Surface and Bulk Acoustic Wave Gyroscope

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INTRODUCTION

Our Planet Is a Giant Gyroscope

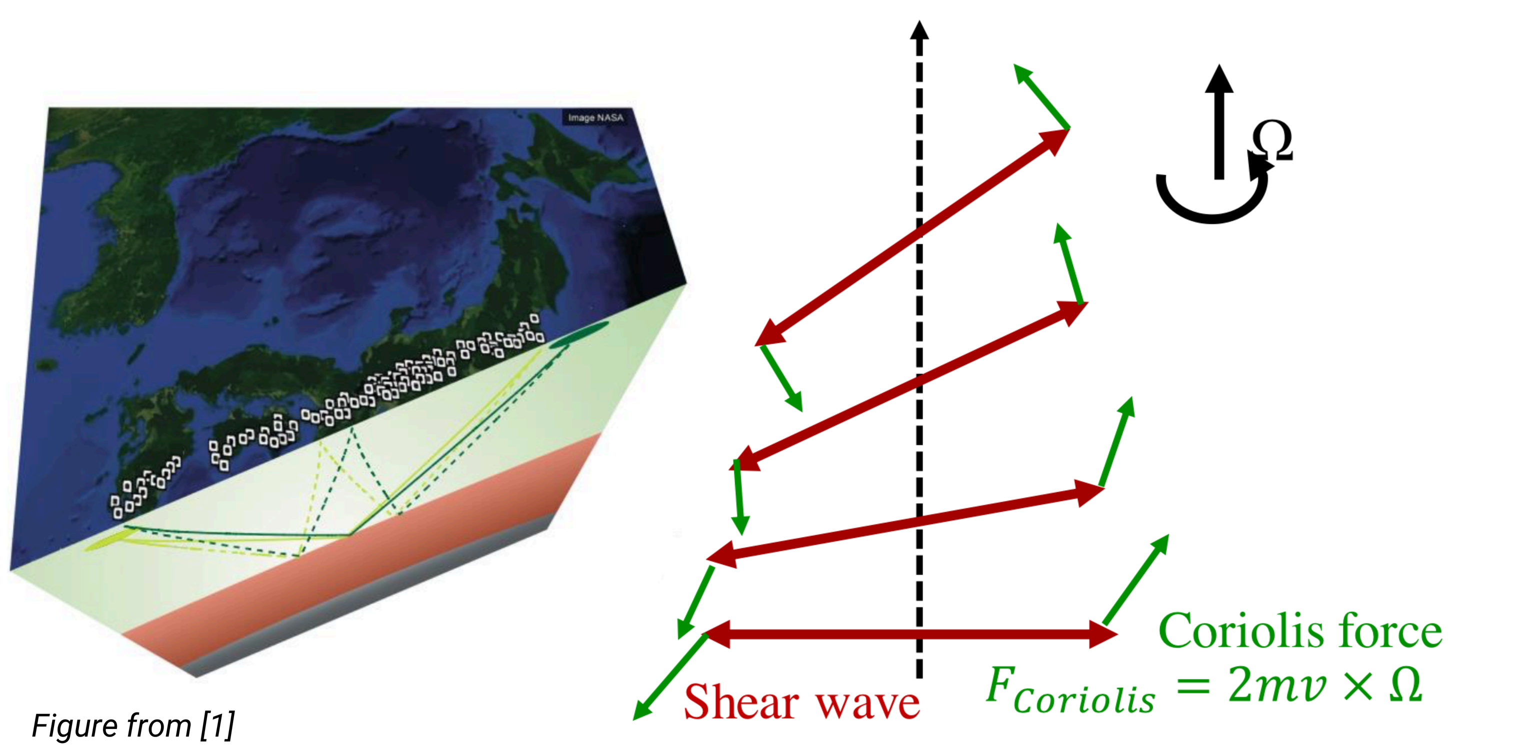


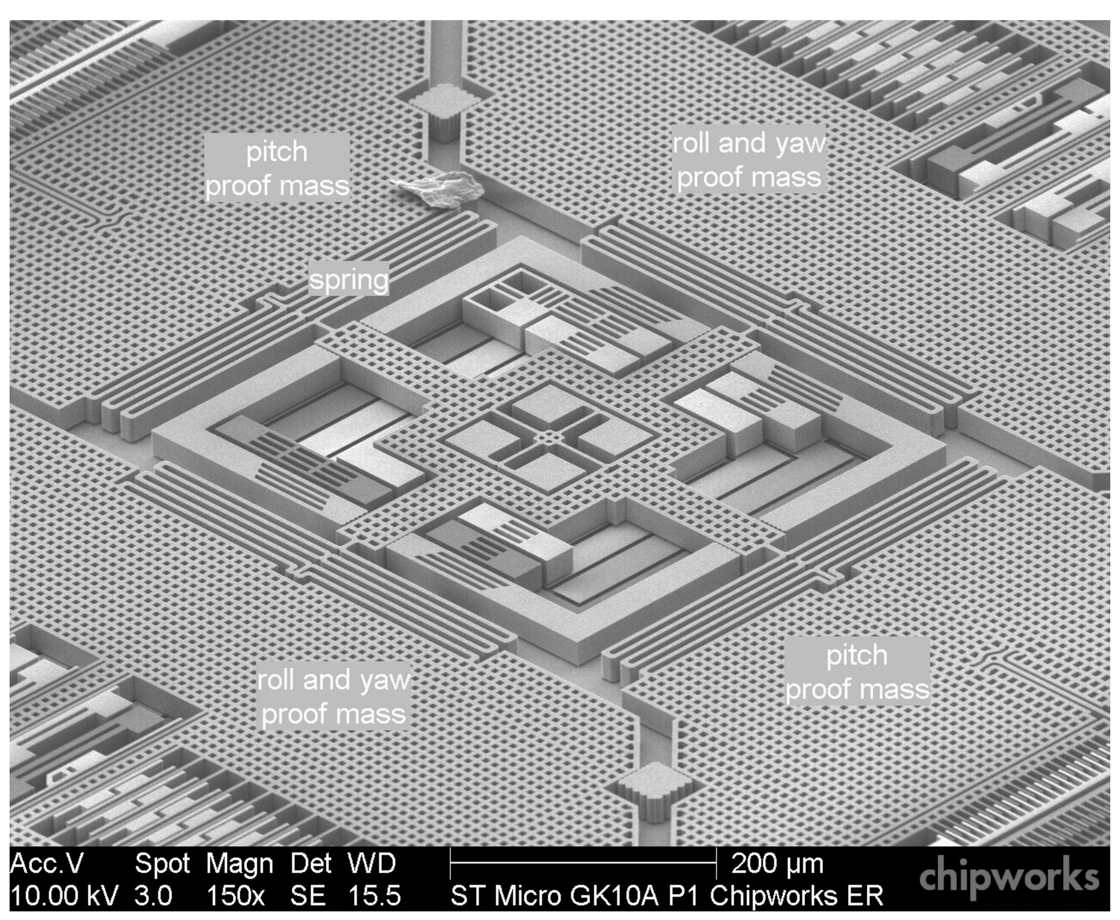
Figure from [1]

$$\dot{\mathbf{q}}_S = -\Omega \cos\theta\, \hat{\mathbf{z}} \times \dot{\mathbf{q}}_S$$

Seismic events trigger shear waves that propagate throughout the inside of the Earth, changing direction due to the Coriolis force.

