KISTLER
measure. analyze. innovate.

Selecting Accelerometers for Modal Analysis

John Kubler
john.kubler@kistler.com
Kistler Instrument Corporation

IMAC XXVI
Orlando
February 6, 2008

Topics

- Sensor Parameters for Modal Testing
- Sensor Technology
- Key Parameters – Important Specifications
- Mass Loading – Mounting Methods
- TEDS – Connectors & Cables
- Summary


KISTLER
measure. analyze. innovate.
PCB
339B01
VIPsensors
1010A

Which one?

Accelerometer Selection Chart

KISTLER
measure. analyze. innovate.

PE & VC Sensors cover broad range of applications

Parameters	
Frequency Response	DC to 20,000 Hz
Range	1g to 100,000g
Sensitivity (Threshold)	0.01mV/g to >1 V/g
Operating Temperature	-320 to 600°F (-196 to 316°C)
Mounting	Adhesive, magnet, stud
Sensor Mass	0.5 gr to 500 gr
Case Configuration	Epoxy or hermetic, various connector locations

Modal Accelerometer

Typical Specifications

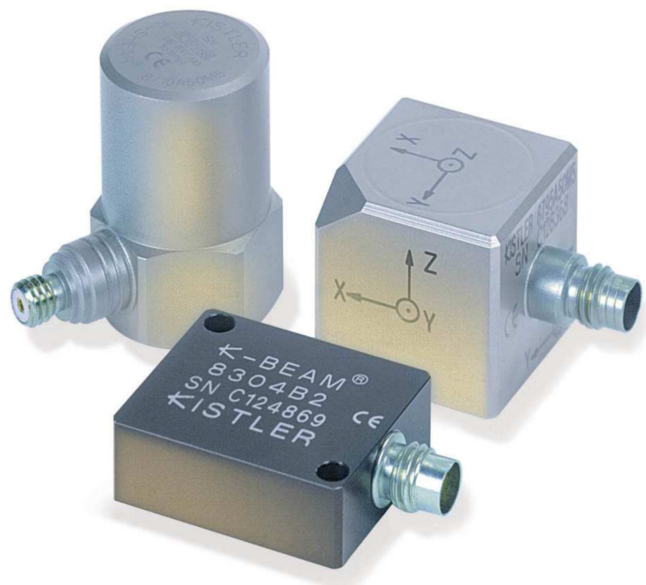
Parameters	
Frequency Response	DC to 5,000 Hz
Range	1g to 20g
Sensitivity (Threshold)	100 mV/g to 1 V/g
Operating Temperature	-65 to 250°F (-54 to 121°C)
Mounting	Adhesive, magnet, (stud)
Sensor Mass	0.5 gr to 20 gr
Case Configuration	Epoxy or hermetic, various connector locations

KISTLER
measure. analyze. innovate.

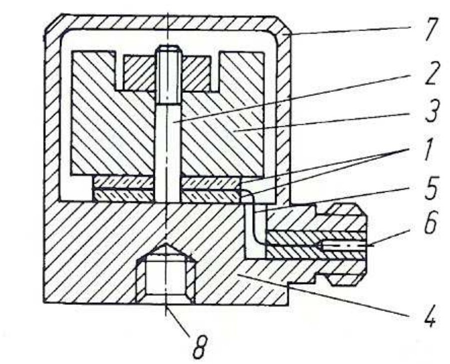
Accelerometer Technology

- **Piezoelectric (PE)**
  - Compression
  - Shear
  - Annular Shear
  - Cantilever

- **Capacitive (VC)**
  - MEMS



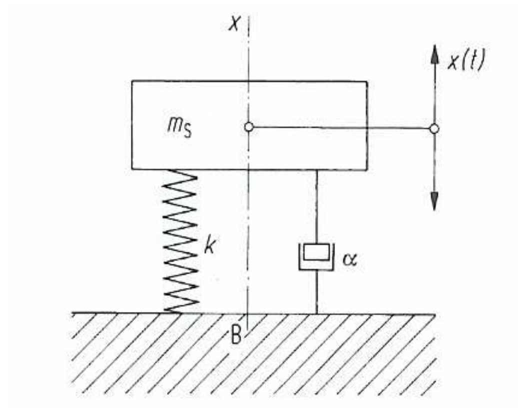
PE Compression



F = m a

↓

a = F/m



m_s	seismic mass
∝	damping
K	spring constant

1. Piezoelectric Crystals
2. Post or preload screw
3. Seismic mass
4. Base
5. Electrode
6. Connector
7. Housing
8. Mounting thread

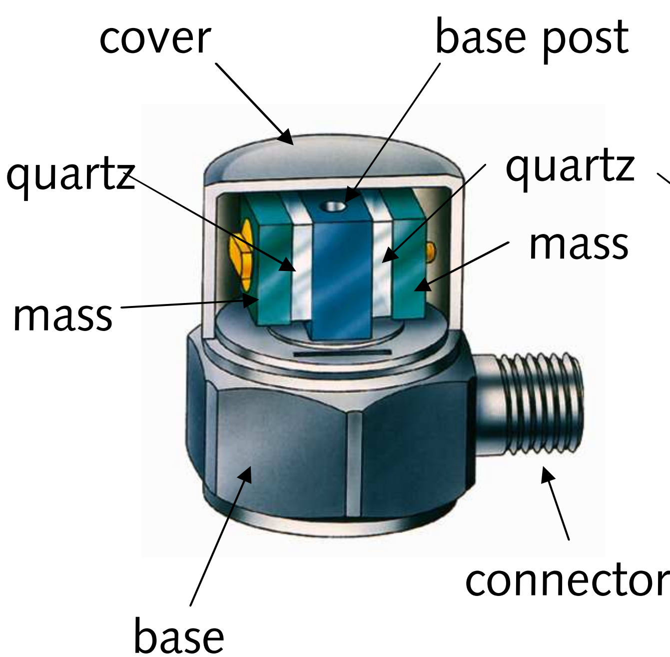
- High f_n
- Thermal and base strain sensitive
- Design still used in some miniature sensors and high shock sensors, calibration standards

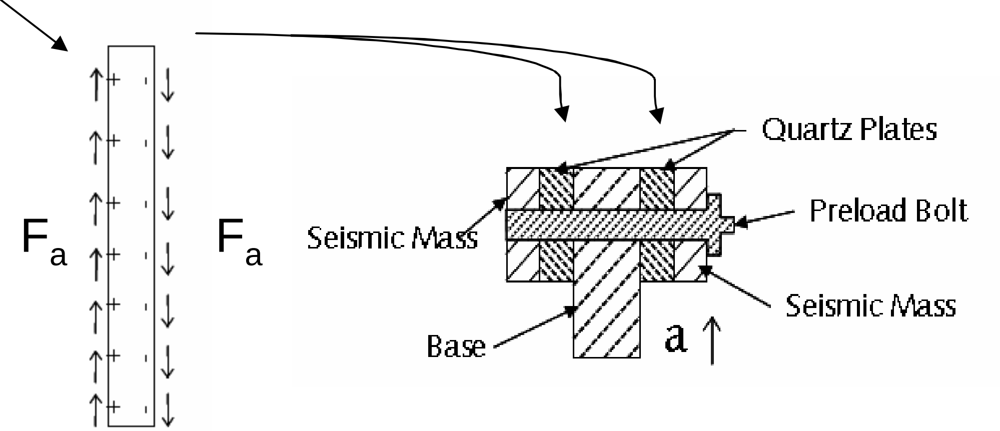
PE Shear

K-SHEAR®

KISTLER
measure. analyze. innovate.

