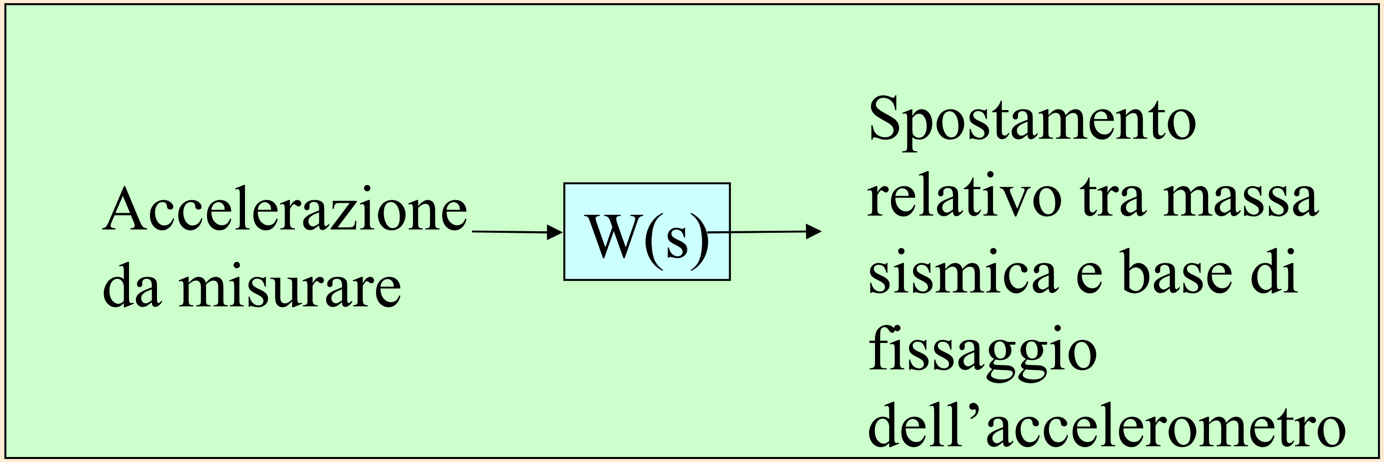
Accelerometri

Funzione di trasferimento:



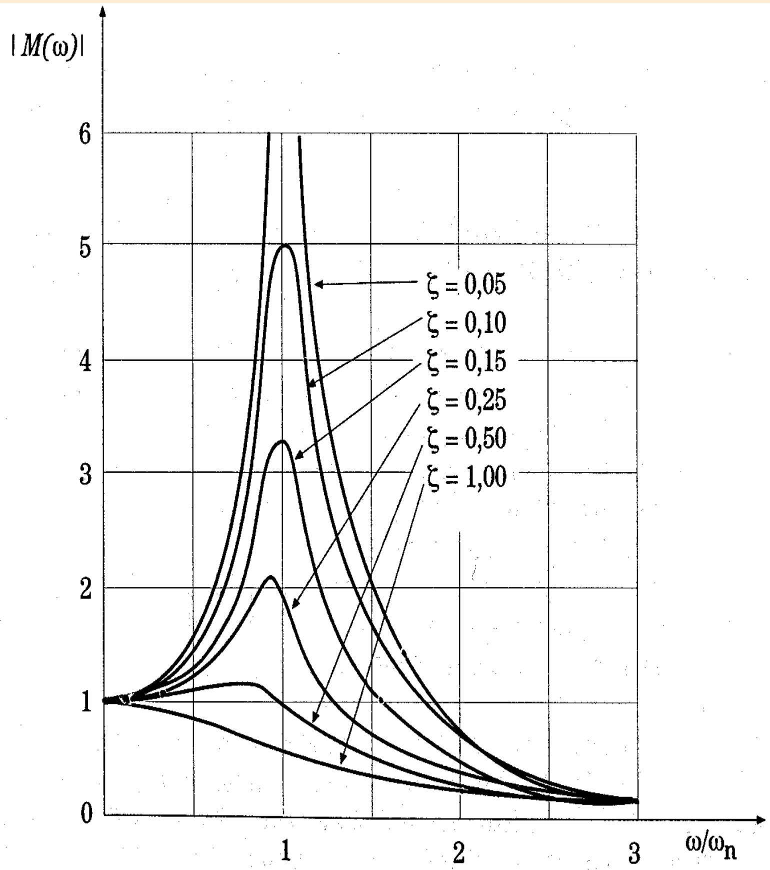
$$W(s) = \frac{Diff.Spostamento(s)}{AccelerazioneBase(s)} = \frac{\frac{1}{\omega_n^2}}{1 + \frac{2\zeta}{\omega_n} s + \frac{s^2}{\omega_n^2}}$$

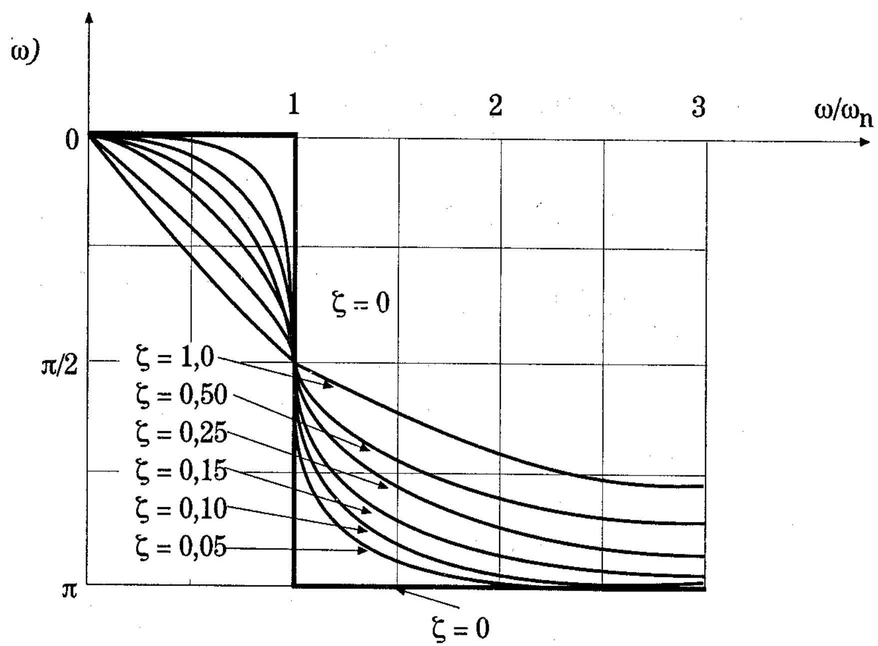
Si noti che la sensibilita' dell'accelerometro (risposta per s=iw=0) e' -1/wn^2 e quindi inversamente proporzionale alla frequenza naturale del'accelerometro.

Piu' ampia e' la banda passante (0-wn) minore e' quindi la sensibilita' dell'accelerometro

Per quel che riguarda il rapporto di smorzamento negli strumenti si fa in modo che il suo valore renda massima la banda passante e lineare la caratteristica di fase.

Per questo motivo negli accelerometri : ζ=0.67





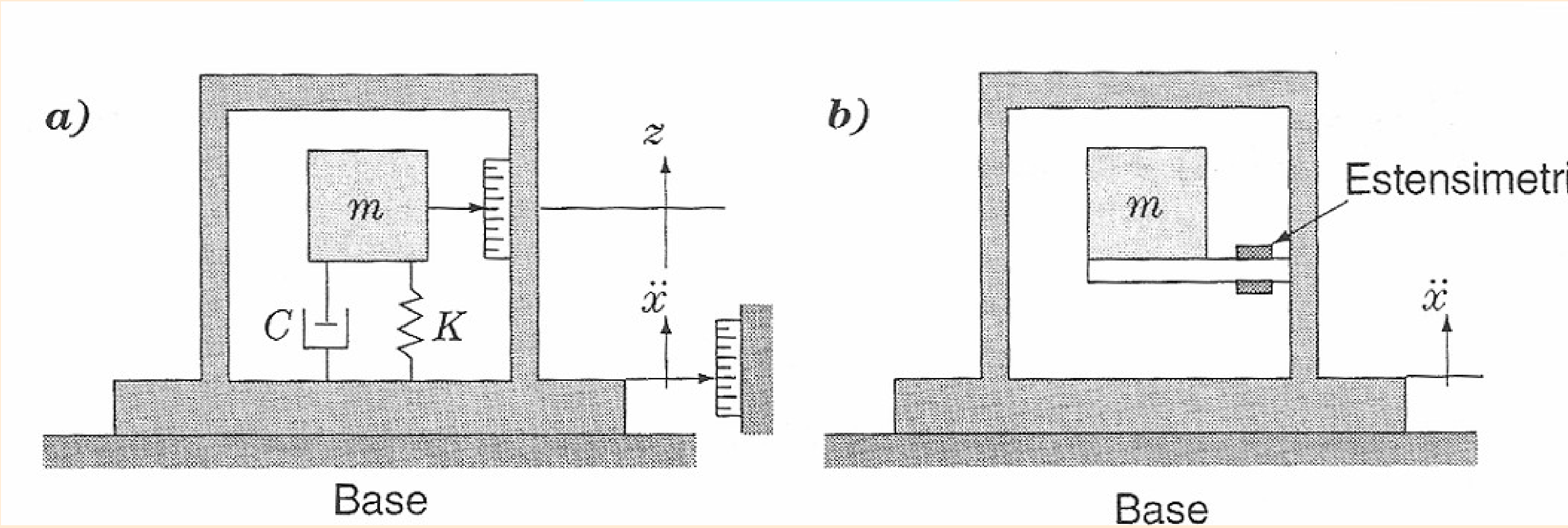
i velocimetri o tachimetri sono misuratori di velocita'

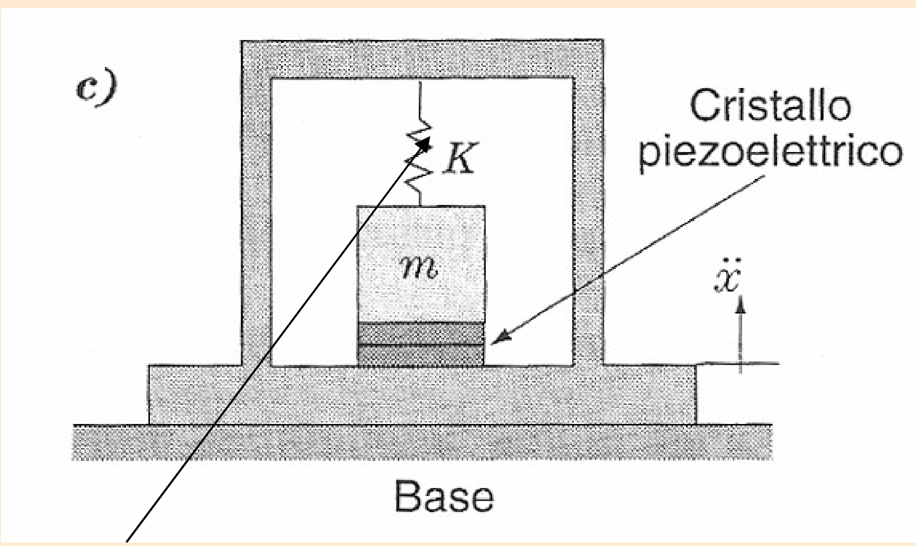
$$W(s) = \frac{Diff.Spostamento(s)}{Velocita'\,Base(s)} = s\,\frac{\frac{1}{\omega_n^2}}{1 + \frac{2\zeta}{\omega_n}s + \frac{s^2}{\omega_n^2}}$$

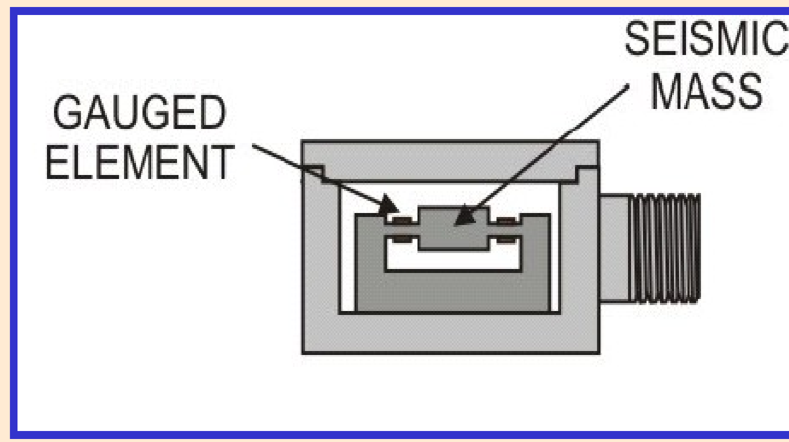
$$W(i\omega) = \frac{\frac{i\omega}{\omega_n^2}}{1 + \frac{2\zeta}{\omega_n}i\omega - \frac{\omega^2}{\omega_n^2}}$$

