Oscillator Performance Beyond the Data Sheet

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Silicon Valley
Timing Device
Laboratory

Synchronization Specifications

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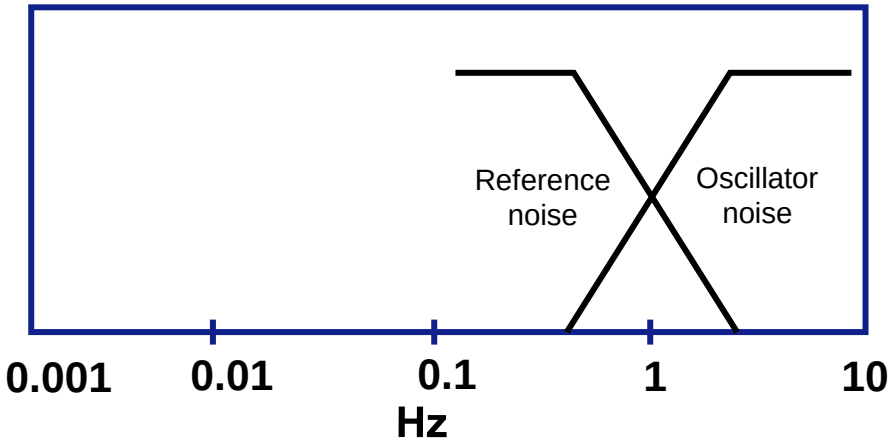
Synchronization in a packet-switched network:

More noise in the network

More filtering required to transfer time information



Oscillators require high phase stability

Most oscillator vendors only specify frequency stability in ideal conditions

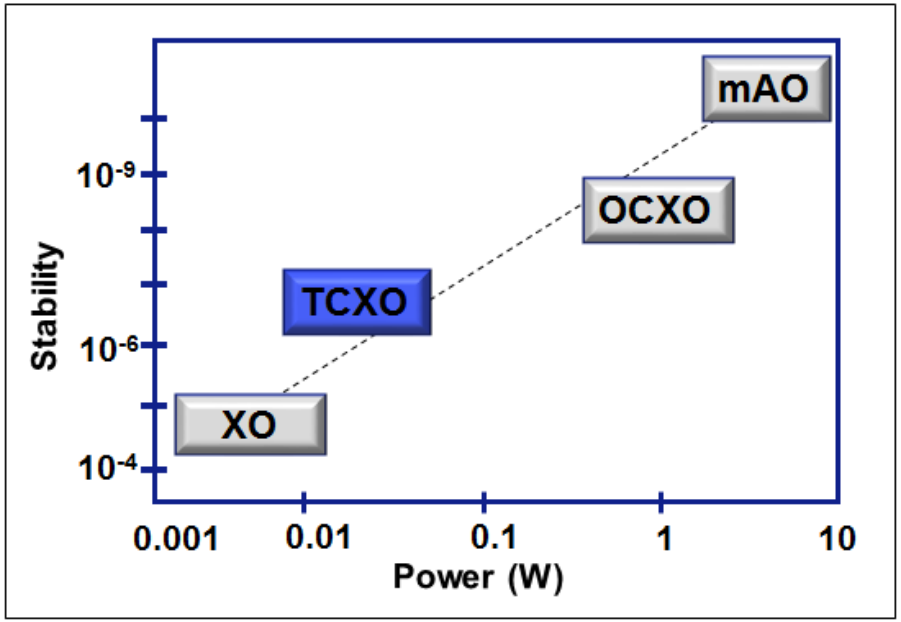
	f/T	24hr drift
S3	±280 ppb	±40 ppb
S3E	±10 ppb	±1 ppb

“Classes” of oscillators have grouped around Stratum spec.

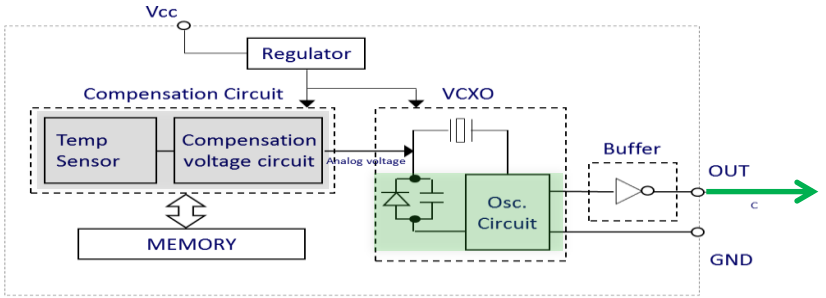
There’s more to the story…

TCXO Basics

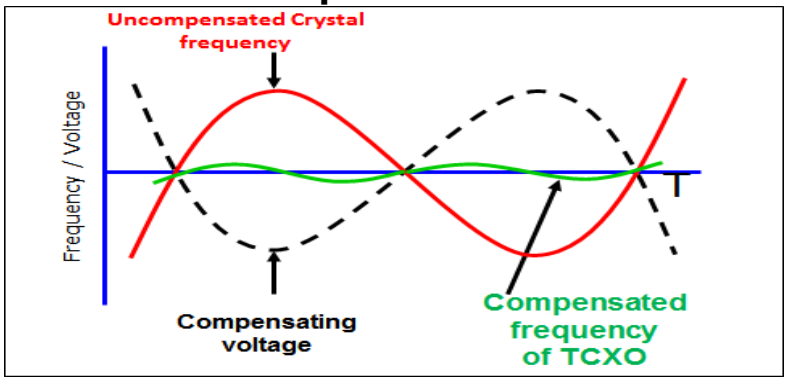
Temperature
Compensated
X = Crystal
Oscillator



Basic Principle: Measure temperature, adjust Freq.



TCXO output: Green curve



Reference: John Vig's Tutorial

TCXO Technology Assessment

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Does current technology meet networking requirements?