- Symmetrical seismic system
- Isolated from base strain & thermal effects
- Low transverse
- Wide usable frequency range, excellent at very low frequencies
- Shear mode crystals are 2x more sensitive than compression
- PiezoStar® is 4x more sensitive



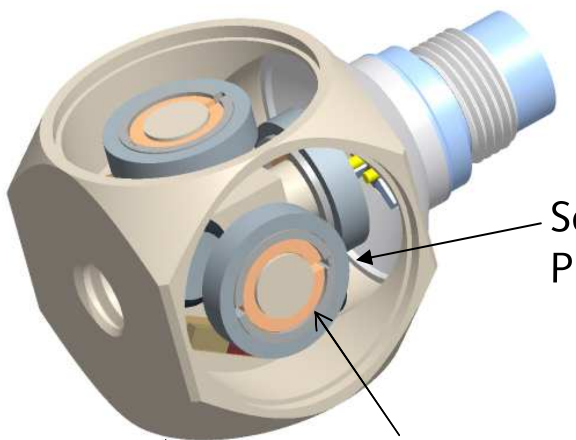


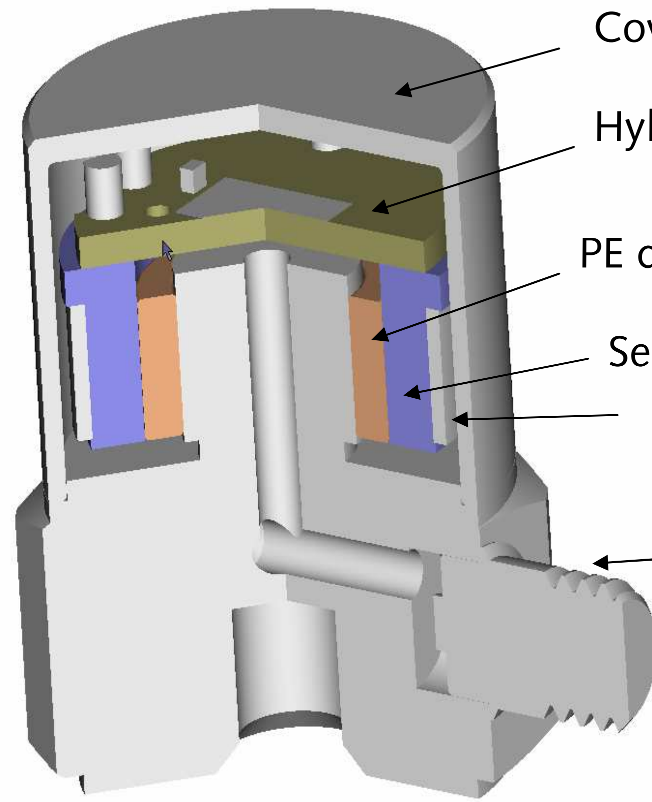
Shear
quartz plate

PE Ceramic Ring Shear:

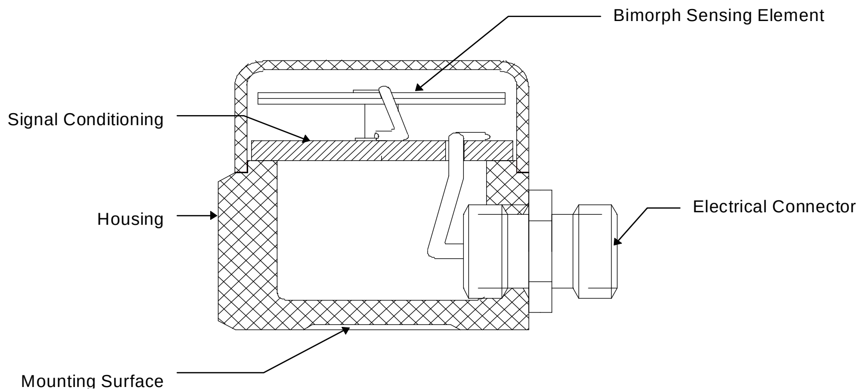
- Preload ring replaces the bolt (or screw)
- Provides compact, efficient designs (fewer parts)
- Only for ceramic elements

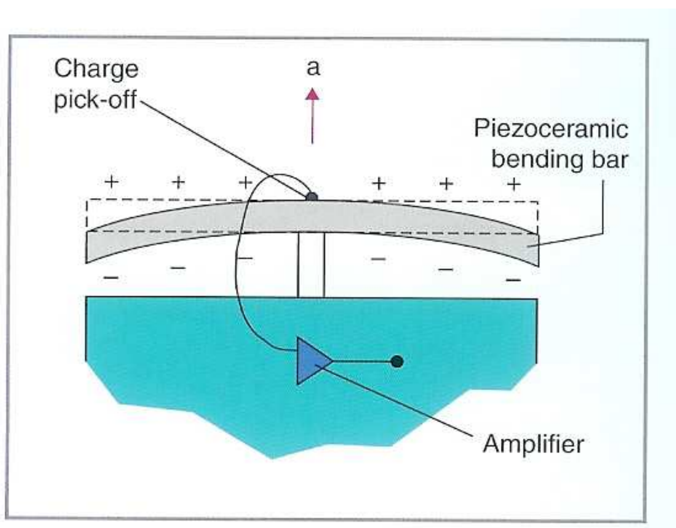
Tri-axial Accelerometer





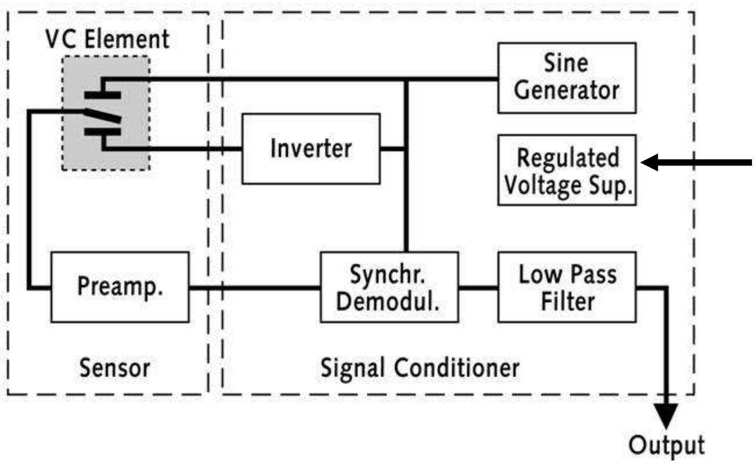
PE Cantilever
PiezoBEAM® Bimorph Element



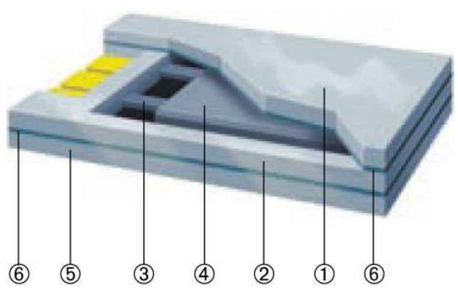


- Intro in 1988 as modal accelerometer
- Cantilever, ceramic bimorph element
- 1V/g and weighs only 4 grams!
- Integral hybrid charge amplifier yields high level output
- Voltage mode 10 mV/g only
- Low transverse sensitivity (<1%)
- Frequency response 5% @ <5kHz
- Lightweight, aluminum case, hard anodized, ground isolated,
- Operating temperature: 0 °C to 65°C
- **High sensitivity with low noise, low mass and low transverse**

