MECHANICALLY AMPLIFIED HIGH-STABILITY MEMS GYROSCOPE

Daniel Lapadatu, *Technical Director*

Outline

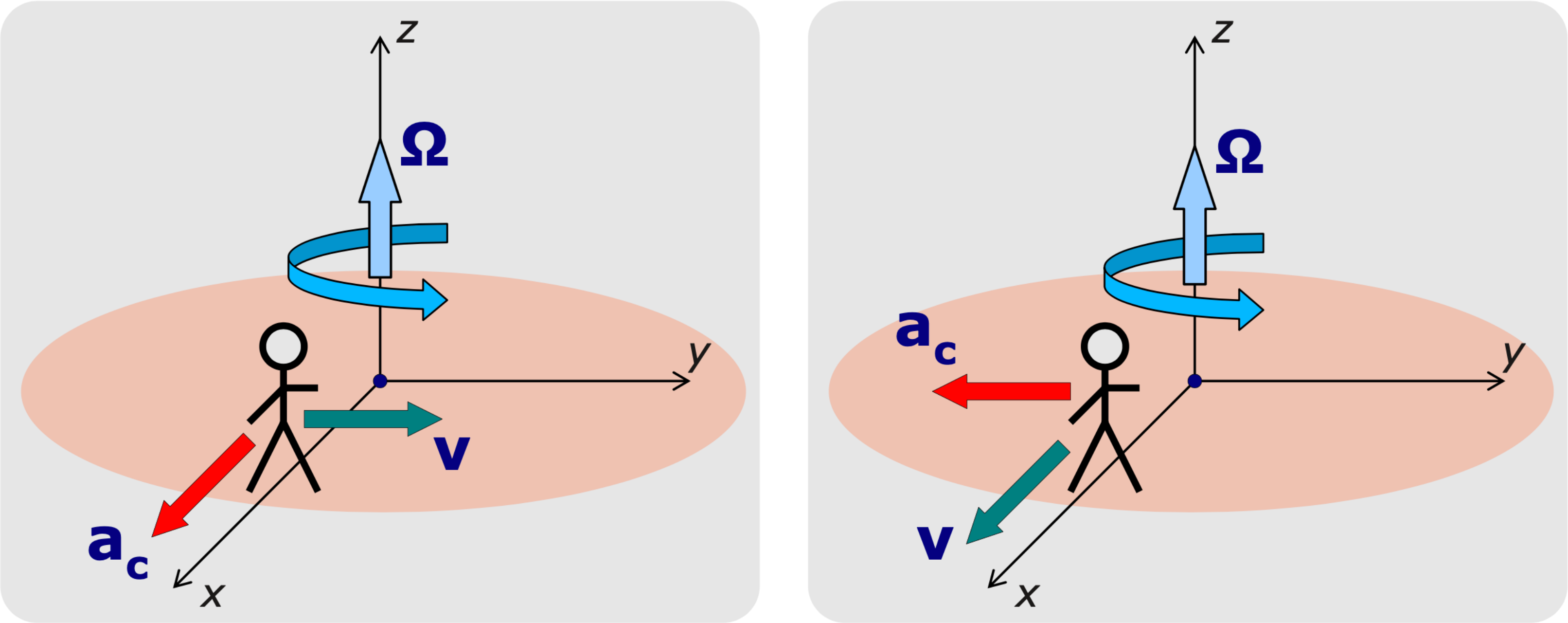
Introduction

- A new *family* of MEMS vibratory gyroscopes with:
  - Mechanically aplifyied Coriolis/sense movement;
  - Mechanically aplifyied drive and sense movements;
  - 2- or 4-mass variants;
  - Lever or frame variants;
  - High rejection of common-mode signals.
- Under fabrication at Philips Innovation Center.
- Patents pending.
- Application: inertial navigation of autonomous electrical vehicles.

Coriolis Force

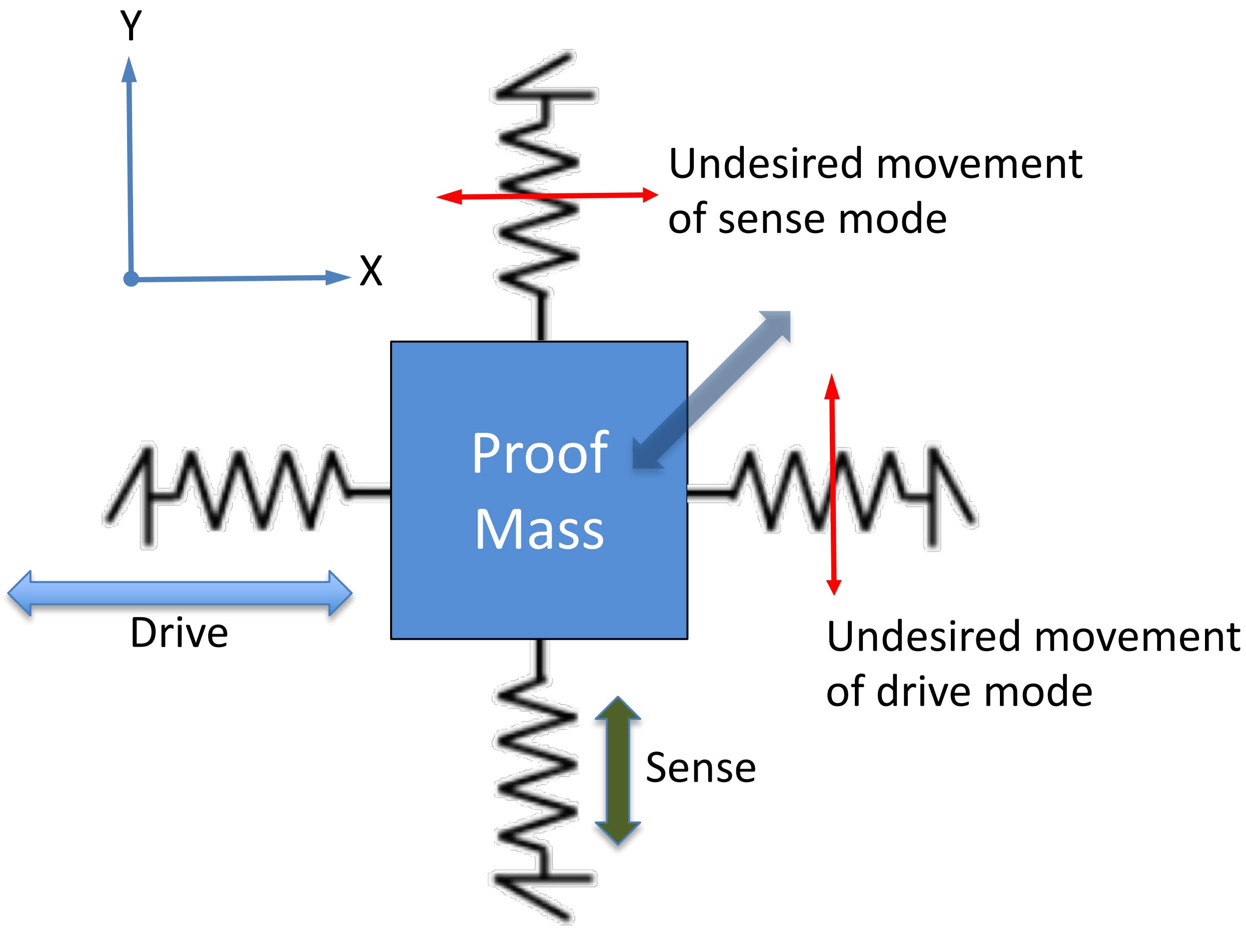
- Acts within *rotating* reference frames on masses that move with a non-zero *linear velocity*.

$$\mathbf{a_c} = 2 \cdot \mathbf{v} \times \mathbf{\Omega}$$

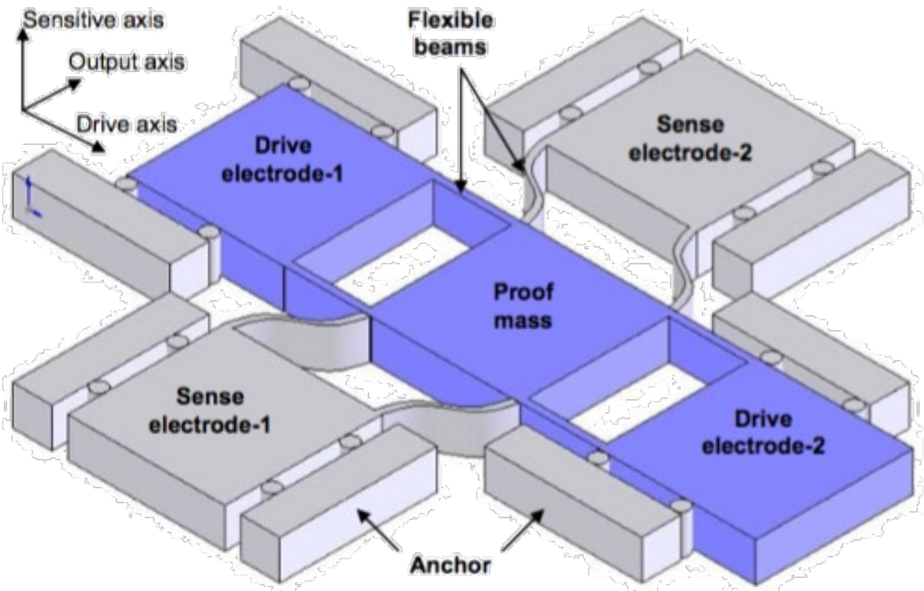


First MEMS Gyroscopes

- Single proof mass, with coupled modes.

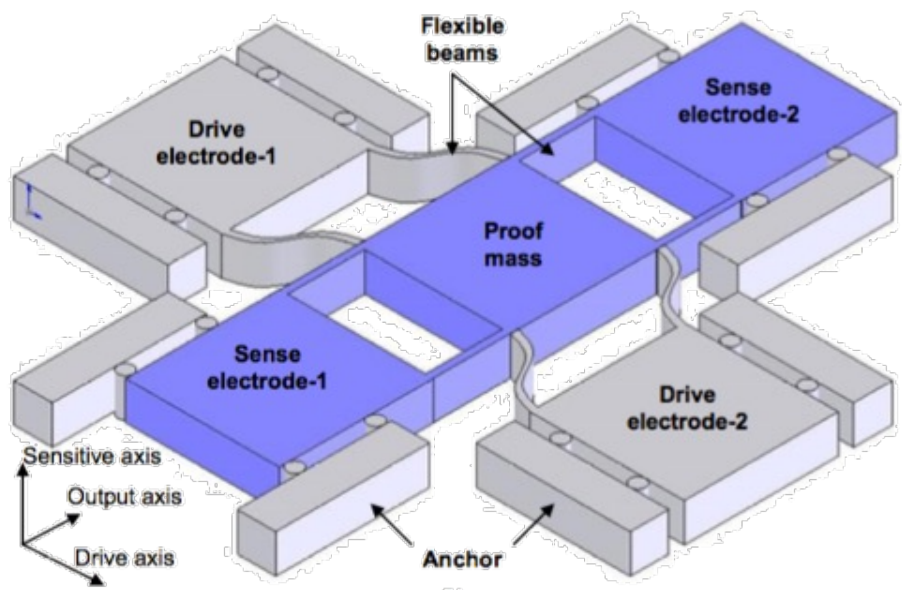


Decoupled Modes



Drive Mode

Sense Mode

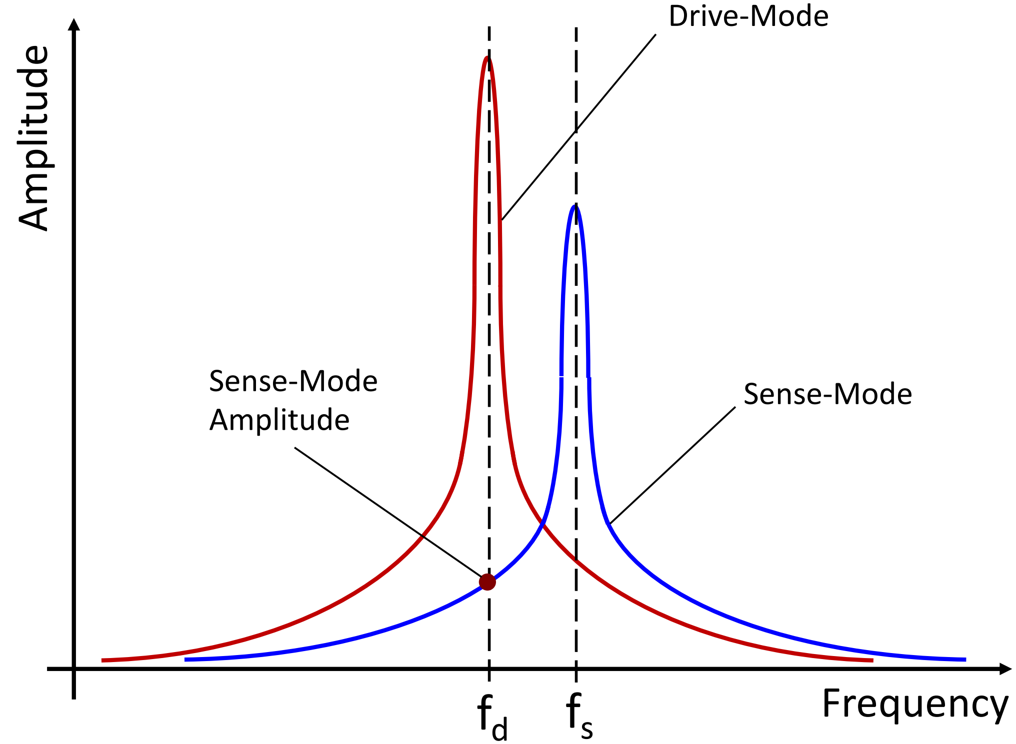


Sense Amplitude

$$Y0(\Omega) := 2 \cdot Q_{eff} \cdot k_g \cdot X_0 \cdot \frac{\Omega}{\omega_{s0}}$$

