Guidance for Measuring Mechanical Shock and Vibration

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Mechanical shock is all around us,

Gun Fire

Consumer Electronics
Testing

Crash Test

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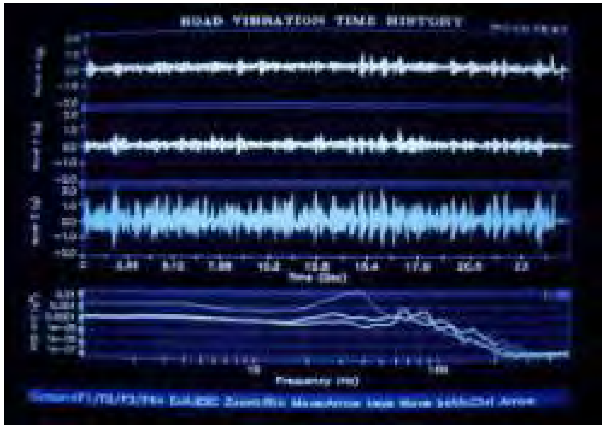
and Mechanical vibration too!

Single-axis shaker

Multi-axis shaker

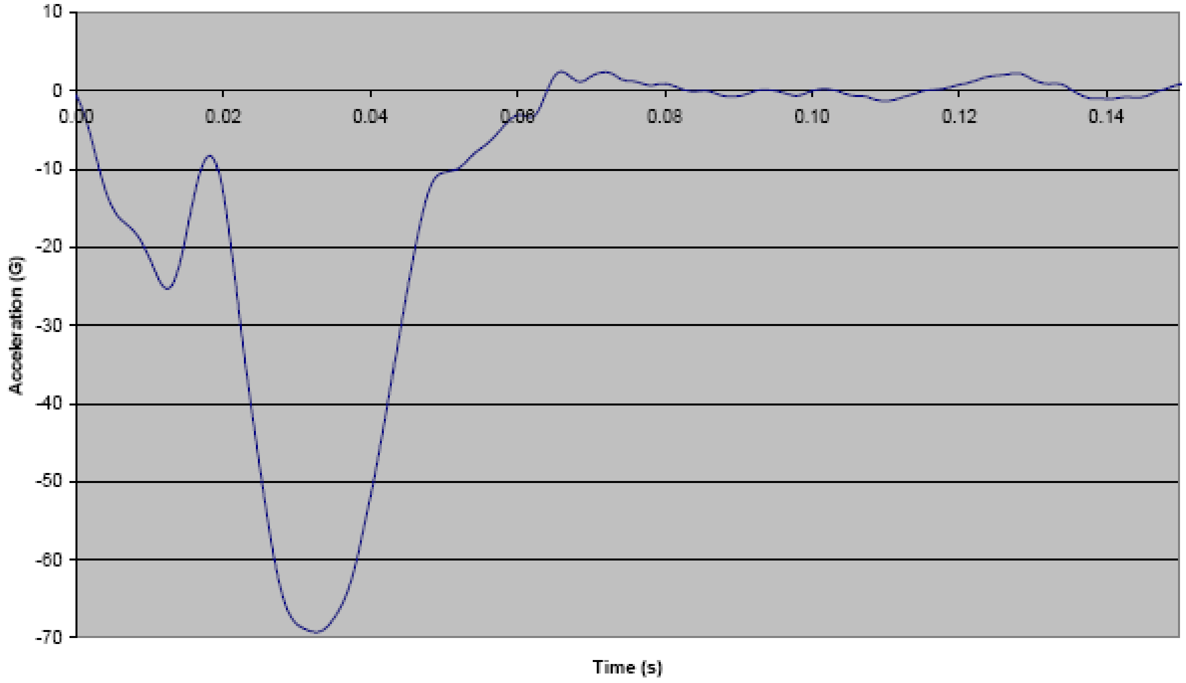
Transmission line vibration



Road induced vibrations

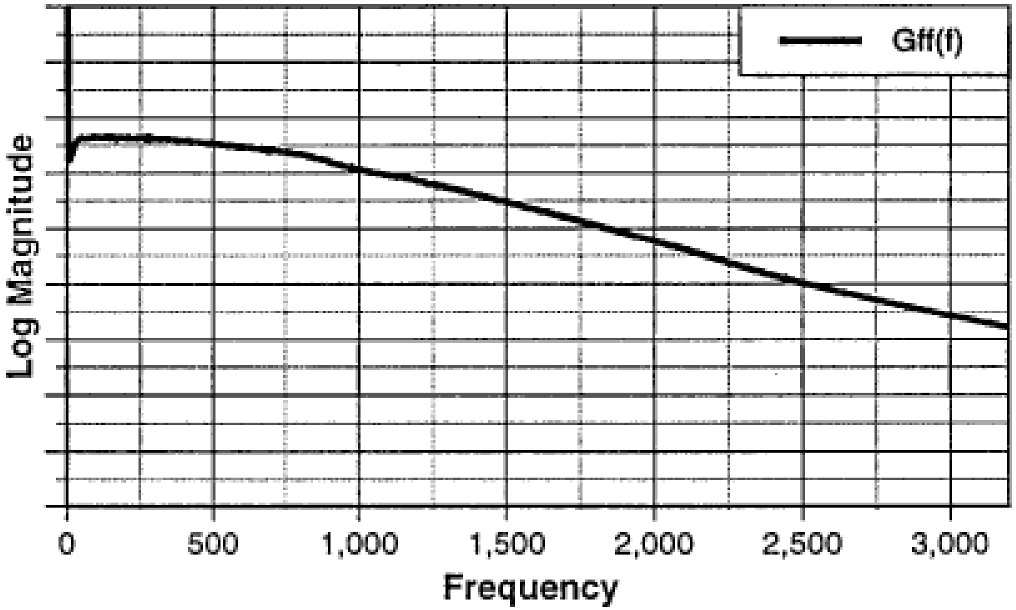
Within the time constraints we have today, we will create a focus on establishing rules for measuring mechanical shock, which is the larger challenge of the two, and point out those specific rules provided that also govern vibration measurements.

Mechanical shock can be represented in the time domain.



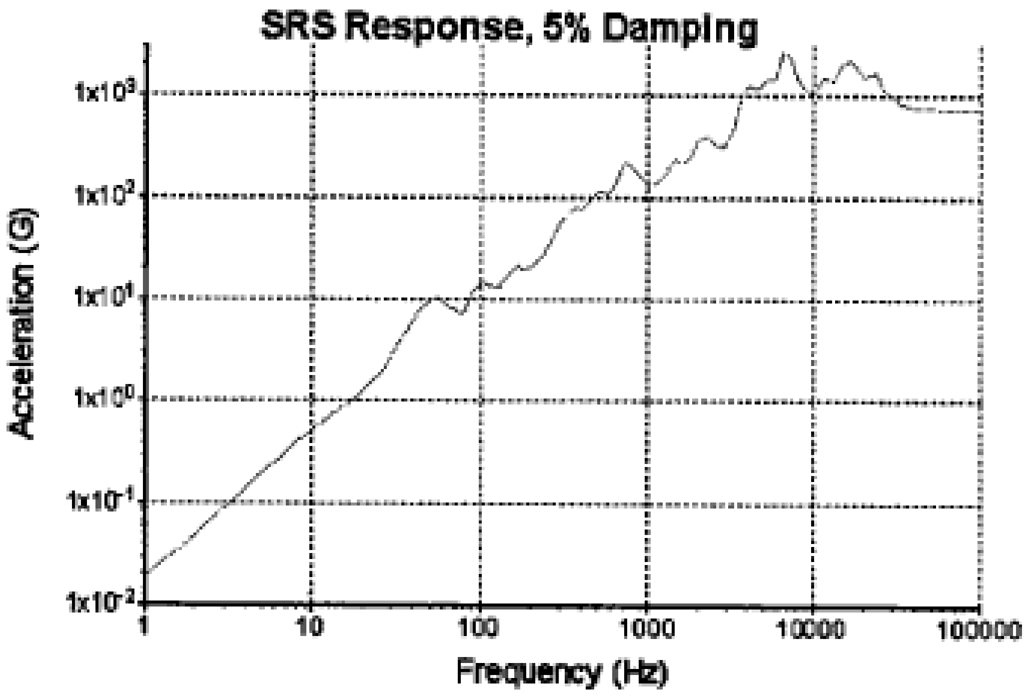
This pulse is the input to test sleds to enable the qualification of head and neck constraint systems for National Association for Stock Car Auto Racing (NASCAR) crashes. Its duration of approximately 63 msec. produces 68 g's at 43.5 mph.

