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# Micro-angle tilt detection for the rotor of a novel rotational gyroscope with 0.47" resolution

**Key words:** Micro-angle detection; Differential capacitive structure; Rotational gyroscope

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# Introduction

- A differential capacitive detecting structure is presented to measure the tilt angle of the rotor of a novel rotational gyroscope. It has potential to obtain higher structural sensitivity than the detecting structures used in levitated rotational gyroscopes.
- Little has been reported on tilt angle measurement of the rotors of rotational gyroscopes using differential capacitive detection.
- An ASIC is designed to convert differential capacitance changes to voltage signals in this work.

# Gyro and its detecting structure

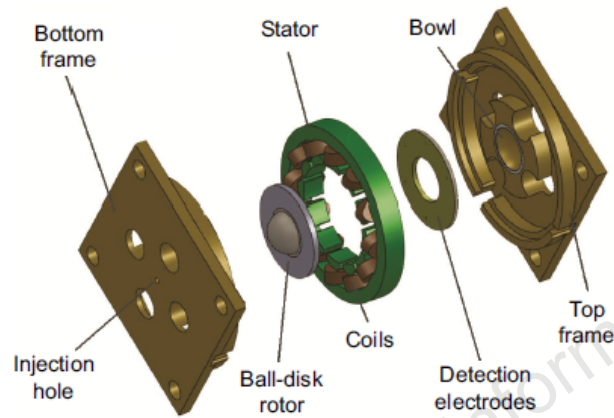


Fig. 1 Assembly drawing of the mechanical structure of the gyroscope

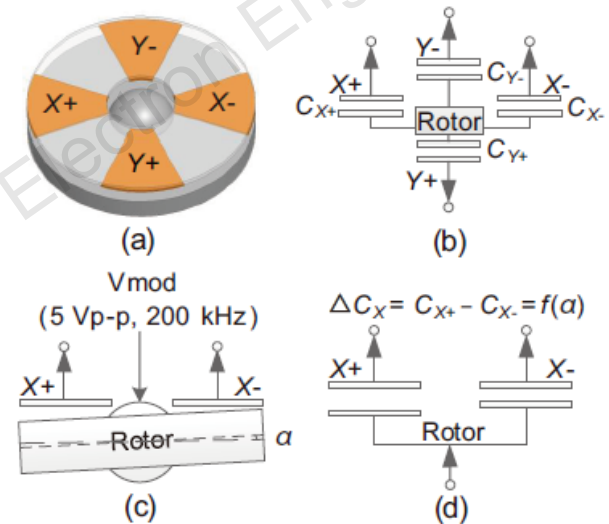


Fig. 2 Schematic of the micro-angle detecting structure (a) and its equivalent circuit (b), and schematic of the detection structure when the rotor tilts away from its null position (c) and its equivalent circuit (d)

# Modeling of the detecting structure

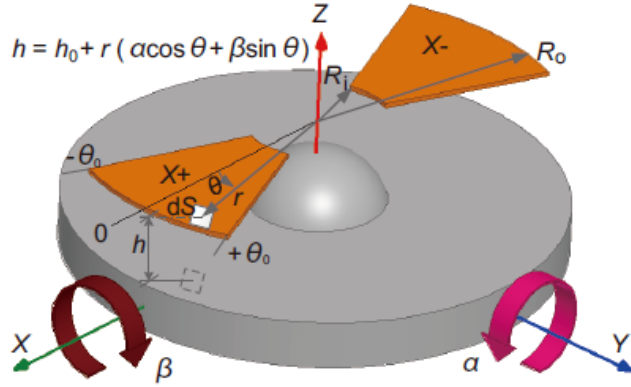


Fig. 3 The differential capacitor pair formed by electrodes  $X+$  and  $X-$  with the rotor where the capacitances are functions of the tilt angles of the rotor

$$\Delta C_X = -4\varepsilon \sum_{\substack{n=2M+1 \\ M=0}}^{M=\infty} \frac{R_o^{n+2} - R_i^{n+2}}{n(n+2)h_0^{n+1}} \sum_{\substack{k=2N+1 \\ N=0}}^{N=\frac{n-1}{2}} \binom{n}{n-k} \sin^{n-k+1} \theta_0 \cos^{k-1} \theta_0 \cdot \left[ 1 + \sum_{l=1}^{\frac{k-1}{2}} \left( \prod_{m=0}^{m=l-1} \frac{k-1-2m}{n-2-2m} \right) \cos^{-2l} \theta_0 \right] \alpha^k \beta^{n-k}.$$

