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Optical Interconnect Design in Space

By
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01 28 2019

Outline

- Market overview
- Applications overview
- Optical transceivers challenge
- Radiation tests
- Thermal vacuum testing (TVAC)
- Lifetime test

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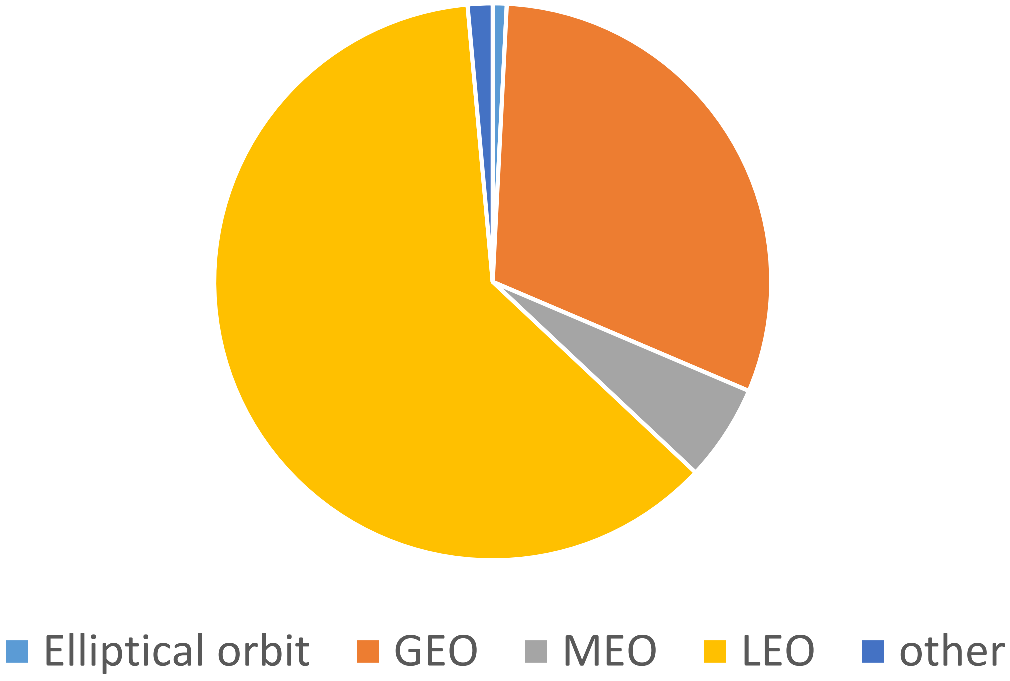
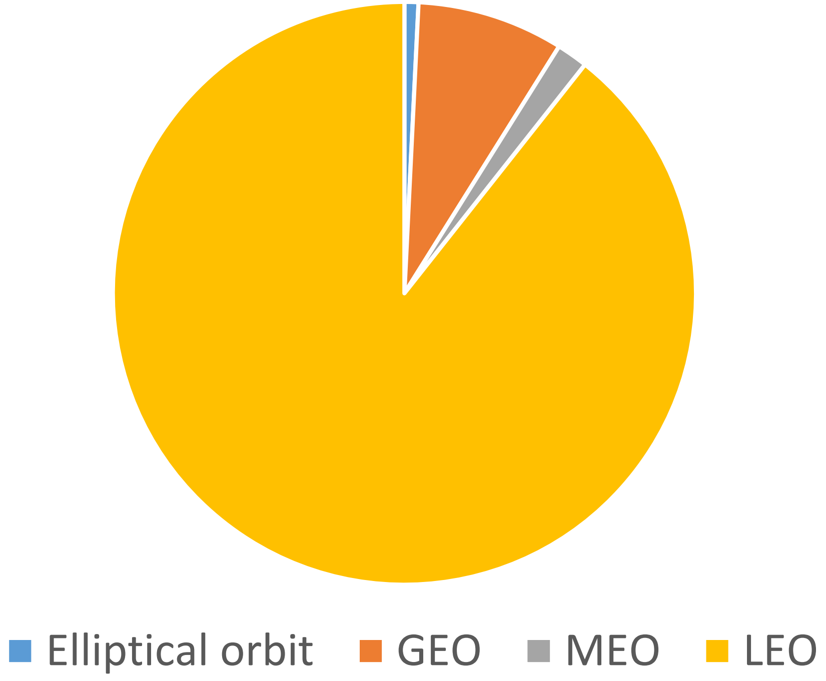
Market – Space – large increase in LEO satellites

1439 Satellites distribution by Orbit 2016



7623 Satellite distribution by Orbit 2025 Projections*



Projections are based on FCC approval given to SpaceX for up to 12000 satellites and on Oneweb, Telesat constellations projections.
ref: Pixalytics website, UCSUSA

