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Using MEMS Accelerometers for Condition Monitoring

ED SPENCE

Marketing Manager

Industrial Sensors Business Unit

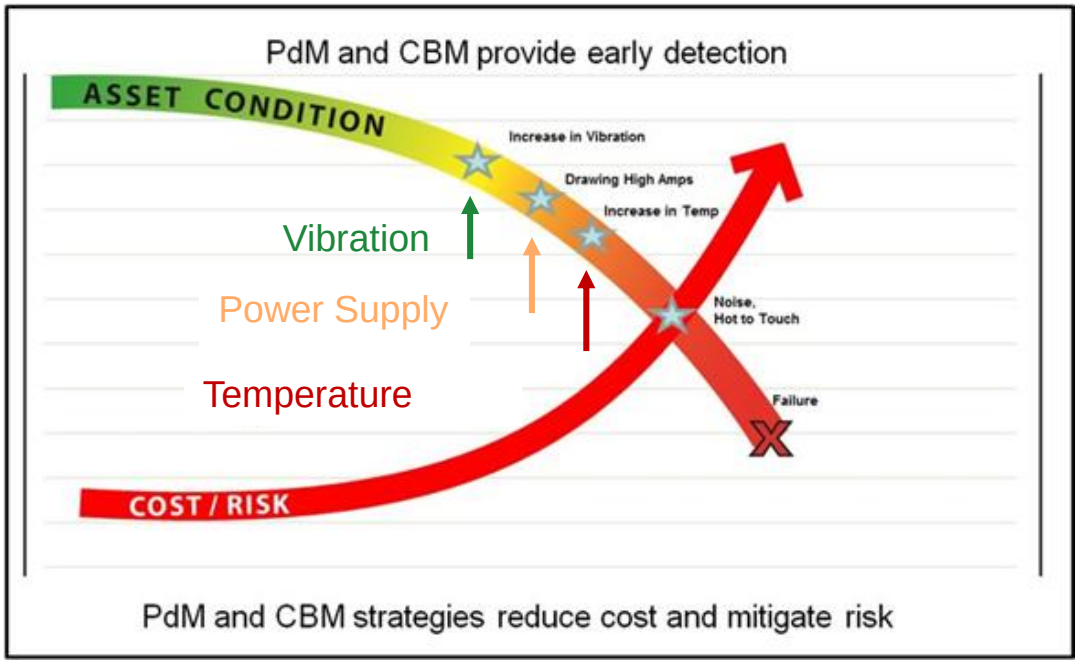
09/21/2016

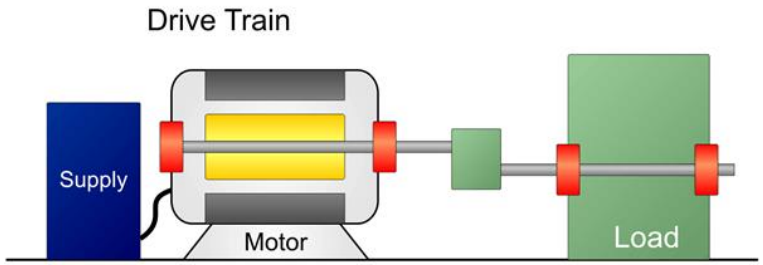
Agenda

- Brief overview of Condition Based Monitoring (CBM) methodologies
- Intrinsic properties of MEMS accelerometers
- Review of the performance history of MEMS accelerometers
- A glimpse into how MEMS is already impacting CBM

CBM Methodologies

Timely Indicators of an Emerging Problem





Supply	Power Quality	EPVA (Voltage)	
Mec. Imbalance or Misalignment	MCSA	Vibration	EPVA
Insulation Faults	Partial Discharge	EPVA	
Stator Electrical Imbalance	EPVA	MCSA	Power Quality
Broken Bars	MCSA	EPVA and IPSA	
Bearing Faults	Vibration	Wavelet on Current	MCSA, EPVA and IPSA
Coupling and Load Mechanical Failures	Vibration	MCSA, EPVA and IPSA	

Significance: High Medium Low

Induction Motors – Modeling and Control, R. Aruajo, 2012

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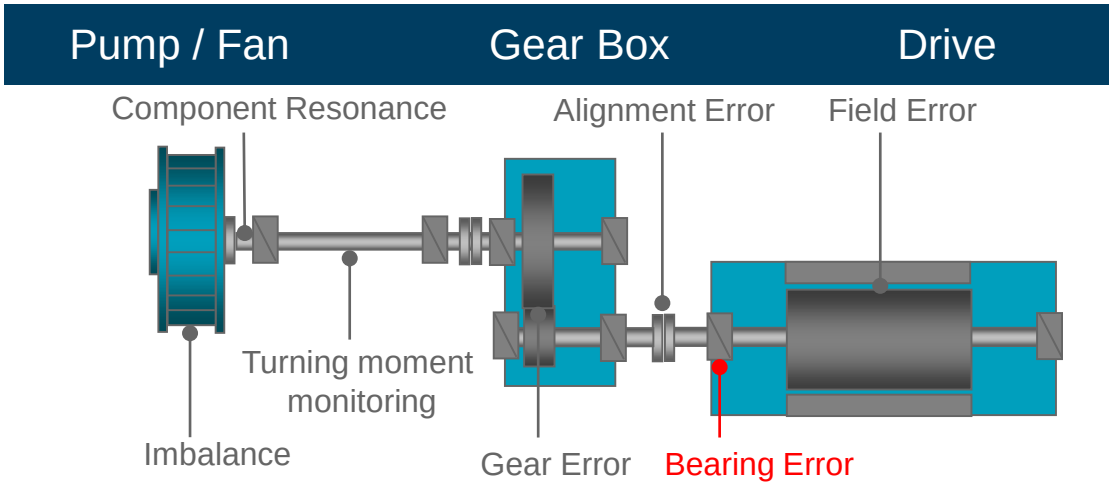
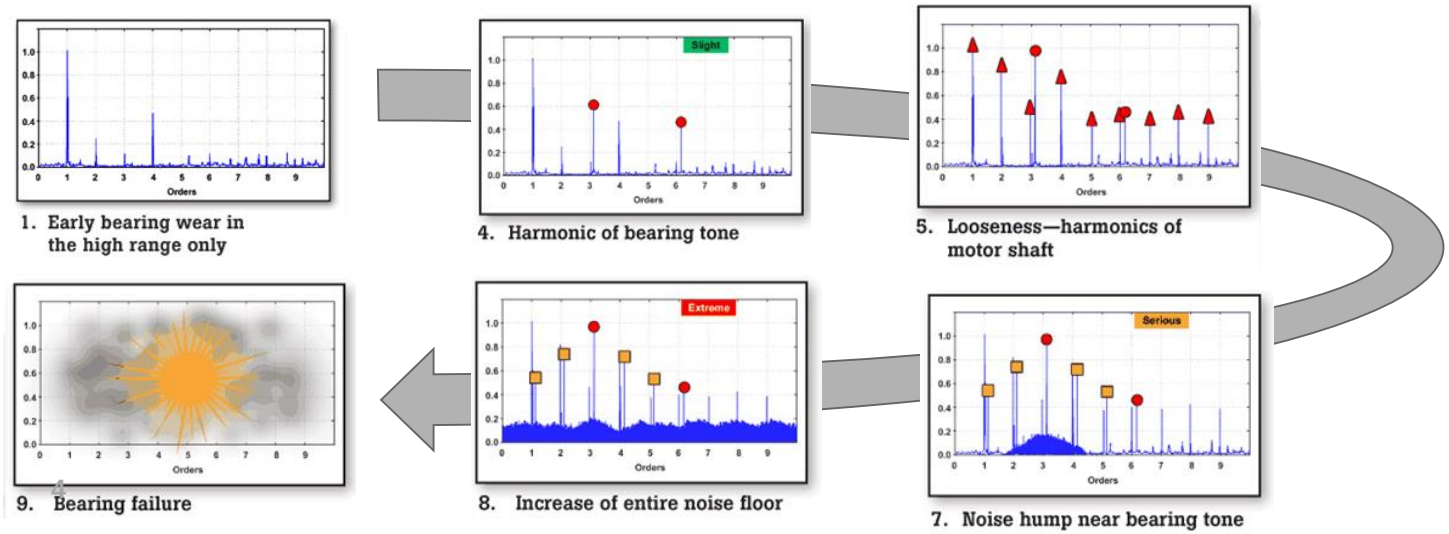
Analysis of Vibration



