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The Next Frontier in TCXO Performance

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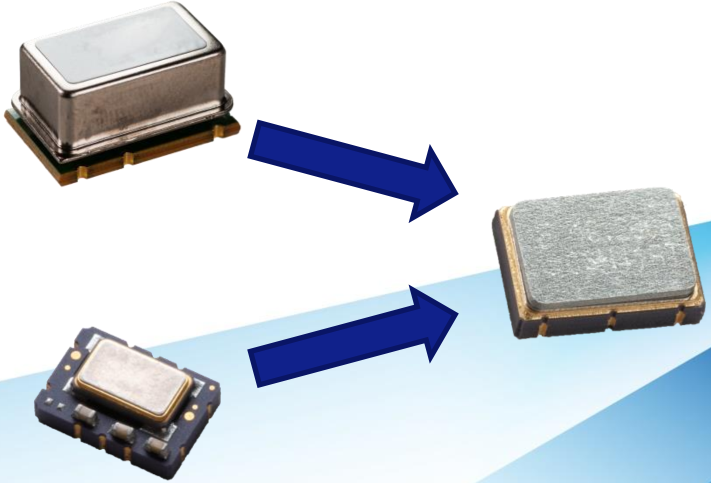
WSTS 2018

June 21, 2018



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Where are we today?

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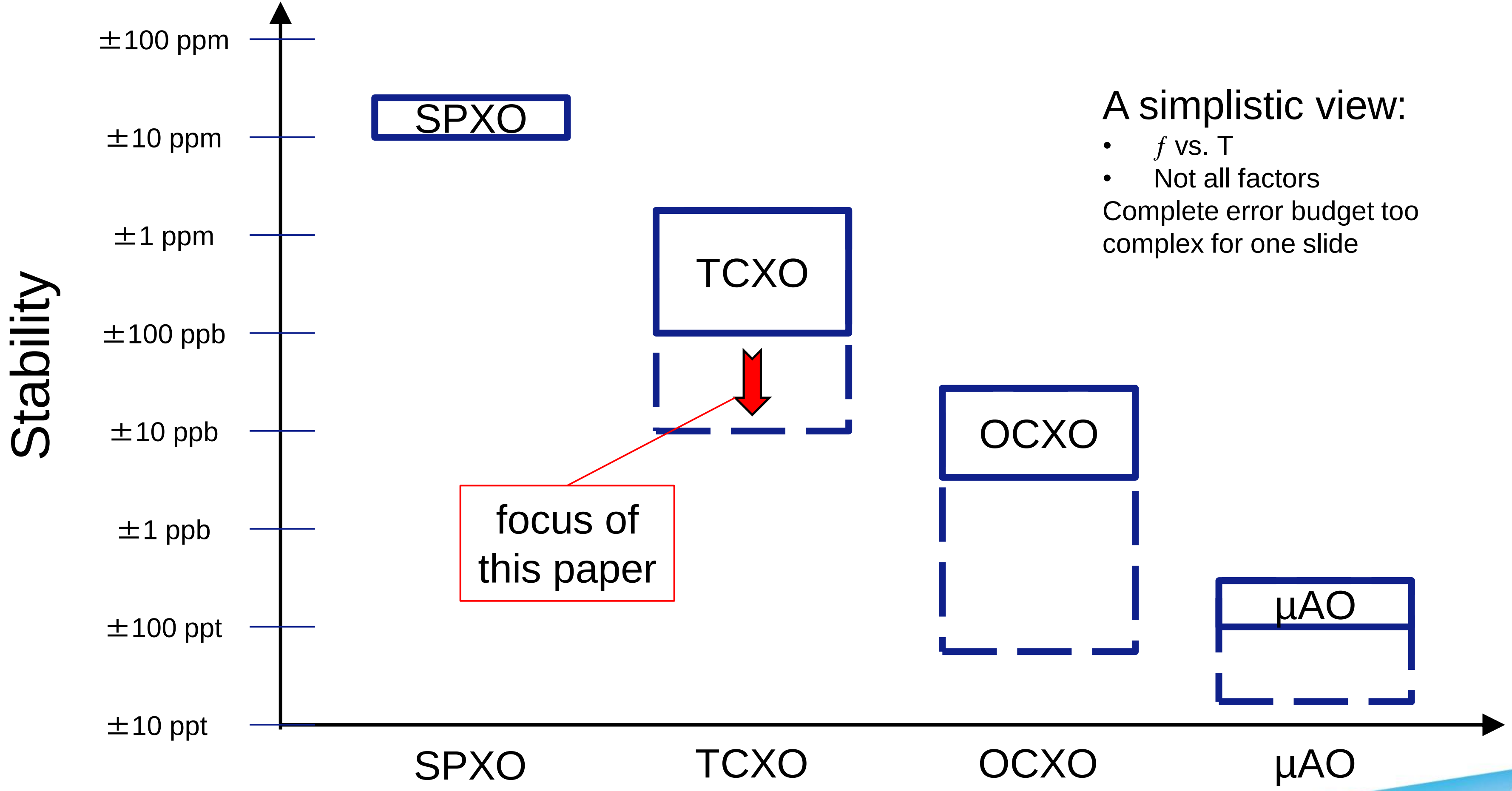

