Collection of Silicon Detectors Mechanical Properties from Static and Dynamic Characterization Test Campaigns

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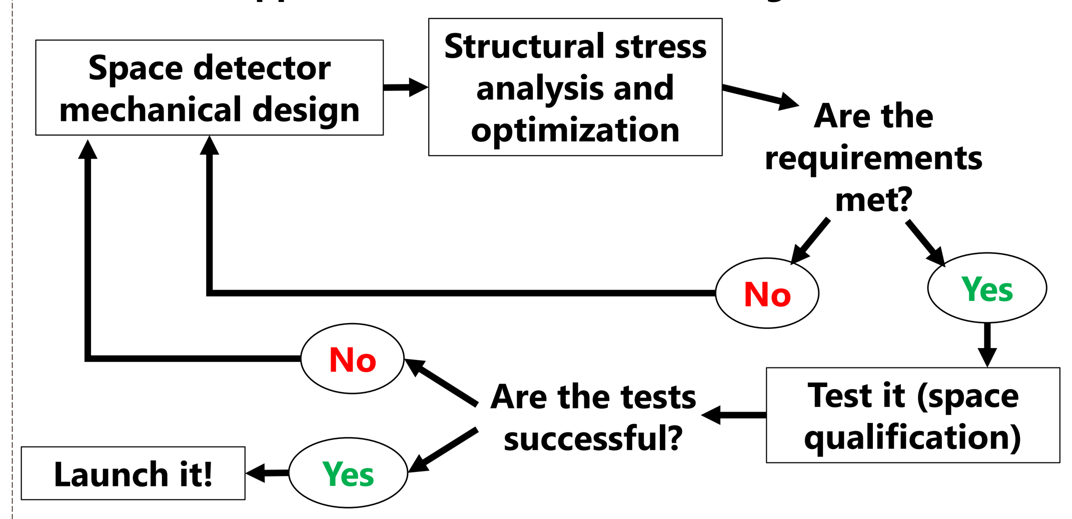
Objective: retrieval of crucial information for the silicon-based spaceborne detectors design

