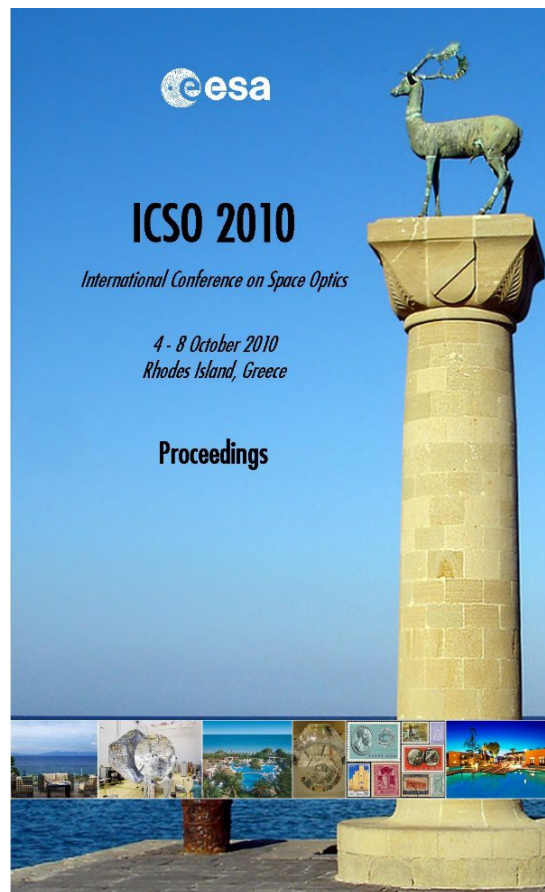


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## ***Innovative on board payload optical architecture for high throughput satellites***

*D. Baudet, B. Braux, O. Prieur, R. Hughes, et al.*



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## INNOVATIVE ON BOARD PAYLOAD OPTICAL ARCHITECTURE FOR HIGH THROUGHPUT SATELLITES

D. Baudet<sup>1</sup>, B. Braux<sup>1</sup>, O. Prieur<sup>1</sup>, R. Hughes<sup>2</sup>, M. Wilkinson<sup>2</sup>, K. Latunde-Dada<sup>2</sup>, J. Jahns<sup>3</sup>, U. Lohmann<sup>3</sup>, D. Fey<sup>4</sup>, N. Karafolas<sup>5</sup>

<sup>1</sup> Astrium SAS, France, <sup>2</sup> Astrium Ltd., UK, <sup>3</sup> University of Hagen, Germany, <sup>4</sup> University of Erlangen-Nürnberg, Germany, <sup>5</sup> ESA/ESTEC, Netherlands

### I. INTRODUCTION

For the next generation of HighThroughPut (HTP) Telecommunications Satellites, space end users' needs will result in higher link speeds and an increase in the number of channels; up to 512 channels running at 10Gbits/s. By keeping electrical interconnections based on copper, the constraints in term of power dissipation, number of electrical wires and signal integrity will become too demanding. The replacement of the electrical links by optical links is the most adapted solution as it provides high speed links with low power consumption and no EMC/EMI.