A simplistic view:

- *f* vs. T
- Not all factors

Complete error budget too complex for one slide

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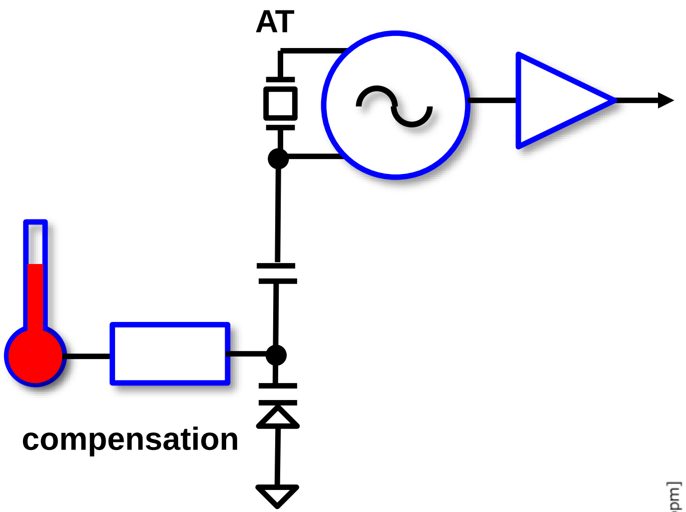
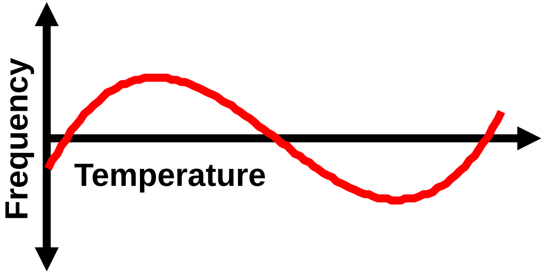
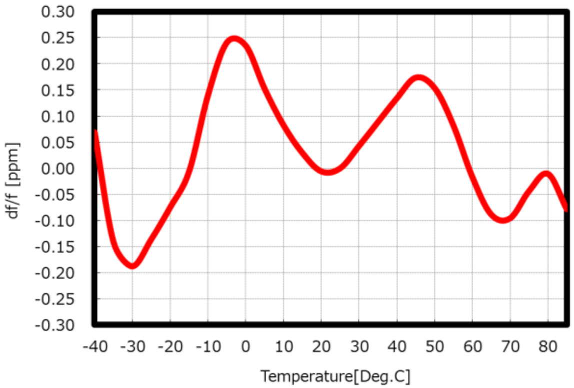
Basics – How a TCXO Works





f vs. T ≈ ±10 ppm
< ±20 ppm

controlled by:
- cut angle
- crystal shape
- crystal dimensions



f vs. T	Compensation
±2 ppm	10x
±1 ppm	20x
±0.5 ppm	40x
±0.28 ppm	70x
±0.1 ppm	200x
±0.01 ppm	2000x

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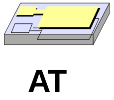
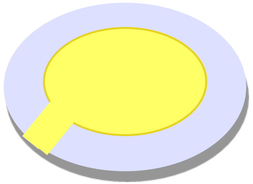
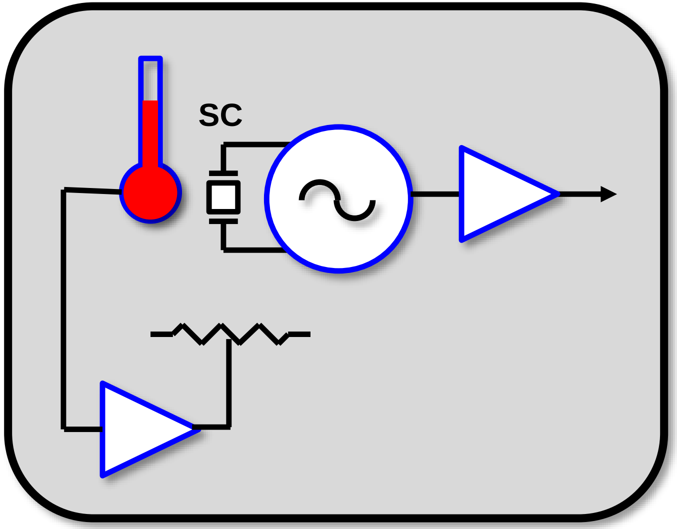
Basics – How an OCXO Works

