

A New Compact High-Stability Oscillator

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OBJECTIVE

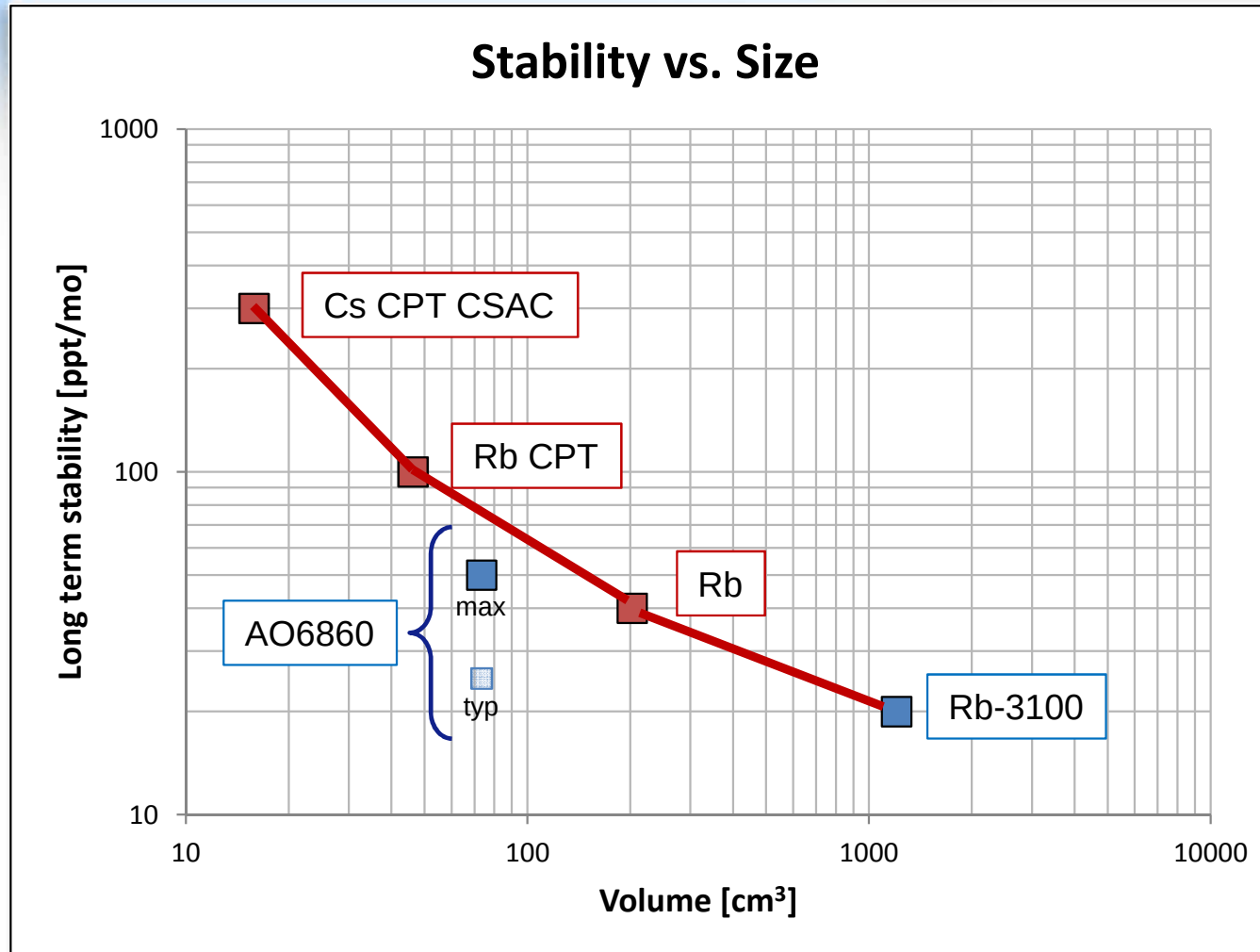
Develop a **new atomic oscillator** that

① is significantly **smaller** than our previous generation

and

② is **smaller** than and has **better stability**
than the existing state of the art.

Comparison: Size & Stability



**smaller
and
better stability
than existing
state-of-the-art**

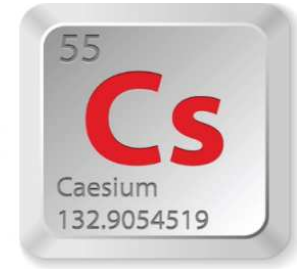
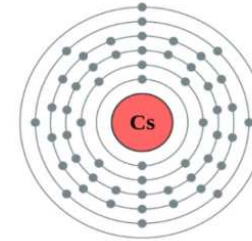
	Existing State of the Art				This Work	Units
	Cs CPT CSAC	Rb CPT	Rb	Epson Rb3100	Epson AO6860	
Size	16	46	203	1204	73	cm ³
Stability (max)	300	100	40	20	50	ppt/month
Stability (typ)					25	ppt/month

TECHNOLOGY

How did we build this?

Technology Overview – Basic Principles

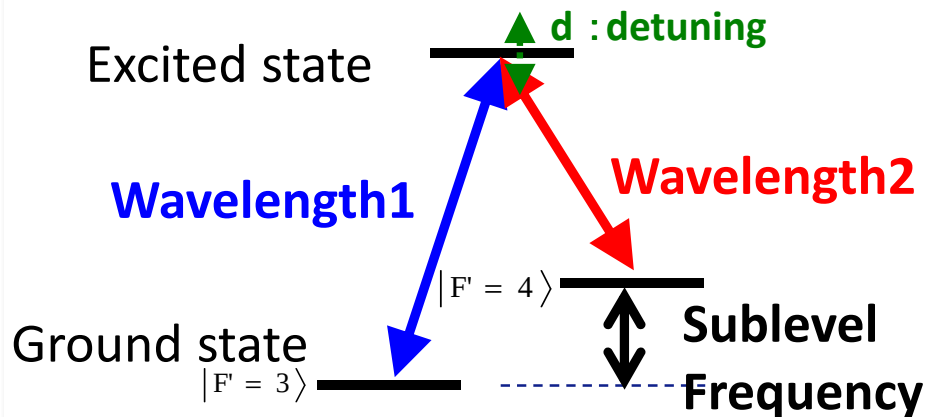
- Coherent Population Trapping
 - Cæsium D1 Transition
 - Many components made by Epson
 - VCSEL (Vertical Cavity Surface-Emitting Laser)
 - TCXO (Temperature-Compensated Crystal Oscillator)
 - Physics Package
 - Synthetic Quartz
 - ICs
- Size: 18 (H) mm x 60 (W) mm x 68 (D) mm



Coherent Population Trapping (CPT)

Select one Sublevel Frequency of Cs.

