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Optical Switch Matrix development for new concepts of Photonic based flexible Telecom Payloads

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ABSTRACT

The next generation of telecom satellite makes the industry facing a technological rupture to reach high data throughput up to 1 terabit/s, while making communications links reconfigurable during all mission phases. That is why the introduction of optical communication technologies like laser links or photonic payloads in telecom satellites is foreseen to revolutionize the space telecom market. Hence the groundbreaking photonic payload will enable reaching the increasing demand of debit and flexibility thanks to miniaturization. In such photonic payload, the proposed optical switch will provide both the added value of optical fiber and new flexibility, redundancy and adaptability functions. Sodern, a recognized space equipment provider is presently spatializing the DirectLight® 1,55 µm Optical Switching Technology from HUBER+SUHNER Polatis Ltd (UK), the worldwide leader in optical switch technology for ground telecommunications and datacenter networks.
This paper focuses on the development activities of Sodern and Polatis on their Space Optical Switch development both for GEO 1 terabit/s high reliability and for low cost LEO constellations. An overview of the technology evaluations and design studies as well as of breadboard performance and environmental testing will be presented. Finally Sodern will explain the product development roadmap including the upcoming EQM.

Keywords: Optical Switch, Geostationary Telecom Satellites, Internet Services Constellations, DirectLight®, photonic payload, flexibility, redundancy

1. INTRODUCTION

The next generation of telecom satellites is expected to provide high data throughput, while making communication links reconfigurable during all mission phases, with high performance and decreased mass, power and cost per bit. For more than a decade, the space industry has put efforts into demonstrating the advantages of photonics technology to obtain such innovative payloads, with a photonic repeater at the core of the payload, instead of an expensive and complex full RF architecture [5] [6] [7]. The combination of conventional Radio Frequency with the emerging photonic solutions, will thus support flexible routing of any RF signal from any input channel, to any output channel at any frequency.

At the core of the repeater, the optical switching is the key enabling photonic technology to bring high flexibility in communication satellite payloads but also to allow redundancy functionalities and optical interconnecting [8] [9]. The optical switching and routing equipment will be responsible for directing incoming optical signals containing Radio Frequency data to suitable output ports.

While many of the satellite payload photonic subsystems can be designed based on already space qualified devices, no technology for optical switching has been brought to a sufficient level of maturity to reach the flight proven level within a few years. The terrestrial technology, named DirectLight® [1] [2] [3] based on 1.55 µm fiber matrices, oriented thanks to piezo actuation, turns out to be the best candidate for a space optical switch of large port number.

This paper thus describes the space Optical Switch Matrix development, based on the DirectLight®, orientable fiber matrix technology. We first give an overview of the future payload architectures, requiring the optical switch function. We then describe the indisputable advantages of the DirectLight® technology for answering space optical switch requirements of reduced optical loss, mass, power and reliability compromise for a large number of ports. We will then focus on the late advances obtained with the first optical switch breadboard for Geostationary telecom satellite that has been successfully submitted to environmental tests, and finally we will explain the perspectives of the optical switch development either for GEO large satellites or LEO satellites constellation.

2. PHOTONICS PAYLOAD FOR TELECOM SATELLITE

2.1 Added value and maturity of photonics for communication satellites

The recent need of GEO telecom satellite capacity and flexibility has drastically increased. The tables below illustrate the expanding demand for geostationary traditional telecom. This implies critical improvement of satellite payloads with regard to equipment numbers, mass, consumption and heat dissipation that the traditional RF technology based telecom payloads is expected to not be able to achieve any more. RF technology has indeed reached its limit of feasibility for price/size/mass launch constraints.

Table 1. Examples of Ka band geostationary data services satellites.

GEO Satellite	Launch Year	Throughput
Wildblue-1	2006	8 Gbps
Spaceway-3	2007	10 Gbps
Ka-Sat	2010	90 Gbps
ViaSat-1	2012	140 Gbps
Viasat-2	2016	>200 Gbps
Viasat-3 EMEA	2020 (ordered)	1 Tbps
Viasat-3 America	2020 (ordered)	1 Tbps
Eutelsat Konnect	2021 (ordered)	500 Gbps
Viasat-3 Asia	2021 (to be ordered)	> 1 Tbps

Therefore, the main challenge of the next Terabit/s generation of HTS is to provide a ten-fold-increased capacity with enhanced flexibility, while maintaining the overall satellite within a "launchable" volume and mass envelope.

In parallel, the emergence of MEO/LEO satellites constellation using laser links enhances the need for full optical signal based telecom satellite with drastically reduced price/size/mass constraints to answer mass production needs. The next table shows the increasing demand for both hybrid or full photonic payloads.

Table 2. Examples of MEO/LEO communication satellites constellations.

