Femtosecond Timing System in SSRF

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2015.10

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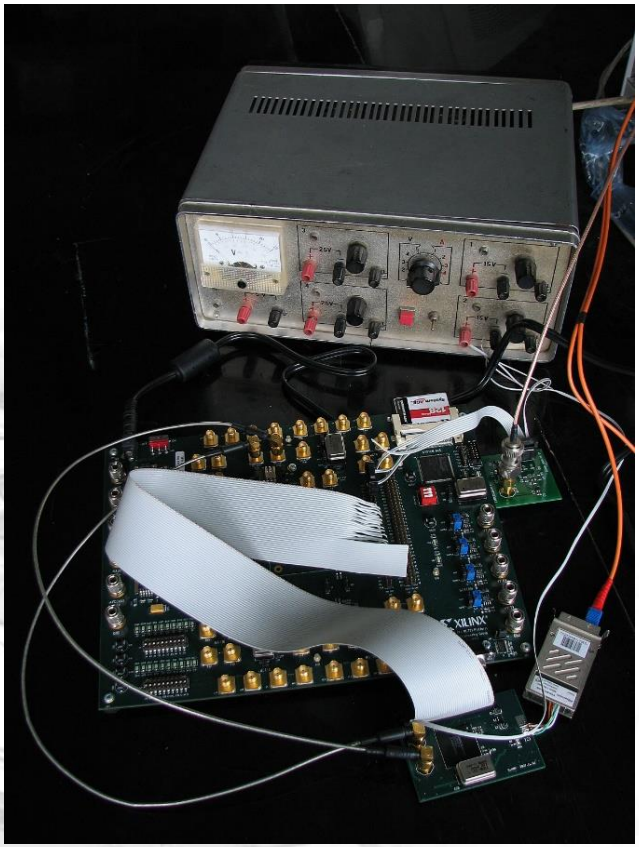
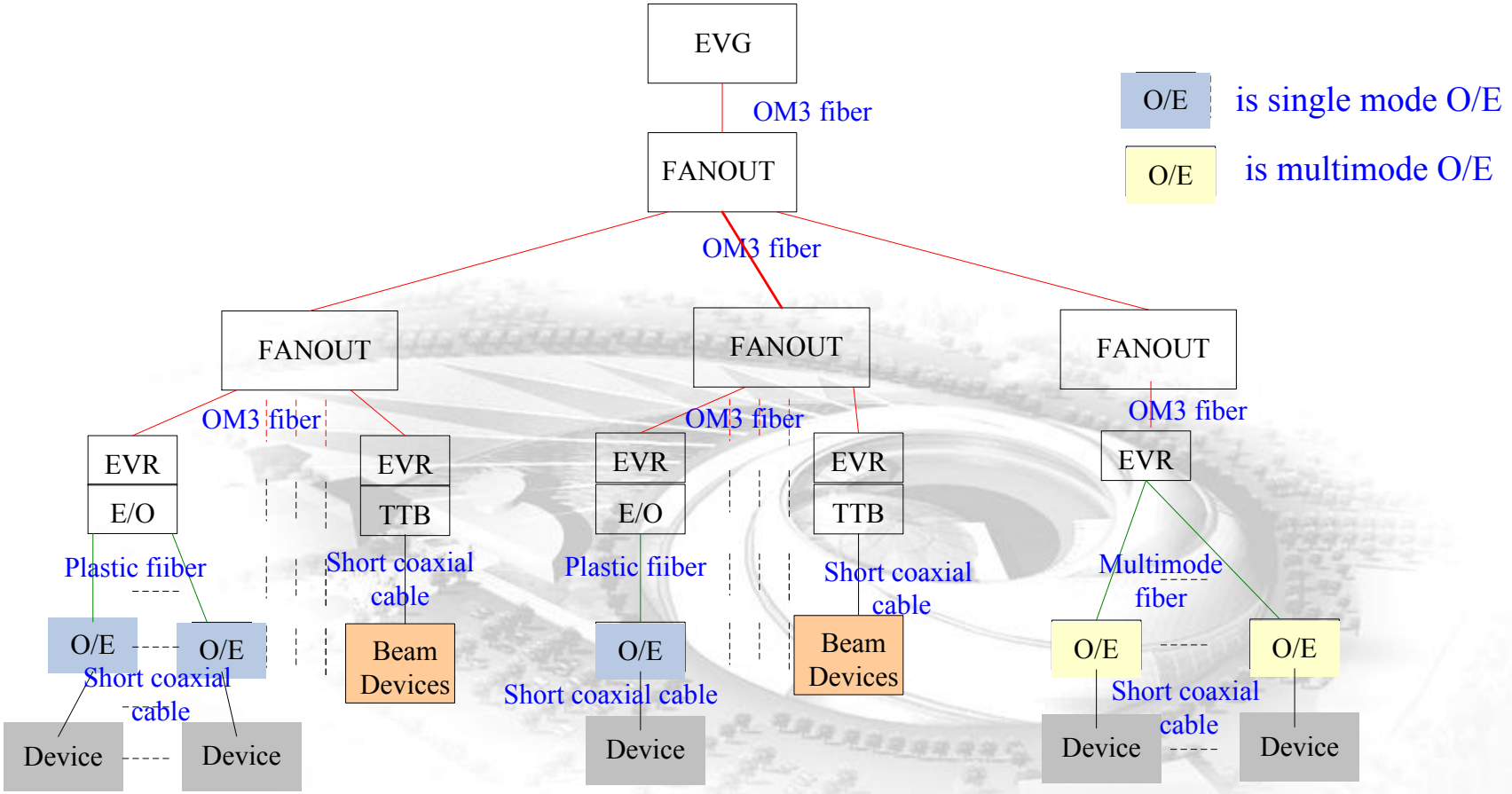
Review of SINAP timing system development

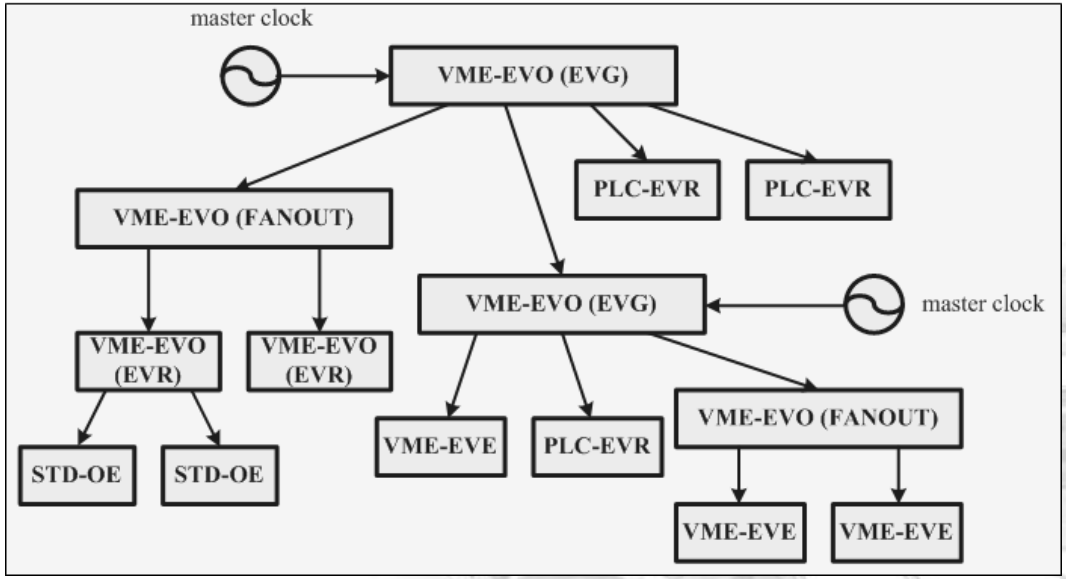
- First EVR prototype based on 1Gbps optical fiber. (2007)



SINAP V1 Timing System Structure



SINAP V2 Timing System Structure

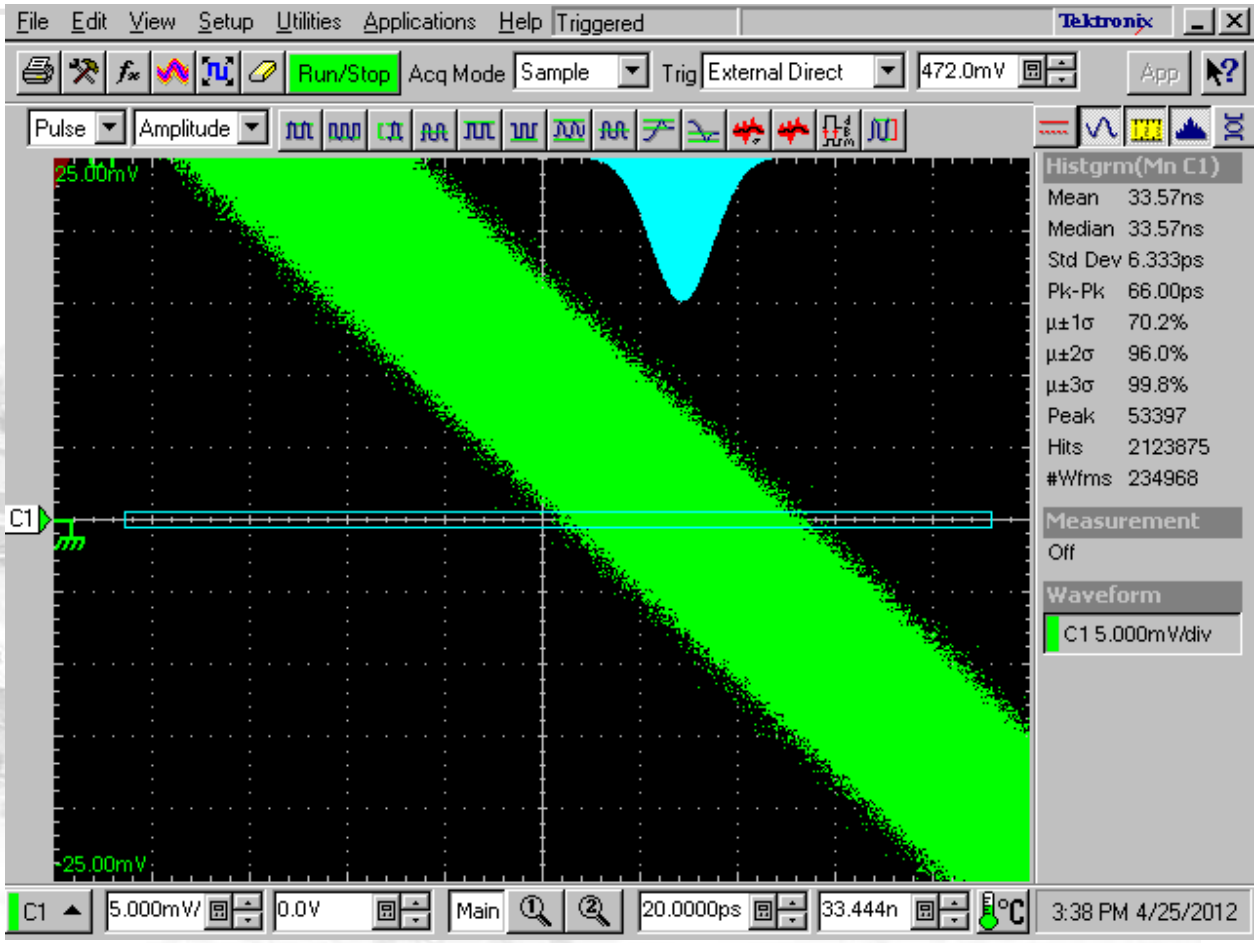


Performance Testing in KEK LAB

- Jitter

EVE TTL output

about 6ps



Goal of Femtosecond Timing System

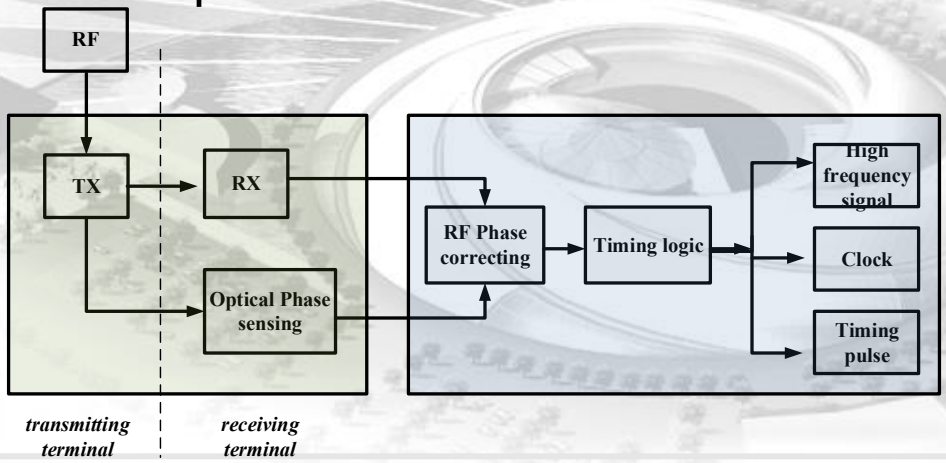
Providing RF signal and timing signal transmission with low temperature drift and low jitter for the experiment and the large accelerator device.

