Optical communications in space

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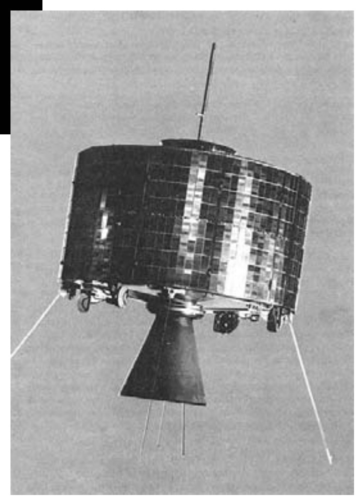
Contents

- *Historical Perspective*
- *Intra-satellite Communications*
- *Inter-satellite Communications*
- *Space qualification*

History was written in parallel

- October 4 1957, Sputnik, the first Satellite is launched
- 16 May 1960, First working laser (Theodore Maiman – Hughes RL)
- 19 August 1964, Syncom, the first GEO Telecom Satellite



Electronic News

THE INDUSTRY'S WEEKLY NEWSPAPER • A FAIRCHILD PUBLICATION

TEN CENTS

Hughes Studies Optical Radar as First Laser Use

Control Units Seen Focus of Europe Parley

Midwest Apathy Hit ...ago Conclave

Research Held Key to Growth On Long Island

Looking Back at Electronic News: October 1960

Pique Leaves Hoffman Post As of Oct. 31

who was first?

Waveguided, Atmospheric or Space Optical Communications?

1410 PROCEEDINGS OF THE IEEE, VOL. 58, NO. 10, OCTOBER 1970

Optical Communications—A Decade of Preparations

NILO LINDGREN

Abstract—This paper, an introduction to this first Special Issue on Optical Communications, follows some of the arguments that have prevailed for and against optics as a viable communications medium for terrestrial and space applications, and assesses the present state of the art of optics devices, systems, and theory, based on discussions with scientists and engineers who have been specializing in the optical field. It also attempts in a small way to give some appreciation of the special problems the traditional communications engineer faces in readjusting his thinking and his "physical intuition" in going from the world of electrons to the world of photons.

WHEN Theodore Maiman, and the Hughes Aircraft Co., held their first excited press briefing in New York in 1960 to announce the successful development of an experimental ruby laser, one of the future possi-

at all. The great promise is to develop techniques that one can use with state-of-the-art devices to get hold of the very large optical bandwidth." But this has been difficult so far.

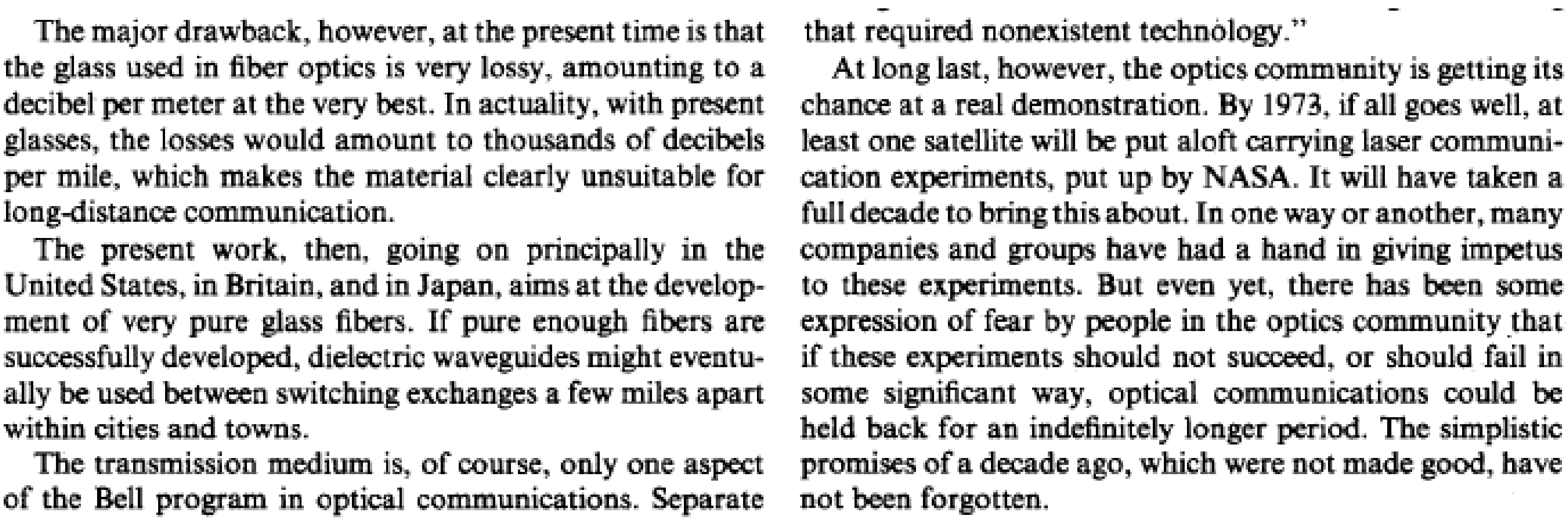
Today, after a decade of slow work, despite the development of many more types of lasers, of more powerful, more efficient, more extraordinary and reliable lasers, despite a growing spectrum of possible laser applications, it is hardly an exaggeration to say that there is, as yet, no *practical* optical communication system in existence.

Moreover, the best judgement today is that practical optical communication systems lie still far in the future.

Despite the persistent work of a preciously small community of researchers, the past decade has produced so far,

“…fiber optic losses…would amount to thousands of dBs per mile” –

“by 1973…at least one satellite would be…carrying laser comms experiments..”


The major drawback, however, at the present time is that the glass used in fiber optics is very lossy, amounting to a decibel per meter at the very best. In actuality, with present glasses, the losses would amount to thousands of decibels per mile, which makes the material clearly unsuitable for long-distance communication.

The present work, then, going on principally in the United States, in Britain, and in Japan, aims at the development of very pure glass fibers. If pure enough fibers are successfully developed, dielectric waveguides might eventually be used between switching exchanges a few miles apart within cities and towns.

The transmission medium is, of course, only one aspect of the Bell program in optical communications. Separate

that required nonexistent technology.”

At long last, however, the optics community is getting its chance at a real demonstration. By 1973, if all goes well, at least one satellite will be put aloft carrying laser communication experiments, put up by NASA. It will have taken a full decade to bring this about. In one way or another, many companies and groups have had a hand in giving impetus to these experiments. But even yet, there has been some expression of fear by people in the optics community that if these experiments should not succeed, or should fail in some significant way, optical communications could be held back for an indefinitely longer period. The simplistic promises of a decade ago, which were not made good, have not been forgotten.

Optical Communications in Space, today

We need Optical Communications <u>inside the Satellite</u> because the intra-satellite communication requirements can reach several Tbps (Com Sat).
Also because of the EMI, low mass, low volume and mechanical flexibility characteristics of fibers that are important in for a Spacecraft

We need free-space laser links <u>between satellites</u> because the higher directivity of the optical beam allows higher data/power efficiency (more Mbps for each Watt of power) This is critical to power-limited systems like a S/C. However it has higher Pointing Acquisition and Tracking requirements.

Intra-Satellite Optical communications

- *Linking equipment with equipment*
- *Board to Board*
- *Chip to Chip in photonic PCBs*

with

- *Digital Communications*
- *Analog Communications*
- *Photonic Processing of Microwave Signals*

IEEE Spectrum August 2002

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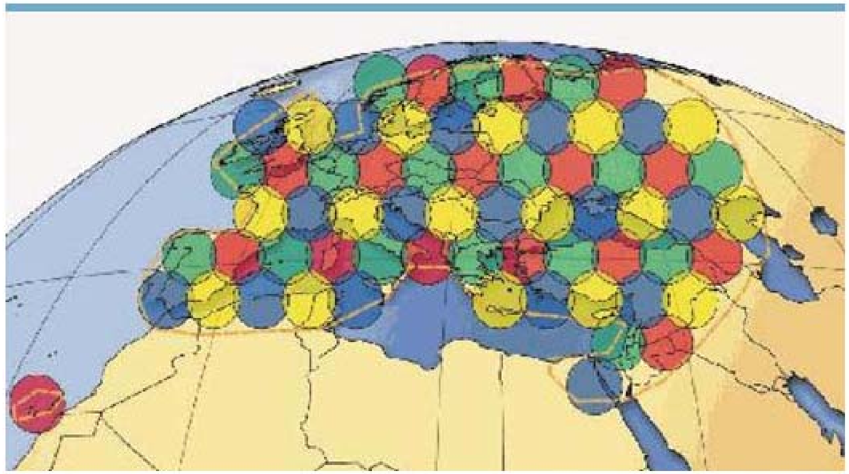
Telecom Satellites set the higher requirements for intra-satellite Optical Communications

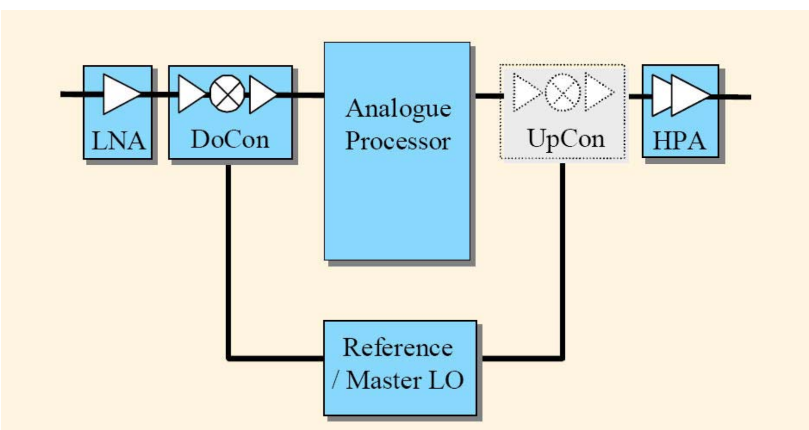
Eurostar 3000 platform

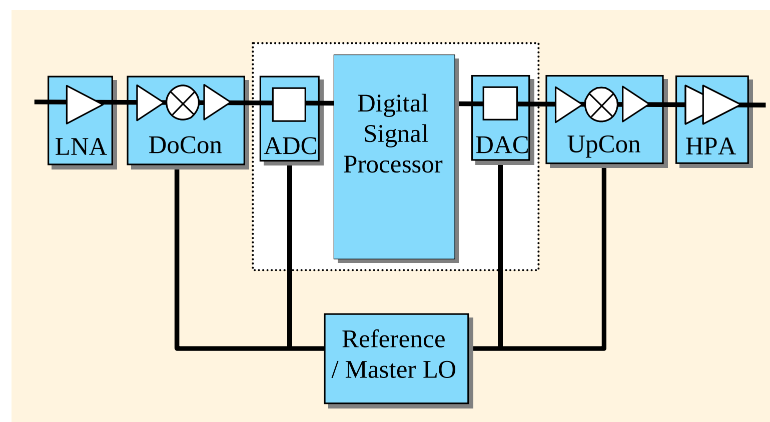
A Telecom Satellite can vary from being a classical Analog Repeater ("transponder")

to a full Digital Exchange Centre



(Alcatel RT 2Q2006)