Constellations	Name	First Launch	# of Sats	Throughput /Sat	Total capacity	Laser link
Operational or Procured systems	O3B	2013	12	~20 Gbps	0.2 Tbps	No
	OneWeb	2019	640	~ 8 Gbps	5 Tbps	No
	O3B m Power	2021	7	~ 250 Gbps	~ 2 Tbps	No
Announced system with procurement activities on going	LEO Sat	2021	108	~20 Gbps	2 Tbps	Yes
	Telesat	2021	200	~20 Gbps	4 Tbps	Yes
	Space X	2022	4000	~20 Gbps	80 Tbps	Yes
	OneWeb 2	2023	1000	~40 Gbps	40 Tbps	Probably

To that extent, the photonic technology offers an adequate answer to the operator's interest for higher capacity and payload flexibility but also for full optics communication payload.

The next figure illustrates, photonic payloads architecture types with RF data over fiber thanks to optical conversion, or full photonic equipment addressing laser links/and feeder links technologies

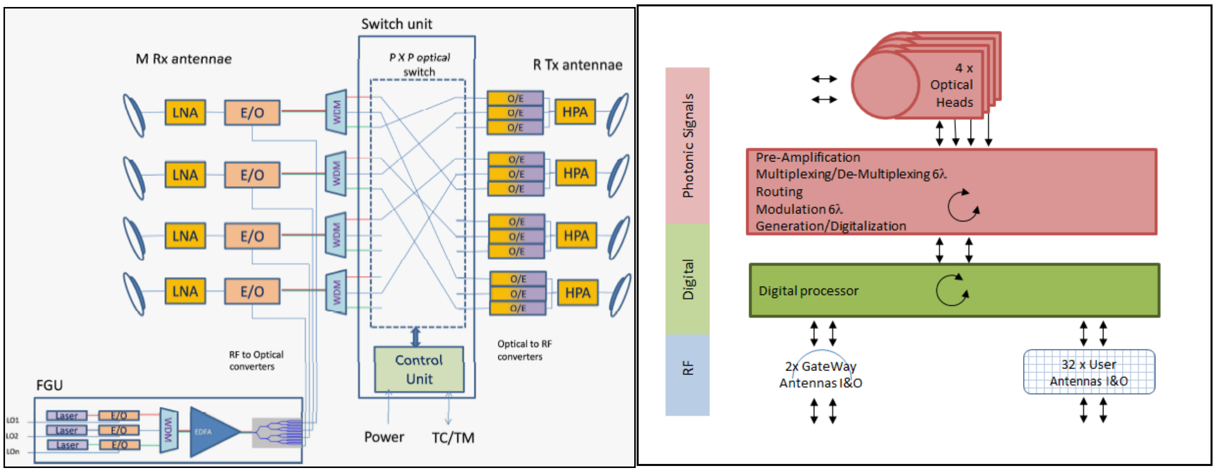


Figure 1. Advanced photonics based payload architecture. Examples of Hybrid RF-photonic payload

2.2 Advantages using optical switch for photonics payloads

One of the main enabling photonic fibered technologies is the optical switching. For GEO satellites, in addition to flexible allocation of gateways, it provides redundancy functionalities and large scale optical interconnecting which is not possible with pure RF technology. To sum up, the switch brings to the payload its flexibility, its versatility and its reconfiguration ability in case of local failure. For LEO constellations, the switch will bring the software defined flexibility that is necessary for routing optical signals at the satellite network scale.

The optical switch is one of the cornerstones of the future architecture for photonic payload. This equipment is in charge of distributing and routing of optical signal carried by optical fiber. Optical Switch functions and advantages are:

- To reconfigure the payload to adapt the configuration with the customer needs during the satellite lifetime, guaranteeing versatile and transparent solutions. The operator has the possibility to progressively deploy capacity or services and follow the evolution of the demand.
- To modify data paths to get around defective equipment or gateway failure.
- To adjust configuration with available channel to respect the frequency allocation. (Today, the gateway to-user beam interconnection has to be defined from the design phase.)
- To dynamically adapt the configuration to arrange the bandwidth with night and day demands – for example, adding interactivity in broadcast systems.
- To vary gateway feeder link with weather availability for high frequency or optical uplink.
- To allow a modular payload by simplifying the modifications of equipment numbers.
- Then to offer a better efficiency and a greater revenues/costs ratio for satellite operators.

Sodern, a recognized optronics space equipment provider and HUBER+SUHNER Polatis, the world leader for terrestrial optical switches in many market segments including telecom and data centers, are therefore developing a new space product to answer this need of an optical switch function in future telecom satellites, whatever the kind of photonics based payload (with RF or digital technologies) is required, for GEO or LEO telecommunications. The first efforts of this development have been focused to answer GEO stationary needs, while development for LEO constellations will start before the end of 2018.

