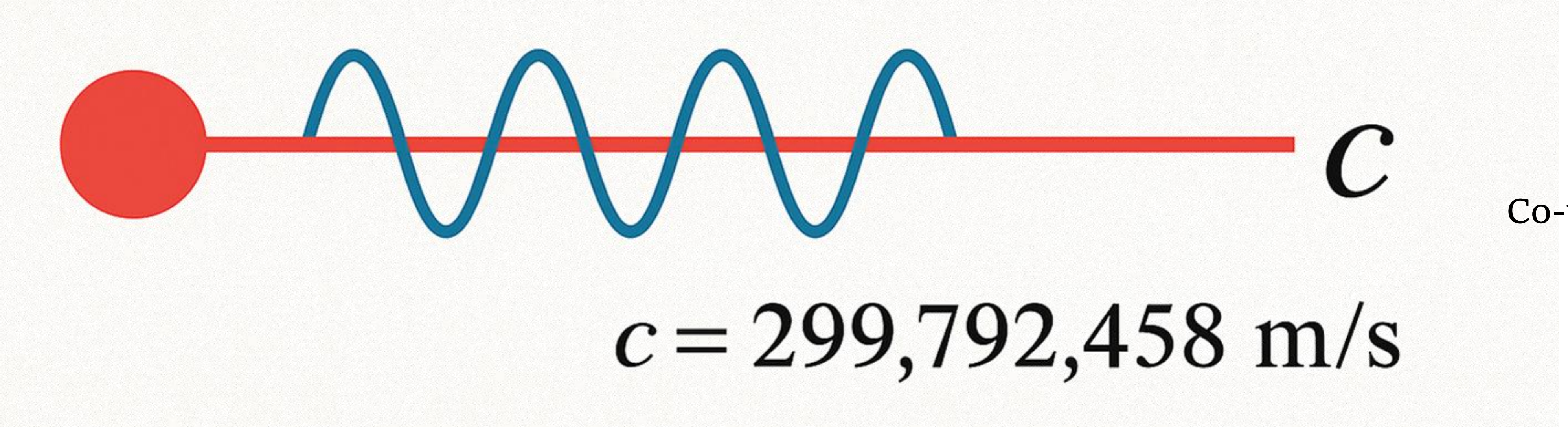
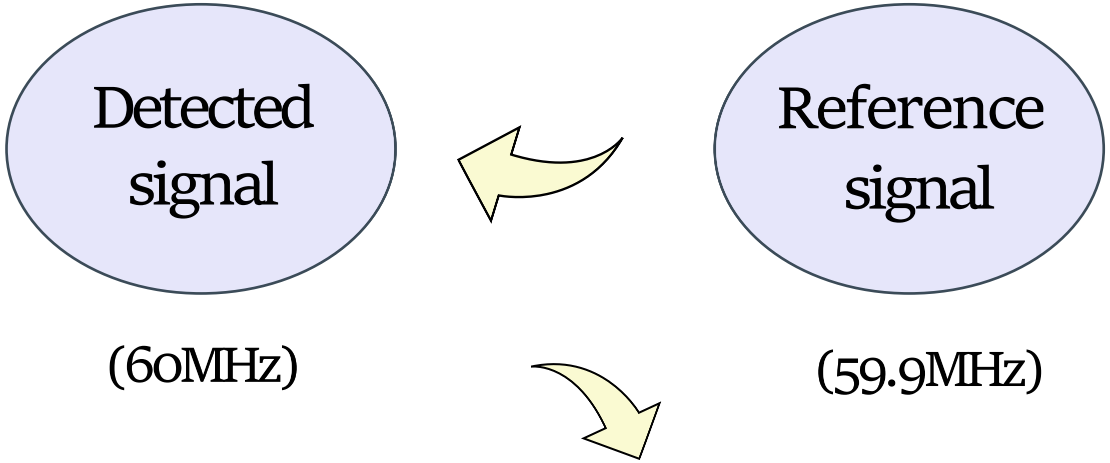
Light speed measurement experiments



Presenter:蔡雨馨
Co-worker:陈般、 洪灿纯
Supervisor:余云鹏

How to detect high-frequency light wave signals?