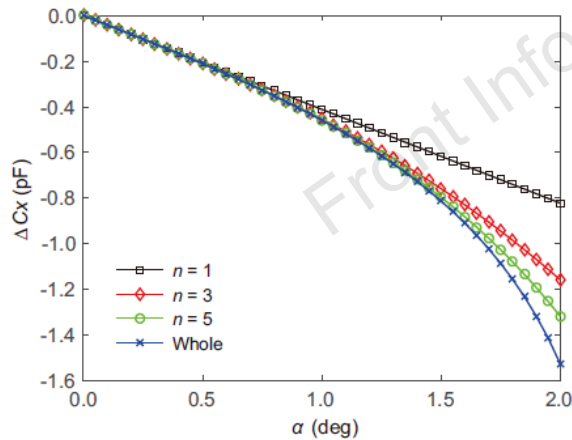


Fig. 5 Comparison of differential capacitances as functions of  $\alpha$  between calculation results ( $n = 1, 3, 5$ ) and numerical integration ( $R_i$ ,  $R_o$ ,  $h_0$ , and  $\theta_0$  are 2 mm, 5 mm, 200  $\mu\text{m}$ , and  $43^\circ$ , respectively)

$$\Delta C_X = -4\varepsilon \frac{R_o^3 - R_i^3}{3h_0^2} \alpha \sin \theta_0 - 4\varepsilon \frac{R_o^5 - R_i^5}{15h_0^4} \cdot [(\cos^2 \theta_0 + 2)\alpha^3 \sin \theta_0 + 3\alpha\beta^2 \sin^3 \theta_0] - \dots$$

# Optimization of the detecting structure

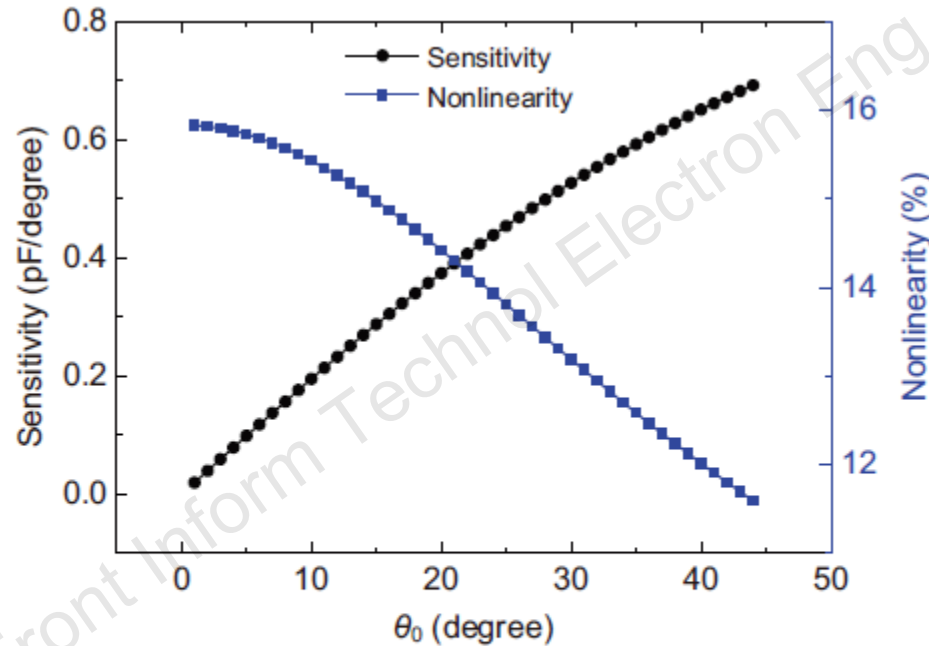


Fig. 4 Structure sensitivity and nonlinearity as functions of  $\theta_0$  when  $R_i$ ,  $R_o$ , and  $h_0$  are 2 mm, 5 mm, and 200  $\mu\text{m}$ , respectively. The maximum tilt angle is  $2^\circ$  determined by the structure parameters

