

# Laser Tracking Measurement System using Dual Femtosecond Optical Frequency Combs

Prof. Weihu Zhou

Academy of Opto-Electronics, Chinese Academy of Sciences

# Outline

**1**

**Introduction of Academy of Opto-Electronics(AOE)**

**2**

**Femtosecond Optical Frequency Comb(FOFC) and Application**

**3**

**FOFC Distance Measurement**

**4**

**FOFC Laser Tracker**

**5**

**Summary**



# *1. Introduction of AOE*

# AOE

## The Technology and Engineering Research Center of Chinese Academy of Sciences (CAS)

- ★ **Founded in Dec. 2003**
- ★ **Dedicated in the research and development of optical remote sensing, laser and its application, space science & technology**
- ★ **5 branch institutes**
- ★ **Responsibilities: Project Organization, System Development, Technology Spin-off.**



# The headquarter of AOE (Beijing)



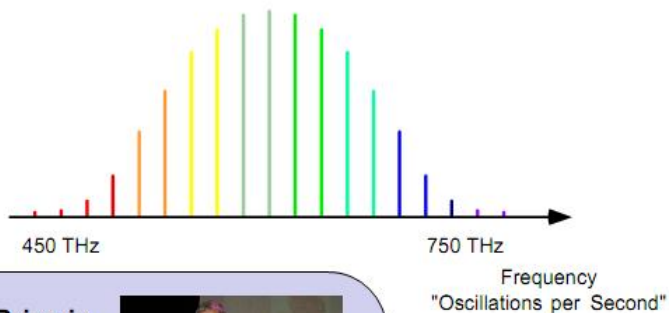


## ***2. FOFC and Application***



## ➤ FOFC: femtosecond mode locked laser with repetition rate and phase controlled.

Ruler in Frequency Space



**The Nobel Prize in Physics 2005**



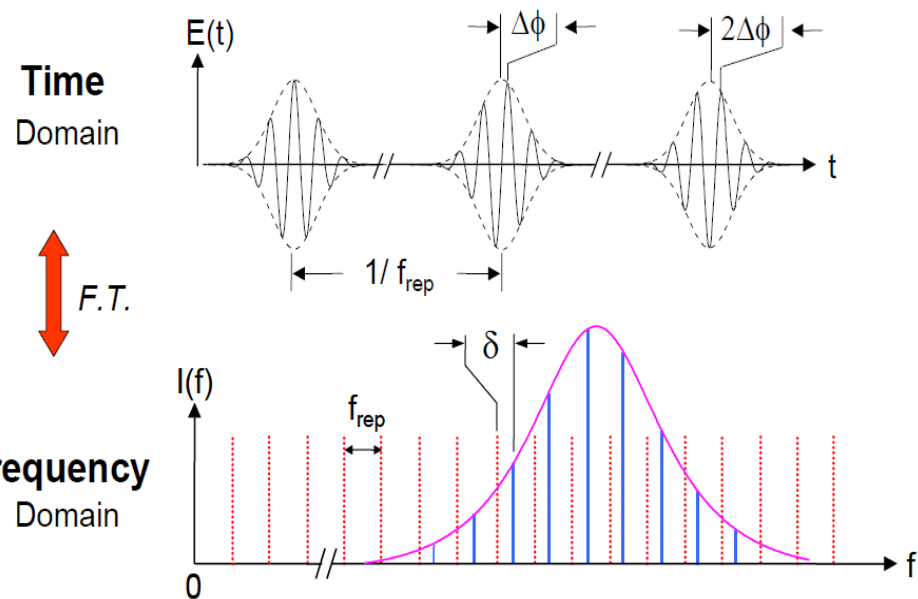
**John L. Hall and Theodor W. Hänsch**

for their contributions to the development of laser-based precision spectroscopy, including the optical frequency comb technique



- Application determines:**
- Wavelength range
  - Mode spacing
  - Repetition rate variation
  - Phase noise requirements
  - Accuracy requirements

### Time Domain ↔ Frequency Domain

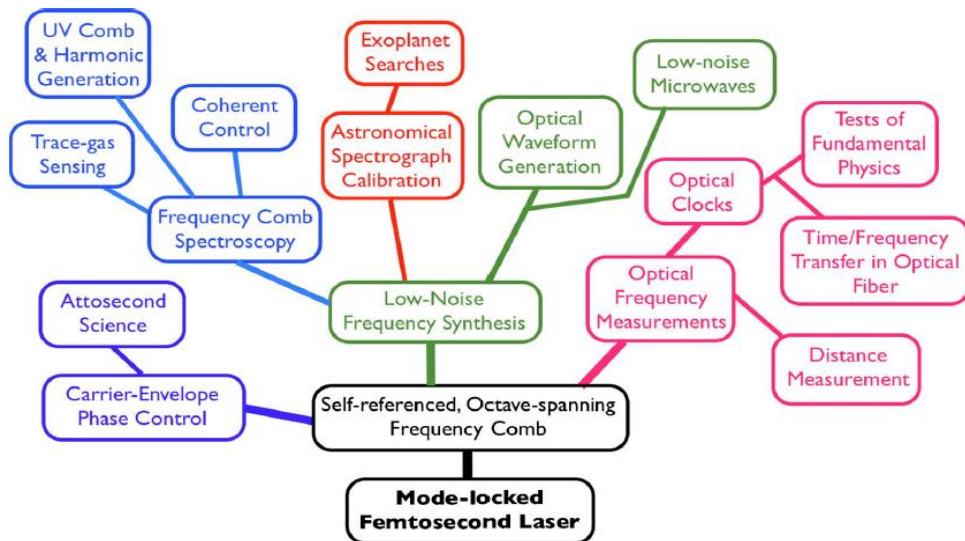


• Frequency modes of the fs pulse are offset from  $f_{n=0}=0$  by  $\delta$

$$2\pi\delta = \Delta\phi f_{\text{rep}}$$



# Application of FOFC



S. Diddams, *JOSAB*, 27(11), 2010.

## ● Measurement

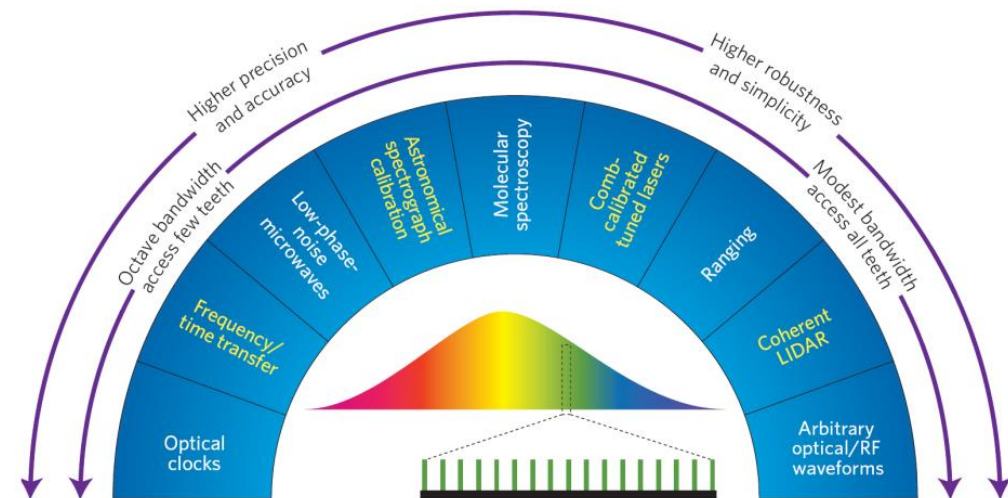
- Absolute distance
- Optical Frequency
- Time/frequency transfer
- Tests of fundamental physics
- Spectroscopy