$$U\cdot U'=[a\cdot\cos(2\pi\cdot f\cdot t-\Delta\varphi)]\cdot[a'\cdot\cos(2\pi\cdot f'\cdot t)]$$

$$=\frac{1}{2}aa'[\cos(2\pi\cdot f\cdot t-\Delta\varphi+2\pi\cdot f'\cdot t)+\cos(2\pi\cdot f\cdot t-\Delta\varphi-2\pi\cdot f'\cdot t)]$$

$$=\frac{1}{2}aa'\cos[2\pi\cdot(f-f')\cdot t-\Delta\varphi]+\frac{1}{2}aa'\cos[2\pi\cdot(f+f')\cdot t-\Delta\varphi]$$

$$f+f'=60.000+59.900=119.000\,\mathrm{MHz}$$

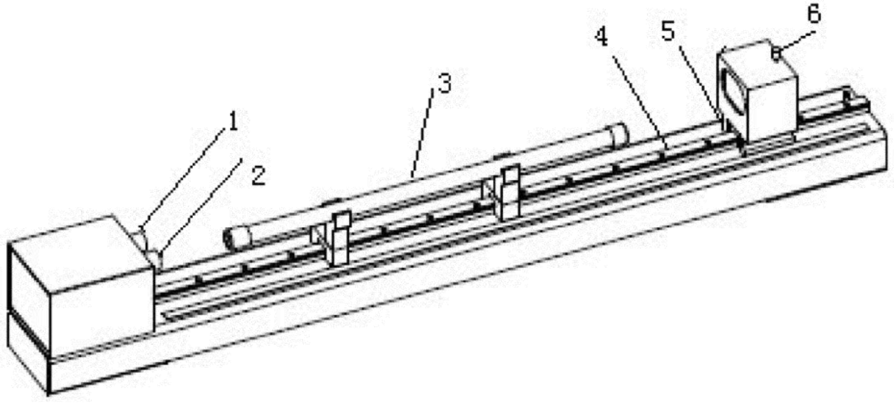
$$f_1=f-f'=60.000-59.900=100\,\mathrm{KHz}$$

1.Phase

$$C_a = \frac{\Delta s}{\Delta t_1} T_1 f$$

Change the optical path→change the phase

$$\Delta \varphi = 2\pi \cdot f_1 \cdot \Delta t_1 = 2\pi \cdot \frac{\Delta t_1}{T_1}$$



Experiment data

编号	测量信号频率(kHz) (f)	T_1 μs	光程差(m) Δs	时间差（μs） Δt_1	光速 $C_a = \frac{\Delta s}{\Delta t_1} T_1 f$	Er
1	59.9994	10	$2 \times 0.4231 \times 10^{-3}$	1.75	291229582	2.8%
2	↓	10	$2 \times 0.5080 \times 10^{-3}$	2.11	29009242	3.3%
3	↓	10	$2 \times 0.2295 \times 10^{-3}$	1	276447884	7.8%

靠近光源

(original)

In air

number	Detected signal f (kHz)	T_1 (μs)	Δs (m)	Δt_1 (μs)	C_a (m/s)	Er
1	59.9994	10	$2 \times 0.4231 \times 10^{-3}$	1.75	291229582	2.8%
2	59.9994	10	$2 \times 0.5080 \times 10^{-3}$	2.11	29009242	3.3%
3	59.9994	10	$2 \times 0.2295 \times 10^{-3}$	1	276447884	7.8%

Experiment data

石英玻璃

编号	测试样品长度 L_m（m）	滑块及反射棱镜的位置 X_1(m)	滑块及反射棱镜的位置 X_2(m)	介质中的光速 $C_m = \frac{C_a}{n_m} = \frac{C_a \times L_m}{L_m + 2X_2 - 2X_1}$ m/s	n(折射率) $= \frac{2\Delta X + Lm}{Lm}$
1	0.5000	0.5277	0.6311	212077290.06	1.4136
2	0.5000	0.7100	0.8221	206981813.35	1.4444
3	0.5000	0.6365	0.7171	226703310.647	1.3224

不容易读出变化

$n_{玻璃} = \frac{n_1+n_2+n_3}{3} = 1.3935$

✓ $n_{玻璃} = \frac{n_1+n_2}{2} = 1.429$

(不考虑误差较大的组3)

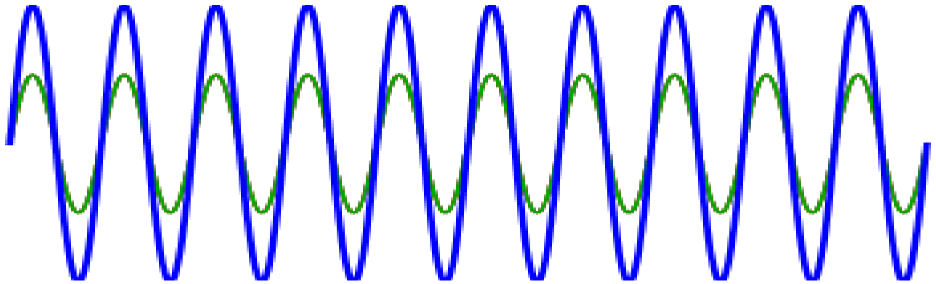
(original)

