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HOSTING THE FIRST EDRS PAYLOAD

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I. INTRODUCTION

The European Data Relay System (EDRS) will provide optical and microwave data relay services between Low Earth Orbit (LEO) satellites at altitudes up to 2000 km and the ground through geostationary (GEO) satellite nodes. Currently, two such nodes have been procured as part of a Public Private Partnership (PPP) between Astrium (now Airbus Defence and Space) and ESA. The first node (EDRS-A) is a hosted payload embarked upon the Eutelsat 9B satellite and scheduled for launch in early 2015 [3].

The Eutelsat 9B satellite is based on the flight proven Eurostar E3000 platform of Airbus Defence and Space. A total of 33 satellites based on this platform are in orbit and have cumulated 170 years of operation. A further 12 are under production or are ready for launch.

The main design adaptations are identified in order to host the Laser Communications Terminal (LCT) of EDRS-A on the Eurostar E3000 platform. Whilst the Eutelsat 9B satellite hosts the complete EDRS-A payload, providing optical and Ka band Inter-Satellite Links (ISL) as well as a Ka band feeder link with the ground system, attention is focused on hosting the LCT for the optical ISL (OISL).

The contractor for the LCT and overall EDRS-A payload is Tesat Spacecom (part of Airbus Defence and Space). The optical communications system is designed to provide data rates up to 1.8 Gbit/s with high availability and is required to switch between different LEO satellites equipped with LCTs to acquire data during links lasting a few minutes. The acquisition sequence is more demanding in terms of attitude and attitude stability than conventional communications satellite missions. The main applicable requirements are reviewed and the design solutions outlined with attention to the perturbing sources. The layout on the Eutelsat 9B satellite is illustrated together with the radiators and heat pipes necessary to keep the LCT within its operating temperature range. In addition to considering the mechanical impacts of the LCT embarkation, the key electrical impacts are summarized including the few adaptations made to the avionics and flight software.

Finally, the ground control system is outlined with a discussion of the telecommand, telemetry and orbital control requirements in support of the optical communications links.

II. THE LASER COMMUNICATION TERMINAL

The design of the LCT is based on a precursor mission launched in 2007, in which two TESAT Spacecom LCTs on TerraSAR X and NFIRE satellites performed 5.6 Gbit/s data links in a LEO to LEO configuration over the past six years [1].

The LCT embarked on the Eutelsat 9B satellite is from the so-called “second generation” and is the fourth LCT built for LEO-GEO communications by Tesat Spacecom.

The overall EDRS system and general design of the LCTs have been previously documented in [2] and [3].

A. Description and Main Performance Characteristics

The LCT used for the EDRS-A mission is a stand-alone instrument designed to establish a 1.8 Gbit/s data relay link between a LCT hosted on a LEO satellite and the Eutelsat 9B hosted payload (EDRS-A) which acts as a data relay for low latency data transmission.

The optical communications principle is homodyne Binary Phase-Shift Keying (BPSK), giving the best photon per bit efficiency and Sun immunity during the data links.

The LCT itself consists of all subunits necessary to perform an optical data relay link, including data electronics for the transmit and receive paths, laser and fibre amplifiers and corresponding driver circuits as well as a computer that manages the operation, monitoring and control of the subunits. The LCT also contains a digital interface with the satellite main data bus, the mechanisms (coarse and fine pointer) and beam expander optics. The satellite bus voltage is converted into stabilized outputs for the internal electronics using a dedicated subunit.

All subunits are implemented on a single Frame Unit System (FUS) as shown in Fig. 1. This unit also embeds part of the Heat Transport System (HTS) collecting power to be dissipated externally to the LCT through a dedicated condenser plate which is the main thermal interface of the LCT with the hosting satellite.

The Coarse Pointing Assembly (CPA) implements two articulations (called azimuth and elevation, see Fig.1) to allow the optical beam to be pointed towards the target during a link: the azimuth rotation axis is perpendicular to the FUS baseplate and the elevation rotation axis is perpendicular to the azimuth rotation axis. The hemispherical CPA is locked in a park position for launch.