Mechanical shock can be represented in the frequency domain.



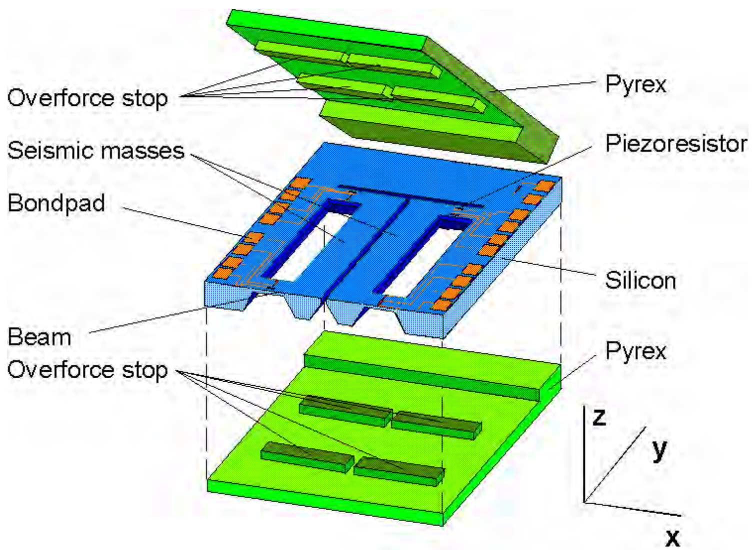
This spectra represents the input-excitation frequencies to a mechanical system whose transfer function is of interest.

Mechanical shock can be represented by its shock spectra.

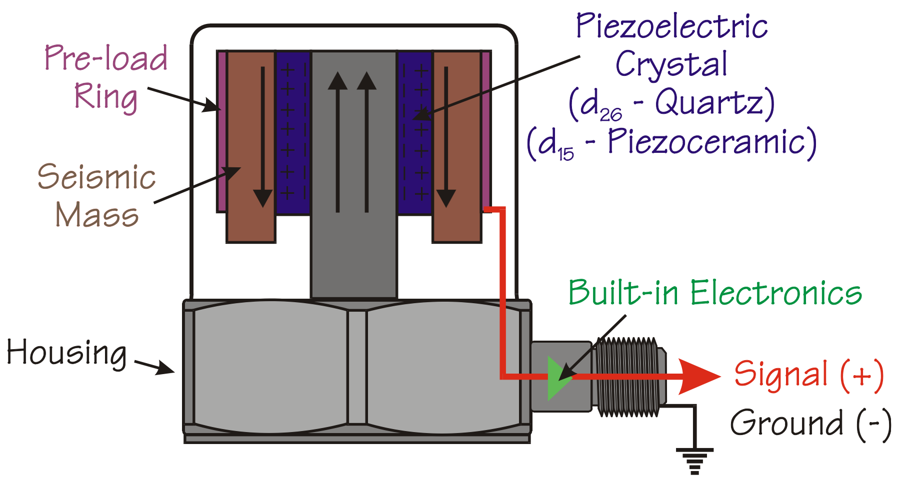


Shock Response Spectrum of Acceleration Pulses Due to Gun Fire: The shock spectrum is a method to describe a shock in terms of its damage potential.

Mechanical shock and vibration is measured by accelerometers.

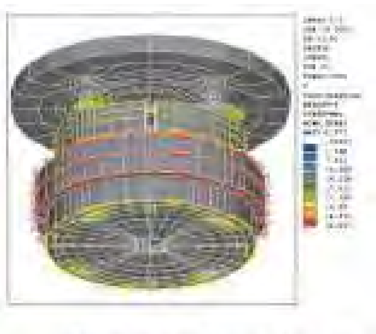


Mechanical Flexure for a MEMS Accelerometer

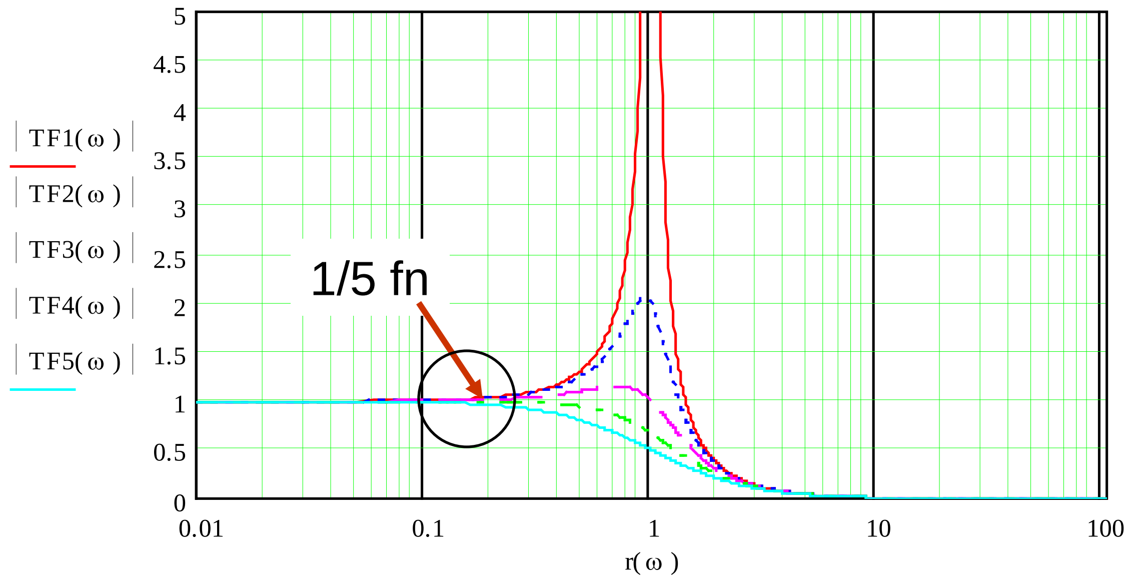


Cut Away of a Shear-Mode Piezoelectric Accelerometer

Although mechanically more complex, we typically model accelerometer as linear 2nd order oscillators.

