

## Status of the European Data Relay Satellite System

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### Abstract

The European Data Relay Satellite System (EDRS) is under implementation within the Advanced Research in Telecommunications Systems Programme (ARTES-7) of the European Space Agency (ESA). After a successful demonstration of the Semiconductor-laser Inter-satellite Link EXperiment (SILEX) in 2001 between Artemis GEO satellite and SPOT-4 LEO satellite, EDRS will become the first commercial European data relay system providing a wide range of operational services (both optical and Ka-band based). A major difference between SILEX and EDRS is the selected optical technology and targeted performances of the laser links between the LEO satellite users and the GEO satellite nodes. The EDRS optical inter-satellite links (O-ISLs) are based on optical Laser Communications Terminals (LCT) which are developed and qualified by TESAT Spacecom under DLR German national funding. These LCTs are featuring a significantly increased data transmission rate, compared to SILEX technology, and at the same time reduced mass and size. The joint European Commission / ESA Global Monitoring for Environment and Security (GMES) programme will be the first customer of the EDRS service (Sentinel 1A/B and 2A/B LEO satellites). This paper will provide an overview of the EDRS project and the current development status of its LCTs.

### 1 Introduction

Europe has repeatedly demonstrated the feasibility of optical communications for inter-satellite links (ISLs) and ground-space links, as well as the technical capabilities of its industry in these fields, [1]. For example:

- the successful demonstration of the Semiconductor-laser Inter-satellite Link Experiment (SILEX) in 2001 between the Artemis GEO satellite and the SPOT-4 LEO satellite [2],
- the in-orbit verification of the homodyne BPSK laser communication link in 2008 between the TerraSAR-X LEO satellite and the NFIRE LEO satellite [3], and
- the experiments between several spacecrafts (e.g., ARTEMIS, TerraSAR-X, NFIRE) and different optical ground stations (e.g. ESA's

OGS in Tenerife (Spain), DLR/TESAT's transportable optical ground station) [4].

The general downturn in the telecom sector at the beginning of this millennium, however, delayed the actual implementation of operational optical ISLs (O-ISLs). At present, the situation has changed with the agreement among the ESA Member States during the Ministerial Council in November 2008 to support the development and implementation of the new European Data Relay Satellite System (EDRS), as part of the Advanced Research in Telecommunications Systems Programme (ARTES-7) of the European Space Agency (ESA).

EDRS will provide a wide range of operational data relay services (both optical and Ka-band based). Optical communication technology required for the implementation of optical ISLs is also considered an attractive solution for links between satellites and aircraft/UAV or between satellites and ground (e.g., optical feeder links), and for scientific missions (e.g., deep-space links, orbiter-lander data relay).

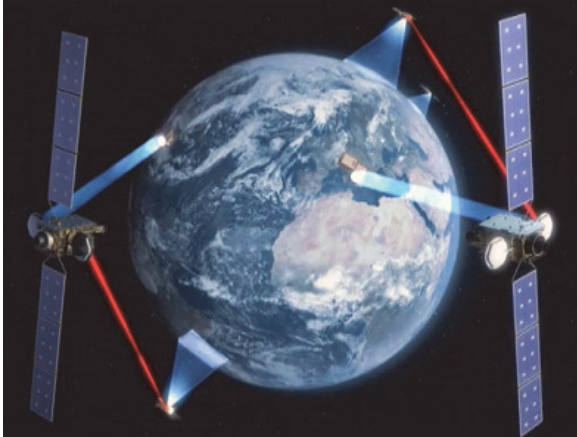


Figure 1. Artist view of the European Data Relay System.

With the implementation of the joint European Commission / ESA Global Monitoring for Environment and Security (GMES) programme, it is estimated that European space/ground telecommunication infrastructure will need to transmit a few Terabytes of data every day from space to ground.

Our present telecom infrastructure is challenged to deliver such large data quantities within short delays, and conventional means of communication may need to be complemented to satisfy the quality of service required by users of Earth observation data.

In addition, Europe currently relies on the availability of non-European ground station antennas to receive data from Earth observation satellites. This poses a potential threat to the strategic independence of Europe, as these crucial space assets are not under full European control.