A Gyroscope With No Moving Parts

Conventional MEMS gyroscopes, much like those found in smartphones, are delicate suspended mass structures supported by beams thinner than a human hair.



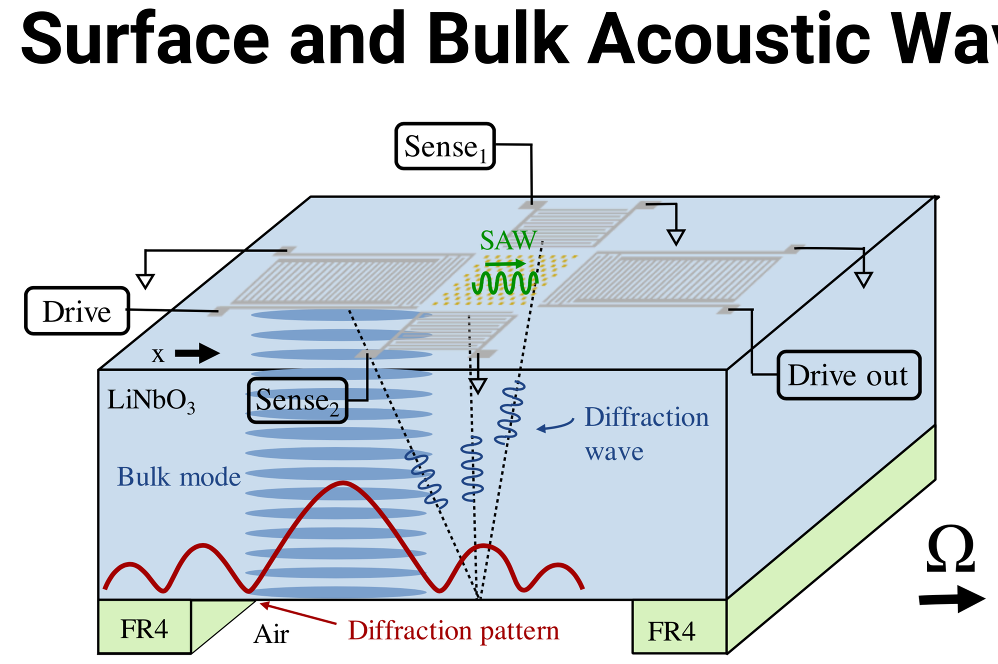
While sufficient for everyday use, this architecture is susceptible to inoperation in high-shock environments. For the latter conditions, a solid-state architecture is preferred.