## ● Frequency synthesis

- Low-noise microwaves
- Optical waveform generation

## ● Carrier-envelope phase control

- Ultrafast science



N. R. Newbury, *Nat. Photonics*, 5, 2011.

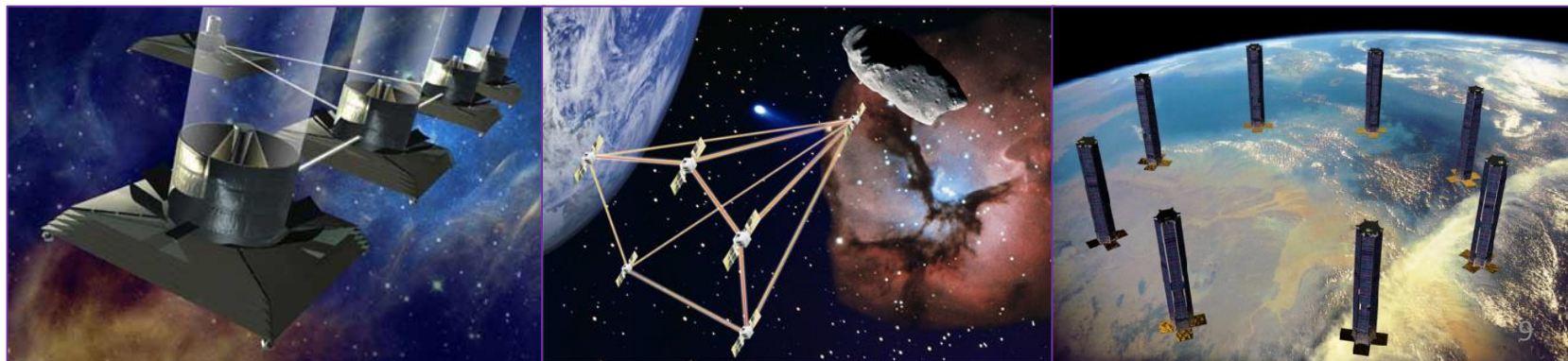




## Large Scale Metrology



## Satellite Flying Formation





## ➤ Requirements

- Precision:  $\sim 1\mu\text{m}$  @  $>10\text{ m}$  (0.1ppm)
- Update :  $<1\text{ms}$

## ➤ Traditional methods

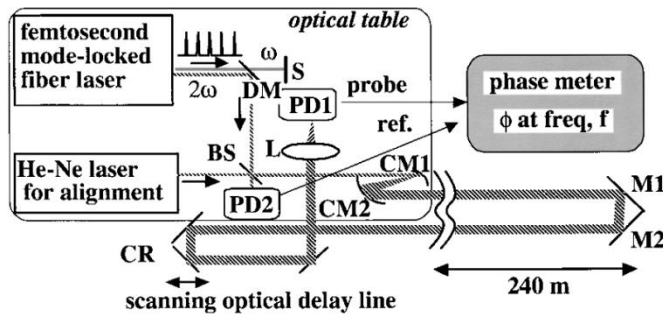
- Time of flight/phase (1ppm)
- Multi-wavelength(1ppm)



# Absolute Distance Measurement by FOFC

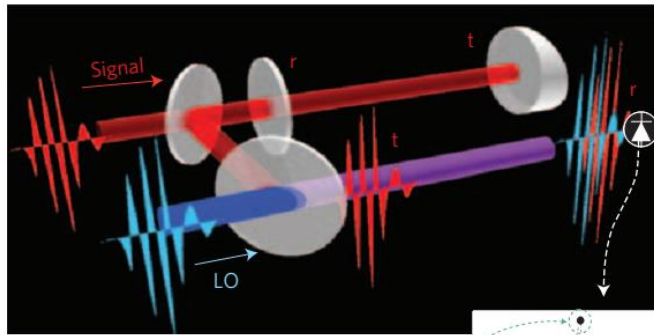
- **Advantages**—Measurement range: km, Precision:  $\mu\text{m}$ , update : ms
- **Application prospect**--**Measurements for satellite flying formation, New laser tracking measurement , High-precision multi-lateral intersection measurement ,** Space science, Earth observation , High-end manufacturing, Surveying and Mapping .

## Synthetic wavelength interferometry



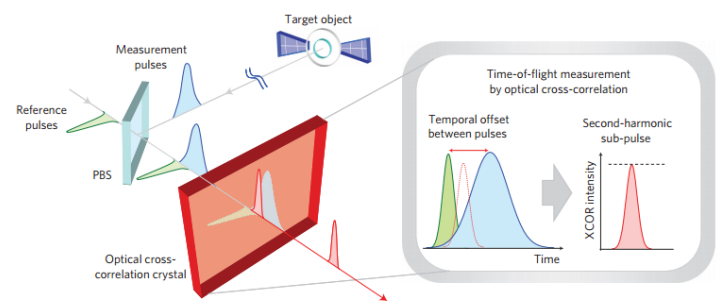
K. Minoshima, et al, Applied Optics.2000.39(30).

## Dual-comb



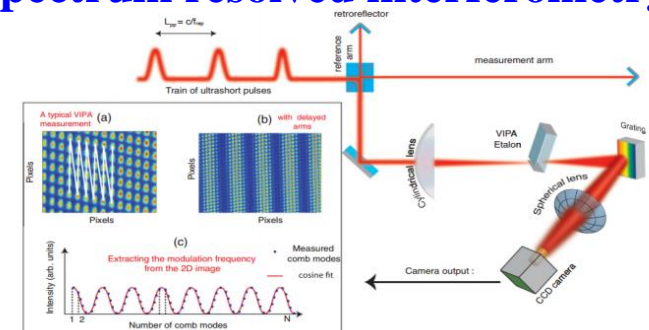
I. Coddington, et al, NPHOTON.2009.94.

## Time-of-flight



Seung-Woo Kim, et al, NPHOTON.2010.175

## Spectrum resolved interferometry



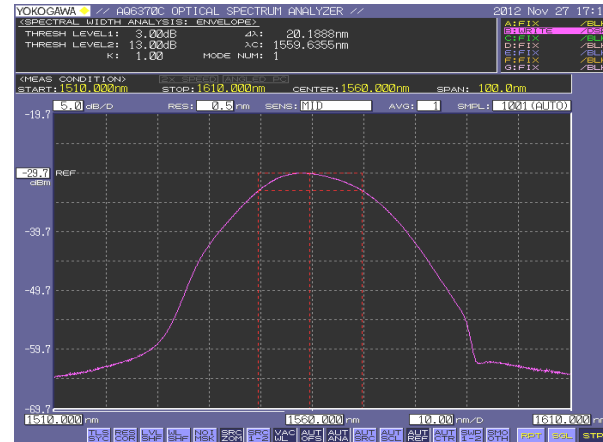
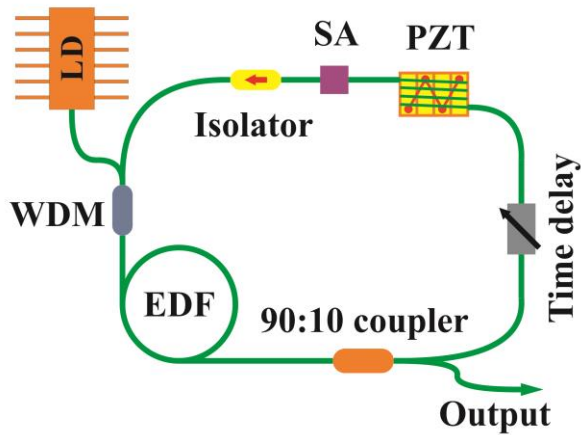
S. A. van den Berg, et al, PRL 108, 183901 (2012)