To fulfil that demand, EDRS will become the first operational European data relay system (see Figure 1) aiming at improving the quality of the data service and thereby enhancing the operational reliability and independence of European and Canadian space infrastructures such as the joint European Commission / ESA Global Monitoring for Environment and Security (GMES) initiative, and many national space assets. In particular, the objectives of ESA's EDRS programme are:

- Provide ESA with the necessary data relay and related services via satellite. The GMES programme will be the first customer of the EDRS service (Sentinel 1A/B and 2A/B LEO satellites). Hence, priority is currently given to the provision of services to the GMES users, given the fact that their needs are more mature and the associated timing is defined. However, the long-term objective for the EDRS programme is to provide full and global data relay services to user communities related to ESA and partners of ESA.

- Foster the development of the satellite data relay services market through the exploitation of the infrastructure with commercial / institutional users beyond ESA.
- Support the standardisation and adoption of optical and Ka-Band data relay technology by means of the availability of technological solutions for the EDRS infrastructure as well as for the user community (Earth observation satellites, UAVs, etc.).
- Achieve a cost efficient programme through a Public Private Partnership (PPP) scheme with satellite operators / service providers for the development of the infrastructure.

Unlike other ESA programmes, the objective of EDRS is to develop a commercially sustainable data relay service, rather than developing only the necessary technical infrastructure (satellite and/or ground segment). Consequently, support to the adoption of EDRS by users beyond GMES is an important element of the programme.

This paper gives an overview of the present status of the ESA's EDRS project: the EDRS system architecture (section 2), the EDRS services (section 3) and the current schedule (section 4). Next, the heritage and the qualification status of the EDRS LCT are described (section 5), and the approach for the In-Orbit Validation of the EDRS LCT is presented (section 6). Conclusions and future developments conclude this paper (section 7).

## 2 The EDRS system architecture

The EDRS will be a constellation of GEO satellites intended to relay user data between LEO satellites (as well as unmanned aerial vehicles (UAV) in the future), and ground stations. EDRS will allow visibility between GEO and LEO satellites for the larger part of the orbits, offering significantly extended communication periods when otherwise LEO satellites only have a very reduced visibility from any ground station. EDRS is envisaged to significantly improve the stringent timeliness requirements of demanding Earth observation missions (i.e., time critical services).

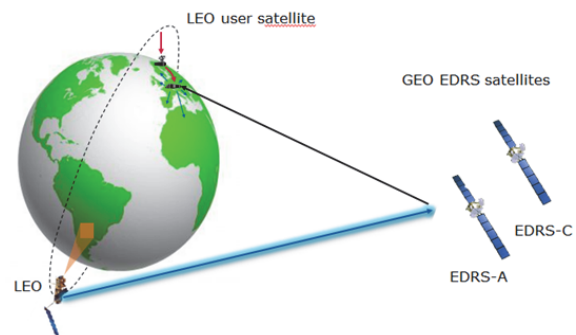


Figure 2. EDRS infrastructure currently under development depicting the EDRS-A and EDRS-C nodes of the space segment.

