ACCELEROMETER DESIGN AND THEORY

THE MODAL SHOP

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MTS SENSORS

PCB PIEZOTRONICS
MTS SYSTEMS CORPORATION

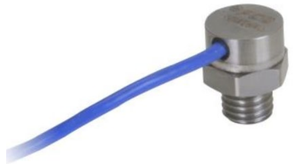
ACCELEROMETER THEORY

- Learning Objectives
  - Common types encountered in Cal Labs
  - Electro-Mechanical
    - Characteristics & Considerations
    - Applications & Cautions
    - Construction & Materials
  - Reference Sensor Considerations

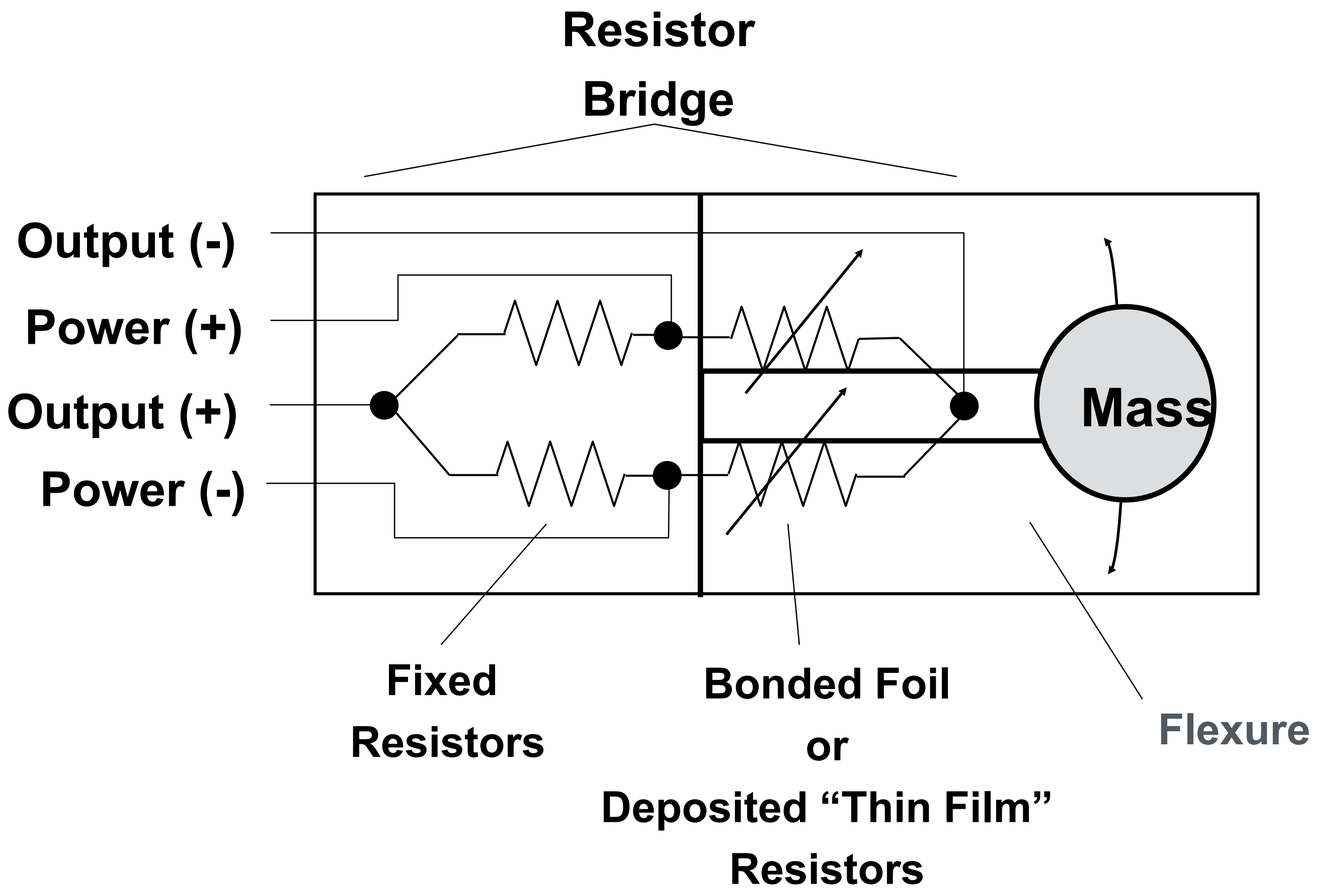
ACCELEROMETER TYPES

- Current accelerometer types
  - Resistive - Strain Gauge, Thin-Film, Piezoresistive
  - Capacitive - Micromachined
  - Piezoelectric