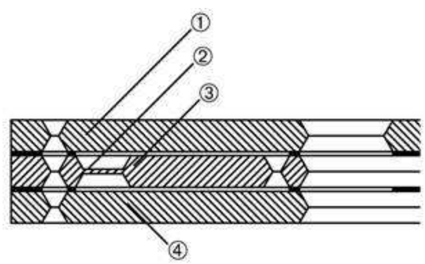
Variable Capacitive (VC)
K-BEAM®



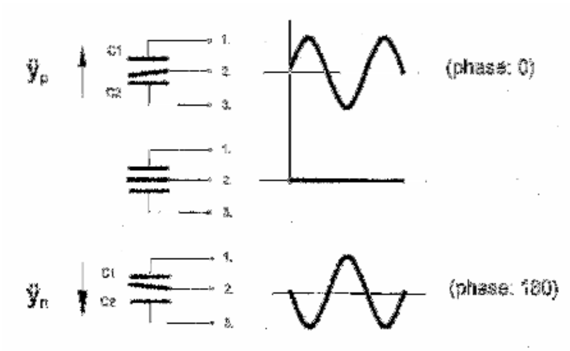
- **<u>Measures static response, gravity</u>**
- The differential capacitance between the top and bottom electrodes referenced to the center mass, is measured and converted to a voltage
- The measured signal is demodulated to obtain a DC level corresponding to the acceleration
- Low pressure Nitrogen provides damping
- 4-wire system (not compatible with IEPE)



① = top electrode
② = frame
③ = spring
④ = mass
⑤ = bottom electrode
⑥ = glass layer

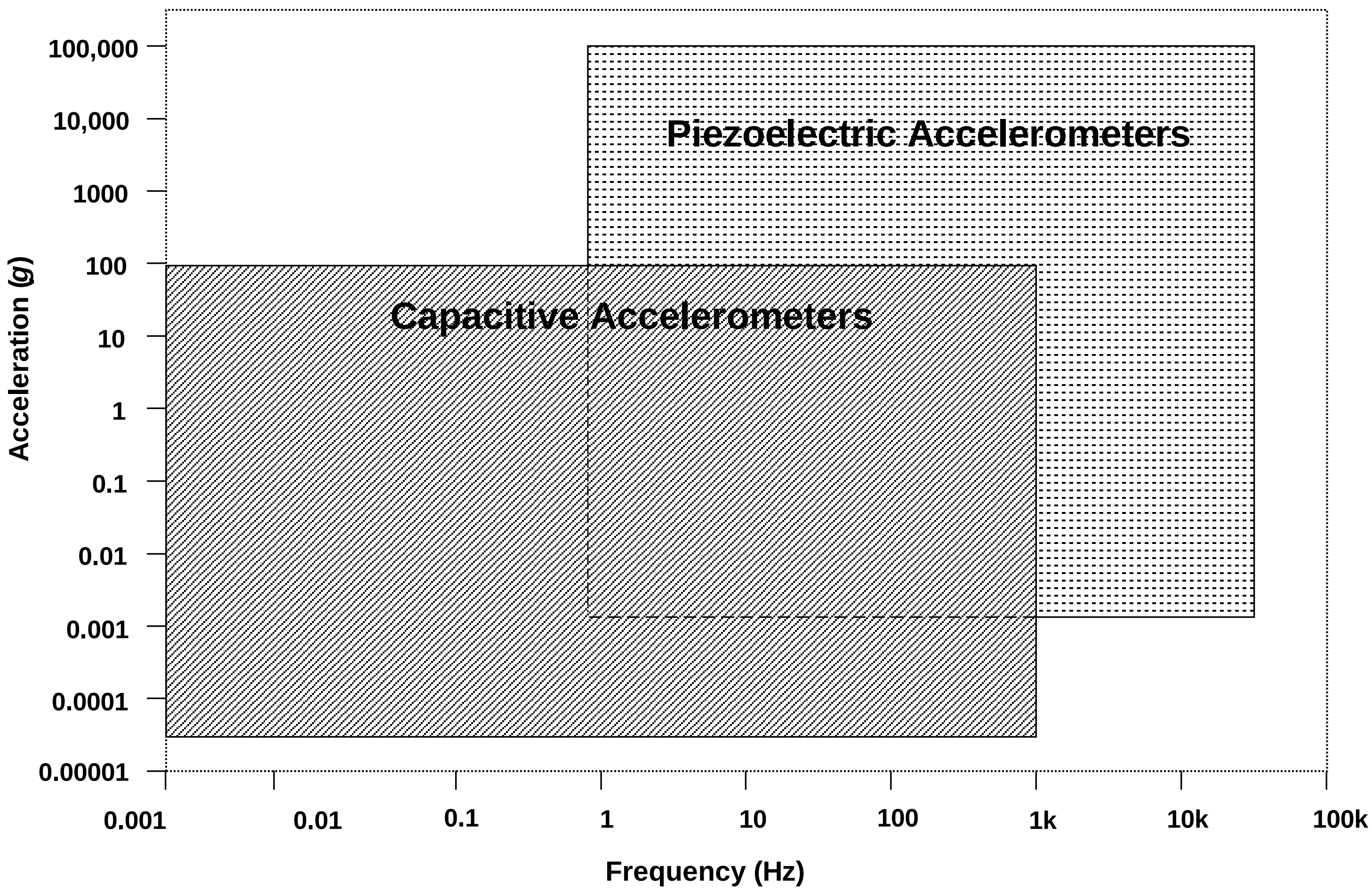


① = top electrode
② = spring
③ = mass
④ = bottom electrode



Key Parameters

VC – PE Accelerometer Frequency and Amplitude Domain



Time Constant of PE Sensors

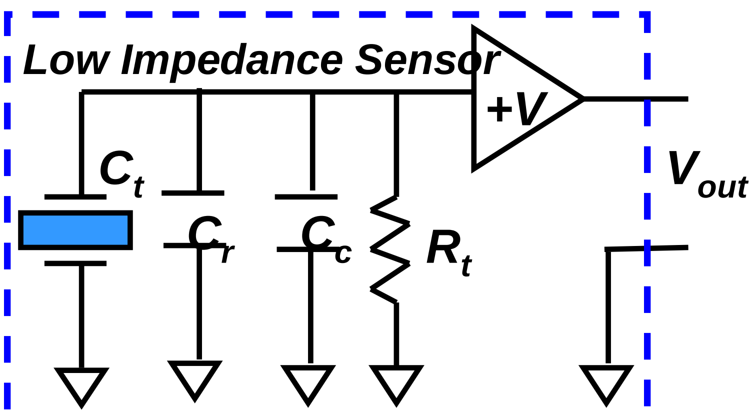
- **Low frequency (P/E)**

$$\frac{V_o}{V_{in}} = \frac{2\pi f(\tau)}{\sqrt{1+[2\pi f(\tau)]^2}}$$

τ = time Constant (sec)

$\tau = R_t\,(C_t + C_\tau + C_c)$

R = Resistor
C = Capacitance



Quartz Accelerometer:

Capacitance C_{tot}: 10 pF
Resistor: $1 \times 10^{11}\ \Omega$
TC = 1 s

Ceramic Accelerometer:

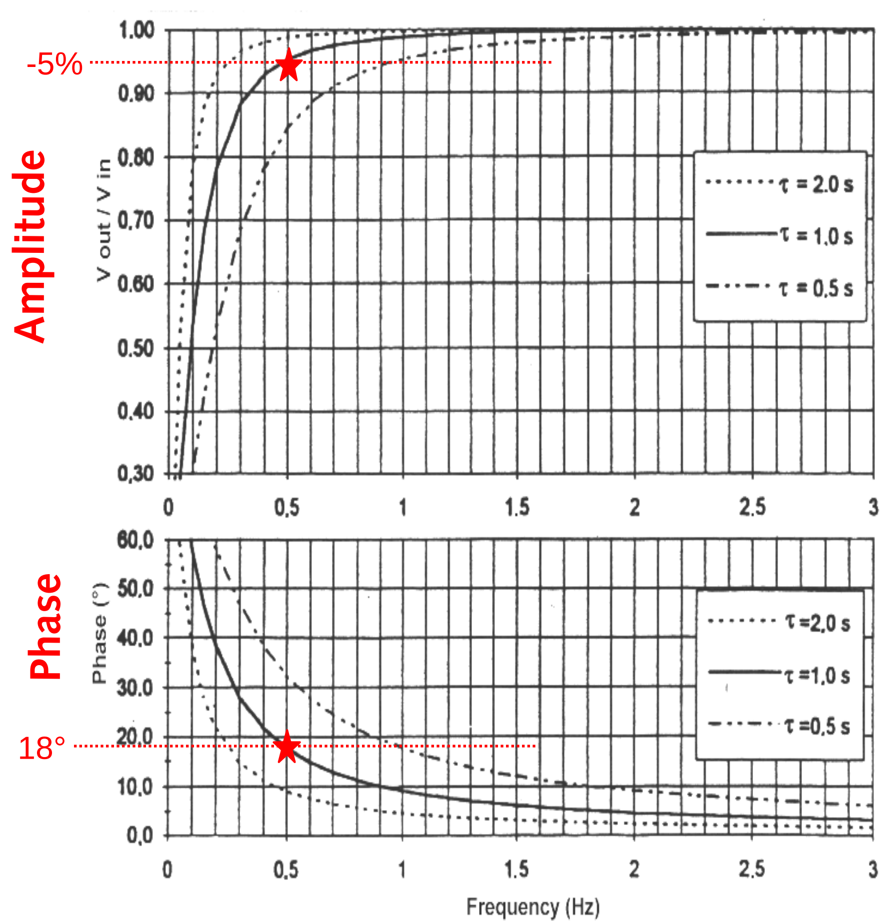
Capacitance C_{tot}: 1000 pF
Resistor: $1 \times 10^{9}\ \Omega$
TC = 1 s

