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Photonics Technology Roadmap at ESA

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04.12.2023

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Content of the presentation

- Introduction (SXS and Harmonisation)
- Technologies covered by the domain “Photonics” at ESA
- Key issues
- State in the art in Europe
- Competitiveness and benchmarking
- Mission needs and Market perspectives
- European strategy interests
- Key points to be know from the Swiss Photonics actors
- Roadmap inputs
- Conclusion

Introduction

- Space Exchange Switzerland

Amplify the voices of the Swiss space ecosystem.

A national platform for the promotion of space in Switzerland funded by the Swiss Space Office (SSO) of the State Secretariat for Education, Research and Innovation (SERI).

It is implemented by five Swiss universities for the whole Swiss space ecosystem

Introduction

- European Space Technology Harmonisation

❖ Goals:

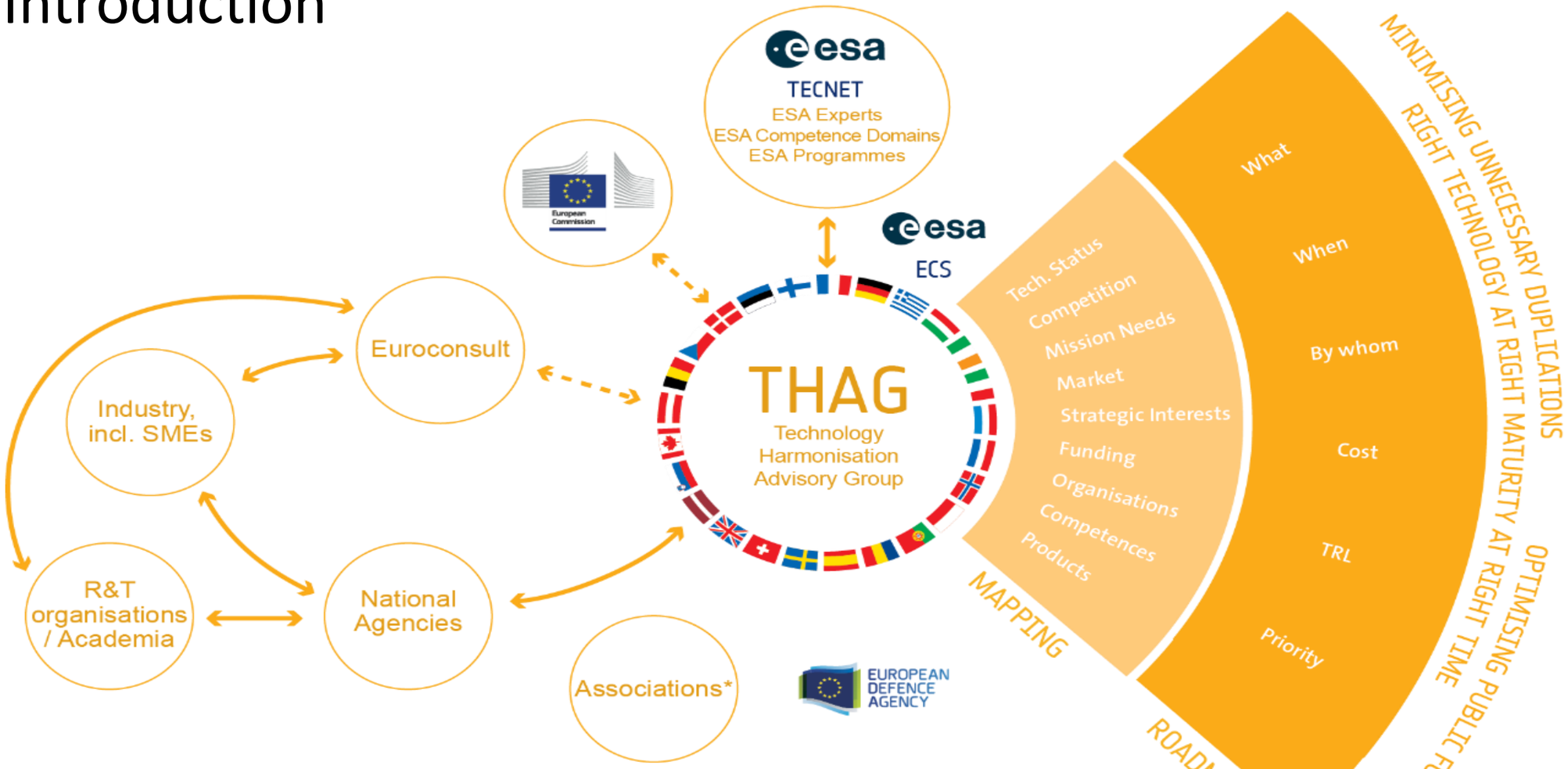
- Harmonise R&D activities among ESA members states and associated. It is a voluntary process, based on exchange and transparency.