The HTS consists of two variable conductance loop heat pipes that enable a temperature control of the FUS under varying environmental and power conditions. The interface temperature of the HTS condenser plate (see Fig.3) is maintained within the operational range (between -10 °C and +15 °C).

The optical data and laser paths are shown in Fig. 2. The transmitted optical beam is generated by the coherent transmitter and correctly pointed towards the counter-part after deviation by point-ahead, fine pointing and CPA mirrors. The incoming beam is deviated by the CPA mirrors, then the fine pointing mirror before reaching the coherent receiver.

The EDRS-A LCT is based on the generic LCT design. Adaptations are limited to some of the LCT interfaces with the hosting satellite which are specific:

- Tubing and shape of the HTS condenser plate (external to the FUS), adapted to the actual LCT accommodation.
- Electrical interface adapted to the satellite power bus voltage.
- Data bus interface adapted to the satellite data bus and protocol.

All these adaptations have been designed for the embarkation on the Eurostar E3000 platform and qualified for the EDRS-A LCT. They are part of the LCT standard adaptation process for each hosting satellite.

A photograph of the EDRS-A LCT is provided in Fig. 3 showing the instrument wrapped in its Multi Layer Insulation (MLI) blanket just prior to delivery for integration on the satellite. The specific satellite thermal interface (condenser) for the HTS is visible below the LCT.

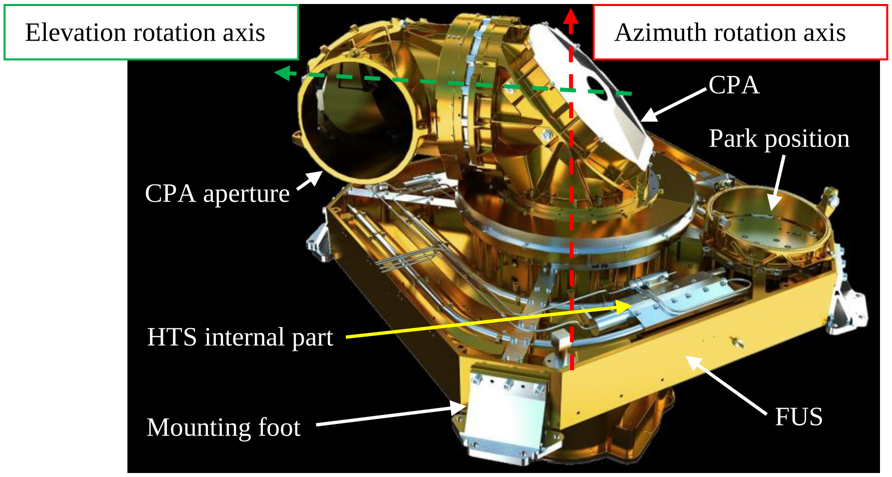


Fig. 1. Generic TESAT Spacecom LCT (with CPA deployed and shown without full HTS)

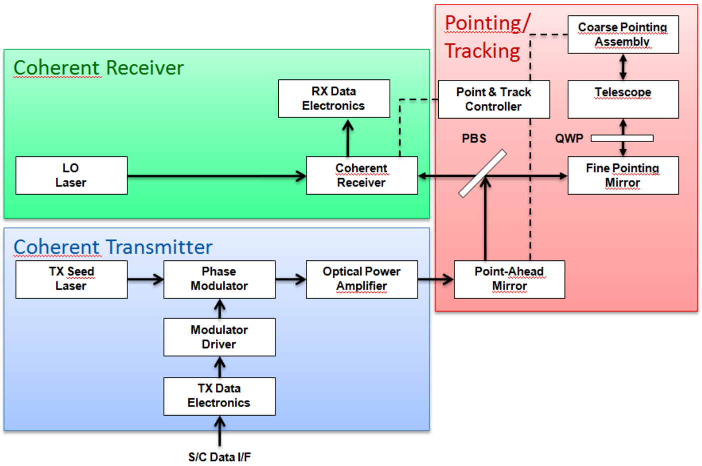


Fig. 2. Block diagram of the LCT (Optical data path and optics section)