Q_{eff} - sensing mode effective Q-factor
k_g - angular gain factor (design choice)
X_0 - amplitude of drive mode
ω_{s0} - sense mode resonance frequency
Ω - input angular rate

- Linear with Ω,
  - provided X_0 is stable.
- Large signal,
  - provided Q_{eff} is large.
- Larger signal,
  - provided $k_g > 1$.

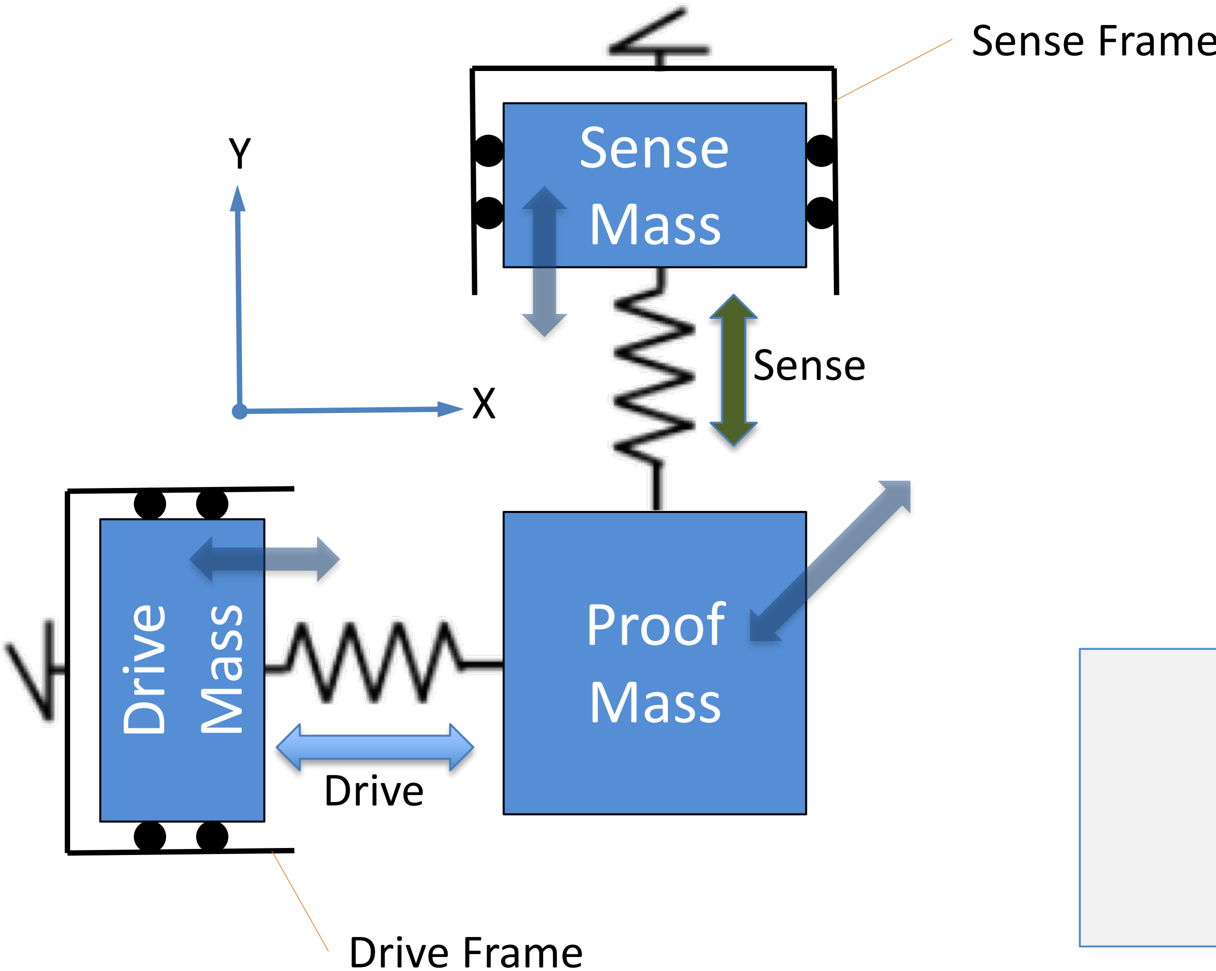


Specifications

PARAMETER	MIN	TYP	MAX	UNIT
Input range		± 400	± 499	°/s
Frequency Range (Bandwidth)	62	100		Hz
Scale Factor @ FSI		0.01		(°/s)/LSB
Non-Linearity		0.03		% FSO (@ 25 °C)
Scale Factor Temperature Coefficient			40	ppm/°C (@ 25 °C)
Angle Random Walk (ARW)		0.05	0.10	°/√h (@ 25 °C)
Bias Instability		0.5	1.0	°/h (@ 25 °C)
Bias Temperature Coefficient			± 1	(°/h)/°C (@ 25 °C)
G-Sensitivity		0.005		(°/s)/g
Shock Resistance	5000			g

Angular Gain Factor (1)

- Without mechanical amplification:

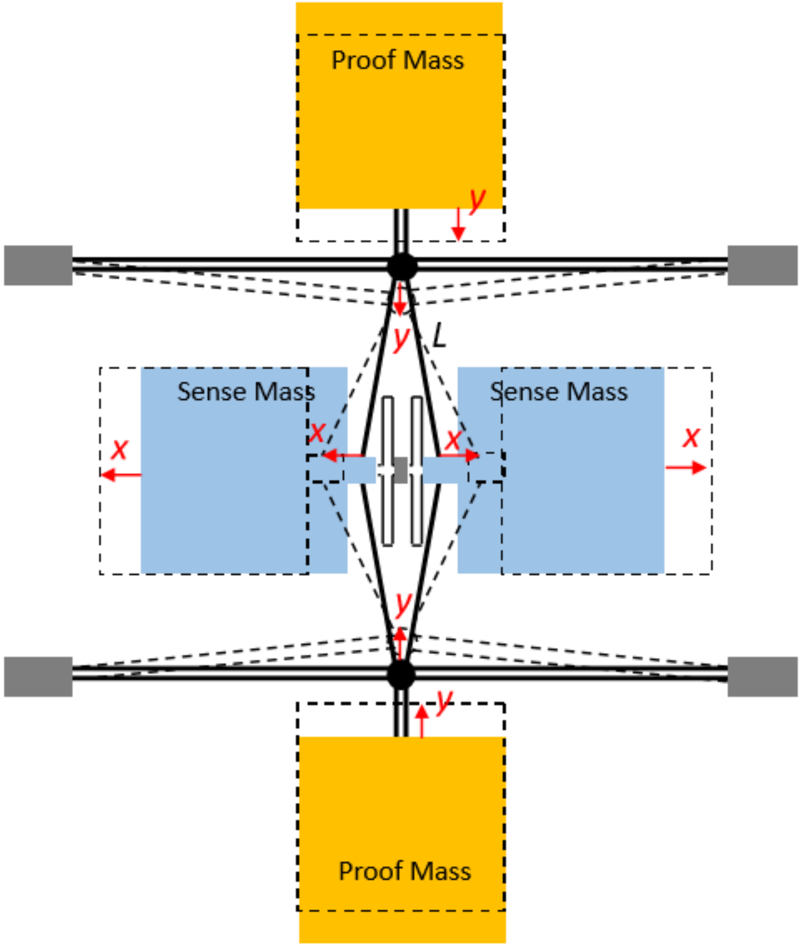


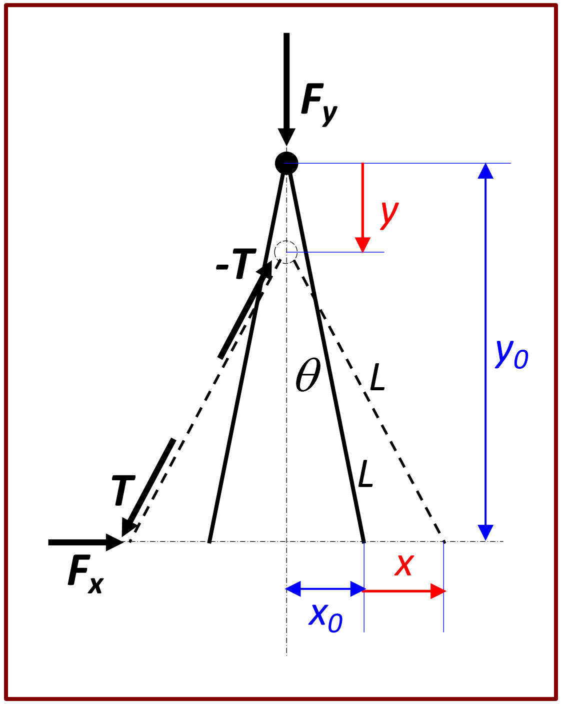
$$k_g = \frac{m_{proof}}{m_{proof} + m_{sense}} < 1$$

k_g is typically 0.85.