3. DIRECTLIGHT® ADAPTATION FOR SPACE OPTICAL SWITCH

3.1 Directlight® technology presentation

No solution has been developed to high level of TRL for now in Europe for the switch function of the Space Telecom photonic payload.

A previous analysis had demonstrated the adequacy of the HUBER+SUHNER Polatis technology with the space optical switch for telecom satellite photonic payload. Polatis terrestrial products address many markets including terrestrial telecom and datacenter, with a core technology capable of providing up to 384x384 ports and beyond. This is then the only identified solution for addressing a large number of ports while reaching 1dB of insertion loss for space applications.

The innovative principle of the HUBER+SUHNER Polatis technology DirectLight® [1] [2] [3] is illustrated in the next figure:

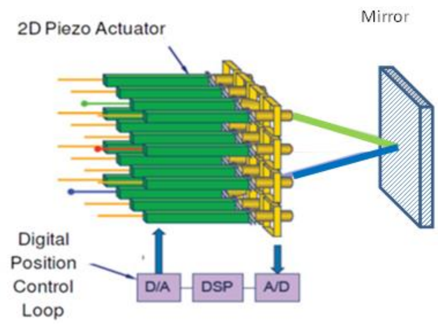


Figure 2. DirectLight® core technology with mirror reflection based configuration.

- Each input fiber is terminated with an optical collimator to generate a parallel beam.
- The collimator orientation is piloted by a 2D piezoelectric actuator. The position is controlled by a local closed loop using an integrated position sensor in order to cancel piezo hysteresis, creep and drift. The collimator is then pointed to the desired output oriented collimator.
- The output collimator focuses the beam on the fiber end, and injects the light in the fiber.
- The link between two ports is established when input collimator and output collimator are aligned facing each other.

The core performance of the DirectlLight® product is based on the slice component composed of 12 fibered collimators with corresponding piezo-actuator and proximity EEE components as shown in the figure below. The integration and alignment of several slices enables to build a complete large switch matrix.

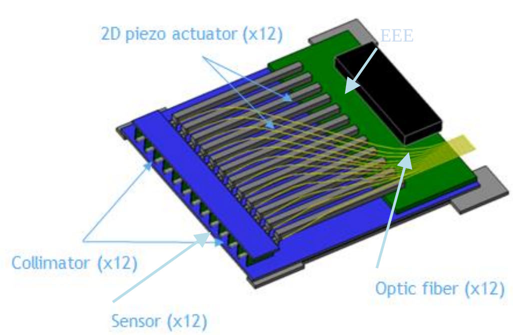


Figure 3. DirectLight® technology brick component : the 12 port slice

3.2 Advantages for space applications

DirectLight® technology is adapted thanks to its main advantages, interesting for space application:

- Optical fiber @1.55µm
- C-band and L-band optical signal compatible
- Low insertion loss (typically <1dB) and no phase noise degradation on optical signal: it is to be noted that the insertion loss due to the optical switch is lower than that due to other components of the photonic payload, modulator, demultiplexer or coupler
- High scalability up to 384x384 with modular design, that enables answering the big satellite market needs for increasing capacity and flexibility
- Dark fiber switching and bidirectional operation, enabling the switch block to be adaptable to many payload architectures
- A high reliability, enabling to place the switch at the core of reconfiguration payload either in operation or in case of an equipment failure
- Proven on ground technology and already tested with moderate level environment,
- Non-critical alignment tolerances – within standard capabilities for assembly automation.

4. GEOSTATIONNARY OPTICAL SWITCH DEVELOPMENT

4.1 Technical objectives of the GEO space optical switch development

Sodern and Polatis objectives to develop the space optical switch with DirectLight® technology, are to define a scalable architecture that makes the best compromise between SWaP (Size Weight and Power) and reliability, in order to reach optical performance identical to terrestrial optical switch performance and to guarantee functionalities and performance within the GEO or LEO required environment. Therefore, the major requirements underlying the space Optical Switch development are as follows:

- insertion loss, fiber connector excluded: 1 dB typ. (2.5 dB max)
- a scalable number of ports from 24x24 to 96x96
- a modular electronic architecture to reach high reliability
- a reduced SWaP adapted to ports number from 24x24 to 96x96
- performances guaranteed in thermal range -10 °C / +60 °C, qualified for mechanical loads (sine at 20g, random at 18.4g RMS, shocks at 1300g SRS [3000 – 10 000Hz]), and resistant to radiations 30krad, 60 MeV.cm²/mg
- without disturbing others light path.