1. Introduction – heritage, scope and objectives

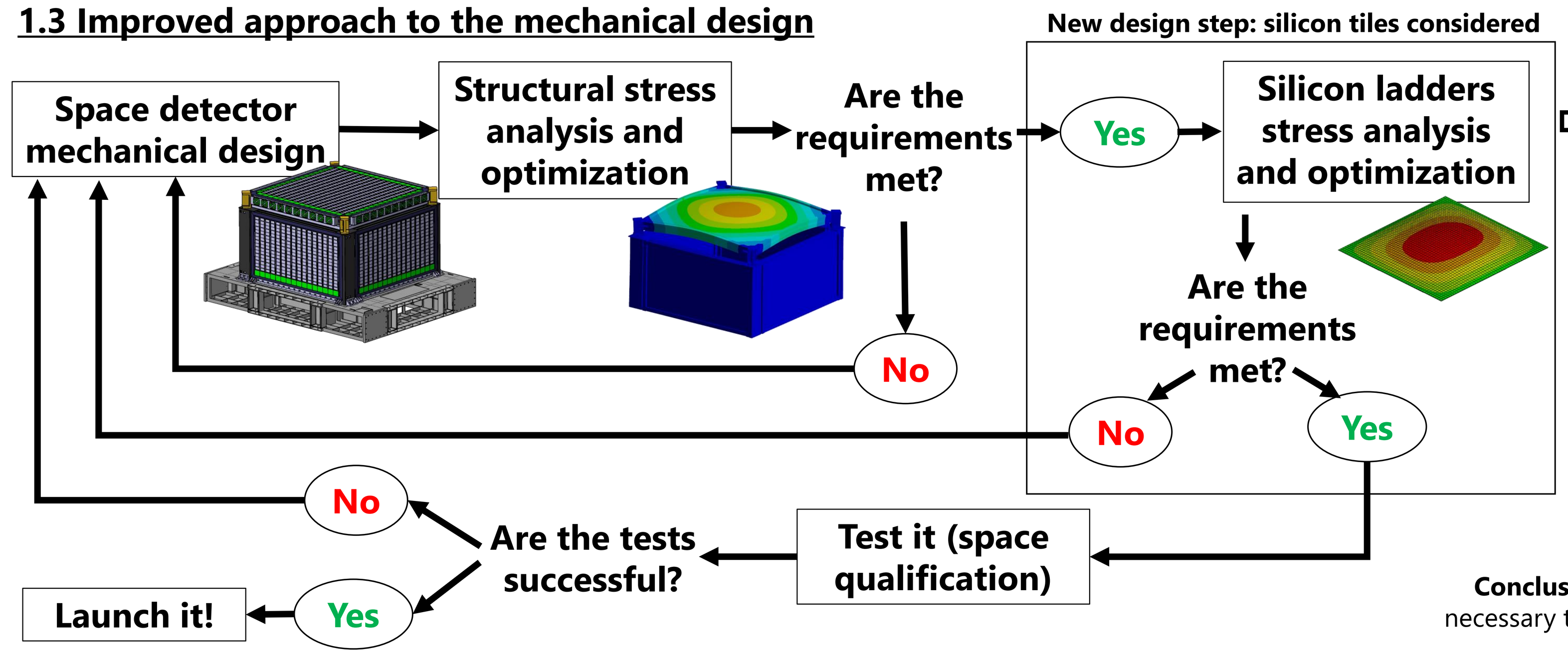
1.1 Heritage and scope

As of today, various space experiments, like DAMPE or AMS, successfully employ Single Sided or Double Sided Silicon Detectors (DSSD or SSSD). Although the previous effort proved the xSSD suitable for space application, they did not consider the detectors' mechanical properties. On this topic, the authors are persuaded that a deeper knowledge of this topic would allow a finer structural optimization leading to structural mass reduction and performance increase.

1.2 Classical approach to the mechanical design



1.3 Improved approach to the mechanical design



Implications:

- Reduced safety margins
- **Reduced** structural **mass** and structure-associated blind spots
- Possibility to develop **experiments with non-standard geometries**

Conclusions: to perform this optimization it is necessary to have a **sound knowledge of** silicon ladders' **mechanical behavior.**

2. Pull test for bond strength analysis

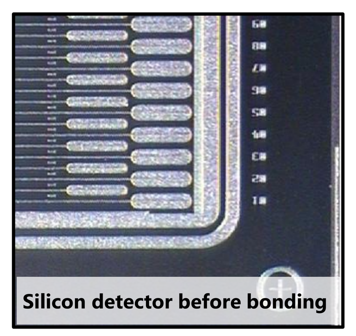
Goal: gather information on the bonds' yielding stress

2.1 Test subject

Bond and wire properties

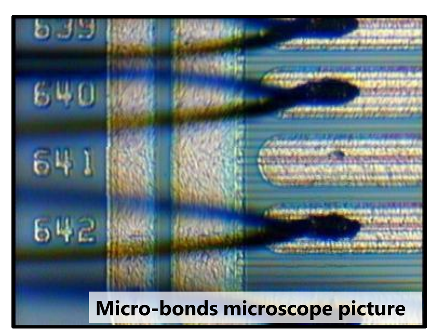
- Wire Al-Si 1% ϕ 25 μm
- Max force: 14 – 16 cN
- Elongation: 1 – 4 %
- Pads distance 1.5 / 2 mm

Bonds manufacturing pictures:

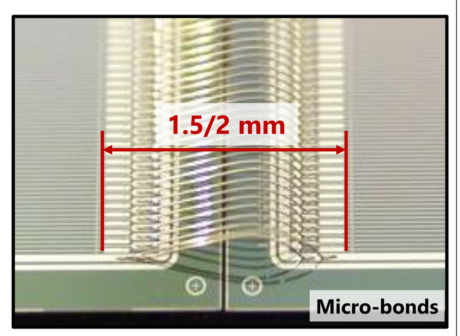


Silicon detector before bonding

Snapshot of bonds manufacturing

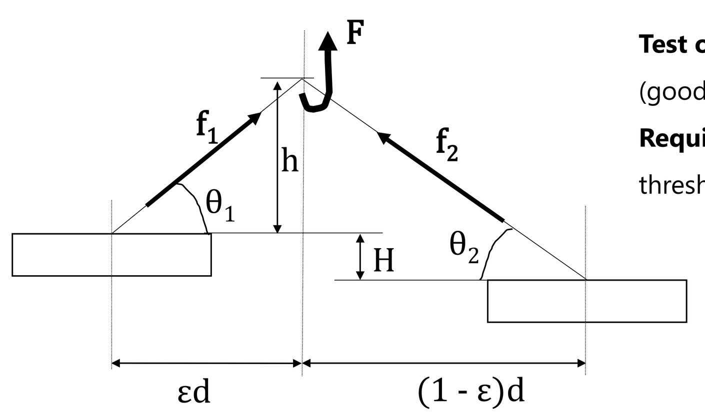


Micro-bonds microscope picture



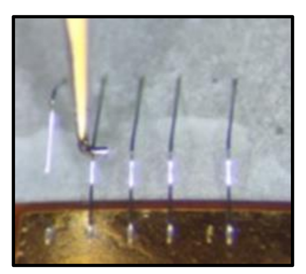
Micro-bonds

2.2 Test description and execution



Test objective: verify the bonds' quality (good surface adhesion)

Requirements: bond failure above threshold, wire failure



Set-up:

Inputs	Values
h	750 μm
H	0 μm
d	1.5 mm
ε	0.5
θ_1	45°
θ_2	45°

Results:

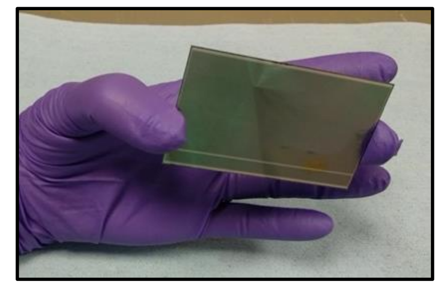
- Pull force: $\mu = 12.471$ gf*, $\sigma = 1.7957$ gf*, 515 samples

*gram-force

3. Silicon Detectors mechanical characterization

Goal: retrieve detectors' mechanical properties.