3 Steps:

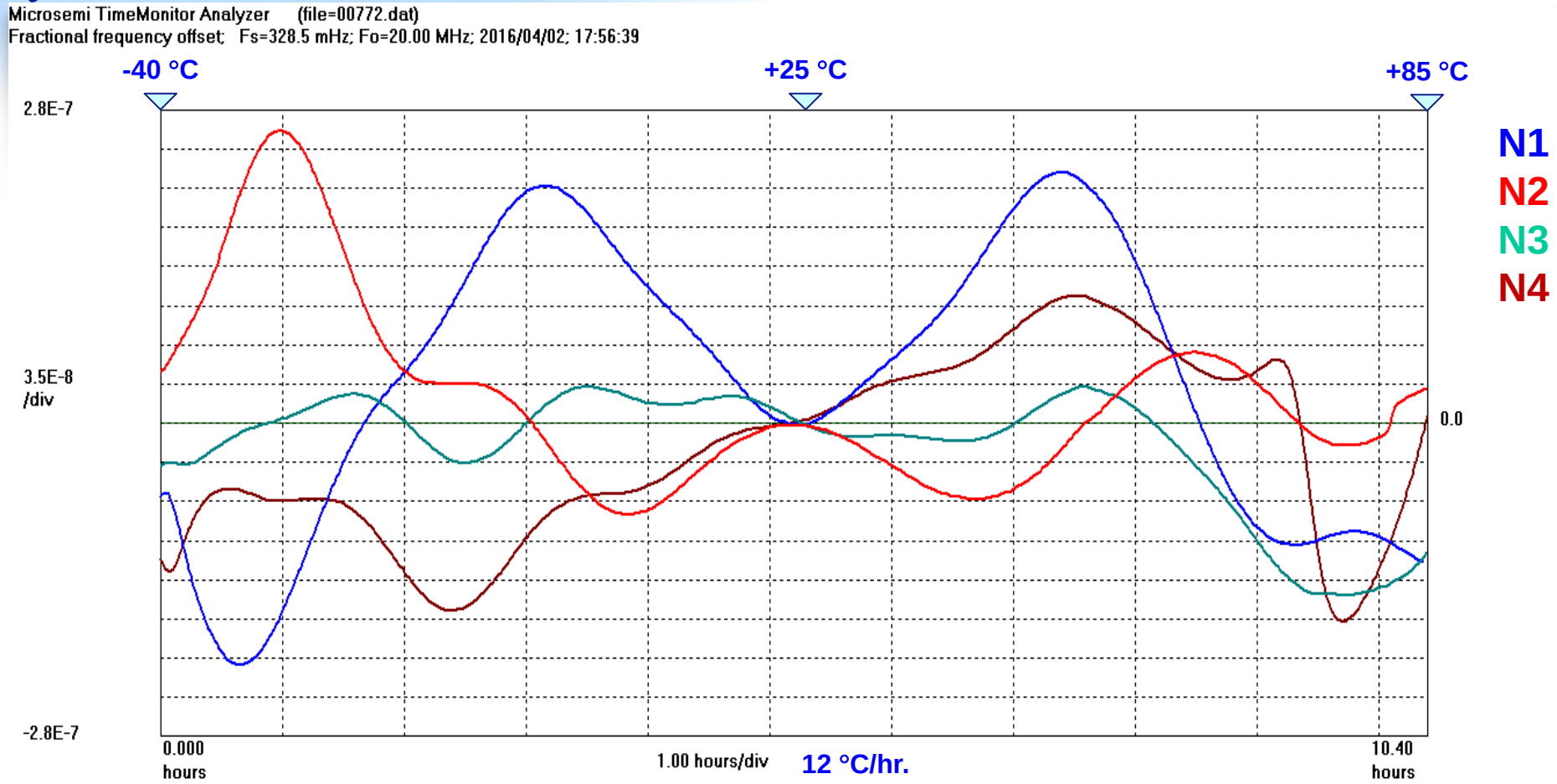
1. **Collect Some TCXOs**
   - 4 networking
   - 2 consumer
   - 1 MEMS
2. **Measure Them**
   - f vs. T
   - Phase noise
   - Short-term stability
   - Airflow
3. **Compare Results**

Common specifications to meet S3

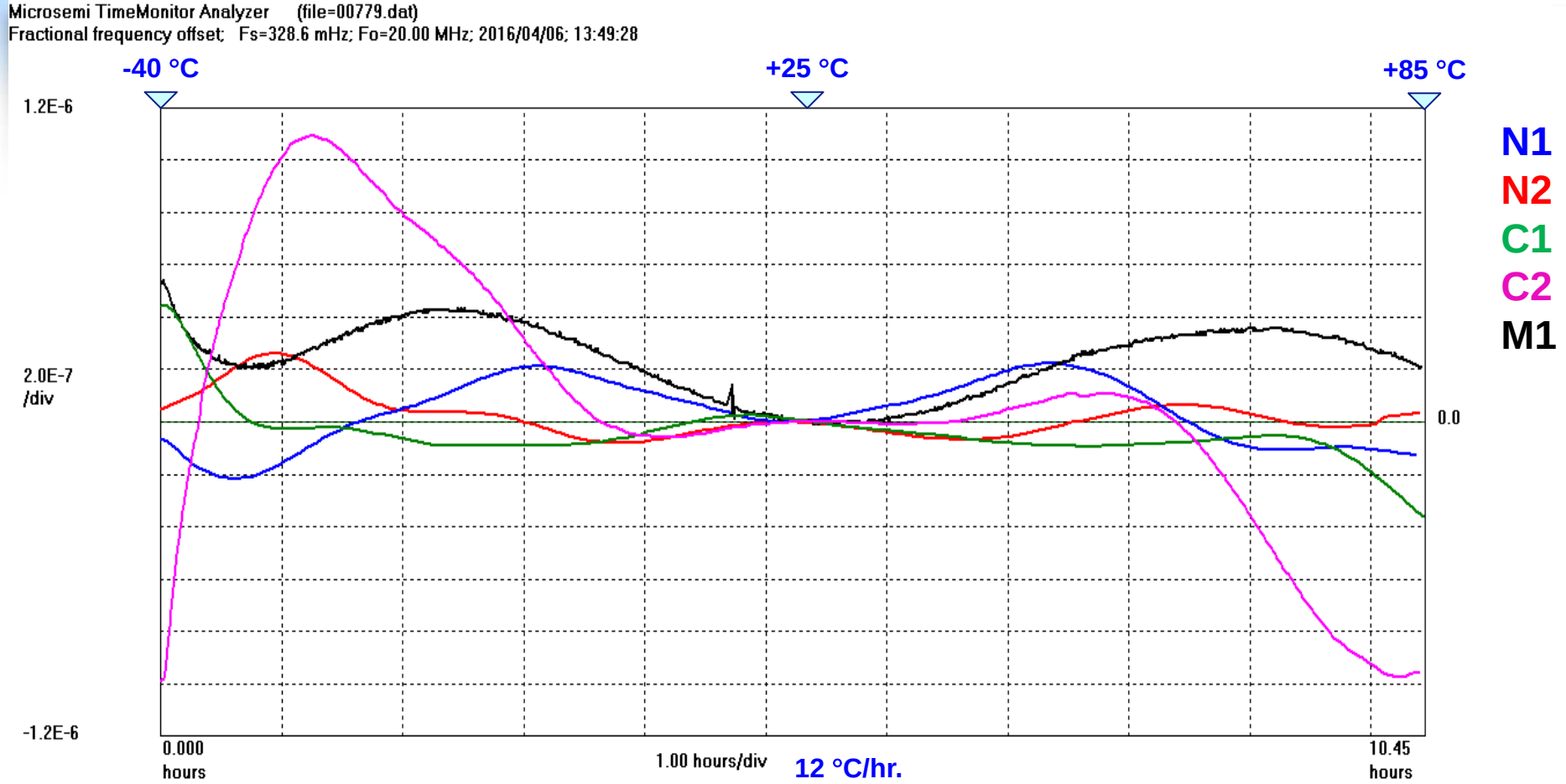
	Frequency Error Budget (ppm)							
	initial	vs. T	vs. C	vs. V	1 yr.	10 yr.	20 yr.	Total
N1	±1	±0.28	±0.1	±0.1	±0.5		±3	±4.6
N2	±1	±0.28	±0.05	±0.05	no spec	no spec	no spec	±4.6
N3	no spec	±0.28	no spec	±0.1	no spec	no spec	no spec	±4.6
N4	±2	±0.28	±0.1	±0.1	±1	no spec	no spec	±4.6
C1	±1	±0.5	±0.025	±0.025	±1	no spec	no spec	no spec
C2	no spec	±2	±0.2	±0.2	±1	no spec	no spec	no spec
M1	±1.5	±5	no spec	no spec	±2.5	±4	no spec	no spec