Note: PE ceramics have lower IR than quartz)

(Typical examples)

KISTLER
measure. analyze. innovate.

PE: Time Constant – Low Frequency Response



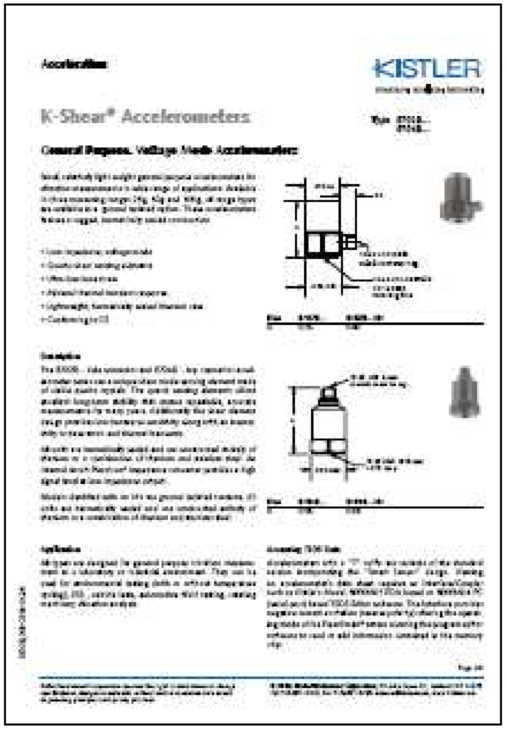
- Longer time constant (TC) = lower frequency (inversely related)
- Total system TC for an accelerometer (τ_a) with a signal conditioner (τ_c):

  $$\tau_{total} = \tau_a \tau_c / (\tau_a + \tau_c)$$

- The shortest TC will dominate the systems low frequency performance
- ★ With a 1 sec TC (-5%), the phase shift is ≈18 degrees
- f (-5%) = 0.5/ system TC
- For frequencies below 0.1Hz (-5%) variable capacitance (VC) accelerometers are the preferred choice
- Accelerometers with TC greater than 1sec can be more sensitive to temperature variations

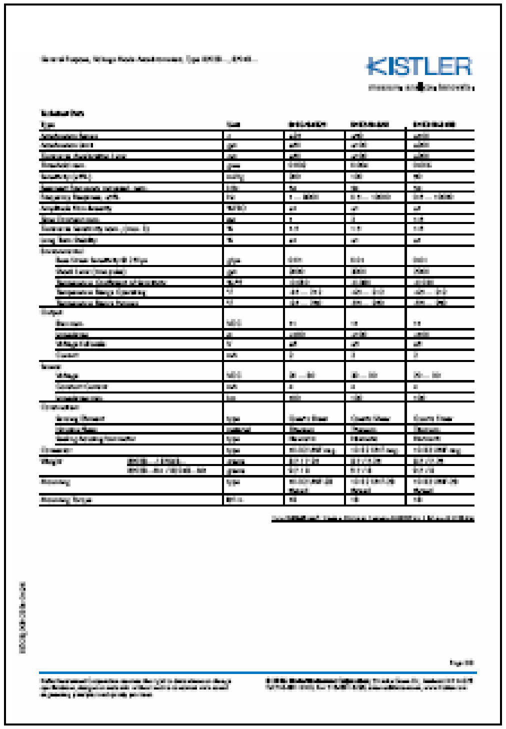
Data Sheets

KISTLER
measure. analyze. innovate.


Acceleration

K-Shear® Accelerometers

General Purpose, Voltage Mode Accelerometers



Data Sheets – PE Accelerometers

KISTLER
measure. analyze. innovate.

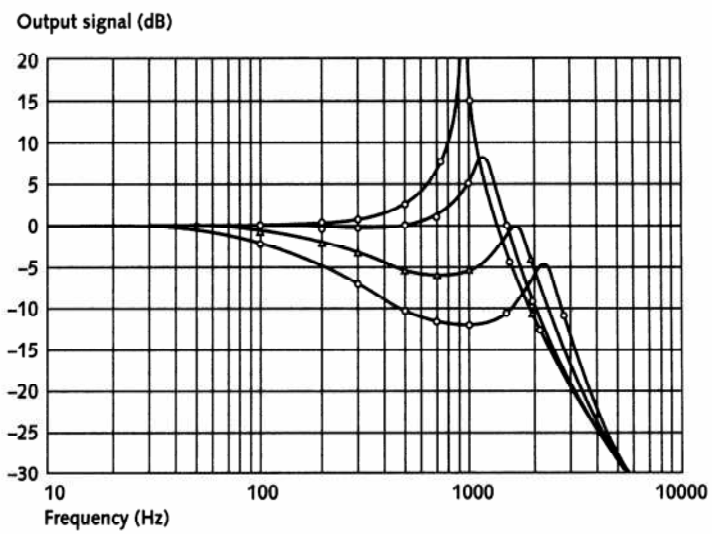
Light weight, Voltage Mode, Modal Accelerometer, Type 8632C…

KISTLER
measure. analyze. innovate.

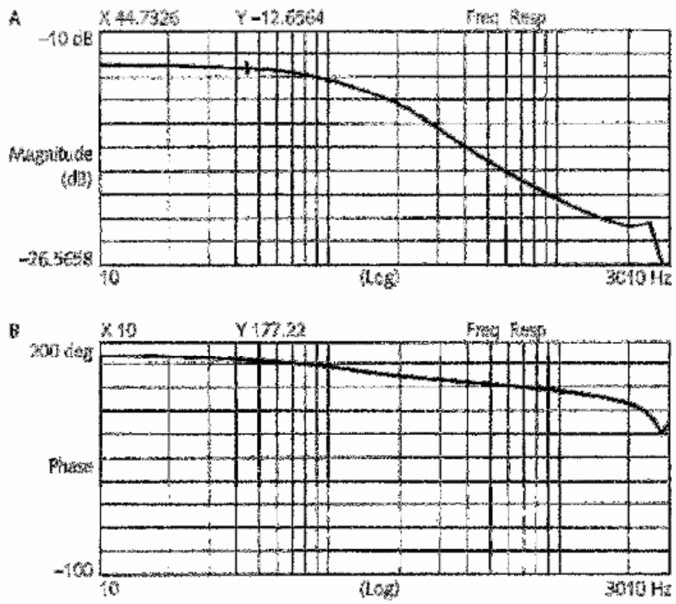
Technical Data

Type	Unit	8632C5	8632C10	8632C50
Acceleration Range	g	±5	±10	±50
Acceleration Limit	gpk	±8	±16	±80
Threshold nom.	grms	0.00012	0.00028	0.001
Sensitivity, ±5%	mV/g	1000	500	100
Resonant Frequency mounted, nom.	kHz	9	22	22
Frequency Response, ±5%	Hz	1 … 3000	1 … 5000	1 … 6000
Phase Shift, <5°	Hz	4 … 2000	4 … 2000	4 … 4000
Amplitude Non-linearity	%FSO	±1	±1	±1
Time Constant nom.	sec	1	1	1
Transverse Sensitivity, max.	%	1	1	1
Long Term Stability	%	±1	±1	±1
Environmental:				
Base Strain Sensitivity @ 250με	g/με	<0.001	<0.001	<0.001
Shock Limit (0.2ms pulse)	gpk	7000	10000	10000
Temperature Coeff. of Sensitivity	%/°F	-0.02	0.04	0.04