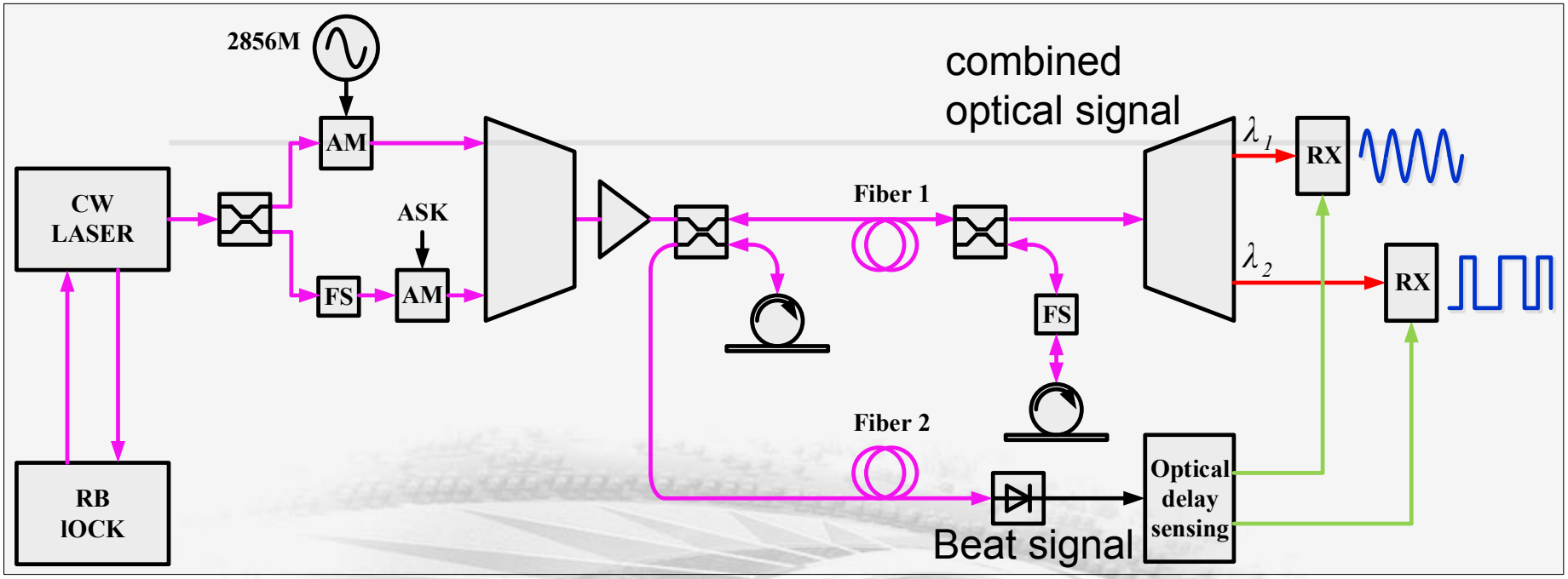
short-term jitter
10fs

long-term temperature drift
100fs

Femtosecond Timing System

- Based on microTCA platform.
- Electronic and optical hybrid system.
- Using ultra narrow linewidth CW laser to satisfy 10fs jitter requirement.
- To achieve femtosecond temperature drift , heterodyne interferometry is implemented to correct the phase shift.





- By implementing a wavelength division multiplexing system, the digital timing signal could be transmitted simultaneous.
- By the mode of phase detection and correction in the receiving node, whole system could be expanded.

Overcome long-term drift

phase detection algorithm

correction of group phase velocity

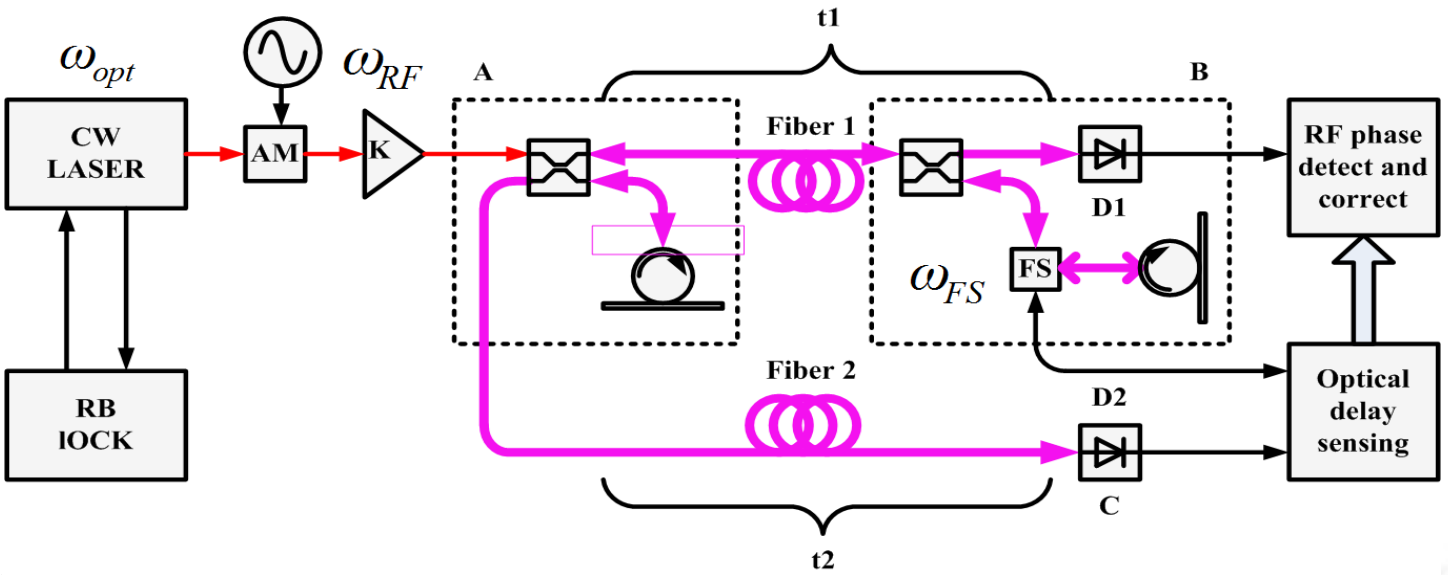
Improve short-term jitter

Influence of polarization state on interference signal

Digital timing signal transmission

System hardware structure

1. Optic Link-Phase Delay Measurement System



- Extremely high sensitivity.
- 1 deg RF=1 deg optical; 1 deg optical=0.014 fse.
- Precision: 10fs.
- frequency stability: 1:10^9

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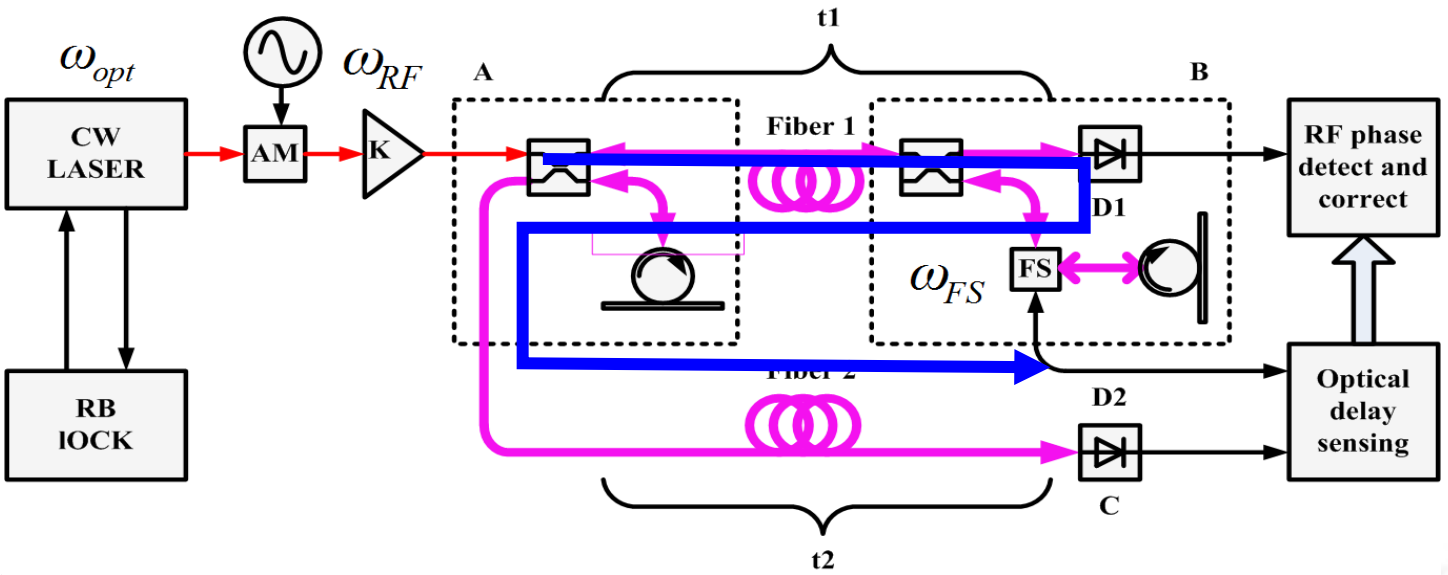

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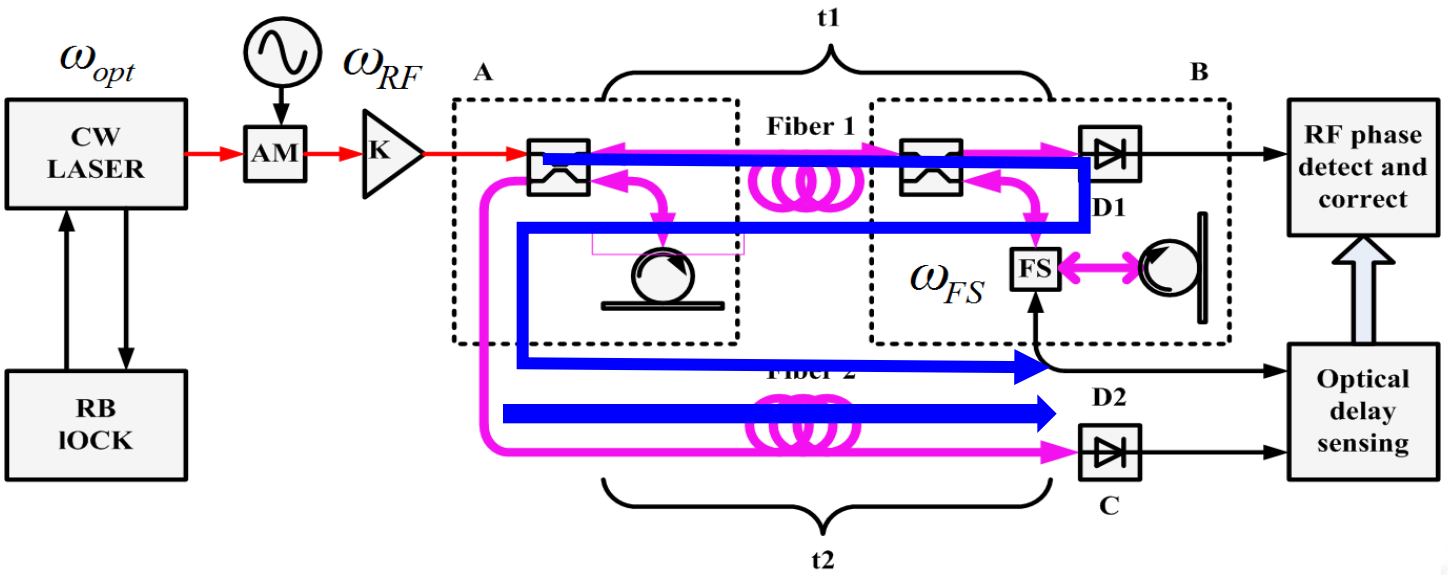

