55th Annual Fuze Conference
Fuzing's Evolving Role in Smart Weapons

Development of a new MEMS High-g Accelerometer

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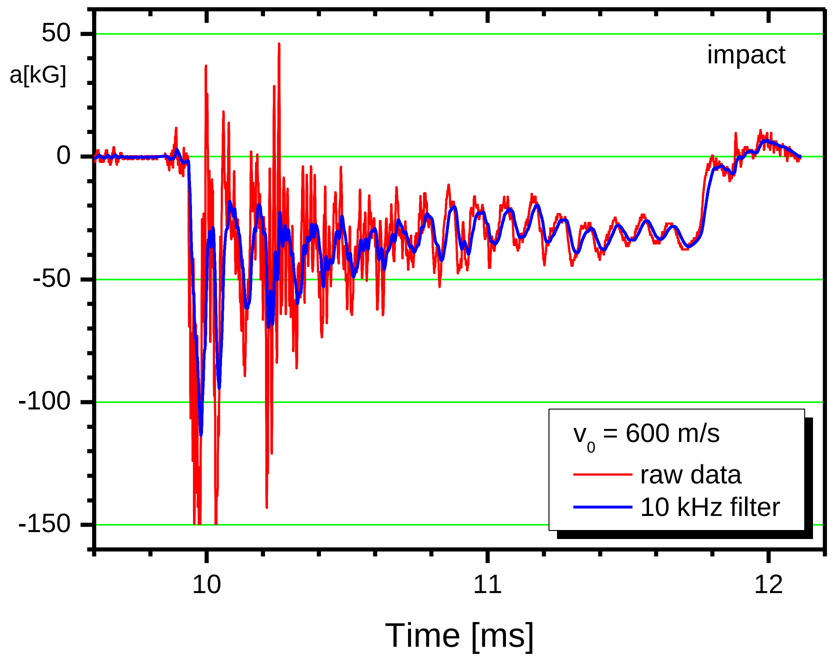
OUTLINE

- Introduction
  - High-g Applications
- Theory
  - Transient Excitations
- Design
- First Experimental Data
  - Hopkinson Bar
  - 200,000 g Measurement
- Summary and Outlook

High-g Applications: Research

- Analysis of highly dynamic processes
  - Shock-testing of electronics
    Measurement range needed: 50,000 g
  - Material characterization
    g-Range > 80,000 g
  - Penetration processes
    g-Range > 100,000 g
  - Near field blast
    g-Range > 100,000 g



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High-g Applications: Military

Pictures: Wikipedia

- High-g hardened fuzing in smart weapons
  - Large warheads
  - Artillery shells
  - Upcoming:
    Smaller calibers
    > 100,000 g

- The smaller the ammunition, the bigger the acceleration

High-g Applications: Military

Pictures: Wikipedia

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  - Large warheads
  - Artillery shells
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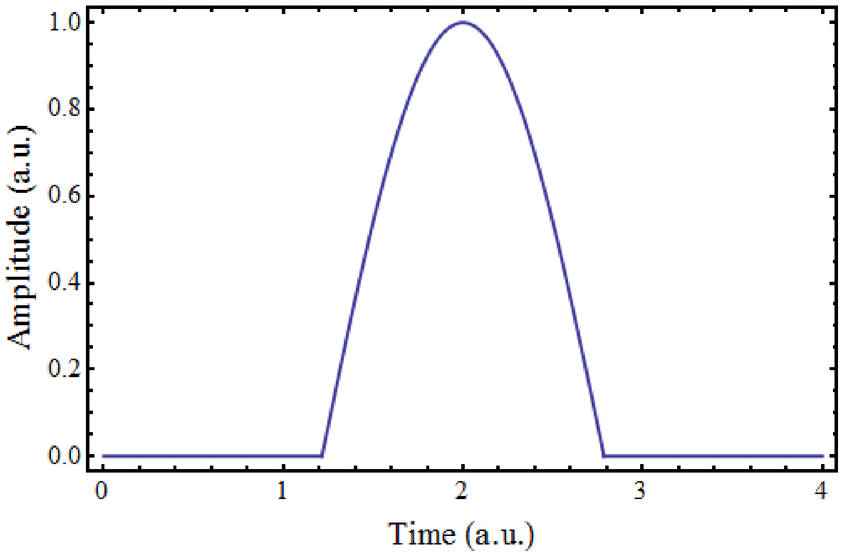
    Smaller calibers
    > 100,000 g

Requirements:
g-Range
Survivability
Size

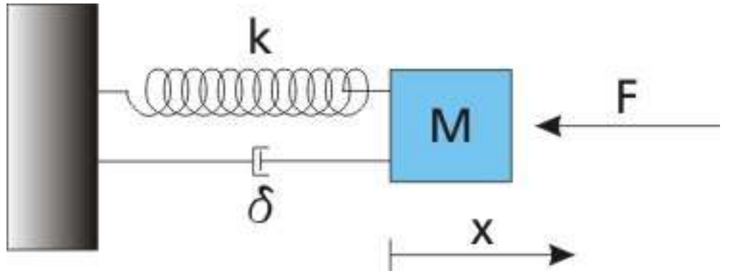
- The smaller the ammunition, the bigger the acceleration
- ➢ Need for small, affordable (very-)high-g accelerometer