Per lo stesso motivo per i velocimetri si ha : ζ>>1

Accelerometri





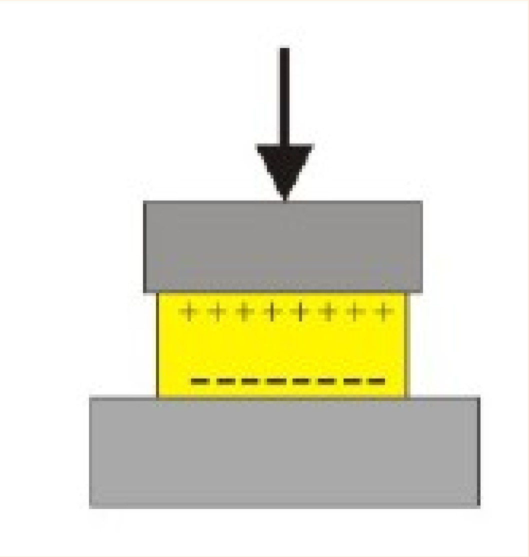


Molla di precarico

estensimetri

Materiali piezoelettrici

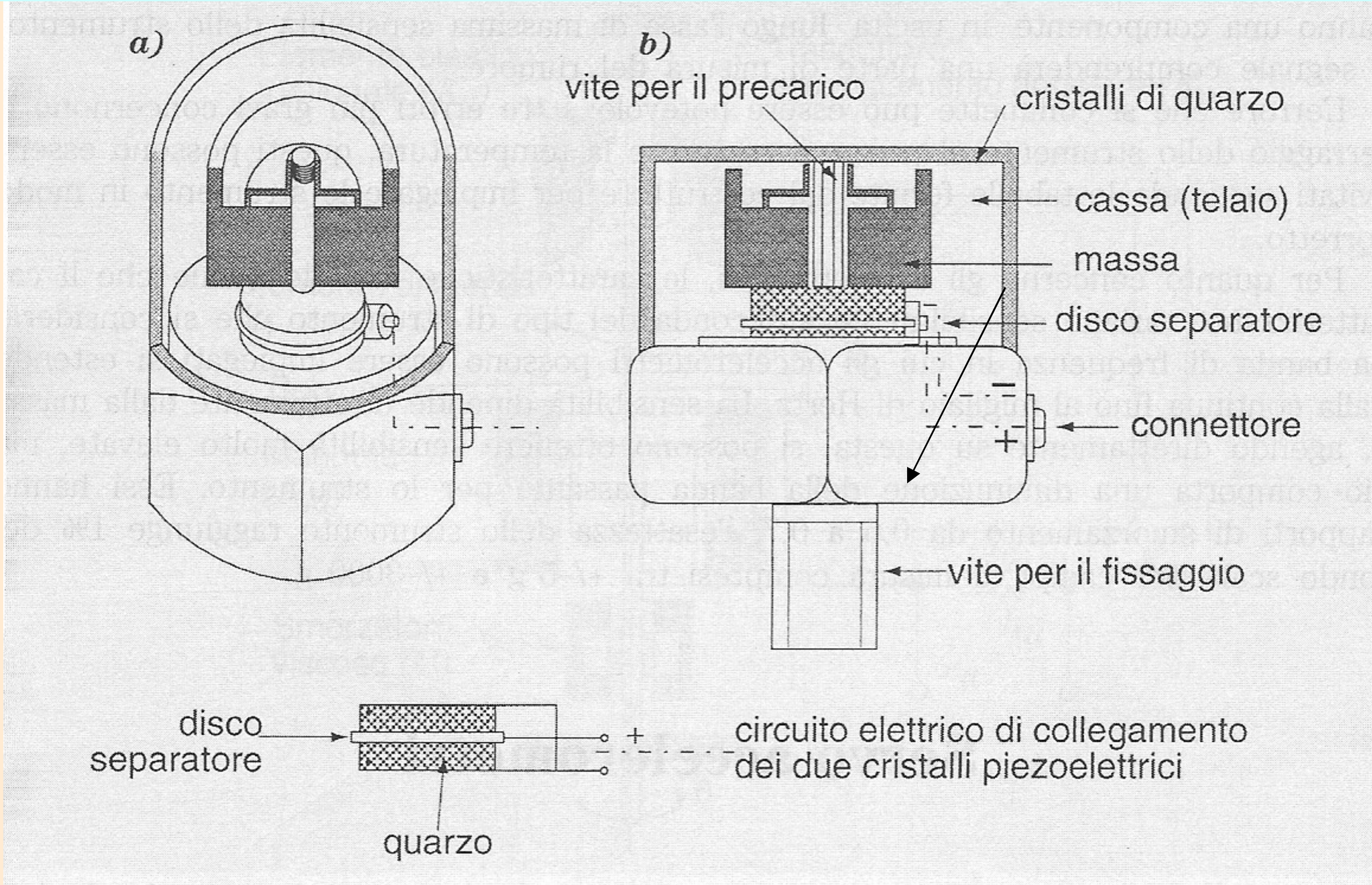
Quando certi materiali vengono deformati, internamente ad essi vengono generate cariche elettriche. Questo fenomeno è reversibile e prende il nome di effetto piezoelettrico. I campi di applicazione sono molteplici: attuatori e sensori (spostamento, forza, pressione)



I materiali piezoelettrici sono principalmente di 3 tipi:

- cristalli naturali (quarzo) e sintetici (solfato di litio, fosfato di ammonio biidrogenato)
- ceramiche ferroelettriche polarizzate artificialmente (titanato di bario)
- alcune pellicole di polimeri

Schema costruttivo di un accelerometro piezoelettrico



- Alla rigidezza K contribuiscono sia la rigidezza propria del materiale piezoelettrico sia quella dell'elemento di precarico;
- Lo smorzamento è dato solo dall'isteresi del materiale piezoelettrico ($\zeta \leq 0.01$, che in genere è accettabile perché ω_n è elevata).

Precarico di un accelerometro piezoelettrico

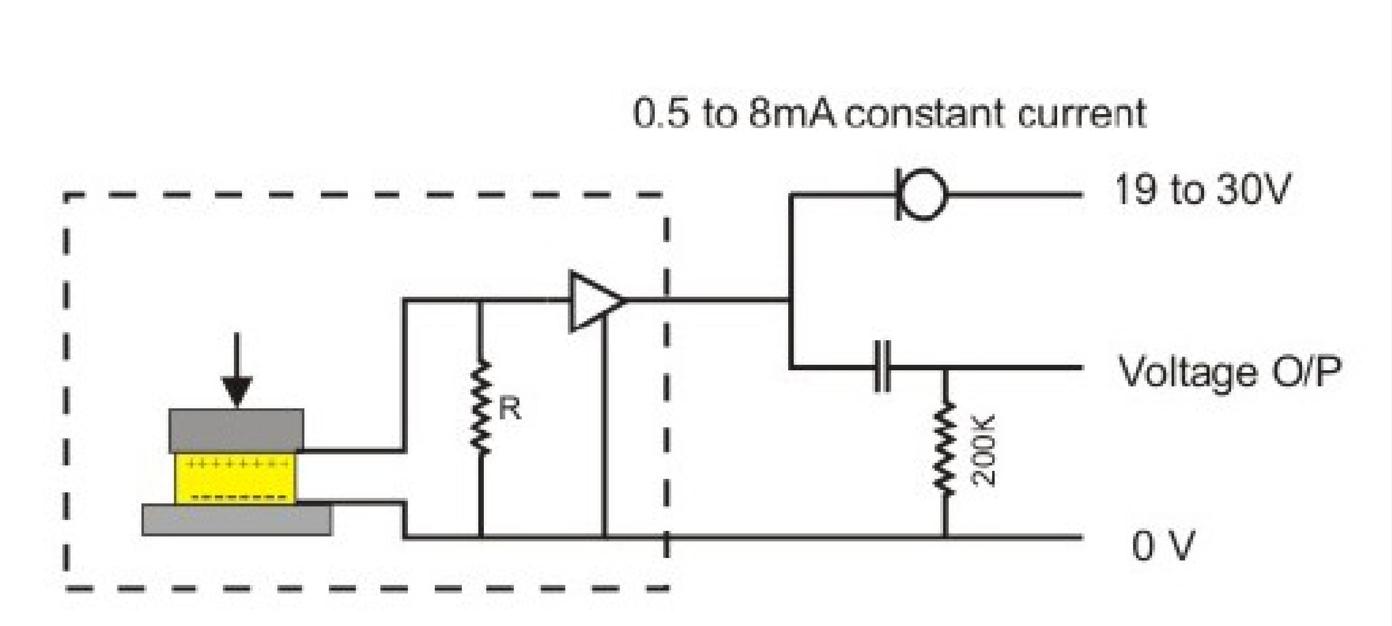
Il materiale piezoelettrico può essere sottoposto ad un precarico opportuno per i seguenti motivi:

• si cerca di far funzionare l'accelerometro in un tratto lineare della curva carica vs. deformazione;

• il precarico permette di misurare sia accelerazioni positive sia negative senza porre in trazione il materiale piezoelettrico e senza rinunciare al segno nel segnale d'uscita. Infatti, il precarico induce una tensione iniziale che progressivamente scompare.

Come viene resa disposibile l'uscita di accelerometro Piezoelettrico?

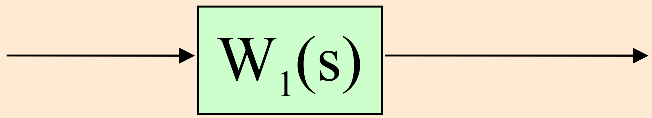
O come il valore della carica (sensibilita': Pico-Coulomb /g) che viene poi elaborata da una unita' esterna di amplificazione della carica o attraverso l'utilizzo di una elettronica supplementare nell'accelerometro è fornita una uscita analogica in Voltaggio. (accelerometro IEPE o ICP)



Funzione di trasferimento di un accelerometro

Alla W(s) del sistema massa-molla-smorzatore bisogna aggiungere la funzione di trasferimento del trasduttore di spostamento relativo $W_1(s)$

Spostamento relativo tra massa sismica e base di fissaggio dell'accelerometro



Tensione elettrica e_0

La W1(s) dipende dal tipo di trasduttore di spostamento relativo:

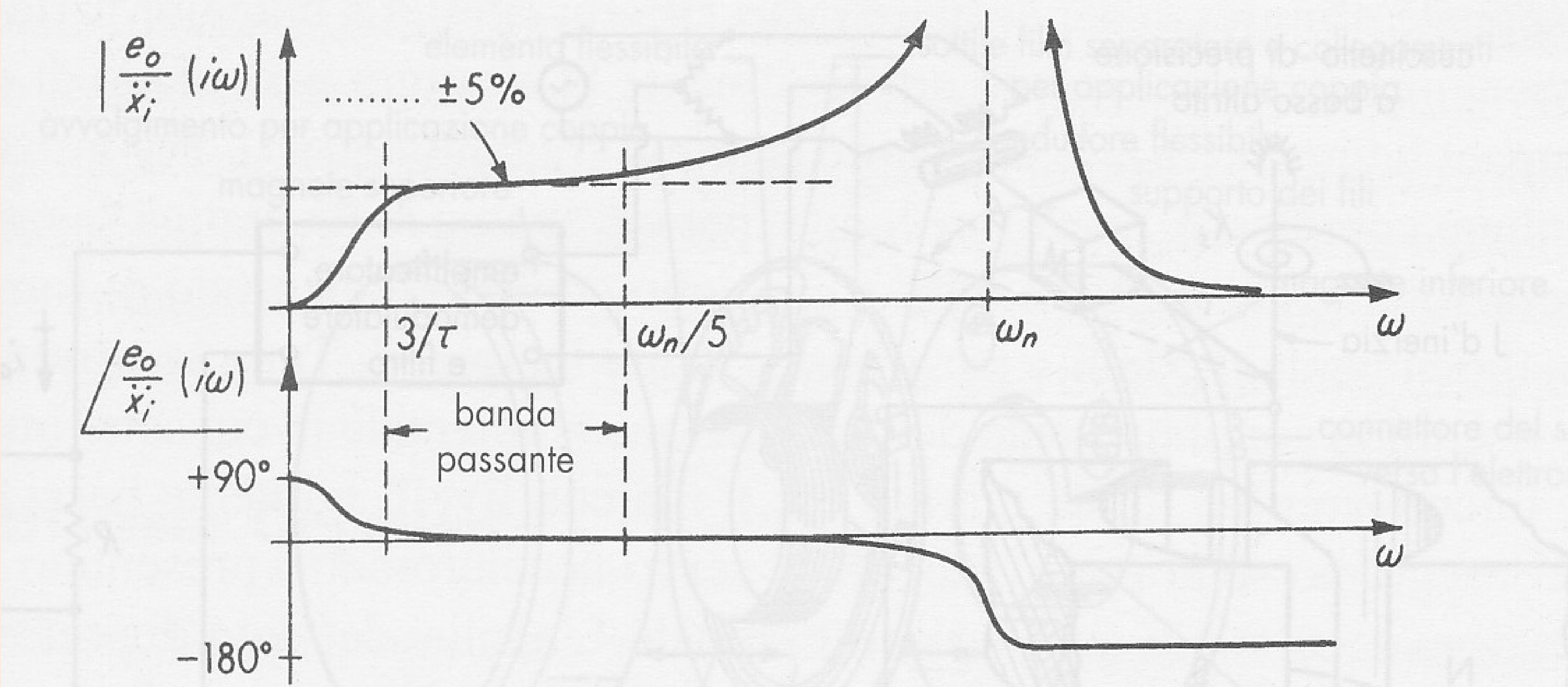
- Può essere una costante K_e per molti trasduttori;
- è un sistema del I ordine passa alto per i trasduttori piezoelettrici.

