ScyLight Optical Technology Roadmap for SatCom

ScyLight Programme Team

12/07/2017

DRAFT ScyLight Optical Technology Roadmap for SatCom

ScyLight Programme Team & European/Canadian Industry

12/07/2017

Workshop on ScyLight Optical Technology Roadmap for SatCom

Agenda - AM

Presentations

9.45 ESA Dr. Hauschildt – 'ARTES ScyLight Roadmap presentation'

Coffee-Break

10.30 Vialight, Mr Müncheberg – 'Laser terminals and ground stations for LEO missions – Status, way forward and feedback to ScyLight Workplan'

10.50 DLR, Mr Fuchs – 'Optical satellite downlinks at DLR'

11.10 Tesat, Dr Zech - 'TESATs LaserCom Product Line

11.30 – 13:15 Lunch Break (& ESA Lunch Lecture in same room)

Agenda - PM

Presentations

13.30 Fraunhofer IOF – Dr Beckert - 'The Engineering Model of a high efficient entangled Photon Source for QKD'

13.50 Thales Alenia Space FR – Mr Le Kernec - 'Thales Alenia Space Optical Communication'

14.10 mBryonics Ltd - Dr Mackey - 'Technology development for end-to-end Lasercom systems in the 5G era'

14.30 Gooch & Housego – Dr Kehayas

14.50 Thales Alenia Space CH - Ms Rugi Grond - 'Thales Alenia Space Optical Communication Products'

15.10 ALTYN Mr Achache

15.30 AIRBUS Mr Haag

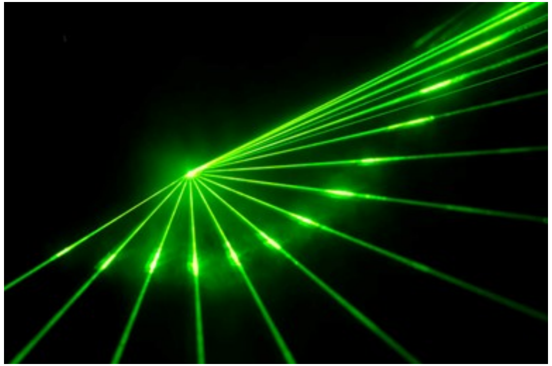
15.30-15.45 Coffee-Break

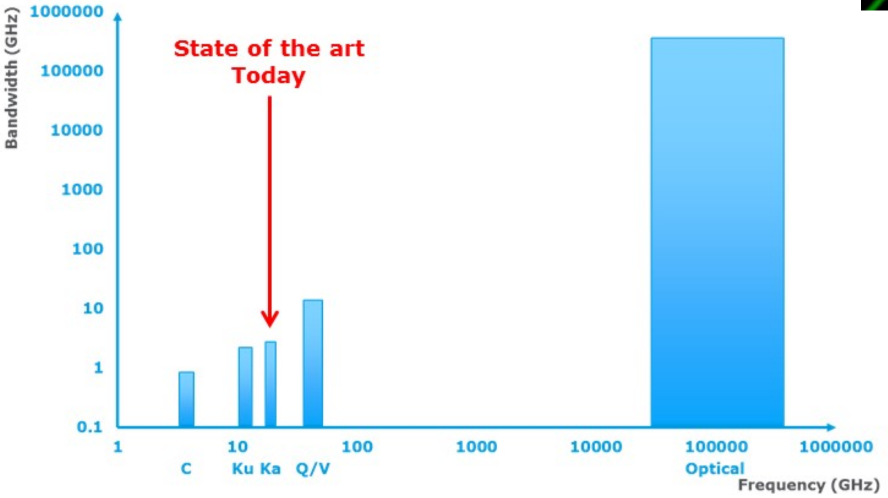
15:45 Bi-Laterals in room BF304, as per individual schedules (15min each)

Optical Telecommunications

Optical telecommunication is the use of light (optical frequency domain) to transmit information:

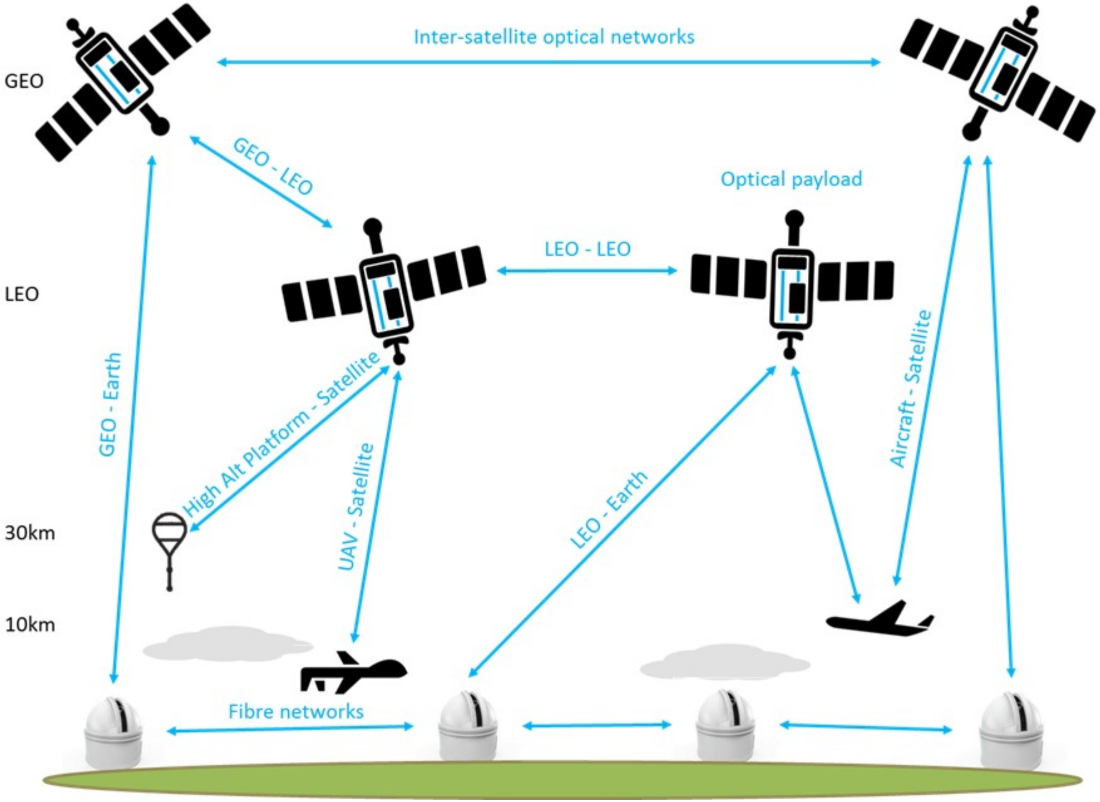
- Wavelengths 0.85 µm to 10 µm (30-353 THz)
- Alternative to the increasing scarce RF spectrum.
- Optical communication offers an unregulated, extremely broad spectrum





