



## Electrical characterization of MEMS gyroscopes with fast frequency sweeps

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# Electrical characterization of MEMS gyroscopes with fast frequency sweeps

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## High- $Q$ , low- $f_0$ resonator parameter estimation

- Obtaining the steady-state response (e.g. Nyquist diagram) from a high- $Q$ , low- $f_0$  resonator requires extremely long acquisitions
  - unpractical
  - cost of adequate environmental control
- Ringdown response (linear/nonlinear) is the fastest estimation approach
  - some parameters are not identified (e.g. transduction efficiency)
  - relies on analytical expression of free resonator response
  - embedded/integrated implementation is difficult (in nonlinear case)

## Proposed approach (1-DOF resonator with polynomial nonlinearity)

- Excite resonator with

$$v_{exc}(t) = V_{exc}(t) \sin \int \omega(t) dt$$

with slowly-varying  $V_{exc}(t)$  and  $\omega(t)$

- Measure (complex) resonator output  $X(t)$
- Estimate  $\dot{X}(t)$ , e.g.

$$\hat{\dot{X}}(t_k) = \frac{X(t_{k+1}) - X(t_{k-1})}{t_{k+1} - t_{k-1}}$$

- Determine parameters  $\Theta = (g, C_0, \dots, C_n)$  in resonator model

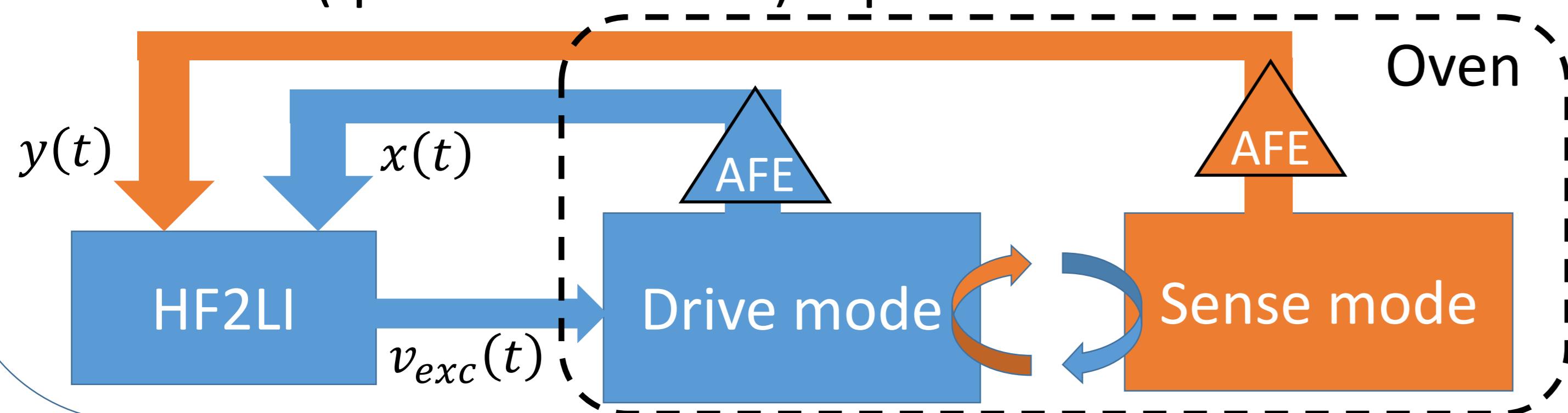
$$F(t, \dot{X}(t), X(t), \Theta) \equiv 2j\omega(t)\dot{X} + \left( C_0 + \sum_{i=1}^n C_i |X|^{2i} - \omega(t)^2 \right) X - gV_{exc}(t) = 0$$

$$\hat{\Theta} = \arg \min \sum_{k=2}^{N-1} \left| F(t_k, \hat{\dot{X}}(t_k), X(t_k), \Theta) \right|^2$$

- Linear LS solution for all  $V_{exc}(t)$  and  $\omega(t)$ , even in nonlinear resonator case!
- Extension to more DOFs is straightforward

