ADI MEMS Solution and Application

Jason Chien

JASON.CHIEN@ARROW.COM

ANALOG DEVICES

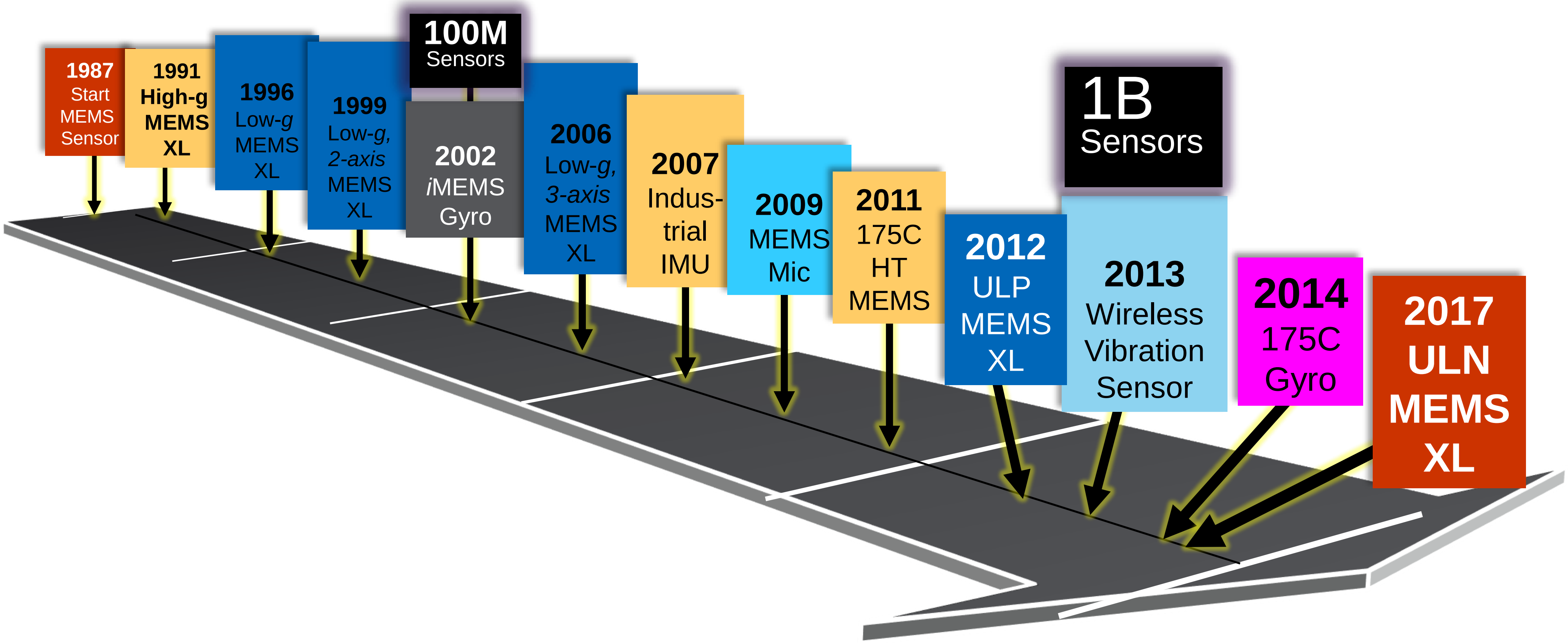
AHEAD OF WHAT'S POSSIBLE™

Agenda

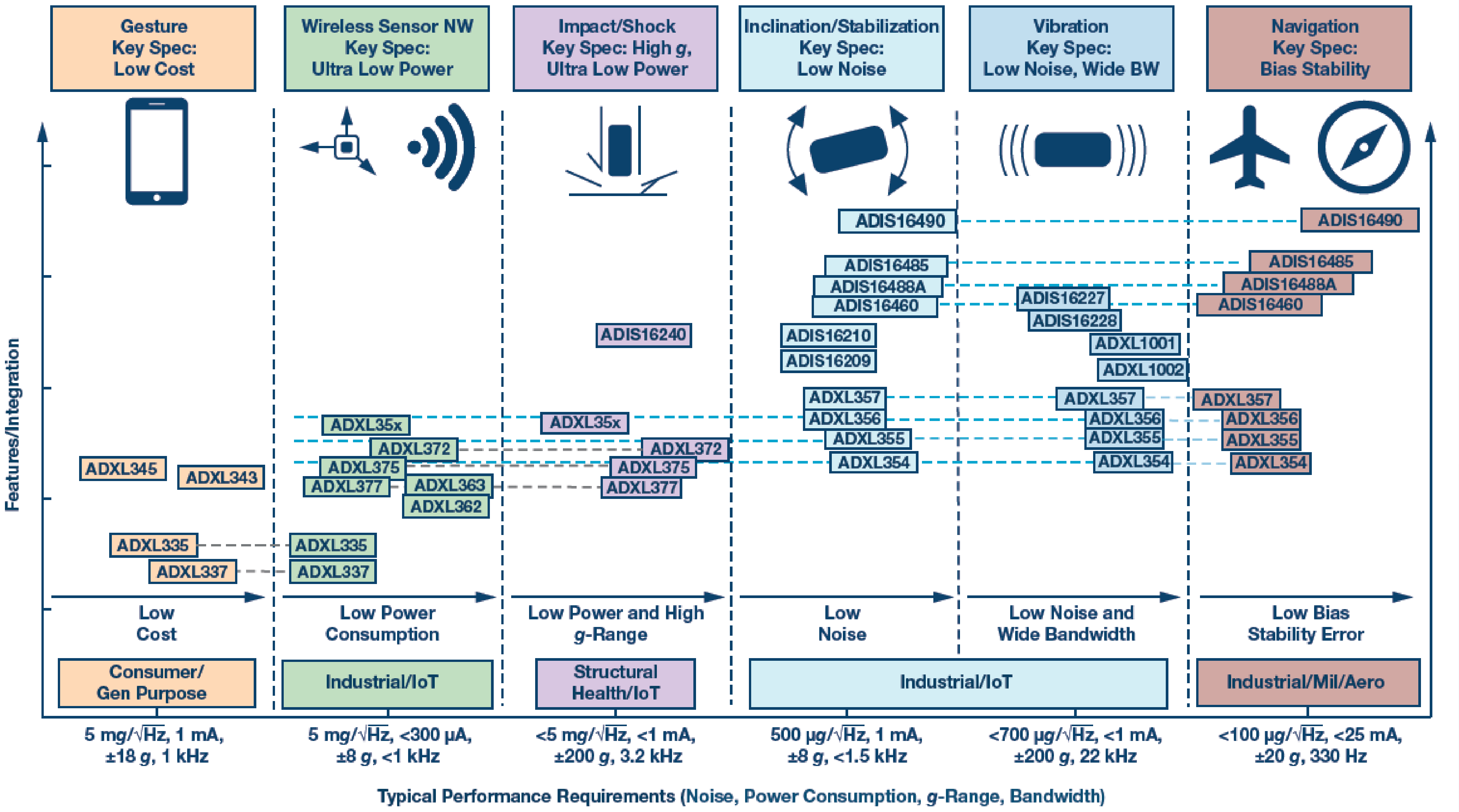
- ADI MEMS introduce
  - MEMS Principle of Operation
  - Important Parameter on Datasheet
- Application and product
  - Tilt detection
  - CbM (Condition Based Monitoring)
  - AGV (Automated Guided Vehicle)

ADI MEMS Positioning

MEMS & Sensor Leadership From Analog Devices : Over 30 Years of Firsts and Milestones

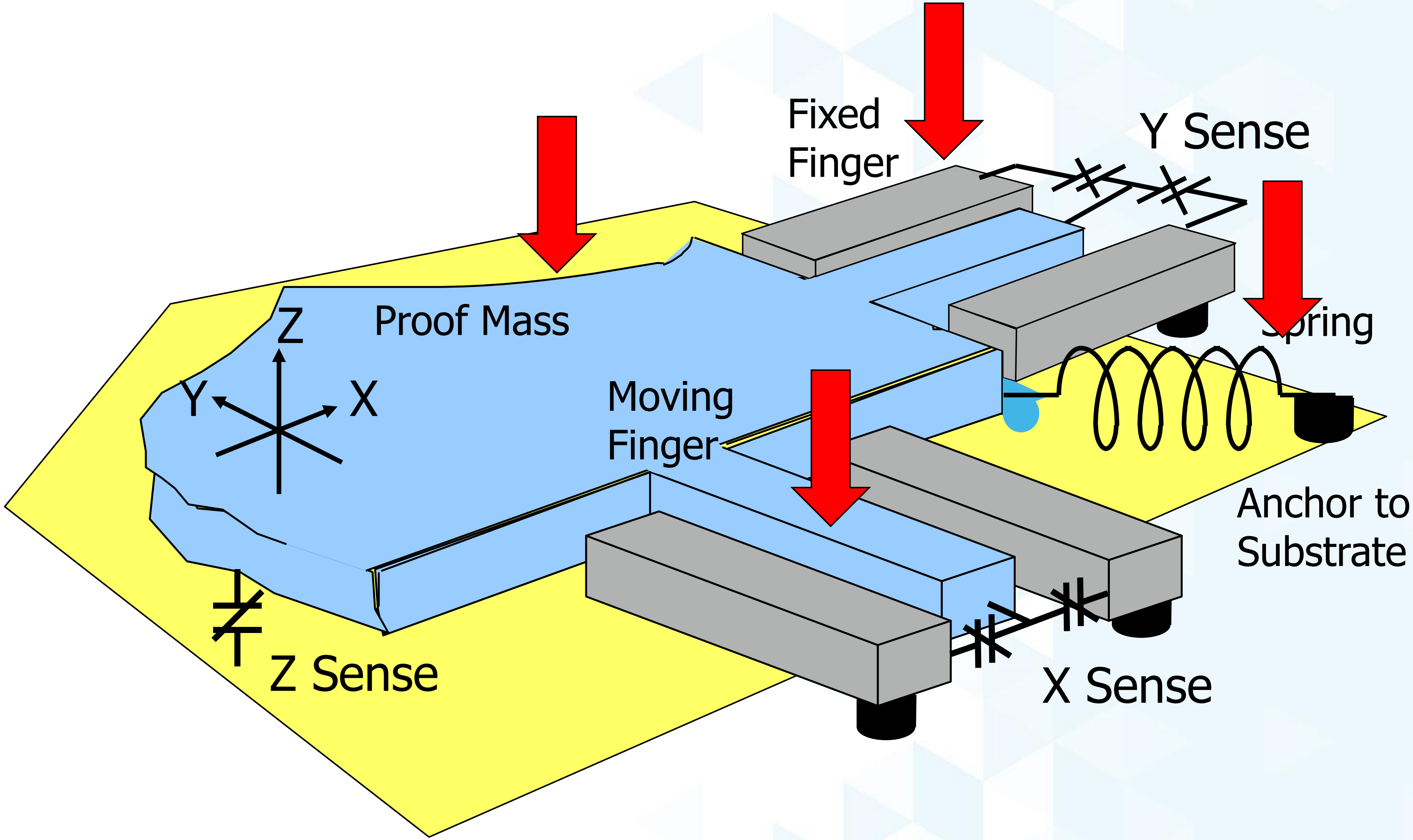


Typical MEMS Accelerometer Applications



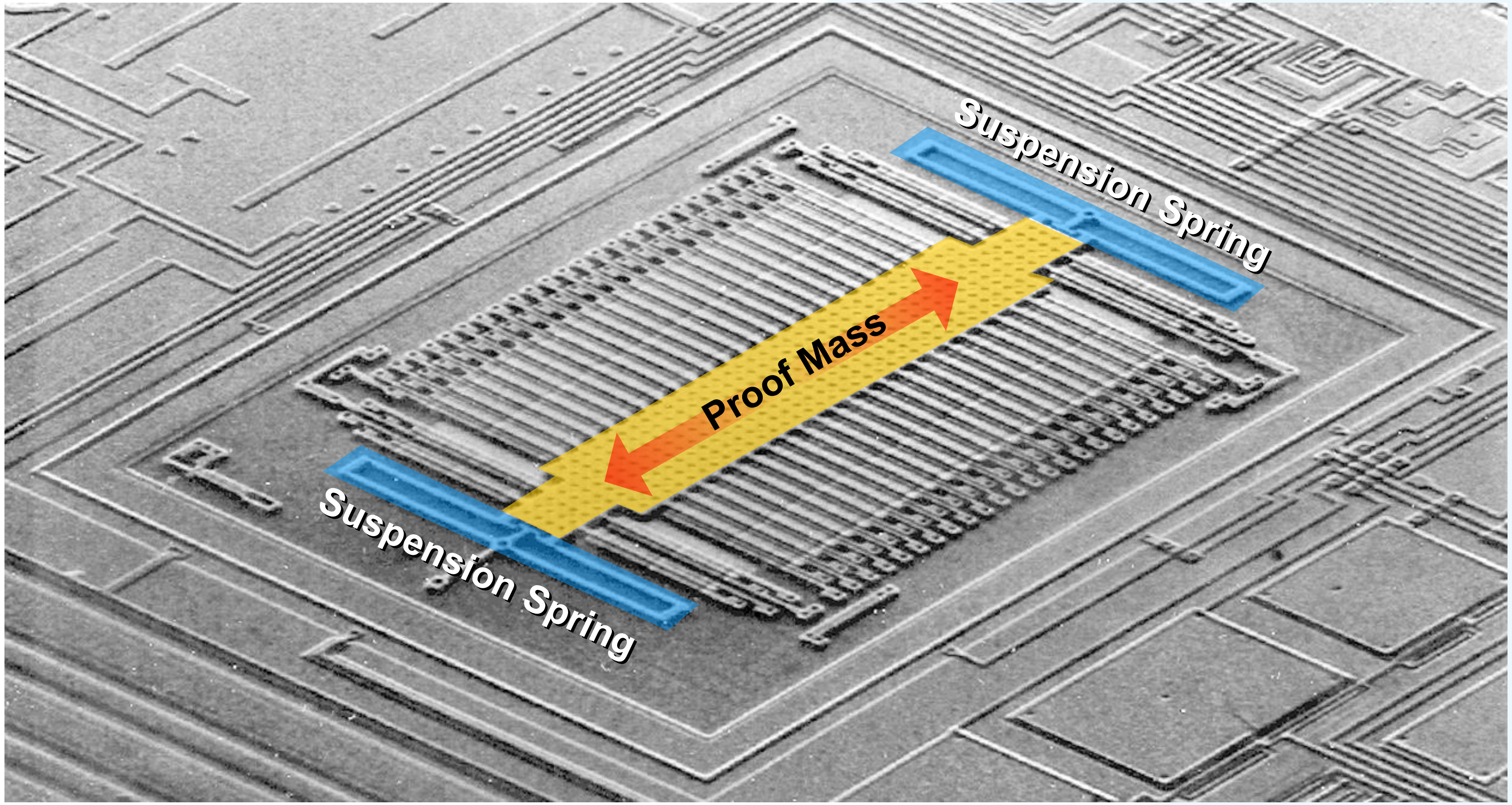
MEMS Principle of Operation

MEMS Principle of Operation



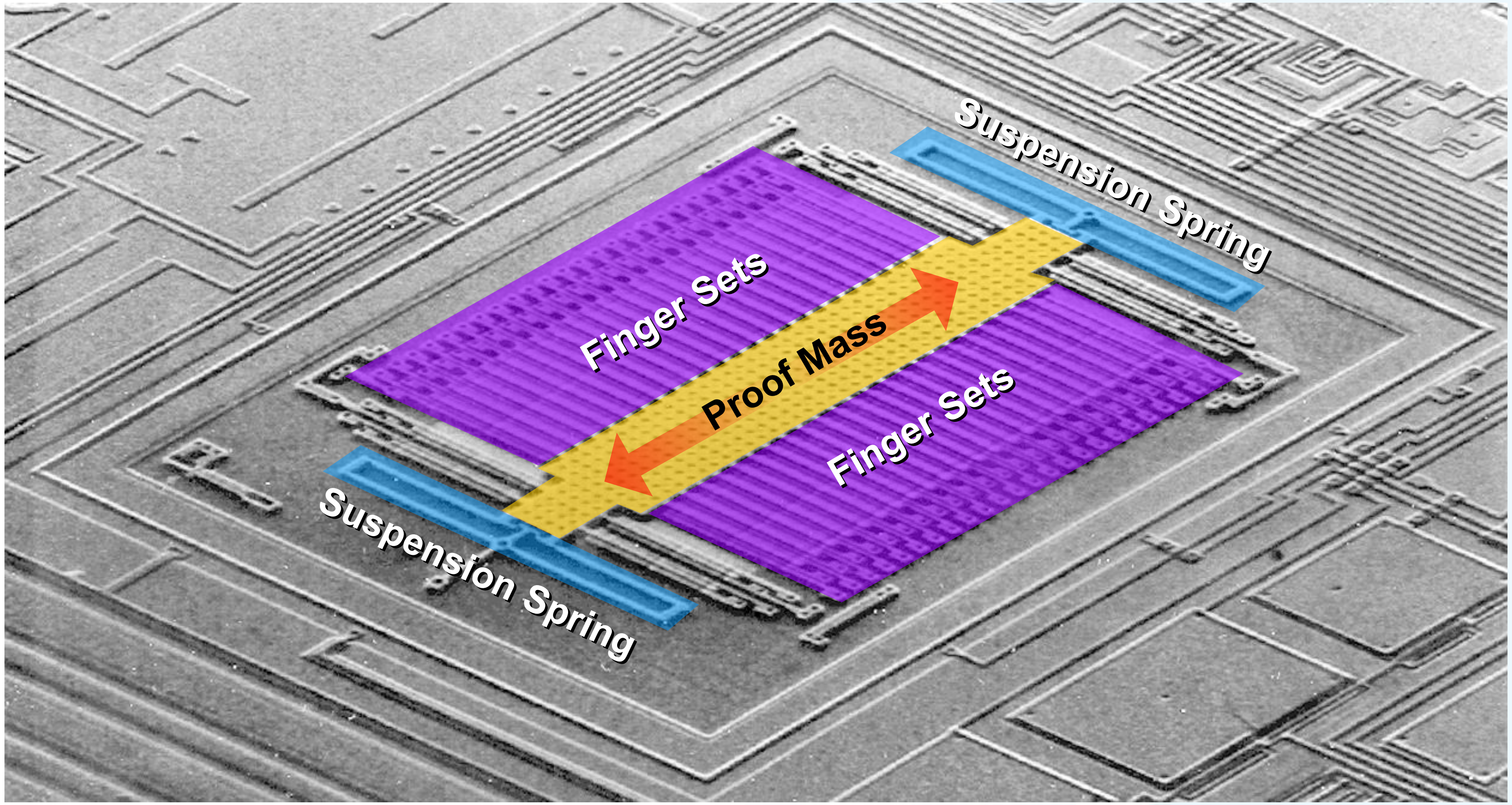
How Do *i*MEMS Accelerometers Work?