World of Optical Telecommunications

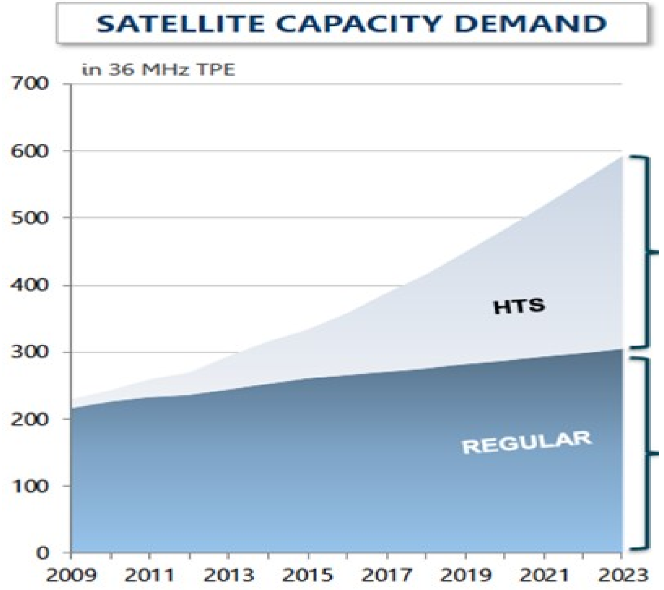
Optical link



NOT TO SCALE

World Market Demand and Opportunities

- Fixed broadband (e.g. HTS - High throughput satellite) and mobile market (e.g. aeronautical, maritime and land) are pushing the satcom capacity demand.
- This capacity needs to be used where needed: Traffic Flexibility in terms of bandwidth allocation and coverage
- Secure communication and service immune to interferences and jammers
- Lower frequencies under threat for satcom applications.
- Conventional RF frequency spectrum becomes a scarce resource.



Optics is a natural step to unleash resources (bandwidth, high capacity) and fulfil this growing demand.

Demand and Opportunities Expressed by European Satellite Operators

- All major European Satellite Operators have expressed interest in Proof-of-Concept Optical Technology as a stepping stone into its adoption in their operational satellite fleet.
- Interest expressed in using optical communications for GEO-ground, GEO-GEO, GEO-LEO, MEO-MEO, and LEO/MEO-ground.
- Different motivational factors:
  - Freeing RF spectrum for user links (optical feeder links).
  - Data security to deliver to certain users (optical downlink).
  - Communication between space assets (inter-satellite links).

Where Optical Technologies Can Make a Difference: Opportunities and Challenges

Optical Link

+

- High data rate (>100 Gbps) with small telescopes
- Abundant unregulated bandwidth and effective use of frequency resources
- Immunity to interception, jamming, interferers and piracy
- Terrestrial optic technology enable space market (investment already made)
- Reduced size/power of ground terminals
- Potential to reduce the number of gateways for HTS architectures

–

- Less mature technology requires R&D effort
- Higher precision laser pointing (but demonstrated)
- Lack of common communication standards

For links through the atmosphere:

- Cloud blockage requires a network of connected ground stations at suitable locations
- Atmospheric conditions (scintillation, beam wander, phase coherence...)
- Eye safety requirements

Where Optical Technologies Can Make a Difference: Opportunities and Challenges

Optical Payload

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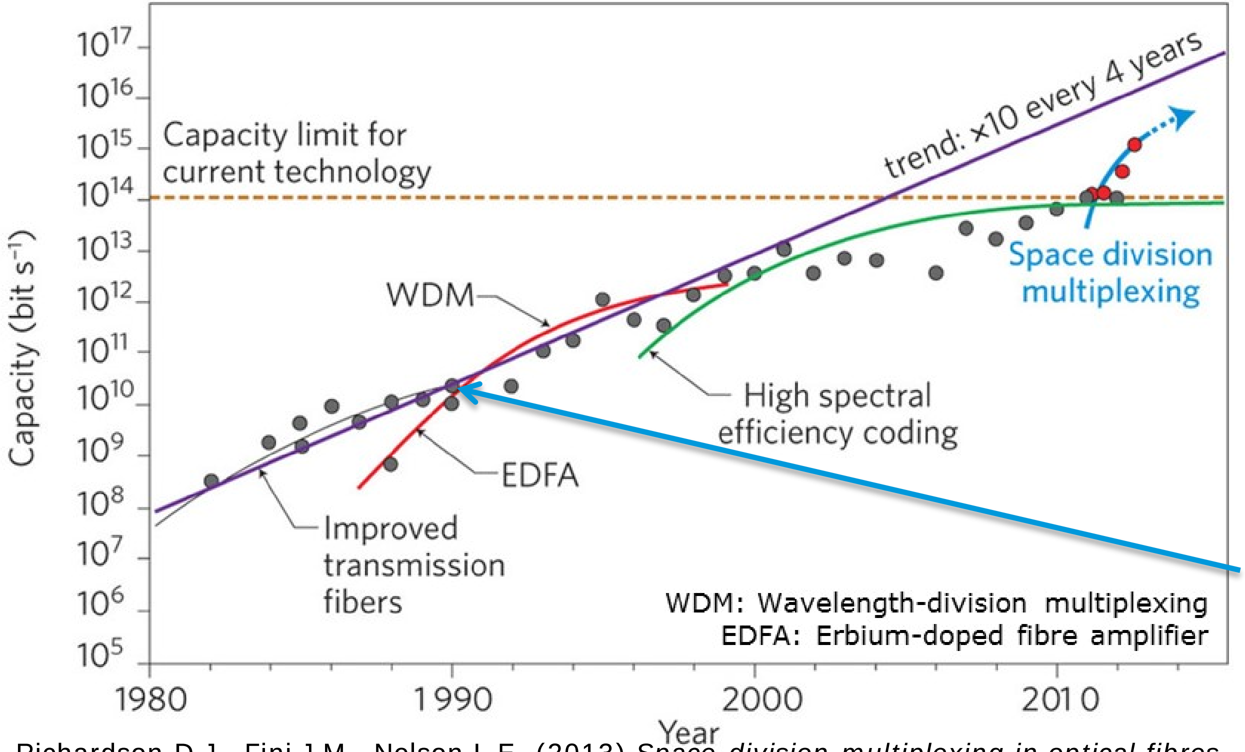
- Low volume and high speed optical harness
- Signal multiplexing without intermodulation
- Immunity to interference
- Generic and frequency independent equipment
- Enables all-optical end-to-end systems "fibre in the sky"
- Some building blocks are available from the terrestrial market