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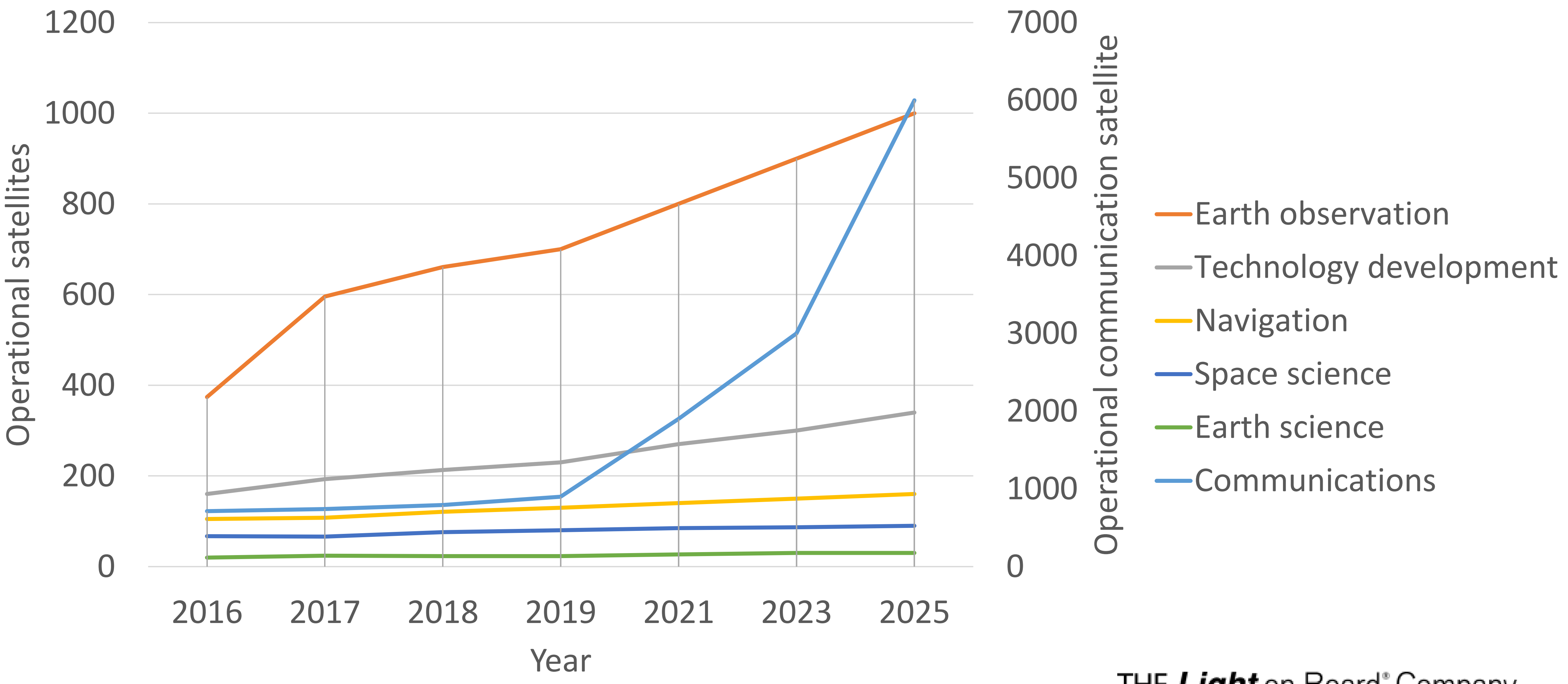
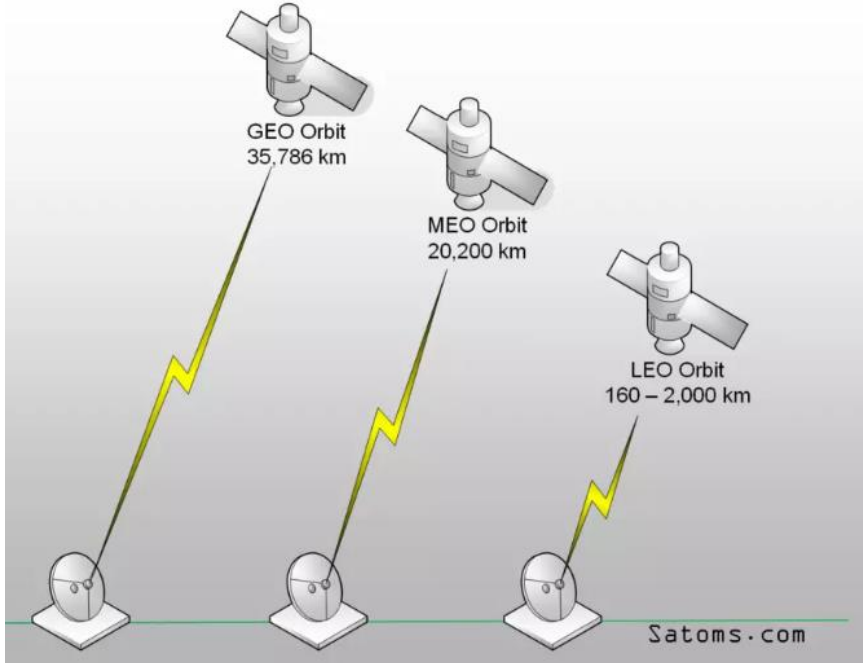
Market – Space – Communication satellites increase



Market – Space – LEO applications



Why are satellites set in LEO and VLEO?

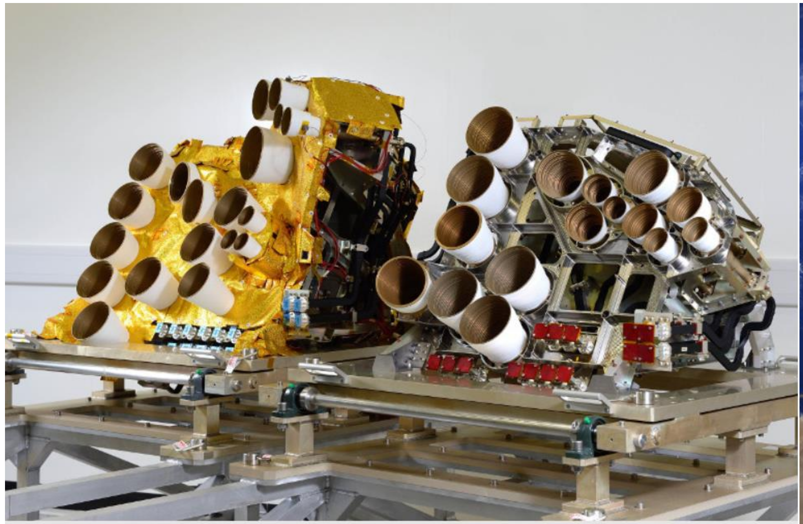
In order to offer low latency and compete with earth fibered network.

Why do we need a large number of satellite or constellations?

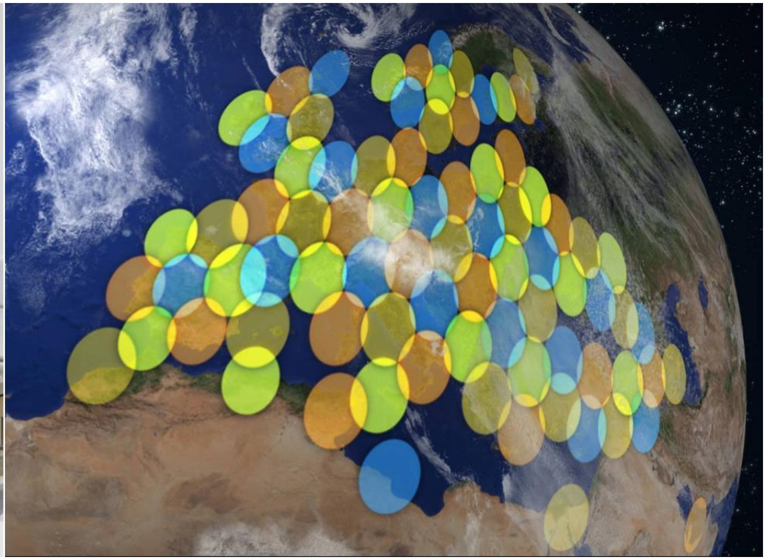
To offer a global coverage and a low latency. since LEOs are closer to Earth, they cover less territory because of the limited field of view from the antennas onboard each spacecraft.

Why the need for optical interconnect?
Optical interconnect helps lowering the weight of every satellite which help reducing the launching price and the resulting price per bit for satellite operator.