- Single axis accelerometer in silicon has the same components
  - Left / Right (X-axis)



(ca. 1992-1995)

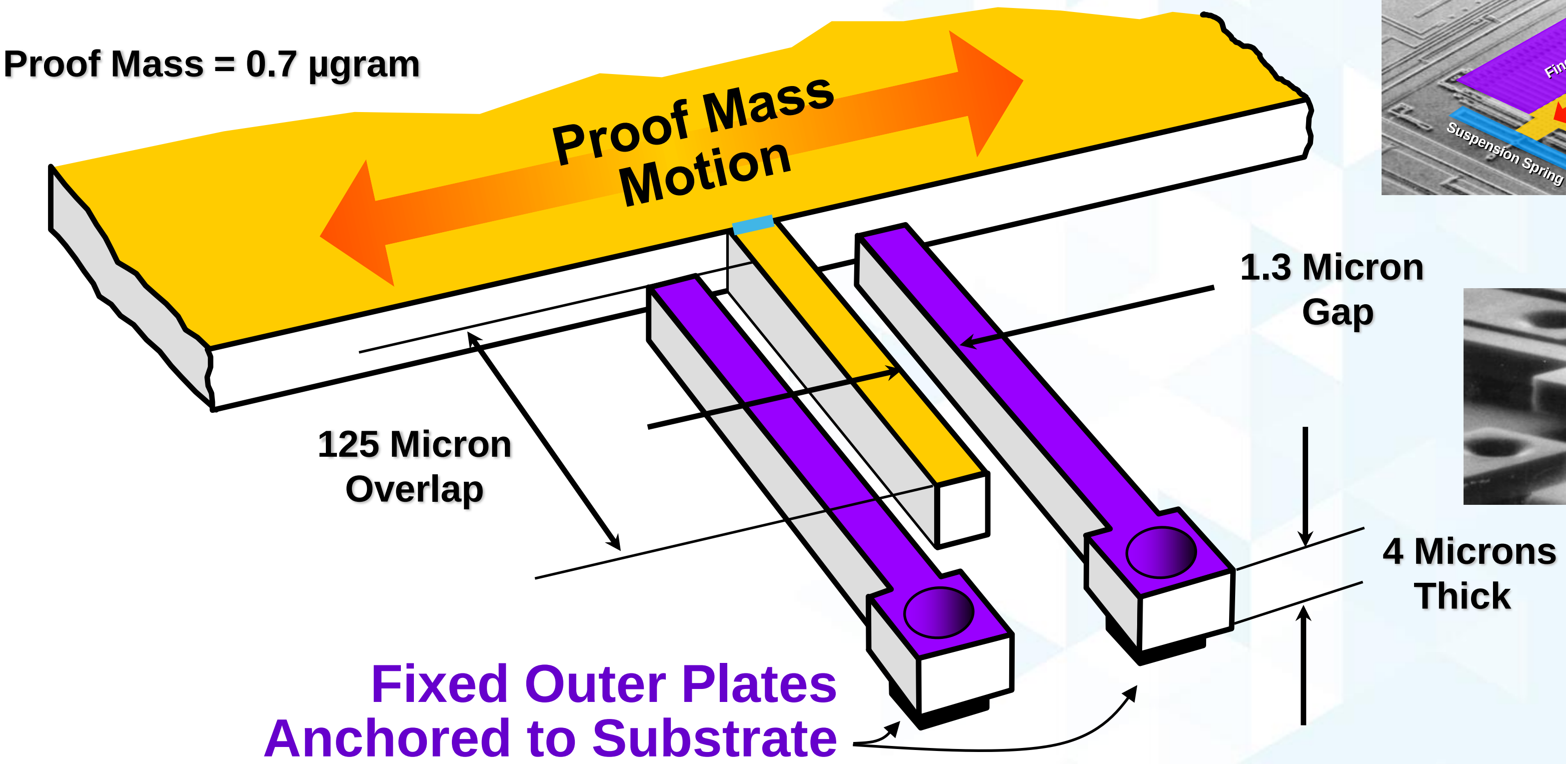
How Do *i*MEMS Accelerometers Work?

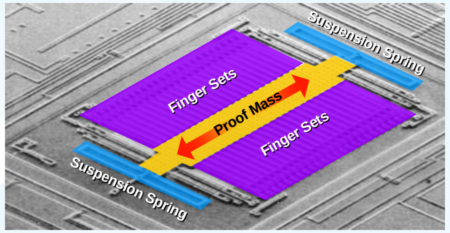


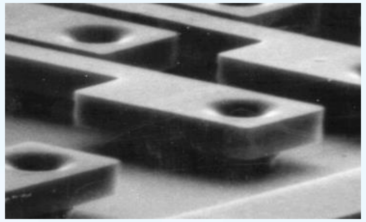
(ca. 1992-1995)

How Do *i*MEMS Accelerometers Work?

- This diagram represents a single finger set
- There are 30 finger sets per axis
- Total capacitance from the entire finger set is 64 fF
- Changes in displacement change the differential capacitance

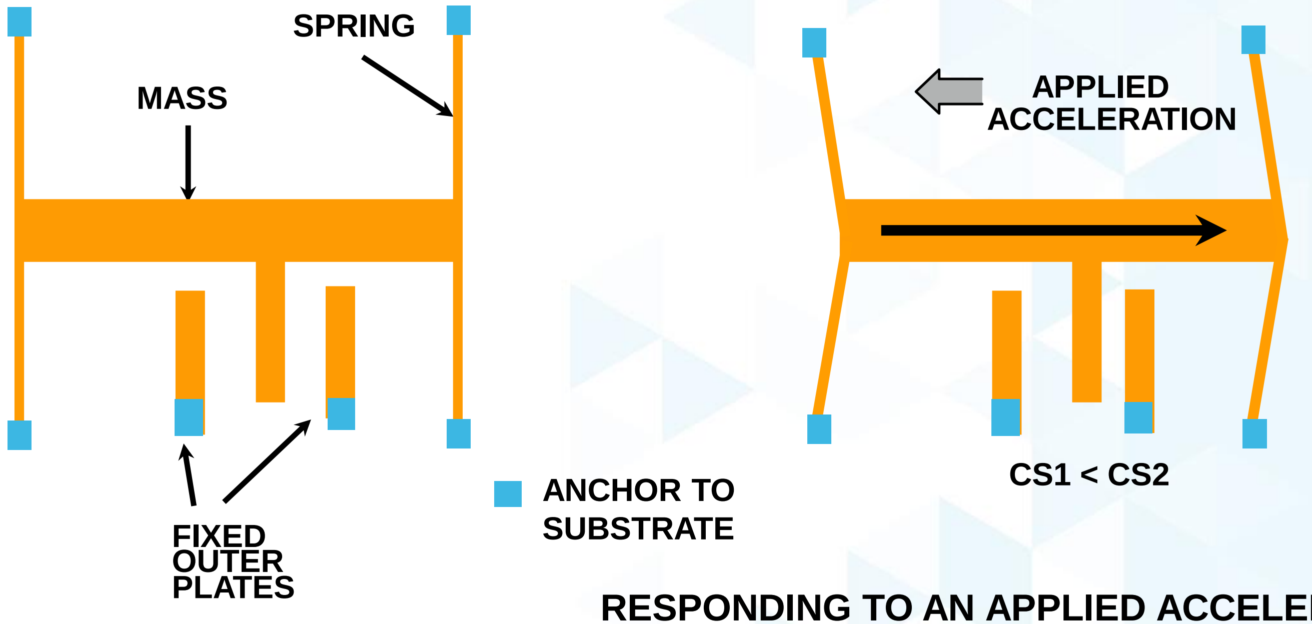






How Do Accelerometers Work?

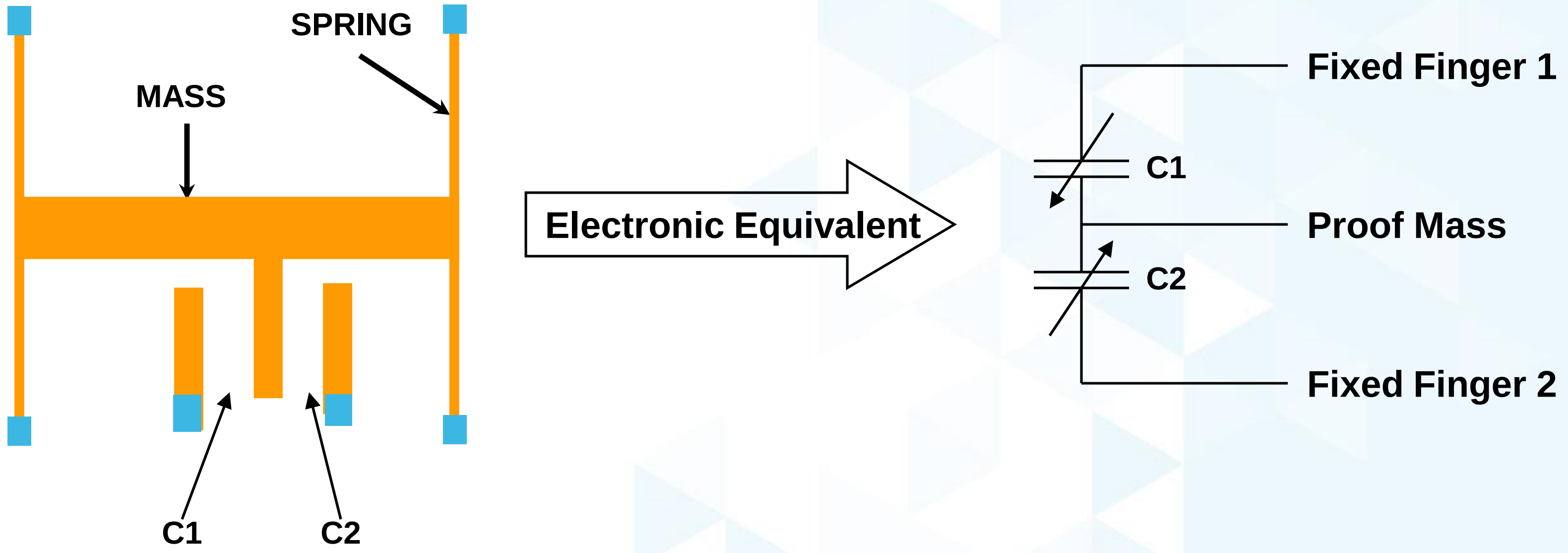
- We use Silicon to make the springs and mass, and add fingers to make a variable differential capacitor
- We measure change in displacement by measuring change in differential capacitance



SENSOR AT REST

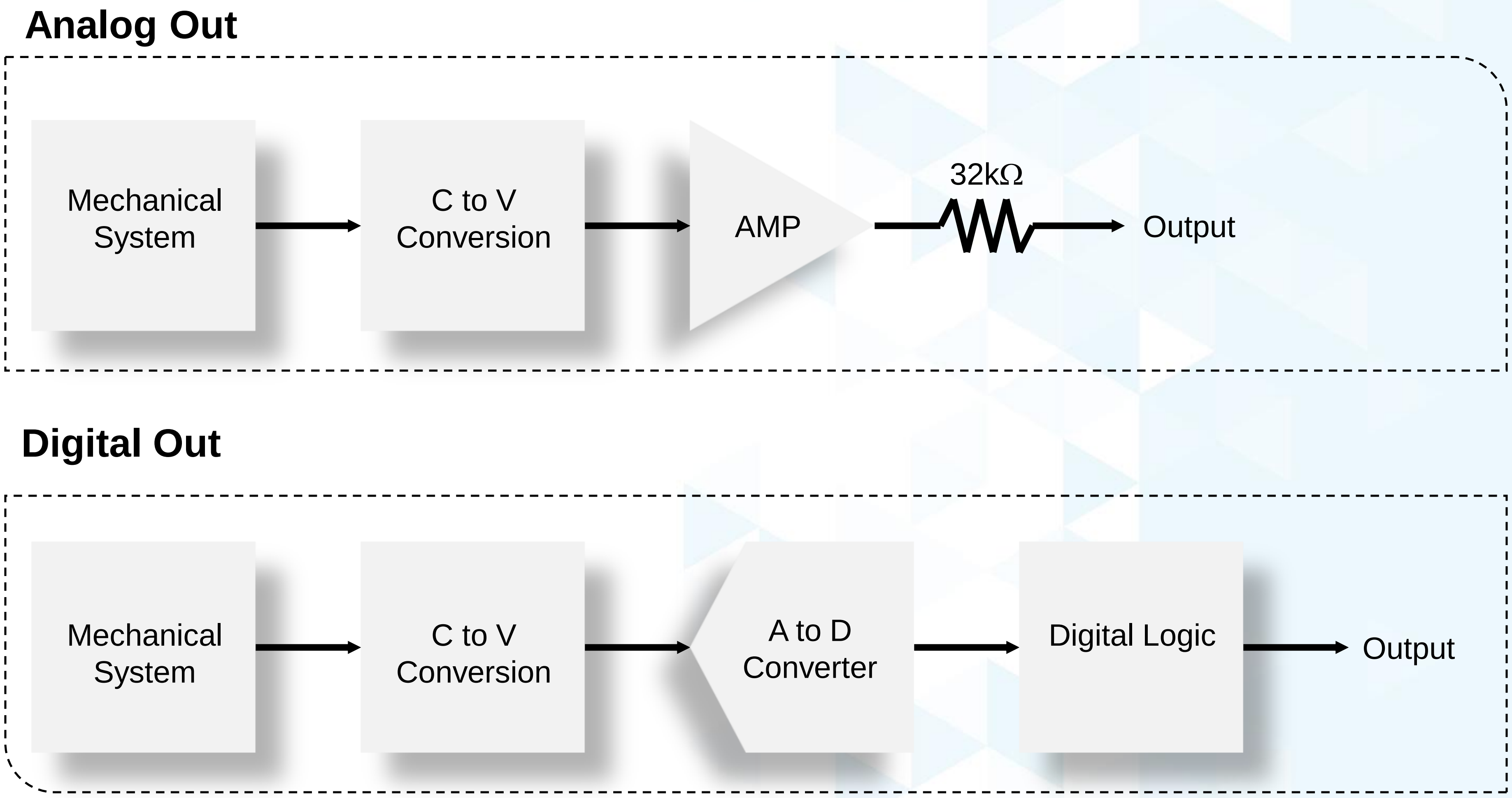
RESPONDING TO AN APPLIED ACCELERATION
(MOVEMENT SHOWN IS GREATLY EXAGGERATED)

How Do Accelerometers Work?



As C1 increases, C2 decreases proportionally

Electronic Architecture



How do Gyroscopes Work?

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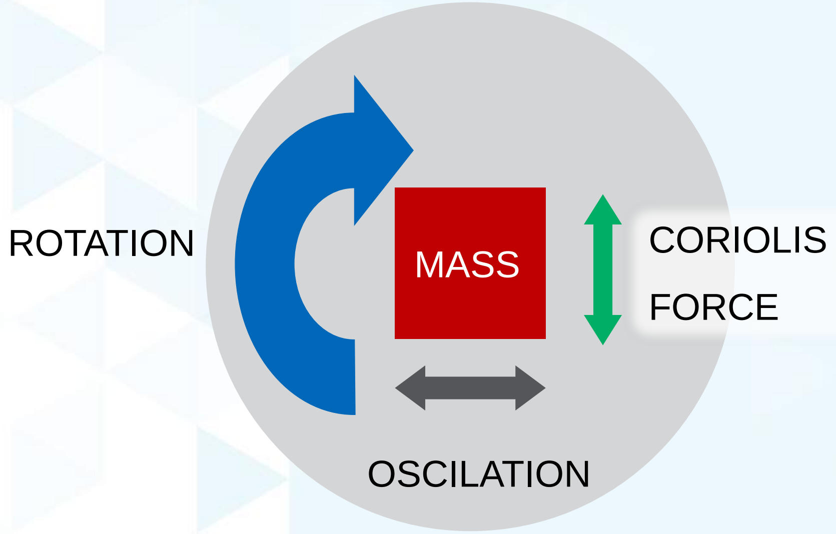
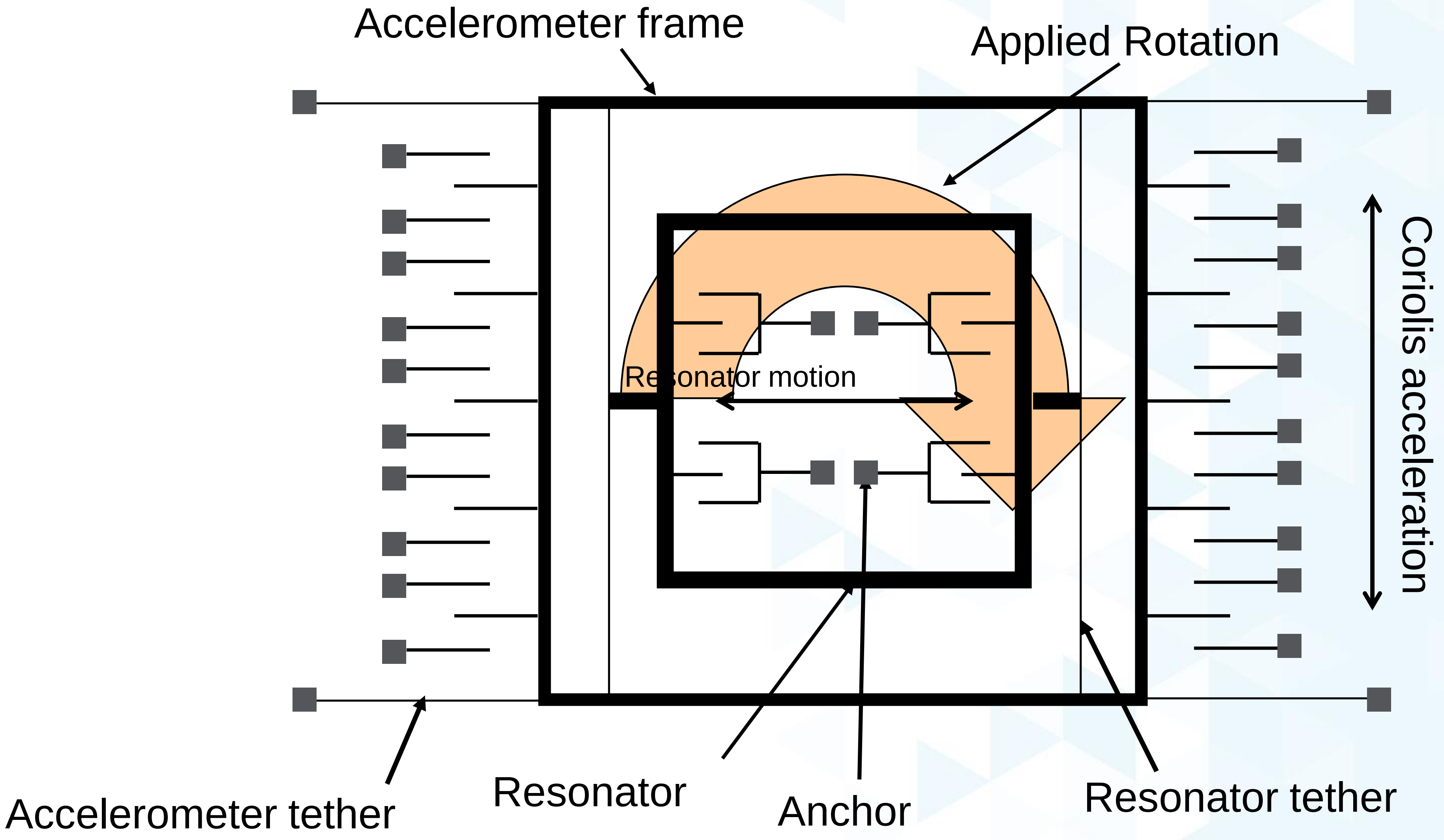
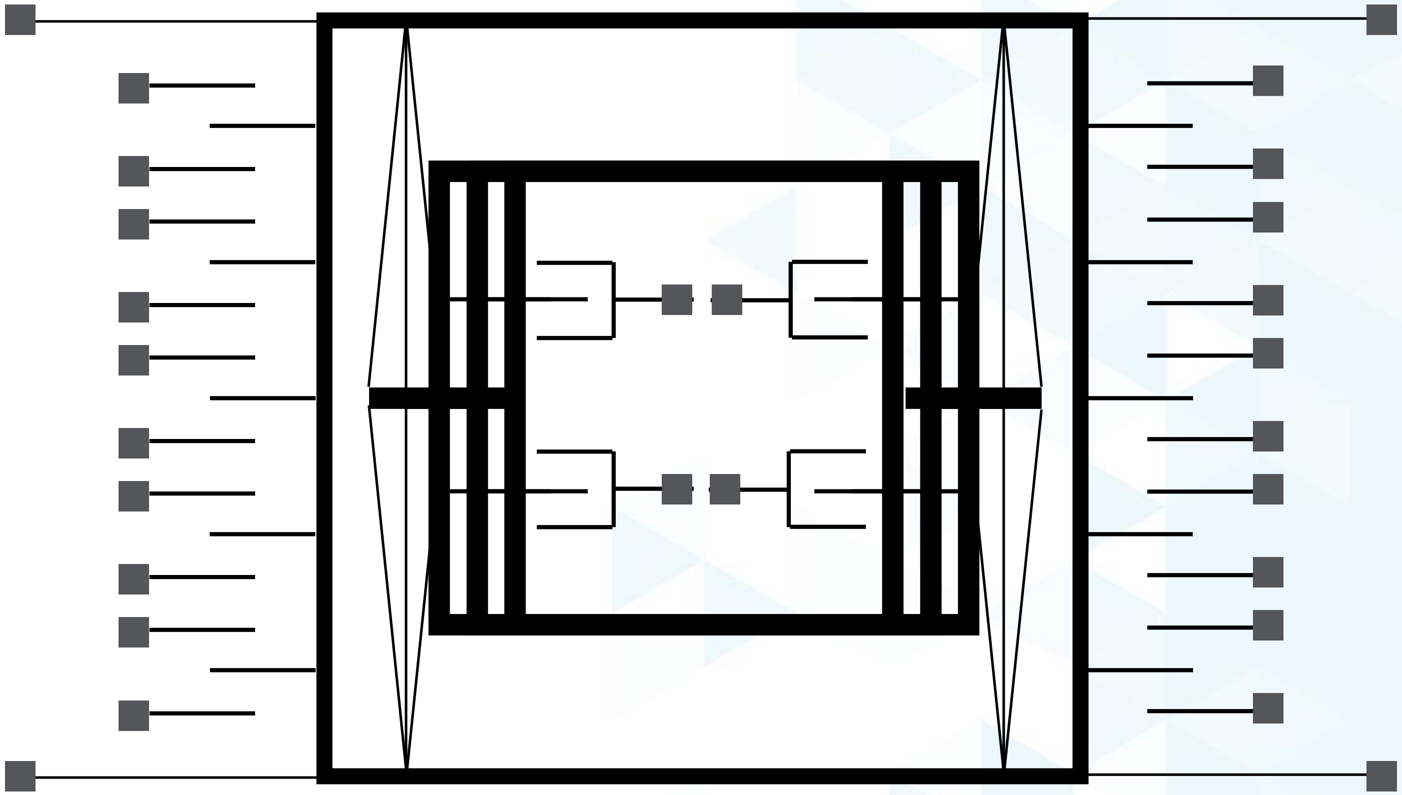
- How does it measure angular rate?
  - By measuring the Coriolis force
- What is the Coriolis force?
  - When an object is moving in a periodic fashion (either oscillating or rotating), rotating the object in an orthogonal plane to its periodic motion causes a translational force in the other orthogonal direction.