VC Accelerometers
Amplitude & Phase Response



Frequency response as a function of damping

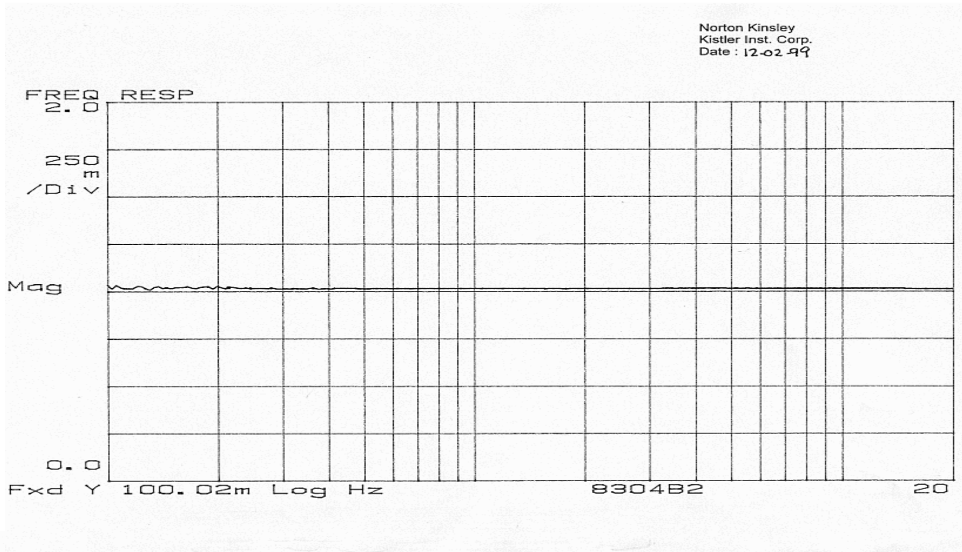


Tuned damping to optimize frequency response (amplitude and phase)

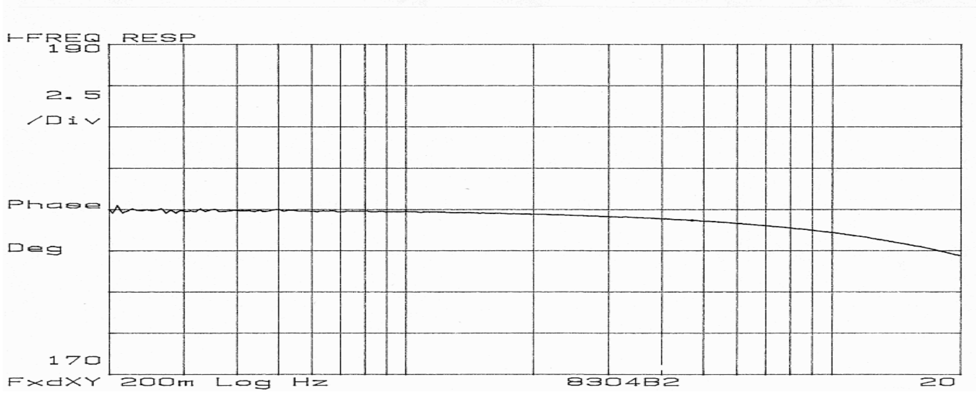
VC Accelerometers
Low Frequency

Unlike piezoelectric, capacitive sensors are damped

Amplitude



Phase



Data Sheets – VC Accelerometers

KISTLER
measure. analyze. innovate.

Light Weight, Low Profile Capacitive Accelerometer, Type 8305B…

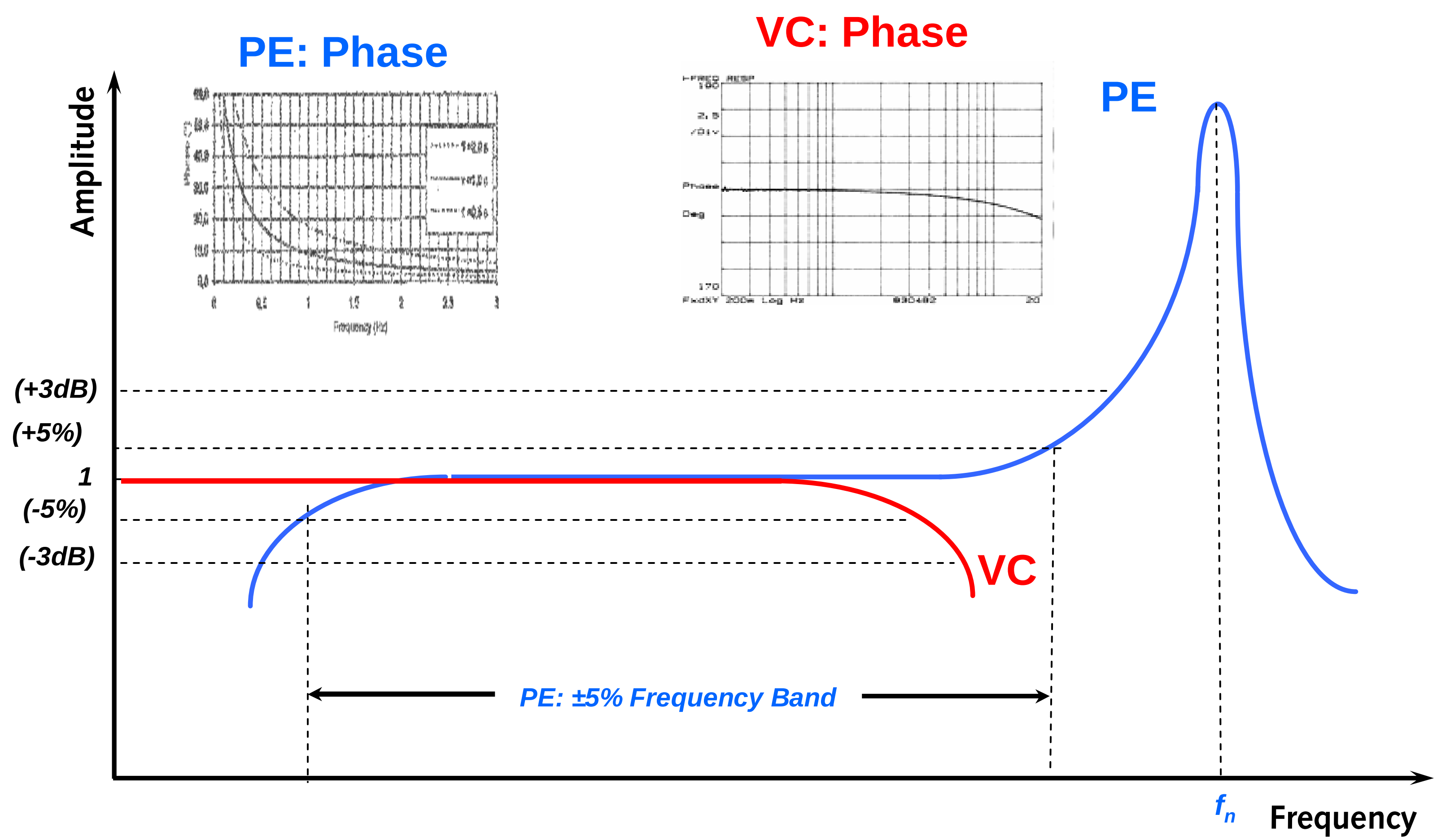
KISTLER
measure. analyze. innovate.