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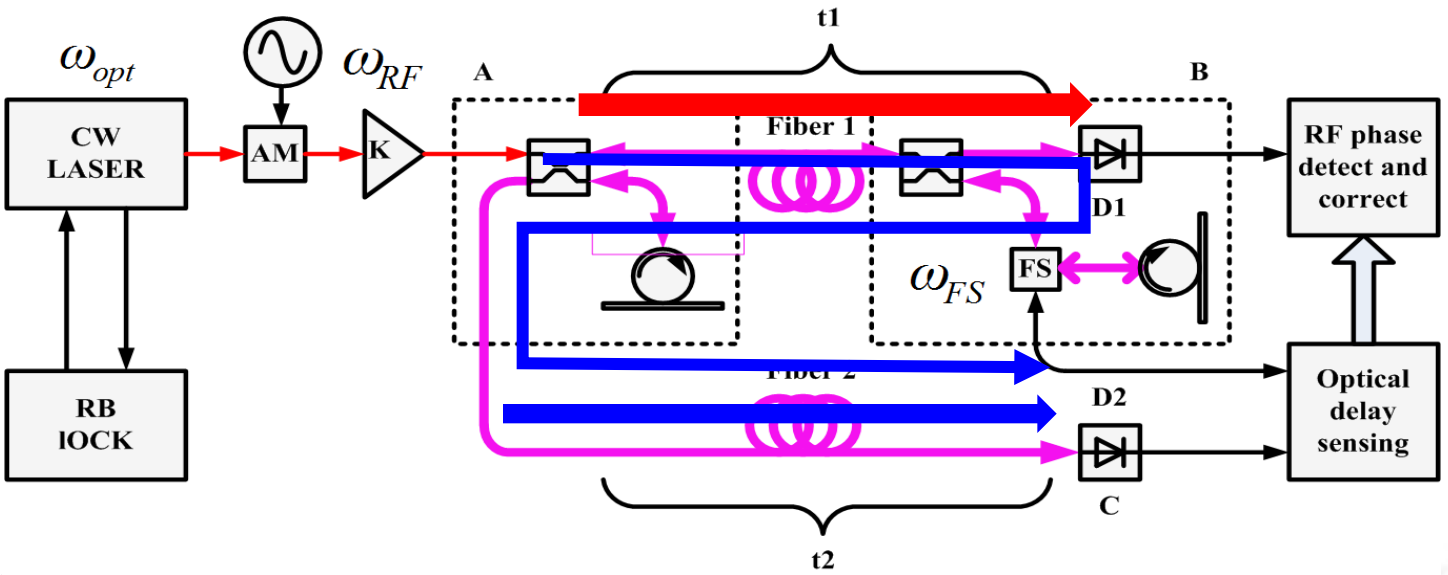

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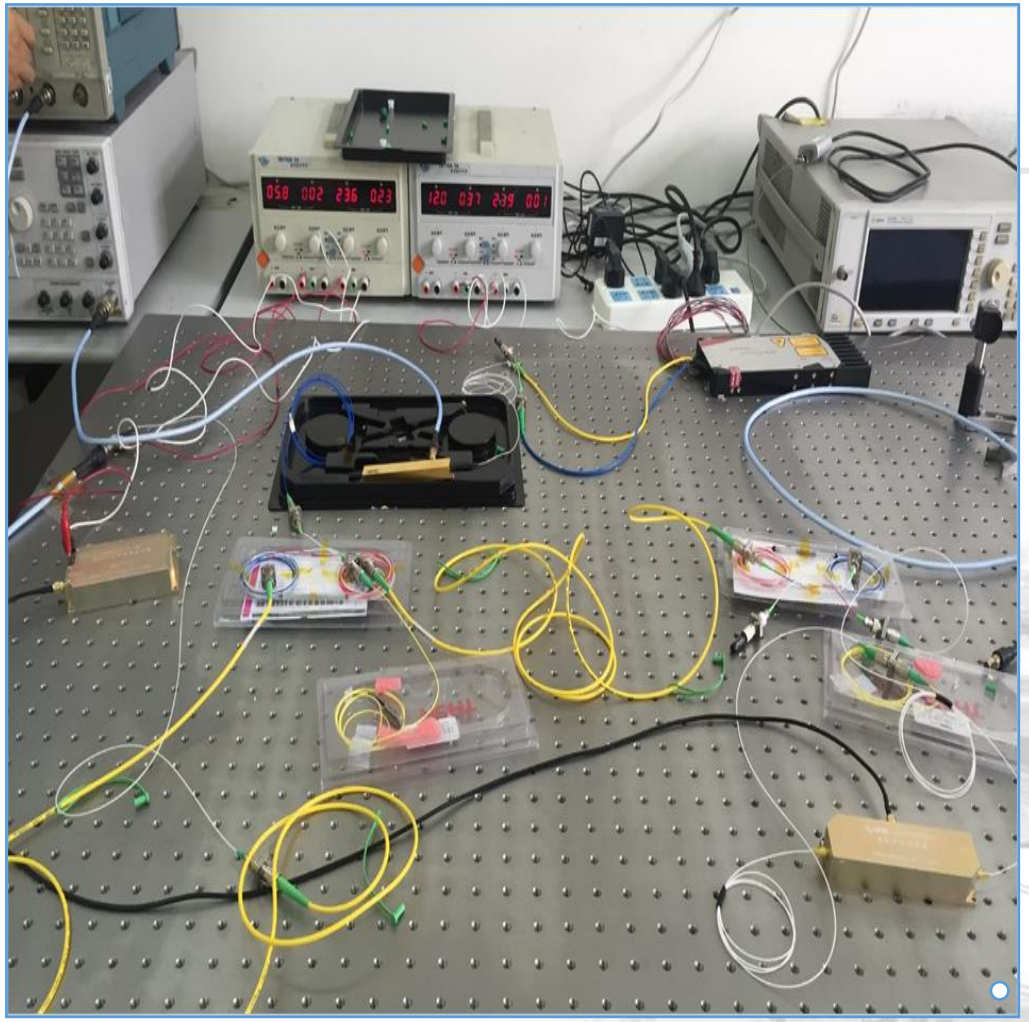
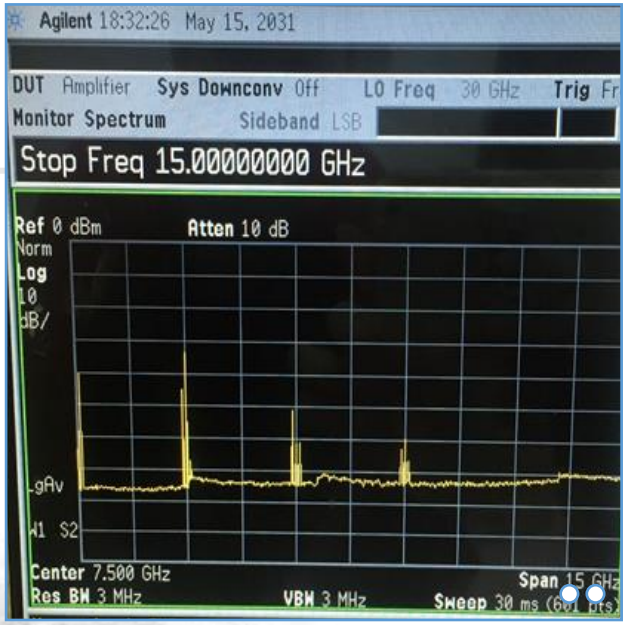
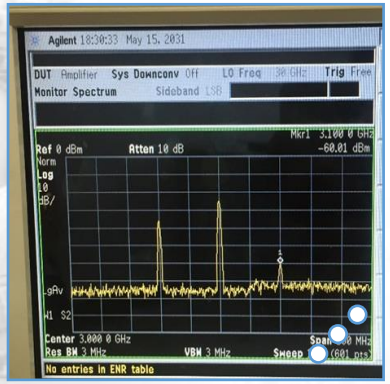
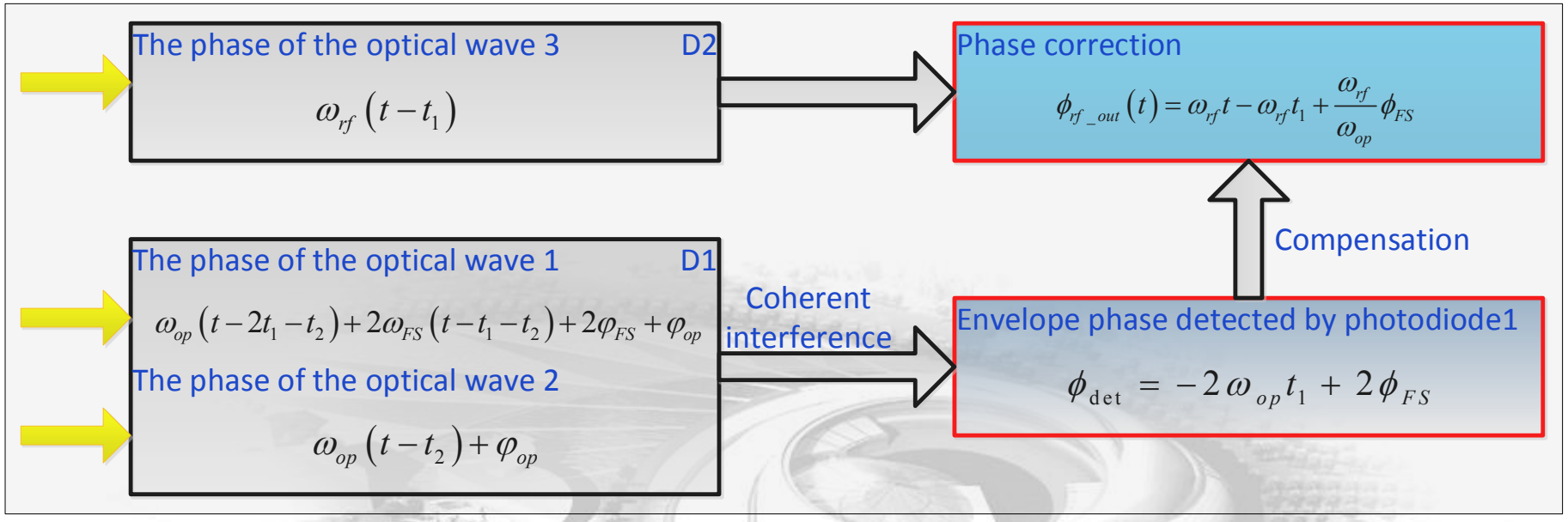



Agilent 18:32:26 May 15, 2031
DUT Amplifier Sys Downconv Off LO Freq 30 GHz Trig Fr
Monitor Spectrum Sideband LSB
Stop Freq 15.00000000 GHz
Ref 0 dBm
Atten 10 dB
Norm
Log
10
dB/
gAv
W1 S2
Center 7.500 GHz
Res BW 3 MHz
VBW 3 MHz
Span 15 GHz
Sweep 30 ms


Agilent 18:30:33 May 15, 2031
DUT Amplifier Sys Downconv Off LO Freq 30 GHz Trig Free
Monitor Spectrum Sideband LSB
Mkr1 3.100 0 GHz
-60.01 dBm
Ref 0 dBm
Atten 10 dB
Norm
Log
10
dB/
gAv
W1 S2
Center 3.000 0 GHz
Res BW 3 MHz
VBW 3 MHz
Span 0 MHz
Sweep (601 pts)
No entries in ENR table

2. Phase Compensation Algorithm



By controlling the size of ϕ_{FS} , the additional changes brought by $\omega_{rf}t_1$ can be offset by.

