SENTINEL-1 HRM SHOCK PROPAGATION

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ABSTRACT

The Sentinel-1 SAR instrument is fixed by 12 identical HRM units, preloaded with 30 kN each. Though the design is based on several Astrium heritage programs, high frequency release shocks turned out to be a major issue in this special application due to the vicinity of sensitive electronics. The paper describes the results and lessons learned of an investigation about emitted high frequency release shocks performed in the frame of the qualification process of the Sentinel-1 HRMs.

1. INTRODUCTION

The Sentinel-1 SAR instrument is fixed to the spacecraft via 6 hold down points per antenna wing, as shown in the figure below.

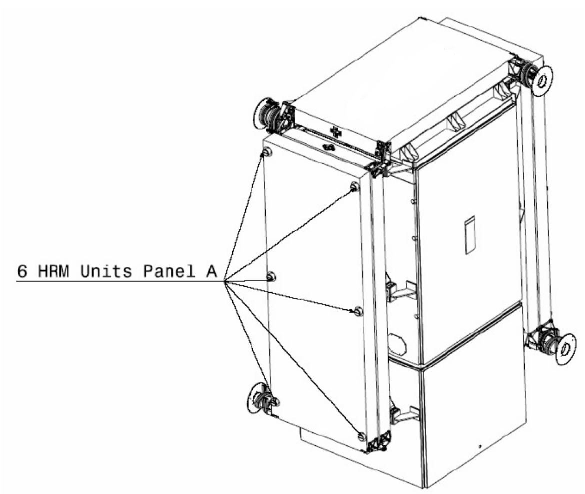

Figure 1: Sentinel-1 HRM Arrangement

Due to the vibration loads of the heavy instrument (~360 kg per wing), the preload force for antenna clamping provided by the HRMs had to be increased several times during the design process, with the final value of 30 kN per HRM point.

This very high preload has been achieved with an HRM design, based on an M10 titanium bolt with an off the shelf NEA release unit and a spring driven retrieval mechanism with an aluminum honeycomb crush damper at the end of the bolt travel. Beside the preload requirement, the clamped length of the antenna stack of 204 mm has been identified as a major design driver. The demand for such a long bolt length however leads to a high stored energy and thus high bolt acceleration during release.

The final HRM design is shown in the figure below.

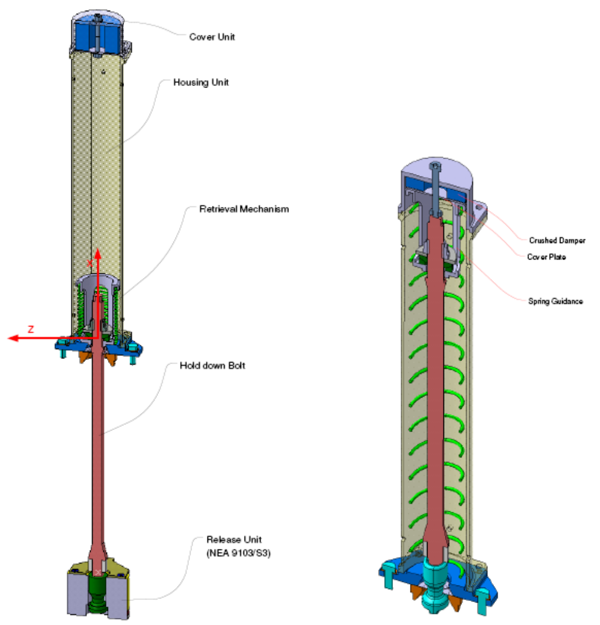

Figure 2: HRM Design

Since it is very difficult to determine the emitted shock during the design phase, a dedicated test session has been defined as part of the unit qualification program with the aim to perform damper fine adjustments and early SRS measurement. As a consequence of the high bolt preload, the initial release test revealed very high shock loadings up to 3000 g for frequencies above 5 kHz.

The following chapters summarize the investigations, tests and analyses, performed to optimize the shock performance of the system and to identify actual loadings of the adjacent hardware.