Basics of High-g Accelerometry

- Shock pulse:
  - “short“, “discontinuous“, “rapidly varying“

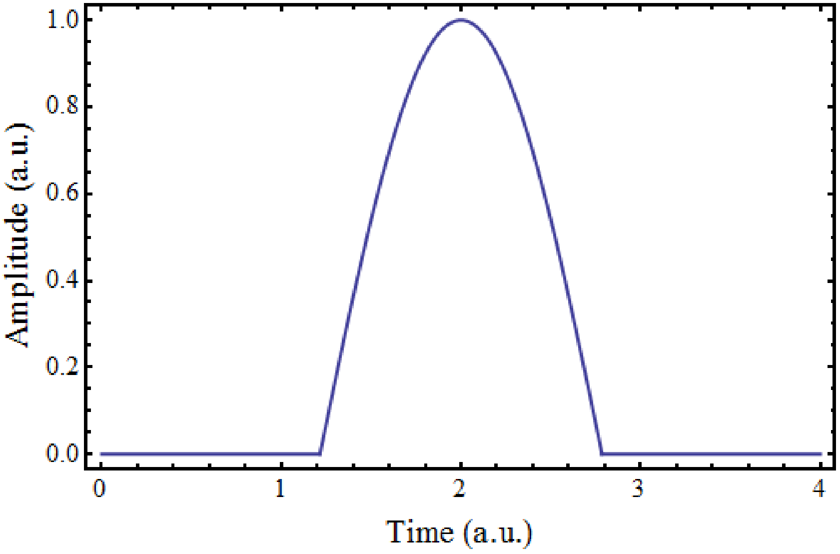


- Accelerometer:
  - Spring-mass-system with resonant frequency
  - Displacement results in signal