- Fill strategic gaps and minimize unnecessary duplications

- Consolidate European strategic capabilities

- Coordinate the European space technology policy and planning

Introduction



*Eurospace, SME4Space, ESRE, EARTO, etc..

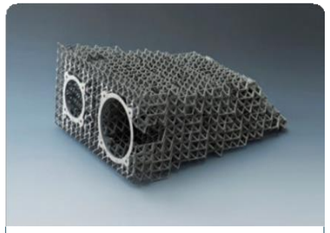
Introduction

EEE COMPONENTS, PHOTONICS, MEMS

- Micro and Nano Technologies
- Optical Detectors
- Photonics

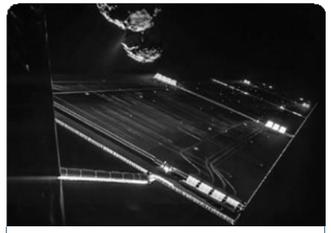
AVIONIC SYSTEMS

- Avionics Embedded Systems
- On-Board Computers, Data Handling Systems and Microelectronics
- On-Board SW
- RF & Optical Metrology
- TT&C Transponders and Payload Data Transmitters
- AOCS Sensors and Actuators
- On-Board Radio Navigation Receivers



STRUCTURES, MECHANISMS, MATERIALS, THERMAL

- Actuators Building Blocks for Mechanisms
- Additive Manufacturing
- Electric Propulsion Pointing Mechanisms
- Heat Transport Equipment and Systems
- Pyrotechnic Devices
- Solar Array Drive Mechanisms
- Technologies for Hold Down, Release, Separation and Deployment Mechanisms
- Coatings
- Deployable Booms & Inflatable Structures
- Composite Materials
- Cryogenics and Focal Plane Cooling
- Technologies for Optical Passive Instruments (Stable & Lightweight Structures)

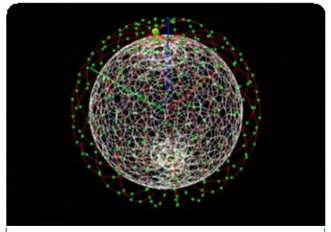


ELECTRIC ARCHITECTURE, POWER AND ENERGY, EMC

- Electromagnetic Compatibility
- Solar Generators and Solar Cells
- Electrochemical Energy Storage
- Power Management and Distribution

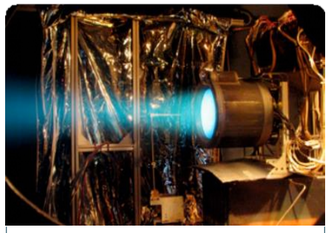
LIFE & PHYSICAL SCIENCES, LIFE SUPPORT & ROBOTICS

- Automation and Robotics
- Life Support Technologies



RADIOFREQUENCY & OPTICAL SYSTEMS AND PRODUCTS

- Array Antennas and Periodic Structures
- Critical Active RF Technologies
- Lidar Critical Subsystems
- Microwave Passive Hardware
- Optical Communications for Space
- Power RF Measurement and Modelling
- Frequency-Time Generation and Distribution
- Reflector Antennas
- Technologies for Optical Passive Instruments (Mirrors)
- Technologies for Passive Millimetre & Submillimetre Wave Instruments