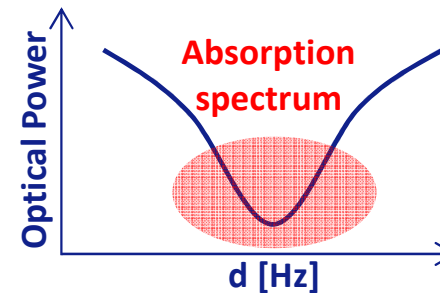
Advantage: Laser enables Miniaturization



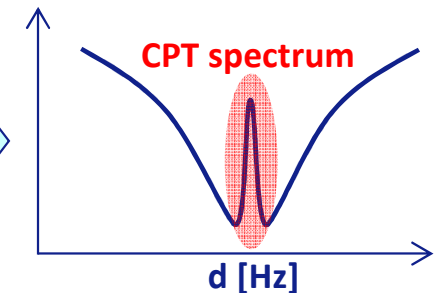
for Cs

Sublevel Frequency = 9.2 GHz

Only one wavelength



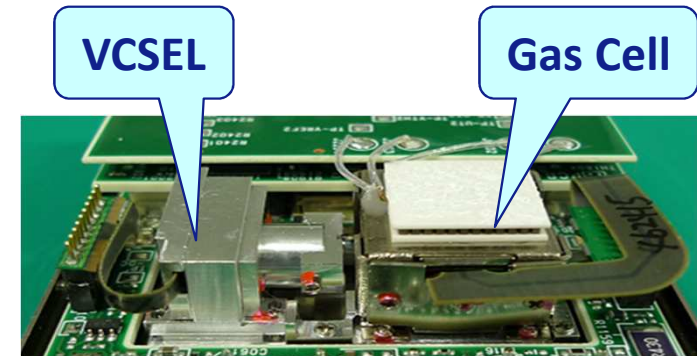
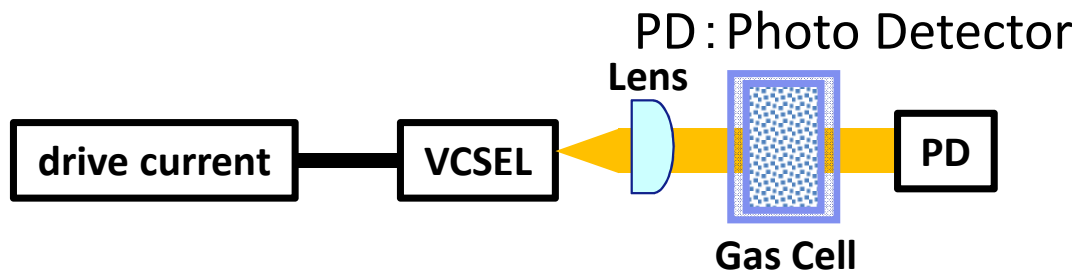
Two wavelengths



Basics

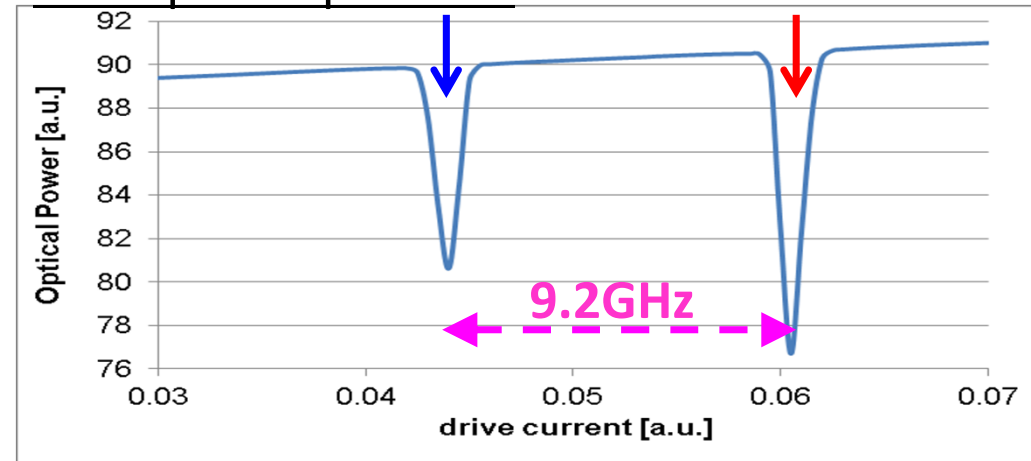
1. Resonance with Cs
2. Two Wavelengths (9.2GHz difference)
3. Frequency difference sweep