Angular Gain Factor (2)

- With mechanical amplification:





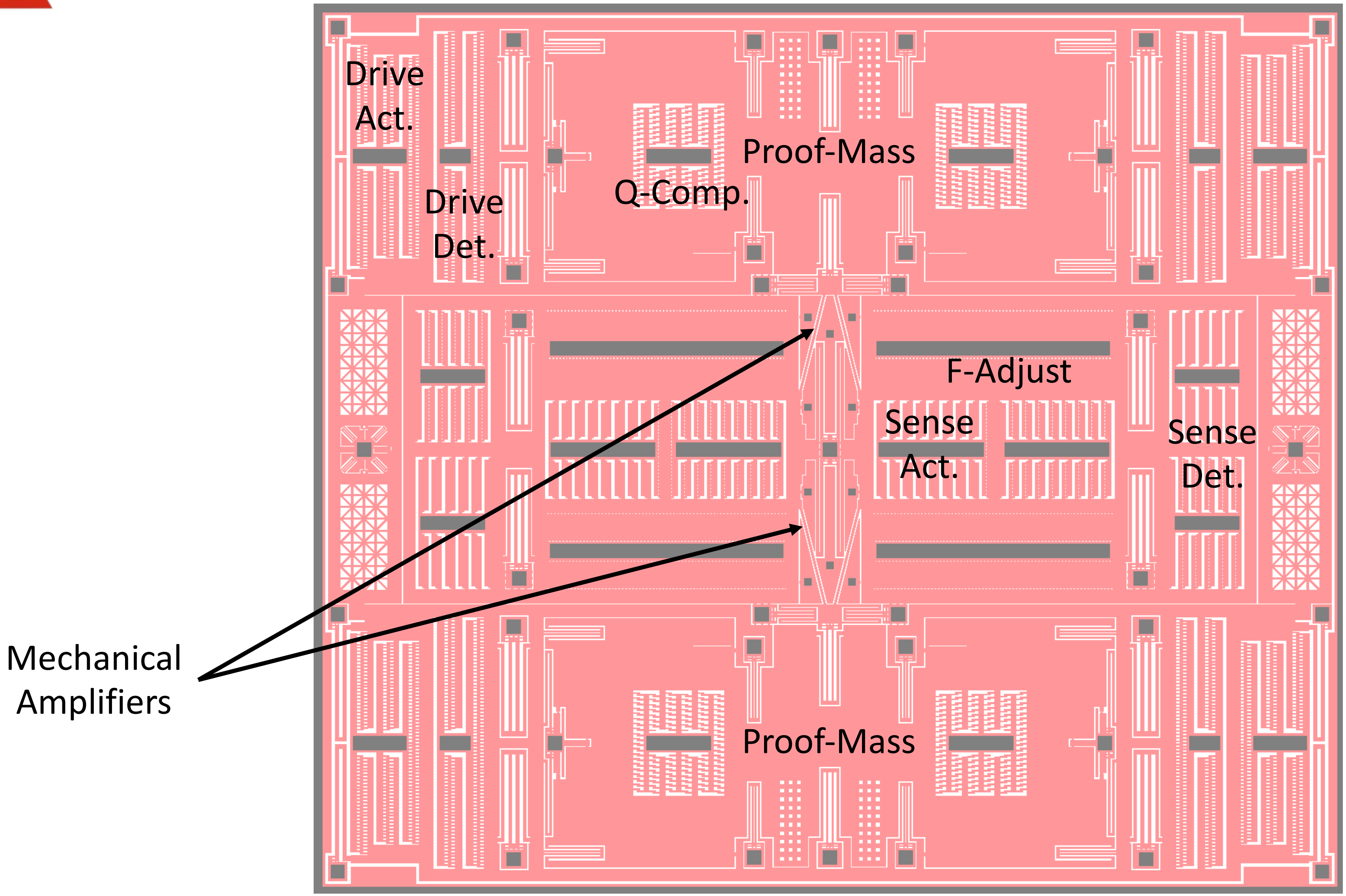
$$\zeta = \frac{x}{y} = \frac{1}{tan(\theta)}$$

$$F_x = \frac{F_y}{\zeta}$$

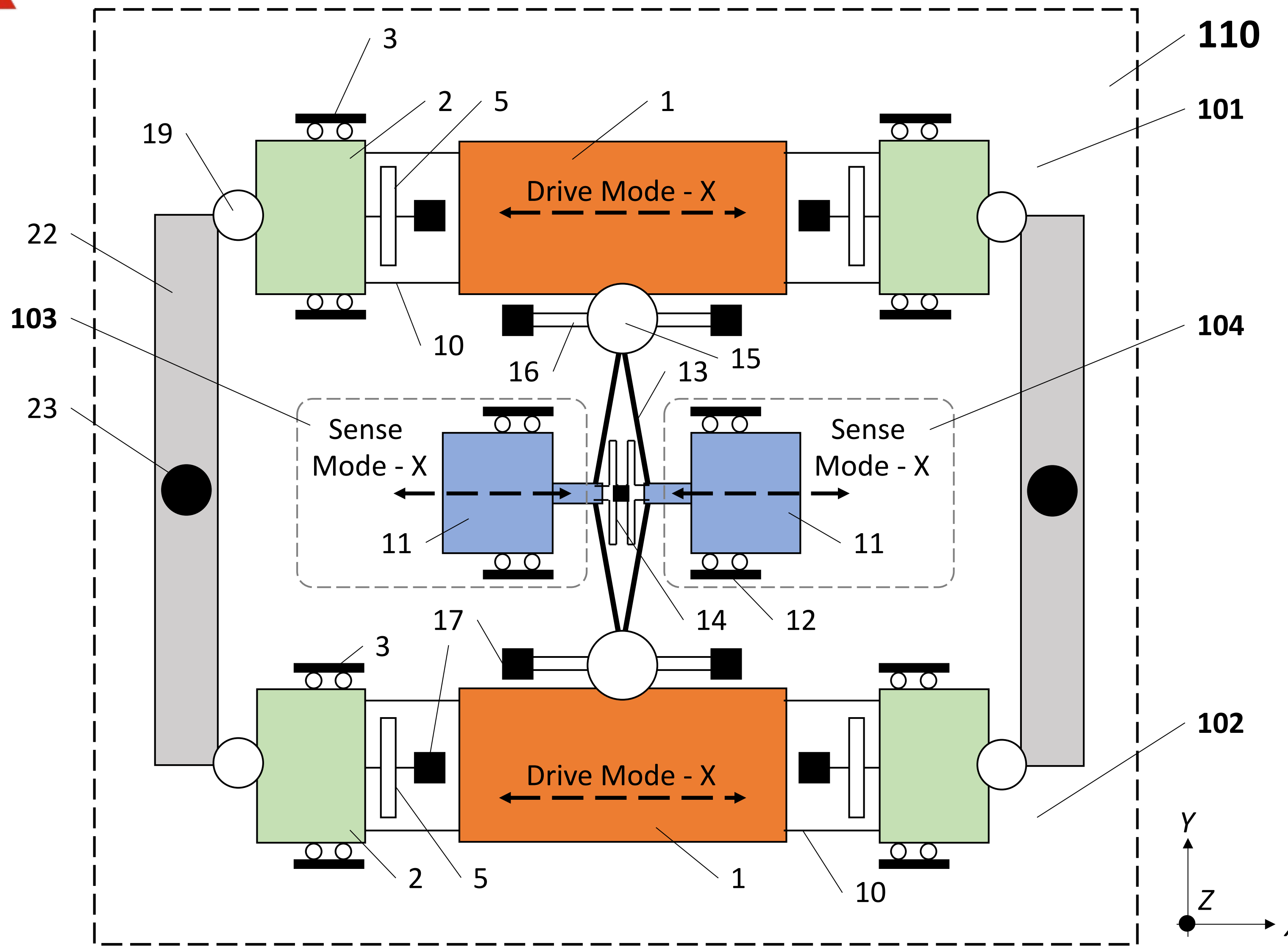
For θ = 15º, ζ = 3.73.