Funzione di trasferimento di accelerometri piezoelettrici

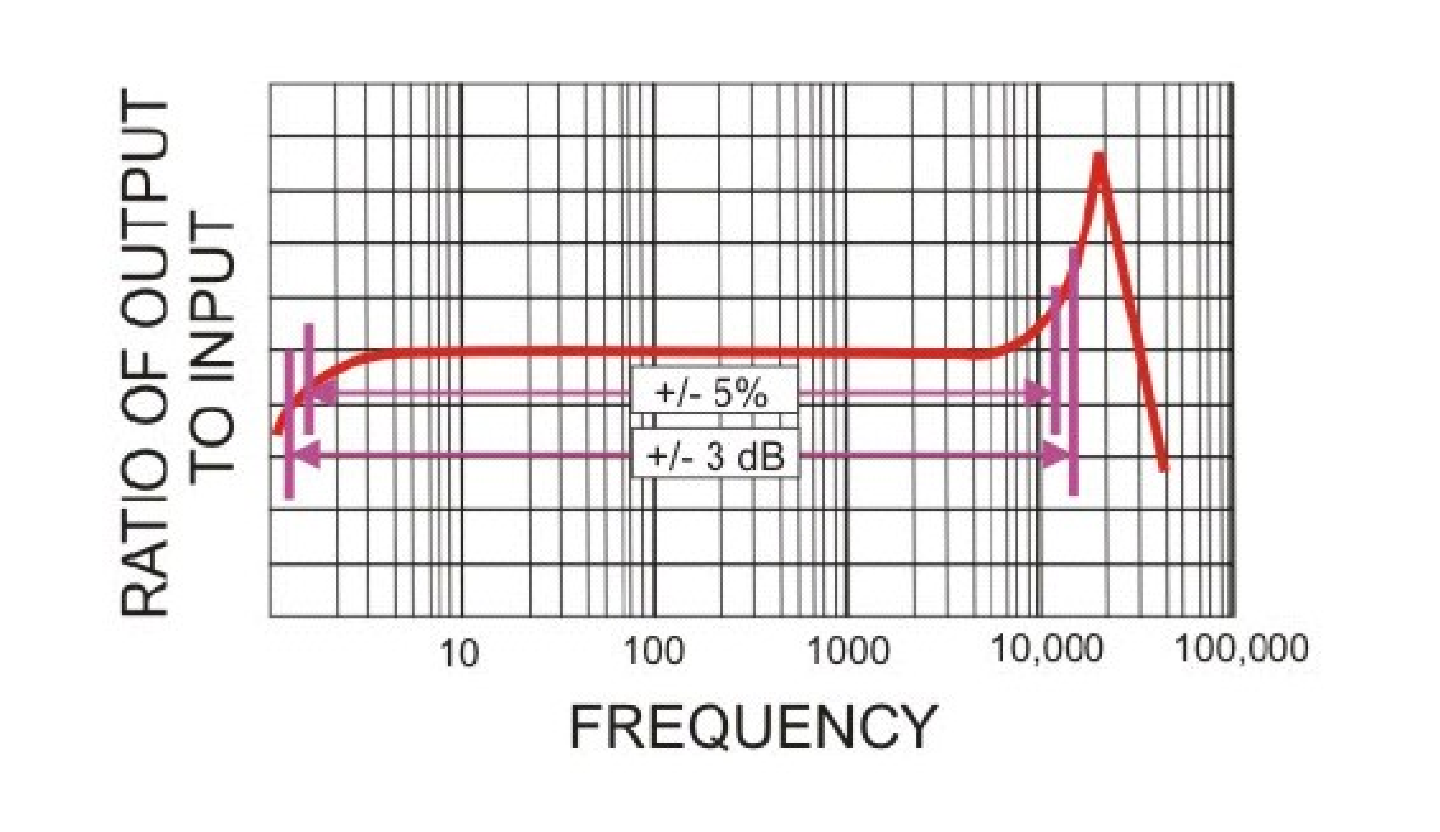
Accelerazione da misurare → $\dfrac{\dfrac{1}{\omega_n^2}}{1+\dfrac{2\zeta}{\omega_n}s+\dfrac{s^2}{\omega_n^2}}$ → Spostam. relativo → $\dfrac{K_q \cdot R \cdot s}{1+\tau \cdot s}$ → Tensione e_0

Accelerazione da misurare → $\dfrac{\dfrac{K_q \cdot R}{\omega_n^2} \cdot s}{\left(1+\dfrac{2\zeta}{\omega_n}s+\dfrac{s^2}{\omega_n^2}\right) \cdot (1+\tau \cdot s)}$ → Tensione e_0

Risposta in frequenza di accelerometri piezoelettrici



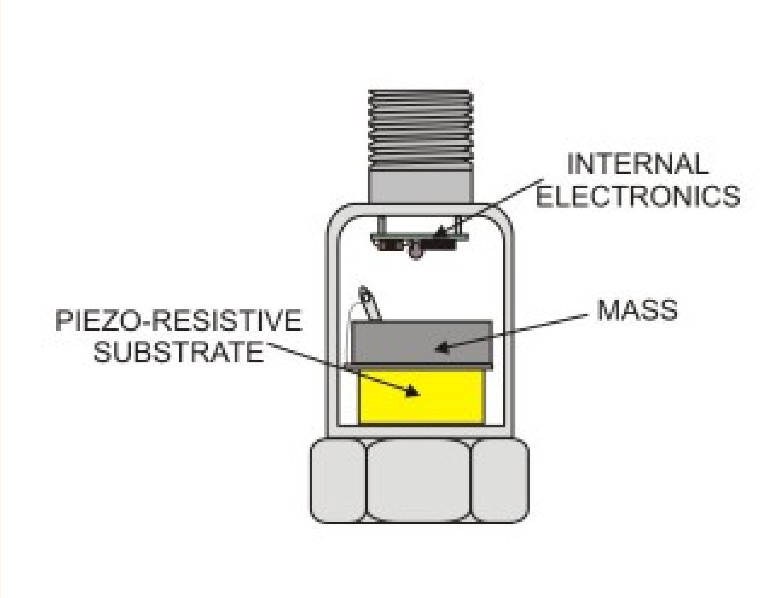
Risposta in frequenza per accelerometri piezoelettrici

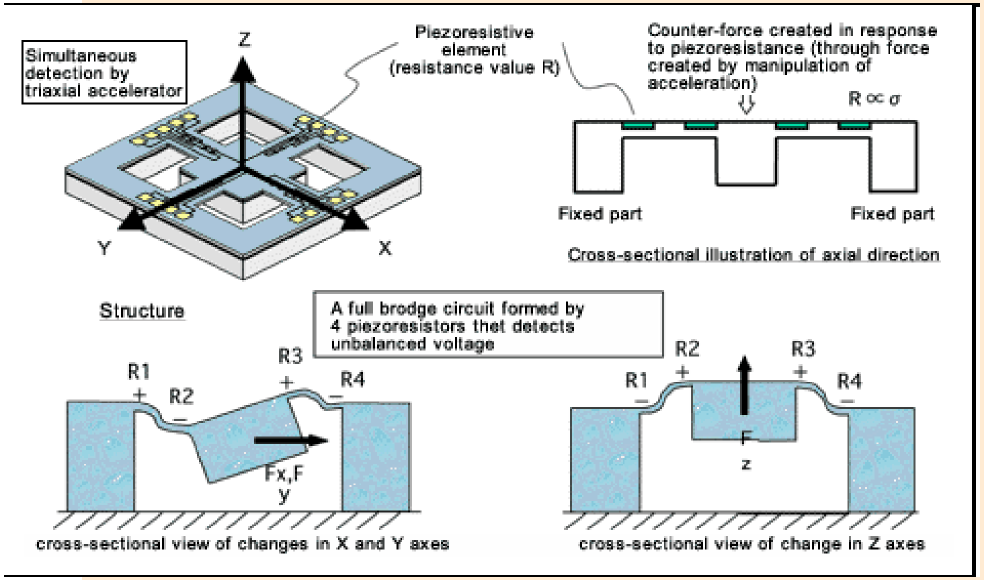


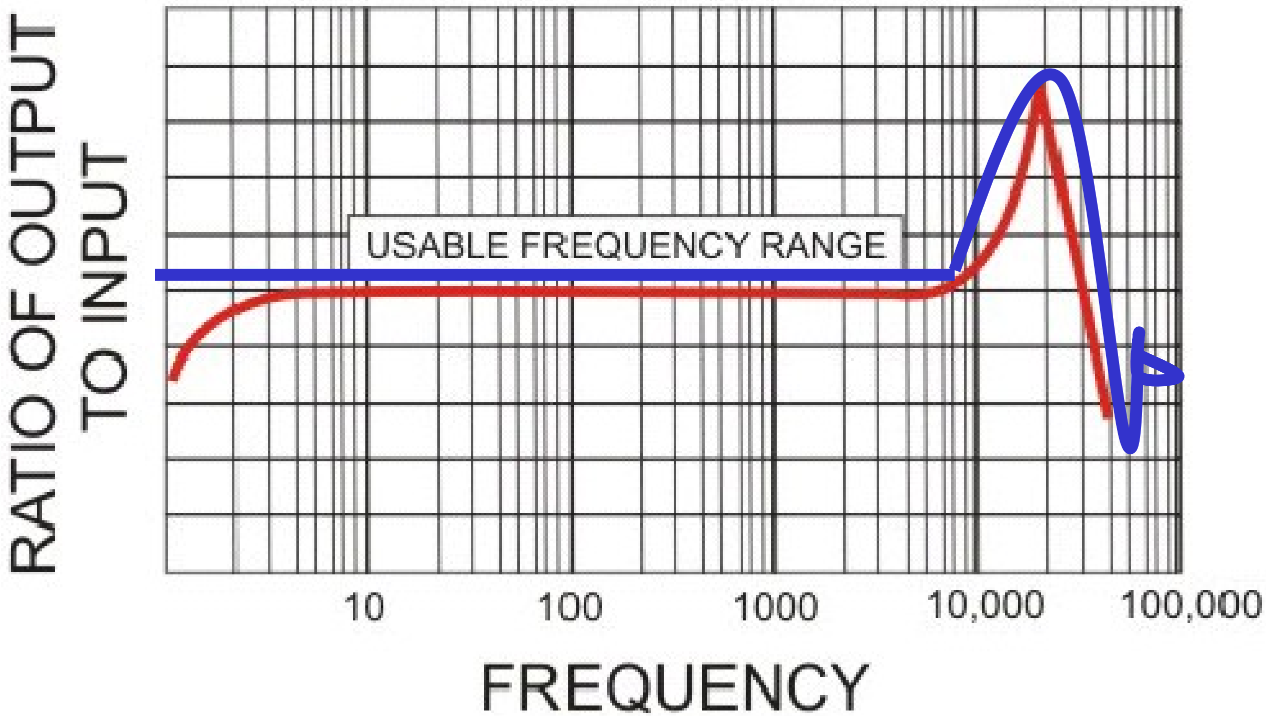
The usable frequency response is the flat area of the frequency response curve and extends <u>to approximately 1/3 to ½ of the natural frequency</u>. The definition of flat also needs to be qualified and is done so by quoting the roll off of the curve in either percentage terms (typically 5% or 10%) or in dB terms (typically +/- 3db)

Per ovviare al problema a basse frequenze (ovvero per leggere accelerazioni costanti) si possono utilizzare accelerometri piezoresistivi che utilizzano un substrato piezoresistivo invece di un substrato piezoelettrico.

In questo caso la variazione di resistenza viene di solita letta in un ponte di Whetastone.