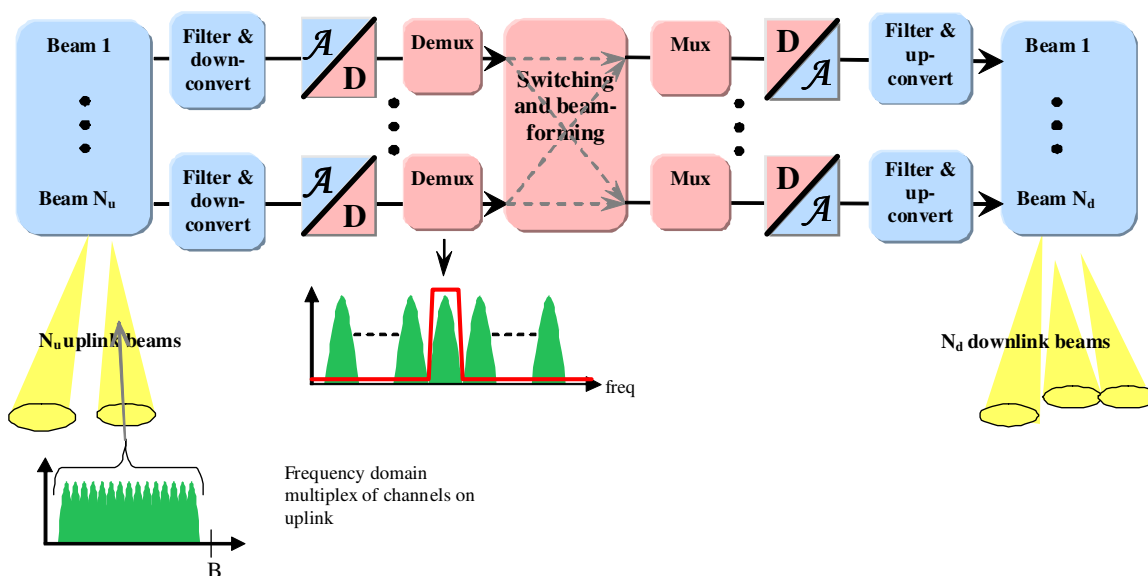
But replacing all electrical links by optical links of an On Board Payload (OBP) is challenging. It is not simply a matter of replacing electrical components with optical but rather the whole concept and architecture have to be rethought to achieve a high reliability and high performance optical solution. In this context, this paper will present the concept of an Innovative OBP Optical Architecture.

The optical architecture was defined to meet the critical requirements of the application: signal speed, number of channels, space reliability, power dissipation, optical signals crossing and components availability. The resulting architecture is challenging and the need for new developments is highlighted. But this innovative optically interconnected architecture will substantially outperform standard electrical ones.

### II. OPTICAL ARCHITECTURE CONCEPT AND PRELIMINARY DESIGN

#### A. High Throughput Satellites Standard Architecture

The current drivers behind the development of technology for high capacity telecomms satellites are transparent routers. The term "transparent" means that the processors do not de-modulate the data they receive, instead they perform fine granularity switching, routing and beamforming operations to direct each channel on the uplink to its intended location on the downlink. The work presented in this paper focuses on the router part of this architecture which means the Demux, Switching, Beamforming and Multiplexing functions showed in the typical block diagram Fig.1.



