LISA Mission and System Architectures and Performances

Peter F. Gath, Dennis Weise, Hans-Reiner Schulte, Ulrich Johann
Astrium GmbH Satellites, 88039 Friedrichshafen, Germany
peter.gath@astrium.eds.net

Abstract. In the context of the LISA Mission Formulation Study, the LISA System was studied in detail and a new baseline architecture for the whole mission was established. This new baseline is the result of trade-offs on both, mission and system level. The paper gives an overview of the different mission scenarios and configurations that were studied in connection with their corresponding advantages and disadvantages as well as performance estimates. Differences in the required technologies and their influence on the overall performance budgets are highlighted for all configurations. For the selected baseline concept, a more detailed description of the configuration is given and open issues in the technologies involved are discussed.

1. Introduction
The starting point for the LISA Mission Formulation study was the design established in the 2000 Final Technical Report (FTR) [1]. During the course of the study, alternative designs were identified that offered a high potential for improvements in the overall payload system and performance.

Figure 1: Different payload designs investigated.
Several trade-off studies have been performed on individual subsystems such as the propulsion system, launch stack configuration, and especially for the payload configuration itself. Among other trades, the main trade-offs performed for the payload are:

- telescope type
- Gravitational Reference Sensor (GRS) vacuum enclosure or open GRS
- optical assembly pointing vs. in-field pointing
- realization of point-ahead angle compensation
- strap-down / two step-interferometry
- Use of optical GRS readout for the drag-free and attitude control system

This paper focuses on the trade off between optical assembly pointing and in-field pointing. Figure 1 gives an overview about the investigated designs.

2. Mid-Term Review: MTR Design

By the time of the mid-term review of the study in June 2006, the established payload design baseline was based on optical assembly pointing, i.e. the whole optical assembly, consisting of telescope, optical bench, and GRS, is rotated around a pivot axis in order to compensate for the varying angle between two LISA interferometer arms. The design was an evolution of the original FTR baseline design and is depicted in Figure 2.

Already by the time of the MTR, an interesting alternative design concept was identified which avoids the articulation of the whole optical assembly. Instead of moving the whole assembly, a small scan mirror within the telescope is compensating the changes in the angle between two interferometer arms.

![Figure 2: MTR design baseline](image)

While this seems to be an attractive concept from the mechanical side, the requirements imposed by this approach on the optical metrology system and especially on the telescope are very challenging. This can easily be understood since the scan mirror is located directly in the interferometry path where pm-stabilities or at least a knowledge about pm changes in the LISA measurement bandwidth are required for the science measurement. When moving the complete optical assembly, several nm can be allowed since this only has an impact on the movement between the proof mass and the GRS housing.

3. Payload Architecture Review 1: PAR-1 Single Active GRS

The first in-field-pointing configuration investigated was a configuration with only one active GRS (Figure 3, left). For redundancy and reliability issues, a second, cold redundant GRS is installed in a geometrically less optimal position on each S/C. However, only one GRS is operated during science
operation, i.e. a full drag-free control can be established in all lateral degrees of freedom of the proof mass and only suspension actuation around rotational degrees of freedom is required.

In order to successfully establish this payload concept, one key point was the development of a telescope design that allows full performance over a large field-of-view of approx. ±0.5°. More details on this are given in [2].

Sizing efforts on the spacecraft and propulsion module showed that for the PAR-1 design, the launch stack mass becomes unacceptably high. Therefore, this particular configuration was not considered to be a reasonable candidate for a potential new baseline. An effort was taken in order to significantly reduce the overall envelope of the payload and a modified design of the single GRS configuration was introduced. This requires that the two GRS are moved together as close as possible, which requires either an open GRS system or a common vacuum enclosure for the two GRS. It was shown that the self-gravity issues can be handled by a proper placement of compensation masses.

The main benefit of this modified configuration illustrated in Figure 3 (right) is that it does not only reduce the payload envelope. By moving together the two GRS, also the science performance requirements can be met with all three interferometer arms in case of a failure of the nominal GRS.