PROPULSION, SPACE TRANSPORTATION, AND RE-ENTRY VEHICLES

- Cubesat Propulsion
- Electric Propulsion Technologies
- Chemical Propulsion – Components
- Fluid Mechanic and Aerothermodynamic Tools

GROUND DATA SYSTEMS, MISSION OPERATIONS

- Functional Verification and Mission Operation Systems
- Ground Station Technology

DIGITAL ENGINEERING

- Model Based for System Engineering
- Big Data From Space
- System Modelling & Simulation Tools

ASTRODYNAMICS, SPACE DEBRIS, AND SPACE ENVIRONMENT

- Radiation Environment and Effects
- De-Orbiting Technologies

As per today, 49 Topics

Technologies covered by the domain “Photonics at ESA”

The Technologies “Photonics at ESA” focus component, devices and equipment based on:

- fiber optics
- integrated optics
- wireless optics for intra-satellite links

applied in:

- Satellite Payloads (Communication Module)
- Satellite Platforms (Service Module)
- Airborne Payloads serving communications with satellites
- Ground test facilities for satellites

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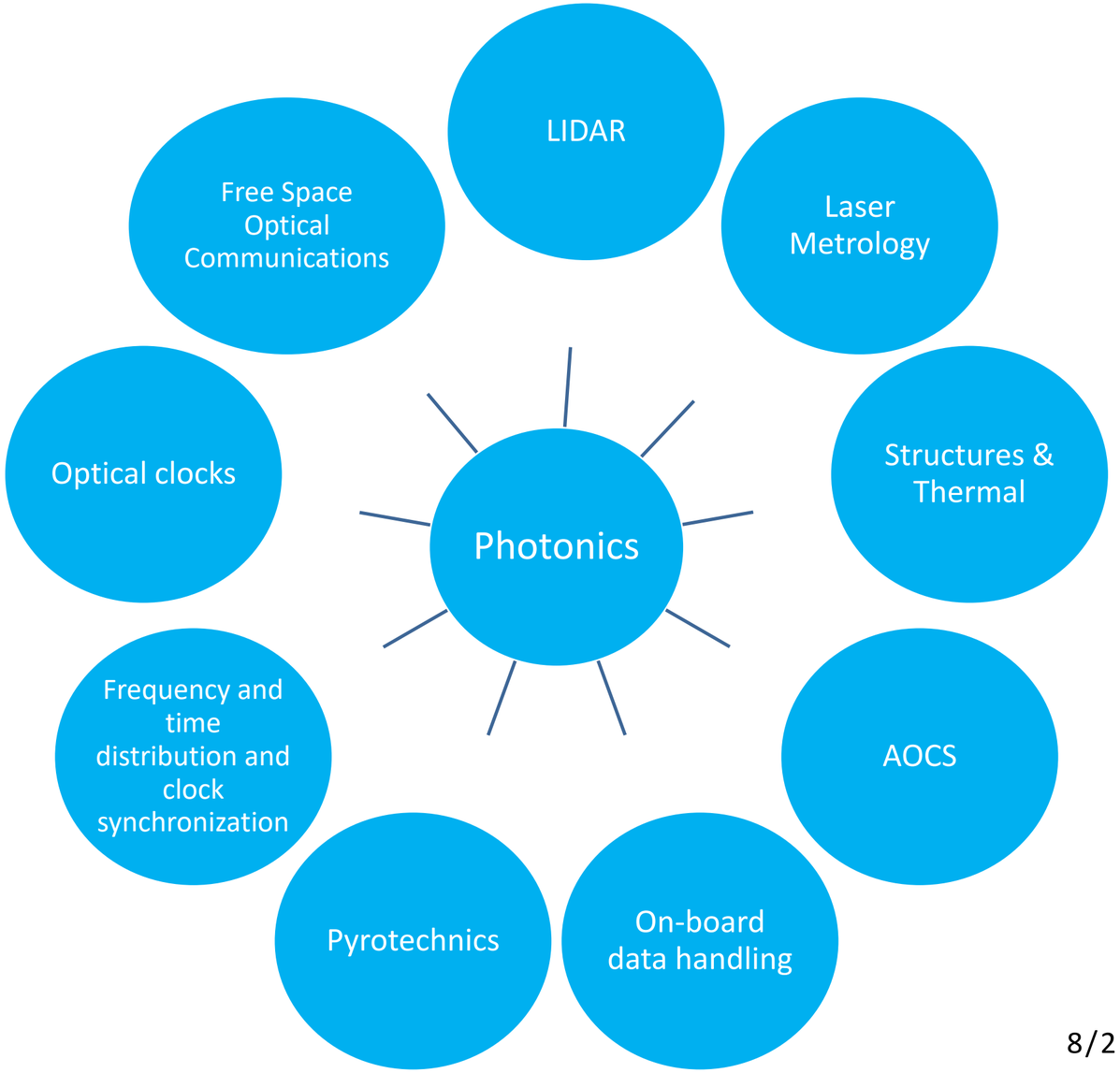
Technologies covered by related topics