Step 1: Establish Resonance with Cs

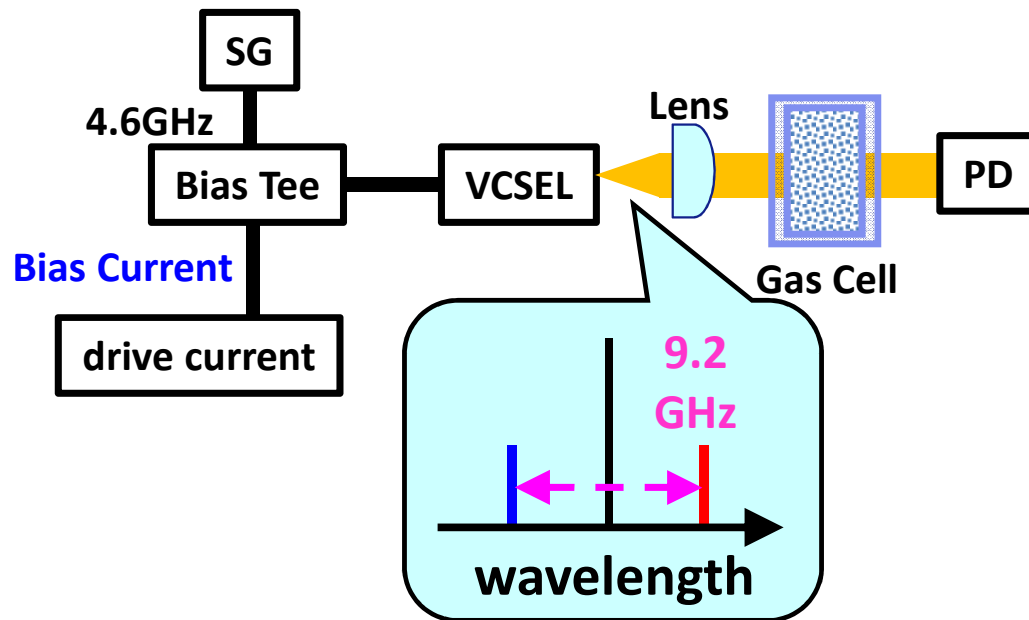


- We use a VCSEL as a light source.
- Temperature of the VCSEL and gas cell are controlled.
- By sweeping the VCSEL drive current:
 - we can sweep laser wavelength.
 - and measure absorption.
- We adjust laser wavelength to around 894nm, and observe two absorption spectrum (AS).
- The difference between the two AS is 9.2GHz.

Absorption spectrum



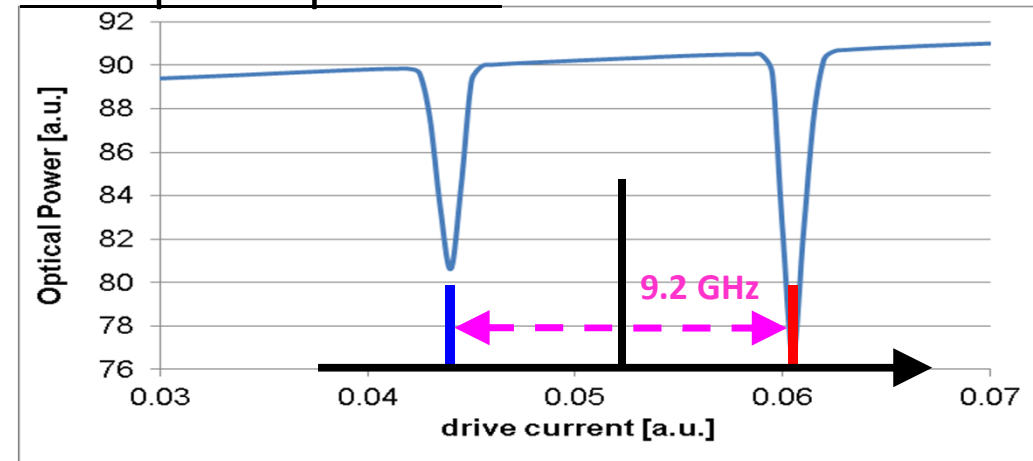
Step 2: Modulate Laser with RF



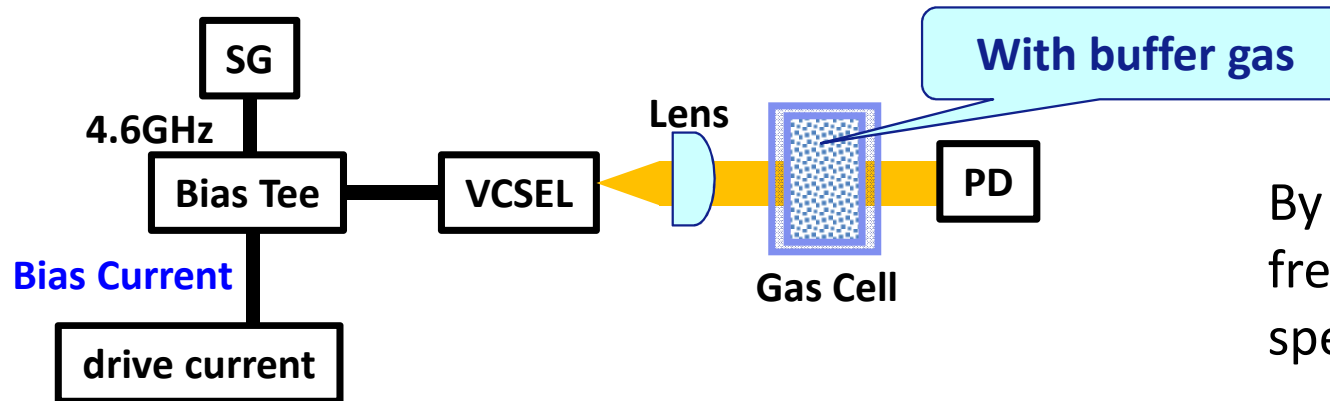
We modulate the laser by changing the drive current to get two wavelengths.

A 4.6 GHz signal creates two laser spectra which are 9.2 GHz apart.

Absorption spectrum

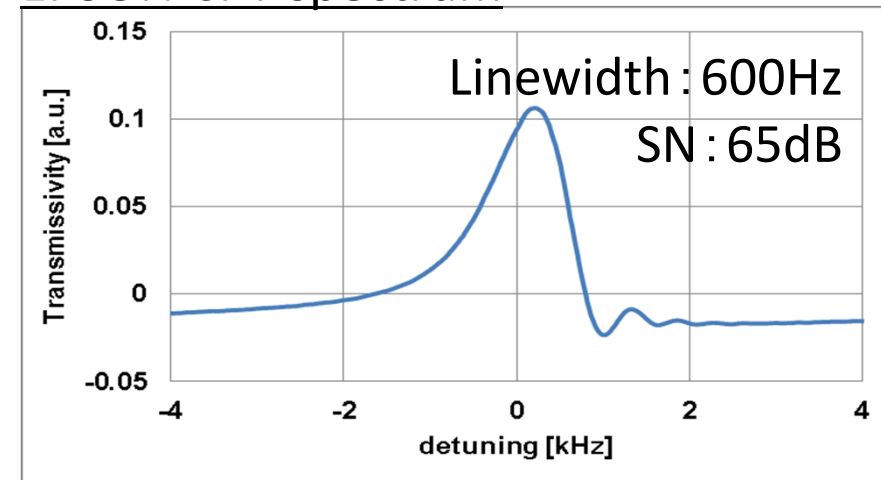


Step 3: Sweep Frequency



By sweeping 4.6GHz microwave frequency, we can get CPT spectrum.