4.2 OPTIMA Switch breadboard objectives

The early development has been funded by an European Commission H2020 Program funding. The project named OPTIMA has the objective to demonstrate and validate the photonics payload concept and its benefits in a relevant industrial environment, which includes delivering a demonstrator of an hybrid RF/photonics payload and the roadmap to such future payload. The OPTIMA consortium gathers European industries piloted by ADS Ltd and constituted of ADS Ltd (UK), ADS SAS(Fr), DAS photonics(Sp), CORDON(It), IMEC(Be), HUBER+SUHNER Polatis (UK) and Sodern(Fr). The project started at the end of 2016 and is planned to be finished by mid-2019. Sodern and Polatis provide the Optical Switch equipment included in the payload demonstrator.

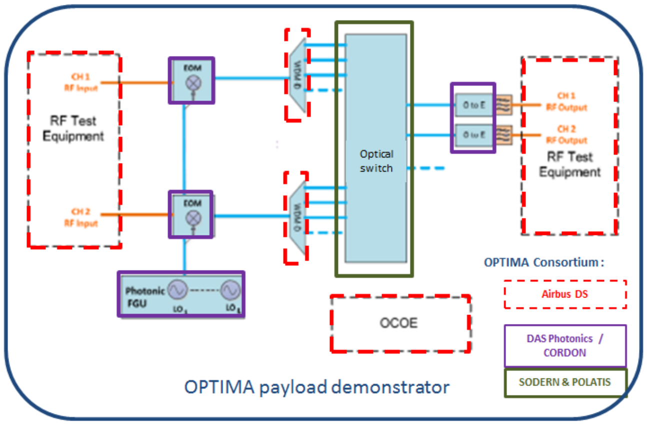


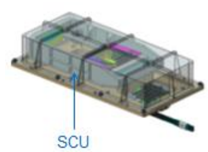
Figure 4. OPTIMA payload demonstrator: block diagram and identification of partners deliverables

At switch level the main objectives in the frame of Optima were then :

- to validate that POLATIS DirectLight® Slice technology can be used for space and demonstrate the overall absence of any showstoppers regarding critical space environment or processes and materials,
- to design, manufacture, test and qualify a 48-port Switch Core Unit Breadboard (24 inputs - 24 outputs) with Polatis COTS EEE (TVC, vibrations, shocks),
- To deliver the breadboard for implementation and testing in the OPTIMA Payload Demonstrator to demonstrate steps to TRL 6.

The OPTIMA Elegant Breadboard is a 24x24 port switch, constituted of the following **sub-systems:**

- **SCU = S**witch **C**ore **U**nit
  that includes the slices, reflection mirror, dedicated mechanical interface mounted on dampers



- **SDE S**witch **D**riving **E**lectronics
  that includes boards with command board, connexion interconnexion boards

In the scope of OPTIMA, the SDE is the Polatis terrestrial control board, while a specific SCU has been designed based on adapted DirectLight® Slices integrated in a specific mechanical structure, to reach compliance to mechanical environment and interfaces for the OPTIMA payload demonstrator. A folding architecture with mirror facing a set of four 12-port slices has been chosen to reduce the overall size.

Though the main effort in the OPTIMA project is focused on addressing slice risk of non-robustness to space, Sodern has evaluated the impact of space grade EEE components on the electronics boards to assess the absence of any showstopper.

4.3 DirectLight® technology preliminary evaluation

As explained before, the core performance of the DirectLight® product is based on the slice component (illustrated earlier in Figure 3).

The first step of the development to be addressed is the slice compatibility to space constraints either with regards to material and process norms or to its ability to sustain any type of LEO/GEO telecom mission's environment.

Sodern has evaluated the compliance of Polatis Slice with respect to European Space Standards (ECSS) and SODERN Standards applied for the Space Telecom market.

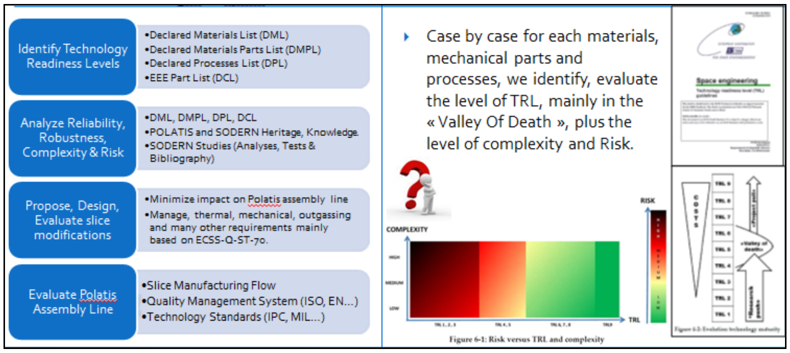


Figure 5. DirectLight® technology compliance to process and material ECSS norms

A thorough analysis of about 15 Materials, 5 Mechanical Parts and 20 Processes, of the slice manufacturing line (machines, tools, test benches, monitoring too), Electronic Assemblies and soldering processes, Gluing processes, Welding processes has been successfully performed to conclude the compatibility of slice manufacturing with space standards.