–

- Immature or non-existing technology (e.g. narrow band filters)
- No flight heritage
- Additional RF/optics conversions needed
- High speed on-board signal processing required
- Marginal benefit for low and medium complex payloads

Achievements and Trends of Terrestrial Optical Telecommunications



Space optical communication technology as of today

Richardson D.J., Fini J.M., Nelson L.E. (2013) *Space-division multiplexing in optical fibres*. Nature Photonics **7**, 354-362

ARTES ScyLight – a quick reminder

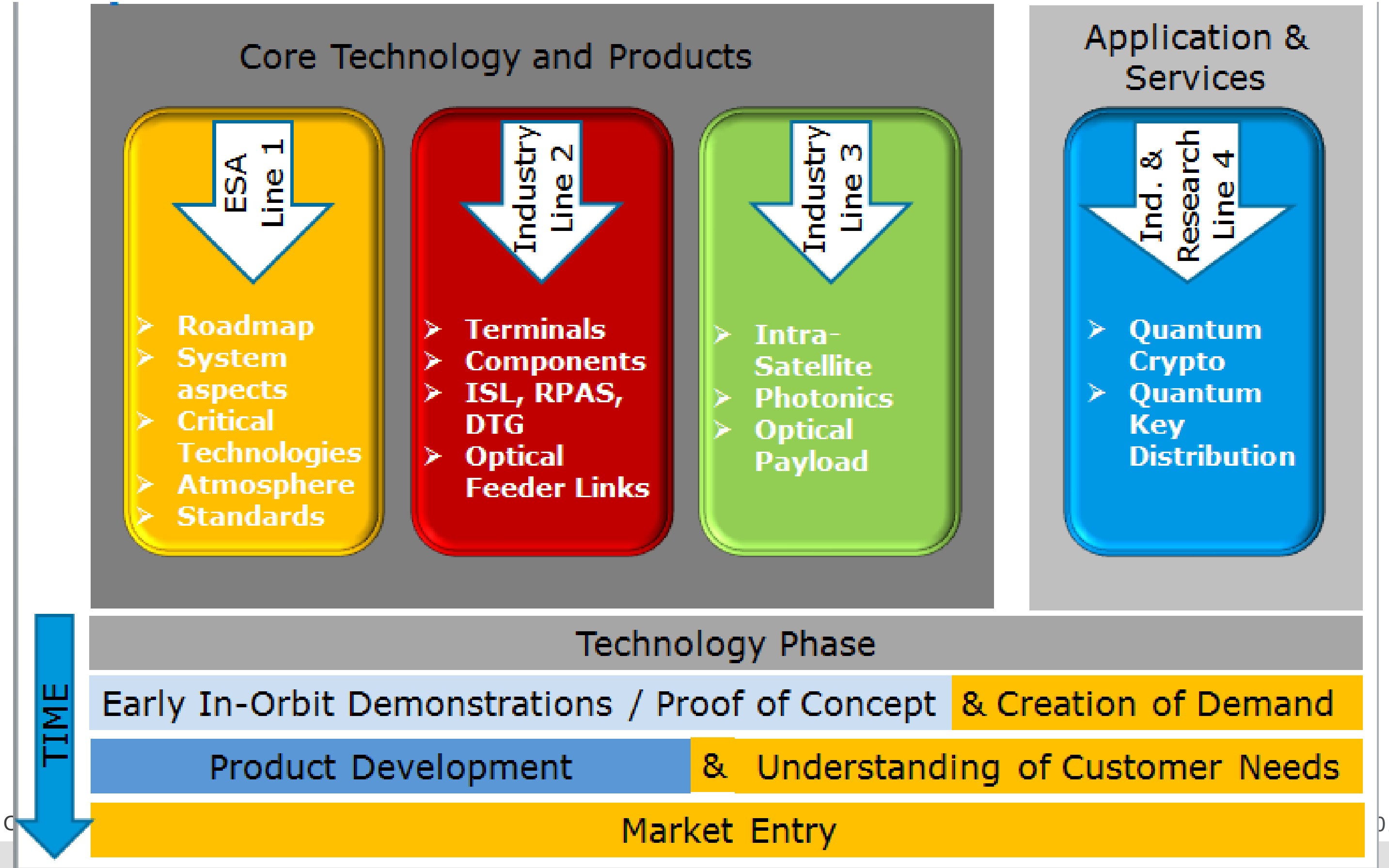
The objectives of ScyLight are:

- Address the development and use of innovative optical technologies for SatCom as well as new market opportunities.
- Demonstrate the maturity of optical communication technology to the end user community.
- Support industry to develop capabilities and competitiveness in the field of optical technologies, enabling related emerging market opportunities for products based on the newly developed technologies.

