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How DoubleSeal™ Technology Improves TCXO Airflow Performance

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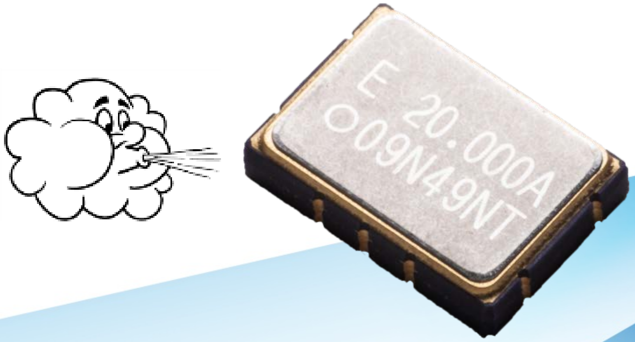

How DoubleSeal™ Technology Improves TCXO Airflow Performance

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Outline:

1. TCXO Basics and Why Airflow is Important
2. Why TCXOs are sensitive to airflow
3. Typical TCXO designs
   - Construction
   - Measured data – airflow performance
4. DoubleSeal™ technology
   - How it works, why it is better
   - Measured data – airflow performance

Basics – How a TCXO Works

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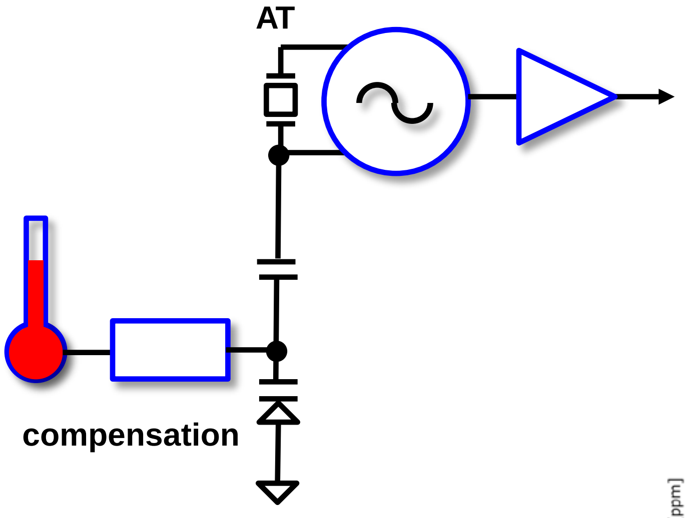
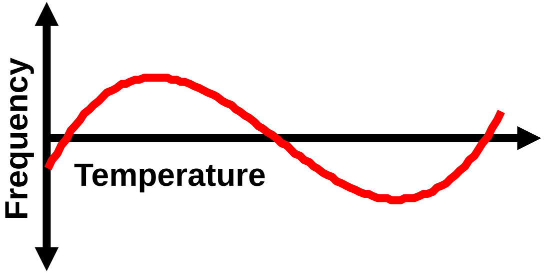
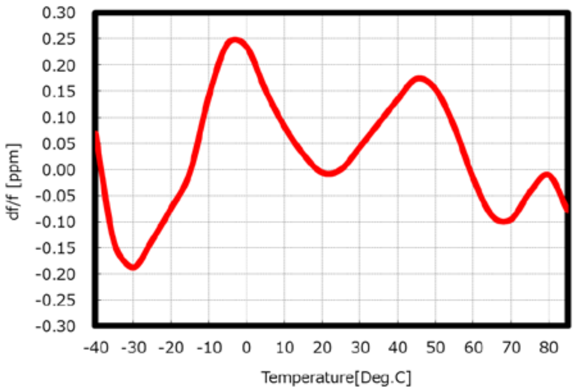




f vs. T ≈ ±10 ppm
< ±20 ppm

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
±0.05 ppm	400x

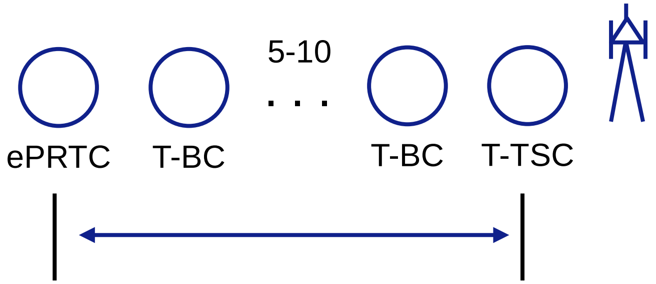
Tighter Specifications

Error Budget

Frequency	Specification
±280 ppb	GR-1244-CORE S3
±100 ppb	LTE 36.104 medium range
±50 ppb	LTE 36.104 wide area

Phase	Specification
±1.5 µs	LTE-TDD
±780 ns	5G proposed
±390 ns	5G proposed

The phase budget applies to the entire chain, not just an individual component



Current → 1.5 µs

Future { 260 ns / 130 ns ?

Σnodes = chain < budget
Σcomponents = node
Σerrors = component

Component specs are getting tougher

- Wander masks tighter
- Cumulative phase error must decrease
- 2nd & 3rd order effects becoming visible

TDM vs. Packet Specifications

Stratum 3 Timing Specifications

Component	Error (ppm)
Initial	±1
f vs. t (aging)	±3
f vs. T	±0.28
f vs. V	±0.1
f vs. C_L	±0.1
Total	**±4.48**

Initial and *f* vs. t (aging): Sandbag (history)

f vs. V and *f* vs. C_L: Small

- Specification < ±4.6 ppm
- Component = system performance
- Defined as
  - Frequency error
  - MTIE & TDEV masks

Packet Timing Specifications

- Defined for equipment and networks, not components (complicated!)
- Defined in terms of phase, not frequency (not as easy to test)

$$\Phi = \int f\,dt$$

  - Wander (short-term stability)
  - MTIE & TDEV masks
- Target must be ns, not µs
  - 10s or low 100s of ns
- Oscillators improving *f* vs. T
  - ±280 ppb → ±140 → ±100 → ±50 ppb
  - As more compensation is applied, 2nd & 3rd order effects become visible (like airflow)
  - Oscillator designers can get surprised, optimizing *f* vs. T can make other parameters worse

Why Airflow is Important

PCB Environment

- Fans on/off
- Turbulent air – nearby components
- Outside equipment

Airflow not previously considered

- By oscillator makers
- By equipment makers

OEMs can be surprised

- System must pass synchronization tests under many different conditions
- Airflow stimulus varies with user conditions
- Airflow performance may vary

Surprises late in design cycle

- Worst case = rare failure (can't find it)

Oscillator Behavior

- Airflow immunity varies by design
- Airflow response varies by direction
- Symmetric vs. asymmetric oscillators
  - Asymmetric = frequency deviation accumulates with each transient
  - Symmetric = frequency recovers after transient is removed
- Even symmetric oscillators accumulate phase for each transient $\Phi = \int f dt$

Workarounds

- Use OCXO – higher power, size, & cost
- Shield TCXO – higher size & cost, still not guaranteed

Preferred Solution:

- oscillator with good airflow immunity

TCXO Mechanical Design – Physical Appearance

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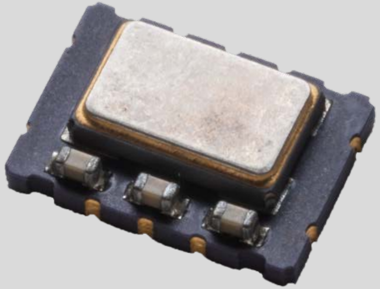
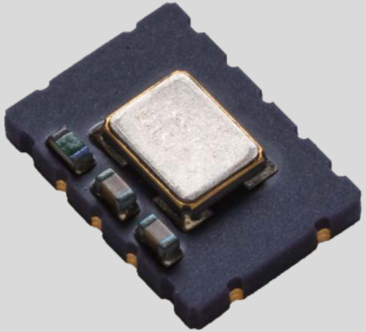
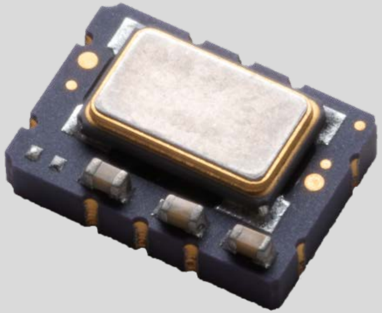


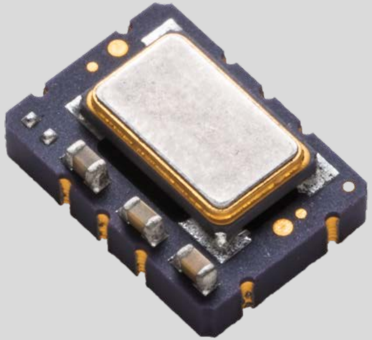
7x5 double-decker



7x5 double-decker

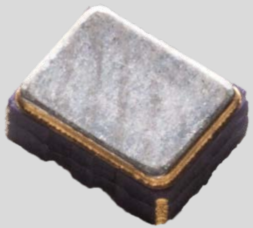


7x5 double-decker



7x5 double-decker

CONVENTIONAL



5x3.2 double-decker

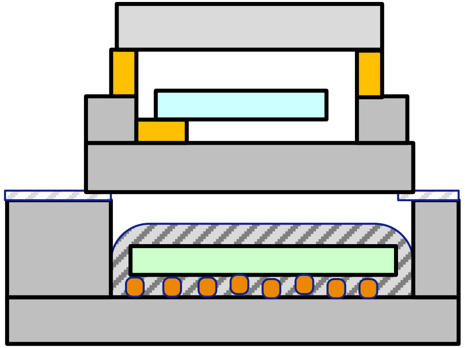
NEW

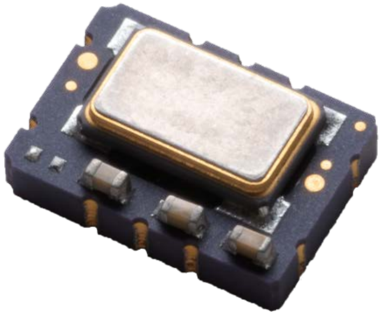
7x5 DoubleSeal™

5x3.2 DoubleSeal™

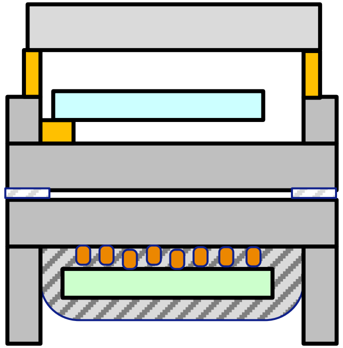
Cross-Section – Conventional TCXOs

Double-Decker 7x5


flip-chip or wirebond



Double-Decker 5x3.2


flip-chip or wirebond

Why TCXOs are Sensitive to Airflow

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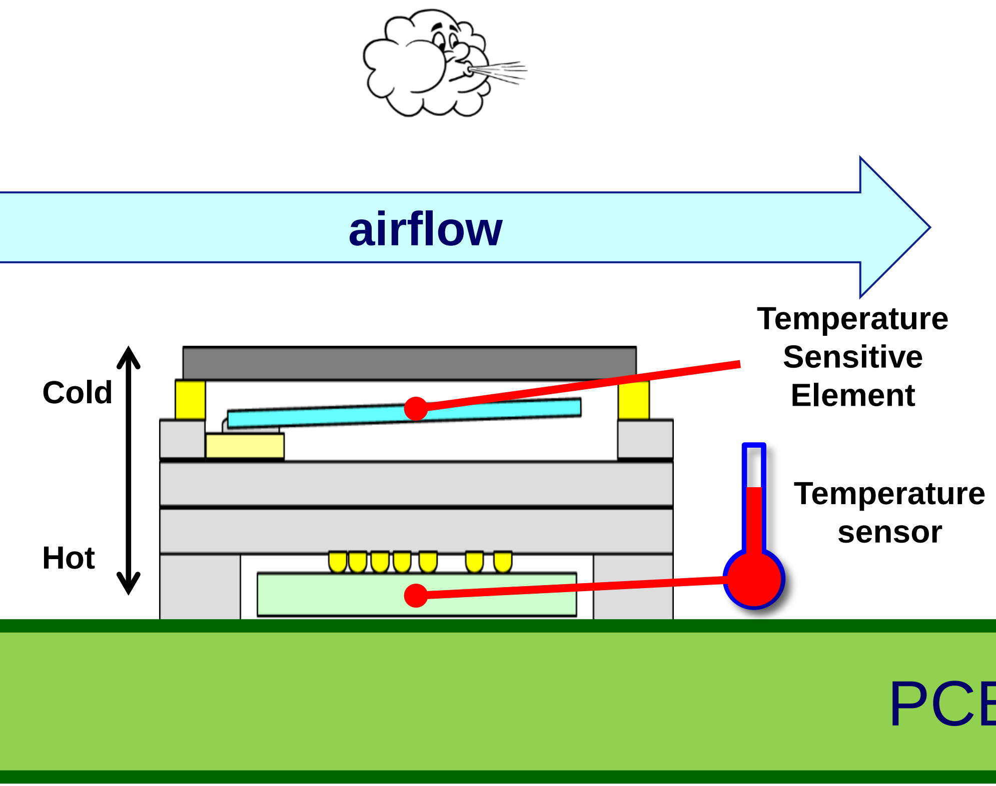