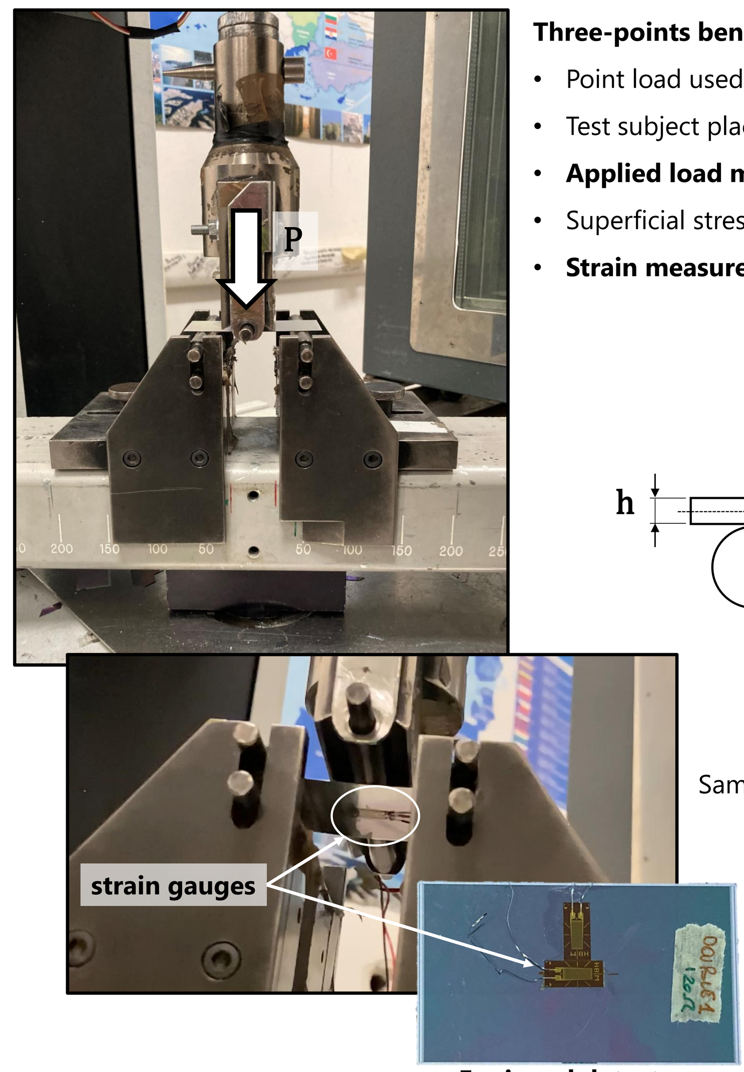
3.1 Physical properties and general information



- Test subjects: AMS spare DSSDs (orientation <111>)
- Dimensions: 72 x 41.4 x 0.3 mm³ (0.01 mm accuracy)
- Density: $\mu = 2392\ \frac{kg}{m^3}$, $\sigma = 69.5\ \frac{kg}{m^3}$, 11 samples used

3.2 Mechanical properties estimation with three-points bending test

3.2.1 Test description

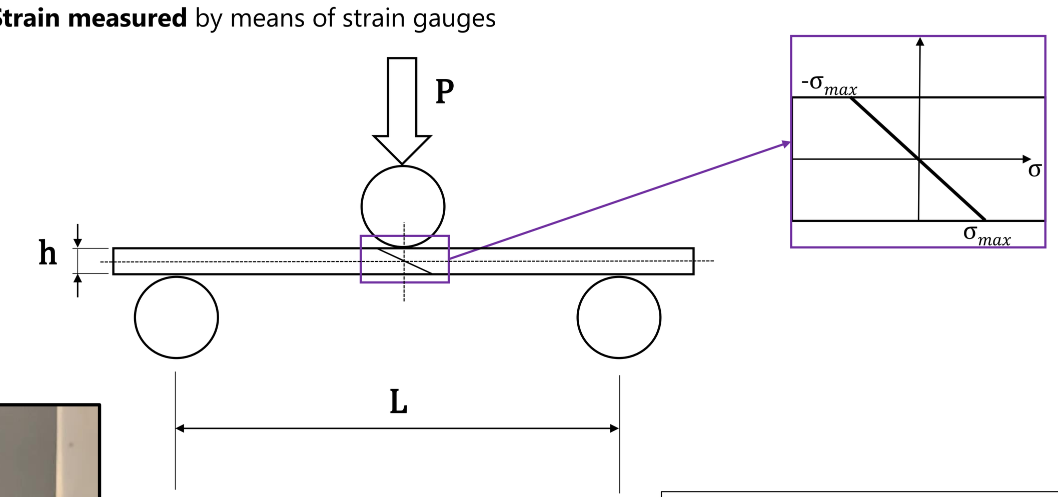


Equipped detector

Three-points bending test:

- Point load used to bend the test subject
- Test subject placed between two supports
- **Applied load measured** by means of a load cell
- Superficial stress computed from the measure point load and the geometrical properties
- **Strain measured** by means of strain gauges

Performed in accordance with ASTM Standard: D 7264 – 07



Sample volume = L x h x b

Retrievable information:

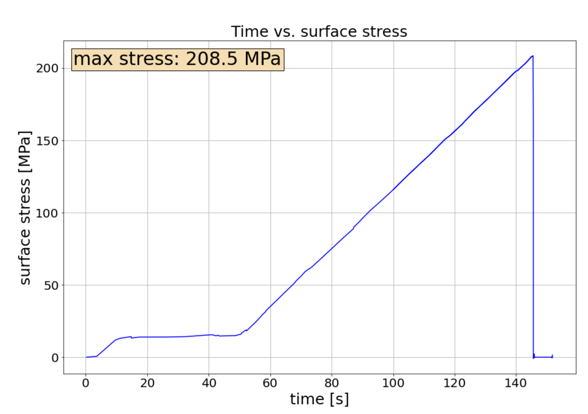
- $\sigma_{surf} = \frac{3PL}{4bh^2}$
- $\sigma_{surfmax} = \sigma_{surf@failure}$
- $\varepsilon_{max} = \varepsilon_{@failure}$
- $E = \frac{\Delta\sigma}{\Delta\varepsilon}$

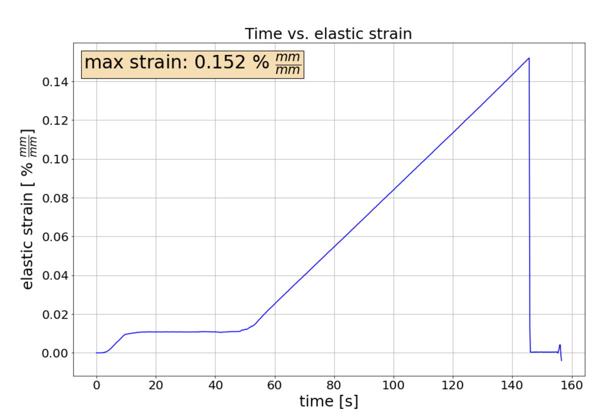
3.2.2 Test campaign

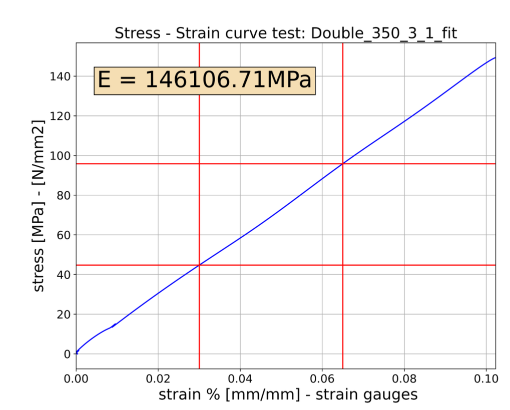
Test	Samples	Measured quantities	Notes	Outputs
Batch_1	6	Force	Single repetition, tested to failure	Max stress
Batch_2	3	Force, strain	Single repetition, tested to failure	Max stress, Max strain, Young modulus
Batch_3	3	Force, strain	Multiple repetitions, tested in the elastic region	Young modulus
Batch_4	2	Force, strain	Multiple repetitions, tested in the elastic region	Young modulus

Results:

- Max stress: $\mu = 251.15$ MPa, $\sigma = 70.60$ MPa, 9 samples
- Max strain: $\mu = 0.1457\%\ \frac{m}{m}$, $\sigma = 0.0430\%\ \frac{m}{m}$, 3 samples
- Young modulus: $\mu = 142.19$ GPa, $\sigma = 10.19$ GPa, 5 samples – 23 repetitions







