A Cost Effective Ultra-High Throughput Space Based Optical Link

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INTRODUCTION

With the new satellite constellations, Fast Optical Intersatellite Link is needed (100 Gbps)

- GEO-LEO (up 40,000 km) or GEO-GEO (up to 80,000km)

LEO-LEO and LEO-Ground line-of-sight time is limited

GEO-Ground visibility angle is almost 180˚

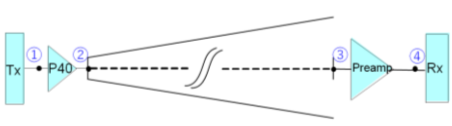
METHODS

Space Optical Links are based on high power Erbium-Ytterbium amplifiers or lasers in the 1.5 µm range

Three main architectures are being proposed

- (1λ x10W x100Gbps) One laser transmitter at high power (10W) Commonly suggested as the most direct method
- (10λ x1W x10Gbps) 10 Lasers x1W at 10 Gbps Much easier technically but with a high cost of the optical cross connection
- Induce artificial well controlled Delay in time during the transmission (Add/Drop Optical Cross Connection) Needs a high level of developed software along with very fast electronic-not considered in this project

- The **optical link budget (dB)** is the first main parameter to compare the two first options:
- It permits to calculate the needed power of an amplifier at the transmitter, to reach a high speed transmission considering :
- the telescope sizes (transmitter and receiver)
- the distances
- the interfacing efficiencies
- the number of photons/bit (or symbol) at the receiver



Simplified schematic of an Optical Intersatellite Link (OISL)

① Transceiver Transmitter Output (Tx) – input to MPB Amplifier-Booster (P40)

② MPB Amplifier-Booster Output into Free Space (1W to 10W optical output at 1550 nm is needed)

③ MPB Preamp –Low Noise Amplifier Input from Free Space, for very low signal down to -48 dBm

④ MPB Preamp Output – Input to Transceiver Receiver (via Optical Band-Passing filter)

To evaluate the link budget we consider:

A) Power related parameters

- Bit/Symbol -depends on the modulation used OOK(1), DPSK (1), DP-QPSK (4), DQPSK (2)
- Number of photons/symbol received at the next relay point ③
- Transmitter electrical power/symbol (mWe/Gbps) (Wall plug efficiency) at ③
- Transmitter Optical signal power (dBm) at ③ (e.g. -28 dBm)
- Optical Signal to Noise Ratio (OSNR) at ④ (e.g.12 dB)
- Total electrical power/symbol (mWe/Gbps) at ④
- Bit(Symbol) Error Rate (BER/SER), it depends on the modulation type and rate

B) Other parameters

- Redundancy
- Optical Cross Connection (case of 10λ x10Gbps)
- Stimulated Brillouin Scattering (at high power: 10 W)
- Size, Weight and Power (SWaP)
- Reliability – Failure In Time (FIT)
- Compatibility with space environment (outgassing, thermal vacuum cycling, radiation)

Link Budget Equation

$$P_R = P_T G_T \eta_T \eta_{ATM} L_{FS} L_p L_{SI} G_R \eta_R \eta_C$$

P_R is the received optical power, detected at distance L

P_T is the transmitted average optical power at wavelength λ

$G_T = (\pi D_T/\lambda)^2$ and $G_R = (\pi D_R/\lambda)^2$ are the transmitter and receiver gains, respectively (D_T and D_R are their telescope diameters)

η_T , η_R and η_C are transmitter, receiver and fiber coupling efficiencies, respectively,

η_{ATM} is the atmospheric attenuation in the case Satellite Ground or Ground-Satellite;

$L_{FS} = (\lambda/4\pi L)^2$ is the free-space loss., L is the distance Transmitter-Receiver

$L_p = \exp(-G_T\theta^2_{BW})$ corresponds to the pointing errors, θ_{Bw} is the pointing jitter

L_{SI} is the scintillation-induced error

- The optical link budget contains very large losses due to the distances in the order 260 to 290 dB in LEO and GEO
- In first verification we compared our code results with those obtained by the International Optical Link Study Group (OLSG)
- NASA had performed studies, evaluating the Maximum Data Rate Achievable and Power Requirements for three cases of optical links: Relay to Ground (35,790 km), LEO-GEO (42,880 km), and GEO-GEO (73,000 km). For each link three levels of transmitter power were considered; 0.5W, 1 or 2.5W, and 5 W (1550 nm). Four sets of transmitter and receiver telescopes were considered for each study, their diameters were selected based on previous or proposed telescopes for NASA missions. The 100 Gbps was possible for the LEO-GEO only with the set of largest telescopes, and the highest transmission was 55 Gbps (5W transmitter) for the GEO-GEO Link. The studies show the need for a higher power (10W) transmitter to have a reliable 100 Gbps at LEO-GEO or GEO-GEO link
- At DLR (Barrios et al; Giggenbach et al.) estimated the BER for the EDRS connection

