Title: *HEMERA – Constellation of passive SAR-based micro-satellites for a Master/Slave configuration*

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The Sustainable Development Goals covered by the HEMERA mission are:

1. Goal 9: Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
2. Goal 11: Make cities and human settlements inclusive, safe, resilient and sustainable
3. Goal 17: Strengthen the means of implementation and revitalize the global partnership for sustainable development

Need

Synthetic Aperture Radar (SAR) technology has been used for Earth Observation (EO) as it permits to obtain high-resolution imagery from the analysis of the spectrum of the received signal collected by a coherent radar system. Currently, this technology is mainly used on large and heavy satellites. To investigate the possibility to decrease weight and cost of platforms carrying a SAR instrument, both private agencies and research groups started several studies to try to reduce these parameters for this type of mission. The HEMERA mission has been conceived in this context, to optimize the spacecraft mass, costs and development time and maintain reliable performances. Indeed, the HEMERA small satellites are equipped with a passive X-band SAR antenna in order to define a new costellation to be used as a low-cost alternative for supporting SAR costellations already in orbit. The defined system architecture is based on a bi-static/Master-Slaves configuration. In particular, COSMO-SkyMed 1-4 are considered the Master satellites and the HEMERA eighteen micro-satellites are considered the Slaves. In this way, the data acquired during the HEMERA mission will be used on a wide range of applications, such as maritime awareness, defence and intelligence and land stability analysis. Indeed, the selected in-flying formation main parameters ensure improvements in terms of ground resolution for differential displacement of faults, structural failure and subsidence monitoring.

Mission Objectives

Primary objective:

- To increase the resolution and the amount of data acquired during the COSMO-SkyMed 1-4 in-orbit operations (3 m x 3 m of COSMO-Skymed in strip-map mode to 1.7 m x 1.5 m of HEMERA)

Secondary objectives:

- Structural failures: monitoring the effects of environmental phenomena, such as earthquakes, floods and avalanches, affecting Italy and other areas at risk;
- Subsidence control: observation over time of the level of soil sinking;
- Earth plates movement monitoring: study of the differential displacement of the faults.

Concept of Operations

Space Segment. The HEMERA mission consists in a 18 small satellites formation. The selected configuration [1] considers the COSMO-Skymed constellation satellites as master and the HEMERA spacecraft as slaves. Each HEMERA spacecraft will board a passive SAR X-band (7 ÷ 12.5 GHz) antenna. The instrument main parameters have been defined in order to be able to receive the reflected power return waves of the signal emitted from the Master satellites. The HEMERA antenna is a passive one, able only to receive the backscattered power. In this way, the proposed constellation is able to be optimazed in terms of spacecraft and antenna weight, power consuption and dimensions if compared to the current operative constellations equipped with active SAR antenna in X-band. Moreover, the bi-static system architecture allows the HEMERA spacecraft to operate with a smaller passive antenna suitable for more Master Constellations, without the need of having on-board its own X-band transmitter,.

Ground Segment. It is composed of eight Ground Stations (GSs) that are located in: Kiruna (Sweden), Katsuura (Japan), Malindi (Kenya), Matera (Italy), Punta Arenas (Chile), Svalbard (Norway). The most important is the Kiruna GS: being in proximity of the North Pole, granting the maximum number of accesses among the Ground Stations. This network has been identified as the most suitable to sustain the needed downlink data rate, as it maximises the visibility time. RX/TX antennas in X band are required in every station.

Launch Segment. The VEGA Small Spacecraft Mission Service (SSMS) [2] has been identified as appropriate for placing satellites in their orbit. Indeed, The reference for its service in terms of orbital parameters is Sun Synchronous Orbit (SSO), at any Low Earth Orbit (LEO) altitude ranging between 400 and 1400 km. The target of HEMERA mission is at 495 km height.

Key Performance Parameters

- Master synchronization. To avoid wasting power, the slaves must know when the transmission by the masters is activated, in order to be synchronized to receive the waves.
- Resolution. The proposed mission objectives require a resolution of at least 10 m. The defined passive X-band SAR system guarantees a resolution of 1.75 m x 1.2 m.
- Interferometry. Since COSMO-SkyMed works with SAR interferometry, HEMERA, acquiring the same return of data from different points of view, can increase the quality and add more perspectives to the already available interferometric data.
- Attitude control system stability. In order to ensure the optimal performances, the SAR antenna pointing shall remain stable at an off-nadir angle of 38 deg. Each HEMERA satellite is provided by a three-axis stabilization platform in order to compensate any types of LEO disturbances.

Space Segment Description

The mission consists in 18 micro-satellites evenly spaced of 20 deg, placed in the same orbital plane (but at a lower altitude of 495 km) of the reference constellation (COSMO-Skymed), whose satellites will act as masters. Each HEMERA spacecraft is equipped with a passive X-band SAR [3] deployable antenna to collect the returned power of the X-band signal emitted by the COSMO-Skymed constellation. The features of the SAR antenna are shown in Table1.

