Ocean Best Practices-Instrument Calibration

On-Site ADCP Calibration

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Outline

1、 Research Background and Meaning

2、Calibration Theory

3、Calibration System

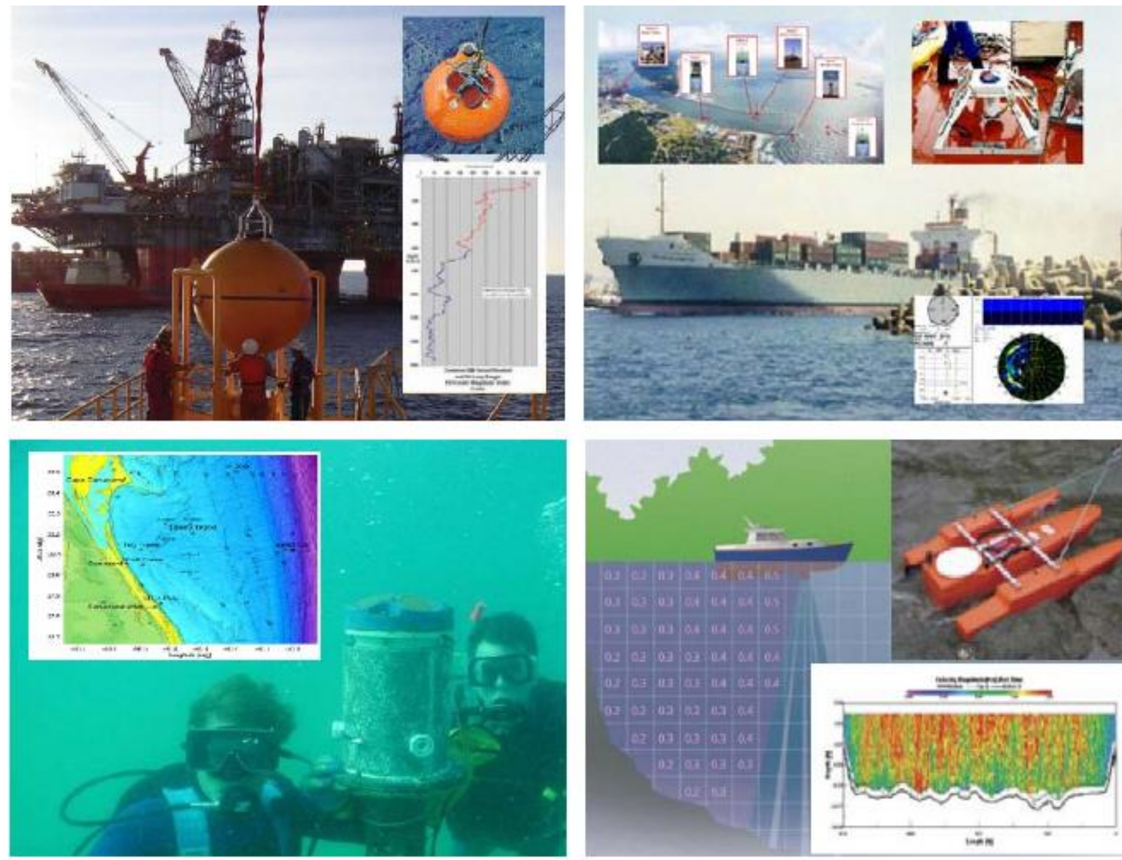
4、Calibration Test

5、 Summary

1. RESEARCH BACKGROUND AND MEANING

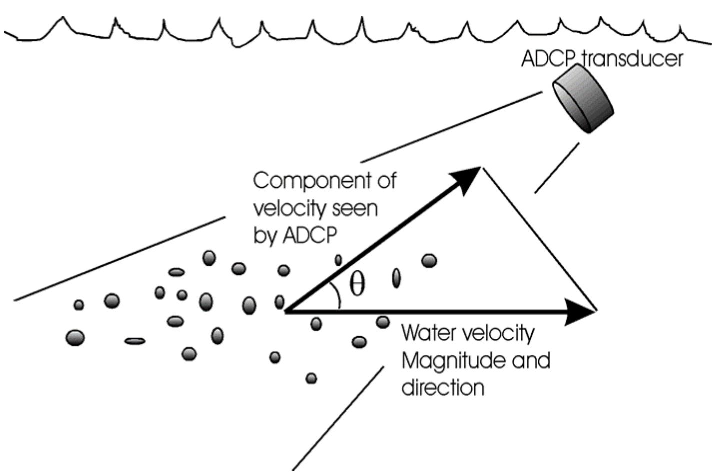
Acoustic Doppler Current Profiler(ADCP)

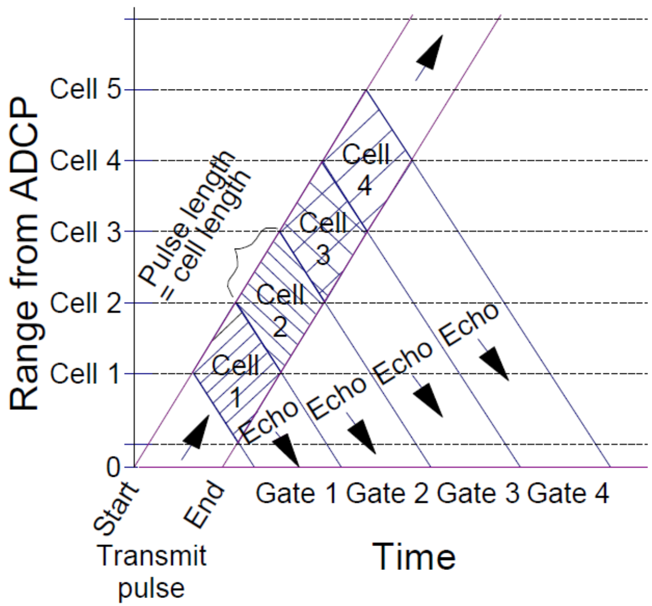
- Real-time
- Less time consuming
- Stratified flow measuring
- Wide scope of measuring velocity
- Don't disturb the flow field
- Widely used in oceanographic survey