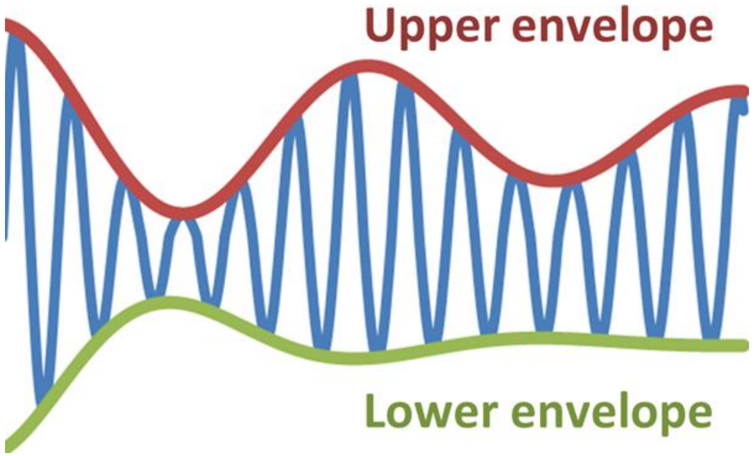
In Glass

number	Lm (m)	X1(m)	X2(m)	Cm (m/s)	n
1	0.5000	0.5277	0.6311	2120772906.06	1.4316
2	0.5000	0.7100	0.8221	2069818133.35	1.4444
3	0.5000	0.6365	0.7171	2267033106.47	1.3224

Note:
Calculation method of average refractive index (excluding group 3):
n = (n1 + n2) / 2 = 1.42
Note: The data of group 3 deviates greatly

2.Beats



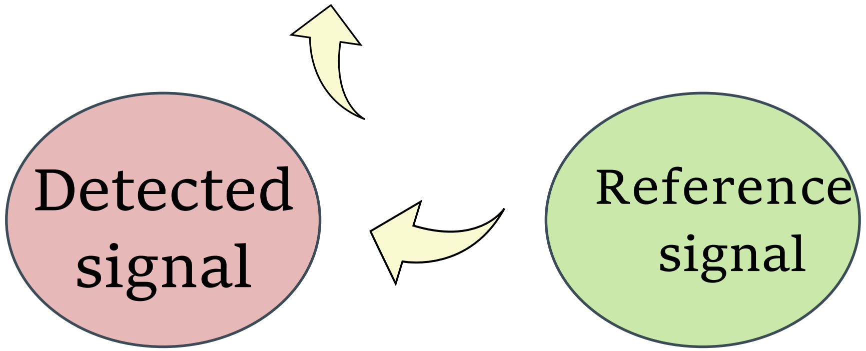


$$E = E_1 + E_2 = 2E_0 \cos\left[\frac{\omega_1 - \omega_2}{2}\left(t - \frac{x}{c}\right) + \frac{\varphi_1 - \varphi_2}{2}\right] \times \cos\left[\frac{\omega_1 + \omega_2}{2}\left(t - \frac{x}{c}\right) + \frac{\varphi_1 + \varphi_2}{2}\right]$$

$$Amplitude:\ 2E_0 \cos\left[\frac{\Delta\omega}{2}\left(t - \frac{x}{c}\right) + \frac{\varphi_1 - \varphi_2}{2}\right]$$