3. Line Width Calculation

Koheras BasiK E15 laser module, central wavelength 1560nm.

When the line width is 10KHz, the coherence length is 30 km. The coherence time is:

$$\tau_c = \frac{\Delta_c}{c} = \frac{3\times10^4}{3\times10^8} = 1\times10^{-4}\,s$$

Transmission delay of two interference signal in optical fiber arm:

$$t = \frac{2L}{v} = \frac{2\times2\times10^3}{3\times10^8} = 1.3\times10^{-5}\,s < \tau_c$$

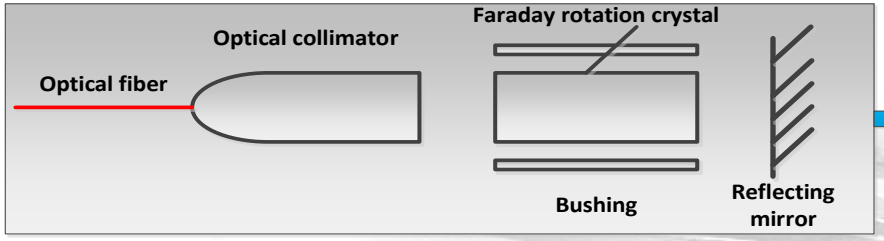
Meet the coherent condition

4. Influence of Polarization State on Interference Signal

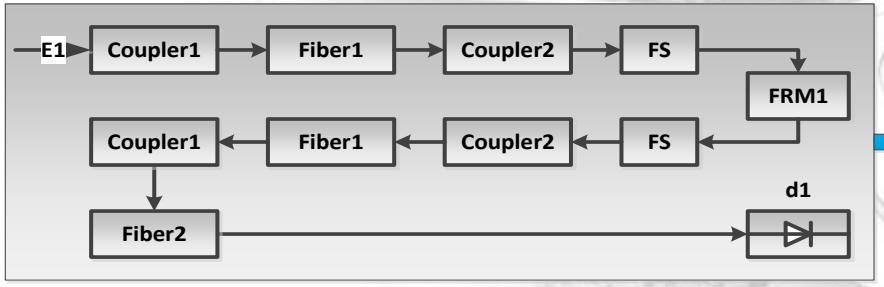
Faraday rotation mirror

eliminate polarization decline.

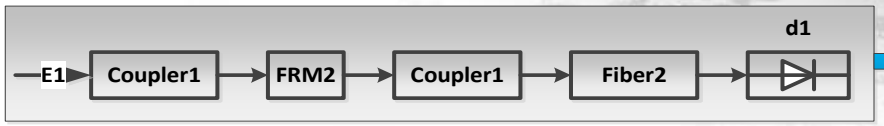
1. Faraday rotation mirror.
2. single mode fiber.
3. Laser polarization-maintaining output.



$$J = RTR' = \alpha^2 t \cdot \begin{bmatrix} 0 & -1 \\ -1 & 0 \end{bmatrix}$$



$$E_{19} = -\frac{j}{4} \cdot \alpha^2 t \cdot \exp(-j2(\omega_{FS} t + \phi_{FS})) \begin{pmatrix} 0 & -1 \\ -1 & 0 \end{pmatrix} E_{in}$$



$$E_{23} = j\frac{1}{2} \cdot t \cdot \begin{pmatrix} 0 & -1 \\ -1 & 0 \end{pmatrix} E_{in}$$

5. Correction of group phase velocity

The dispersion changes the phase of the amplitude modulation. This will lead to a delay in the modulation of the modulation of the RF phase in the signal transmission and the difference of the group delay.

The difference between group delay and phase delay caused by the dispersion in optical fibers are corrected *by factor* k_{group_phase}

$$\phi_{rf\_out}(t) = \omega_{rf} t - \omega_{rf} t_1 + \frac{\omega_{rf}}{\omega_{op}} \phi_{FS} \cdot k_{group\_phase}$$

Photoelectric diode recovery RF signal in optical receiver, measure the change of group velocity, and compare to the change of optical fiber phase velocity.

6. optical reflection loss and temperature control

Due to the continuous nature of the signal, retroreflections anywhere in the fiber optic signal path can cause random fluctuations of the received rf signal phase. *Using APC connector and high return loss device to reduce optical reflection loss.*

In optical system, the error caused by temperature change can be eliminated. In the electronics system, *the temperature-controlled container is used to stabilize the temperature of the key parts*.

overcome long-term drift

Improve short-term jitter

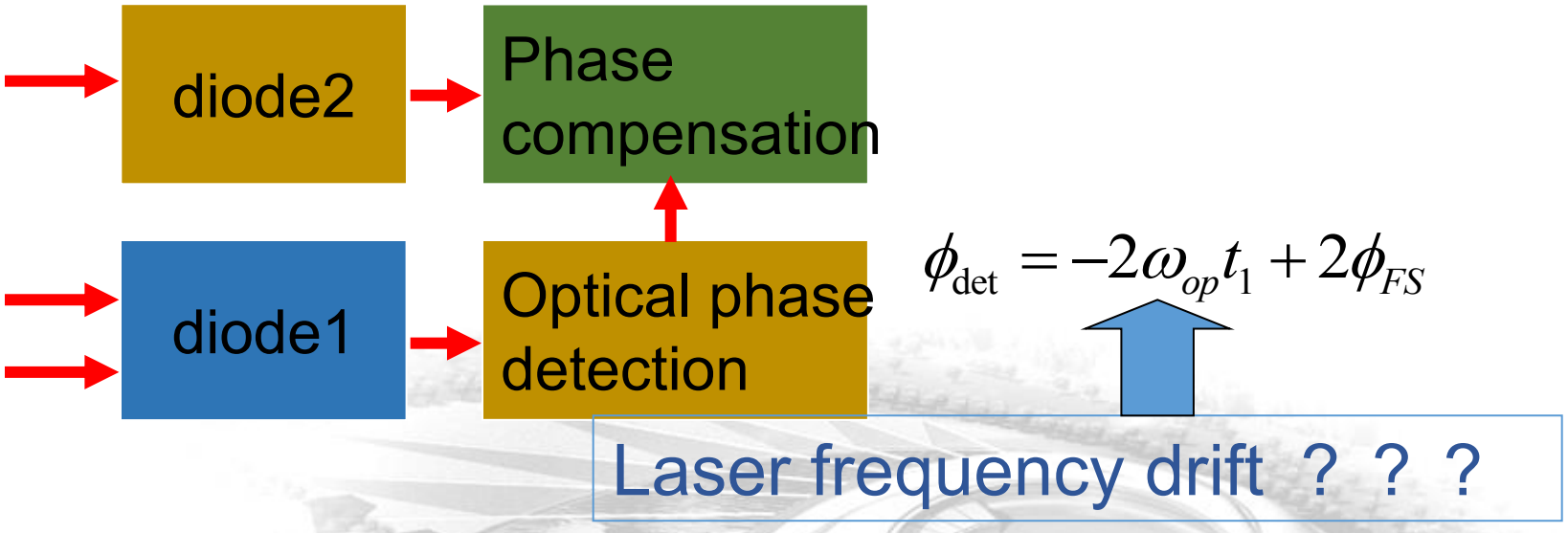
Digital timing signal transmission

System hardware structure

laser frequency stabilization

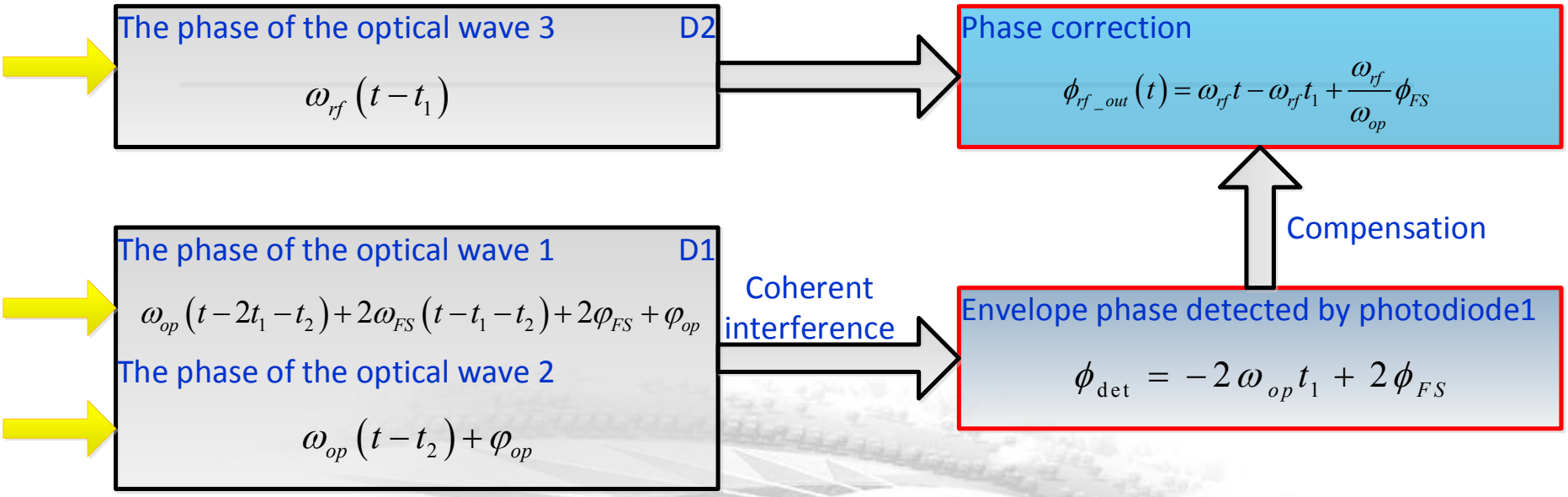
Frequency stability test

The condition of coherent detection



Frequency stabilization measures:

- Lasers with excellent frequency stability.
- The two beams from the same laser, the frequency offset of the light.
- laser frequency stabilization system.

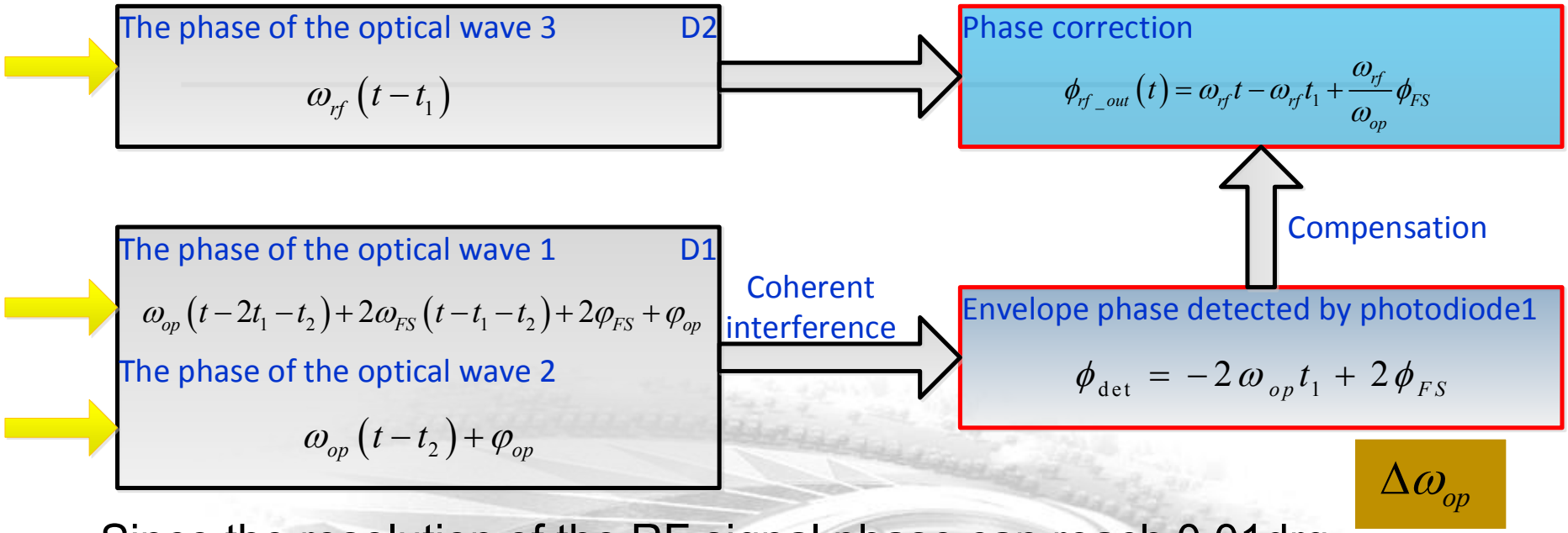


Since the resolution of the RF signal phase can reach 0.01drg.