- Mechanical system
- Signal analysis techniques and algorithms apply



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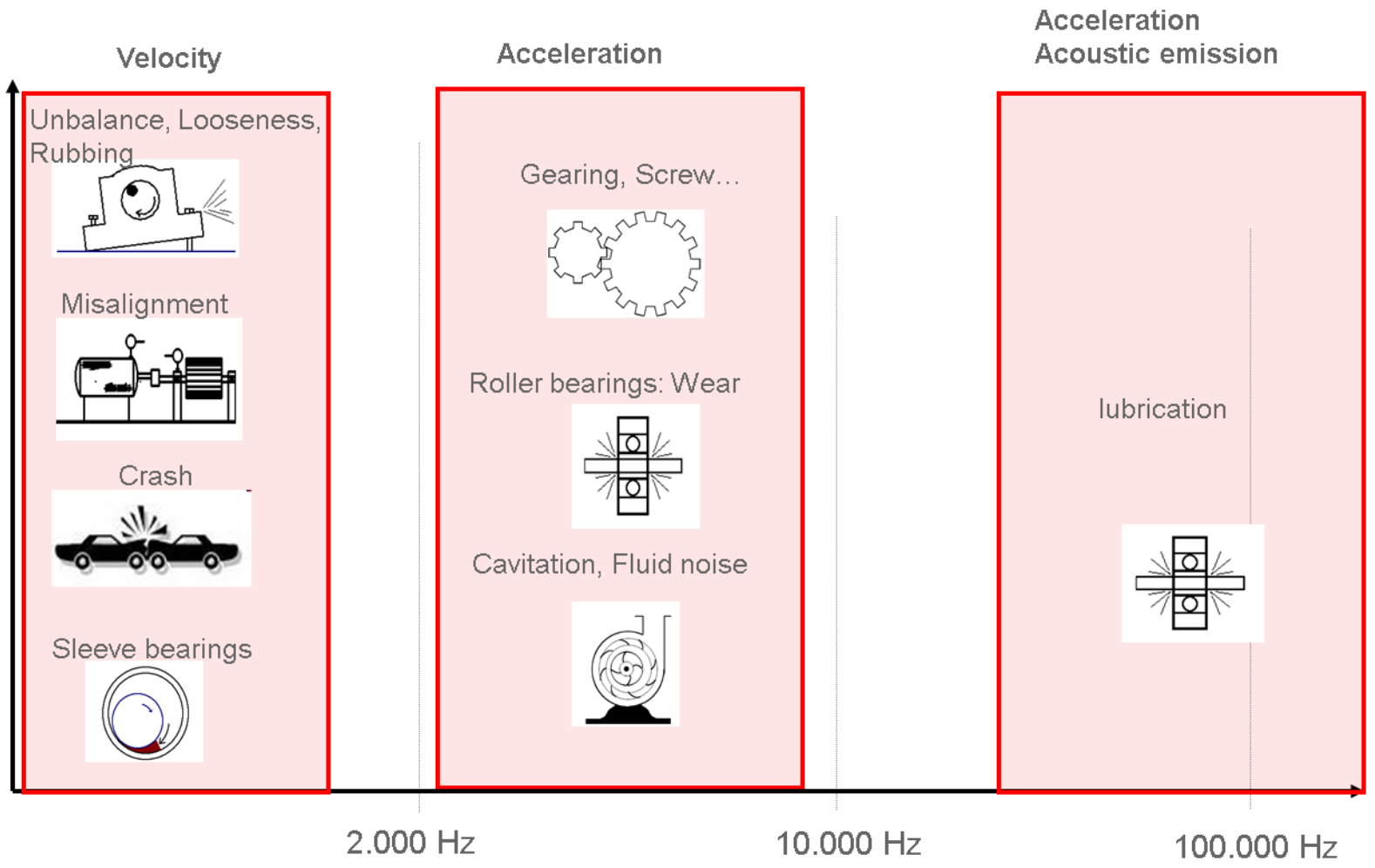
Machine Faults and Vibration Frequencies

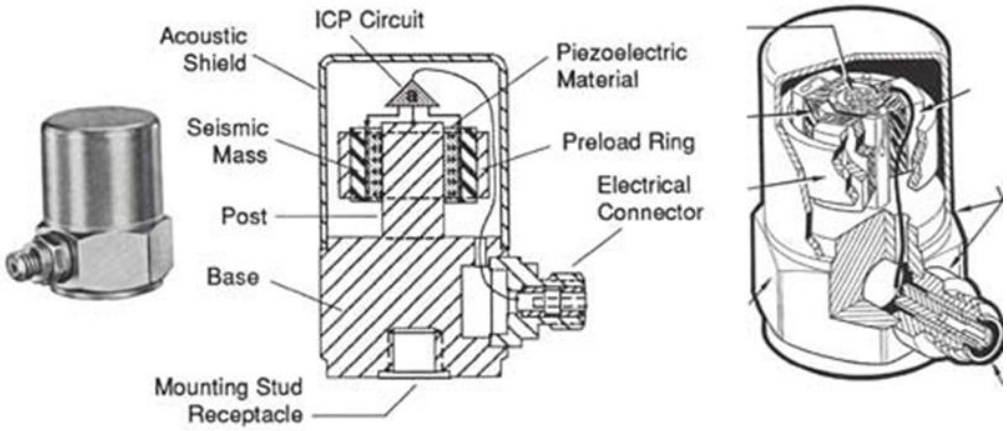


General machine vibrations (ISO 10816)
10Hz ...1000 Hz or 2Hz ... 1000 Hz

Mechanical wear
2000 Hz … 6000 Hz

Courtesy: IFM Efector

Condition Monitoring Accelerometers Today



- Low noise over very high frequency operation
- Industrial power supply levels (e.g. 24V)
- Assembled mechanical technology – manual intensive manufacturing techniques
- Sensitivity changes with shock or drift (requires recalibration if dropped)
- Charge output device SNR typically drops at lower frequencies
- Limited self test
- Not particularly easy to integrate into a sub-system