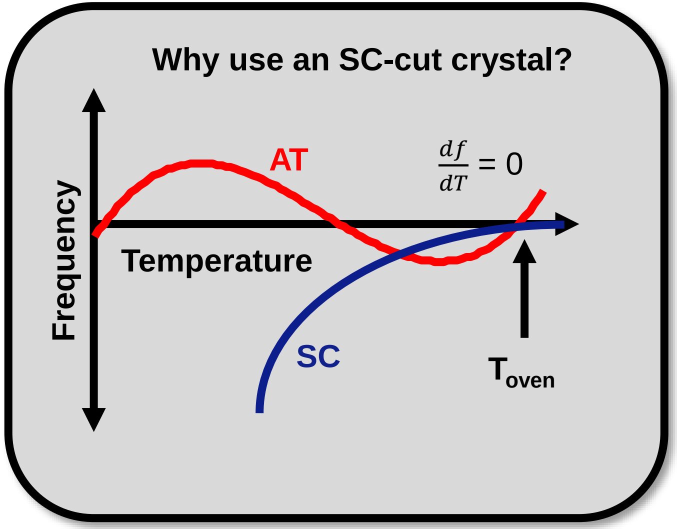




SC

- **Size**
- **Shape**
- **Cut angle**
- **Stress**





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Characteristics of TCXOs vs. OCXOs

What We have Today

Performance

	TCXO	OCXO
f vs. T	±0.1-0.28 ppm	±10-50 ppb
ADEV @ 1s	1E-9	1E-10
Aging 20-yr	< ±3 ppm	< ±1 ppm
Aging 24-hr	< ±40 ppb	< ±1 ppb
Airflow	ok	Much better

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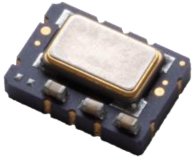
Practicality

	TCXO	OCXO
Size (WxL)	5x3.2	25x22 21x13 14x9
Size (H)	1.5-2.0	9-12
Cost	\$\$	\$\$\$
Power	<< 30 mW	< 1-2.5 W
Reliability	Much better	ok



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What Else Needs to be Done?

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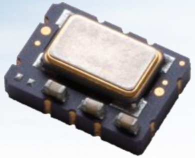
Performance

- *f* vs. T
- Wander
- Aging
- Holdover
- Airflow

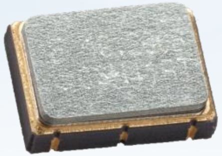
OCXO

Practicality

- Size
- Cost
- Power
- Reliability



TCXO



next-gen oscillator

How do we get there?

- Compensation & Calibration Techniques
- SPC & Manufacturing Discipline
- IC Design
- Mechanical & Thermal Design
- Packaging Technology
- Crystal Design & Fabrication Techniques

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How can we make TCXOs perform like OCXOs?

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Existing State of the Art – Recent Innovations

1. **IC design & calibration techniques** – f vs. T

2. **XTAL design** – wander

3. **Package & structure** (thermal design) – airflow & stability for small T variations

What do we need to do next?

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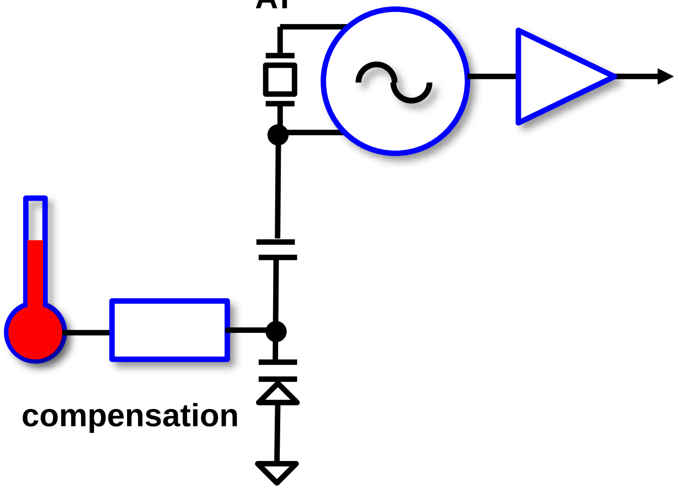
TCXO Concept – Compensation