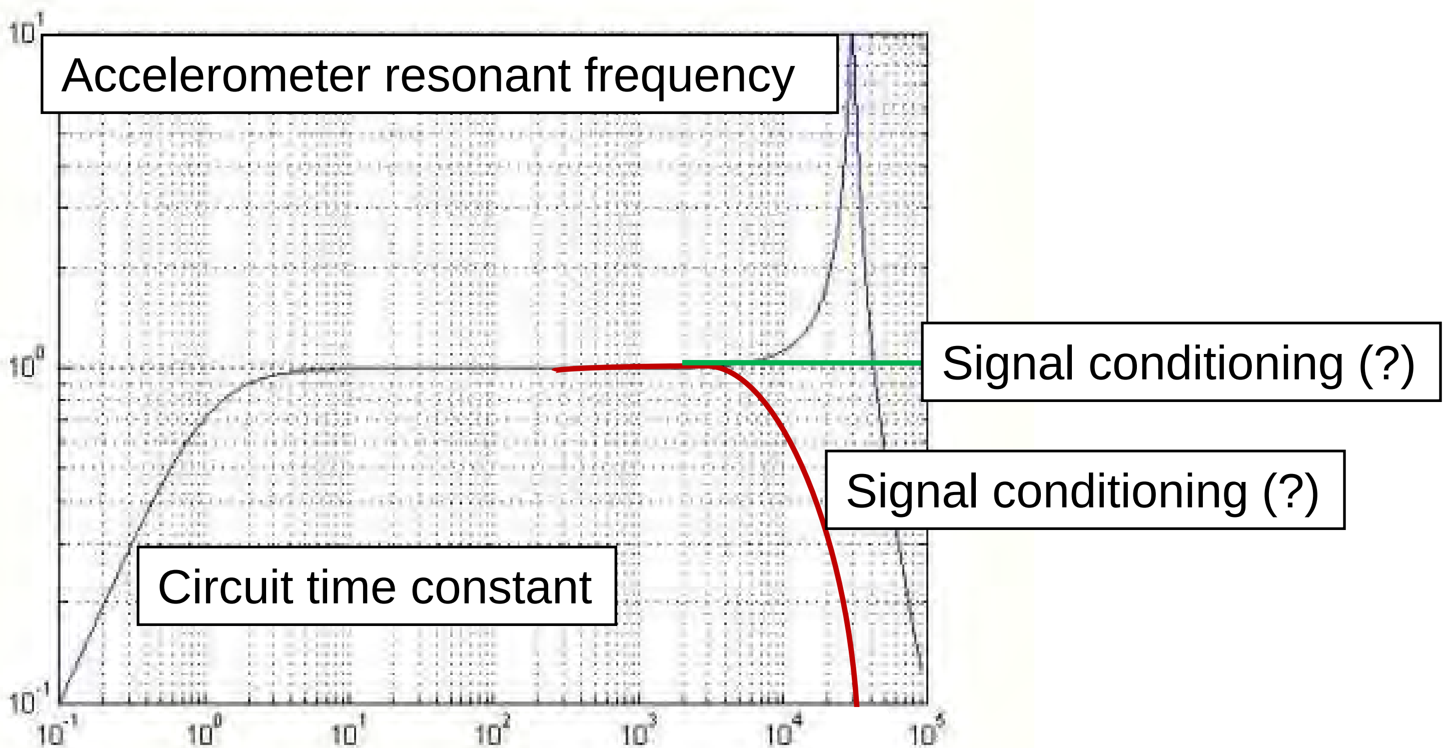


Structurally Complex

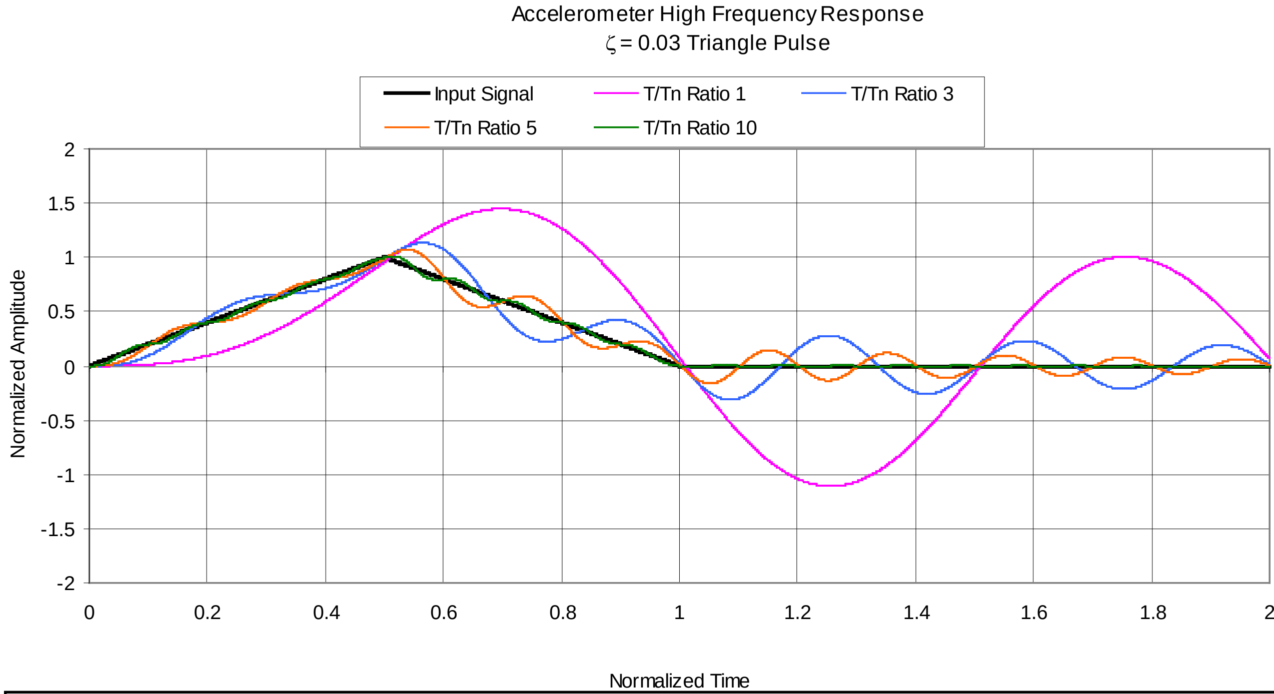


Amplitude-frequency

In any data system, the high frequency limitation can be imposed by either the accelerometer or the signal conditioning electronics. For piezoelectric accelerometers (almost exclusively used for vibration measurements), the low frequency limitation is imposed by the circuit time constant.