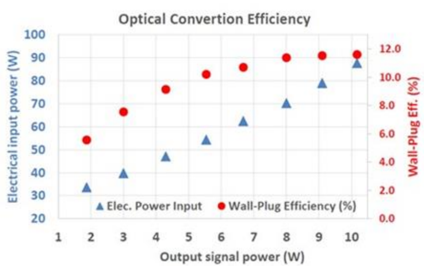
Option (1λ x10W x100Gbps)

The losses in space are simulated experimentally using different Variable Optical Attenuators (VOA)

Diagram: **Transceiver-Output (0-1 dBm) => MPBC 10W Amplifier => VOA(s) => MPBC Low-Noise-Amplifier => Input-Transceiver**

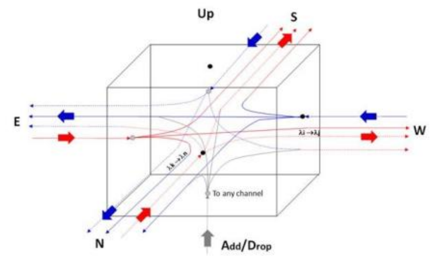
The demonstrator with the 100 Gbps transceiver is being built in collaboration with the supplier. This product is still in the prototype stage, MPB will perform its space qualification during the collaboration.

Picture of the 10W (1552 nm) three-stage Erbium-Ytterbium-doped Fiber Amplifier built and being qualified for space at MPB

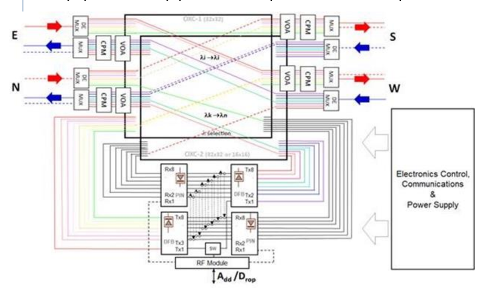


Wall-plug Power conversion efficiency of the (1552nm) output power. Blue points are electrical input and red points are wall-plug efficiency

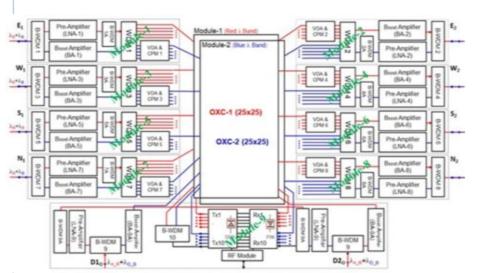
Option (10λ x1W x10Gbps)



Space Reconfigurable Optical Add-Drop Multiplexer (ROADM) Design - 4 satellites each in one direction noted East (E), South (S), West (W), and North (N), with a fifth option to the Add/Drop to Ground



Space ROADM Design- Connection of the channels (wavelengths)



Space ROADM Design- Summary of Electronics and Optical components

High cost of Cross connection of 10 Transmitters at 1W (10λx10Gbps), leads to reduce to 2x2 demonstrator to verify the technology and compare the results to available satellite data at close rate

Diagram:

2x 10GbpsTransceivers-Output (0-1 dBm) => 2xMPBC 1W Amplifier => VOA(s) => 2x2 SWITCH => MPBC Low-Noise-Amplifier => Input- 2x 10 Gbps Transceivers

Preliminary Comparison

Parameter	1λx 10Wx100Gbps	10λ x 1Wx 10Gbps
Redundancy	Only one transmitter	10 transmitters, if one fails the others continue to be functional
Bit /Symbol Error Rate	Lower	Higher
Modulation techniques	Simple techniques are convenient in most applications	Complex techniques with increased bit/symbol are needed
Max Distance	More convenient as distance increase e.g. for GEO-GEO 73,000km	Less convenient as the distance increases LEO-LEO and some LEO-GEO
Other application than OISL	Lidar (CO2), Ranging, 3D-Imaging, Altimetry, Topology,	MxN intra-satellite optical link (e.g. Optical Microwave cross-connection
Space qualification status	To complete the space qualification of the 10W transmitter Space qualify the 100 Gbps transceiver	We can find suppliers of space-qualified components included in the demonstrator

REFERENCES

Please see the conference paper associated to this poster it contains more complete information.