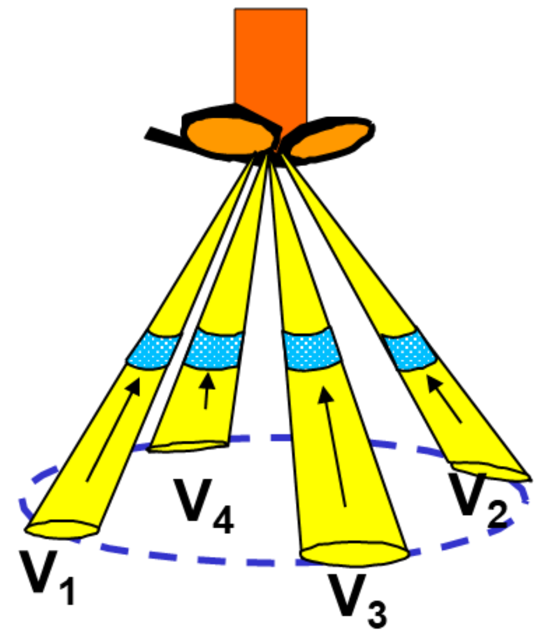


1. RESEARCH BACKGROUND AND MEANING

Working Principle







Doppler Shift

$$\Delta f = 2 f_0 v / c$$

Stratified Flow Measuring

$$D = D_t + \frac{ct}{2}\cos\alpha$$

Coordinate System Conversion

$$\boldsymbol{v_c} = \left(\mathbf{B}^{\mathrm{T}}\mathbf{B}\right)^{-1}\mathbf{B}^{\mathrm{T}}\boldsymbol{v_b}$$

1.RESEARCH BACKGROUND AND MEANING

Current Status：

- **Water tank trailer**： Construction, maintenance and test costs are high
- **DGPS lake trial comparison**： Due to the limitation of the minimum ship speed, it is difficult to realize the calibration of the small flow rate below 2 m/s.
- **Ocean current meter comparison** ： Single point calibration，poor efficiency

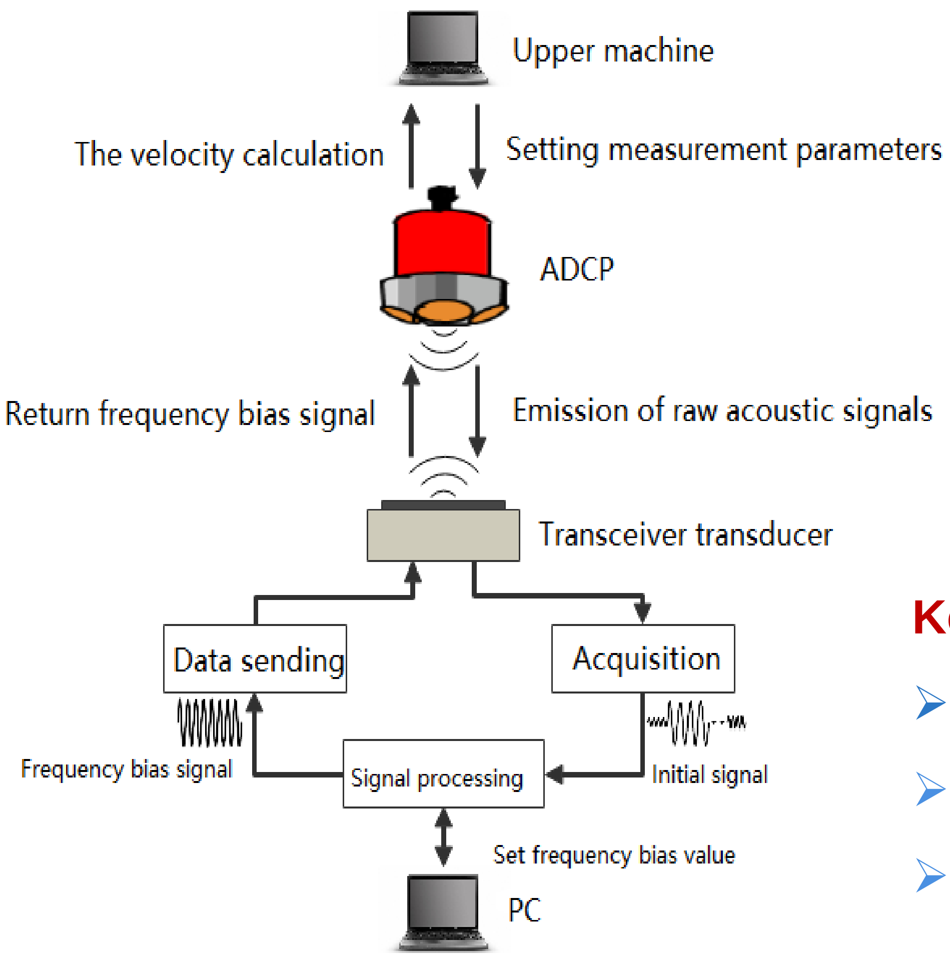
Calibration Method of This Research：

Frequency offset acoustic transponder： high precision frequency offset acoustic signal is used to simulate water velocity

Subject Source：

NQI-2017： Development of calibration device and field calibration technology for portable Acoustic Doppler velocity Profiler