Market – Space – GEO applications



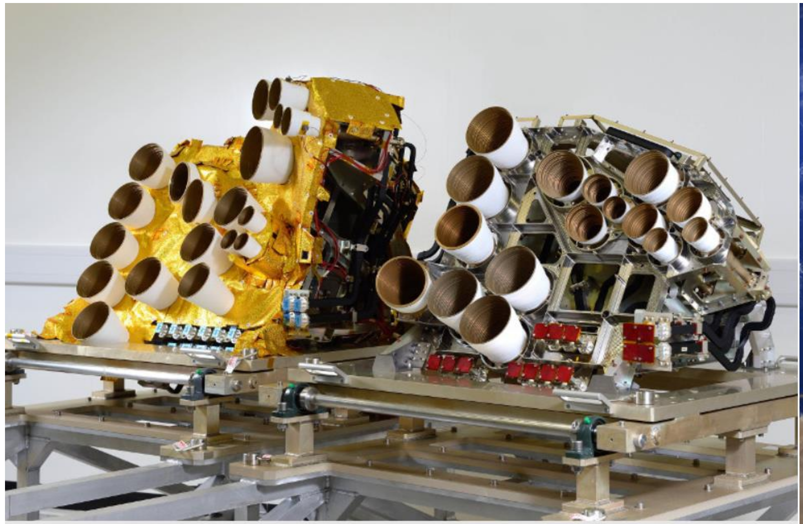
Airbus Defence & Space's new Large Multiple-spot Feed Array. Credit: AD&S



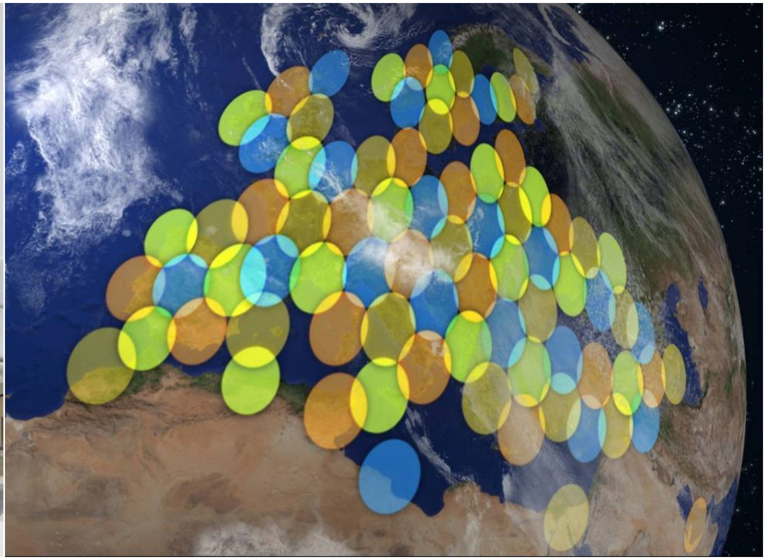
Why high-throughput geostationary communications satellite have higher data transfer rate then previous technologies?

- New multi-beam satellite can have around 200 K_a band spot-beams. Those multi-beam satellites have increased data lane that needs to be routed and can support higher baud rate given the fact that the transmission frequency is higher. This also has the benefit of reducing the price per bit.
- Information streams are directed from one beam to another inside a data processing switch.
- Data transfer rate through the switch increase by a very large amount as high throughput satellite deal with up to 100Gb/s which is more then 20 time standard data rate for Fixed-satellite service.
- Payload can be made more flexible if all the spot beam signals goes through switches. In order to mitigate the Ka band network loss of connectivity because of water absorption, data flow can get directed or supported by adjacent spot beam.
- It also means that the same payload can be <<repurposed>> more easily from one client application to another client application thus given a faster ROI to payload developper and enabling more economical solution for satellite operator

Market – Space – GEO applications



Airbus Defence & Space's new Large Multiple-spot Feed Array. Credit: AD&S



Why optical interconnect are needed inside high-throughput geostationary communications satellite?

- Optical interconnect solutions reduce the impact on payload weight and harnessing complexity.
- Optical interconnect makes High-throughput Multibeam Ka band satellite a cost-effective solution.

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GEO and LEO
Mission Requirements and Optical Transceivers Challenges

Market – LEO vs GEO – Use case analysis

Applications	
LEO constellation satellite	**GEO satellite**
Satellite-based internet (Lower latency than MEO and GEO)	High-throughput geostationary communication satellite
High number of satellite needed by constellation	15 years mission
Small satellite and shorter optical link, around 1−5 meter connection	Larger satellite, up to 15−meter optical link
Around 10 optical transceivers per satellite	Few hundreds optical transceivers per satellite
5−10 years mission	10−20 years mission
Redundancy (downtime permitted)	No redundancy (no downtime permitted)
TAM of approximately 5000−10000 optical transceivers per year over the next 5−10 years	**TAM of approximately 5000 optical transceivers per year over the next 5-10 years**

LEO vs GEO – distinct challenges for optical transceivers

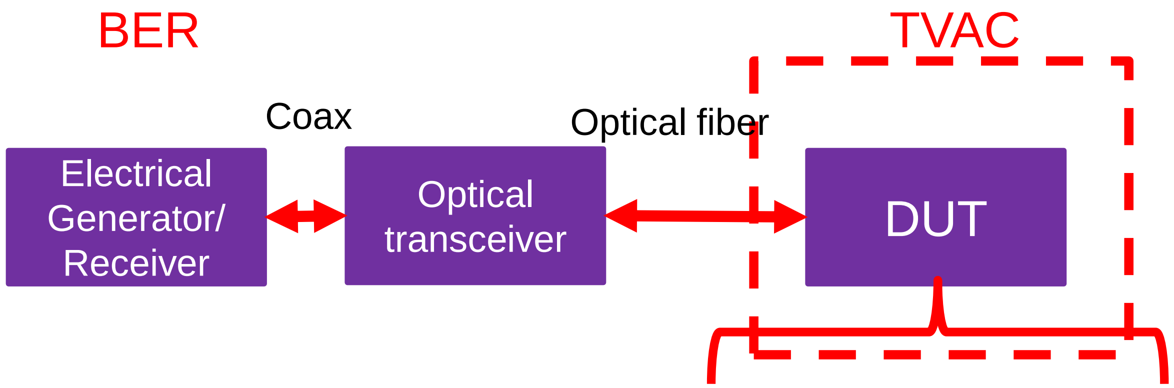
LEO constellation satellite (5−10 years mission from 500 to 2000 km)	GEO satellite (10−20 years at 35 000 km)
84 to 127 minutes orbit period leads to short period temperature cycles. (11 to 17 temperature cycles per day)	1 temperature cycle per day
Total ionizing dose up to 10 krads/year	Total ionizing dose up to 100 krads/year
Cost effectiveness	VCSELs optical power degradation over the whole mission
SEL*, SEB* that can permanently damage the electronics	SEU*, SEL*, SEB* risks
Downtime is permitted, constellation redundancy	Downtime is not permitted
Outgassing, operation under vacuum	

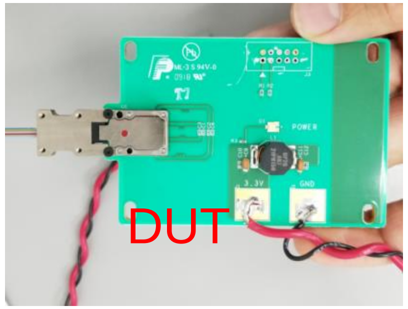
Single event phenomena can be classified into three effects (in order of permanency):
1. SEU: Single event upset (soft error); Bit flipping
2. SEL: Single event latchup (soft or hard error); High current
3. SEB: Single event burnout (hard failure); permanent physical damage