Technical Data

Type	Unit	8305B2	8305B10	8305B25	8305B50	8305B100
Acceleration Range	g	±2	±10	±25	±50	±100
Sensitivity, ±5%	mV/g	500	100	80	40	20
Sensitivity-Differential (5%)	mV/g	1000	200	160	80	40
Zero g Output (5%)	mV	2500 ±125	2500 ±125	2500 ±125	2500 ±125	2500 ±80
Zero g Output-Differential (5%)	mV	0 ±25	0 ±25	0 ±25	0 ±25	0 ±160
Amplitude Non-linearity	%FSO	0.4	0.4	1	1	1
Resonant Frequency nom.	kHz	1.4	2.7	3	3.5	4.5
Frequency Response (±5%, 100 Hz Ref.)	Hz	≥200	≥180	≥300	≥500	≥500
Noise typ. (0,5 ... 100Hz)	µgrms	200	1000	1760	3620	3910
Noise Density (0…100 Hz) typ.	µgrms/√Hz	20	100	180	370	400
Phase Shift max. @ 0 Hz	degree	0	0	0	0	0
Phase Shift max. @ 10 Hz	degree	<2	<2	<1	<1	<1
Phase Shift max. @ 100 Hz	degree	<10	<10	<5	<5	<5
Phase Shift max. @ 200 Hz	degree	<25	<25	<8	<8	<8
Sensitive Axis Misalignment typ. (max.)	mrad	≤10 (≤30)	≤10 (≤30)	≤20 (≤35)	≤20 (≤35)	≤20 (≤35)
Transverse Sensitivity typ. (max. 3)	%	±1	±1	±1	±1	±1

Frequency Response Comparison PE vs VC

KISTLER
measure. analyze. innovate.



Summary:
Accelerometer Technologies

Type	Material	Remarks
PE Compression	•Quartz, •Ceramics •Piezostar®	*Industrial, shock, miniature* *Higher base strain & thermal shift than shear* *Very high temperature applications (> 250° C)*
PE Shear	•Quartz •Ceramics •Piezostar®	*Shock & vibration, low transverse & base strain* *Ceramics have higher charge output, Quartz & Piezostar have higher temperature stability*
PE Annular Shear	•Ceramic	*Shock & vibration, high charge sensitivity, low transverse, low base strain*
PE Bimorph	•Ceramic	*Very low mass, high sensitivity with +5% at 5 kHz* *Very low transverse sensitivity, limited high temp.*
Capacitive	•Silicon	*Ideal for low frequency and low g measurements* *Static capability*

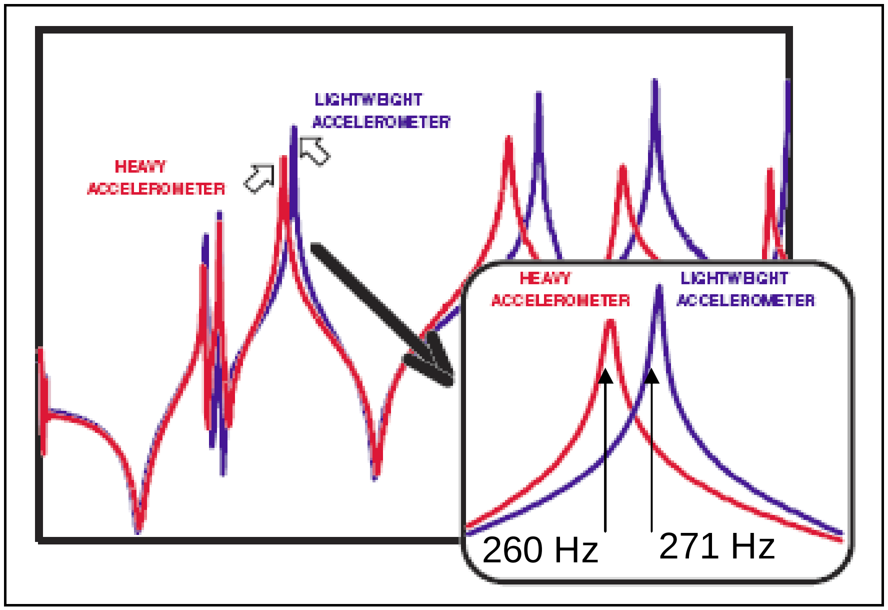
Mounting Effects

Mass Loading

KISTLER
measure. analyze. innovate.

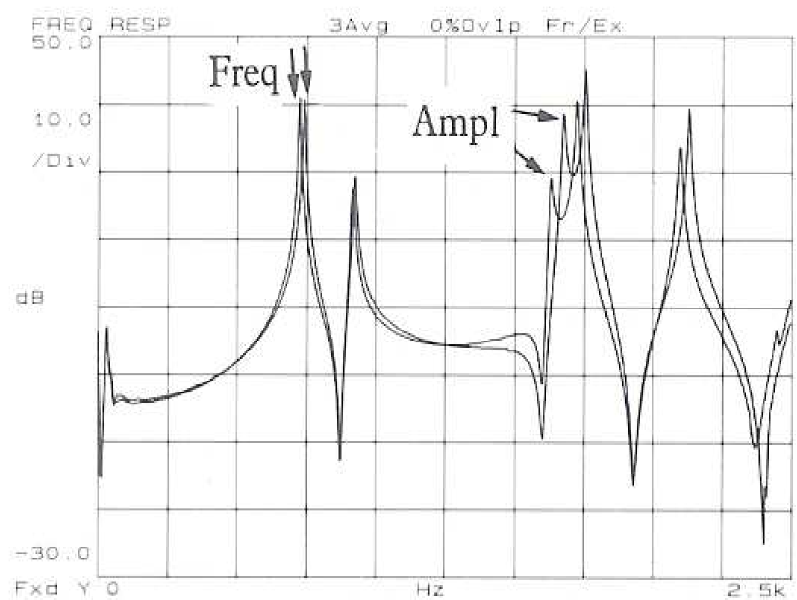
How much will the sensors affect my test?

- Adding test instrumentation to a structure affects the measured frequency response
- The effect depends on the mass of the structure under test
- Higher frequency modes are affected by a greater degree