…but these specifications are no longer sufficient

f vs. T – Network TCXOs



f vs T – Network & Consumer



f vs. T – Conclusions

Network TCXOs

- All networking TCXOs measured meet Stratum 3 requirements of ±280 ppb

Consumer TCXOs

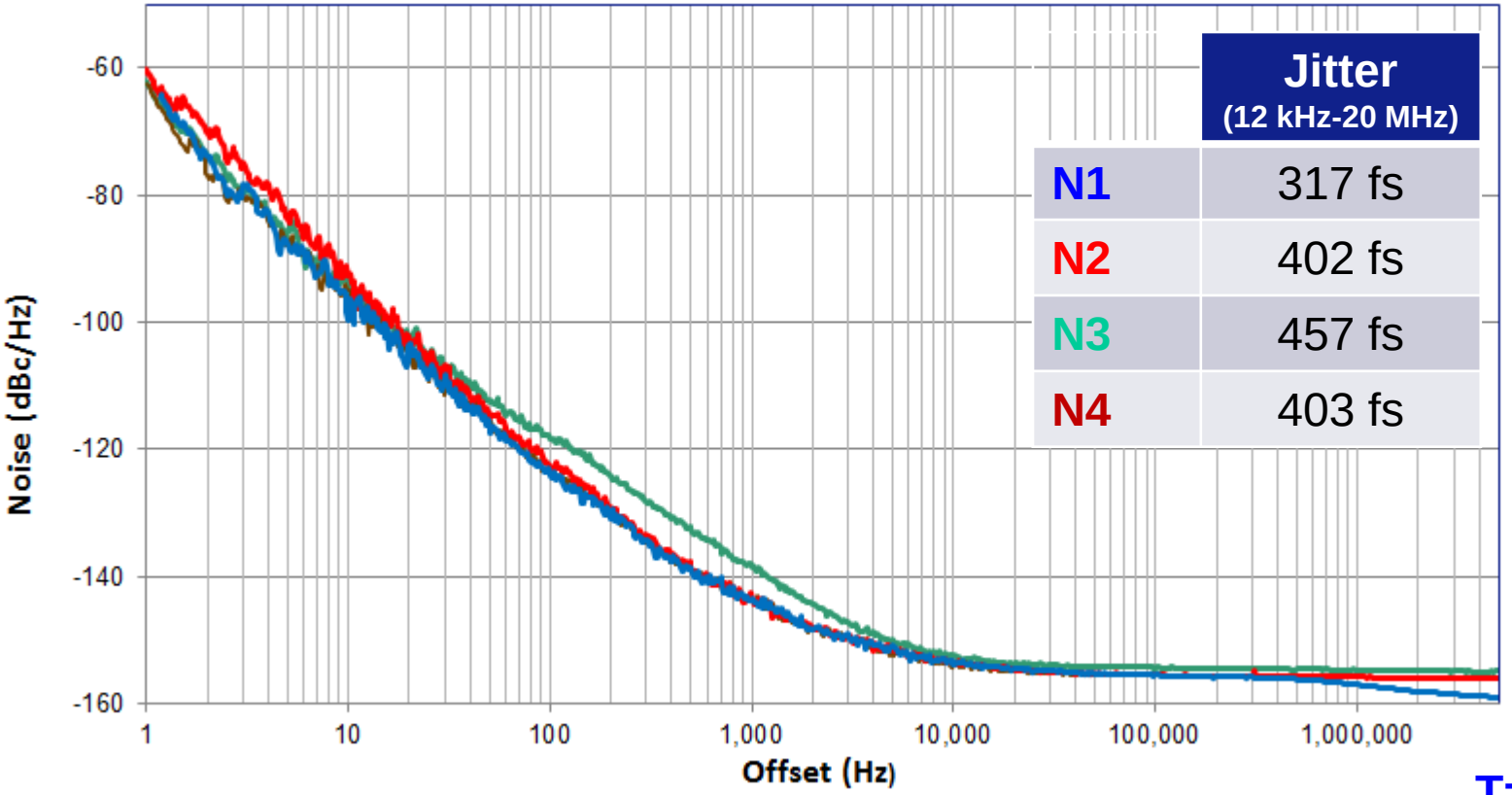
- Consumer TCXOs meet their specifications but do not meet Stratum 3 requirements

MEMS TCXO

- MEMS TCXO meets its specifications but does not meet Stratum 3 requirements

	f vs. T (-40 to +85 °C)	
N1	+229	-218
N2	+261	-85
N3	+35	-154
N4	+116	-147
C1	+437	-362
C2	+1090	-990
M1	+532	-0
	ppb	