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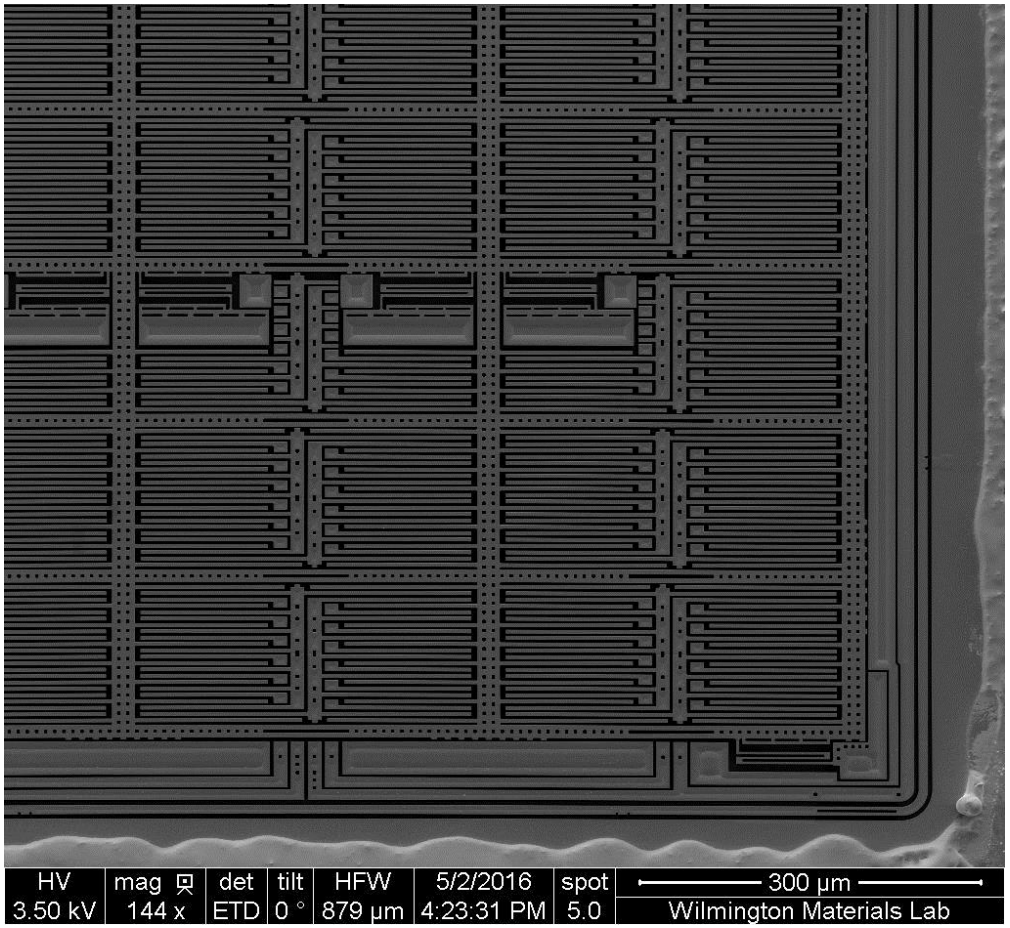
MEMS Accelerometers – Intrinsic Properties

MEMS Accelerometers for Condition Monitoring

Intrinsic Properties

- Stable sensitivity
- DC Response
- Shock tolerant
- Electro-static self test
- High reliability
- Low power
- Highly integrated
- Small size
- Scalable manufacturing



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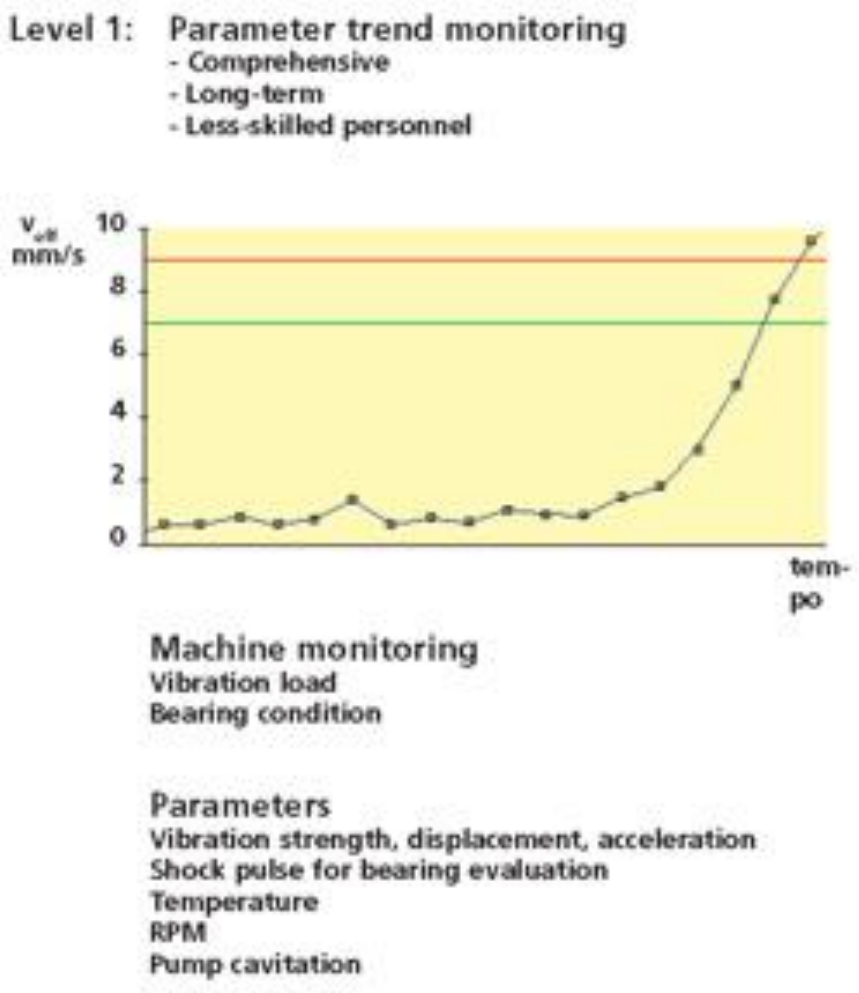
Intrinsic Properties of MEMS Accelerometers
Stable Sensitivity

