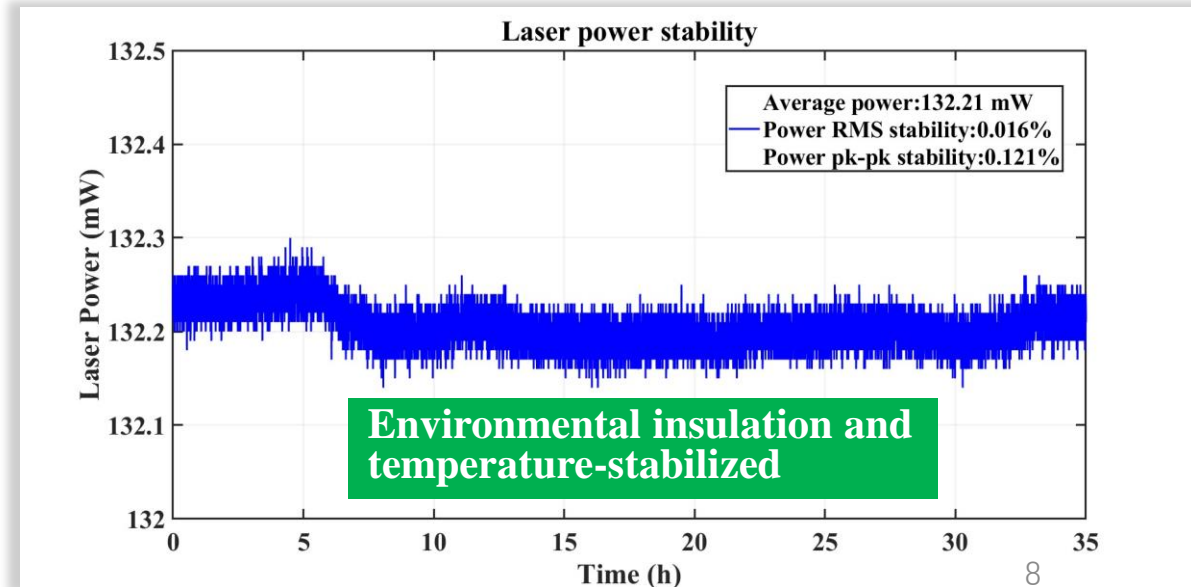
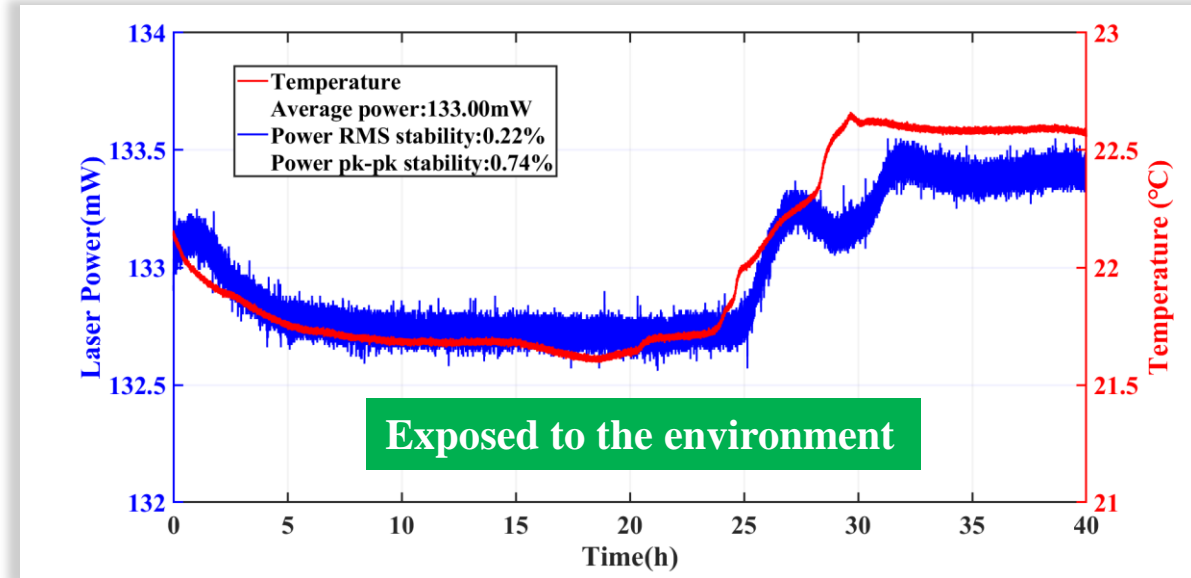


Reference

Optical Master Oscillator (OMO)

Menhir passive mode-locked laser

- Environmental insulation and temperature-stabilized
- Average power **>130 mW**
- Power stability **0.016%**

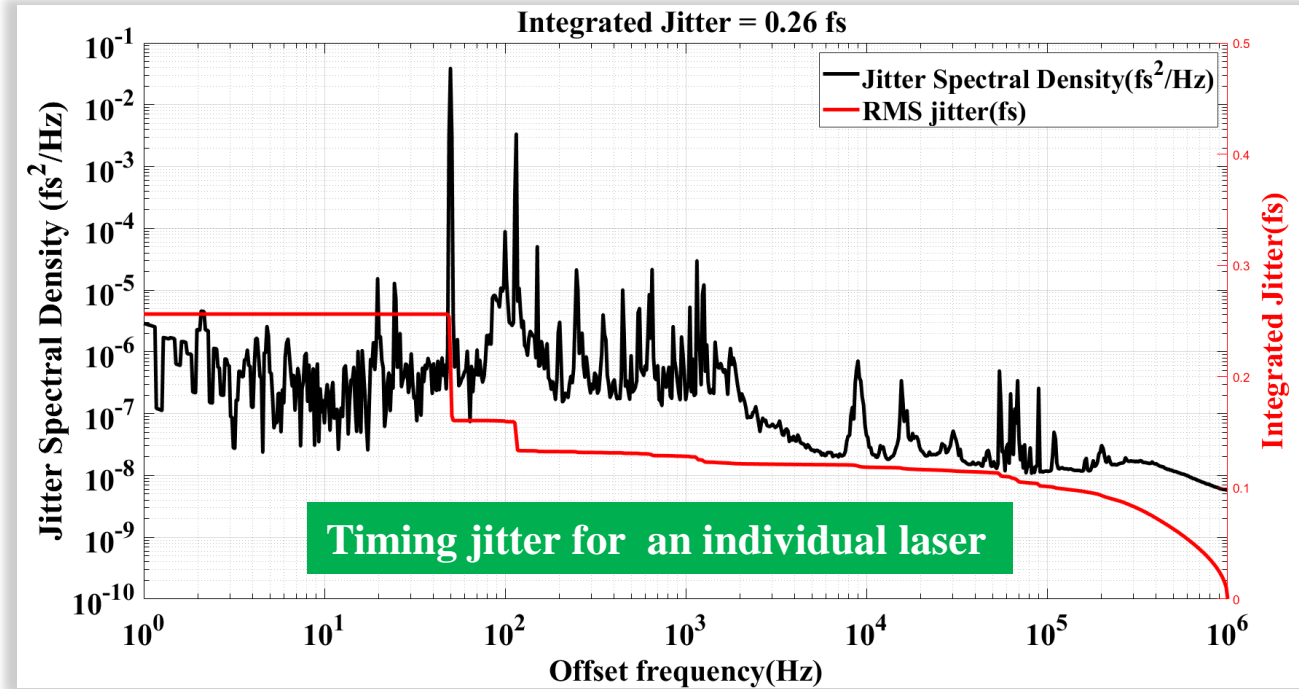


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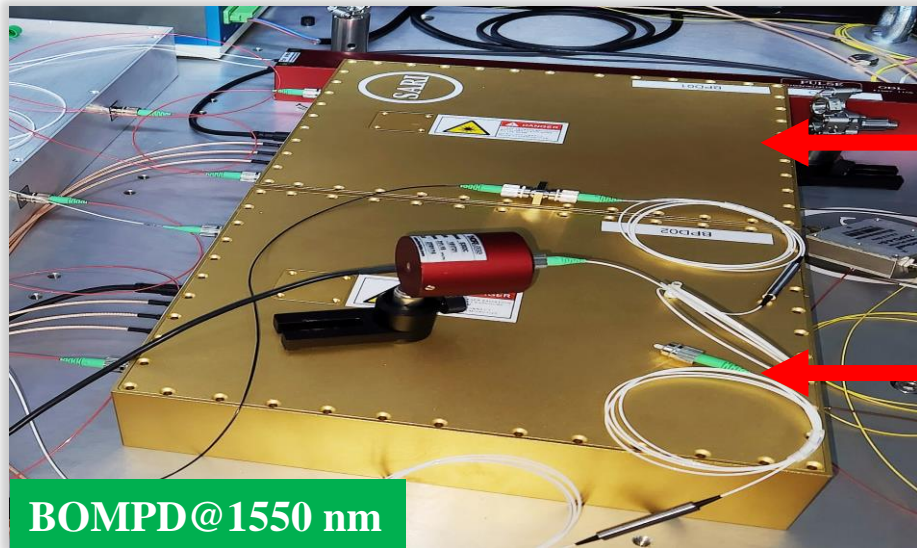
Timing jitter measurement of the ultra-low noise laser

- Integrated jitter **< 270 as**, [1Hz, 1MHz]
- Integrated jitter **< 129 as**, [1kHz, 1MHz]