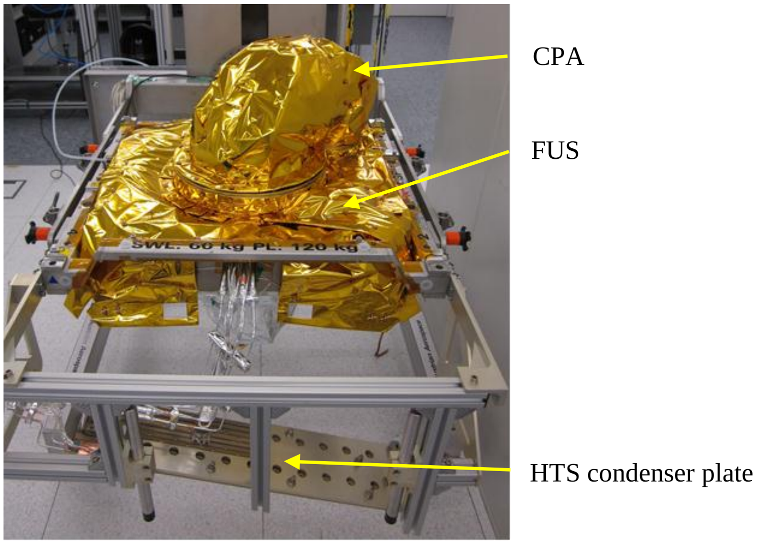


Fig. 3. EDRS-A LCT Flight Model – FM – (LCT in delivery configuration, MLI installed)

B. Main LCT Hosting Requirements

Most of the LCT hosting requirements are similar to interface requirements of other equipment installed on the hosting platform (e.g. electrical interface, mechanical interface, data bus interface) and are handled following Eurostar E3000 standard processes.

Special care was paid to a few requirements that are specific to the LCT. They are similar to requirements for hosting other optical instruments which require high pointing stability.

The LCT power dissipation depends on the mode in which it is running. Its maximum power dissipation is similar to Travelling Wave Tubes (TWT) used on telecommunications satellites. A specific feature of the LCT is that it requires an interface temperature at HTS condenser level lower than 15 °C.

Pointing towards a target and following its trajectory is performed by combining CPA rotations around azimuth and elevation axes. By design, this two-axes mechanism is such that for a given target speed, the closer the pointing direction is to the azimuth rotation axis, the faster the azimuth rotation speed will be. The azimuth rotation axis is tilted with respect to the nadir direction to be outside the operational Field Of View (FOV), thereby limiting the maximum azimuth rotation speed. The trajectories of LEO satellites for altitudes up to 2000 km, seen from a geostationary position, are all within a cone of 11.5 degrees half cone angle. The geometrical accommodation also needs to ensure a FOV free from obstructions when in operating conditions to allow performing a link with a target that can have an orbit altitude up to 2000 km, as shown in Fig.4.

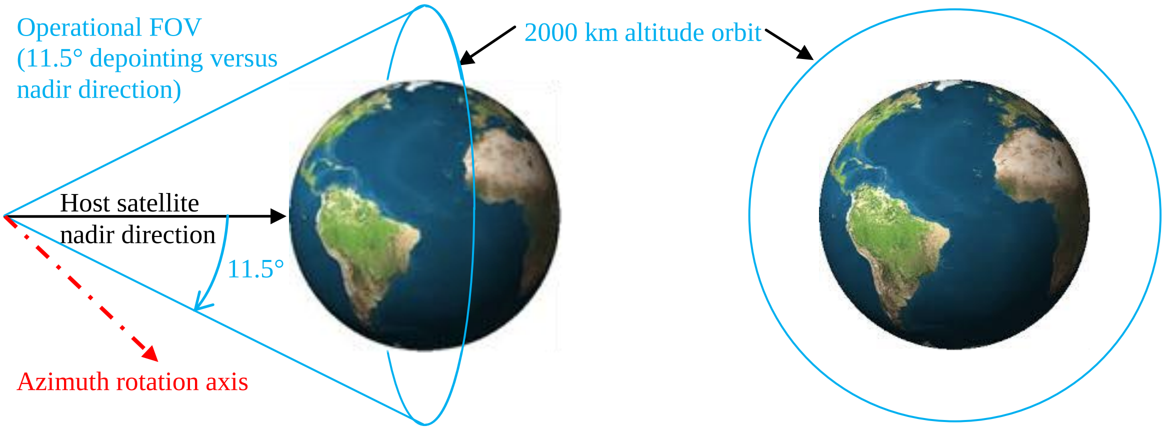


Fig.4. LCT Operational FOV (versus the hosting satellite nadir direction)