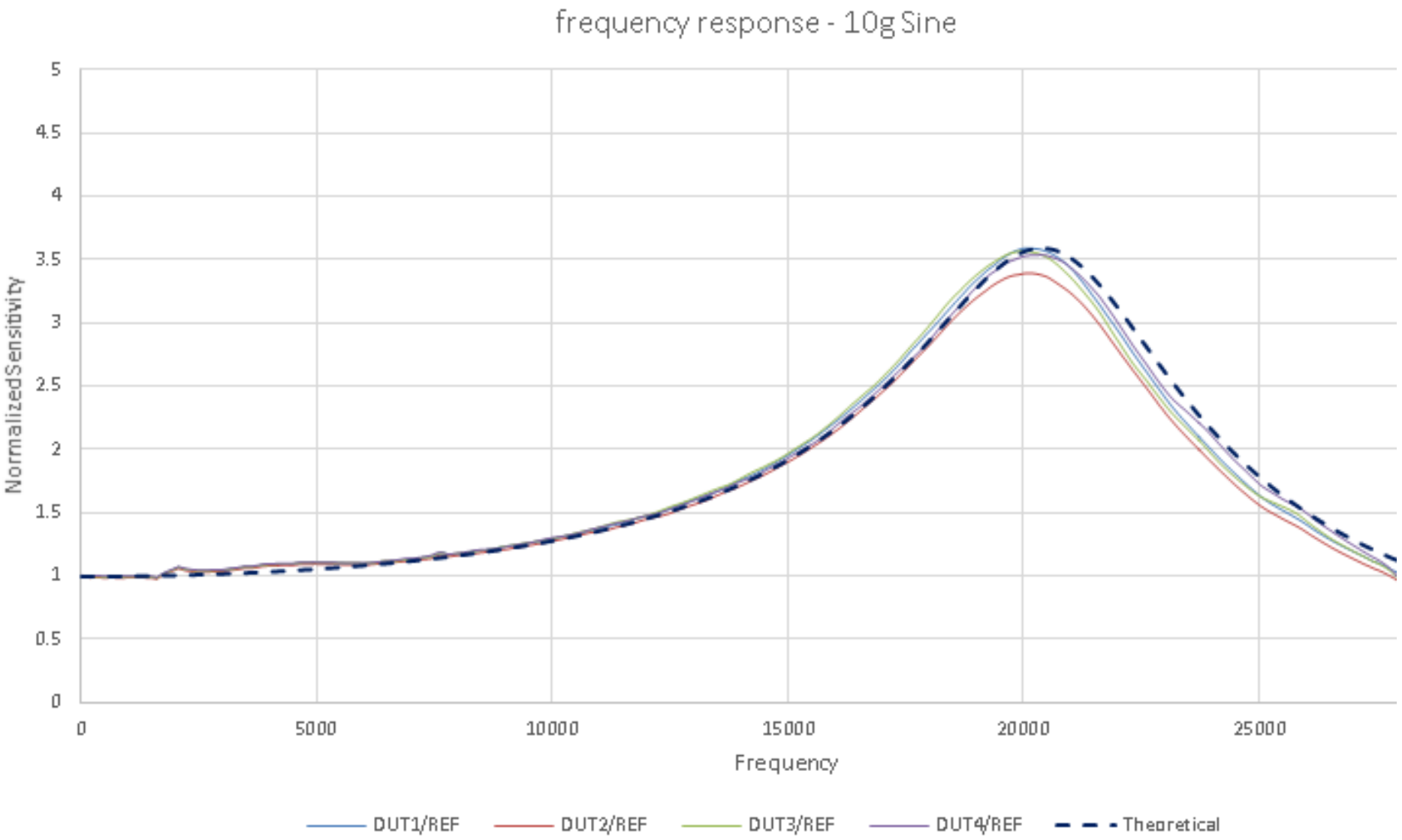


- Integrated acceleration (velocity) is tracked over time
  - A baseline is established and changes to nominal behavior are monitored
- Frequently cited problems with mechanical accelerometers
  - Sensitivity can shift over time and temperature, or when subject to shock
- Stable sensitivity introduces less error
  - MEMS accelerometer sensitivity typically remains within ±5% over the full temperature range

Courtesy: Pruftechnik
May 2010 Application Note

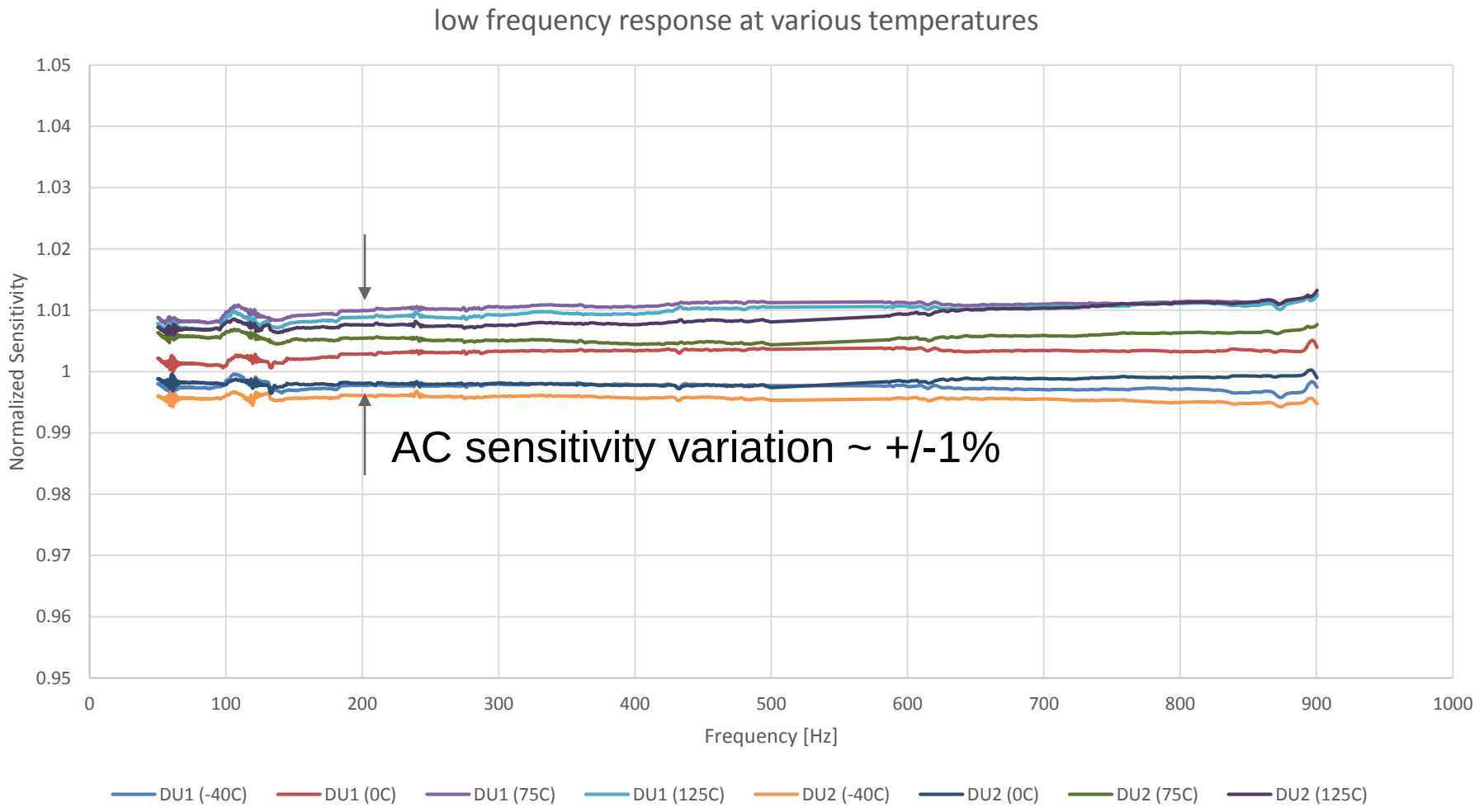
Frequency response at 25C

FSR ±50g



Frequency response v. temperatures

25g sine



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Intrinsic Properties of MEMS Accelerometers