OMO phase-locked to RMO

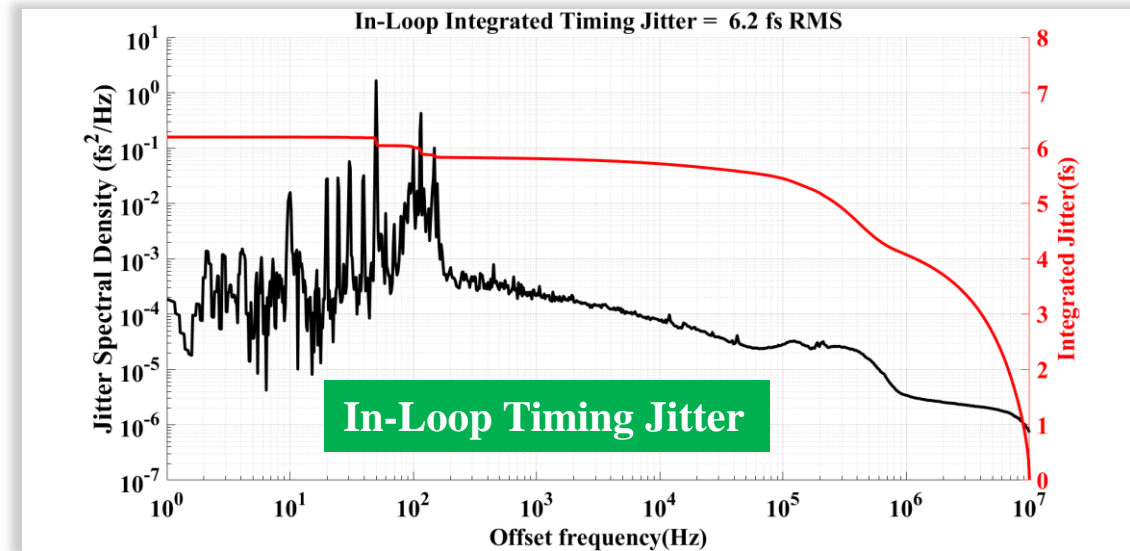
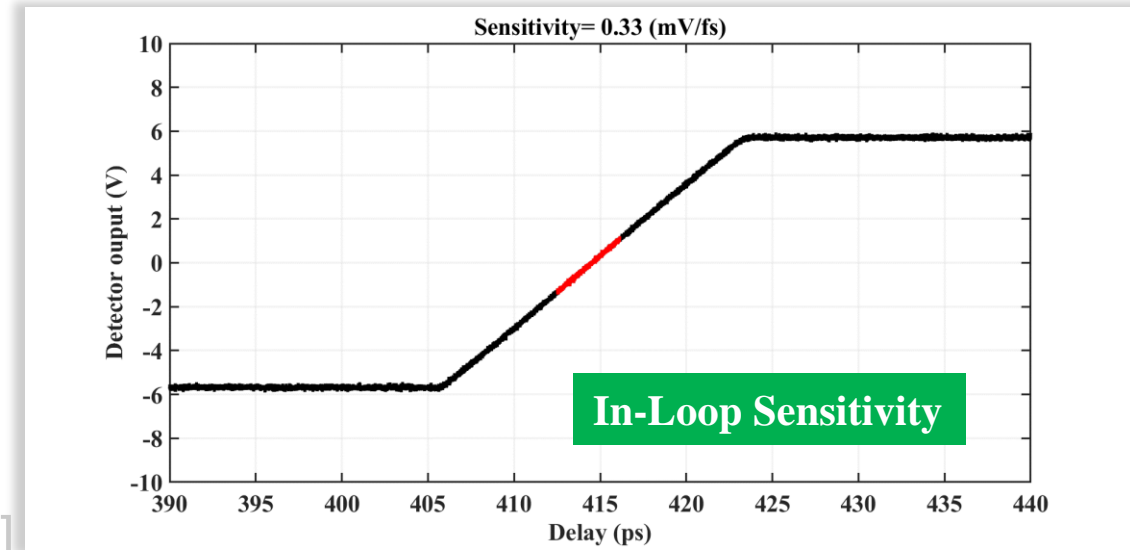
Balanced Optical Microwave Phase Detector

- Scheme based on 3X3 coupler BOMPD
- In-loop sensitivity **0.33 mV/fs**
- In-loop integrated timing jitter **6.2 fs [1Hz,10MHz]**
- Out-of-loop sensitivity 0.38 mV/fs
- Out-of-loop integrated timing jitter 4.9 fs [1Hz,10MHz]



In-Loop

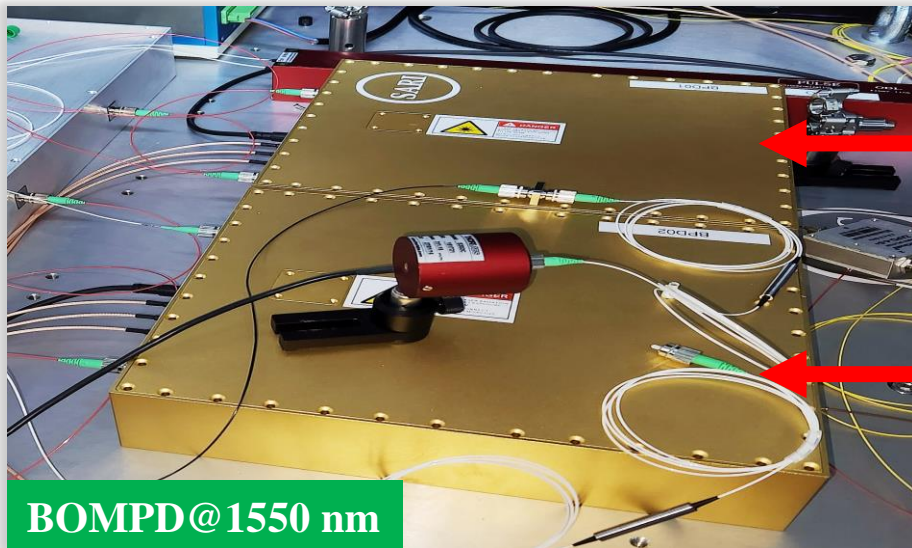
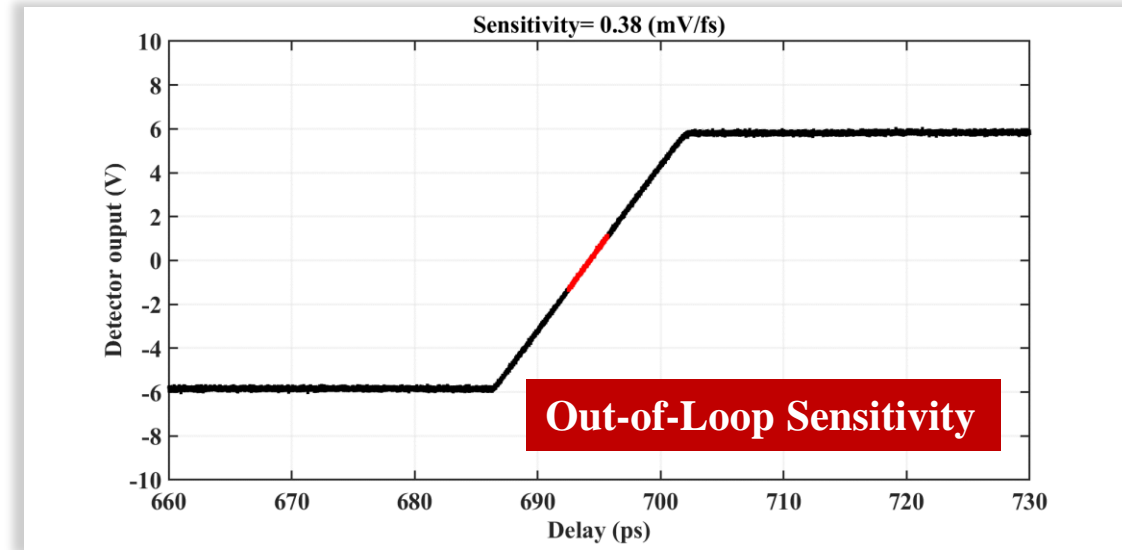
Out-of-Loop



OMO phase-locked to RMO

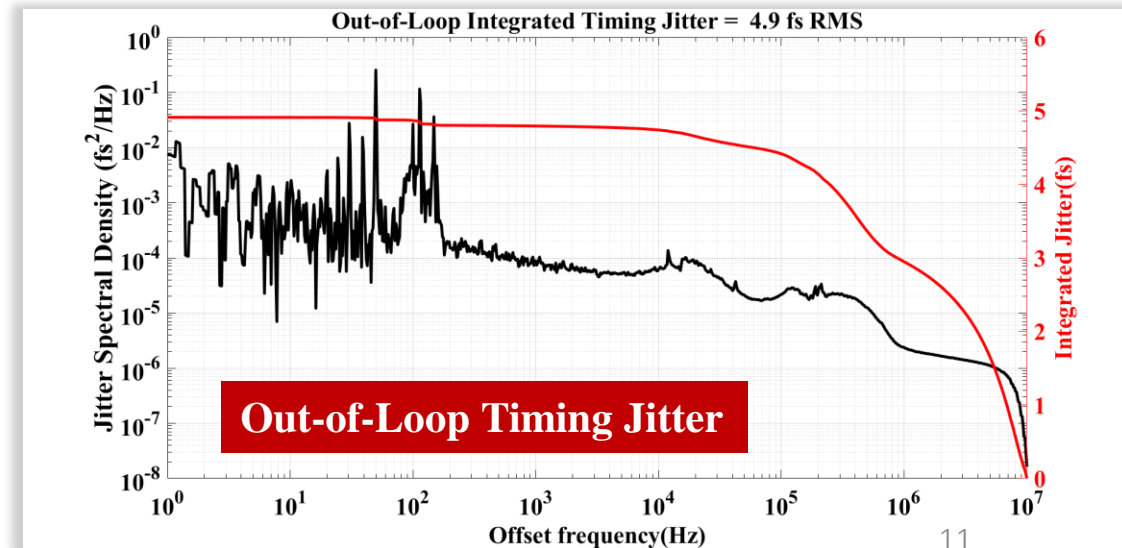
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In-Loop