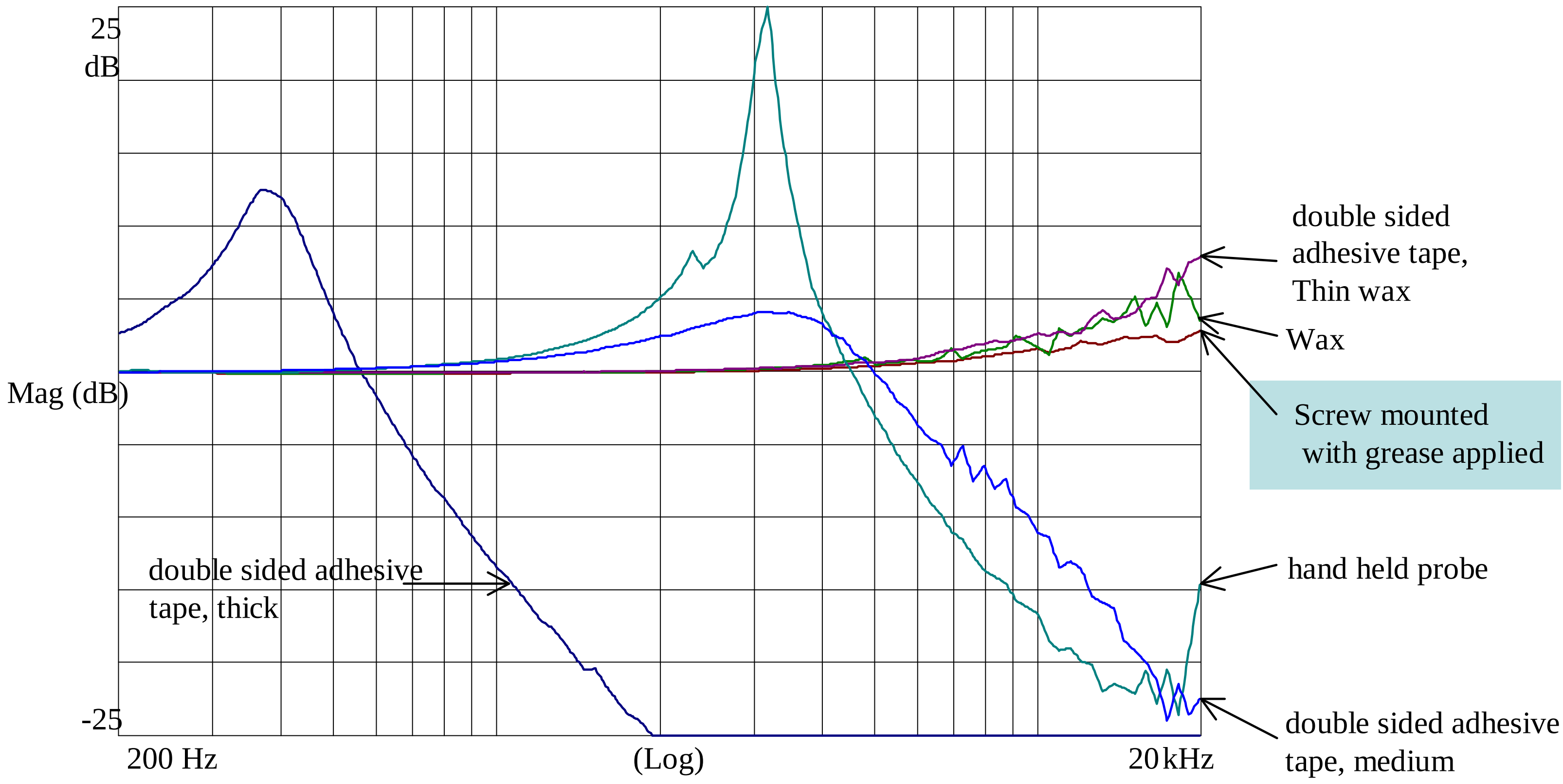


FRF with two different accelerometer masses

Source: Experimental Techniques, Jan/Feb 2002



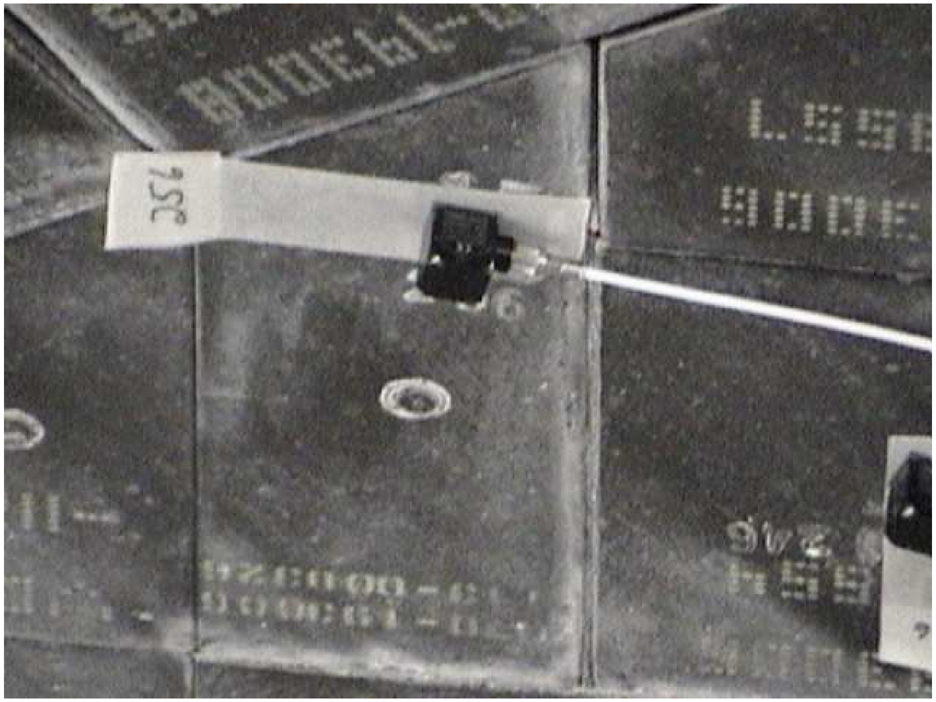
Accelerometer Mounting
Frequency Response Comparison



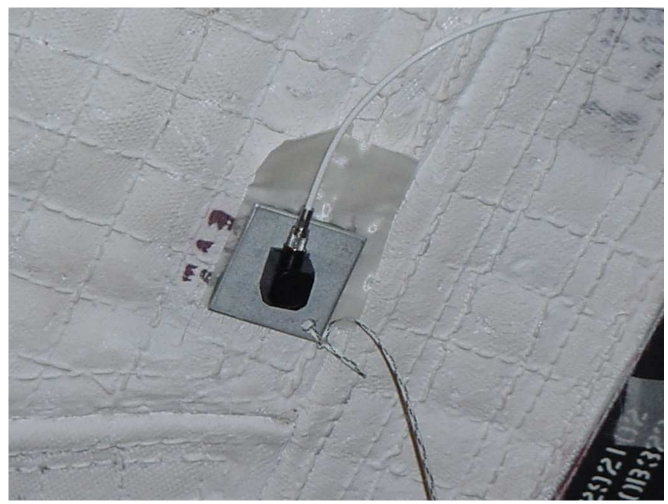
- Mount the accelerometer to provide a rigid path to the object under test
- Stud Mounting is preferred for high frequency measurement

Accelerometer Mounted to Space Shuttle Tiles

KISTLER
measure. analyze. innovate.

