GPS-disciplined MEMS oscillators for amateur radio applications

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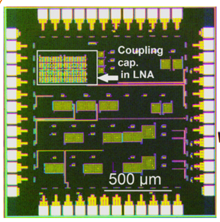
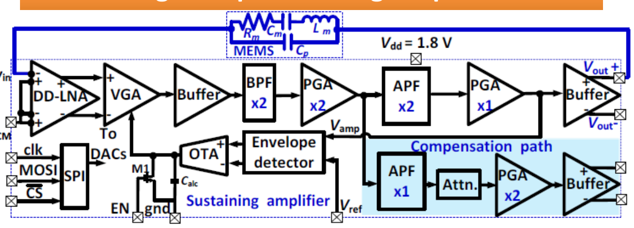
Abstract & Perspectives

The frequency stability of reference oscillators (ROs) is a key performance limiter for all applications that require a timing or frequency reference, including precision sensing, inertial navigation systems, and reconfigurable radio transceivers for amateur radio stations. ROs based on ultra-high-Q micro-electromechanical systems (MEMS) resonators are promising replacements for conventional designs based on quartz crystals due to their compactness, amenability to monolithic integration with CMOS fabrication processes, low cost, and low power consumption. Here, we have demonstrated (i) a custom-designed single-chip CMOS sustaining amplifier, and (ii) a highly-stable RO based on combining the amplifier with a vacuum-encapsulated breath-mode single-crystal silicon resonator ($Q \approx 10^5$) [1]. The free-running RO has a short-term Allan deviation $\sigma_A^\tau \approx 8\times10^{-8}$ at integration time (τ) of 10 sec and relatively small oscillation amplitudes ($P_{osc} \approx -2$ dBm). After injection locking to a custom-built GPS-disciplined frequency standard (GPSDO)[2],[3], the MEMS-referenced oscillator's stability improved to $\sigma_A^\tau \approx 7\times10^{-11}$ at $\tau = 3\times10^4$ sec.

Single Chip Sustaining Amplifier

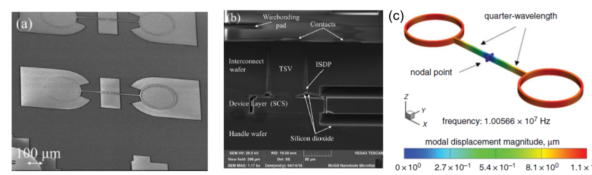


Die micrograph of the chip.



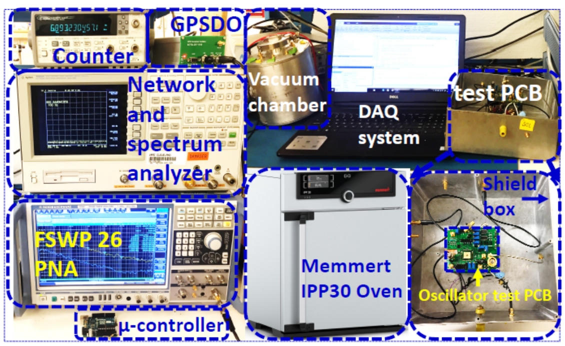
Block diagram of the MEMS resonator and chip.

Breath Mode MEMS Resonator

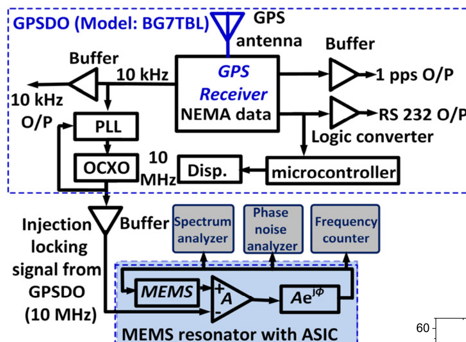


(a)-(b) SEM images: (a) top view, (b) cross section, (c) Simulation results.

Integrated System Level Setup and Experimental Results

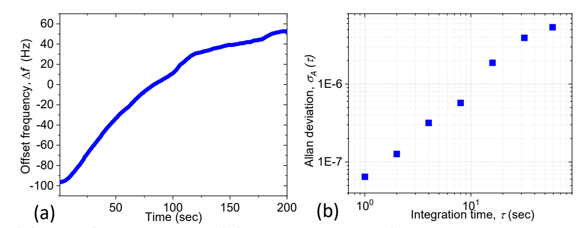


Experimental setup for testing the MEMS-based GPSDO.