$$k_g = \frac{m_{proof}}{m_{proof} + m_{sense}} \cdot \zeta > 1$$

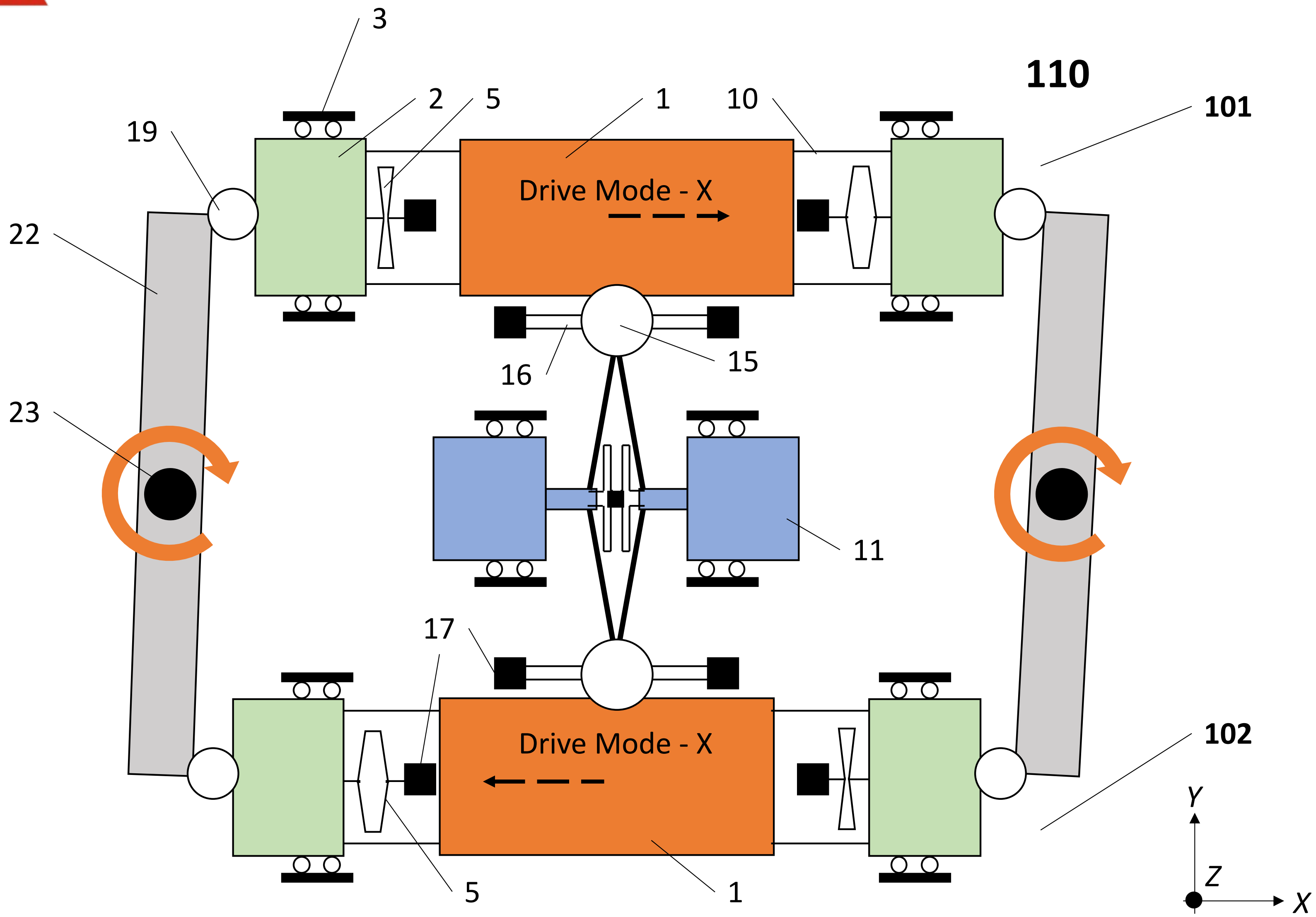
Layout of 2-Mass Gyro



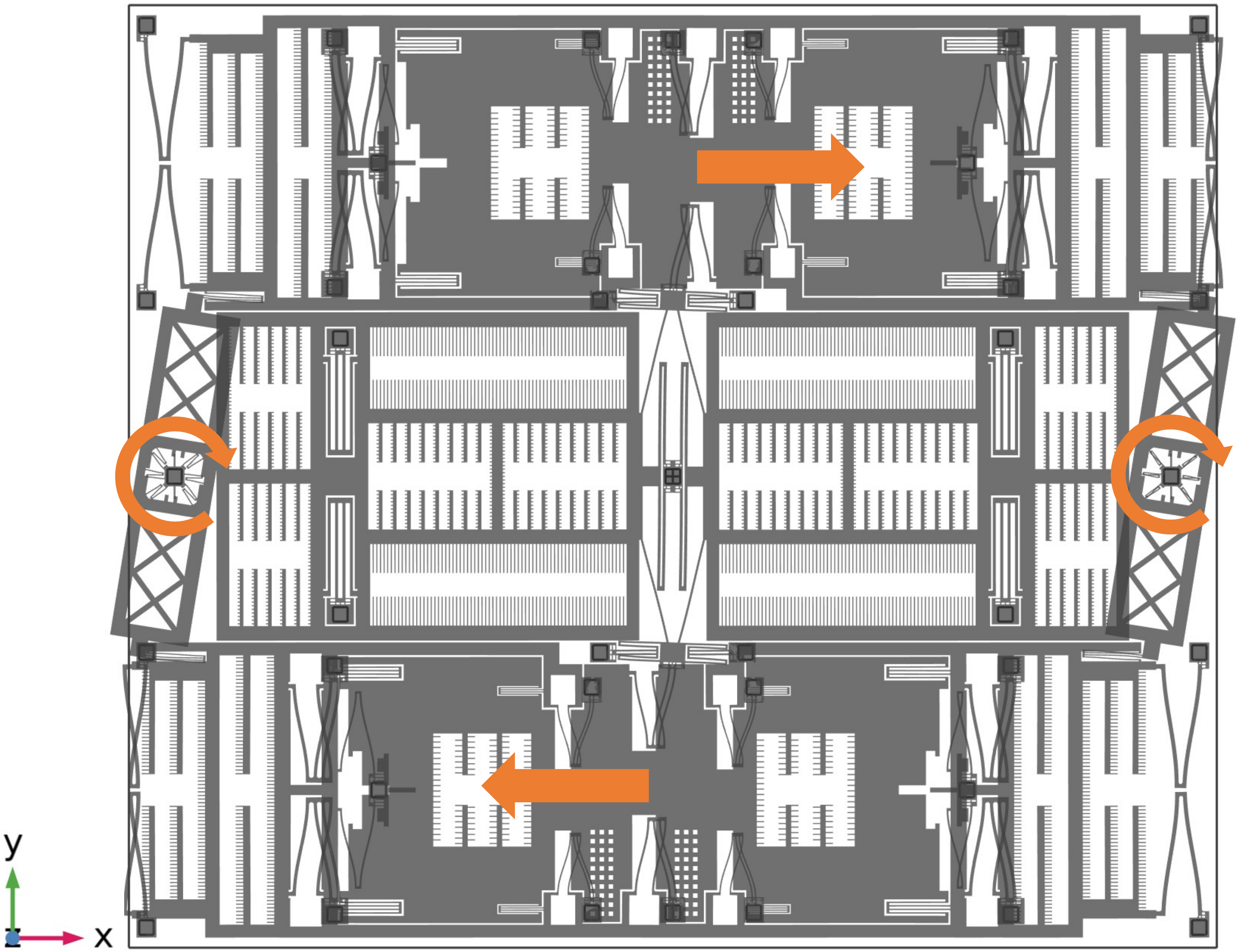
Schematic of 2-Mass Gyro



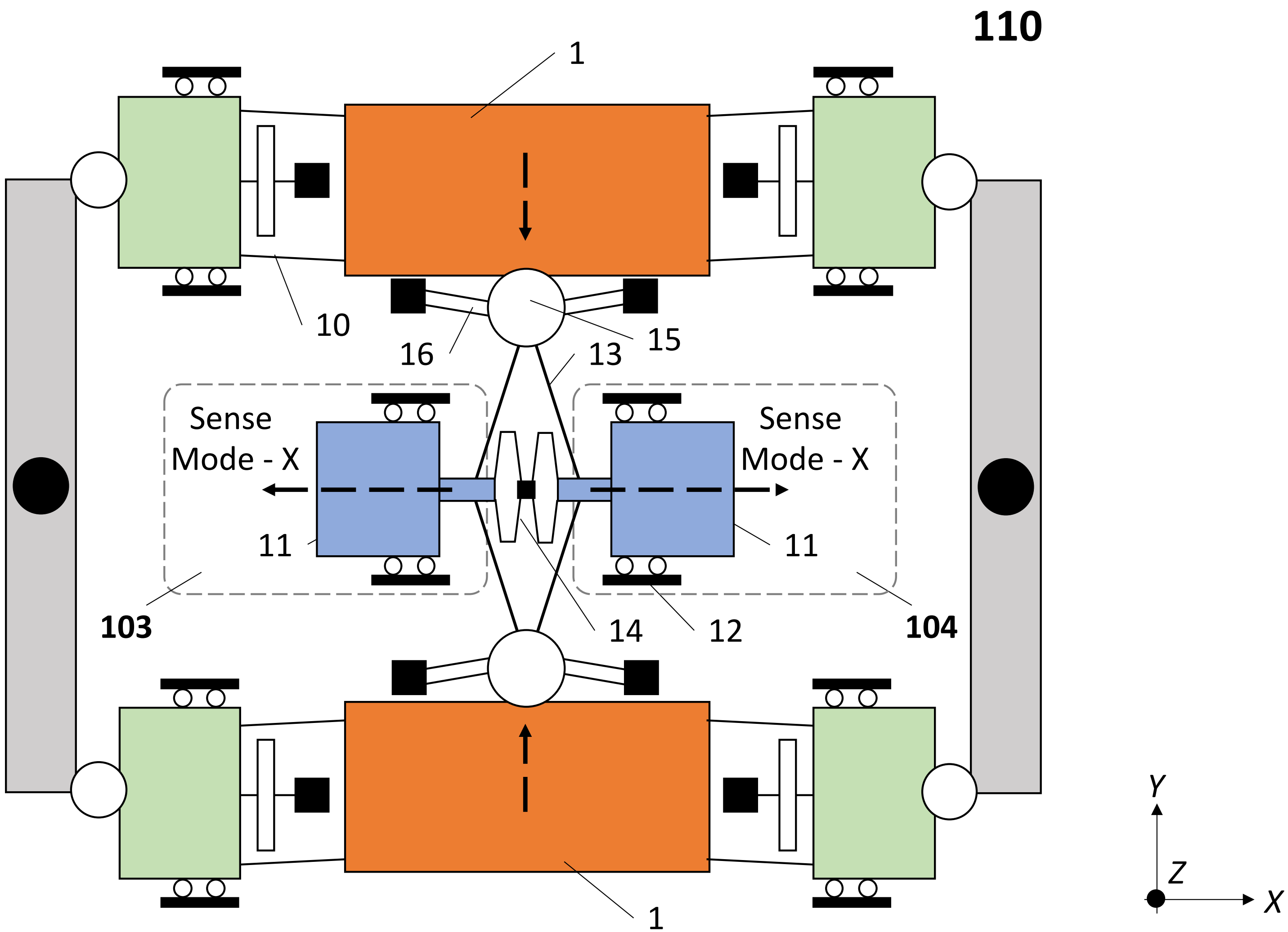
Drive Mode Schematic



