State-of-the-art MEMS Gyroscopes for Autonomous Cars

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mems tohoku 検索

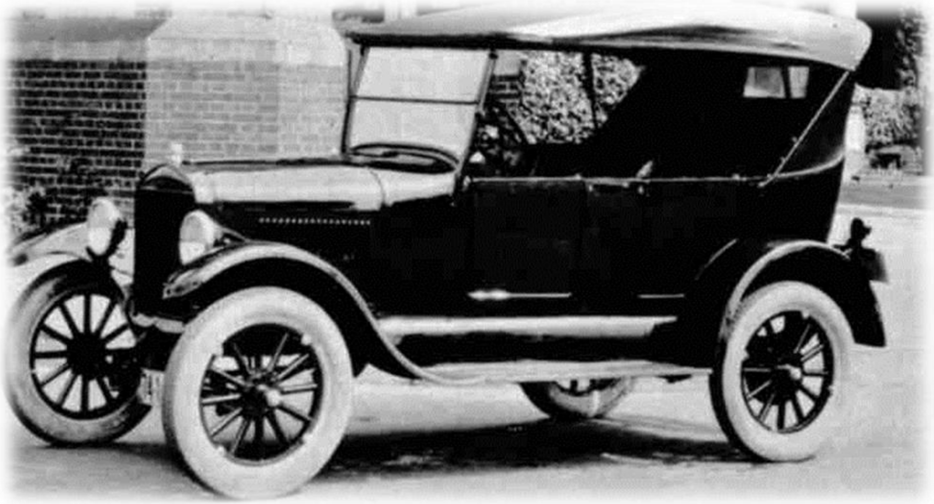
Automobile Museum at Division of Mech. Eng.

Automobile Museum　自動車の過去未来館
at Division of Mechanical Engineering, Aobayama Campus

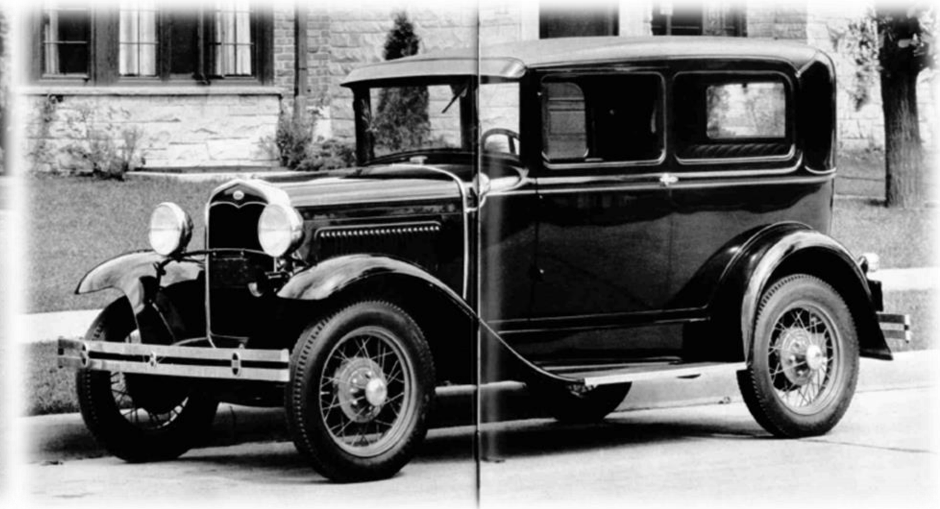
Ford Model T and A, and Toyota Motor’s F1 engine

Ford Model A and T

世界の自動車44　フォード1, 二玄社



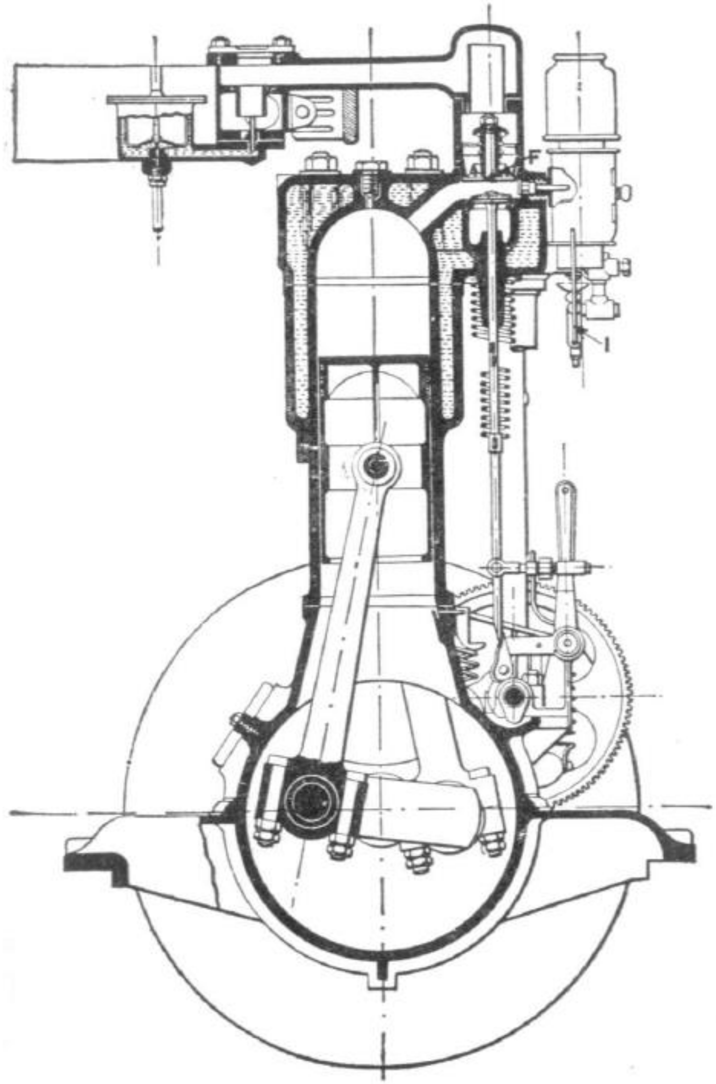
Model T Touring (1925)



Model A Deluxe 2-door Sedan (1931)

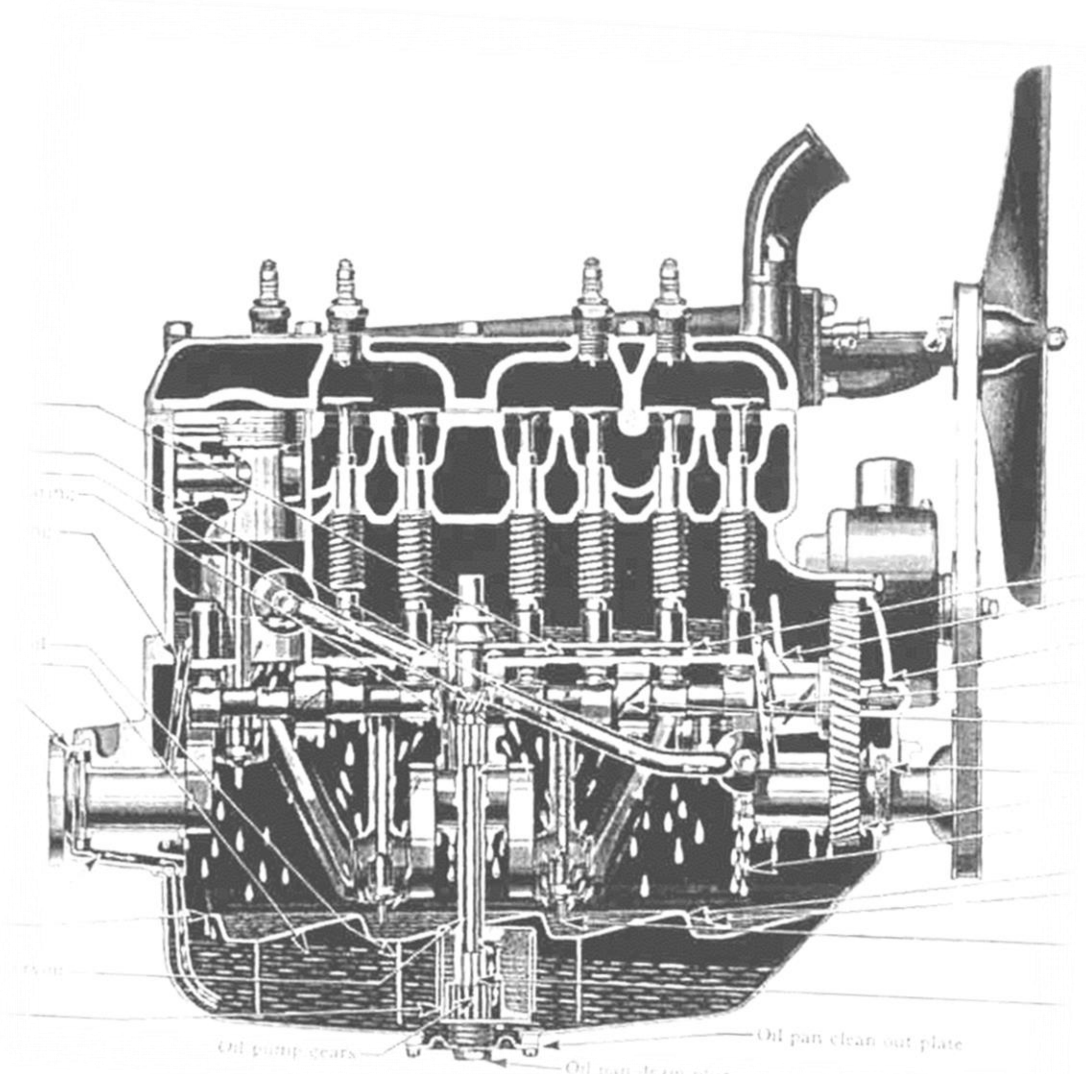
Restore in 2008

Classic Automobile Engines



Daimler’s engine (1883)