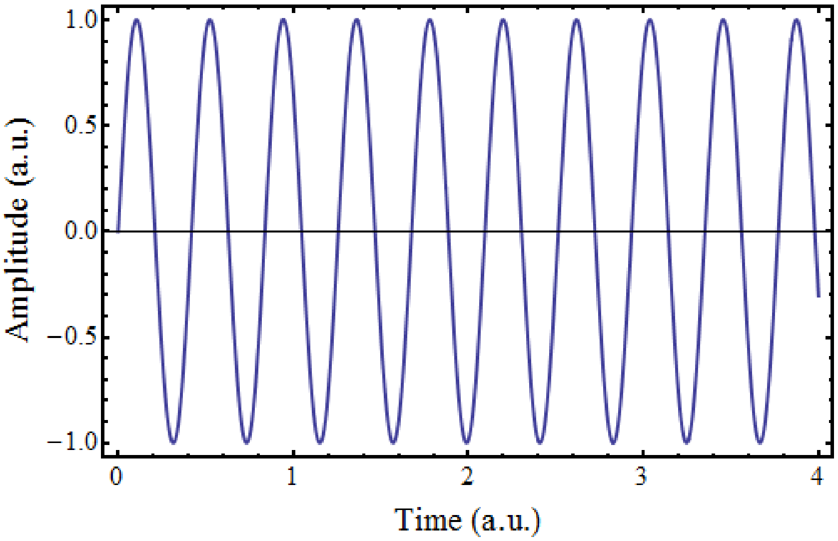


Excitation of a Spring-Mass-System: Sample Pulse

Shock-Pulse



Spring-Mass-System



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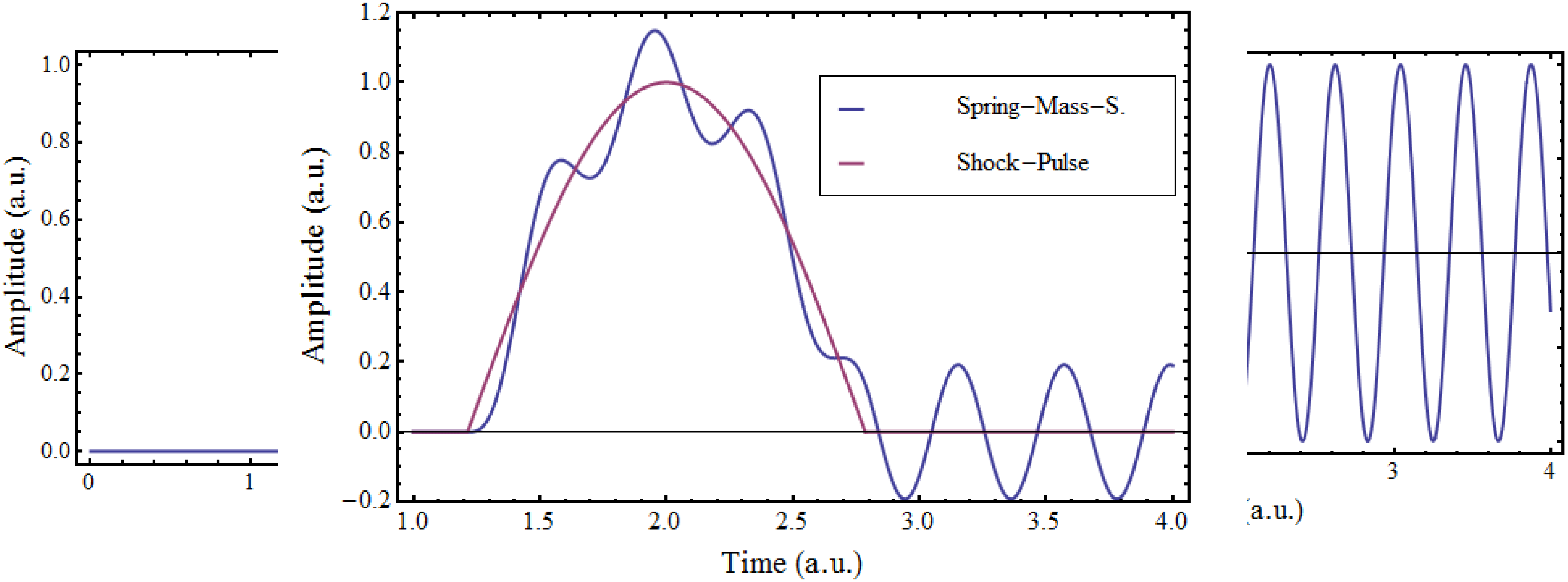
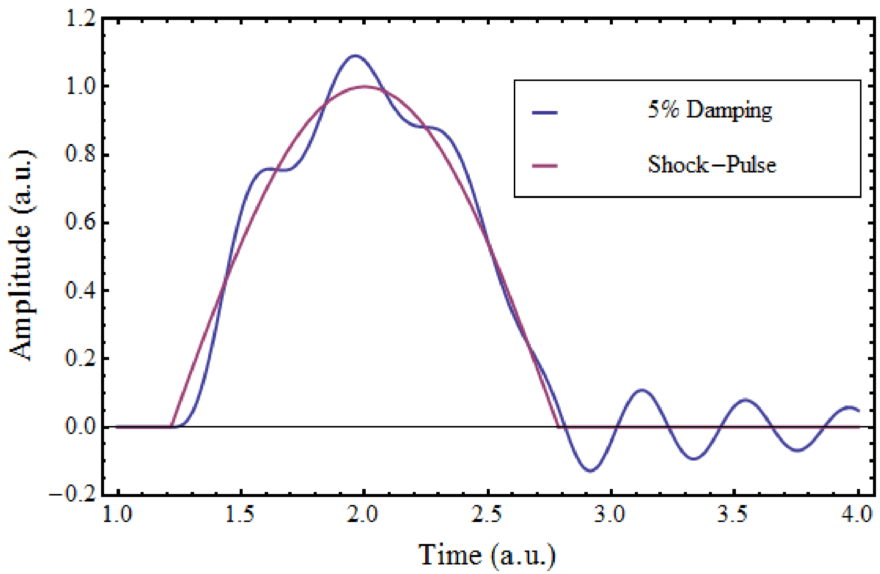
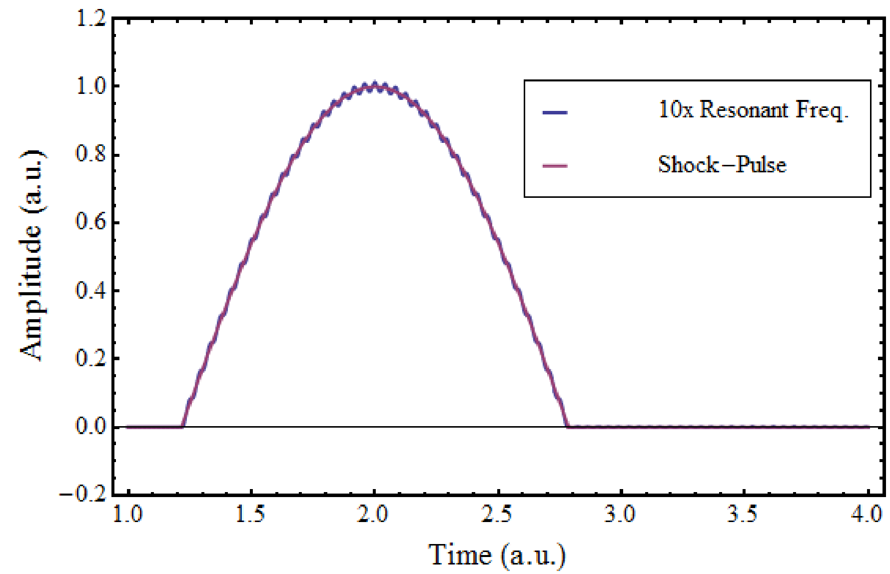
Excitation of a Spring-Mass-System: Analytical Solution



- How to avoid oscillations and over-excitation?
  1. Damping (+ stops)
  2. Higher resonant frequency

Reducing Oscillations





- 5% Damping:
  - Over-excitation 15% -> 10%
  - Oscillations 20% -> 10% -> 0%
- 10x Resonant Frequency:
  - Over-excitation 15% -> 2%
  - Oscillations 20% -> 2%

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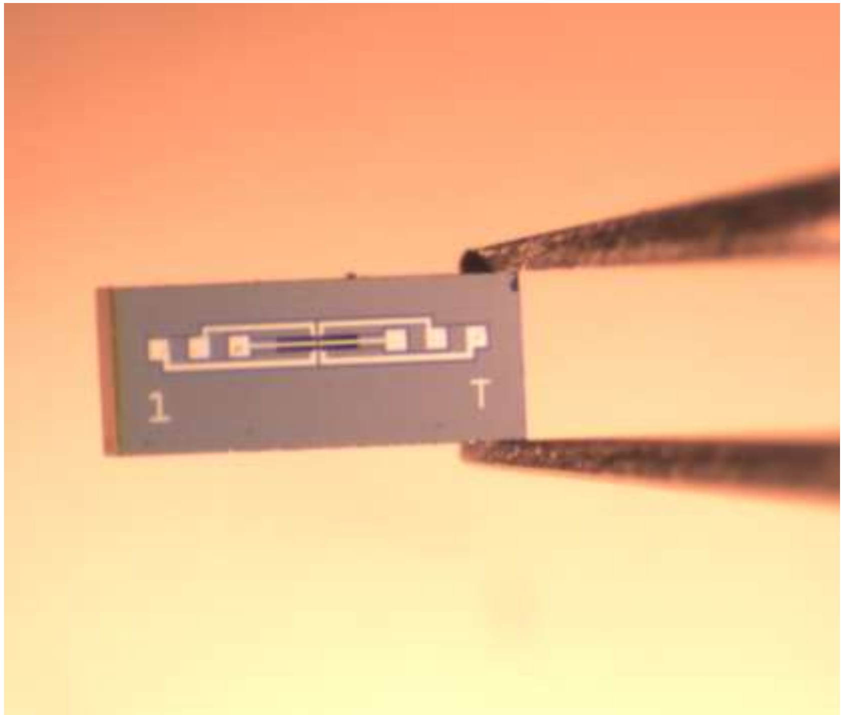
EMI Accelerometer