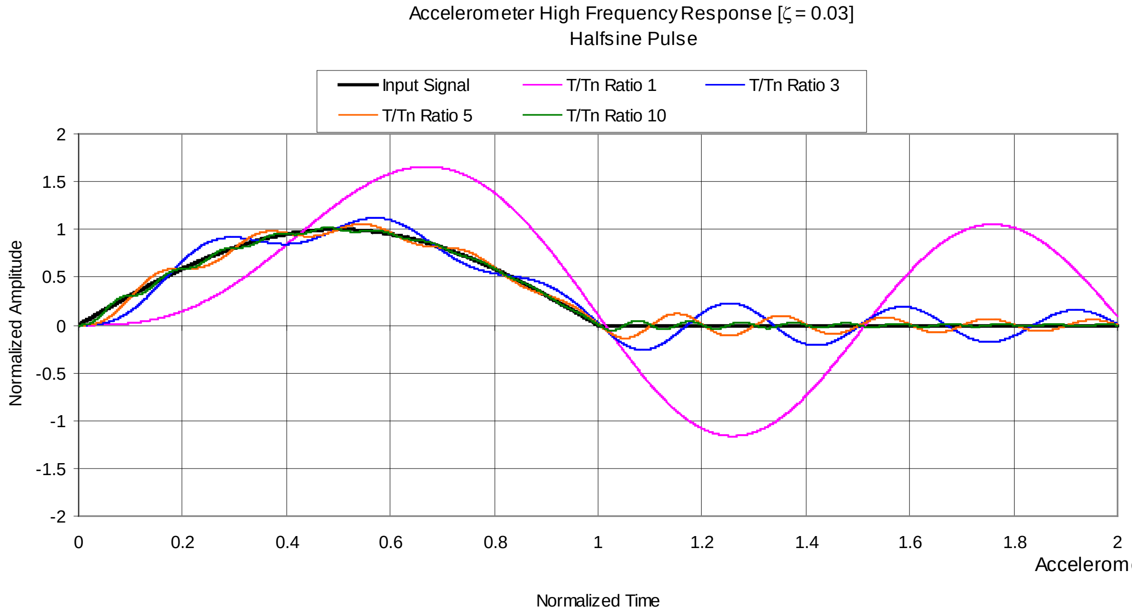


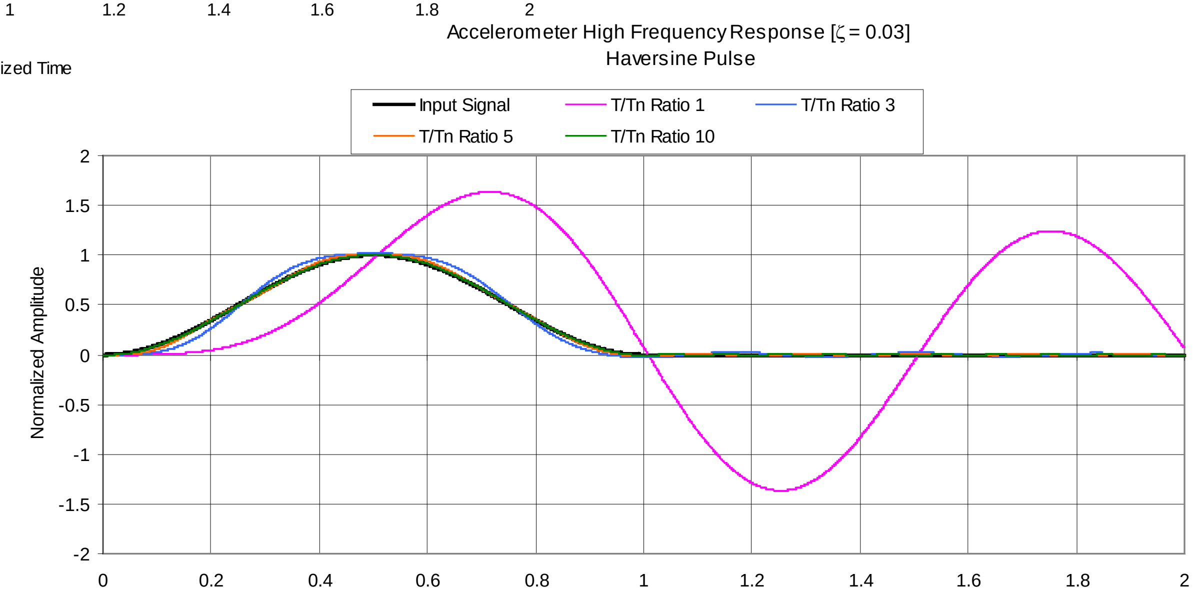
If the shock pulse is analyzed in the frequency domain, and if considerable frequency content is found above 1/5th of the accelerometer's resonant frequency, increasingly greater errors will exist in the data. This rule can also be applied to vibration. Illustrative time histories follow:



Rule: $f_n = 1/T_n$ & $T/T_n > 5$ yields peak error less than 10%.

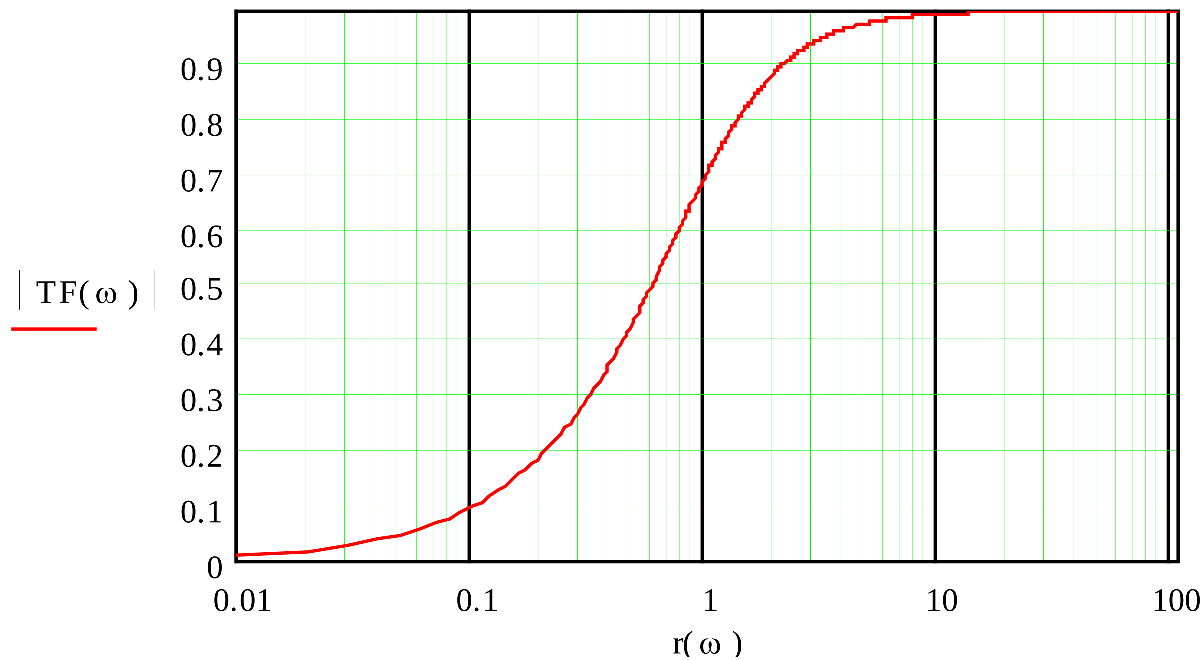
and additional verification plus a rule for valid pulse rise times!





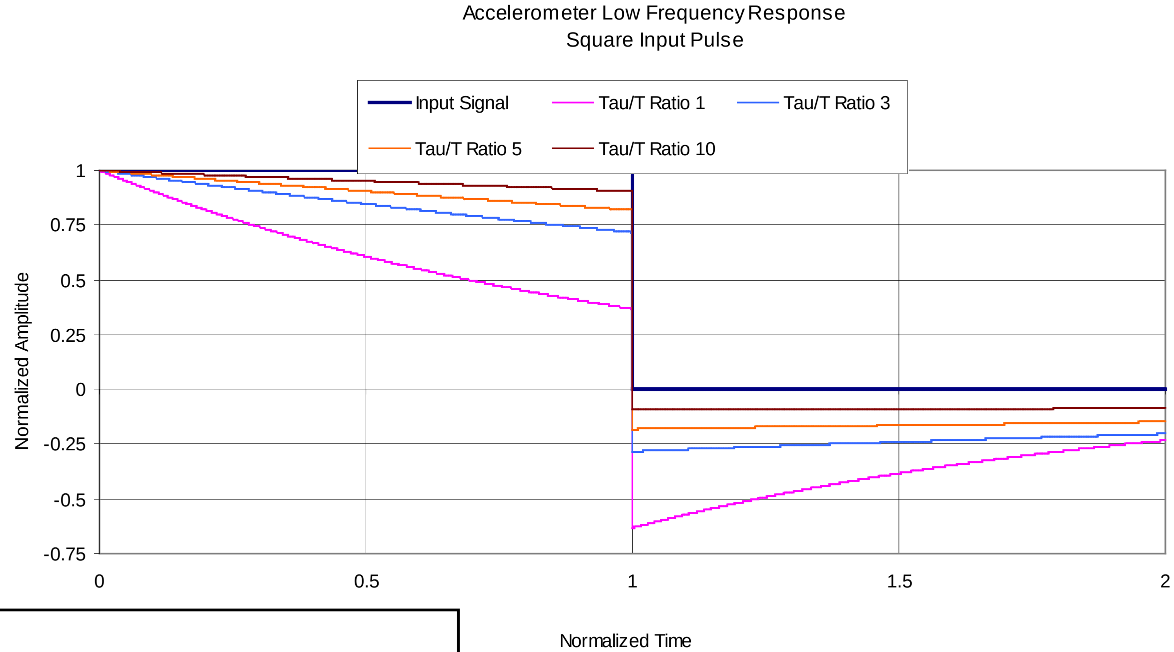
Rule by analogy:
$f_n = 1/T_n$ & $t_r/T_n > 2.5$
yields peak error less than 10%,
based on 10-90% rise time

If the shock pulse is recorded by a piezoelectric accelerometer, and it is analyzed in the frequency domain, frequency content below $\boxed{f\tau \text{ ¤ } 0.5}$ will have more than 5% attenuation. This rule can also be translated to vibration.