DC Coupled, Low Resistance Output

- Low rotation rate equipment integrates velocity down to 0.1Hz
- In addition, low resistive output means faster recovery from saturation
- Frequency response can be tailored by the user with external components

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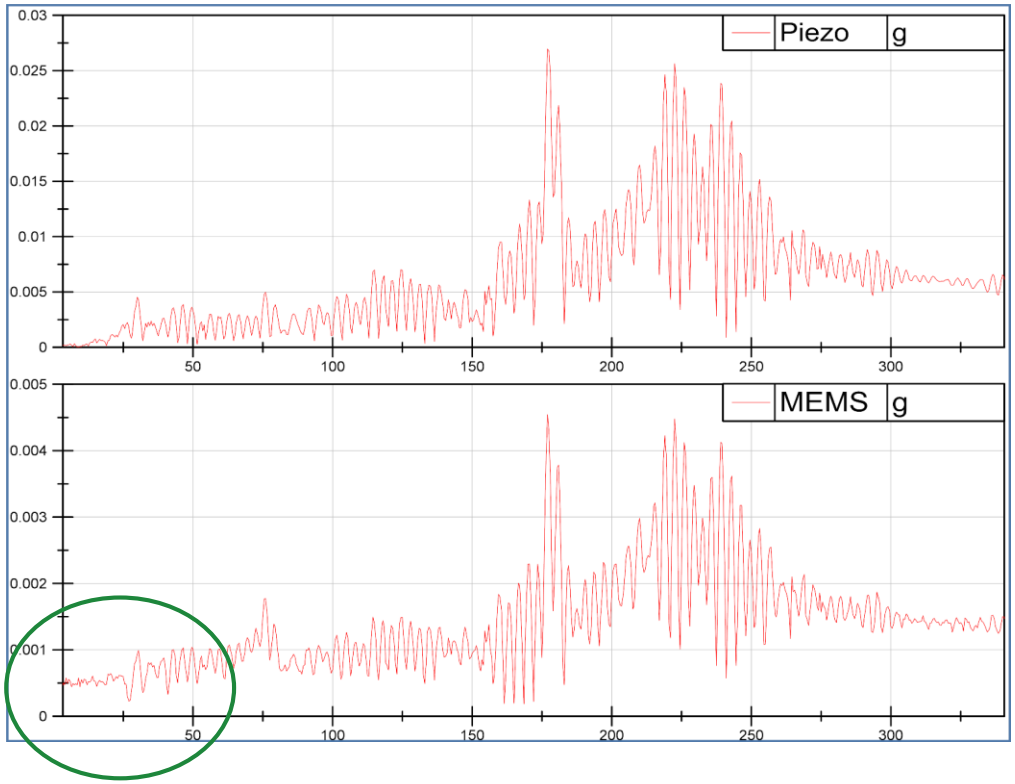
Intrinsic Properties of MEMS Accelerometers
DC Response



- Side by side comparison of MEMS and PZT
- Accelerometers subjected to a mild shock while recording data and computed the FFT
- The results show the MEMS accelerometer resolving down to DC…

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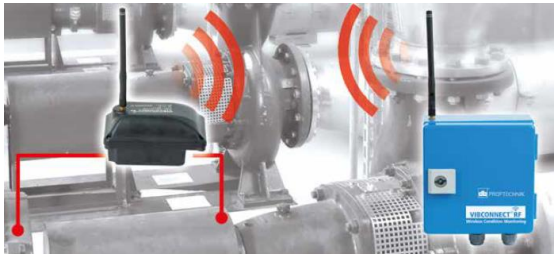
Intrinsic Properties of MEMS Accelerometers

Low Power Electronics

- Single supply signal conditioning electronics
  - Supply voltages of +5V or less replace high industrial voltages
  - Easier to interface
- Lower power sensor electronics extend battery life
- Lower cost power management BOM
  - Broader selection of components
- Smaller form factors
  - Dominated by battery size, antenna



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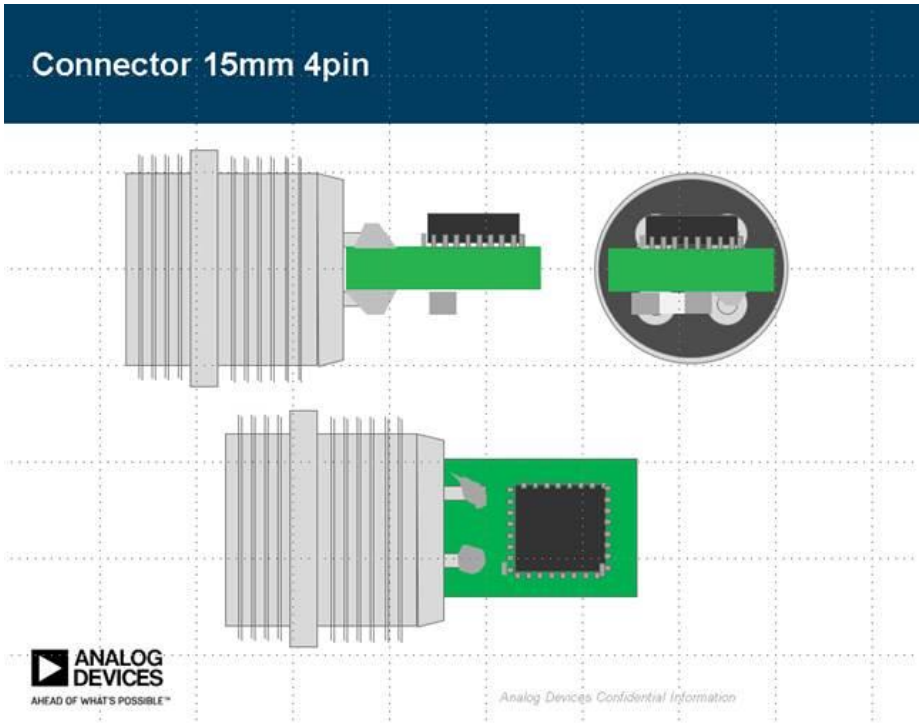
Intrinsic Properties of MEMS Accelerometers
Small Size

- Embedding in the machine or asset
- Integration within standard through-hole package is possible
- +5V Analog interface supported by most DAQs or Controllers
  - Other interface modes are possible
- Do optimized locations lead to higher quality transmission of mechanical vibration?