- Undamped, piezoresistive, MEMS accelerometer
- Status of development
  - Design is patent pending
  - First specimens were successfully manufactured and tested
- Different variants exist:
  - Measurement range > 100,000 g
  - Resonant frequency 1 – 3 MHz
  - Sensitivity 0.1 – 1 µV/V_{exc}/g



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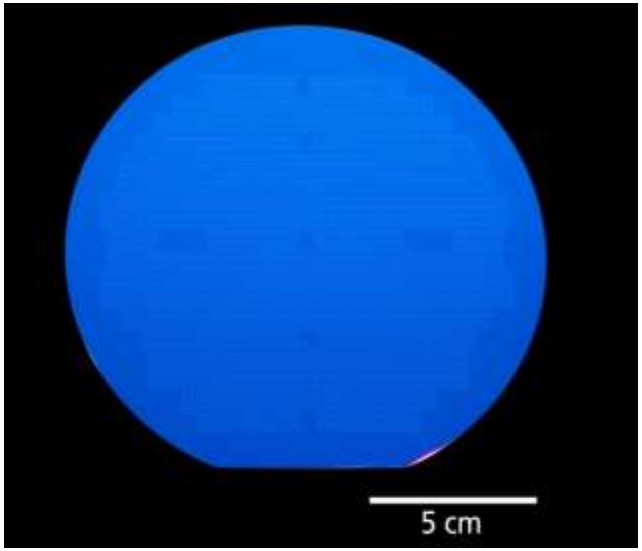
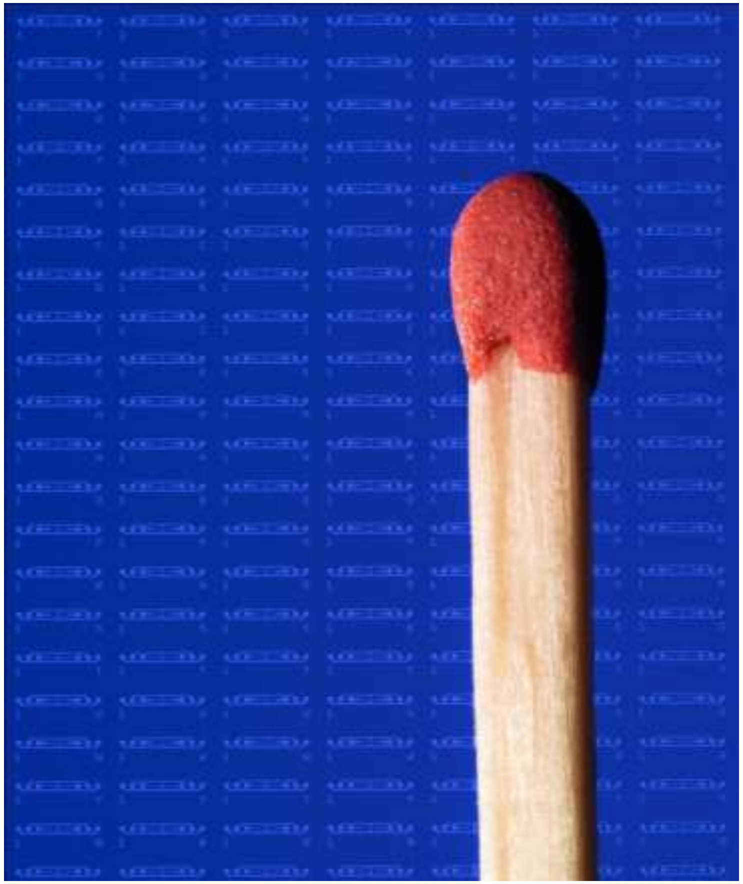
EMI Accelerometer

- Manufactured with standard silicon processes, single sided
- Sensor-chip about 2 x 1 mm^2
- Straightforward integration of 2D and 3D measurement capabilities