### ***3. FOFC Distance Measurement***

# Femtosecond Optical Frequency Comb

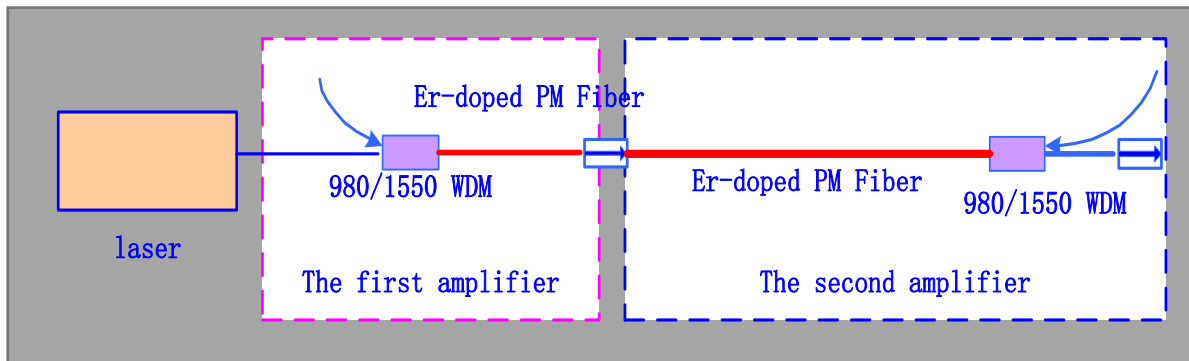
## Femtosecond oscillator



Polarization-maintain fiber laser

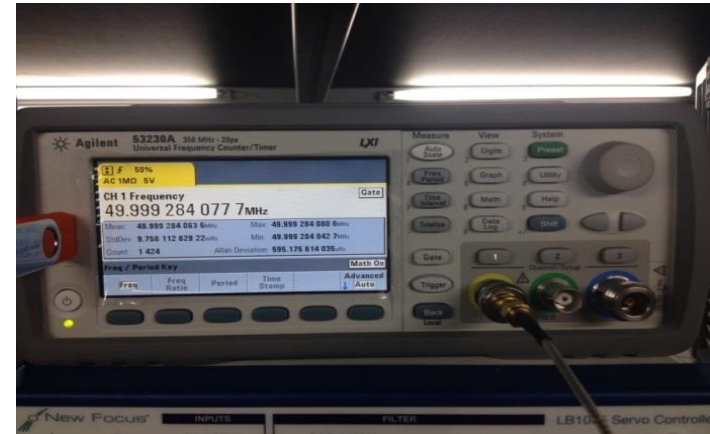
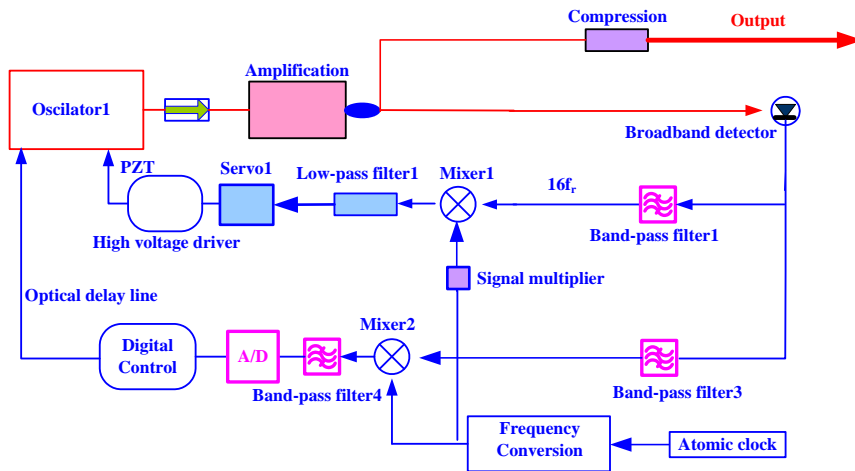
Output spectrum

## Pulse Amplification and Compression

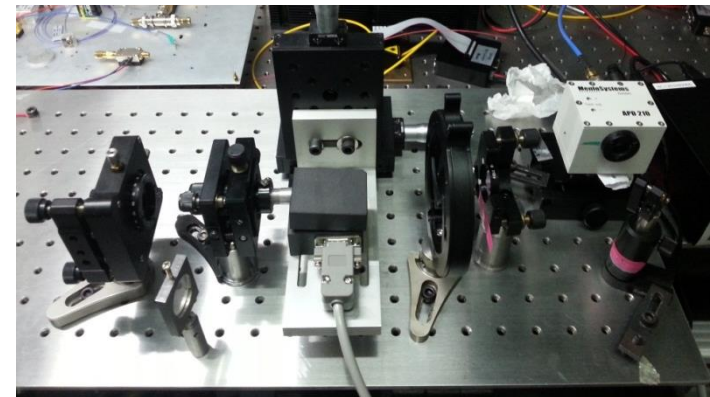
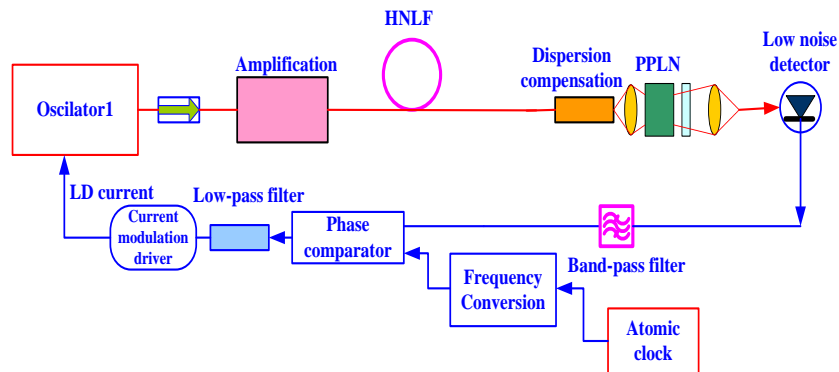


# Femtosecond Optical Frequency Comb

## Repetition Rate Feedback Control



## Carrier Envelope Phase Control



CEP feedback control diagram

# Dual-Comb



Rb clock



Frequency synthesizer  $\times 2$

Frequency counter

Pump current source

Phase locked loop

Servo  $\times 2$

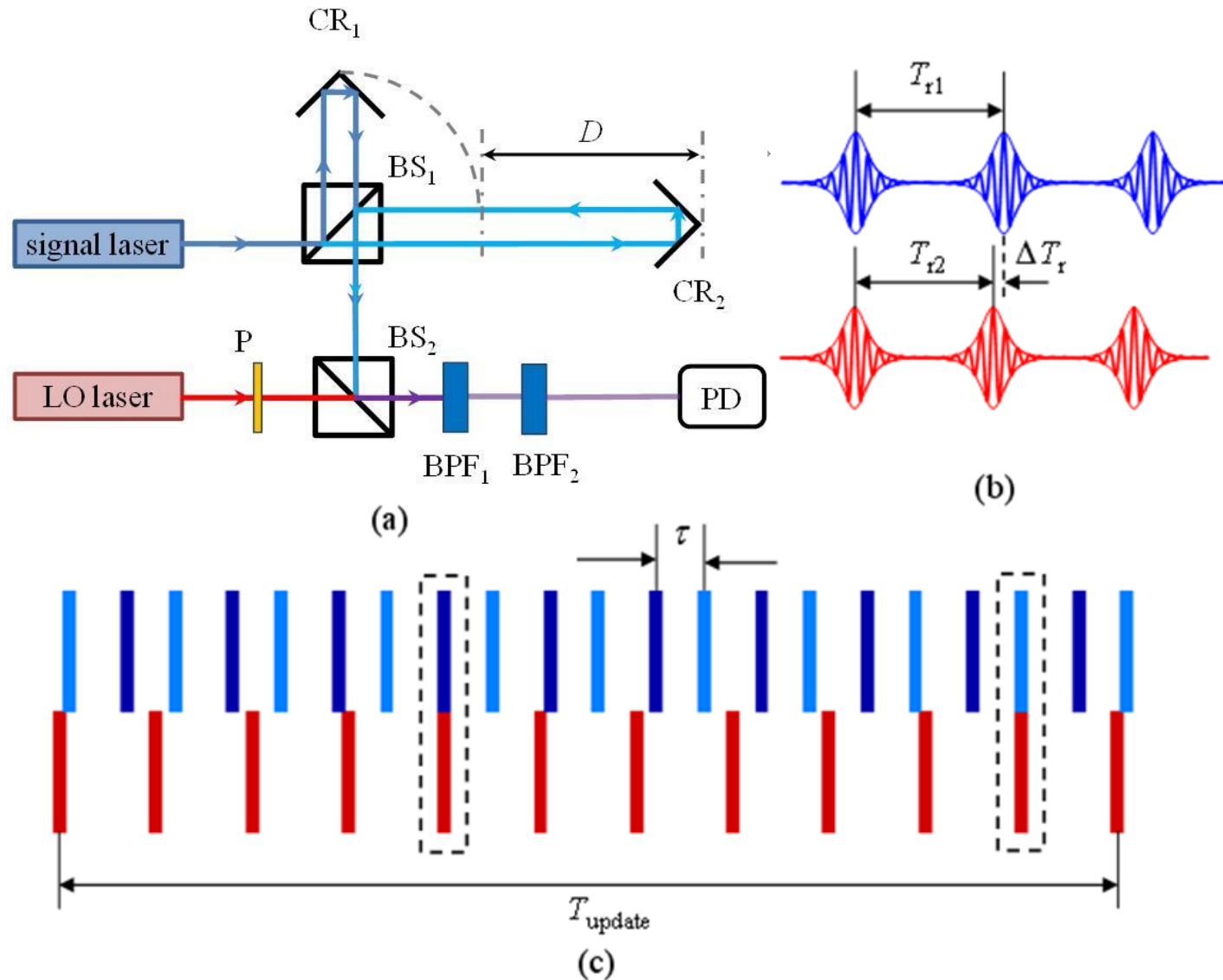
Coarse stabilization module of repetition rate