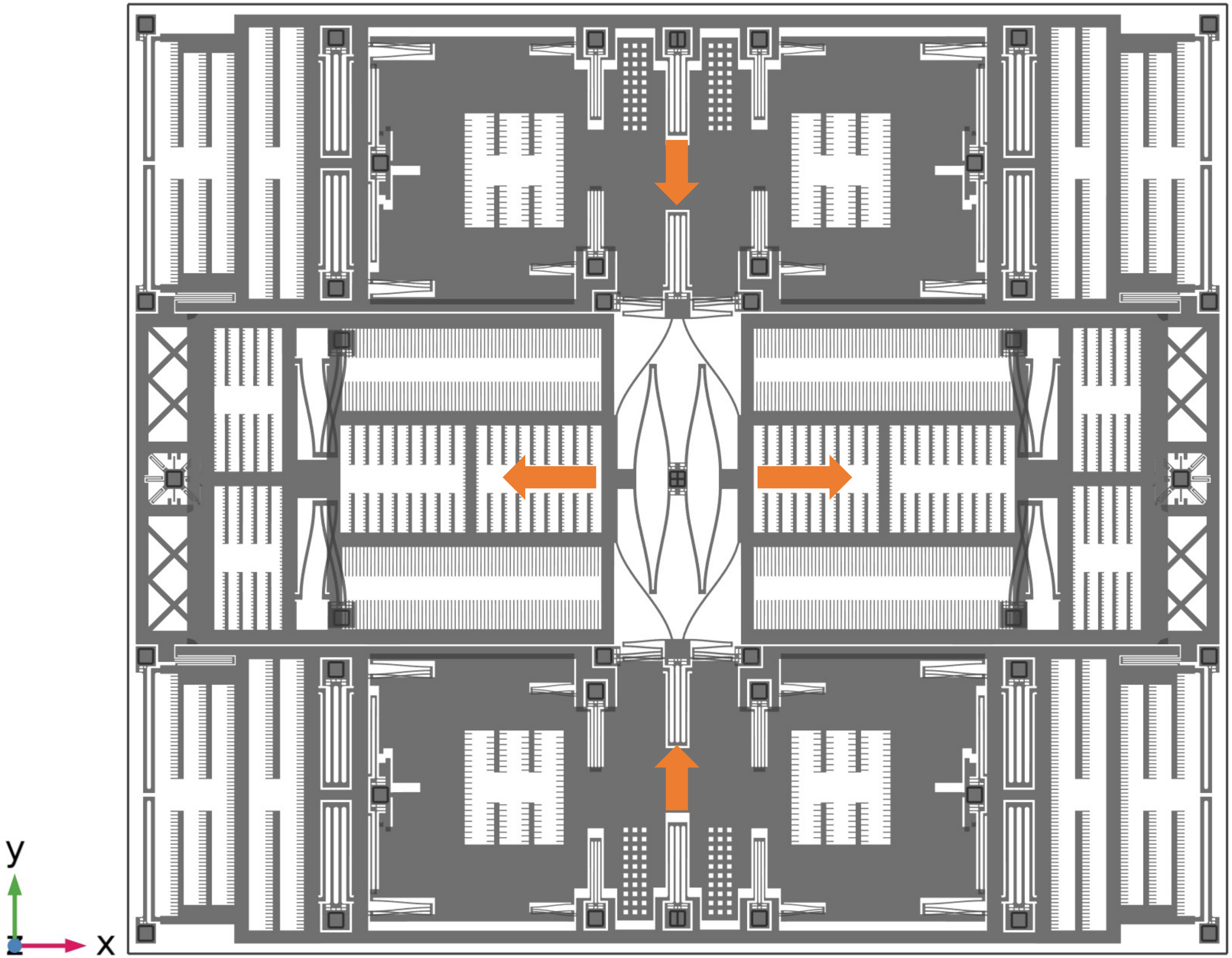
Drive Mode – 10000 Hz



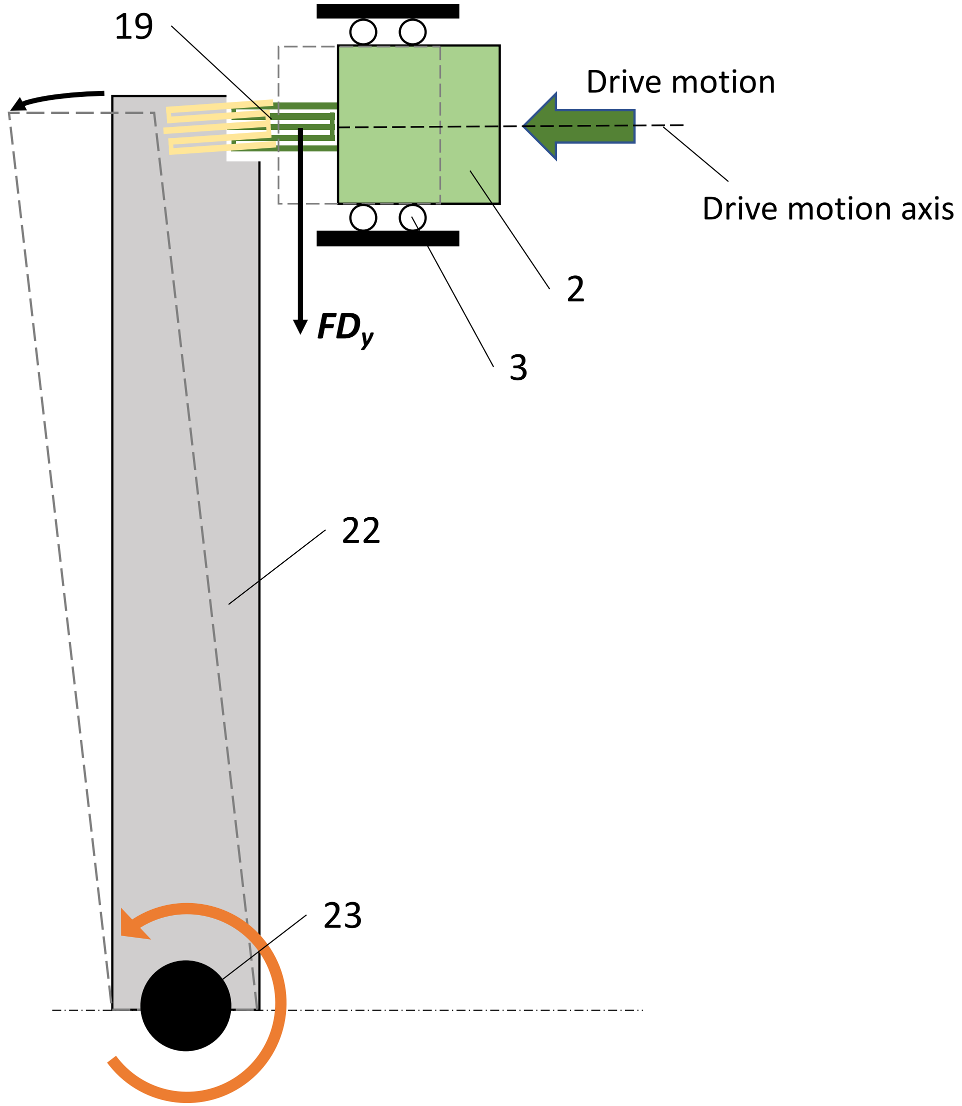
Sense Mode Schematic



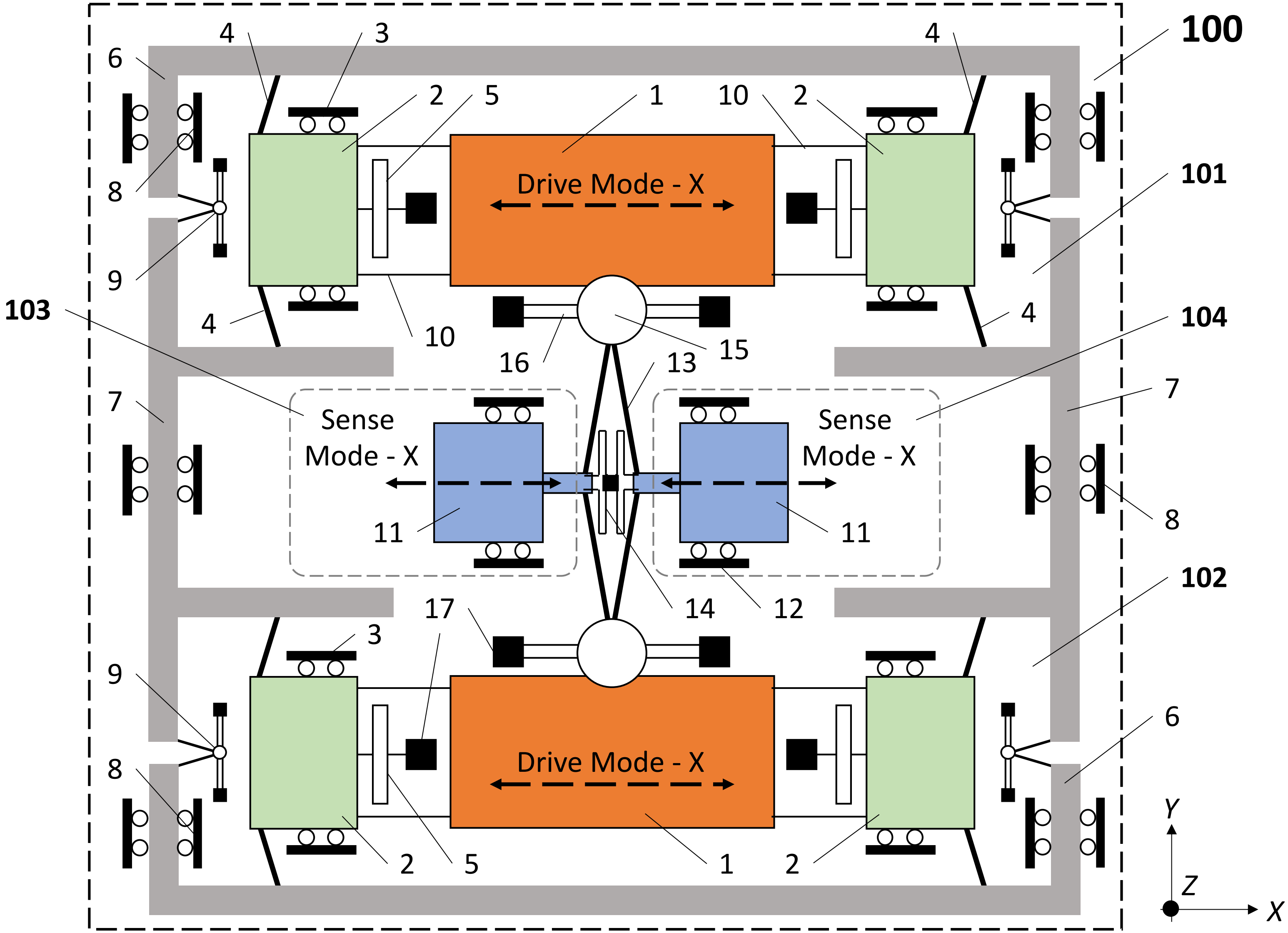
Sense Mode – 10100 Hz



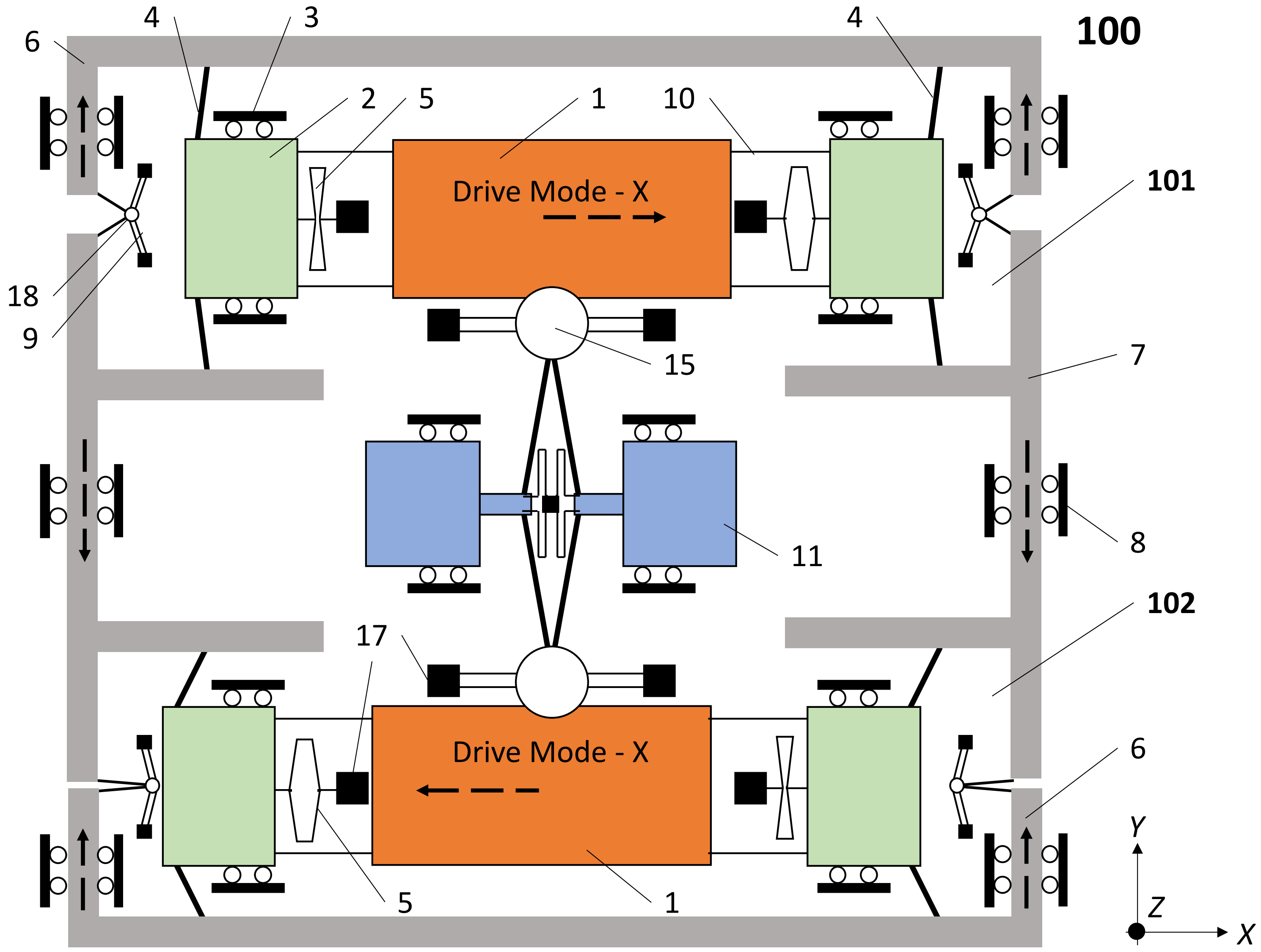
Lever Decoupler



Drive- and Sense-Amplified 2-Mass Gyro