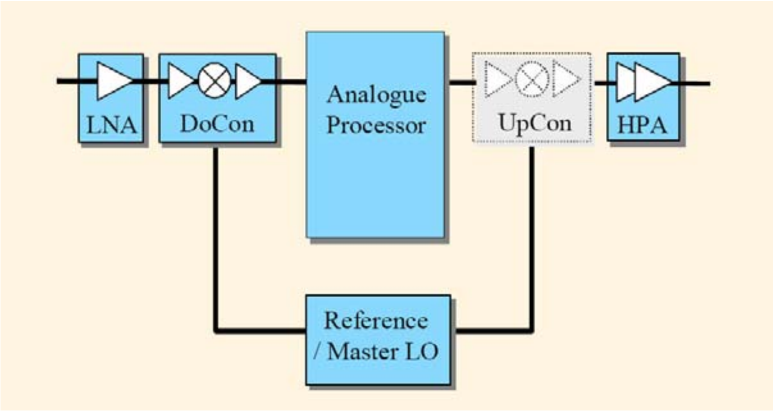
In Analog Repeater type of Payloads Photonics are considered for:

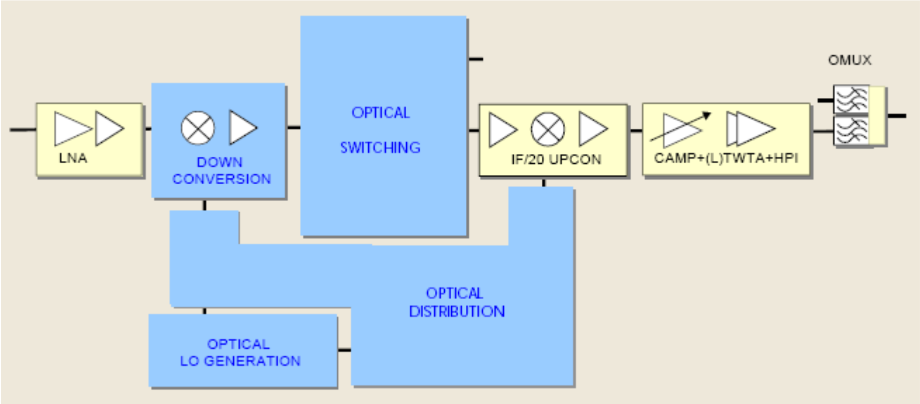
<u>communications:</u>
- distribution of a LO (with minimal added phase noise)

<u>and</u>

<u>signal processing functions:</u>
- generation of LO (AM with DSB/SC)
- microwave down-conversion
- cross-connect (circuit) switching

Main drive in introducing Photonics is the reduction in Mass, Power and Volume of the Payload

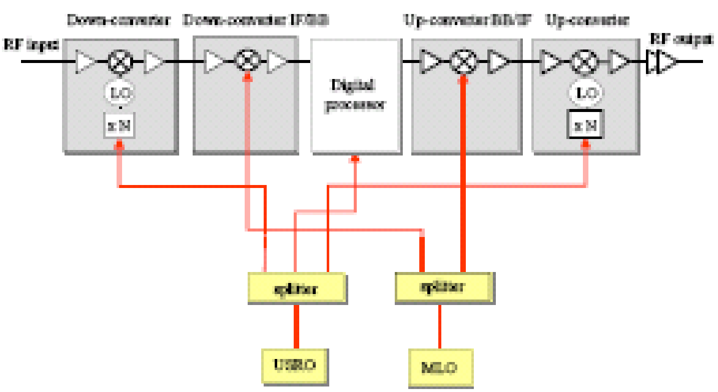


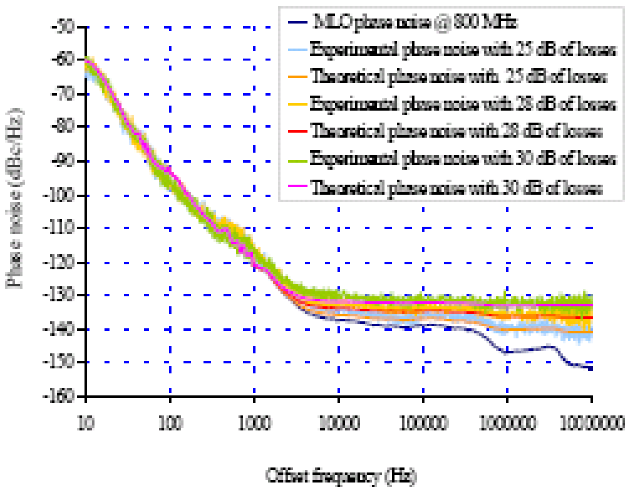


- Optical distribution of a microwave LO requires extremely low phase noise analog transmission of signals (from some MHz to some GHz)

- The use of EDFA is mandatory for a splitting ratio more than 100

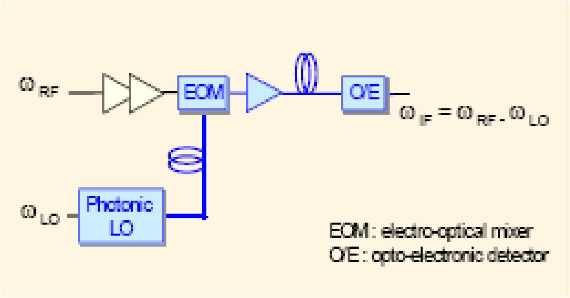
(B. Benazet et.al, ICSO 2004)

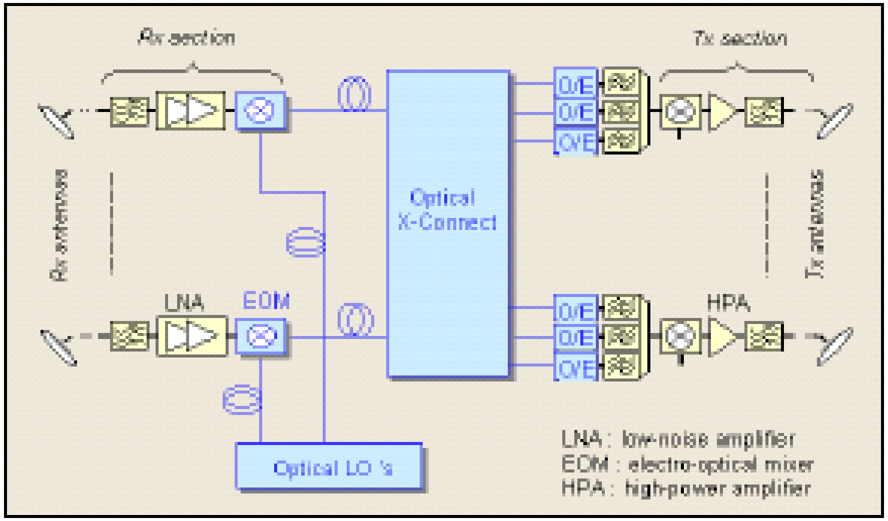


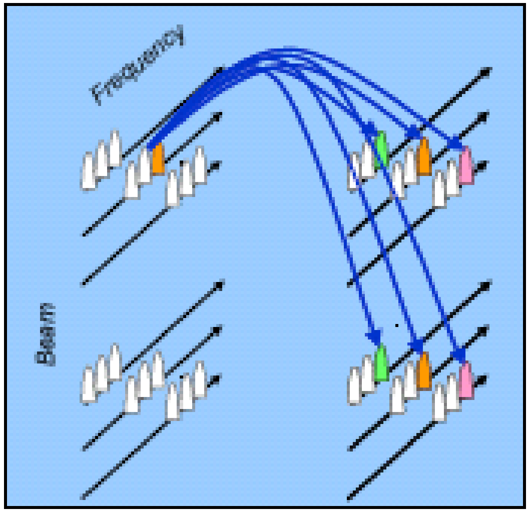


A Reconfigurable Crossconnect Repeater enables any frequency band from an Uplink beam to be switched to any Downlink beam

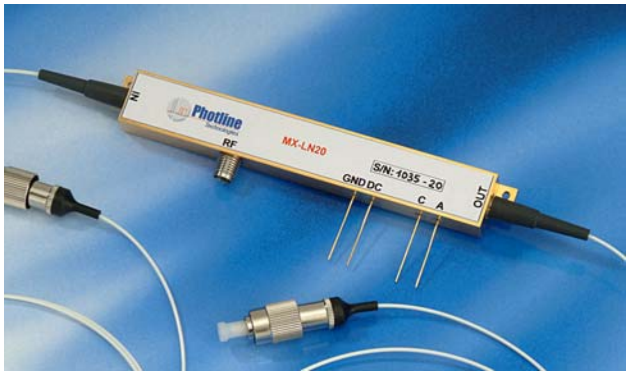
Photonics are considered for:
- LO generation (DSB/SC AM)
- microwave down-conversion (from RF to IF)
- circuit switching e.g 50x50
- A dilated switch fabric allows higher granularity

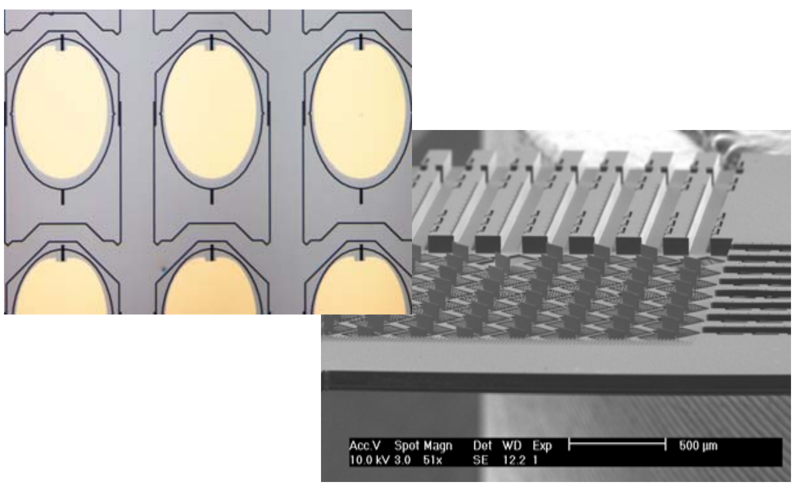






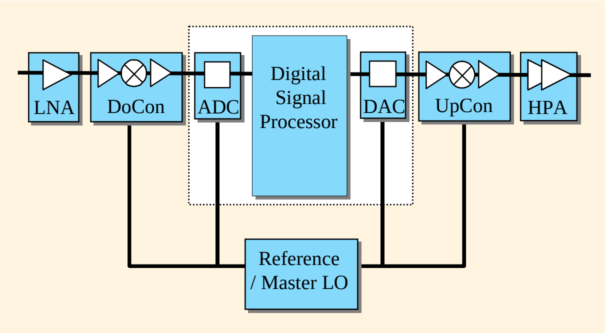
Photonic Technologies Basis
MZI optical modulators as used as "mixers" for downconversion
MOEMS as the crossconnect switch
EDFAs for high splitting ration in LO distribution