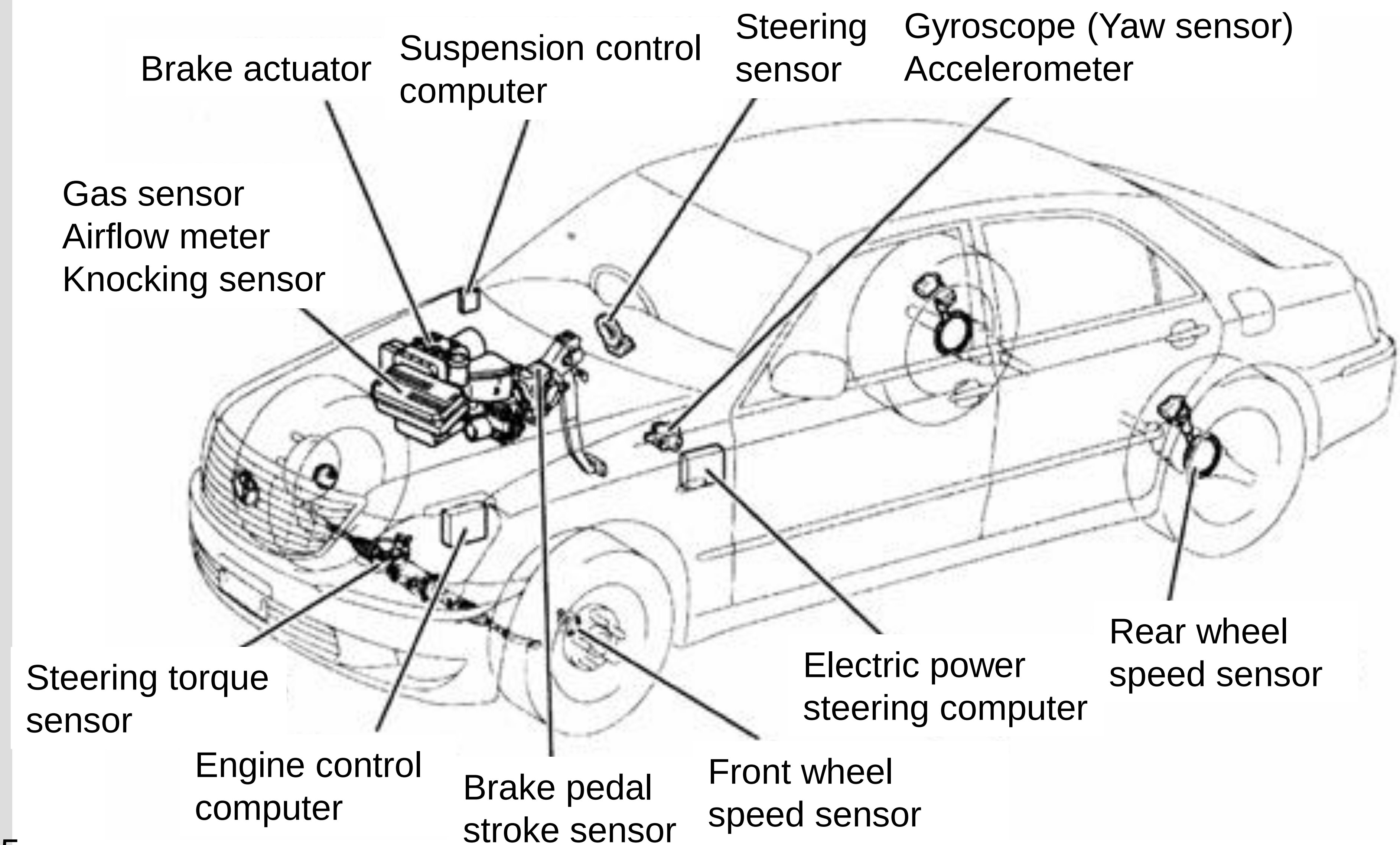
富塚清, 内燃機関の歴史, 三栄書房 (1969)



Engine for Ford Model A (1927)
3285.5 cc, 4 cylinders, 40 ps/2200 rpm

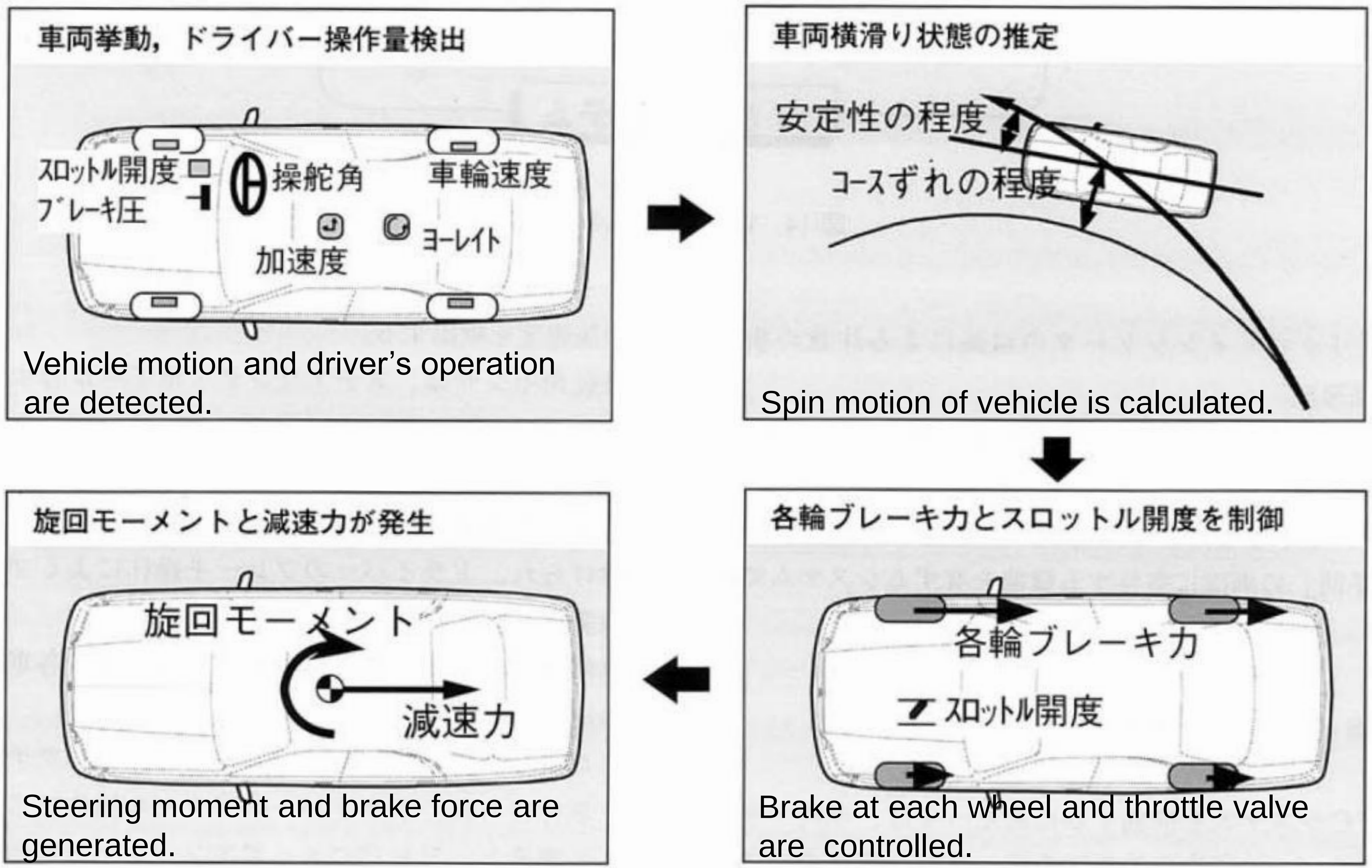
Sensors in Automobiles

野々村(豊田中央研究所), 自動車用センサとその小型化, センサ・シンポジウム2010



Vehicle Stability Control (Toyota Motor)

杉山 他(トヨタ自動車), VSC(車両安定性制御)システム, 富士通テン技報, 27号, 14, 1 (1996)