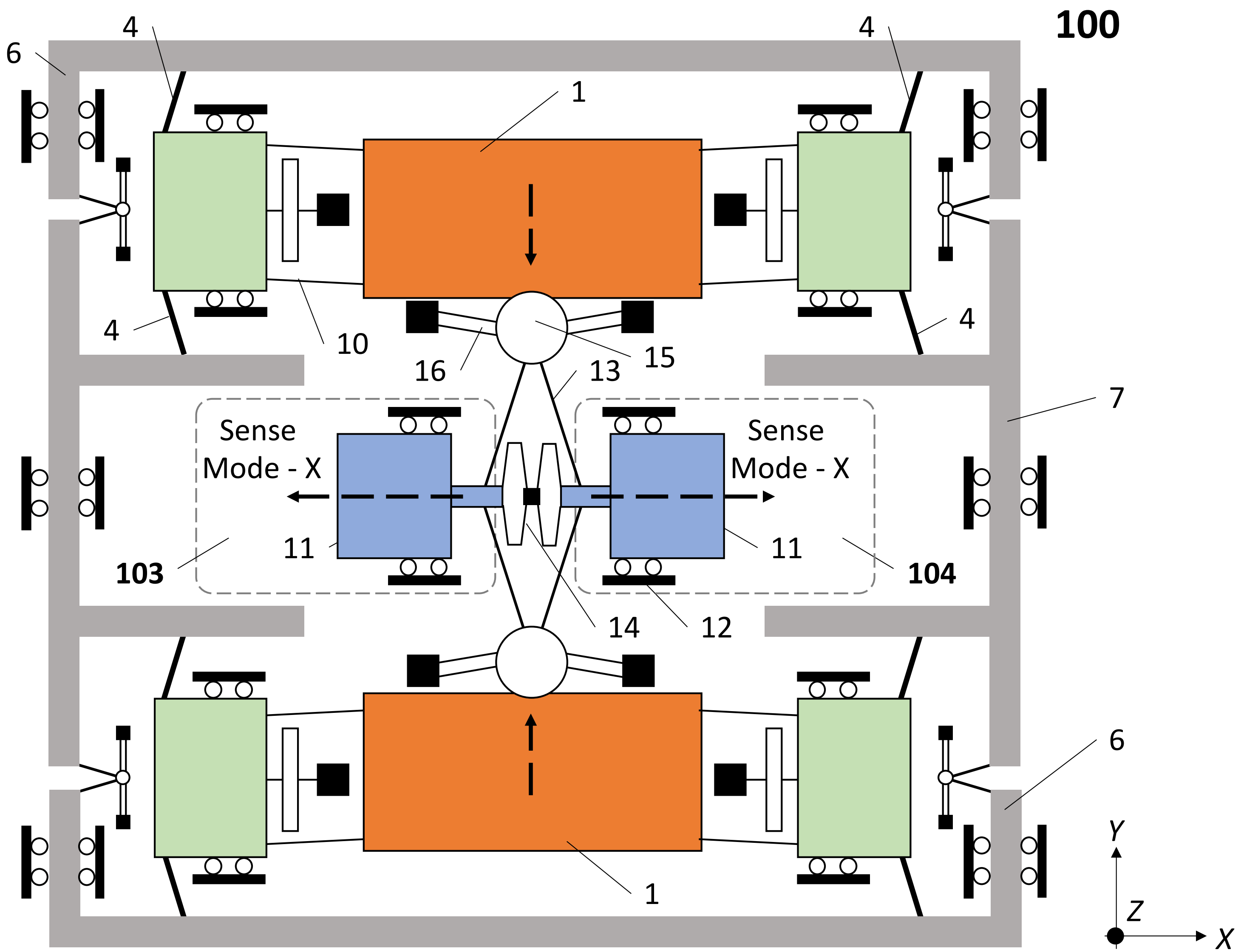


Drive Mode



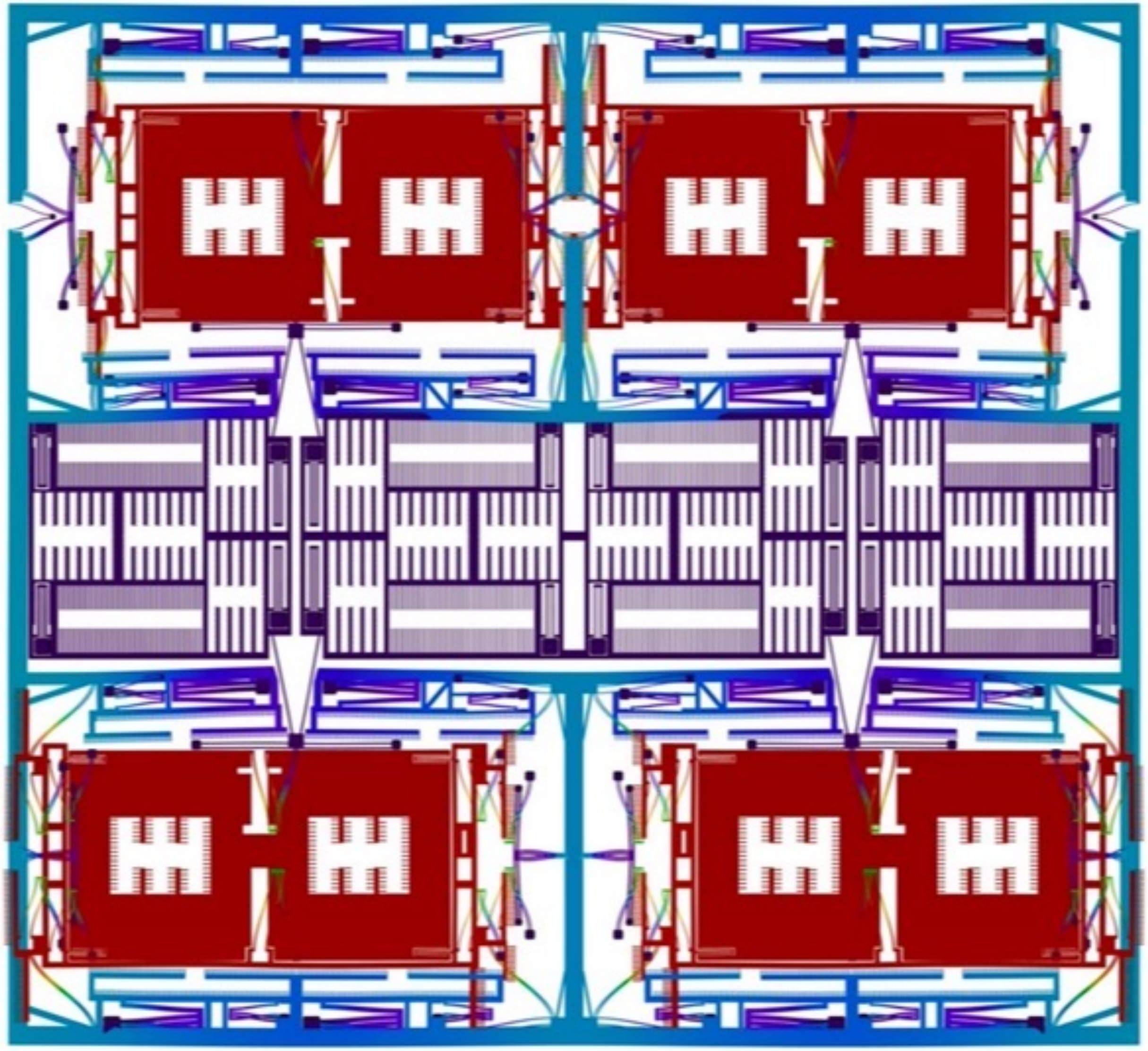
100
6
4
3
4
2
5
1
10
101
Drive Mode - X
18
9
15
7
11
8
102
17
Drive Mode - X
6
5
1
Y
Z
X

Sense Mode


100
1
4
6
10
16
13
15
7
Sense
Mode - X
Sense
Mode - X
11
11
103
104
14
12
1
6
Y
Z
X

