SILEX: The First European Optical Communication Terminal in Orbit

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Optical communication is presently in a rapid expansion phase, since it offers a considerable growth potential to the constantly increasing useful transmitted data rate demand. Planned constellations of communication satellites will benefit from the use of optical communication's ability to transmit the increasingly higher data rates with compact, low-mass terminals, while avoiding interference problems and radio frequency band saturation. In addition to semiconductor lasers and highly sensitive wide bandwidth optical communication sensors,optical communication implies utilisation of a wide range of leading-edge technologies, e.g. ultrastable structural materials, high-precision pointing mechanisms, large CCD matrices, fast digital signal processing, high precision optics, optical coatings with high reflectivity or narrow filter bandwidth and accurate thermal control.

In 1991 the development phase of an optical communication system, SILEX (Semi-Conductor Inter Satellite Link EXperiment) was started with MMS (F) as prime contractor leading a large European consortium.

The step from the optical bench in the laboratory to an optical terminal in orbit is enormous. This step was achieved when PASTEL (PASsager TELecom) on SPOT-4 was successfully launched on 22 March 1998.

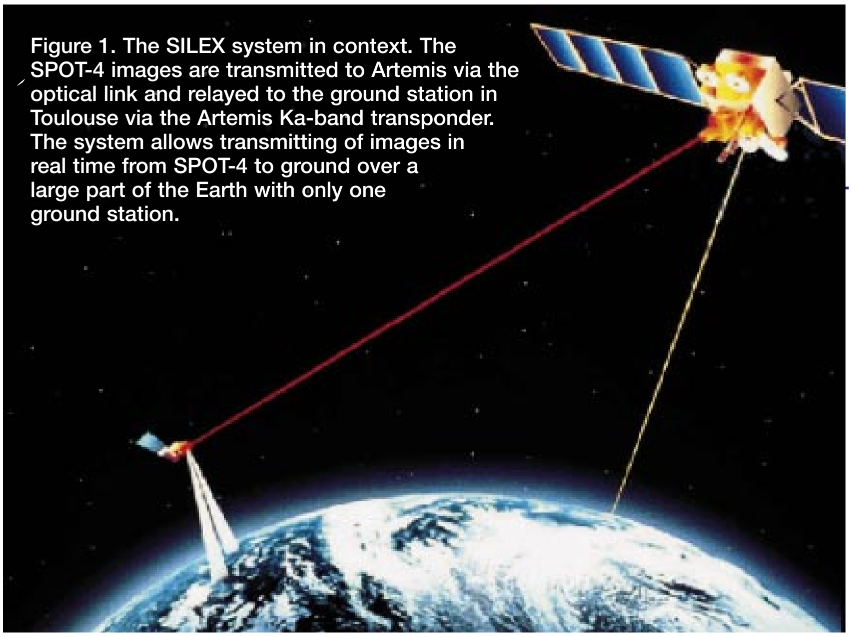

Figure 1. The SILEX system in context. The SPOT-4 images are transmitted to Artemis via the optical link and relayed to the ground station in Toulouse via the Artemis Ka-band transponder. The system allows transmitting of images in real time from SPOT-4 to ground over a large part of the Earth with only one ground station.

The SILEX mission

The SILEX system comprises two optical terminals: PASTEL on board the French earth observation satellite SPOT-4 and OPALE (Optical PAyload for Inter Satellite Link Experiment) to be embarked on the European communications satellite Artemis.

The objectives of SILEX are to perform optical communication link experimentation in orbit and to transmit SPOT-4 imagery to Artemis, which will relay it to the ground via its Ka-band payload. The use of the Artemis satellite in a high geostationary orbit allows communications to be achieved between SPOT-4 and its ground facilities in Europe over a much greater area of the globe than can be achieved directly (Fig. 2).