0.01drg @2856GHz
= 10fs

$$\frac{\Delta\omega_{op}}{\omega_{op}}=\frac{0.01}{\omega_{rf}\cdot t_1}=\frac{0.01}{360\times2856\times10^6\times\frac{4}{3}\times10^{-5}}=10^{-9}$$

Through calculation, about 2 km long fiber optic network, to the resolution of 10 fs, the frequency of the laser must be stable to 1：10^9.



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$$\Delta\phi = \frac{\omega_{rf}}{\omega_{op}} \cdot \Delta\omega_{op} \cdot t_1$$

The phase of the optical wave 3 D2

$$\omega_{rf}(t - t_1)$$

Phase correction

$$\phi_{rf\_out}(t) = \omega_{rf} t - \omega_{rf} t_1 + \frac{\omega_{rf}}{\omega_{op}} \phi_{FS}$$

Compensation

The phase of the optical wave 1 D1

$$\omega_{op}(t - 2t_1 - t_2) + 2\omega_{FS}(t - t_1 - t_2) + 2\varphi_{FS} + \varphi_{op}$$

The phase of the optical wave 2

$$\omega_{op}(t - t_2) + \varphi_{op}$$

Coherent interference

Envelope phase detected by photodiode1

$$\phi_{det} = -2\omega_{op} t_1 + 2\phi_{FS}$$

$\Delta\omega_{op}$

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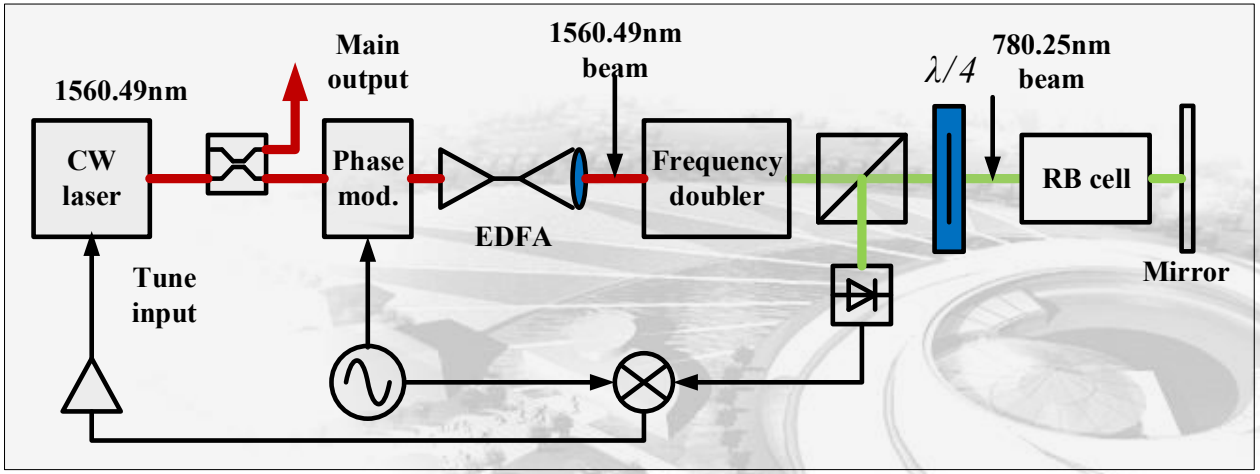
laser frequency stabilization

Extraction of laser sample, frequency doubling, locked to the saturated absorption spectrum of rubidium vapor cell line.



error signal:

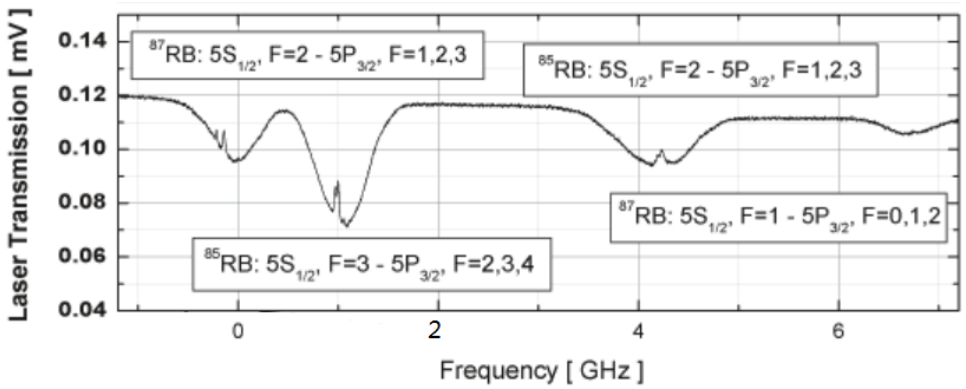
the change of laser power.

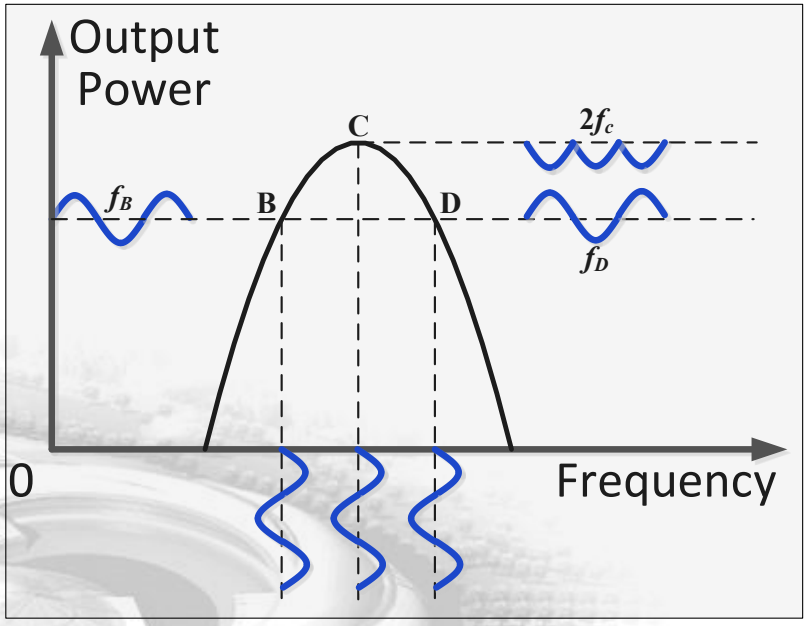
feedback signal：

value is proportional to the error signal.

plus or minus depends on phase relationship between the error signal and the modulation signal

laser frequency stabilization



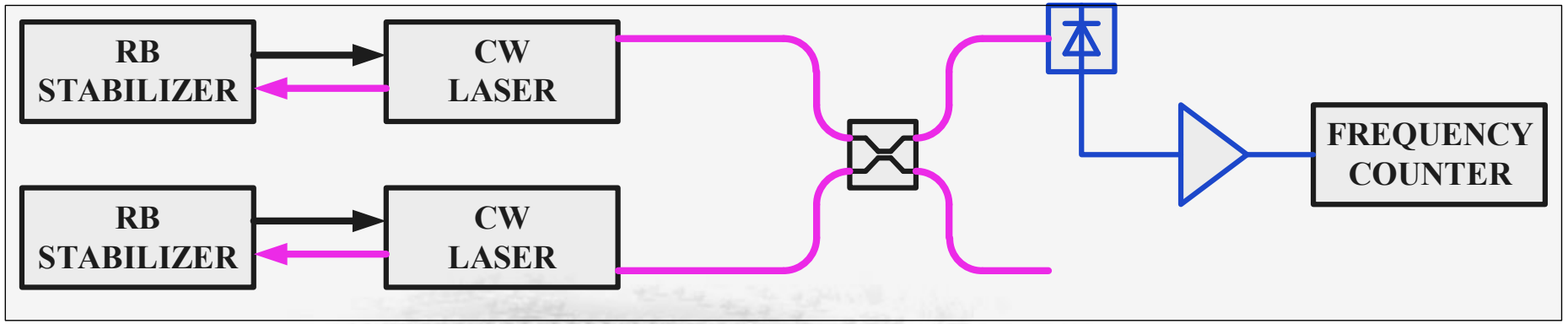


The spectra show the saturated absoption of the D_1 line of Rubidium at 780nm

If error signal and modulation signal have the same phase , Output is a positive dc voltage.

If error signal and modulation signal have opposite phase , output is a negative dc voltage

Frequency stability test



Two locked lasers beat together.

Measure the stability and frequency drift of the beat signal.