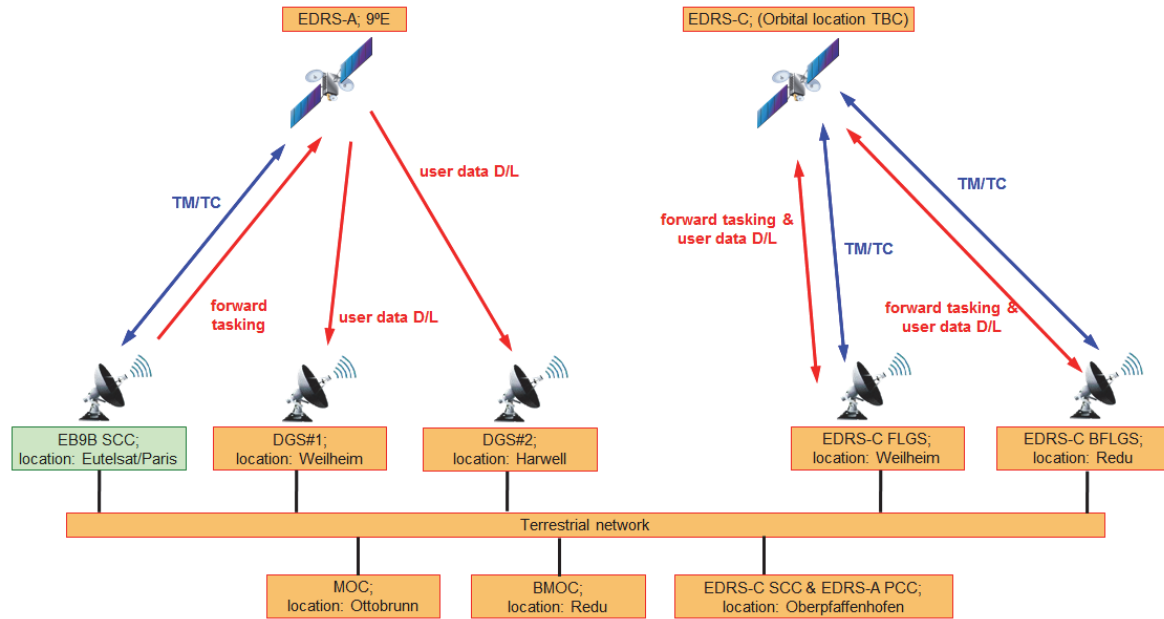


Figure 3. The EDRS system architecture including the various elements of the space and ground segments.

The EDRS is being built through a Public Private Partnership between ESA and Astrium GmbH, BU Services, Germany (“Astrium Services”). This approach is to minimise the cost to ESA and to ensure later commercial exploitation of the space based system. The overall EDRS contract between ESA and Astrium Services was signed in October 2011.

Astrium Services has the overall responsibility for designing and developing the complete space and ground infrastructure. Astrium Services will then acquire ownership of EDRS and is committed to its operation for the next 15 years and to provide services to ESA, starting with the Sentinel 1A and 2A LEO satellites of the GMES programme. Sentinel 1A is a C-band synthetic aperture radar satellite, which provides continuous imagery (day, night and all weather), whereas Sentinel 2A is a multi-spectral high-resolution optical imager, which provides coverage over global terrestrial surfaces.

The EDRS infrastructure currently under development (see Figure 2) includes the necessary items for the space segment and the ground segment.

The EDRS space segment is composed of two elements:

- The EDRS-A payload, which contains a Laser Communications Terminal (LCT) and a Ka-band terminal for O-ISL and Ka-band ISL respectively. The EDRS-A payload will be placed as a piggyback payload on-board Eutelsat 9B commercial telecommunication GEO satellite manufactured by Astrium Satellites (France). The Eutelsat 9B satellite,

which is based on Astrium’s Eurostar E3000 bus heritage, will be launched in late 2014 and will be positioned at 9°E.

- The EDRS-C platform (dedicated satellite manufactured by OHB (Germany)) carrying the EDRS-C payload (which includes an LCT for O-ISL). The EDRS-C Satellite is based on the OHB developed SGE0 (Small GEO) platform with an increased payload capability of about 360 Kg and 3 kW and a lifetime of 15 years. The EDRS-C satellite is planned to be launched early 2016. The final orbital location is currently under assessment taking into account the needs from other payloads on board.

The development and manufacturing of both the EDRS-A payload and the dedicated EDRS-C satellite (including the EDRS-C payload) are executed in parallel. EDRS-A and EDRS-C payloads (including the LCTs) are manufactured by TESAT Spacecom (Germany).

The Eutelsat 9B satellite, in addition to Eutelsat’s main payload and the EDRS-A payload, will also host the so-called ASI Opportunity Payload, funded by the Italian Space Agency. Furthermore, the EDRS-C Satellite will also embark the so-called Hosted Payload (HP), an opportunity offered by ESA to fill up the spare payload capacity on the EDRS-C platform. The Hylas-3 Ka-band payload has been selected by ESA for embarkation as a HP. The contract between ESA and the commercial satellite operator Avanti Communications (UK), the owner of the Hylas-3 payload, has been signed in July 2012. The Hylas-3 payload is procured by Avanti Communications, and the integration and test activities

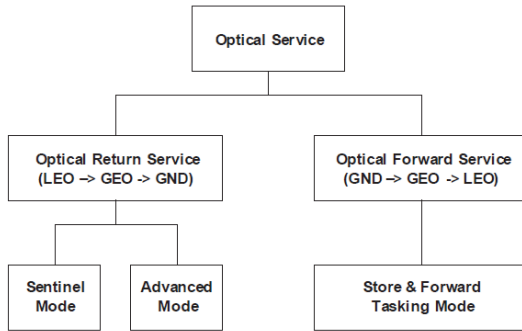


Figure 4. Overview of the EDRS Optical services.

