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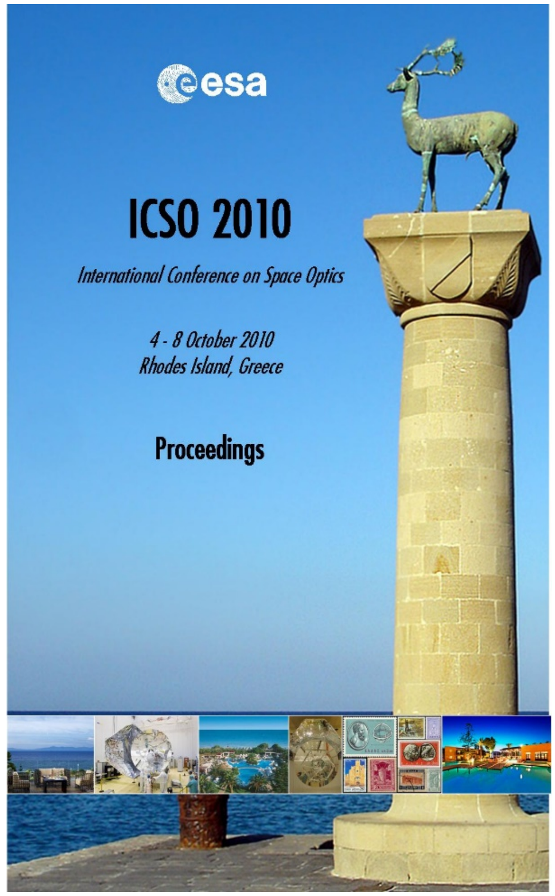

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DIGITAL AND ANALOGUE OPTOELECTRONIC LINKS FOR INTRASATELLITE COMMUNICATIONS

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I. INTRODUCTION

The limitations of the current copper harness used for analogue and digital intrasatellite communications are clear: high mass, thick shielded cables and EMI susceptibility. Within this scenario fiber optic has been identified as candidate to overcome copper cables limitations and improve transmission performances.
DAS Photonics have developed suitable solutions to replace the copper cables used in satellite harnessing for analogue and digital communications.
For digital links DAS has solutions to substitute the copper cables for control buses application (MIL-STD-1553 or CAN BUS) and point-to-point links (i.e. SpaceWire). At this moment the first flight units for digital links have been developed and submitted to validation campaigns, at system and component level with successful results. Two representative models (two full duplex links @1Mbps for bus communications and two full duplex links @100 Mbps for point-to-point links) are going to be included in Alphasat TDP8 to prove their behavior in a real in-orbit environment.
For analogue links DAS has a wide range of solutions covering high performance transmissions of signals from baseband up to frequencies in excess to 40 Ghz. Currently DAS is involved in the development of similar optical links for different on-board applications. For example for some Science or Earth Observation instruments where the EMI immunity become a basic requirement that shall be guaranteed for a successful implementation of the mission, this technology can also bring advantages to the distribution of LO signals with negligible phase noise degradation.

II. DIGITAL OPTOELECTRONIC LINKS

The optical transceivers to substitute digital communications onboard developed by DAS Photonics have been designed taking into account the requirements of the most important protocols and communications systems used for intrasatellite equipments interconnects, such as SpaceWire, clock signals and control buses.

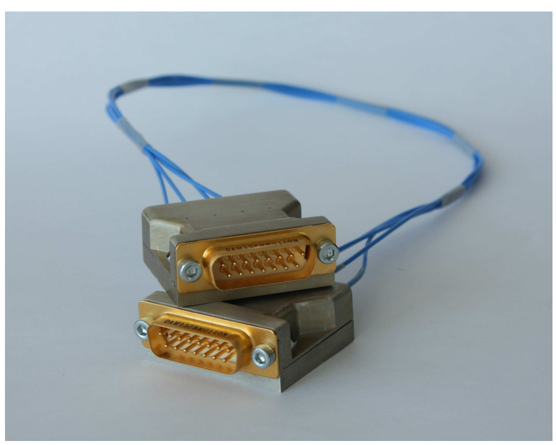

Fig 1 DAS Photonics' SIOS

First developments of the proof of concept were demonstrated under the project "Sistema de Interconexiones Ópticas para Satélites" (SIOS) framed in the Spanish National Space Program. This development consisted in the manufacturing of five breadboards and then submitted to a complete validation campaign including electrical, mechanical, environmental and radiation tests.
Next steps to continue the developments of this optronic solution to replace current copper harness in satellite, were focused on demonstrating the capabilities of these transceivers in a real flight mission, where all radiation and environmental performances could be tested at same time. This opportunity became because of Alphasat platform; Alphasat is a telecommunication satellite that is foreseen to be launched in 2012. In addition to the telecommunication payload, Alphasat will include five Technology Demonstration Payloads (TDP). Alphasat radiation Environment and Effects Facility (AEEF) is one of these five payloads. AEEF will be in charge of