High-pass RC Filter

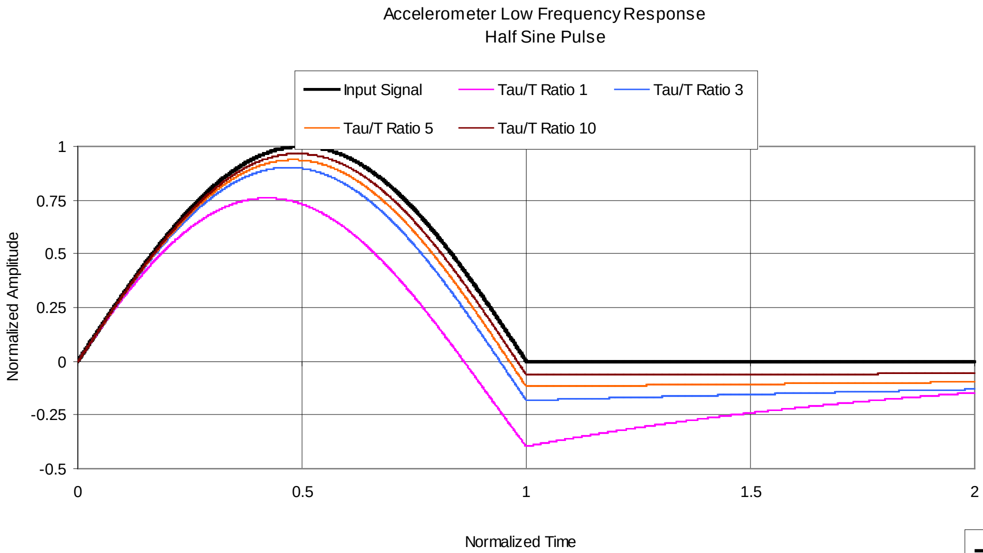
In the time domain, inadequate low frequency response will cause droop and undershoot.

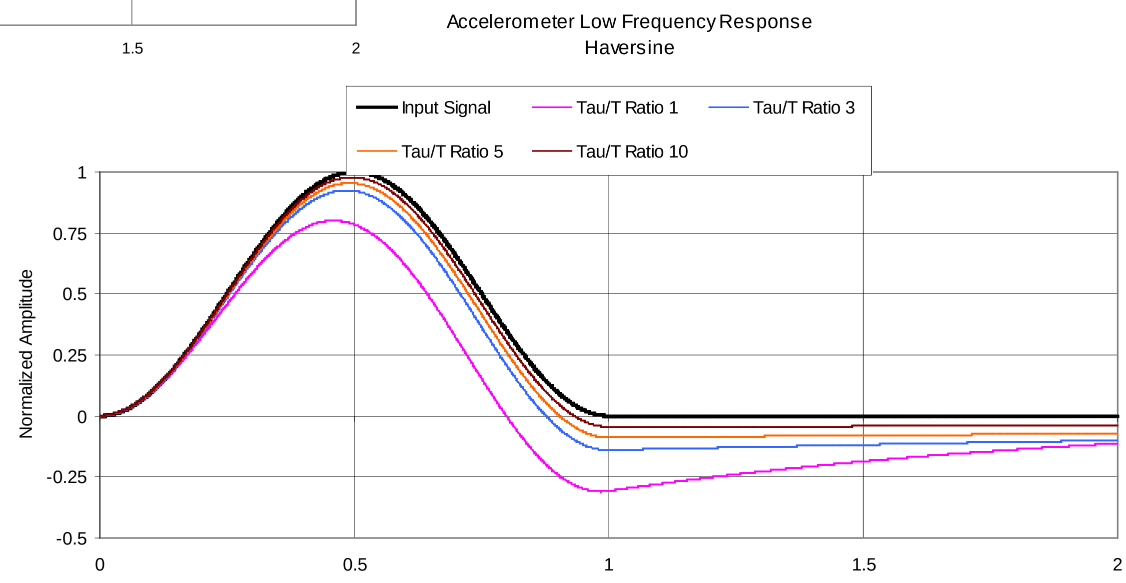


Rule is $\tau/T > 10$

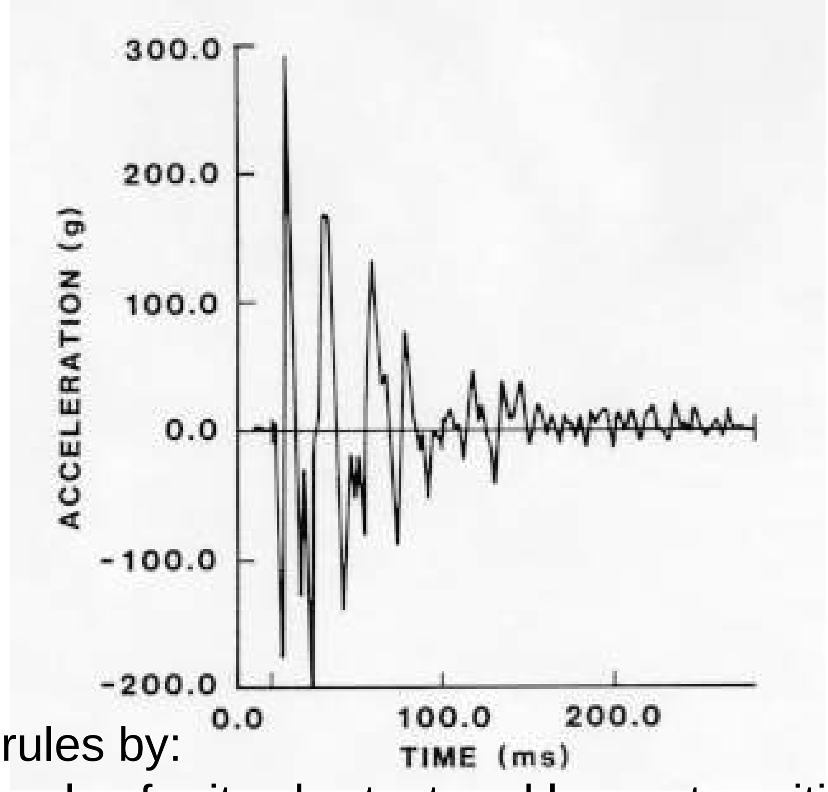
$\tau/T > 10$ results in: 10% droop square pulse
2.4% error peak haversine
3.4% error peak half sine
2.6 % error peak triangular

In the time domain, inadequate low frequency response will cause droop and undershoot.





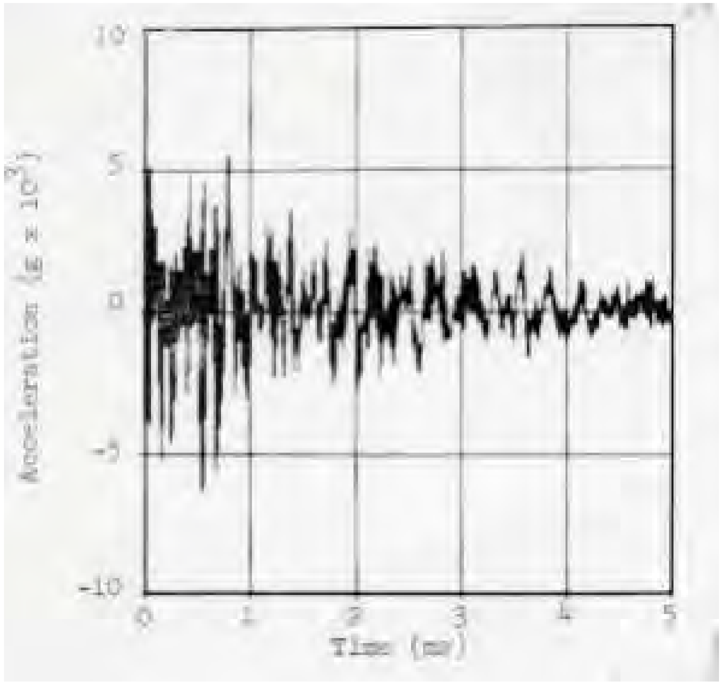
What do we do with real-life complex pulses in the time domain?