Photonics4Space

Photonics are used as the building blocks in many satellite sub-systems



Technologies covered by related topics

This Dossier **DOES NOT COVER** the **Photonic equipment** used in **free space Optical Communication Terminals, LIDARs, RF & Optical Metrology, QKD and Optical Clocks** which are covered in other harmonisation topics. While not covering the previously mentioned areas at equipment/system level, the photonics topic however does contribute by covering a broad range of **generic components** which serve as **building blocks** for these areas.

To exploit synergies, this topic has to be closely coordinated with the ones mentioned above. In particular, close coordination is required between the following technical dossiers:

- **AOCS Sensors and Actuators** (Optical Gyro Technology). Last harmonised in 2020 Cycle 1.
- **LIDAR Critical Subsystems**. Last harmonised in 2022 Cycle 1.
- **Micro and Nano Technologies** (Optical Switches and Microphotonics). Last harmonised in 2020 Cycle 1.
- **Optical Communications for Space** (QKD, Optical Terminals). Last harmonised in 2022 Cycle 2.
- **Pyrotechnic Devices** (Opto-pyro for launchers). Last harmonised in 2020 Cycle 2.
- **Frequency and Time Generation and Distribution - Space and Ground**. Harmonised in 2023 Cycle 2.
- **On-Board Computers, Data Handling Systems and Microelectronics** (Space-Fiber). Last harmonised in 2021 Cycle 1.
- **Array antennas and Periodic Structures**. Last harmonised in 2022 Cycle 1.
- **PCB and Electronic Assembly Technologies**. Last harmonised in 2022 Cycle 1. Contains Photonic PCB.
- **Actuator Building Blocks for Mechanisms** (covering encoders). Last harmonised in 2021 Cycle 2.

Key Issues for Photonics4Space

Experience of the first 3 Photonic products (Fiber Optic Gyroscope, Fiber Optic Digital Interconnects and Opto-pyrotechnics for launchers) that have been adopted by the space market revealed key challenges:

- Focus on developing the technologies to offer a **distinct advantage** on the targeted application. Identifying such an advantage is key for any decision to change technology for a specific application. For example, the key issue in introducing Photonic Analog Links in COMSAT PLs is the need to reduce power consumption through uncooled transmitters and to increase the density of transmitters/receivers by use of Photonics Integrated Circuits (PICs).