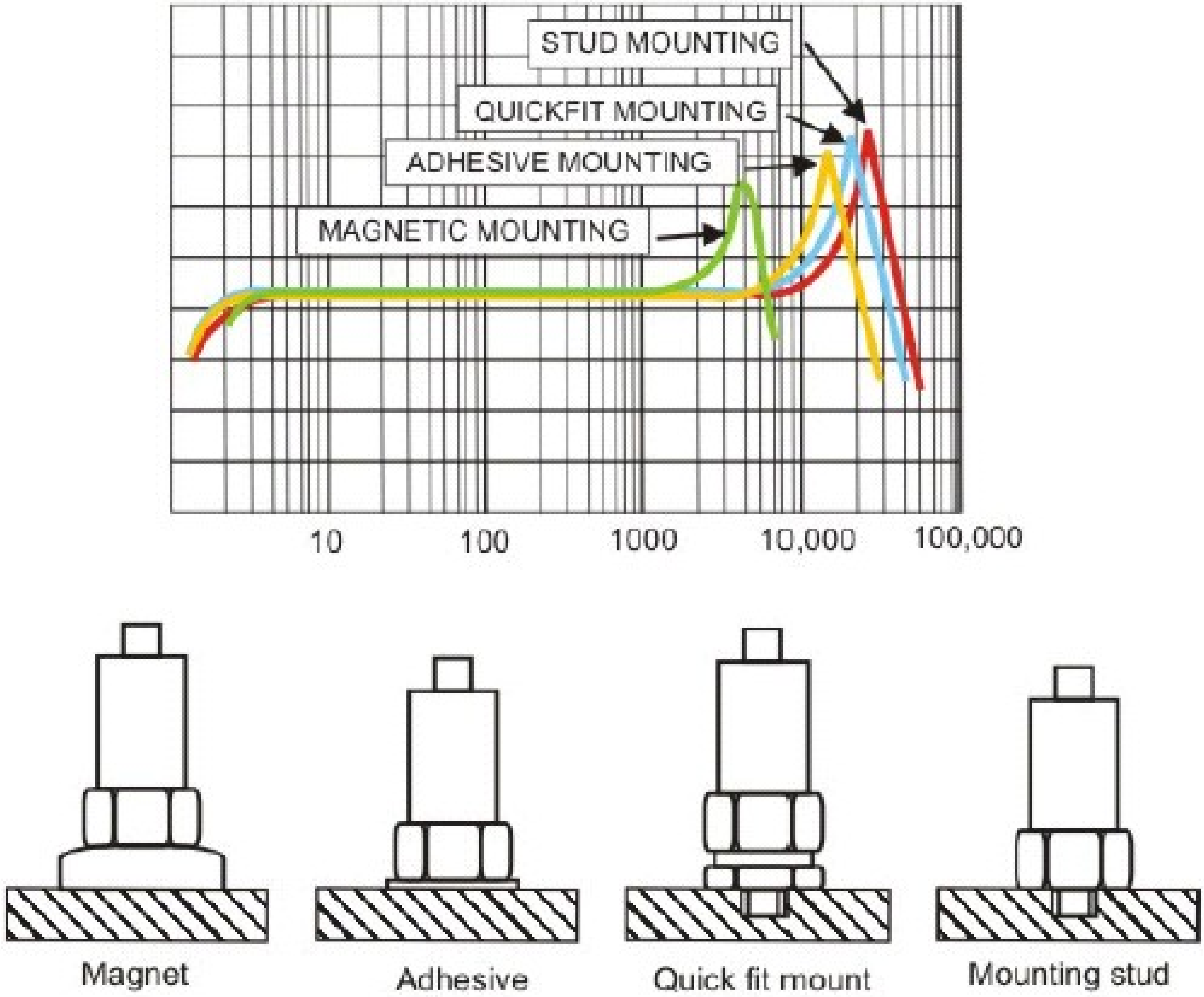




Typical Piezo-electric frequency response curve.

piezo-resistive

Accelerometer Type	Advantages	Disadvantages
Single ended compression	Robust Highest natural frequency High shock resistance	Poor base strain characteristics
Isolated base compression	Robust High natural frequency	Better base strain performance
Shear	Best base strain performance Best temperature transients immunity Smallest size	Less robust Lower shock resistance
Charge output	High temperature operation Suitable for radiation environments Small size	Requires local charge amplifier Susceptible to tribo-electric effect
Piezo-resistive	Measures down to zero Hz	Limited high frequency response
Strain Gage based	Measures down to zero Hz High shock resistance	Limited high frequency response



STUD MOUNTING
QUICKFIT MOUNTING
ADHESIVE MOUNTING
MAGNETIC MOUNTING
10
100
1000
10,000
100,000
Magnet
Adhesive
Quick fit mount
Mounting stud

Navigation

Highest inertial navigation-grade performance sensors

Control

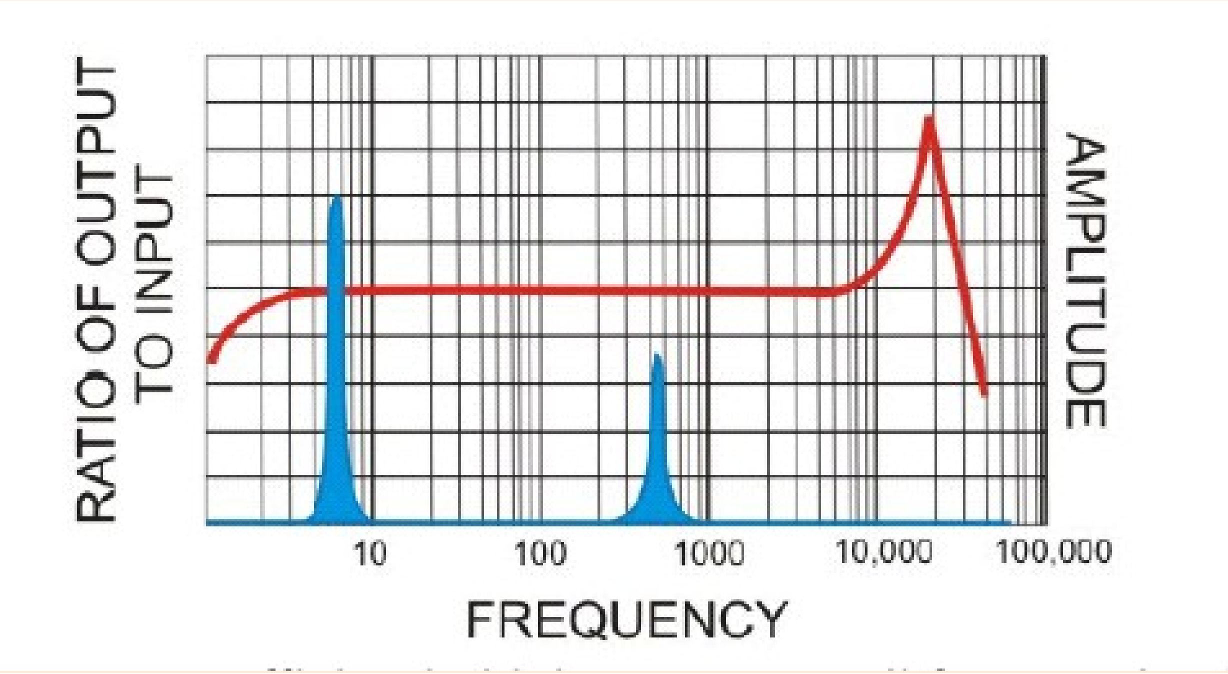
Cost-effective inertial-grade sensors

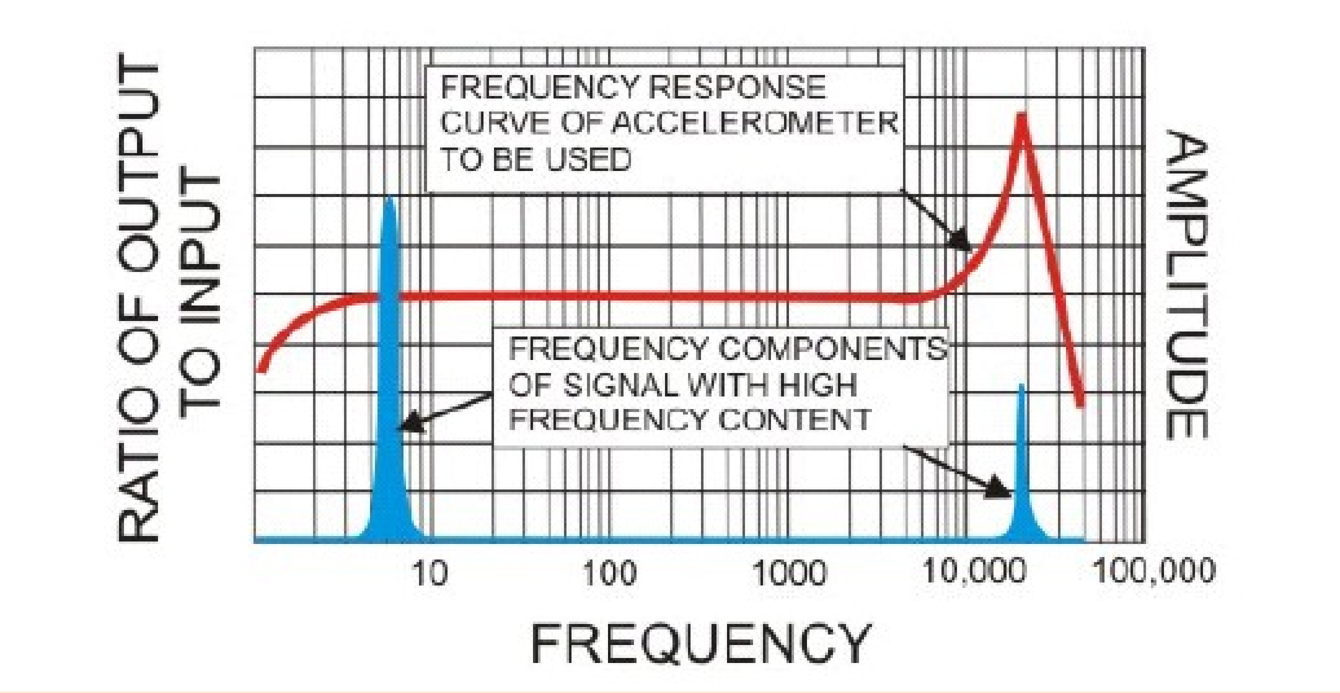
Measurement

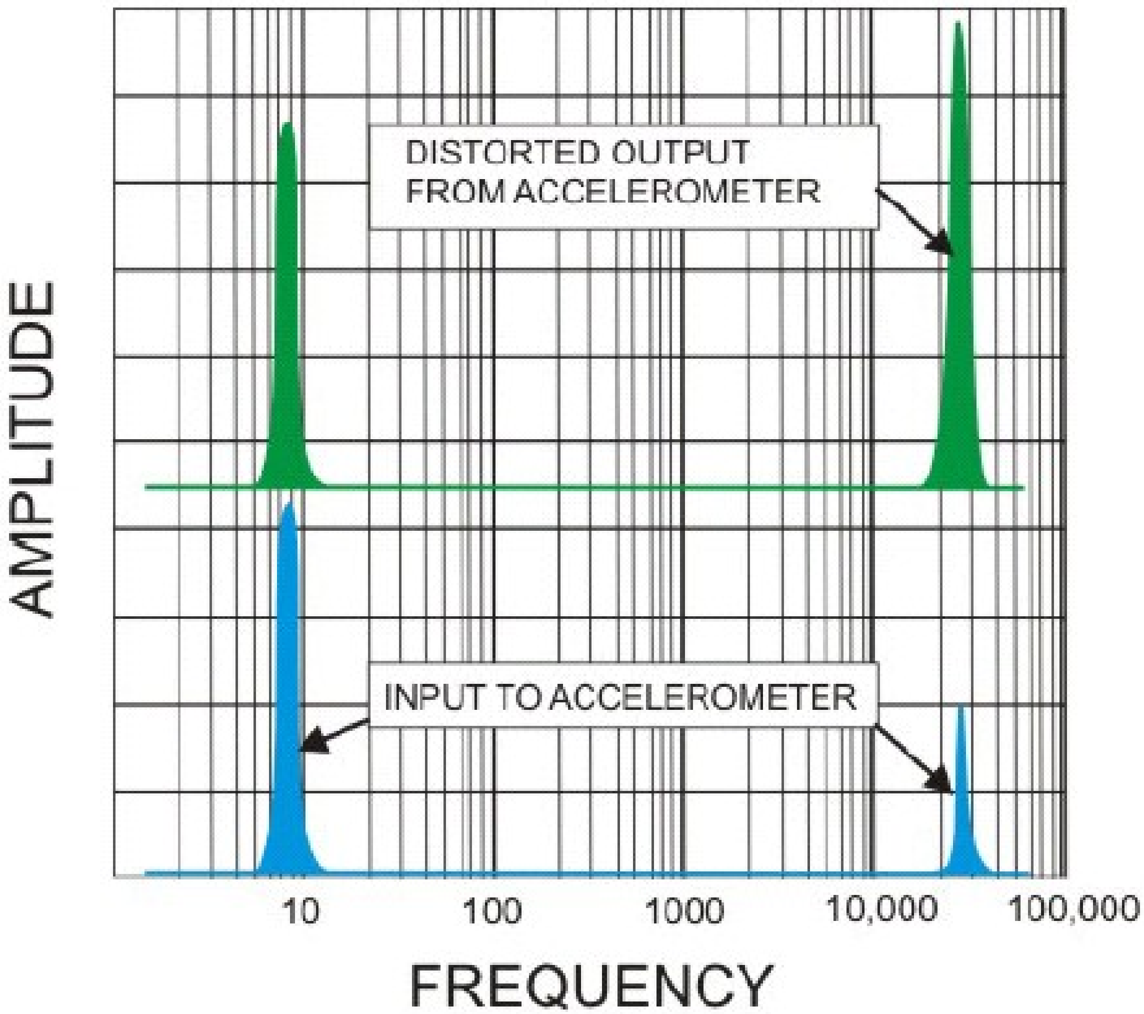
Economical sensor for moderate performance