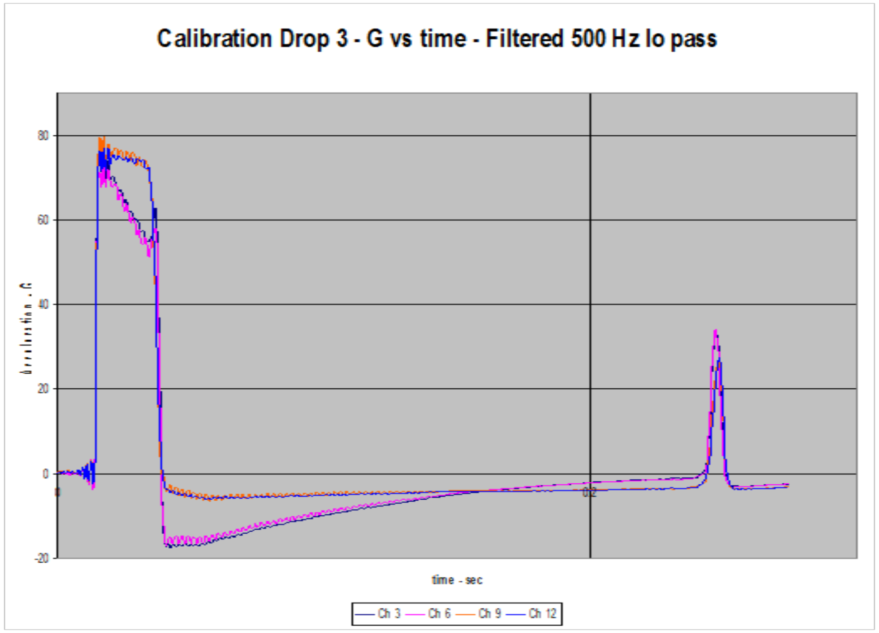
- Apply the previous rules by:
  - ➢ Dissecting the pulse for its shortest and longest positive- or negative-going excursions
  - ➢ Dissecting the pulse for its shortest positive or negative rise-time.

Since today all data are recorded in digital format, these simple rules can be readily programmed into a software data analysis package.

We do see these pulses in application.

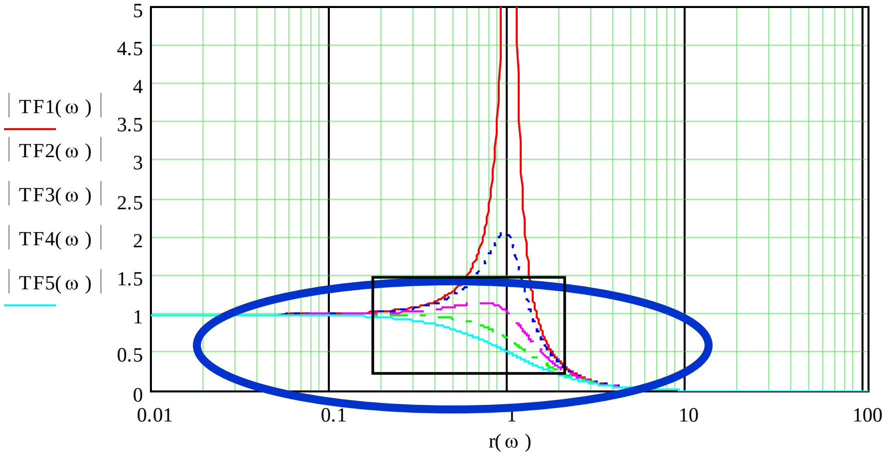


Accelerometer Resonant Frequency Excited



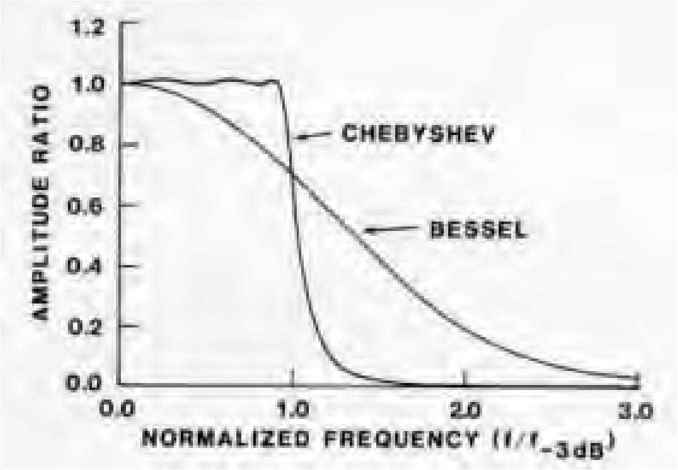
Inadequate Circuit Time Constant

Other considerations: What if a monotonic frequency roll-off limits the high frequency response?



Damped accelerometers

Filters, amplifiers, etc.



$$t_r f_{-3dB} > 0.45.$$

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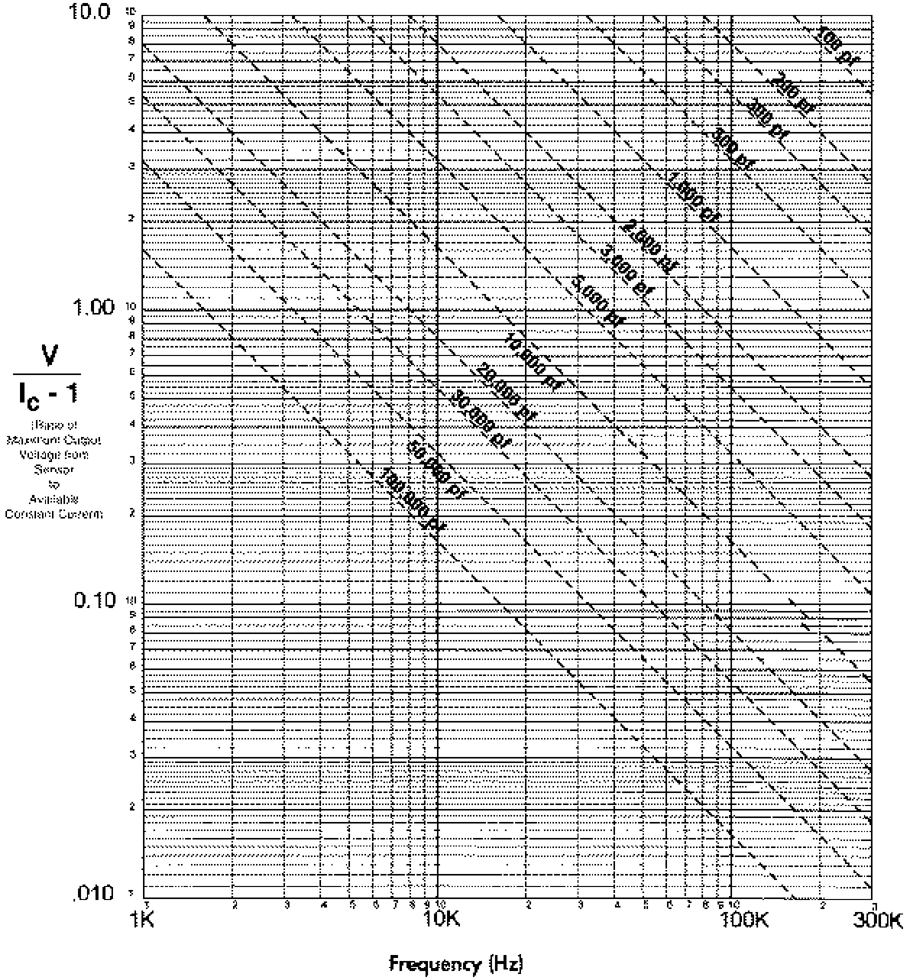
Other considerations: High-frequency cable limitations with ICP®