EPSON CPT spectrum



- CPT spectrum affects short term stability.
- A narrow and strong peak is best.

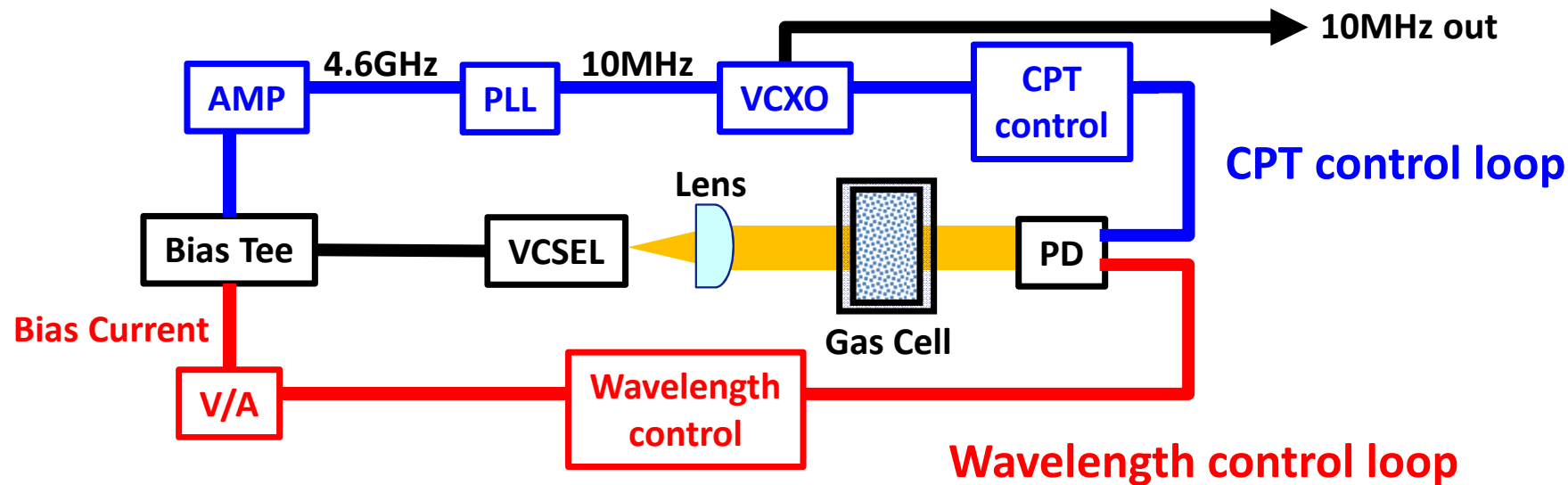
$$\text{short term stability} = \frac{A}{SN} \times \frac{\text{Linewidth}}{9.2\text{GHz}}$$

- We mix buffer gas in gas cell for better short term stability.

Block Diagram of the Atomic Oscillator

CPT control loop

- Controls modulation to match the CPT spectrum.

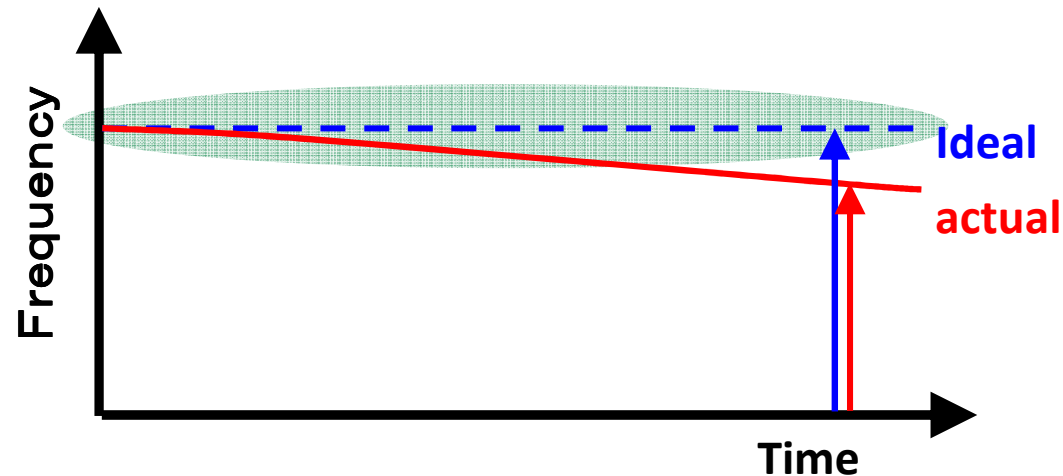


Wavelength Control Loop

- Adjusts VCSEL bias current to center the wavelength.

Both loops are controlled by one IC.

How did we achieve better accuracy?



About Aging

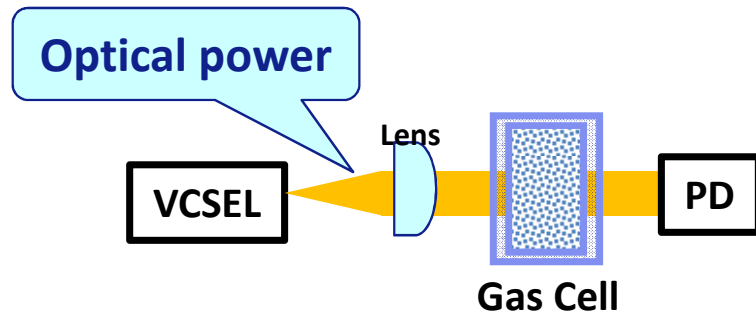
Good aging

⇒ merit : maintenance free

⇒ target : $5e-11$ /month

Change of Physical material (in particular optical power) causes:

[parameter about optical power]



① Laser wavelength

~ Along with change of wavelength,
drive current changes laser power.

② Transmissivity

③ 4.6GHz microwave power ~ bigger sensitivity

Affect frequency parameter

(Parameter aging) × (Sensitivity)

⇒The influence is reduced.