Energy

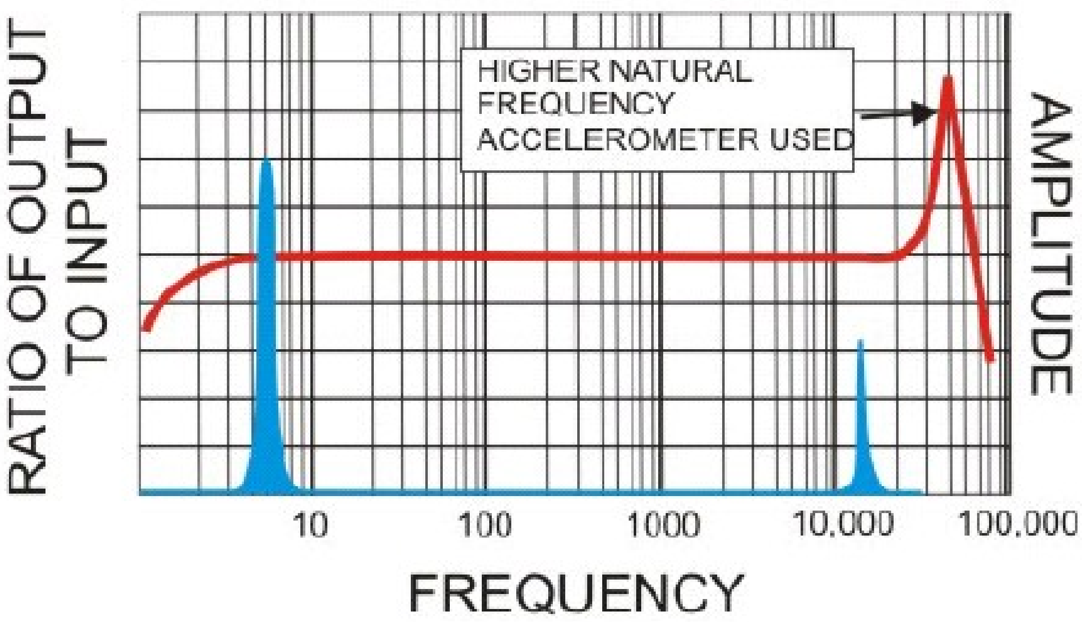
Performs in demanding down-hole applications (MWD)


RATIO OF OUTPUT
TO INPUT
AMPLITUDE
10
100
1000
10,000
100,000
FREQUENCY


RATIO OF OUTPUT
TO INPUT
AMPLITUDE
FREQUENCY RESPONSE
CURVE OF ACCELEROMETER
TO BE USED
FREQUENCY COMPONENTS
OF SIGNAL WITH HIGH
FREQUENCY CONTENT
10
100
1000
10,000
100,000
FREQUENCY

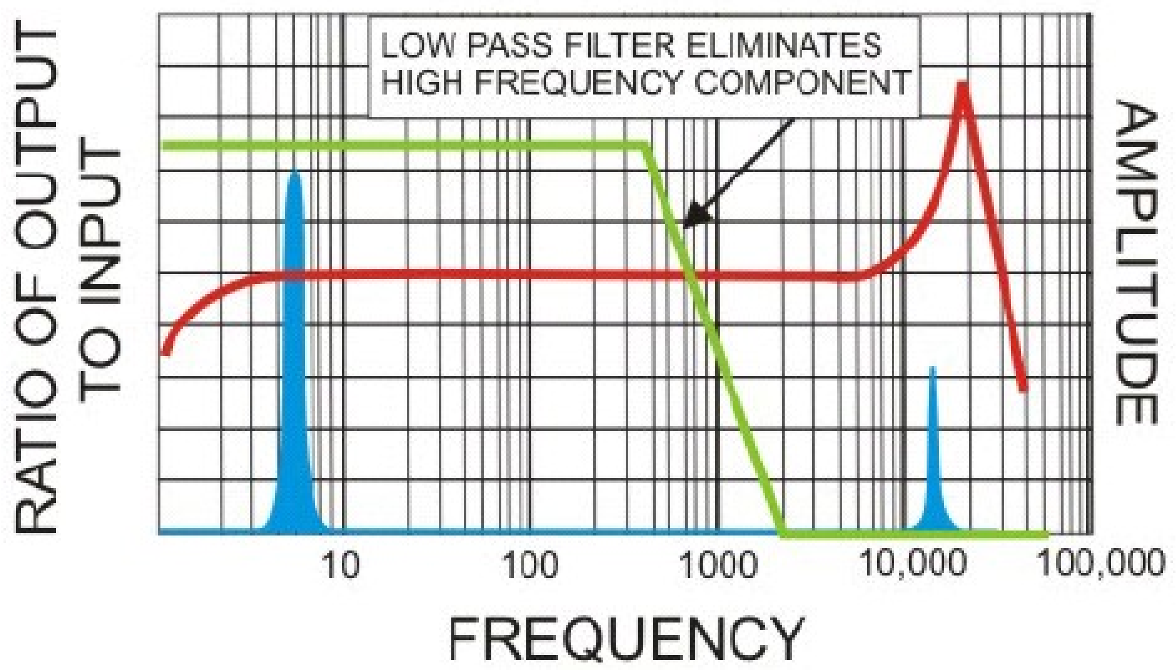


Acceleration signal is misrepresented by non-unity gain of the higher frequencies



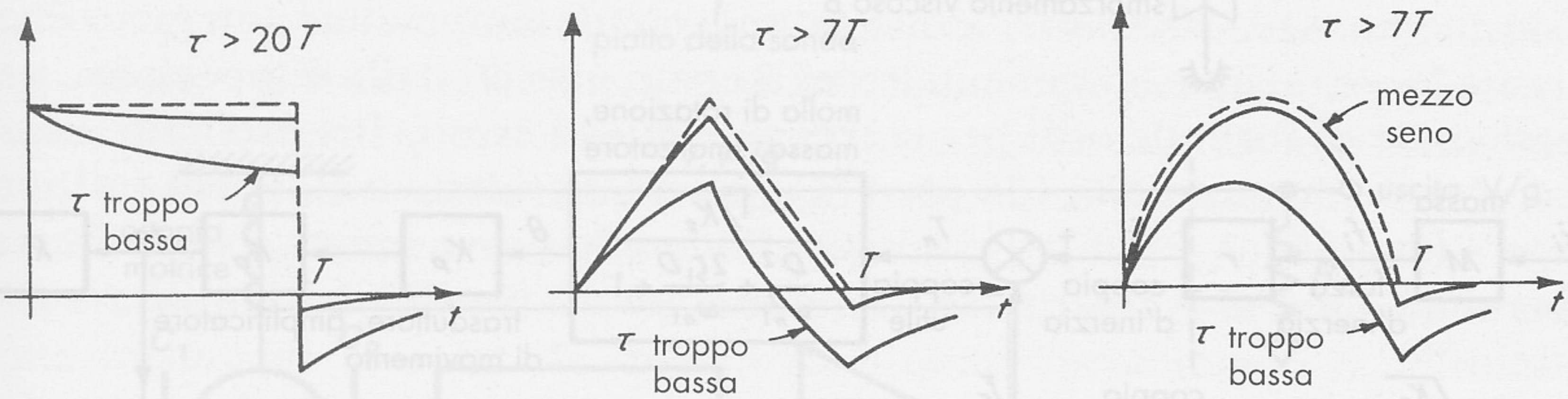
A higher natural frequency accelerometer solves the problem of measuring high frequency accelerations

If the higher frequencies are not required to be measured then using a low pass filter should filter them out.



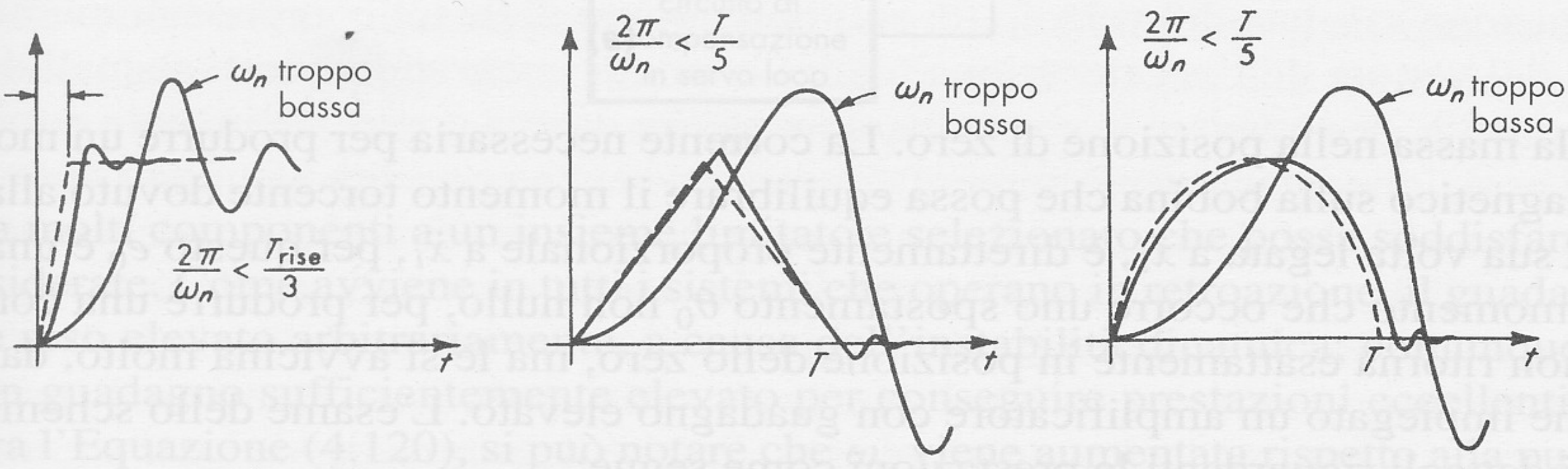
A low pass filter removes high frequency components of the measured signal

Specifiche sul comportamento dinamico di uno strumento



Specifiche per misure di picchi con accuratezza del ± 5%

Problemi di risposta a bassa frequenza (solo piezoelettrici)



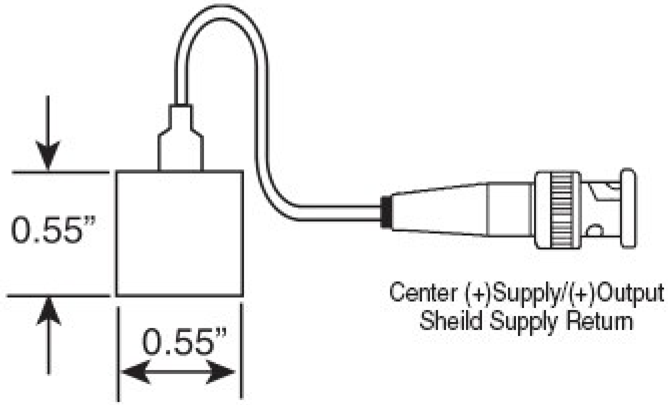
Specifiche per misure di picchi con accuratezza del ±10%

Problemi di risposta ad alta frequenza (tutti gli accelerometri)

Esempi accelerometri

Esempi accelerometri

Specifications



Order Code AG914

Sensitivity	1 V/g
Usable frequency range	5 kHz to 14 kHz ±10%
Mounted base resonance	25 kHz
Dynamic range	± 10 g
Temperature sensitivity	0.145 per degree F
Transverse sensitivity	5% max
Amplitude linearity	Better than1% linearity
Temperature range	-70° F to 250° F
Sealing	IP 65/Nema 2
Input	Constant current
Supply voltage	18-30 V
Current range	0.5 mA to 8 mA
Bias voltage	12 V
Cable	PTFE
Standard cable length	16 ft.
Isolation	Base isolated
Weight	0.3 oz.
Case material	HE 30 Aluminum
Mounting	beeswax or adhesive
Different sensitivity	100 mV/g
Cable length	Specify at time of ordering