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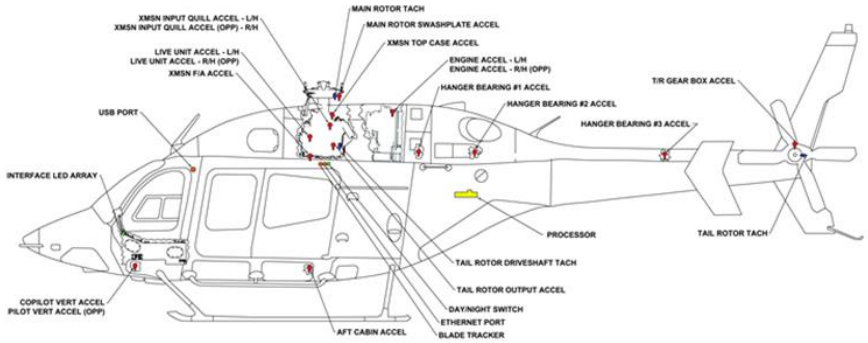
Intrinsic Properties of MEMS Accelerometers
Low Weight

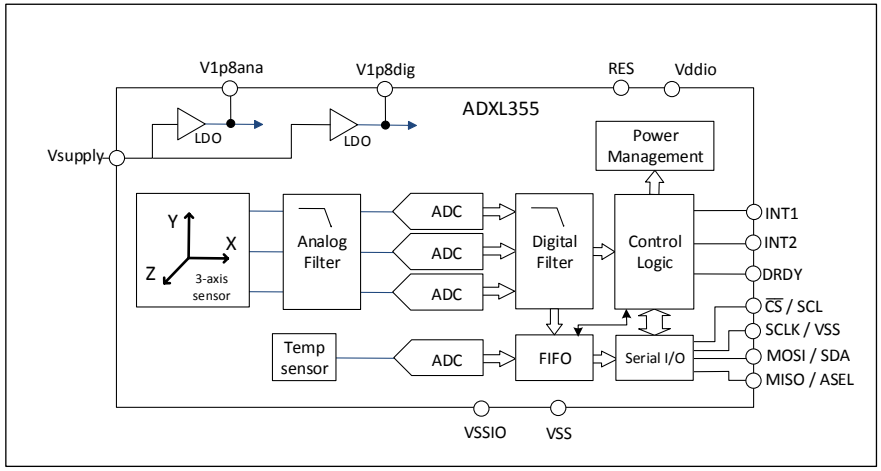
- A high performance accelerometer in 6 x 6 mm LCC weighs less than 1 gram
- Digital interface can reduce cable costs and weight
  - Single supply signal conditioning enables higher integration levels
- Airborne applications will benefit from reduced fuel costs



Accelerometers used as part of a HUMS monitoring system

Single Supply Signal Conditioning Electronics
Enabling Enhanced Features

- Electro-static self test
  - Deflection of the MEMS movement transmitted through the full signal chain
- Over-range indicator
  - Quickly assess cause of ‘ski slope’
- Integrated ADC and Digital interface
  - Higher EMI immunity
  - Lower cost cables
  - Digital filtering
  - Memory buffers



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MEMS Accelerometers – Performance History

High Frequency MEMS Accelerometer Vintage 2009

- ±70 g to ±500 g Full Scale Range
- 22 kHz resonant frequency
- 2.5mA typical power supply current
- Integrated self-test
- -40C to +125C
- 5 x 5 mm 8-pin LCC
- 4mg / √Hz noise density

  (500mg (RMS) in 10kHz)

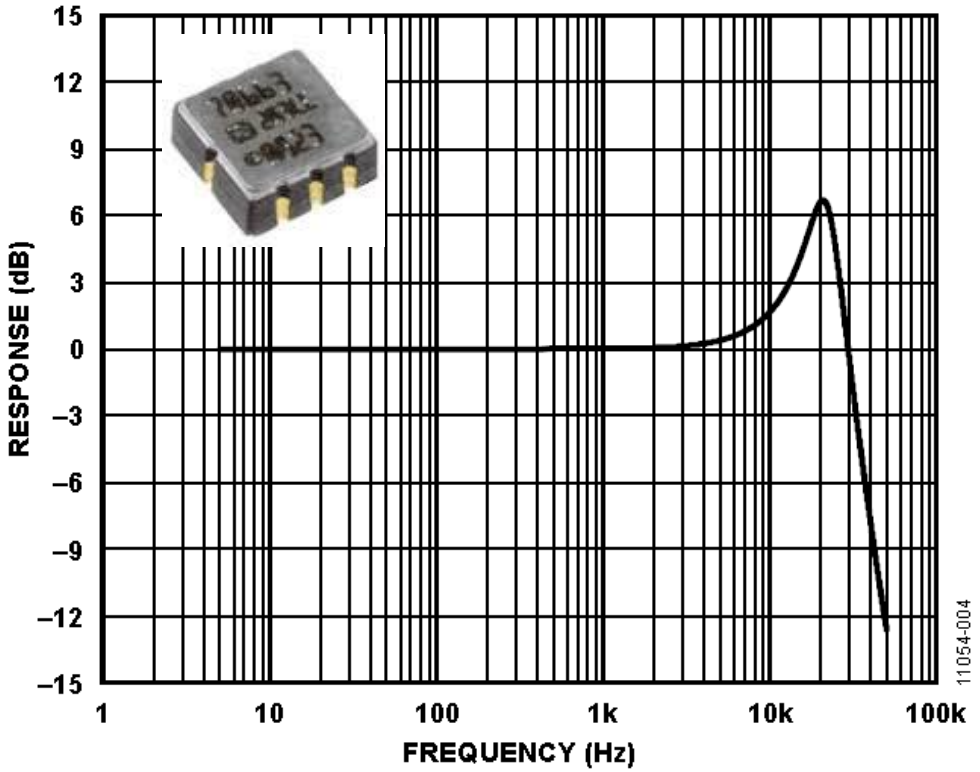

Figure 4. ADXL001 Frequency Response

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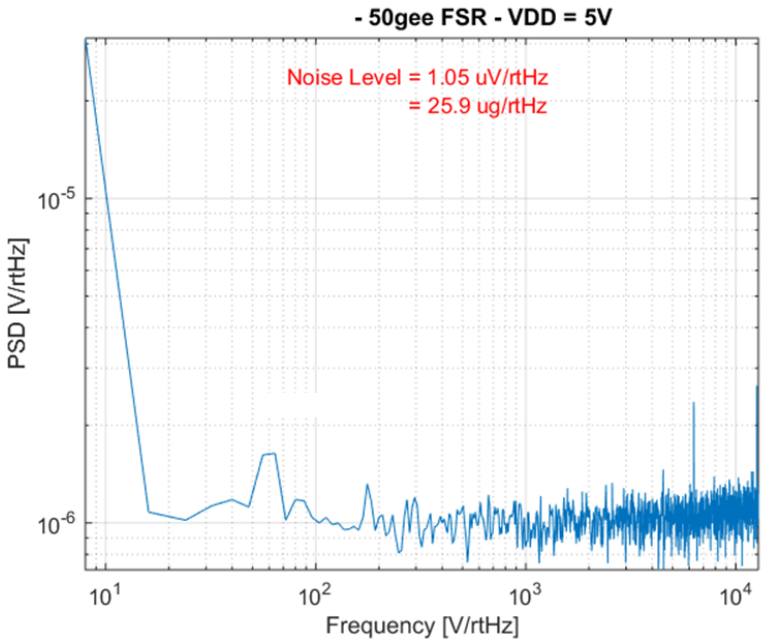
Upgraded Accelerometer Performance in 2016

Are MEMS Accelerometers Finally Ready for Mainstream CBM?