Fundamental Mechanism

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

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

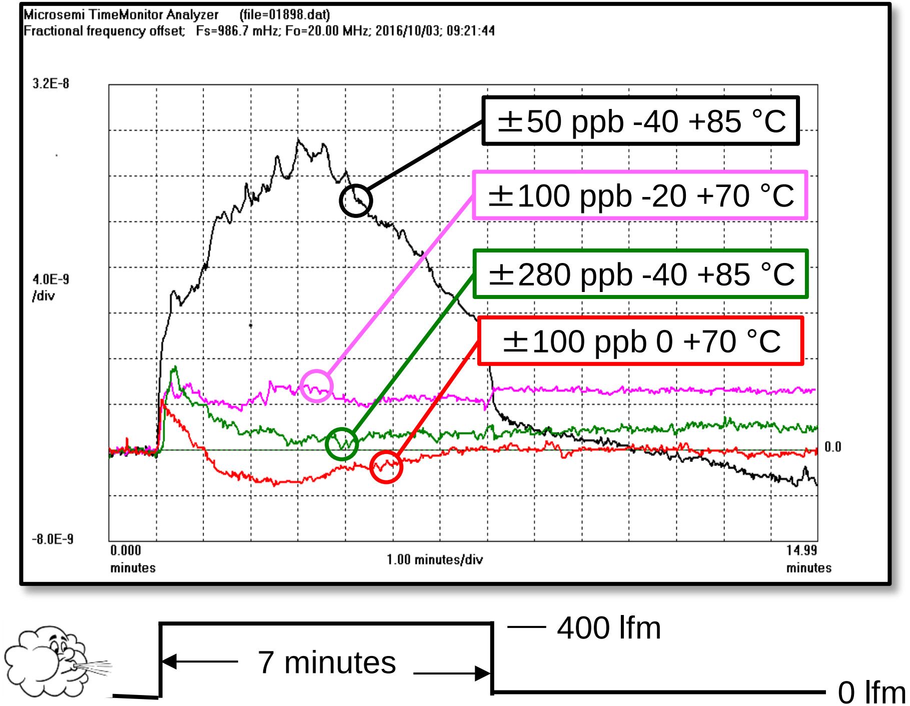
vs. $30\ ppm/°C$ for Silicon

- How much temperature gradient can we tolerate?

$$3\ ppb \div 0.3\ ppm/°C = 0.01°C$$

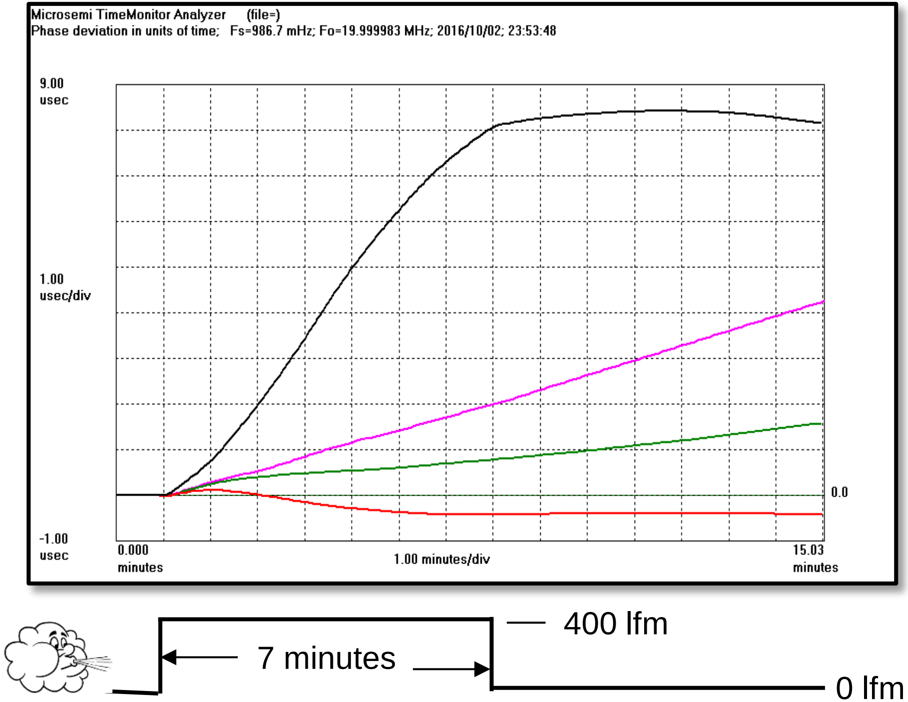
Conventional TCXOs – Airflow Performance @ 25 °C