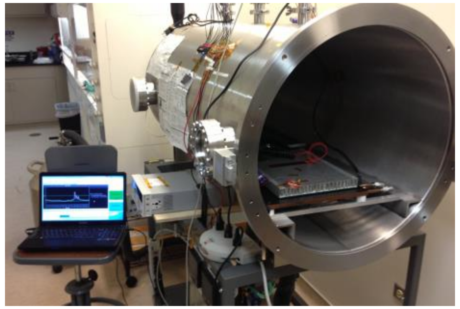
Optical transceivers
Space environment qualification tests

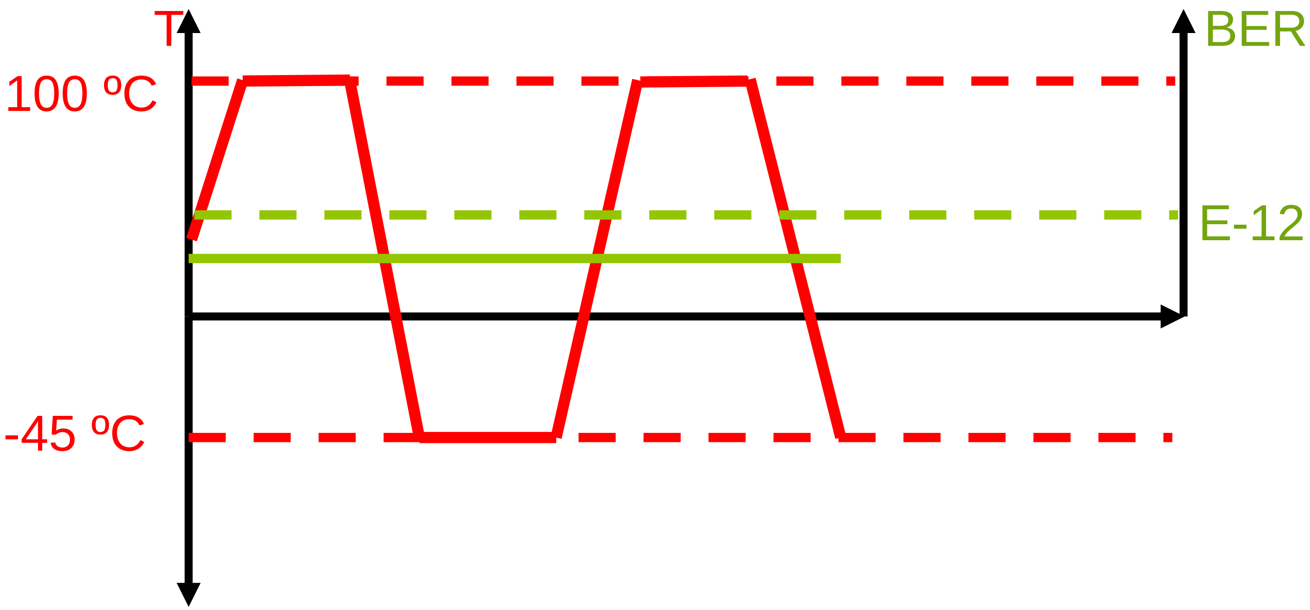
Thermal vacuum testing

- Simulate operation under vacuum.
- Simulate temperature cycling.
- Monitor BER during the cycles.
- Pressure: $5*10^{-5}$hPa
  (approx. $1*10^{-5}$ ounce/square inch).



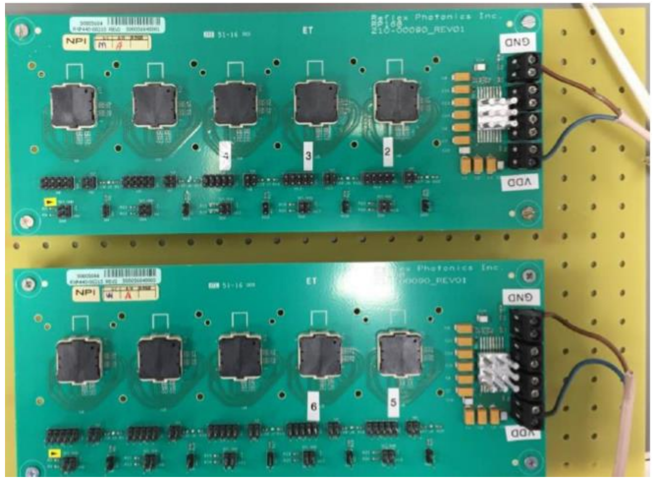






TID – Cobalt 60 tests

- Functional tests on devices before exposure.
- The Gamma-ray dosing rate is set at roughly 100 rad/h.
- The cumulative doses must aim for 100 krad.
- Thermal annealing
- Functional tests on devices after exposure.