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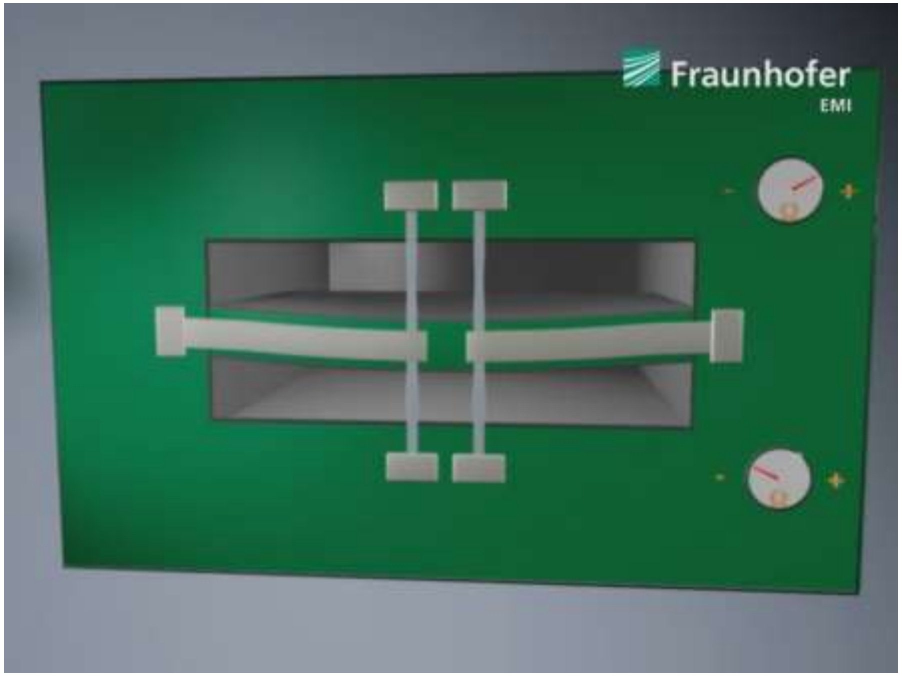
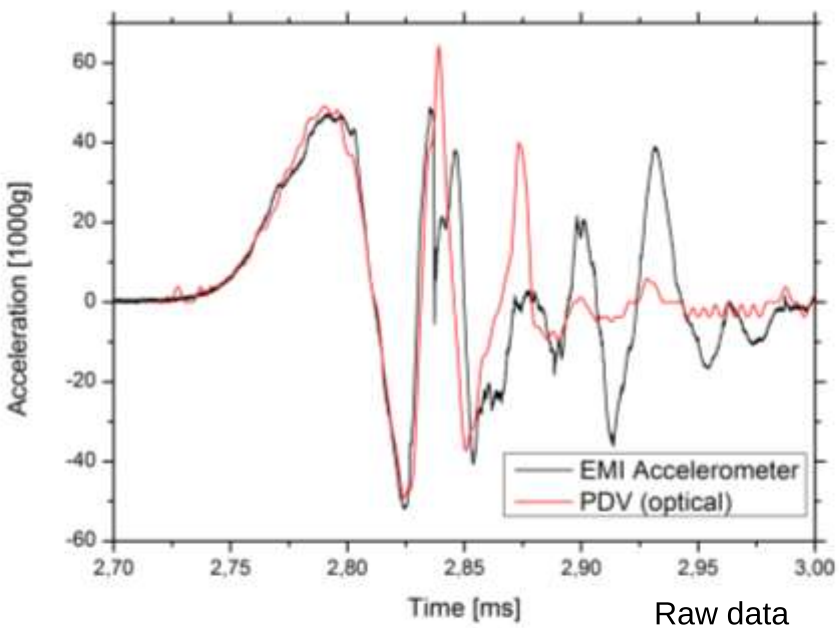
EMI Accelerometer: Functional Principle

- Main components:
  - Flexural plate
  - Self-supporting piezoresistive elements
  - Full Wheatstone-bridge
- Functional principle:
  - Inertial forces cause deflection of plate
  - Straining of piezoresistive elements
  - Change in resistance is measurement signal

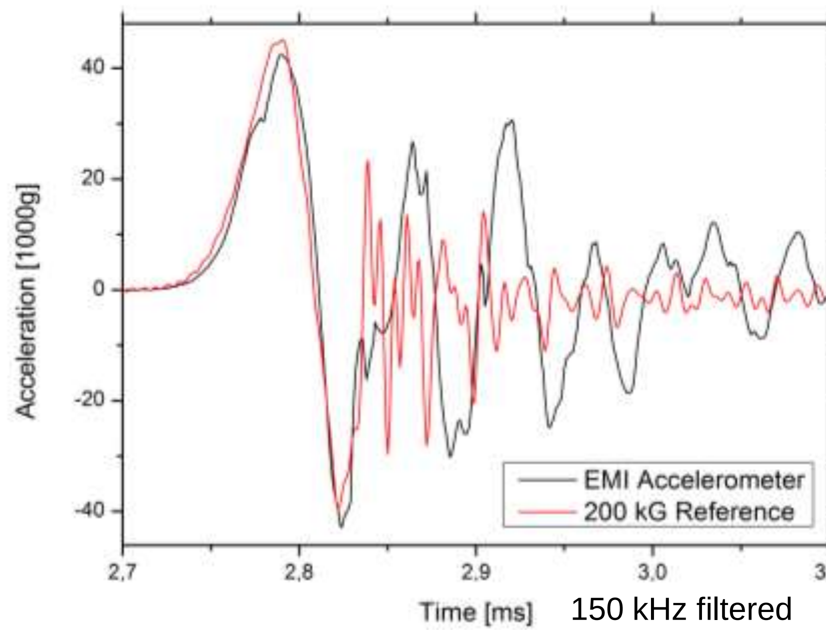


Hopkinson Bar Measurements

- Assessment of accelerometer performance on Hopkinson bar
- Comparison:
  - First peak well reproduced
  - Differences after breakaway