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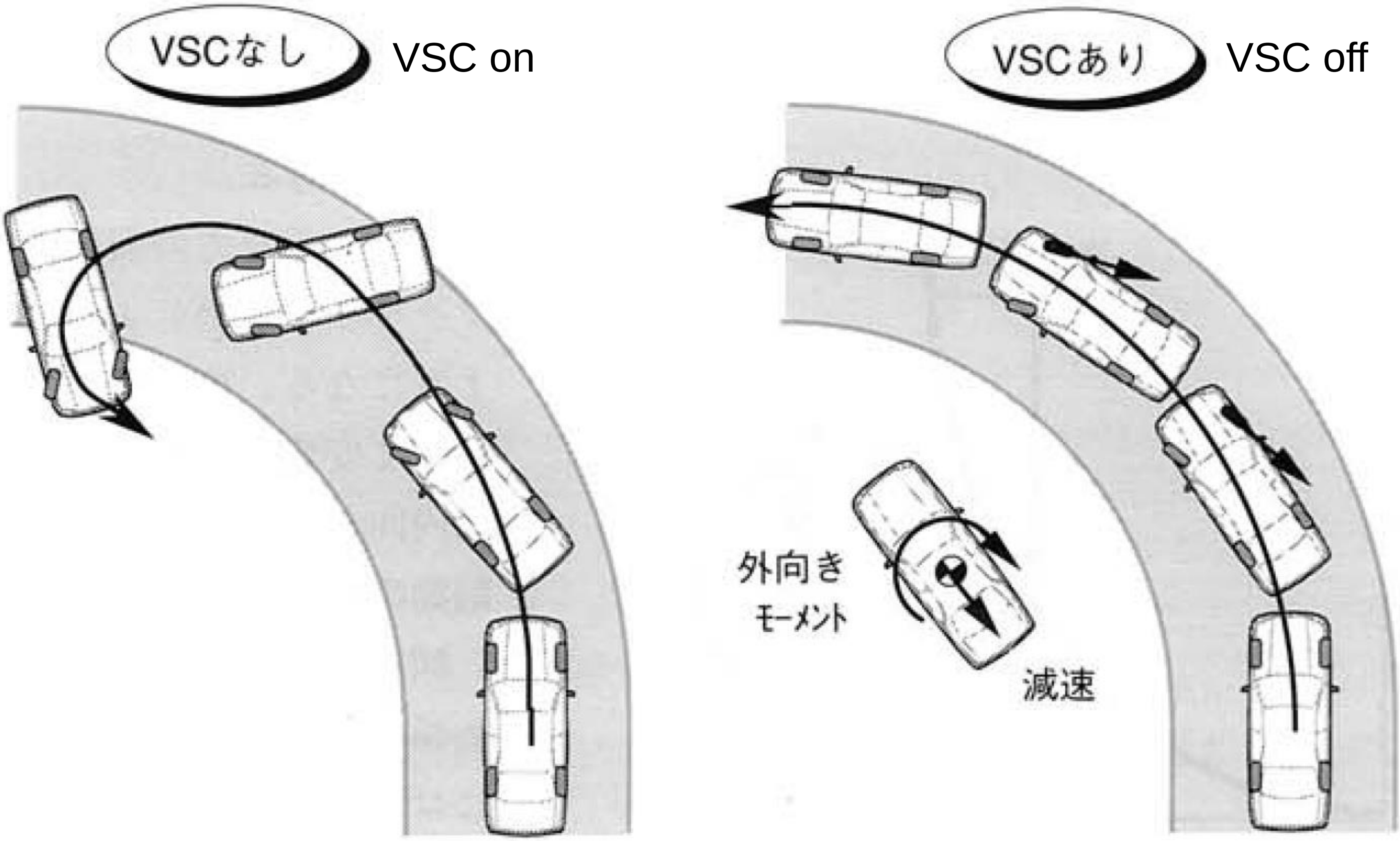
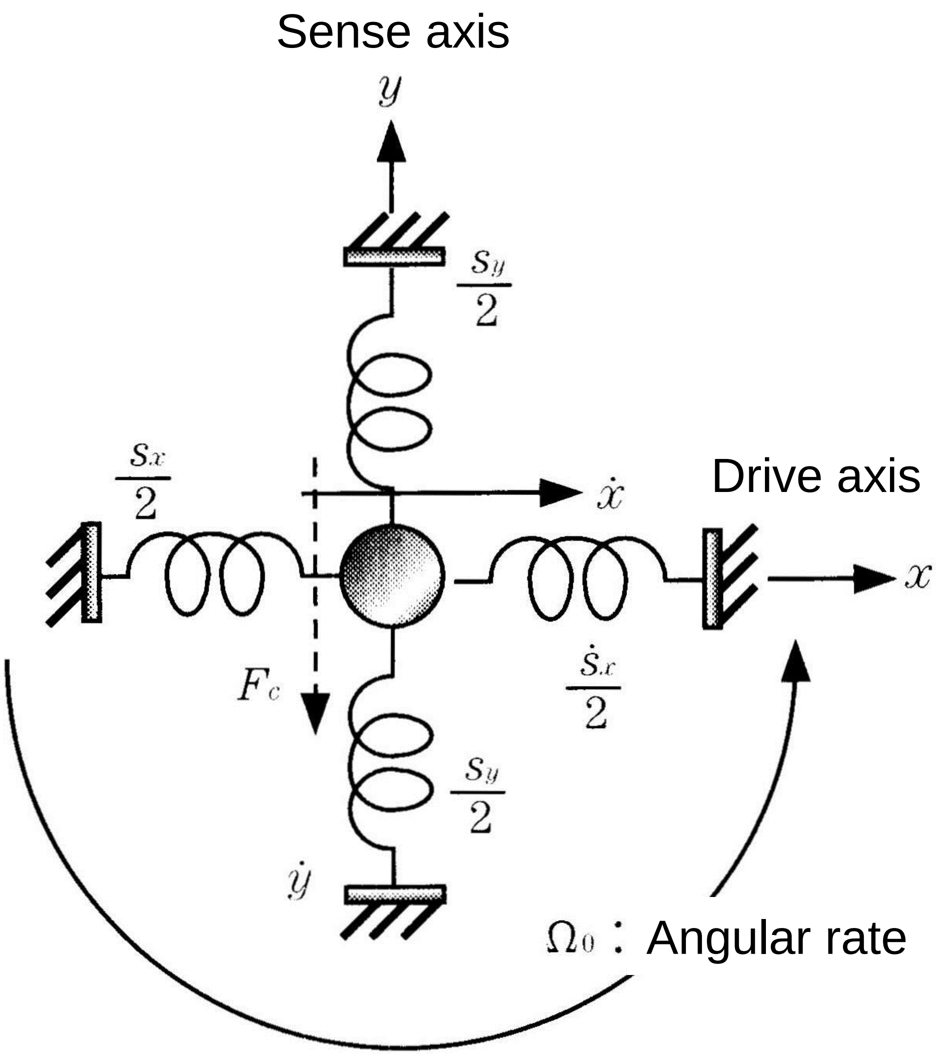
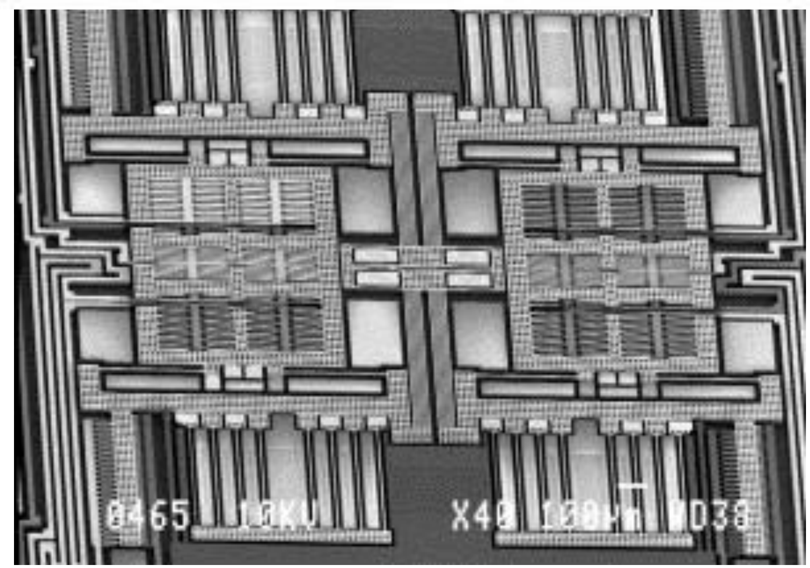


MEMS Vibratory Gyroscope



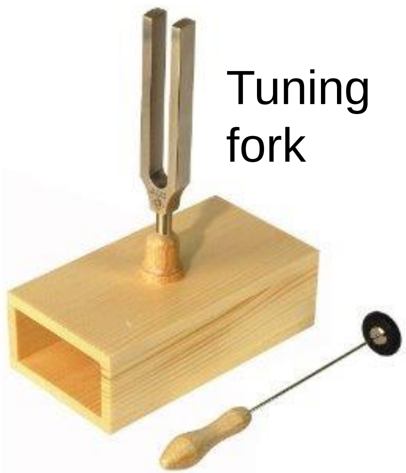
Colioris force $F_{cy} = 2m\Omega\dot{x}$



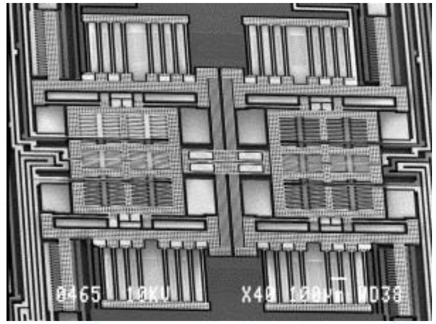
Gyroscope for vehicle stability control (Toyota Motor, Tohoku Univ.)