$$f = \frac{\omega}{2\pi}, \quad \omega = \frac{\Delta\omega}{2}$$

$$\Delta f = \frac{\Delta\omega}{4\pi}$$



$$\Delta\varphi = 2\pi \Rightarrow \Delta \mathrm{L} = \Lambda$$

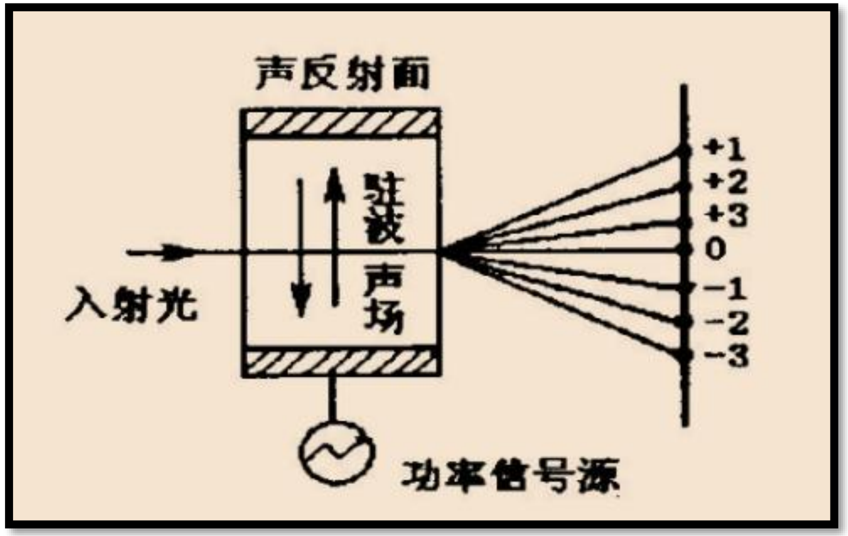
$$c = \Delta f \cdot \Lambda$$

2.1 Get Δf

ultrasonic wave(超声波)

Acousto-optic effect

Incident light (to be measured)



$$f_{L,m} = f_0 + (L + 2m)F$$

L: diffraction order

F: frequency of ultrasonic power signal source

m: standing wave mode

L=1

m=0 (basic standing wave mode (i.e. minimum thickness))

m=1 (One more round trip than m=0)