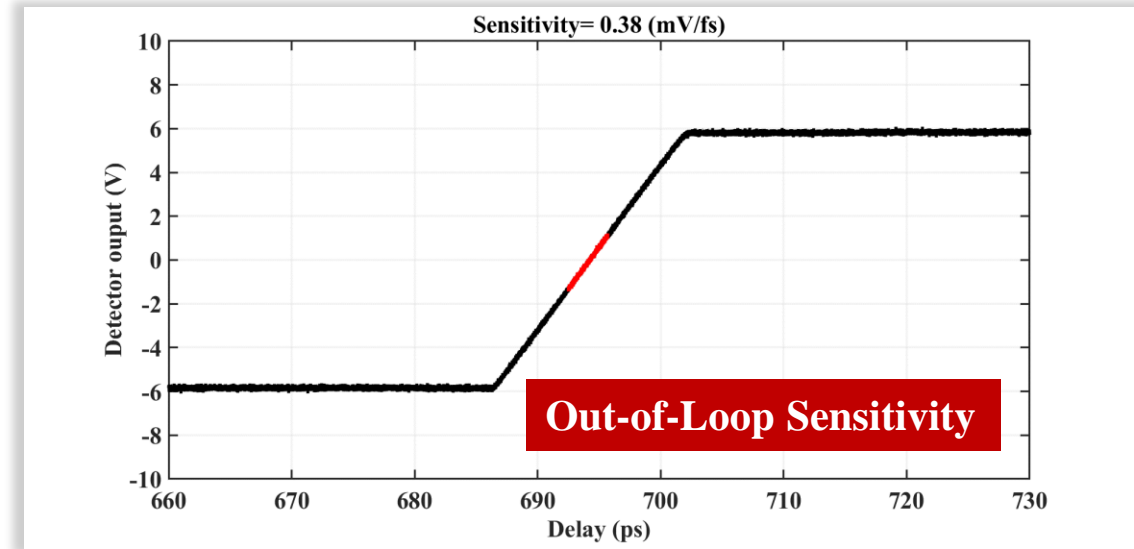
Out-of-Loop



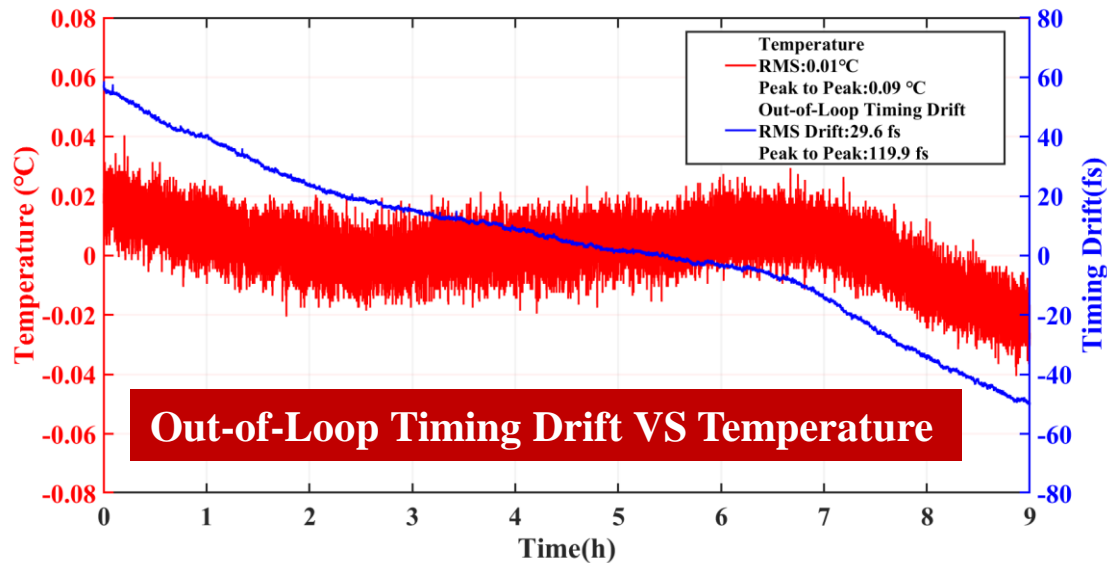
OMO phase-locked to RMO

Optical Microwave Balanced Phase Detector

- Scheme based on 3X3 coupler BOMPD
- Out-of-loop sensitivity **0.38 mV/fs**
- Out-of-loop timing drift RMS **29.6 fs (earlier result)**
- Out-of-loop timing drift RMS **5.65 fs (new result)**

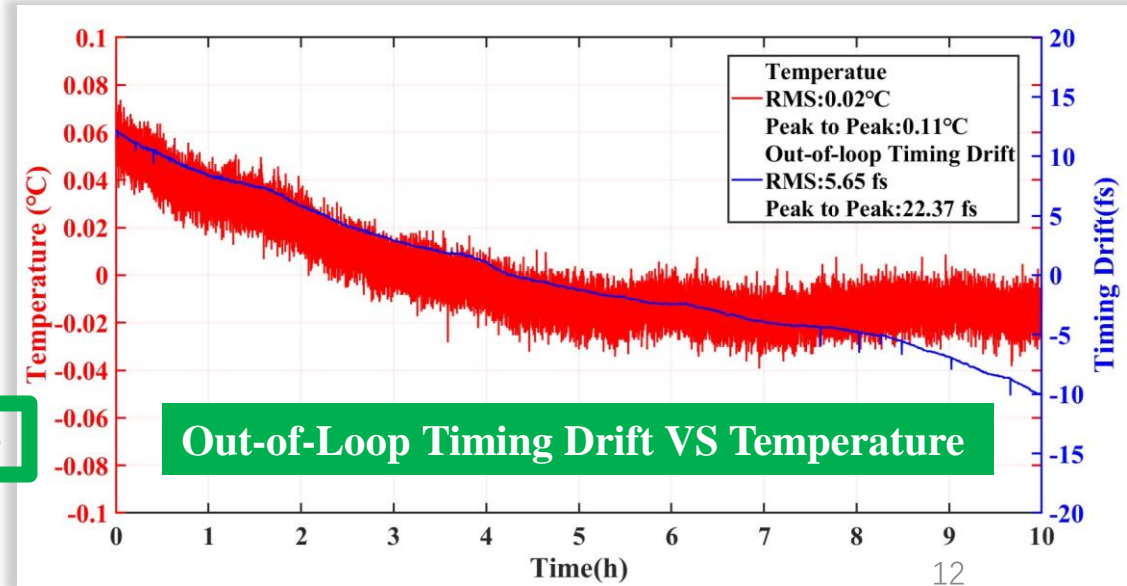


Earlier Result



Improve

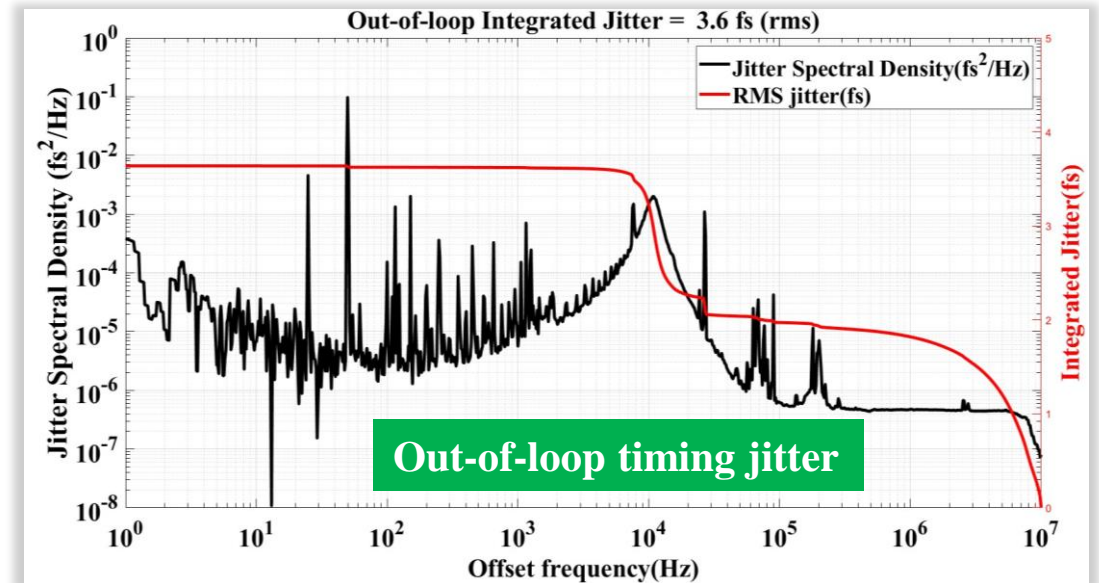
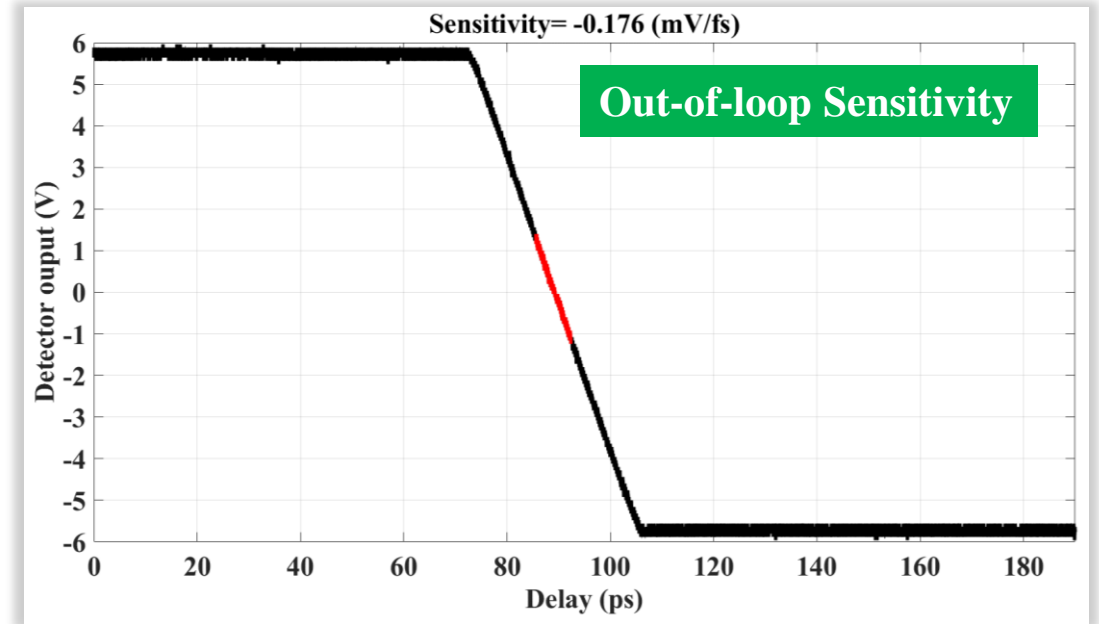
New Result