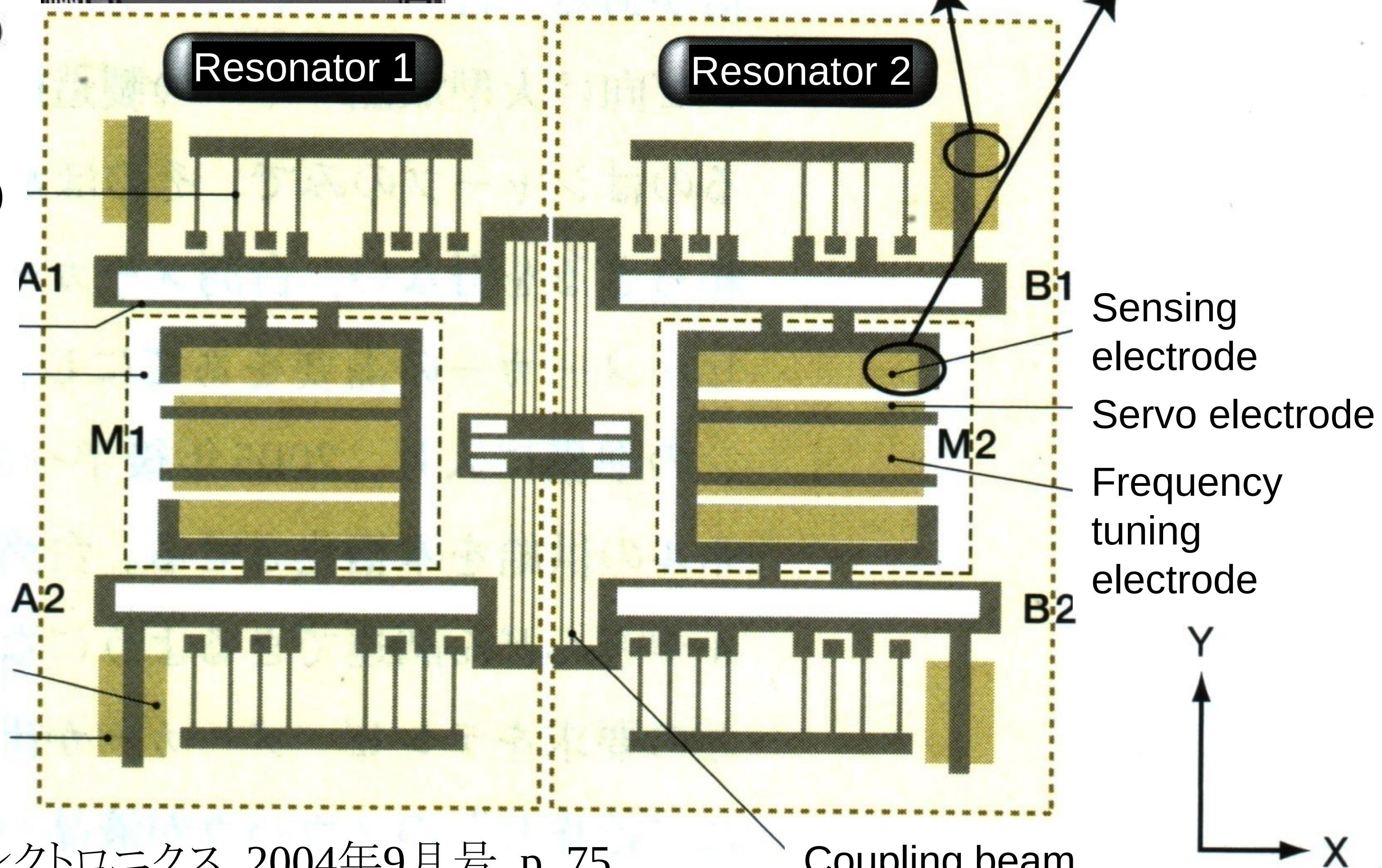
多摩川精機, ジャイロ活用技術入門, 工業調査会 (2002)

MEMS Vibratory Gyroscope (Toyota Motor)