- Identify the **"entry" (first) customer** in the commercial market

- Meet the **cost/price** targets set by the customer

- Identify the **suitability of parts to operate in space** which in many cases may require redesign or accommodation of performance issues at system level. This can be the case of qualifying COTS which may suffer from radiation effects and/or inadequate packaging.

- Ensure a **reliable supply chain**

About the importance to perform **In Orbit Demonstrations (IoD)**. It is possible and appropriate. However, experience from the 3 Photonic products adopted by the space market has proved that having an IoD is not critical in decision making for commercial exploitation. Hence, the cost/benefit for an IoD should be assessed case by case for any Photonic product considered for commercial use.

State of Art in Europe

The suppliers of Photonic solutions for Space are categorised in 3 main categories:

- Components and Hybrid devices
- Entire equipment (as defined in the Technology Harmonisation Dossier)
- Integrators

So far, only 3 Photonic Technologies have been adopted commercially: **Fiber Optic Gyroscope, Fiber Optic Digital Interconnects, Opto-pyrotechnics** for **Launchers** (considered now for ARIANE 6), each consisting of several photonics and electronic components. At present, the industrial landscape can be distinguished in companies that offer commercially available space products (TRL 8/9) and the ones that are in development level. There are:

- Less than 20 suppliers of commercially available **components/hybrid devices** from France (EXAIL, LUMIBIRD, CILAS, RADIALL, SOURIAU), UK (G&H, TE Connectivity), Norway (KDA), Canada (Smiths Interconnects, MPBC, Lumentum), **Switzerland (Diamond)**, Germany (Eagleyard-Toptica, Nanoplus, Schafter-Kirchhoff, TRUMPH), Netherlands (Draka).

- Numerous other companies from Norway (T&G Elektro), The Netherlands (LIONIX), Belgium (Antwerp Space, IMEC), UK (AXENIC, ALTER-UK), Portugal (PIC Advanced), Germany (TESAT, Microwave Photonics GmbH, Spacetech), Greece (LEO Space Photonics), Ireland (mBryonics), **Switzerland (ALBIS, VERSICS, IDQ...)** currently develop such component/devices at TRLs that at present are below flight grade.

- At **equipment level** only DAS Photonics can claim in flight experience through dedicated demonstrations. TAS-F and ADS-UK have demonstrated in the laboratory several equipment, but none flown yet. Cosine (NL) is probably the first company to introduce microphotonics into scientific instrumentation for Earth observation.

- At **integrator level** ADS, TAS and MDA have been actively involved in assessing Photonics in their VHTS Payloads and Platforms. Furthermore, OHB, ADS and TAS are continuously assessing Photonics for Payloads for Earth and Space Science missions

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State of Art in Europe

Commercially available photonic products in Europe:

Product	Supplier	Country	TRL (estimate)
ASTRIX- Fiber Optic Gyroscope	EXAIL	FR	9
Spaceable-28 Gbps optical interconnects	Smiths Interconnect	CA	9
Opto-pyrotechnics for launchers – Optical safety Barrier	KDA	NO	7
Opto-pyrotechnics for launchers – Laser Firing Unit	Thales	BE	7
Opto-pyrotechnics for launchers – Optical Harness	Souriau	FR	7
Opto-pyrotechnics for launchers – Photon Counting OTDR	IDQ	CH	8/9
Amplifier at 1550nm	MPBC	CA	8/9
Amplifier at 1064nm	MPBC	CA	8/9
Amplifier at 1550nm	G&H	UK	8/9
Amplifier at 1550nm	EXAIL	FR	8/9
Amplifiers at 1550nm	CILAS	FR	7/8
Amplifiers at 1550nm	LUMIBIRD	FR	7/8
Flexible Fiber Boards	TE Connectivity	UK	8/9
Analog Interconnects	DAS Photonics	ES	8/9
Frequency Converters	DAS Photonics	ES	8/9