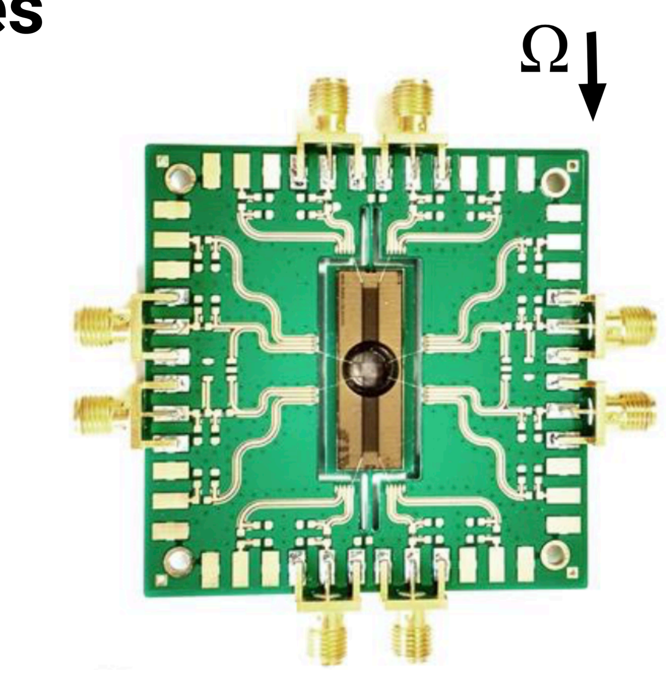
Military and Civilian Applications

Applications for this new kind of gyroscope may be found in missile guidance and other defense systems, as well as in high-impact automobile safety systems.