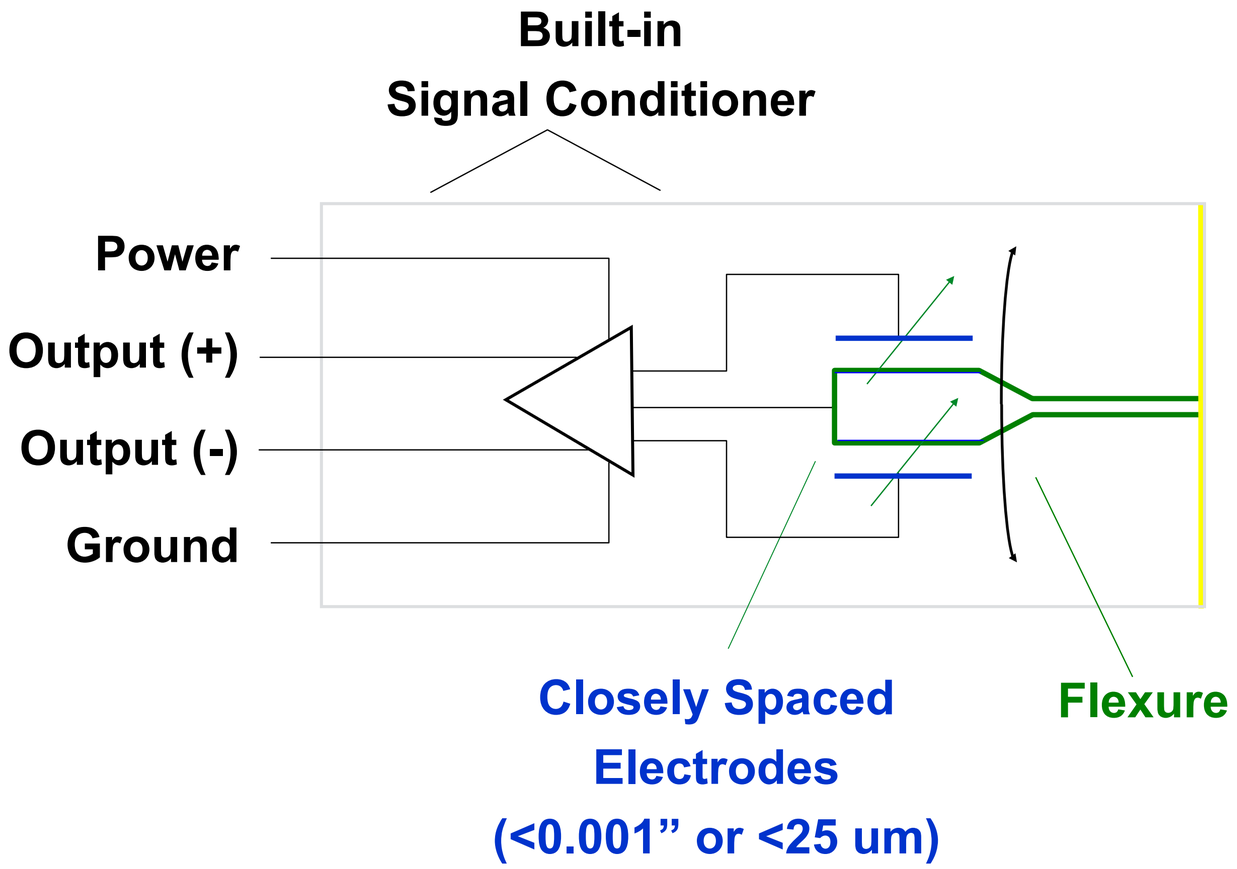
- Other less common types
  - Servo / Force-Feedback
  - Vibrating Quartz
  - Slide-wire potentiometer
  - Variable Inductance
  - Fiber Optic
  - Piezotransistor



RESISTIVE


Resistor
Bridge
Output (-)
Power (+)
Output (+)
Power (-)
Mass
Fixed
Resistors
Bonded Foil
or
Deposited “Thin Film”
Resistors
Flexure

CAPACITIVE


Built-in
Signal Conditioner
Power
Output (+)
Output (-)
Ground
Closely Spaced
Electrodes
(<0.001” or <25 um)
Flexure

RESISTIVE AND CAPACITIVE

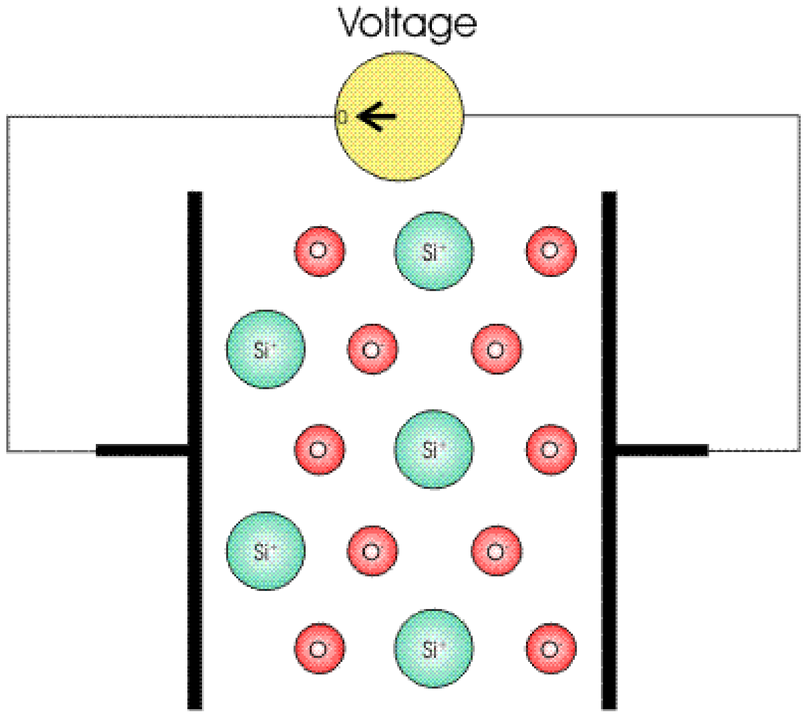
- Typical Characteristics:
  - DC aka 0 Hz measurement
  - Limited dynamic range (~80 dB = 10,000:1)
  - Limited high frequency range (<10 kHz)
  - Sensitivity varies with excitation (mV/g per V)
  - Multiple wire interface

RESISTIVE AND CAPACITIVE

- Typical Applications:
  - Long Duration/Low Frequency Events:
    - Automobile Acceleration/Deceleration
    - Aerospace Modal Surveys
    - Suspension Road Response
    - Robotics
    - Whole Body Ordnance Effects Testing
    - Crash Dummy Instrumentation
  - Tilt Sensors
  - Airbag Industry (Low Cost)

PIEZOELECTRIC ACCELEROMETERS

- Piezoelectric crystal – electrical charge output per strain input
- Seismic mass – converts acceleration to strain