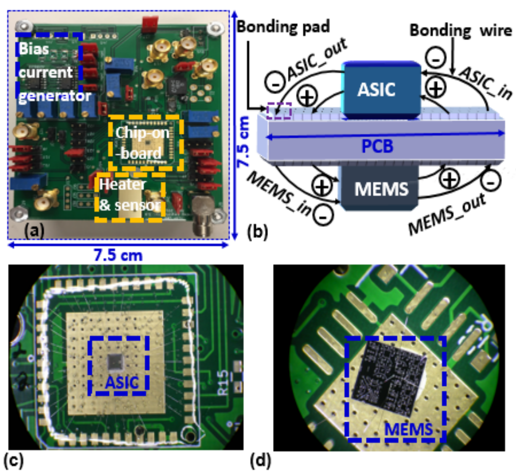


Overall architecture of the GPS-disciplined MEMS oscillator.

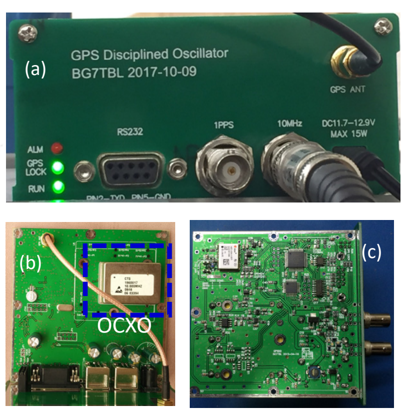
Experimental parameters	
Sustaining amplifier	Single chip, voltage sense, 0.18 µm CMOS technology node
MEMS resonator	Vacuum encapsulated, dual ring breath mode
Q of the MEMS resonator	~10^5
Resonance frequency (f_{osc}) of the MEMS device	10.01 MHz
MEMS DC polarization voltage (Vp)	17 V
GPS receiver and model of GPSDO	uBlox NEO-6M GPS unit and BG7TBL
Allan deviation @ τ = 1s	9 x 10^{-10}
Allan deviation @ τ = 3000s	9 x 10^{-11}



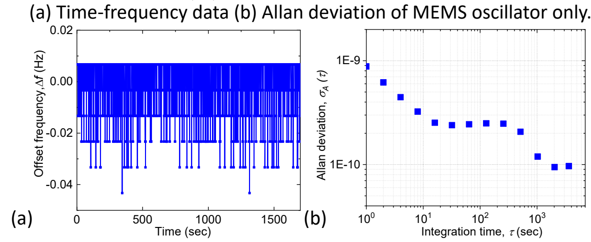
(a) Time-frequency data (b) Allan deviation of MEMS oscillator only.



(a) Test PCB. (b) MEMS and chip integrated into the PCB. (c) Wire-bonded chip on the PCB. (d) Wire-bonded MEMS on the PCB.



(a)-(c) Commercial GPSDO used for injection locking the MEMS-based oscillator: (a) front view, (b) top side of PCB, (c) bottom side of PCB.



(a) Time-frequency data (b) Allan deviation of MEMS-based GPSDO.

Merits of the MEMS-referenced GPSDO

- Enables batch manufacturing with low fabrication cost.
- Comparable long-term performance to quartz oscillators
- Low-phase noise is possible by operating the MEMS device in a nonlinear regime (this reduces amplitude to phase noise [AM-PM] conversion) [4].

Summary and Future Perspectives

We have successfully demonstrated, for the first time, a 10 MHz GPS-disciplined oscillator based on a breath mode dual ring MEMS resonator. The device is suitable for use as a miniaturized, low-cost, and rugged secondary frequency standard in amateur radio applications. We have also outlined potential benefits of nonlinear operation for further improving short- and medium-term stability of the oscillator.

References: **[1]** G. Xereas et al., *SPIE Journal of Micro/Nanolithography, MEMS, and MOEMS*, (2016). **[2]** Michael A. Lombardi, *NCSLI Measure*, 56-65 (2016). **[3]** Michael A. Lombardi, *Proc. Joint Mtg. IEEE Intl. Freq. Cont. Symp. and PTTI Mtg.*, (2005). [4] Ming-Huang Li et al. , *IEEE TCAS-I* (2018).

Acknowledgements: We acknowledge financial support from NSF (Grant: ECCS-1509721) and technical support from our collaborators. We are grateful to Europractice-IC for chip fabrication and Teledyne Dalsa for fabricating the MEMS resonator.