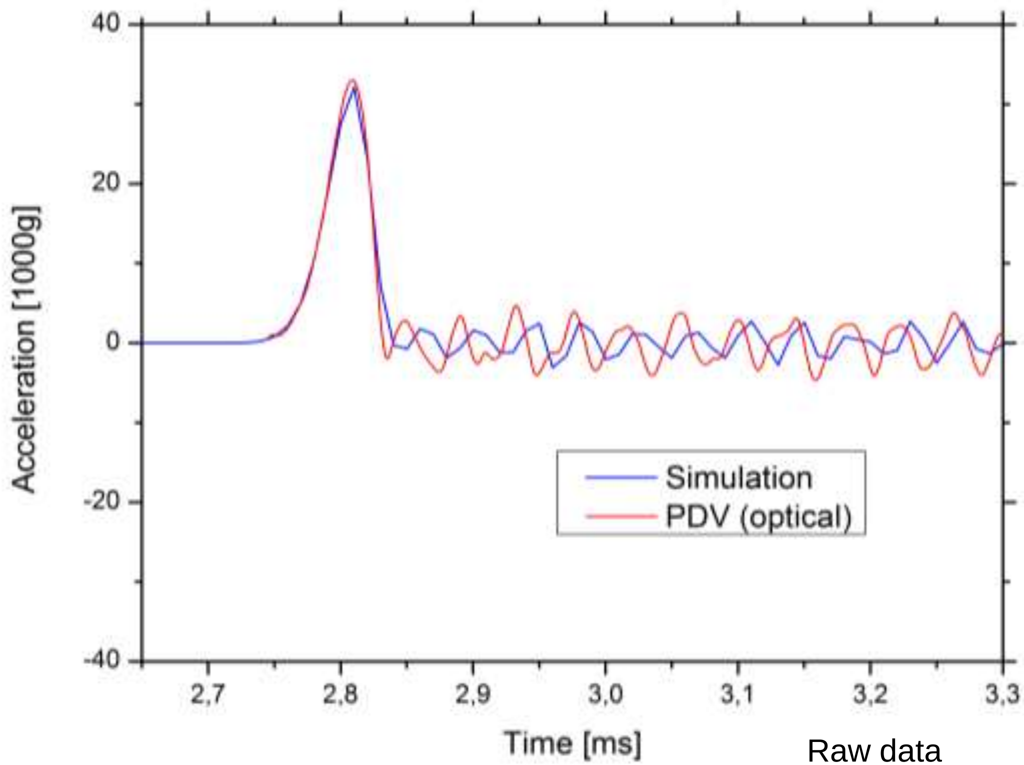


Raw data



150 kHz filtered

Shock Plate Test: Reference



Raw data

- Test of accelerometers on shock plate
- Simulation and reference measurement with PDV
  - 30,000 g pulse
  - Plate shows oscillations with 23 and 46 kHz (1st and 2nd harmonic)

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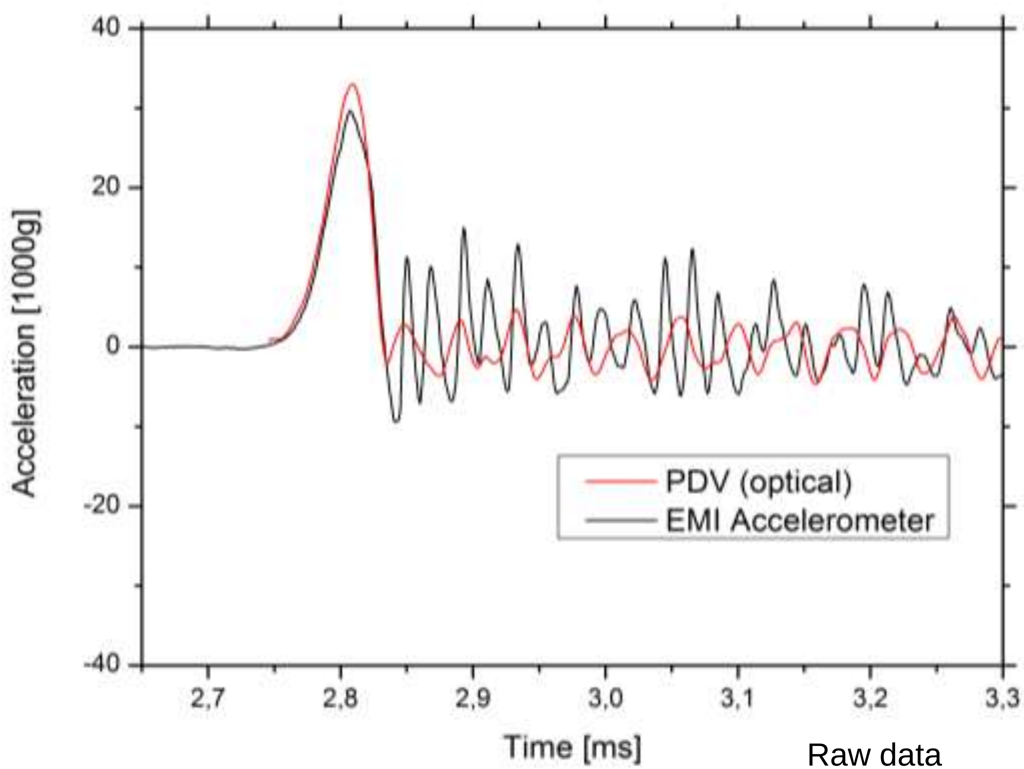
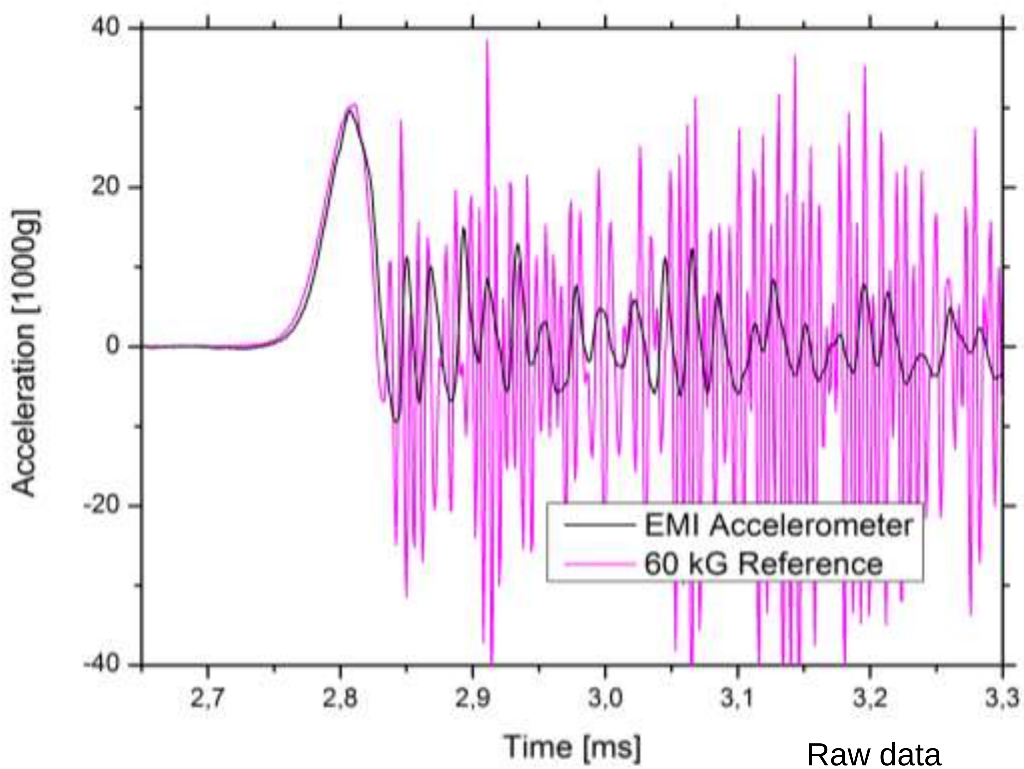
Shock Plate Test: Comparison