2 Important Choices:

1. Analog vs. Digital
2. How do you compensate?

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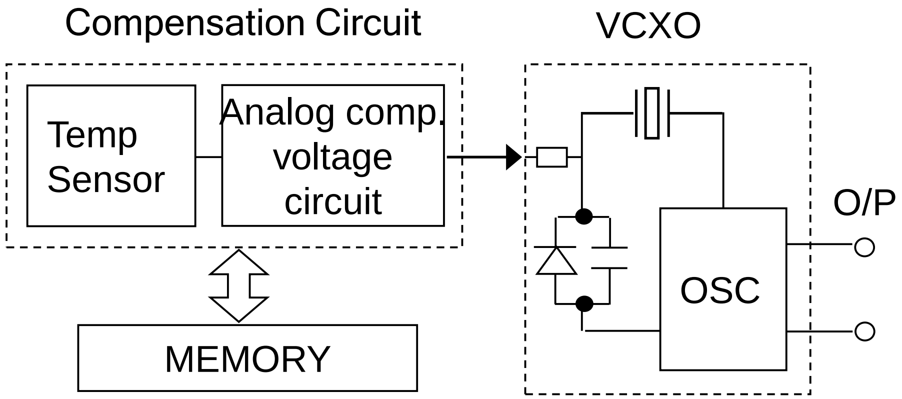
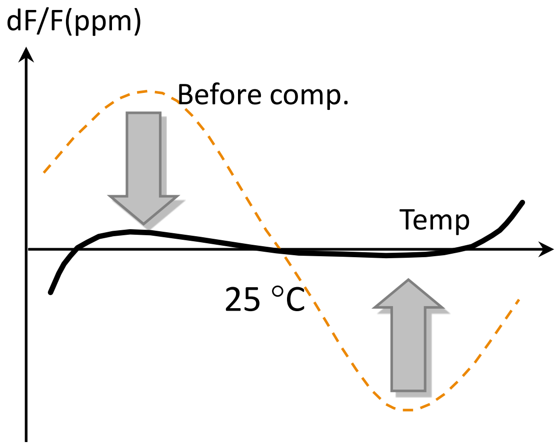
Analog Compensation



Analog Compensation Method



Advantage: No discrete phase jumps

Challenge: fitting error

- Crystal cutting & design optimization
- Calibration techniques – accuracy vs. cost

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Digital Compensation

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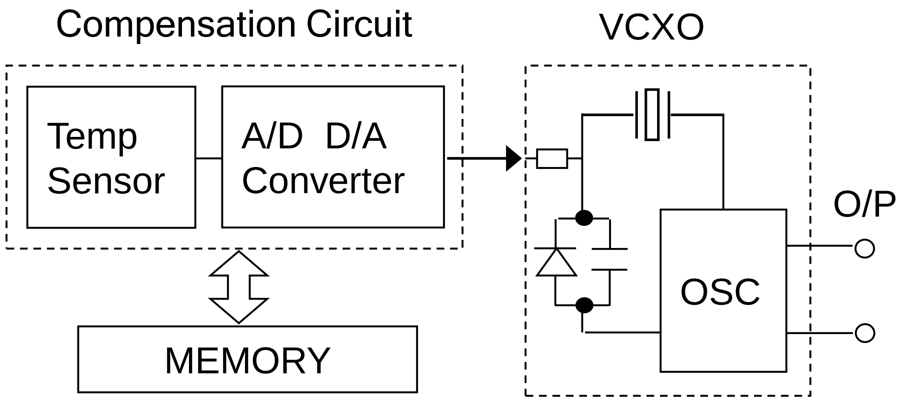
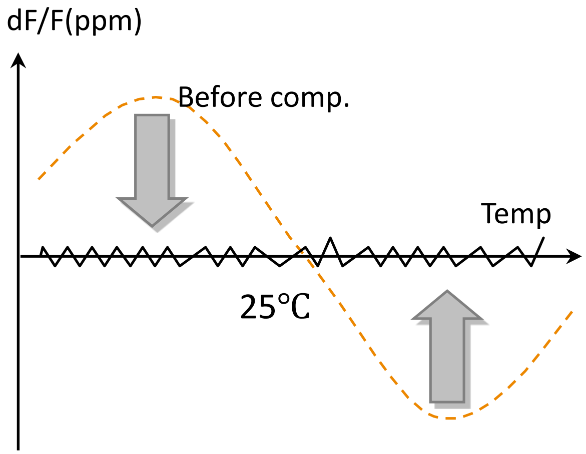


Digital Compensation Method



Advantage: less fitting error (lots of points!)