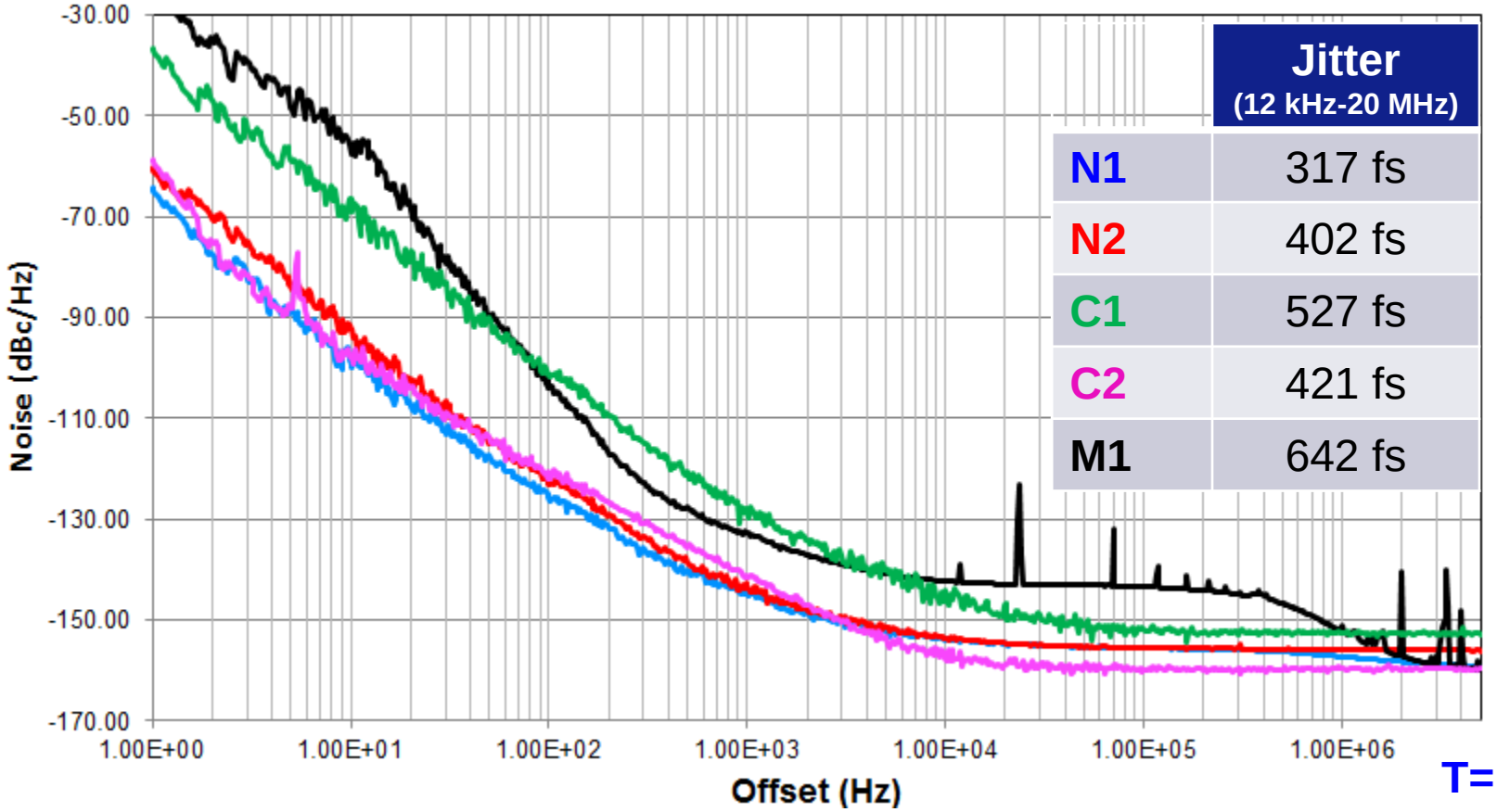
Phase Noise – Network TCXOs



	Jitter (12 kHz-20 MHz)
N1	317 fs
N2	402 fs
N3	457 fs
N4	403 fs

T= +25 °C

Phase Noise – Network & Consumer TCXOs



	Jitter (12 kHz-20 MHz)
N1	317 fs
N2	402 fs
C1	527 fs
C2	421 fs
M1	642 fs

T= +25 °C

Phase Noise – Conclusions

Network TCXOs

- Phase jitter (12 kHz – 5 MHz) varies by 1.5x from 317 fs to 457 fs

Consumer TCXOs

- Phase jitter (12 kHz – 5 MHz) is a little bit higher than networking TCXOs at 421 & 527 fs

MEMS TCXO

- Phase jitter (12 kHz – 5 MHz) of MEMS TCXO is the highest at 642 fs
- Fractional-n PLL contributes spurs
- High phase noise at low offset due to resonator Q

	Phase Jitter (12 kHz-20 MHz)	Phase Noise @ 1 Hz
N1	317	-62.1
N2	402	-59.6
N3	457	-62.1
N4	403	-62.5
C1	527	-45.3
C2	421	-56.0
M1	642	-23.0
	fs	dBc/Hz

Short-Term Stability – Network TCXOs

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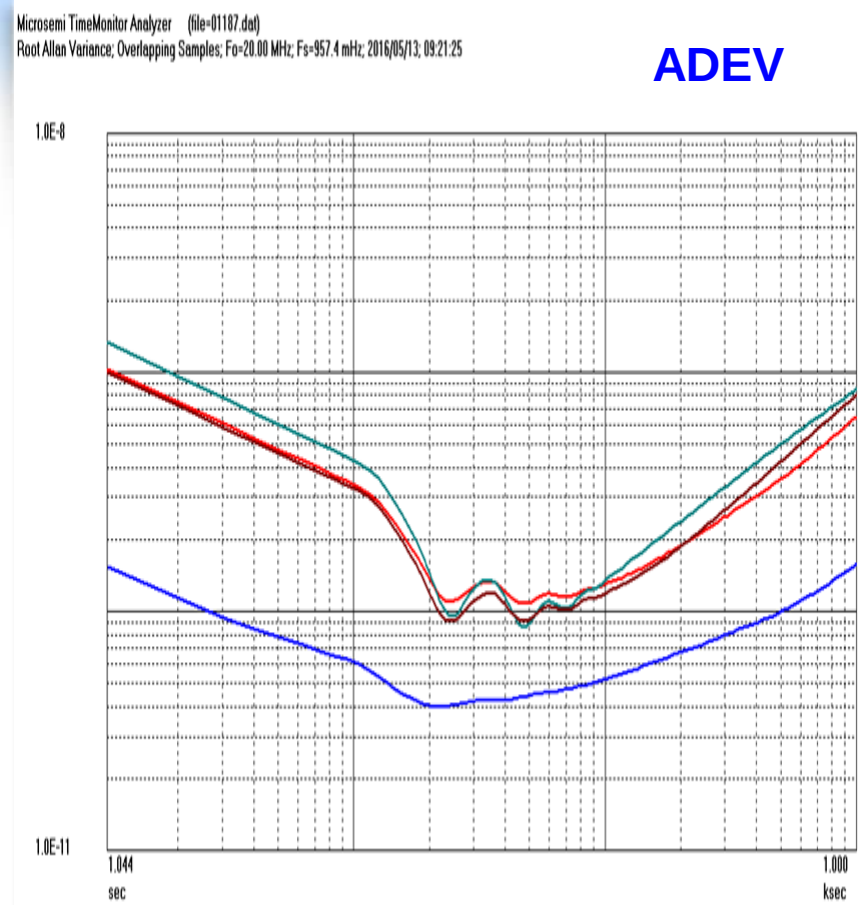
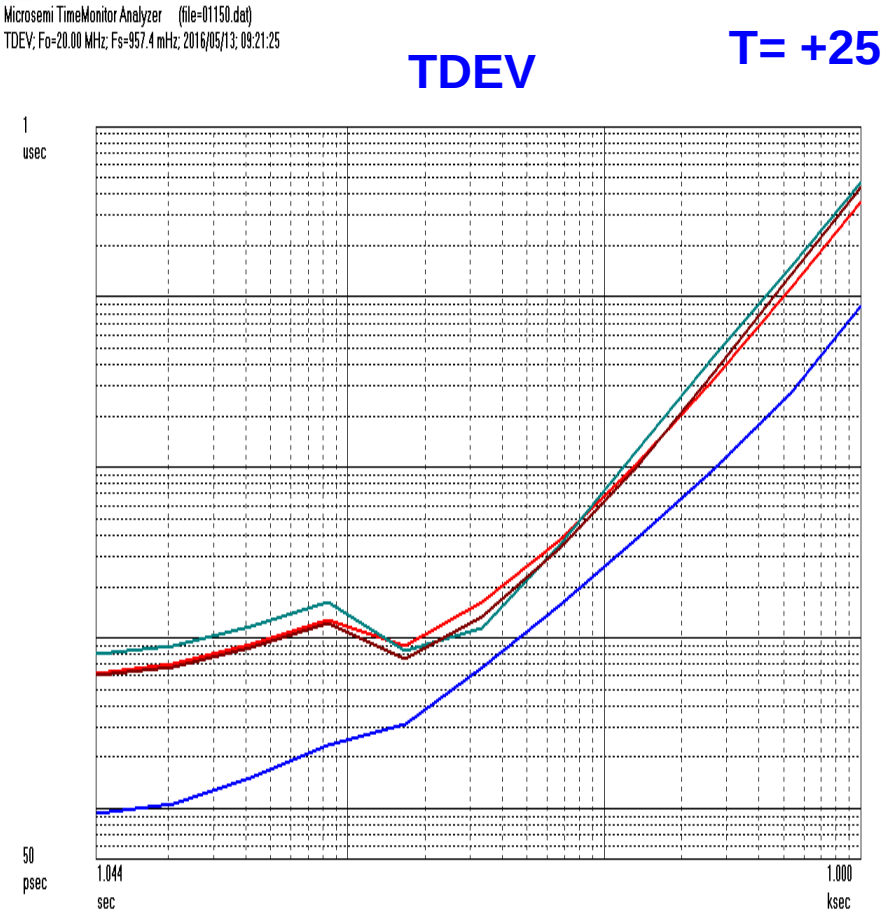
T= +25 °C