three functions: radiation environment monitoring, radiation effects experiments, and component technology demonstration. AEEF includes two technology demonstration boards: one SIOS optical link demonstration board and one GaN board. SIOS optical link demonstration board will include 4 low data rate (1Mbps) and 4 medium data rate (100 Mbps) optical links, with different power budgets among them to check the impact on each power output in flight conditions. The experiment will be running during 3-5 years, testing their power consumption and monitoring BER in real flight conditions. The EQM is planned to be delivered in August 2010 and the FM in November 2010.

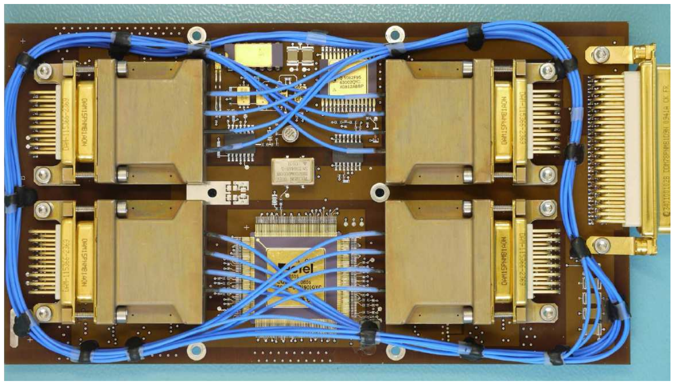

Fig 2 EQM of SIOS experiment for TDP8

To obtain an optical solution capable of substituting copper harness and withstand with space environment, some key factors must be considered in the design,
To complete the tests needed to include the optical transceivers in the experiment board, and due to the fact that the key components to be used are COTS VCSELs and Photodiodes, it was mandatory to surpass an exhaustive assessment of components to demonstrate the suitability of these COTS devices in the space environment.

A. Target applications

In addition, at this moment DAS Photonics is developing, under a ESA GSTP activity called Active Optical Cable, a complete set of optical cables to substitute those harness links where the substitution of copper harness by optical cables could improve the most critical parameters for space applications, such as mass , volume, EMI susceptibility , cables handling and earth loops. During first steps of the developments, one of the most important tasks is to identify the most interesting applications to use optical cables.
It is clear that the omnipresent MIL-STD-1553 bus is a communications standard present in practically all onboard equipments, although CAN BUS could be an alternative in the future, but for the short time the 1553 is the most used bus.
It is well known the complexity of the 1553 because of the connectors, backshells, couplers and wires used to communicate the equipments inside the satellite to be controlled. That number of parts used to build the bus affect directly to the mass and cost of it, as indicated by Table 1.

Table 1. LISA PATHFINDER mass budget for 1553 BUS

Element	Mass (min) gr.	Mass (Max)gr.
Connectors	198.0	198.0
Backshell	143.9	143.9
Couplers	246.0	246.0
Wire	1010.5	1050.0
Total	**1598.4**	**1637.9**

Next step to be taken is to determine the mass impact that result of the substitution of the copper 1553 BUS by and active optical bus. Using data collected from GAIA satellite and the description of the complete 1553 BUS, the estimated mass saving for the buses used in this satellite have been calculated in Table 2.

Table 2 GAIA mass saving estimated for 1553 BUS

SVM 1553 BUS		**PAYLOAD 1553 BUS**	
Copper harness bus mass	~2000 gr	Copper harness bus mass	~1700 gr
Optical bus harness mass	~600 gr	Optical bus harness mass	~500 gr
Mass saving	~1400 gr	Mass saving	~1200 gr
Bus harness mass reduction	**~60-70 %**	**Bus harness mass reduction**	**~60-75%**

Other used communications system is the SpaceWire standard (SpW), used for high speed communications from 100 to 400 Mbps. This standard is well know by space community as well as their problems due to the low flexibility, EMI and ground loops because of the characteristics of the copper cable. With a maximum allowed mass of 80 g/m and the protections used, the SpW cable has a handicap in terms of mass and handling. These problems could be solved with optic fibre, being a light transmission medium.
Again, using real data from GAIA satellite for SpW harness it is possible to demonstrate the advantages of using optical cables for SpaceWire communications. These results are shown in Table 3.