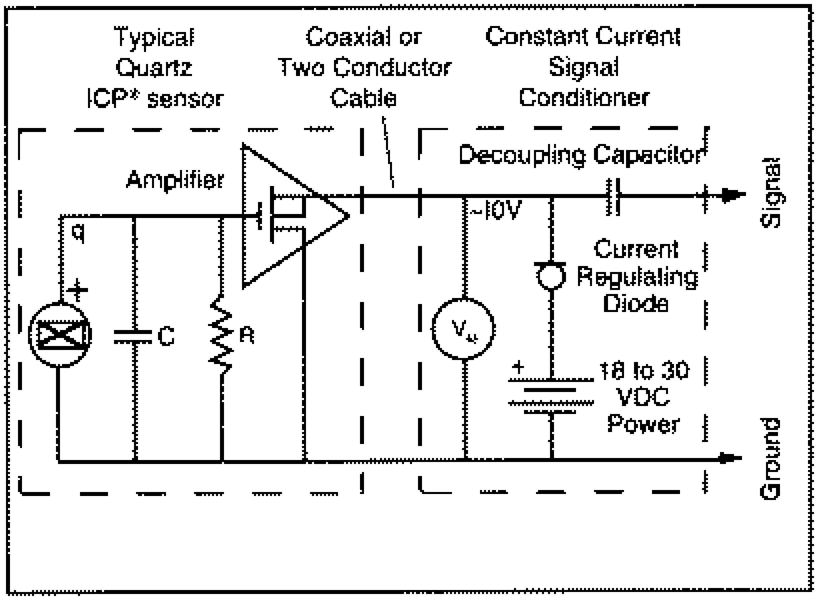


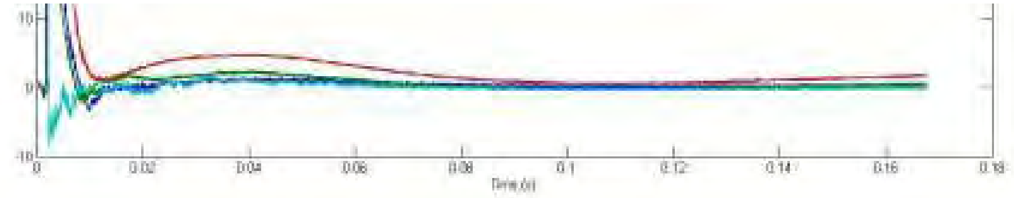
f_{max} = Maximum frequency given the following characteristics

C= Cable capacitance (pF)
V= Maximum output voltage from sensor (volts)

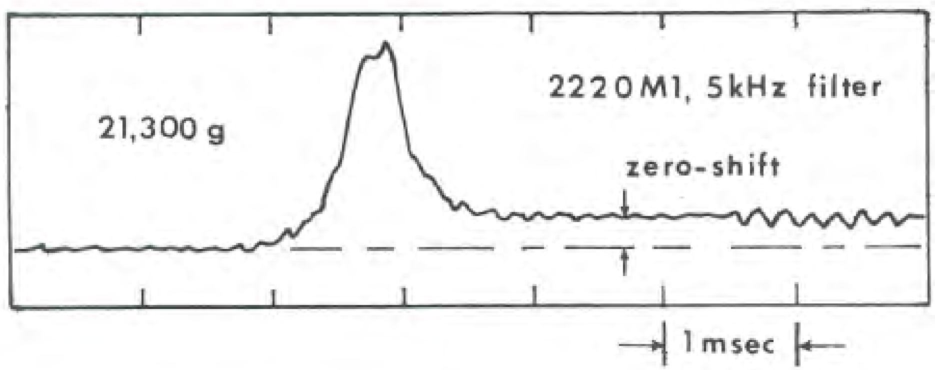
I_c= Constant current level from power unit (mA)
10^6= Scale factor to equate units

Other considerations: ICP® Circuit Recovery





Other considerations: PE versus PR (MEMS): Zero Shift



Zero-shift

Potential Solution

At sufficiently high frequencies the resonance of any accelerometer can be excited, but a unique characteristic of ceramic materials is that this excitation can result in a zero-shift of the signal. This remained a mystery until 1971, when the cause-effect relationship of the zero-shift in ceramic materials was established, and this work brought about an increased focus on MEMS accelerometers for shock applications. Theoretically, MEMS accelerometers <u>do not</u> zero shift.

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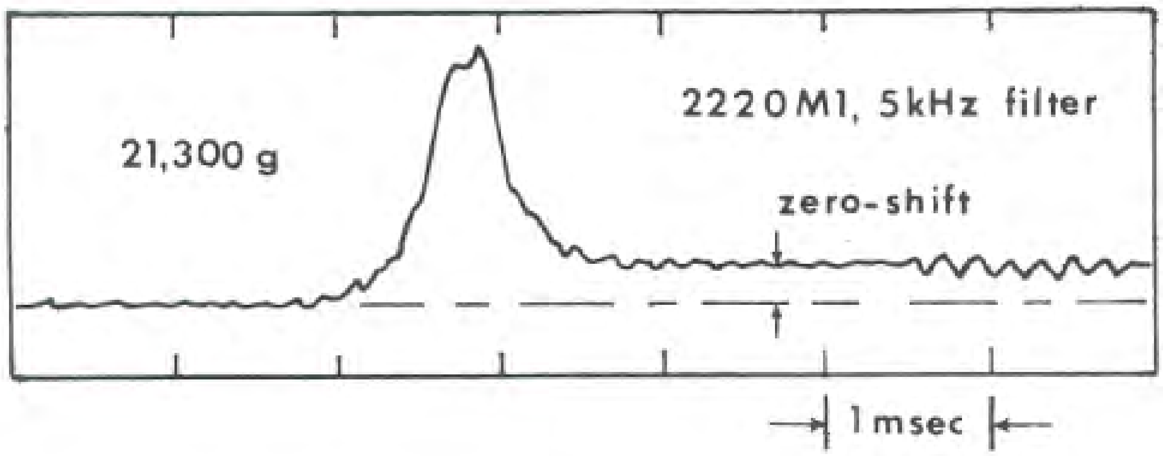
A side note on zero shift:

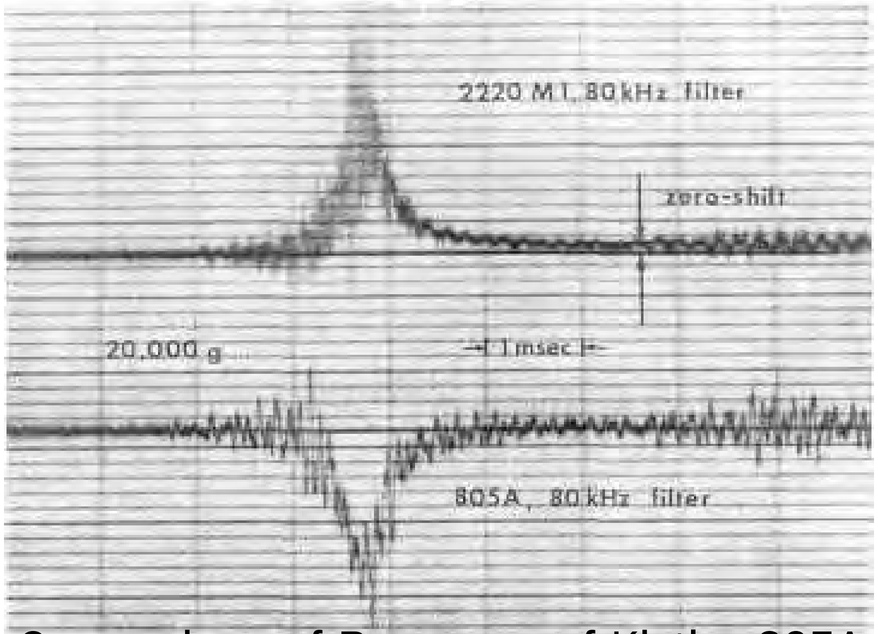
Ferroelectric ceramic transduction elements zero shift!