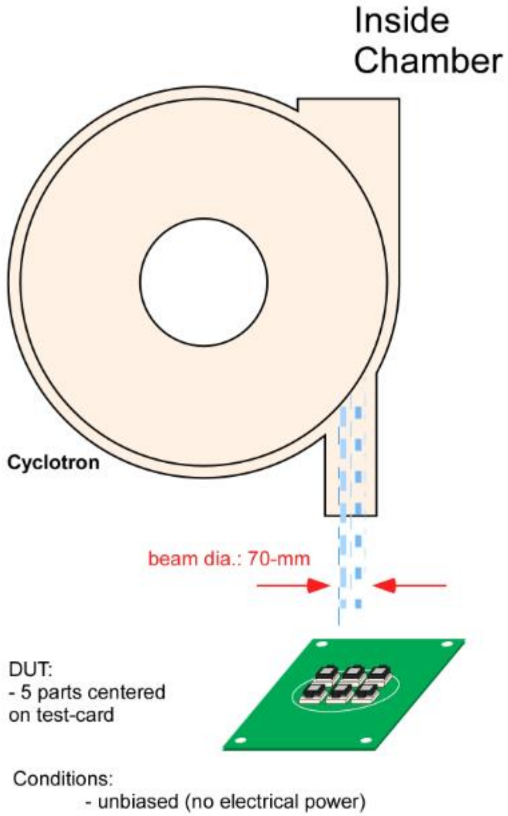


PCB to support the powered optical transceivers

University of Saskatchewan

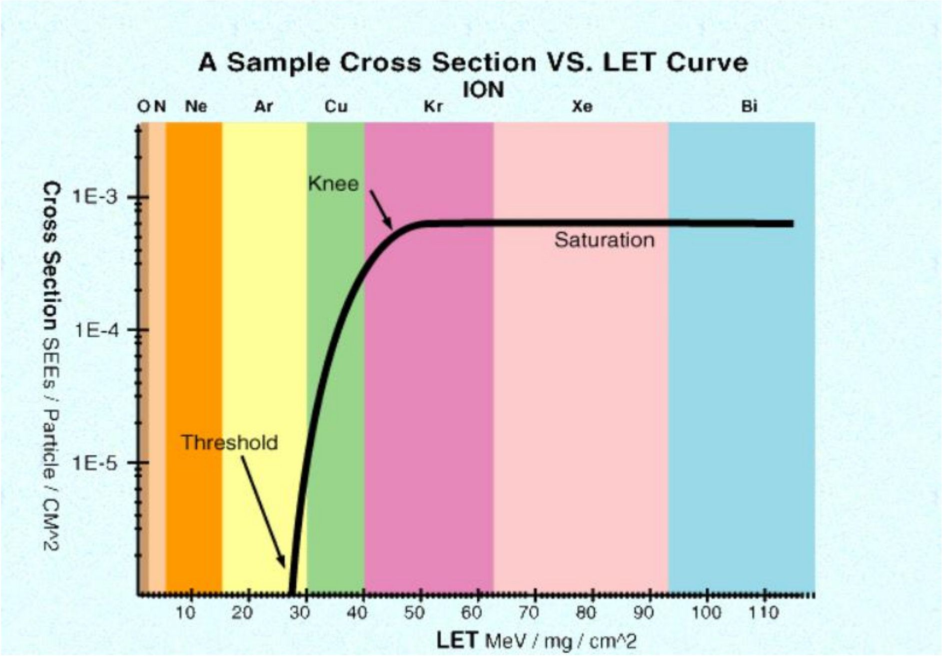
TNID – Proton tests

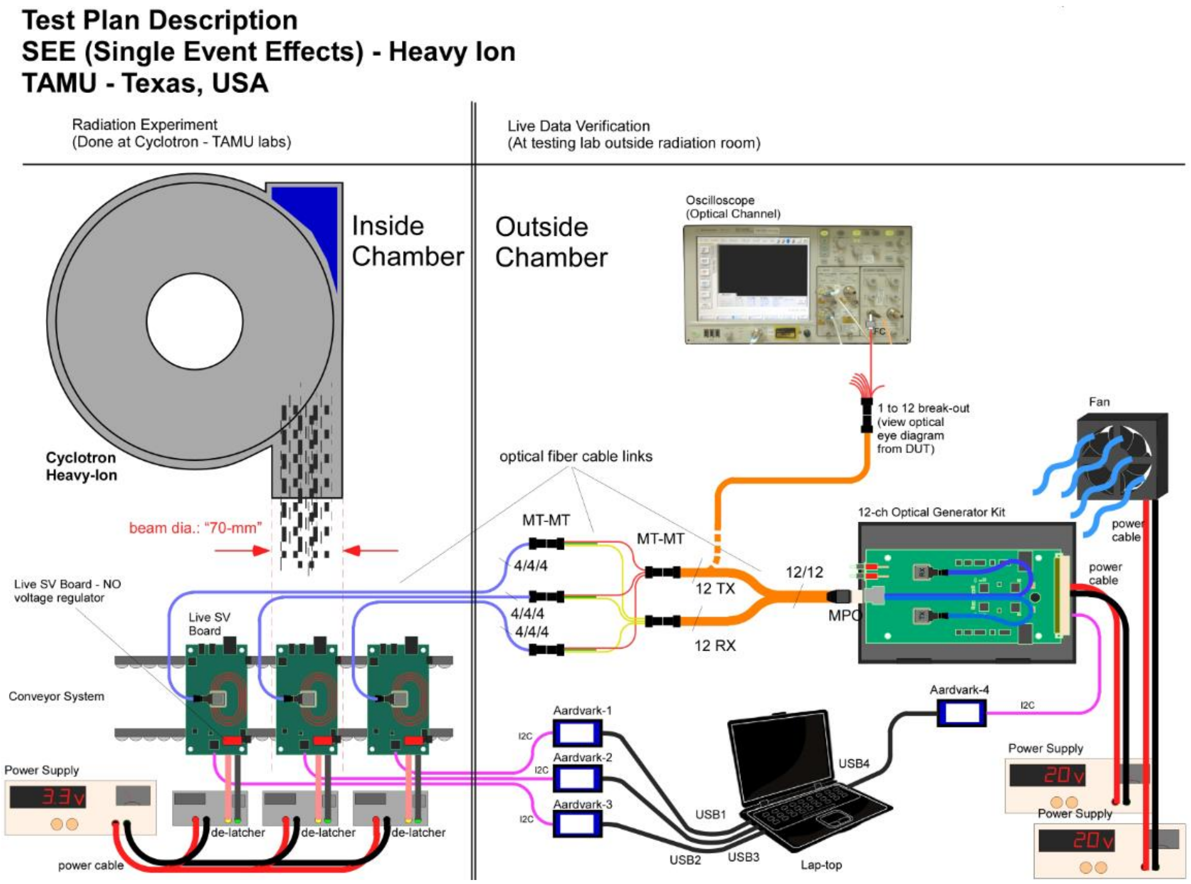
- Functional tests: BER.
- 100 MeV proton energy beam in 70-mm diameter.
- 168 h at 100 ºC post annealing step.
- Functional tests after exposure.



Heavy-ion tests

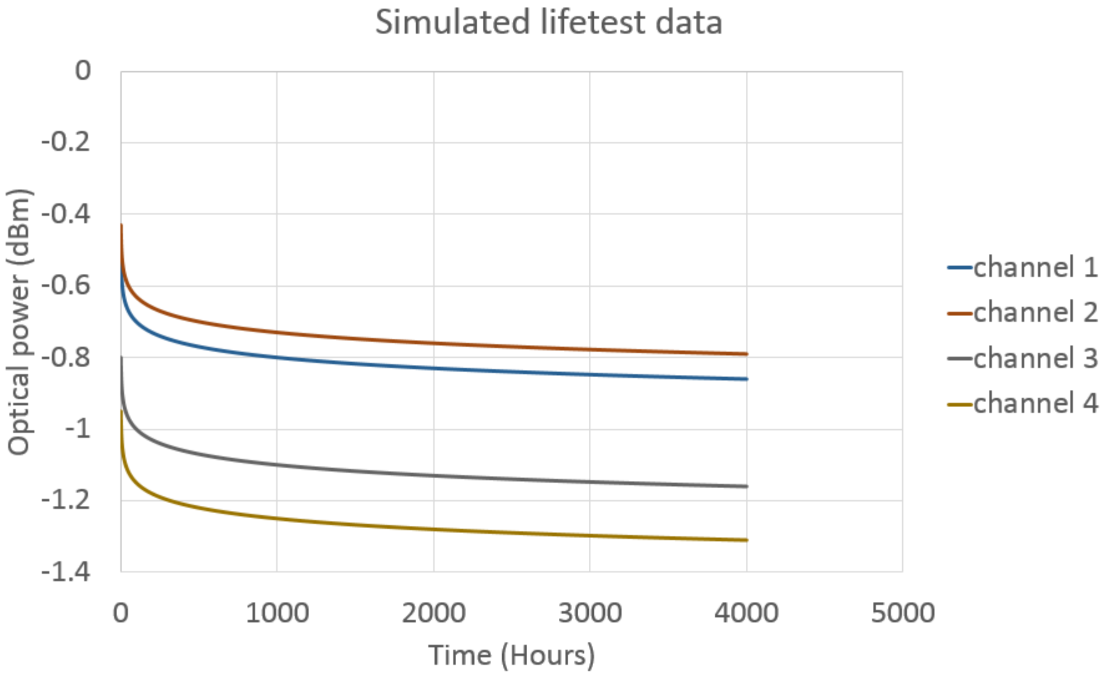
- Active DUT.
- Running BER tests and analyzing the number of events during radiation.
- Measuring the LET threshold.
- Measuring the Error saturation level.