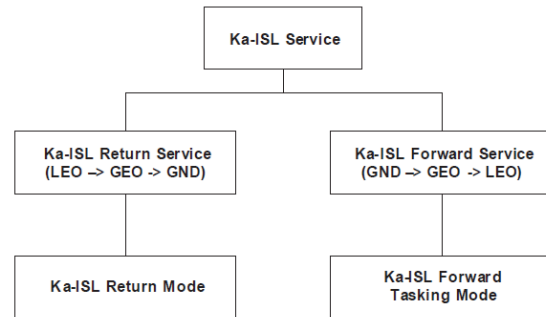


Figure 5. Overview of the EDRS Ka-band services.

with the EDRS-C platform will be conducted jointly with OHB.

In addition to the space segment, EDRS will develop the necessary ground segment infrastructure, consisting of:

- the EDRS Satellite Control Centre (SCC) facilities. The dedicated EDRS SCC is linked to the EDRS-C spacecraft Operator (i.e., DLR in Oberpfaffenhofen), while for the EDRS-A payload this is a Payload Control Centre (PCC) operated by DLR in conjunction with the Eutelsat operated SCC for the 9B satellite.
- the EDRS Mission Operations Centre (MOC) and the Back-up Mission Operations Centre (B-MOC), which are the interface to the users for the planning of the EDRS services requests. The primary MOC will be in Ottobrunn (Germany), while the backup MOC will be installed at Redu Space Services (Belgium).
- the EDRS Data Ground Stations (DGS), enabling reception of user data on ground. Two EDRS DGS shall be operational to provide service after completion of the EDRS-A LEOP (Launch Early Orbit Phase) operations and in-orbit commissioning.
- the Feeder Link Ground Station (FLGS) and the Back-up Feeder Link Ground Station (B-FLGS), enabling user data reception as well as providing EDRS-C TM/TC capability. The FLGS and the B-FLGS shall be operational in line with the deployment of the EDRS-C satellite.

Astrium Services has signed a contract in June 2012 with DLR (German Aerospace Centre) to implement and operate major parts of the ground network. The agreement covers the design, implementation, delivery and operation of four ground stations: two DGS for the EDRS-A satellite in Weilheim (Germany) and in Harwell (United Kingdom) respectively, and the FLGS / B-FLGS for EDRS-C in Weilheim (Germany), and in Redu (Belgium). As part of the agreement DLR will also implement and operate the PCC for EDRS-A and

the SCC for EDRS-C in Oberpfaffenhofen (Germany). Major parts of the Ground Segment have been co-funded by DLR and the Free State of Bavaria.

The space and ground segment of the EDRS user are intrinsically part of the end-to-end system, including space-to-space, space-to-ground as well as ground-to-ground interfaces. A joint GMES/EDRS System team has been established in support to the definition and implementation of all aspects of the end-to-end link involving the Sentinels. This includes the definition of key performance indicators (KPI), applicable to a Service Level Agreement (SLA) between GMES and Astrium Services. Up to four Sentinels satellites are currently planned to be served simultaneously, with an average of 10 minutes of communication per orbit each. The current draft SLA expects a start of service by 2015, extendable in phases until about 2030.

The EDRS concept of operation can be summarized as follows: Communication link sessions are planned and coordinated between the EDRS MOC and the user's MOC, making use of the visibility windows available between EDRS and the user satellites. The EDRS and the user's space infrastructure will be configured according to each link session parameters. User data will be transmitted from LEO user satellites to either of the EDRS payloads (i.e., EDRS-A, EDRS-C) and relayed to the DGS and/or FLGS/B-FLGS on the ground, from where it will be made available through terrestrial network to the users' sites (see Figure 3). The users can also operate their own user ground stations to receive directly the user data.