ADEV



TDEV



N1
N2
N3
N4

Short-Term Stability – Network & Consumer

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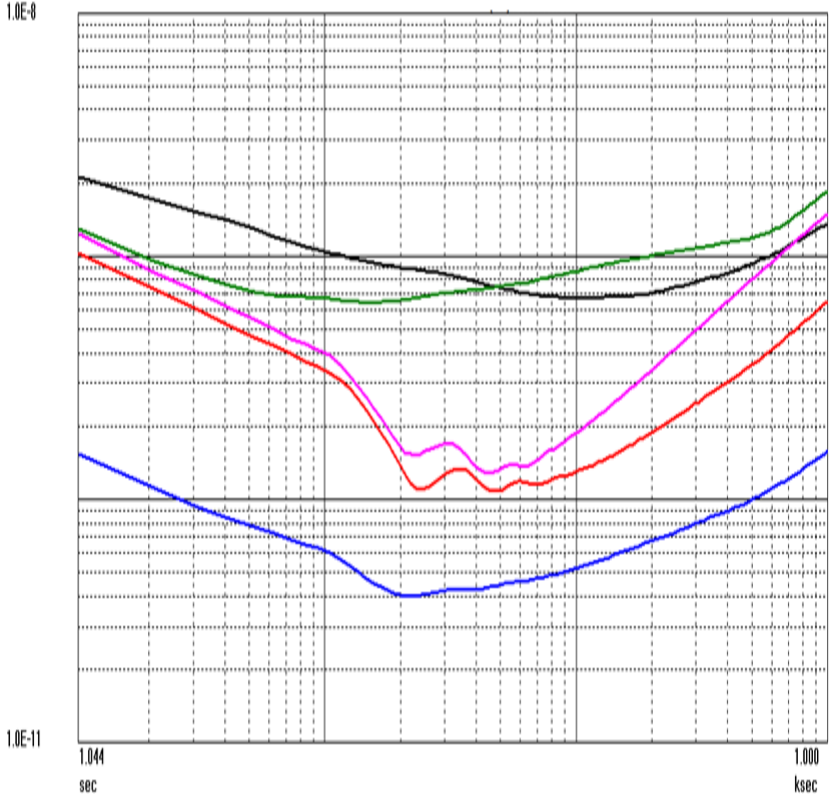
Microsemi TimeMonitor Analyzer (file=01187.dat)
Root Allan Variance; Overlapping Samples; Fo=20.00 MHz; Fs=957.4 mHz; 2016/05/13; 09:21:25

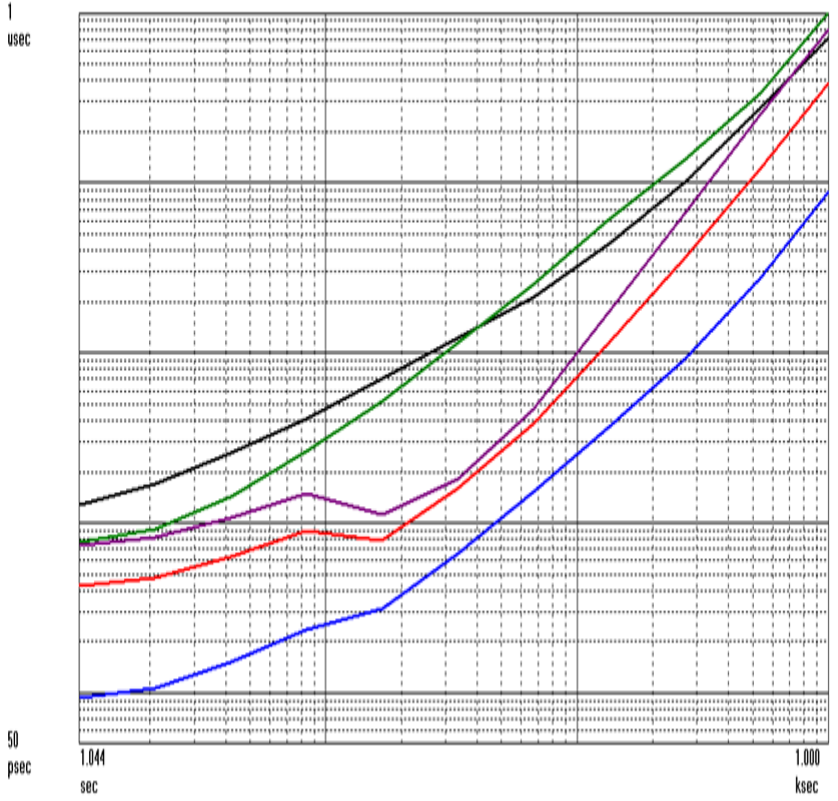
ADEV



Microsemi TimeMonitor Analyzer (file=01187.dat)
TDEV; Fo=20.00 MHz; Fs=957.5 mHz; 2016/05/13; 09:22:15