$$f_{1,1} - f_{1,0} = f_0 + (1+2)F - [f_0 + (1+0)F]$$

$$\Delta f = f_{1,1} - f_{1,0} = 2F$$

2.2 Get ΔL

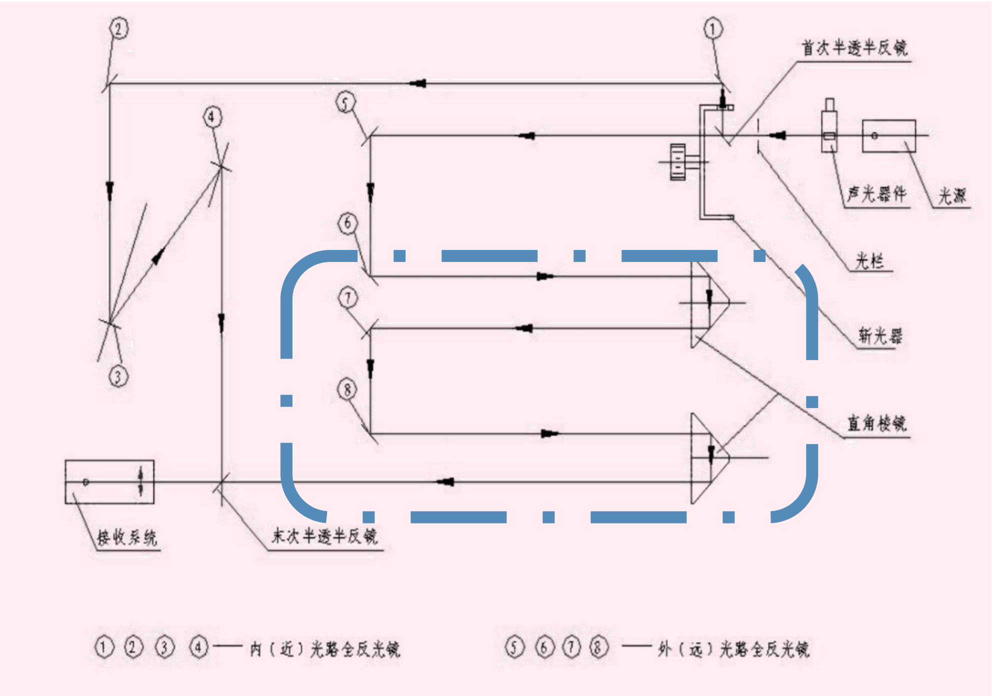
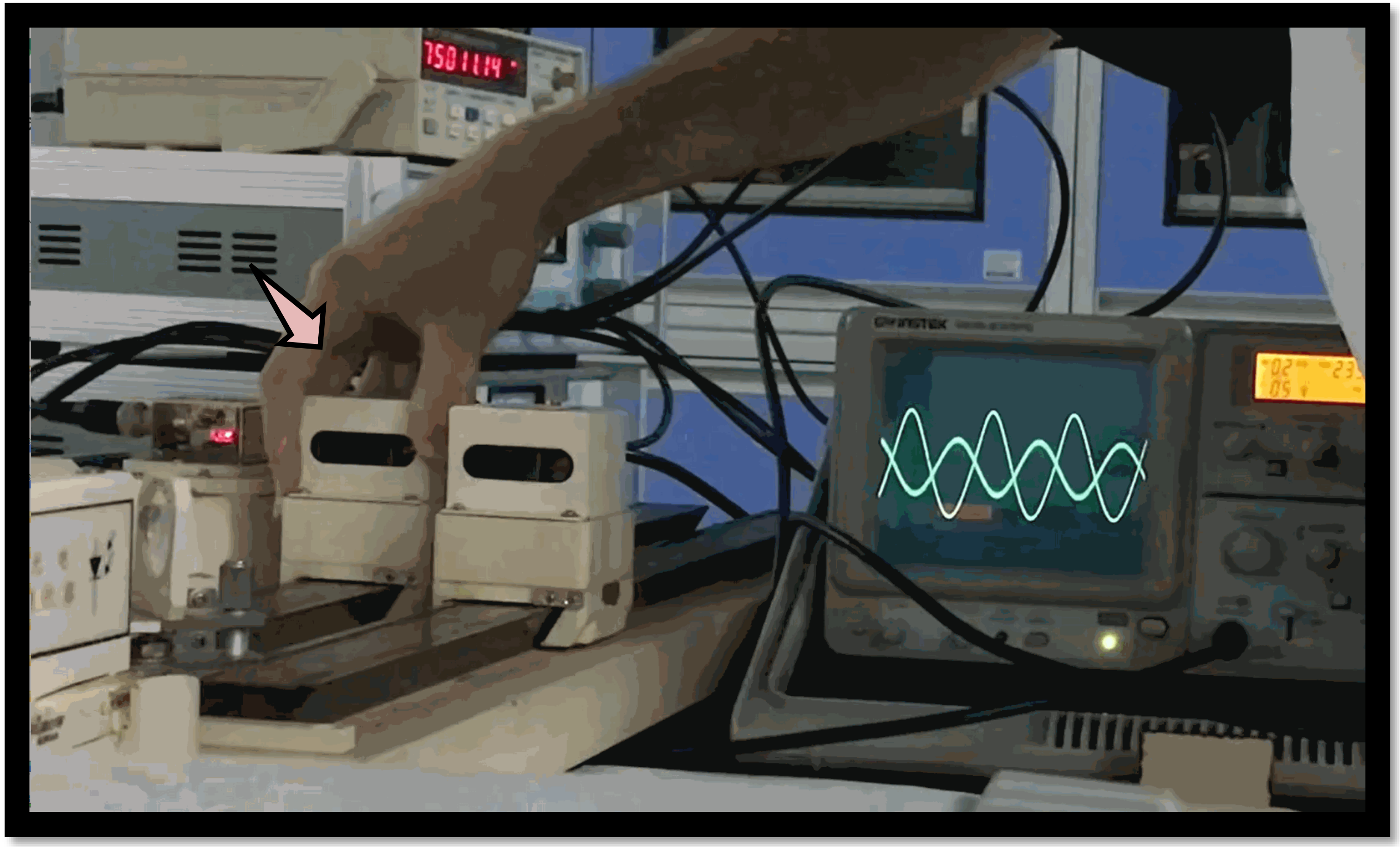
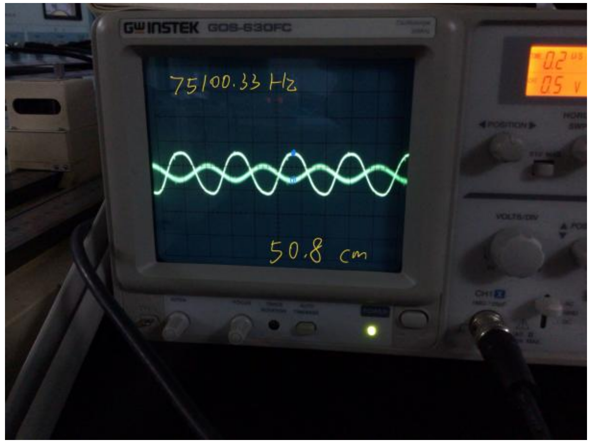