The link acquisition process is performed in open loop and requires both high pointing accuracy of the beam towards the counter-part as well as high pointing stability of the beam:

- In order to establish a link, both terminals have to be pointed accurately towards each other. The pointing direction of each terminal is computed taking into account the orbit position and velocity of the counter-part, the orbit position and velocity of the hosting satellite and the attitude of the hosting satellite. The maximum pointing error that remains during this open loop pointing phase defines the Uncertainty Cone (UC). This UC is larger than the beam divergence, but must be kept lower than the LCT acquisition sensor FOV (2500 µrad half cone angle). It is also important to note that the acquisition process is such that the smaller the UC is, the shorter the link acquisition duration will be.

  The positions and velocities of the satellites hosting the two terminals during the link are predicted using orbit models computed by the operational ground segments. The relevant information is transferred to the corresponding LCTs in advance of the link by uploading a set of five telecommand blocks.
- One key step of the acquisition process is the scanning of the UC with the beam to ensure the counter-part will be illuminated at least once during one complete scanning. The detection of the incoming beam once per scanning allows the counter-part to reduce its own pointing error. Pointing stability of the hosting satellite is consequently a key asset during this phase to ensure a good coverage of the whole UC when scanning the narrow beam.
- Start of the acquisition process needs to be time-synchronized between the two terminals which will go through a scanning / repointing process until the beam of each terminal is repointed and tracked accurately on its Tracking Sensor (TS).

Regarding the hosting satellite, the LCT acquisition process therefore requires:

- Accurate absolute time reference: the start of the link acquisition process has to be synchronized with accuracy better than 0.5 sec between the 2 LCT's engaged in the link.
- Accurate orbital position knowledge for the hosting satellite: conventional orbit determination methods using ground station ranging are sufficient for the hosting geostationary satellite. The orbital position of the target is propagated autonomously on-board the LCT itself using a dedicated model.
- Accurate pointing knowledge: the satellite pointing performance is one of the contributors to the UC. The standard pointing performance of a telecommunications satellite results from several errors (e.g. initial alignment and stability between attitude sensors and payload, attitude control performance, thermo-elastic distortions). The maximum pointing error is in the range of 1200 µrad to 1500 µrad, but the contribution to the LCT Line Of Sight (LOS) pointing error is usually not accurate enough with respect to the LCT requirements (an overall pointing error of 1500 µrad is targeted to ensure a short enough link acquisition duration). The contribution of the satellite can be improved by using the pointing knowledge using the Attitude and Orbit Control System (AOCS) sensors instead of relying on the pointing performance itself.
- Stable pointing: the required stability of the LCT LOS is far more demanding than the standard performance of a telecommunications satellite. The LCT requires stability in the order of magnitude of 1 µrad peak-to-peak for frequencies greater than 100 Hz, which is 10 to 100 times more stringent than what is achieved in the worst case on standard satellite platforms.

The LCT also needs to be protected against the space environment (radiation and micro-meteorites mainly).

III. SATELLITE CONFIGURATION

A. Eutelsat 9B Layout

The LCT is accommodated on the hosting satellite Earth deck to allow pointing towards the Earth direction within the operational FOV, without any obstruction.

The Eutelsat 9B satellite configuration is shown in Fig.5 with focus on the Earth deck where the LCT is accommodated.