	Gen 1	Gen 2
FSR	±70 g to ±500 g	±50 g to ±100 g
F0	22kHz	21kHz
Supply Current	2.5mA	1.0mA
Self Test	Yes	Yes
Temp Range	-40C to +125C	-40C to +125C
Package	5 x 5 mm 8 pin LCC	5 x 5 mm 32 pin LFCSP
Noise Density	4000µg / √Hz	<30µg / √Hz



2 orders of magnitude drop in RMS noise
from 500mg to 3mg
(1 to 10kHz)

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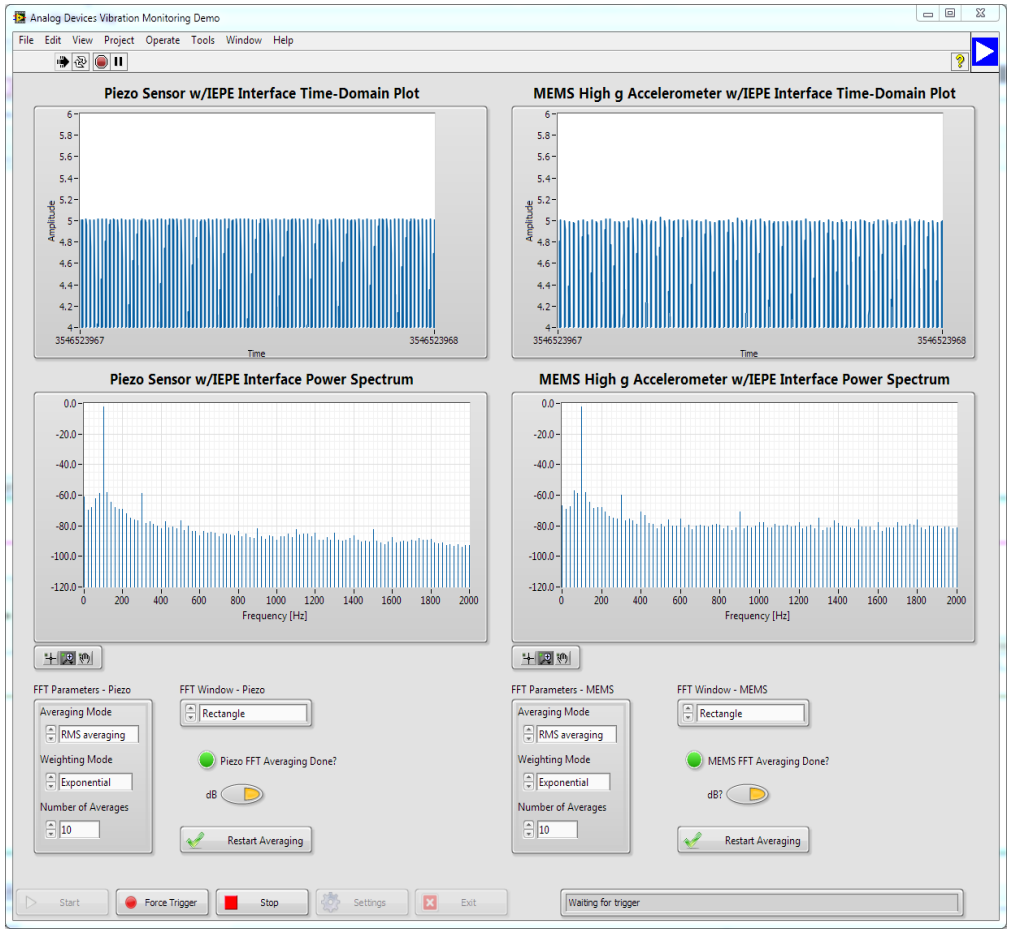
Accelerometer Technology Comparison

Test Set Up to Compare Commercially Available PZT to a New 21kHz MEMS Accelerometer



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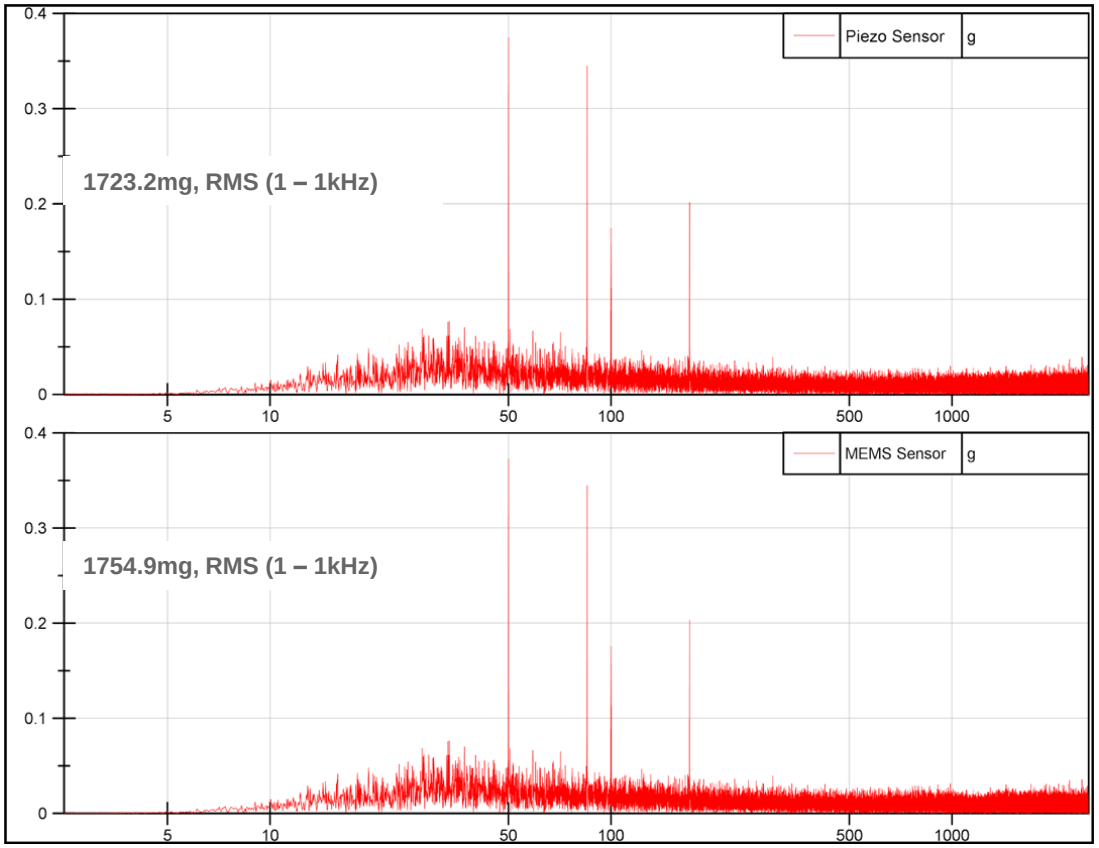
Motor Misalignment Simulation[1]

Harmonics Added to the Stimulus



R B Randall, Vibration-based Condition Monitoring, 2011
John Wiley & Sons, Hoboken, NJ, Page 34.