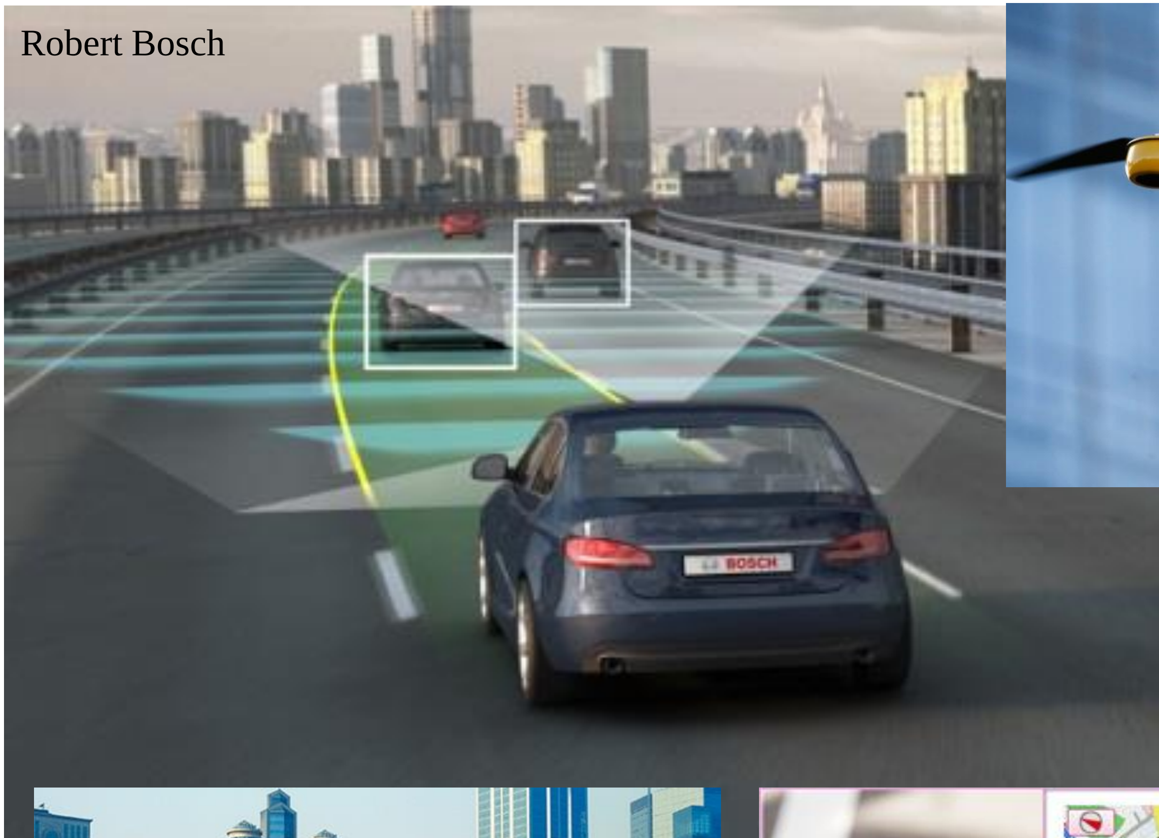
Tuning fork





 野々村裕, 日経エレクトロニクス, 2004年9月号, p. 75

Future Applications of MEMS Gyroscopes



Robert Bosch

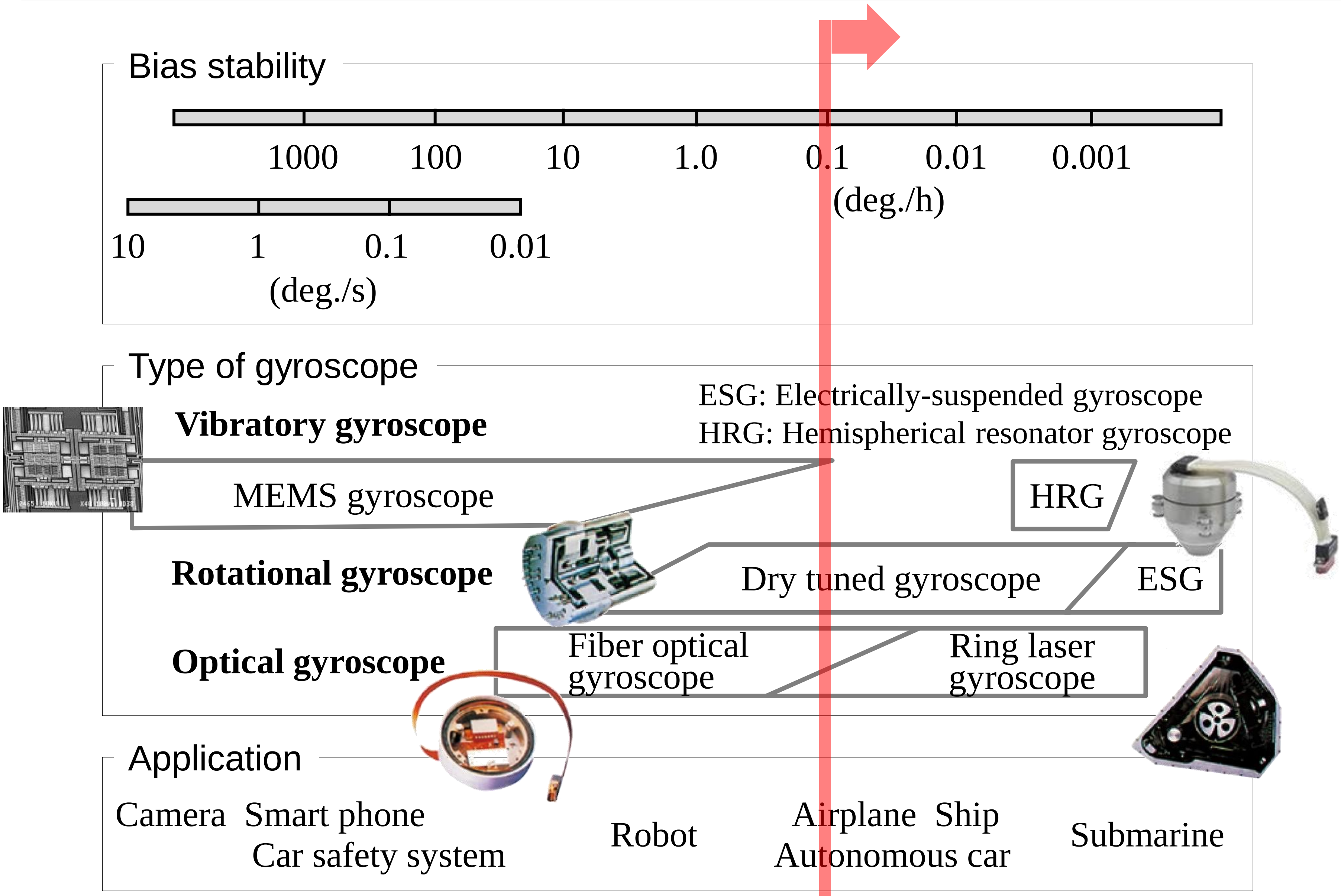
DHL

Gigamen


All About, Panasonic

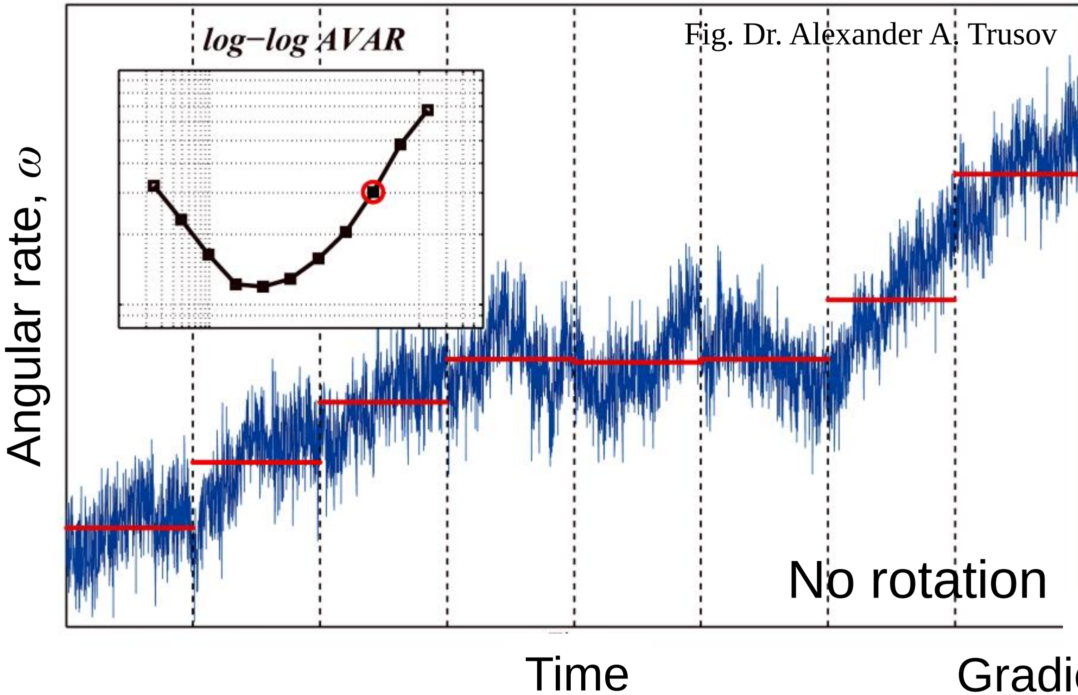
Honda Motor

Performance of Gyroscopes



DTG，FOG，RLGの図：多摩川精機　HRGの図：Northrop Grumman

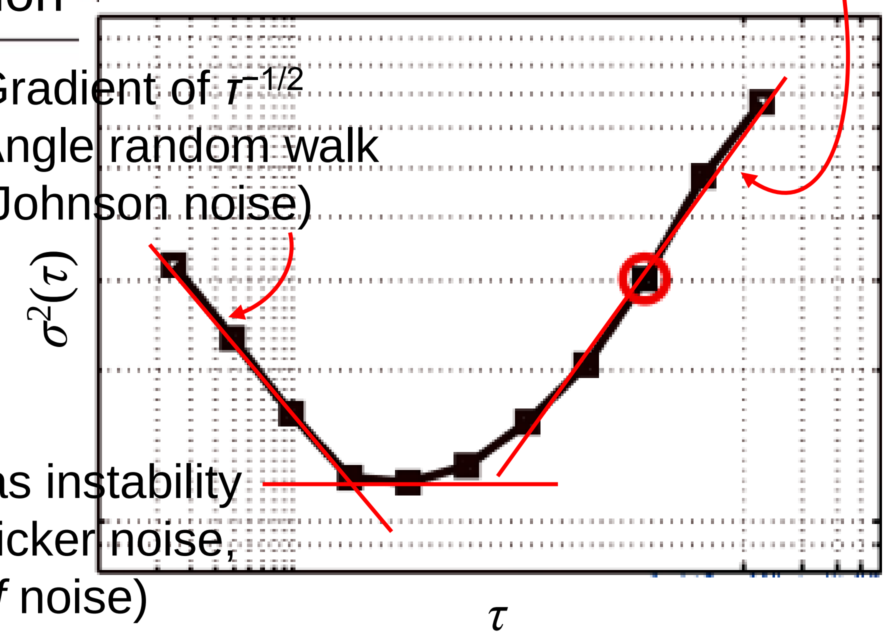
Bias Stability of Gyroscope



White noise and random walk of angular rate

Gradient of $\tau^{1/2}$
Angular rate random walk
(White noise accumulation)

Log-Log AVAR



<u>Allan variance (AVAR)</u>

$$\sigma^2(\tau) = \frac{1}{2}\left\langle \left(\omega_{k+m} - \omega_k\right)^2 \right\rangle$$

$$\sigma^2(\tau) = \frac{1}{2\tau^2 (N-2m)} \sum_{k=1}^{N-2m} \left(\theta_{k+2m} - 2\theta_{k+m} + \theta_k\right)^2$$

Change of ω is averaged
over different time constants τ

Difficulties of MEMS Gyroscope

Any small imperfections result in error.

- Imperfect orthogonality of drive and sense axes
- Mechanical and electrical coupling between drive and sense axes
- Unideal amplifier

etc.

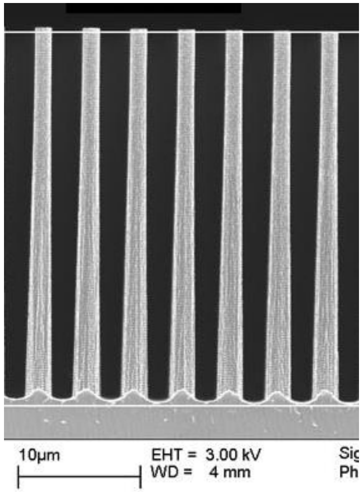
“Compromises” are made to avoid difficulties.

- Intentional mismatch in resonance frequency between drive and sense axes (Mode mismatch)
- Low quality factor

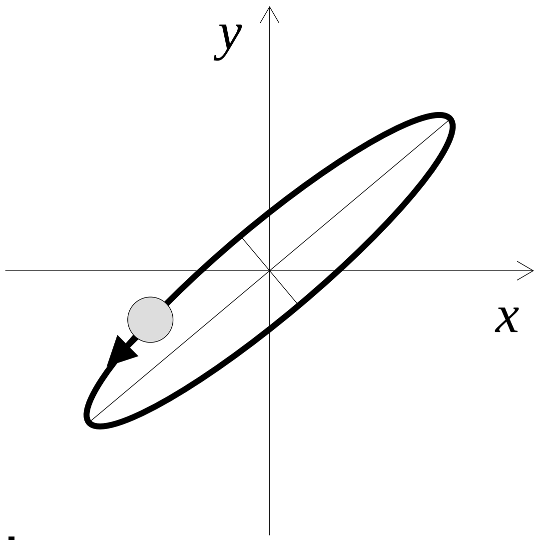
→ Limit in performance

→ Mode matching and high quality factor

→ Much better structure and advanced control



Deep reactive ion etching

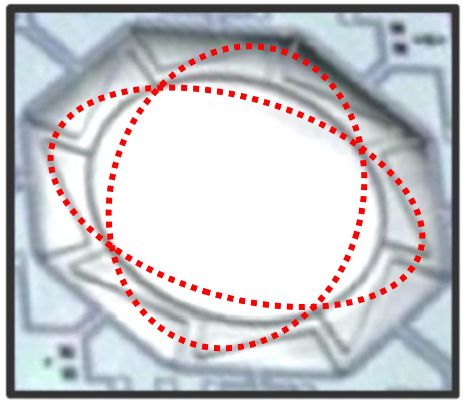


Quadrature error

High-Performance MEMS Gyroscope (SSS)