### 3 The EDRS services

The data relay services offered by the EDRS will improve the European capabilities for transmitting user data from user space assets (e.g., Earth observation LEO satellites) in terms of user data volume and timeliness.

Furthermore, the EDRS offers flexibility in the manner the user data is transmitted. Compared to conventional direct LEO-to-ground downlinks where the access time for communications per ground station is restricted by the visibility time (around 10% of the LEO satellite's orbital



period), data relay via GEO satellite increases substantially the available communication time to the LEO user satellites thanks to the long visibility periods inherently available from the GEO location (e.g., one GEO satellite already enhances the visibility time to around 50% of the LEO satellite’s orbital period). Besides, the data relay downlink over a wide European coverage. Data can thus be downlinked directly to DGS and the FLGS or user’s own ground stations, which reduces user data repatriation costs and facilitates data dissemination to final users.

In addition to the downlink capabilities, the EDRS can also provide quasi real-time access from ground to the LEO user satellite during periods of direct line-of-sight, which can be used to re-configure the EO (Earth observation) LEO payload / satellite, and hence, shortening the reaction time of EO LEO satellites in case of emergency events (i.e., request on-demand).

The EDRS provides different types of Optical and Ka-band services, using optical inter-satellite links (O-ISLs) and Ka-band inter-satellite links (Ka-ISLs) respectively (see Figure 4 and Figure 5). Both ISLs between the LEO user and the GEO satellites are bi-directional, and are referred as the Return link (RTN, from LEO user to GEO) and the Forward link (FWD, from GEO to LEO user). The EDRS-A and the EDRS-C payloads offer Optical services, whereas the Ka-band services are implemented on the EDRS-A payload only.

The Optical services are split into RTN and FWD services. The Optical RTN service is a high data rate channel transferring the user data from the LEO user satellite to ground via the GEO relay satellite. The user data rate for the Optical RTN service is 600 Mbps for the so-called Sentinel mode (e.g., for Sentinel 1A and Sentinel 2A) and 1.8 Gbps for the so-called Advanced mode to cover future user needs. The EDRS RF feeder link is accordingly dimensioned to support these user data rate requirements. The Optical FWD service is a

Daily capacity (Terabyte/day)	Sentinel mode	Advanced mode
EDRS-A node	5.4	16.2
EDRS-A & EDRS-C nodes	10.8	32.4

Table 1. Maximum handling capacity of the EDRS system currently under development considering one or two GEO nodes and operating in Sentinel / Advance mode.

low data rate channel (limited by the uplink TMTC channel) to transmit telecommands to the LEO user satellite in quasi-real time (e.g., for reconfiguration of the Earth observation LEO payload / satellite).

Alternative to the Optical RTN service, the EDRS also offers the Ka-ISL RTN service, which relays the user data from the LEO user satellite to ground at a user data rate up to 300 Mbps.

A summary of the maximum user data volume handling capabilities of the EDRS system is presented in Table 1 for the Sentinel mode and the Advanced mode.

#### 4 EDRS schedule

The current schedule of the EDRS project is depicted in Figure 6, indicating the major reviews at System level and also at various EDRS segment levels (EDRS-A space segment, EDRS-C space segment and ground segment).

The SRR (System Requirements Review) has been closed-out in July 2012. In parallel the EDRS-A PDR (Preliminary Design Review) has been successfully completed in April 2012. Coming milestones are the EDRS-C PDR, the Ground Segment and the System PDR which are planned in September 2012.

Delivery of the EDRS-A / EDRS-C payloads to corresponding satellite integrators is scheduled end of 2013 and mid of 2014, with a satellite launch planned