Gyro Principle of Operation

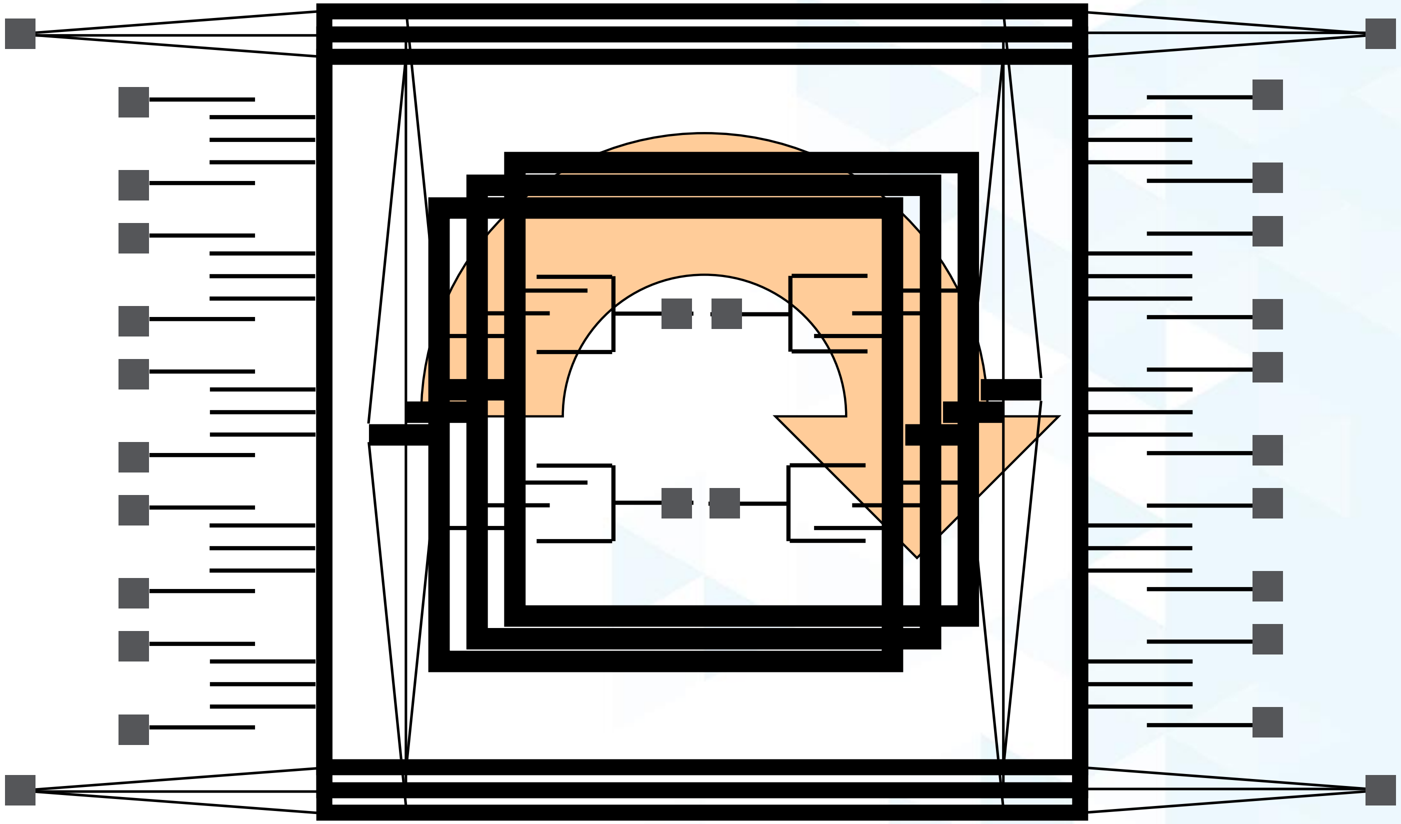


Gyro Principle of Operation



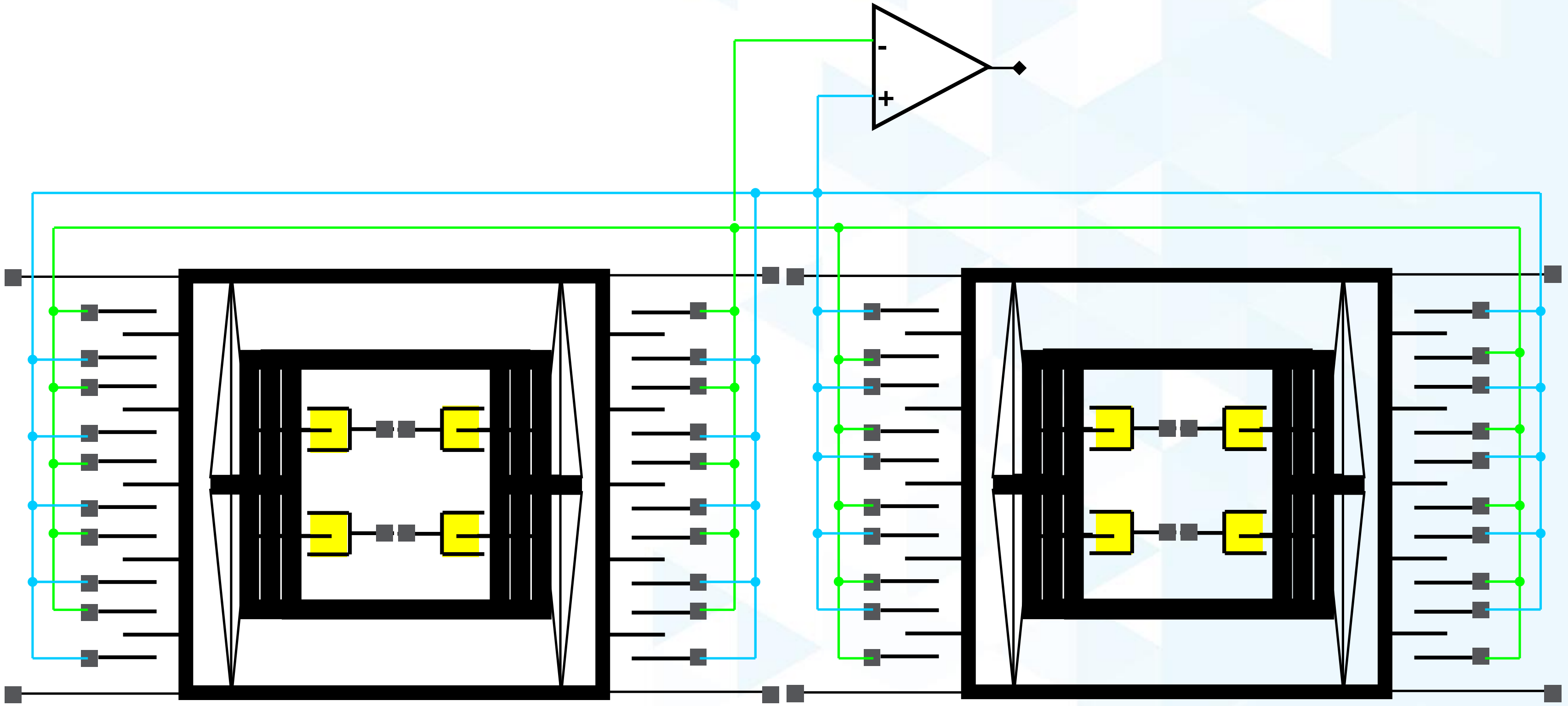
No Rotation

Gyro Principle of Operation



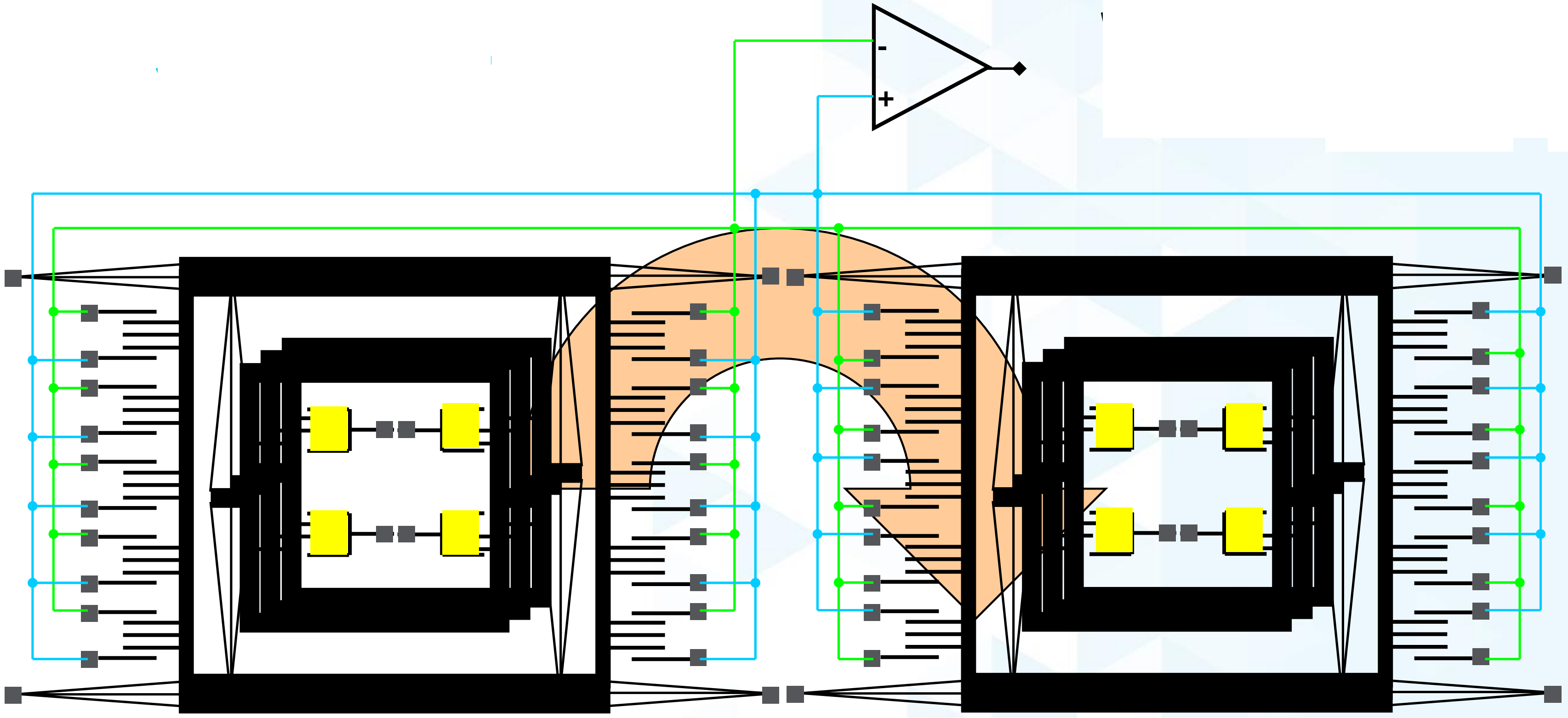
Rotation Applied

Gyro Principle of Operation



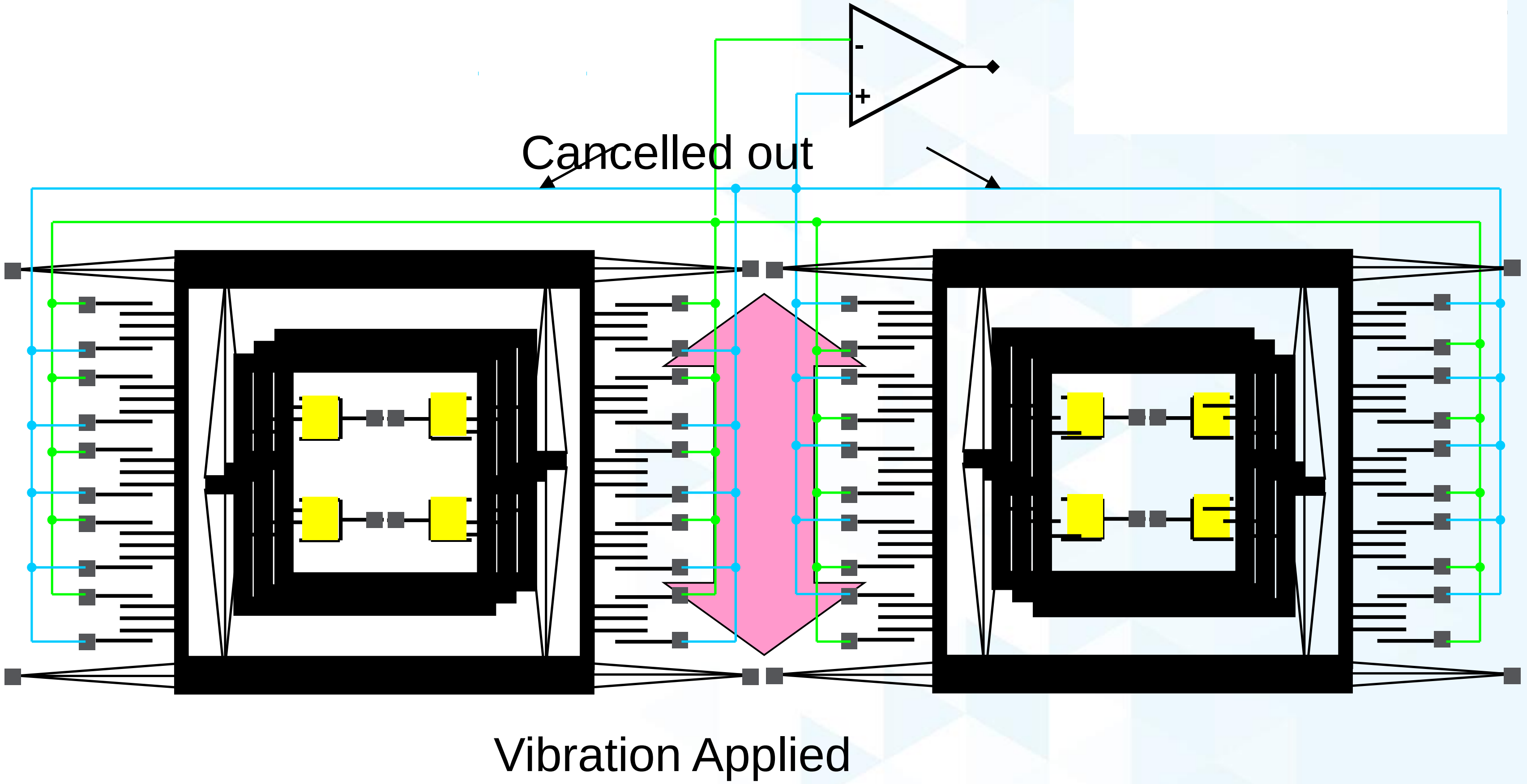
No Rotation

Gyro Principle of Operation



Rotation Applied

Gyro Principle of Operation



Important Parameter on Datasheet

ADXL355 Datasheet

Parameter	Test Conditions/Comments	Min	Typ	Max	Unit
SENSOR INPUT	Each axis				
Output Full Scale Range (FSR)	User selectable		±2.048		*g*
			±4.096		*g*
			±8.192		*g*
Nonlinearity	±2 *g*		0.1		% FS
Cross Axis Sensitivity			1		%
SENSITIVITY	Each axis				
X-Axis, Y-Axis, and Z-Axis Sensitivity	±2 *g*	235,520	256,000	276,480	LSB/*g*
	±4 *g*	117,760	128,000	138,240	LSB/*g*
	±8 *g*	58,880	64,000	69,120	LSB/*g*
X-Axis, Y-Axis, and Z-Axis Scale Factor	±2 *g*		3.9		µ*g*/LSB
	±4 *g*		7.8		µ*g*/LSB
	±8 *g*		15.6		µ*g*/LSB
Sensitivity Change due to Temperature	−40°C to +125°C		±0.01		%/°C
0 *g* OFFSET	Each axis, ±2 *g*				
X-Axis, Y-Axis, and Z-Axis 0 *g* Output		−75	±25	+75	m*g*
0 *g* Offset vs. Temperature (X-Axis, Y-Axis, and Z-Axis)[1]	−40°C to +125°C	−0.15	±0.02	+0.15	m*g*/°C
Repeatability[2]	X-axis and y-axis		±3.5		m*g*
	Z-axis		±9		m*g*
Vibration Rectification[3]	±2 *g* range, in a 1 *g* orientation, offset due to 2.5 *g* rms vibration		<0.4		*g*
NOISE DENSITY	±2 *g*				
X-Axis, Y-Axis, and Z-Axis			25		µ*g*/√Hz