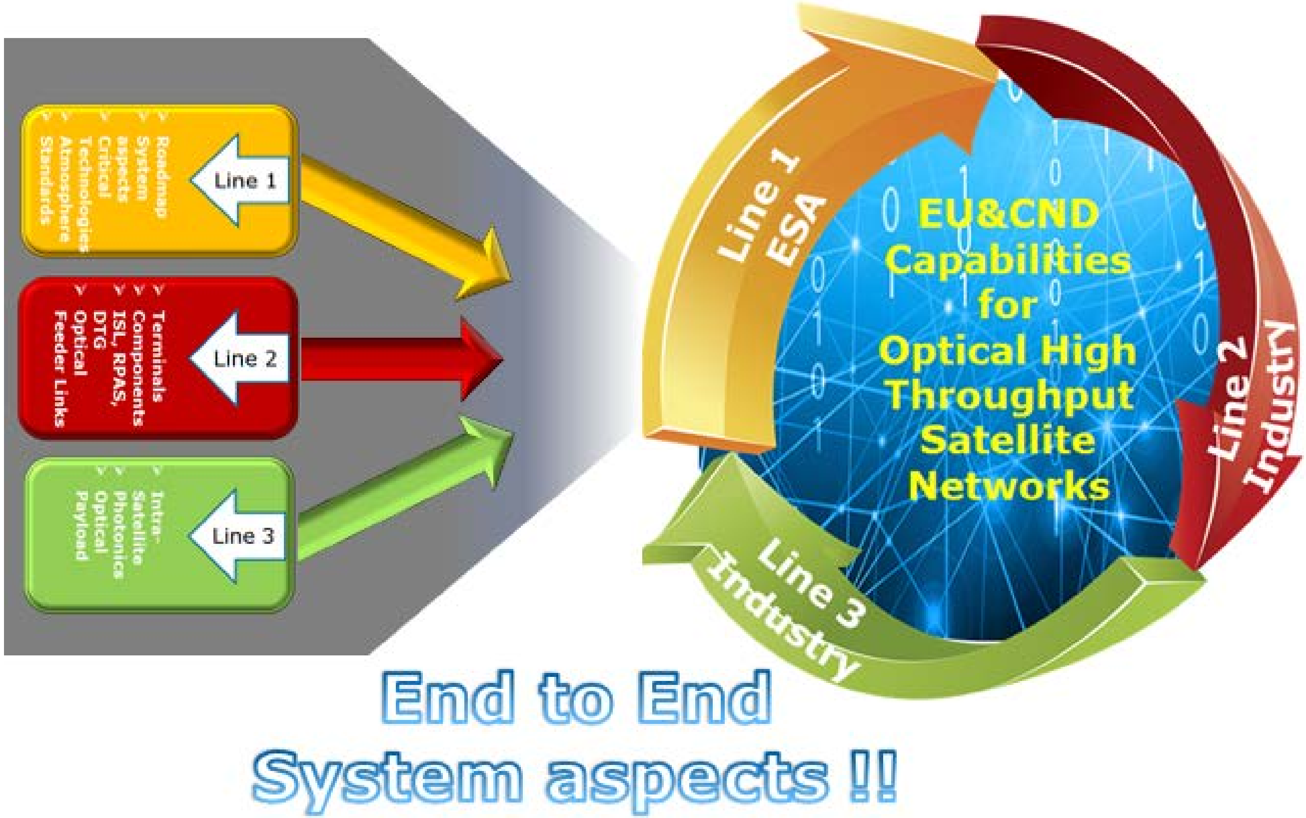
ScyLight will address the following thematic areas:

- Common System &Technologies Activities
- **Optical Communication Terminals and components**
- **Intra-Satellite Photonics / Optical Payloads**
- **Quantum Cryptography Technologies**

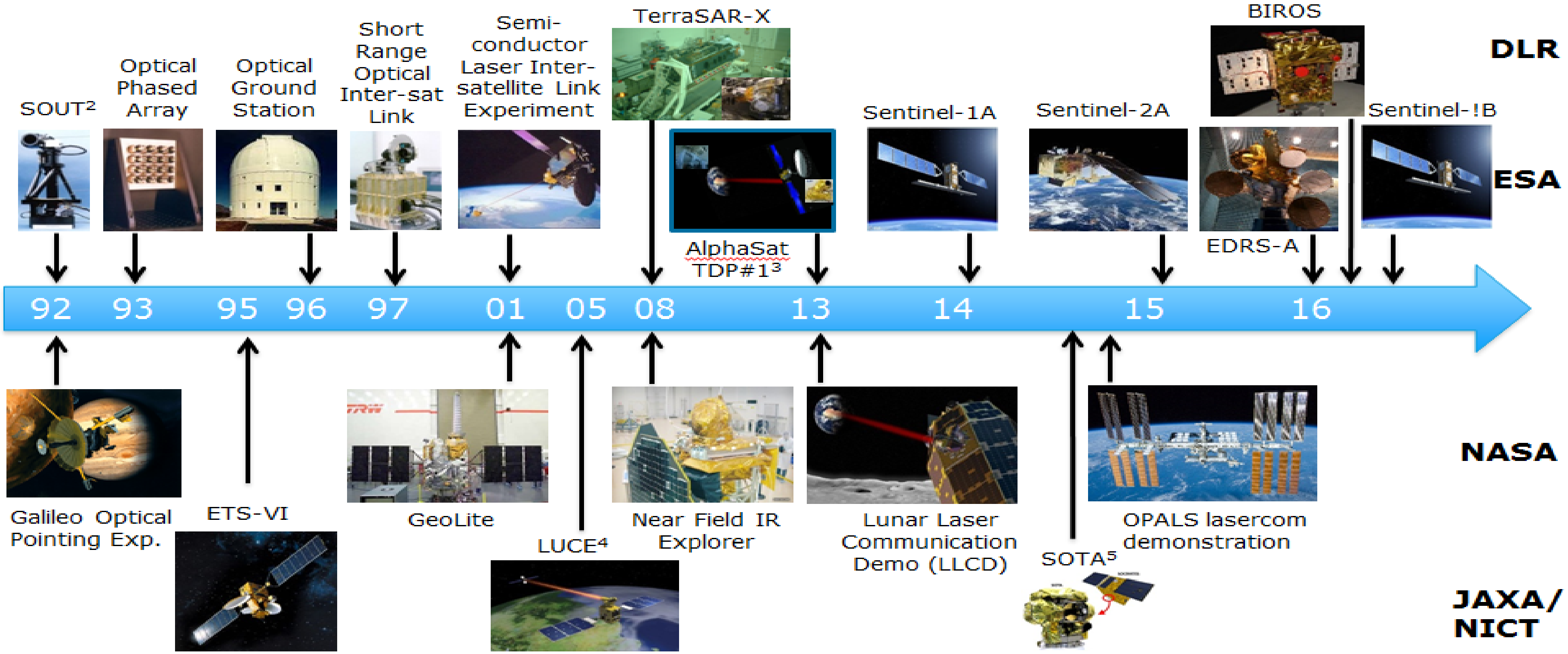
ScyLight – Thematic Lines



Unleash full capacity of Optical Communication Technology and ensure competitiveness