SLAVE		
Dimensions		
Antenna length	3.5	[m]
Antenna height	0.7	[m]
Antenna parameters		
Carrier Frequency	9.65	[GHz]
Signal Bandwidth	300	[MHz]
Incidence angle (access region)	[22 : 54]	[°]
Azimuth resolution	1.750	[m]
Variable ground range resolution	[1.2307 : 0.5722]	[m]
Signal Noise Ratio (SNR)	[9.8401: 1.1103]	[dB]
Radar Cross Section (RCS)	20	[dB]
Instantaneous Data Rate	[1.1256e+08 : 9.6557e+06]	[bit/s]
Antenna Gain	43.167	[dB]
Ground Range Swath	46.729	[km]

Table1.

Since a stable pointing is required for mission purposes, each HEMERA satellite needs three reaction wheels for a three-axis stabilization [4] and three magnetorquers (together with a magnetometer) for their desaturation. A Sun sensor (attitude accuracy between 0.005 deg to 3 deg) and a star sensor (attitude accuracy between 0.0003 deg to 0.01 deg) have been chosen to ensure HEMERA satellites attitude determination both in light conditions and in the eclipse. The platform is also provided with body-mounted solar panels (composed by 316 cells to ensure about 1W per cell) configurated [4] with a mean solar radiation incidence angle of about 30 deg. Two lithium-ion batteries are also included on-board in order to take care of the subsystems activity during the eclipse phases (80 Whr provided). Each satellite is equipped with an On Board Computer (OBC), which exploits an OBC-15 technology based on the proven processor ERC32 [5], for high performances on the LEO orbit. The OBC is used for the data handling, control and attitude functions of the satellites and for monitoring the other subsystems. The satellite will collect data of the Area of Interest (AOI) in cooperation with the COSMO-Skymed in-flight operations. Those data will be stored in mass memory and downlinked to the nearest ground station. Due to the huge amount of data generated by the SAR, an X-Band antenna (working at a frequency of 8 GHz) has been chosen for communicating with ground (X-band transmitter and receiver are

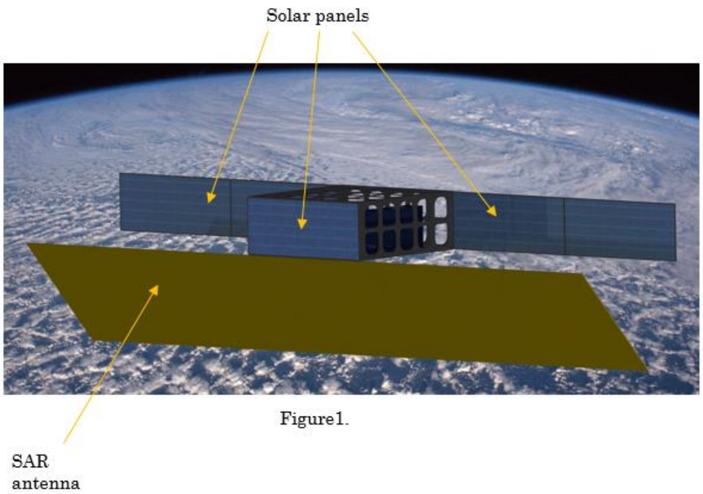

Figure1.

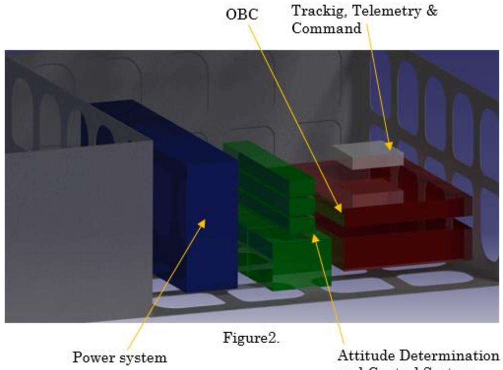

Figure2.

included). Table2 highlights the performed Link Budget, while the described platform and satellite configuration are shown in Figure1-2. The total mass estimated for each HEMERA satellite is about 40 kg. As previously explained in the Launch Segment, the VEGA SSMS has been selected for the HEMERA in orbit insertion. The total delta-V required for such a target is about 8.5 ÷ 9 km/s, considering velocity losses such as the gravitational and the drag ones.

Link Budget	Downlink	Uplink	
RF Power (tx)	4.8	3.0	[dBW]
Antenna Gain (tx)	7	13	[dB]
G/T (rx)	15	3	[dB]
Path Loss	175.1	163.1	[dB]
Atmospheric Loss	2.5	2.5	[dB]
Pointing Loss	3	3	[dB]
Additional Loss	1	1	[dB]
Required Data rate	67.0	56.0	[dB-Hz]
Eb/N0	7.8	23.0	[dB]
Required Eb/N0	2	2.7	[dB]
Margin	5.8	20.3	[dB]

Table2.