資料: Silicon Sensing Systems

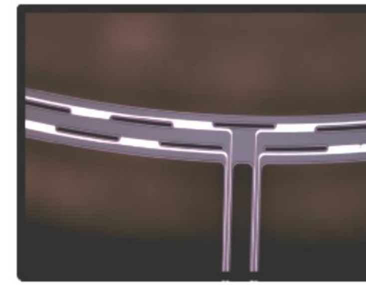
SGH01
2000年量産開始



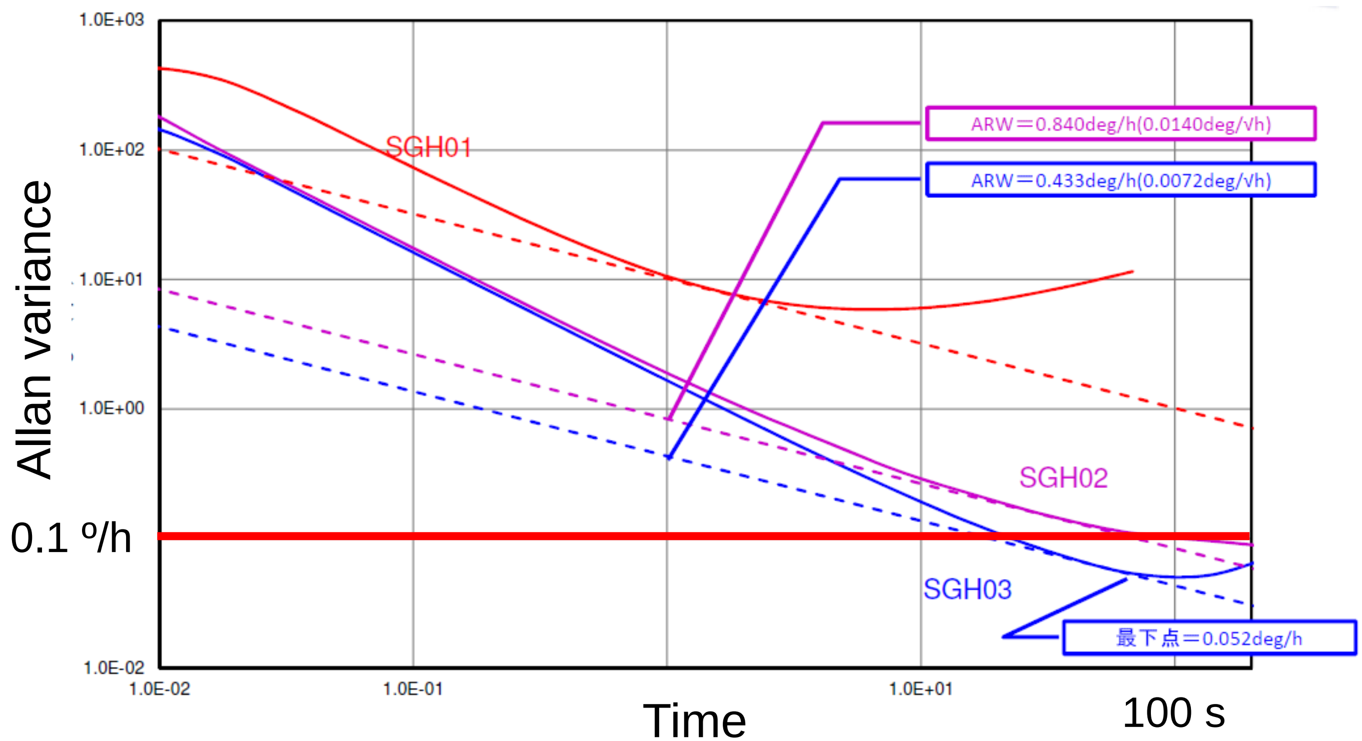
Segway

Mode-matched, force-rebalanced gyroscope

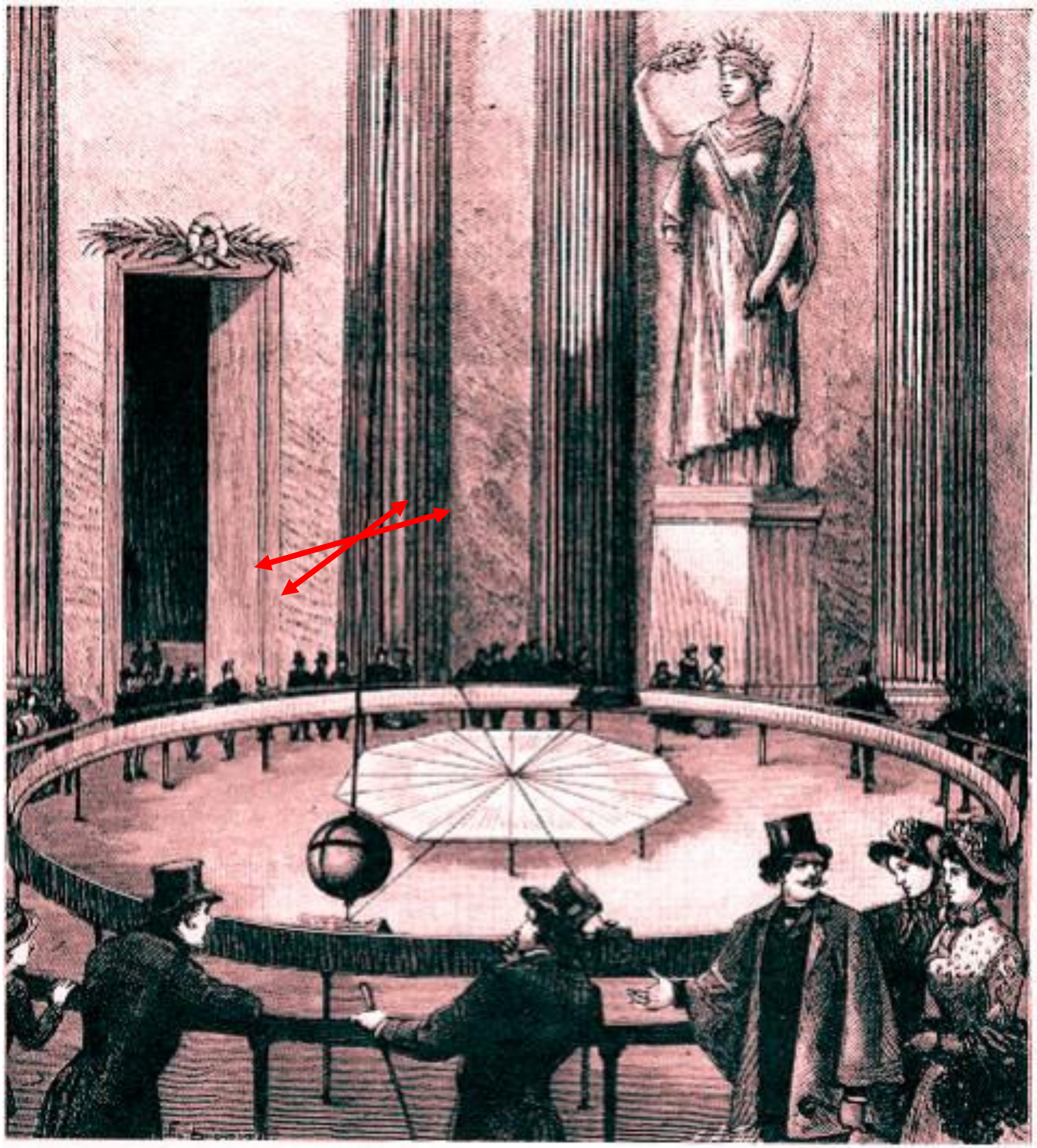
SGH03



Production by Sumitomo Precision and
Design by UTC Aerospace Systems (UK)



Foucault Pendulum



Wikipedia

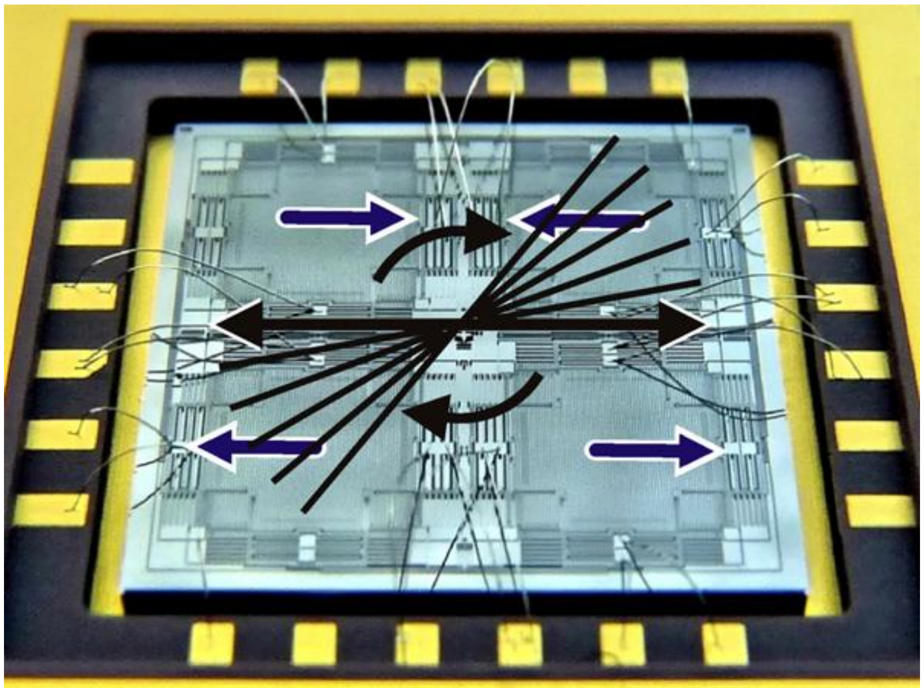
In 1851, French physicist Jean Bernard Léon Foucault (1819-1868) demonstrated the revolution of the earth using a pendulum of 67 m and 27 kg suspended in Panthéon de Paris.

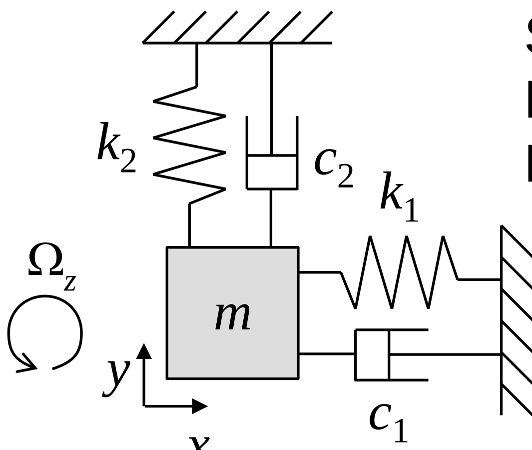
The vibration plane rotates, although only gravity works on the mass.

Foucault pendulum is a rate-integrated gyroscope (whole angle mode gyroscope).

Whole Angle Mode Gyroscope (UC Irvine)

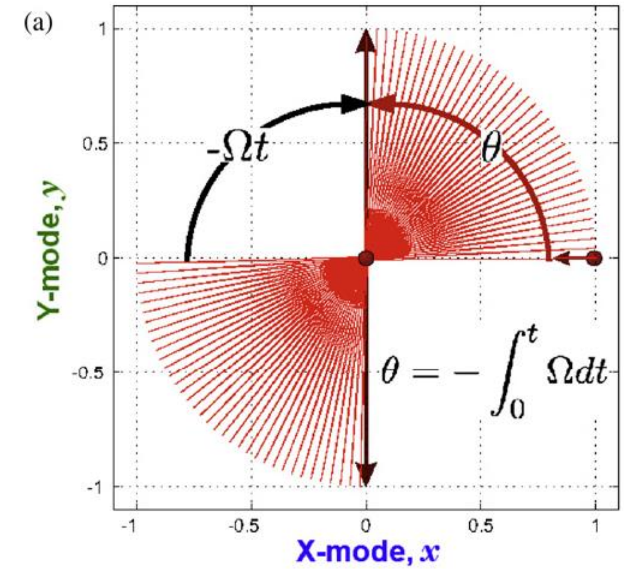
I.P. Prikhodko *et al.*, Sensors and Actuators A, 177 (2012) pp. 67–78