Challenge: discrete phase jumps

- Easy answer: resolution < stability
- How well can you measure temperature? How well do you know your crystal?

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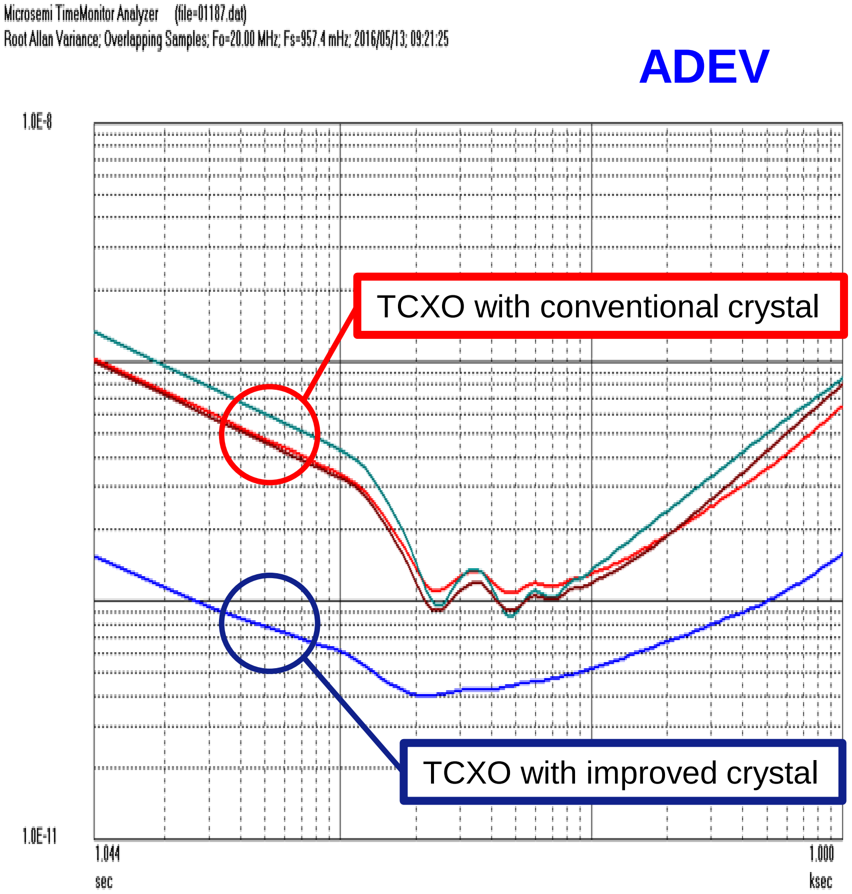
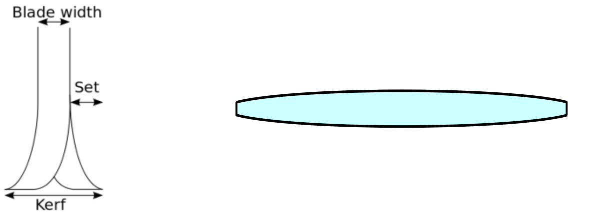
Short-Term Stability (Wander)



Crystal Design Improvements

① Material Purity

② Crystal Processing



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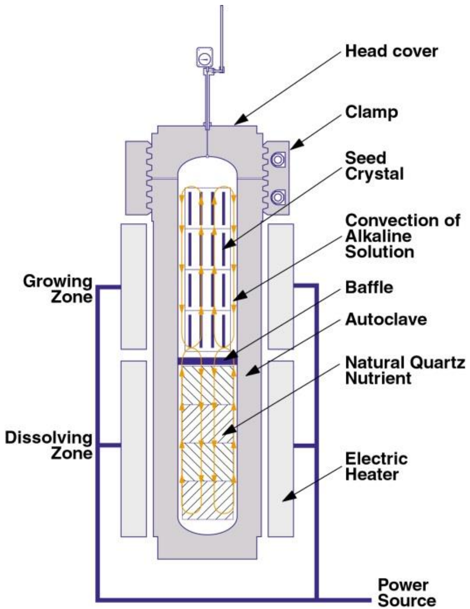
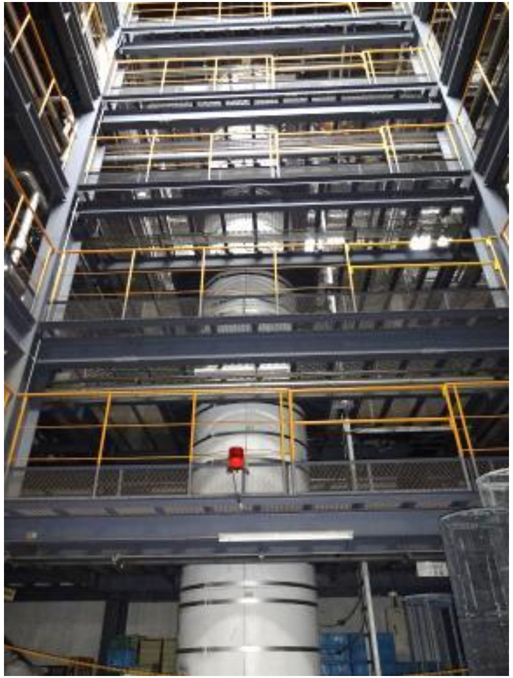
Material Purity (Autoclave)