Table 3 GAIA mass saving estimated for SpW communications

SpaceWire	
Copper harness bus mass	~5600 gr.
Optical bus harness mass	~3000 gr.
Mass saving	~2600 gr.
Bus harness mass reduction	**~45-55%**

Other communications protocols will be considered in the initial estimations to detect the mass saving and the impact of the substitution. At the end of the present GSTP activity the final conclusions will present the optimal targets to be substituted and the advantages of that.

B. SIOS Design

Based on the studies performed before about the most common links being used, we concluded that the communications must be divided in two categories, depending on the bit data rate, low speed and medium speed. DAS Photonics developed a suitable solution optimal for each category, increasing the mass saving and decreasing power consumption.

- **Low Speed:** this solution, with a maximum data rate of 10Mbps, covers all control buses such as 1553 and CAN. Also is suitable to substitute other low speed links such as TM/TC signals or even low speed clocks.
- **Medium Speed:** this solution, with a maximum data rate of 500Mbps, covers all SpW data links (with low skew/jitter) usually used from 100 to 400 Mbps. Also is suitable to substitute other medium speed such a clocks or commands.

The designs are not static, these could be adapted to any configuration with different connectors or transmitters/receivers distribution, even combining medium and low speed links in the same backshell, being the optical cable of DAS a powerful way to reduce harness mass for intrasatellite communications.
Key devices of the SIOS are the optronic devices and their drivers/amplifiers, they allow the transceivers to have low mass and to reduce the power consumption of the transceivers. In first developments, the maximum power consumption for a full duplex link was around 800mW. For the SIOS included in Alphasat TDP8 the new objective in terms of maximum power consumption was settled as 450mW for a full duplex link. With a more efficient electrical design, this maximum valued has been reduced up to 330mW, with no penalties in terms of bit error rate or reliability.
The components used were selected in order to reduce the power consumption of the optical cables, which is the major handicap of the active optical elements compared with passive copper cable. All optical devices and electronic drivers/amplifiers are COTS, therefore validation campaigns were established to assure the quality and suitability of the COTS for space environment. These COTS have also been submitted to different component test, as a constructional analysis, RGA…, to have more exhaustive data of them to allow their inclusion on the high-rel space environment.

C. Validation campaign

Because of the use of COTS in the optical transceivers, the validation campaigns were focused on both, system and component level.
During the Spanish National Space Program, electrical, mechanical, environmental and radiation test activities were performed, all at system level, to assure the suitability of the parts and the design for space environmental conditions. This campaign was defined using most common levels for space missions in order to assure that the transceivers will accomplish with the target applications detected in previous analysis in a wide range of onboard platforms. The results of this campaign were presented in last ICSO conference.
As part of the qualification activities performed for the acceptance of the transceivers for Alphasat TDP8 experiment, additional tests at system and component level were scheduled in parallel to the General Experiment Board design. This campaign included additional electrical, mechanical and environmental (thermal vacuum and radiation) tests, but in this case, the transceivers submitted were not only electrically tested (from a

digital communications point of view), they included also an analogue output to monitor the VCSELs output optical power and the photodiodes input optical power.
Each transceiver comprises four communication links, which were designed with different power budget to check their behavior during the test campaign. This way the impact of the tests on each link can be evaluated based on the power budget. The power budget was designed identical to the power budget to be implemented in the Alphasat experiment.
The campaign had two purposes, to check the suitability of the optical transceivers for the Alphasat experiment, and to check the impact of the tests upon the COTS devices.
The validation campaign comprised the following tests:
At system level:

- **Vibration and shock**
- **Radiation:TID**
- **Radiation: Protons**
- **Thermal Vacuum Cycling Test**. The low and medium transceiver were submitted to 8 cycles between (-40/85)ºC

At component level:

- **Radiation: Heavy Ions**
- **Constructional Analysis**.
- **Residual Gas Analysis (RGA),** for optical devices.
- **Outgassing**.
- **Glass seal, fine and gross leak,** for optical devices.
- **Thermal Vacuum Cycling Test,** all COTS devices were submitted to 300 cycles between (-40/85)ºC,
- **Fiber-Pull Test**, all fiber coupling techniques were tested up to 5N of tensile strength.
- **Catastrophic optical damage threshold** (COD threshold), for VCSELs.
- **Thermal Conductance,** all COTS devices.