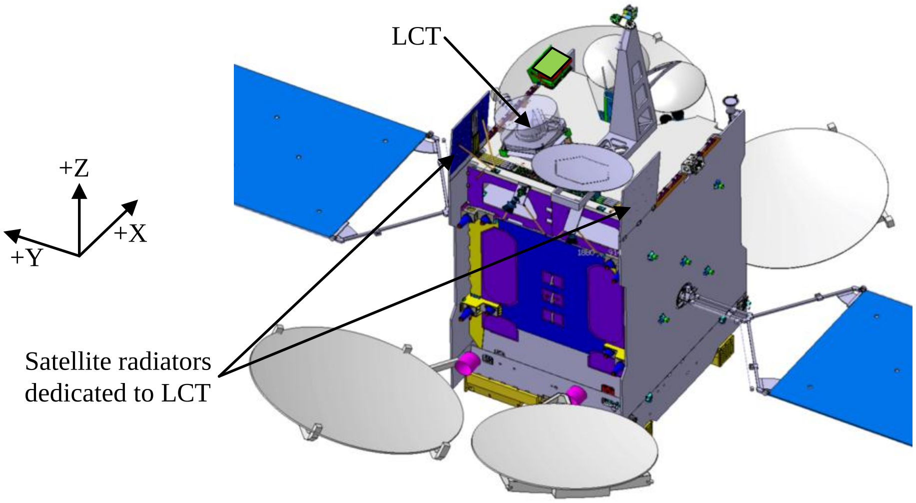
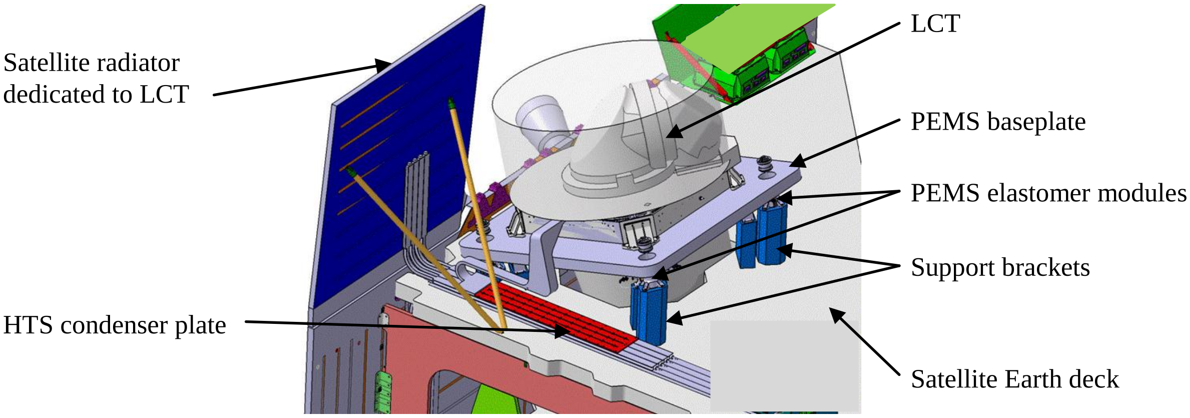


Fig.5. Eutelsat 9B Satellite Configuration

The LCT FUS baseplate is tilted by 15 degrees with respect to the Earth deck plane to ensure the CPA azimuth rotation axis is far enough (more than 3 degrees) from the edge of the operational FOV. Fig.6 shows the tilted FUS baseplate and HTS condenser plate interface to the satellite. The condenser plate is connected to dedicated radiators through heat pipe networks.

The LCT accommodation guarantees its FOV is free of any obstruction (as shown in Fig.7). The “bean shape” of the actual FOV is due to the fact that the CPA aperture is offset with respect to the azimuth rotation axis and to the specific coupling between azimuth and elevation angles when pointing in a required direction.

Dedicated shielding screens and MLI blankets are implemented between the LCT FUS baseplate and the satellite top floor covering the HTS tubing and condenser plate to provide protection of the LCT against the space environment (radiation and micro-meteorites).