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2. DAMPER SELECTION

In the early phase of the project, a trade-off between different impact shock dampers has been performed, with the aim to find a re-useable system with the required performance. Beside the robustness and the capability to absorb the high impact energy, the wide operational temperature range of -80°C to +80°C turned out to be the a major design driver.
According to this, 3 possible solutions where identified:

- Silicone rubber ring, made of Elastosil RT607
- Metal wool pieces in different configurations
- Pre-crushed Aluminum honeycomb

The different damper designs are shown in the figures below:

Figure 3: Silicone ring

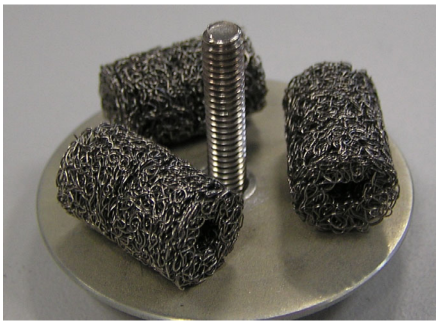

Figure 4: Metal wool

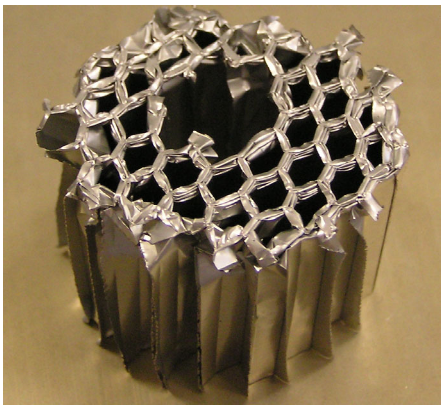

Figure 5: Pre-crushed honeycomb

During impact testing with representative bolt preload, the following SRS figures have been recorded:

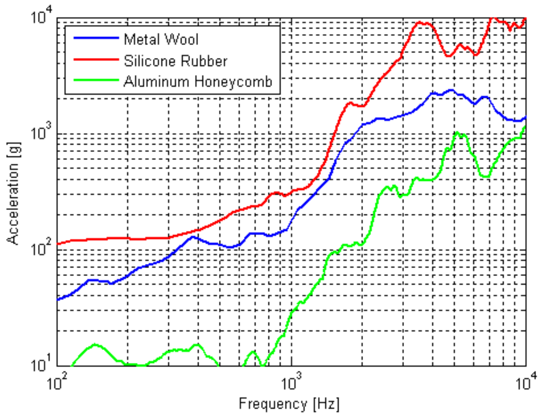

Figure 6: SRS Results of different Shock Dampers

From these results, it was clear that the silicone rubber does not provide a sufficient damping. It was also assumed that the performance of the rubber would decrease significantly at lower temperatures leading to even higher shocks. The metal wool, although it provides a better damping performance and almost no temperature dependency, has also been discarded since it was permanently deformed after testing. The pre-crushed aluminum honeycomb however provided excellent damping capabilities without temperature dependency.
For the application within the SAR system however, aluminum crush dampers are considered critical due to the possible liberation of metallic particles from the HRM envelope to the antenna aperture. This has been prevented by a dedicated particle seal made from 2 layers of Kapton foil in form of a collar around the bolt.

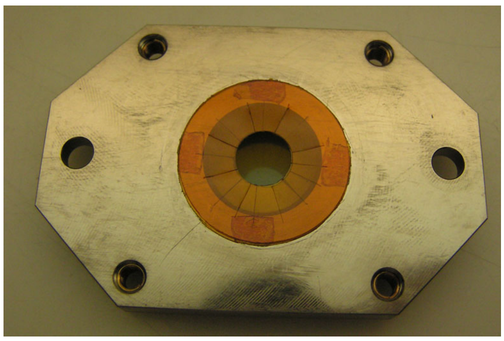

Figure 7: Kapton particle seal

During life testing, it was demonstrated that the particle seal encloses the inner HRM envelope successfully, even after 40 release operations.

3. INITIAL RELEASE TEST RESULTS

After optimization of the impact damping system, a representative release test at ambient condition has been performed. The time data and SRS results are shown in the figures below.