4. Adhesive damping estimation

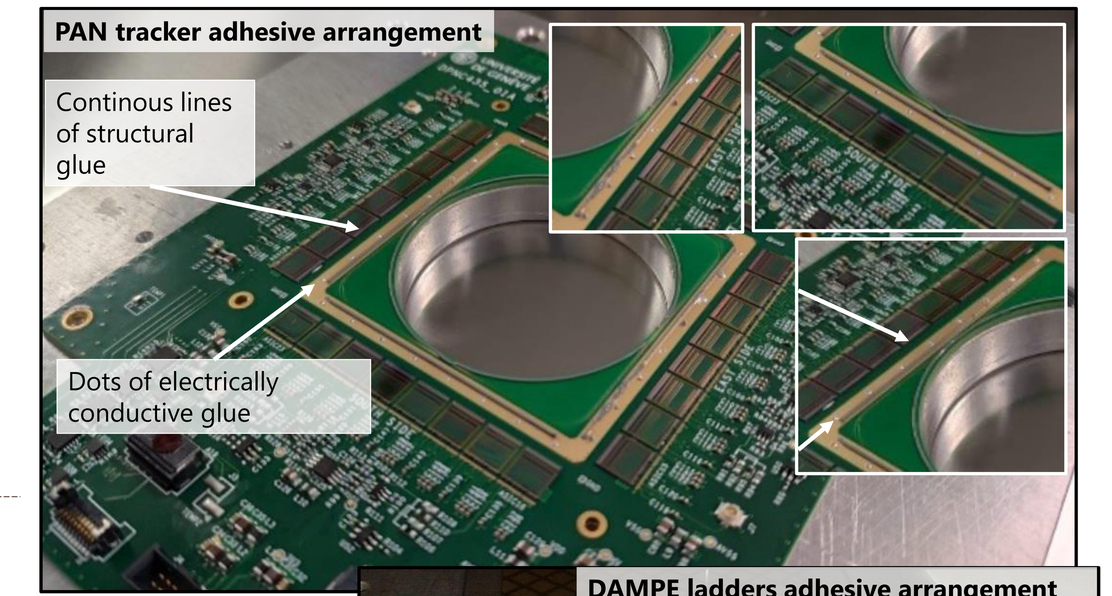
Goal: estimate the effect of the adhesive on the detectors' dynamic response with a particular focus on damping.

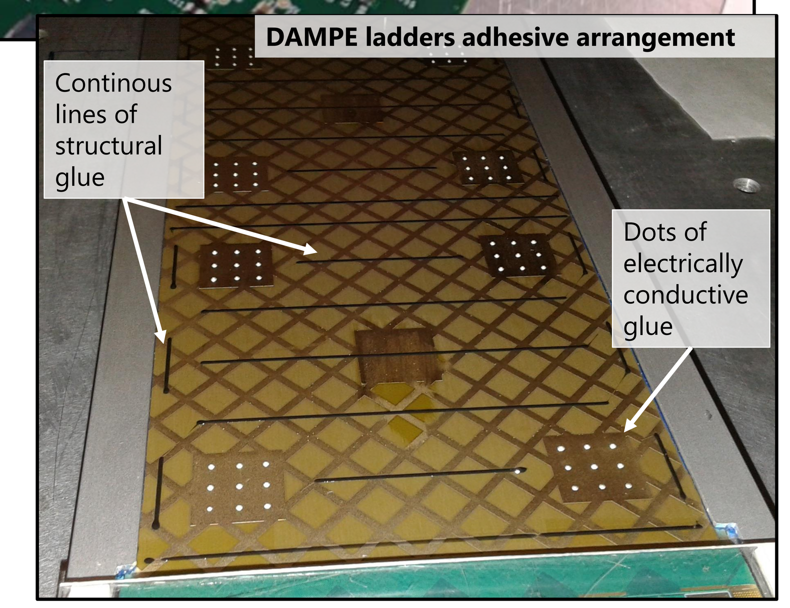
4.1 Introduction

Space components are subjected to vibrations and shocks. The stresses coming from these dynamic loads are strongly dependent on the system damping.

At the same time, the damping depends on how the detector bonding materials. On this topic, a previous study demonstrated the **critical role of adhesive**.