Figure 3: Single active GRS configuration with in-field pointing (left) and with full GRS redundancy (right)

4. Payload Architecture Review 2: PAR-2 Two Active GRS

The second in-field pointing configuration investigated was a configuration with two active GRS, each GRS serving one interferometer arm. From a DFACS point of view, such a configuration is very similar to the MTR baseline, except that no telescopes need to be moved. The configuration is shown in Figure 4.

It turns out that by crossing the two lines of sight of the two telescopes, the most compact payload configuration can be achieved. However, as for all in-field pointing designs, there exists a very strong coupling between the subsystems in terms of alignment.

Figure 4: Two active GRS configuration with in-field pointing
5. MTR-Design with Interface Structure
For the trade-off study, also the MTR baseline was modified by introducing a common interface structure between the two separate optical assemblies and the spacecraft. This significantly simplifies the interface definition to the S/C and also improves the AIVT process. The design of this structure followed the same mechanical requirements as they were imposed on the in-field pointing configurations. The resulting configuration is depicted in Figure 5.

![Figure 5: Moving optical assemblies with interface structure](image)

6. Performance Comparison and Trade-Off
In terms of overall performance it turned out, that all configurations can meet the LISA science requirements. When compared with the MTR design, the PAR-2 configuration showed a slight increase of the noise at low frequencies. This is mainly due to a larger contribution from the path-length error, based on the assumptions made for thermal stability and its frequency dependency.

The single active proof-mass configurations show a slightly better performance at medium frequencies due to the full drag-free control in lateral degrees of freedom. However, the performance is still very close to the performance of the MTR configuration with moving optical assemblies.

A comparison of the configurations is shown in Figure 6.

The complete trade-off study took into account 71 different parameters evaluated for the different configurations. These also included estimates for the risks of technology developments, launch stack mass, power consumptions, number of required measurement channels etc. It turned out that all configurations show a similar overall “performance” when performing a weighted trade-off analysis.

Due to the very similar performance of all configurations, the MTR design was finally chosen as the baseline configuration for the remainder of the LISA Mission Formulation study. This decision was mainly driven by a reduced complexity of the optical system, especially the telescope, and the elimination of the scan mirror with a fairly large dynamic range and pm stability requirements from the optical metrology path. Especially this scan mirror was considered to be a very high risk for the in-field pointing designs.

![Figure 6: Comparison of strain sensitivity](image)
7. Mission Design Review: Moving Optical Assemblies

The baseline adopted for the mission design review was derived from the MTR design and includes many lessons learned during the study of the in-field pointing designs. In order to reduce the risk of stray-light, an off-axis telescope was also designed for this configuration, but with a smaller field-of-view which significantly simplifies the design. Also the overall envelop of the design could be improved by integrating the interface structure to the spacecraft directly into the payload design. This is illustrated in Figure 7.

![Figure 7: Moving optical assemblies – MDR Baseline](image)

In order to significantly improve the telescope pointing knowledge and allow for ground calibrations of pointing sensitivities, an additional optical metrology system for the point ahead angle actuator is introduced in the design. The estimated jitter of this mechanism was limiting the pointing knowledge in the MTR design.

Another element introduced into the design is the optical truss which measures any path-length change in the telescope subsystem. While this was originally thought to be mandatory for achieving the performance in the in-field pointing designs, it turned out to be an excellent tool during ground testing and AIV. On orbit, it serves as a backup system in case of any unexpected path-length change effects, e.g. due to material outgassing, and thus increases the robustness of the mission. The optical bench design is shown in Figure 8.

![Figure 8: Optical bench – MDR baseline](image)
8. Conclusions
Detailed trade-off studies were performed on all mission and system levels during the LISA Mission Formulation study. This paper describes the particular trade-off for different payload configurations. Lessons learned during the investigation of the alternative payload designs were included in the finally selected baseline design, i.e. a final iteration on the payload design was included after a baseline concept was selected. This new payload design is now complemented with the required specifications for a further refinement in the next phase of the LISA project.

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