ADXL356/357 Enable High Accuracy Tilt Sensing In Vibration Condition

- As high as 40gee range with 80μ*g*/√Hz noise density
- Outstanding VRE (Vibration Rectification Error)
  - **VRE is the offset error introduced when accelerometers are exposed to broadband vibration**
  - **VRE = (average output with vibration - average output without vibration)**

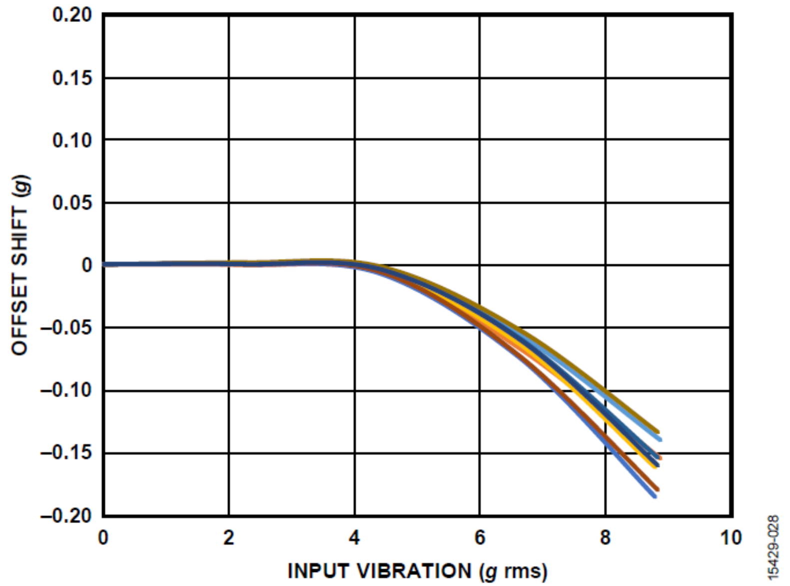


Figure 28. ADXL356 Vibration Rectification Error (VRE), Z-Axis Offset from +1 g, ±10 g Range, Z-Axis Orientation = +1 g

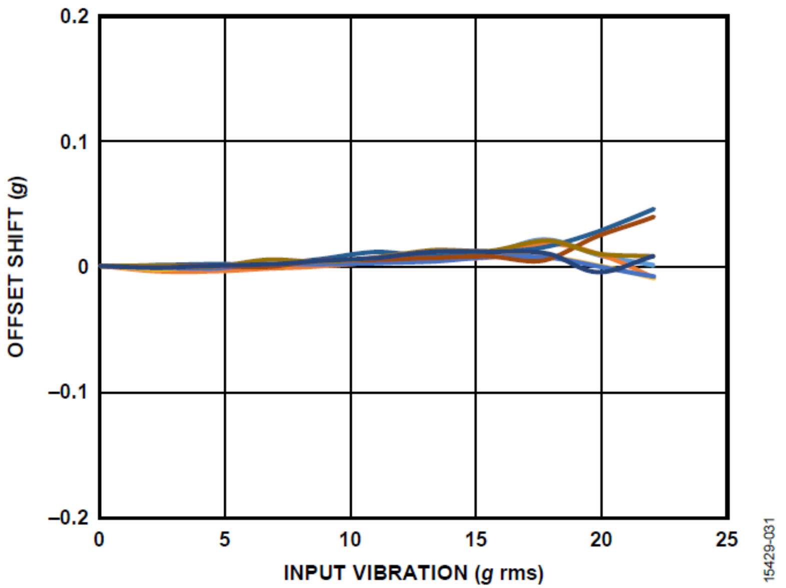
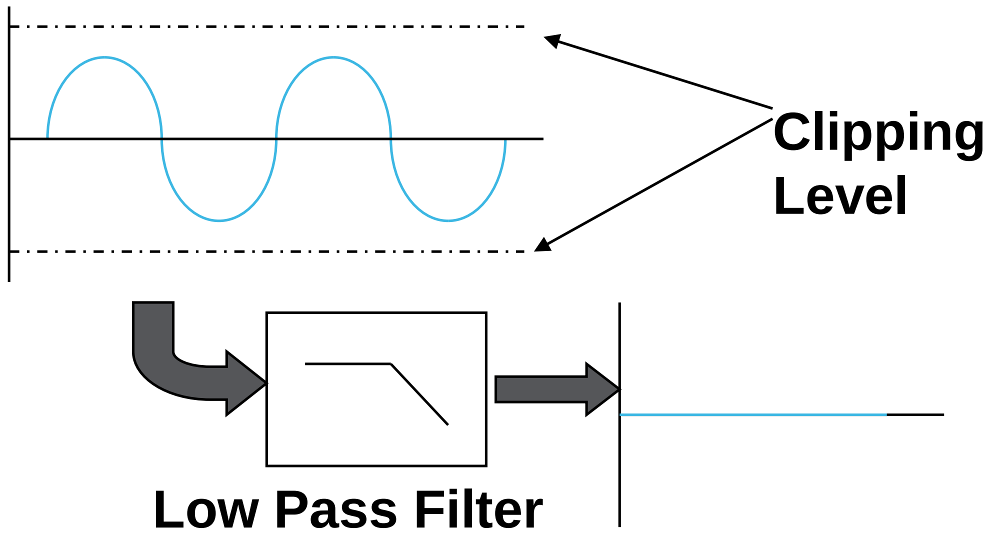
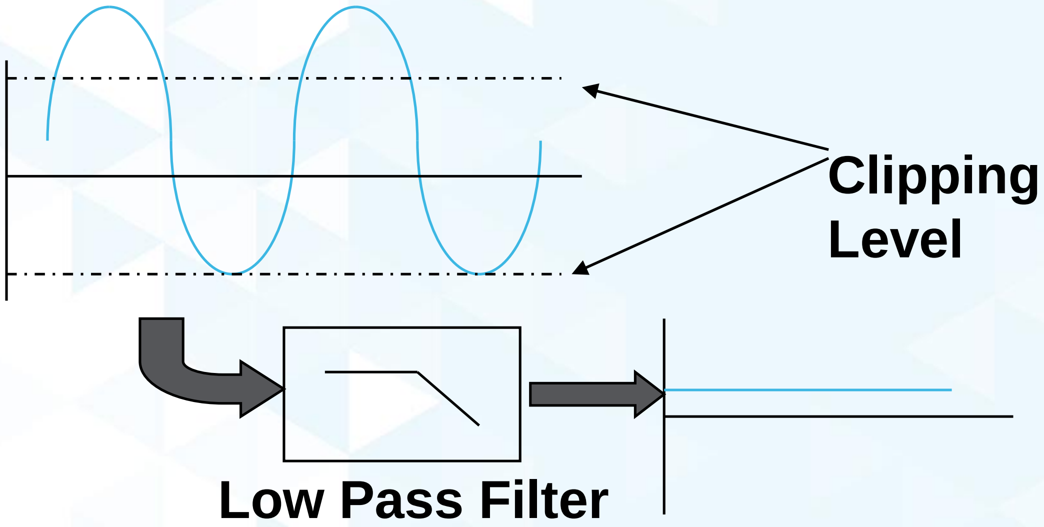


Figure 31. ADXL356 Vibration Rectification Error (VRE), Z-Axis Offset from +1 g, ±40 g Range, Z-Axis Orientation = +1 g

Wide Measurement Range Help To Avoid Clipping – No Offset Shift





- How did you get an asymmetric signal?
  - Vibration in the 1g field of gravity
  - Asymmetric clipping levels
  - Shock with fast rise time and slower decay

ADIS16495 Datasheet

GYROSCOPES					
Dynamic Range	ADIS16495-1BMLZ	±125			°/sec
	ADIS16495-2BMLZ	±450		±480	°/sec
	ADIS16495-3BMLZ	±2000			°/sec
Sensitivity	ADIS16495-1BMLZ, 32-bit		10485760		LSB/°/sec
	ADIS16495-2BMLZ, 32-bit		2621440		LSB/°/sec
	ADIS16495-3BMLZ, 32-bit		655360		LSB/°/sec
Error Over Temperature	−40°C ≤ T_C ≤ +85°C, 1 σ		0.2		%
Misalignment	Axis to axis		±0.05		Degrees
	Axis to frame (package)			±0.25	Degrees
Nonlinearity[1]	1 σ, ADIS16495-1BMLZ, FS = 125°/sec		0.2		% FS
	1 σ, ADIS16495-2BMLZ, FS = 450°/sec		0.2		% FS
	1 σ, ADIS16495-3BMLZ, FS = 2000°/sec		0.25		% FS
Bias					
In Run Bas Stability	1 σ, ADIS16495-1BMLZ		0.8		°/hr
	1 σ, ADIS16495-2BMLZ		1.6		°/hr
	1 σ, ADIS16495-3BMLZ		3.3		°/hr
Angular Random Walk	1 σ, ADIS16495-1BMLZ		0.09		°/√hr
	1 σ, ADIS16495-2BMLZ		0.1		°/√hr
	1 σ, ADIS16495-3BMLZ		0.18		°/√hr
Error over Temperature	−40°C ≤ T_C ≤ +85°C, 1 σ		0.1		°/sec
Linear Acceleration Effect	Any axis, 1 σ (CONFIG register, Bit 7 = 1)		0.007		°/sec/*g*

IMU new products: ADIS1649x Family

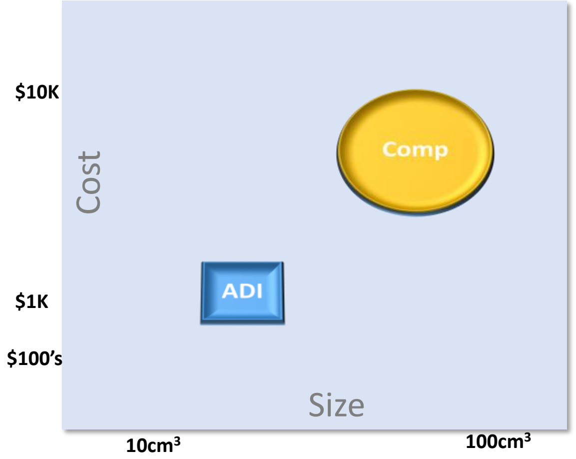
High perfromaces - All Condition Stability for the Most Dynamic and Complex Motion

System ready implementation through proven *i*Sensor® integration, calibration, and reliability with tactical grade performance

	ADIS16490	ADIS16495	ADIS16497
Dps	100	2000	2000
Range	8g	8g	40g

Application: Navigation and Stabilization system

- Industrial (heavy machinery)
- Military



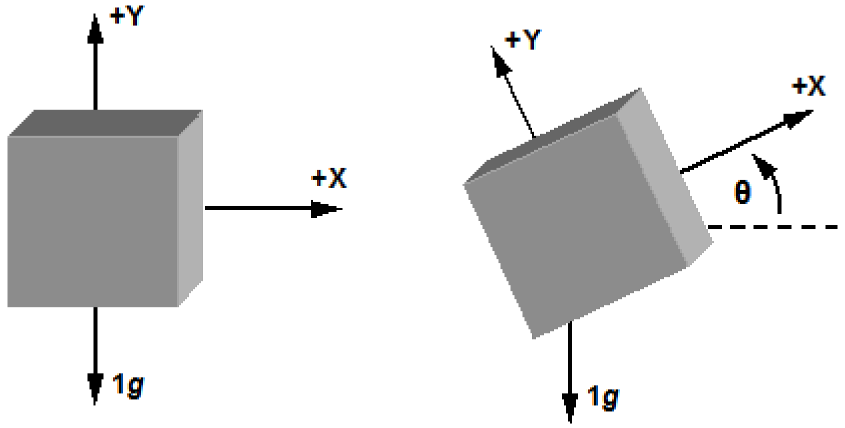
Key Features

- Tri-axis linear and rotational sensing
- Gyroscopes
  - Angular random walk: 0.07°/√hr, Noise: 1.6 mdps/√Hz, in-run bias: 0.8°/hr
- Accelerometers
  - Velocity random walk: 0.008 m/sec/√hr, Noise: 16 µg/√Hz, in-run bias: 3.6 µg
- Vibration Rejection – INDUSTRIAL BEST!
  - Linear-g rejection: 0.006°/sec/g
- Sensitivity Tempco
  - Gyroscope: ±24 ppm/°C, Accelerometer: ±16 ppm/°C
- Alignment
  - Axis-to-axis: 0.05°. Axis-to-frame: 0.25°
- Bandwidth: 480 Hz gyroscope; 750 Hz accelerometer
- Size: 47 mm × 44 mm × 14 mm

Application and Product-Tilt

What is Inclinometer

- Inclinometer is an instrument for measuring angles of slope (or tilt), elevation or depression of an object with respect to gravity.
- Inclinometer is also known as a tilt meter, tilt indicator, slope alert, slope gauge, gradient meter, gradiometer, level gauge, level meter, declinometer, and pitch & roll indicator.



Where the Inclinometer is Used – Industrial and Communication

- Industrial and Instrument
  - Widely used in construction machinery, minerals, railway, home improvement tools, wind energy source, solar energy…

Levelling & Safety Control

Altitude Difference Detection

Mine Hydraulic Support

Optimize Generated Energy

- Communication
  - Precision tilt sensing, to optimize base station antenna coverage area, prevent base station inclined fall, improve radar antenna stability and reliability…

Base Station, Fall Prevention

Radar Antenna, Stability & Reliability

Where the Inclinometer is Used – Consumer and Healthcare

- Consumer
  - Widely used in Mobile phone, projector, camera, toy robots for playing games, ECompass, improve user experience…

ECompass Navigation

Handsets Games

LCD Projector

Horizontal Detection

- Healthcare
  - Precision tilt sensing, to prevent patient complications/injury, improve measurement accuracy, fall detection …

Rehabilitation Seat

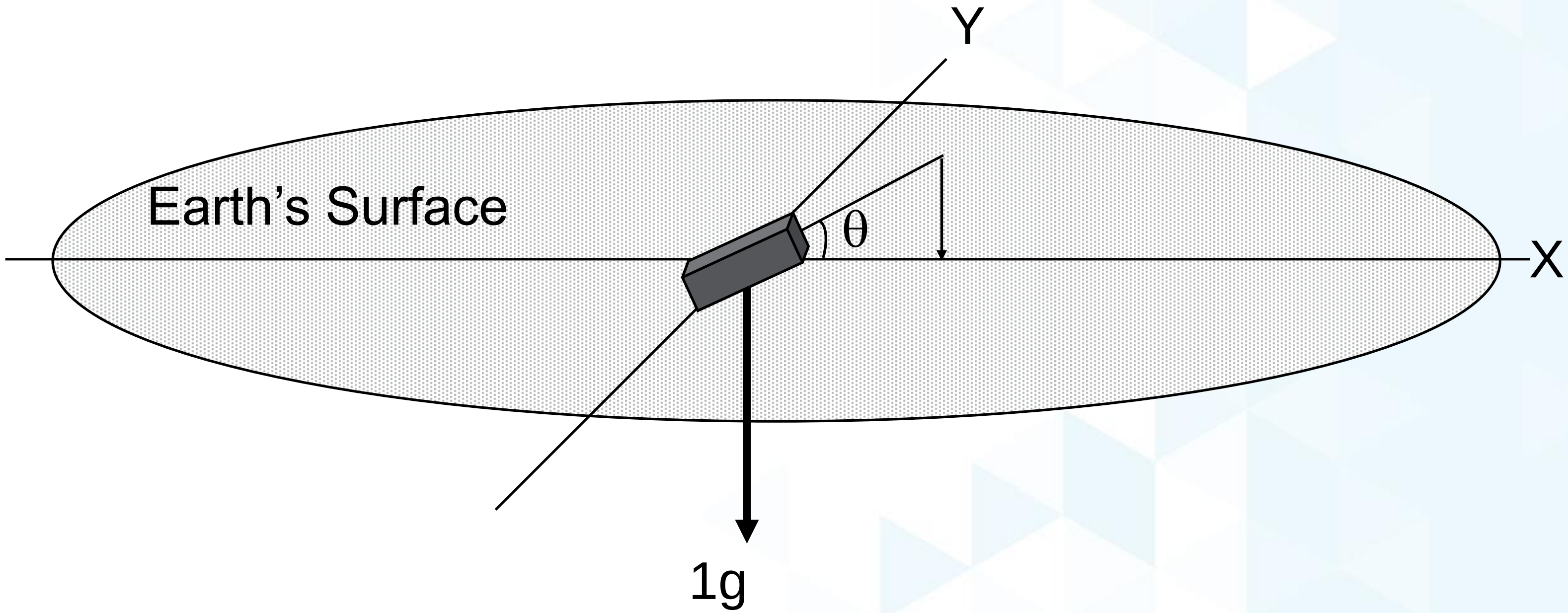
Scan Equipment Safety

Pneumonia,
Aspiration Prevention

Sphygmomanometer, accurate blood pressure measure

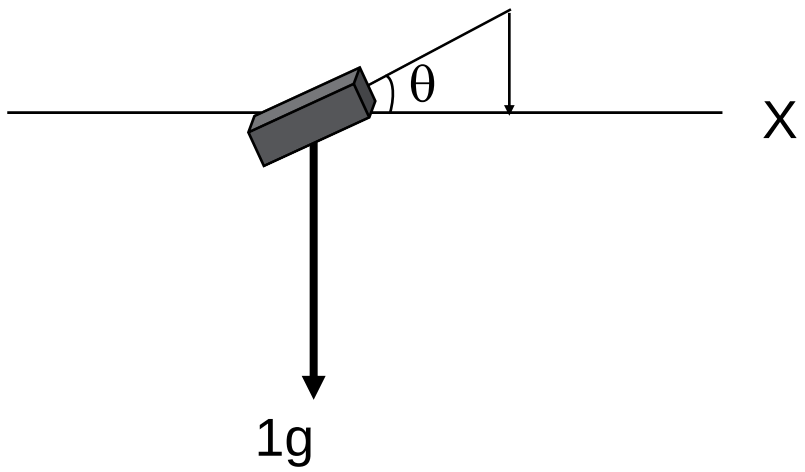
How to Realize Inclinometer with MEMS Accelerometer