Raw data

- Second flyer plate experiment with EMI accelerometer and 60 kG lightly damped sensor
- 2nd harmonic more distinct in this test

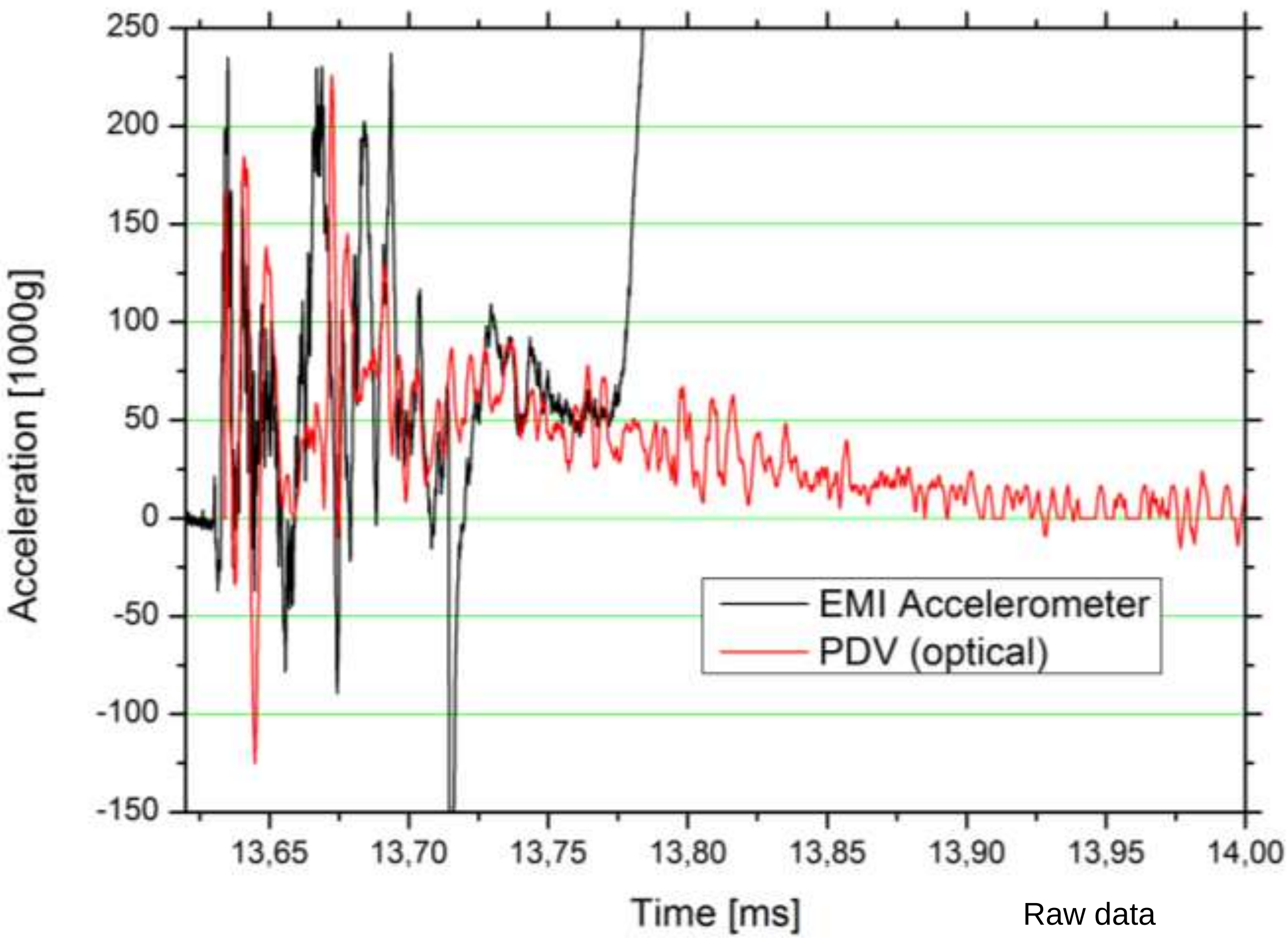
Flyer Plate Test: Comparison



Raw data

- Second flyer plate experiment with EMI accelerometer and 60 kG lightly damped MEMS
- 2nd harmonic more distinct in this test
- Both sensors reproduce first peak
- EMI: Plate oscillations with 23 and 46 kHz are well visible
- 60 kG: 165 kHz resonant frequency overlays plate dynamics