TDEV

T= +25 °C



N1
N2
C1
C2
M1

Short-Term Stability– Conclusions

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Network TCXOs

- Large variation among networking TCXOs
  - 2.5-10x difference in AVAR
  - 2.5-10x difference in TDEV

Consumer TCXOs

- Similar to poorer networking TCXOs
  - ~2x worse @ 1000s
  - A lot of variation @ 10-100s

MEMS TCXO

- A little worse than consumer

	ADEV				TDEV (ns)			
	1s	10s	100s	1000s	1s	10s	100s	1000s
N1	1.5e-10	6e-11	5.2e-11	1.6e-10	0.093	0.253	2.61	87.8
N2	1e-9	3.4e-10	1.3e-10	6.5e-10	0.624	1.16	6.79	364
N3	1.4e-9	4.2e-10	1.3e-10	8.5e-10	0.802	1.36	7.33	465
N4	1e-9	3.3e-10	1.2e-10	8e-10	0.603	1.08	6.35	440
C1	1.3e-9	6.7e-10	8.6e-10	1.9e-9	0.778	3.12	42.4	1004
C2	1.2e-9	3.9e-10	1.9e-10	1.5e-9	0.741	1.37	10.29	805
M1	2.1e-9	1e-9	6.7e-10	1.4e-9	1.28	4.68	32.1	709

Frequency during Airflow – Network TCXOs

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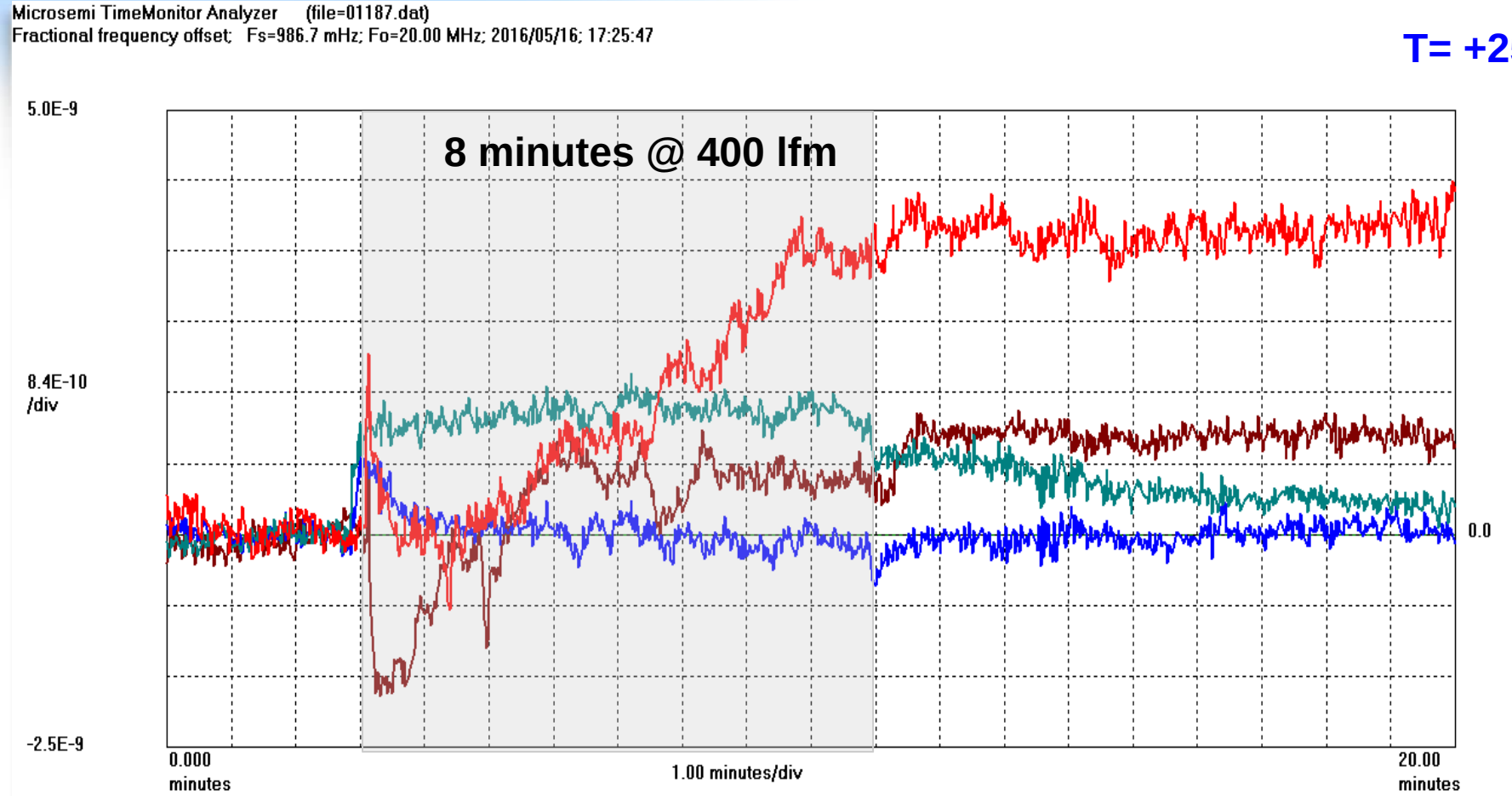