In Digital Processors type of Payloads Photonics are necessary to carry Tbps

- *100 beams with two polarizations*
- *750 MHz per beam per polarization are fed to 200 ADCs*
- *Each ADC samples at 2 Gsps at 10 b plus extra coding*
- *Each ADC outputs about 25 Gbps*
- *5 Tbps reach the DSP from the ADCs*
- *5 Tbps leave the DSP for the DACs*
- *A DSP can be, for example, a 3-stages Clos Network*
- *Inside the DSP the traffic is multiplied by several times*



Conclusion:

Modern Satellite Payloads carrying Digital Processors require optical communications to handle several Tbps with minimum power consumption

ESA targets <10mW/Gbps i.e <100 W for 10 Tbps

The technological basis for digital communications

- Tx: VCSELs (850nm) (GaAs)
- Rx: Pin (850nm) (GaAs – more rad-hard)
- Modulation: Direct modulation
- Fibers: GIMM
- Fiber Cables: Single and Ribbon Fiber
- Cable jackets: (no out gassing)
- Connectors: With anti-vibration mechanism for both parallel and single fiber
- No amplifiers are employed (max distance of 100 m for the ISS, typ. <10m)
- Parallel Tx/Rx Modules are currently preferred over WDM for reliability reasons

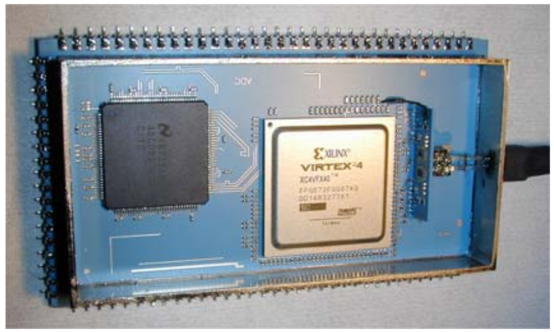
Single fiber for links <10 Gbps
VCSEL-GIMM fiber-PiN

ESA produced the "SpaceFiber" extending to high bit rates the "SpaceWire" standard

Parallel Tx/Rx for Links > 10 Gbps

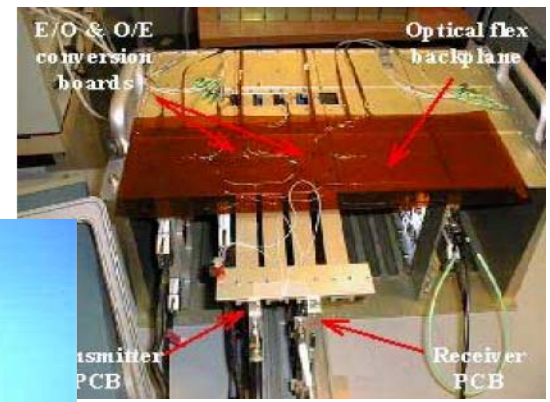
using the same technology basis as the single fiber links

ADC-DSP-DAC



Board to Board inside the DSP

(N. Venet, ICSO 2004)



IR Wireless Optics

Wireless Optics considered for:

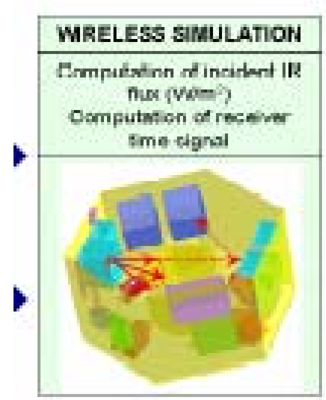
• diffused IR transmission between a Master Unit and tens of sensors

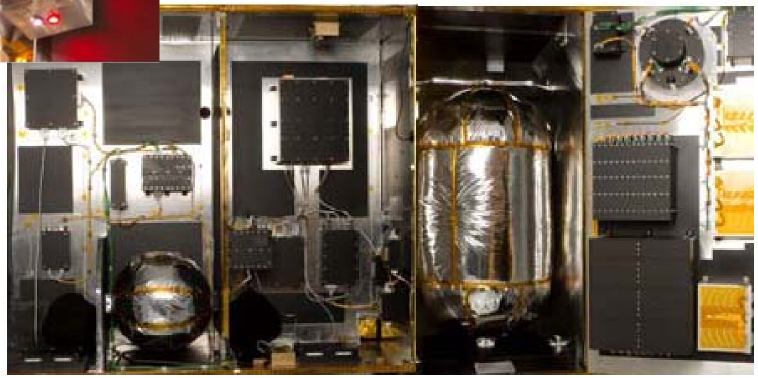
• Reduction of AIT time and effort

• Specialty applications on board S/C

• using battery-powered LEDs with adapted IR antennas and

• supported by simulation of the S/C interior





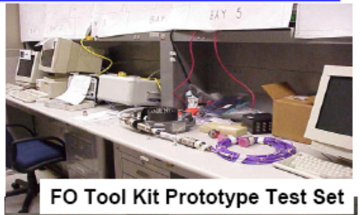
First operational massive use of fiber optic communications in Space was for the International Space Station

decision taken in late 80's
technologies of 90's

FO Tool Kit Development

BOEING

HB Avionics/Electrical Systems (AES)



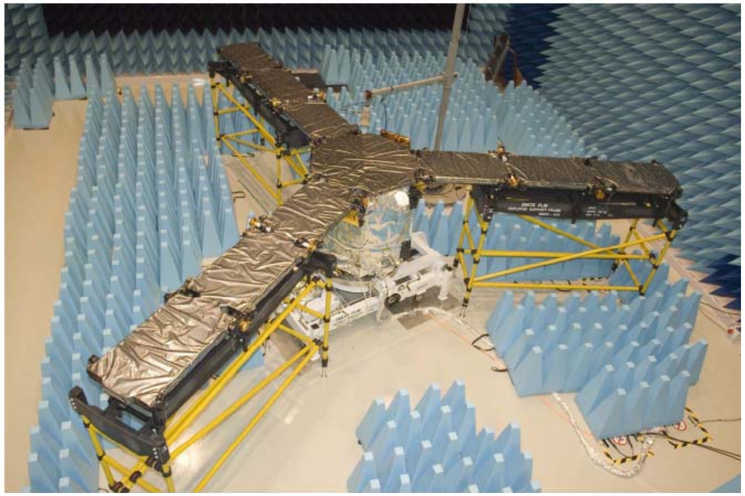
FO Tool Kit Prototype Test Set

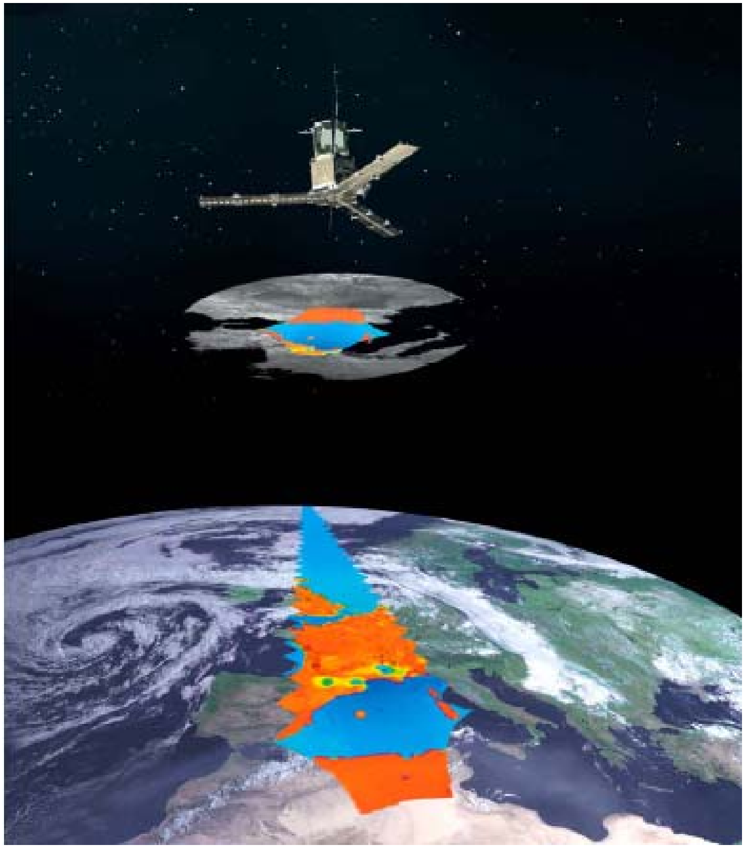
Crew Bench Review 3/20/01

4/00	ATP for OTDR Development
5/00	OTDR Requirements Developed
7/00	ATP for FO Tool Kit Development
9/00	FO Tool Kit Requirements Developed
11/00	OTDR & FO Tool Kit Prototypes Completed
11/00	OTDR Outgas
10/00	OTDR Radiation Testing
12/00	FO Tool Kit Prototype Testing Initiated
12/00	PDGF Crew Walkdown with installation scenarios
12/00	OTDR Burn-in Testing
01-01	OTDR Vibration Testing
01/01	OTDR Thermal Cycling Testing
12/00 – 3/01	FO Cable Functional ATPs
3/01	Electrical Cable (28VDC) Functional ATP
1-3/01	Other COTS tools and miscellaneous Outgassed
3/16/01	Kit Sharp Edge Inspection
3/16/01	Kit Connector Fit Checks (IVA OTDR, Patch Cables, Reel, and all test adapters
3/20/01	Crew Walkdown and Bench Review
3/23/01	Stowage in MPLM Racks
3/26/01	Equipment Stowed in MPLM
3/26/01	Development Equipment used in Flight-like System Level Testing (still ongoing as of 6/9/01)
4/19/01	6A Launch
6/12/01	Operations Training Session
	FO Tool Kit Deorbited
	FO Tool Kit Placed in KSC Stores

esa

SMOS (Soil Moisture and Ocean Salinity) is the first Satellite Payload to rely critically on fiber optics (to be launched this year)