overcome long-term drift

Improve short-term jitter

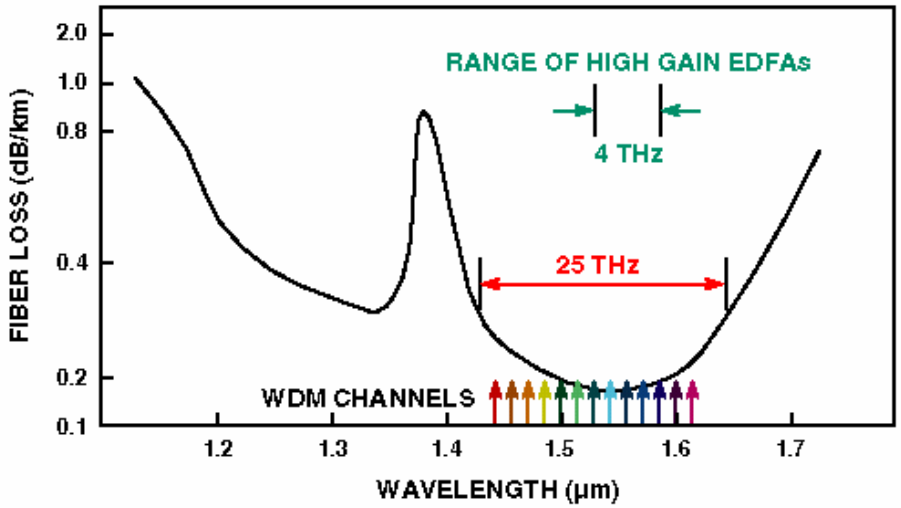
Digital timing signal transmission

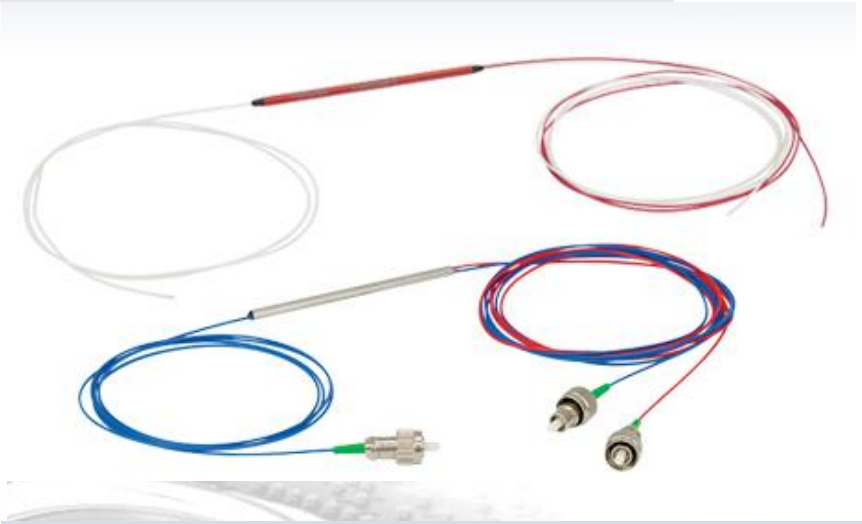
System hardware structure

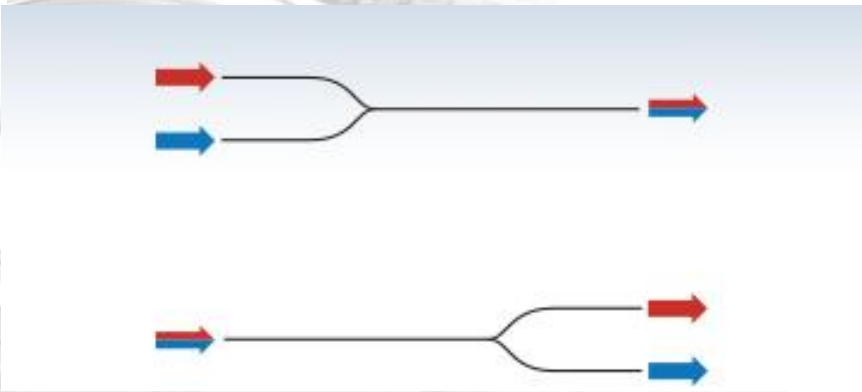
Wavelength Division Multiplexing

ASK signal demodulation

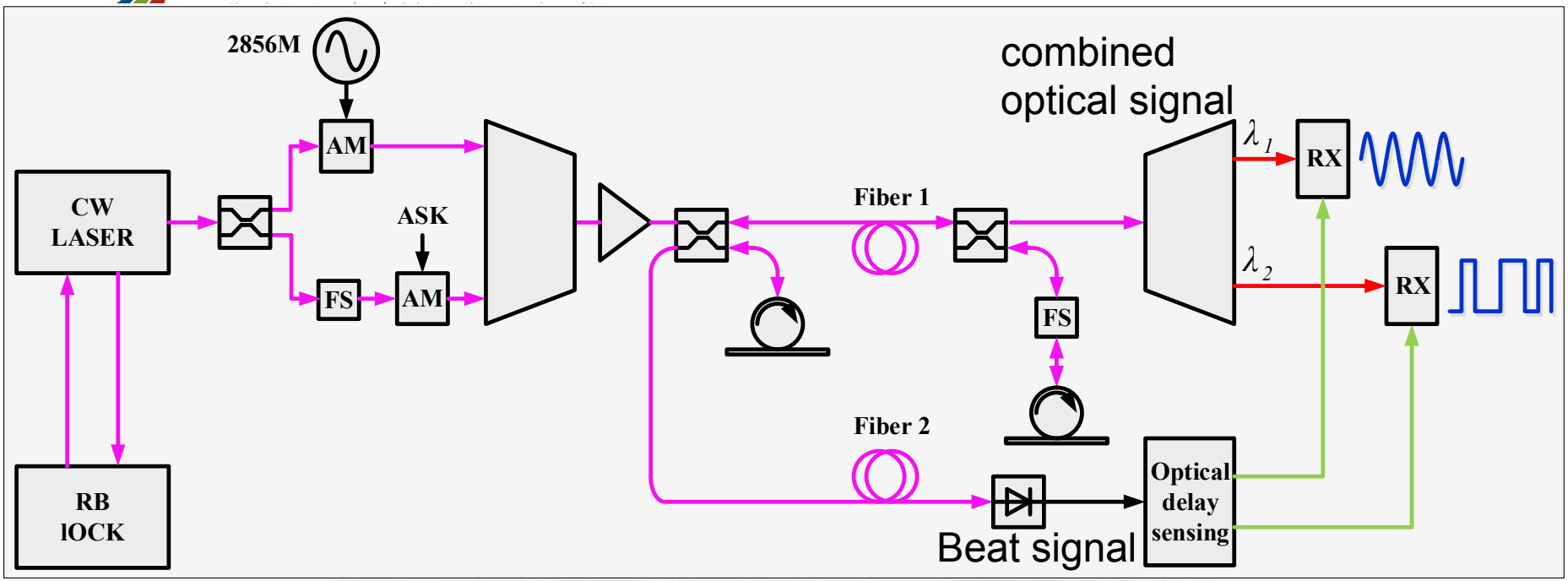
Wavelength Division Multiplexing





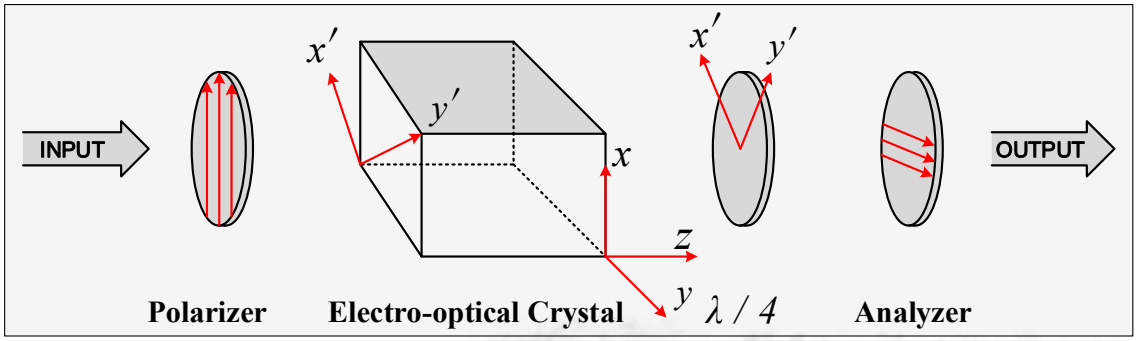


WDM: Combine or Split Single Mode Signals by Wavelength.



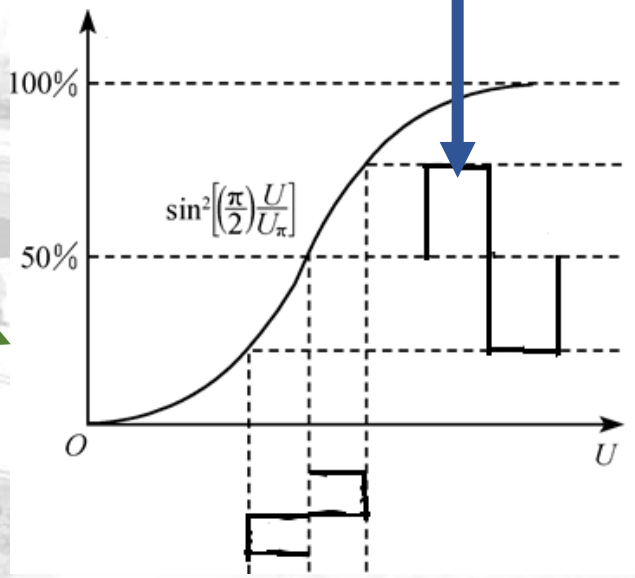
- Full use of the huge bandwidth of fiber (low loss band) .
- Simultaneous transmission of a variety of different types of signals, digital signal and analog signal, etc.
- By constructing a wavelength division multiplexing system, the digital timing signal is transmitted simultaneous.