## Experimental setup and method

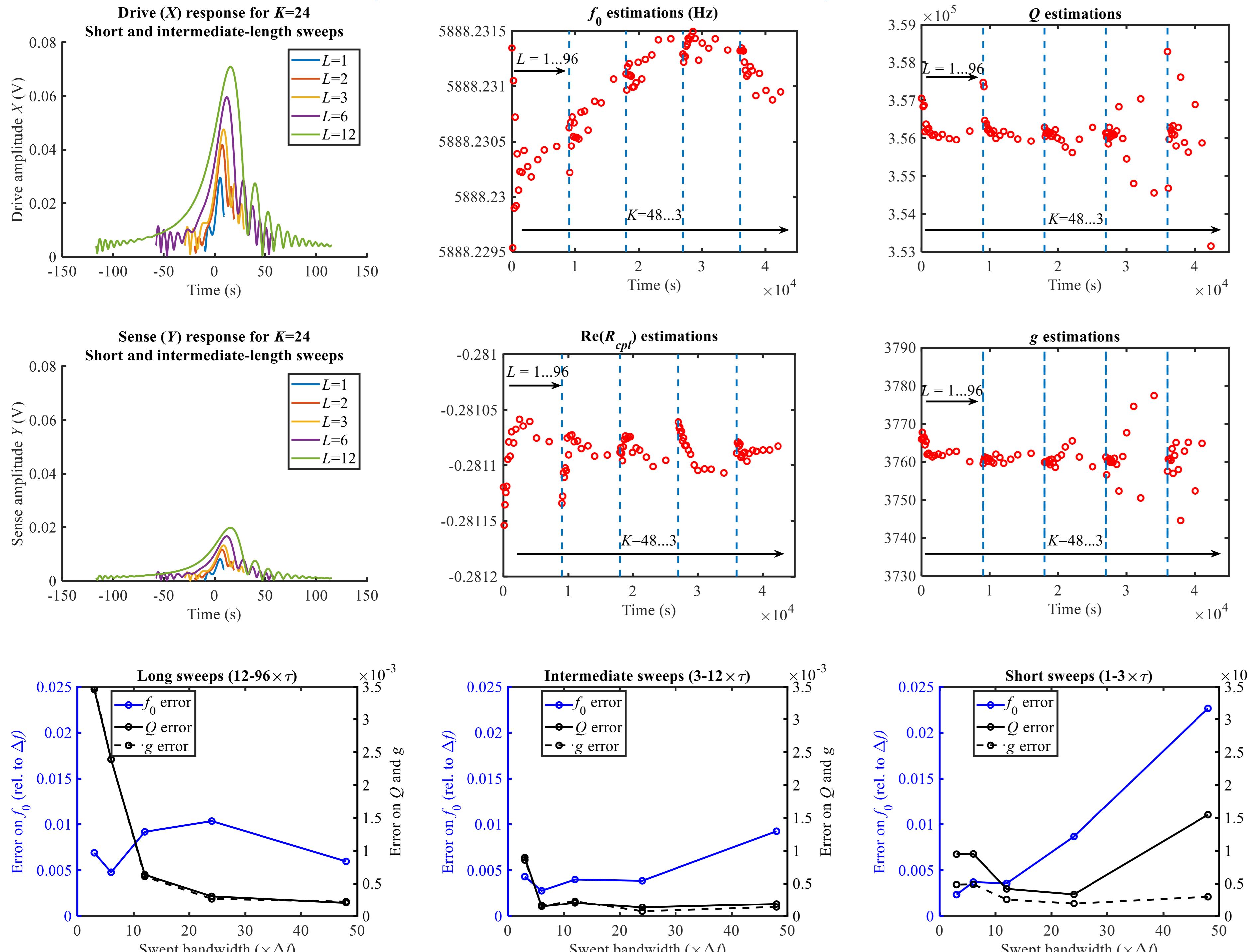
- ONERA's VIG gyroscope
  - 2-DOF resonator
  - Drive mode characteristics :  $f_0 \approx 5888.2$  Hz,  $Q \approx 3.6 \times 10^5$ ,  $\Delta f = f_0/2Q \approx 8.2$  mHz,  $\tau \approx 19.5$  s
  - Sense-drive frequency mismatch  $\approx 111$  Hz
  - Near to no feedthrough, but mechanical coupling (quadrature error) is present



- Resonator is placed inside  $\pm 0.1$  °C regulated oven
- Drive mode is harmonically excited with lock-in amplifier, both drive ( $X$ ) and sense ( $Y$ ) modes are detected
  - « Fast » linear frequency sweeps around  $f_0$
  - Sweep bandwidth  $K \times \Delta f$ ,  $K = 48, 24, 12, 6, 3$
  - Sweep duration  $L \times \tau$ ,  $L = 1, 2, 3, 6, 12, 24, 48, 96$
  - 2 sweeps performed for each  $\{K, L\}$
- estimate drive mode parameters with proposed approach
- estimate coupling coefficient  $R_{cpl}$  from

$$(\hat{R}_{cpl}, \hat{R}_{FT}) = \arg \min \sum_{k=1}^N \left| Y(t_k) - R_{cpl}X(t_k) - R_{FT}V_{exc} \right|^2$$

## Raw data, extracted parameters and uncertainty assessment



- Visible drift in  $f_0$  over time (follows temperature regulation)
- Overall excellent estimation of resonator parameters (better than 0.1% for  $Q$  and  $g$ , than 1% for  $f_0$  w.r.t.  $\Delta f$ )
- For small bandwidths / long durations,  $Q$  and  $g$  estimations have « large » variance, with strong correlation
- For large bandwidths / small durations, errors result from finite difference approximation and from reduced SNR
- 1st coefficient of nonlinearity ( $C_1$ ) is close to zero

## Conclusion

Experimental validation of a transient parameter estimation approach

- nearly as fast as ringdown
- model- and response-agnostic
- yielding all resonator parameters
- small computational and integration complexity
- moderate hardware requirements