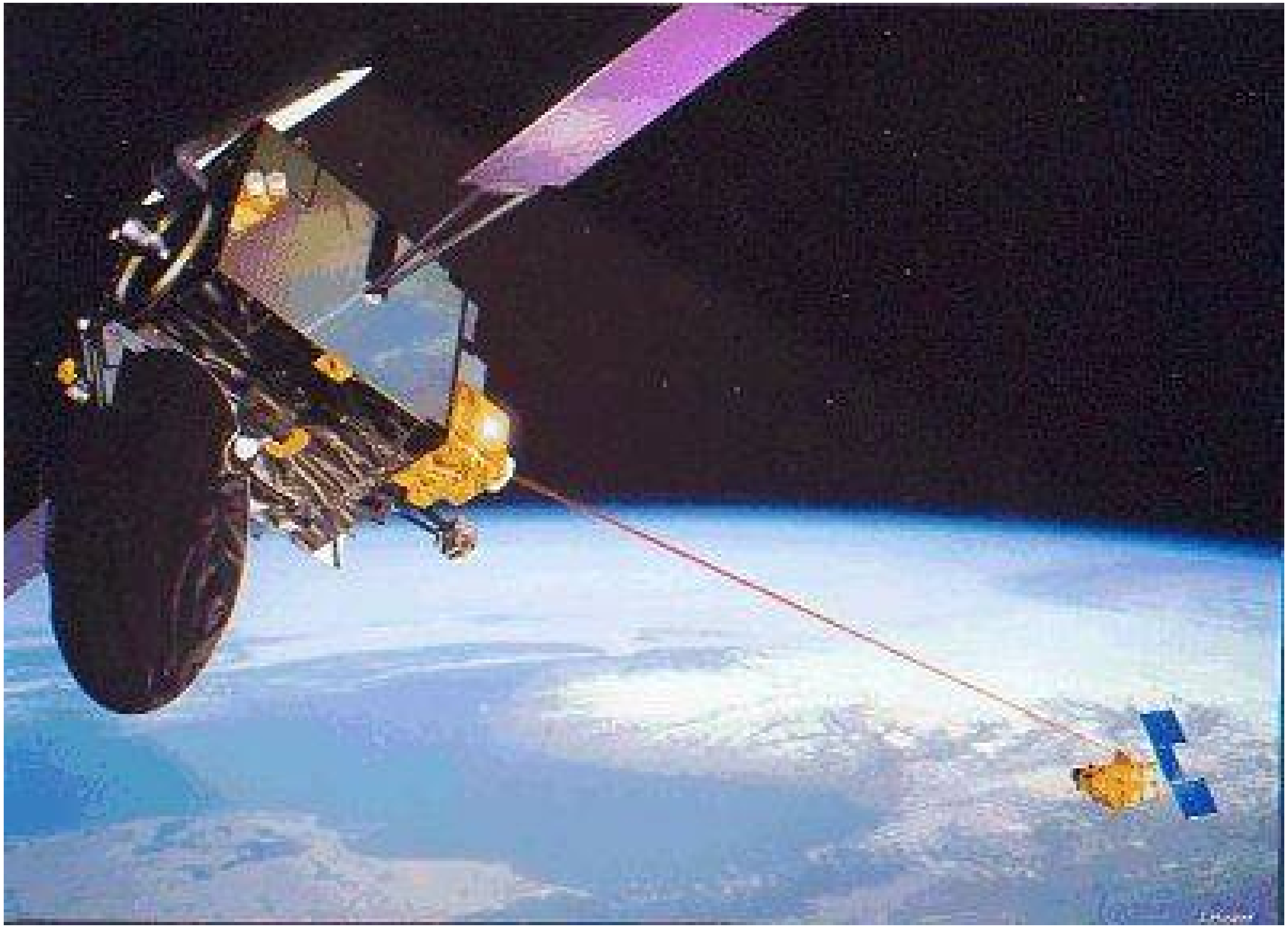




144 links at 110 Mbps (72 to and 72 from antenna elements)

- very low EM emission levels (from Tx/Rx)
- galvanic isolation
- mechanically flexible and lightweight
- better phase stability when bended

Inter-satellite Optical Communications



Inter-satellite optical communications

For Applications in

1. *Data relay (like the Tracking and Data Relay Satellites that serve the Space Shuttle)*

(Mbps from a LEO/GEO satellite or aircraft to earth via another GEO satellite)

2. *For broadband (multigigabit) links (over thousands of Kms)*

(in Telecom Constellations among S/C in LEO/MEO/GEO)

3. *For Space Science Links (Mbps or Kbps over millions of kms)*

(between Lagrange Points of Interplanetary Space to Earth Stations or GEO)

Technologies

- *First Generation of terminals were in 800-850nm band-ASK(PPM)-Direct Detection*
- *Second Generation were in 1064nm-BPSK-Coherent Detection*
- *1550nm-ASK-Direct Detection has been studied and demonstrated in ground*
- *Currently European Suppliers promote the power efficient Coherent solution*

ESA's 30 years developments on ISLs

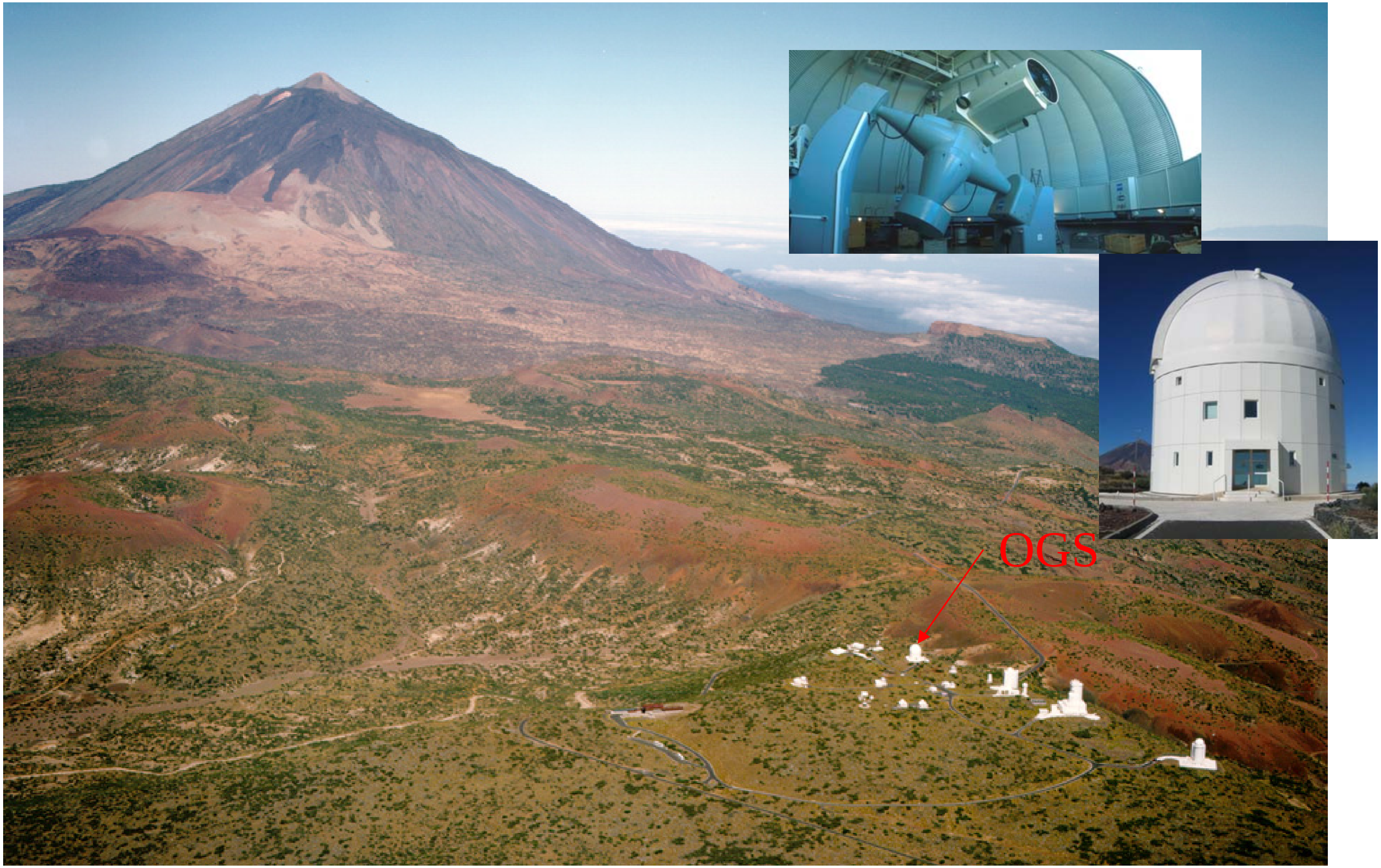
Since late 70's	Development of components for ISL terminals
Late 80's	SILEX (Semiconductor laser Inter-satellite Link Experiment) is decided
90's	SILEX is developed using incoherent technology
90's	Coherent ISL terminals are developed targeting the commercial broadband satellite networks
Since 2001	Inter-satellite flight demonstrations • ARTEMIS-SPOT-4 • ARTEMIS-OICETS • ARTEMIS-Airplane • TerraSAR - NFIRE

Flying S/C equipped with ISL terminals

• ARTEMIS (ESA)	in GEO (2Mbps-819nm-DD)
• SPOT-4 (CNES)	in LEO (50Mbps-847nm-DD)
• OICETS (JAXA)	in LEO (50Mbps-847nm-DD)
• TerraSAR-X (DLR)	in LEO (5.5Gbps-1064nm-CD)
• NFIRE (USA)	in LEO (5.5Gbps-1064nm-CD)

ESA maintains an Optical Ground Station in Tenerife, Spain to support experiments for Ground-Space links

Observatorio del Teide in Izaña, Tenerife, Spain



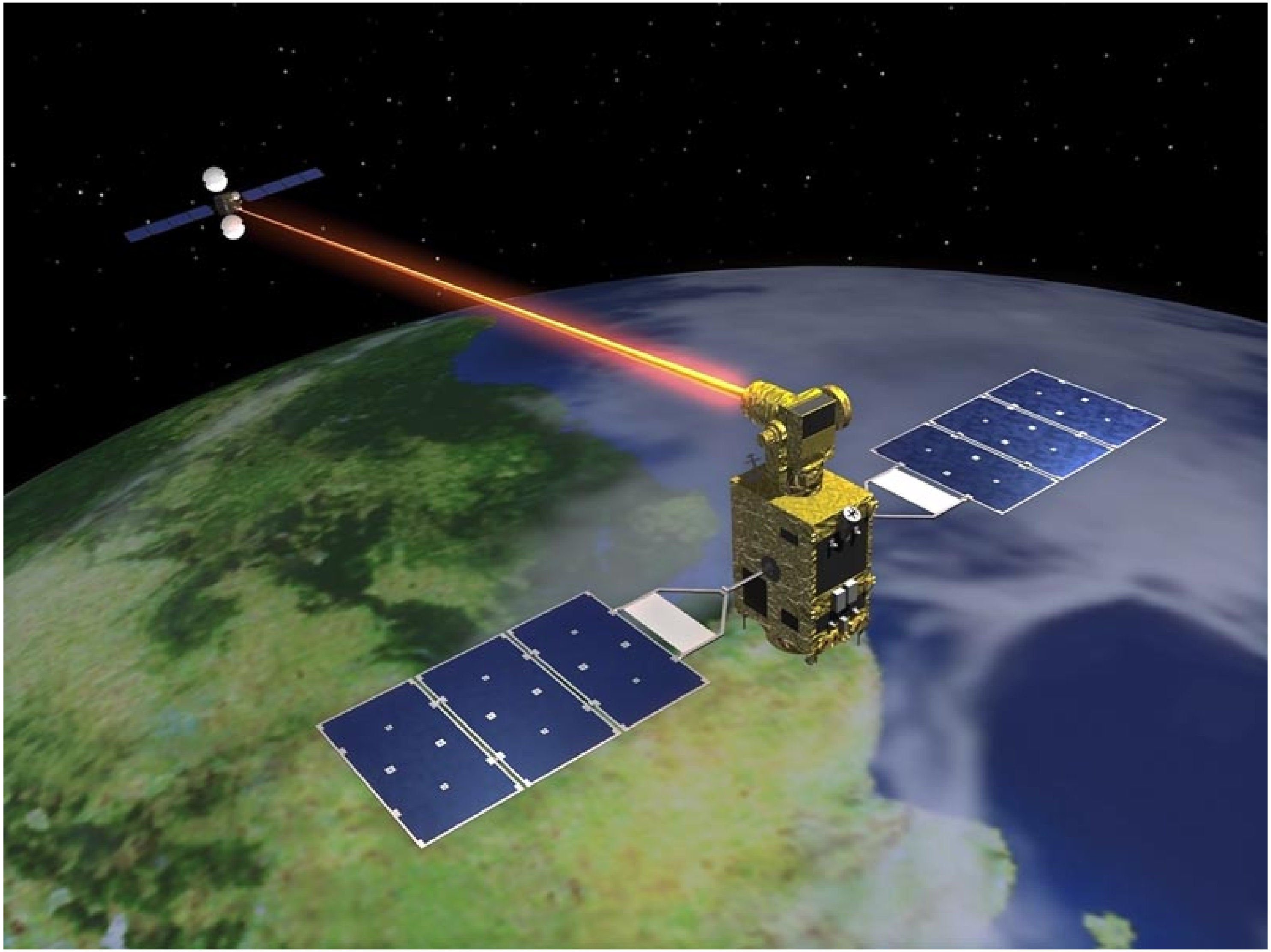
Data Relay Mission
First Image Transmitted by SILEX