Zero-shift From Ferroelectric Ceramic Accelerometer
(circa 1970)

It was noticed that quartz accelerometers were less prone than quartz to zero shift.

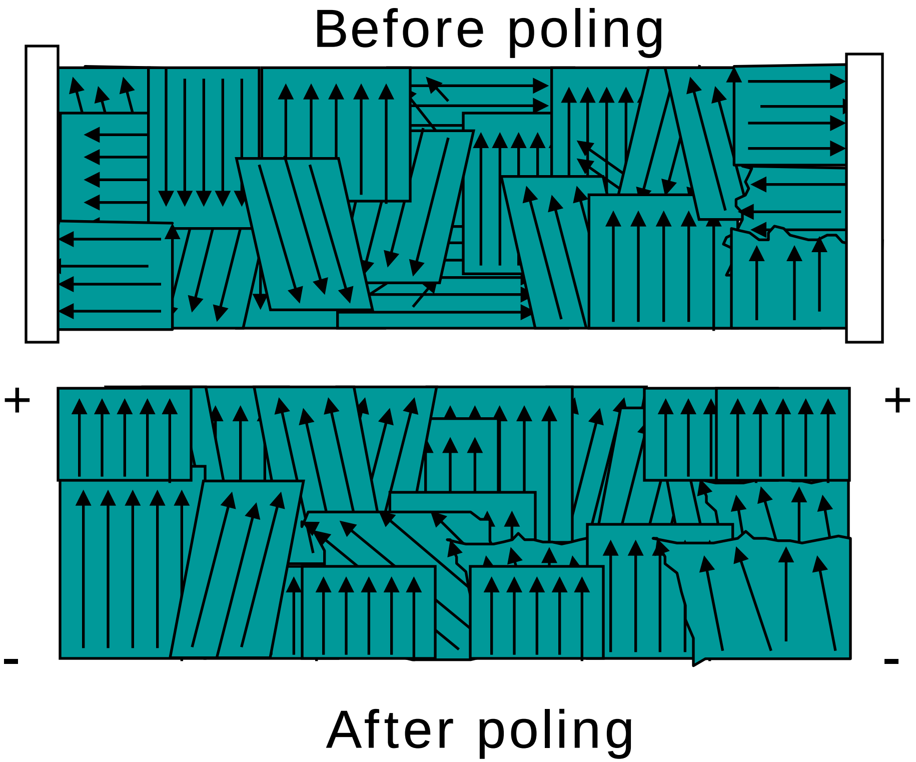
1966 (used early 1970s): Kistler 805A: (first quartz 100,000 g accelerometer/compression design)



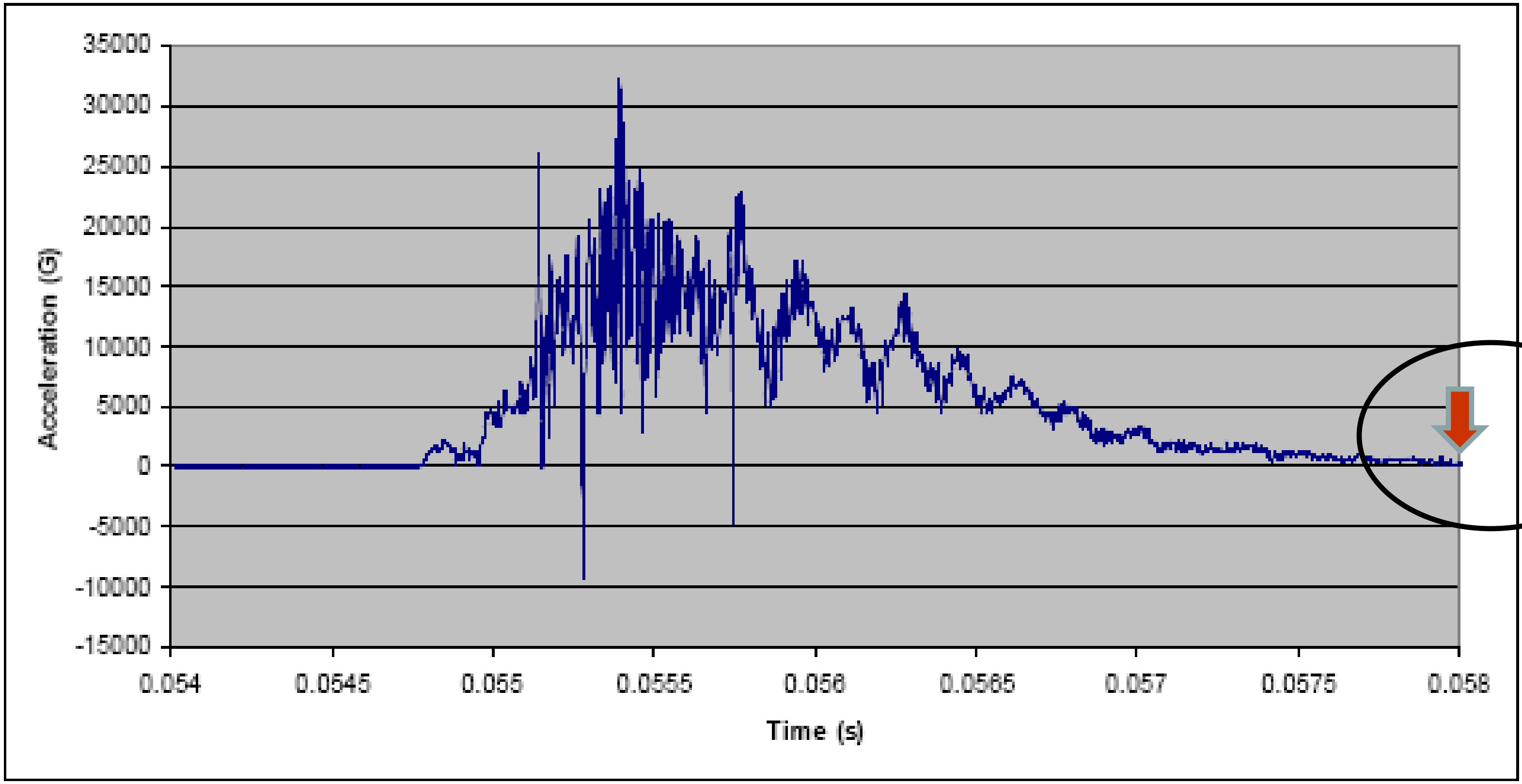
Comparison of Response of Kistler 805A With Ferroelectric Ceramic Accelerometer

Why zero shift

Poling at .2-10KV
200-400^o F



MEMS seem to solve the zero shift problem: e.g., Acceleration while penetrating 2 feet of concrete



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Please refer to PCB TN 24 for a refresher.
I hope this overview proved helpful.
The rules work and won't leave you out in the cold!