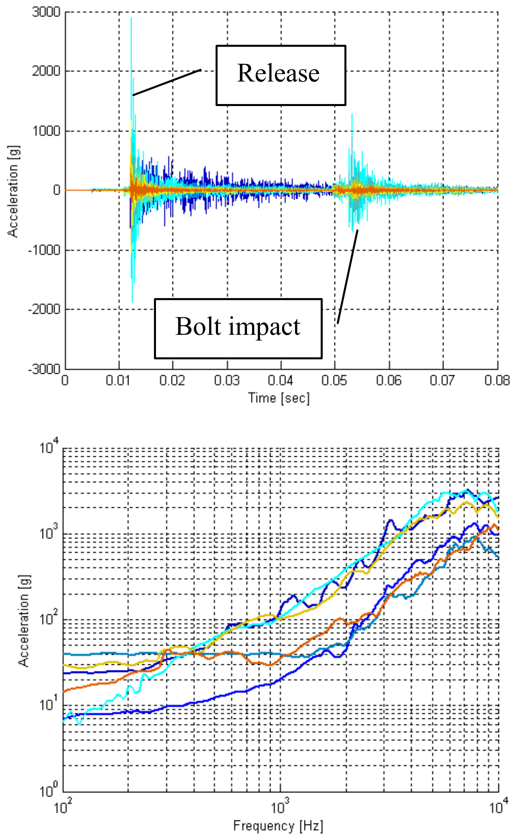

Figure 8: SRS from initial release

From this results, it is obvious that the shock, produced by the impact of the bolt to the damper is negligible compared to the release shock. Furthermore it is noticeable that the system has a very low shock for frequencies below 2 kHz. For high frequencies however the accelerations increase up to 3000 g in several directions, which has been considered critical for the SAR electronics on the antenna.

4. BOLT MATERIAL SELECTION

In order to decrease the high SRS levels during the release operation (while maintaining the required preload) it was investigated whether the stored energy of the system could be reduced by a different bolt material. Due to the fact that the bolt release by the NEA is more a sliding movement in the first milliseconds than a sudden release, it was assumed that a smaller bolt elongation could gain additional advantage since a higher percentage of the stored energy would be transferred to sliding. In addition, following the relation between the stiffness k, the stored energy E_P and the displacement x it is clear that a higher young's modulus leads to a lower stored energy, since x is considered quadratic in the equation.

$$E_P = \frac{1}{2} \cdot k \cdot x^2$$

Due to the high preload however, the amount of possible bolt materials is limited. From the few alternatives on the market a bolt made from Inconel has been chosen for further testing, since the calculated stored energy is only about 65 % of the one of the Titanium. The SRS results however showed the opposite effect. Although the levels are identical for lower frequencies, the Inconel bolt doubles the accelerations above 5 kHz.

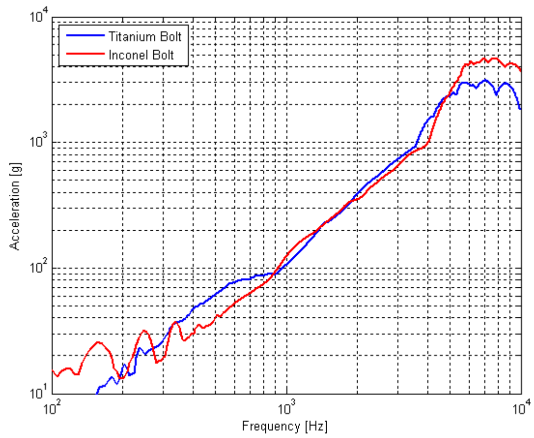

Figure 9: SRS comparison Titanium - Inconel Bolt

This was not expected, but the explanation is conclusive. Due to its higher stiffness, the Inconel bolt is less elongated by the pre-tension. Consequently the energy has to be released in a shorter length/time. This leads to higher shock levels in the higher frequency range.