**Fig. 1.** Transparent processed payload functional block diagram

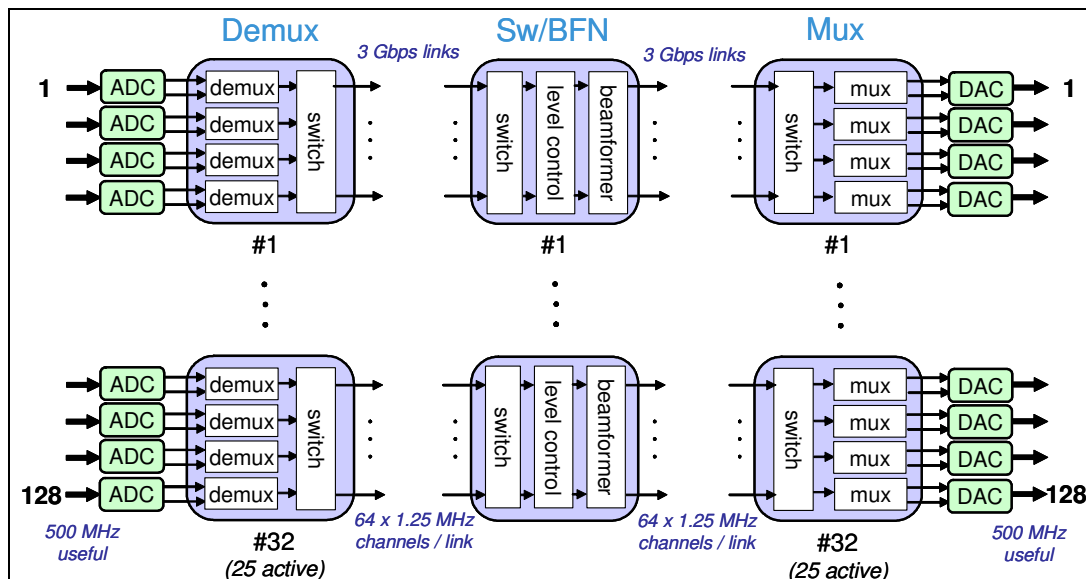


Fig. 2. Transparent processed payload functional block diagram

The next generation of high capacity telecoms satellites is represented by the High Throughput concept, which is a fully-processed transparent payload architecture that has been carefully optimised as part of an ESA R&D contract to maximise the capacity of a single satellite. This system is based on a three stages switch network with chip to chip High Speed Serial Links (HSSL) electronic interconnect. The next generation of ASICs (Demux, Mux, Beamforming), available for such projects will have HSSLs running at approximately 3Gbps. This future HighThroughPut Satellite architecture presented in Fig.2 will be considered as the State of the Art and used as an entry point for the definition of the innovative optical architecture. One difficult point of this kind of switch network is the large number of crossovers in the interconnect between one rank of ASICs and the next.

Due to all the constraints for introducing a new space qualified technology, an important step in term of performances and benefits must be proven. The major constraints identified for standard electrical links are power consumption due to the copper resistivity and the number of cabling as lower link speeds require more interconnections. At ground level, standard optical links can go easily at 10Gibts/s with low power consumption so optical interconnections have then the potential to cross this step.

### B. Optical Architecture Concept

First, it is considered that ADC/DAC links to ASICs will be optical links as previous ESA study showed the feasibility [1]. The second point taken into consideration is the use of optical links at 10Gbits/s with VCSEL and PIN diodes. These components are already well mature for ground applications and proven their flight worthiness for space applications. Comparatively to the Electrical Architecture presented in Fig.2, the use of 10Gbits/s optical links instead of 3 Gbits/s electrical links allows to reduce the number of 32 ASIC per column to 16 ASICs per column which is already a large gain.

The principal bottleneck identified is the power dissipation of the ASICs estimated to 20W. Following Astrium experience on the previous satellites generation it will not be possible to dissipate this much heat using 'traditional' methods i.e. direct conduction of the heat through conventional PCB materials to an outside wall of the spacecraft. A solution based on assembly of ASICs on ceramic MCM (MultiChipModule) was then selected. The second important point was to have as baseline packaging a modular and flexible architecture. The modules are ASICs (1 or more) packaged in MCMs and the modules are connected to one another using optical interconnection. The system's ADCs and DACs, and power supply shall be packaged in their own modules and be connected separately to the MCMs.

For MCM to MCM interconnection, two solutions were envisaged. The first was to make all connections point to point by single optical fiber. And the second one is to use an "optical backplane" to make the crossing and routing of numerous optical signals. As all the MCMs must be linked one to the other, the second solution was chosen to reduce the number of cabling operations. Optical PCBs with polymer embedded waveguides are not enough mature to be used for space applications. So to perform the function of optical backplane an optical flex

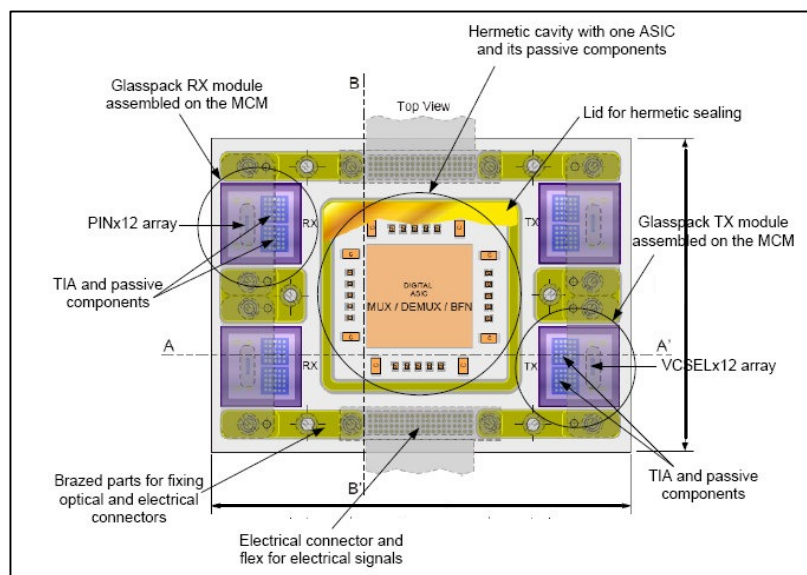
solution is envisaged. The possibility to use Planar Integrated Free Space Optics (PIFSO) technology from Hagen University is also investigated but not presented in this paper.