State of Art in Europe

Commercially available photonic products in Europe:

Product	Supplier	Country	TRL (estimate)
High Speed Photoreceiver	ALBIS	CH	8
Passive Fiber Optics (splitters, coupler, combiner etc)	G&H	UK	9
Connectors	DIAMOND	CH	9
Fiber Bragg Grating Sensor Interrogator	MPB	CA	8
Butterfly-packaged DFB laser diodes at 850nm	Eagleyard	DE	9
TO-5 packaged DFB laser diodes SWIR	Nanoplus	DE	9
Pump Laser for Optical Amplifiers	Lumentum	CA	9
Modulators at 1064nm	EXAIL	FR	9
Modulators at 1550nm	EXAIL	FR	8/9
Pump laser modules at 980nm	II-VI	CH	8/9
Laser Diodes for Opto-pyrotechnics (940nm)	Lumibird	F	8
Optical Fiber Cable Assembly	RADIALL	F	9
Photonic magnetometer	IWF	A	9

Competitiveness and benchmarking

Non-European Industry involved in Space Photonics and associated products

Company/Institution – Nationality	Type of Product	Remarks
RENESAS – USA	VCSEL Drivers for Digital Interconnects at 28 Gbps	Rad-hard drivers, power consumption
RENESAS – USA	TIAs for Digital Interconnects at 28/56 Gbps	Rad-hard TIAs, power consumption
BROADCOM – USA	VCSEL for digital links at 28/56 Gbps - 100Gbps (PAM4)	Extended temperature and Radiation tested, current consumption, numerical aperture
COHERENT - USA	VCSEL for digital links at 100 Gbps (PAM4)	
BROADCOM – USA	Photodiodes for digital links at 28 Gbps – 100 Gbps (PAM4)	Extended temperature, responsivity, aperture diameter
COHERENT - USA	Photodiodes for digital links at 100 Gbps (PAM4)	
EMCORE – USA	Lasers (for microwave transmission)	Low TEC consumption
HAMAMATSU – JAPAN	DFB laser sources	Maturity at TRL-9
EOSPACE – USA	Optical Modulators	Stable operation
XL Photonics – USA	Photodetectors	Large Surface-High power
HAMAMATSU – JAPAN	Fiber coupled photoreceiver	Maturity at TRL-9
OSI Optoelectronics - USA	Fiber coupled photoreceiver	Maturity at TRL- 9
Micron Optics – USA	FBG Interrogator for ground testing ‘Hyperion”	Large BW offers High degree of multiplexing in a single channel

Competitiveness and benchmarking

Non-European competitive products (benchmarks) compared to current European ones

Name of the Product	Technical Characteristics of benchmark product	Technical Characteristics of European product	TRL of Non European product
Laser Drivers for Digital Interconnects	Rad-hard, very low power consumption drivers at 28/56 Gbps – 100 Gbps (PAM-4)	The development is in low TRL	TRL-8
VCSELs or other lasers for digital transmission	Extended Temperature operation at 28/56 Gbps operation, current consumption numerical aperture	Slightly higher power consumption	?
Photodiodes for digital reception	Extended Temperature operation at 28/56 Gbps, responsivity, aperture diameter	Competitive and almost similar to the US one	?
TIAs for digital reception	Rad hard, very low power consumption TIAs operating in 28/56 Gbps	The development is in low TRL	
Lasers for Analog Transmission	Uncooled operation	High TEC consumption	TRL-6
Modulators for Analog transmission		In the process of qualifying – not yet stable	TRL-8
Photodetectors for analog reception	Large surface-higher power handling capability, up to 50 GHz	Small surface-lower power handling capability	
Fiber Coupled Photoreceivers	Maturity on TRL-9	Less mature	5-6
FBG Interrogators for ground testing			
Optical Delay Trimmers	Existing	Non-existing	N/A