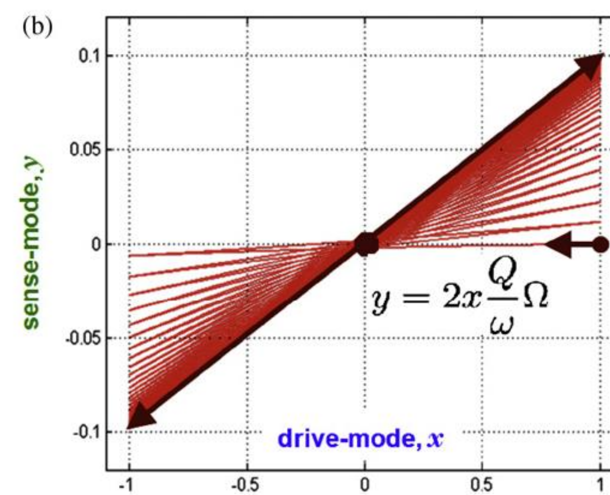


Symmetric structure
Mode matching
High Q factor

Whole angle mode

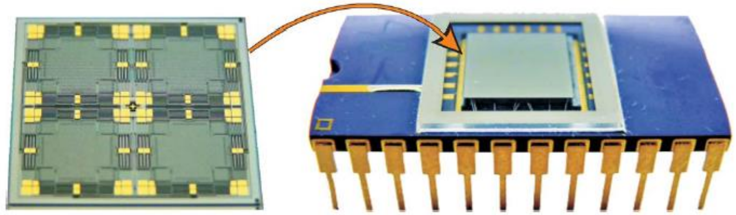


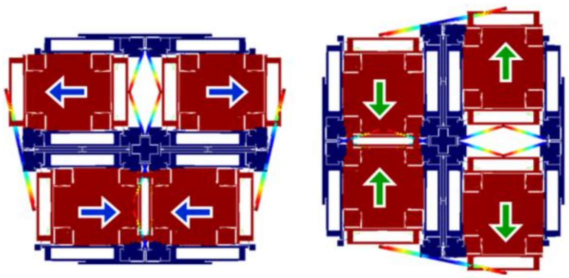
Force rebalance mode

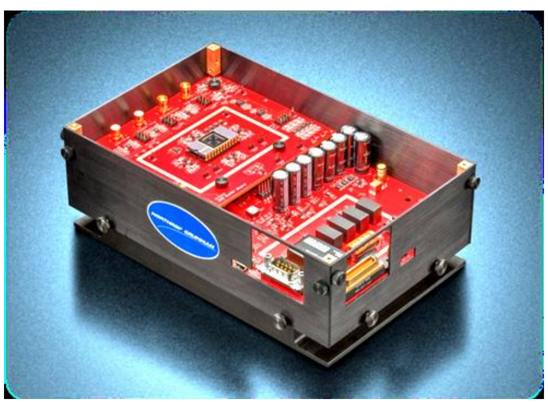


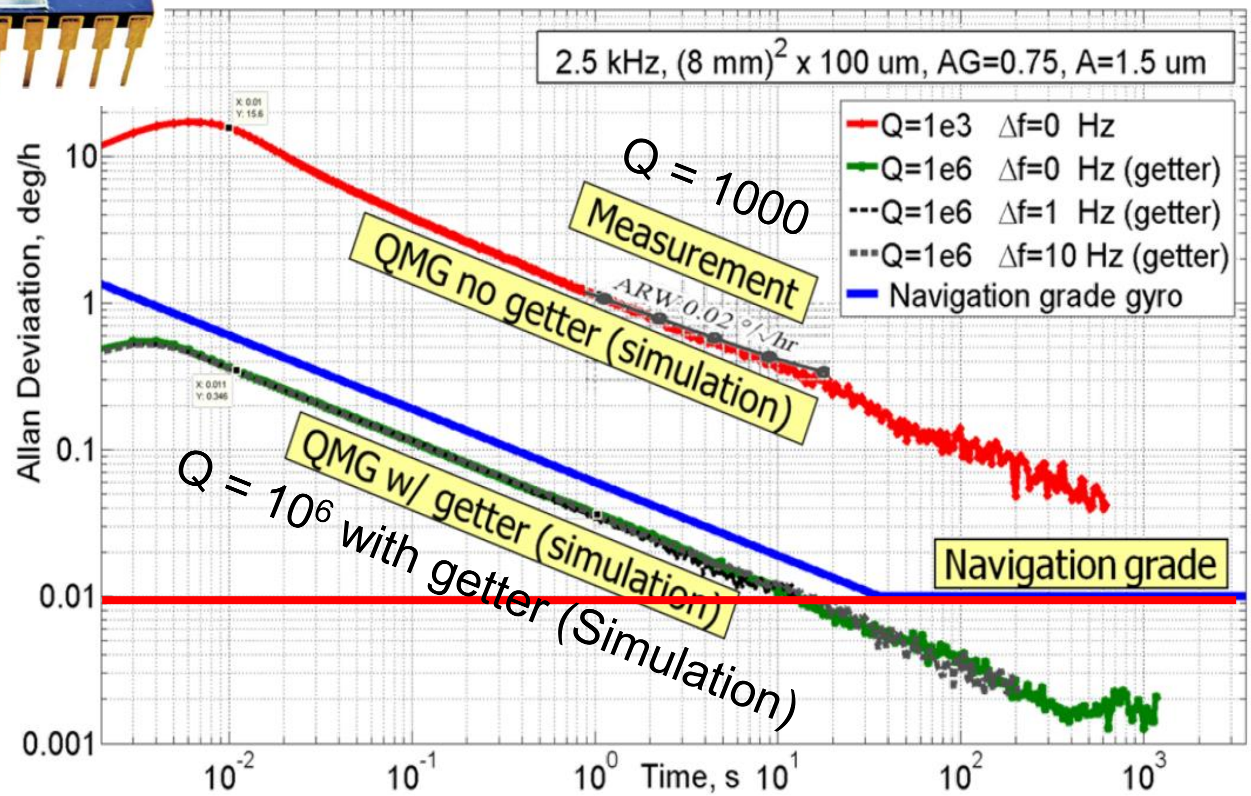
High-Performance MEMS Gyroscope

Northrop Grumman, UC Irvine (Prof. Shkel), Hilton Head Island Workshop 2014









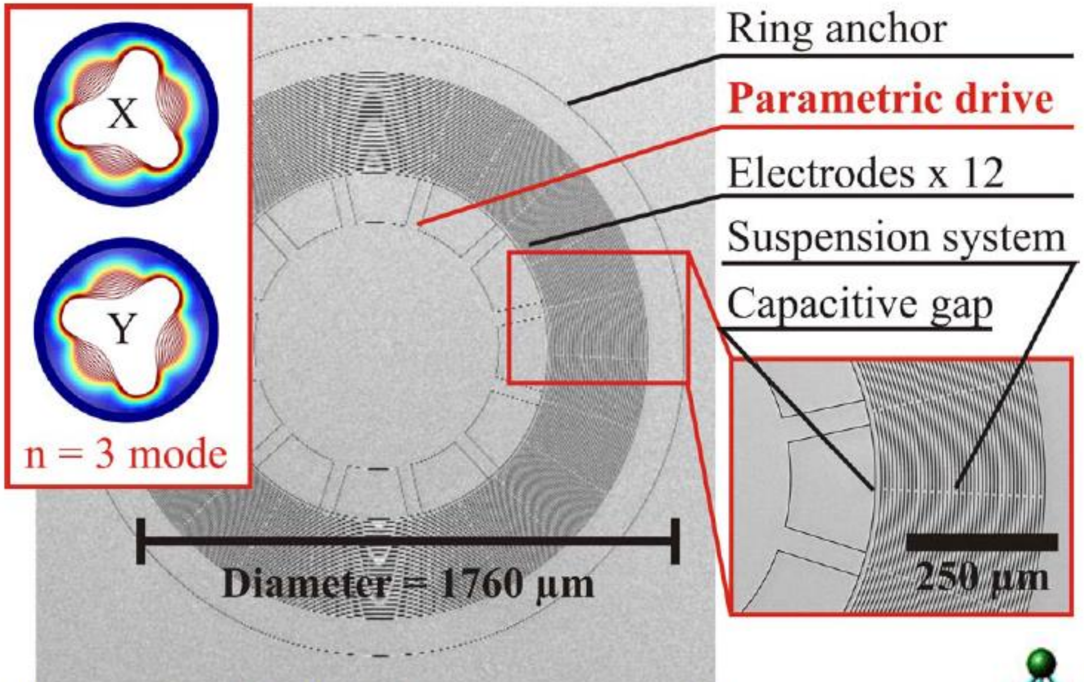
Allan variance for force rebalance mode

Force rebalance mode and whole angle mode can be switched.

- Scale factor stability is 3 ppm in whole angel mode.
- FR-mode is less affected by frequency mismatch.

Whole Angle Mode Gyroscope

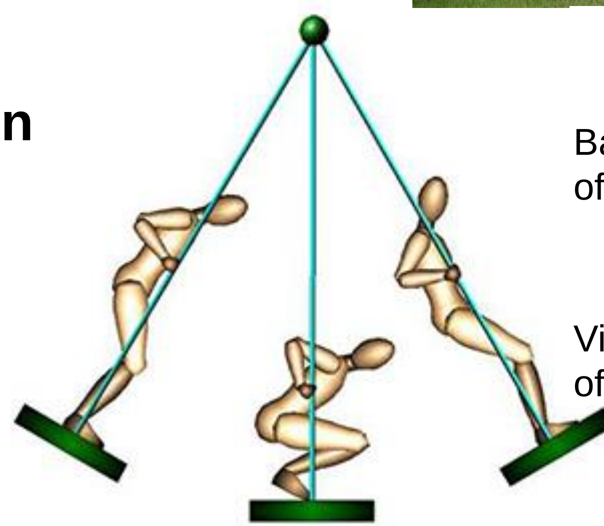
D. Senkal1, … T.W. Kenny2, A.M. Shkel1, 1UC Irvine, 2Stanford Univ., IEEE MEMS 2015



How to sustain free vibration without perturbation?