digital signal modulation

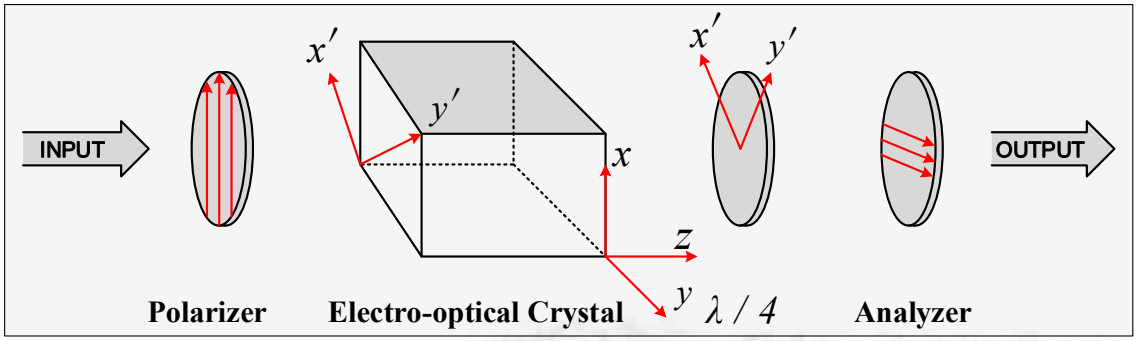


Amplitude Shift Keying

Light intensity modulation signal



digital signal modulation



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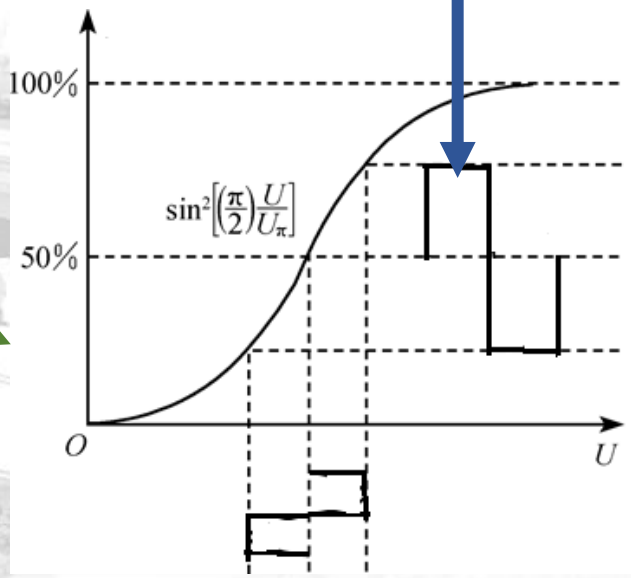
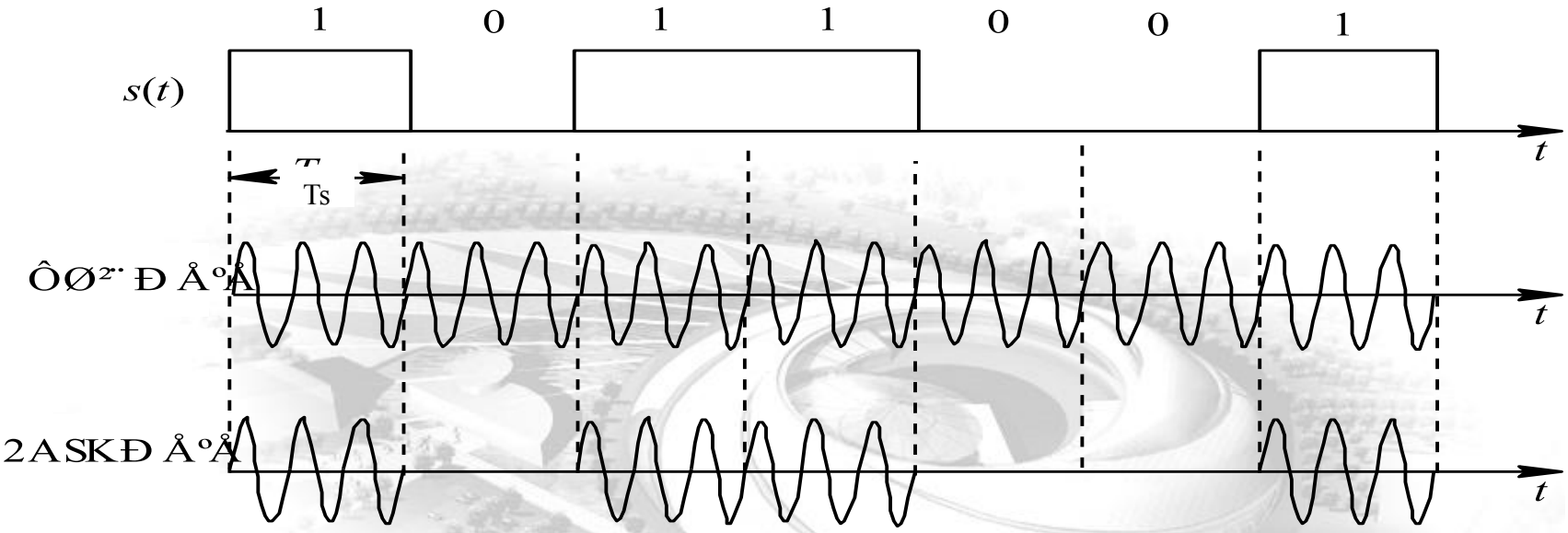
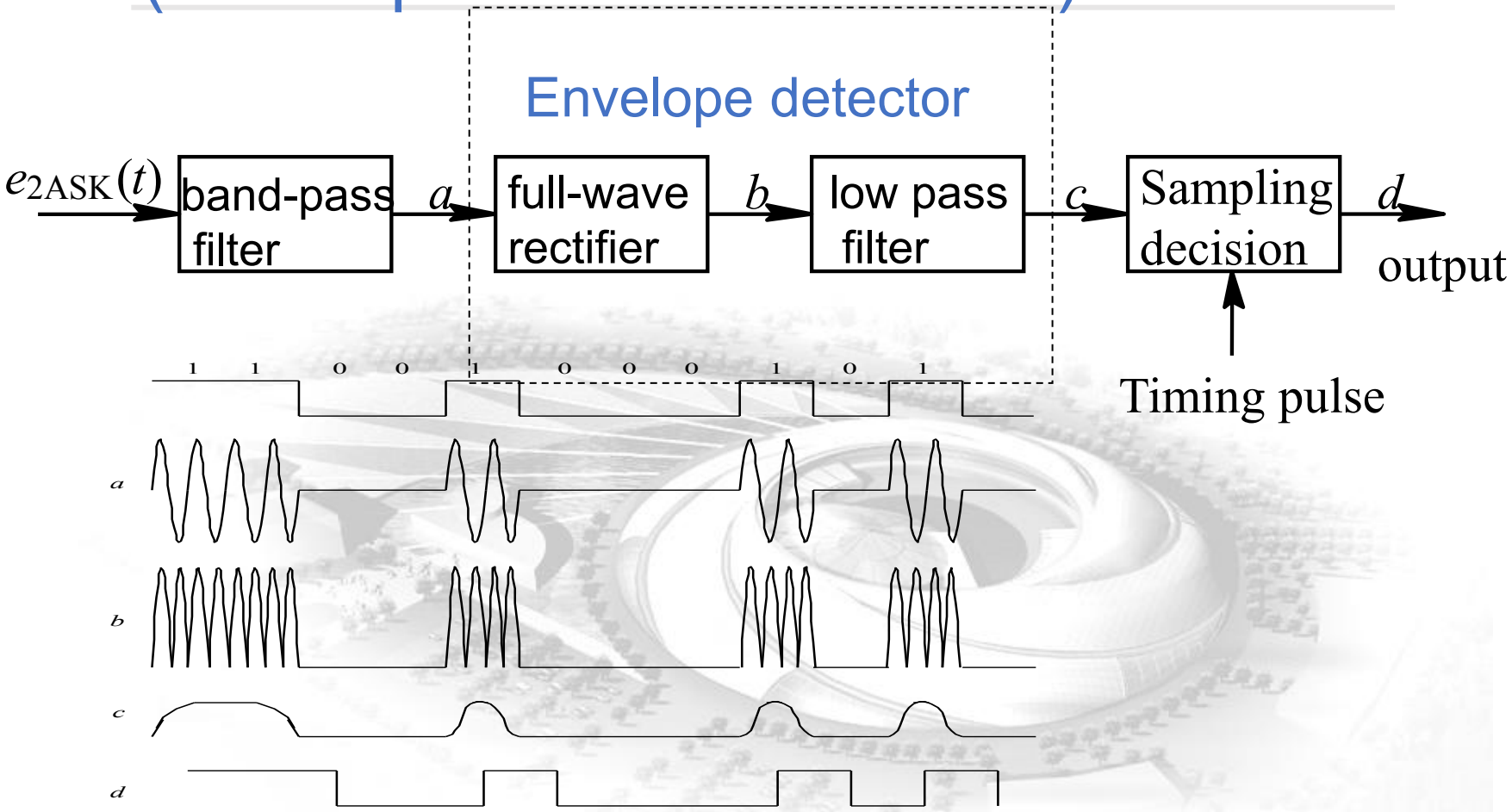


The transmitted light intensity is modulated by the signal voltage.

Time waveform of ASK signal

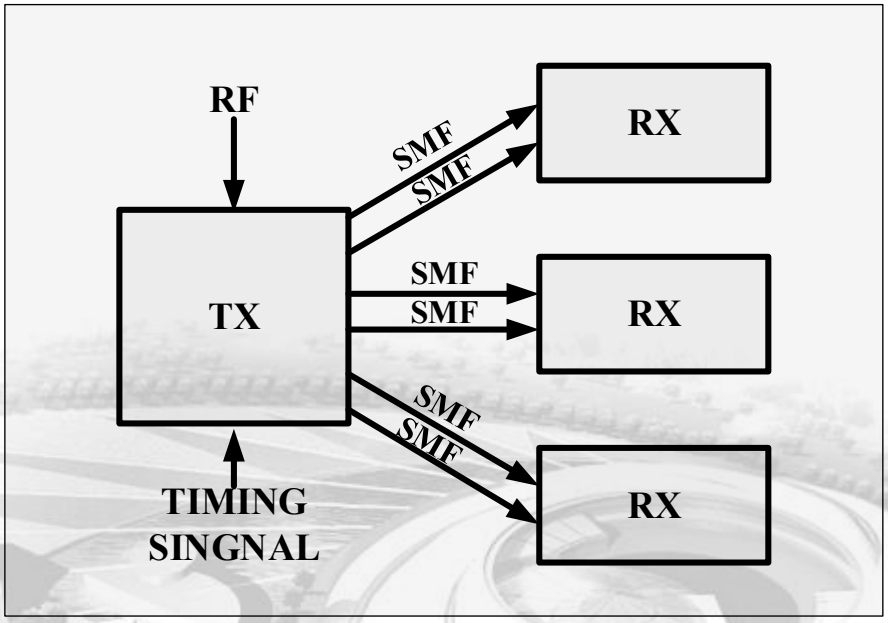


ASK signal demodulation (Envelope detection method)



- overcome long-term drift
- Improve short-term jitter
- Digital timing signal transmission
- System hardware structure
  - TX module
  - RX module
  - SMF28 fiber

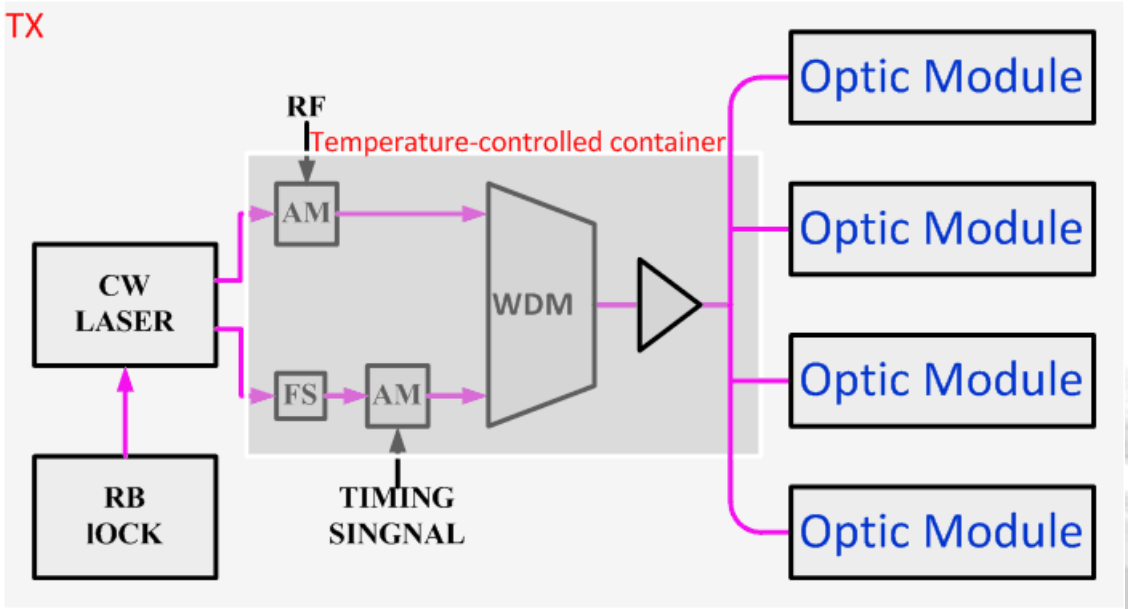
System hardware structure

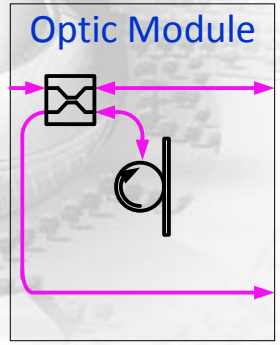


Hardware List

- TX
- RX
- SMF28 fiber

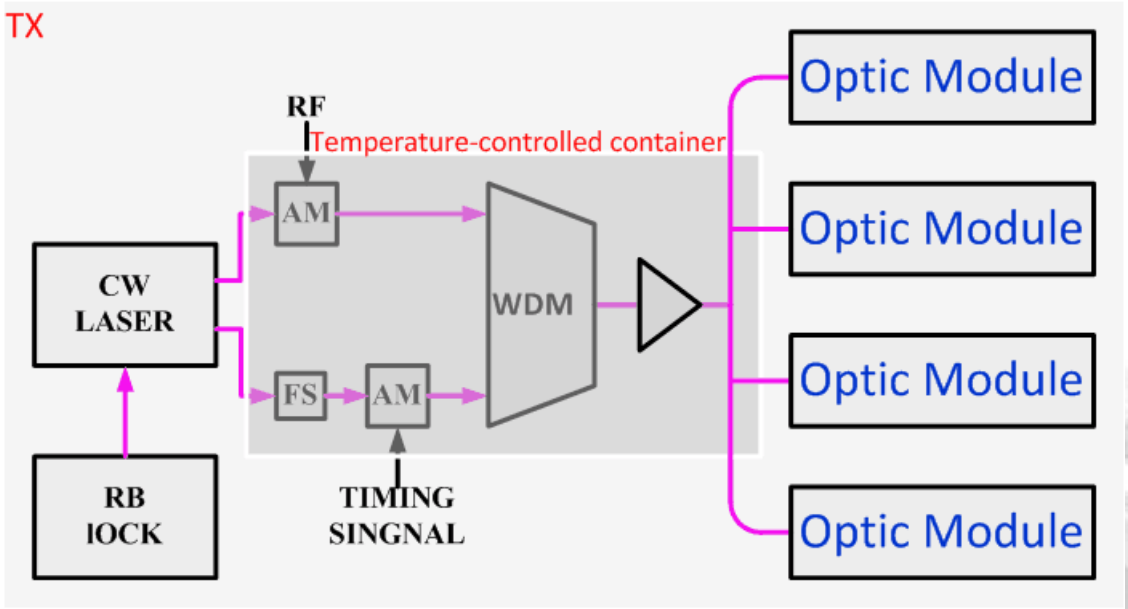
TX module



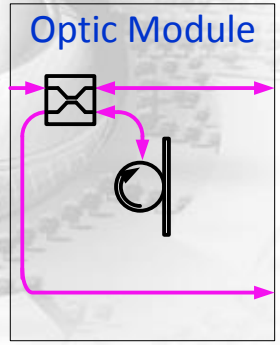


CW single mode fiber laser;
EDFA (Erbium Doped Fiber Amplifier);
Multiplexer;
laser frequency stabilization module;
temperature-controlled container;