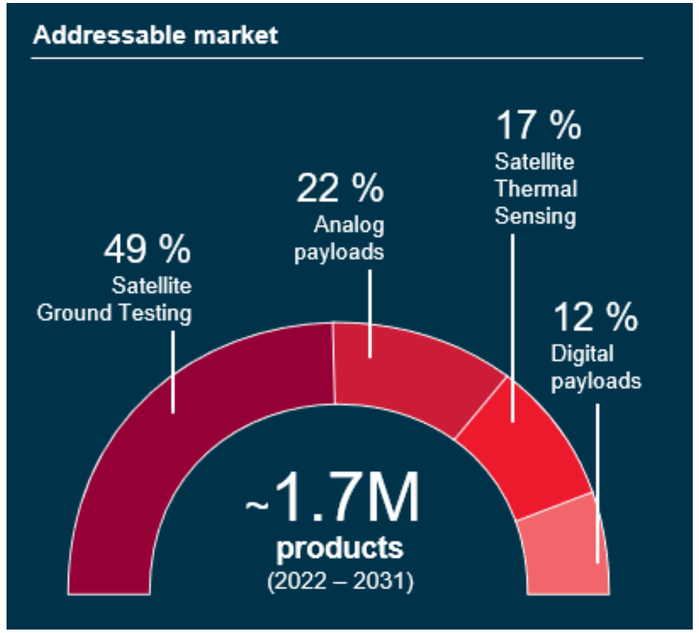
Mission Needs and Market Perspectives

Missions and types of Payloads or spacecraft that will need Photonic Technologies

Mission / Mission Type	Technology Development Need	TRL Target
COMSAT PAYLOADS	Rad-hard VCSEL drivers and TIAs for Digital Links	8
	Lasers-Modulators-Detectors for analog links antenna-DSP-antenna	8
	High density, temperature stable modulators for FGU, Frequency Converters	8
	Qualified Photonic Switches	6
	Qualified Photonic BFN	6
	Qualified Photonic RF Filters and (DE)MUXs	6
SCIENCE PAYLOADS	Photonic Digital Links for high data rate instruments	8
	Photonic Analog Links for SAR	6
	Photonic Instrumentation in EO and Space Science	6
	Optical Wireless Power Transfer for lunar robotic vehicles	6
ALL TYPES SpaceCraft PLATFORMS	Fiber Links for OBDH	8
	Optical Wireless	8
	Optical Temperature Sensors	8
LAUNCHERS	Opto-pyrotechnics	8
	Fiber Optic Sensors for structural monitoring	8
GROUND SEGMENT	Optical Wireless	6
	Fiber Optic Sensors	6

Mission Needs and Market Perspectives

Key Take-Aways:



Source: Euroconsult

- Satellite ground testing equipment represent most the Photonic devices given the critical step of ground testing every spacecraft before their launch, independently of their applications.
- Analog Photonic devices are expected to outnumber digital ones nearly 2 to 1, likely due to their suitability for high-speed communication applications.
- As the reusability rate increases over time, it is expected that the Health monitoring systems market would decrease if the launch rates do not increase significantly.
- Given the large number of satellites in Telecom and Earth Observation constellations, most of the satellite ground testing and thermal sensing market are covered by these two applications.

European Strategic Interest

- Europe has invested significantly in Photonics for Space since 2001 and an **ecosystem of photonic companies** that have the aspiration to be the preferred suppliers of photonic components, devices, equipment and payloads has been formed.

- Three Photonic products have by now been adopted by the space market creating also the **first to enter the market suppliers**. To a large extend this influences the supplier's potential for the next decade since the first selected supplier would be in position to claim space heritage for upcoming RFQs.

- Europe/Canada must ensure that their companies are the selected suppliers in order to maintain the current dynamic fuelled by tens of Meuros of investment. If this does not happen then the danger is **that US competitors will appear to harvest** the fruits of more than 20 years of European/Canadian efforts to establish Photonics as a standard technology in satellites.