30 November 2001 17:45 Lanzarote, Canary Islands, in the Atlantic ocean west of Africa, the first image transmitted via optical intersatellite link from SPOT4 to ARTEMIS and then to SPOTIMAGE in Toulouse, France via ARTEMIS' Ka-band feeder link

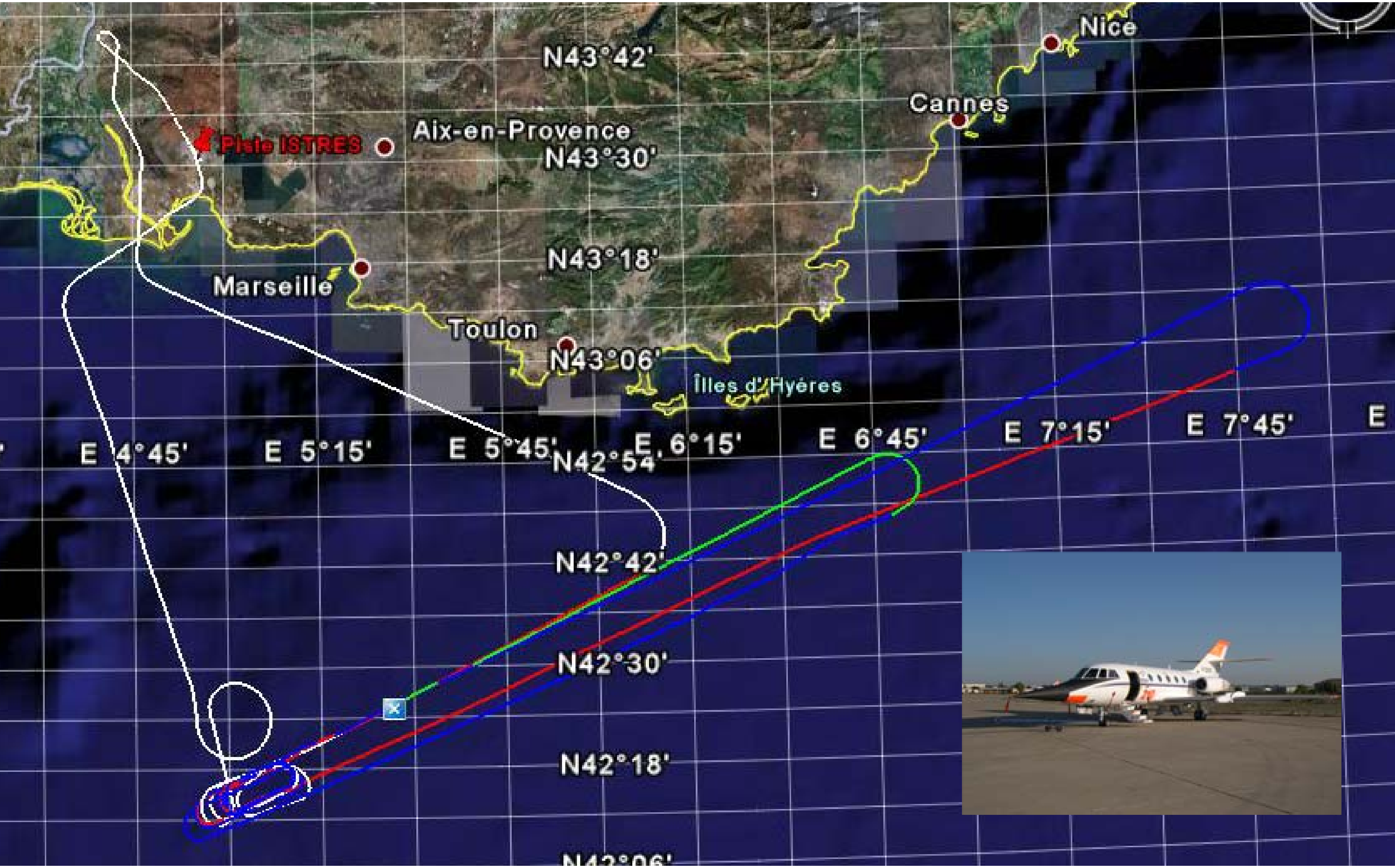
SILEX Parameters

	ARTEMIS	SPOT-4
Antenna diameter Rx:	250 mm	250 mm
Beam diameter Tx ($1/e^2$):	125 mm	250 mm
Transmit power:	5 mW	40 mW
Transmit data rate:	2 Mbps	50 Mbps
Transmit wavelength:	819 nm	847 nm
Transmit modulation scheme:	2-PPM	NRZ
Receive data rate:	50 Mbps	none
Receive wavelength:	847 nm	819 nm
Receive modulation scheme:	NRZ	none
Link distance:	<45000 km	
Beacon wavelength:	801 nm	none
Optical terminal weight:	160 kg	150 kg

OICETS and ARTEMIS Link

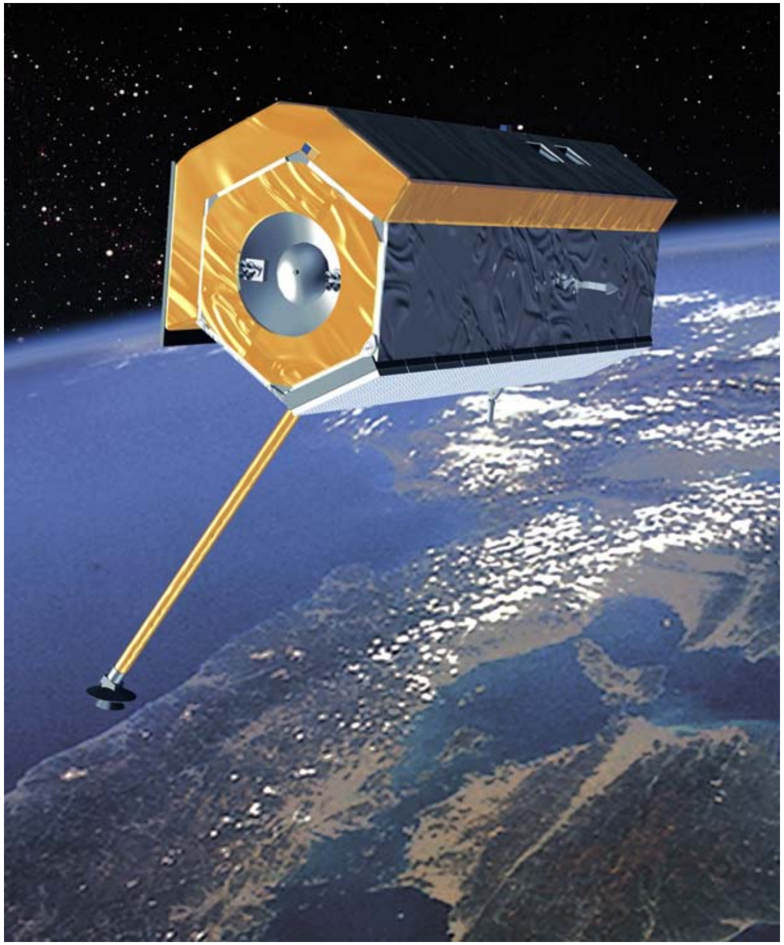


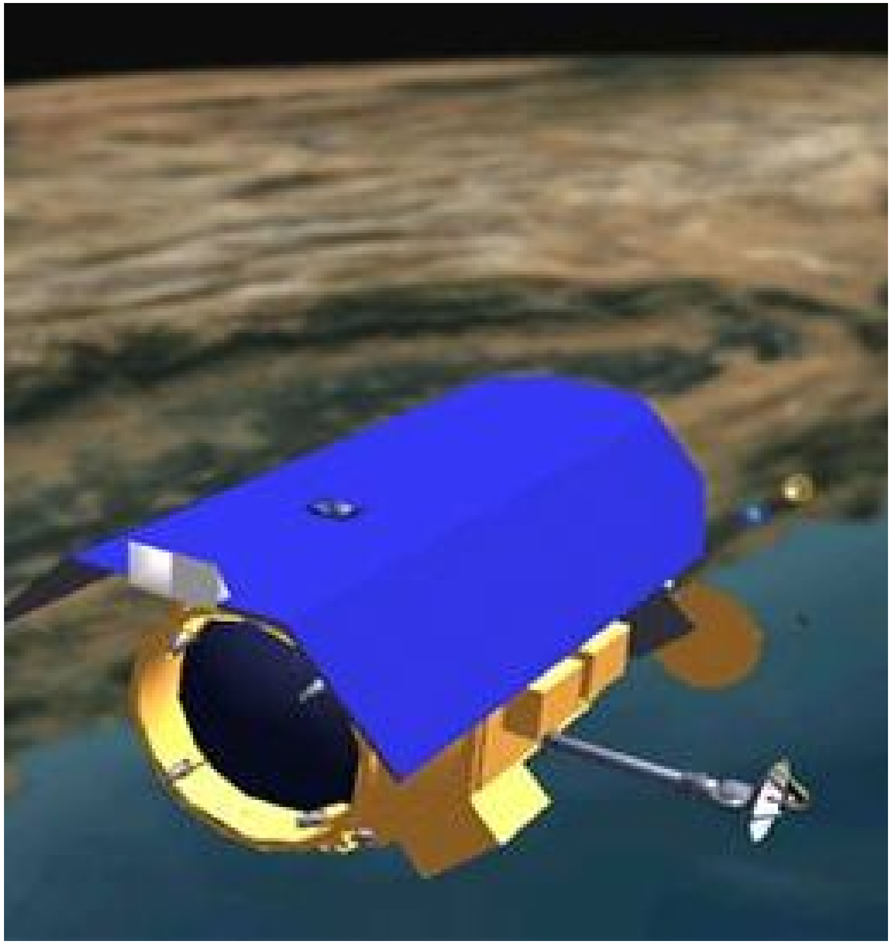
Airplane (flying over Cote d' Azur) to ARTEMIS link