FFO vs. time



Maximum df/f = 28 ppb

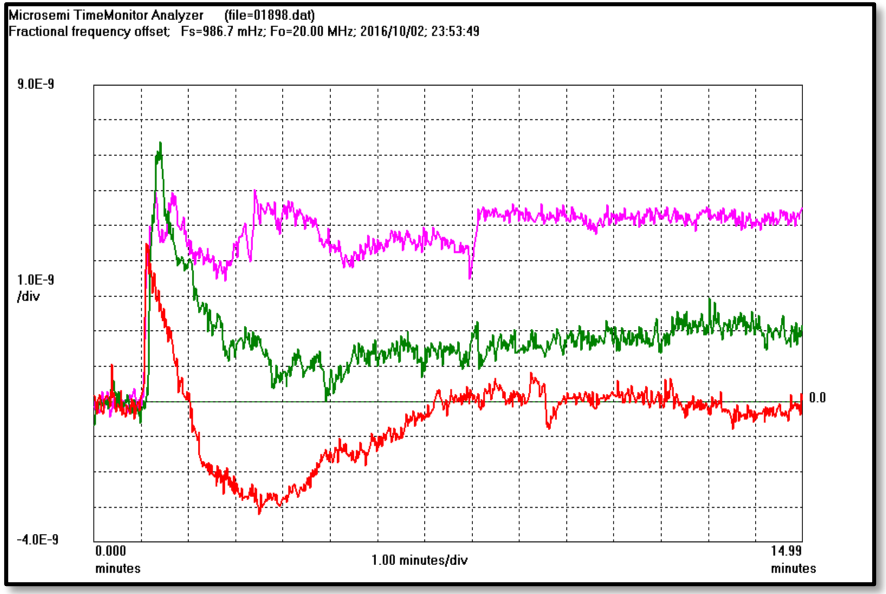
Phase vs. time

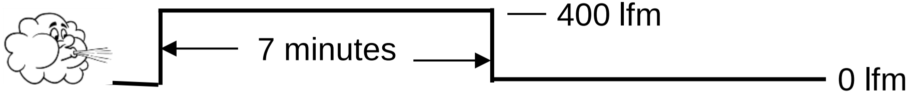


Maximum dΦ = 8.5 μs

Conventional TCXOs – Airflow Performance @ 25 °C

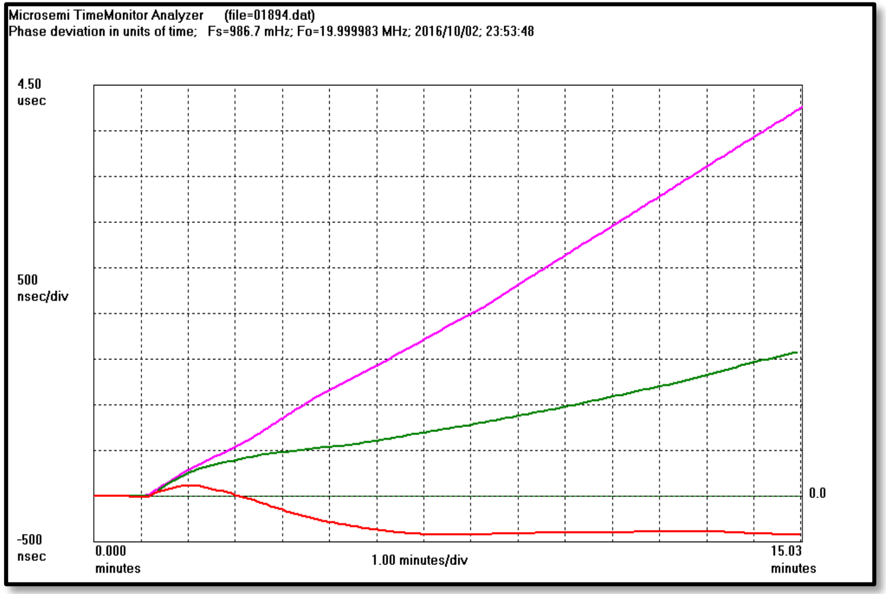
FFO vs. time

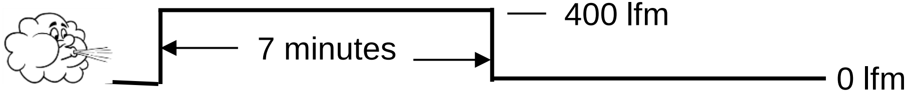




Maximum df/f = 7.5 ppb

Phase vs. time

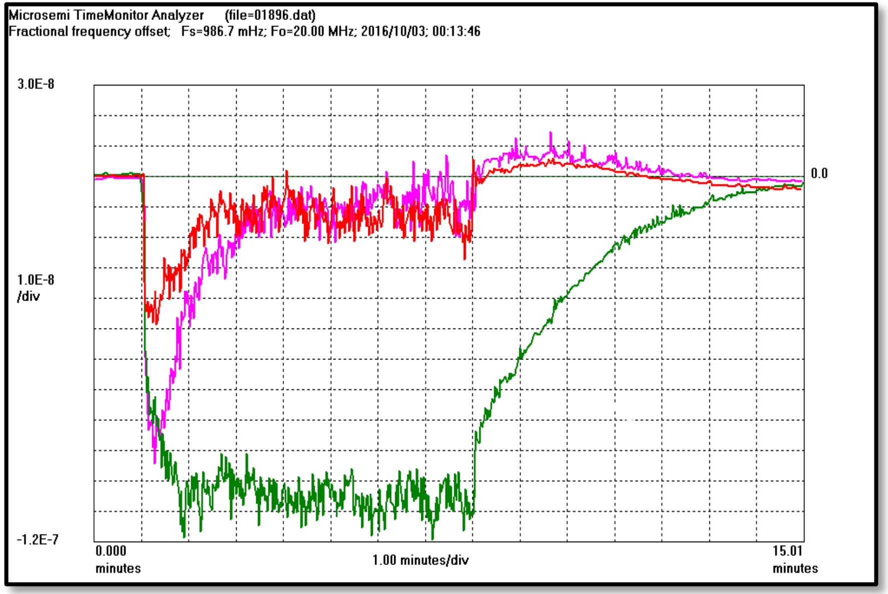


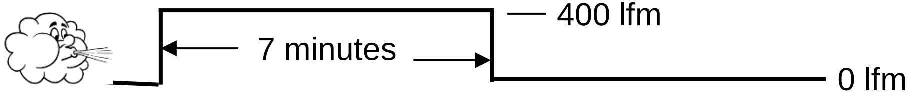


Maximum dΦ = 4.25 μs

Conventional TCXOs – Airflow Performance @ 40 °C

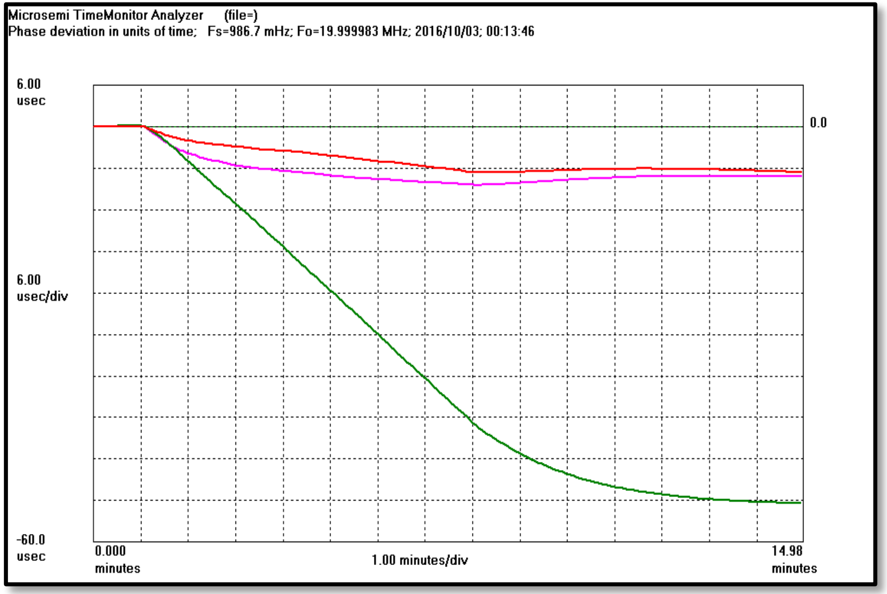
FFO vs. time

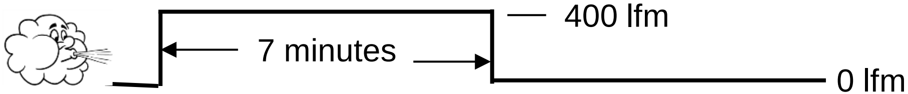




Maximum df/f = -12 ppb

Phase vs. time

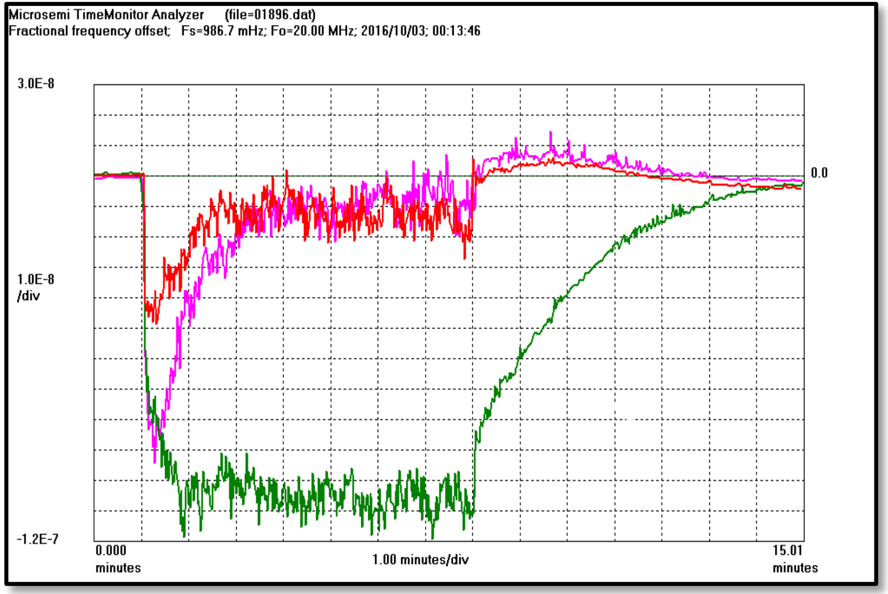


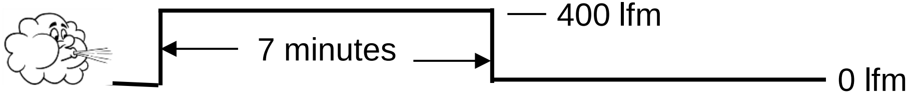


Maximum dΦ = -54 μs

Conventional TCXOs – Airflow Performance @ 40 °C