Sodern has then performed FEM modeling of the slices and an extensive vibration tests campaign on different specimens to identify the slice mechanical weak point, its origin and possible modifications.

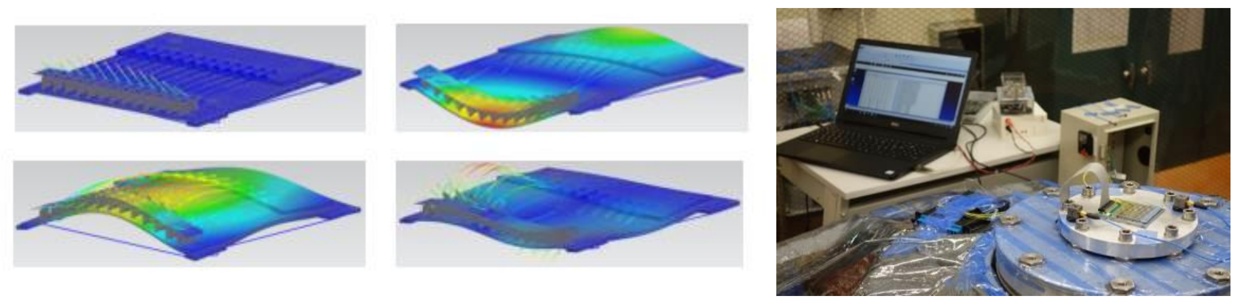


Figure 6. DirectLight® slices analysis: CAD slice models and vibrations tests set up @Sodern

The main conclusions of slice models and tests correlation is that the terrestrial slice needs modifications to sustain high mechanical environment up to about Random Vibration=26 gRMS at slice interface. A trade-off has shown that the minimum modification concerns its baseplate stiffening and change of its material. However, this sole modification is not sufficient to drastically reduce vibration levels at collimator and piezo level, which will necessitate finding some compensation with the mechanical structure.

4.4 OPTIMA Switch Breadboard design approach

The objectives of the Switch Core Unit design, is thus to minimize vibration modes without degrading functionality of the slices and maintain them in an accurate and stable position. The figure below shows the mechanical structure maintaining the set of 4 slices:

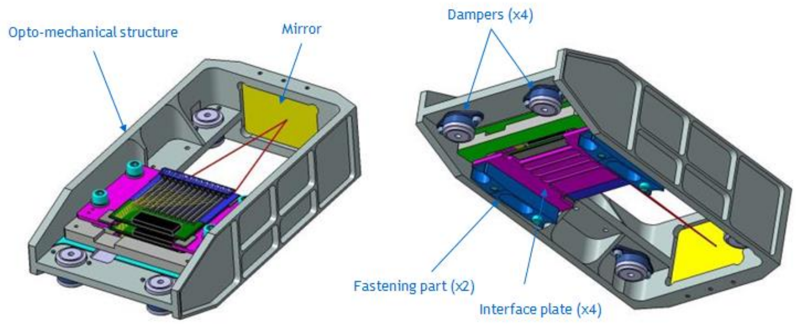


Figure 7. OPTIMA Optical Switch Breadboard: Switch core Unit design.

This design has been optimized via mechanical analyses using a FEM model, to check that there is no issue regarding acceleration on the slices, stresses and screwed loads on the overall Switch Elegant Breadboard, submitted to different loading cases. The main criterion defined during the mechanical tests is the acceleration criteria on the slice limited to 26gRMS random vibrations. High frequency dampers, which are located underneath the SCU as shown in the above figure, enable to limit slice vibration to 26 gRMS with entrance level at switch interface at 16 gRMS.

4.5 OPTIMA Switch Breadboard tests results

All slices have been produced by Polatis, on its production line, taking into account required modification. Other sub-assemblies – mirror, mechanical structure, dampers – have been procured by Sodern to Polatis for integration of the OPTIMA Switch Elegant Breadboard.

Figure 8. OPTIMA Optical Switch Breadboard: design integration and full integrated Elegant Breadboard.

Ahead of breadboard integration, some Lot Acceptance Tests on slices have been performed in vibration and TVC, and have successfully passed all functional tests after each environment tests.

The integration and calibration of collimator positioning has been performed at Polatis premises in addition to characterization of initial electrical and optical performance (using standard Polatis ambient test facilities), while environmental tests in non-operational mode are performed at Sodern. During this campaign of environmental tests, functional go/no-go tests to check closed-loop collimator positioning performance and insertion loss stability (with a measurement accuracy of ±0.5dB) have been successfully performed between each environmental test.