Broadband Links Applications

TerraSAR-X and NFIRE Link



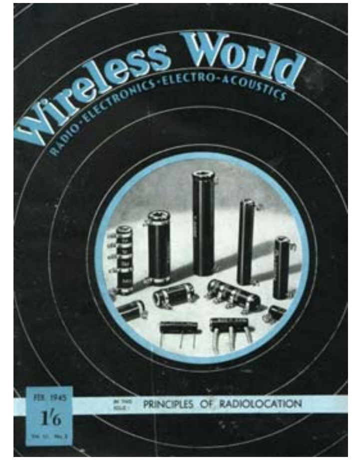


TerraSAR-X (TSX) – NFIRE Parameters

	TSX	NFIRE
Antenna diameter Rx:	125 mm	125 mm
Antenna diameter Tx ($1/e^2$):	125 mm	125 mm
Transmit power:	<1000 mW	<1000 mW
Transmit data rate:	5500 Mbps	5500 Mbps
Transmit wavelength:	1064 nm	1064 nm
Transmit modulation scheme:	BPSK	BPSK
Receive data rate:	5500 Mbps	5500 Mbps
Receive wavelength:	1064 nm	1064 nm
Receive modulation scheme:	BPSK	BPSK
Link distance:	<8000 km	
Beacon wavelength:	none	none
Optical terminal weight:	35 kg	35 kg

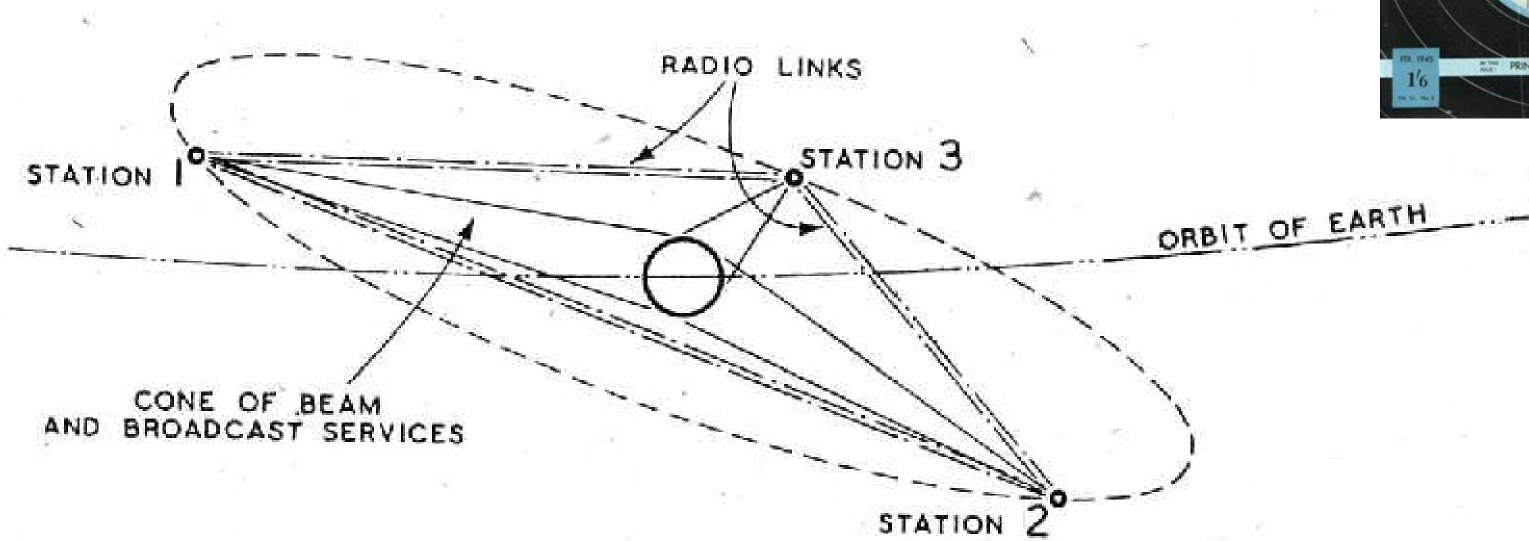
the first Optical Communications Network
"a global 3-nodes ring topology-Clarke Network"

proposed by A. Clarke in October's 1945 issue of "Wireless World"

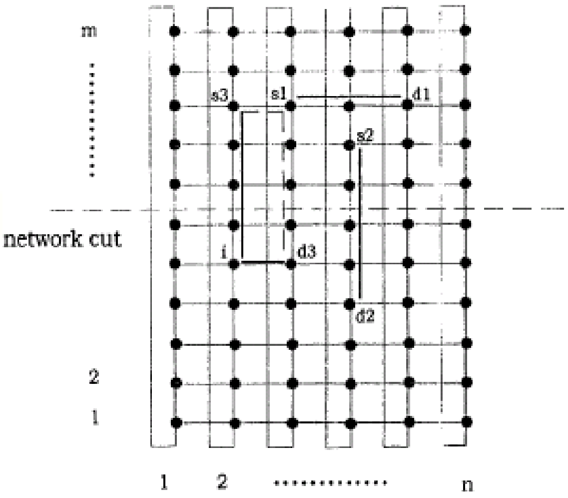


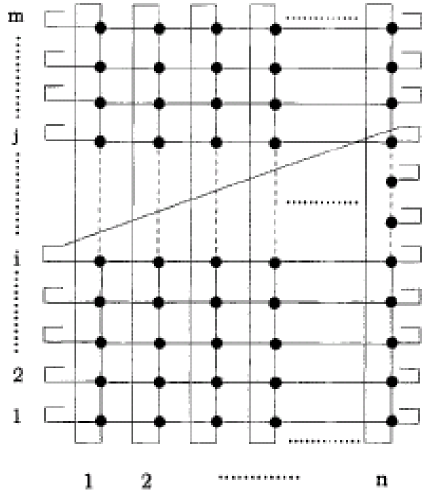
…The stations in the chain would be linked by radio or optical beams,

and thus any conceivable beam or broadcast service could be provided…"



Satellite constellation networks form a b-MSN network topology that can be served by an ISL-OTN



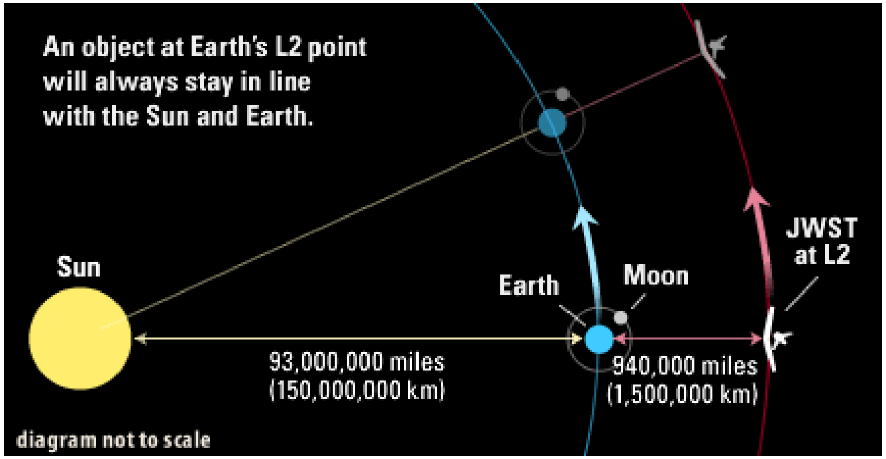


http://www.stratosglobal.com/documents/factsheets/irid _whitePaper_satelliteDataServices.pdf

N.Karafolas, S. Baroni, JLT 12/2000

esa

Space Science Links Applications
The L points:parking places for telescopes



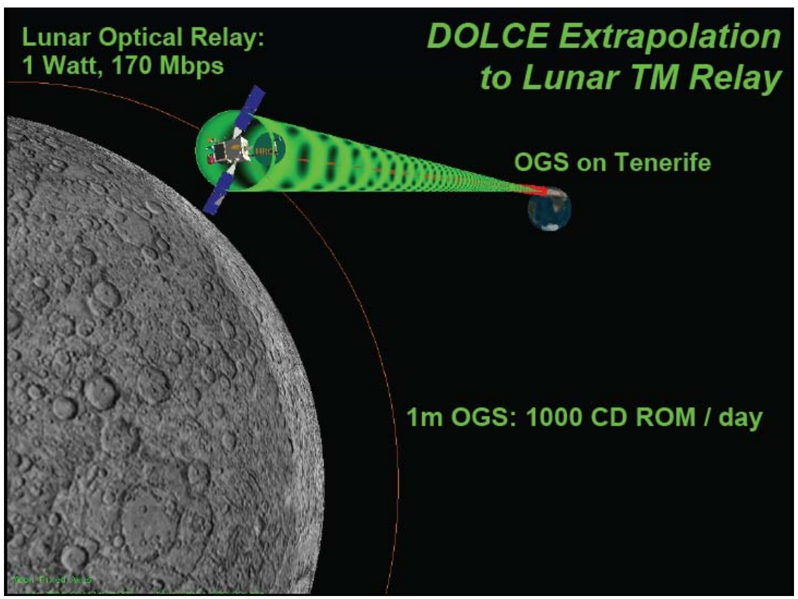
Parameter	Value
User data rate	10 Mbit/s
Communication wavelength	1060 nm
Transmitter architecture	Master oscillator, power amplifier
Average transmit power	1 W
Transmit aperture diameter	10 cm
Modulation format	Pulse position modulation
Link distance	1'500'000 km
Receive aperture diameter	1.016 m
Receiver field of view	> 90 µrad
Target receiver sensitivity	60 photons/bit
Link features	Forward error correction, interleaving

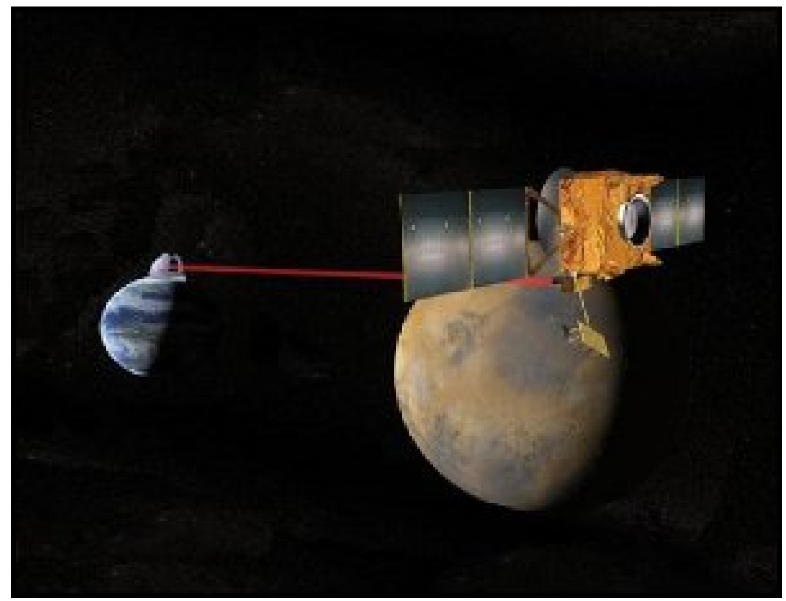
Oelrikon, CH.