DRO phase-locked to pulses

RF-based & BOMPD

- RF-based: “coarse-tuning” for setting phase-point
- BOMPD: “fine-tuning” for precise synchronization
- FPGA-based controller
- Out-of-loop sensitivity **0.176 mV/fs**
- Out-of-loop integrated timing jitter **3.6 fs, [1Hz, 10MHz]**



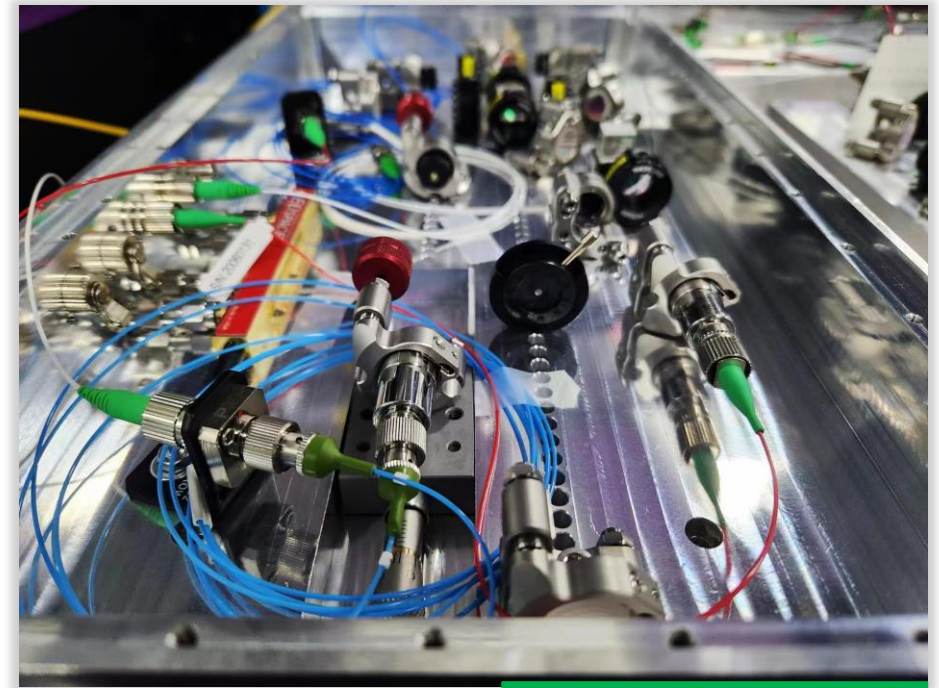
RF phase-locked to pulses

REFM-OPT

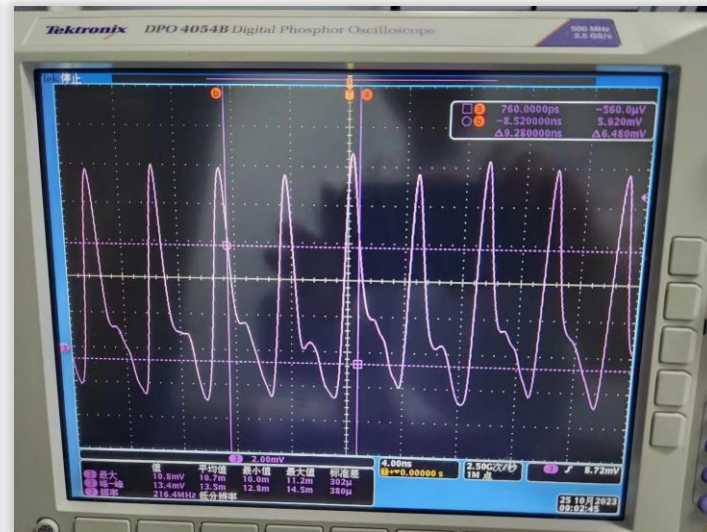
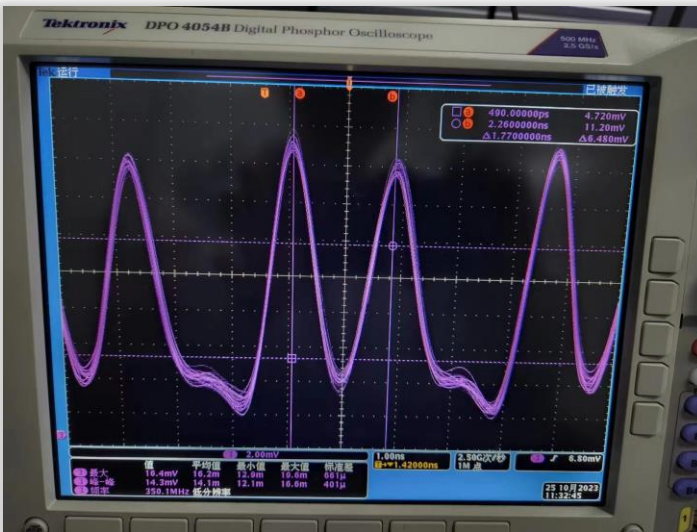
- Integrated optics for the L2RF phase detector
- Integrated front-end electronics
- Dedicated FPGA-based controller

First delay

Second delay



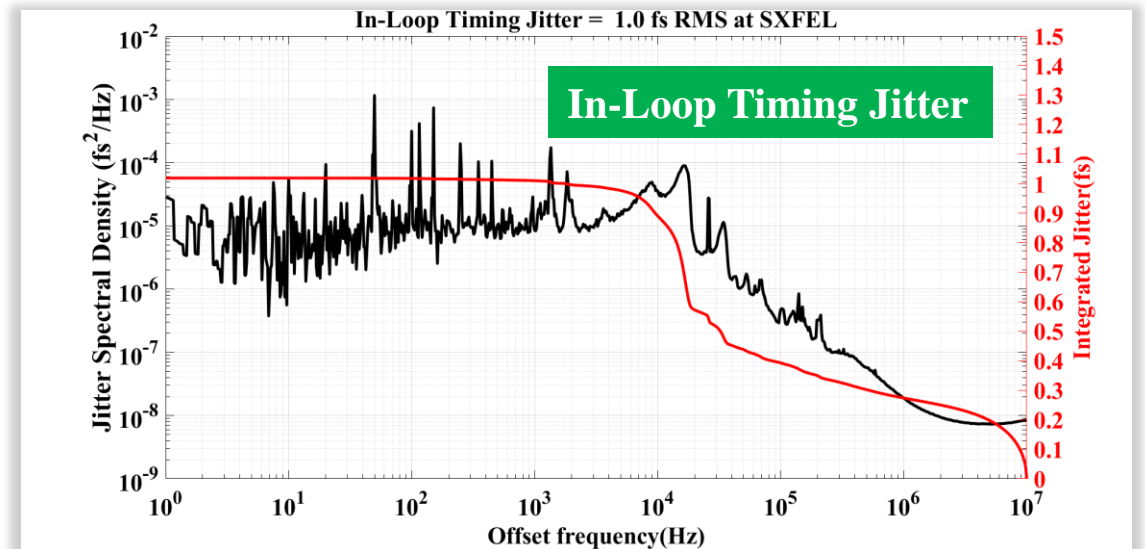
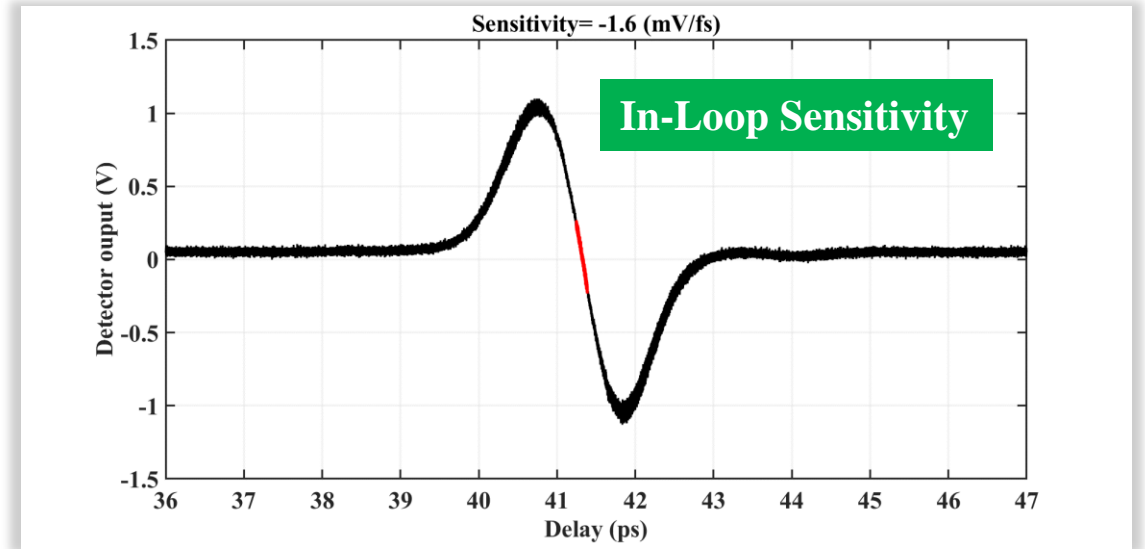
L2RF Phase detector