2.CALIBRATION THEORY



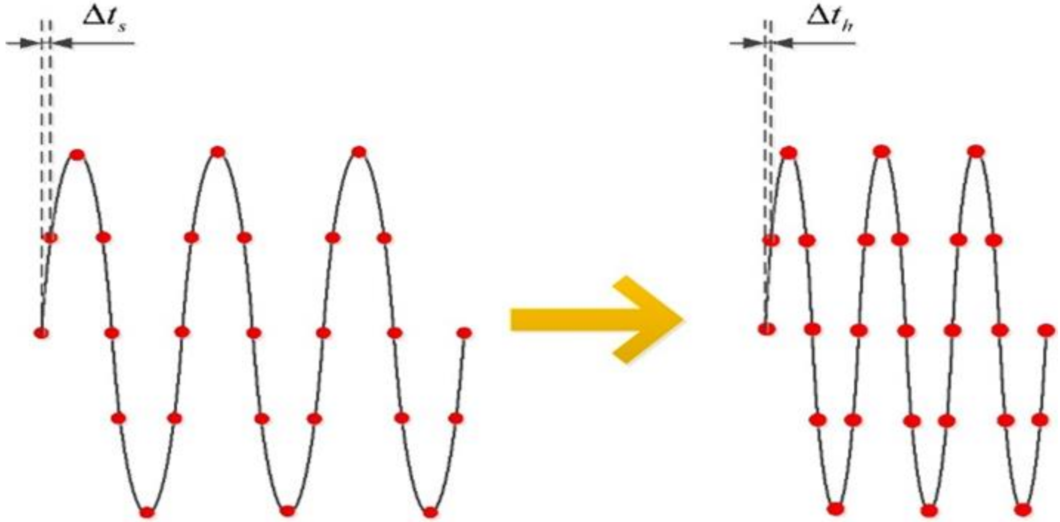
$$v_r = \frac{c}{2f_0}(f_1 - f_0) = \frac{c}{2f_0}\Delta f$$

$$\Delta v = \frac{f_d}{2f_0}\Delta c + \frac{c}{2f_0}\Delta f_d + \frac{cf_d}{2f_0^2}\Delta f_0$$

Key parameters：

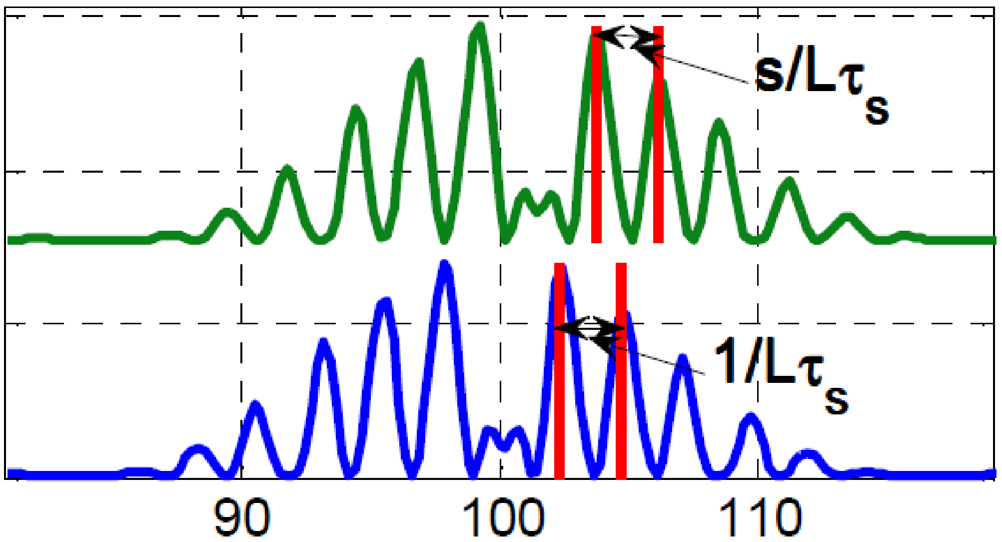
- **sound velocity**
- **frequencies of ADCP signals**
- **frequencies of acoustic transponder**