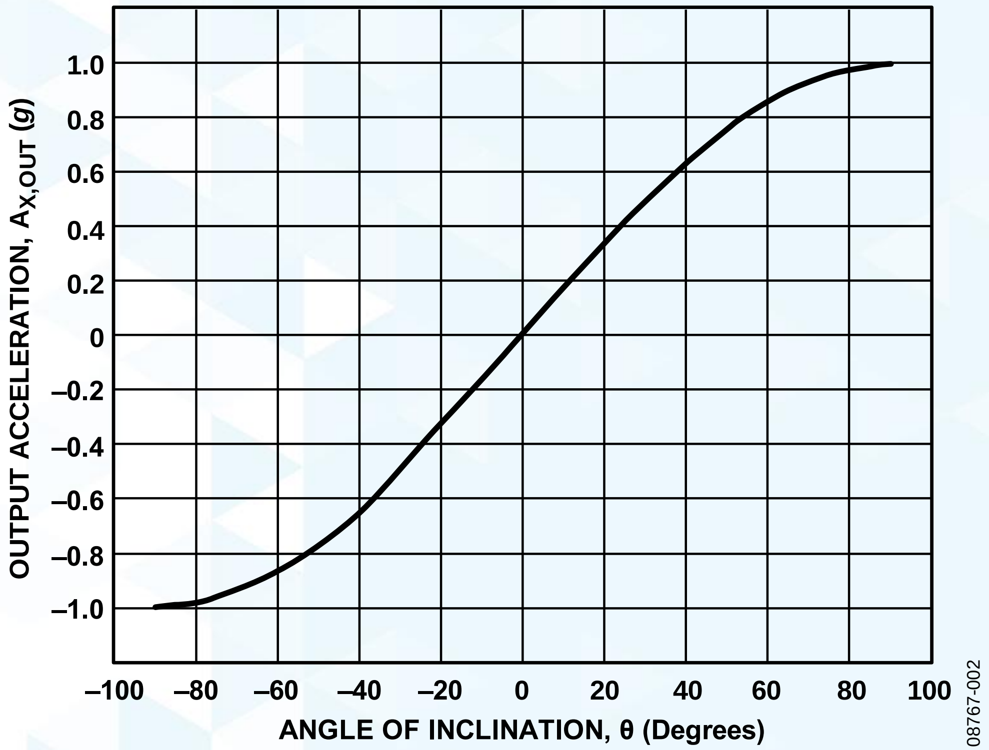
- MEMS Accelerometer can measure both dynamic acceleration and static gravitational force.
- Inclinometer can be accomplished by measuring the amount of the gravity vector that is reflected on different axis of the MEMS accelerometer.



How to Realize Inclinometer with MEMS Accelerometer – Single Axis

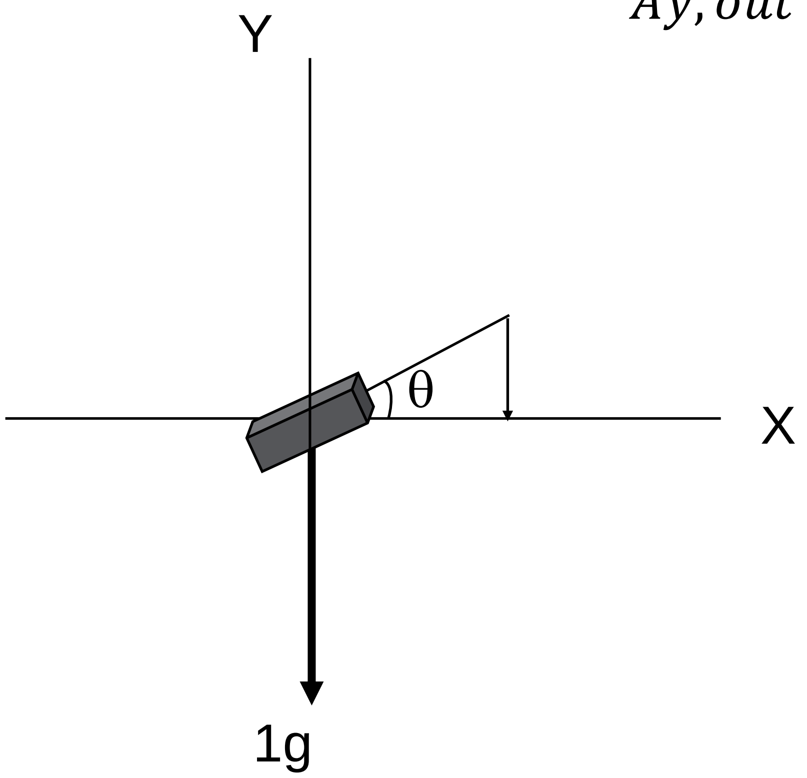
$$A_{x,out}\ [g] = 1\ g * \sin(\theta)$$

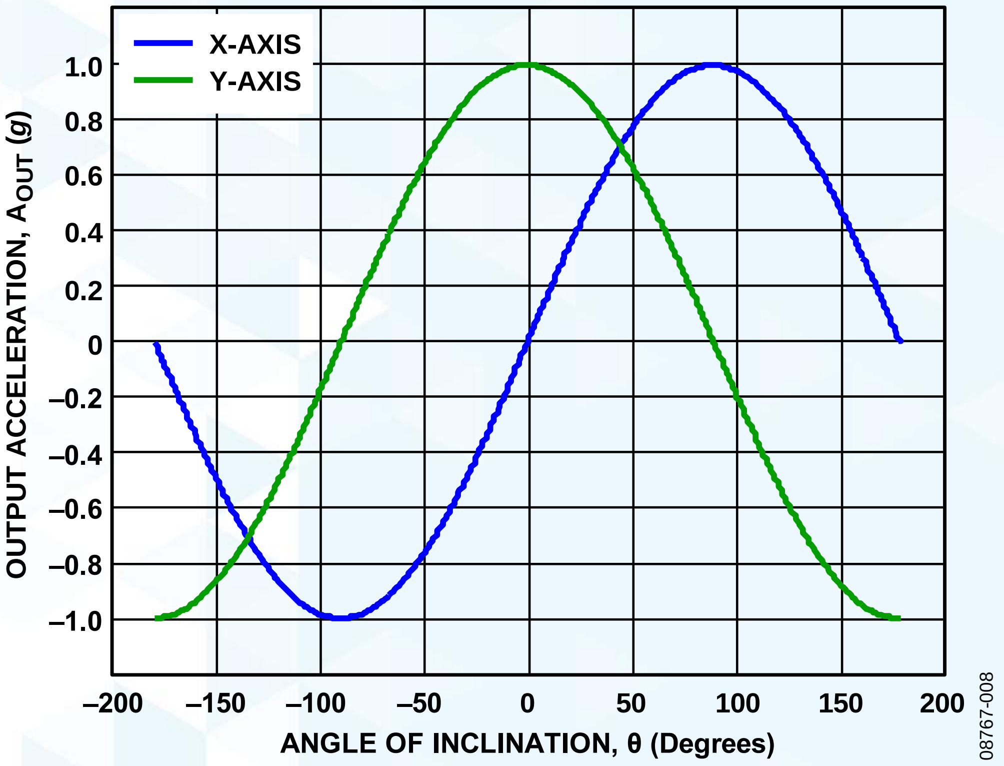




How to Realize Inclinometer with MEMS Accelerometer – Dual Axis

$$\frac{Ax,out}{Ay,out} = \frac{1g \ * \sin\theta}{1g \ * \cos\theta} = \tan\theta$$





Tilt Accelerometer Specifications

- Range
  - For Tilt Applications, low range of +/-1gee or +/-2gee are typical and provide best resolution
  - When sensing in High Vibration environment, additional range many be required
  - With Dynamic Range will dictate resolution, linear range

- Bandwidth
  - For Tilt Applications, DC Response is required
  - Low frequency response of 10’s of Hz is common
  - Higher frequency response of 100’s of Hz or more is better in movement or vibrations environments

- Degrees of Freedom
  - How many angles of tilt are required
  - Greater angle range requires at least 2 axis

Tilt Accelerometer Specifications

- Accuracy / Repeatability / Noise Density / F0 / Linearity
  - Noise Density will dictate performance over bandwidth
  - Repeatability depends on lifetime (5 or 10 year) degradation, broadband noise, temperature hysteresis
  - Linearity requirement depends on many factors, may require characterization or calibration
    - Could influence calibration

- Resolution
  - For Tilt Applications, adequate resolution is required and will dictate ultimate performance (RAV curve help identify optimal averaging time)

- Offset TempCo
  - How much will Offset drift over temperature; minimize calibrations required. This specification could dictate the ultimate system level specification.

- Analog or Digital Interface
  - Some interfaces work better in applications

Ultra Ultra Low Noise

ADXL354/355 Enable High Accuracy Inclinometer In IIOT

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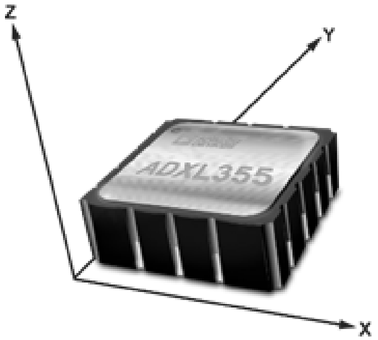
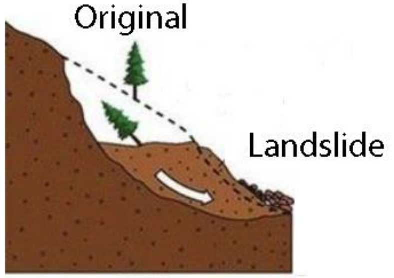
- Selectable measurement range: ±2*g*, ±4*g*, ±8*g*
- Offset temperature coefficient of <0.15m*g*/°C (max) with minimal hysteresis
- Ultralow noise density: 25µ*g*/√Hz
- Hermetic ceramic package for long-term stability
- Low power:
  - 200 µA in measurement mode
- Analog and Digital SPI/I2C interfaces
- Integrated temperature sensor
- Operating Temperature Range: -40°C to 125°C
- Repeatability: ±3.5m*g for X and Y,* ±9mg for Z
- Repeatability is predicted for a 10 year life and includes shifts due to the high temperature operating life test (HTOL) (TA = 150°C, VSUPPLY = 3.6 V, and 1000 hours), temperature cycling (−55°C to +125°C and 1000 cycles), velocity random walk, broadband noise, and temperature hysteresis.



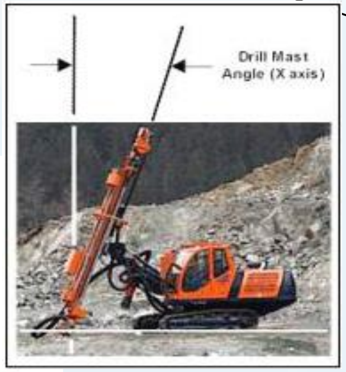


Examples of High Vibration Environments requiring Inclinometers

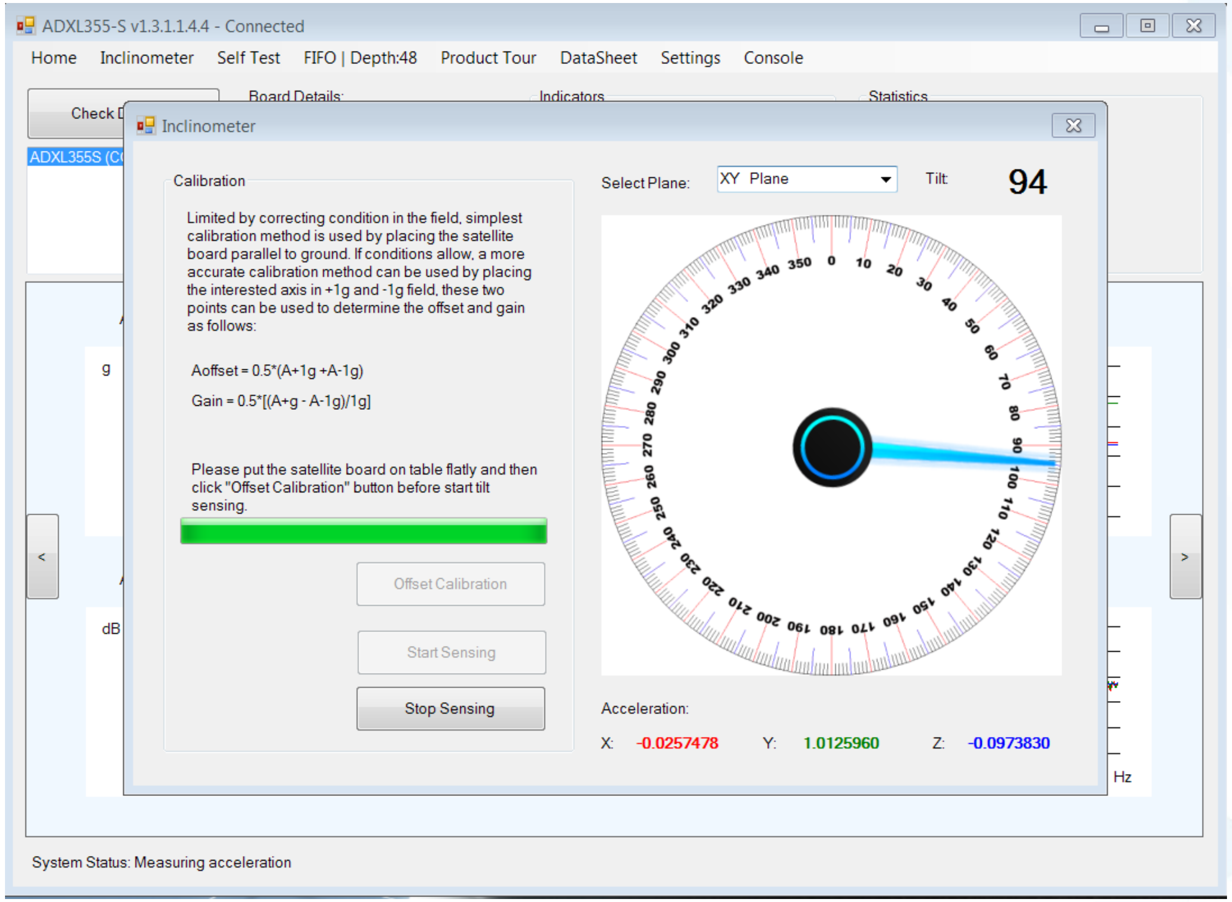
Images from: http://www.spectronsensors.com/targetapps.php

- “Tipping” sensors
  - Boom lifts
  - Manlifts, aerial work platforms
  - Crane safety systems

- “Alignment/Leveling” sensors
  - Down-hole mining
  - Telescoping handlers
  - Construction lasers
  - Road graders
  - Airplane boarding bridges



ADXL355 Eval Board

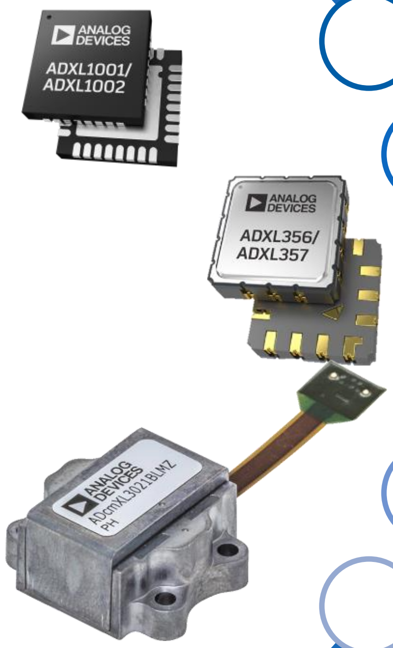


EVAL-ADXL355/7-MLP

Application and Product-CbM

Performance Enables Deeper Insights, Driving Diagnostic, and Predictive Solutions

Measurement of vibration generally means a survey of the frequency spectrum to determine whether a fault is emerging on the machine or equipment.