Full performance tests on all port links are only performed at the end (again using Polatis test facilities). Underneath table synthesis main tests results on initial insertion loss on all ports links, and IL stability in between environments on a reduced number of ports links:

	Tests Configuration	Tests Results
OPTIMA slice tests		
1. Vibration of ruggedized slice (1)	*Sine and random vibration 26gRMS*	*Functional after vibration*
2. Thermal Vacuum Cycle of ruggedized slice (1)	*One cycle [+20°C ;+75°C] non operational*	*Functional after TVC,*
OPTIMA switch Breadboard tests		
3. Integration, calibration, initial performance tests of Switch BB(2)	*-5°, +25° and +55° in operational conditions*	Insertion Loss within 1dB+/-0,8dB at 20° Mass 3,6kg without fiber connector and with COTS components Power consumption 4.65 W
4. Vibration tests of Switch BB(1)	*Sine Vibrations 20g, Random vibration 16g RMS*	*Functional after vibration (electrical close loop error compliant), Insertion loss stable within +/-0.5dB see figure10 for details*
5. TVC Non operational of Switch BB(1)	*TVC Non operating temperature [-40°C; +70°C], vacuum 10^{-6}mBar*	*Functional after TVC - Insertion loss stable within +/-0.5dB see figure10 for details*
6. Shock tests of Switch BB(3)	*Up to 1300g on each axis.*	*Functional after shocks*
7. Final performance tests of Switch BB(2)	*Before/after functionality*	*To be performed*

Figure 9. OPTIMA SEB Acceptance tests sequence results performed at Sodern(1), Polatis(2) or by Sodern at IABG(3)

The graph below focuses on insertion loss performances measured for now:

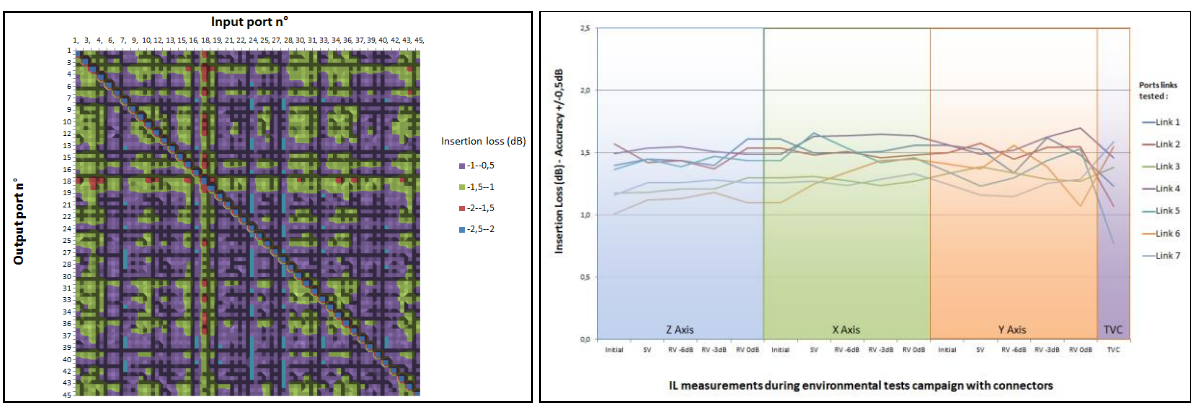


Figure 10. OPTIMA SEB Acceptance tests : Initial insertion loss performances cartography of all ports links (left) - Relative before/after environmental tests Insertion Loss measurement on 7 ports links (right) : maximum drift 0.62dB , and 0.19 dB RMS dispersion

As a preliminary conclusion, integration, calibration and environmental tests have been passed successfully, at slice level and Switch Elegant Breadboard level. At the time of writing, functional tests after TVC are being performed at Sodern, and final performance measurements are planned afterwards back in Polatis with standard Switch bench.

At this stage of the breadboard tests, the main conclusions of the first step of space switch development are:

- Identification of DirectLight® slice modification for space use have successfully been validated
- Necessity of dampers to absorb mechanical environment are the best solution to complete slice modification
- Impact of vibrations, TVC and shock tests to be drawn afterwards. (no failures observed between environmental tests)
- Performance of the switch, Insertion loss < 2.5 dB max without connectors, is maintained after vibrations and thermal vacuum environments without recalibration
- Analysis of slice materials, processes: minor evolutions to compliance to ECSS
- The electronics architecture presents no showstopper for implementation with space EEE components.

4.6 GEO Switch Architecture

In parallel with OPTIMA switch bricks validation towards space constraints, Sodern has started defining the Space Optical switch new architecture, both regarding electronics boards and in terms of SWaP optimization.

In cooperation with Polatis, the electronics architecture has been analyzed to identify solutions for replacing EEE proximity components of slice or controlling board while maintaining identical functionality and performance.