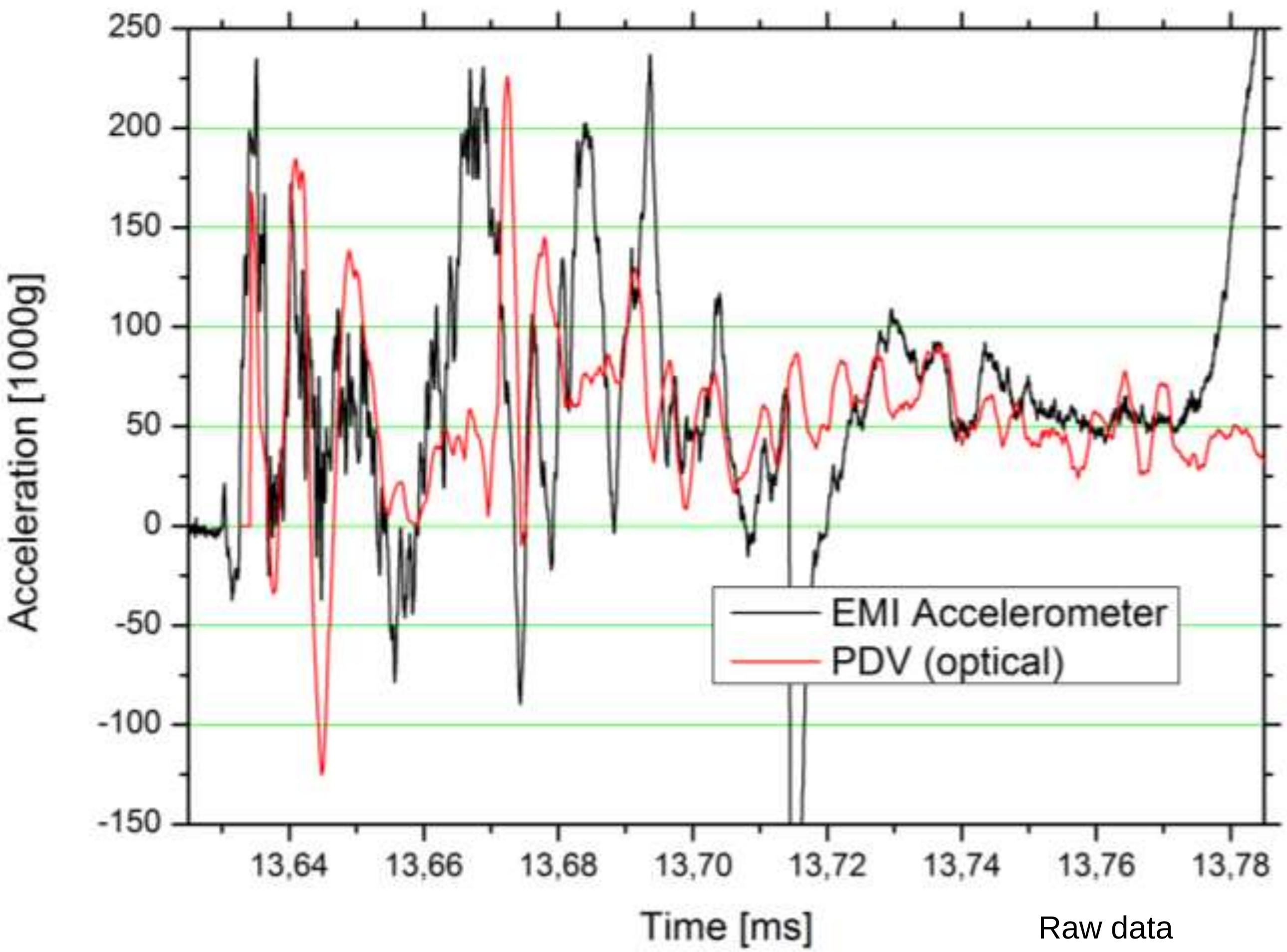
200,000 g Measurement



Raw data

- Impact experiment with PDV measurement
- Overall agreement is good
- Failure of cable connection

200,000 g Measurement



Raw data

- Confirmed acceleration over 200,000 g
- Defective contact at 13.72 ms and failure of cable at 13.78 ms
- No resonant oscillation
- Sensor-chip is completely intact!

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Summary

- EMI accelerometer has been designed and manufactured
  - Design patent pending
  - Standard silicon processes
  - Successful proof of concept

- The EMI design combines:

  … the sensitivity of medium g-range sensors (> 0.2 µV/V_{exc}/g) (proven)

  … with the survivability of high g-range sensors (> 200.000 g) (proven)

  … while having a uniquely high bandwidth (> 2 MHz) (not meas. yet)

Outlook

- Determination of accelerometer performance is to be completed

- Further development will focus on:
  1. Realization of an “easy to use” and robust package
  2. Monolithical integration of bi- or tri-axial accelerometers

Thank you for your Attention!

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