Two different types of glue are employed to form the bond between the detective tiles and the substrate (generally a PCB or Kapton foil): the first, **structural,** ensures the mechanical bond between substrate and detectors; the second, **electrically conductive,** allows the detectors' bias plane polarization by electrically connecting it to the bias path on the substrate.





4.2 Structural glue

Shock test performed on DAMPE Quarte Plane

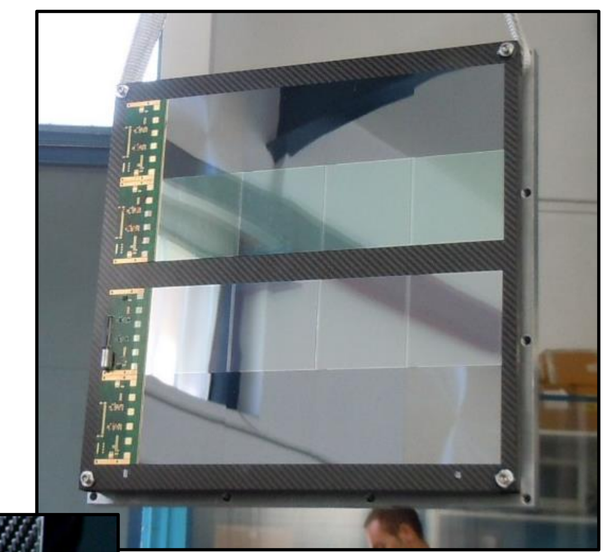
The failed test on DAMPE mock-up shown the need for a less stiff and more elastic adhesive.

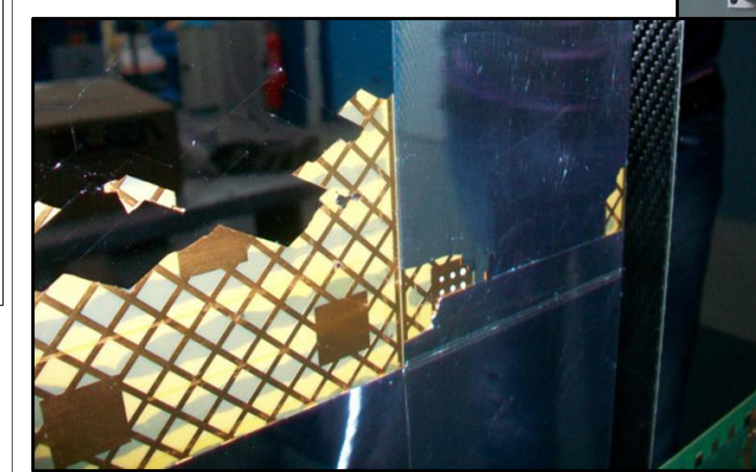
Epoxy glue, E ~ 1-2 GPa

⇩

Silicon glue, E ~ 1-2 Mpa

Since then, silicon glue has been employed in the assembly of detectors due to its higher compliance and energy-damping properties. With this solution, the system is less rigid, and the shock-associated high-frequency stresses reduced



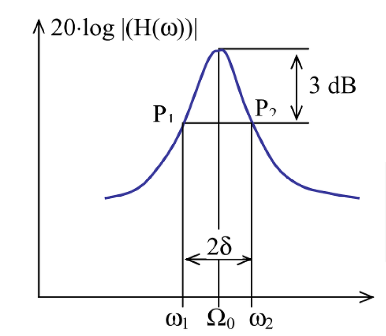


4.3 Conductive glue

Introduction

Although remarkably beneficial, the glue substitution does not completely solve the problem. Indeed, **the conductive glue is as well epoxy based.**