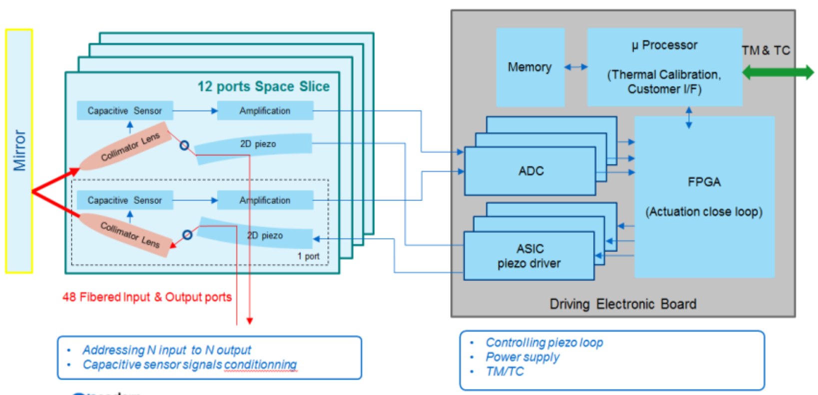


Figure 11. Optical Switch electronics architecture : block diagram and sub function definitions

For now, a smart preliminary architecture has been retained without redundancy in order to optimize the overall size and mass compromise.
In the figure below, the implementation concept is foreseen with an electronics architecture showing the SDE boards placed around the SCU that enables to have a compact monobloc equipment. The damping function defined in OPTIMA is maintained, while evolution of SCU relies on slice orientation perpendicular to the interface plane.

Figure 12. Optical Switch future concepts of mono-bloc implementation from 24x24 ports to 96x96 ports.

The choice of electronic architecture and overall switch implementation enables Sodern and Polatis to propose a modular concept of switch with a large number of ports and reduced size and mass summarized underneath:

Table 3. Foreseen GEO Optical Switch Mechanical interfaces.

Optical Switch Mechanical interfaces			
Size (L,W,H)	24x24 ports < 33x20x20 cm 48x48 ports < 35x30x22 cm 96x96 ports < 35x43x22 cm	Mass	24x24 ports <8 kg 48x48 ports <13 kg 96x96 ports <20 kg

Rough orders of magnitude of maximum power consumption have been assessed leading to ranges as follows: 8-24 W for 24x24ports, 17-49 W for 48x48 ports and 33-97 W for 96x96 ports. Preliminary reliability evaluations are also being processed. Though no redundancy has been designed at this stage of preliminary evaluation, the modularity of the foreseen concept will enable to propose necessary redundancy, with the best reliability SWaP compromise proposed above.

5. ROADMAP TO OPTICAL SWITCH FLIGHT MODEL

5.1 Roadmap to GEO FM optical switch

While the space telecom industry has been working for years now on introducing photonics in telecom payloads, lately a rapid increase in demand has spurred satellite manufacturers onto working on IOD or ground demonstrators to highlight the assets of photonics. Sodern is now working in cooperation with primes to prepare the switch product for PFM/IOD within a few years. The figure below shows Sodern's development plan to an Optical Switch flight model.

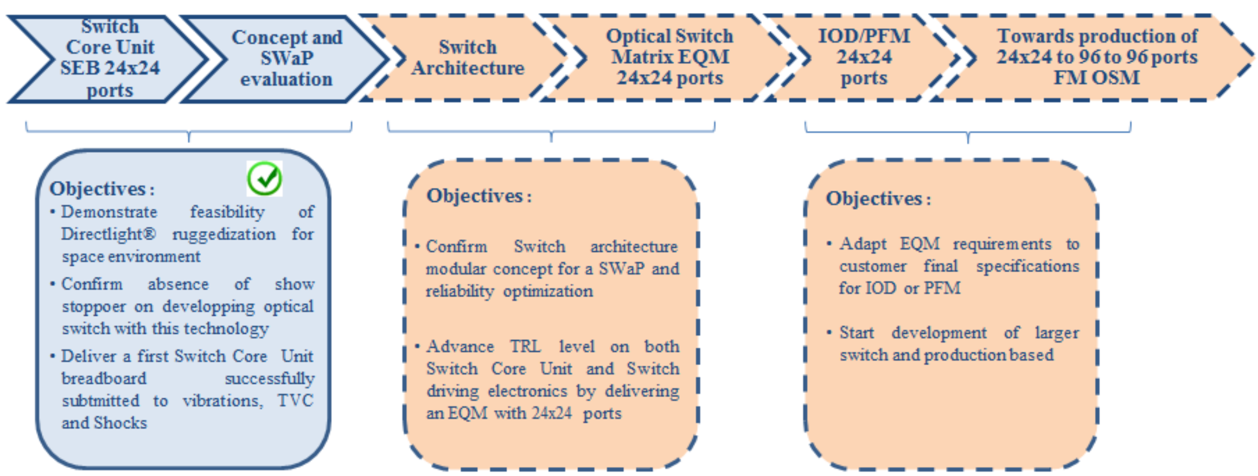


Figure 13. GEO Optical Switch Roadmap to flight model plain lined boxes achieved in 2016-2018 , dotted lined boxes foreseen in next years

OPTIMA breadboard has confirmed that DirectLight® technology is the most appropriate technology for reaching a high level of reliability and optical performance for large switches. The next step is to produce an Engineering Qualification model, with representative slice electronics and that will be submitted to qualification tests either at component, sub-assembly or EQM levels. The step to an IOD or PFM will depend on satellite primes' requirements. This roadmap will enable to answer large telecom satellite market for small series of 1 to 5 switches a year.