PIEZOELECTRIC

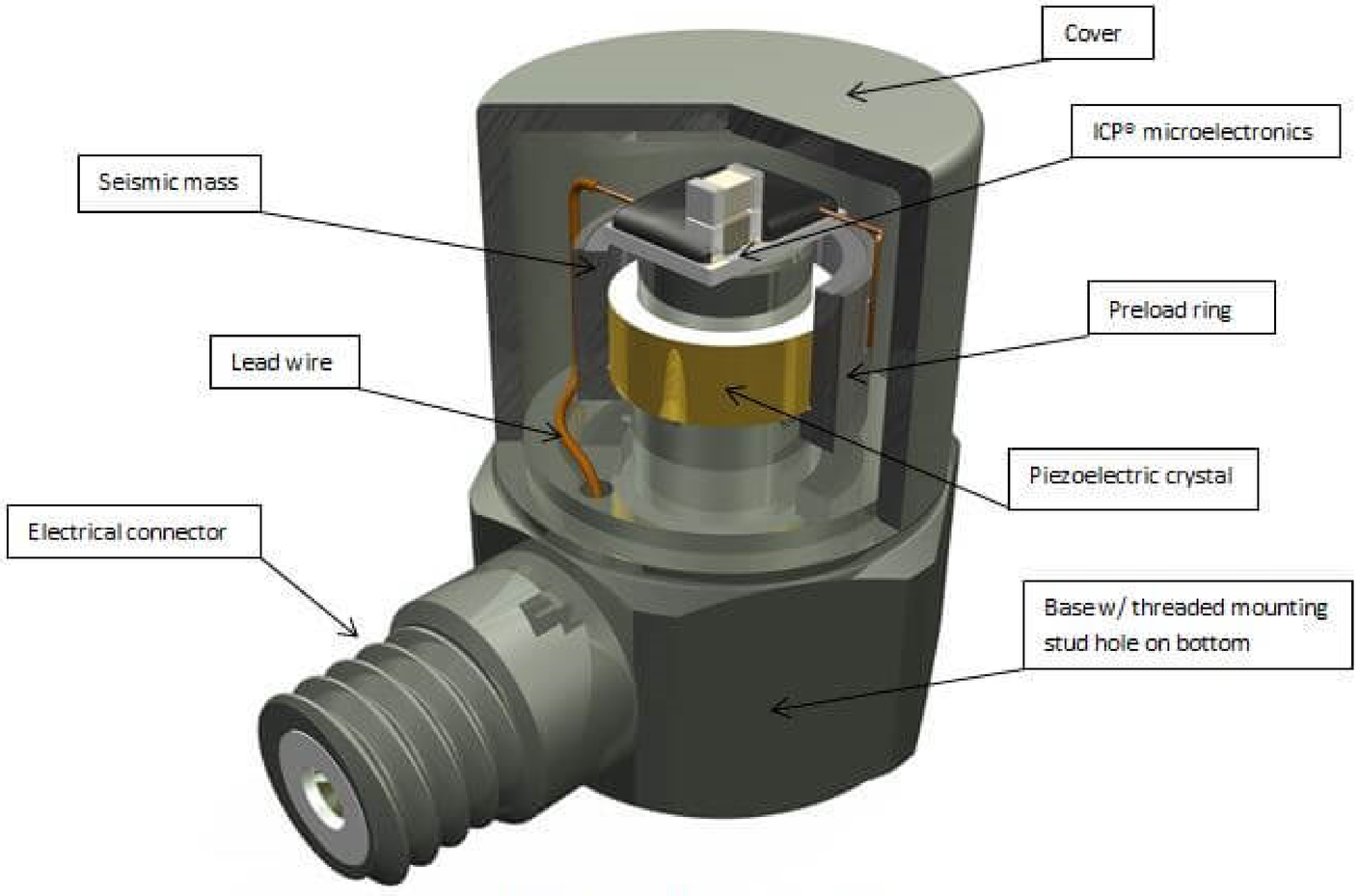


Figure 1: Typical ICP® Accelerometer

PIEZOELECTRIC

- Typical Characteristics
  - Dynamic events only (>0.1 Hz)
  - Wide dynamic range (>120 dB = 1,000,000:1)
  - Wide bandwidth (>10 kHz)
  - Operates over two wires
  - Rugged
  - High temperature versions (1240 F [650 C])

PIEZOELECTRIC

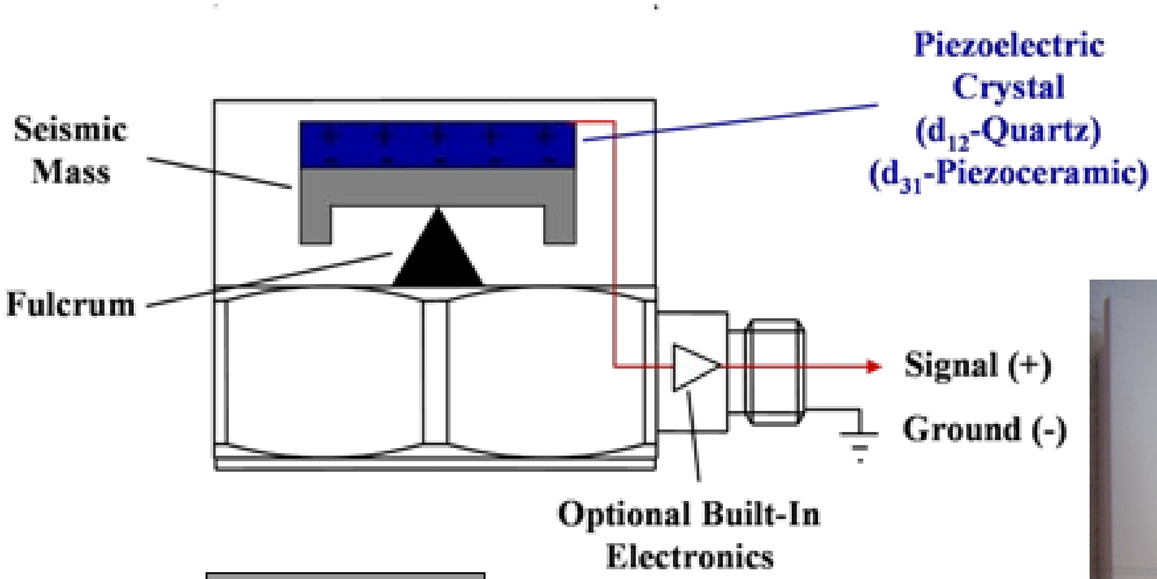
- Typical Applications
  - Rotating equipment operation
  - Automotive
  - Aerospace
  - Consumer goods
  - Industrial machinery