Lifetime tests

- Goal: Validate budget link over the whole mission.
- Tests: Accelerated lifetime at 100 ºC optical transceiver case temperature and 9mA VCSELs bias.
- >15 years optical link reliability based on Eyring model prediction.



The final frontier

Indeed, the insatiable human need for better and faster information will continue to drive the need for improved communication system for many years to come.

The Multibeam GEO satellites and the LEO constellations will improve all the nations connectivity and give a better global coverage.

Indeed, improved processors and systems that can scale-up require interconnect solutions that can also scale-up.

Optical interconnect is speeding humanity technological progress toward the final frontier...

References

- *High-throughput optical inter-board interconnects for next-generation on-board digital transparent processors.* N. Venet, M. Sotom, H. Gachon, V. Foucal, M. Pez, V. Heikkinen, T. Tuominen, S. Pantoja
- *Facilities and Radiation Test Methods*, Ari Virtanen 1,1 University of Jyväskylä, Finland
- *Proton Test Guideline Development*, Stephen Buchner, Paul Marshall, Scott Kniffin and Ken LaBel NASA/Goddard Space Flight Center

Backup

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Thank you!

The significant increase in capacity is achieved by a high level frequency re-use and spot beam technology which enables frequency re-use across multiple narrowly focused[1] spot beams (usually in the order of 100s of kilometers),[1] as in cellular networks, which both are defining technical features of high-throughput satellites. By contrast traditional satellite technology utilizes a broad single beam (usually in the order of 1000s of kilometers)[1] to cover wide regions or even entire continents.[1] In addition to a large amount of bandwidth capacity HTS are defined by the fact that they often, but not solely, target the consumer market.[6] In the last 10 years, the majority of high-throughput satellites operated in the K_a band, however this is not a defining criterion, and at the beginning of 2017 there was at least 10 K_u band HTS satellites projects, of which 3 were already launched and 7 were in construction.

Despite the higher costs associated with spot beam technology, the overall cost per circuit is considerably lower as compared to shaped beam technology.[1] While K_u band FSS bandwidth can cost well over $100 million per gigabit per second in space, HTS like ViaSat-1 can supply a gigabit of throughput in space for less than $3 million.[6] While a reduced cost per bit is often cited as a substantial advantage of high-throughput satellites, the lowest cost per bit is not always the main driver behind the design of an HTS system, depending on the industry it will be serving.[7]

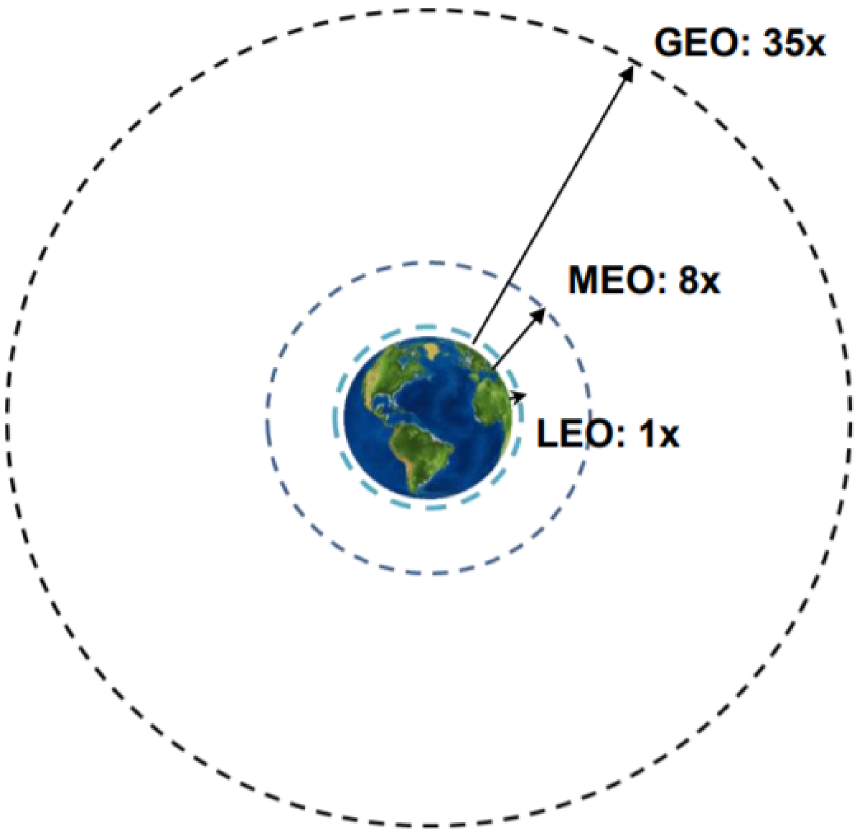
HTS are primarily deployed to provide broadband Internet access service (point-to-point) to regions unserved or underserved by terrestrial technologies where they can deliver services comparable to terrestrial services in terms of pricing and bandwidth. While many current HTS platforms were designed to serve the consumer broadband market, some are also offering services to government and enterprise markets, as well as to terrestrial cellular network operators who face growing demand for broadband backhaul to rural cell sites. For cellular backhaul, the reduced cost per bit of many HTS platforms creates a significantly more favorable economic model for wireless operators to use satellite for cellular voice and data backhaul. Some HTS platforms are designed primarily for the enterprise, telecom or maritime sectors. HTS can furthermore support point-to-multipoint applications and even broadcast services such as DTH distribution to relatively small geographic areas served by a single spot beam.

A fundamental difference between HTS satellites is the fact that certain HTS are linked to ground infrastructure through a feeder link using a regional spot beam dictating the location of possible teleports while other HTS satellites allow the use of any spot beam for the location of the teleports. In the latter case, the teleports can be set up in a wider area as their spotbeams' footprints cover entire continents and regions like it is the case for traditional satellites .[8]

Industry analysts at Northern Sky Research believe that high-throughput satellites will supply at least 1.34 TB/s of capacity by 2020[8] and thus will be a driving power for the global satellite backhaul market which is expected to triple in value – jumping from the 2012 annual revenue of about US$800 million to $2.3 billion by 2021.[9]