Table 4 Test campaign at system level (transceiver units)

Test	**Value**
Sine vibration	5-16.3 +-9mm 16.3-100 6.4g (peak) Performed on three axes
Random vibration	23.76g Performed on three axes
Shock	3000 @10KHz Performed on three axes
Thermal vacuum	(-60/+85)ºC @4E-8 mbar 8 cycles
Gamma TID	150Krad @45rad/h
Protons radiation	Energy: 60, 100, 200 MeV Flux: 1E8 p/cm^2/s Fluence: 1E10 p/cm^2 Tilt: 0º, 15º, 30º

Radiation tests were performed using two units, the nominal and a golden unit. The design of the golden unit was identical to the nominal one. The nominal unit was irradiated while the golden was only taken as reference for results comparison. These golden units were maintained in the same environmental conditions during the testing and annealing.

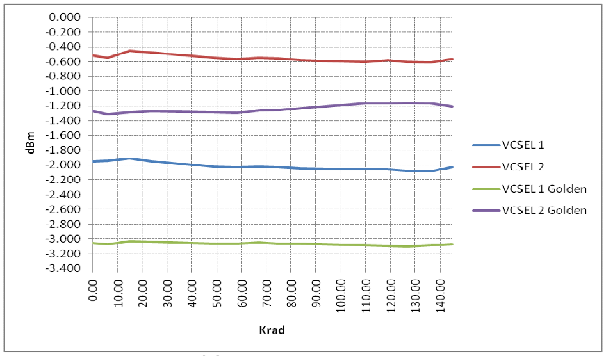

Fig 3 VCSEL degradation on TID test

Proton test was performed on two fresh units (one medium data rate and one low data rate) and in a unit already submitted to 150Krad TID, with energy and flux levels mentioned before. No errors nor power consumption increment were detected on the fresh transceivers irradiation, the degradation on the power output of the lasers was slight and not sufficient to produce errors on the transmission.
One of the transceivers submitted to 150Krad-Si TID, low data rate transceiver in that case, to see the combined effect of TID plus proton irradiation. This combined test allowed determining the cross section because of the detection of single bit errors in the transmitted patterns.

Table 5 SEE results summary on SIOS transceiver preirradiated in TID test

Energy (MeV)	tilt	# errors channel 1	# errors channel 2	Xsection channel 1 (#/cm2)	Xsection channel 2 (#/cm2)
200	0	14	3	1.40E-10	3.00E-11
100	0	0	1	< 5E-11	5.00E-11
200	45	1	0	7.40E-11	<7.4E-11
200	60	0	0	<1E-10	<1E-10
200	90	0	1	<1E-10	1.00E-10
100	45	0	0	<1E-10	<1E-10
100	60	1	0	1.00E-10	<1E-10
100	90	0	0	<1E-10	<1E-10

The errors distribution was not concentred in a single point and after the irradiation no errors were produced again, not being critical for BER values even in low power budget links.
All tests provided very good results, confirming the suitability of the COTS for space environment. For example, for the thermal vacuum case, the maximum deviation in the power output of the lasers (most delicate part in terms of temperature stability) between maximum and minimum temperature was less than 1dB.

Table 6 Maximum deviation on VCSELs output optical power for TVC

Name in report	**Output power dBm**			**Maximum deviation (dB)**
	Ambient temperature (25ºC)	**Minimum temperature (-42.7ºC)**	**Maximum temperature (91.1ºC)**	
VCSEL1	-0.84	-0.70	-1.30	0.60
VCSEL2	-0.83	-0.82	-1.25	0.43
VCSEL3	-0.82	-0.68	-1.27	0.59
VCSEL4	-1.35	-1.47	-1.68	0.33
VCSEL5	-4.73	-4.83	-5.44	0.71
VCSEL6	-2.86	-3.73	-3.69	0.83
VCSEL7	-2.83	-3.12	-3.67	0.84
VCSEL8	-3.38	-4.17	-4.17	0.79

For the fiber pull test, the value obtained before fiber/coupling cracks or the losses were higher of the maximum value, was much higher than the 5N of the requirements, in fact, the maximum tensile load before fiber/coupling broken was around 30N.