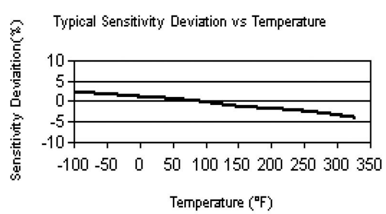
Esempi accelerometri

ACCELEROMETER, ICP®

Revision B
ECN #: 14822

Performance	ENGLISH	SI	
Sensitivity (±10 %)	5 mV/g	0.51 mV/(m/s²)	
Measurement Range	±1000 g pk	±9810 m/s² pk	
Frequency Range (±5 %)	2.0 to 10000 Hz	2.0 to 10000 Hz	
Frequency Range (±10 %)	1.5 to 18000 Hz	1.5 to 18000 Hz	
Frequency Range (±3 dB)	0.7 to 30000 Hz	0.7 to 30000 Hz	
Resonant Frequency	≥60 kHz	≥60 kHz	
Broadband Resolution (1 to 10000 Hz)	0.02 g rms	0.02 m/s² rms	[1]
Non-Linearity	≤1 %	≤1 %	[2]
Transverse Sensitivity	≤5 %	≤5 %	[3]
Environmental			
Overload Limit (Shock)	±10000 g pk	±98100 m/s² pk	
Temperature Range (Operating)	-100 to +325 °F	-73 to +163 °C	
Temperature Response	See Graph	See Graph	[1]
Base Strain Sensitivity	≤0.0005 g/με	≤0.005 (m/s²)/με	[1]
Electrical			
Excitation Voltage	18 to 30 VDC	18 to 30 VDC	
Constant Current Excitation	2 to 20 mA	2 to 20 mA	
Output Impedance	≤100 ohm	≤100 ohm	
Output Bias Voltage	8 to 12 VDC	8 to 12 VDC	
Discharge Time Constant	0.25 to 1 sec	0.25 to 1 sec	
Spectral Noise (10 Hz)	1600 μg/√Hz	15696 (μm/s²)/√Hz	[1]
Spectral Noise (100 Hz)	840 μg/√Hz	8240 (μm/s²)/√Hz	[1]
Spectral Noise (1 kHz)	60 μg/√Hz	589 (μm/s²)/√Hz	[1]
Physical			
Sensing Element	Quartz	Quartz	
Sensing Geometry	Shear	Shear	
Housing Material	Titanium	Titanium	
Sealing	Welded Hermetic	Welded Hermetic	
Weight	0.07 oz	→ 2.0 gm	[1]
Electrical Connector	5-44 Coaxial	5-44 Coaxial	
Electrical Connection Position	Side	Side	
Mounting Thread	5-40 Male	5-40 Male	
Mounting Torque	8 to 12 in-lb	90 to 135 N-cm	

CE [4]



All specifications are at room temperature unless otherwise specified.
In the interest of constant product improvement, we reserve the right to change specifications without notice.
ICP® is a registered trademark of PCB group, Inc.

Optional Versions (Optional versions have identical specifications and accessories as listed for standard model except where noted below. More than one option maybe used.)

A - Adhesive Mount [5]
Supplied Accessory: Model 080A90 Quick bond Gel (for use with accelerometer adhesive mtg bases to fill gaps on rough surfaces)

J - Ground Isolated

Frequency Range (5 %)	8 kHz	8 kHz
Frequency Range (10 %)	12 kHz	12 kHz
Frequency Range (3 dB)	25 kHz	25 kHz
Resonant Frequency	≥50 kHz	≥50 kHz
Electrical Isolation (Base)	$>10^8$ ohm	$>10^8$ ohm
Size (Hex x Height)	0.38 in x 0.38 in	9.7 mm x 9.7 mm
Weight	0.11 oz	3.1 gm

M - Metric Mount
Supplied Accessory: Model M080A15 Metric adhesive base, 0.31" hex x 0.125" thk, M3 x 0.50 thd, aluminum with insulating hardcoat finish

W - Water Resistant Cable

Electrical Connector	Sealed Integral Cable	Sealed Integral Cable
Electrical Connection Position	Side	Side

Notes
[1] Typical.
[2] Zero-based, least-squares, straight line method.
[3] Transverse sensitivity is typically <= 3%.
[4] See PCB Declaration of Conformance PS023 for details.
[5] Mounting stud removed, adhesive mounting base not required.

Supplied Accessories
080A109 Petro Wax (1)
080A15 Adhesive Mounting Base (1)
ACS-1 NIST traceable frequency response (10 Hz to upper 5% point). (1)

Entered: RJL	Engineer: DJS	Sales: SGL	Approved: EJV	Spec Number:
Date: 05/29/2002	Date: 05/29/2002	Date: 05/29/2002	Date: 05/29/2002	**12001**

PCB PIEZOTRONICS VIBRATION DIVISION

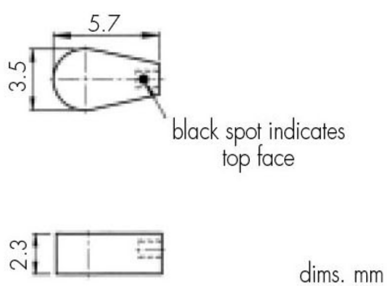
Address: 3425 Walden Avenue
Depew, NY 14043
United States
Phone: 888-684-0013
Fax: 716-685-3886
E-mail: vibration@pcb.com
Web site: www.pcb.com

Micro-miniature piezo-electric accelerometer

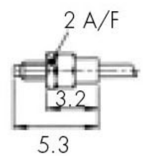
A/28/E

0.4pC/g nom. • 0.25gm wt. • 200°C max. temp.

A/28/E

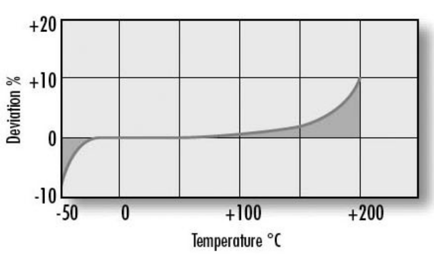


L8 CONNECTOR



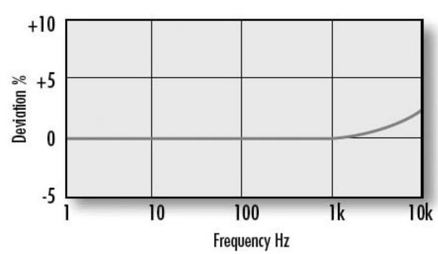
CONVERSION MODE	KONIC
Charge sensitivity pC/g	0.3/0.6
Capacitance pF	250/420
Resonant frequency kHz	> 45
Cross axis error % max	5
Temperature range °C	-50/+200
Charge sensitivity deviation re 20°C	-5 % @ -50°C +10 % @ +200°C
Max continuous accn. g sine	5000
Max shock g pk., rise time μ sec.	10000, 20
Case material	s/steel 303 S31
Mounting	adhesive
Weight gm	0.25
Connector	L8
Case seal	welded

TEMPERATURE RESPONSE



FREQUENCY RESPONSE

Results obtained using loctite 496 adhesive



Esempi accelerometri MEMS

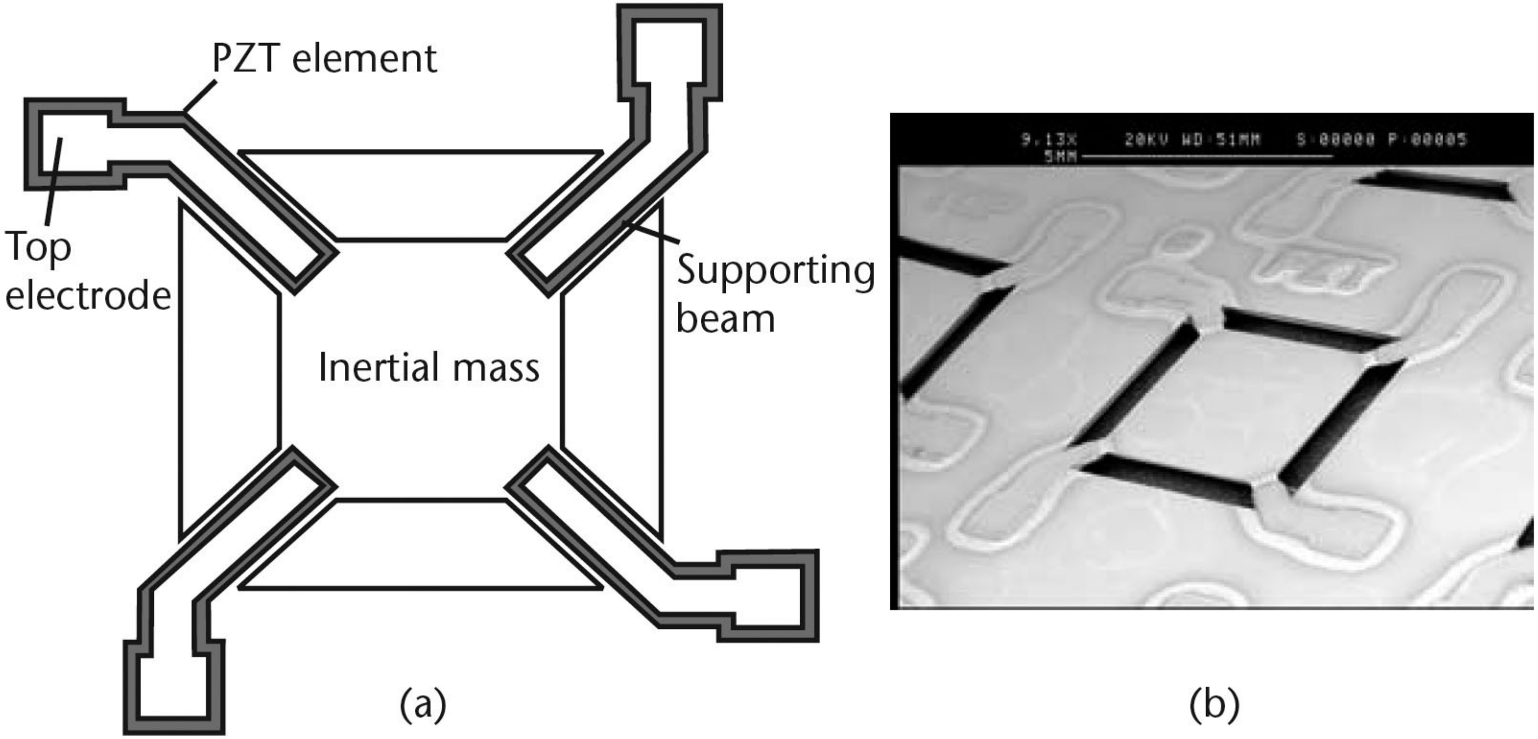


Figure 8.12 (a) Design of a piezoelectric accelerometer using thick-film printed PZT. (b) SEM photograph of the sensing element.

Esempi accelerometri MEMS

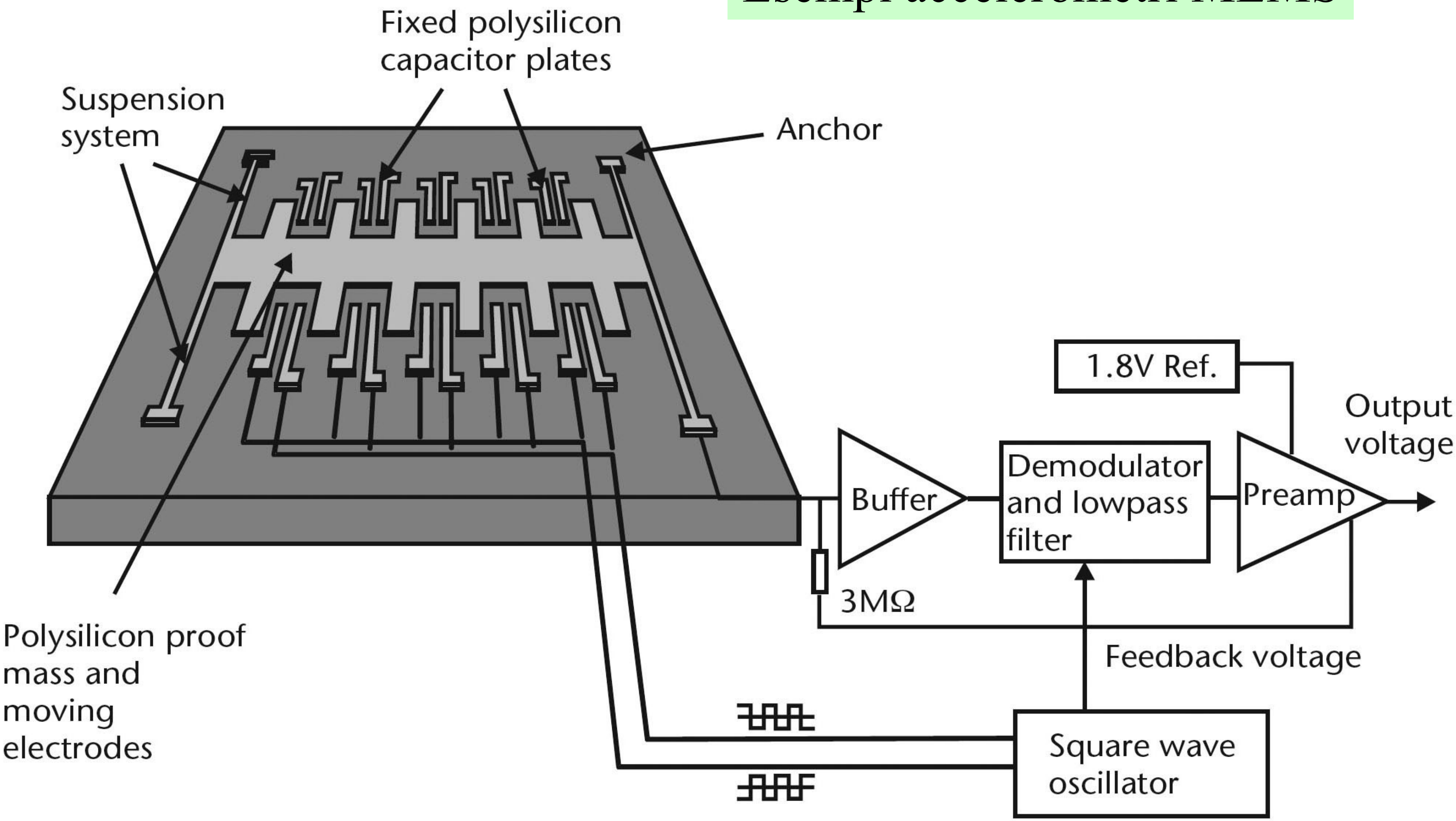


Figure 8.17 Block diagram of the ADXL50 accelerometer.