Temperature control module



Oscillator  $\times 2$   
amplification and  
compression system  $\times 2$

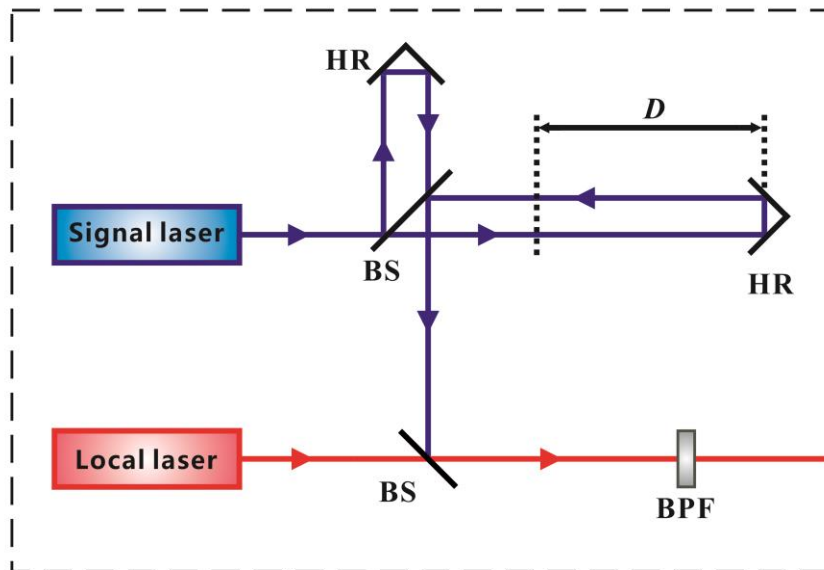
# Dual Comb Distance Measurement



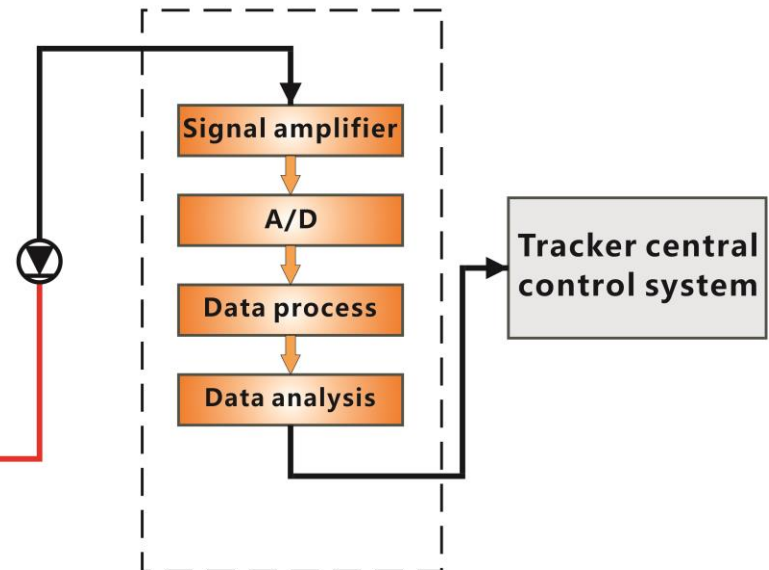


# Dual Comb Distance Measurement

## Optics

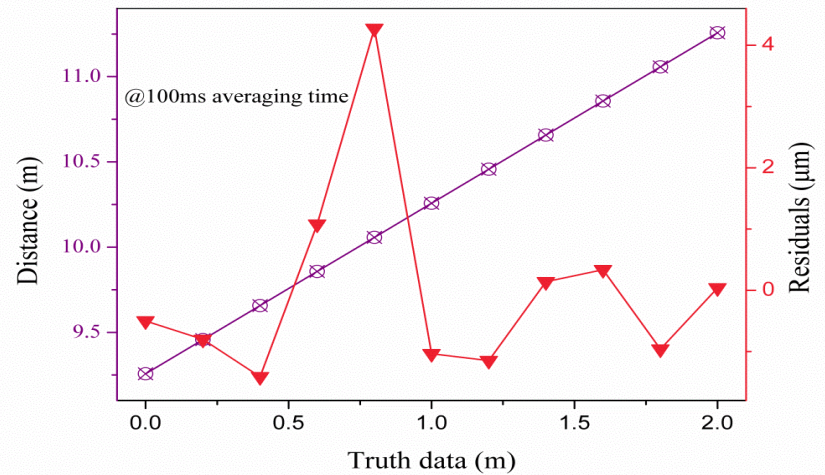
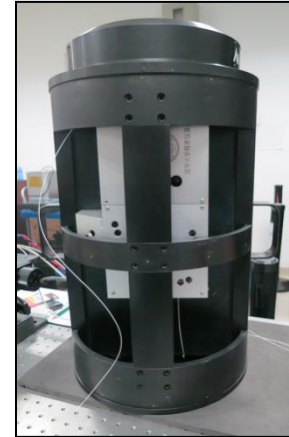
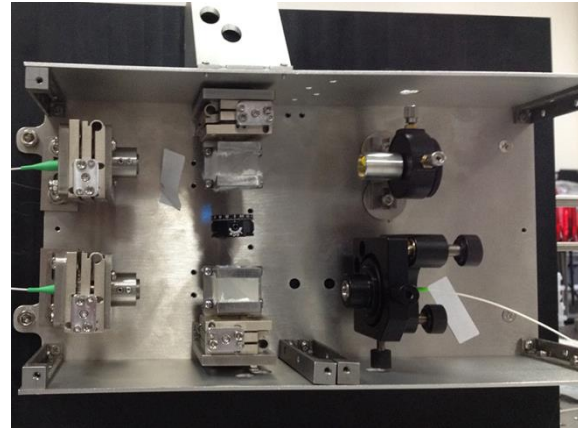
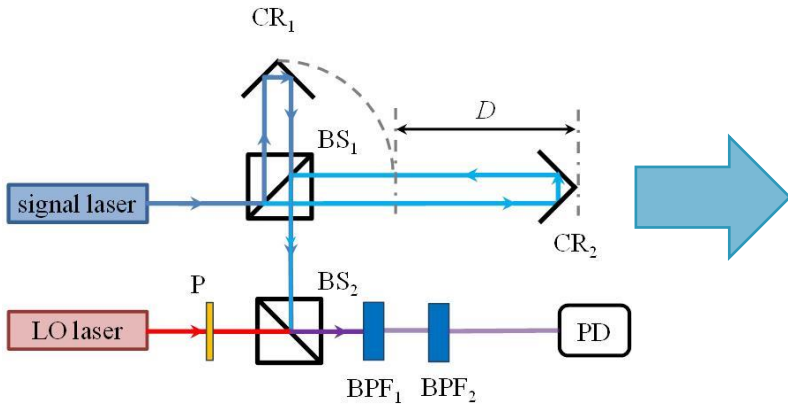
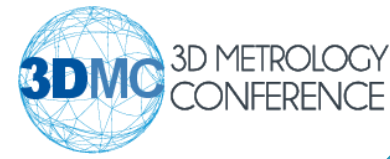


## Data Processing





# Distance Precision Test



Precision:  $20\mu\text{m}@26\text{m}$  (comparison to interferometer)