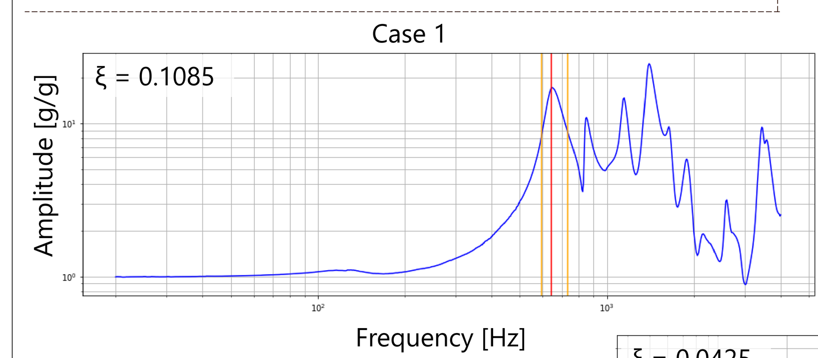
Hence, the need to study the effect of this glue on the system dynamics. For this reason, the authors estimated the system damping for two different bonds.



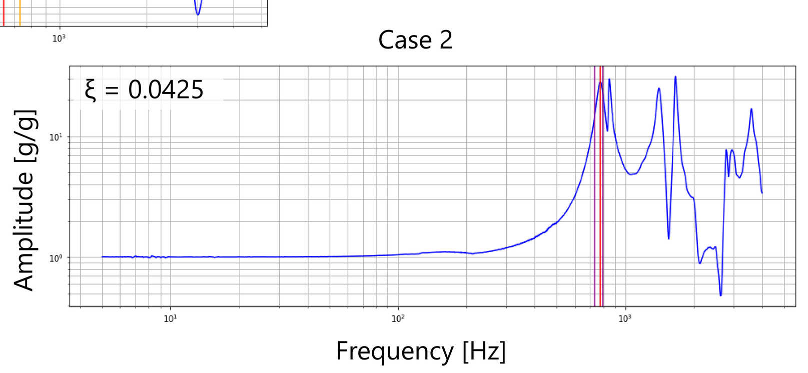
3 dB damping estimation method, in the frequency domain

$$\xi = \frac{(\omega_2 - \omega_1)}{2 \cdot \Omega_0}$$

Case 1

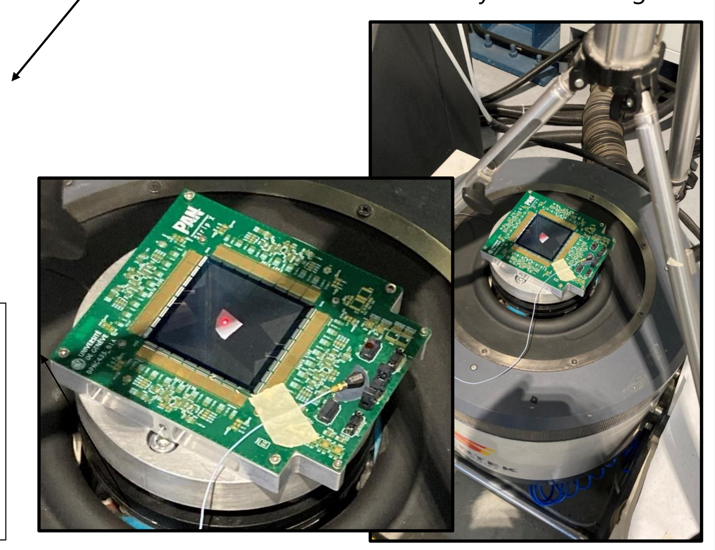


Case 2



Set-up

- PAN tracker vibrated on the shaker
- Frequency Response Function measured with a laser interferometer
- 1st mode damping estimation for
  - **Case1:** tracker bonded with structural glue alone
  - **Case2:** tracker nominally (see figure above "PAN tracker adhesive arrangement") bonded with both structural and electrically conductive glue



Results:

- Stresses on the detector, especially those shock-associated, can be reduced by employing silicon-based glues in place of epoxy-based ones.
- A over usage of electrically conductive glue is hazardous for the detectors since the former glue increases the detector-substate bonding stiffness and reduces the bond's energy dissipation capabilities.