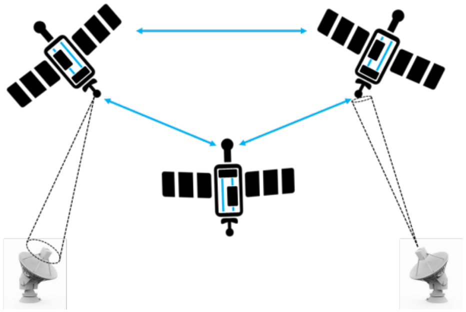
History of System and Optical developments for Space



[1] Miniaturised Optical Monolithic Terminal
[2] Small Optical User Terminal
[3] Technology Demonstration Payload #1
[4] Laser Utilising Communication Equipment
[5] Small Optical Transponder Antenna

Applications and Impact of Optical Satcom
Inter-Satellite Optical Links

- High-capacity data relay links
- Inter-satellite constellation links
- Backbone connectivity



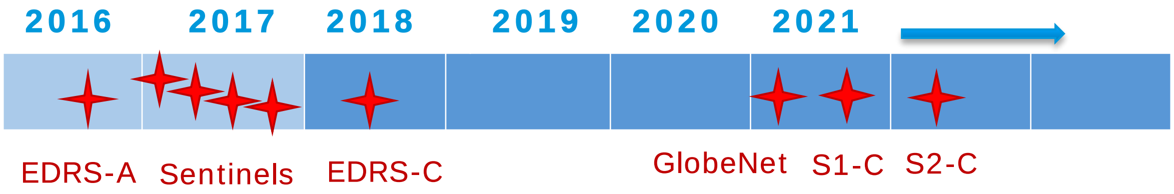
- Government, commercial, scientific users

- Global Real-time data access via (E)DRS/GlobeNet
- High throughput and high volume data dumping
- Security, interference immunity
- Flexible connectivity, direct transmission
- Bi-Directional links, forward tasking

Challenges
- Industrialisation of telescope assembly, frame unit structure, coarse pointing assembly, laser terminal reliability
- Temperature, volume, mass and cost constraints

e.g. Sentinel - EDRS (2015), GlobeNet (2021)

Technology roadmap



Applications and Impact of Optical Satcom Satellite to Ground Optical Links

- Direct data downlink from LEO

- Government and scientific users, mobile terminals

- High rate data dumping to ground
- Immunity to interference and jammers
- Size/power compatible with small satellites

Challenges
- Volume reductions
- Radiation hardness
- Thermal environment
- Increase the current data rates
- Cost of new optical ground station network
- Operational constraints

On-board demonstrator on ISS

Technology roadmap

2014 2015 2016 2017 2018 2019 2020

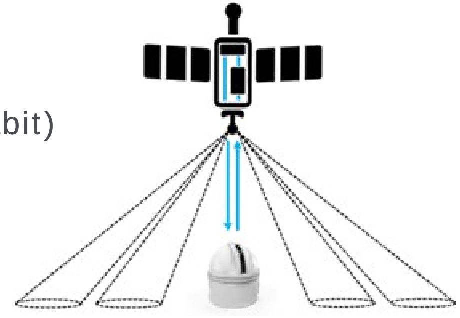
T-AOGS

Tesla Optel-u

OGS adapt optics

Applications and Impact of Optical Satcom
Ground-Satellite Optical Links

- High capacity gateway links
- GEO-ground optical links



- Commercial users for high throughput multi-beam systems (e.g. terabit)

- Virtually unlimited capacity with one single gateway
- Fewer ground stations
- Immunity to interference and jammers, security
- Increases available RF spectrum for user link

Challenges

- Adaptive optics on uplink and downlink
- On-board high speed data processing
- Ground stations at reliable (weather, political) locations
- Cost of new optical ground station network
- Hand-Over Concepts/ConOps

➡ Gateway link (2025)

Technology roadmap

Applications and Impact of Optical Satcom
Airborne Optical Links

- Communication with aircraft, UAV, high altitude platforms (HAPs)

- Government and commercial users

- High capacity
- Link unaffected by clouds for HALEs
- Security
- Small terminals
- French experiment LOLA link demonstrated to ARTEMIS (2006)

Challenges

- High precision laser beam steering
- Vibration and attitude stability
- Optical terminals meeting aircraft technology certification and standards to be developed
- Long lasting/Continuous links require dedicated terminals onboard the satellite

On-board technology demonstrator (2021)