Fiber Length Stabilizer

Balanced Optical Cross-correlator (BOC)

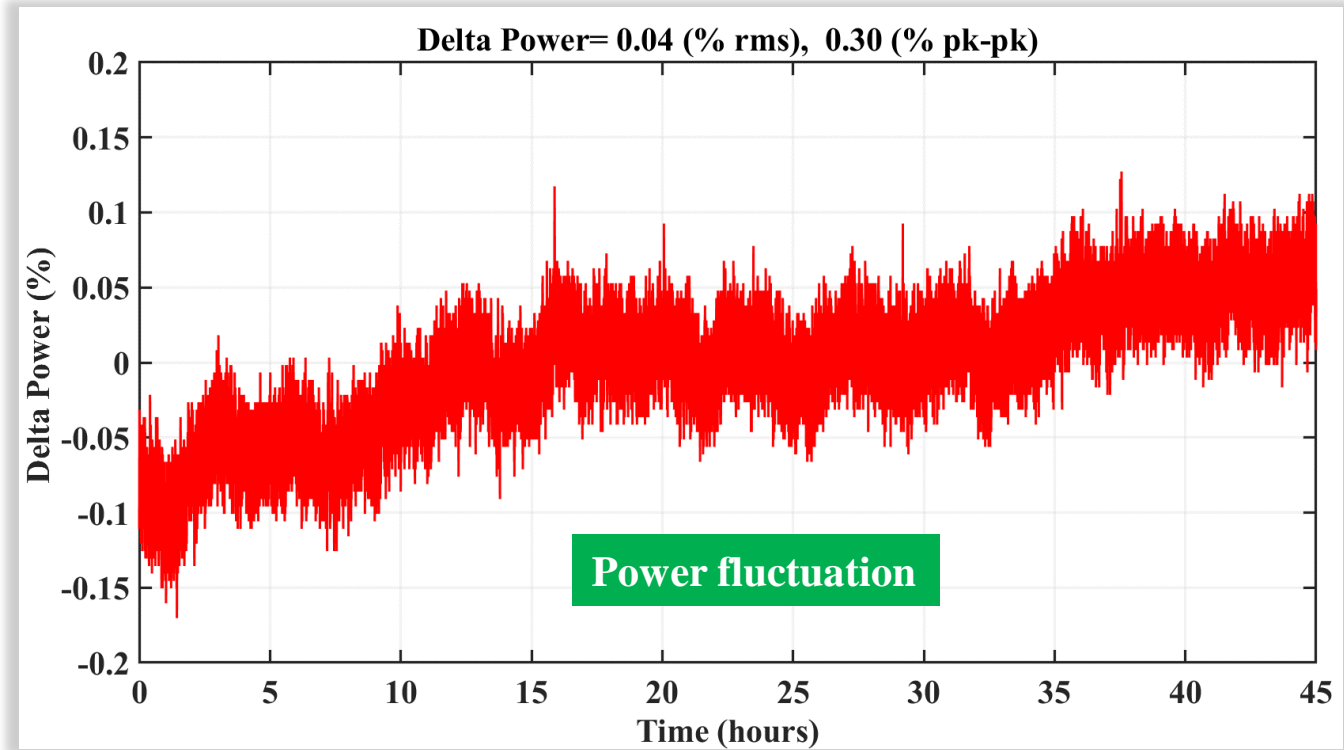
- Polarization maintaining fiber
- FPGA-based controller
- BOC sensitivity **1.6 mV/fs**
- In-loop timing jitter **1.0 fs** [1Hz, 10MHz]



Fiber Length Stabilizer

Balanced Optical Cross-correlator (BOC)

- Polarization maintaining fiber
- FPGA-based controller
- BOC sensitivity **1.6 mV/fs**
- In-loop timing jitter **1.0 fs** [1Hz,10MHz]



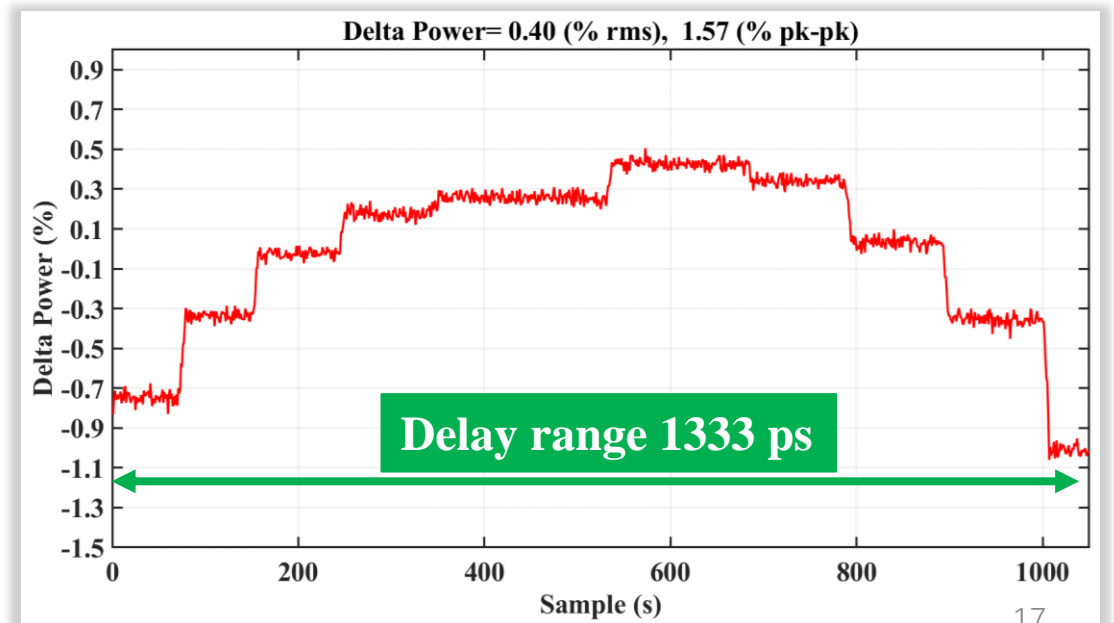
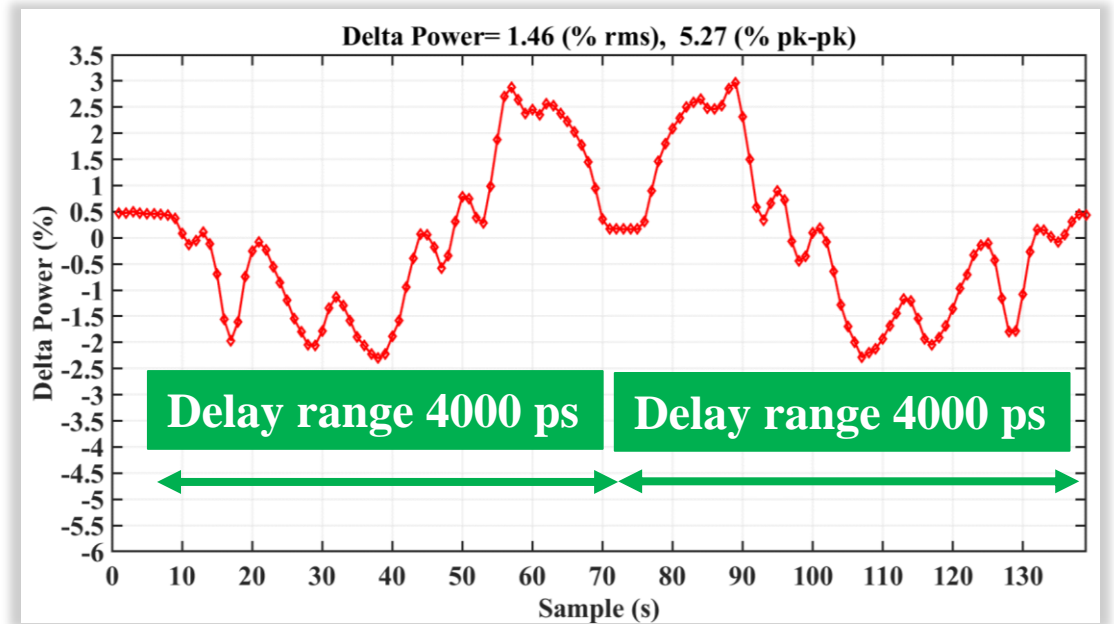
Output power fluctuation of the BiEDFA