→ Parametric amplification

Spring constant is modulated at doubled frequency of resonance frequency.



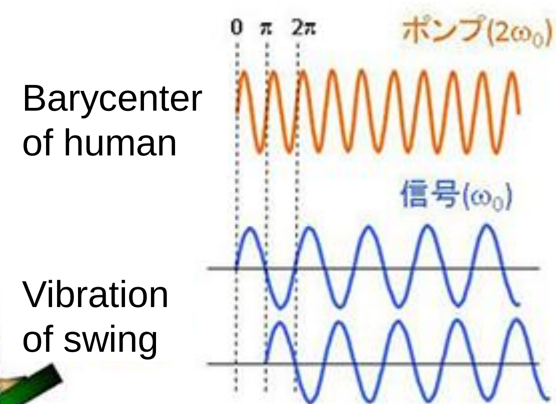
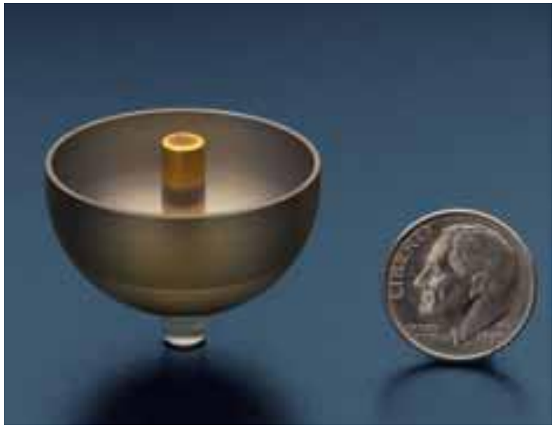


図:理化学研究所

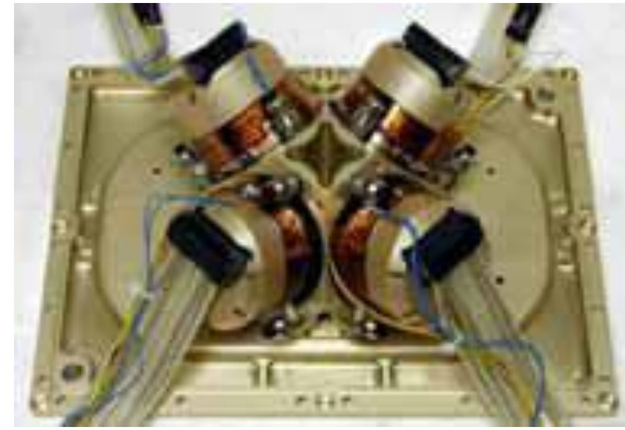
Hemispherical Resonator Gyroscope

High-end gyroscope for aerospace applications (Northrop Grumman)



Hemispherical resonator made of fused silica ($Q = 25 \times 10^6$)

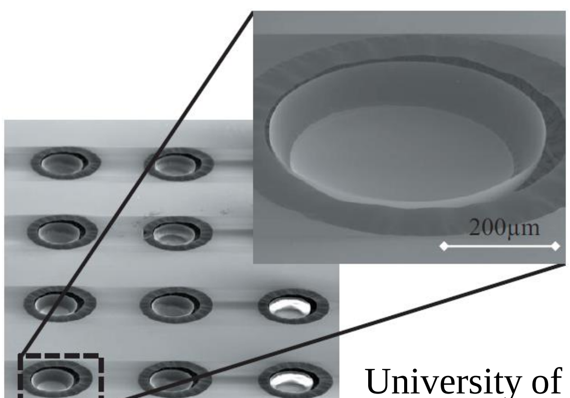
Bias stability 0.005 º/h



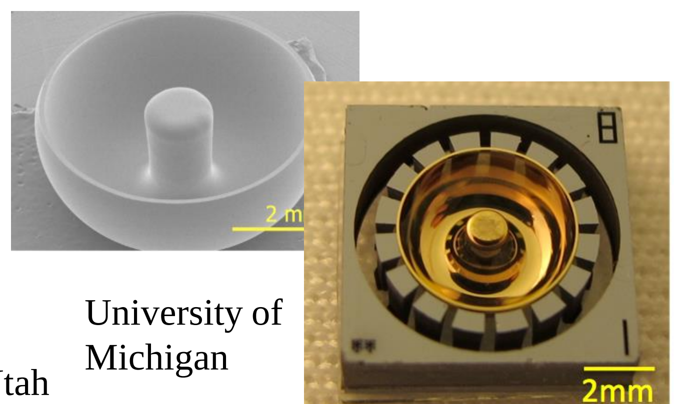
Bias stability 0.0005 º/h

Price ～1M US$?

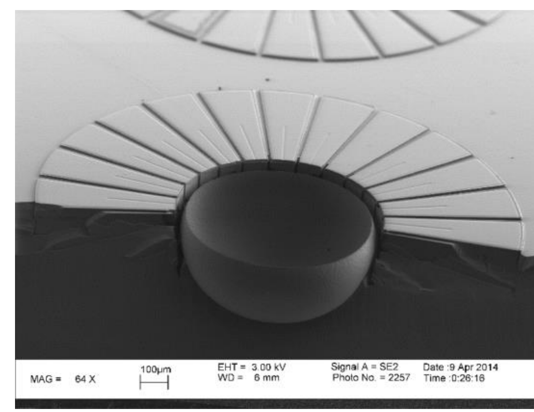
Miniaturization by MEMS technology (DARPA project)



University of Utah



University of Michigan



Georgia Institute of Technology

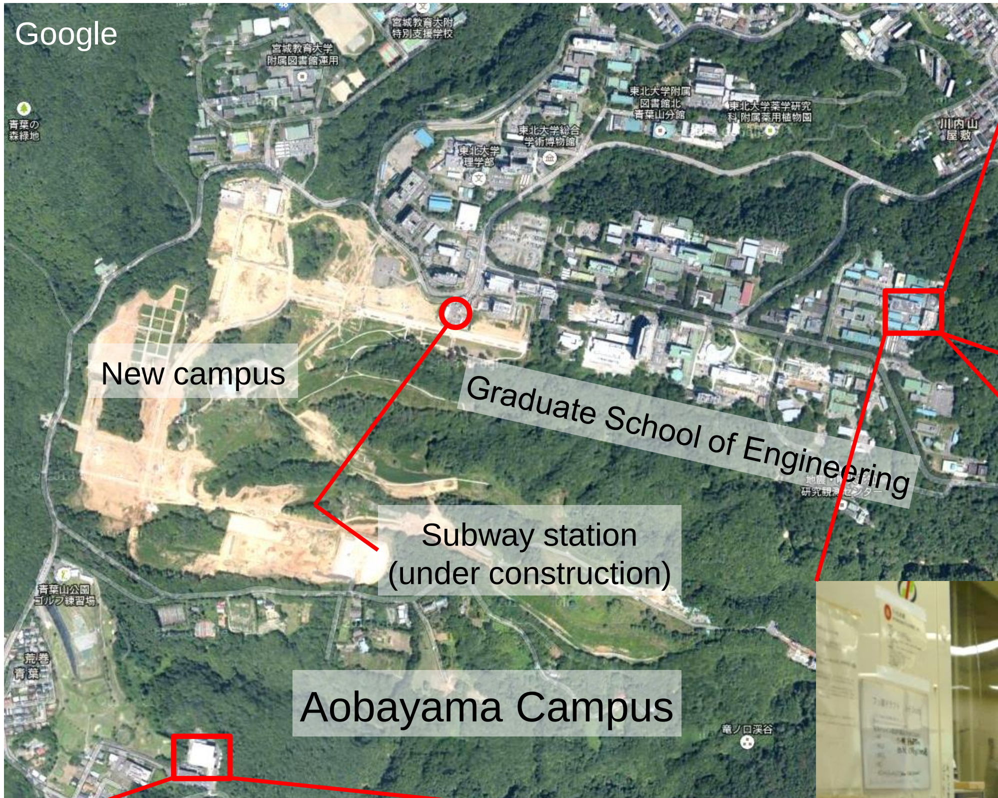
Summary

- A high-performance gyroscope of affordable price is a key component for autonomous cars.
- A bias stability of 0.1 º/h or better is required.
- This level of bias stability is realized by fiber optic gyroscopes, but the price is two or three orders of magnitude higher than expected.
- The required bias stability is two orders of better than that of the present MEMS gyroscopes for consumer applications.
- Drastic improvement in the performance of MEMS gyroscopes is theoretically possible but practically challenging.

【Requirements】

- Perfectly-symmetric two-axis orthogonal resonators with ultrahigh quality factor
- Advanced control system to compensate any imperfection and low-noise analog frontend

MEMS Facilities in Aobayama Campus



Micro/Nano-Machining Research and Education Center (MNC)

Microsystem Integration Center

S. Tanaka Laboratory Cleanroom

MEMS R&D Centers

- From proof-of-concept on small pieces to prototype development on 4 or 6 inch wafers
- Prototyped devices in Microsystem Integration Center can be basically utilized for business, i.e. as commercial samples and provisional products.
- For mass-production in small-to-medium volume, developed technology can be smoothly transferred to our partner foundry, MEMS Core in Sendai, Japan.

S. Tanaka Lab's cleanroom

Small piece

Micro/Nano-Machining Research & Education Center

4 inch wafer

Microsystem Integration Center (μSIC)

6 inch wafer

Micro Electro Mechanial Systems lab
Tanaka Shuji Laboratory

Tohoku University, Department of Bioengineering and Robotics

S. Tanaka Laboratory

Chair of Advanced Bio-Nano Devices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Please visit S. Tanaka Laboratory website
at http://www.mems.mech.tohoku.ac.jp/index_e.html

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Matsushima Bay and Sendai MEMS City

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