In addition to the poor release characteristic, it has to be considered that the higher density of the Inconel, compared to the Titanium increases the moving mass of the bolt. Hence the crush damper would need to deal with a more severe impact energy. Accordingly, the Titanium bolt was maintained as baseline for the HRM design.

5. TRANSFER FUNCTION MEASUREMENT & INTERPRETATION

In order to identify the shock loading of the most critical electronic equipments, the transfer function from the shock source through the structure needed to be determined. Since the shock path contains several bolted interfaces, as well as some complex geometries, it was considered impractical to apply analytical methods or FEM. The direct shock path is shown in the figure below:

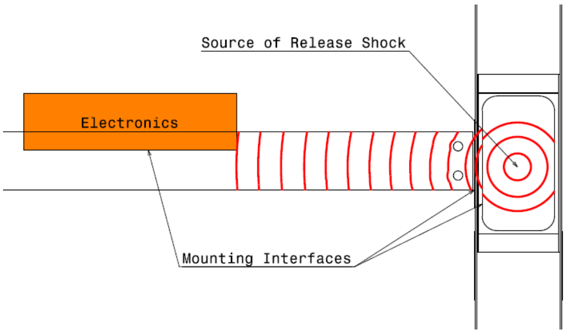

Figure 10: Shock Path

Due to the distance from the source to the electronics of about 200 mm, the attenuated loading can be characterized as mid field shock. This means that the loading spectrum contains both, direct shock waves as well as structural resonances.
Since the fully equipped antenna panel frame was not available for testing at the time of the HRM qualification, a structural test sample with representative mounting interfaces has been used instead, see figure below.

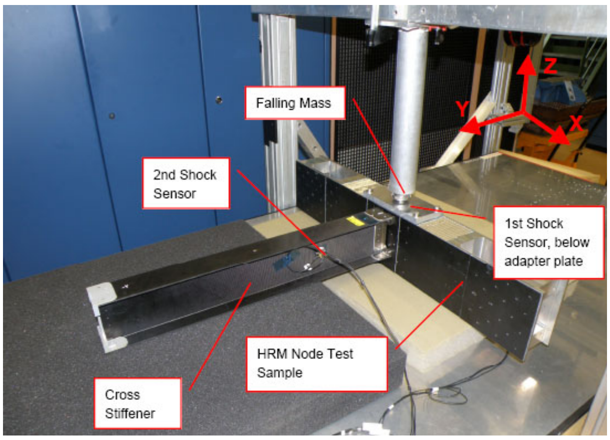

Figure 11: HRM Transfer Function Test Sample

This simplification however has complicated the interpretation of the transfer function measurement, as only the direct shock wave propagation can be considered accurate due to the representative shock path. The structural resonances however are considered to be very different, compared to those of the later antenna environment due to the simplified boundary conditions of the setup. For the preparation of the transfer functions, the differentiation between resonance amplification and direct shock propagation is a major task. Taking a look at the measured transfer functions, it is clear that the attenuation for frequencies above 4 kHz is sufficient to protect the adjacent electronics. It is however also noticeable that amplifications in the frequencies below 2 kHz achieve up to 34 dB.

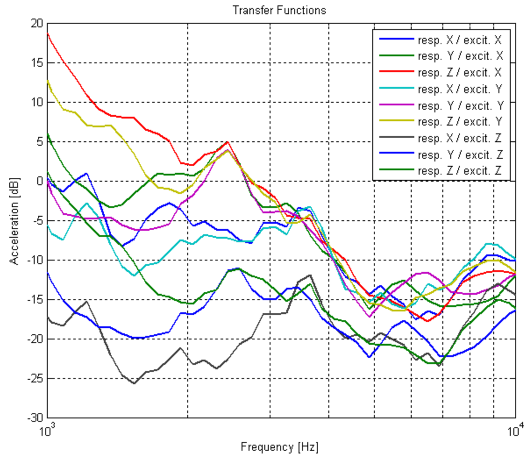

Figure 12: Transfer Function Summary

To clarify the characteristics of the mid field shock at the electronics level, the source signal, as shown in the figure below, and the attenuated signal have been compared in a spectrogram.