Esempi accelerometri MEMS

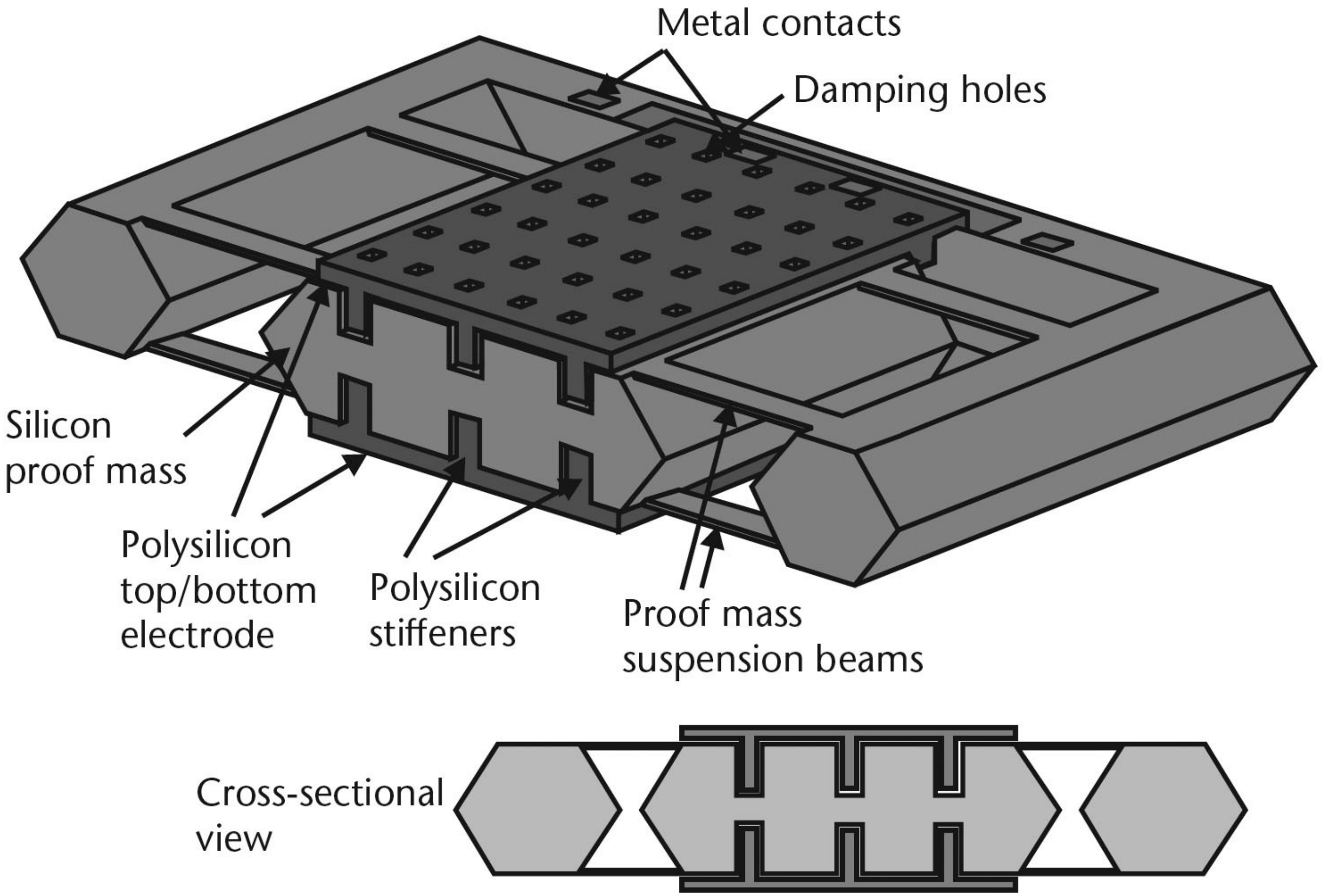
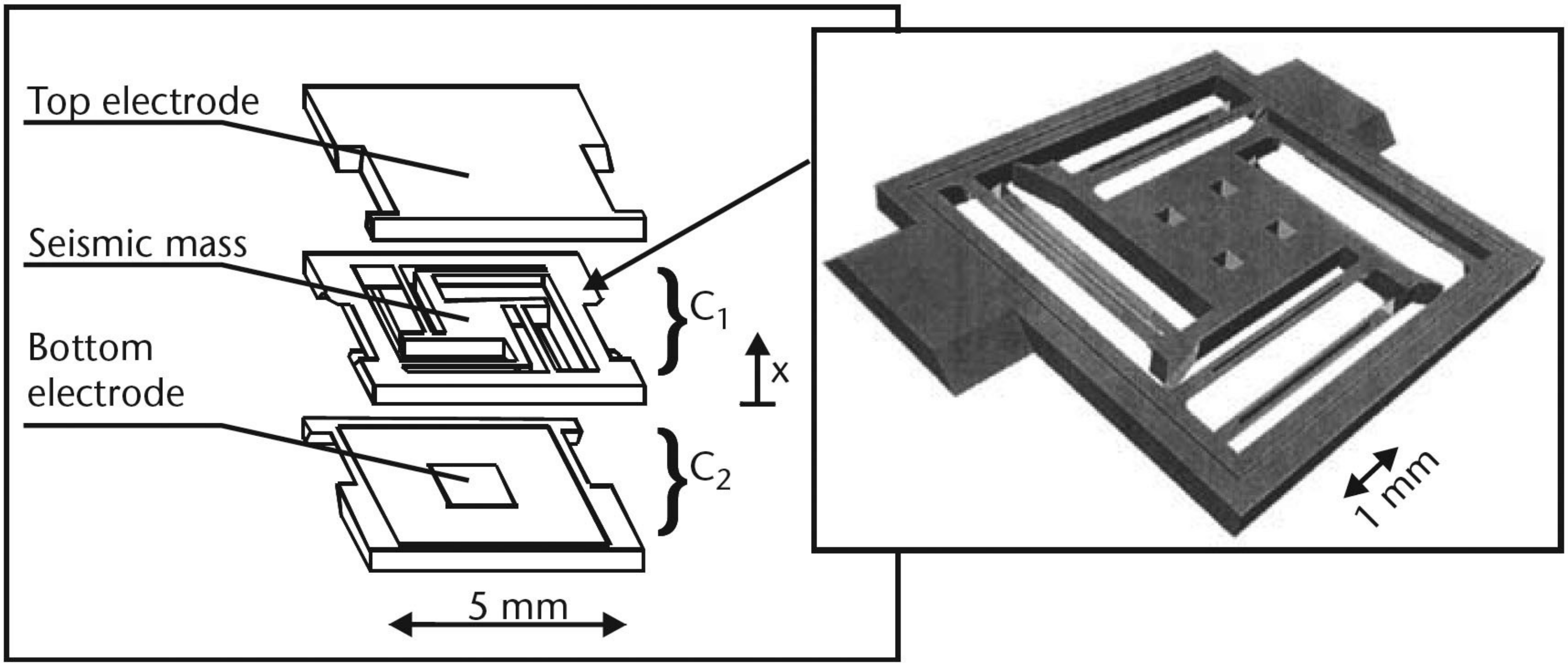


Figure 8.11 High-performance capacitive accelerometer using a combination of surface and bulk-micromachining techniques. The polysilicon electrodes include stiffening ribs. (*After:* [33].)

Esempi accelerometri MEMS



A bulk-micromachined accelerometer with capacitive signal pick-off.

Classificazione accelerometri:

1. Tecnologia classica: risposta costante per $\omega=0$
    - Con potenziometro
    - Con LVDT
    - Con estensimetri incollati
    - Con estensimetri non incollati
    - Con trasduttore capacitivo

1. Tecnologia classica: risposta nulla per $\omega=0$
    - Con trasduttori piezoelettrici

1. Tecnologia MEMS: risposta costante per $\omega=0$
    - Con trasduttore capacitivo
    - Con traduttore piezoresistivo