Phase during Airflow – Network TCXOs

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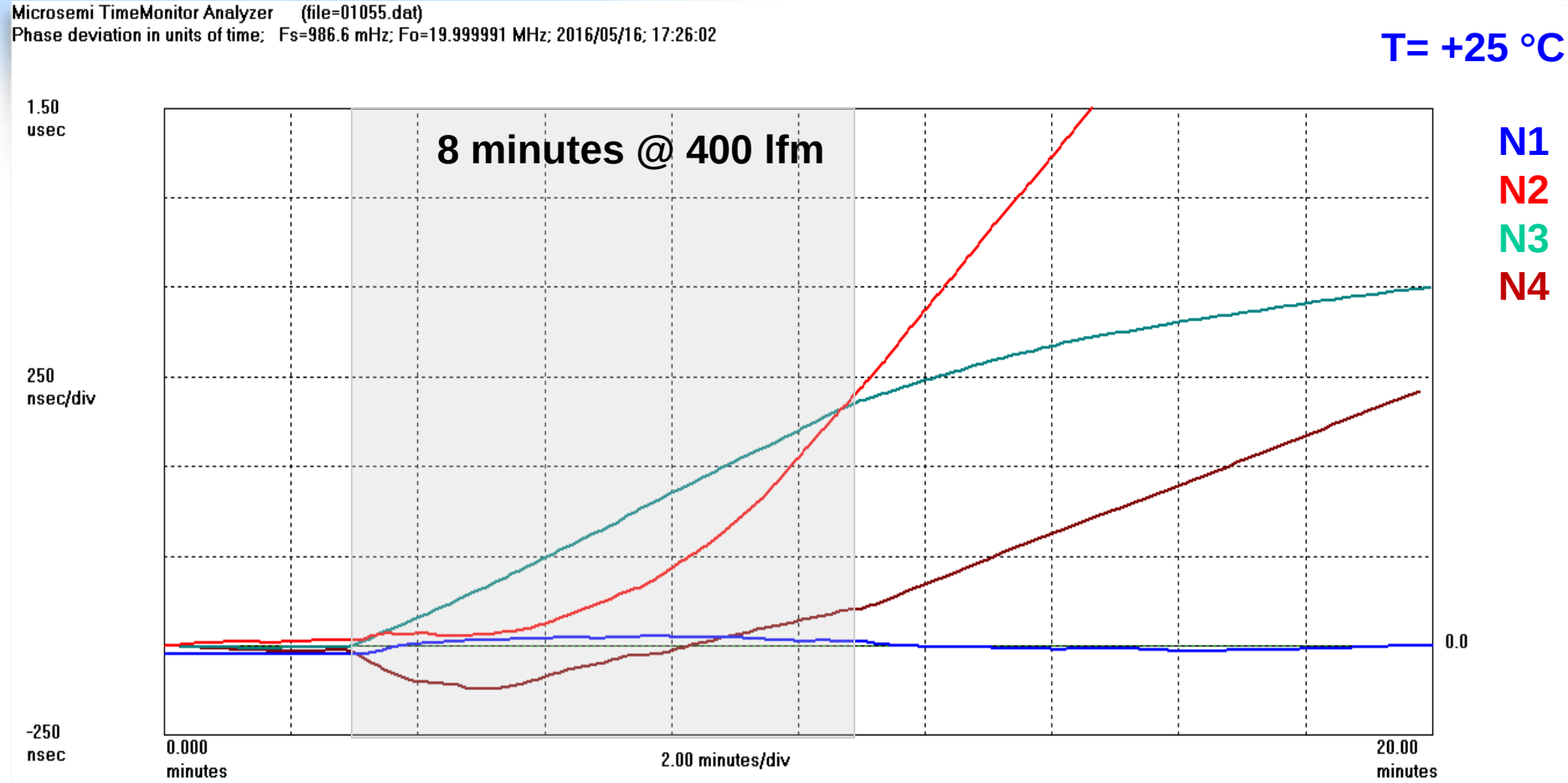

Frequency during Airflow – Network & Consumer

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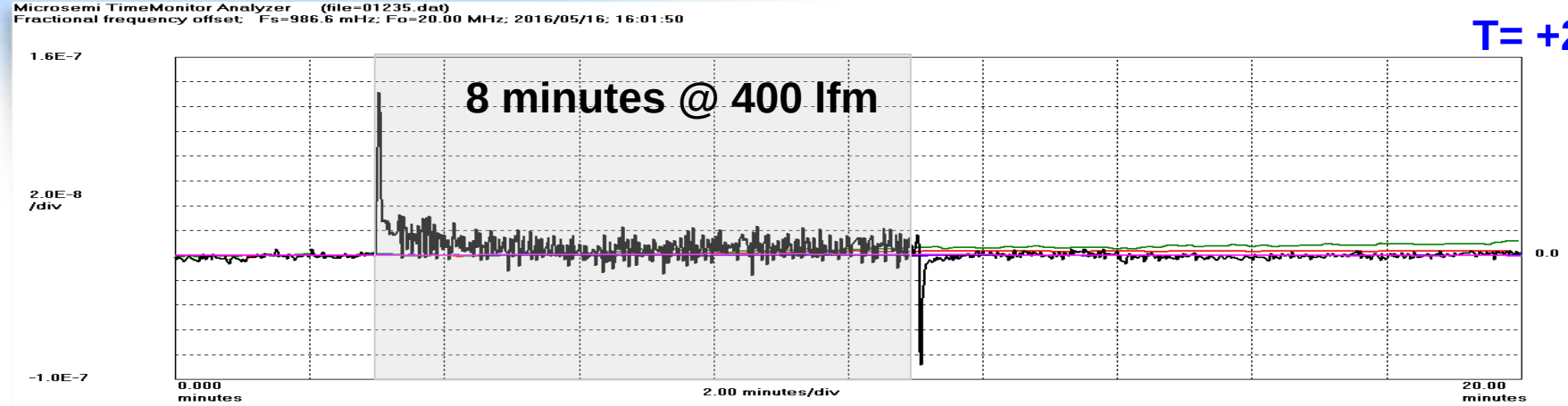
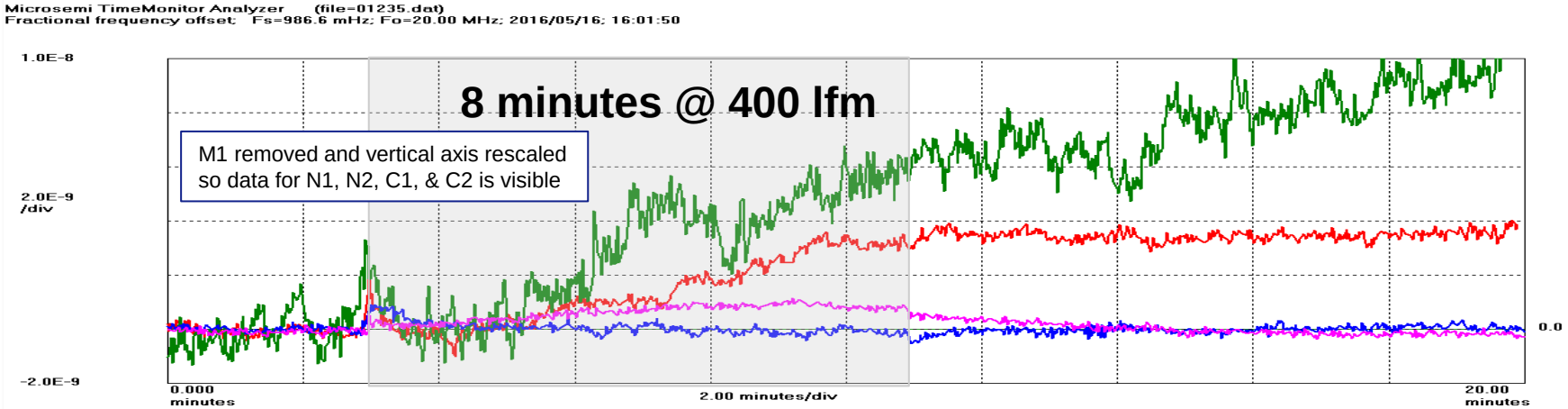
T= +25 °C