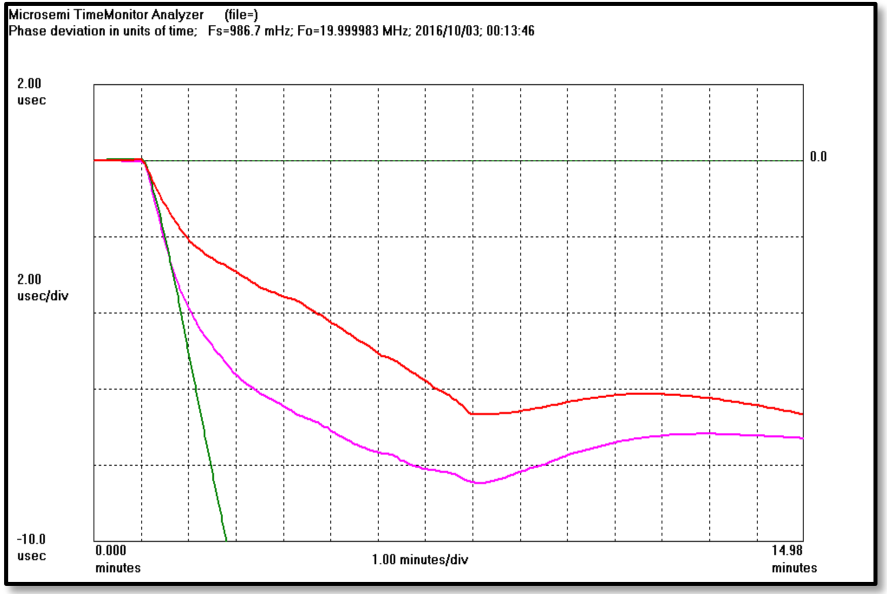
FFO vs. time

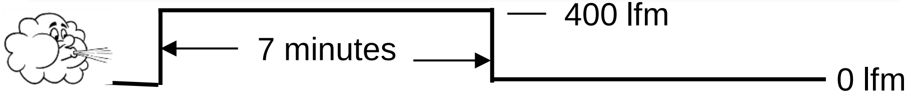




df/f = -12, -9.5, -5 ppb

Phase vs. time





Maximum dΦ = -7, -8.5, -54 µs

Introducing DoubleSeal™ Technology

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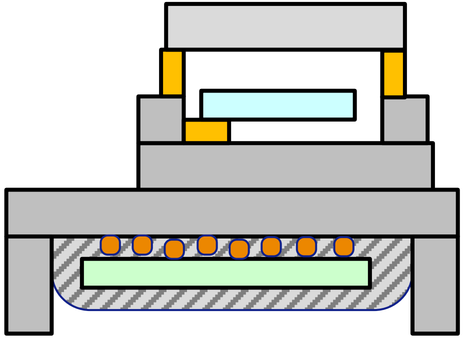
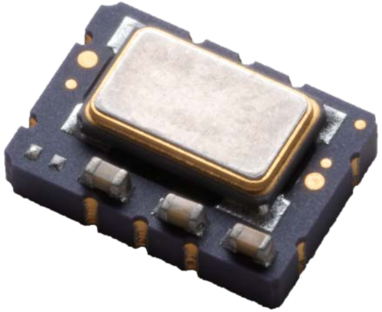
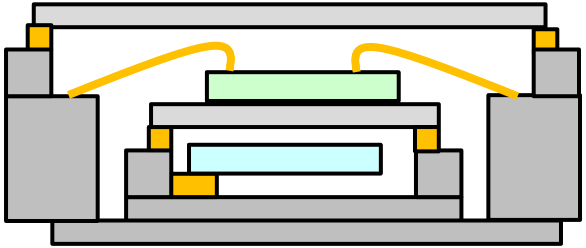
Construction – Double-Decker vs. DoubleSeal™

Double-Decker





DoubleSeal™



- Thermal island
- Coupled to bottom (PCB)
- Isolated from top (airflow)

US & Japanese patents

Measured Airflow Performance – FFO @ 25 °C

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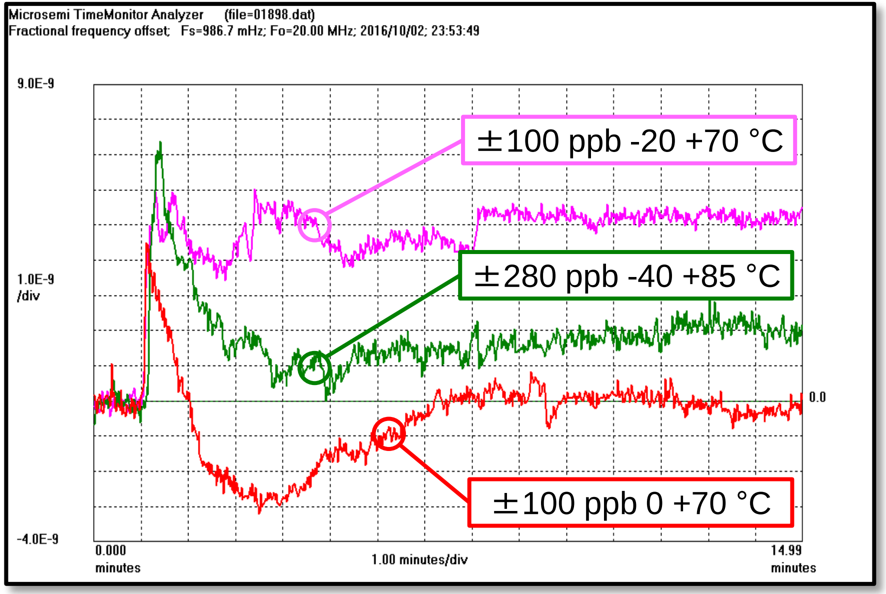
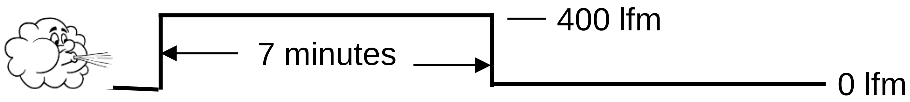
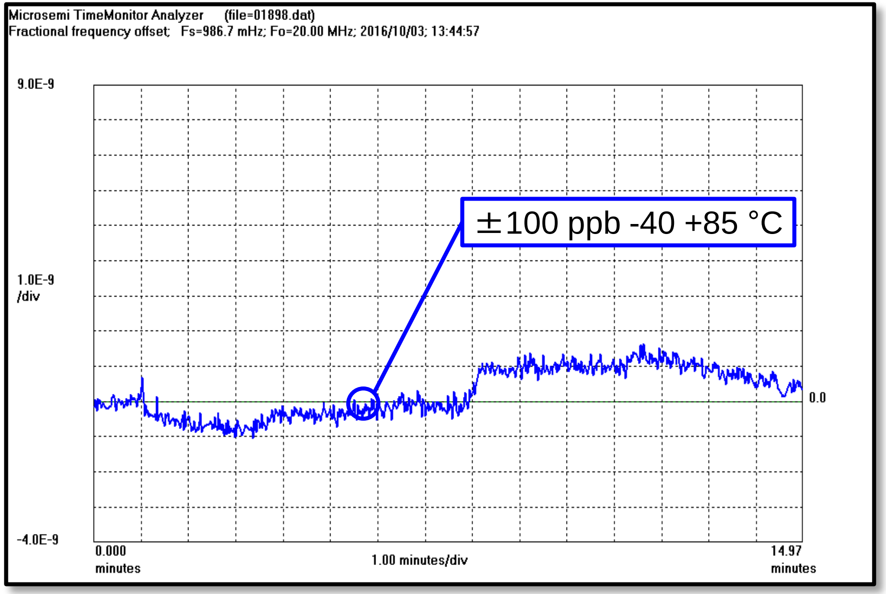
Double-Decker