Parameter	aging /month
① Laser Wavelength	+6E-12
② Transmissivity	-1E-11
③ 4.6 GHz Microwave power	±1E-11

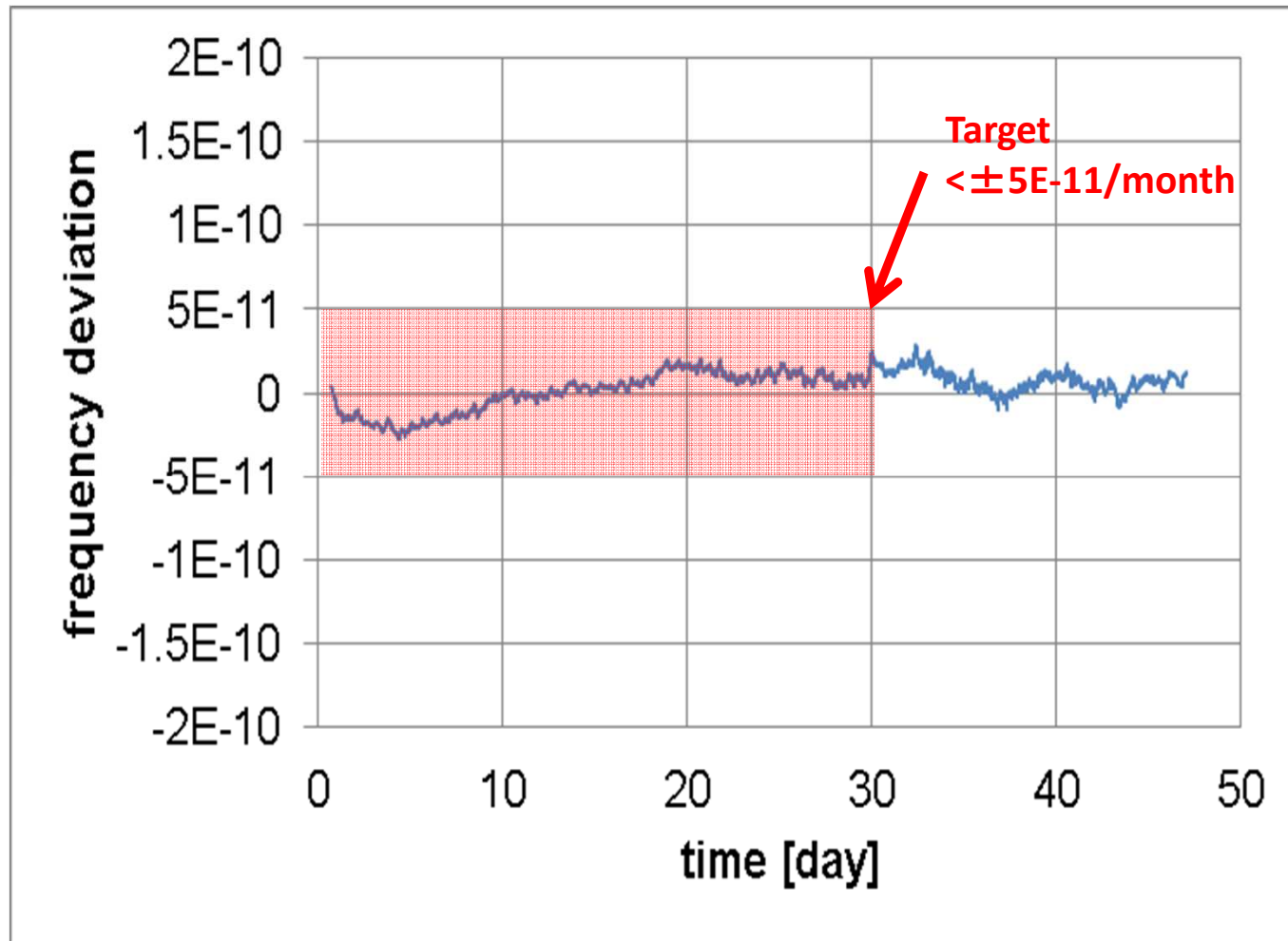
SUM:-1.4E-11 ~ +6E-12

⇒All parameters are reduced,
and the aging characteristic is achieved.

MEASURED DATA

1. Long-Term Stability (Aging)
2. Short-Term Stability (Allan Variance)
3. Warm-Up Time
4. Temperature Stability
5. Phase Noise

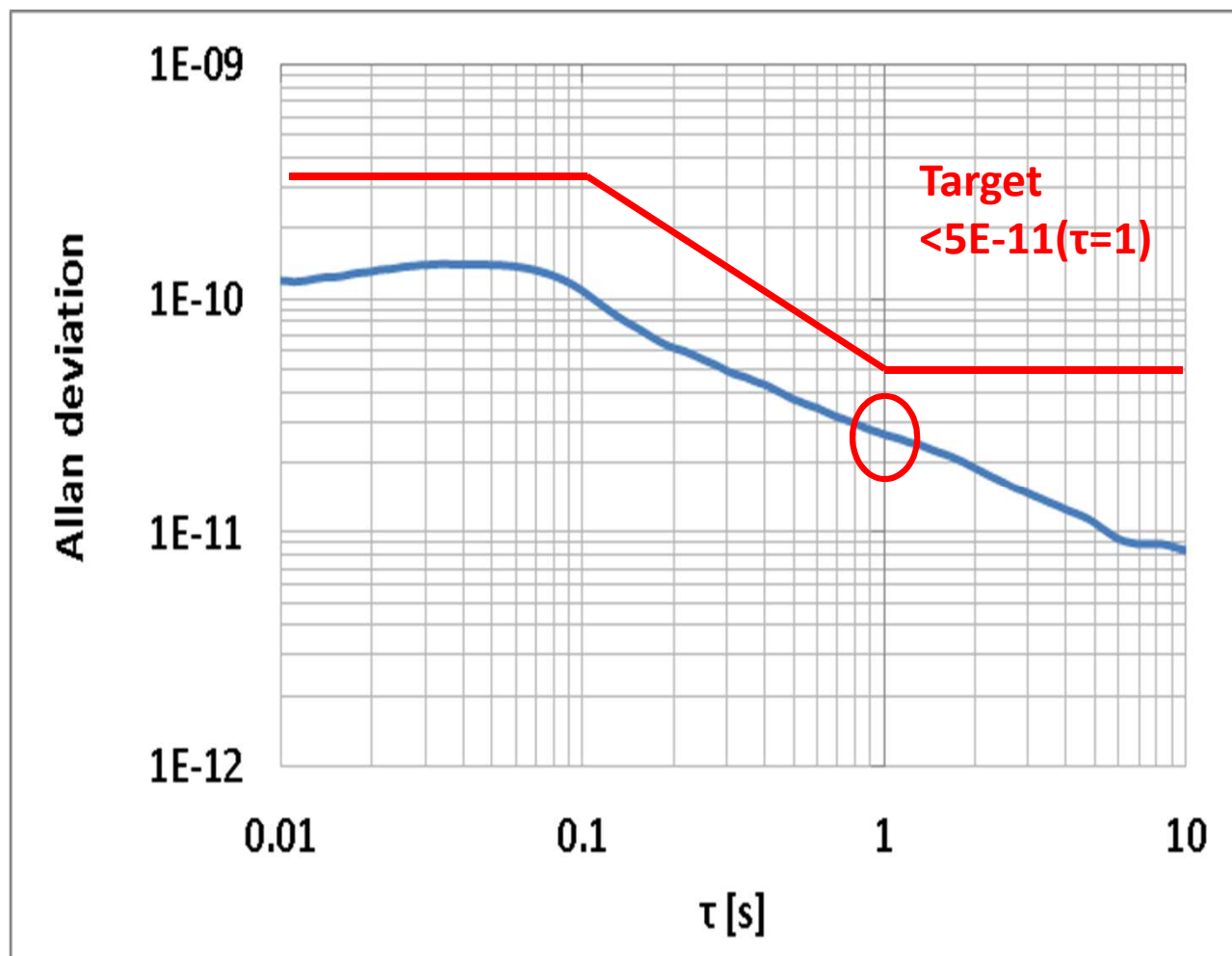
Long-Term Stability (Aging)