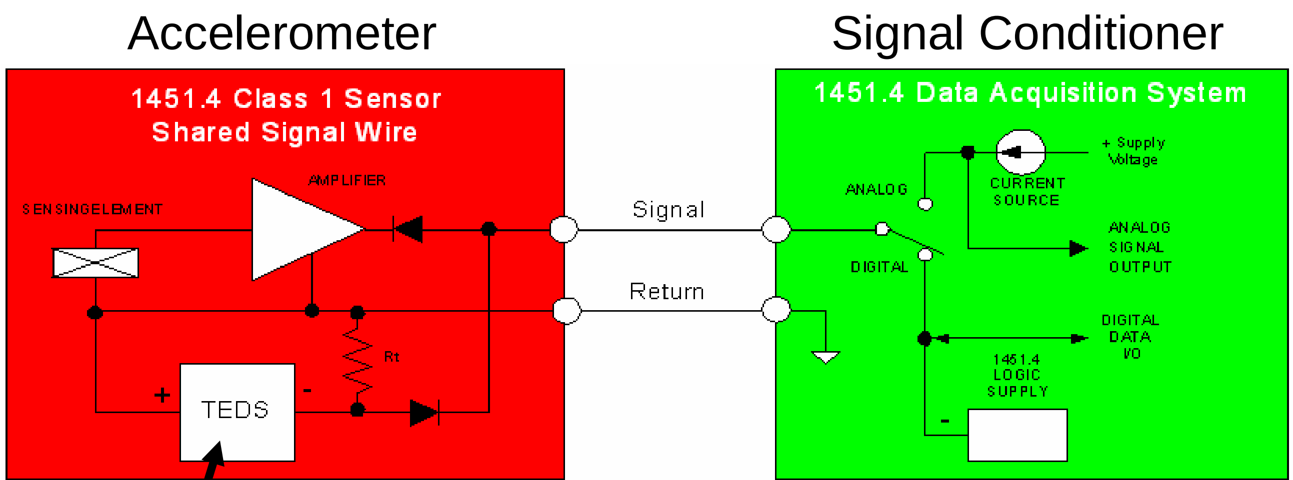


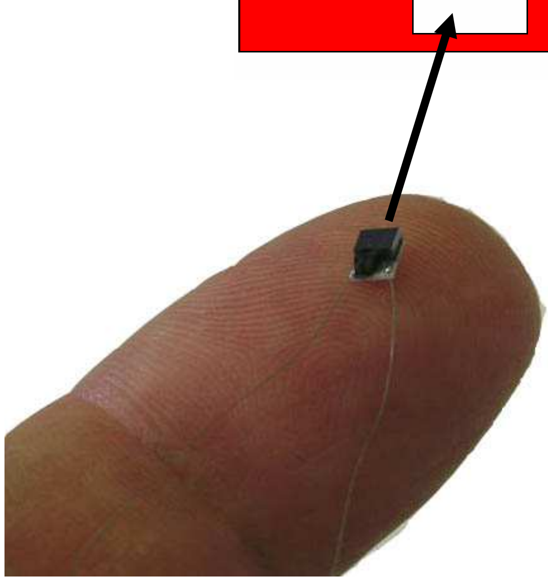
- Sensor is attached using cloth-like tape and adhesive
- Adhesive is dissolvable with alcohol



Other Considerations

IEEE 1451.4 Mixed Mode Interface
Analog Signal & TEDS Data Share Connection





- TEDS = Transducer Electronic Data Sheet
- Software activated mode
- Transparent to the end–user

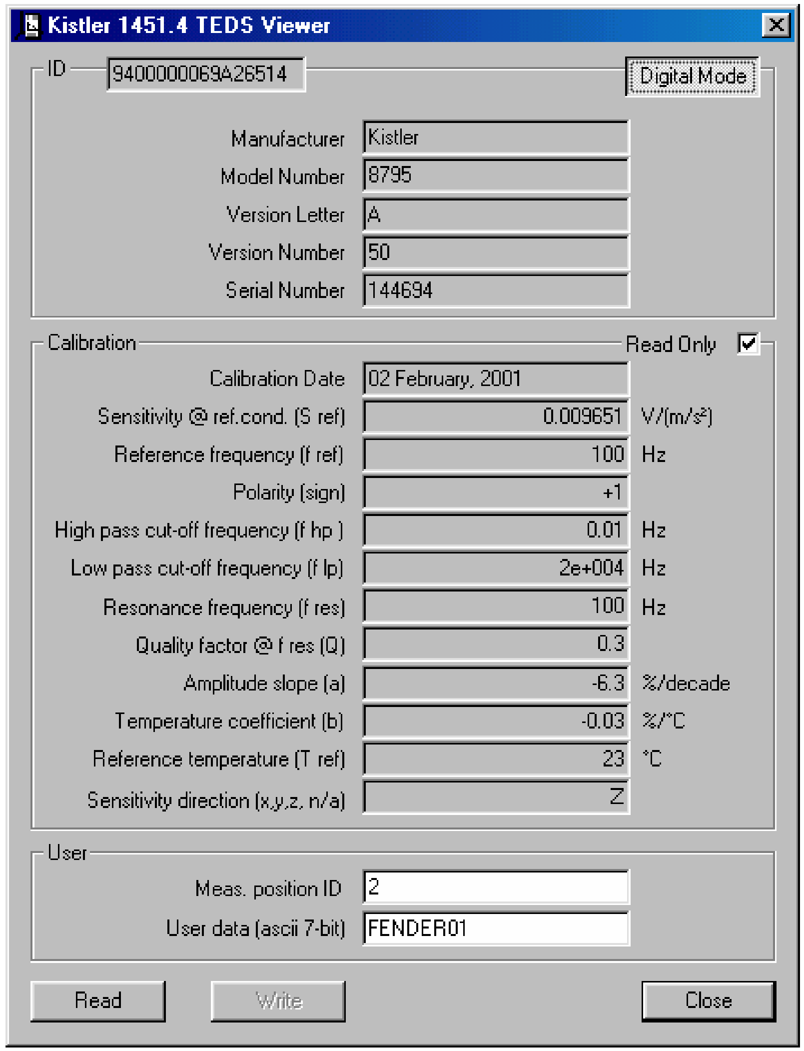
TEDS Editor: Example

Established by EEPROM Manufacturer

Entered at Factory

Updated as Required (ISO, Internal Company Standards etc)

User Defined Data



Orientation (x,y,z)

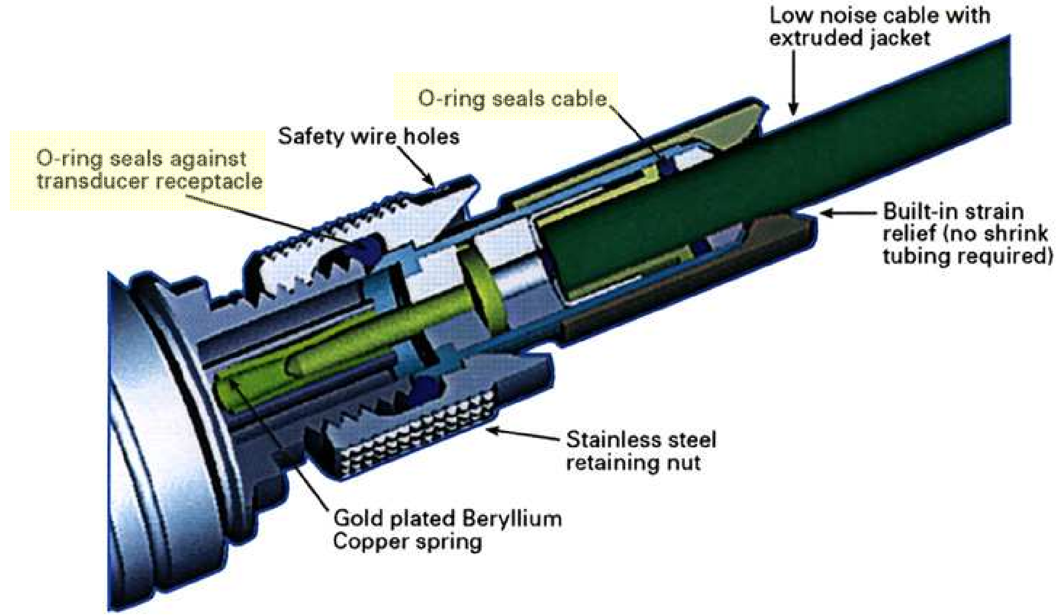
User Defined Tag

TEDS Advantages

- TEDS reduces record keeping errors and maintains a high integrity with broad band analog signals.
  - Debugging/Validation
  - Data normalization
  - User specific information
- For sensors without TEDS (legacy sensors)
  - Virtual TEDS using National Instruments web data base

Photo: NASDA, Japan

Cables & Connectors



- Stainless construction, not plated brass = smaller, lower weight
- Internal O-ring seals = eliminates shrink tubing
- Built in strain relief = smaller cable bending radius
- Extruded Teflon = water tight cable jacket
- Wide temperature range (-320 °F to +465 °F)
- High reliability

Cable Connections Are Important!

KISTLER
measure. analyze. innovate.

KISTLER
measure. analyze. innovate.

Configurations

PE Accelerometers


8636


8632


8702


8704


8732

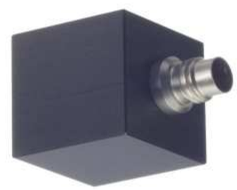

8778


8776


8728


8791


8692


8690


8795

triaxial

VC Accel


8305


8310


8393

triaxial

KISTLER
measure. analyze. innovate.

Thank you!