Technology roadmap

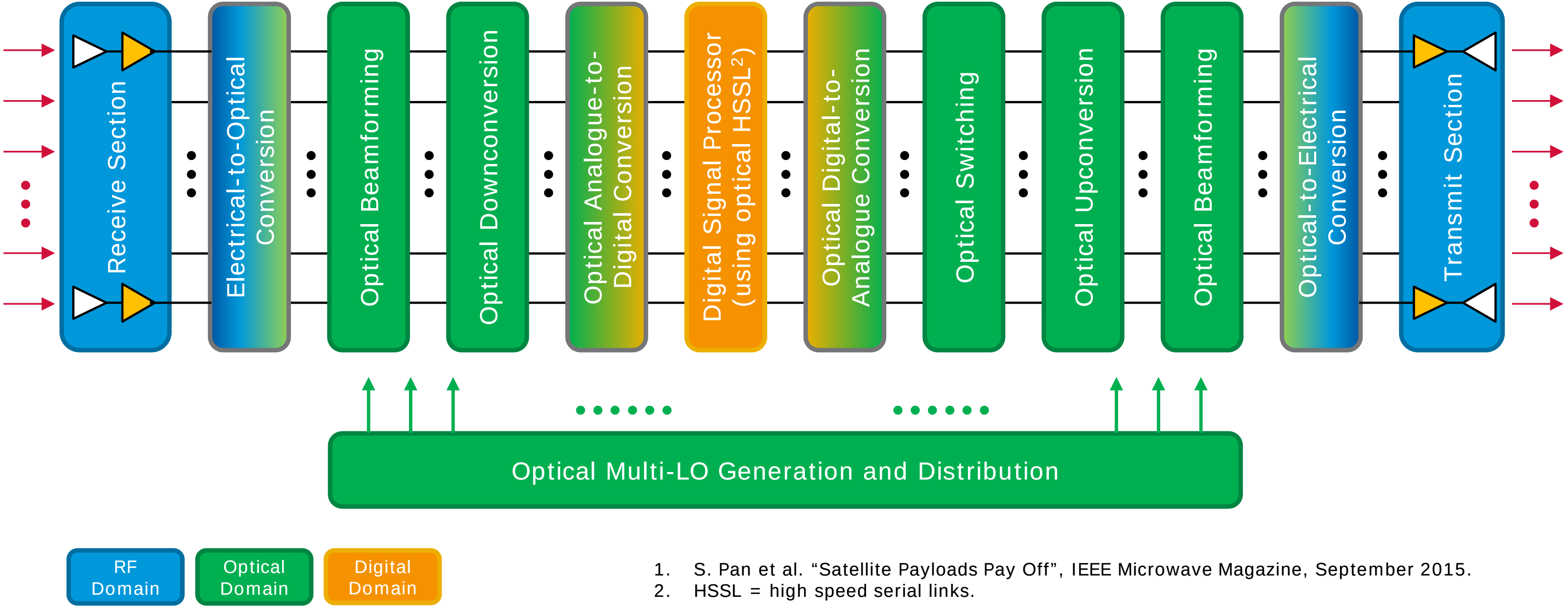
2014 2015 2016 2017 2018 2019 2020 2021

Demonstrator via EDRS

GlobeNet

Intra-Satellite Photonics/Optical Payload

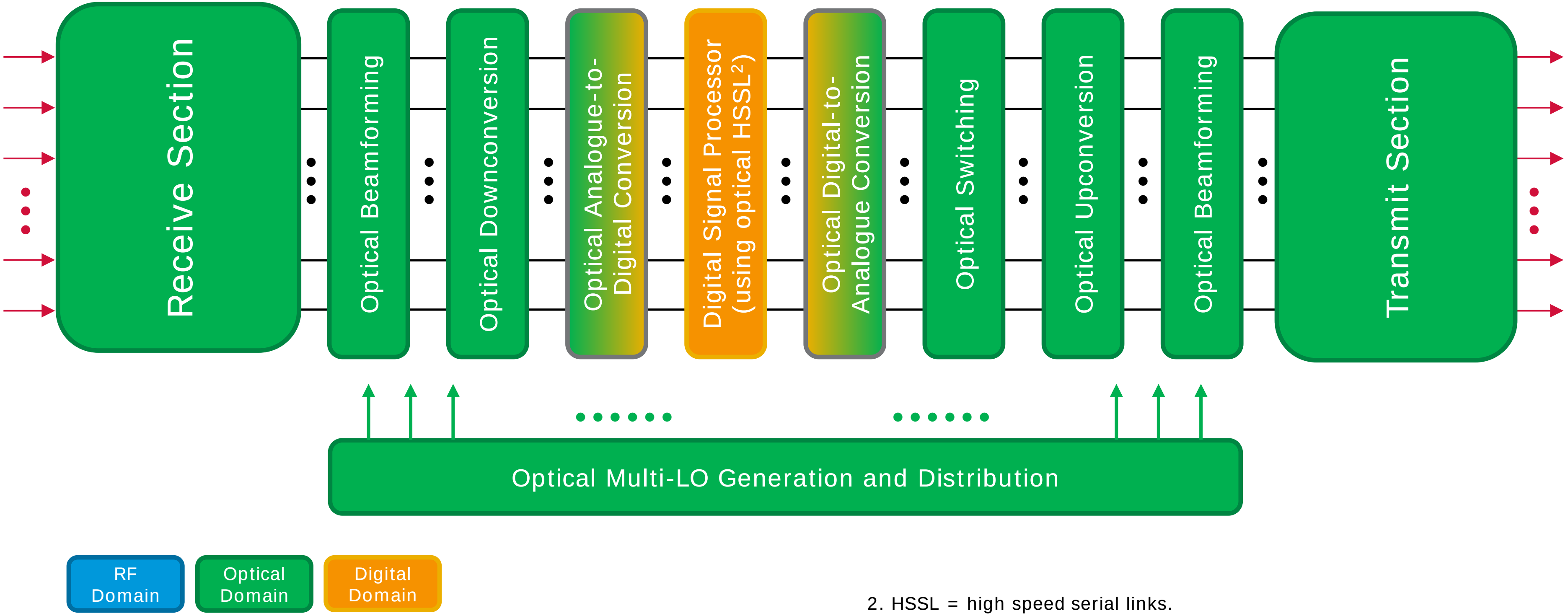
Conceptual Block Diagram[1]



1. S. Pan et al. “Satellite Payloads Pay Off”, IEEE Microwave Magazine, September 2015.
2. HSSL = high speed serial links.

Intra-Satellite Photonics/Optical Payload

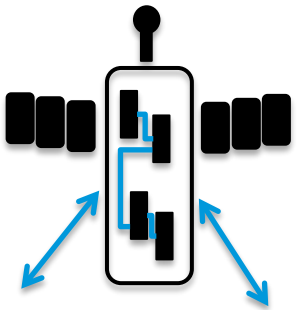
All optical Conceptual Block Diagram



2. HSSL = high speed serial links.

Applications and Impact of Optical Satcom
Intra-Satellite Photonics/Optical Payload

- Communications



- Satellite operators

- High capacity
- Simplification
- Mass and power reduction
- Lower losses, increased efficiency

Challenges
- Vibration and environmental stability, lifetime
- Translation of ground to flight technologies – miniaturization
- System design digital, RF and optical
- A complete payload – not just equipment (to unleash full capabilities)
- Narrow band filtering

➡ On-board technology demonstrator (2021)

Technology roadmap **See following slide**

Intra-Satellite Photonics/Optical Payload

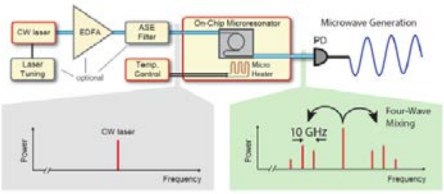
Technology Roadmap	2017	2018	2019	2020	2021	2022	2023	2024	2025	….
Optical Beamforming							Photonic beamforming unit			
Optical Frequency Conversion				Photonic frequency conversion unit			Photonic RF filtering			
Optical A/D & D/A Conversion				Frequency downconversion unit & sampler						
Optical High Speed Serial Links				Optical interconnects			ASICs with embedded optical I/Os			
Optical Switching					Photonic routing unit					
Optical Multi-LO Generation & Distribution		Photonic distribution of RF LOs		Photonic frequency generation unit						
(All)Optical Demo									(all) optical demo mission	

Photonic Integrated Circuits - Microphotonics

ESA is in the forefront of introducing micro-photonics in its COMSAT PLs.