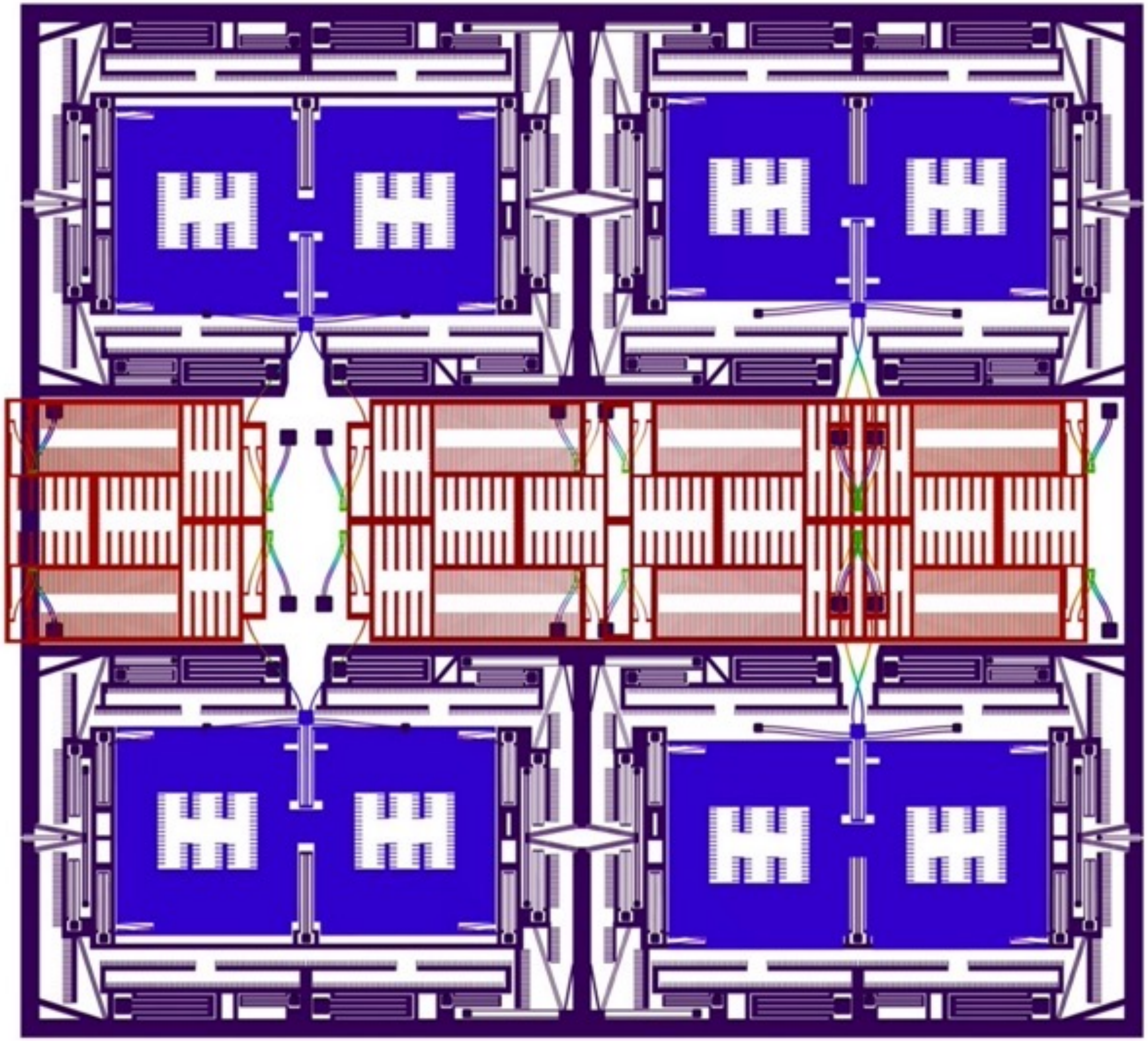
Drive- and Sense-Amplified 4-Mass Gyro

Drive Mode

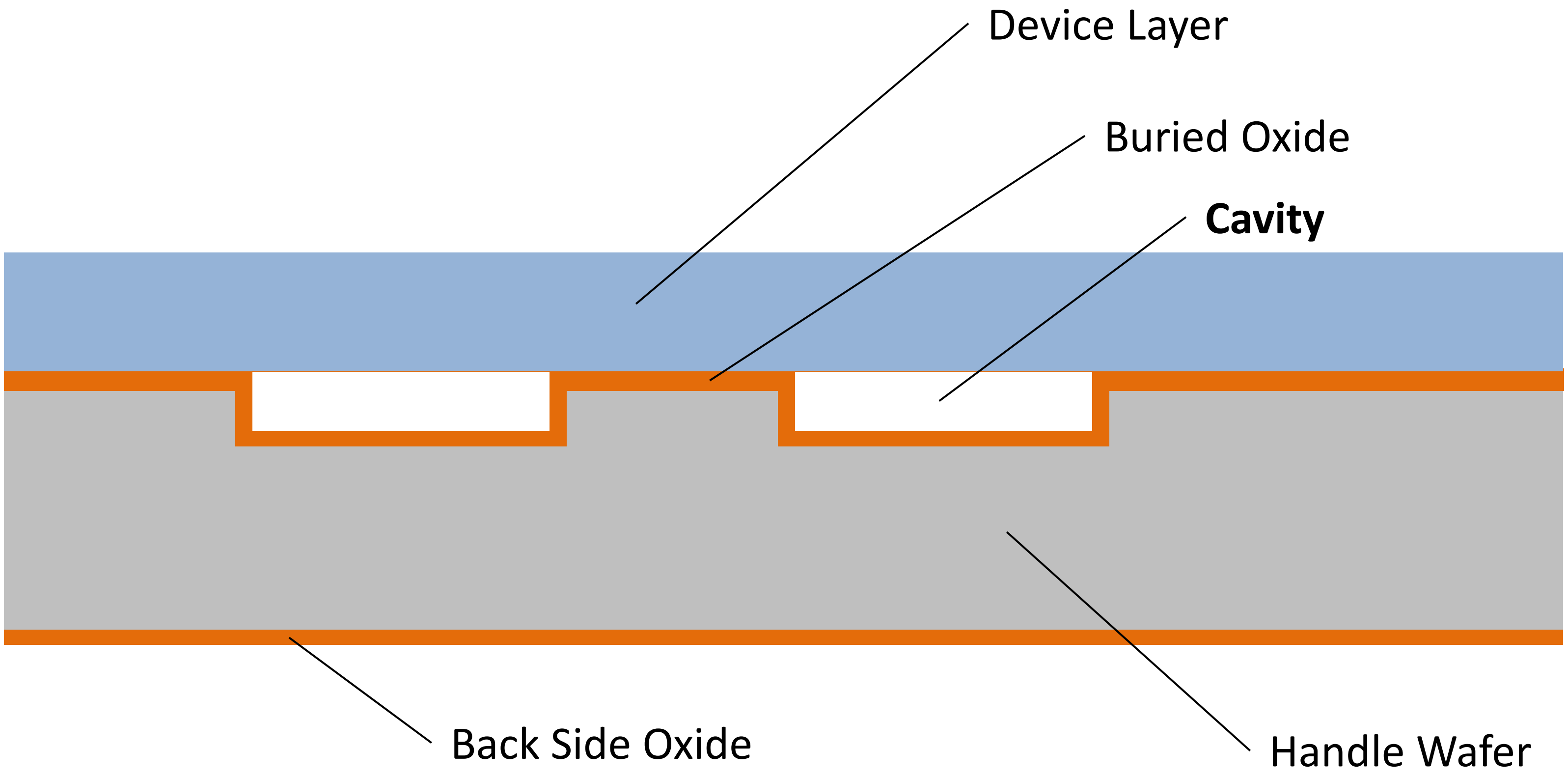


Drive- and Sense-Amplified 4-Mass Gyro

Sense Mode

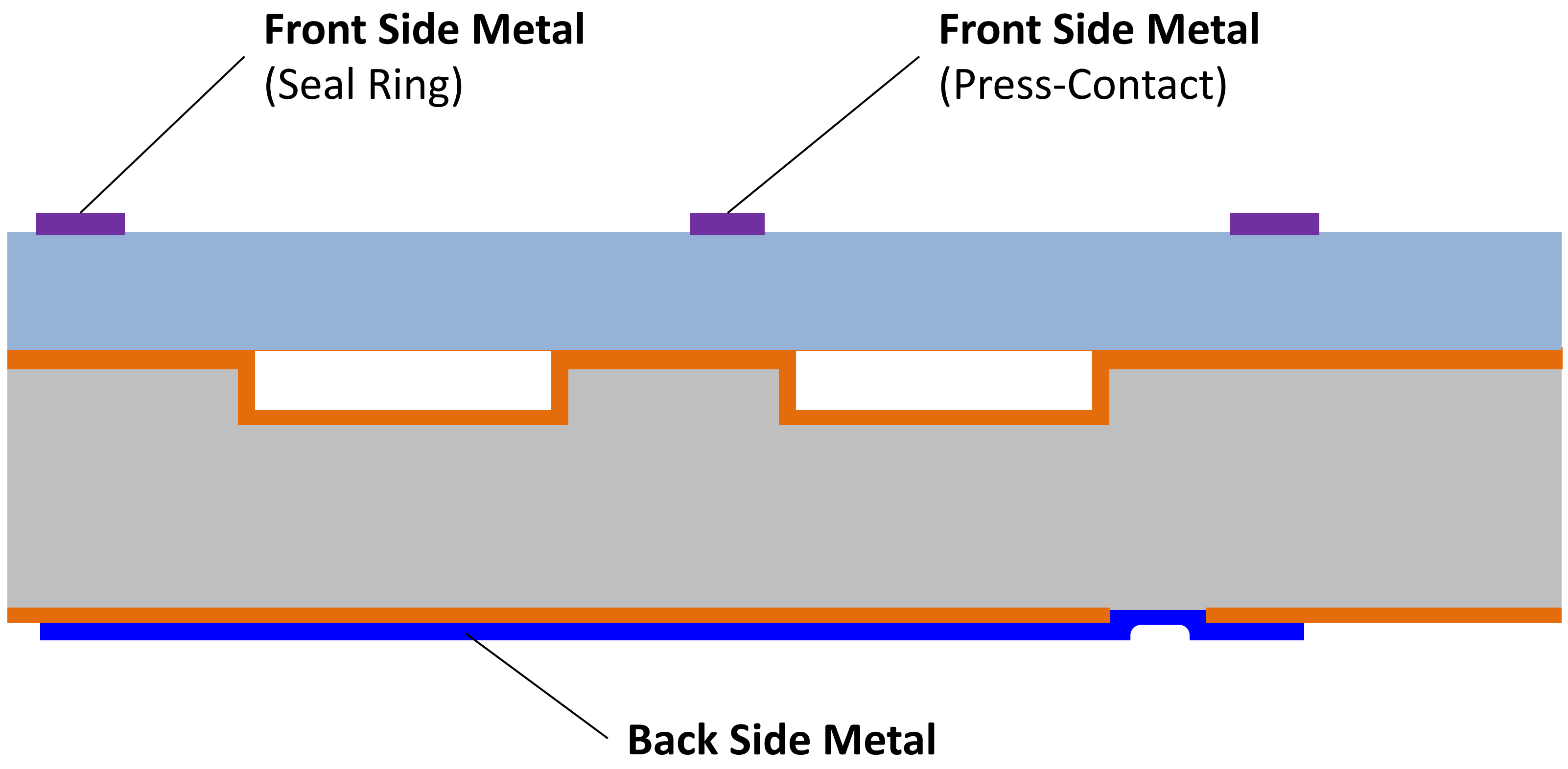


Fabrication Start: Cavity-SOI Wafer

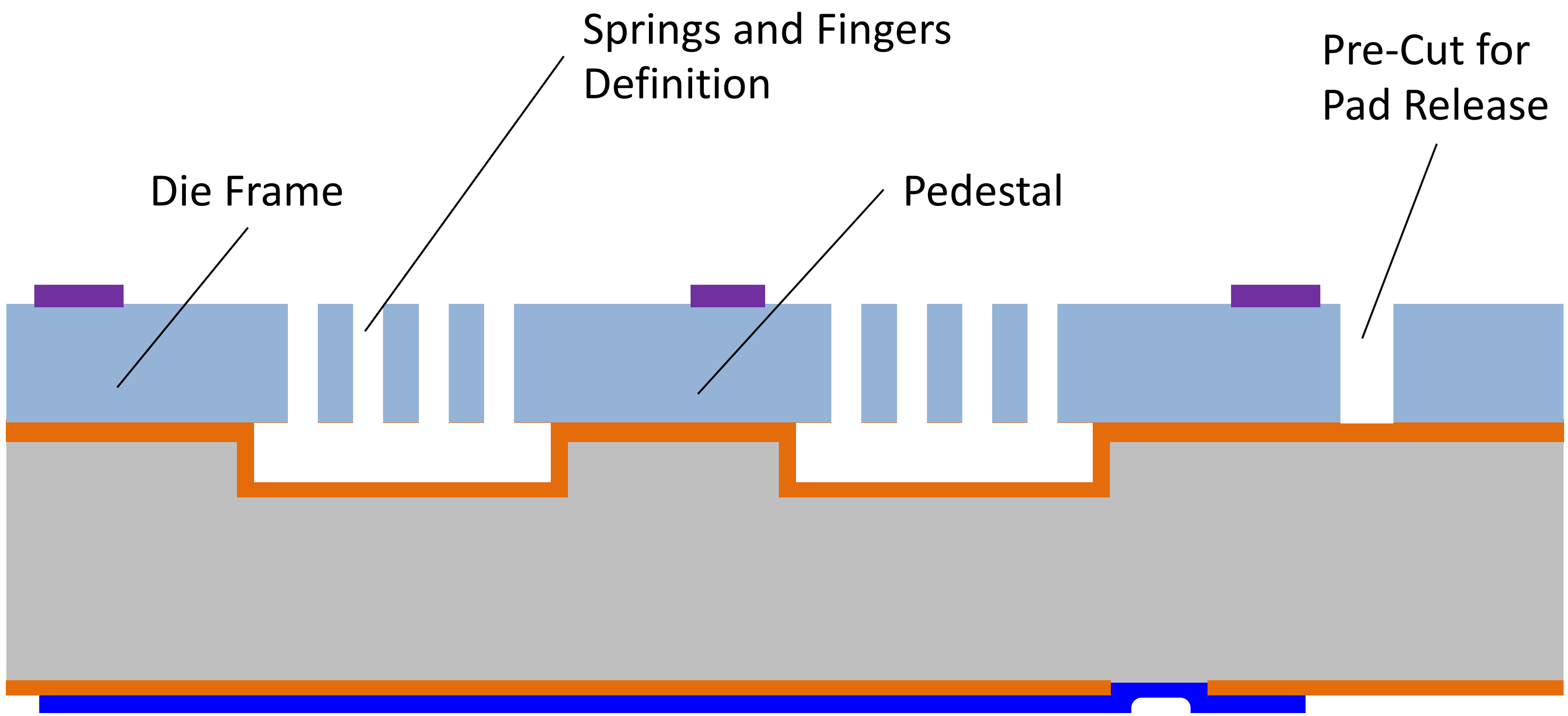


Metal Depositions

- Back side deposition.
- Front side deposition.

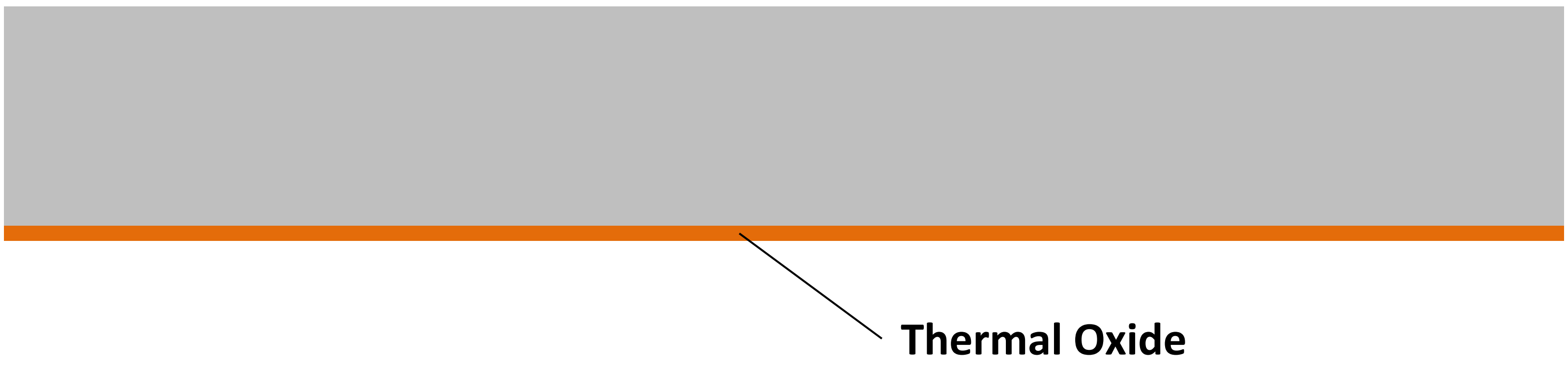


DRIE


Springs and Fingers
Definition
Pre-Cut for
Pad Release
Die Frame
Pedestal

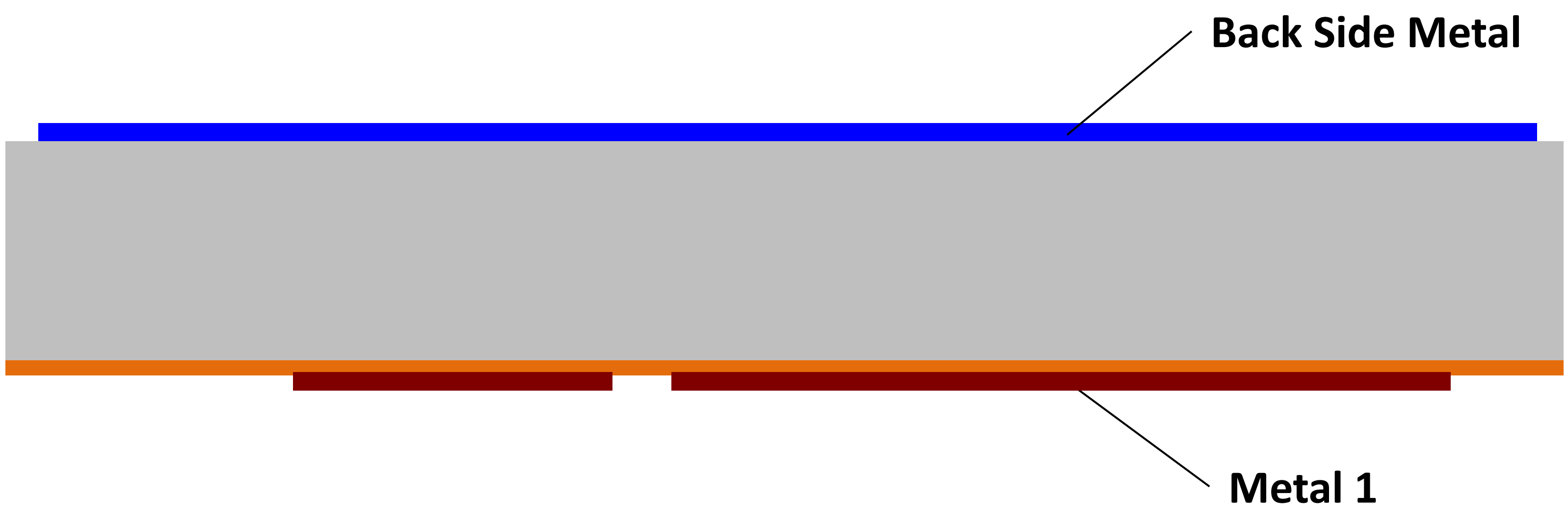
Capping Wafer Oxidation

- Insulating thermal oxide.