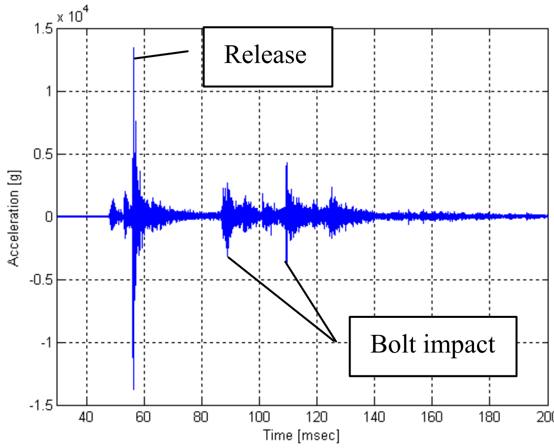

Figure 13: Shock Time Signal

From the source spectrogram it is obvious that the emitted shock is highly transient and thus dominated by high frequency accelerations.

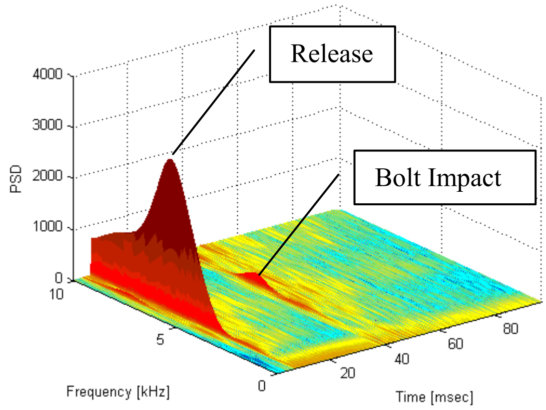

Figure 14: Spectrogram Source

To assess the characteristics of the attenuated signal, the above mentioned transfer functions have been applied to the transient signal of the near field shock. This reveals that the high frequency accelerations above 5 kHz are significantly damped, so that it can be concluded that they no longer pose a thread for the adjacent electronics. On the other hand, amplification at frequencies below 1 kHz can be identified during release as well as during impact. These clearly are amplifications due to structural resonances, since they did not appear in the near field signal.

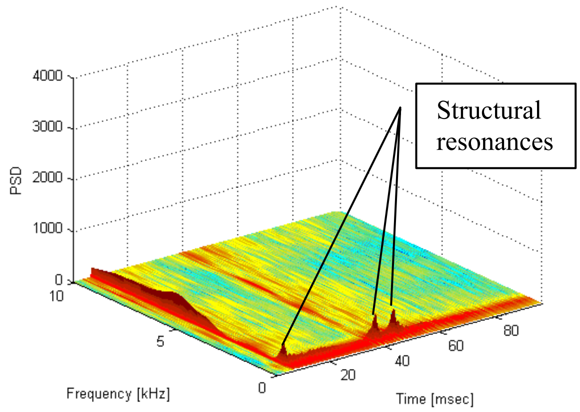

Figure 15: SRS at Electronics Level

6. LESSONS LEARNED

Since the emitted shock of a release system is mainly driven by the level of preload in stowed condition, the actual SRS levels could not be reduced significantly by changing the bolt material. This has been demonstrated by a comparing release test with bolts made of Inconel and Titanium.

The demand for a re-useable impact damping system has lead to a number of bread board tests with different materials and principles. It was however identified that shock energies above a certain level always require a system based on plastic deformation. This was realized in form of a standard aluminium honeycomb crush damper, proving high shock absorbing capability, low mass and excellent reproducibility over a high operational temperature range.

The actual mid field SRS levels due to the direct shock wave propagation can be measured and calculated in form of transfer functions. For the transfer function measurement, structural samples with a representative direct shock path deliver sufficient results. However, it has to be considered that low frequency accelerations due to structural resonances are not representative using a simplified structural setup.

7. ACKNOWLEDGEMENTS

We would like to thank the ESA / ESTEC experts for their expertise and support during the investigations, analyses and test phases of the HRM project.