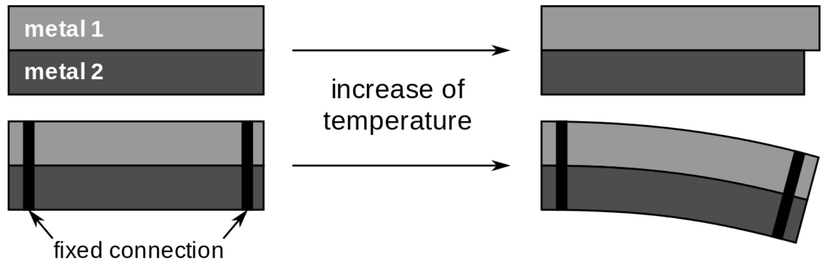
PIEZOELECTRIC MECHANICAL DESIGN

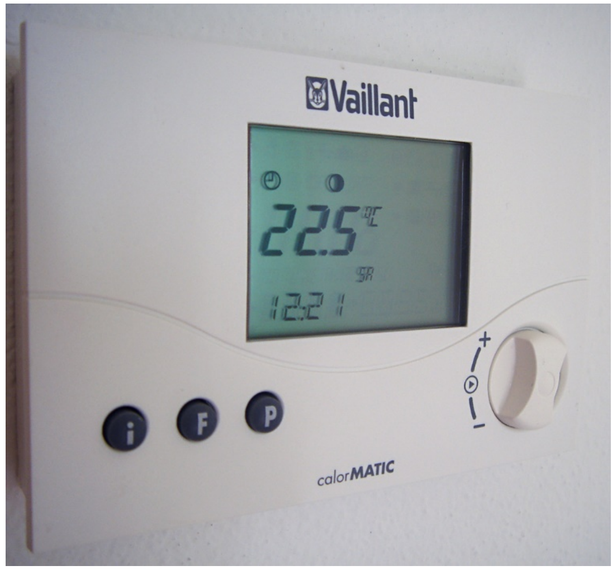
- Element Configurations
  - Compression
  - Inverted Compression
  - Beam
  - Shear
  - Tri Shear
  - Annular Shear