Currently microphotonic technologies are considered for most equipment involved in Microwave Photonics Payloads:

- Photonic Frequency Generation Unit
- Photonic Frequency Conversion Unit
- Photonics Routing Unit
- Photonic RF Filtering
- Photonic Beam Forming



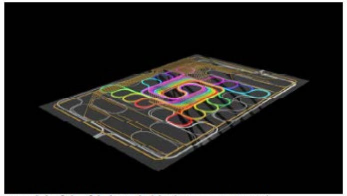
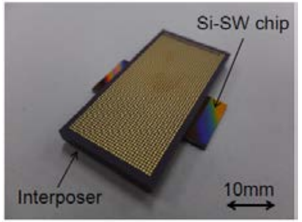


Fig. 4 3D model of the fabricated chip (55 mm x 35 mm)



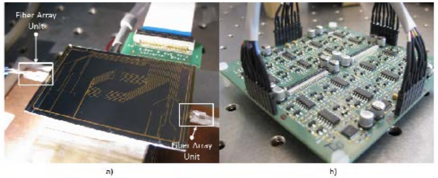


Fig. 5 a) Fabricated chip in TripleX^{TM}; b) Control Board for thermo-optic tuning.

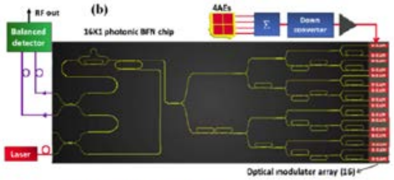
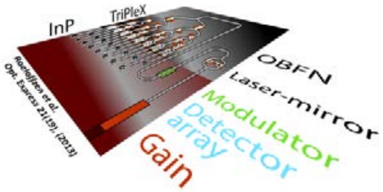
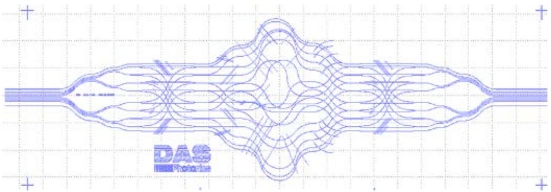
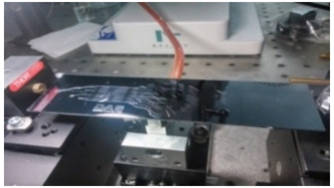


Figure 2.3: Possible OBFN layout with antennas, lasers, modulators and detectors





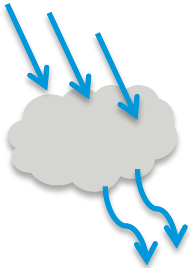


Applications and Impact of Optical Satcom System activities

- System Studies

  - Government and commercial users

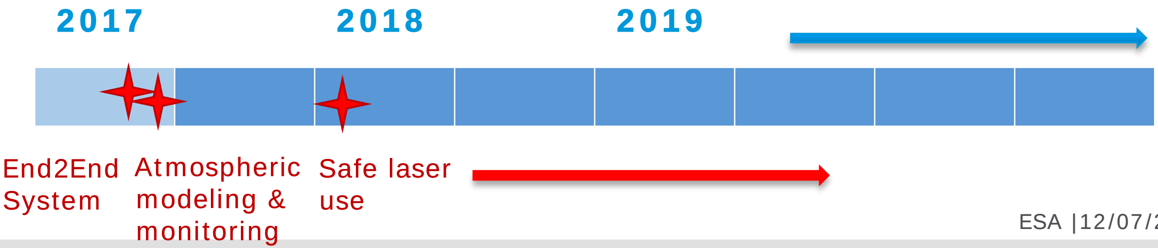
  - Marketing
  - Technology
  - Safety
  - Atmospheric modeling and long term monitoring
  - Complete end-to-end system uses



Challenges

- Site diversity/modeling
- Space Standards on optical are missing – including safety
- Identifying new market opportunities or expanding existing markets
- Technology gap or products

Technology roadmap



Status of Optical Technologies for Telecom Payloads
Quantum Key Distribution (QKD):

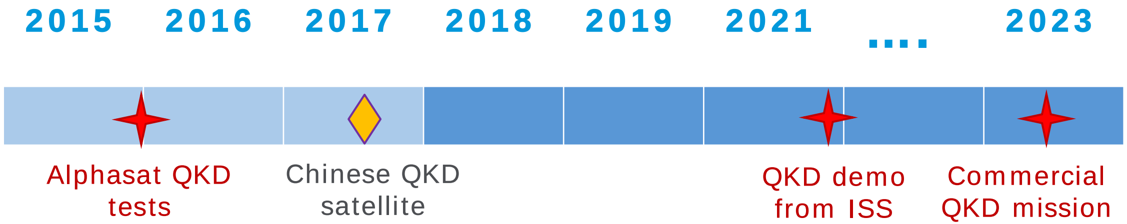
- Defense, Government, Financial, Telecom, Utility services

- Counter Quantum computing power - hacking
- Fewer ground stations – removed security risk
- Immunity to interference and jammers - detectable
- International need for secure key distribution

Challenges

- Space Qualified Quantum receivers/transmitters
- QKD Protocol
- On-board and on-ground data processing
- Ground station locations/Atmospheric influence
- Optical Terminals compatible to link budget
- Stringent requirements and size/mass/power constraints
- Concept of Operations

Technology roadmap



Applications and Impact of Optical Satcom: International Summary

Development and deployment of optical technology on-board satellites

Applications roadmap	2016 – 2021
Inter-satellite optical links	EDRS-A; EDRS-C; Globenet
Direct downlink from LEO	Tesla Optel-u; OGS adapt optics
Gateway and GEO-ground links	LCRD; Gateway link
Airborne optical links	EDRS demonstrator; Globenet
Intra-satellite optical payload – please see detailed slide	LO distribution; Multiple Photonic equipment

Key: ✦ ESA; ◆ Non-ESA (LCRD)

OPALS: Optical Payload for Lasercomm Science (NASA)
OSIRIS: Optical Space Infrared Downlink System (DLR)
ISS: International Space Station
SOTA: Small Optical Transponder (NICT)
LCRD: Laser Communications Relay Demonstration (NASA)
EDRS: European Data Relay System (ESA)

Optical Communications Challenges to be tackle?