5.2 Opportunities for LEO constellation optical switch

Sodern and Polatis have proposed to take part to a European Commission H2020 consortium including MDA UK, and DAS photonics. The proposal, named SODaH, plans to consolidate concepts of LEO broadband constellations using OISL and RF Up/Down links enabling an optical space data highway and demonstrate the feasibility of a “Software Defined”, “Hybrid Photonic/Digital” payload. Activities could start before the end of 2018.

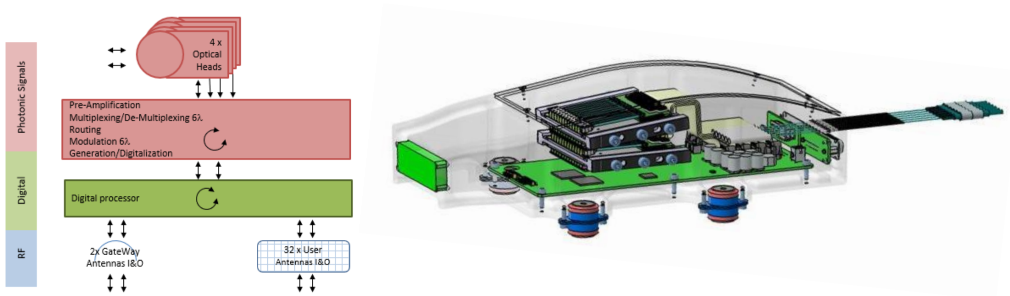


Figure 14. Advanced payload architecture using for OISL and foreseen new space switch concept.

For the switch function, Sodern and Polatis proposes the same mechanisms as those of the GEO switch: the core technology will be based on the same DirectLight® slice. The proposed use of Screened COTS EEE components and additive layer manufacturing will enable to reach a new range of requirement: an optimized SWaP (2 $dm^{3,}$ 2 kg, 5 W), a low-cost switch for a high volume manufacturing (100s /year) answering future constellation needs.

6. CONCLUSION AND PERSPECTIVES

Sodern has demonstrated that the HUBER+SUHNER Polatis terrestrial 1.55 µm optical switch, with its core DirectLight® technology can be ruggedized to sustain space environment while maintaining a very low level of insertion loss. First in the scope of the European Commission Horizon 2020 OPTIMA project, Sodern and Polatis have designed, manufactured and tested a 24x24 port Switch Core Unit Breadboard, based on ruggedized slices and an optimized mechanical structure. A test campaign was run both at switch component (slice) level, and at Breadboard level to characterize, adjust and demonstrate robustness of the space design to vibrations up to 16g RMS, shocks up to 1300g SRS and Thermal vacuum cycles up to [-40 °C;+60 °C]. Throughout the environmental tests sequence, the main optical performance, insertion loss, has proved to be stable within ±0.5 dB, with average insertion loss of 1 dB for all 48 ports, which is a very low contributor to the whole future photonic sub-systems for telecom satellites. Those results have brought DirectLight® to a high level of maturity for space application.

In parallel, Sodern has also evaluated the DirectLight® controller board adaptation with space norms and space qualified components, to conclude that its space equivalent Switch Driving Electronics will enable Sodern and Polatis to propose a mono-bloc 1.55 µm Optical Switch concept, with a good level of compromise between size, mass and power ranging from 24x24 ports to 96x96 ports for Geostationary telecom satellites. The next step of development for the GEO optical switch is to design and manufacture the 24x24 ports Engineering Qualification Model including space designed Driving Electronics and ruggedized DirectLight® slices in a Switch Core unit benefitting from the OPTIMA Breadboard conclusions. With this new step and further adaptation to future customers’ needs, Sodern and Polatis will be in a position to propose an In Orbit Demonstration of a 24x24 Optical Switch Matrix for GEO satellite within less than 5 years, and get the “flight proven” level paving the road for Sodern and Polatis to develop and produce Optical Switch up to 96x96 ports.

Sodern and Polatis are also working on a demonstrator of a low cost DirectLight® based optical switch matrix for new space constellations. It will present significant added value for concepts for LEO broadband constellations using OISL and RF Up/Down links via an Hybrid Photonic/Digital, payload.

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