PIEZOELECTRIC MECHANICAL DESIGN

- Element Configurations
  - Beam

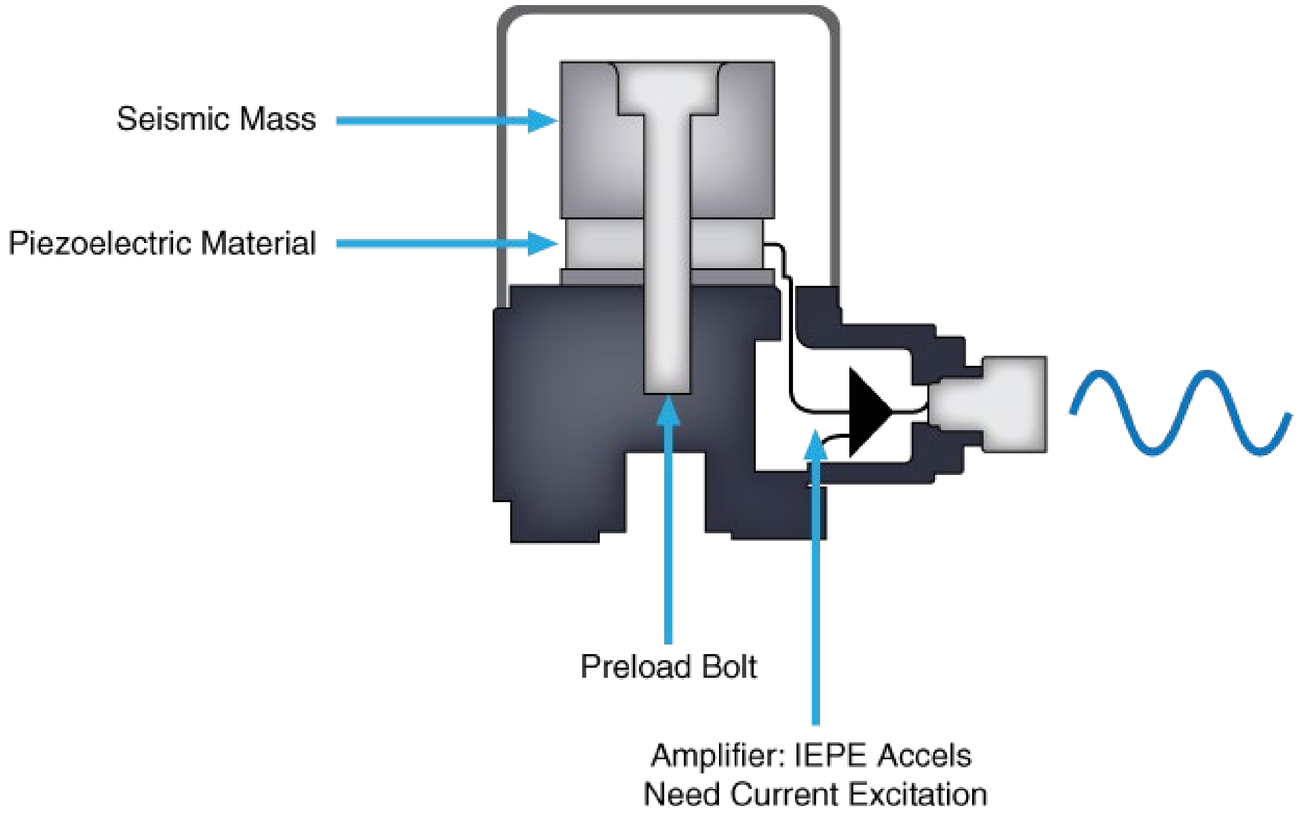






PIEZOELECTRIC MECHANICAL DESIGN

- Element Configurations
  - Compression
  - Inverted Compression

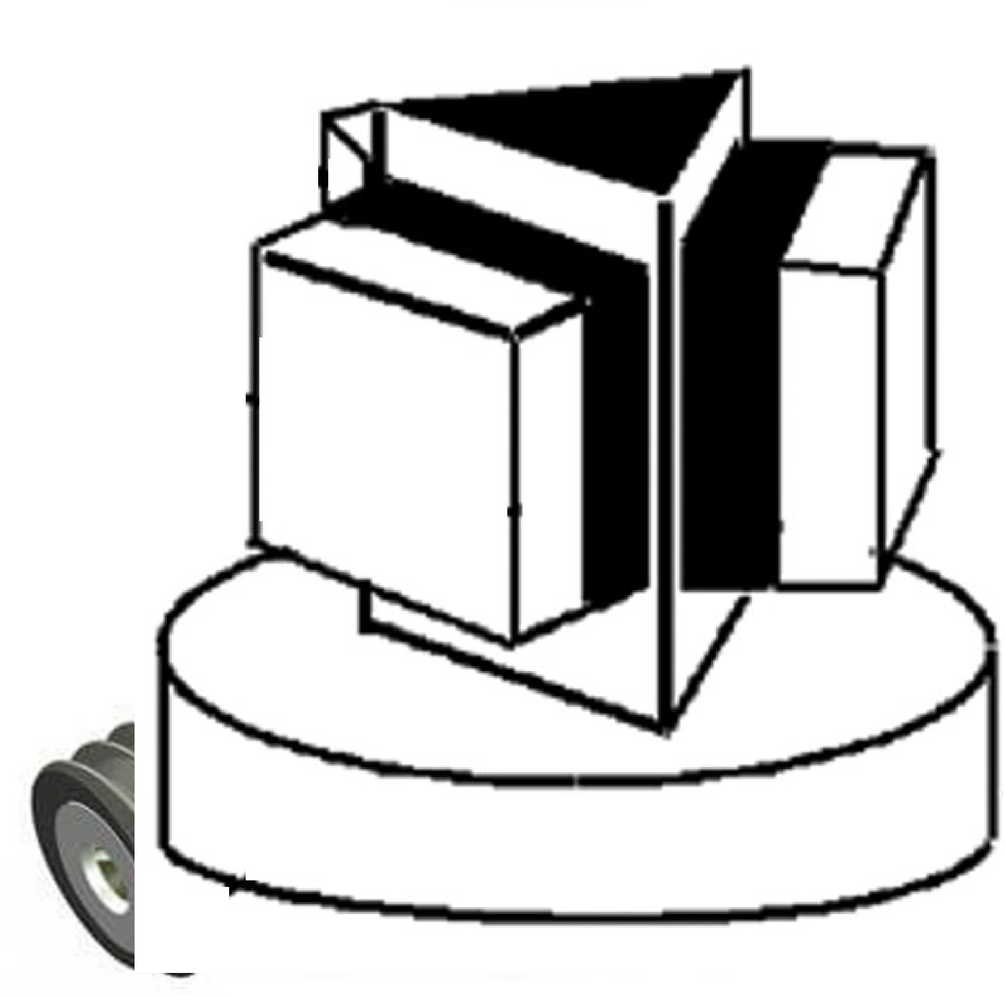


PIEZOELECTRIC MECHANICAL DESIGN

- Element Configurations

  Shear

  - Annular Shear
  - Tri Shear

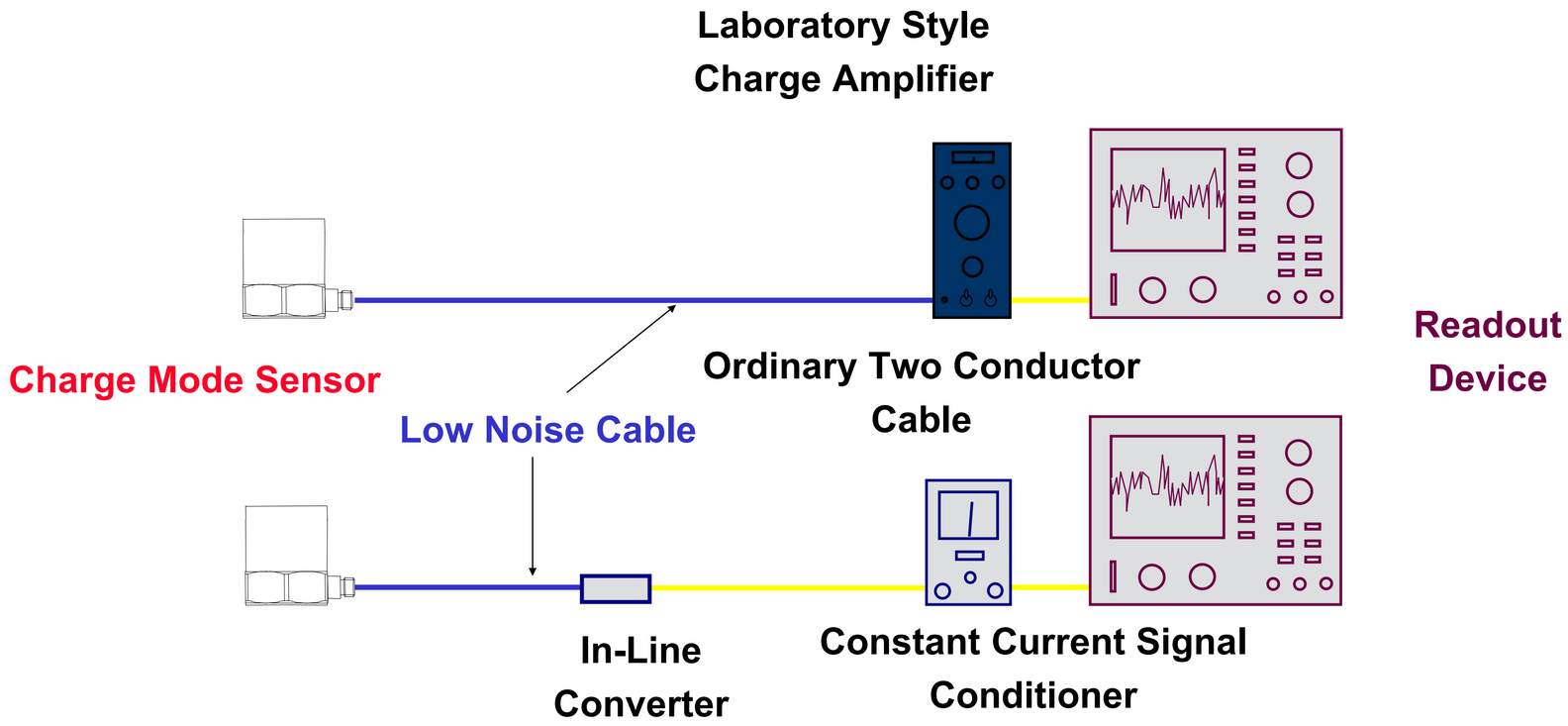


PIEZOELECTRIC SENSING MATERIALS

	Quartz	Ceramic
High Sensitivity		✓
High Operating Temperature		✓
(Lack of) Thermal Sensitivity	✓	
Long Term Output Stability	✓	