Equipment

- Laser terminals
- Adaptive Optics
- Pre-distortion techno
- Ground stations
- Filtering
- Coarse pointing mechanisms
- Telescope Assemblies

System

Atmospheric modelling

System definition

Standards:
- Safety
- Signals
- Modulation
- Coding
- Acquisition strategy

Technology

Size and power compatibility

Market identification and penetration

Flight qualification

Reliability

Wall-plug efficiency of lasers and amplifiers

Conclusions (1/2)

- Optical communication is still a brand new solution with unique, not yet unleashed potential
- The DRAFT roadmap has identified potential applications and the main challenges. Excellent results have already been achieved.
- Europe is currently in the lead for optical inter-satellite communications, however:
  - Non-ESA countries, USA & Japan in particular, are moving quickly, targeting full optical systems within 10 years.
  - ESA is implementing and running activities to increase the TRL level for key technologies/products in ScyLight, ARTES C&G/AT and TRP.
  - ESA needs to undertake a substantial system study to analyse technical requirements, assess the feasibility
  - ESA needs to proof the maturity of the technology and define solid solutions
- Optical technologies cover the entire value chain: an opportunity for small and medium-size enterprises.
- .

Conclusions (2/2)

- Via ScyLight and ARTES, ESA is continuously supporting optical technologies to bring the optical technology to commercial success.
- BUT….

- **What is missing?**
- **Where are uncovered gaps?**
- **What are the challenges identified by Industrial Players?**

- **If not today in your presentations and bi-laterals, please provide any comments or additions that you wish to share:**

→ ScyLight@esa.int

ARTES ScyLight work plan activities - current

Activity Ref.	Title	Priority	Planned for
SL.001	Optical technologies for next generation communication satellites	P1	Q4/17
	System and sub-system performance requirements for the next generation VHTS and a development roadmap for the critical enabling technologies.		
SL.002	Optical technologies for next generation optical inter-satellite links	P1	Q3/18
	System and sub-system performance requirements for the next generation of optical inter-satellite links and a development roadmap for the critical enabling technologies.		
SL.003	Optical communication requirements for scientific missions and the Moon village	P2	n/a
	System and sub-system performance requirements for scientific missions or in general long distance communications and a development roadmap for the critical enabling technologies.		
SL.004	Guidelines for the safe use of laser technology	P1	Q1/18
	In this activity the various risks associated with the use of laser technology in the implementation and operation of a satellite communication system shall be identified and categorised. Handling and operational constraints and protection measures shall be established for each of the identified risk scenarios and consolidated in a set of safety guidelines for industry and operators.		

Priority P2 = ESA ITT only issued on request by Delegations

ARTES ScyLight work plan activities - current

Activity Ref.	Title	Priority	Planned for
SL.005	Atmospheric monitoring to assess the availability of optical links through the atmosphere	P1	Q4/17
	Improved knowledge of the optical link availability for selected optical ground station locations and validation of long term optical link availability prediction methods.		
SL.006	Uninterrupted handover for optical earth-space links using site diversity	P1	Q1/18
	Validated site diversity concepts for optical earth-space links.		
SL.007	Assessment of analogue optical links through the atmosphere	P1	Q2/18
	Demonstration of reliable analogue optical links through the atmosphere.		
SL.008	Space assessment of optical amplitude modulators	P2	n/a
	Understanding of the environmental effects (e.g., temperature, radiation, charging) impacting the bias point behaviour of optical amplitude modulators. Verification of countermeasures to minimise drift of the bias point of amplitude optical modulators.		

Priority P2 = ESA ITT only issued on request by Delegations

ARTES ScyLight work plan activities - current

Activity Ref.	Title	Priority	Planned for
SL.009	Photonics phased array for optical feeder links	P1	Q1/18
	Feeder link technology based on photonics phase shifters, without deformable mirrors.		
SL.010	Use of secure optical communication technologies to protect European critical infrastructure	P1	Q3/17
	Technical and operational requirements for the protection of critical infrastructure by space-based systems and a development roadmap for the critical enabling technologies.		
SL.011	Quantum key distribution protocols for space applications	P2	n/a
	Model for quantum key distribution protocol performance prediction and a development roadmap for the critical enabling technologies		
SL.012	Space qualified faint pulse laser source for quantum key distribution	P2	n/a
	Increase the technical readiness level of faint pulse laser sources suitable for quantum key distribution applications from 5 to 7.		

Priority P2 = ESA ITT only issued on request by Delegations

ARTES AT activities – 2018 work plan

Activity Ref.	Title	Priority	Planned for
5C.353	Compact high power laser source for low earth orbit to ground use	P1	
	The objective of the activity is to develop a high power compact directly modulated laser source for data transmission between LEO satellites and ground with an average output power greater than 1W and with a beam quality factor of less than 1.3.		
5C.364	Large scale integrated photonic switch matrix	P1	
	The objective of the activity is to develop a packaged, photonic integrated switch matrix as needed for on board photonic front ends with at least fifty individual input and outputs.		
3B.035	Optical feeder-uplink pre-compensation based on double-stars	P2	
	The objective of this activity is to carry out a measurement campaign and develop waveform pre-compensation model based on information coming from double-stars.		

Priority P2 = ESA ITT only issued on request by Delegations

Wrap up – Feedback on the ScyLight Roadmap

Confirmation of ScyLight Concept on:

- Need for Networking between industrial partners ✓
  - also for development of building blocks or subsystems
- System Level Aspects important ✓
- Early In Orbit Demonstrations required (e.g. ScyLight Demo Phase) ✓
- Need for Standardization activities in different bodies ✓
- Need for coordination ESA/EC
- BUT: we need to speed up...

Additional Topics for the Roadmap and the Line 1/ESA Workplan

- Constellations Technology/LEO-LEO ISLs
- Mass and Cost Reduction/Series Production Methods
- Precision Engineering Methods

Comments?

Please provide any comments or additions that you wish to share after todays presentation:

ScyLight@esa.int

Note 1: Presentations will be made available via the ScyLight Web pages

Note 2: Pickup for the bi-lateral Meeting will be at the reception/main entrance