2.CALIBRATION THEORY



ZOOM the sampling interval

$$\frac{f_1}{f_0} = \frac{f_h}{f_s}$$

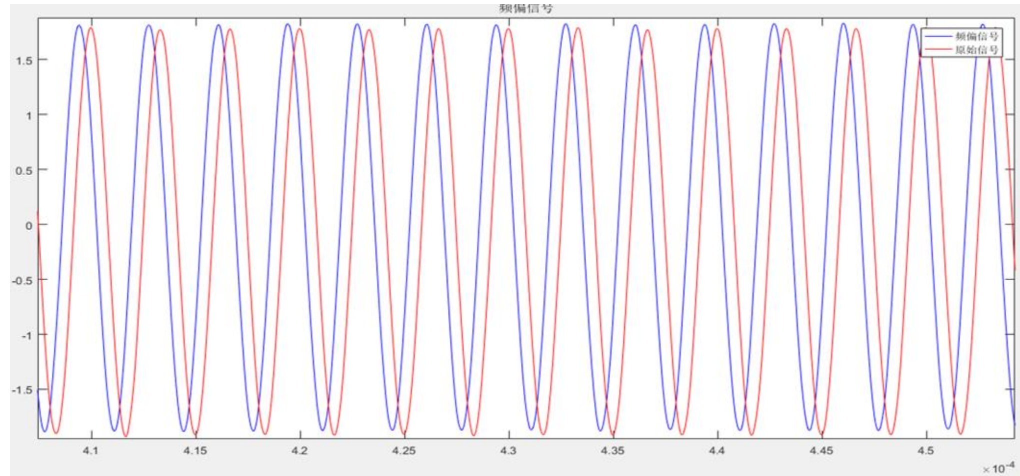


$$s=(c-v)/(c+v)$$

Clock Precision

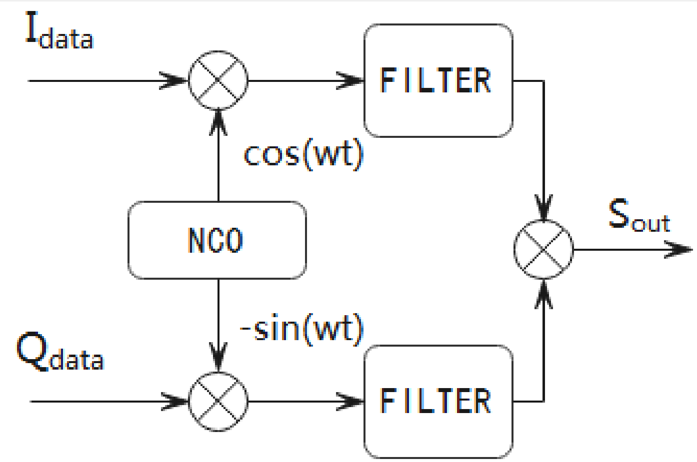
2.CALIBRATION THEORY

Digital up converter



$$S_I(t) = \cos(\varphi(t) + \varphi_0)$$

$$S_Q(t) = \sin(\varphi(t) + \varphi_0)$$



$$S_{out} = I_{data}\cos(\omega t) - Q_{data}\sin(\omega t)$$

digital controlled oscillator (DCO) precision

2.CALIBRATION THEORY

COMPARE PRECISION

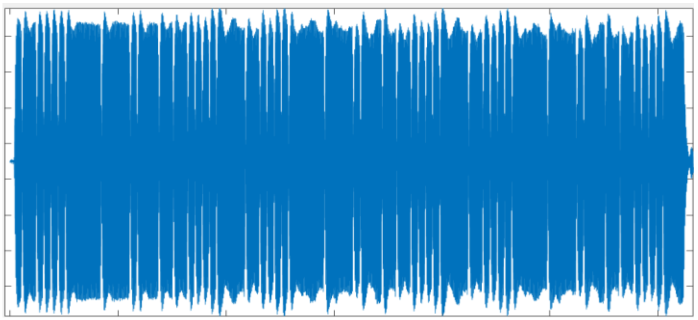
- **Velocity range**： 0.02 m/s~1 m/s
- **Clock precision**： 10 ns
- **ADCP transmitting frequency**： 300 kHz； **Sampling rate**： 1 MSPS， **Sound velocity**： 1500 m/s

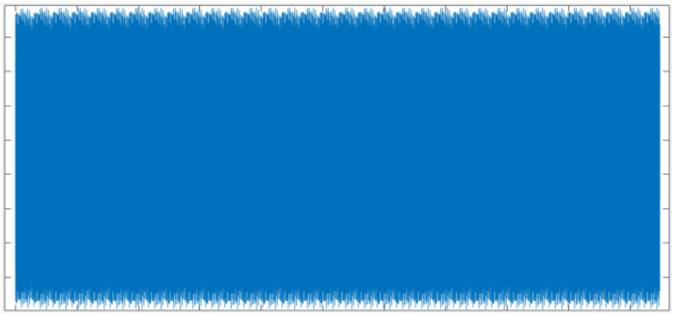
Simulated flow rate(m·s-1)	Theoretical frequency deviation value(Hz)	Actual frequency deviation value （Hz）			
		Digital Frequency Conversion Method		Variable sampling method	
		Frequency bias value	Deviation	Frequency bias value	Deviation
0.02	8	8.0001	0.0001	3030.303	3022.303
0.2	80	79.9999	0.0001	3030.303	2950.303
0.4	160	160.0001	0.0001	3030.303	2870.303
0.6	240	240.0000	0.0000	3030.303	2790.303
0.8	320	320.0001	0.0001	3030.303	2710.303
1.0	400	400.0000	0.0000	3030.303	2630.303

Digital up converter is better

2.CALIBRATION THEORY

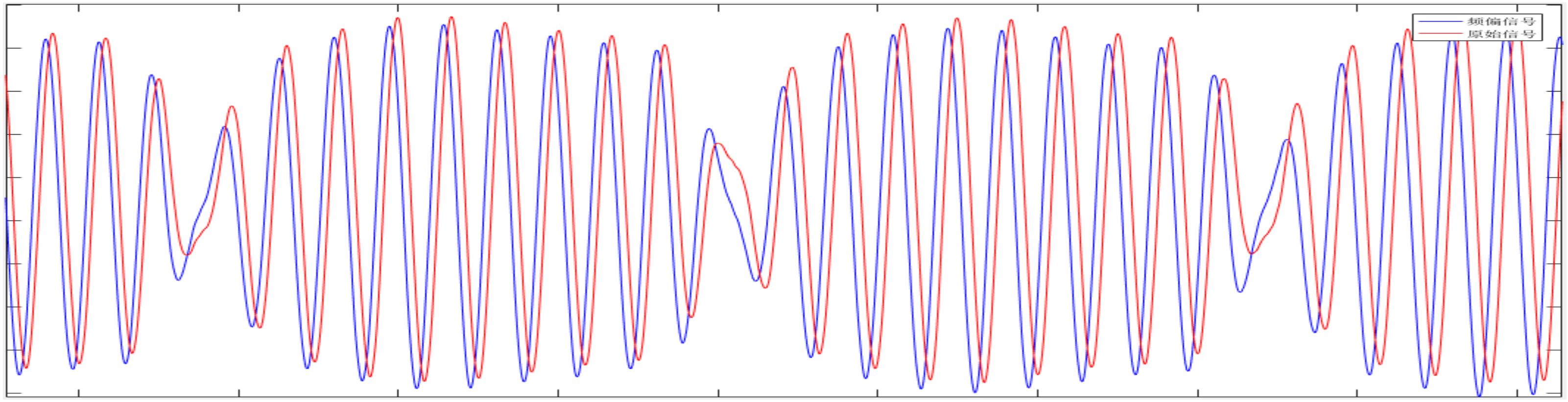
Digital signal processing flows





ADCP signal acquisition

Interception
Time domain extension
Digital frequency conversion



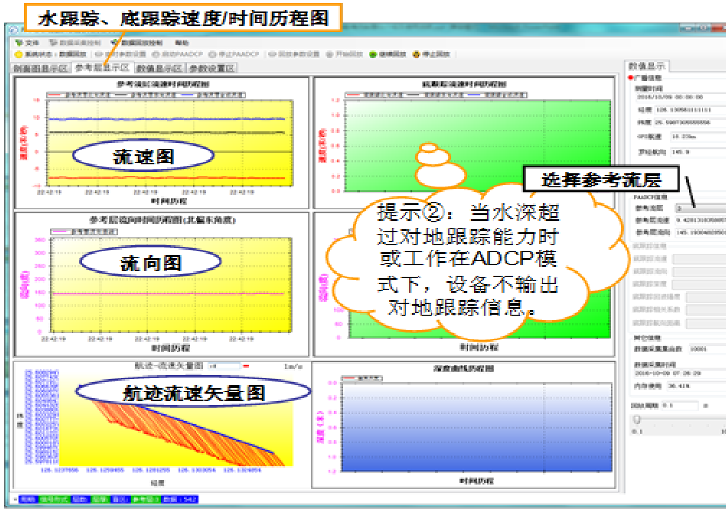
3.CALIBRATION SYSTEM

Calibration Object

Specifications:

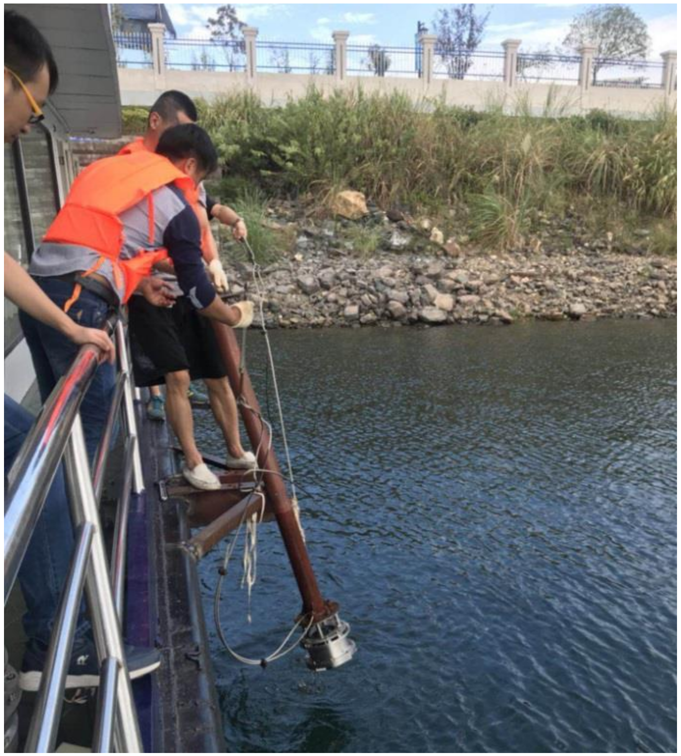
- **Mid-frequency**: 300kHz;
- **Beam**: 4 beams, 20°;
- **Velocity range**: -10m/s ~ 10m/s;
- **Velocity accuracy**: ±0.5%V±0.005m/s;
- **Depth range**: 4m~100m;

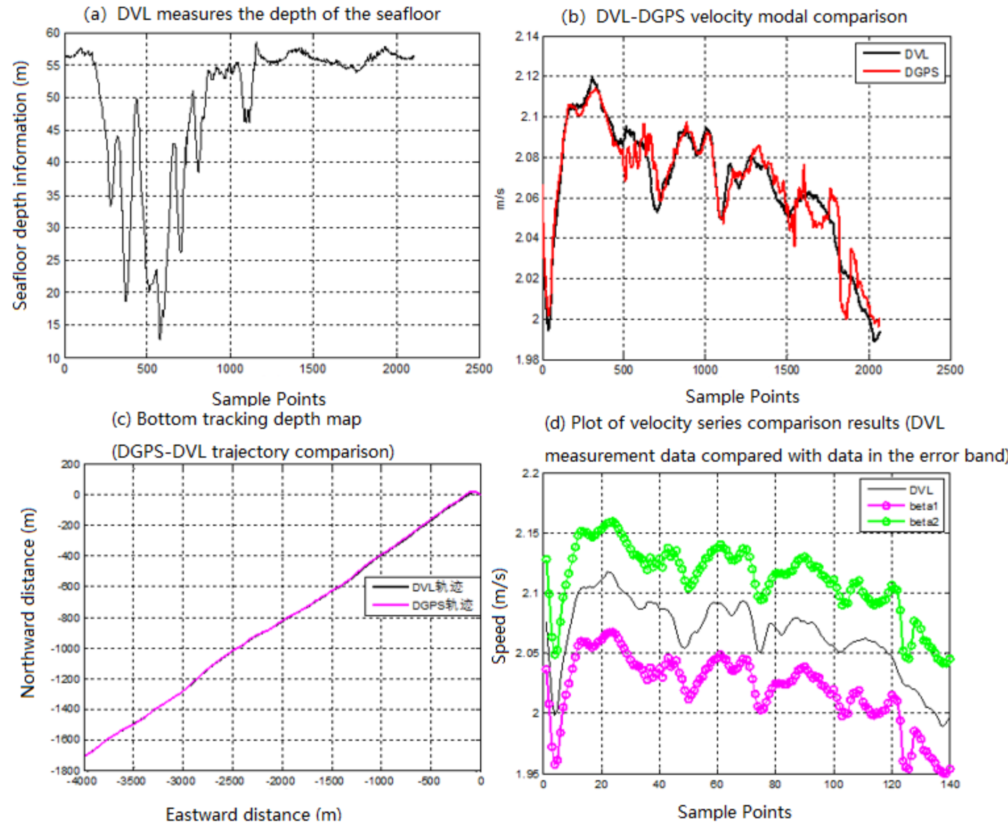
Calibration interface:



- **Transmitting synchronization signal**
- **Single beam velocity value**
- **Original signal readout**
- **Turn off transmitting signal, Self-inspection mode**

3.CALIBRATION SYSTEM



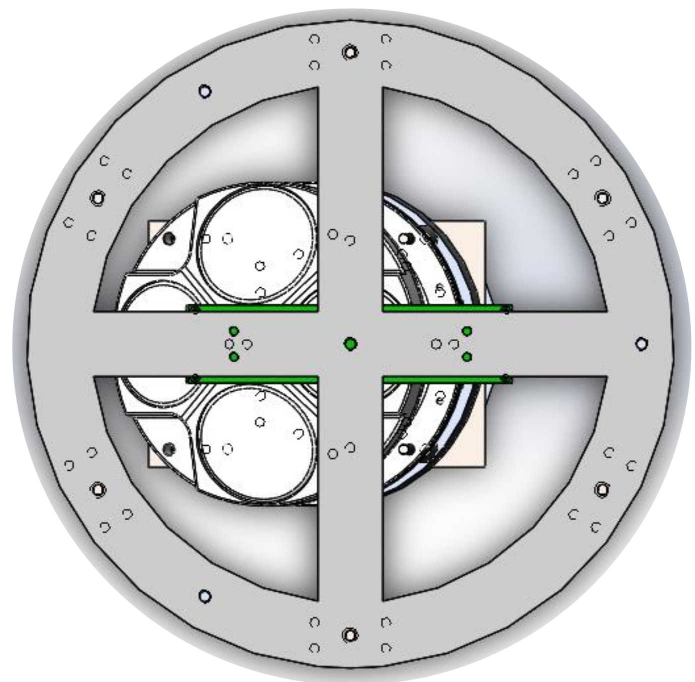


Speed (kn)	DGPS speed (m/s)	DVL Speed (m/s)	Correlation coefficient r	Probability of Confidence (%)	Number of detected data sets	Voyage solving accuracy (%)
4	2.0667	2.0658	0.9662	100	140	0.1946
6	3.1857	3.1908	0.9956	100	169	0.1259
8	3.9482	3.9480	0.9919	100	141	0.4770