- Wide Bandwidth
- Wide Measurement Range
- Low Noise
- Stability over Temp and Life
- Multiaxis
- Small Form Factor

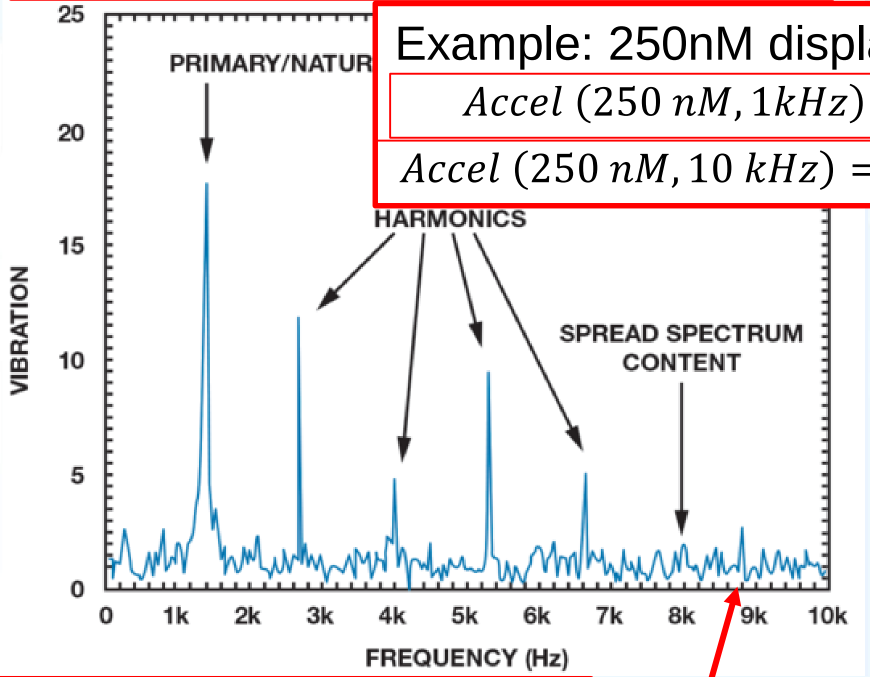
Higher frequency signals create larger accelerations, requiring wider measurement ranges

$$Accel(d, f) = 4 \times \pi^2 \times f^2 \times Disp.$$

Example: 250nM displacement

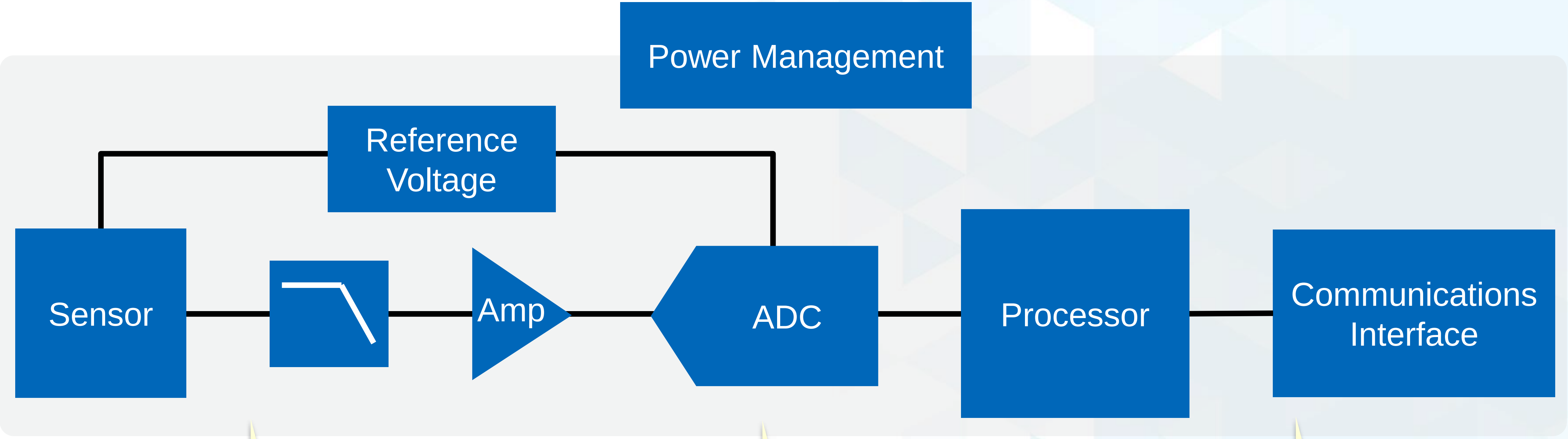
$$Accel\ (250\ nM, 1kHz) = 1\ g$$

$$Accel\ (250\ nM, 10\ kHz) = 100\ g$$



Wider bandwidths and lower noise enable earlier detection of initial signs of wear

Extracting Value from the Sensors Requires an Optimized Signal Chain and Signal Processing



Sensor Considerations

- Analog vs. digital
- Single vs. multiaxis
- Bandwidth
- Measurement range
- Noise

Signal Chain Considerations

- Sampling/frequency planning
- Single vs. multichannel sampling
- Simultaneous sampling
- Design for low noise
- Power considerations

Signal Processing Considerations

- Data acquisition techniques
- Digital filter design
- Real-time data rate requirements
- Time vs. frequency domain processing
- Preprocessing of data and statistics

Communication Link Considerations

- Wired vs. wireless
- Diagnostics at edge
- Data rate requirements
- Cable lengths
- Noise immunity
- Synchronization

Flexible Signal Conditioning Portfolio Enables MEMS-based Solutions for Various Use-Cases

System and Machine-Level Diagnostics:

- BW: DC→ >10 kHz
- Low noise: <125 µg/√Hz
- Wide dynamic range: >50 *g*
  - **ADXL1001**
  - **ADXL1002**
  - **ADXL1003**
  - **ADXL1004**
  - **ADXL1005**

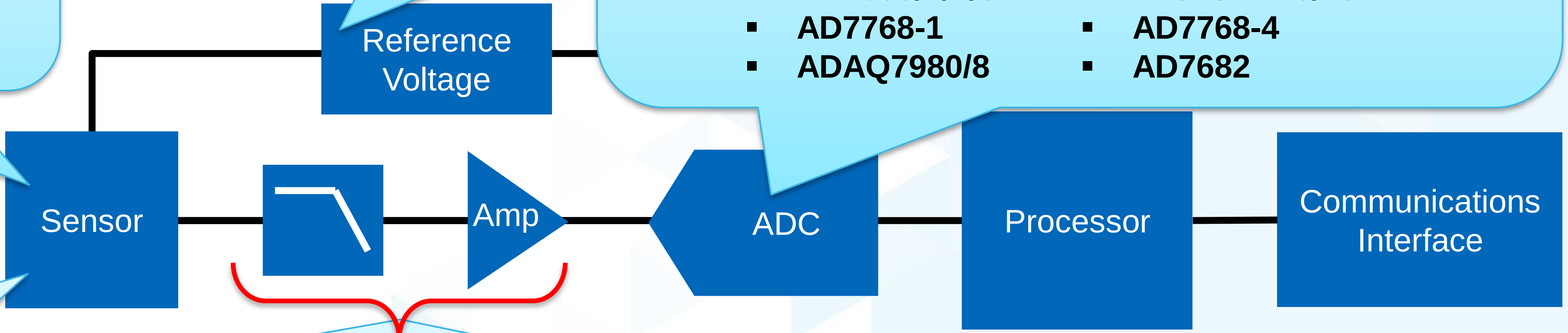
System Reference and Power:

- Stable, low noise outputs
- Flexible voltage inputs/outputs
  - **ADR4540**
  - **LTC1928-5**

Precision Data Converters

- Higher sampling rates preserve wider sensor bandwidths, while minimizing unwanted signals and noise from folding back
- Early signature detection for bearing faults and precision misalignments require lower noise and higher resolutions

Single-Channel	**Quad-Channel**
AD4000/2/4/8	**LTC2344-16/18**
AD7768-1	**AD7768-4**
ADAQ7980/8	**AD7682**



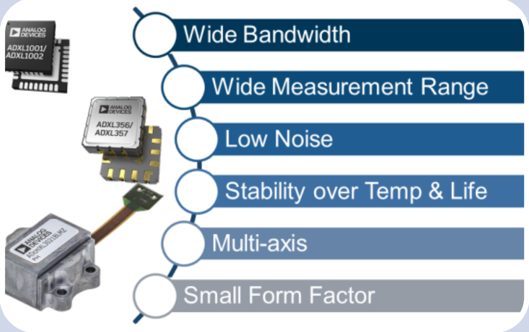
System Level Diagnostics:

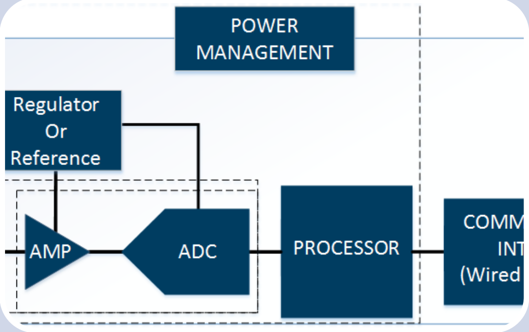
- BW: DC→ >1.5 kHz
- Low noise: <125 µg/√Hz
- Wide dynamic range: ±10 *g* to ±40 *g*
  - **ADXL356**

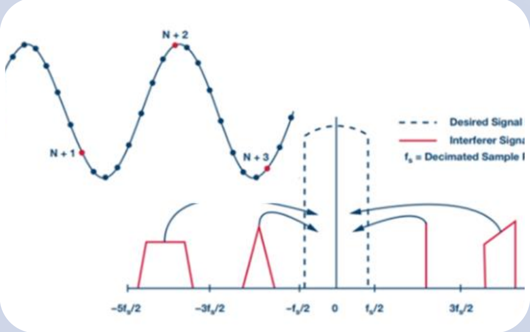
Signal Conditioning and ADC Drivers:

- External filters and drivers minimize unwanted signals and noise from aliasing or folding back in-band
- Influences such as sensor resonance, high frequency clocks, and noise from both electrical components and dynamic environments impact early signature detection
  - **AD8606**
  - **LT6013**
  - **AD8422**
  - **ADA4625-1**
  - **ADA4522-1**
  - **ADA4610-2**
  - **ADA4807**
  - **ADA4805**

Integrated Modules Solve Challenging Problems and Accelerate Solution Development







Sensors

- Next-generation sensing technologies

Signal Chain

- Complete signal chain offering complements performance requirements

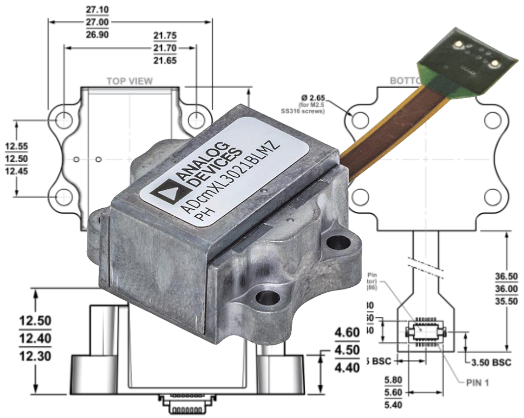
Signal Processing

- Sampling considerations maximize sensor performance

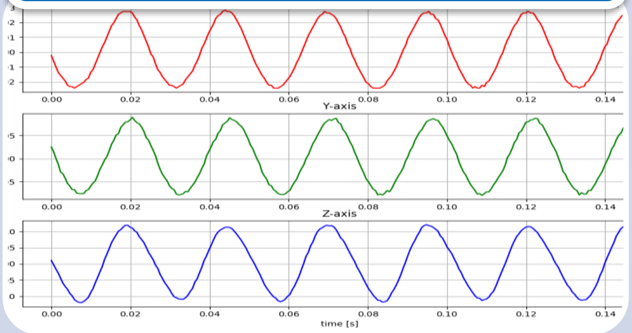
Packaging

- Mechanical design considerations support industrial environments

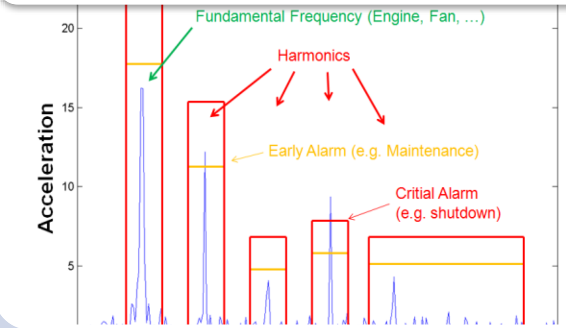
ADcmXL3021 Combines Embedded Processing into a Mechanically Optimized Package



Time Domain Modes



Frequency Domain Modes



ADcmXL3021 Highlights

- Triaxial vibration sensor
- ±50 *g* measurement range
- Wide bandwidth: DC to 10 kHz
- User configurable
- Operating temperature: –40ºC to +105ºC

Features (Time Domain)

- Real-Time Streaming
- Manual Time Capture

Features (Frequency Domain)

- Manual FFT
- Automatic FFT

Mechanical Considerations Are Required for Optimized Vibration Monitoring Solutions

Location, Location, Location!

- Placement at the vibration source is ideal
- Attenuation occurs due to absorption and scattering of the vibration waves as they travel through different mediums
- Closer sensor placement minimizes damping, improving the quality, and reliability of the measured signals

Attachment is Critical

- Direct, rigid sensor attachment is required to maximize energy transfer across the desired bandwidth
- Stud or screw mounting in conjunction with adhesives maximizes the frequency response

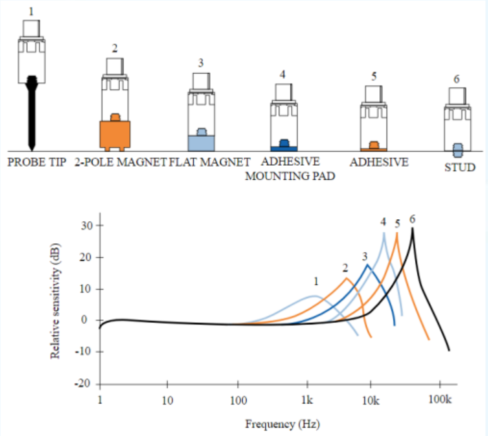
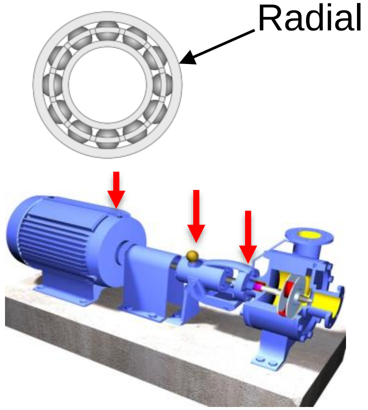


Figure courtesy of DEWESoft

Vibration Waves are Directional



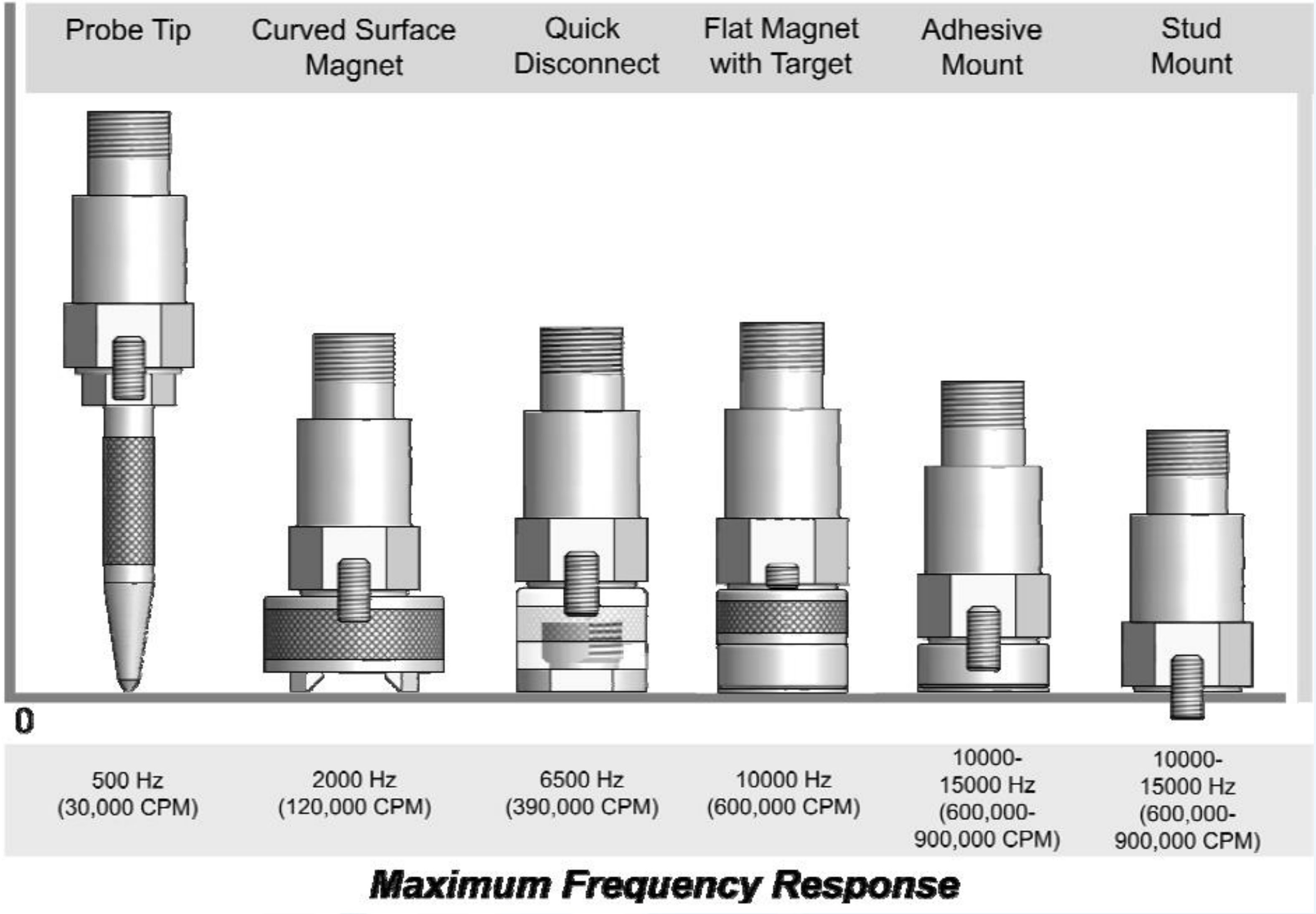
- Typically, bearing vibration solutions require low noise and wide bandwidth in the radial direction … at a minimum
  - MEMS solutions enable multiaxis measurement for deeper diagnostic insights
- System-level faults such as misalignment, require multiaxis data to identify and distinguish the correct fault type

Size Matters

- Larger PCBs, packages, enclosures, batteries, etc. impact the sensor response
- Resonances introduced into the mechanical design degrade the quality of the data extracted from the sensor and impact the ability to identify critical signatures

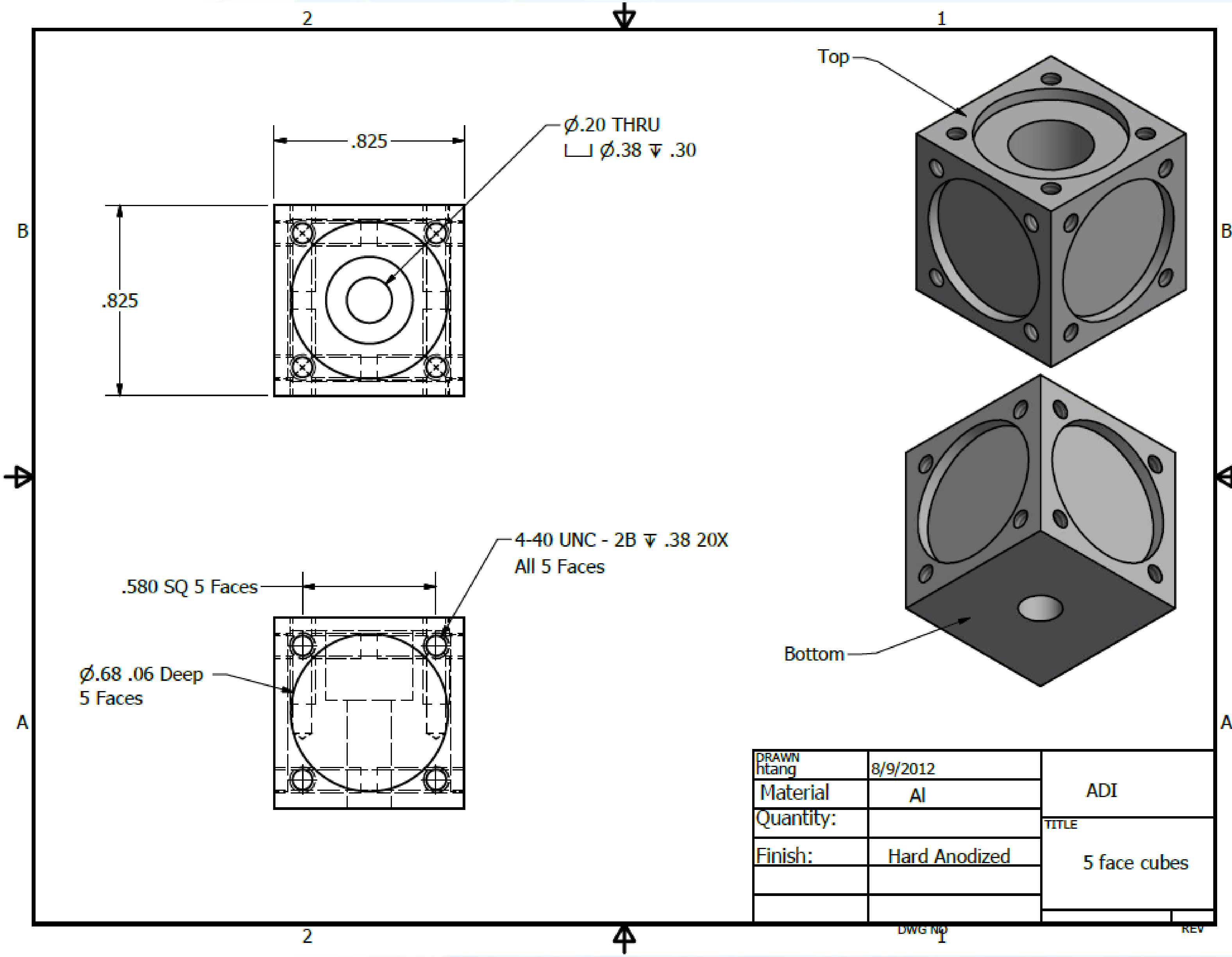
Condition Monitoring – Mounting strategies

- First consideration must be capability of the Sensor
- Almost as critical is mounting strategy
- For MEMS, PCB thickness and mounting need consideration
- **Warning:** Magnetic mount can generate significant *g* force and care must be taken when placing on equipment.