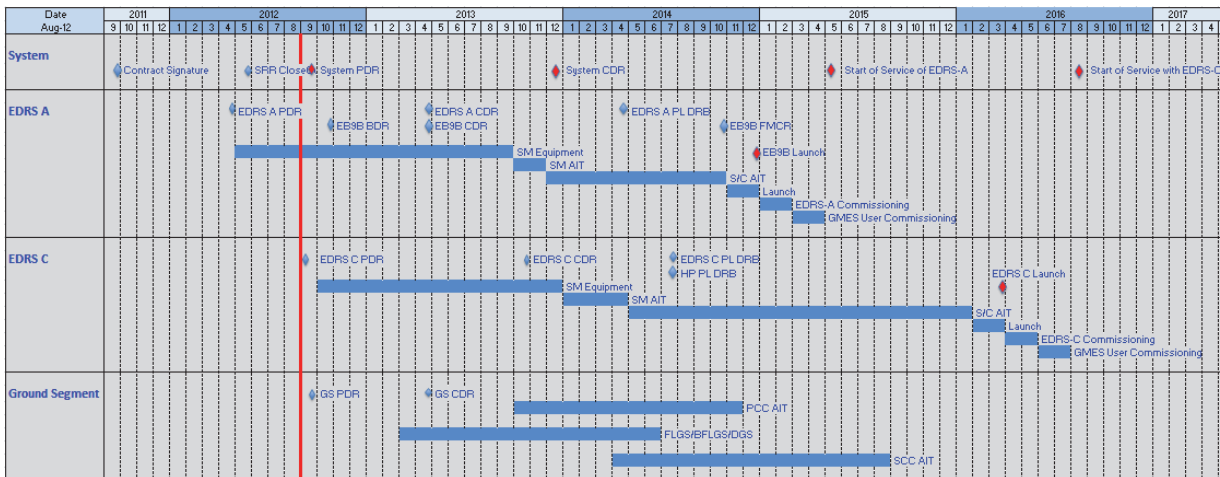


Figure 6. Schedule of the EDRS project until start of service.

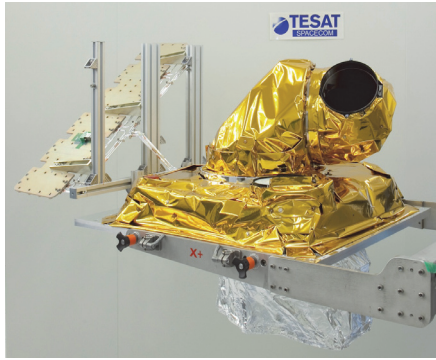


Figure 7. The TESAT LCT flight model embarked on Alphasat as a technology demonstration payload.

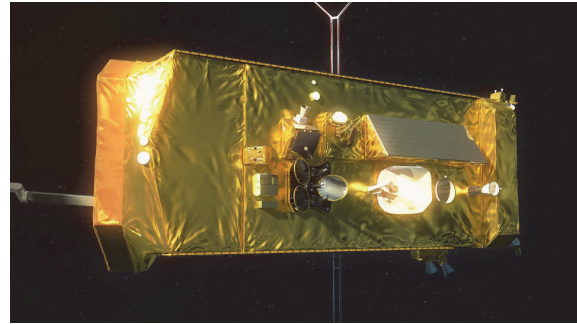


Figure 8. The TESAT LCT (in parking position) accommodated on the Alphasat Earth deck (at the left hand side of the radiator).

end of 2014 and early 2016 respectively.

The MOC shall be deployed and operational right from the start of the EDRS service provision. The DGS (respectively the FLGS/B-FLGS), enabling reception of user data on the ground via EDRS-A payload (respectively via EDRS-C payload), shall be operational in due time prior the deployment of the Eutelsat 9B satellite (respectively the EDRS-C satellite).

## 5 LCT for EDRS

A major difference between SILEX and EDRS is the selected optical technology and targeted performances of the laser links between the LEO user satellites and the GEO satellite nodes (see Table 2). The EDRS O-ISLs are based on Laser Communication Terminals (LCT) which are developed and qualified by TESAT Spacecom (Germany) under DLR German national funding, [4]. These LCTs feature a significantly increased data transmission rate compared to SILEX technology, and at the same time reduced mass and size.

The LCTs embarked on the EDRS satellites, [5], correspond to the 2<sup>nd</sup> generation TESAT LCT. This 2<sup>nd</sup> generation LCT can transmit at data rates up to 1.8 Gbps over distances of up to 45000 km, between the GEO EDRS spacecraft and satellites in LEO orbit.