TX module



Input: RF signal
timing signal
16 Outputs: SMF28



CW single mode fiber laser;
EDFA (Erbium Doped Fiber Amplifier);
Multiplexer;
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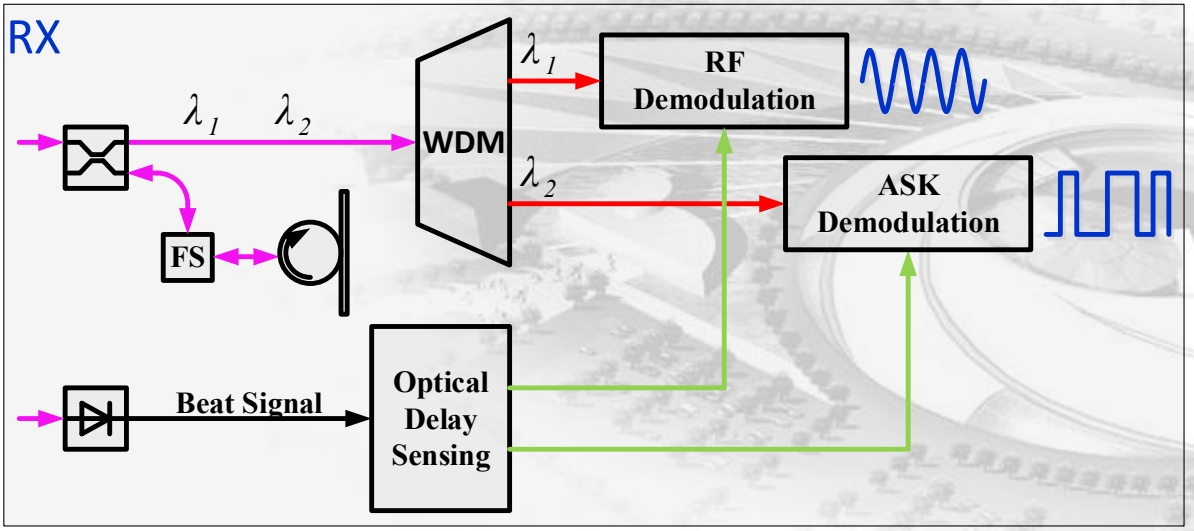
RX module

- uTCA.4 module (Double-width and RTM)
- RF Demodulation
- ASK Demodulation
- Optical Delay Sensing module
- Demultiplexer



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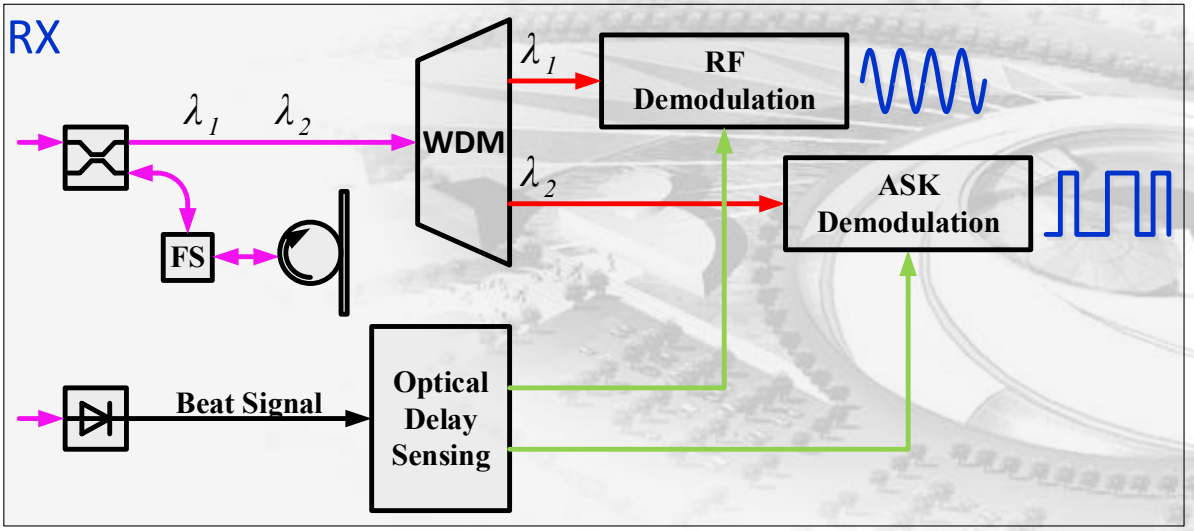
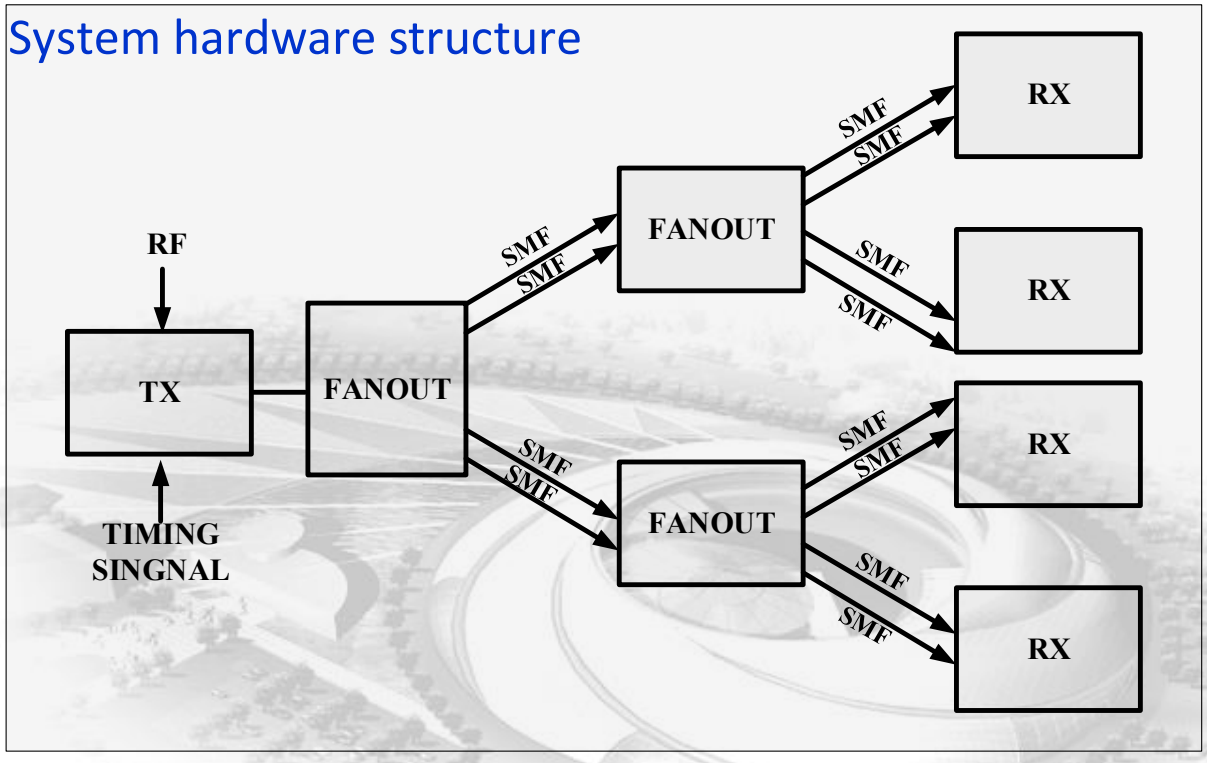
- Optical Delay Sensing module
- Demultiplexer



Input: combined optical signal
Beat signal
Output: RF signal
timing signal

FOUT development in future



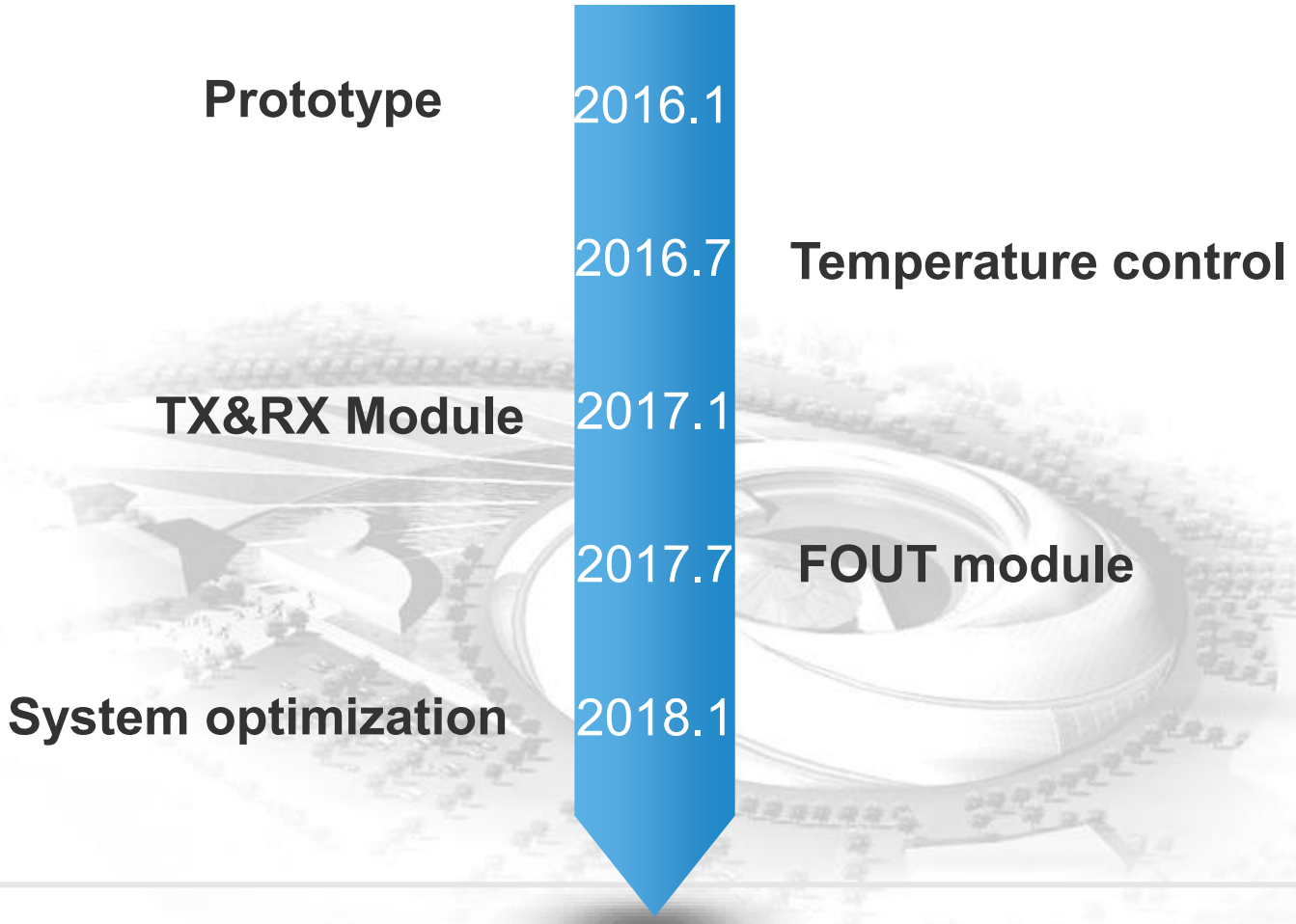
Character of Femtosecond Timing System

- Providing RF signal and timing signal transmission with low temperature drift and low jitter

- Transmission distance can reach 30 km

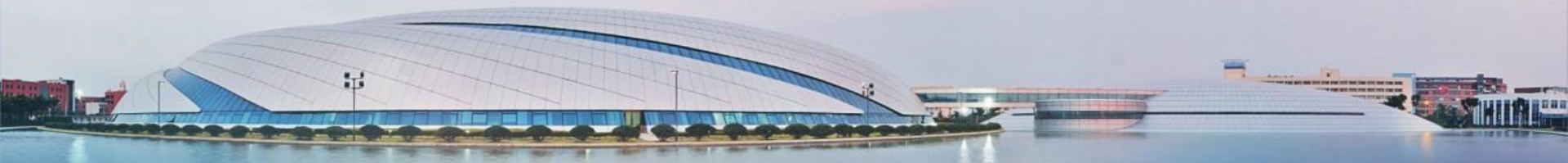
- Simultaneous transmission of RF signal and digital timing signal

Project schedule



Thank you!

Questions?



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