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Crystal Processing

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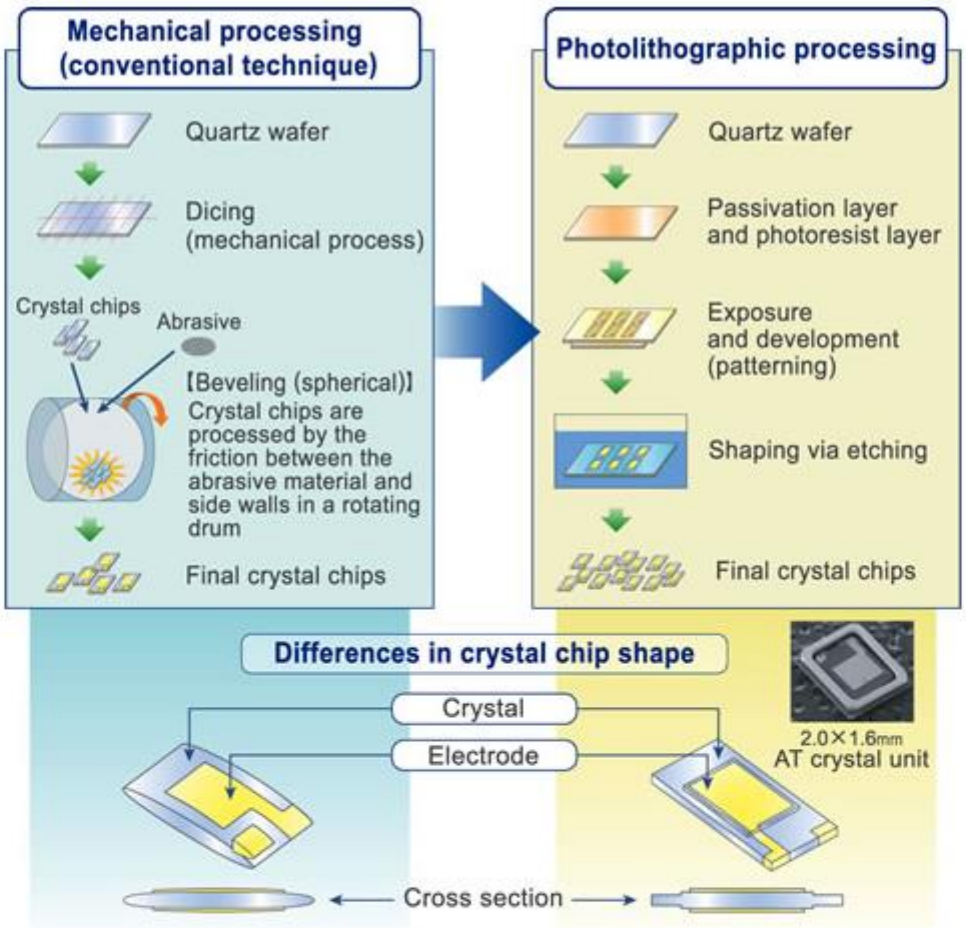
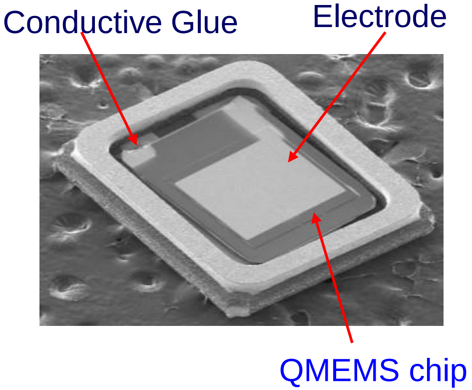
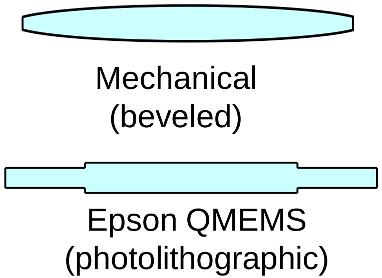