The EDRS LCTs will benefit from the space heritage attained in the following in-orbit demonstrations led by DLR (German Aerospace Center):

- the in-orbit verification of the 1<sup>st</sup> generation TESAT LCT as part of the LEO-LEO O-ISL between TerraSAR-X (German LEO satellite) and NFIRE (US LEO satellite), which took place in 2008, at a data rate of 5.6 Gbps over link distances of about 5000km, [3]. It demonstrated the feasibility of beaconless spatial acquisition and the communications performance of the homodyne BPSK detection scheme (data stream of 5.625 Gbps with a BEP  $<10^{-9}$ ).

- the in-orbit validation, in cooperation with ESA and the Swiss Space Office, of the 2<sup>nd</sup> generation TESAT LCT as part of the LEO-GEO O-ISL between the GEO LCT embarked on ESA's Alphasat satellite, [6], (see Figure 7 and Figure 8) and the LEO LCTs on board Sentinel 1A/2A satellites. It will demonstrate a LEO-GEO bidirectional link. Furthermore, it will perform end-to-end pre-operational experiments between Sentinels 1A/2A satellites and Alphasat (i.e., EDRS precursor) at 600 Mbps user data rate. The launch of Alphasat is scheduled for 2013, whereas the launch of Sentinel 1A and Sentinel 2A satellites is expected in 2013 and 2014 respectively.

The key parameters of the 2<sup>nd</sup> generation TESAT LCT embarked on the Alphasat, Sentinel S1A / S2A and the EDRS spacecrafts are listed in Table 2.

The qualification of this 2<sup>nd</sup> generation LCT is currently being executed by TESAT under DLR development contracts, which have in scope the DLR procurement of LCTs for Alphasat and Sentinel 1A/2A. To verify that the project specific qualification can also be made applicable to EDRS, DLR has set up a dedicated EDRS qualification review scheme. Here, the qualification status of the 2<sup>nd</sup> generation LCT including its various sub-units is in detail assessed in a series of qualification reviews. The resulting formal confirmation of qualification is expected to be complete by mid of 2013. Specific adaptations for the LCT accommodation on the Eutelsat 9B and the EDRS-C satellites are managed as part of the EDRS project in close cooperation with DLR. For each EDRS LCT, special attention is taken to guarantee that the qualification status at overall LCT level remains applicable. The accommodation of the LCTs for Sentinel 1 and Sentinel 2 is managed by ESA as part of the Sentinel satellite developments with the Prime contractors, Thales (Italy) and Astrium (Germany) in close cooperation with DLR as provider of the LCTs.

	SILEX Optical Terminal	1st generation TESAT LCT	2nd generation TESAT LCT
Wavelength (nm)	810-850	1064	1064
Modulation type	OOK-NRZ / 2-PPM	BPSK	BPSK
Detection scheme	Direct detection	Coherent homodyne	Coherent homodyne
User data rate (Gbps)	0.05	5.625	1.8
Range (km)	> 45000	> 5100	> 45000
Bit Error Probability	$< 10^{-6}$	$< 10^{-11}$	$< 10^{-8}$
Transmit power (Watts, average)	0.06	0.7	2.2
Telescope diameter (mm)	250	125	135
Mass (kg)	157	35	56
Power consumption (Watts, average)	150	120	160
Envelope (m <sup>3</sup> )	NA	0.5 x 0.5 x 0.6	0.6 x 0.6 x 0.7
Application	LEO-GEO OISLs	LEO-LEO OISLs Space-ground optical links	LEO-GEO OISLs Space-ground optical links

Table 2. Performance comparison between SILEX optical ISL technology and TESAT LCT technology. 2<sup>nd</sup> generation TESAT LCTs will be employed in the EDRS system.

## 6 In-Orbit Verification of LCT for EDRS

EDRS operations will take advantage of the LEO-GEO O-ISL experiments between the GEO Alphasat satellite and the LEO Sentinel 1A/2A satellites planned after the launch of the first Sentinel. The payload data rate requirement for Sentinel 1A/2A satellites is 600 Mbps, which is well within the capabilities of 2<sup>nd</sup> generation TESAT LCT. The objectives of these experiments with Alphasat and Sentinel 1A/2A satellites are:

- to optimise the technical performances of the LEO-GEO O-ISL (including GEO-ground tests) and,
- to perform an early validation of the end-to-end data relay system, which includes the LEO-GEO O-ISL, the RF feeder link between Alphasat and its ground segment, and the interfaces and operations with the GMES ground segment.