N1
N2
C1
C2
M1



Phase during Airflow – Network & Consumer

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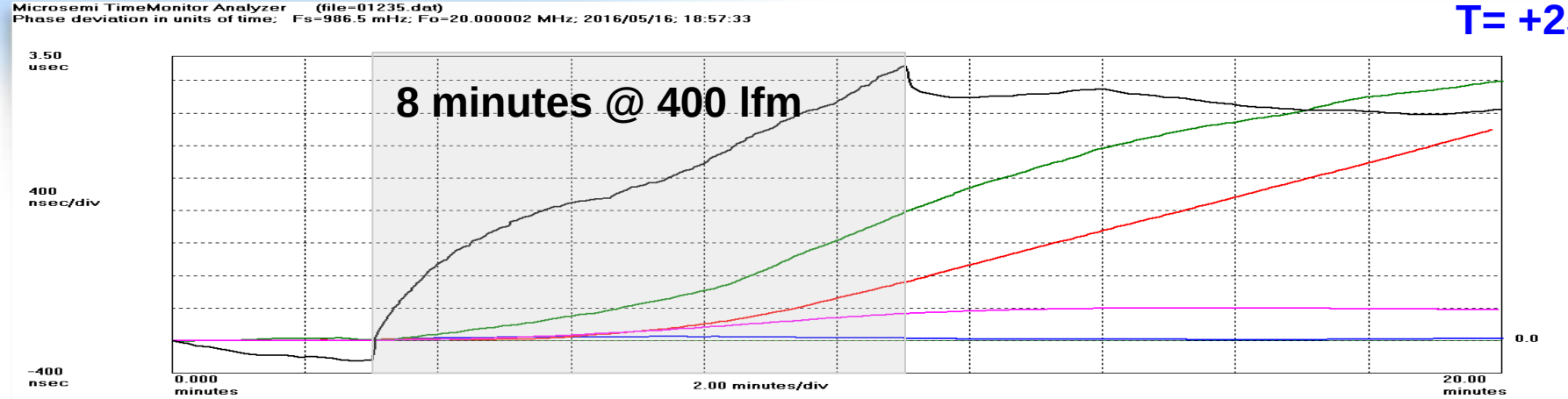
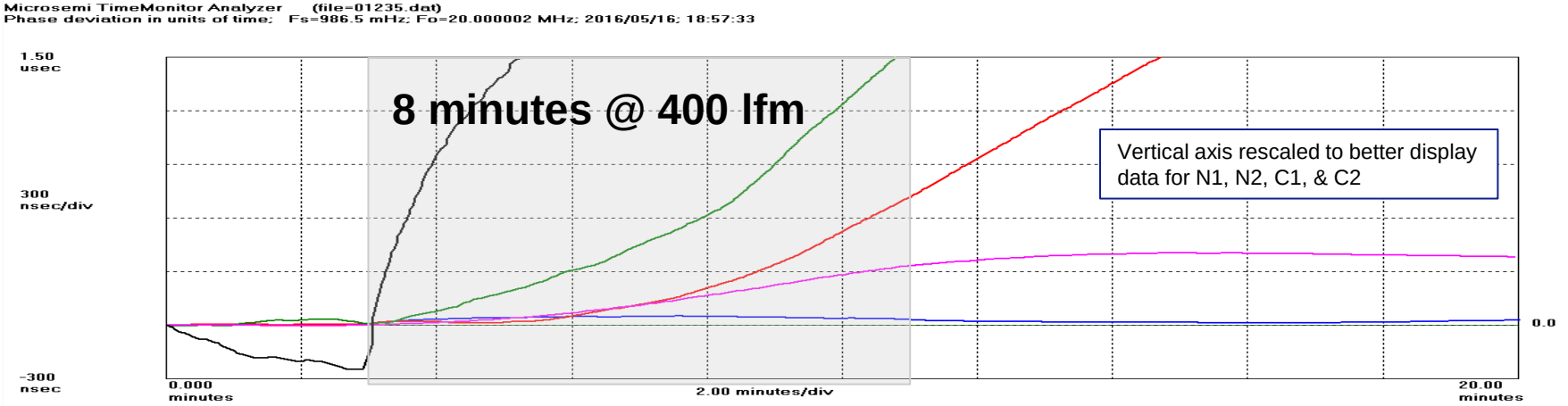
T= +25 °C





Air Flow – Conclusions

Network TCXOs

- Large variation between designs
  - 4x variation in Δf
  - >20x variation in MTIE

Consumer TCXOs

- Large variation between designs
  - C1 violates 1.5 µs limit in 8 minutes
  - C2 in range of networking parts

MEMS TCXO

- Much worse than Quartz
  - Initial spike in Δf
  - Violates 1.5 µs limit in 2 minutes

	8 min @ 400 lfm	
	Δf	Δt (MTIE)
N1	0.9	0.033
N2	3.8	0.717
N3	1.8	0.674
N4	1.8	0.120
C1	6.8	1.53
C2	1.4	0.338
M1	132	3.35
	ppb	µs

Summary of Measured Results

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		Network				Consumer/GPS		MEMS		
		N1	N2	N3	N4	C1	C2	M1	Units	Notes
Power		3.24	2.57	2.93	2.74	1.03	0.94	33	mA	3.3V
f vs. T		±0.229	±0.180	±0.160	±0.261	±0.437	±1.09	±0.532	ppm	-40 to +85 °C
Φ_N	Jitter	317	402	457	403	527	421	642	fs	12 kHz – 20 MHz
	@ 1Hz	-62.1	-59.6	-62.1	-62.5	-45.3	-56.0	-23.0	dBc/Hz	@ 1 Hz
Short-Term Stability/Wander	ADEV 1	1.5e-10	1e-9	1.4e-9	1e-9	1.3e-9	1.2e-9	2.1e-9		
	ADEV10	6e-11	3.4e-10	4.2e-10	3.3e-10	6.7e-10	3.9e-10	1e-9		
	ADEV100	5.2e-11	1.3e-10	1.3e-10	1.2e-10	8.6e-10	1.9e-10	6.7e-10		
	ADEV1000	1.6e-10	6.5e-10	8.5e-10	8e-10	1.9e-9	1.5e-9	1.4e-9		
	TDEV 1	0.093	0.624	0.802	0.603	0.778	0.741	1.28	ns	
	TDEV 10	0.253	1.16	1.36	1.08	3.12	1.37	4.68	ns	
	TDEV 100	2.61	6.79	7.33	6.35	42.4	10.29	32.1	ns	
	TDEV 1000	87.8	364	465	440	1004	805	709	ns	
Airflow	Δf	0.9	3.8	1.8	1.8	6.8	1.4	132	ppb	8 min @ 400 lfm
	Δt (MTIE)	0.033	0.717	0.674	0.120	1.53	0.338	3.35	µs	8 min @ 400 lfm

all meet S3 spec

5x range of performance

20x range of performance

Conclusions

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1. Synchronization systems use oscillators in **real-world conditions.**
2. Oscillators with similar specs **do not perform the same** under these conditions.
3. We are studying how to **improve performance** in these non-ideal conditions.

THANK YOU

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TIMING DEVICES

#1
SHARE
$432M in 2015

#1 in VERTICAL INTEGRATION

#1
COMPLETE
PRODUCT
PORTFOLIO

TCXOs

OCXOs

µAO

SYNCHRONIZATION PRODUCTS