PEMS: Payload Elastomer Mounting System

Fig. 6. Embarkation of the EDRS-A LCT on Eutelsat 9B

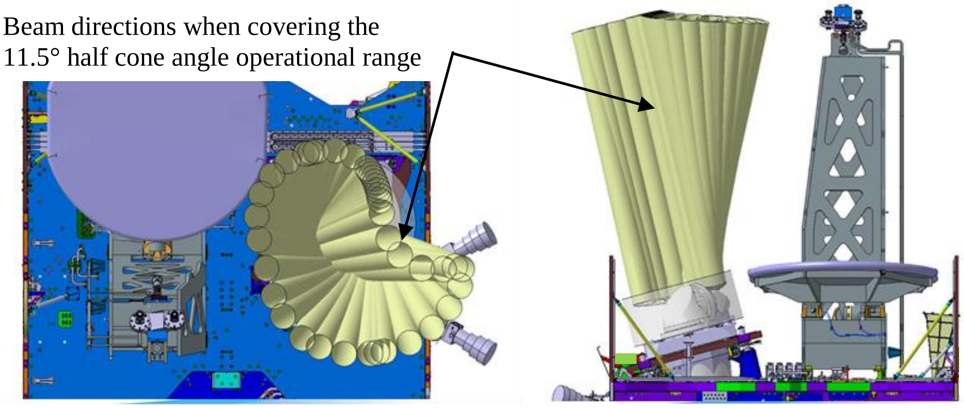


Fig.7. LCT Beam Pointing Direction over Operational FOV

B. EDRS-A Payload

The part of the EDRS-A payload related to the OISL is sketched in Fig.8. The data received by the LCT are transferred to modulators through the Data Processing Unit (DPU). Modulators generate the corresponding Radio-Frequency (RF) signal which is amplified and transferred to the ground via the dedicated antenna.

Apart from the LCT accommodation which has been described in paragraph IIIA, all other units are accommodated following standard Eurostar E3000 processes, as per standard telecommunications payload units.

IV. EUROSTAR E3000 ADAPTATIONS

Co-engineering between the teams involved in the project has allowed optimizing the overall adaptations to host the LCT. In particular, simulations were run at an early stage of the programme to assess the impacts of pointing and pointing stability errors including the effects of micro vibrations on the acquisition performance.

The main hosting requirements that required specific adaptations are linked to the software interface with the LCT, attitude knowledge and pointing stability required by the LCT. Other hosting requirements like power dissipation, interface temperature control and LCT accommodation on the Earth deck were taken into account during the customization process of the Eurostar E3000 product to the Eutelsat 9B / EDRS-A mission.

A. On-Board Software

Dedicated flight software has been developed to manage the LCT and provide the required interfaces. The Eurostar E3000 software architecture allows implementing such new software without impacting the rest of the satellite generic software.

This software also implements a specific feature which allows performing on ground an accurate LCT time estimation with respect to the EDRS reference time, thus ensuring accurate time synchronization for the link acquisition process.

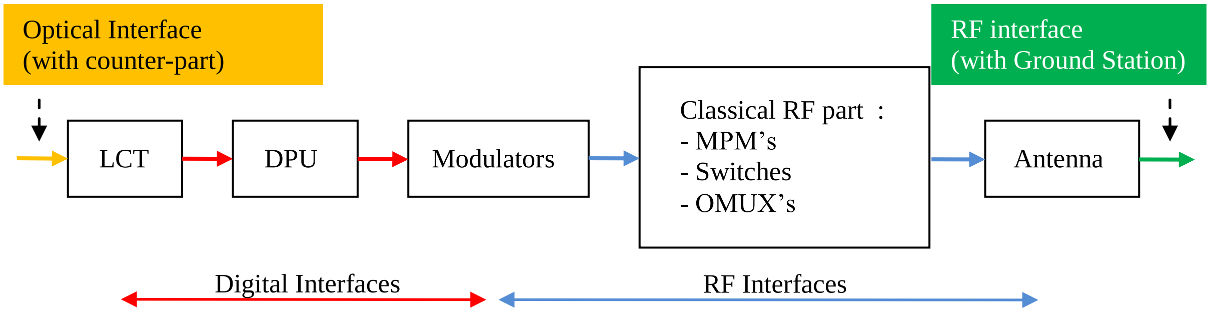
B. Attitude Knowledge

The worst case pointing performance of the LCT on the hosting satellite, taking into account all contributors up to a frequency of a few tenths of a Hertz, is not accurate enough to meet the accuracy required by the LCT acquisition process.

Some key contributors to this worst case pointing performance are actually measured by the star tracker used by the AOCS.