Servo-accelerometri

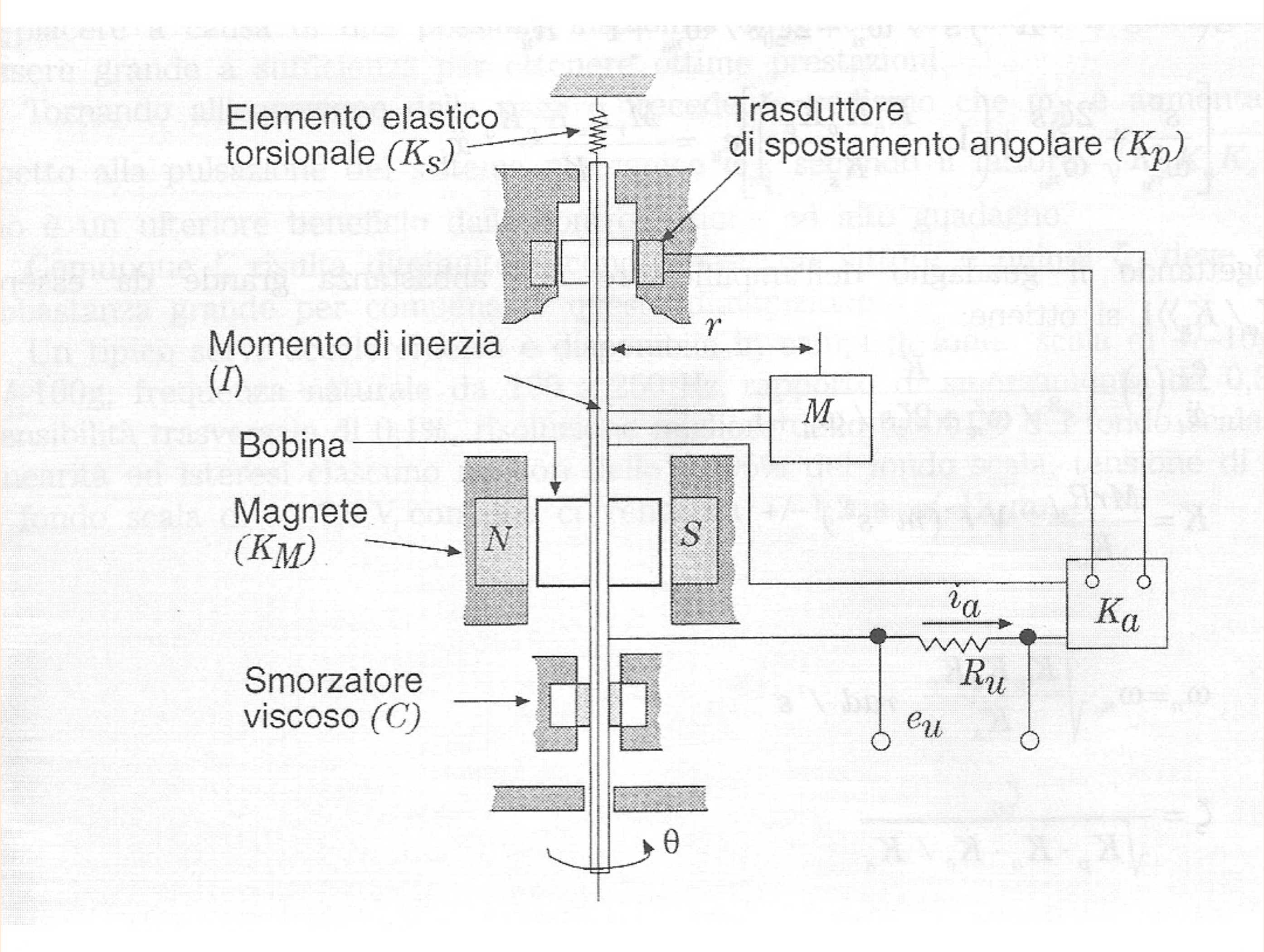


Fig. 1.62. *Esempio di servo-accelerometro*

Servo-accelerometri

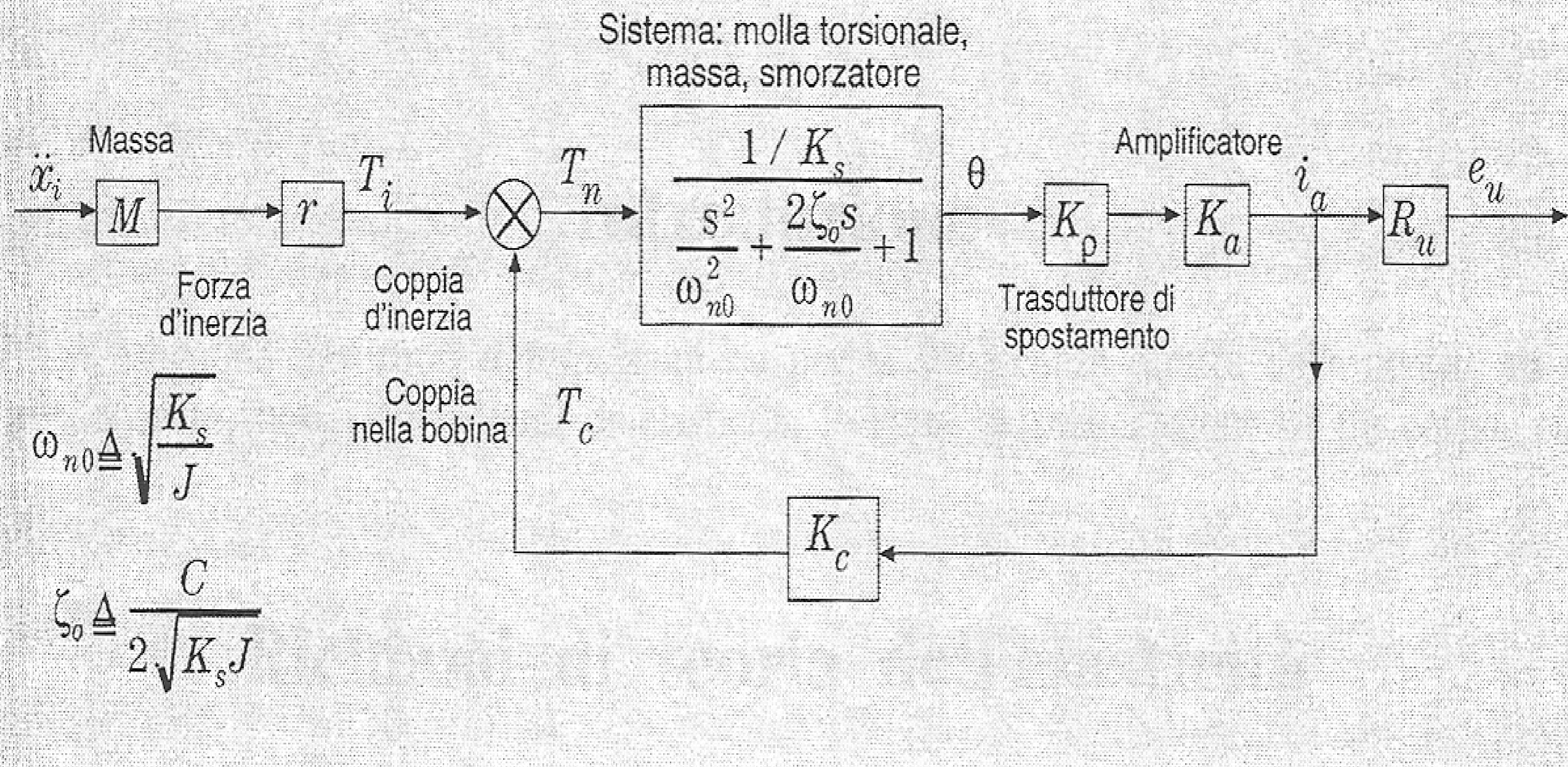


FIG. 1.63. *Diagramma a blocchi dello schema funzionale di un servo-accelerometro*

Servo-accelerometri

$$\left(Mr\ddot{x}_i - \frac{e_u K_c}{R_u}\right)\frac{K_p K_a / K_s}{s^2/\omega_{n_0}^2 + 2\zeta_0 s/\omega_{n_0} + 1} = \frac{e_u}{R_u}$$

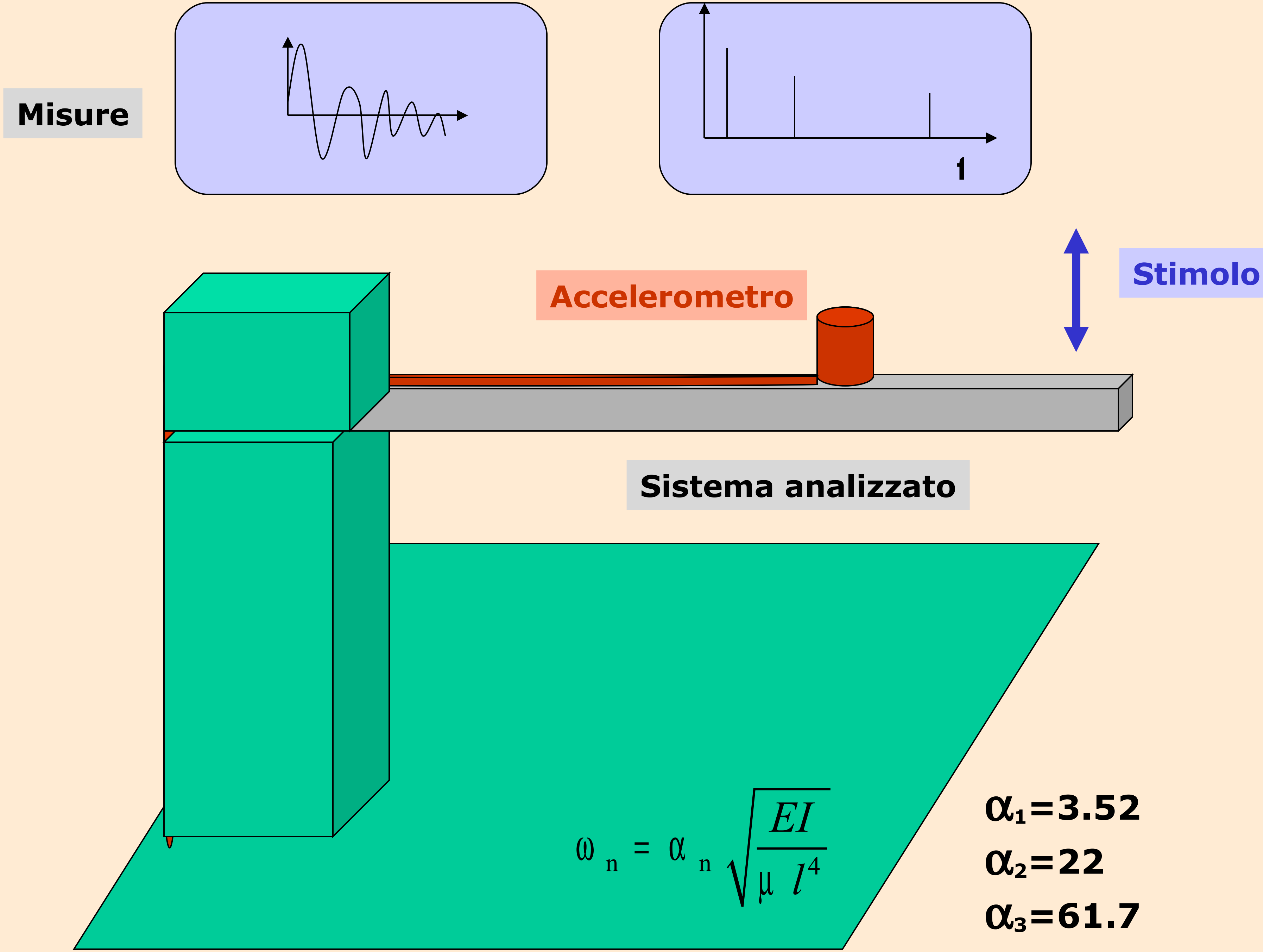
$$\left[\frac{s^2}{\omega_{n_0}^2} + \frac{2\zeta_0 s}{\omega_{n_0}} + \left(1 + \frac{K_c K_p K_a}{K_s}\right)\right] e_u = \frac{Mr R_u K_p K_a}{K_s}\ddot{x}_i$$

$$\frac{e_u}{\ddot{x}_i}(s) = \frac{K}{s^2/\omega_n^2 + 2\zeta s/\omega_n + 1}$$

$$K = \frac{MrR_u}{K_c} \quad V/(m \ \ s^2)$$

$$\omega_n = \omega_{n_0}\sqrt{\frac{K_p K_a K_c}{K_s}} \quad rad/s$$

$$\zeta = \frac{\zeta_0}{\sqrt{K_p \cdot K_a \cdot K_c / K_s}}$$



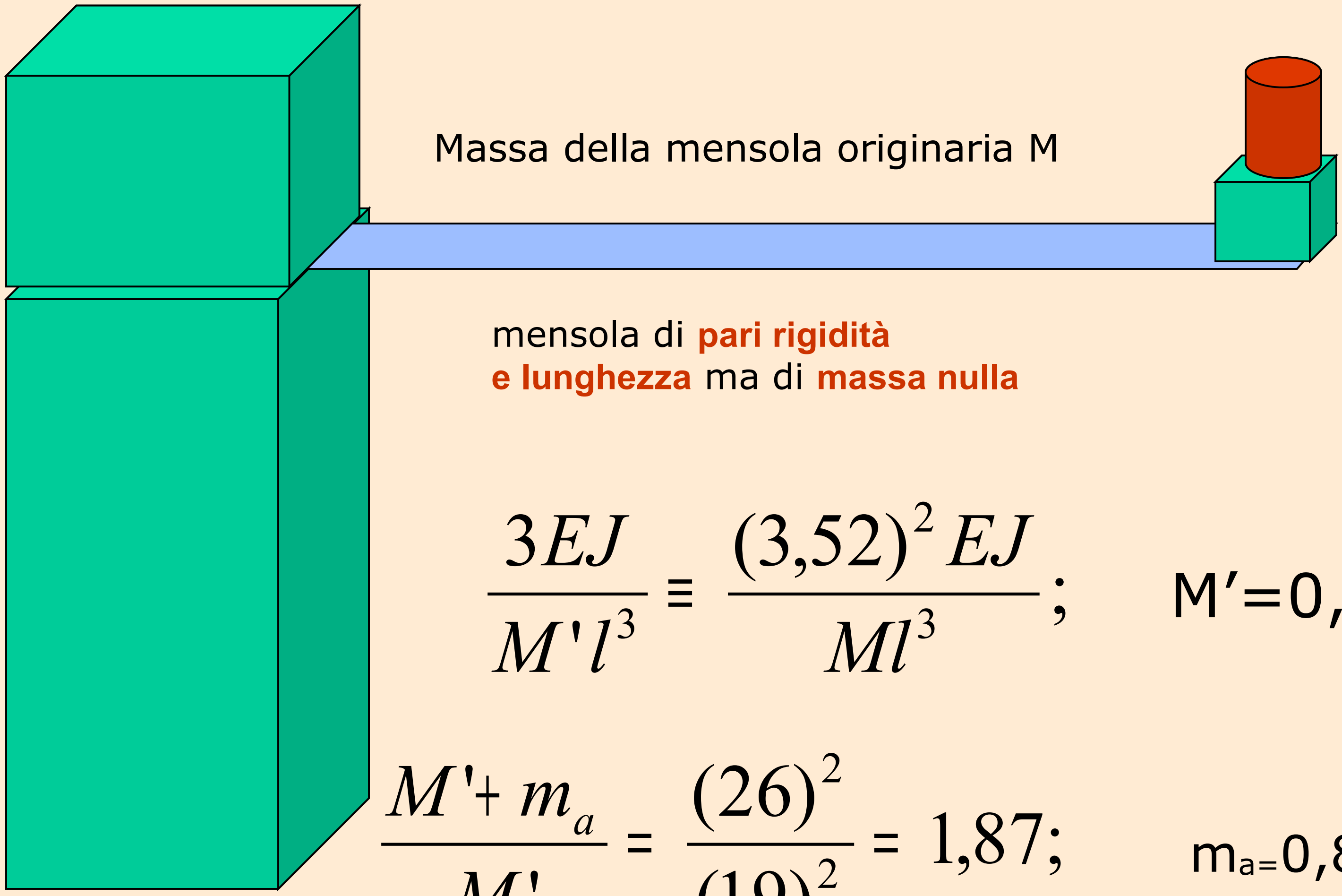
$$\omega_n = \alpha_n \sqrt{\frac{EI}{\mu\, l^4}}$$

$\alpha_1 = 3.52$

$\alpha_2 = 22$

$\alpha_3 = 61.7$

Calcolo approssimato della discretizzazione



$$\frac{3EJ}{M' l^3} \equiv \frac{(3{,}52)^2 EJ}{M l^3};$$

M’=0,242M

$$\frac{M' + m_a}{M'} = \frac{(26)^2}{(19)^2} = 1{,}87;$$

m_a=0,87M’ =0,21M