While SPOT-4 is already in orbit the full SILEX experiment cannot be carried out until Artemis is launched in early 2000. However, in spite of the missing partner, an in-orbit test programme has been undertaken, successfully performing all the internal calibrations, acquiring and tracking selected stars, and characterising the dynamic interaction between the host platform and the terminal.

PASTEL in-orbit performances

A particular problem to be overcome in the design and operation of optical links is that of signal acquisition and tracking. The divergence of the communication beam is only 8 µrad, which is several orders of magnitude lower than the open-loop pointing accuracy of a typical orbital platform. This is why a dedicated acquisition sequence must be undertaken where, while both terminals coarsely point to each other in open loop on the basis of spacecraft orbital models, OPALE on Artemis systematically scans a wide-angle (750 µrad) beacon beam in the direction of PASTEL on SPOT-4. When PASTEL is illuminated by the beacon beam, it rapidly corrects its line of sight and directs its narrow communication beam towards OPALE. Similarly OPALE detects the incoming PASTEL signal, aligns its line of sight, and transmits its narrow communication beam towards PASTEL. The two terminals then remain locked on each other in closed-loop tracking and the communication begins. Furthermore, due to the finite velocity of light

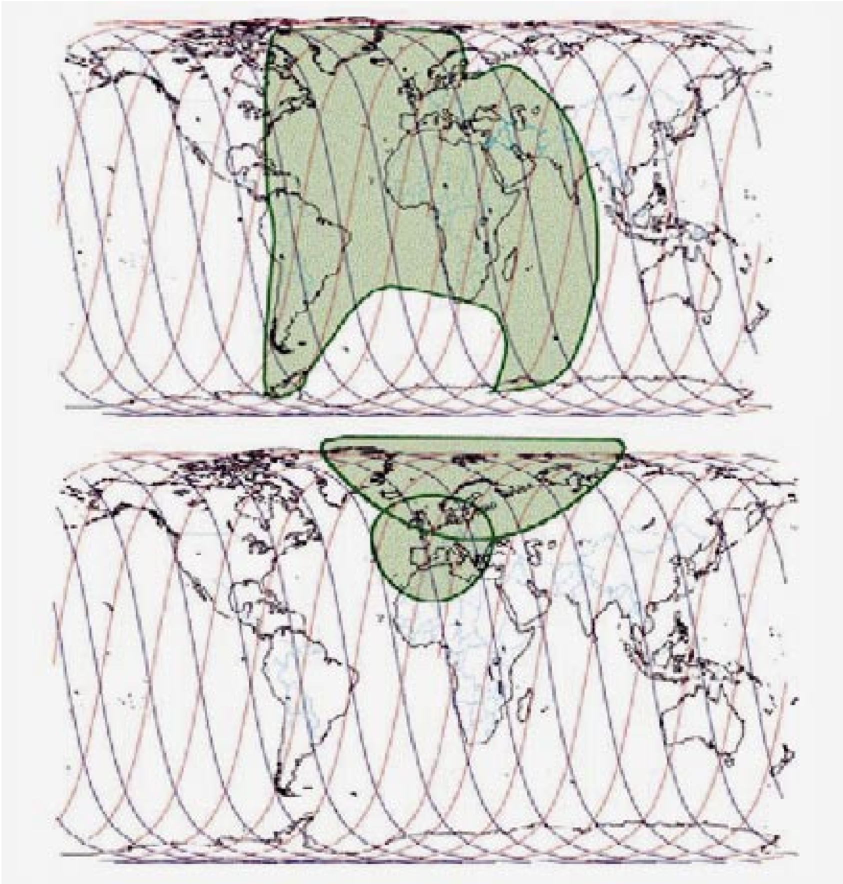

Figure 2. The ground coverage where real-time images can be relayed via Artemis to the ground stations in Toulouse (upper figure) compared to the coverage from the direct X-band link from SPOT-4 to the ground stations in Kiruna and Toulouse (courtesy CNES)