The actual LCT pointing accuracy has been improved by copying the star tracker measurement to the LCT software (in addition to its use by the AOCS closed loop control). This measurement is processed by the LCT software which implements a dedicated filter to compensate for low frequency disturbances (e.g. oscillations generated by the flexible solar arrays) up to a few tenths of a Hertz.

These adaptations allow reaching a maximum overall pointing error in the range of 1000 µrad to 1500 µrad, completely in line with LCT requirements.



DPU : Data Processing Unit
OMUX : Output MULtiplexer
MPM : Microwave Power Module
RF : Radio-Frequency

Fig.8. EDRS-A Payload

C. Pointing Stability

The heritage of Airbus Defence and Space in the domain of micro vibrations from design analyses to test has allowed addressing this topic at the very beginning of the programme.

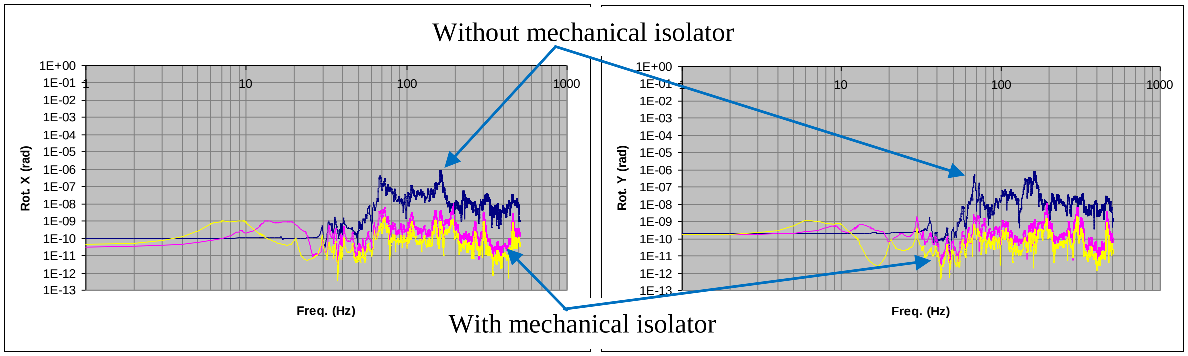
The root causes of pointing instabilities are mainly the disturbances generated by the rotating mechanisms which can be amplified by the system dynamics through the structural paths to the LCT Line Of Sight (LOS). Rotating mechanisms generate disturbances which have harmonic frequencies depending on their actual rotation speed. The reaction wheels used to control the satellite attitude are well known to be the major source of such disturbances at high frequencies (above 10 Hz typically).

A coupled Finite Element Model (FEM) of the satellite including the LCT has been built to assess achievable performances. The main outcome of analyses run with this model is that the “standard” pointing stability is not adequate for what is acceptable by the LCT, especially for high frequencies (typical transfer function providing LCT rotation when applying 1 Nm torque at wheel interface is shown in Fig.9, upper curve).

A solution has been developed to allow filtering high frequency perturbations. A mechanical filtering has been implemented with a cut-off frequency selected to provide high rejection starting around 20Hz. The Payload Elastomer Mounting System (PEMS) developed by Airbus Defence and Space makes use of elastomers which have been used on previous missions. As shown in Fig.6, it consists of a baseplate supporting the LCT, which is mounted on 4 elastomer modules (providing the mechanical filtering), connected to the support brackets installed on the satellite Earth deck.

Special care has been taken for the implementation and accommodation of all connections between the LCT FUS and the satellite Earth deck to ensure such mechanical filtering is not bypassed. In particular, all harnesses are ensured to be sufficiently flexible and flexibilities have been added to the HTS tubing to ensure sufficiently soft connections as shown in Fig.10.

The mechanical filtering allows a reduction by a ratio 10 to 100 of the disturbances at high frequencies (typical transfer function is shown in Fig.9, lower curves) which ensures that the pointing stability of the LCT is sufficient.