Resulting Shape (cross section)



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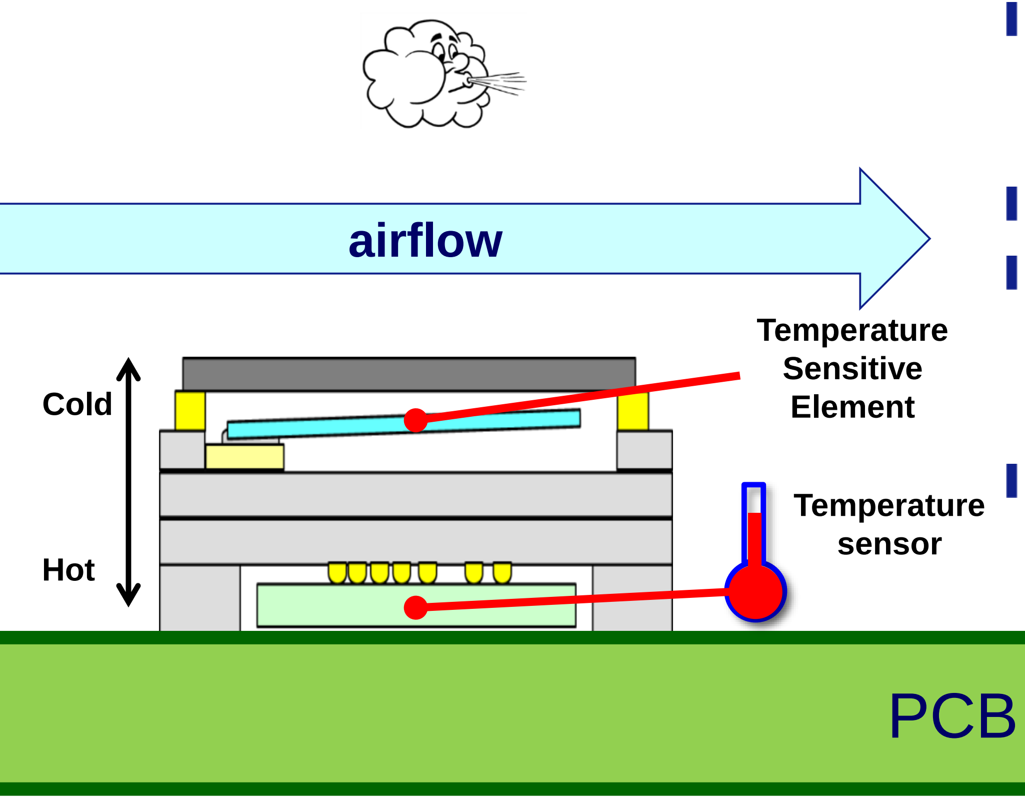
Why TCXOs are Sensitive to Airflow



Fundamental Mechanism

- Temperature-sensitive element (crystal) and temperature sensor (IC) are not in the same place
- Airflow causes Temperature gradient
- How sensitive is Quartz?

$$\frac{df}{dT} = \frac{20\ ppm}{60\ °C} = 0.3\ ppm/°C$$

vs. $30\ ppm/°C$ for Silicon

- How much temperature gradient can we tolerate?

$$1\ ppb \div 0.3\ ppm/°C = 0.003\ °C$$

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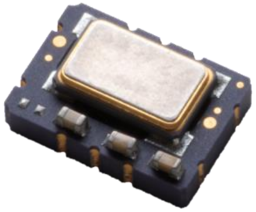
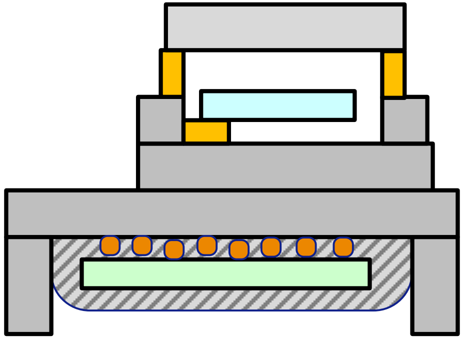
Construction – Double-Decker vs. DoubleSeal™