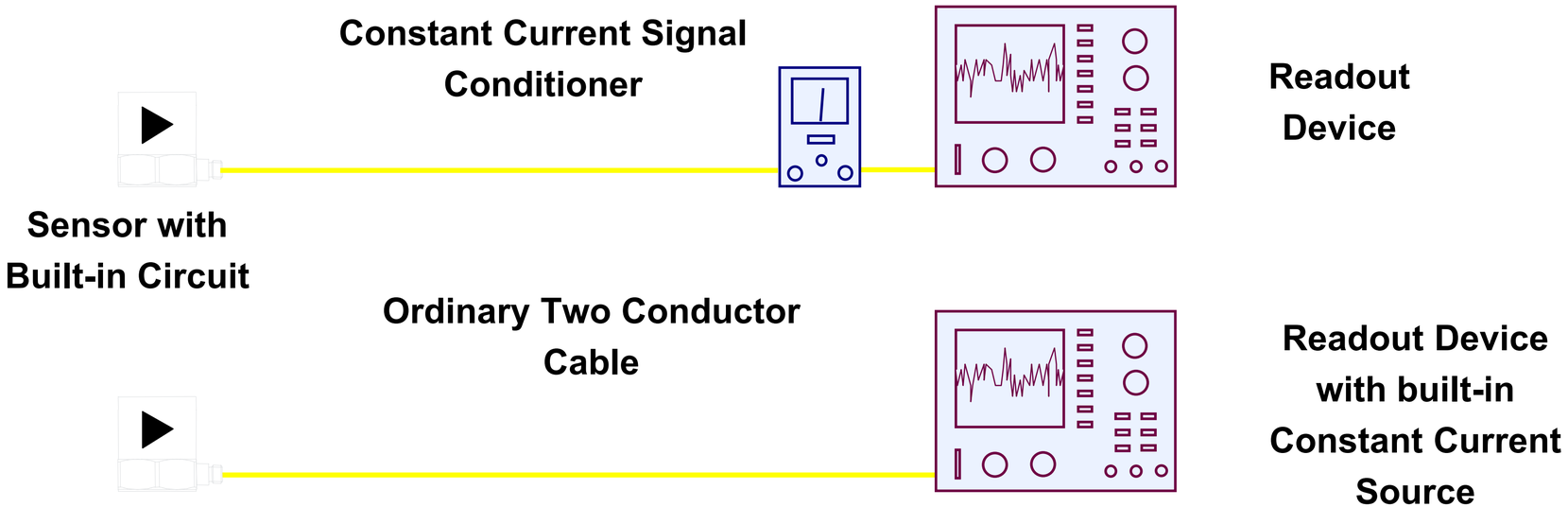
PIEZOELECTRIC ELECTRICAL DESIGN

- Charge Output (externally amplified)



PIEZOELECTRIC ELECTRICAL DESIGN

- IEPE (internally amplified) aka ICP®



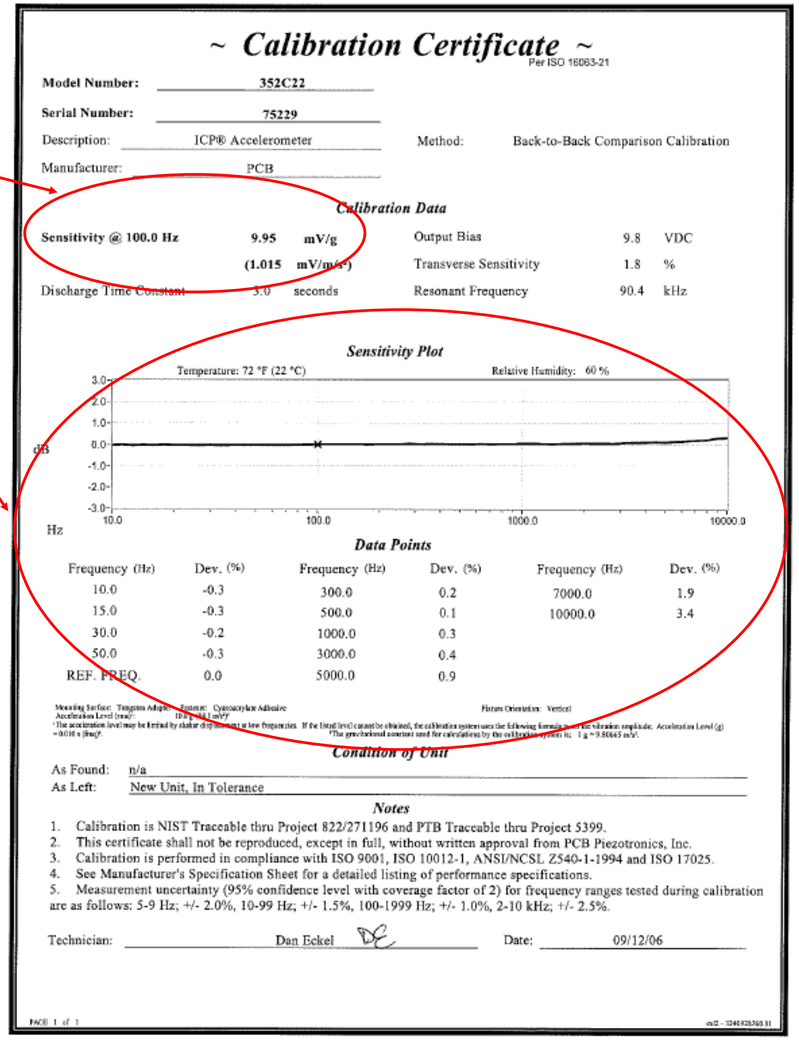
PIEZOELECTRIC ELECTRICAL DESIGN

	IEPE (ICP®)	Charge
Dynamic Range		✓
High Operating Temperature		✓
EMI/RFI Resistance	✓	
Resistance To Cable Effects*	✓	

* - Cable length, cable motion, cable contamination

CALIBRATION CERTIFICATE

- Displays both Sensitivity (at reference frequency) and Frequency Response
- Each have different tolerance specifications
- These specifications are not the same thing as accuracy and uncertainty



~ *Calibration Certificate* ~

Per ISO 16063-21

Model Number: 352C22

Serial Number: 75229

Description: ICP® Accelerometer Method: Back-to-Back Comparison Calibration

Manufacturer: PCB

Calibration Data

Sensitivity @ 100.0 Hz	**9.95**	**mV/g**	Output Bias	9.8	VDC
	(1.015	**mV/m/s²)**	Transverse Sensitivity	1.8	%
Discharge Time Constant	3.0	seconds	Resonant Frequency	90.4	kHz