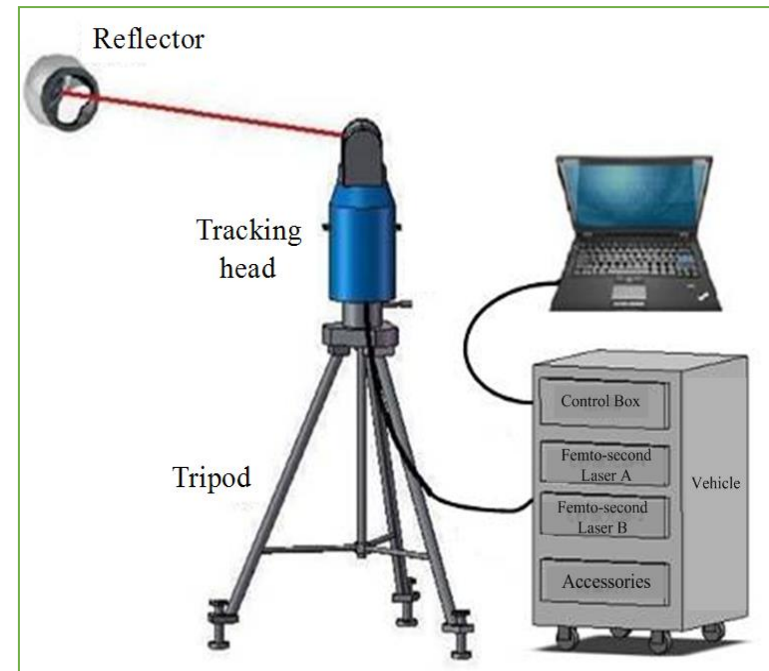


## ***4. FOFC Laser Tracker***

# Laser Tracking Measurement System

Portable laser tracking measurement system is used to get high precision 3D geometric with high measurement speed (1000pts/s), high precision(5-10ppm), large range(30-60m).

The system has wide application in scientific research and manufacturing industries.



**Diagram of Hardware System**

# Application



**Aerospace**



**Heavy machinery**



**Automobile**



**Shipbuilding**



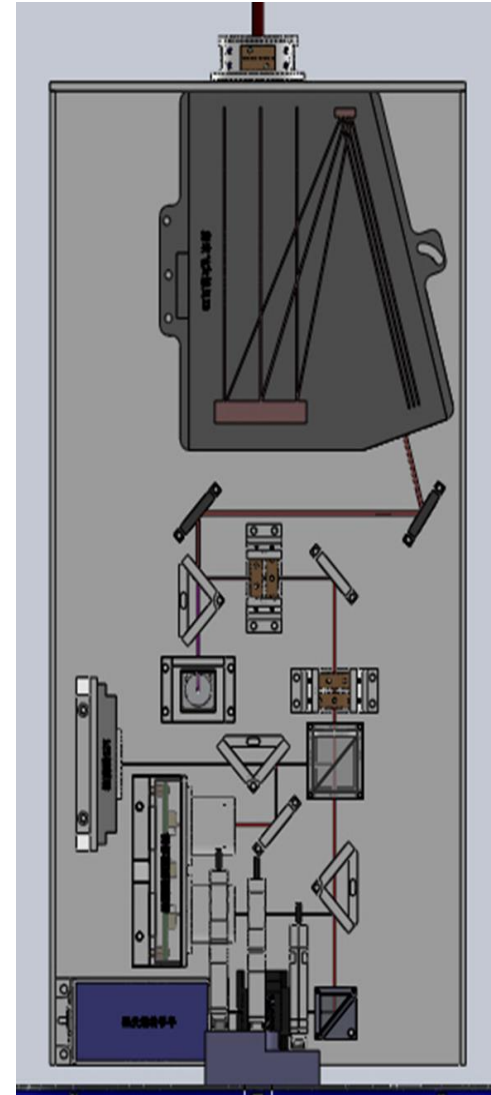
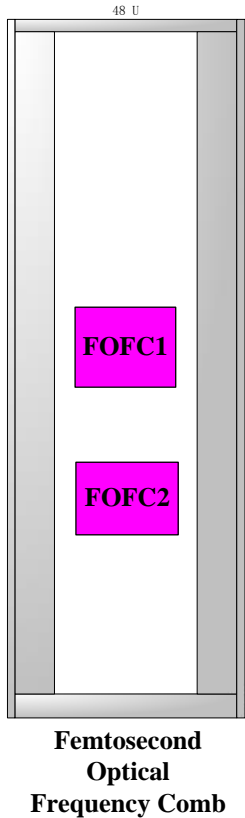
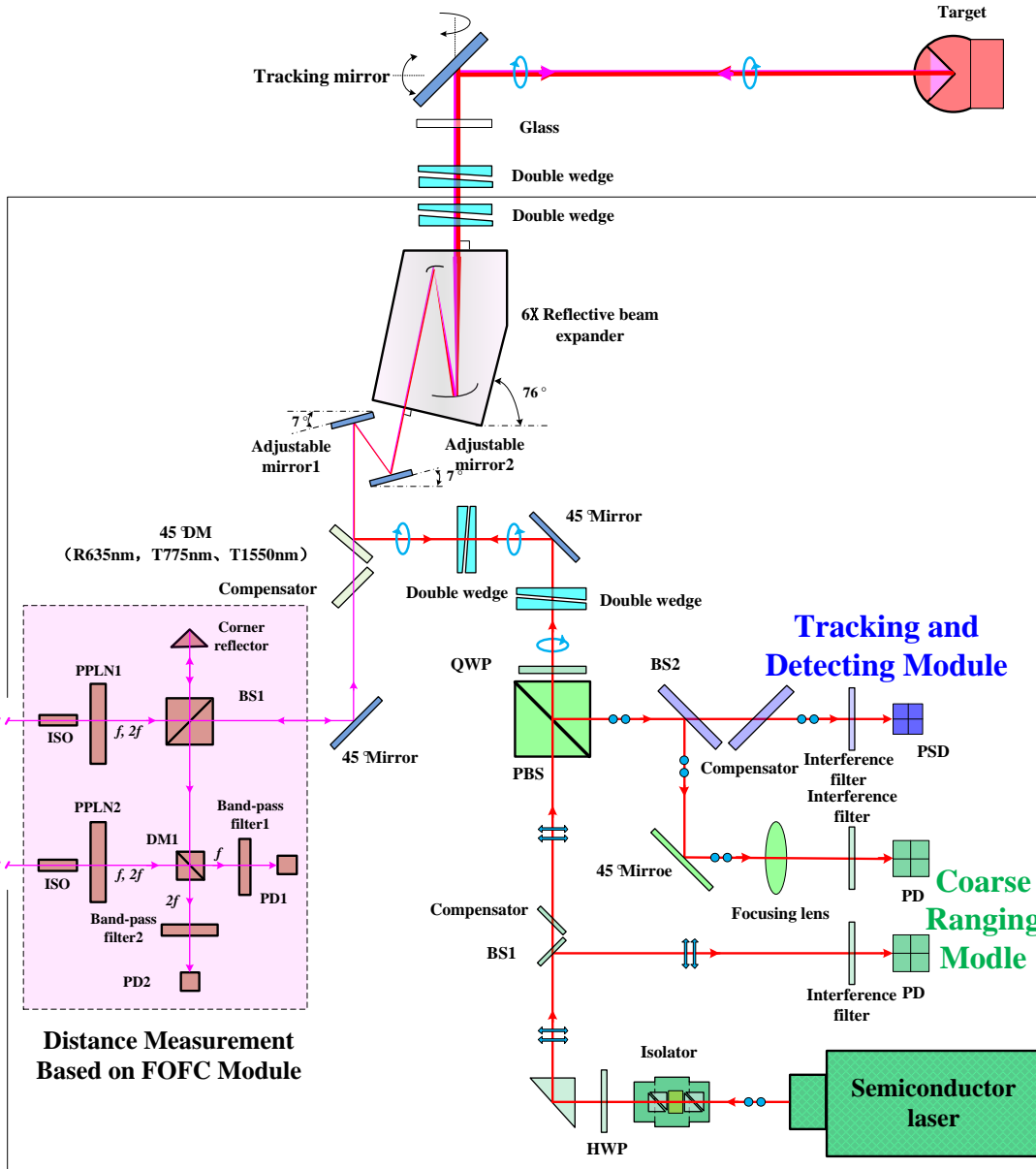
**Energy equipment**