ADXL1001/ADXL1002 Evaluation requirements - Mounting Cube +

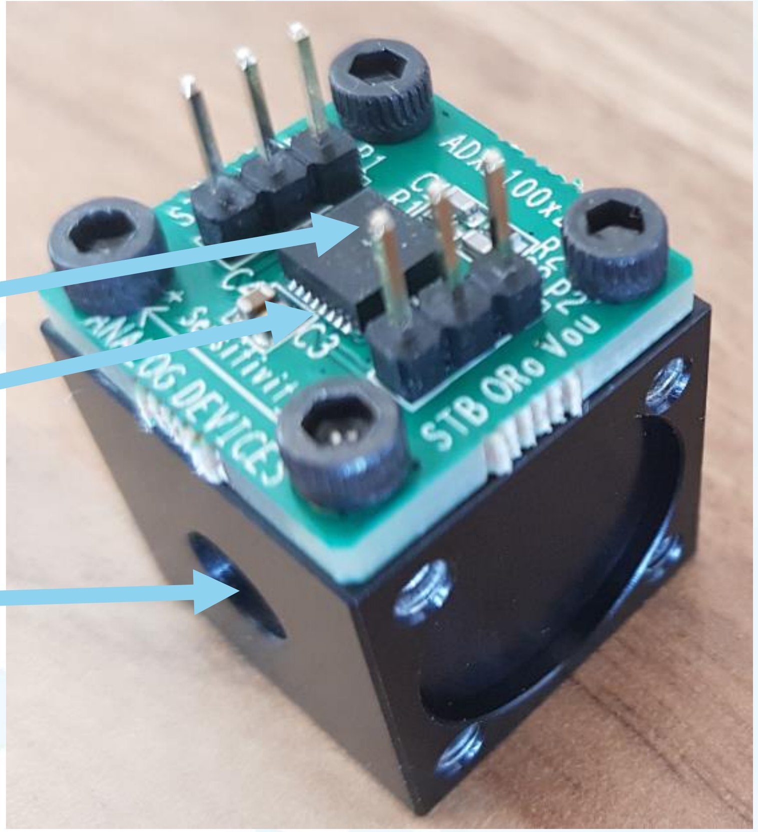
- Initial evaluators struggled connecting ADXL1001/1002 to shaker table or motors
- ADI modified the Board and developed a mounting cube with a place for a stud mount
- Board fits on cube (small) and is 90 mils thick to increase resonance
- ADC and Low pass filtering is documented to achieve best performance



ADXL1001/ADXL1002 Evaluation requirements - Mounting Cube +

- The entire mechanical interface is important also.

- The Accelerometer output is a combination of:
  - sensor response,
  - PCB (including solder),
  - PCB mounting to machine
  - machine vibration
  - other mechanical vibration in the area not isolated

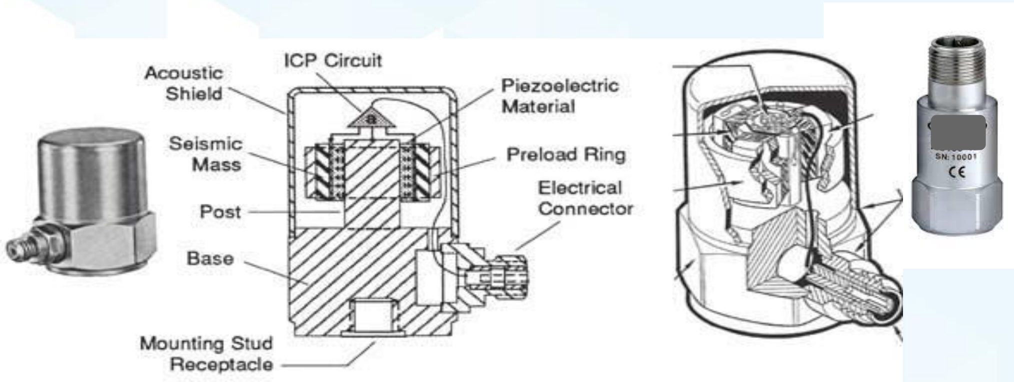


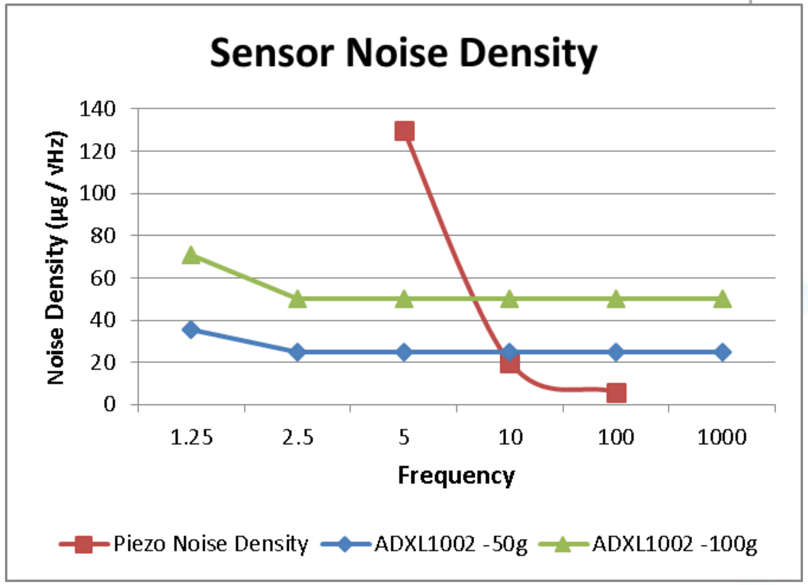
MEMS Accelerometer Value Proposition for Condition Monitoring

As MEMS Accelerometer performance improves (frequency increases and noise decreases), coming closer to that of the mechanical sensor, intrinsic attributes of MEMS have become compelling, driving market penetration and expansion …

Intrinsic MEMs benefits -

- Enables higher level of functionality
  - Full electro-mechanical self-test
- Shock tolerant (reliable sensitivity)
- Low frequency response
- Scalable Manufacturing
- Low SWaP
- Low cost
- Stable over temp





Expensive mechanical sensors liabilities include:

- Hand assembled, limited manufacturing scale
- Periodic calibration required (particularly if dropped)
- Expensive and unwieldy interface
- Poor low frequency response
- Limited self test
- Sensitive to temperature variation (*Accuracy ~10%*)

ADXL354/ADXL355/ADXL356/ADXL357: High Performance 3-axis Accelerometers

Features and Specifications

- **ADXL354/5 ±2g/ ±4g/ ±8g**
  - 20/25µg/√Hz noise density
  - Guaranteed 0.15mg/C offset drift
  - 200µa power supply current (ADXL355)
  - -40C to +125C operation
  - Hermetic package
  - Both analog and digital interface modelS
- **ADXL356/7 ±10g/ ±20g/ ±40g**
  - 80µg/√Hz noise density
  - Guaranteed 0.75mg/C offset drift
  - 200µa power supply current (ADXL357)
  - -40C to +125C operation
  - Hermetic package
  - Both analog and digital interface models

Portolio Positioning	ADXL203	ADXL354	% Delta
Noise (µg/√Hz)	110	20	-77%
0-g Tempco (mg/C Max)	0.8	0.15	-81%
Power supply current (µa, per axis)	350	60	-83%
Orientation (DoF)	XY	XYZ	

Noise Density

- **ADXL356 is an upgrade to ADI's best selling ADXL22037 – with 30% less noise at 1/5th the power**
- **Single axis Colibrys MS900x at 12x the price, 7.5x the power.**
- **2-Axis VTI SCA100T at 10x the offset spec, 30x the power.**

ADXL100x High Performance Accelerometers

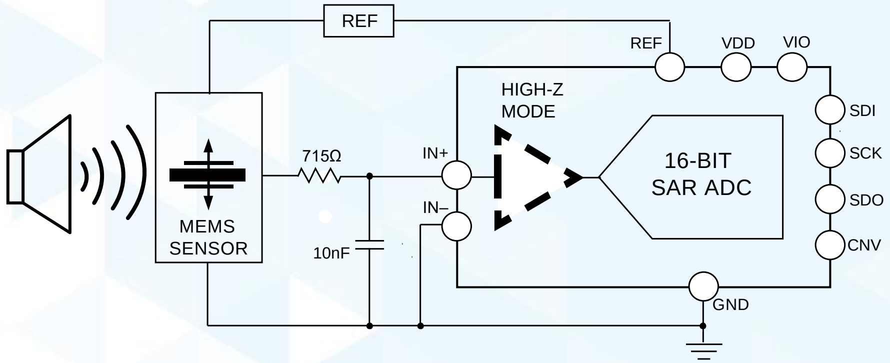
Higher resonant frequencies, pin compatible with ADXL1001 and ADXL1002

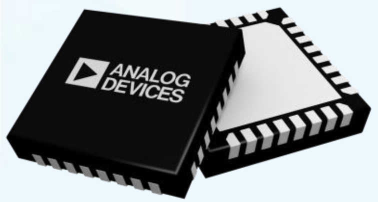
Features and Specifications

- ADXL1001/2/3/4/5
  - **High Full Scale Ranges (FSR) ±50g to ±500g**
  - Low noise density
    - **25 to 80µg/√Hz noise density**
  - Single, in-plane orientation
  - Analog output
  - Overrange indicator (OR)
  - Electro-static Self test (ST)
  - **21kHz to 45kHz resonant frequencies**
  - 1mA power supply current
  - -40C to +125C operation
  - **5x5mm LFCSP package**

Typical Interface

ADXL1002 **AD4000**

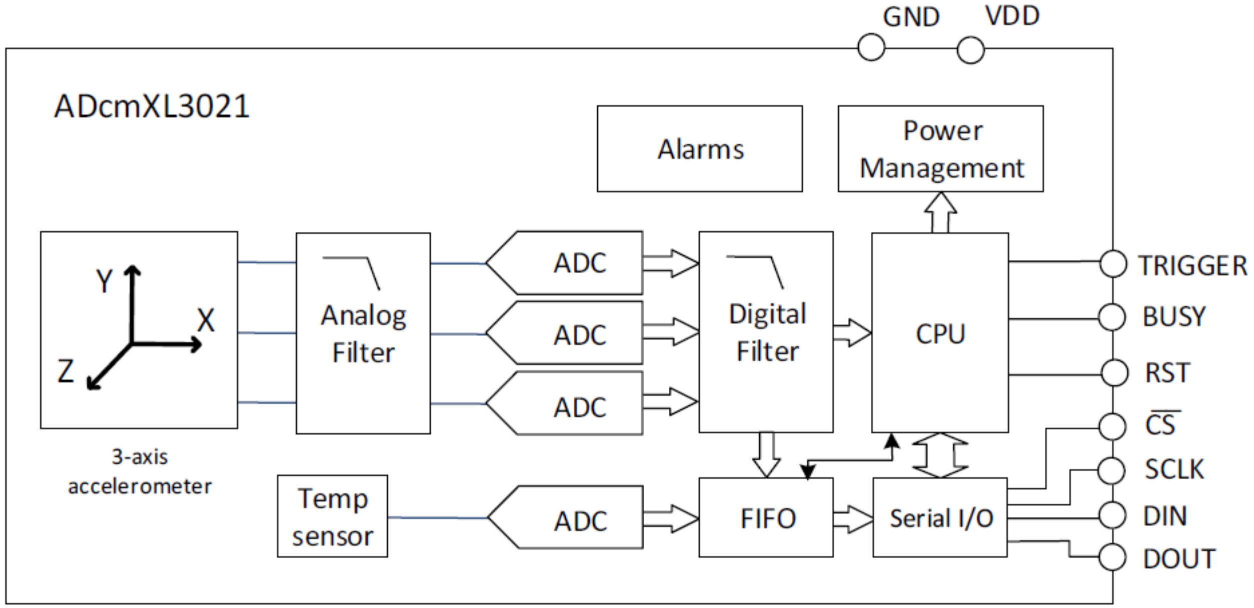




5 x 5 x 1.8mm LFCSP package
Single, in-plane axis

ADcmXL3021 - Mountable Condition Monitoring Platform

- Configured for single, dual or tri-axis sensing.
- Sub-system integrates a Microcontroller for edge node data processing
- Integrated filtering, time based statistics and frequency transform (FFT) are included.
- Record Data
- Spectral Alarms



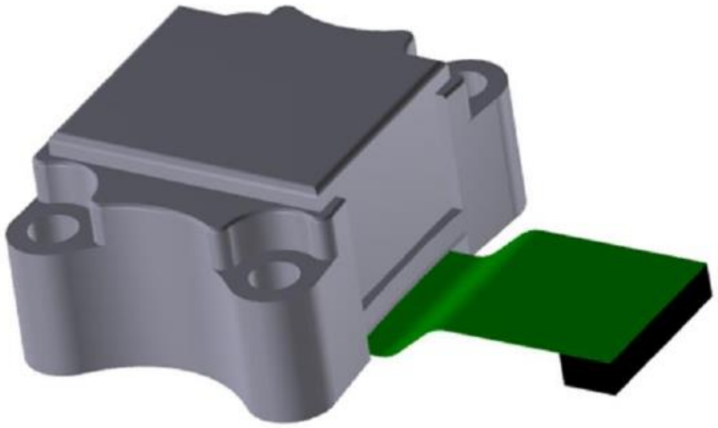


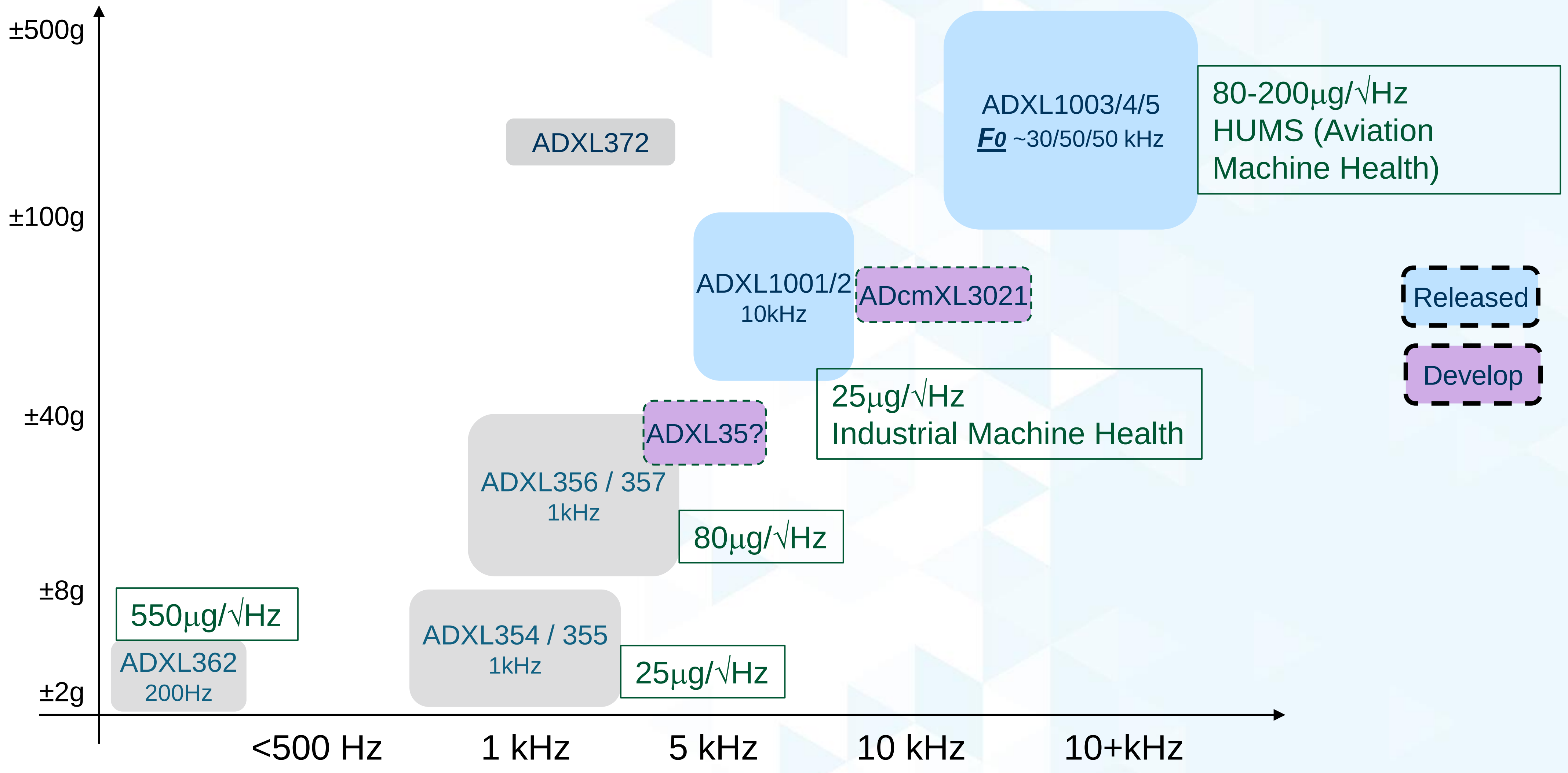
Figure 8. Module with Integrated Connector. Dimensions in millimeters (24x18x12mm)

MODEL	ORIENTATION	OUTPUT DATA RATE (KSPS)	ACCELEROMETER F0 (KHZ)
ADCMXL3021	XYZ	27.5	21
ADCMXL2021	XY OR XZ OR YZ	27.5	21
ADCMXL1021	X OR Y OR Z	27.5	21

Table 1. Available derivative models of the ADcmXL3021 platform.