### C. Optical MCM Preliminary Design

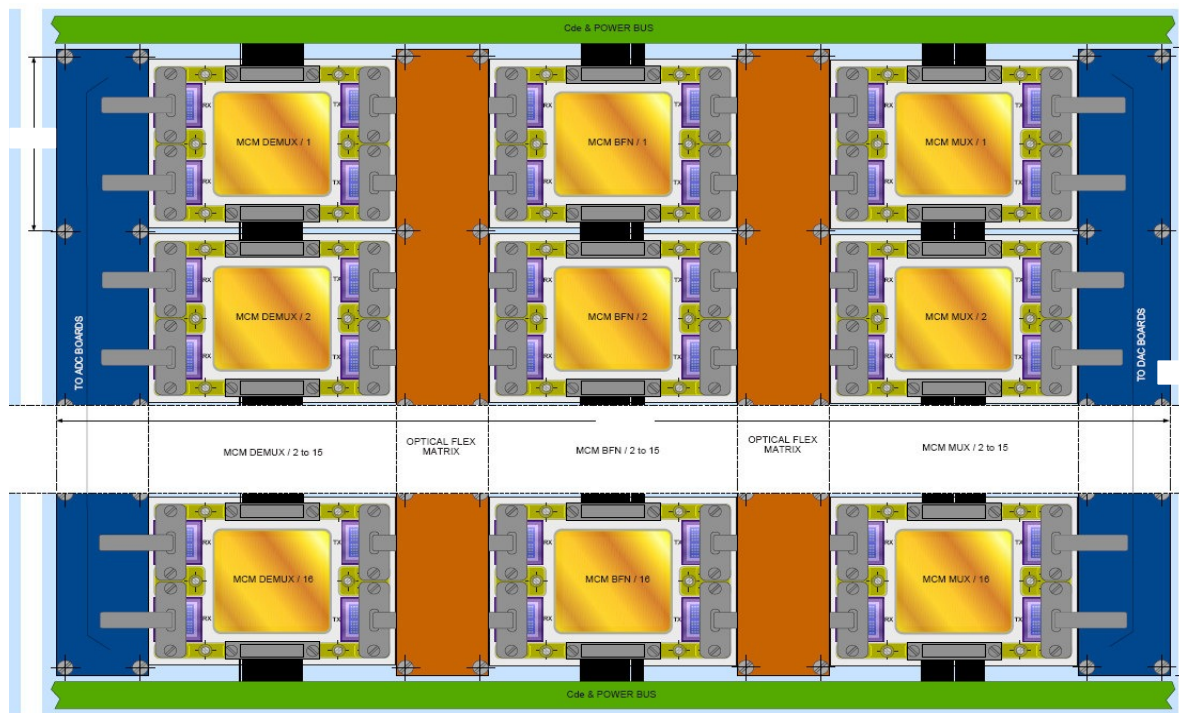
The architecture is based on ceramic MCMs linked together with optical interconnections. The Optical MCM will consist of: one ASIC (BFN, Mux or Demux) with its associated passive components, the optical transmitter/receiver modules (TX/RX) and the electrical connections for power, ground or control. The preliminary design of this MCM is presented in Fig. 3.

The ASIC in the form of bare die and its passives will be assembled in a hermetic cavity for space environment reliability.

The optical transmitter and receiver module needed should have: Space reliability (thermo-mechanical, radiation, thermal), hermeticity, high number of channels (at least 8), high speed channels at 10Gbits/s, compatible for assembly on ceramic MCM, optical connector for plugging/unplugging fibre bundles. Currently, there is no optical transmitter/receiver module on the market which fits perfectly to the application requirements. Various possible solutions have been identified from academic and commercial sources. But in each case some developments are needed to achieve all the requirements. So in the MCM design presented in Fig.4 , the optical TX/RX modules are a representation of what could be achieved in the future.



**Fig. 3.** Optical MCM preliminary design (top view).



**Fig. 4.** Top view of the optical OBP architecture with the 3 columns of 16 MCM linked by optical flexes.

### C. Full Optical Architecture

The complete optical architecture will consist of 3 columns of up to 16 MCMs linked by optical flexes. The optical flexes will ensure the optical signal crossing and routing between the different MCM. A representation of this “Innovative optical Architecture is presented in Fig.4.