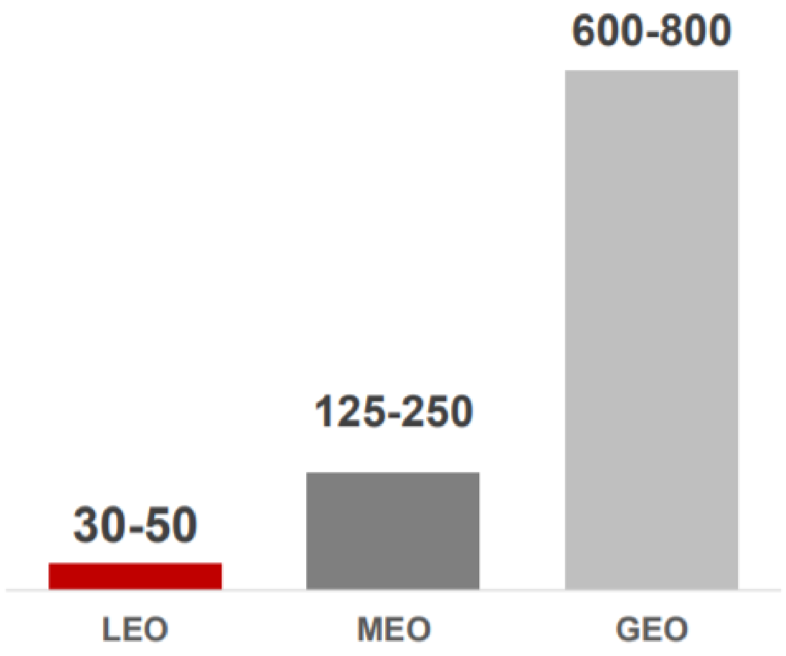
Relative distance of satellites from Earth

1x = 1,000 km



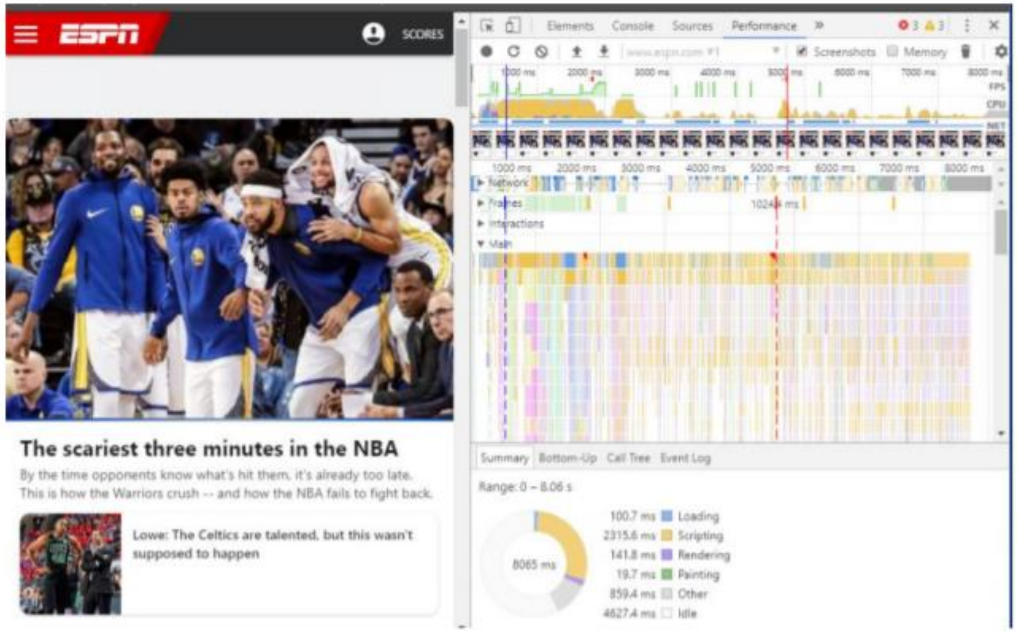
Round Trip Time

Milliseconds



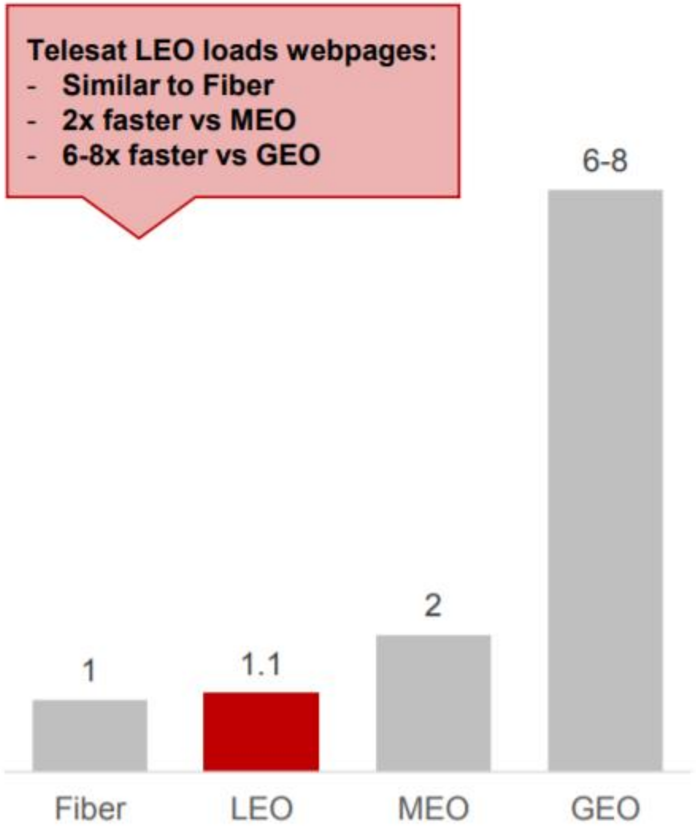
GEO = Geostationary orbit; MEO = Medium Earth Orbit, LEO = Low Earth Orbit

Faster web pages



Relative time to load website

Ratio vs Fiber load time



Tests conducted in Telesat simulation lab with latency setup based on a Caribbean location to Miami:
LEO=28-32 ms, MEO=150 ms, GEO=700 ms (no acceleration)
Each test repeated 5 times to record average results

Lifespan of LEO vs GEO, continued

- LEO costs ~$5000/kg to place in orbit, whereas GEO is still ~$30,000/kg
- Ironically, luni-solar orbital perturbations at GEO have till now had a very strong life limiting effect on GEO satellite lifetimes through the typical mission requirement to control the evolution of orbital inclination, though advances in propulsion technology are easing the limitations of propellant lifetimes.
- However, despite this, the basic premise of the question still holds, design lifetimes of commercial geostationary satellites have crept up from 7 to 15 years since the 1970s whilst those of, for example LEO remote sensing missions have evolved from 3 to 10, though I confess to being a little more shaky on the latter evolution.
- I think the reasons relate to the high level emergent behavior of the customers when faced with their own economic cycle of which I can only suggest some starting ideas:
- it costs more to get to GEO so the businesses of these satellites could be more sensitive to economies
- the functions of most GEO satellites for communications is electrical power intensive, thus mass and launch cost enhancing, thus reinforcing the benefit of longer life to maximize the return on capital
- Some features of LEO, such as ~15 eclipses per day, may have been technically demanding in terms of electrical and thermal stress.

Lifespan of LEO vs GEO, continued

- For LEO satellites, their death tends to be due to poor batteries. The batteries are very stressed due to the constant use that they require. GEO satellites tend to end their lives when the fuel runs out. Fuel requirements are usually easier than batteries.
- LEO satellites tend to require a constellation to work effective. The redundancy in many ways is that there are usually other satellites in orbit that can "pick up the slack" if one of them fails. GEO satellites tend to require being in a specific location, Bottom line is, LEO satellites are built smaller, cheaper, and with lower lifetimes, and have more battery stress than GEO satellites.
- and cannot support that kind of redundancy.