- Comparable performance over 10kHz….
- PZT is 30mg, RMS lower (1 – 1000Hz)
  - 1.7% delta between sensors

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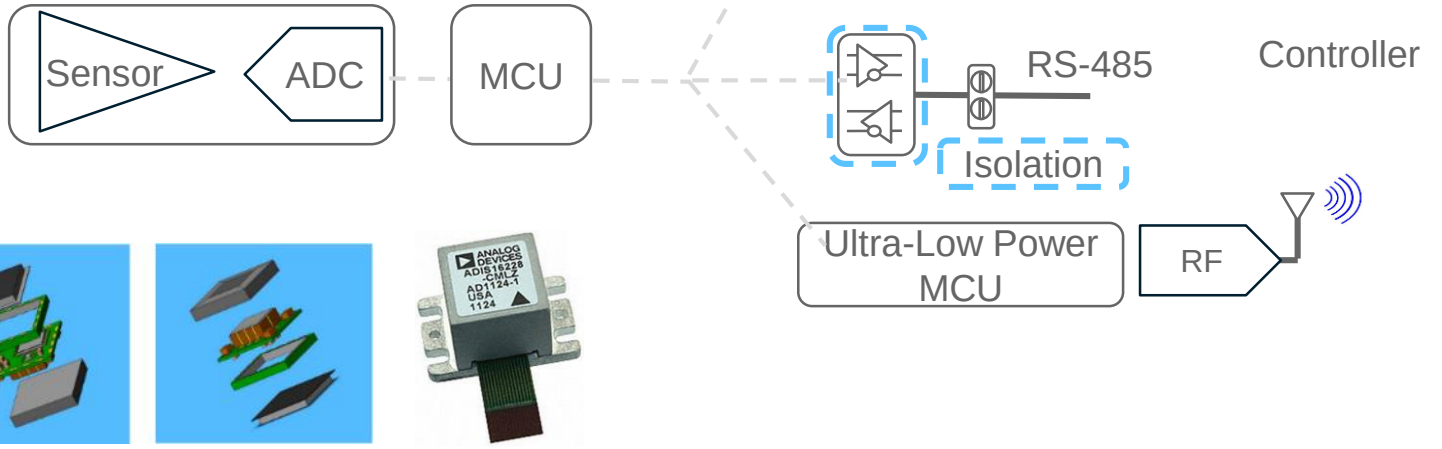
MEMS Accelerometers for CBM – Implications and Future Developments

MEMS Accelerometers Enable Highly Integrated Solutions

- High frequency accelerometers
- Portfolio of signal conditioning solutions
  - ADCs
  - MCUs
  - Interface PHY
- SIP manufacturing capability



System-in-Package (SIP) Manufacturing

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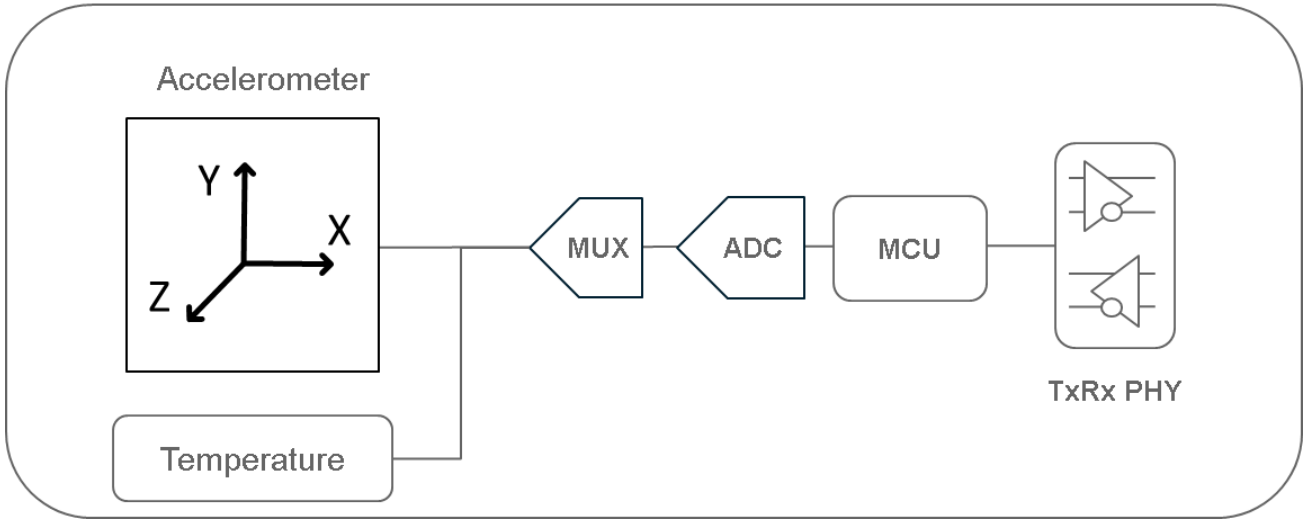
Embedded, Connected, Smart Sensors for Condition Monitoring

Example Concept



- High frequency, low noise MEMS accelerometers
- Low power, +3V signal chain
- Applications processing
- Industrial interface (e.g. RS-485)
- 105C operation
- Less than 125 mm^2 footprint

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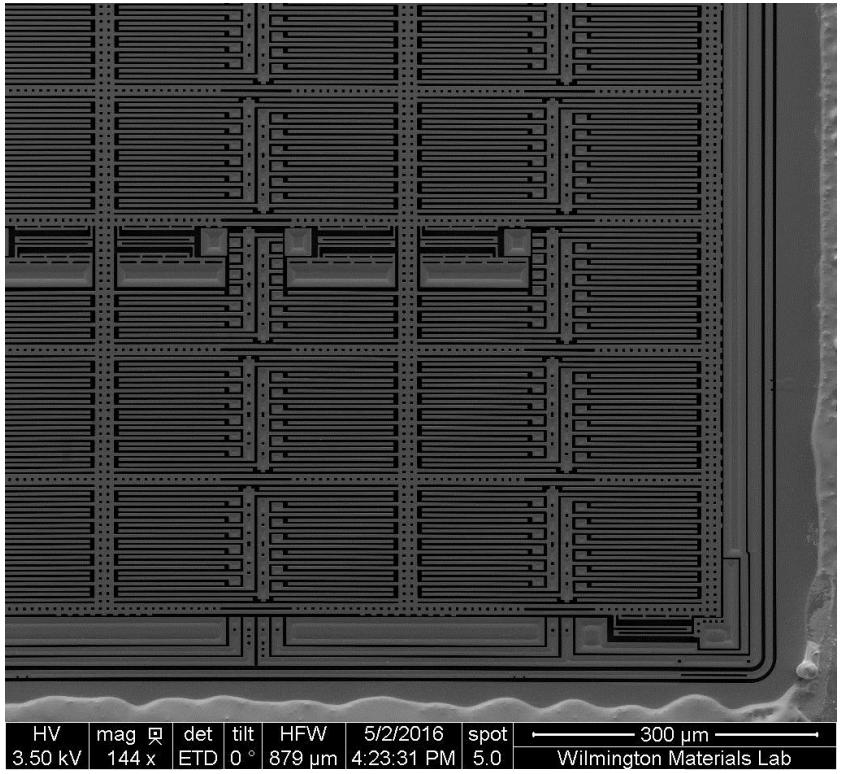
Summary

MEMS Accelerometers offer compelling, intrinsic attributes that can change the way CBM is practiced today.

Making exciting new products possible -

- Smart sensors
- Wireless / Portable
- Embedded solutions



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