- Δ power, rms, **0.04%**
- Δ power, Peak to Peak, **0.3%**

Fiber Length Stabilizer

Output power fluctuation of the ODL

- 4ns ODL version
1.46%(rms), 5.27%(pp) for BAMs
- 1.33ns ODL version
0.4%(rms), 1.57%(pp) for LINKs



Fiber Length Stabilizer

Balanced Optical Cross-correlator (BOC)

- Polarization maintaining fiber
- Optical delay line **> 4 ns**, self-built
- FPGA-based controller
- BOC sensitivity **1.6 mV/fs**
- In-loop timing jitter **1.0 fs** [1Hz, 10MHz]

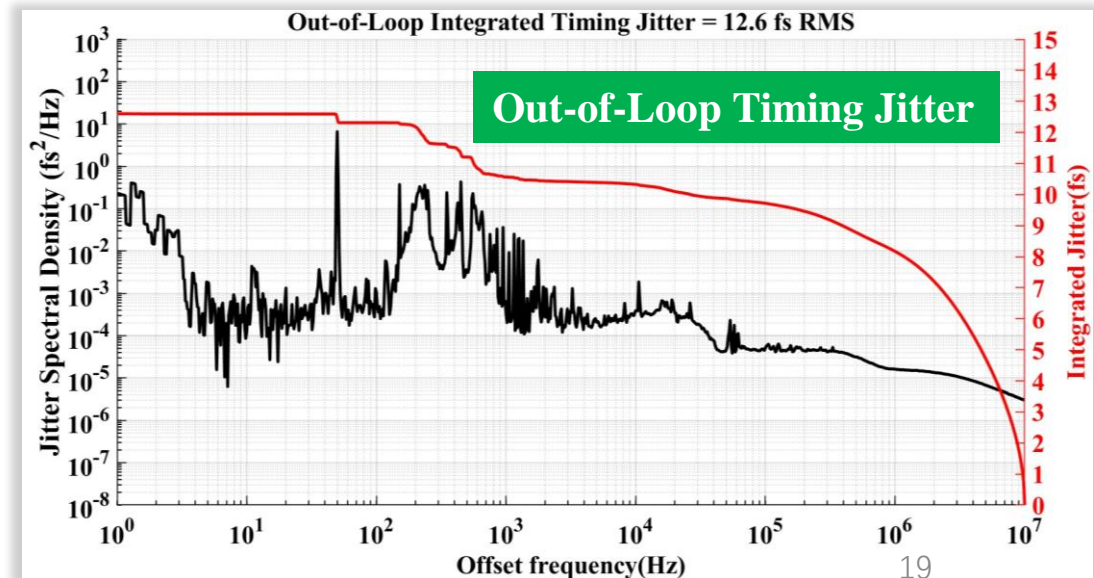
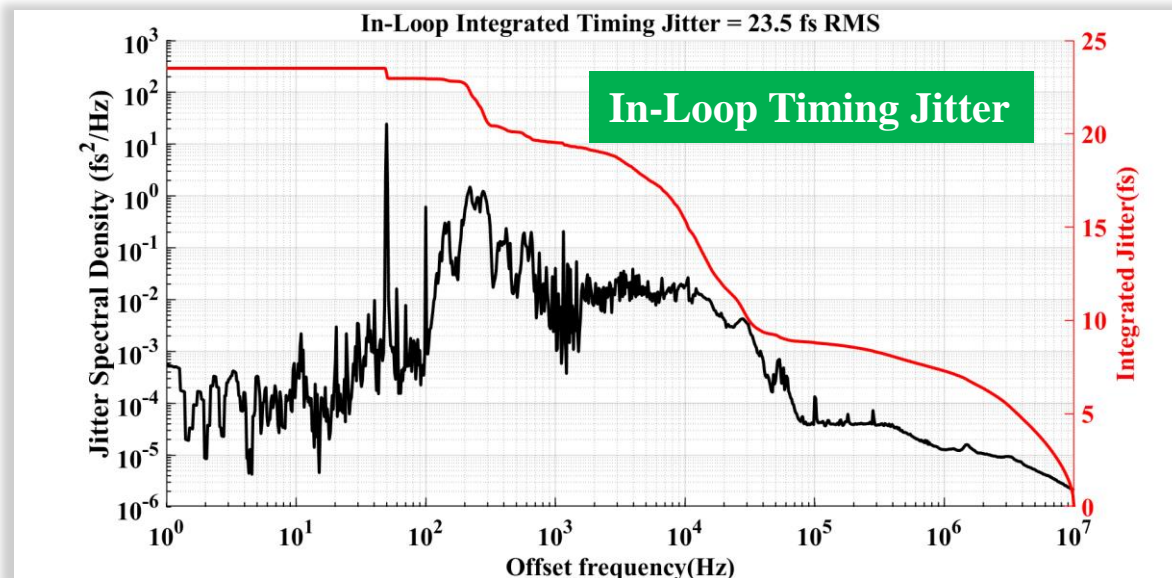
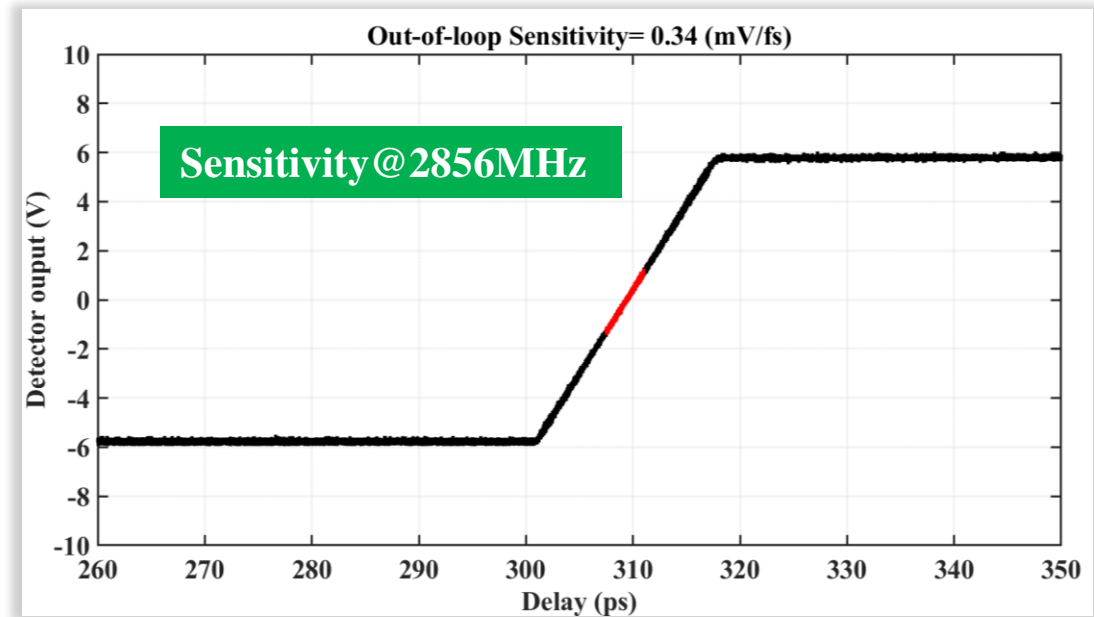


800nm BOMPD(3X3) for Ti:Sa Laser

Measurement bandwidth 1Hz to 10MHz

Synchronization frequency 2856 MHz (SXFEL)