# Detecting circuit

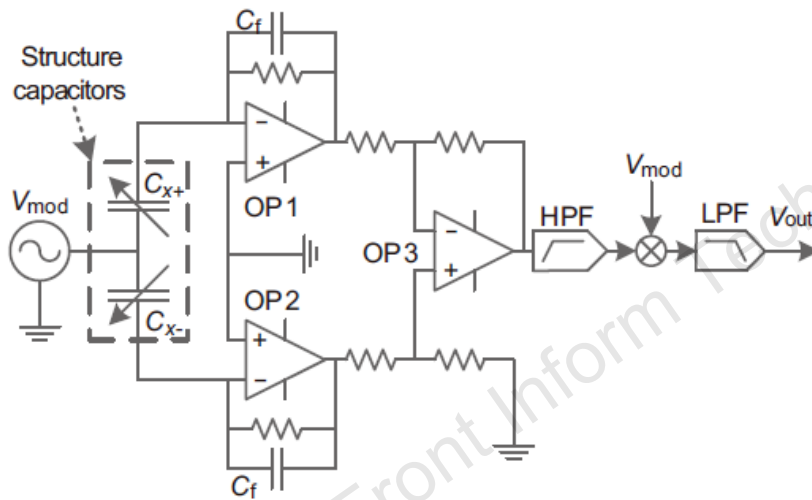


Fig. 6 Schematic of the detection circuit

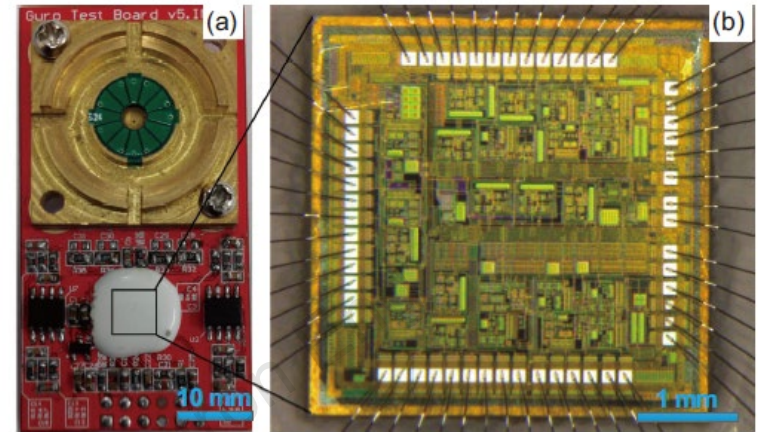


Fig. 7 Detection board (a) and micrograph of the readout ASIC (b)