Sensitivity Plot

Temperature: 72 °F (22 °C) Relative Humidity: 60 %

Data Points

Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)	Frequency (Hz)	Dev. (%)
10.0	-0.3	300.0	0.2	7000.0	1.9
15.0	-0.3	500.0	0.1	10000.0	3.4
30.0	-0.2	1000.0	0.3		
50.0	-0.3	3000.0	0.4		
REF. FREQ.	0.0	5000.0	0.9		

Mounting Surface: Tungsten Adapter Epoxy: Cyanoacrylate Adhesive Fixture Orientation: Vertical

Acceleration Level (rms)*: 10.0 g, 98.1 m/s²

*The acceleration level may be limited by shaker displacement at low frequencies. If the listed level cannot be obtained, the calibration system uses the following formula to set the vibration amplitude. Acceleration Level (g) = 0.01 x (freq)². *The gravitational constant used for calculations by the calibration system is: 1 g = 9.80665 m/s².

Condition of Unit

As Found: n/a

As Left: New Unit, In Tolerance

Notes

1. Calibration is NIST Traceable thru Project 822/271196 and PTB Traceable thru Project 5399.
2. This certificate shall not be reproduced, except in full, without written approval from PCB Piezotronics, Inc.
3. Calibration is performed in compliance with ISO 9001, ISO 10012-1, ANSI/NCSL Z540-1-1994 and ISO 17025.
4. See Manufacturer's Specification Sheet for a detailed listing of performance specifications.
5. Measurement uncertainty (95% confidence level with coverage factor of 2) for frequency ranges tested during calibration are as follows: 5-9 Hz; +/- 2.0%, 10-99 Hz; +/- 1.5%, 100-1999 Hz; +/- 1.0%, 2-10 kHz; +/- 2.5%.

Technician: Dan Eckel Date: 09/12/06

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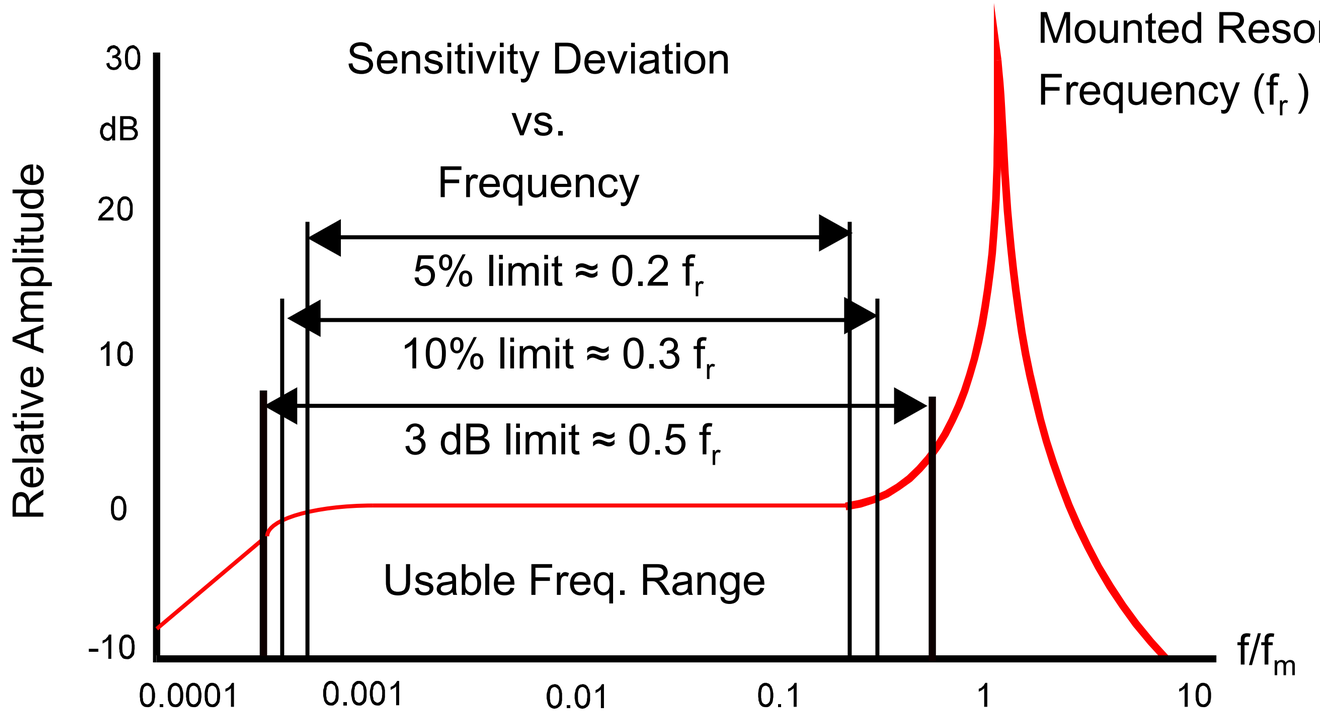
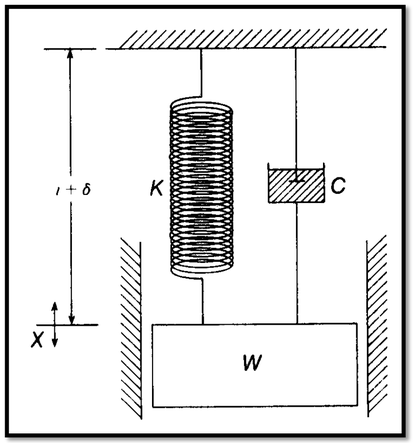
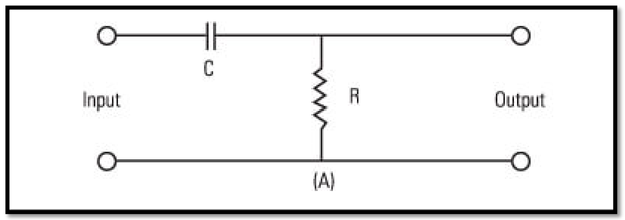
FREQUENCY RESPONSE