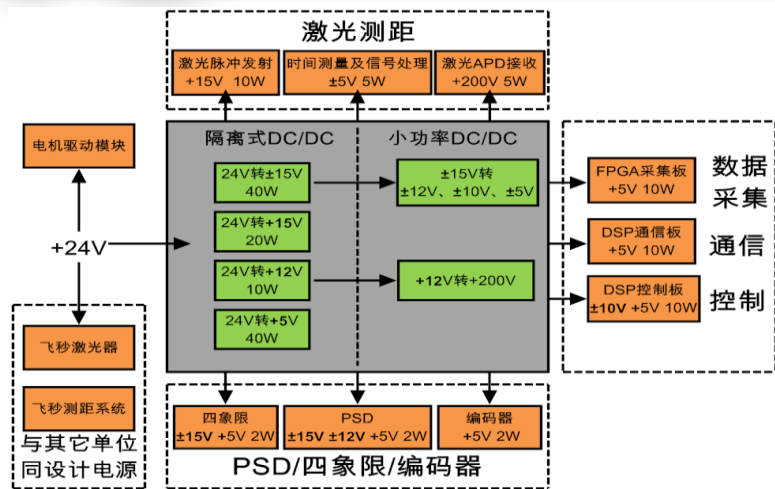


**Scientific research**

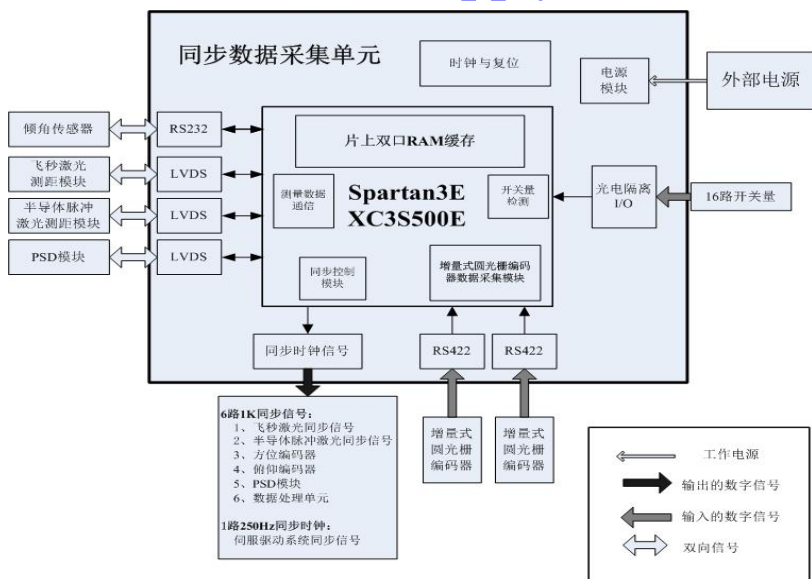


# Optics Design

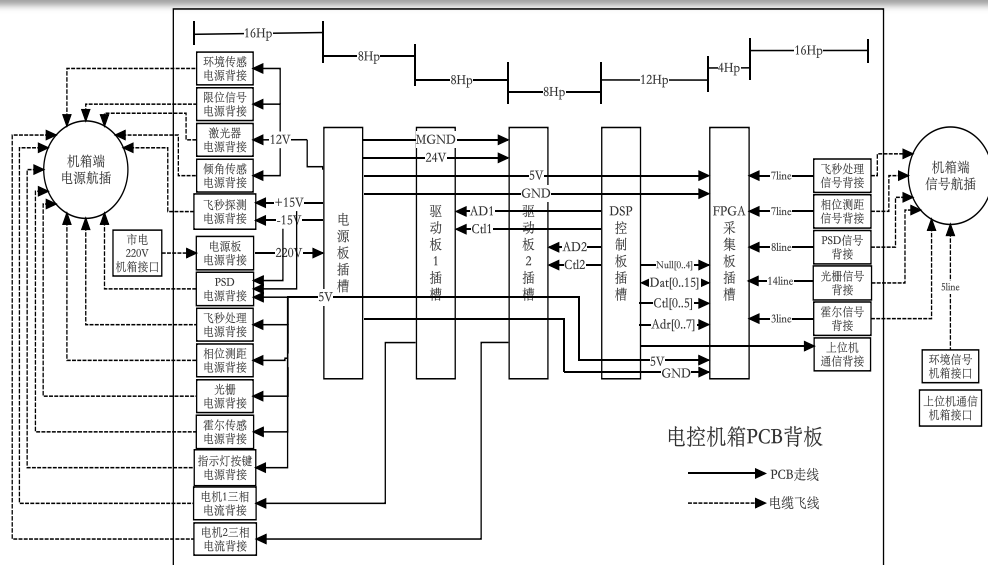




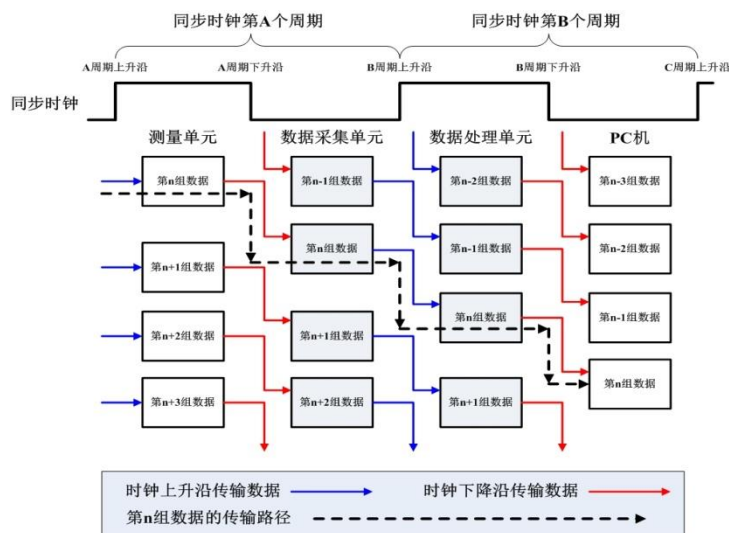
## Power Supply



## Data Acquisition



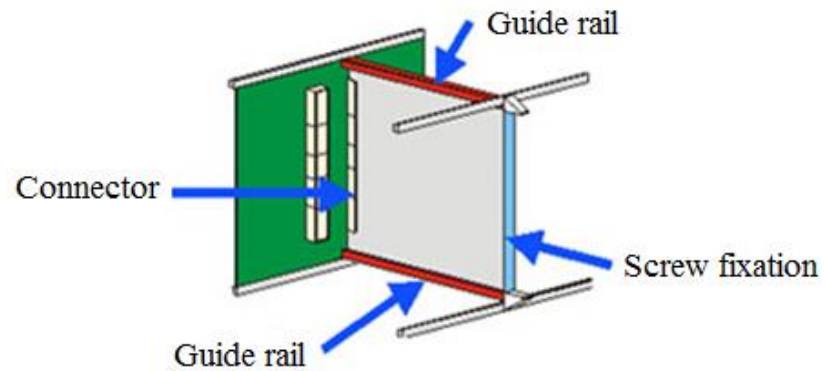
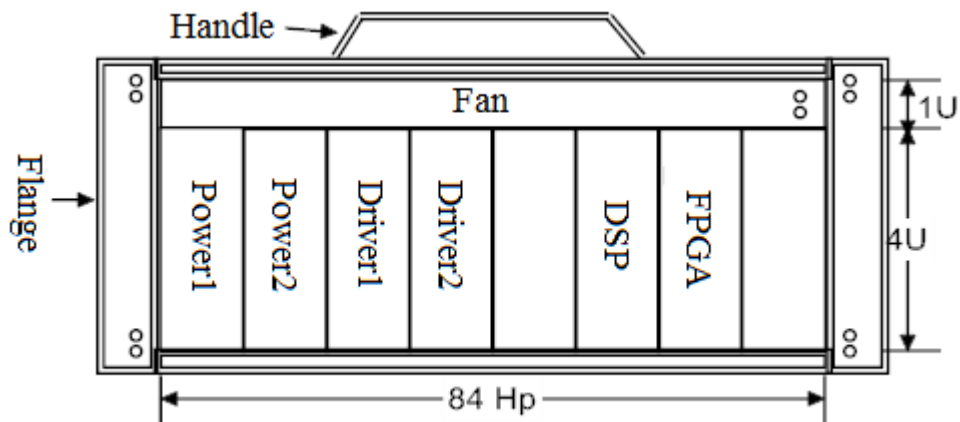
## Bus Diagram