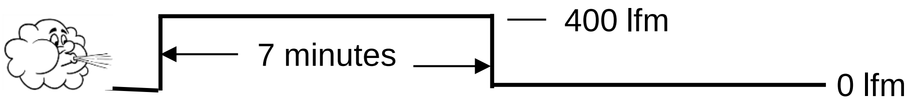




Max df/f = 4.5, 6, 7.5 ppb

DoubleSeal™





Max df/f = 1.5 ppb

Δ = 3:1, 4:1, 5:1

Measured Airflow Performance – Phase @ 25 °C

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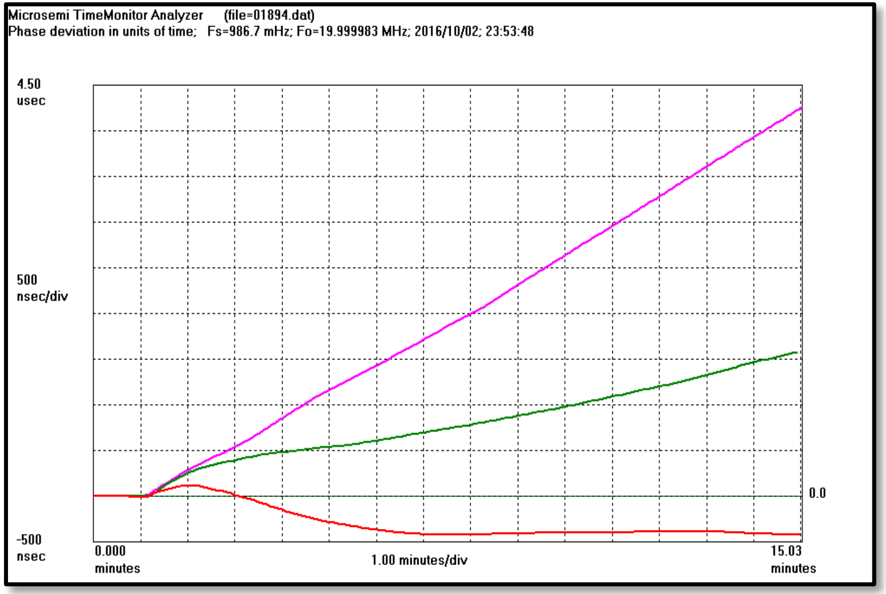
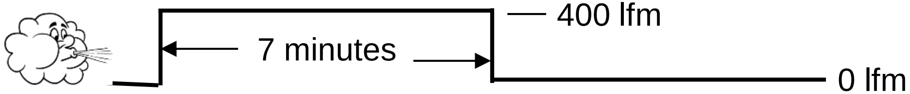
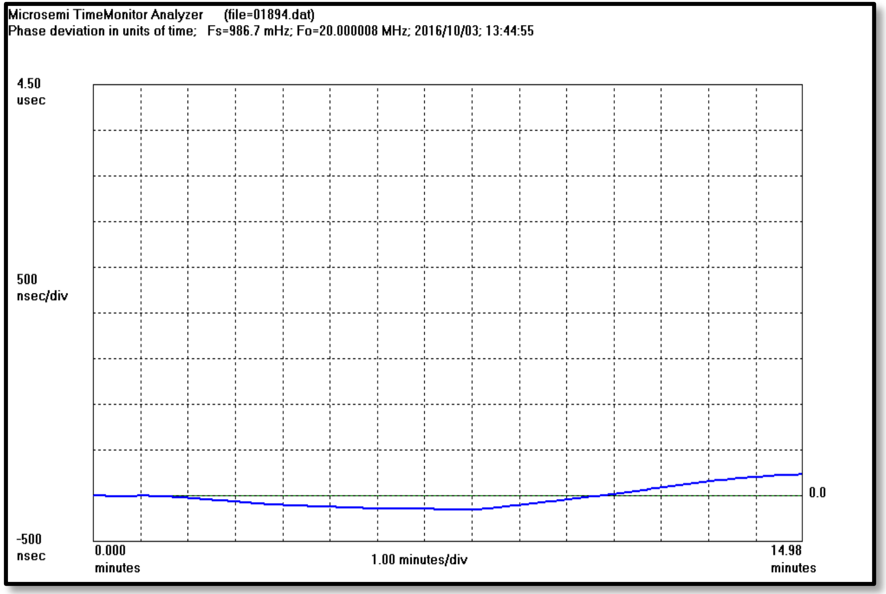
Double-Decker