DESIGNING A SOLID-STATE GYROSCOPE

Surface and Bulk Acoustic Waves

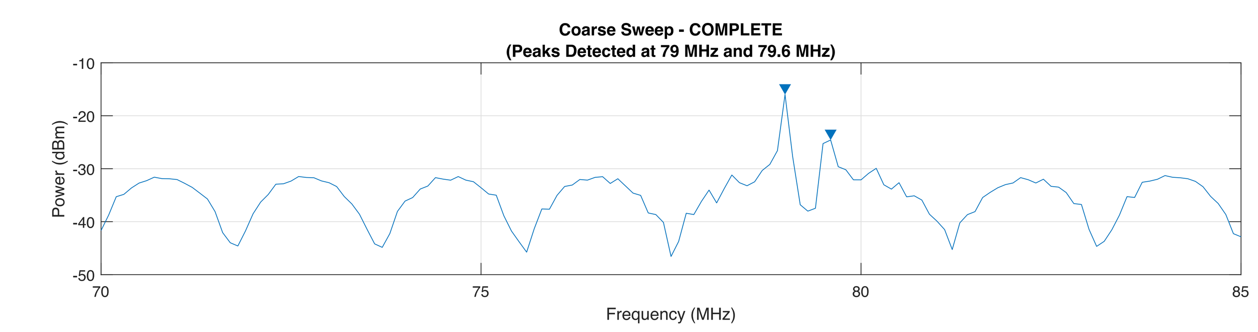


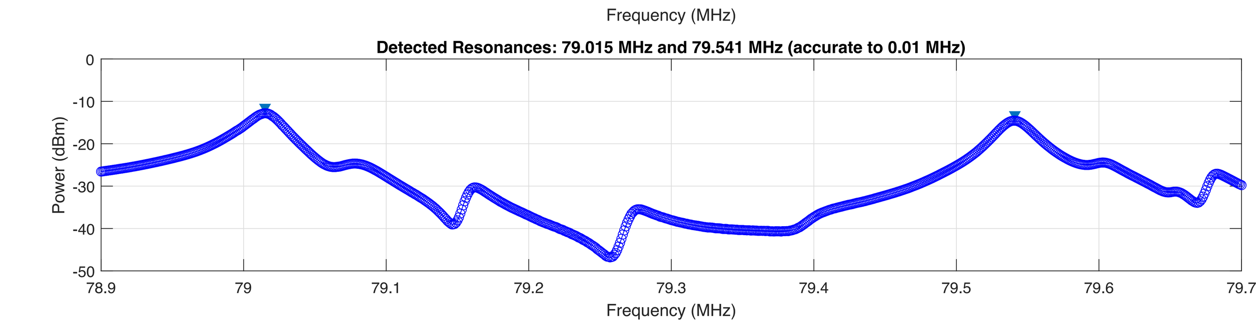


SAWs are generated and received via mechanoelectrical transduction by placing *interdigitated transducers (IDTs)* on a lithium niobate ($LiNbO_3$) substrate. This material was selected for its piezoelectric and elastic material properties, as well as its high electromechanical coupling coefficient (K^2 = 5.3%) [2].

Insertion Losses

In this *in situ* measurement scheme, two SAW modes and the corresponding scattering parameter S_{21} for each were found by conducting coarse and fine frequency sweeps to find minimal power loss.





SAW modes were found at 79.016 MHz and 79.541 MHz with insertion losses of -14.8 dB and -17.7 dB, respectively. These results are consistent with the intended 80 MHz design.

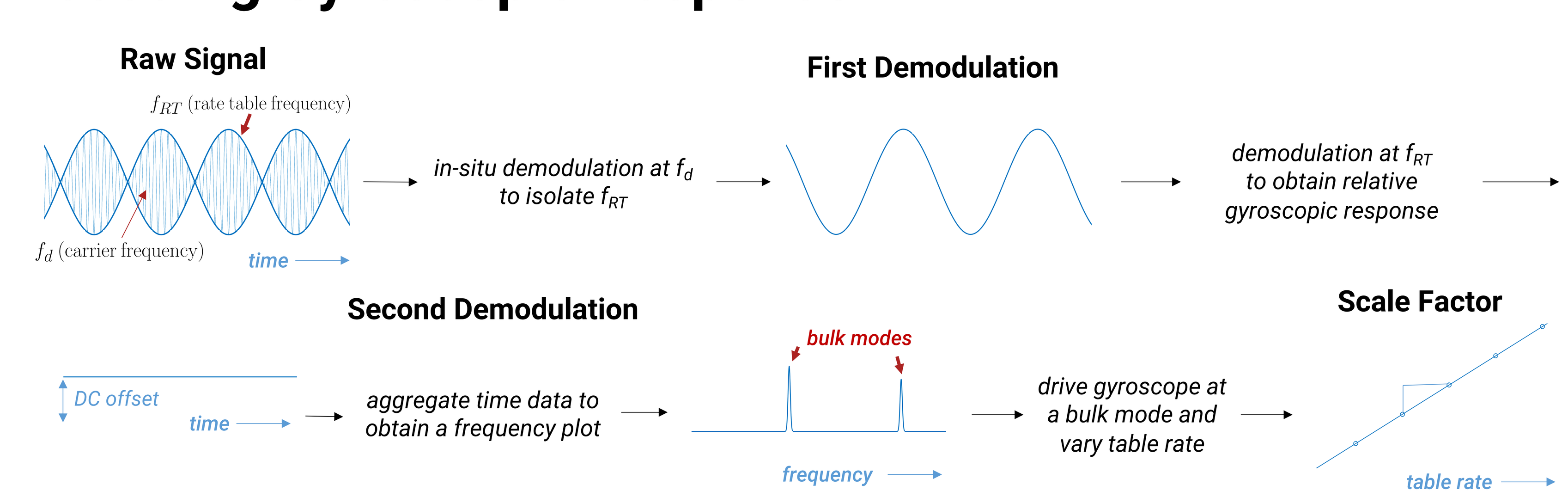
MEASUREMENT SCHEME

Untethered Inertial Testbed

An *in-situ* measurement framework was developed around the Moku:Lab instrument; its small form factor enables unrestricted rate table rotation. A mount was custom designed to position the sample directly over the center of rotation of the rate table.