## Clock



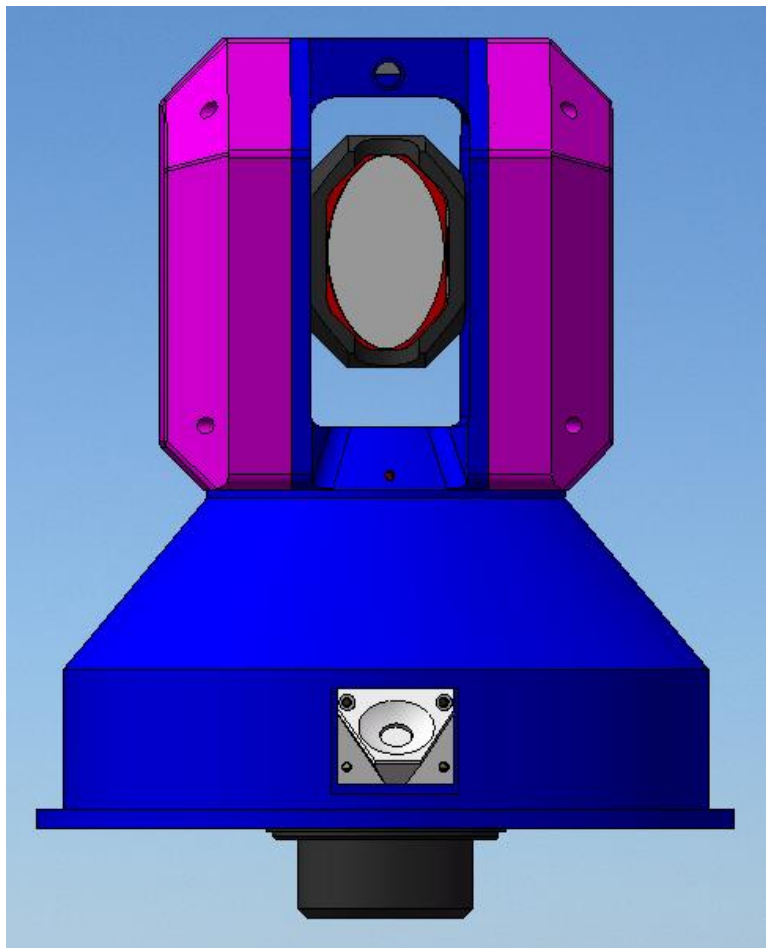
# Electronics







# FOFC Laser Tracker Diagram



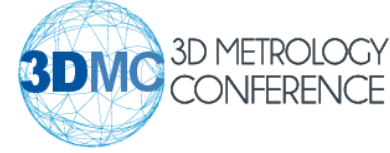
**Tracking Head**



**Main Machine**

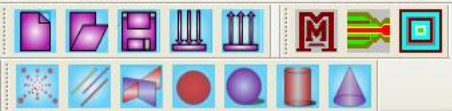


# Software

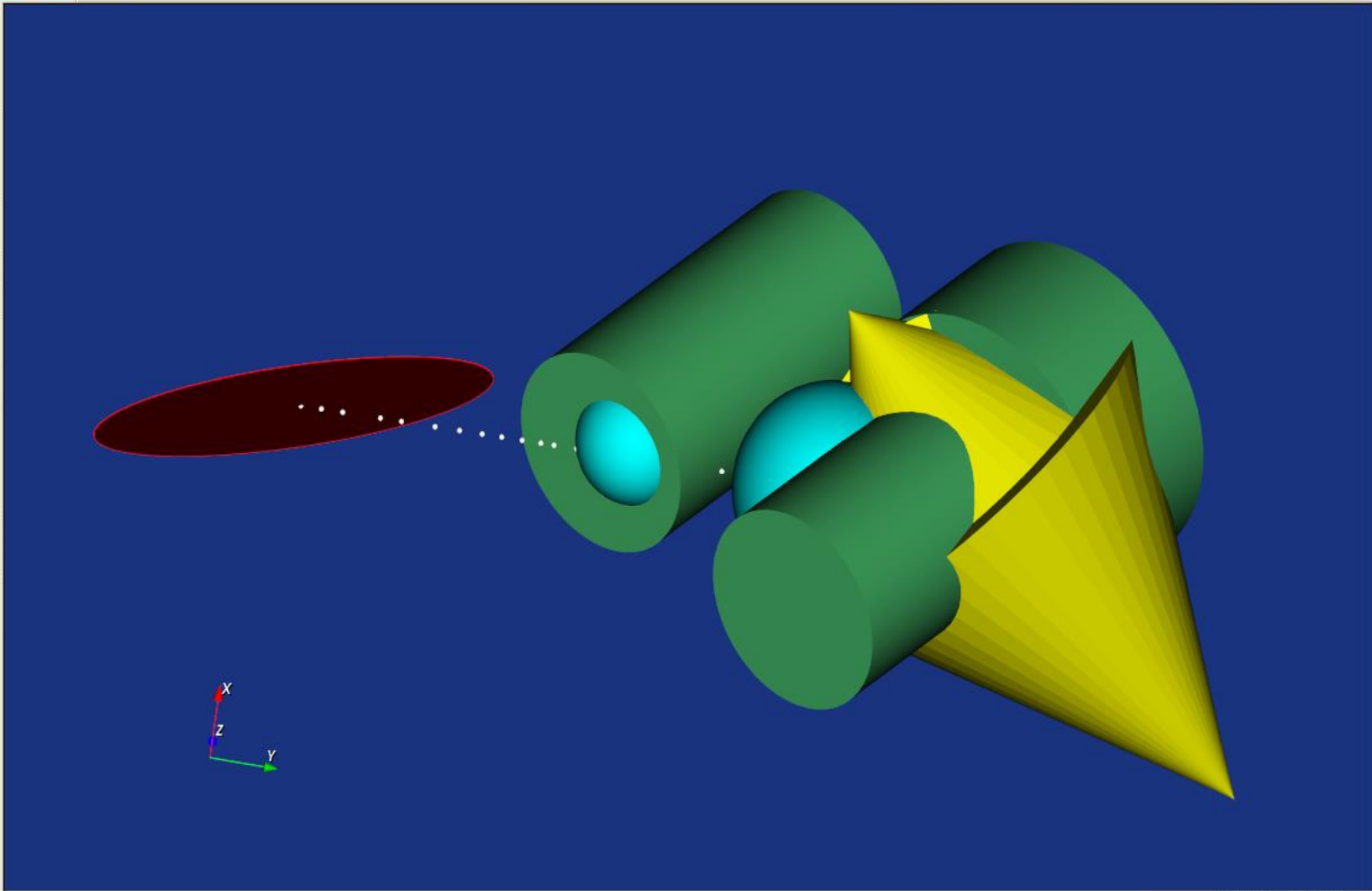


LaserTracker

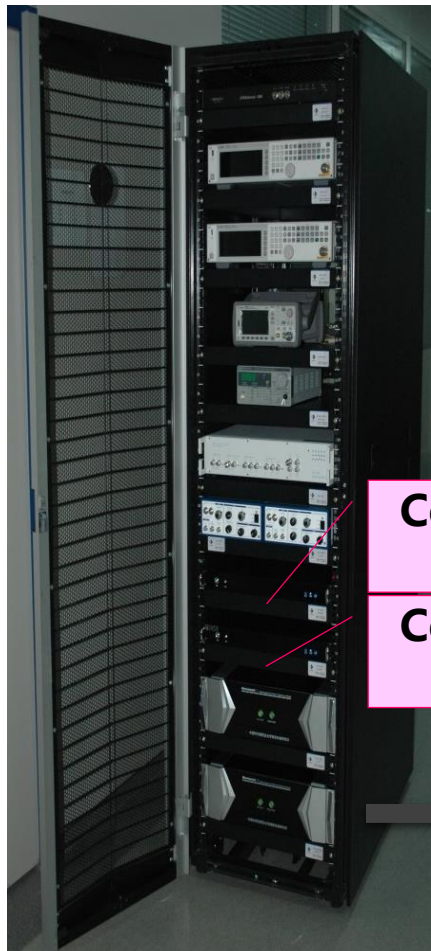
文件(F) 编辑(E) 视图(V) 设置 测量 构造 分析 坐标系 查询 报告 帮助(H)