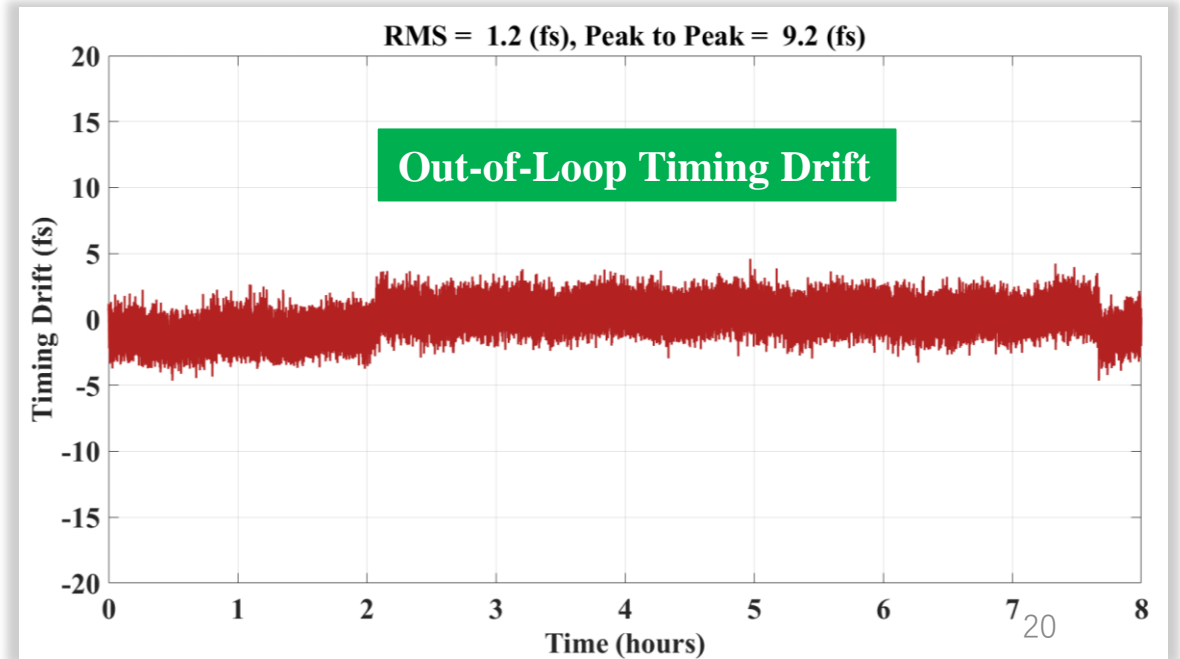
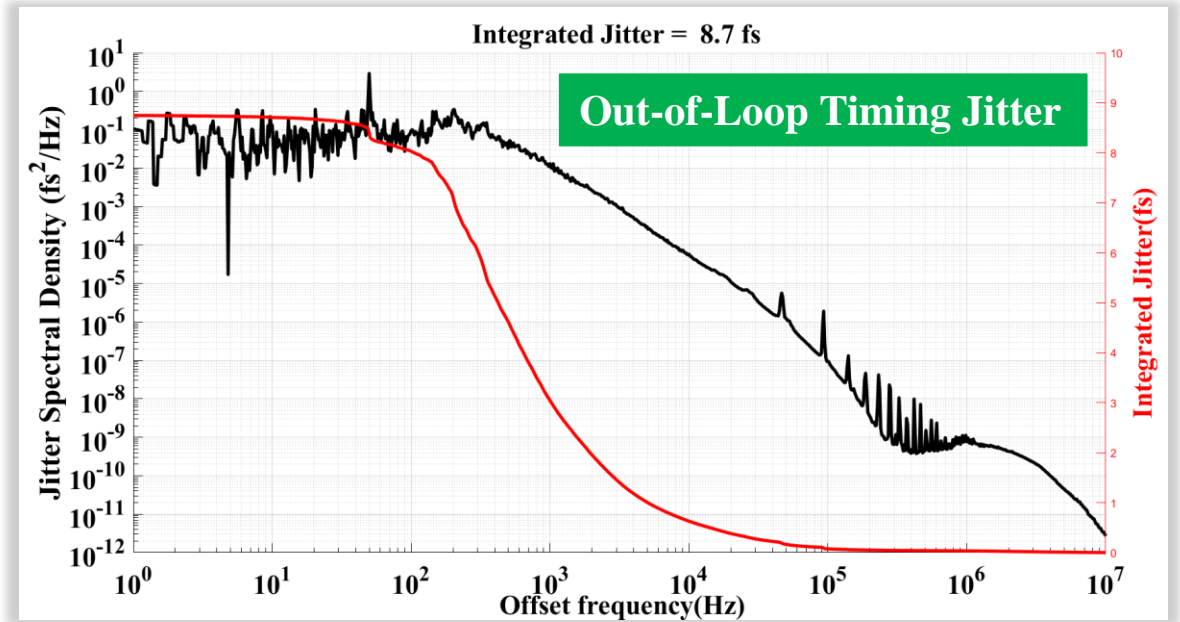
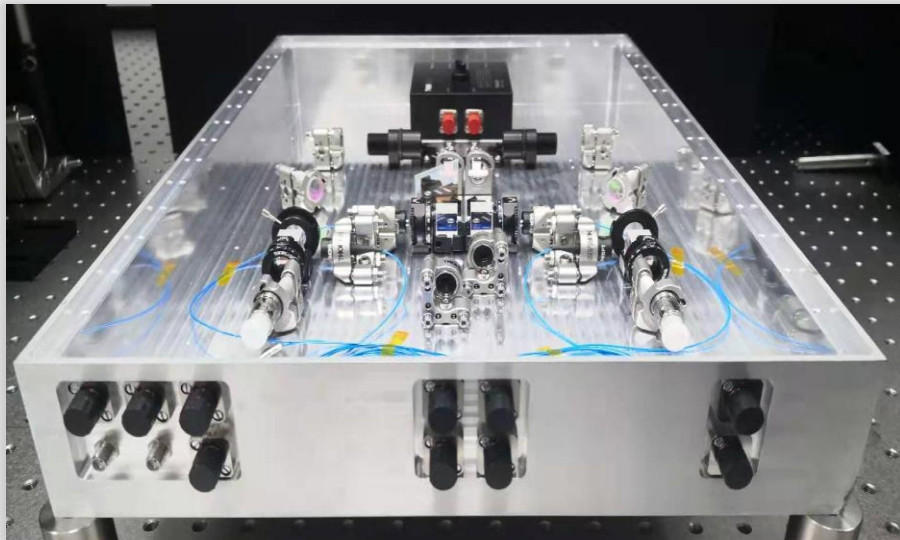
- Sensitivity **0.34 mV/fs**
- Linear detection range more than **20 ps**
- Locked In-loop integrated jitter **23.5 fs** [1Hz,10MHz]
- Out-of-loop integrated jitter **12.6 fs** [1Hz,10MHz]



Two-color laser synchronization

Two-Color Balanced Optical Cross-correlator (TCBOC)

- BBO crystal
- FPGA-based controller
- TCBOC sensitivity **>3 mV/fs**
- Out-of-loop timing jitter **8.7 fs** [1Hz,10MHz]
- Out-of-loop timing drift **1.2 fs** RMS



Components Installation



Room-02(SHINE MO and Hardware Devices)



Room-01(Optical Sync.)

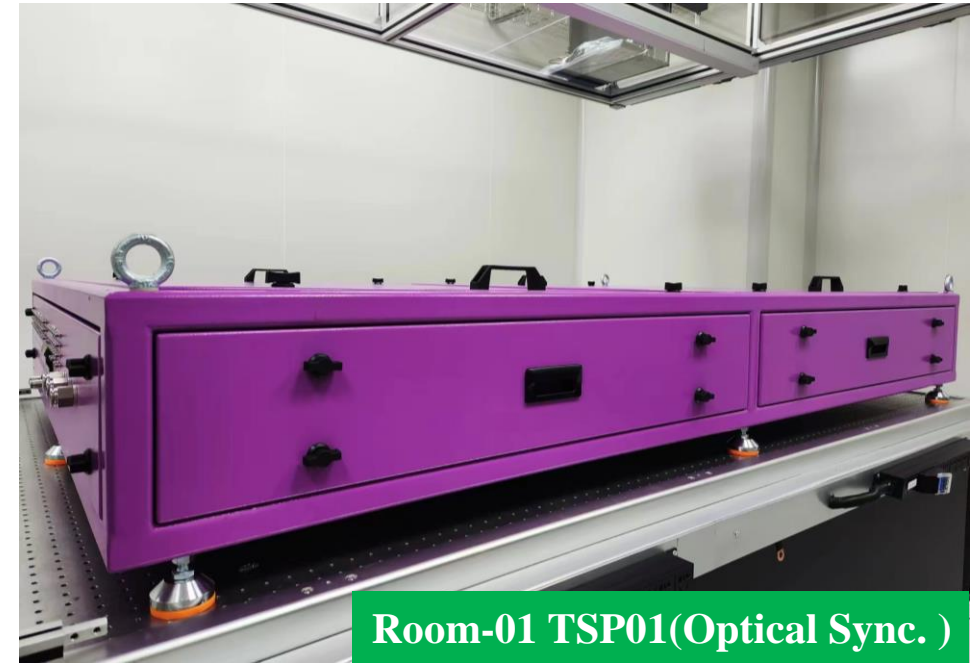


Room-03(Optical Sync.)

Components Installation



SHINE RMO and RF Reference Distribution



Room-01 TSP01(Optical Sync.)



Room-03(Optical Sync.)