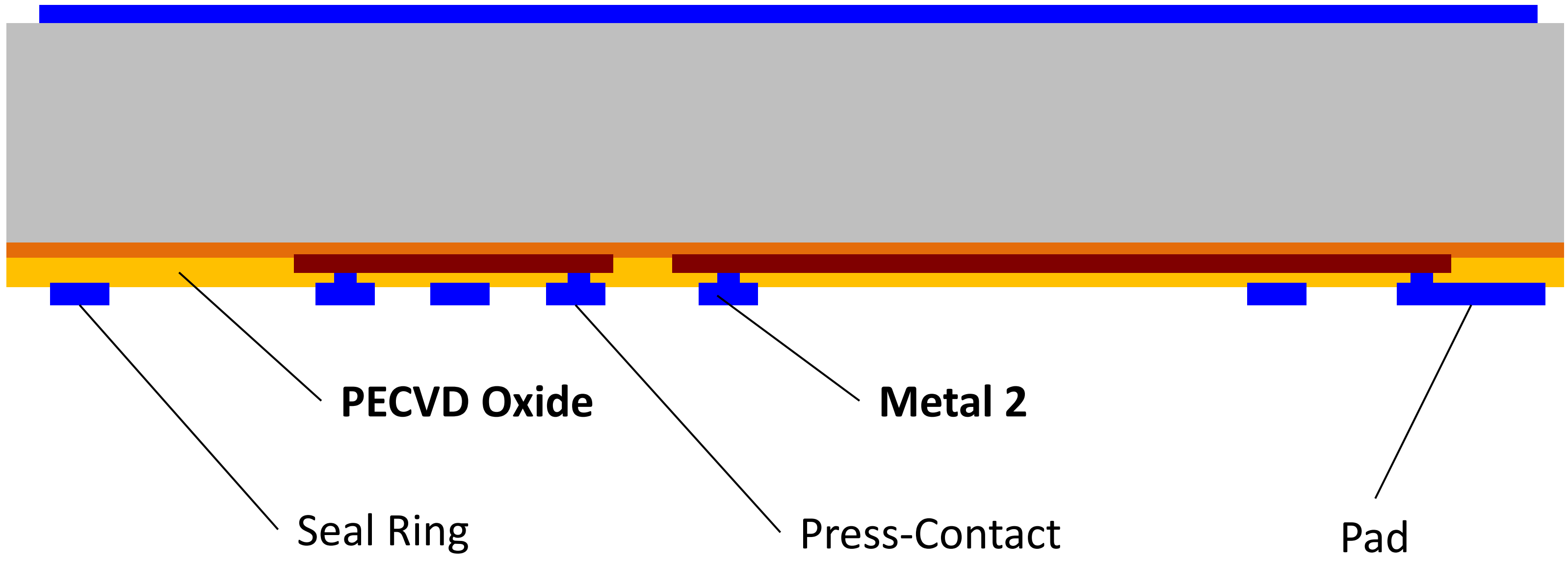
Metal Depositions

- Back side metal deposition.
- Front side metal deposition (Metal 1)

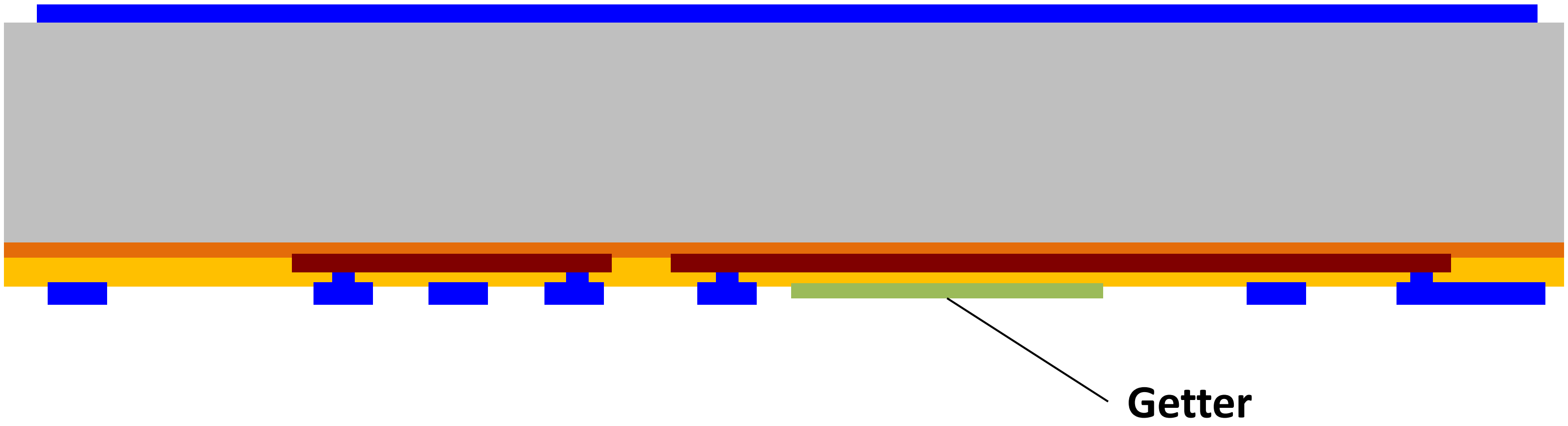


PECVD Oxide and Metal Depositions

- PECVD oxide deposition.
- Front side metal deposition (Metal 2)

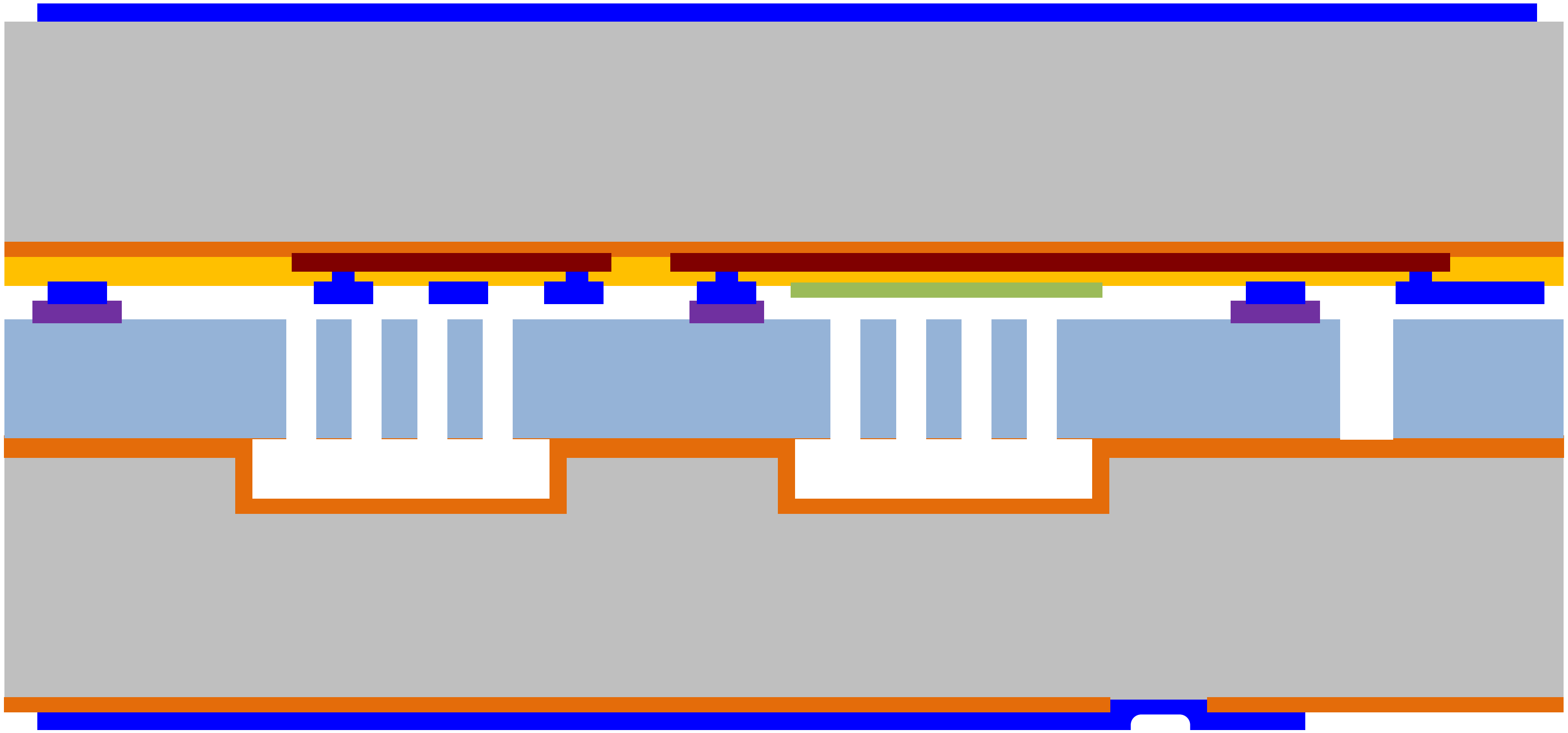


Getter Deposition



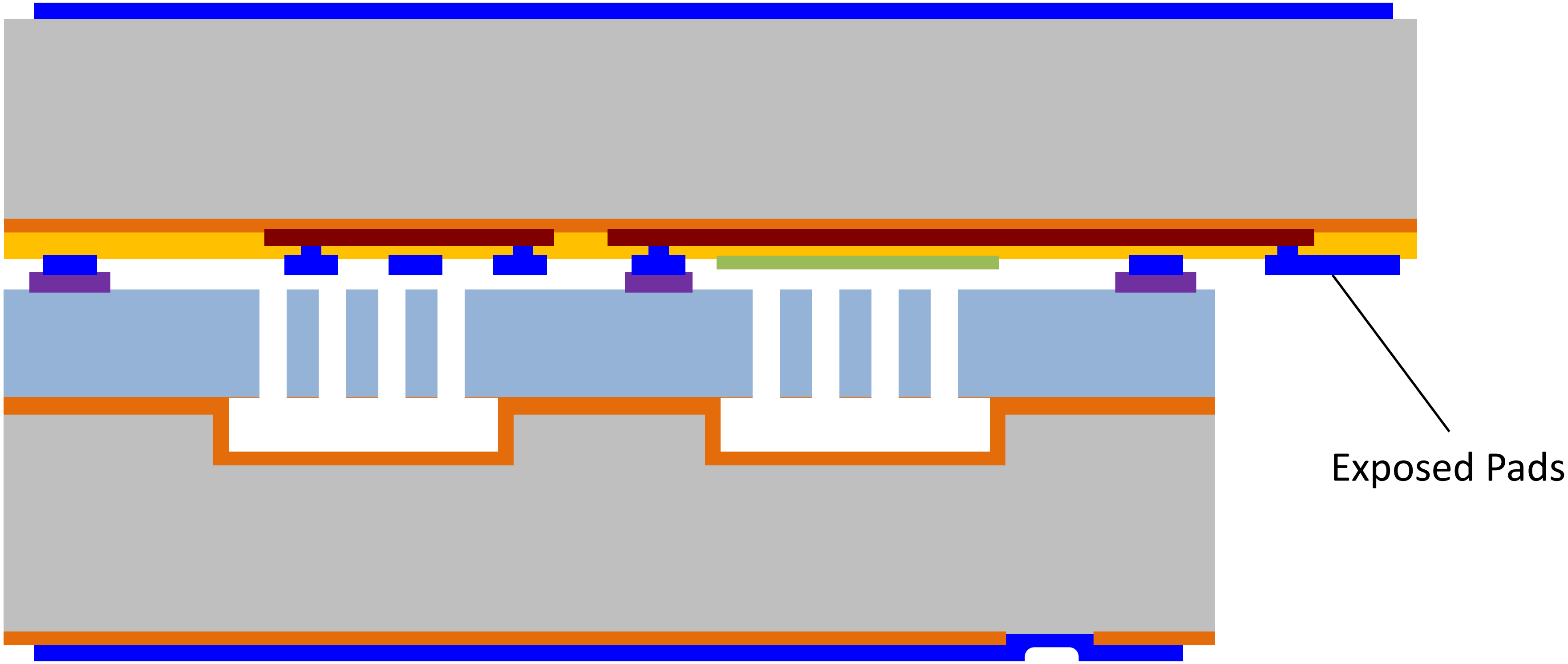
Wafer-Level Bonding

- High-vacuum wafer-level eutectic bonding.
- Getter activation.



Testing and Dicing

- Sawing to release the pads.
- Electrical testing.
- Dicing.



Thank You!