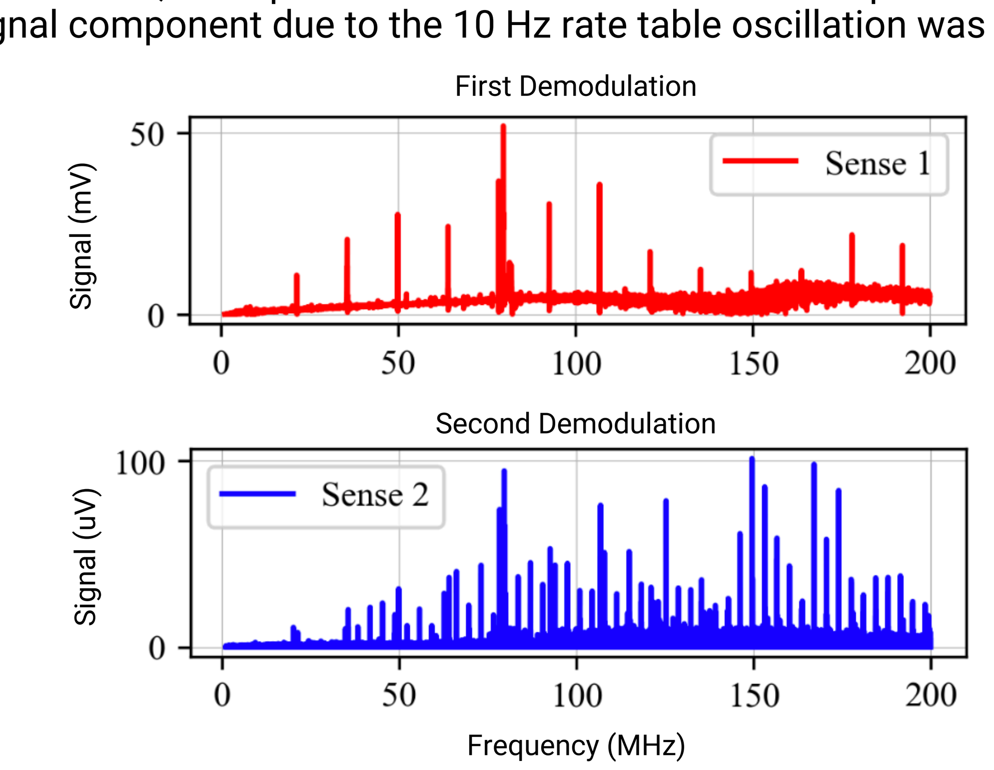
Scripts were written in MATLAB to simultaneously wirelessly interface with the instrument and drive the rate table.

Decoding Gyroscopic Response



Gyroscopic Response

The rate table was driven at a 10 Hz back-and-forth oscillation. To identify bulk modes, sweeps were conducted to find the frequencies at which the signal component due to the 10 Hz rate table oscillation was maximized.



While further investigation of gyroscopic scale factor at each detected mode is needed to determine whether the sample functions as a gyroscope, these results indicate the SAW device's veritability as a solid-state inertial sensor.

ACKNOWLEDGMENTS

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REFERENCES

1. R. Snieder, et al, **"Seismic shear waves as Foucault pendulum"**, *Geophysical Research Letters*, vol. 43, no. 6, pp. 2576 -2581, 2016.
2. B. Davaji, V. Pinrod, S. Kulkarni and A. Lal, **"Towards a surface and bulk excited SAW gyroscope,"** *2017 IEEE International Ultrasonics Symposium (IUS)*, Washington, DC, 2017, pp. 1-4.
3. V. Pinrod, B. Davaji and A. Lal, **"Coexisting Surface and Bulk Gyroscopic Effects,"** *2018 IEEE International Ultrasonics Symposium (IUS)*, Kobe, 2018, pp. 1-4.

ABSTRACT

Often referred to as Coriolis vibratory gyroscopes, most commercially available microelectromechanical systems- (MEMS) based gyroscopes are comprised of a moving, resonating spring-mass system, making use of the Coriolis effect to sense multiple degrees of freedom. While widely used and practical for most consumer use, such devices are often unreliable when used in special defense and military applications where extreme forces and accelerations are present. The purpose of this project is to develop a MEMS gyroscope suitable for placement on high-velocity ballistics. Using bulk-micromachining and surface acoustic wave (SAW) technology, a solid-state version of the conventional MEMS gyroscope on piezoelectric, lithium niobate substrate is fabricated, intended for use in advanced inertial micro-sensing for high-velocity munitions. While further investigation of gyroscopic scale factor is needed to determine whether the sample functions as a gyroscope, results indicate the SAW device's veritability as a solid-state inertial sensor.