- Special efforts will be required to mature the solutions based on **Photonic IC technologies** frequently **co-packaged with Electronic ICs** as it is likely that only such a solution will be able to meet the specifications of the various applications

- Due to the increasing importance of Photonics in many applications it has to be ensured that a **sufficient and sustained level of funding** is made available in Europe to keep the leadership position by sustaining a reliable supply chain.

Key points to be know from the Swiss Photonics actors

- The photonic dossier is relevant at ESA. The dossier remains a means to catch critical photonic components which span across many technology domains, and which are managed by the **Photonics Component Working Group** at ESA.
- The potential of PICs (in particular related to SWaP advantages) calls for further addressing **development efforts vs commercial viability**. Also, the **electronic-photonic integration** will be a key element in the development towards making photonics competitive to present electronic solutions.
- Photonics technologies for space applications can **greatly benefit from developments in non-space sectors** (European technology platform Photonics21 and their activities to identify spin-in opportunities).

Roadmap inputs

DRAFT VERSION, FINAL VERSION WILL BE PUBLISHED IN Q1 2024

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Ref.	Title	Description
AIM A	Developments for COMSAT PLs – Photonically linked	• Develop space qualified electronics for the Tx/Rx of digital link at 56Gbps, 112 Gbps and even higher. • Develop co-packaged ASICS with optical I/Os • Develop cooler-less, very low power consumption and very high-density Photonic Analog Links
AIM B	Developments for COMSAT PLs – Microwave Photonic Equipment	• Develop microphotonic MRO/LO generators • Develop microphotonic Frequency Converters • Develop microphotonic Switches • Develop microphotonic RF filters • Develop microphotonic Beam Former
AIM C	Developments for SCIENTIFIC PLs	• Adapt Photonic Digital and Analog links of COMSAT PLs to Scientific PLs (EO and Space Science) • Investigate the use of microphotonics for scientific instrumentation
AIM D	Developments for PLATFORMS	• Develop Space qualified SpaceFiber products • Develop stable fiber optic sensors • Develop Optical Wireless solutions
AIM E	Developments for LAUNCHERS	• Qualify the Opto-pyro in time for the ARIANE-6 launch • Transfer the Opto-pyro for ARIANE-6 know-how to VEGA • Consider fiber optic sensors for health monitoring • Consider fiber optic links for OBDH
AIM F	Developments for GROUND SEGMENT and AERONAUTICS	• Use of Optical Wireless in AIT • Develop qualified and cost effective microphotonic BFN for airplanes
AIM G	Special measures for Photonic ICs and Packaging	• Optimised integration of photonics and electronic ICs • Optimised packaging of electro-photonic ICs

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Conclusions

- Since ESA initiated a comprehensive R&D program in 2001 on Photonics, **3 products have been adopted by the Space industry**: Fiber Optic Gyroscopes, Optical Digital Interconnects and Opto-pyrotechnics (considered now for ARIANE 6)
- New applications will include Optical Analog Interconnects, Equipment like Frequency Generation Units, Frequency Converters, Switches and Beam Forming Networks.
- For these applications to succeed a change of technology from **discrete photonics to Photonic ICs** is followed as the path to **reduce SWaP ratio**, the mass-volume and if possible also the power consumption.
- Experience showed that the most important thing is to identify a compelling competitive advantage and a **first adopter of the technology**. An In orbit Demonstration was not critical and although still useful it has to be assessed against the cost and schedule issues on a case by case basis → **opportunities and partnership with LSI and end users.**
- Europe/Canada maintain a leading position on the supply of Photonic Devices/Equipment. However a number of components such as the electronic circuits for the Optical Digital Interconnects are still procured by the US. It is essential that **ESA and MS take measures** to replace the source of such components by European/Canadian suppliers.
- Special measures have to be taken to mature the photonics ICs and packaging technologies.