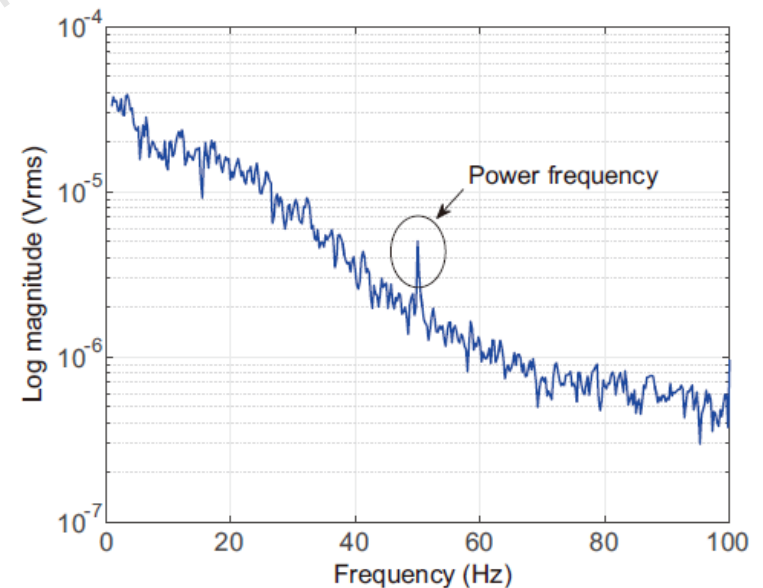


Fig. 8 Static output noise of the detection circuit

# Measurement

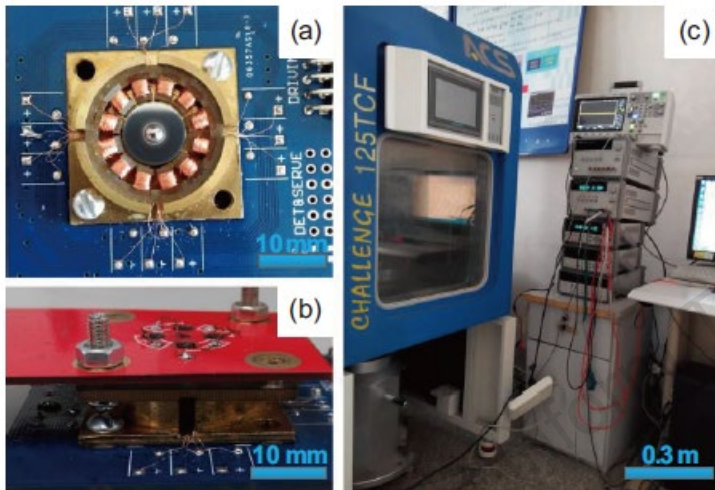


Fig. 9 Driving structure of the gyroscope with its rotor running at 7000 r/min (a), gyroscope structure (b), and the rate table test platform (c)

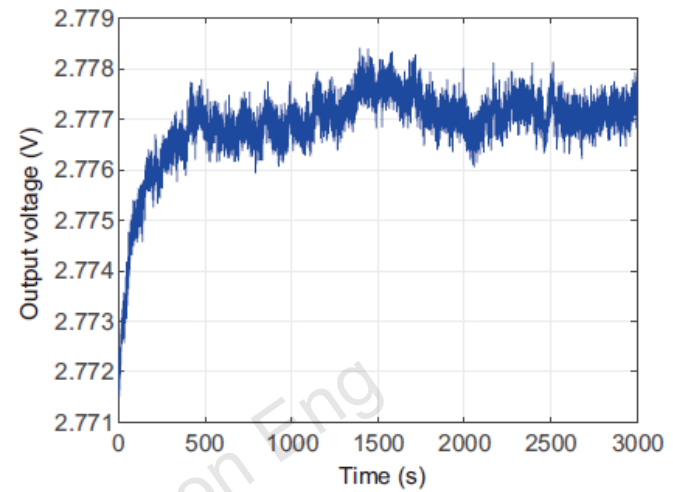


Fig. 10 Static output voltage of the detection circuit with the rotor rotating at 7000 r/min, measured for 50 min after the rotor reaches the speed

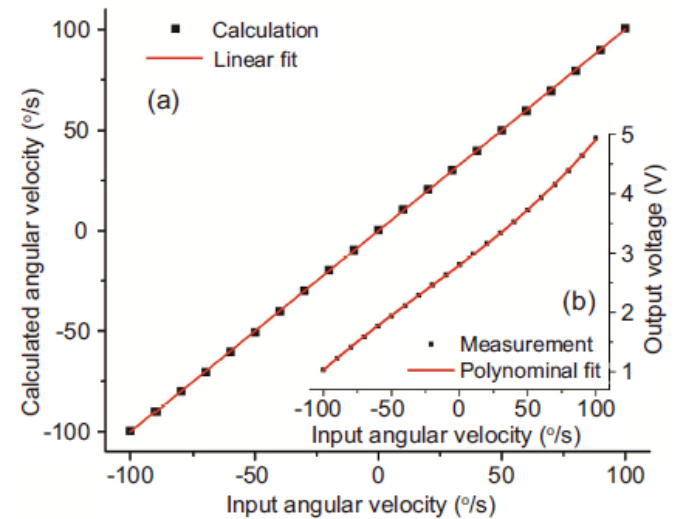


Fig. 11 Calculated angular velocity versus input angular velocity (a) and cubic polynomial fitting of the stable detection circuit output versus input angular velocity (b)

# Performance comparison

**Table 1** Comparison of this work and the literature

| Reference                  | Circuitry | Resolution | Nonlinearity |
|----------------------------|-----------|------------|--------------|
| Huang <i>et al.</i> (2007) | PCB       | 0.04°      | 2.3%         |
| This work                  | ASIC      | 0.00013°   | 0.33%        |

# Conclusions

- A special differential capacitive detection structure is presented to detect the tilt angle of the rotor of a novel rotational gyroscope.
- A detailed model of the differential capacitance of the detection structure is built and used to optimize the size parameters of the detecting structure.
- Test on the gyro shows that the smallest resolvable tilt angle of the detecting structure is less than  $0.47''$ , which can be further improved.