图 4　光学系统示意图

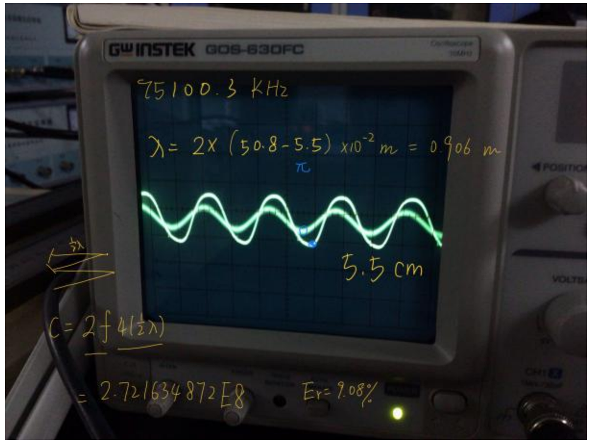
Experimental apparatus



Experiment data



π



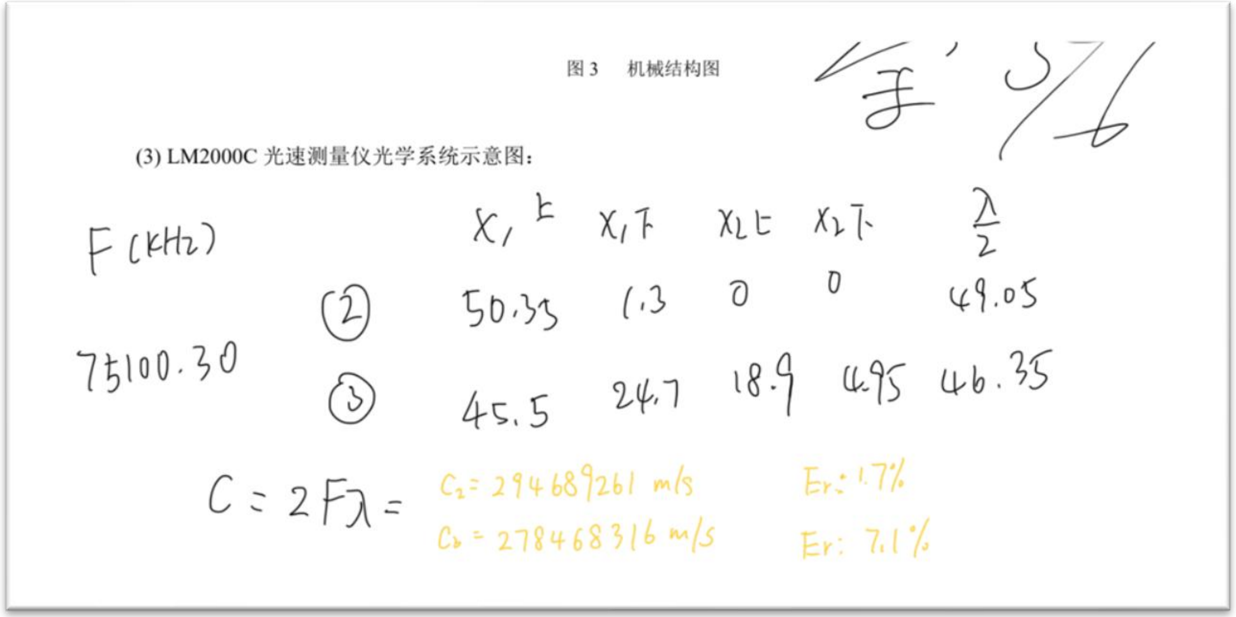


图 3　机械结构图

(3) LM2000C 光速测量仪光学系统示意图：

F (kHz)		X_1上	X_1下	X_2上	X_2下	$\frac{\lambda}{2}$
	②	50.33	1.3	0	0	49.05
75100.30	③	45.5	24.7	18.9	4.95	46.35

$C = 2F\lambda =$ C_2= 294689261 m/s　Er: 1.7%
C_3 = 278468316 m/s　Er: 7.1%

C1=2.721634 872
E8 m/s
Er1=9.08%

C2=2.94 689261
E8 m/s
Er2=1.7%

C3=2.78468316
E8 m/s
Er3=7.1%

Error analysis

I. Systematic Errors

- Low instrument sensitivity

Even a 0.001 m error can significantly affect the final refractive index.

- Optical path is not aligned

If the light doesn't pass perpendicularly, the actual optical path differs from the assumed Lm

- Neglected boundary effects

At the edges, scattering or unstable fringes can disturb interference pattern reading.

II. Random Errors

- Reading error
- Table vibration or air disturbance
- Variable sliding friction

Uneven resistance during movement may cause the slider to overshoot or rebound slightly, affecting position readings