Lifespan of LEO vs GEO, continued

At this altitude, there are atmospheric molecules present, leading to increased drag that translates to orbital decay (more so during solar maxima, due to the expansion of gases in the atmosphere). Hence, these LEO orbited satellites need to be constantly reboosted to overcome this drag, otherwise their orbital velocity decreases, and they spiral into the lower atmosphere.

Meanwhile, the geostationary orbit is a circular orbit 35,786 kilometres (22,236 mi) above the Earth's equator, and the atmospheric drag is comparatively smaller at these heights.

So, in a nutshell, the difference in atmospheric drag is the main reason for longer orbital lifetime of GEO orbited satellites, than LEO orbited satellites.

Market – Space – LEO applications Requirement summary

LEO Applications	
Requirement	**Reflex offer**
Lifetime around 5-7 years	Standard lifetime up to 10 years
Low cost	Standard lifetime SpaceABLE are price competitive compare to Ultra communication or Radiall devices
High IO count	The upcoming SpaceABLE 12TRX and SpaceABLE28 offers high communication density.
Low power consumption	<100 mW per lane consumption on 10G SpaceABLE and < 130 mW per lane on 28G devices.
A certain level of radiation immunity (not critical)	Standard chipset (LEO) inherited from the same family of devices that is used on the extended lifetime (GEO) chipset.

Market – Space – GEO applications Requirement summary

GEO Applications	
Requirement	**Reflex offer**
Lifetime up to 20 years (15 year mission)	Extended lifetime chipsets (up to 20 years)
High IO count	The upcoming *Space*ABLE 12TRX and *Space*ABLE28 offers high communication density.
Low power consumption	<100 mW per lane consumption on 10G *Space*ABLE and <130 mW per lane on 28G devices.
TID (GEO application needs >100 krad (Si))	Cobalt60 electron source dose up to 100 krad (Si)
TNID	Heavy ion tested up to LET (linear energy threshold) of 79.2 MeV/cm^2/mg,
Protons	100 MeV proton of up to 5^{e12} p/cm^2 fluence

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Market	SPACE	MILITARY	AVIONIC/INDUSTRIAL	COMPUTER
Embedded Line	***Space*****ABLE SM, *****Space*****ABLE LL *****Space*****CONEX SC**	***Light*****ABLE LM, *****Light*****ABLE LL, *****Light*****CONEX**	***Light*****VISION VM**	***Light*****MATRIX MM (In development)**
	SM,SL,SC	LM,LL,LC	VM	MM
Case Operation Temperature	-40 to 100C	-40 to 100C	-40 to 85C,0 to 70C	0 to 70C
Sensitivity	Up to -9 dBm	Up to -12 dBm	Up to -9 dBm	Up to -9 dBm
Budget link	Up to x dBm	Up to x dBm	Up to x dBm	Up to x dBm
Qualification	ECSS	MIL	Industrial	GR468
Radiation resistant	Yes	No	No	No
Thermal shock qualified	Yes	Yes	No	No
Random Vibration qualified	26G random	26G random	20G sinusoidal	No
Mechanical shock qualified	40G	40G	26G	No
Damp heat qualified	85% 85C, (Long period)	85% 85C, (Long period)	No	No
Encapsulation	Yes	Yes	No	No
Optical interface	Microclip, screw-in, pigtail	Microclip, screw-in, pigtail	*Light*SNAP™ MPO	MPO
Electrical interface	SMT, MegArray, LGA	SMT, MegArray, LGA	LGA	MegArray
Coupling technology	Glass and polycrystalline	Glass and polycrystalline	Glass and polycrystalline	Plastic coupler
Application vehicle	Spacecraft, Communication satellite, radiation intensive environment	Jet fighters and naval Phase array radar, guided missiles.	Backend server, Ground application, HPC, test platform, controlled environment, IFEC	HPC, Backend server
Reflowable option	Yes	Yes	No	No
Storage temperature	-55 to 127	-55 to 127	-55 to 105	-55 to 105

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New datasheet available

LL, LC 28 Gbps per lane

Data Sheet

*Light*ABLE28™ 4TRX Parallel Optical Engine

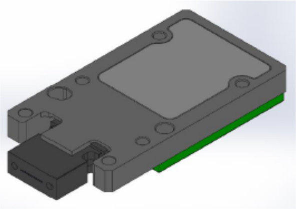


Figure 1: LL 28G 4TRX Parallel Optical Engine (POE)

Product Summary

The Reflex Photonics *Light*ABLE28™ 4TRX includes 4 optical transmit channels and 4 optical receive channels. The electrical interfaces are based on CML logic levels and support data rates per channel of up to 28.05-Gbps (a total bandwidth over 100-Gbps full duplex).

The module integrates an industry standard 1x12 MT optical interface using the QSFP28 compatible (4-Tx/4-n.c./4-Rx) channel configuration.

The low-profile screw-in module (4.5 mm) mounts to the board via an LGA connector which is available in different heights.

The modules contain preprogrammed internal microcontrollers for configuration – only power and high-speed signalling is required.

Qualification

MIL-STD-883:

- ✓ Vibration tests. Method 2007.3
- ✓ Mech., shock tests, Method 2002.4
- ✓ Thermal shock tests, Method 1011.9
- ✓ Thermal cycling tests, Method 1010.8

MIL-STD-202:

- ✓ Damp heat tests, Method 103B

MIL-STD-810:

- ✓ Cold storage tests, Method 502.5

Summary Specifications

- ✓ Industrial Temp. -40°C to 85°C
- ✓ Sensitivity up to -9 dBm
- ✓ Up to 28.05 Gbps per channel
- ✓ Short-Reach 850-nm VCSELs
- ✓ Standard 1x12 MT optical interface
- ✓ 4 Differential CML Inputs
- ✓ 4 Differential CML Outputs
- ✓ LGA electrical interface
- ✓ Link Distance up to 100-m (OM3 fiber)
- ✓ Asynchronous channel operation
- ✓ Data protocol agnostic, balanced code

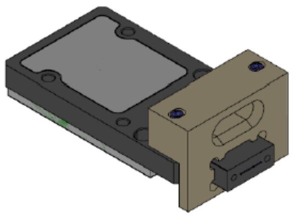
Application

The LL 28G 4TRX module targets following applications:

- ✓ Phased array radar
- ✓ CCD/CMOS imaging sensor
- ✓ Data intensive applications

Data Sheet

*Light*CONEX28™ 4TRX Parallel Optical Engine



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- ✓ 4 Differential CML Inputs
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- ✓ Link Distance up to 100-m (OM3 fiber)
- ✓ Two-wire Serial Control Interface
- ✓ Asynchronous channel operation
- ✓ Data protocol agnostic, balanced code

Application

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- ✓ Phased array radar
- ✓ CCD/CMOS imaging sensor
- ✓ Data intensive applications