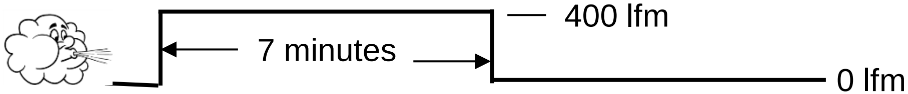




Max dΦ = -0.4, +1.6, +4.3 μs

DoubleSeal™





Max dΦ = +0.3 μs

Δ = 1:1, 5:1, 15:1

Measured Airflow Performance – FFO @ 40 °C

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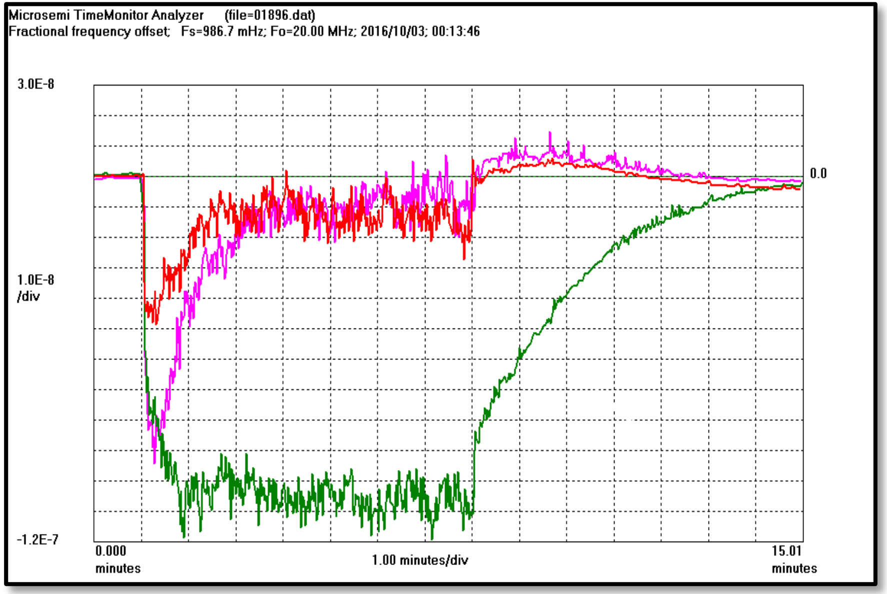
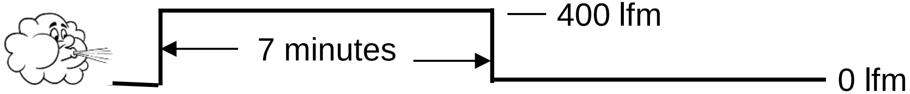
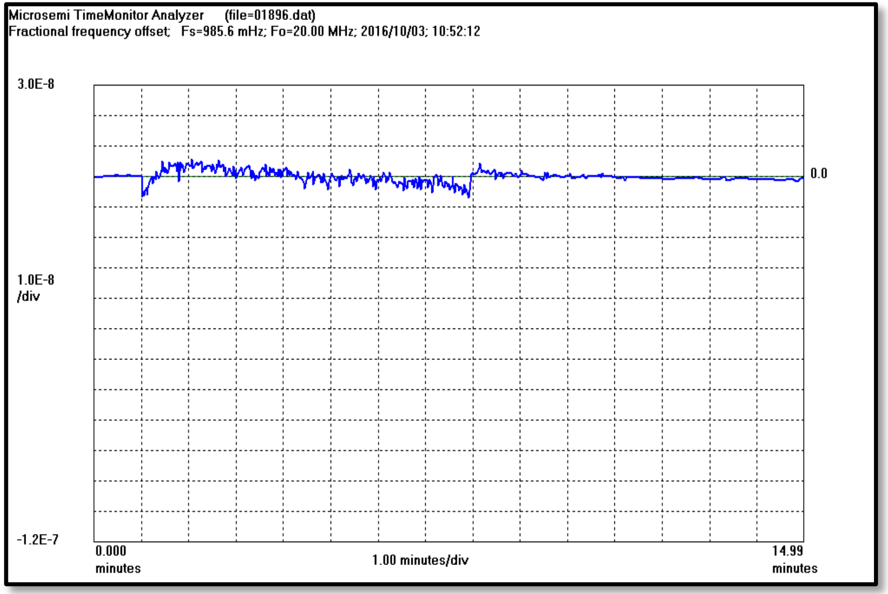
Double-Decker

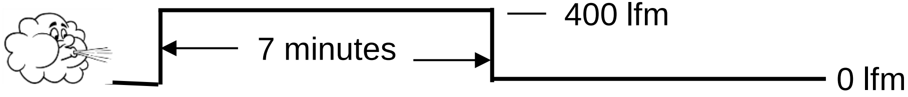




Max df/f = -5, -9.5, -12 ppb

DoubleSeal™





Max df/f = -0.5 ppb

Δ = 10:1, 20:1, 25:1

Measured Airflow Performance – Phase @ 40 °C

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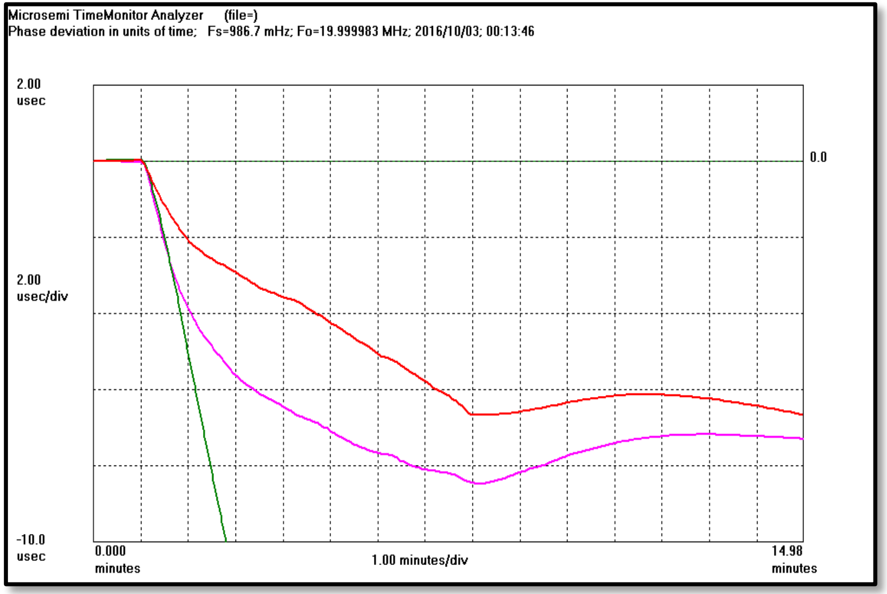
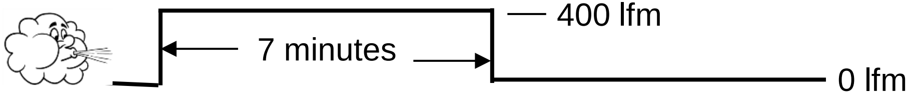
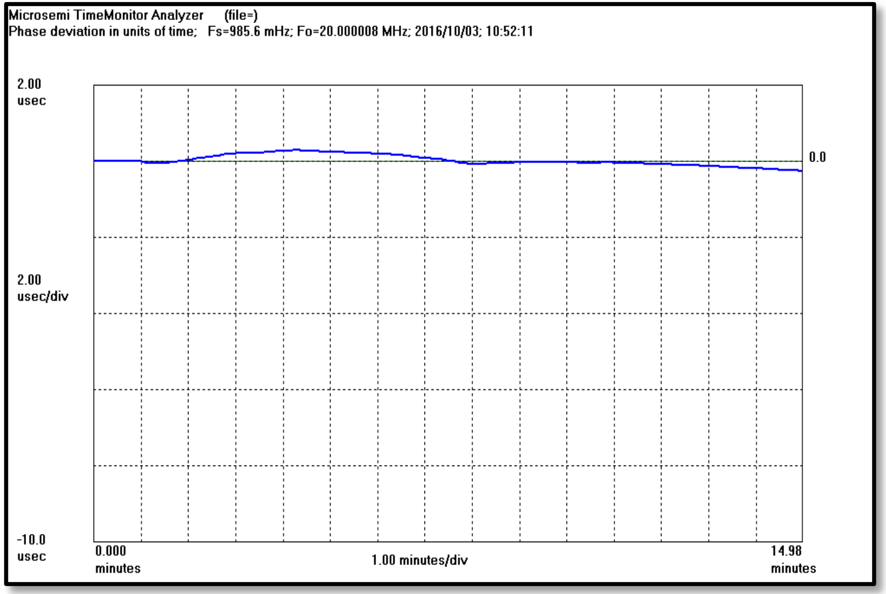
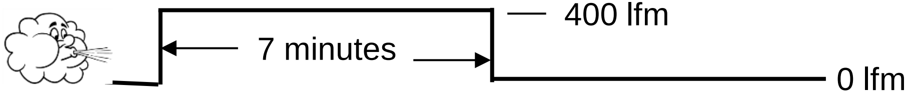