Points for Long-Term Stability (Aging):

- Laser wavelength
- Transmissivity
- Microwave power

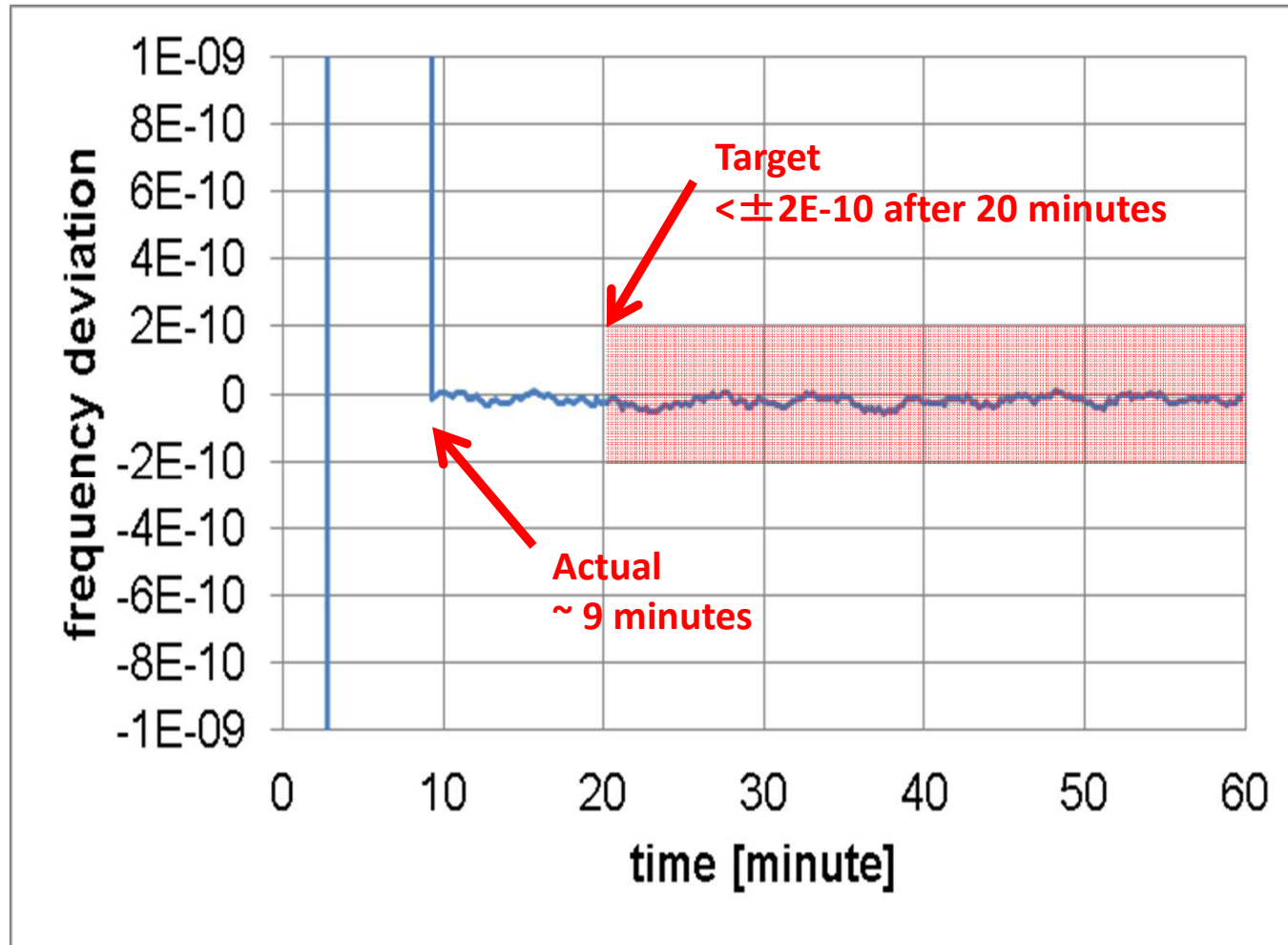
Short-Term Stability (Allan Variance)



Points for Short-Term Stability:

- Cell Scale
- Buffer gas pressure
- Optical power
- PLL CN
- Loop gain

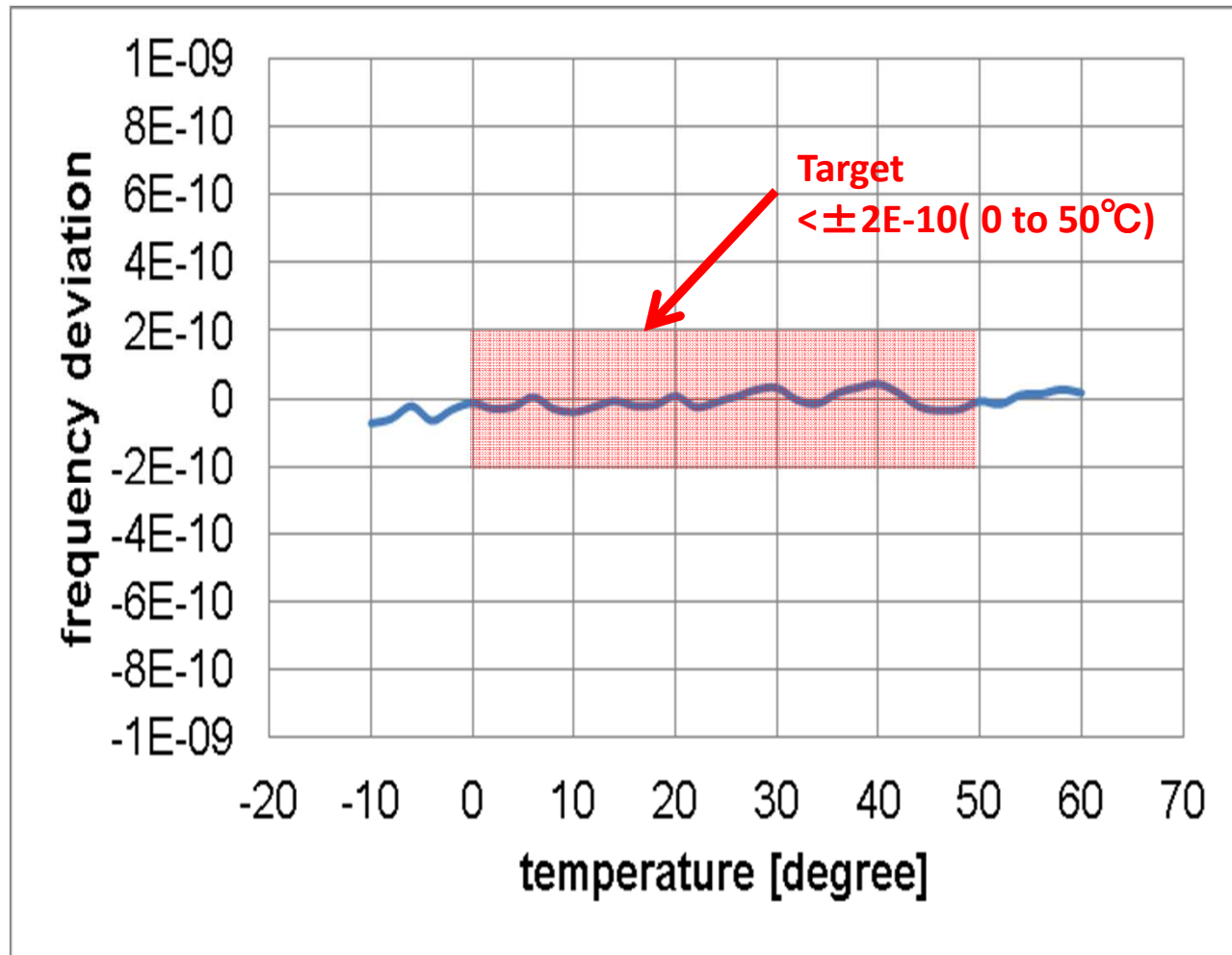
Warm-Up Time



Points for Warm-Up:

- Temperature control loop

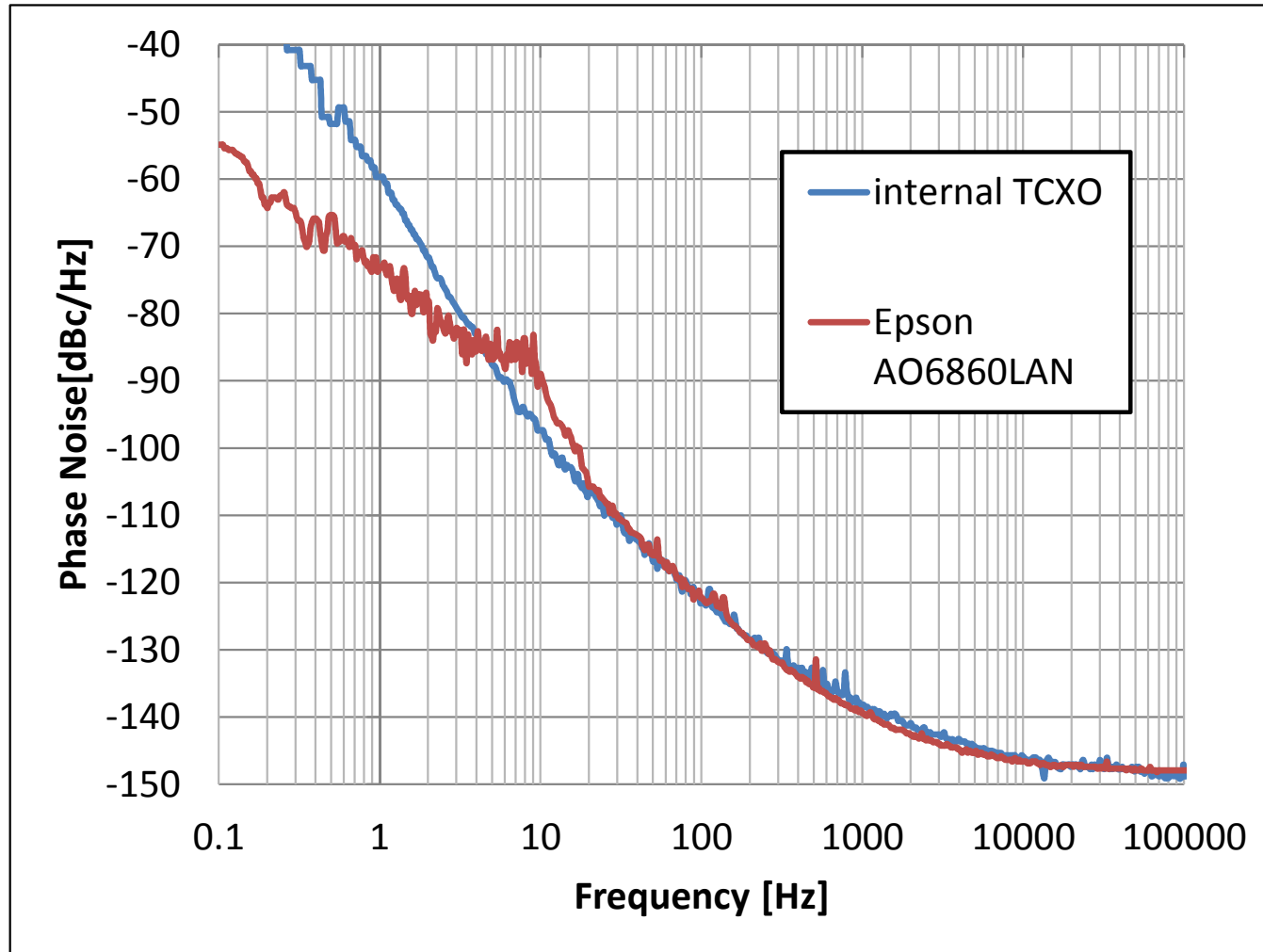
Temperature Stability



Points for Temperature Stability:

- Cell temp stability
- VCSEL temp stability
- Mixed buffer gas

Phase Noise



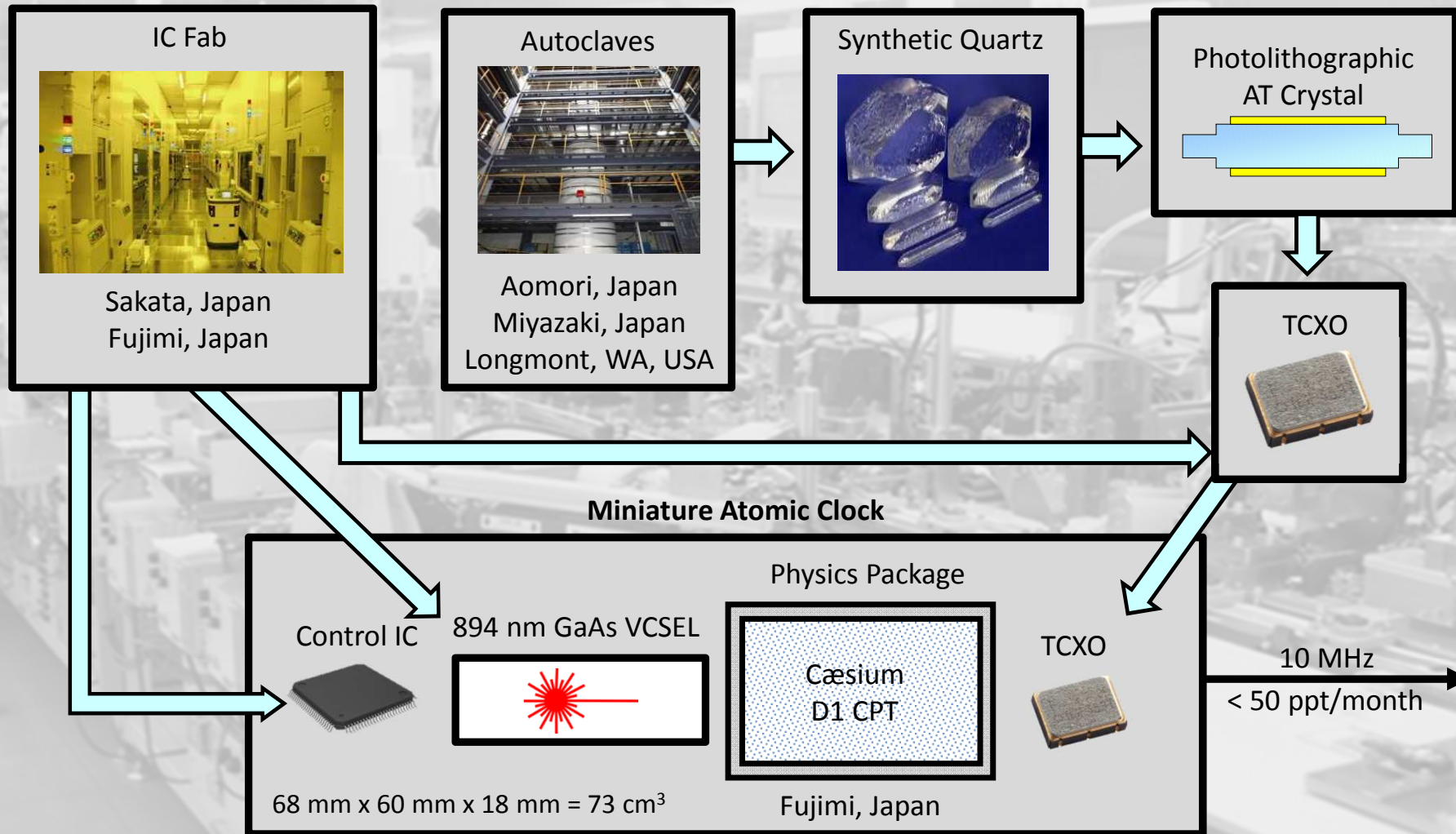
Points for Phase Noise:

- Gas cell determines phase noise below the PLL loop bandwidth
- Local oscillator determines phase noise above the PLL loop bandwidth
- Cut off frequency is 10Hz

SUMMARY

- **Technology**
- **Performance Achieved**

Technologies Used in Miniature Atomic Clock



Performance Achieved

Parameter	Target	Typical	Units
Stability			
Long-Term	< 50	25	ppt/mo.
Short-Term ($\tau=1$)	< 50	25	ppt
vs. Temperature	< 200	± 50	ppt
Warmup (200 ppt)	< 20	9	minutes
Temperature	0 ~ +50 -10 ~ +60		° C
Supply			
Voltage	3.3		V
Power (operating)	3	3	W
Power (turn-on)	20	20	W
Dimensions	68 x 60 x 18		mm

$< \pm 5 \times 10^{-11} / \text{month}$

73 cm^3

ありがとう
Thank You!!!



吉田啓之
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