- 工程-001\_Origin
  - 点
    - 点
  - 直线
    - 直线名 [矢量]L
    - 1 [1, 2, 3, 4, 5,
  - 平面
    - 平面名 [矢量]L
  - 圆
    - 圆名 [矢量]L, 夕
    - [-9, 3, -5, -1000
    - [5, 5, -5, 1000,
  - 球
    - 球名 [X坐标, \
    - [-15, 3, -5, 300
    - [-600, 10000, -
  - 圆柱
    - 圆柱名 [底面X
    - Cylinder01 [-73
    - Cylinder02 [10
    - cylinder03 [100
  - 圆锥
    - 圆锥名 [底面X
    - Cone01 [1000,
    - Cone02 [1000,
    - cone03 [1000,

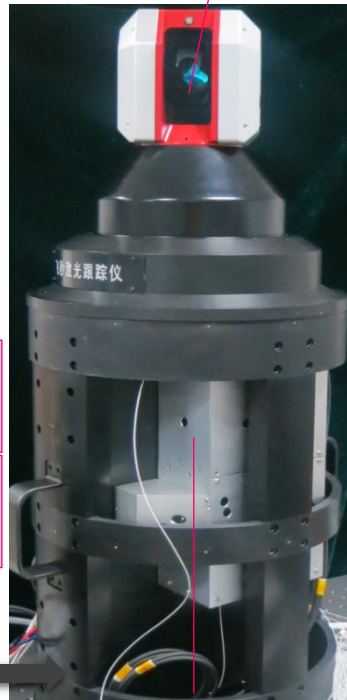


# Femtosecond Laser Tracker Prototype



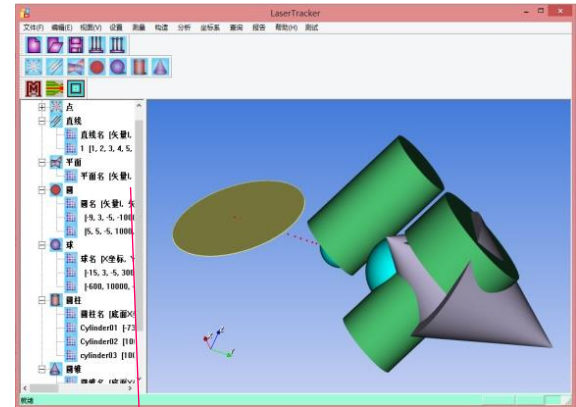
Comb 1

Comb 2



2D rotation table

Distance measurement setup



Calibration compensation System software

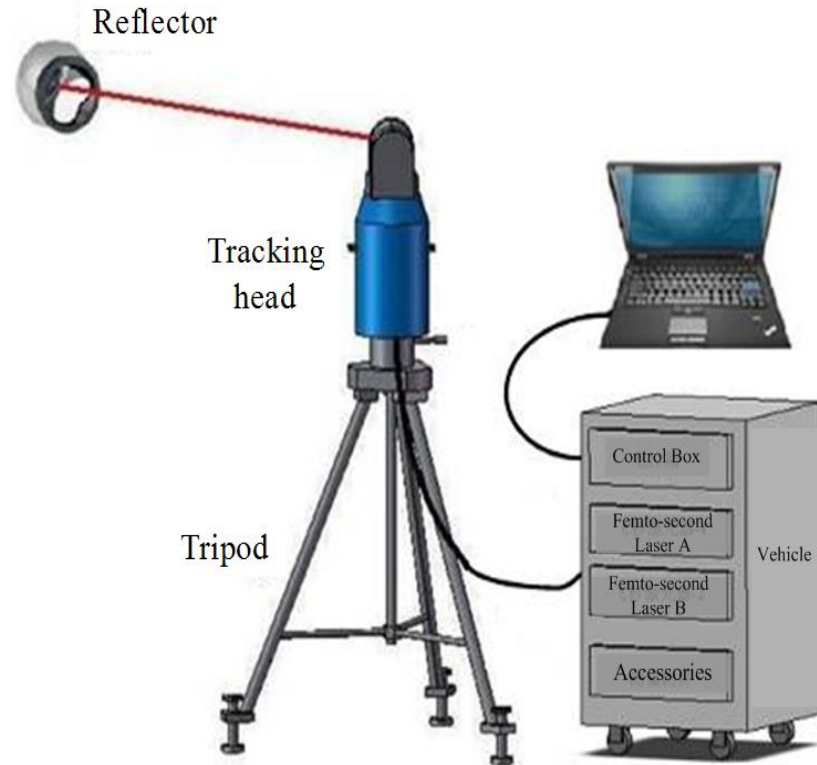
Electronics



# Femtosecond Laser Tracker Prototype

## Specification

<b>Working range</b>	60m
<b>Coordinate precision</b>	10 $\mu$ m/m ( 2 $\sigma$ )
<b>Distance precision</b>	1 $\mu$ m+0.5 $\mu$ m/m
<b>Horizontal range</b>	$\pm 320^\circ$
<b>Vertical range</b>	-50 $^\circ$ ~ +50 $^\circ$
<b>Angle resolution</b>	0.1"
<b>Angle precision</b>	5 $\mu$ m/m ( 1" )
<b>Sample speed</b>	1000 /s
<b>Tracking speed</b>	2rad/s
<b>Acceleration</b>	1rad/s <sup>2</sup>





# Femtosecond Laser Tracker Demonstration

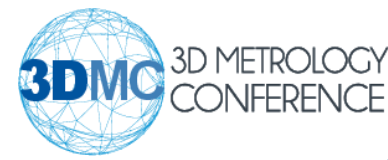
系统测距值	1705.15618		
飞秒测距值	1705.15618		
水平角H	-4.02466		
垂直角V	3.44430		
X坐标值	1697.87867		
Y坐标值	-119.46166		
Z坐标值	102.44276		
PSDX	-0.50395	PSDY	0.20518



[Click to play video](#)



# Summary



## 1. FOFC

Repetition rate  $\sigma$  :  $141\mu\text{Hz}$  ( $2.8 \times 10^{-12}$ @1s)

Carrier envelope offset frequency  $\sigma$  :  $850\mu\text{Hz}$  ( $1 \times 10^{-10}$ @1s)

## 2. Distance Measurement

Dual-comb Measurement Precision:  $20\mu\text{m}$ @60m

## 3. Laser Tracker

Working Range: 0-60m

Angle measuring precision:  $0.6''$

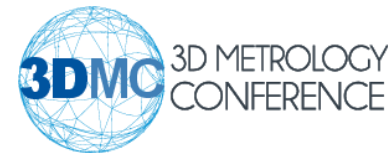
Coordinate Measurement Precision: 10 ppm

## 4. Future Work

Laser tracker industrialization, Formation flying measurement,  
Multilateration measurement, .....



# Acknowledgement



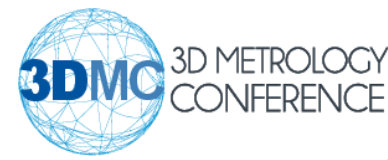
- **Chinese Ministry of Science and Technology**
- **National Science Foundation of China**
- **Chinese Academy of Sciences**
- **Partners**

**Tsinghua University**

**Xi'an Institute of Optics and Precision Mechanics, CAS**



# Contact Information



Tel: 00-86-10-82178679

Email: [zhouweihu@aoe.ac.cn](mailto:zhouweihu@aoe.ac.cn)

Add: No 9, Deng Zhuang South Road, HaiDian  
District, Beijing, 100094, China





# Thanks !