superior to 0.5%V

3.CALIBRATION SYSTEM

- Size： Φ500*950mm；
- Weight： 25kg；
- Distance ： 0.6m
- acoustic transponder ： 21 transducers



3.CALIBRATION SYSTEM

Acoustic Tra

Transmit voltage respo ... ansponder array

Frequency (kHz)	tage response (dB)
250	148.1
280	149.4
300	149.7
315	148.9
350	147.6

0mm；

n；

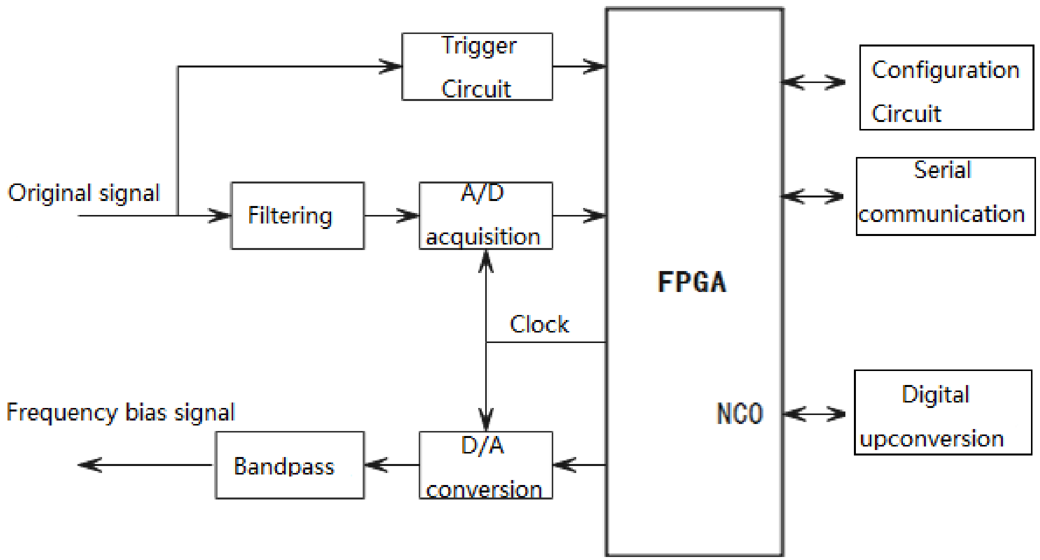
；

21 array element sensitivity

Array element marker	Sensitivity (dB)
1	-210.2
2	-211.1
3	-212.1
4	-213.5
5	-211.6
6	-208.9
7	-208.5
8	-203.0
9	-205.0
10	-204.5
11	-206.8
12	-203.0
13	-204.7
14	-209.2
15	-209.5
16	-211.6
17	-206.0
18	-212.5
19	-210.5
20	-205.9
21	-205.8