Max dΦ = -7, -9, -54 μs

DoubleSeal™



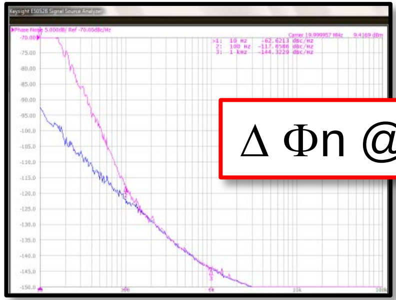


Max dΦ = ±0.2 μs

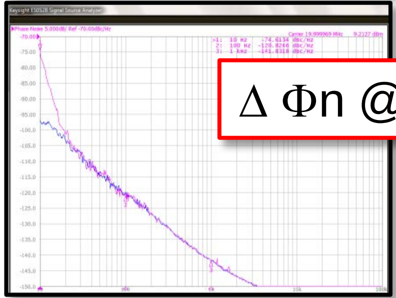
Δ = 35:1, 45:1, 250:1

Additional Advantage – Phase Noise @ 40 °C

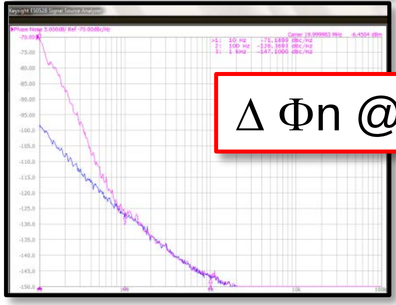
Double-Decker TCXOs



$\Delta\ \Phi n$ @ 10 Hz = 30 dB



$\Delta\ \Phi n$ @ 10 Hz = 21 dB

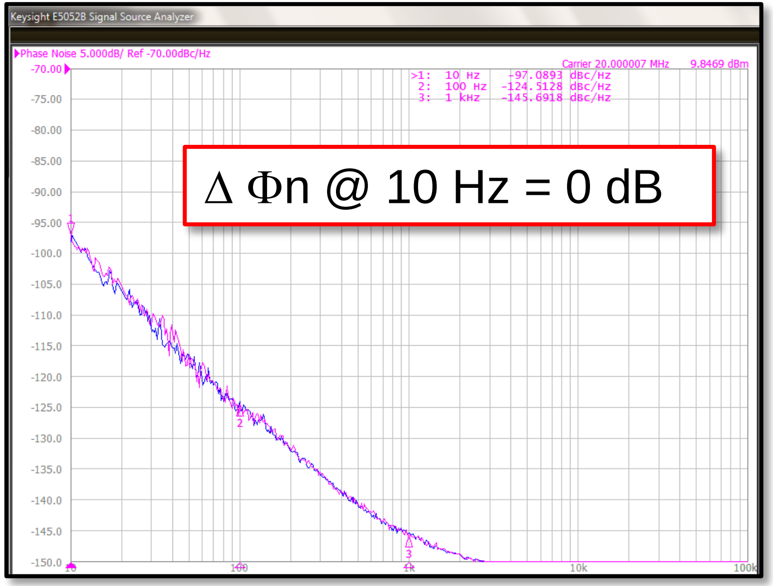


$\Delta\ \Phi n$ @ 10 Hz = 28 dB

Why?

Turbulence modulates frequency

Double-Seal TCXO



$\Delta\ \Phi n$ @ 10 Hz = 0 dB

DoubleSeal™ structure protects resonator from turbulent air.

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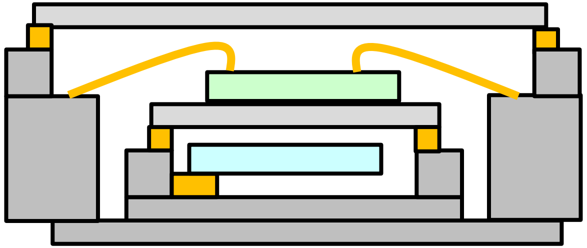
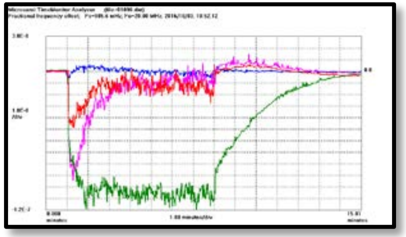
Technology



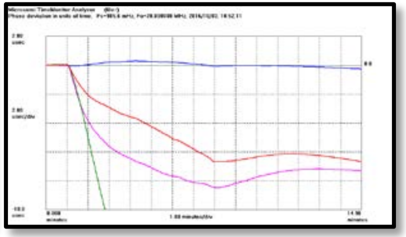
Better Thermal Design
- Thermal island
- Resonator & T sensor co-located
- Isolated from airflow

US & Japanese patents

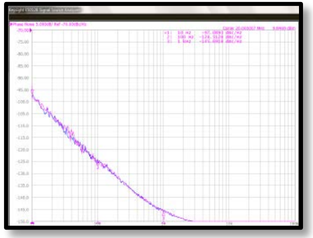
Performance under Airflow



Better Frequency Stability
3-25x



Better Phase Stability
1-250x



Better Phase Noise
no degradation

Dependable Synchronization

What Else Needs to be Done?

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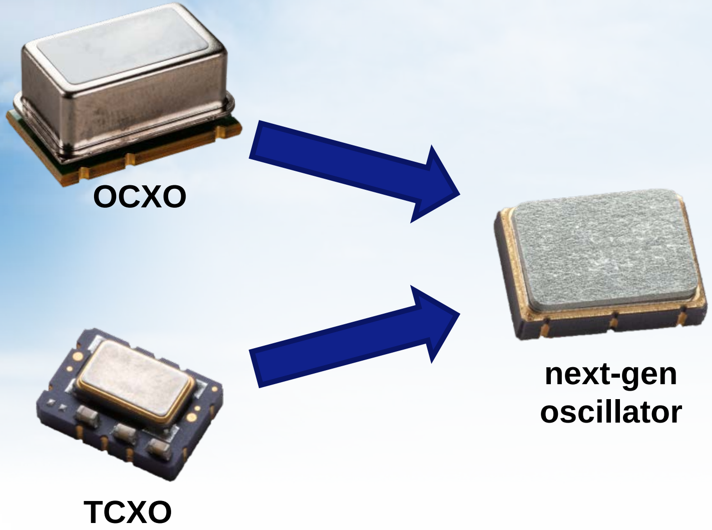
Performance

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

Practicality

- Size
- Cost
- Power
- Reliability



How do we get there?

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

THANK YOU

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