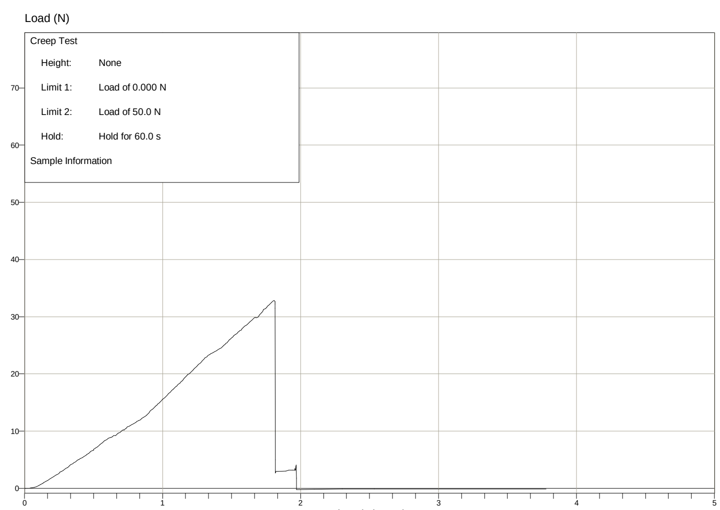

Fig 4 Maximum tensile load before coupling cracks

The results of the RGA, outgassing, glass seal and thermal conductance were all according to the European Space Agency requirements for flight missions.
No major issues were detected during the validation campaign; however, degradation on the optical devices was found, especially during radiation tests. In any case, the final conclusion for the assessment of the components was that all COTS devices are suitable to be used in the Alphasat experiment and for future missions.

III ANALOGUE OPTICAL LINKS

For analogue links DAS has developed a wide range of solutions for ground segment covering high performance transmissions of signals from baseband up to 40 GHz. Currently DAS is involved in several programs devoted to the development of similar optical links for different on-board applications, since none of the terrestrial components have space heritage. For on-board applications the optical fiber properties are a very important and give attractive advantage (ultra low losses, enormous bandwidth, immunity to EMC, ease of cabling).
As part of a general study DAS has evaluated the viability of implementing an analogue photonic link for transporting RF signals from the LNA, located close to the antenna, to the receivers modules in a scientific satellite, where the EMI immunity becomes a basic requirement that shall be guaranteed for a successful implementation of the mission. As conclusion of this program we have that optical harness will provide a significant mass and volume reduction in comparison to copper harness, considerable improvement in terms of cable management and besides RF parameters are not affected by photonic technology.
Under another ESA contract, DAS is in charge of the development of part of a photonic LO distribution system with high-purity oscillator signals in the range of 10MHz and 100 MHz. Photonic distribution allows for mass and volume reduction for superior phase noise requirements.
The LO distribution system comprises three main blocks, the E2O unit that performs the electro-optical conversion, the Cable and Splitting (CS) unit that distributes the LO photonic signal among the receivers, and the O2E unit that converts the optical signal to an electrical LO signal. DAS is responsible for the design and manufacturing of an elegant bread board (EBB) of the E2O units for the low frequency links. Currently the program is in the Detail Design Phase, and the manufacturing and environmental testing will start in the upcoming months.
The key component for the E2O units is the laser. As no space qualified optoelectronic components are available, a commercial laser from a European manufacturer will be used. Due to this, the selected laser will be submitted to a battery of functional and environmental tests, in order to evaluate its performance in extreme conditions.

IV. CONCLUSSIONS

DAS Photonics' analogue and digital optical links to substitute copper transmission medium for space applications have been positioned as an alternative option with high degree of suitability due to the experience of DAS on optical communications for space.
The activity about to design and manufacture different active optical links, leaded by DAS under ESA supervision, to replace a wide range of copper harness in intrasatellite communications will allow determining the impact of the optical fibre for these target links. Initial estimations have fixed the mass' saving around 50%, depending on satellite size and number of links used. At the end of the activity these results will be more accurate. Also, the results obtained from activities and test campaigns performed during Alphasat TDP execution, will add more heritage to DAS' space developments, mainly optical links for intrasatellite communications.

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