3.CALIBRATION SYSTEM

High precision signal acquisition and transmitter

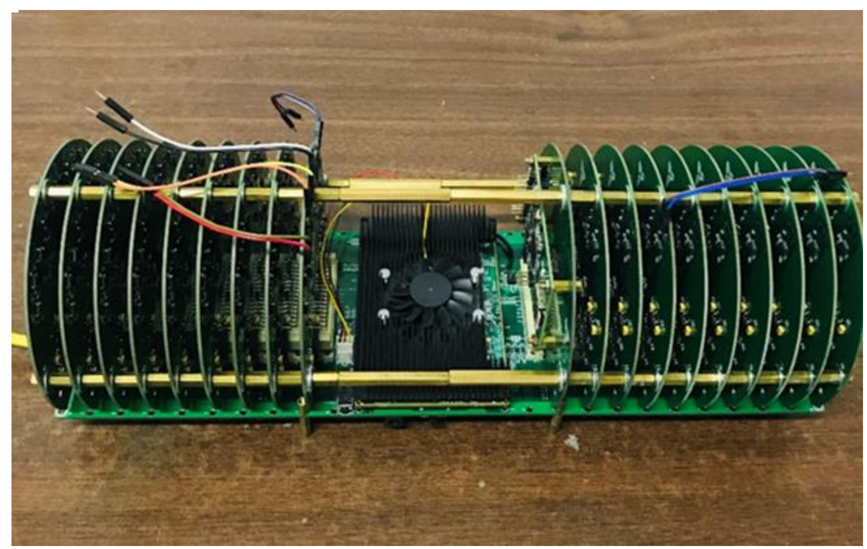


$$V = \frac{c\Delta f}{2f_0}$$

Δf → 0.024Hz

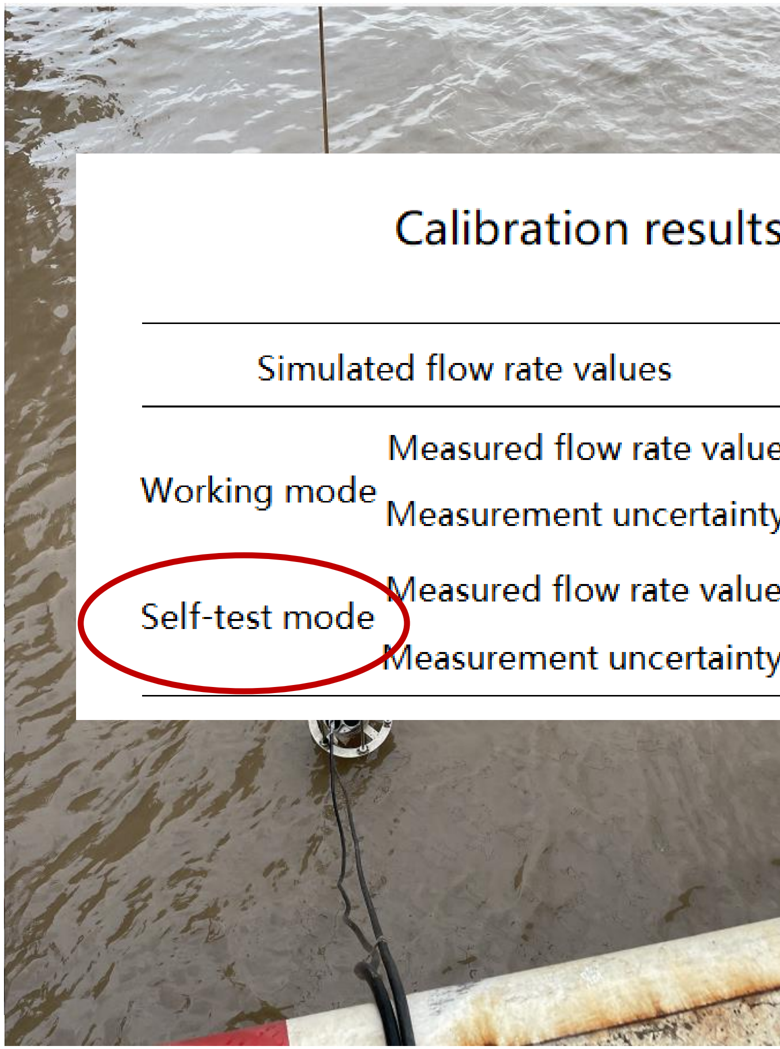
V → 0.02m/s*0.3%+5mm/s

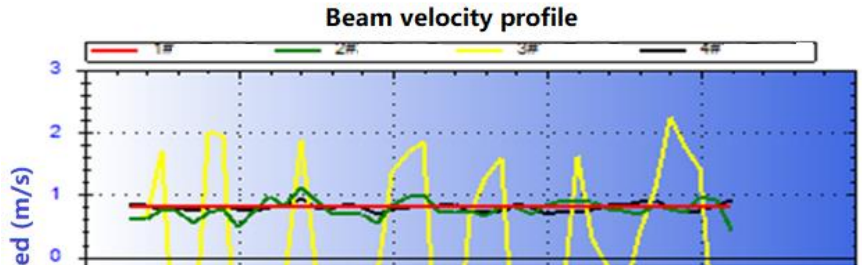
- **Signal acquisition：** **10MSPS，20 channels，16bit;**
- **Signal transmit：** **10MSPS,;**
- **time precision：** **2us;**
- **frequency accuracy ：** **0.01Hz**



4. CALIBRATION TEST

Verify the impact of ocean currents

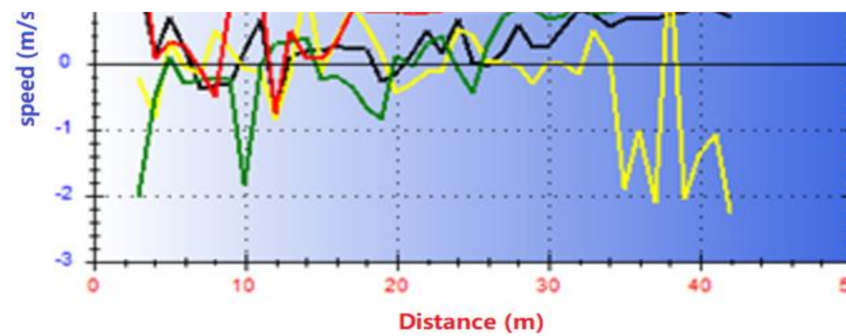




Calibration results in two operating modes

mm/s

Simulated flow rate values		20	200	400	600	800	1000
Working mode	Measured flow rate value	18.9	195.5	389.7	582.8	778.6	975.4
	Measurement uncertainty	16.2	11.4	18.2	11.2	14.6	16.6
Self-test mode	Measured flow rate value	20.5	194.8	390.8	587.2	783.2	978.6
	Measurement uncertainty	7.0	6.0	14.0	4.6	6.8	10.8



Working mode

4. CALIBRATION TEST

Testing Circumstance：

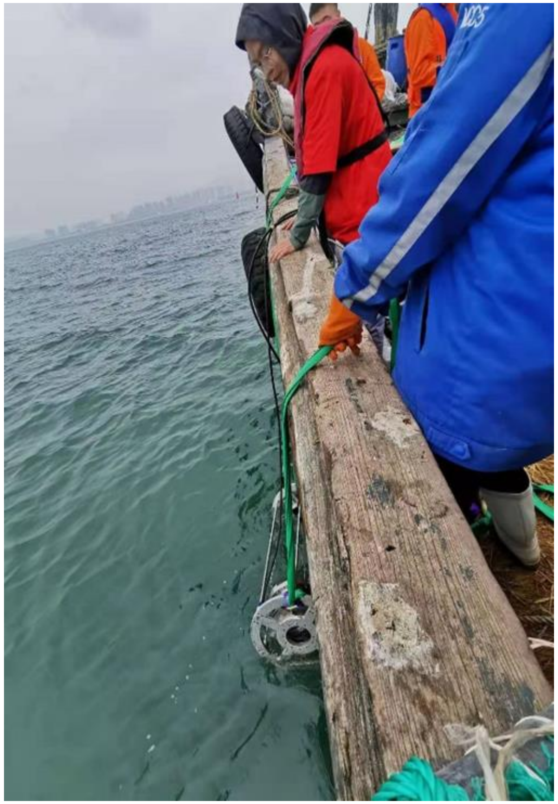
- **Water Depth**： 10m
- **Water Temp**： 14.8℃

ADCP Configuration:

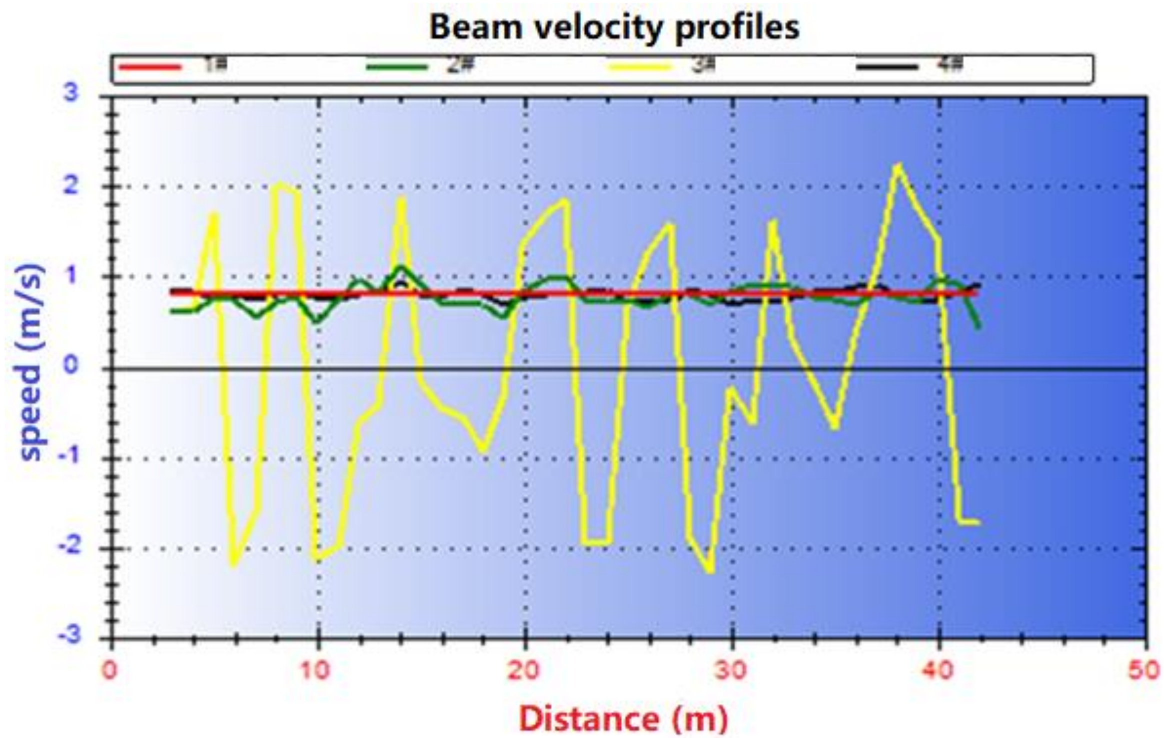
- **Velocity range：** **0.02 ~ 1 m/s**
- **thickness of layer：** **1 m**
- **number of plies：** **40**
- **Pulsing Interval：** **1 s**

1# transducer 20m water layer depth 250 measurements of flow velocity output data (simulated flow velocity of 1m / s)

Serial number	Flow rate mm/s	Serial number	Flow rate mm/s	Serial number	Flow rate mm/s	Serial number	Flow rate mm/s	Serial number	Flow rate mm/s
1	981.8	51	982.8	101	981.8	151	980.8	201	981.8
2	982.8	52	982.8	102	980.8	152	983.8	202	982.8
3	982.8	53	981.8	103	980.8	153	982.8	203	983.8
4	982.8	54	982.8	104	982.8	154	981.8	204	982.8
5	980.8	55	981.8	105	981.8	155	982.8	205	983.8
6	981.8	56	980.8	106	982.8	156	981.8	206	981.8
7	981.8	57	983.8	107	981.8	157	981.8	207	983.8
8	982.8	58	982.8	108	981.8	158	981.8	208	981.8
9	982.8	59	981.8	109	981.8	159	981.8	209	982.8
10	981.8	60	981.8	110	981.8	160	981.8	210	982.8
11	981.8	61	982.8	111	982.8	161	982.8	211	982.8
12	981.8	62	981.8	112	981.8	162	980.8	212	981.8
13	981.8	63	979.8	113	981.8	163	981.8	213	980.8
14	982.8	64	981.8	114	981.8	164	982.8	214	982.8
15	981.8	65	982.8	115	981.8	165	983.8	215	982.8
16	981.8	66	981.8	116	981.8	166	982.8	216	982.8
17	981.8	67	981.8	117	981.8	167	981.8	217	981.8



4. CALIBRATION TEST



Calibration Result

Simulated flow rate values（mm/s）	19.6	196	391	587	782	978
Flow rate measured value（mm/s）	19.9	194	390	586	784	982
Measurement error（mm/s）	+0.3	-2	-1	-2	+2	+4

4. CALIBRATION TEST

Uncertainty Of Measurement

Uncertainty sources	Uncertainty Type	Simulated flow rate values					
		20	200	400	600	800	1000
Measurement repeatability	A	0.8000	0.9000	0.8000	0.9000	0.8000	0.8000
Original signal frequency	B	0.0200	0.0200	0.0200	0.0200	0.0200	0.0200
Return signal frequency	B	0.0250	0.0250	0.0250	0.0250	0.0250	0.0250
Temperature	B	0.0140	0.1400	0.2000	0.4000	0.6000	0.7000
Depth	B	0.0000	0.0001	0.0002	0.0004	0.0005	0.0006
Synthetic uncertainty	u	0.8000	0.9000	0.8000	1.0000	1.0000	1.1000
Extended Uncertainty	U	1.6000	1.8000	1.6000	2.0000	2.0000	2.2000

5. SUMMARY

- The method proposed in this study can be easily used for on-site ADCP calibration. Install ADCP which has been used a period of time on a rigid bracket, align the transponder array to the transducer of ADCP, place the calibration device with flexible connection under the water, calibration completed.
- It can calibrate any flow rate theoretically, easy to use and with low cost.
- In the future, it can promote the gradual opening of calibration interfaces for ADCP, improve the relevant standards, and promote the on-site calibration and laboratory calibration of ADCP in small pools.

Thank You