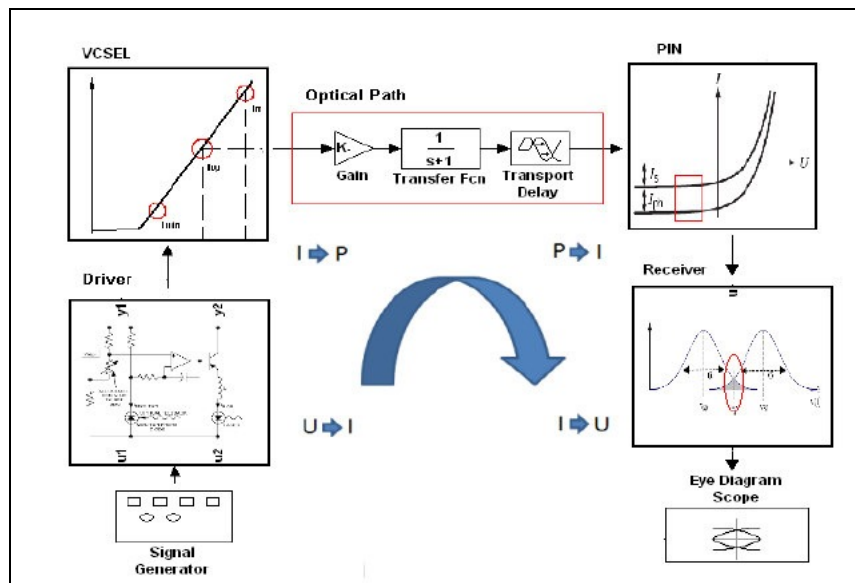
## III. ESTIMATION OF PERFORMANCES

### A. Optoelectrical link simulation and power budget estimation

The power budget of the optoelectrical link was estimated by simulation of the whole link as presented in Fig.5. The simulation system is based on MATLAB libraries for communication and signal analysis to implement functions such as “bit error rate (BER) calculation” and “eye diagram scope”. Using appropriate PSPICE libraries a combination between intrinsic laser functions and electrical functions of the components (VCSEL driver) was realized.

The intrinsic function of the VCSEL and the PIN diode are realized using the datasheets for commercial components.

The minimum VCSEL modulation current delta and then the power budget of the link is dependent on temperature and the targeted BER of  $10^{-9}$ . Simulations were done for temperature up to  $85^{\circ}\text{C}$ . For the recommended parameters of VCSEL current the following power dissipation per channel was then calculated to be  $115\text{mW}$  ( $11,5\text{mW}/\text{Gb/s}$ ) for a temperature of  $85^{\circ}\text{C}$ .