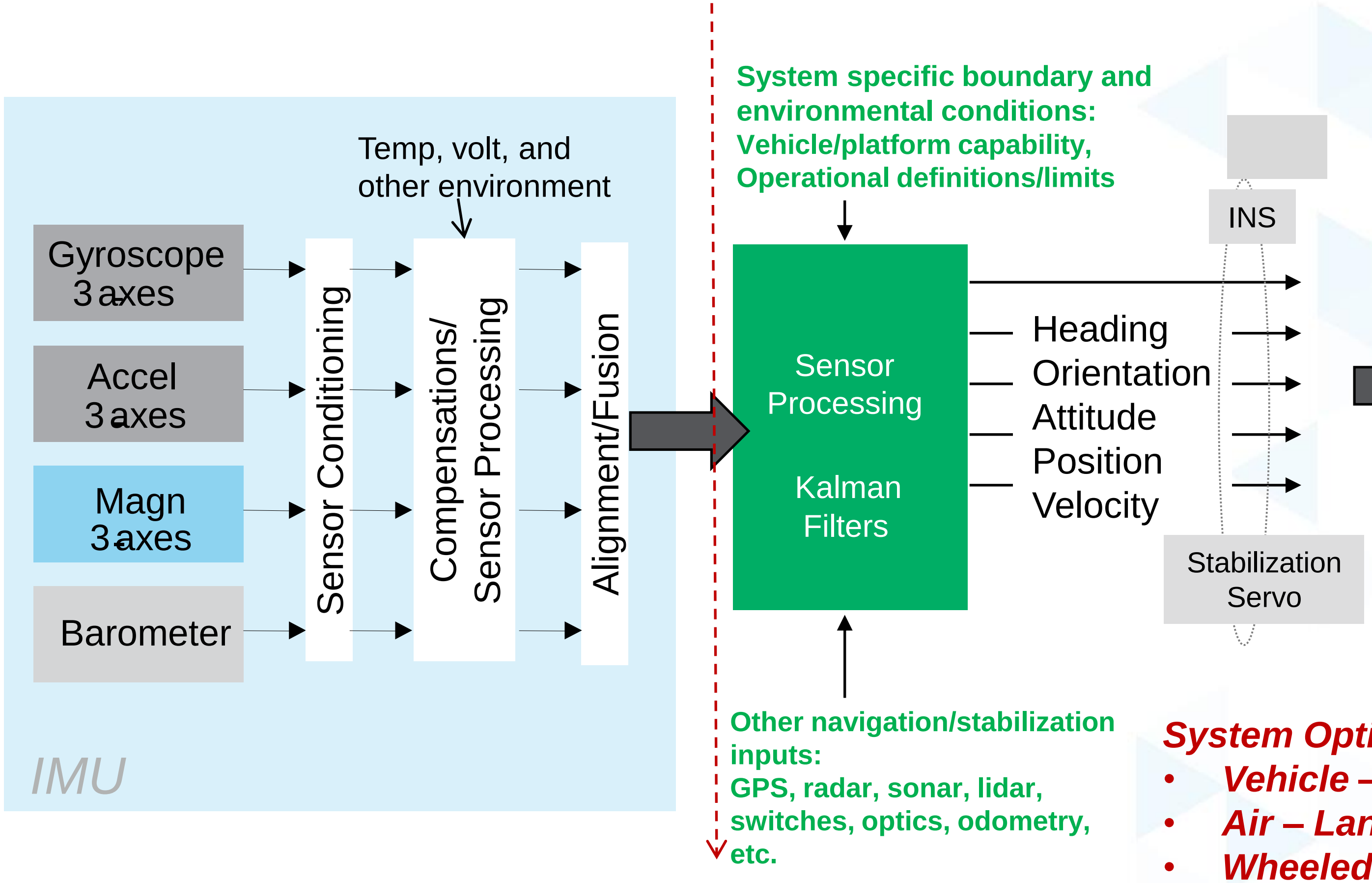
To be Announced at Electronica

Low Noise Accelerometer Landscape



Application and Product-AGV

What are IMUs used for?



Desired Output

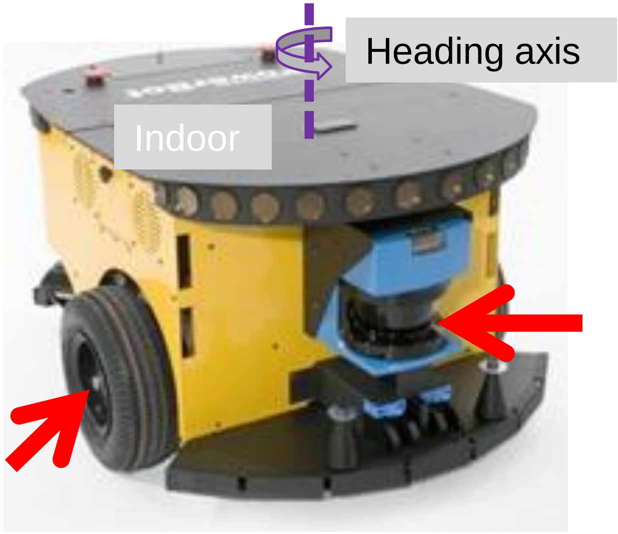
- ► Precision
- ► Confidence / Trust
- ► Full State Coverage
- ► Cost-Effective

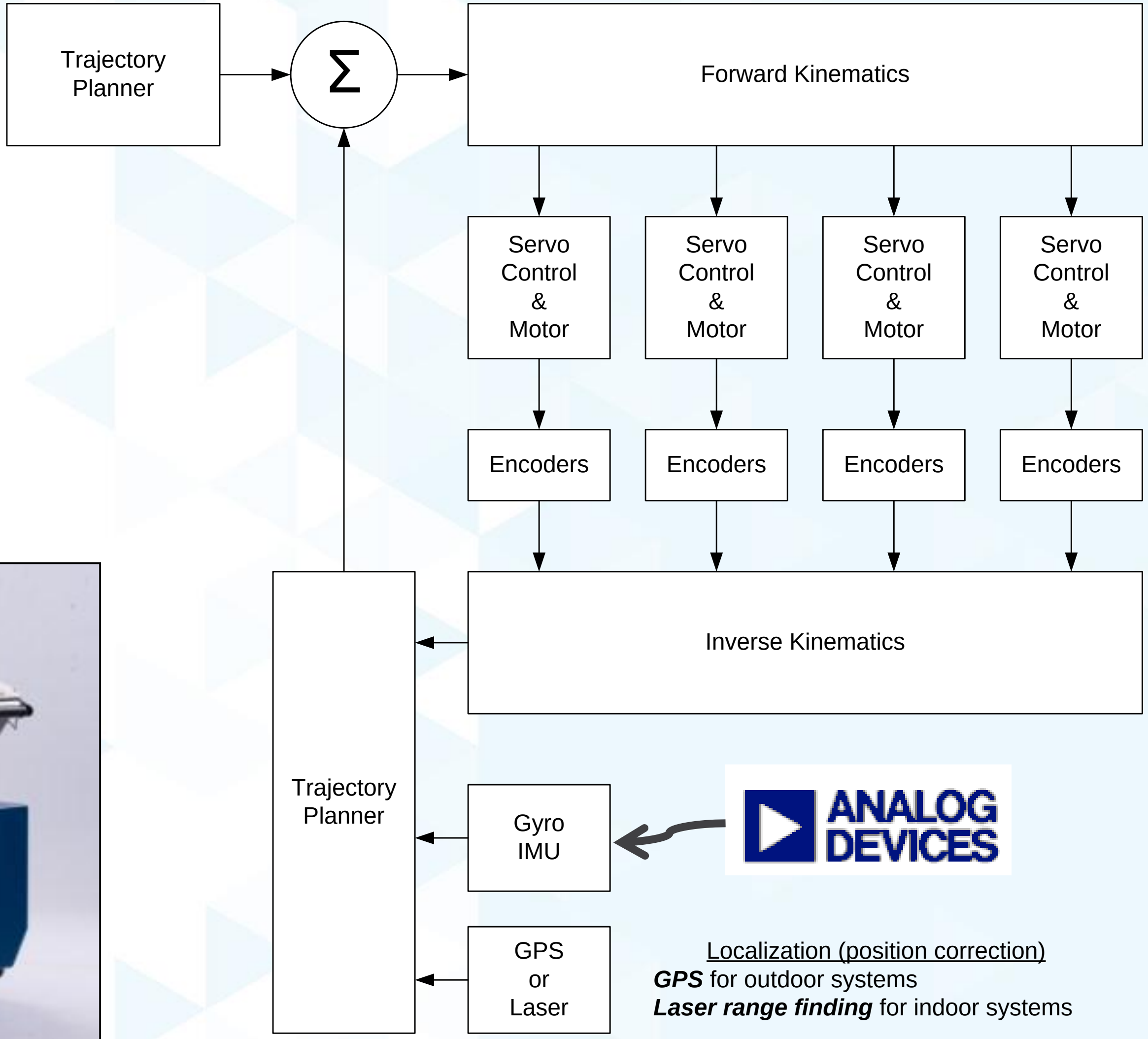
System Optimization Requires Comprehension of:

- ***Vehicle – Body – Instrument***
- ***Air – Land- Sea***
- ***Wheeled – Tracked – Other***
- ***Indoor – Outdoor***
- ***AvailableAiding Sensors***
- ***Environmental Conditions/Boundaries/Limits***
- ***Desired % State Coverage – Confidence Level -…***

- **Partitioned for Performance Optimization and Flexibility at System Level**
- **20-50X performance enhancement**
- **High Confidence across Environment**

IMUs are Usually Part of a More Complex System





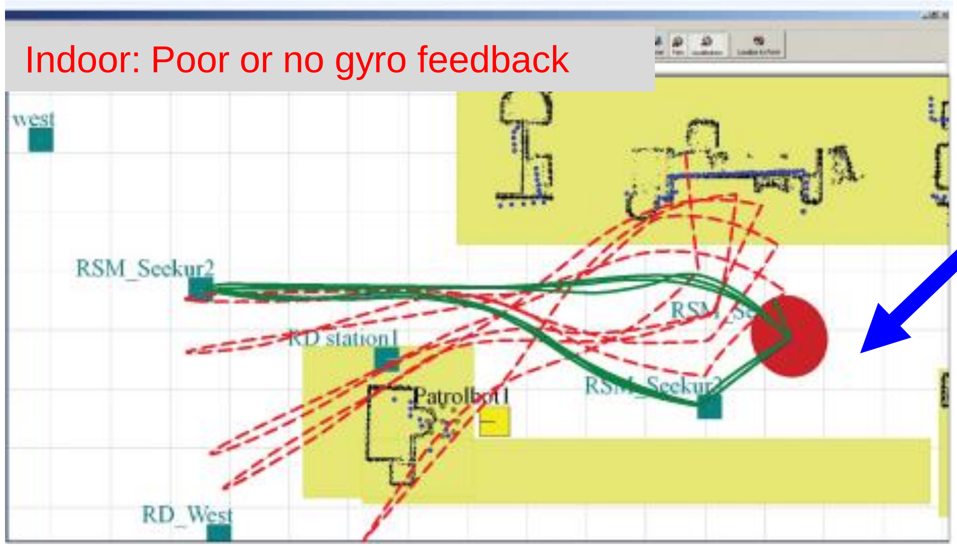
Localization (position correction)

GPS for outdoor systems

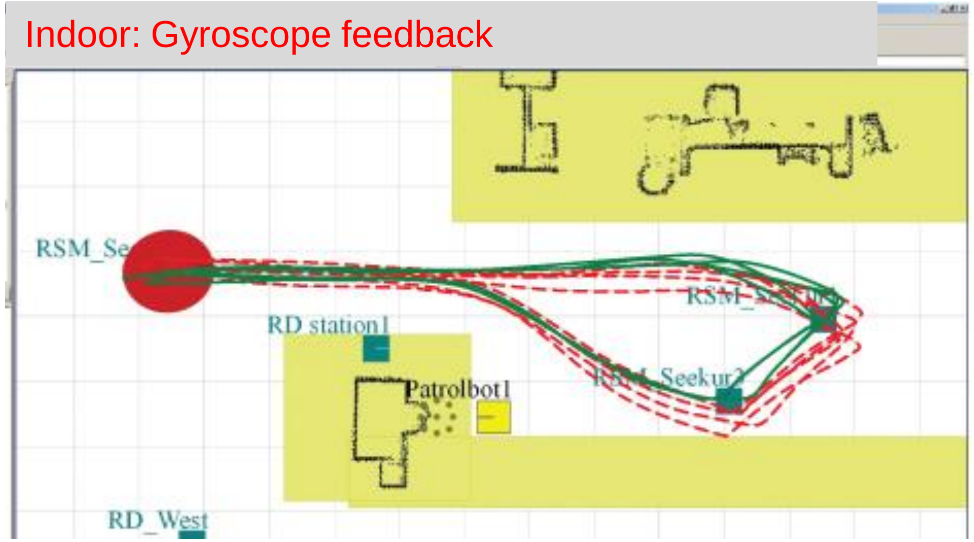
Laser range finding for indoor systems

Emerging as a *contributor* for position tracking

Indoor: Poor or no gyro feedback

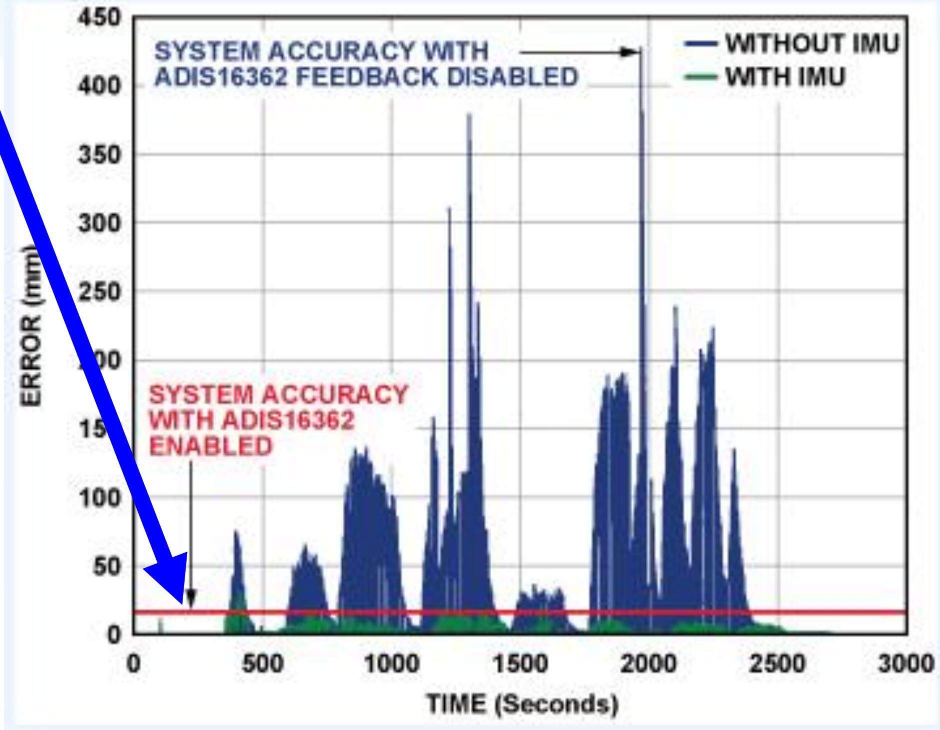


Indoor: Gyroscope feedback



Massive improvement, expansion of robot capability

Outdoor:
- Uncertain terrain
- GPS obstruction management



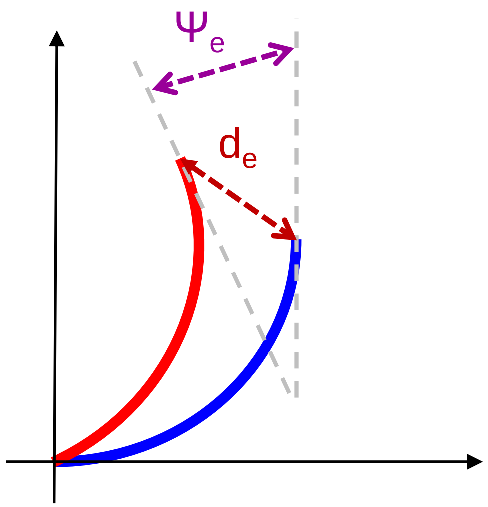
http://www.analog.com/en/analog-dialogue/articles/inertial-sensors-and-autonomous-operation-in-robots.html

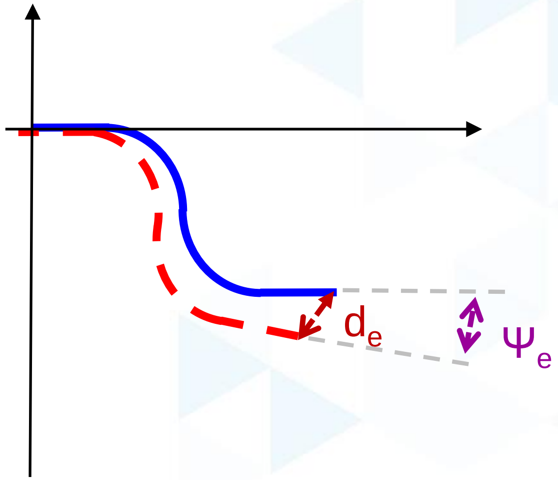
Quick reference to typical cause/effect

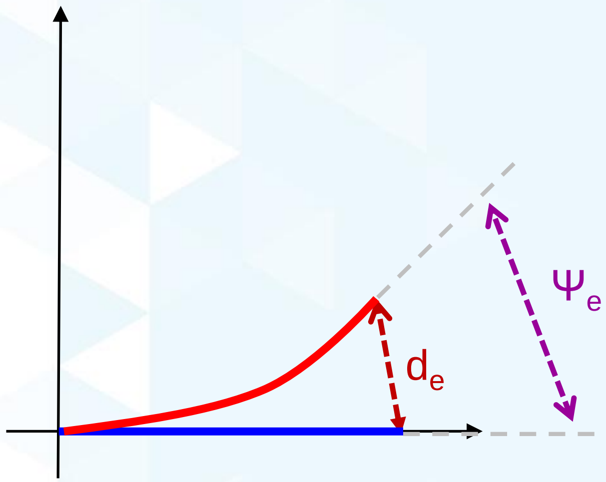
Sensitivity error causes heading and position errors during a turn

Nonlinearity (2nd order) causes a heading error that can show up in patterns like an S-turn

Bias causes a drift in heading and position errors, even when there is zero turning.







Proper path, heading position in blue

Error-burdened path in red

Heading error = Ψ_e

Position error = d_e

ADIS16495:
+/-0.2% error over temperature
0.05% end of life!

Summary

Consumer Grade MEMS

- Compromised performance
- Added cost from test/calibration/yield-loss
- Added cost of complex packaging, vibration/thermal isolation
- Life-cycle performance drifts from plastic packaging
- Component obsolescence
- Compromised reliability ... operational failure

Industrial Grade MEMS

- Superior performance
- Ruggedized, application-ready
- Stability: performance and supply/availability
- Reliability: up to full avionics certifiable (DO178/254)
- Lower overall system size, weight, power, and cost

Thank You