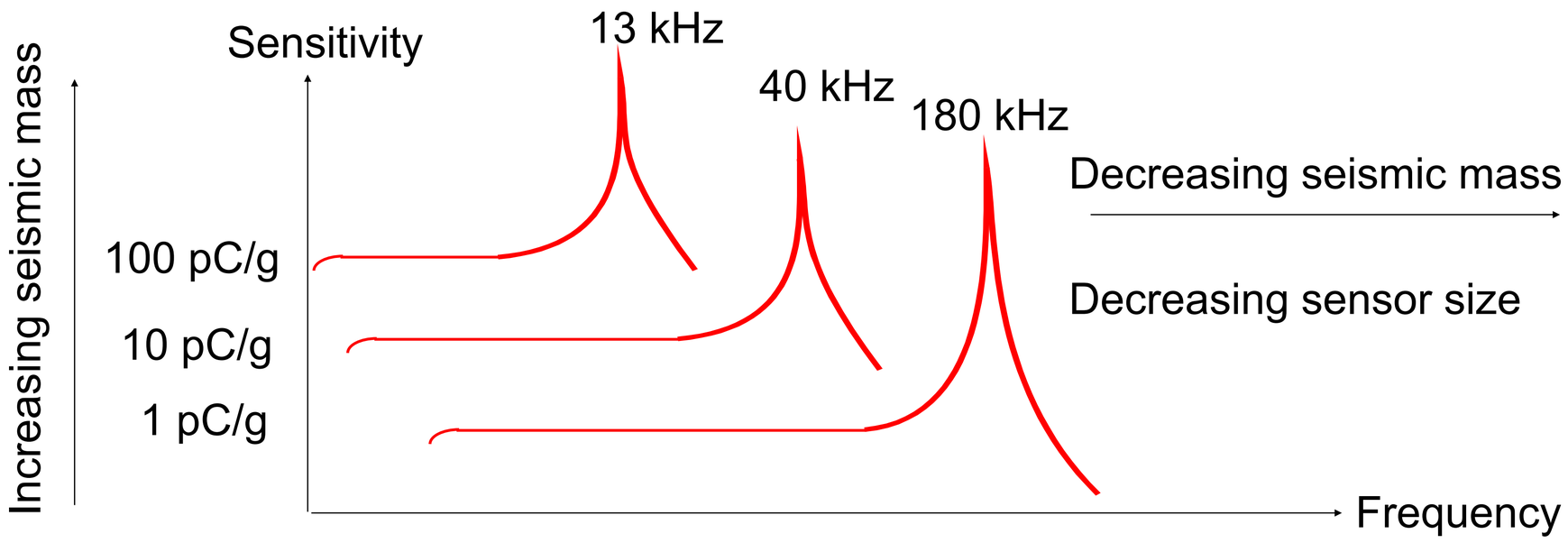






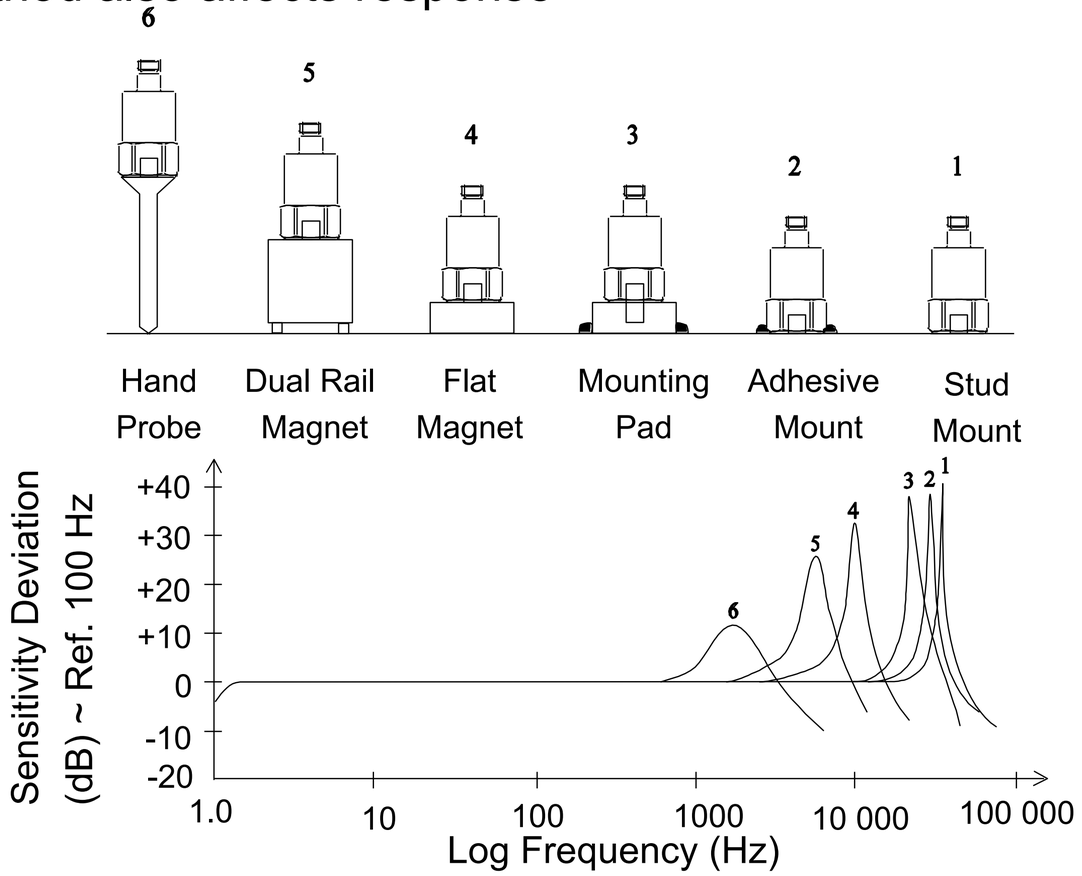
FREQUENCY RESPONSE

- Accelerometer Design
  - **Trading Sensitivity vs High Frequency Response**



FREQUENCY RESPONSE

- Mounting Method also affects response



IDEAL REFERENCE ACCELEROMETER

Design Parameter	Choice For Reference Accelerometer
Element Design	Piezoelectric
Mechanical Design	Tri-shear
Crystal Material	Quartz
Electrical Design	IEPE aka ICP®

QUESTIONS?