Figure 3. X-ray view of a SILEX terminal. The telescope and optical bench is located on the mobile part, which is mounted on a gimbal with a hemispherical pointing range. On the optical bench are located the acquisition and tracking sensors, the communication sensors, the laser diode transmitter packages, the fine pointing mechanism, the point-ahead mechanism, and all the necessary optical relays and filters.
The telescope mirrors and main structural elements are made of Zerodur. The acquisition and tracking sensors are based on CCD matrices, the laser diodes are of the GaAlAs type (0.8 μm), and the communication detectors are avalanche photo-diodes

Figure 4. The optical terminal PASTEL, located on the anti-Earth side of the SPOT-4 platform (photo courtesy CNES)

and the transverse velocity of the two host satellites, the transmitted beam must be offset with respect to the received beam direction by the so-called 'Point Ahead Angle'. This angle in the case of GEO-LEO communication is up to 70 µrad. The two terminals autonomously calculate the pointing directions based on orbital models of the two satellites. Because of the criticality of these operations it has been highly desirable to verify them as far as possible. In the absence of Artemis in orbit this has been achieved using a series of stars.

Arcturus, Betelgeuse and Sirius have each been successfully acquired and tracked several times, all at the first attempt. No acquisition failure has been observed, despite the fact that the irradiance from the stars is in some cases below the minimum beacon signal from OPALE and orders of magnitude below the telecom signal from OPALE. The terminal open-loop pointing error has also been demonstrated to be very small with respect to the acquisition field of view of 8000 µrad (Fig. 5).

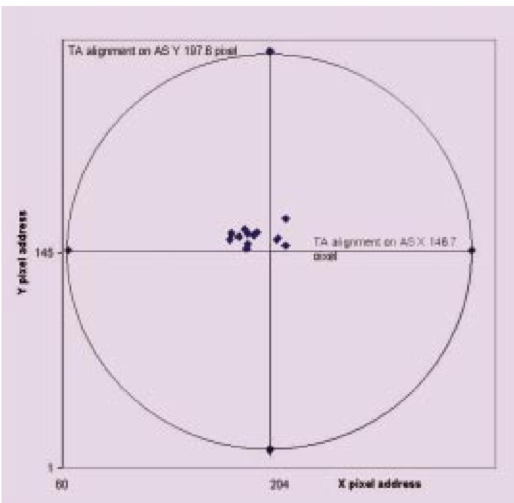

Figure 5. The open-loop pointing error of PASTEL compared to the acquisition field of view. The figure represents the first detected pixel position on the acquisition sensor during 12 star acquisitions performed over a period of one month. No in-orbit correction of alignments has been performed

Open loop error in µrad	x	y
Average	-333	251.5
Max from average	645	177.5

The time necessary to detect the incoming signal, correct the 'Line of Sight' and enter closed-loop tracking has been demonstrated to be only 90 ms.

The tracking error, which due to the very low incoming power level is dominated by quantification errors, has been shown to stay within the allocated budget with significant margins.

Tracking error		
1 σ µrad	Ex	Ey
Sirius	0.12	0.19
Arcturus	0.12	0.19
Betelgeuse	0.10	0.12

Internal calibrations allow measurement of the alignment stability between the reception optical path and the emission optical path. This stability over a typical communication session duration is as low as 0.1µrad in the worst case.

Calibrations of acquisition and tracking sensors and of laser diode transmitters have confirmed the good health of this essential equipment.

The temperature stability of the optical bench has been measured to be better than 0.2°C, which is promising for stable emission wavelength and alignment stability.

Conclusion

The conclusion of a detailed in-orbit test campaign is that PASTEL is in very good health and that the verified performances are excellent. Another important conclusion is that the ability to predict pre-flight the in-orbit performances, through a combination of both test and modelling, has now been validated.

Although the first optical intersatellite communication link will only be completed in early 2000 with the launch of OPALE, the present achievement of successful launch and demonstrated in-orbit test performances of PASTEL puts Europe a step ahead in the development of next-generation space telecommunication systems. esa