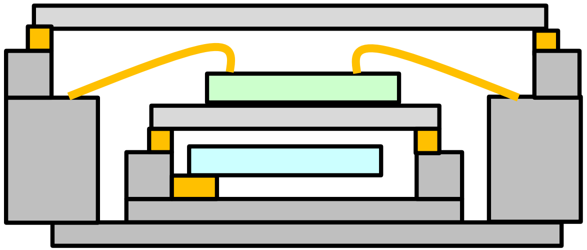




Double-Decker

Phase transients due to to airflow

- **Crystal and IC not thermally coupled**



DoubleSeal™

Better Thermal Design

- **Protected from airflow and board turbulence**
- **More stable for small T changes**

US & Japanese patents

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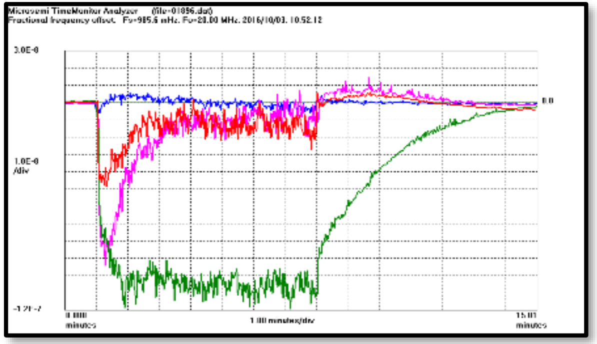
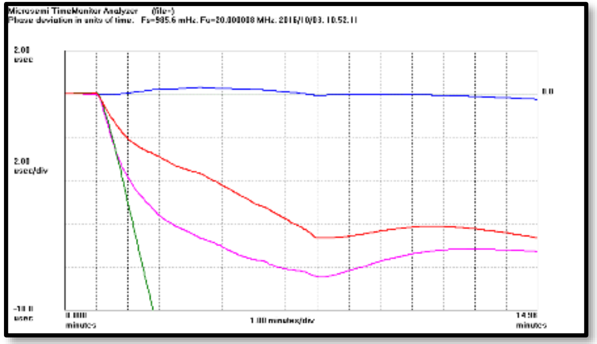
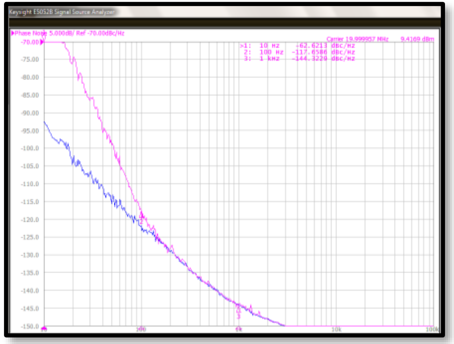
Performance under Airflow



Better Frequency Stability
3-25x



Better Phase Stability
1-250x



Better Phase Noise
30 dB @ 10 Hz

Dependable Synchronization

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Comparison of Specs




	Conventional TCXOs	DoubleSeal™ TCXO	Future TCXO	Current OCXOs
Aging	±3 ppm	±3 ppm	<< 1 ppm	±1 ppm
Initial	±1 ppm	±1 ppm	±1 ppm	±500 ppb
vs. T	±0.1-0.28 ppm	±0.1-0.28 ppm	→ ±10 ppb	±10 ppb
vs. V	±0.1 ppm	±0.1 ppm	→ ±10 ppb ✓	±10 ppb
vs. C_L	±0.1 ppm	±0.1 ppm	→ ±10 ppb ✓	±10 ppb
TOTAL	**< ±4.6 ppm**	**< ±4.6 ppm**	**< ±4.6 ppm**	**< ±4.6 ppm**

24-hour drift	±40 ppb	±5 ppb	→ ±1 ppb	< ±1 ppb
ADEV (1s)	1E-9	2E-10	→ 1E-10	0.5-1E-10

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So how close are we? Next Steps?

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Where are we now?

- TCXOs easily meet S3, but not S3E
- Many PTP systems need OCXOs
- TCXOs getting a **lot** better

Solved problems

- Greatly improved wander due to improved crystal design
- Airflow issues solved with thermal design techniques
- 24-hour drift getting a **lot** better, approaching OCXOs

What's next?

- Improve f vs. T through calibration techniques – ±100 ppb → ±10 ppb
- Further improvement of wander and 24-hour drift

How soon can this be done?

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THANK YOU

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#1 SHARE $432M in 2015

#1 in VERTICAL INTEGRATION

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TCXOs OCXOs µAO

SYNCHRONIZATION PRODUCTS