Upper curve: without mechanical isolator
Lower curves: with mechanical isolator below the LCT

Fig.9. LCT Barycentre Rotations perpendicular to the LOS

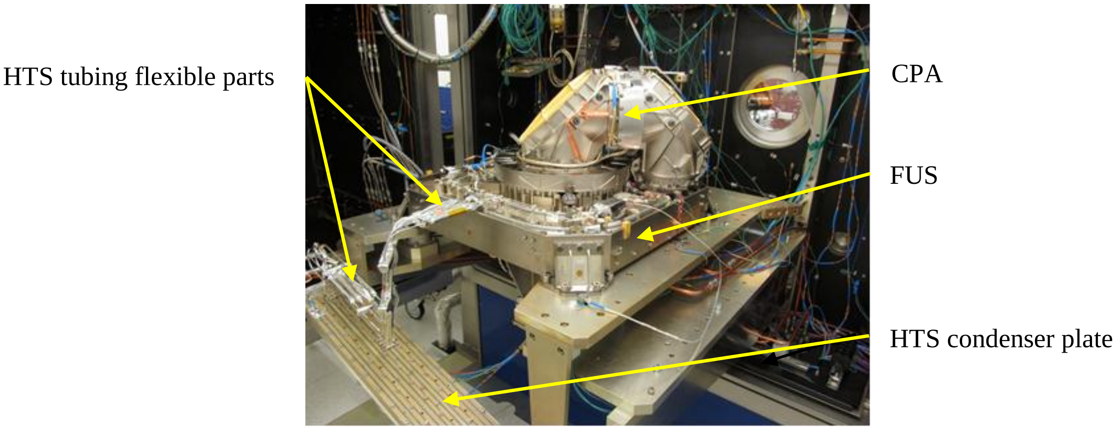


Fig.10. Flexibilities added to the HTS tubing (EDRS-A LCT FM in test configuration)

V. GROUND CONTROL SYSTEM

The operational planning identifying the LEO satellites and timing of required links originates from the EDRS Mission Operations Centre (MOC). This information is provided to the EDRS Devolved Payload Control Centre (DPCC) which builds command parameter sets and sends them to the Eutelsat Satellite Control Centre (SCC) in an agreed format together with the execution times over a secure leased line. The EDRS commands are encrypted before being uplinked to the satellite. The raw telemetry from the satellite is distributed back to the EDRS DPCC for processing.

The satellite is also capable of transmitting a dedicated telemetry stream in addition to the normal housekeeping stream to allow a dwell on LCT parameters during in orbit tests and in the event any reprogramming is required that necessitates memory dumps. Such telemetry would be received directly from a dedicated EDRS ground antenna without passing through the Eutelsat SCC.

The command sets necessary to programme the LCT for a LEO acquisition session include the pointing instructions (azimuth and elevation) for the CPA for the start of the LEO satellite trajectory, the relevant start times and duration of the session as well as a set off Chebyshev coefficients identifying the LEO satellite trajectory. This data is loaded in satellite time-tag registers in advance of the link establishment, thereby removing timing criticality from the SCC once the commands are received from the DPCC.

Inter satellite link sessions are avoided in times of satellite station keeping manoeuvres in view of the satellite attitude transients which may interfere with the acquisition process. Furthermore, any required momentum wheel offloading is confined, under nominal operations, to be within the station keeping manoeuvre periods which are planned and published in advance of their execution. No special measures are planned for the station keeping of Eutelsat 9B which is planned to follow the usual cycle of one North / South manoeuvre every two weeks followed typically two days later by a single East / West manoeuvre. The orbit control manoeuvres keep the satellite within 0.1° of the desired longitude and the orbit inclination within 0.1° of the equatorial plane. The orbit is computed after manoeuvres and sent to the DPCC so that the entity controlling the LEO satellite can ensure the LEO satellite LCT is appropriately pointed to the GEO satellite LCT for link acquisition.

VI. CONCLUSION

The first EDRS payload (EDRS-A) is shown to be accommodated on the Eutelsat 9B satellite with relatively few adaptations of the Eurostar E3000 platform, benefiting from the platform architecture and on-board software flexibility. Some pointing stability improvements were achieved in support of the LCT acquisition requirements, taking benefit of Airbus Defence and Space heritage in accurate pointing and pointing stability missions. Engineering activities started at an early stage of the programme involving all stakeholders enabled an optimized design without oversizing the hosting platform or redesigning the generic LCT.

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