Orbit/Constellation Description

The orbit of HEMERA is a circular Low Earth Orbit (LEO), located at 495 km, with an inclination of 97.86 deg. In order to optimize the Master/Slave sinergy with the COSMO-SkyMed constellation [6], the same orbit at a lower altitude has been selected for locating the eighteen different slaves. This configuration allows each COSMO-SkyMed satellite to work in the described Master/Slave configuration with HEMERA satellites every two orbital periods of the master. A re-entry analysis has been performed by using the NASA DAS2.0 software to ensure the HEMERA Constellation is compatible with the ESA Space Debris Mitigation Guidelines. As main results, considering the features of each spacecraft and the selected orbital configuration, each spacecraft will remain in orbit at maximum for two years, enough to guarantee the success of the mission and for allowing not to include an active re-enter subsystem. The orbit parameters are higlighted in Table3 and the mission configuration is shown in Figure3.

Orbital parameters	
Inclination	97.86 deg
Semi Major Axis	6873 km
Eccentricity	0
Number of Satellites	18
Phasing	20 deg

Table3.

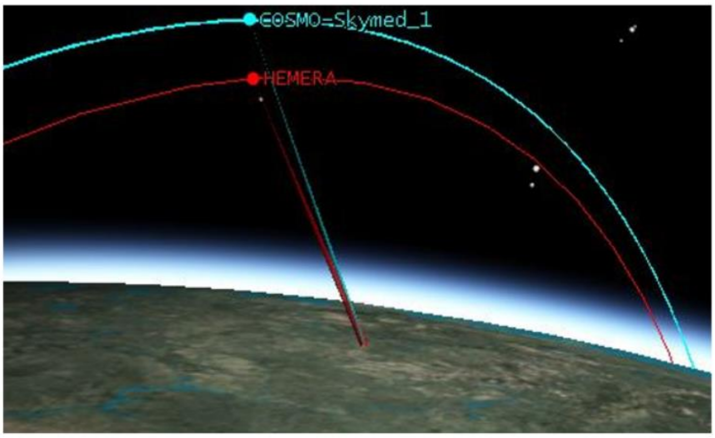

Figure3.

Implementation Plan

The HEMERA Mission will be able to collect coherent data if the time synchronization with the Master constellation is ensured. Indeed, an agreement with the companies (the Italian E-Geos and Telespazio) responsible for COSMO-SkyMed ground segment, data and operations management is needed. The HEMERA mission will increase the amount of available data, with respect to the current performances offered by the COSMO-Skymed constellation, thanks to the higher Synthetic

Aperture Period (SAP). Furthermore, an higher resolution and the improvements in terms of new and different view angles are only two of the many reasons these company has being interested in signing such agreement and in supporting the HEMERA mission. The projected cost for each satellite is expected to be within the range 569,600 : 808,000 $ (14,240 : 20,200 $ per kg).

The following Table4 highlights the main HEMERA implementation phases and steps.

Name	Begin date	End date
HEMERA Mission Design Phase	01/06/18	07/12/18
Agreement Implementation Phase	06/09/18	07/12/18
SAR antenna development	07/12/18	07/09/19
Subsystems development	11/05/19	07/09/19
Assembly and Integration	07/09/19	07/01/20
Testing phase	07/01/20	07/04/20
Launcher integration	07/04/20	07/06/20

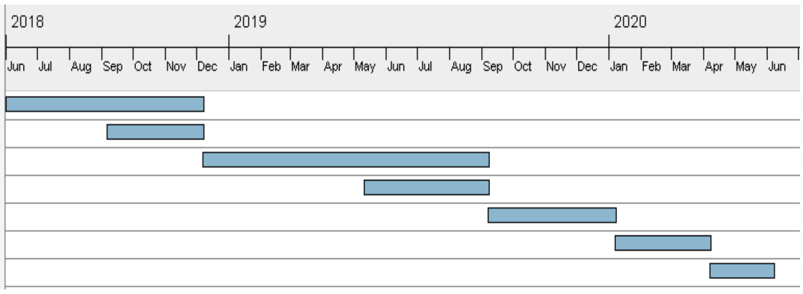

Table4.

Top 5 risks:

1. Lack of data reception by the master due to the antenna displacement with respect to ground pointing.
2. Access periods must be precisely monitored to facilitate data transmission. Furthermore, storage must not be overloaded in order to ensure the proper downlink and data rate.
3. Failure in orbit reaching. The achievement of the orbit is essential for data acquisition and to realize the right passive configuration with the master.
4. No stability in the spacecraft pointing. Both the SAR antenna and the ground communication phase are affected by the stability of the pointing system.
5. Delay in components obtaining. The delay in procuring the components leads to a slowdown in the development of the entire mission and to failure to meet important deadlines such as testing and launch.

References

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[2] REPORT: State of the art analysis about current launch opportunities and dispensers compatible with CubeSats standard

[3] Moreira, A., Prats-Iraola, P., Younis, M., Krieger, G., Hajnsek, I., Konstantinos P. Papathanassiou, K. P., A Tutorial on Synthetic Aperture Radar, Microwaves and Radar Institute of the German Aerospace Center (DLR), Germany

[4] Larson, W. J., Wert, J. R., *Space Mission Analysis and Design*, 3rd ed., Microcosm Press, El Segundo, California

[5] http://www.agilspace.com/pdf/onboard/06_OBC_ONBOARD.pdf

[6] Italian Space Agency, COSMO-SkyMed mission, COSMO-SkyMed System Description &User Guide