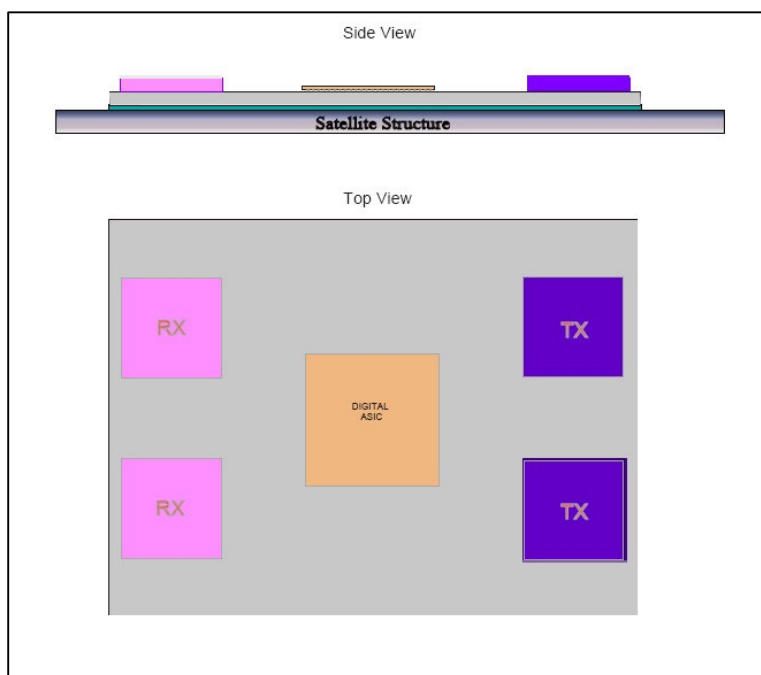


**Fig. 5.** Function modules of the model and the sequence of signal conversion (current to opt. power to current).

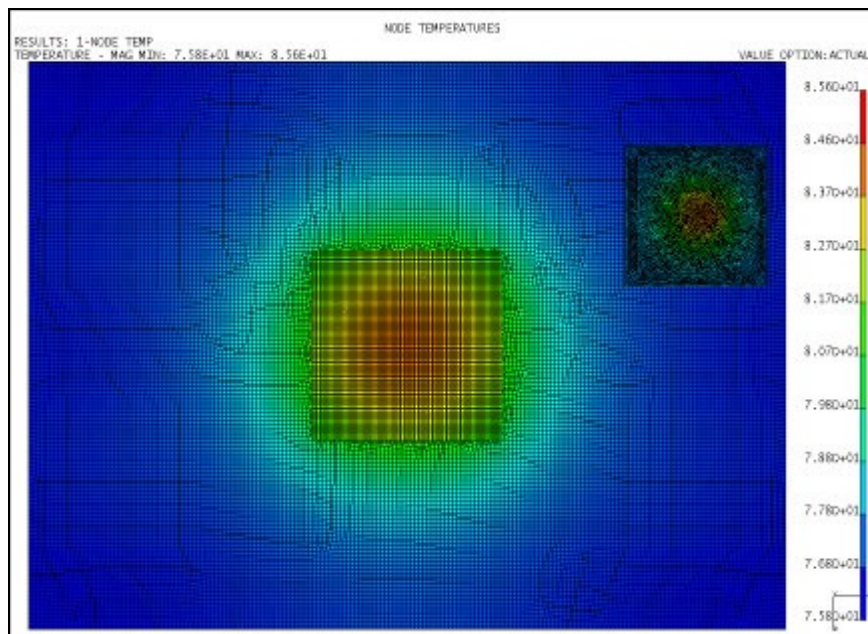
*B. Thermal behavior simulation*

Thermal behavior of the optical MCM was investigated through simulation by FEM analysis. The major concern was the power dissipation of the different components, in particular the 20W ASIC and its effect on the other components assembled on the MCM.

To be able to dissipate easily the power from the MCM to the outside wall of the satellite it is foreseen to fix directly the MCM on the satellite structure with heat pipes just below. The simplified schematic used for the thermal simulation is presented on Fig.6. Due to the MCM symmetry, only the optical transmitter on the upper right was completely simulated with its exact geometry. For the two receivers and the other transmitter, an equivalent power dissipated into the MCM was taken into consideration. A temperature of 75°C was taken as boundary conditions on the satellite structure.



**Fig. 6.** Simplified sketch for thermal simulation of the optical MCM.



**Fig. 7.** Thermal simulations results for the optical MCM.

The results of the simulation are given in Fig.7. Even with 20W of power dissipated, the ASIC die temperature stays below 85°C thank to the high thermal conductivity of the ceramic substrate. One interesting result is also that the temperature does not spread from the ASIC to the transmitter.

The most sensitive electronic component is the VCSEL as its performances and life time are highly dependent on the temperature. The accurate simulation done on the transmitter showed that the VCSEL temperature stayed below 85°C. VCSEL can be operated at this temperature of 85°C but it can impact its life time. To be able to cover mission duration of 15 years in space, a diminution of the temperature of the satellite structure below the MCM has to be considered.

#### IV. CONCLUSION

The “Innovative On Board Payload Optical Architecture for High Throughput Satellites”, presented in that paper, has been elaborated and studied within the frame of ESA study contract AO/1-5750/08/NL/EM. This architecture concept shows high potential benefits in terms of data throughput and modularity compared to a standard electrical architecture with low power consumption and achievable thermal management . Nevertheless, technical developments are needed to transform this concept into a real flight worthiness one. In particular, one of the most critical point is the current availability of an optical transmitter and receiver fulfilling all the requirements needed.

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