the Moon and the Mars links

Moon-Earth (OGS) simulated link by Oerlikon in ESA's DOLCE project

MTO: The cancelled (due to budget constraints) NASA 2010 mission for a Mars Telecom Orbiter

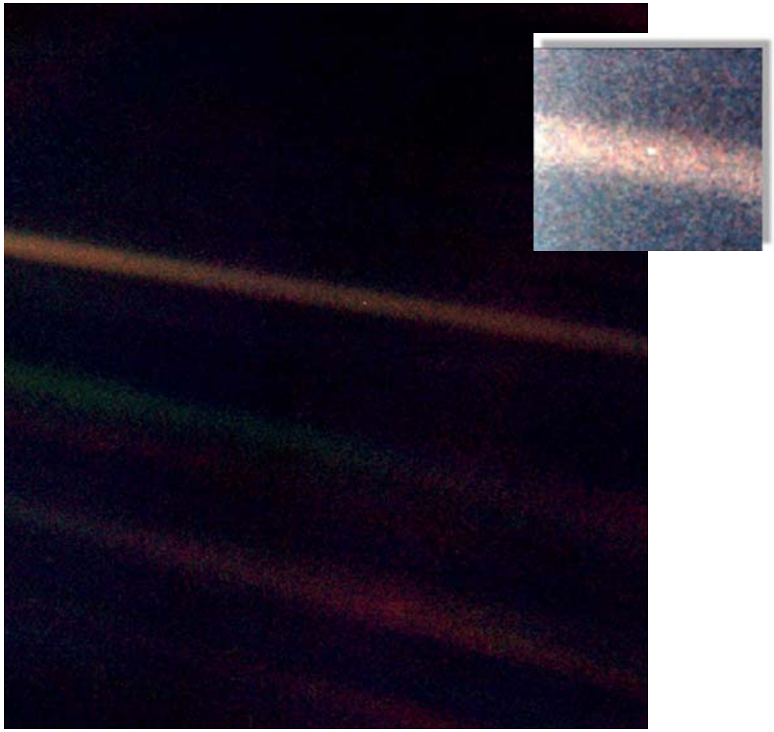




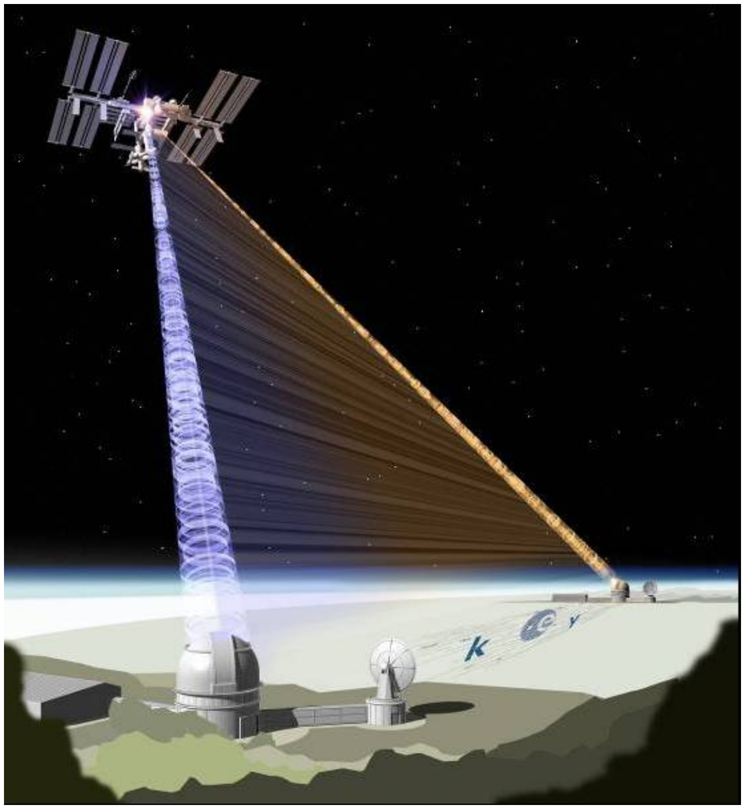
…..is anybody out there?

The Mars horizon with Earth at the sky seen by a Mars rover

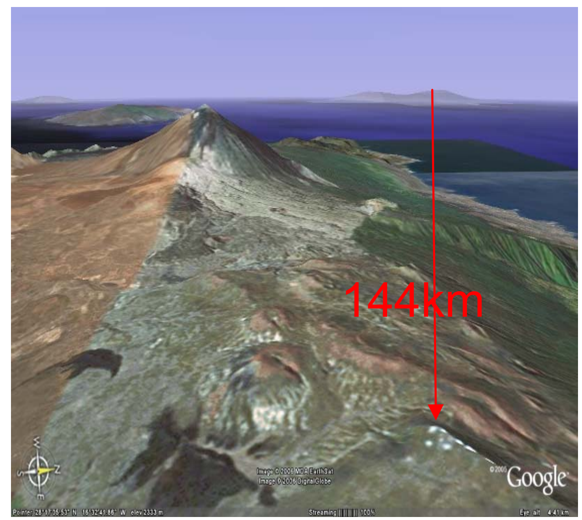
This photo of the Earth was taken by Voyager 1 in 1990 at a distance of 6.6 billion Km, 32 degrees above the plane of the Solar System



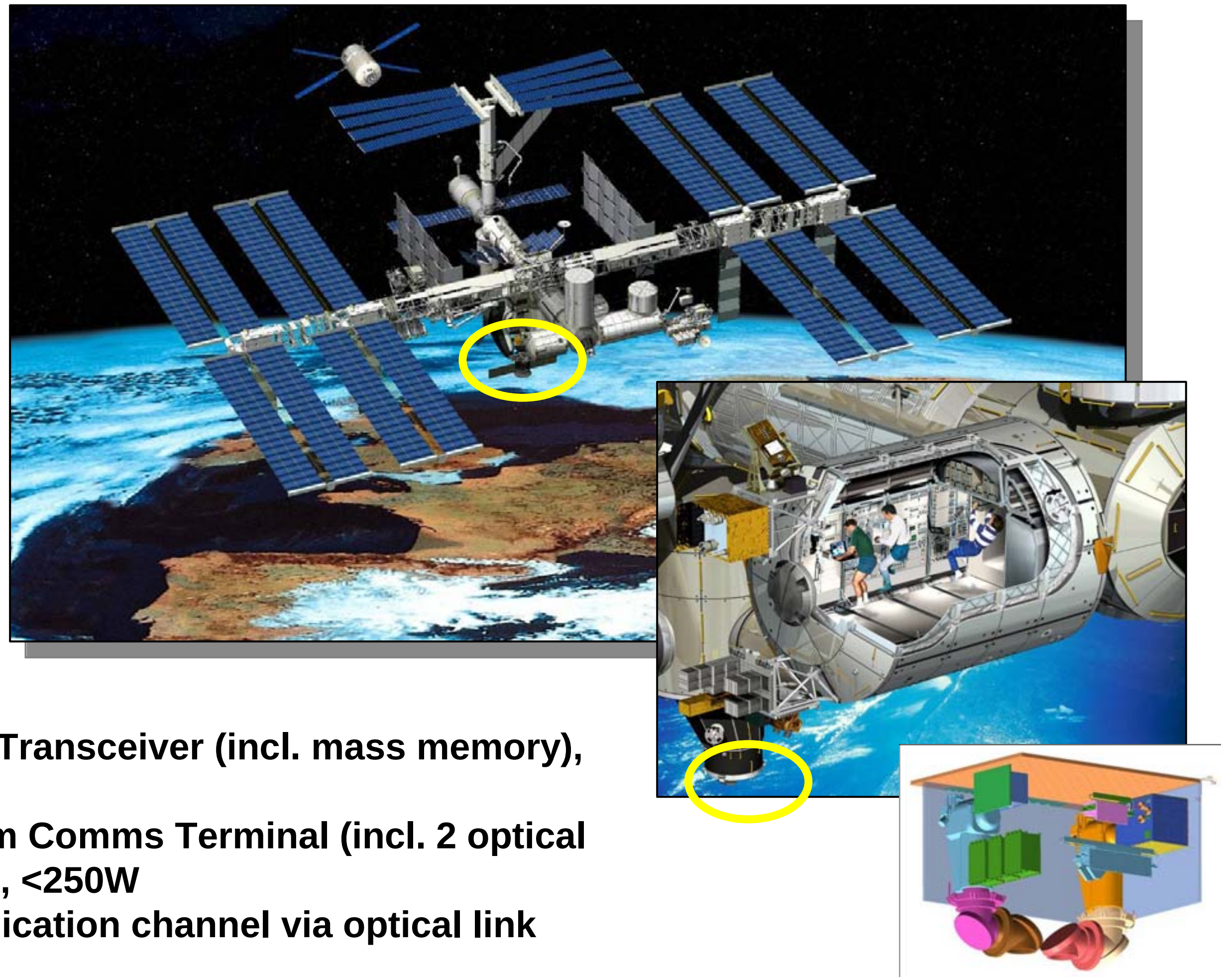
Demonstrations:
Quantum Communications via Space



Longest demonstration worldwide over 144kms inter-island link at Canary Islands.



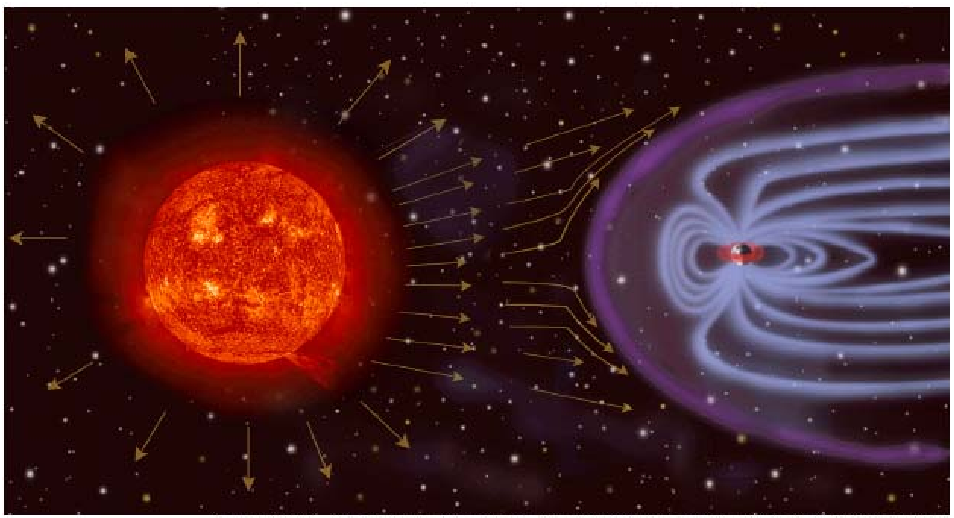
Space-QUEST on ISS
(proposed to ESA by TU Vienna)



- **Quantum Comms Transceiver (incl. mass memory), <10kg, <50W**
- **Complete Quantum Comms Terminal (incl. 2 optical terminals), <100kg, <250W**
- **Classical communication channel via optical link**

Space Qualification

..a S/C has to be launched on a rocket and then …live in space

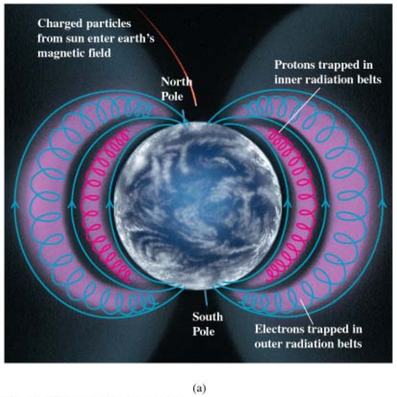


Source: NASA. "Living in the Atmosphere of the Sun." [updated 20 Jan 2000, cited 29 March 2004.] http://www-istp.gsfc.nasa.gov/exhibit/main.html

…where the weather is strange..