Schedule

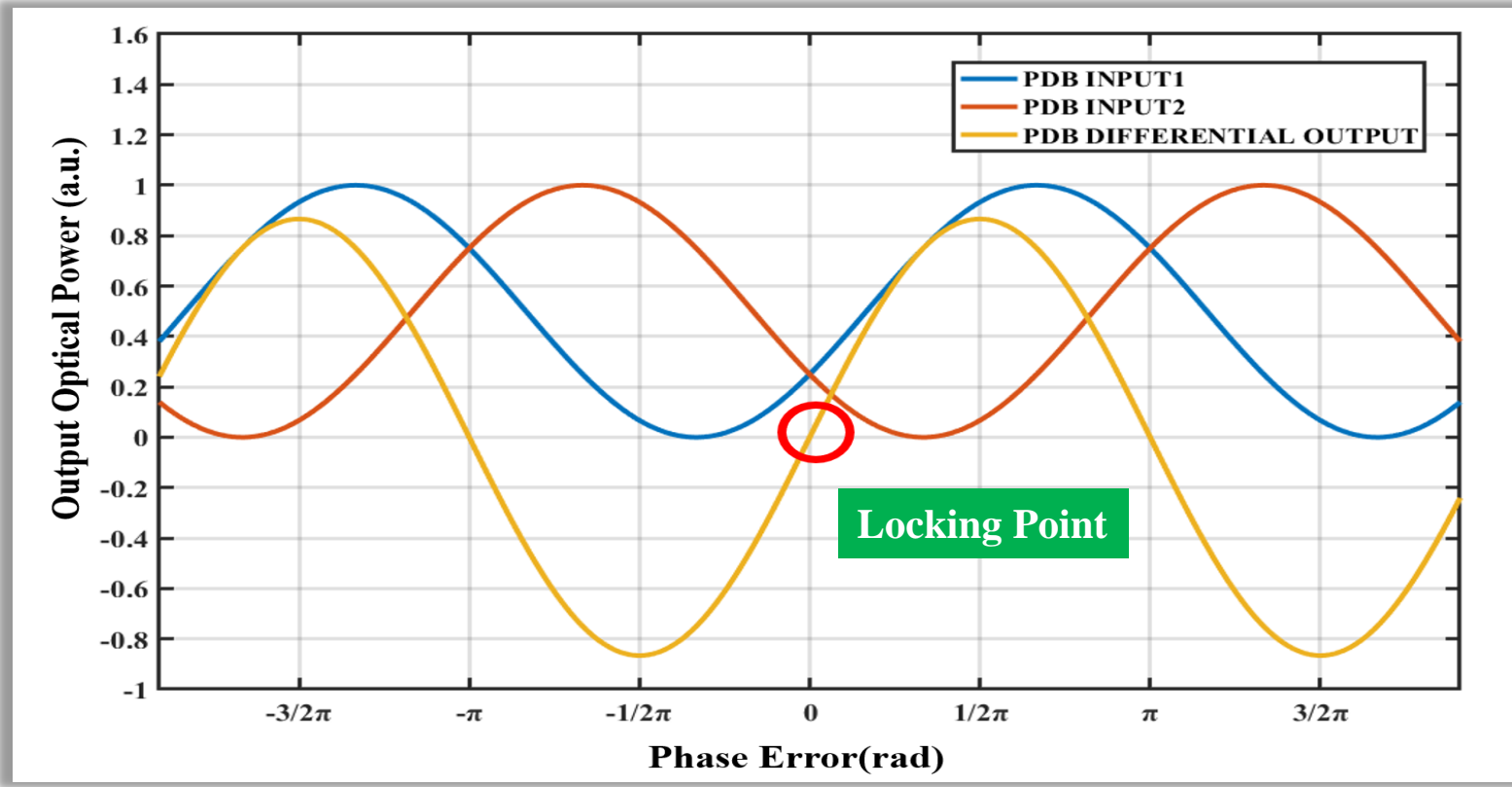
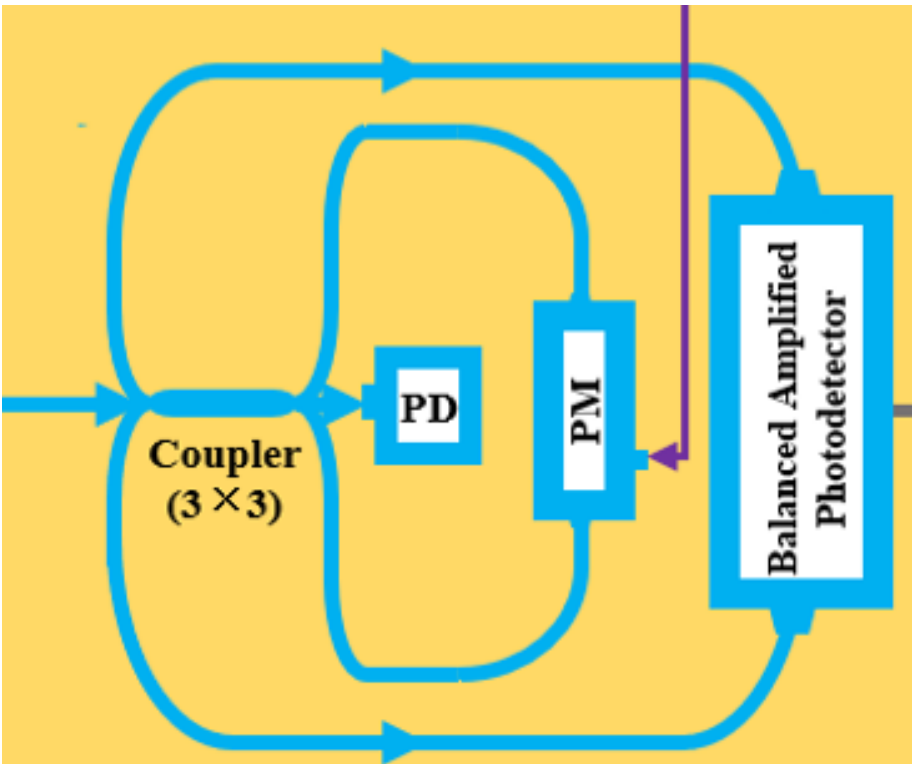
	2023		2024		2025		2026		2027	
	1-6	7-12	1-6	7-12	1-6	7-12	1-6	7-12	1-6	7-12
Injector	1RMO+2TSP+1OMO+ 11FLS+3BPD+6TCBOC									
L1		2FLS+2BPD								
L2			2TSP+1OMO+ 3FLS+3BPD							
L3				4FLS+4BPD						
L4					5FLS+5BPD					
FEL-I					3FLS+3BPD					
FEL-II					3FLS+3BPD					
FEL-III							3FLS+3BPD			
2#				4TSP+2OMO+2BPD+12FLS+6TCBOC						

An aerial photograph of a large, modern stadium with a distinctive, curved, white facade and a blue stripe. The stadium is surrounded by greenery and several smaller buildings. In the background, a city skyline is visible under a vibrant sunset sky with orange and red hues. The sun is low on the horizon, casting a warm glow over the scene.

Thank you for your attention!

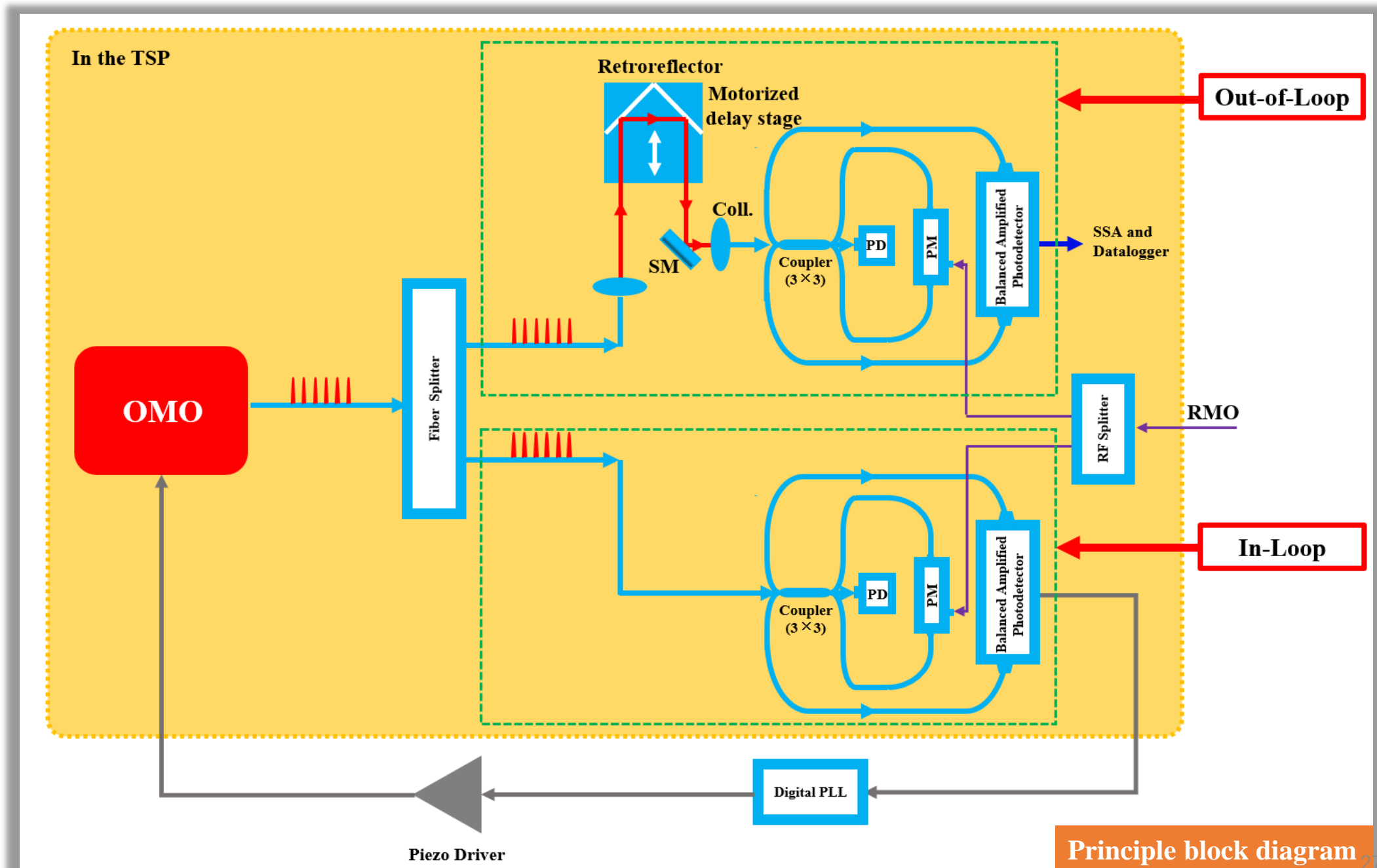
wangjg@sari.ac.cn

Backup slide



$$K_d \propto \frac{P_{in} V_0}{V_\pi}$$

The 3x3 coupler generates a 120-deg phase difference



Principle block diagram 27