Experience gained from these experiments will be taken into account during the IOV (In-Orbit Verification) activities of the LCTs on board Eutelsat 9B and EDRS-C satellites and for the validation of the end-to-end EDRS performances.

The approach for the IOV of the LCTs is as follows:

- LCT self-test: this test is performed during commissioning to check out the LCT performances after launch. A functional end-to-end test of the entire data transmit and

receive chain (including the telescope and the coarse pointer) can be performed while the LCT is in parking position thanks to a mirror mounted in the parking position unit.

- IOV with an OGS: these trials are required in order to calibrate the LCT setting parameters (e.g., acquisition scanning parameters, misalignment matrix between satellite coordinate reference system and LCT coordinate reference system, clock offset and other propagator parameters, etc.) and to verify the full PAT (Pointing Acquisition and Tracking) performances (e.g., uncertainty cone, link acquisition time, etc.). The baseline is to use the ESA's OGS in Tenerife (Spain) with some adaptations, [7], [8] (see Figure 9). As a mean of cross support, DLR's mobile OGS can on request be used as back-up. The DLR mobile OGS is intended for experimental space-to-ground optical links with GEO satellites (e.g. Alphasat) or lower altitude vehicles (e.g. Sentinel 1A, Sentinel 2A).
- IOV with LEO user satellite: these tests are to further fine tune the LCT setting parameters, and to validate the LEO-GEO O-OISL acquisition, tracking and communications performances. The LCTs on board the LEO Sentinel 1A/2A satellites will be used as counter terminals.

After successful completion of the remaining commissioning activities (e.g., EDRS space segment with EDRS ground segment commissioning, joint EDRS-GMES service commissioning) to verify the full operational capability of the overall EDRS system with the user (i.e., GMES), the EDRS will enter into operational phase by mid of 2015.

## 7 Conclusion

ESA and its Member States achieved a forefront position in optical communications with the SILEX development and its successful flight demonstration, which was further fostered by the DLR's in-orbit verification of the homodyne BPSK laser communication link between the



Figure 9. The telescope of ESA's optical ground station (OGS) on Tenerife used for the experiments is a Zeiss 1 meter Ritchey-Chrétien/Coudé telescope supported by an English mount.

TerraSAR-X and the NFire LEO satellites. In the light of commercial perspectives, Europe has strong interest in maintaining its privilege position to guarantee its independence.

The synergy between ESA's and European National Agencies' efforts –in particular DLR and SSO- and developments has converged towards the implementation of the new EDRS system, the first operational European data relay system commercially exploited by Astrium Services, which is planned to start the operational service in 2015 with GMES satellites Sentinel 1A and 2A as first customers, followed by Sentinel 1B and 2B models.

The technology selected for the optical ISLs is based on the Laser Communication Terminals developed by TESAT Spacecom under DLR German national funding (1064 nanometer wavelength, BPSK modulation, coherent homodyne detection). This technology provides the highest receiver sensitivity and robustness against any kind of background illumination, especially sunlight. For the first time, the 2<sup>nd</sup> generation LCT will be operational as part of the EDRS commercial service.

Europe will take full profit of the new EDRS system once the complete set of GMES Sentinels 1 and 2 is deployed. In the future, the EDRS will commercially provide an operational service to other public institutions, governmental organizations and private enterprises.

In this endeavour, ESA is preparing a proposal to be presented at the next Ministerial Council in November 2012 for an expanded data relay service, called GlobeNet. It would provide support to the adoption by customers beyond GMES and proposes a third node in GEO orbit to provide redundancy and increase the availability and the flow of data from Earth observation satellites and UAVs to users, as well as to enhance near real-time services, including GEO-GEO O-ISL capabilities.

Besides, laser communication systems are able to extend the communication performance by an order of magnitude into the 10 Gbps range. At those data rates, the RF feeder link could become a bottleneck, and it opens the door towards the implementation of an optical feeder link to complement the constraints of the RF feeder link performances, [9].

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