During launch:

- Vibrations
- Mechanical Shock due to the release of different rocket-stages and fairing opening



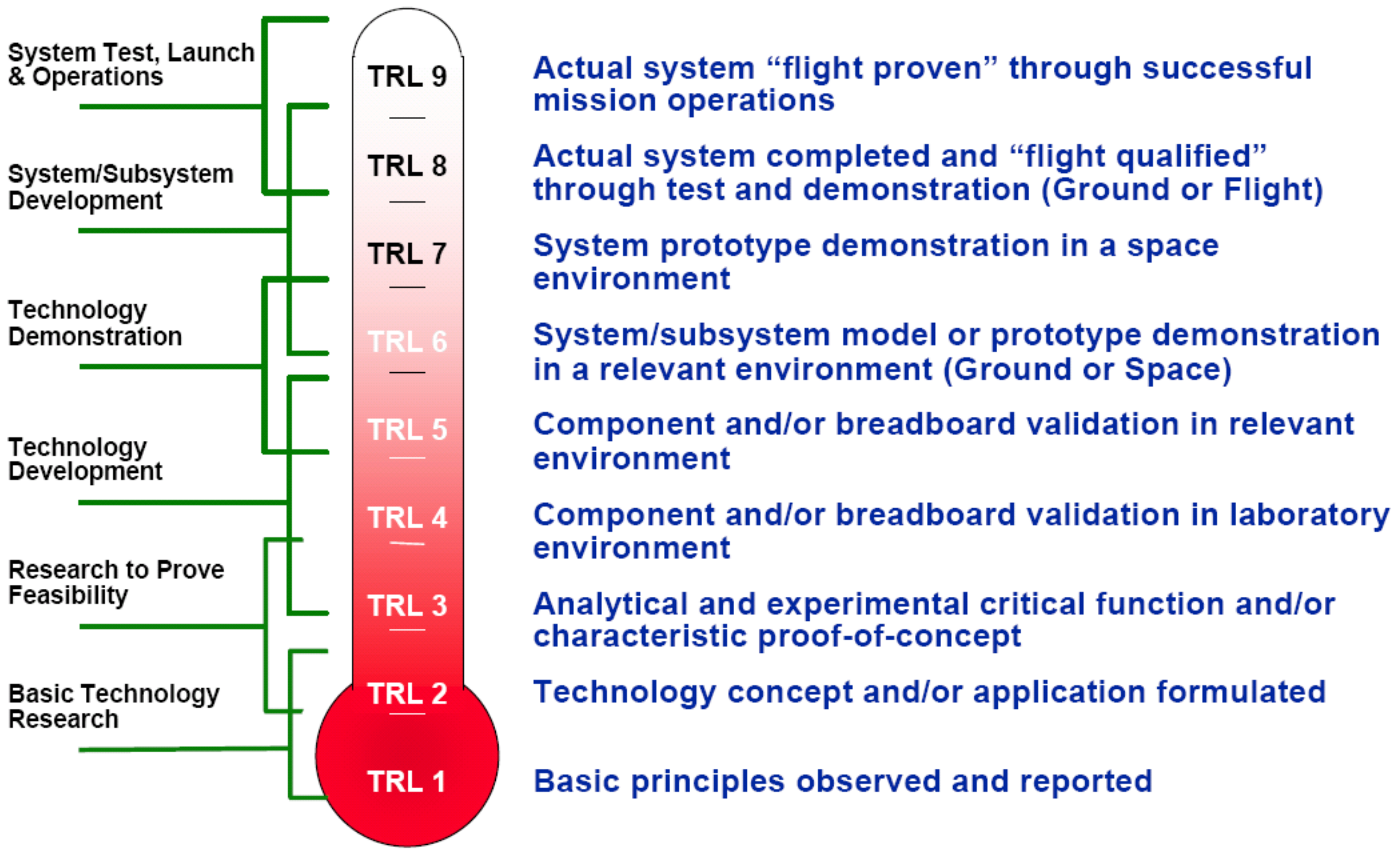
Once in Space:

- Galactic Cosmic Rays
- Solar Wind High Energy Particles
- Magnetically trapped charged particles dependant on solar activity
- Thermal variations
- Vacuum (there is not heat convection in vacuum – out gassing occurs that may impair microelectronics and optical surfaces)

Qualifying photonics for up to 15 years operation in Space

- No COTS components can be used readily.
- All technologies require rigorous space qualification
- Similarity with under-sea cable qualification specs (25yrs operation)
- Space agencies and S/C companies prefer to space qualify COTS components instead of developing from scratch dedicated ones.
- Currently ESA has a program of assessment all types of Photonic Components (DFBs, VCSELs, detectors external modulators, optical amplifiers, optical fibers, jackets for fiber cables, connectors, detectors, MOEMS etc)

Technology Readiness Level for Space



Qualification Plan Approach for COTS

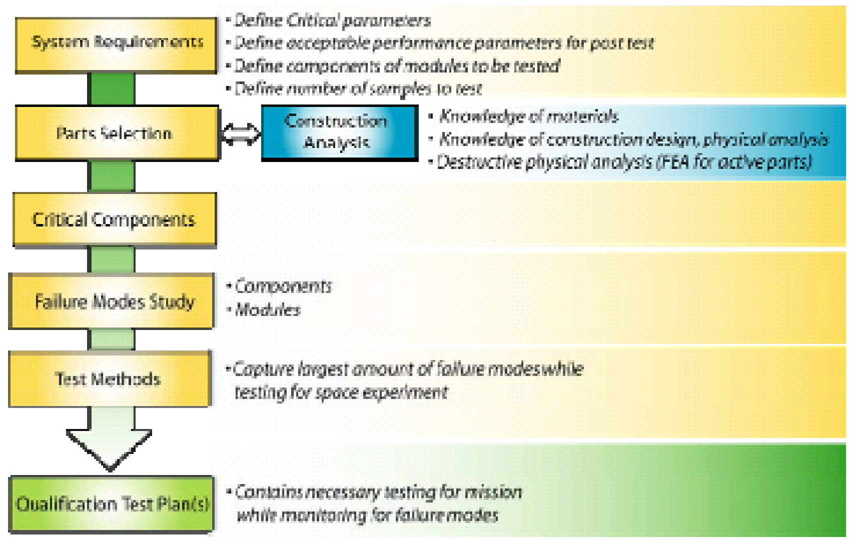
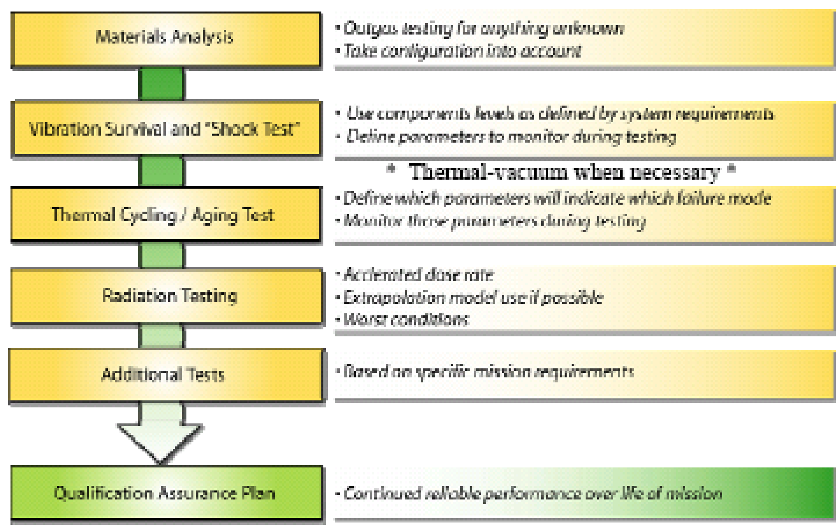


Figure 2: Steps to a Qualification Test Plan; NEPP Technology Assurance Approach [6



from http://photonics.gsfc.nasa.gov/

Telcordia Standard (GR-468-CORE) is a good start to assess the qualification potentials of a COTS

from http://photonics.gsfc.nasa.gov

	NASA Requirements		Telcordia Requirements
Vibration Testing	Vibration conducted on each of three axes	3 minutes / axis	
	Frequency (Hz)	Protoflight Level	20-2,000 Hz-min/cycle
	20	.052 g2 / Hz	
	20-50	+6 dB / Octave	
	50-800	.32 g2 / Hz	
	800-2000	-6 dB / Octave	20G, 4 cycles/axis
	2000	.052 g2 / Hz	
	Overall	20.0 grms	
Thermal Cycling Testing	-20°C/+85°C, 30 cycles for pass/fail, 42 cycles for info		-40°C/+70°C, 100 cycles for pass/fail, 500 cycles for info

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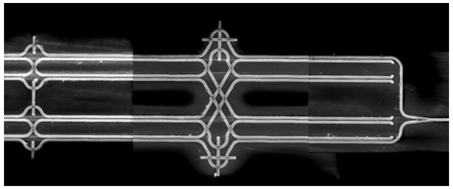
The 2020 Horizon

- to establish the means to generalize the use of Photonics in S/C Engineering by achieving the signal processing functionalities currently under R&D and hence creating entire Photonic systems such as Photonic Payloads (including electro-photonic ADCs and BFNs) and fully Photonic communication (and Sensing) harness.

- to increase the efficiency of Photonics in terms of power, mass and volume by moving from distinct Photonic devices to Microphotonics and Photonic ASICs.



As space funding is limited ESA's main strategy is to monitor the technological developments for ground applications, and at the right time to provide the required funds to tailor these technologies to meet the needs of space applications.

So, <u>we wait for your developments and breakthroughs!</u>

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Acknowledgments

Unless specifically stated in the slides, the work presented in this presentations was performed by the industrial and academic contractors of ESA under full or partial funding by ESA.

For information on Space Qualification of Photonics look at the free web-resources:

- http://photonics.gsfc.nasa.gov/ maintained by Ms Melanie Ott
- www.escies.org (►technologies ►photonics)

Thank you!

and for more information on….

….ESA in general, look at www.esa.int

….how to make business with ESA, look at the industry portal at www.esa.int *and register your company/institution to EMITS*

..on ESA's work on Photonics, contact me